RESEARCH ON FISHWAY PROBLEMS
MAY 1960 TO APRIL 1965

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INTRODUCTION

The increasing number of water use projects in the Columbia River system poses a constant threat to the anadromous fishery resource by obstructing the natural migratory routes of these fish. Fish passage facilities are normally provided in these circumstances, and considerable planning is often necessary to achieve the safest and most efficient conditions for fish. In line with these needs, the U. S. Army Corps of Engineers has sponsored a program of fisheries engineering research to secure design criteria for such structures.

The Fisheries-Engineering Research Laboratory at Bonneville Dam was completed as a part of the above program and has been operated continually since 1955 by the Bureau of Commercial Fisheries under contract to the Corps. The primary aim of research at Bonneville has been to provide basic knowledge of the behavior, abilities and requirements of fish in fish passage situations. Major emphasis has centered on seeking means of reducing the cost of fish passage facilities without impairing their efficiency. The laboratory has contributed materially to fishway design criteria in several areas, resulting in major savings in construction and operational costs. This report summarizes research conducted during the second 5-year period (May 1960-April 1965) of operation.

INVESTIGATIONS

1. FISHWAY SLOPE

Discussion

Earlier studies on fishway slopes at the Fisheries-Engineering Research Laboratory demonstrated that a slope steeper than 1-on-16 was suitable for fish passage if proper hydraulic conditions were maintained. This work led to further development and testing by the Corps of Engineers Hydraulic Laboratory and ultimately resulted in the design of the 1-on-10 slope ladder for Ice Harbor Dam on the Snake River. Evolution of this ladder initially included development of suitable hydraulic conditions by model studies at the Hydraulic Laboratory. This was followed by study of fish passage in a full scale 6-pool section of the ladder in the Fisheries-Engineering Research Laboratory. The final stage was reached when the prototype ladder was tested during its first year of operation at Ice Harbor Dam.

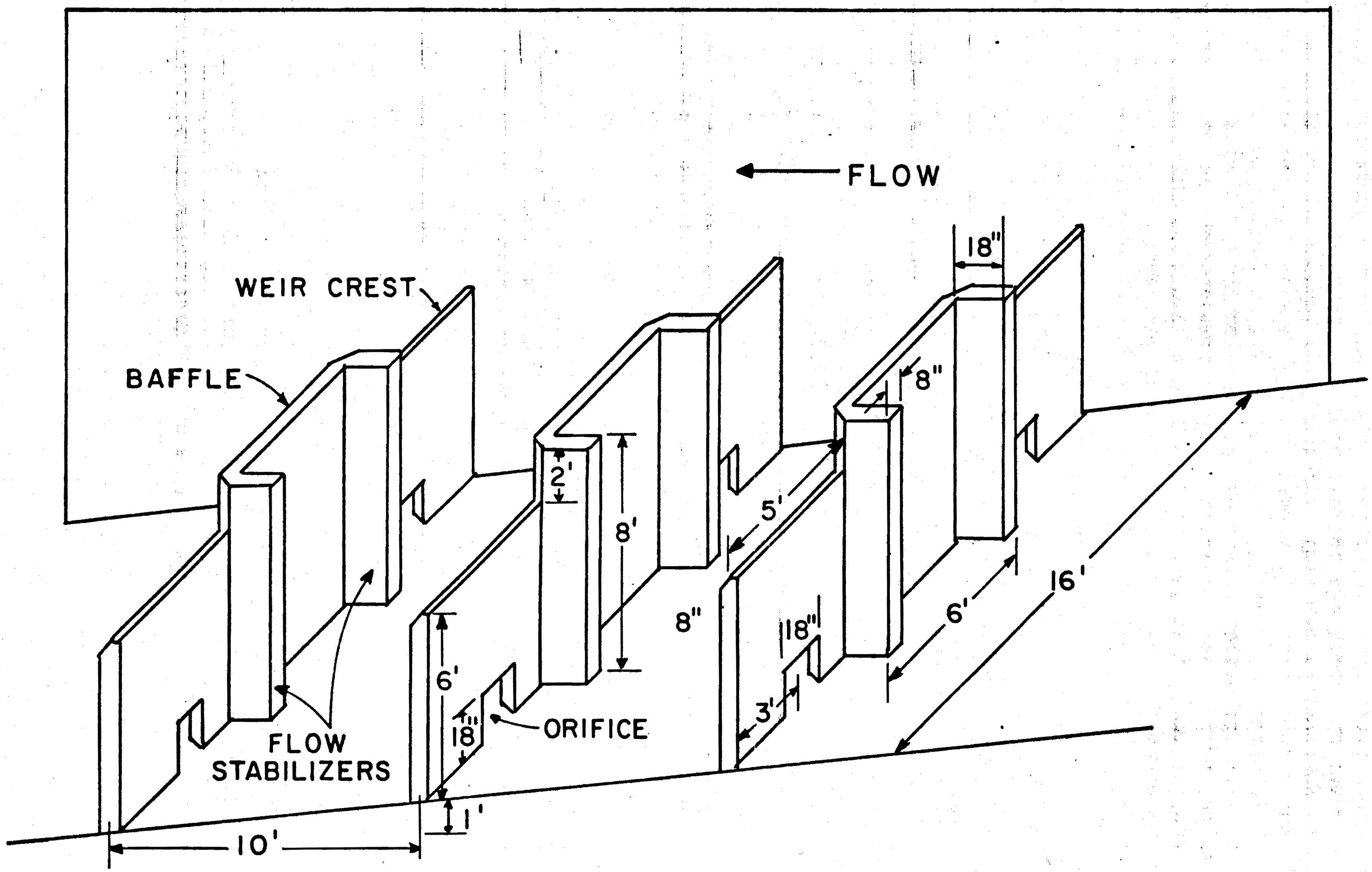

Figure 1 - Pool and Weir Dimensions of the Ice Harbor Fishway Design

The new 1-on-10 slope fishway is a pool-and-overfall type with submerged orifices, flow stabilizers and a non-overfall section in the middle of each weir (Fig. 1). There is a 1-foot rise between pools, and average water depth under normal operating conditions is 6.5 feet. The fishway tested in the laboratory was constructed of wood so that it could be modified to produce a variety of test conditions.

a. Laboratory Evaluation. Performance and behavior of chinook salmon (*Oncorhynchus tshawytscha*), sockeye salmon (*Oncorhynchus nerka*), coho salmon (*Oncorhynchus kisutch*), and steelhead trout (*Salmo gairdneri*) were evaluated under normal operating conditions of the fishway. Tests were also conducted with a half-width fishway (Fig. 2), orifice flows only (non-overfall flow), overfall flow only, and higher than normal flow. Three weir crest designs--McNary type, The Dalles type, and plane-surface ogee type--were tested. Underwater viewing facilities were provided for observing fish behavior and hydraulics.

Tests were carried out using individual fish in the fishway, groups of mixed species, and capacity type concentrations which were similar to group releases, but involved larger numbers of fish.

Passage times were obtained to assess performance of fish ascending the ladder under various operational conditions. A comparison of passage times of salmonids under half-width and full-width fishway conditions shows that chinook made significantly faster ascents under the half-width fishway condition than under the full-width condition, but that sockeye and steelhead performed about the same under either condition. Capacity tests were conducted in the half-width fishway. Several trials were run of which the largest group tested in a 1-hour period numbered 1,371 fish. However, the numbers of fish available were considered insufficient to demonstrate that capacity of the fishway had been reached. During the passage of these large groups, there was no evidence that movement of fish was impeded.

In a comparison of weir crests, McNary and plane-surface ogee crests appeared to improve hydraulic conditions and hasten fish passage slightly when they were used in lieu of a Dalles-type crest specified in the original design.

Observations were made on effect of various flow conditions on the passage of fish. Chinook and steelhead made significantly faster ascents under an overfall and orifice flow condition when the head on the weir was increased from 0.95 foot to 1.20 feet. With the orifices closed both species made significantly slower ascents when the head on weir was increased from 0.95 foot to 1.20 feet. Steelhead and chinook accepted this condition quite readily and ascended the fishway without difficulty. Preference for overfall or orifice passage appeared to vary seasonally with chinook and steelhead, but sockeye favored the overfall. Carp, suckers and squawfish favored the orifice, and shad the overfall.

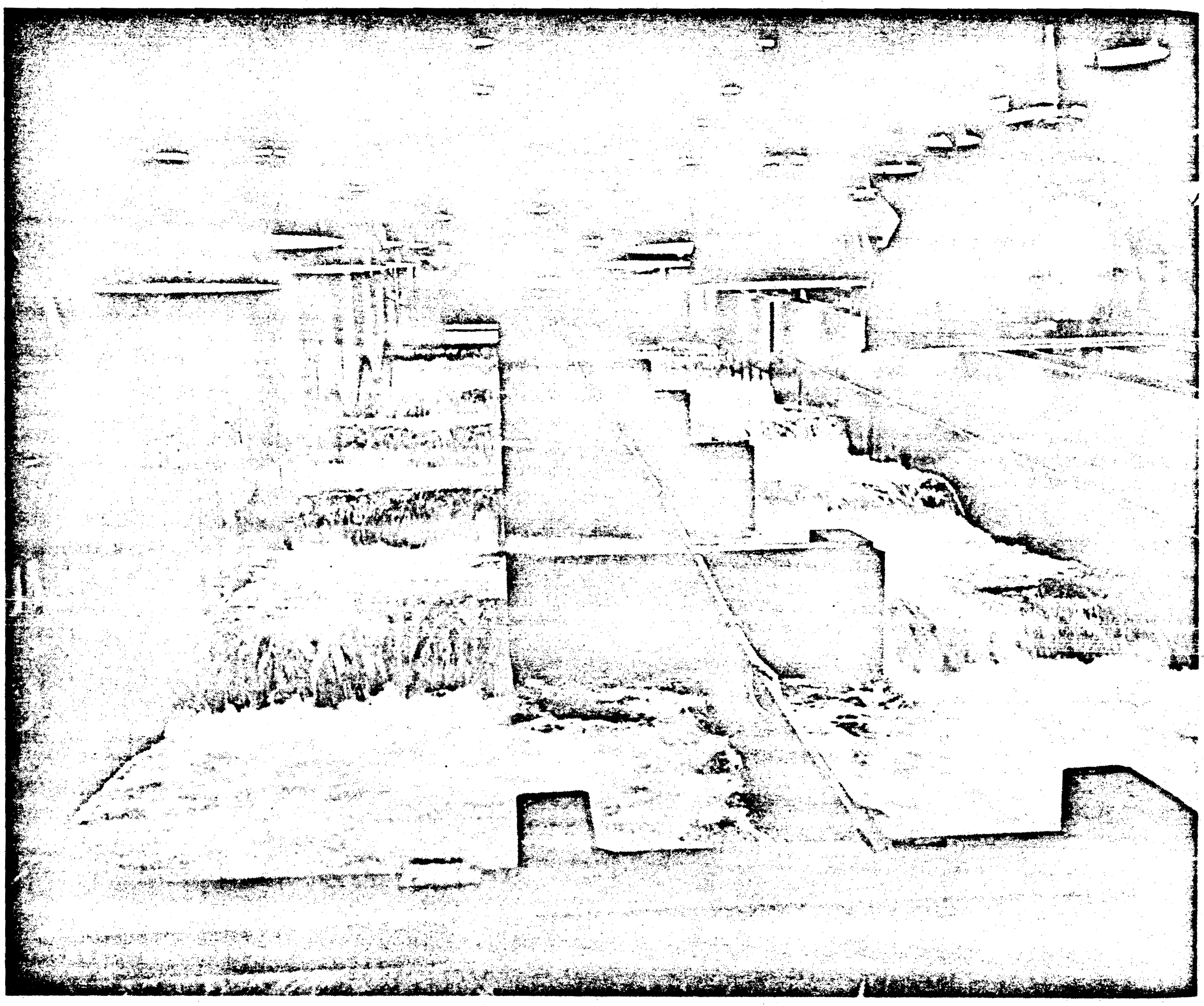

Figure 2. - Ice Harbor Design Fishway Showing Divider Wall in Center to Produce Half-Width Condition.

In brief, the laboratory studies indicated that the 1-on-10 slope fishway would be as suitable for passage of fish as the conventional 1-on-16 slope fishways now in use on the Columbia River.

b. Field Evaluation. The field evaluation of the 1-on-10 slope Ice Harbor design fishway was conducted from May 10 to October 5, 1962, at Ice Harbor Dam on the Snake River. Fish passage facilities at the dam consist of two pool-and-overfall fish ladders: (1) a 1-on-16 slope fishway, 24 feet wide of conventional design (Fig. 3), and (2) a 1-on-10 slope fishway 16 feet wide usually referred to as the Ice Harbor design (Fig. 4).

The objective of the evaluation was to determine if the new 1-on-10 slope fishway would satisfactorily and safely pass salmonids over the dam. This was done by comparing performance of fish ascending the 1-on-10 slope fishway with performance of fish ascending the 1-on-16 slope fishway. Criteria employed in comparing performance of fish in the two ladders included: (1) Proportions of fish successfully negotiating comparable sections of the two ladders during a given period; (2) Rates and patterns of movement through comparable test sections (same or similar number of pools); and (3) Fallback activity (downstream passage within the test area).

Observations were made within a 74-pool test area in each ladder. Temporary partitions were installed longitudinally throughout the test area dividing each ladder into a test and bypass side. Only the test side was employed in the study. Count stations installed at several different elevations within the test area (Fig. 5) provided means of comparing the performance of fish as they ascended various segments of the test areas in each ladder.

Relatively few salmonids failed to complete the test section in either ladder during the individual test periods. Comparisons of salmonid passage patterns at count stations encompassing comparable test sections indicated similar patterns of movement in the 1-on-10 slope and 1-on-16 slope ladders. Passage times based on the time at which 50 percent of the salmonids had crossed each counting station indicated that there was little difference in the rates at which salmonids ascended the entire test area of the two ladders. Average passage times for the 74-pool test section were 1.36 minutes per pool in the 1-on-10 slope ladder and 1.41 minutes per pool in the 1-on-16 slope ladder. Observations of fallback (downstream passage) activity of salmonids during the tests failed to demonstrate any abnormal occurrences in the 1-on-10 slope ladder.

Incidental observations of the behavior of suckers (Catastomus sp.), squawfish (Ptychocheilus oregonensis), and carp (Cyprinus carpio) revealed their performance in both ladders was characterized by consider-

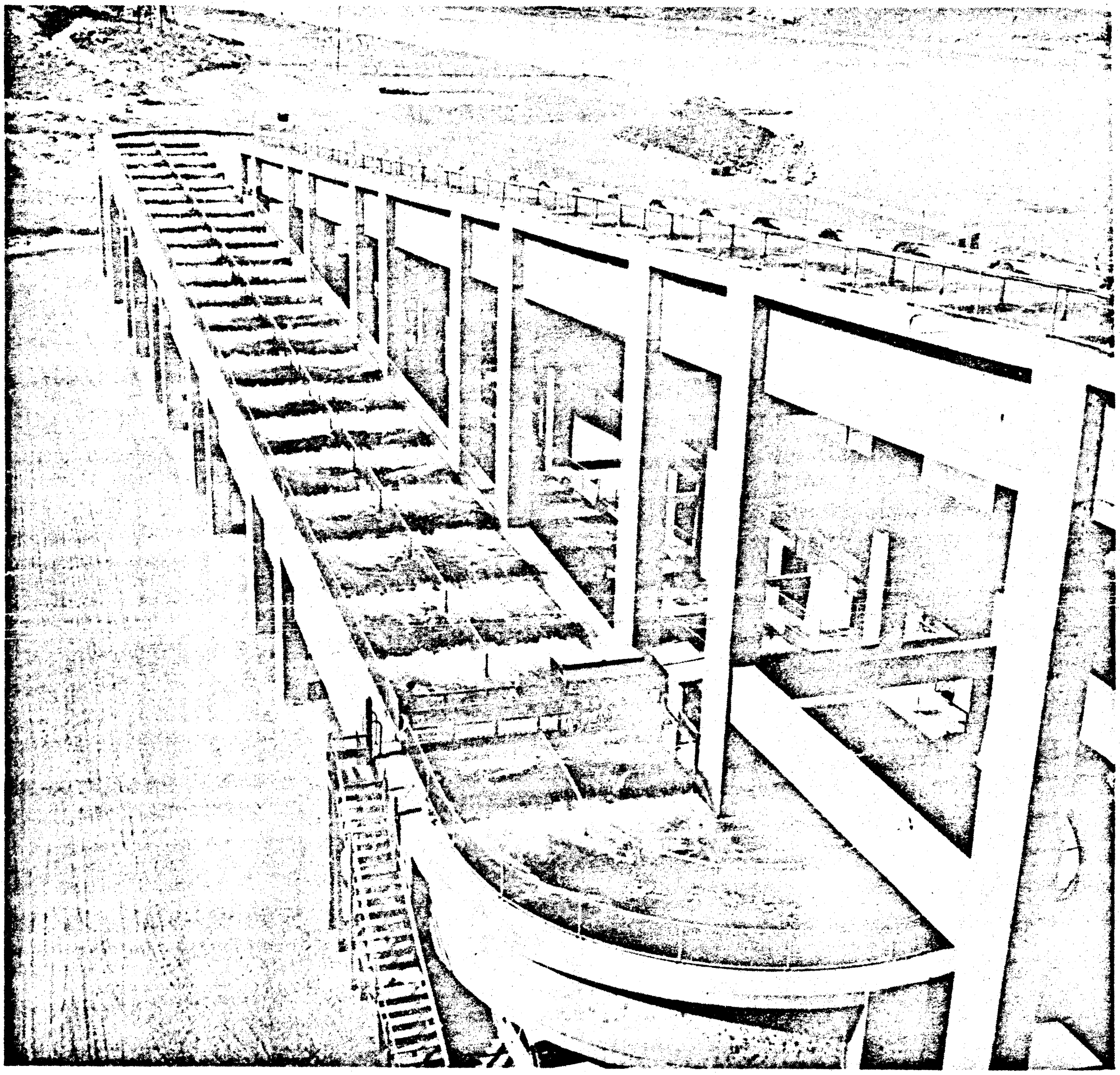

Figure 3 - South Shore 1-on-16 Slope Fish Ladder Showing the Divider Screen and Count Stations for Weir Elevations 380 (to right of bridge) and 381 (on the bridge).

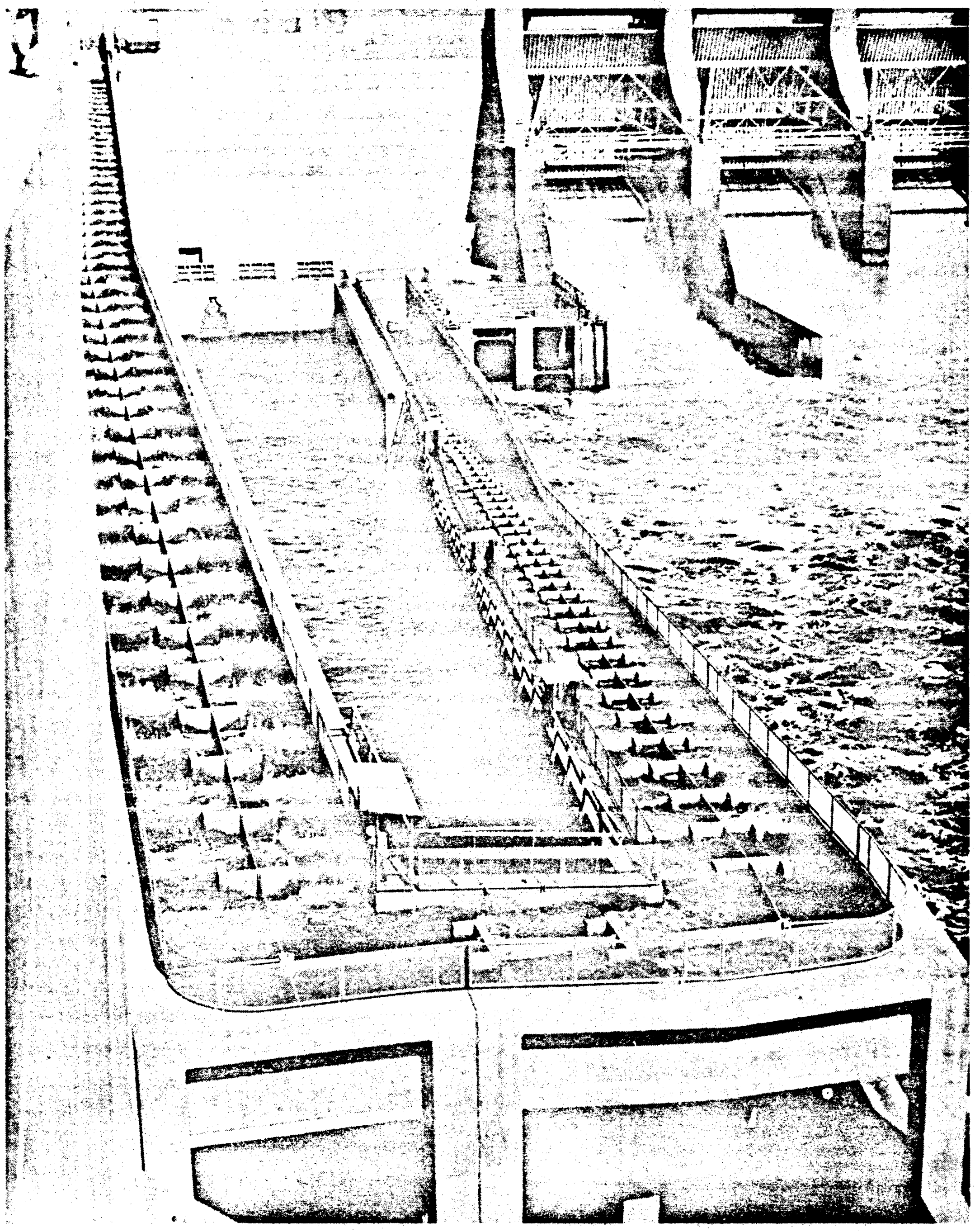

Figure 4 - North Shore 1-on-10 Slope Fish Ladder Showing the Timber Divider Wall and Location of the Five Count Stations. The Uppermost Count Station (Elevation 433) is Barely Visible at the Upper Left Corner.

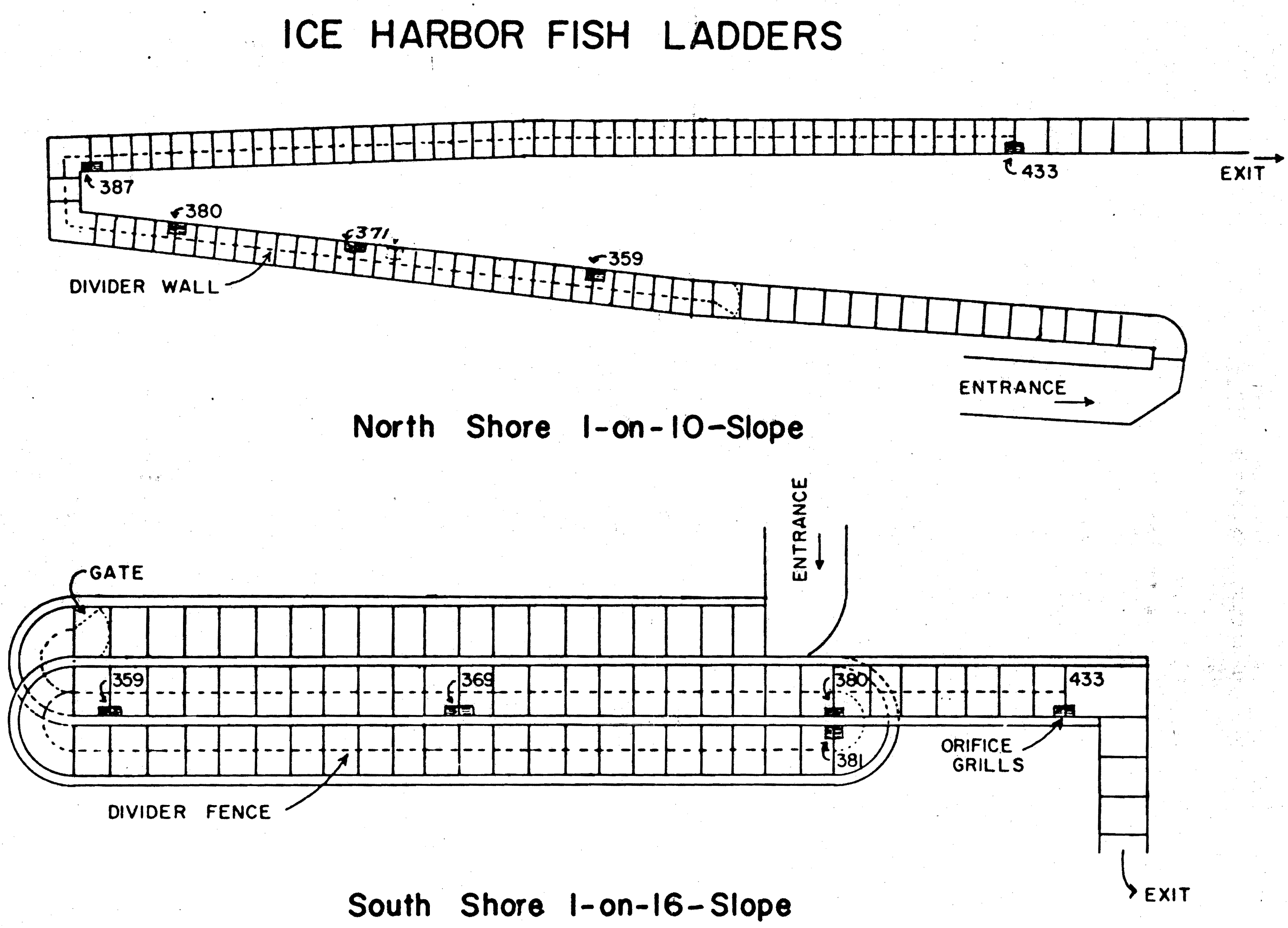

Figure 5 - Ice Harbor Fish Ladders Showing Locations of Count Stations.

able fallback activity and a much slower rate of passage than salmonids. There was no indication that these fish encountered more difficulty in the 1-on-10 slope ladder than in the 1-on-16 slope ladder.

Results

On the basis of preceding results, it was concluded that the 1-on-10 slope ladder will provide adequate passage for the number and species of fish it may be expected to accommodate at Ice Harbor Dam. Since little difference could be detected between performance of salmonids in the two ladders, there is no reason to doubt that a 1-on-10 slope ladder could pass salmonids as efficiently as a conventional 1-on-16 slope ladder designed to accommodate the same number of fish.

2. DIFFUSION WATER VELOCITY

Discussion

Diffusion water, also termed attraction water or auxiliary water, is the water flow that is added to a fish passage facility through a floor or wall diffusor. It is needed to maintain prescribed flows in the lower ends of fishways, in fish collection channels, at fishway entrances, and occasionally in other sections of fishways where depth and width increase.

The presently accepted criteria for gross diffusion water velocities are 0.25 feet per second (f.p.s.) through a flood diffusor and 0.50 f.p.s. through a wall diffusor. The primary objective of this study was to determine the effect of various gross diffusion water velocities on the passage of salmonids in a transportation channel. If higher velocities than those presently accepted do not appreciably deter fish passage, then smaller diffusors could be used in new fishways with a resultant savings in construction and maintenance costs.

Test facilities consisted of a fish transportation channel into which auxiliary water was added from either a floor- or wall-type diffusor. Diffusion water velocities ranged from 0.25 to 1.25 f.p.s. through the floor diffusor and from 0.25 to 2.00 f.p.s. through the wall diffusor. The channel was 4 feet wide by 91 feet long exclusive of a short introductory area (Fig. 6). Water depth was 6 feet, and velocities upstream of the diffusion area were maintained at approximately 2 f.p.s. The installation for the floor diffusor was essentially the same for the wall diffusor (Fig. 7) except that the former discharged up through the bottom of the channel.

The effect of diffusion water velocity on fish passage was determined by timing individual fish through the channel (A to B, Fig. 6). A Latin Square design was used in conducting the experiments with some variation in design between years.

Median and mean passage times of spring chinook (Table 1) show that the addition of diffusion water at any velocity through the floor diffusor delayed the passage of fish. This was also true of fall chinook and steelhead. A comparison of median passage times of chinook through

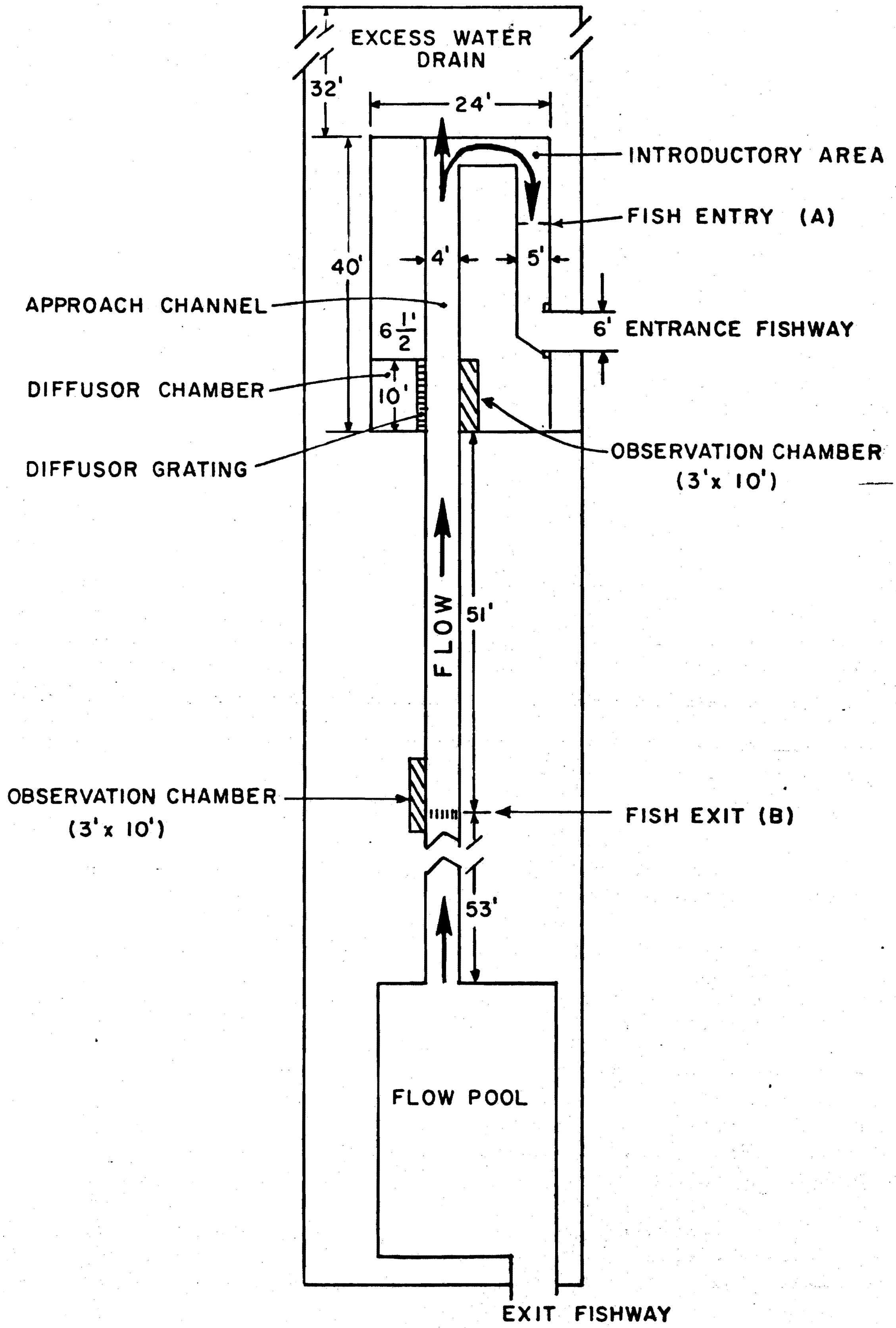

Figure 6 - Plan view of experimental area for testing response of salmonids to gross diffusion water velocities from a wall diffusor.

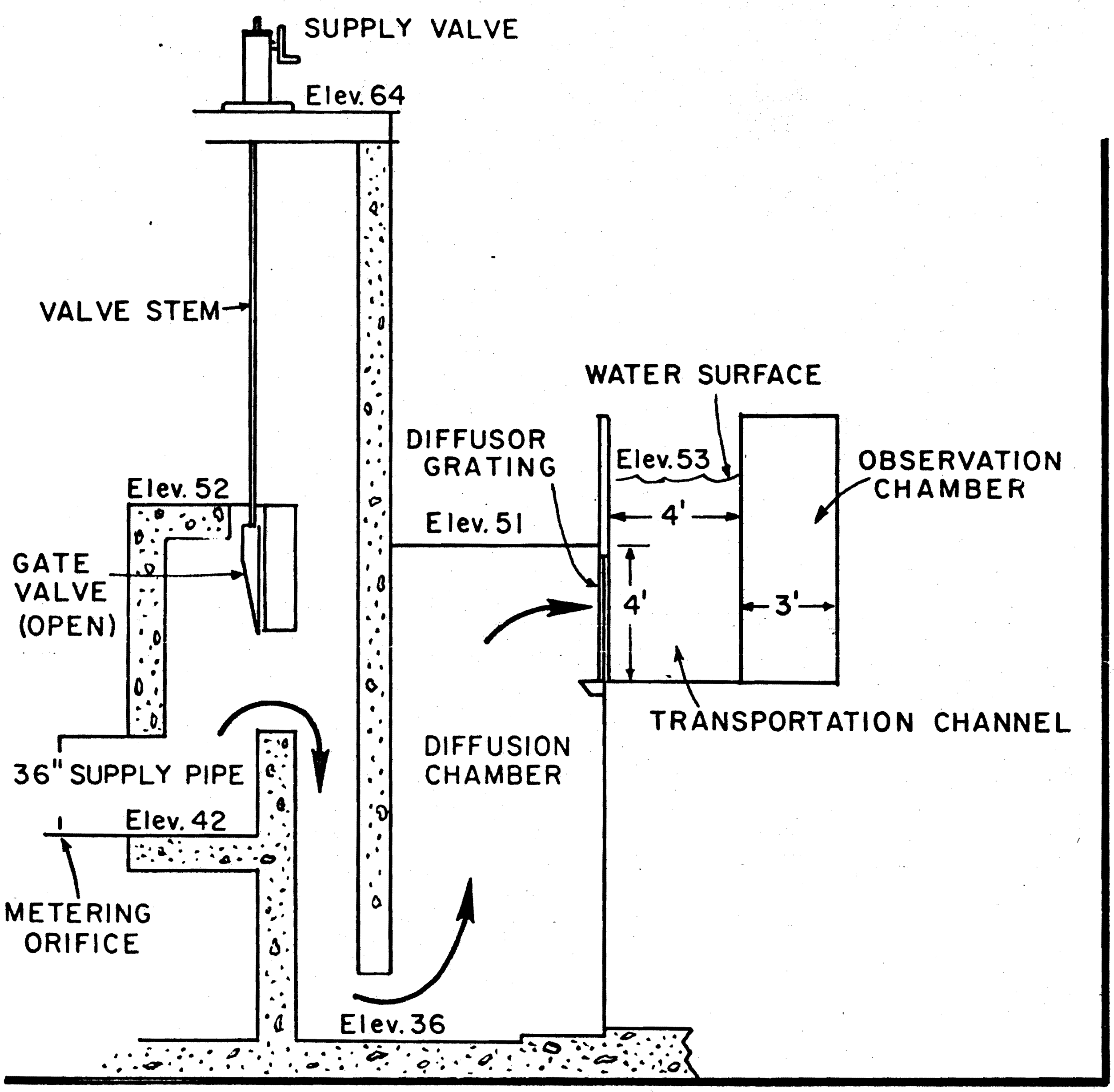

Figure 7 - Sectional view showing wall diffusor, water supply system and observation chamber.

the channel with and without entrained air in the water (Fig. 8) demonstrated that air had no effect on fish passage. Operation of the diffusor without a grating indicated that this might not be practical as both chinook and steelhead entered the diffusor opening even when no water was flowing out.

Table 1 - Mean and Median Passage Times of Chinook Salmon in a Transportation Channel with Gross Floor Diffusion Velocities of 0.25 to 1.25 f.p.s., May 2-23, 1961

Gross Diffusion Velocity F.p.s.	Sample Size Number	Mean Passage Time Minutes	Sample Size Number	Median Passage Time Minutes
0.00	19	9.9	20	4.1
0.25	18	13.2	20	9.7
0.50	17	11.9	20	10.6
0.75	18	17.2	20	15.9
1.00	16	17.4	20	19.4
1.25	16	10.3	20	10.4

Results

Wall diffusor tests were conducted in 1962 using velocities of 0.25, 0.50, 0.75, and 1.00 f.p.s. and in 1963 using velocities of 0.00, 0.50, 1.00, and 2.00 f.p.s. Passage times of chinook, sockeye and steelhead in 1962 under the various diffusion velocities did not differ greatly, except that passage time increased slightly at the 1.00 f.p.s. velocity. Passage times of chinook, sockeye and steelhead in 1963 (Table 2) demonstrated that an increase in passage time occurred as gross velocity increased. From a practical standpoint, however, there was little difference in passage times under the velocities tested.

The tests with floor and wall diffusors demonstrated that introduction of diffusion water at any velocity slowed the passage of salmonids through the channel, and there was a general tendency for passage times to increase at the higher velocities. It appears, however, that the standards for floor and wall diffusors (0.25 and 0.50 f.p.s. respectively) could be increased 100 percent without creating an appreciable delay in fish passage.

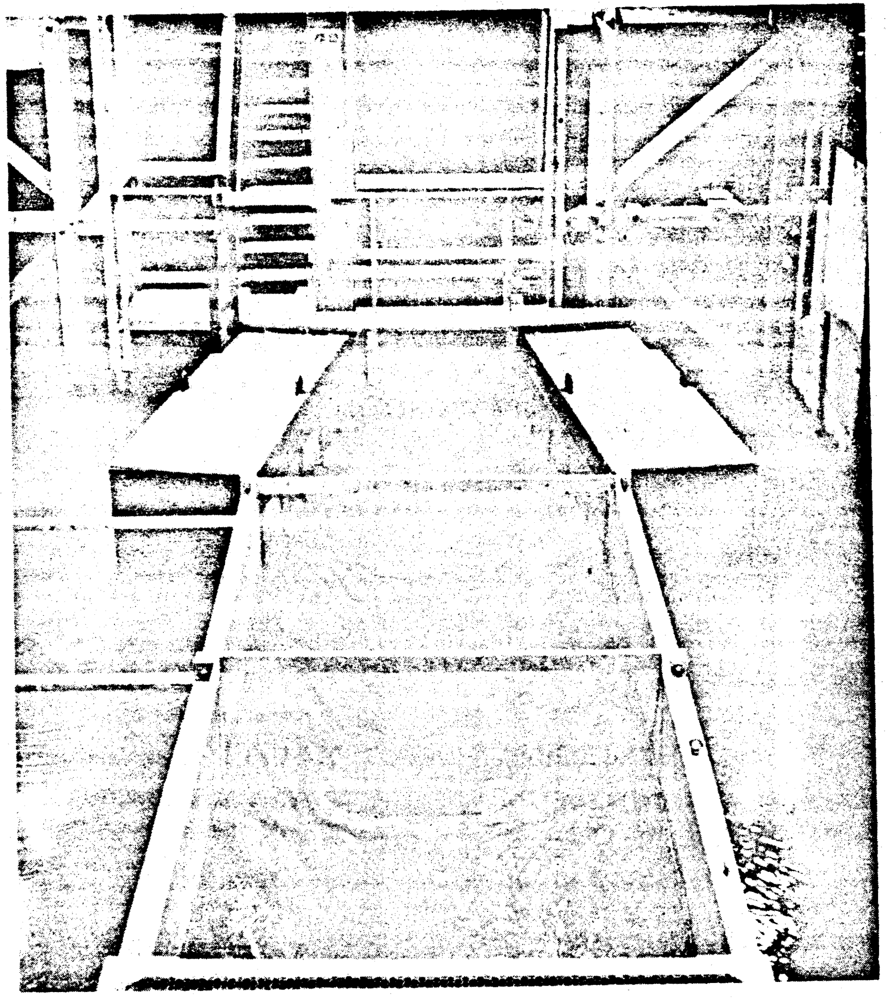

Figure 8 - Diffusion area and transportation channel with air being introduced through the diffusor (bottom) and without air (top).

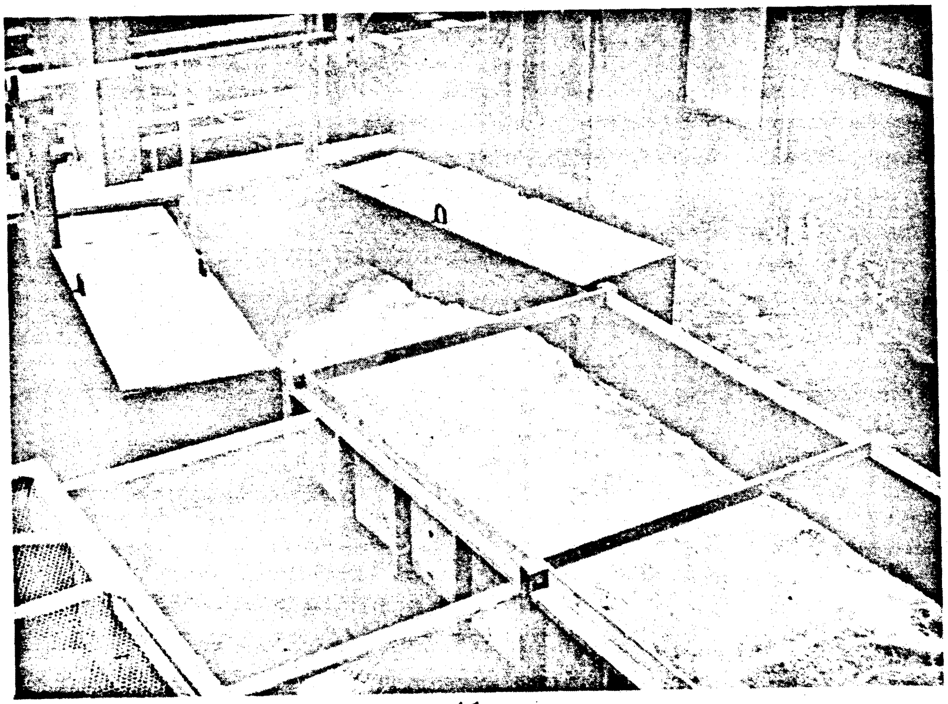

Table 2 - Effect of Wall Diffusion (Gross Velocity 0.00 to 2.00 f.p.s.) on the Passage of Chinook Salmon, Sockeye Salmon and Steelhead Trout, 1963.

Species and Date	Gross Diffusion Velocity	Sample Size	Mean Passage Time	Sample Size	Median Passage Time
	F.p.s.	Number	Minutes	Number	Minutes
Chinook	0.0	238	3.2	239	2.4
	0.5	208	4.4	211	3.2
April 15	1.0	139	5.4	143	3.4
to	1.5	146	6.3	151	5.2
May 9	2.0	102	7.8	105	6.8
Sockeye	0.0	172	2.4	172	1.4
	0.5	132	3.4	136	1.9
June 18	1.0	130	5.3	131	2.4
to	1.5	137	4.3	142	2.3
July 13	2.0	94	6.3	98	4.6
Steelhead	0.0	188	4.0	189	2.2
	0.5	152	5.3	153	2.7
July 4	1.0	128	5.6	131	2.8
to	1.5	112	5.5	113	3.4
July 20	2.0	108	5.7	111	2.7

3. ATTRACTION OF FISH

Discussion

Studies conducted in 1957 demonstrated that a majority of chinook and steelhead, when given a choice between channels with a "high" and a "low" velocity (Fig. 9), would select the channel with the higher velocity. Additional studies were made in 1961 to examine the response of sockeye salmon to opposing velocity conditions and to consider the effects of quantity as well as velocity of the water. Sockeye salmon responded in the same manner (Table 3) as the chinook and steelhead in the earlier tests, i.e., they generally showed a preference for the higher velocity.

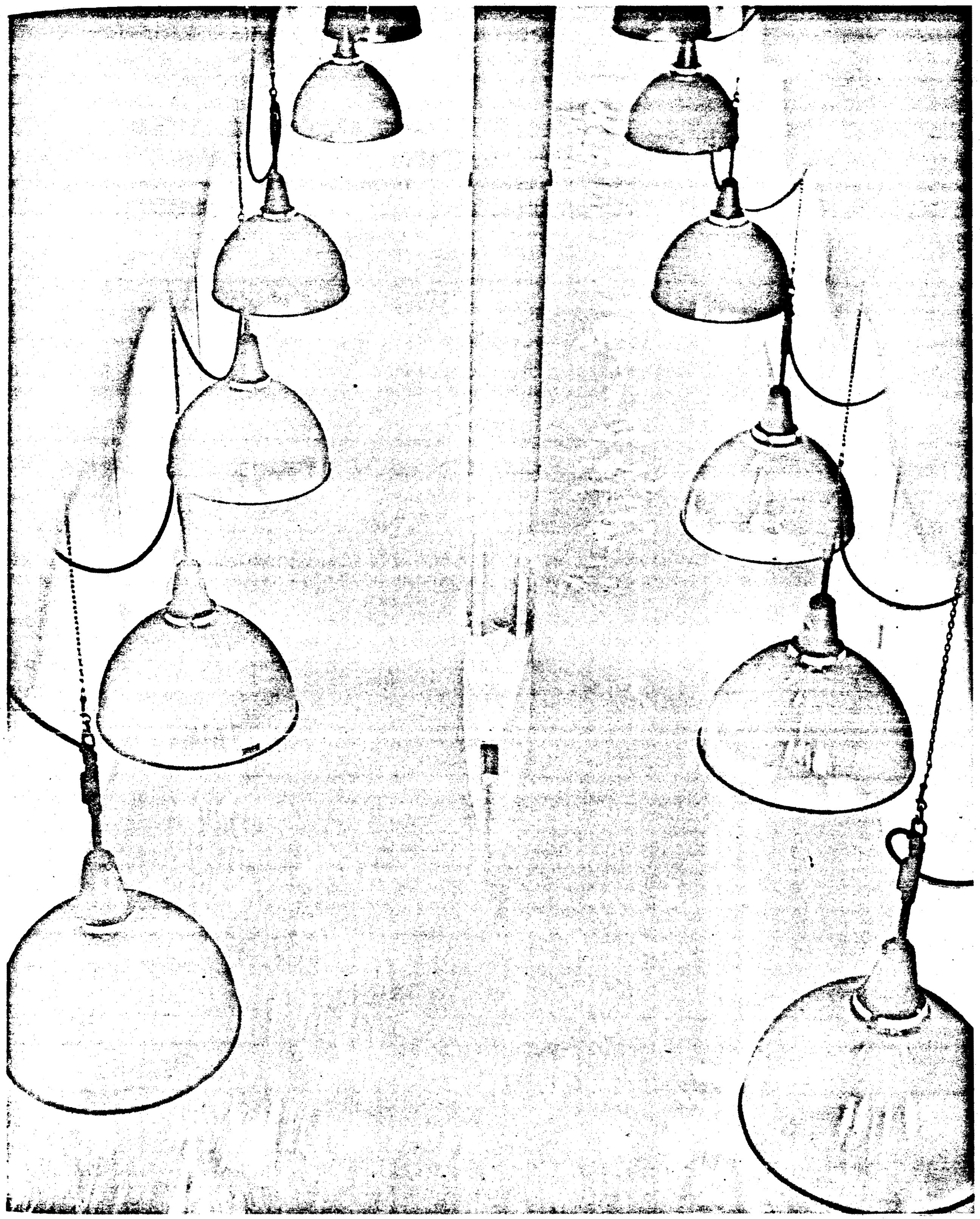

Figure 9 - Choice Area and Two Velocity Channels
(6 f.p.s. in left and 2 f.p.s. in right).

Velocity and quantity of flow were studied to determine if fish selecting a higher velocity were responding to velocity or quantity of flow. Fish were given the choice of entering one of two adjacent channels (Fig. 10) with contrasting velocities. The high-velocity channel was restricted in width so that the quantity of flow from this channel was about the same as that from the low-velocity channel.

Results

The response of chinook and steelhead showed that a majority selected the high-velocity side (Table 4) even though the discharge was the same on both sides.

Table 3 - Response of Sockeye Salmon to a Choice in Water Velocities Ranging from 2 to 8 f.p.s., June 26-July 10, 1961

Test Condition	Number of Fish Selecting Each Channel
North - 6 f.p.s.	11
South - 8 f.p.s.	9
North - 8 f.p.s.	19
South - 2 f.p.s.	1
North - 4 f.p.s.	13
South - 4 f.p.s.	13
North - 2 f.p.s.	10
South - 2 f.p.s.	10
North - 4 f.p.s.	4
South - 6 f.p.s.	16
North - 6 f.p.s.	5
South - 2 f.p.s.	2

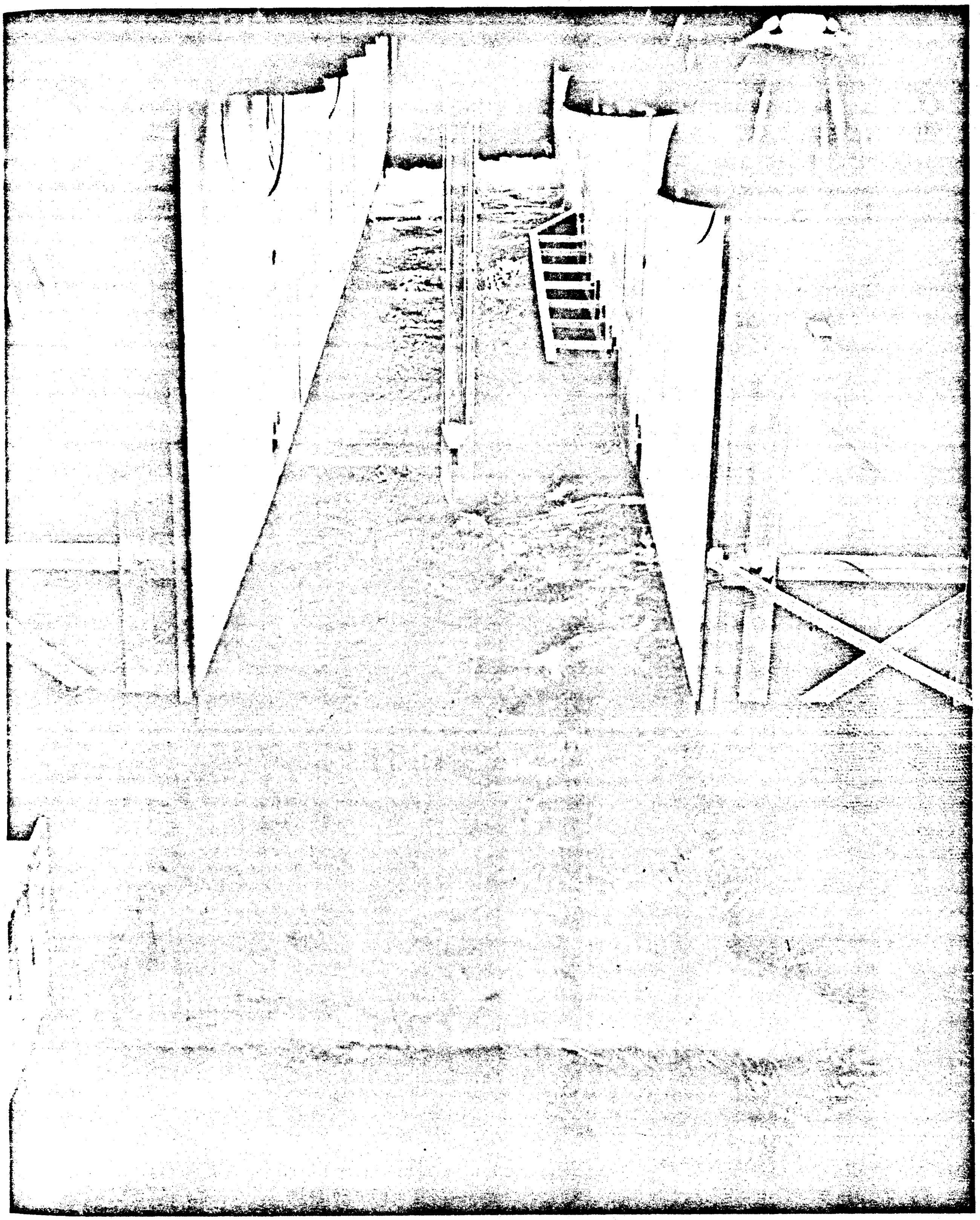

Figure 10 - Channels Used in Quantity vs. Velocity Study. Channel on Left has Greatest Quantity and Channel on Right, Highest Velocity.

Table 4 - Response of Salmonids to Velocity and Quantity of Flow in a Choice Situation, 1961.

Test Date	Number of Fish Selecting Low[1] and High[2] Velocity Channels by Species					
	STEELHEAD			CHINOOK		
	Low Velocity	High Velocity	Total Tested	Low Velocity	High Velocity	Total Tested
8-11	2	5	7	1	1	2
8-12	1	7	8	2	4	6
8-13	5	2	7	1	5	6
8-14	9	13	22	4	15	19
8-15	2	14	16	4	2	6
8-16	8	6	14	2	6	8
8-17	5	6	11	1	3	4
8-18	13	17	30	2	5	7
Total	45	70	115	17	41	58
Percent	39.1	60.9		29.3	70.7	

1/ Velocity 3.34 f.p.s., channel width 5 ft., quantity 32.1 c.f.s.

2/ Velocity 5.97 f.p.s., channel width 2.5 ft., quantity 28.7 c.f.s.

4. SWIMMING ABILITY OF FISH

Studies in 1957 demonstrated that all chinook and steelhead could ascend an 84-foot flume against a velocity of 8 f.p.s., but only 50 percent of the chinook and 91 percent of the steelhead were able to do so when the velocity was increased to 13.4 f.p.s. Studies were then conducted in 1961 to determine the velocity at which performance of chinook began to decline. Tests were carried out at velocities of 11.4, 12.6, 13.2 and 13.6 f.p.s. All of the fish tested (Table 5) were able to ascend the 84-foot flume at these velocities. This suggests that there may be seasonal or racial differences in swimming ability. The 1957 studies were conducted with fall-run chinook and steelhead, and the 1961 tests were conducted with summer-run chinook and steelhead.

Table 5 - Numbers of Chinook Salmon and Steelhead Trout Passing Through an 84-foot Flume in Velocities Ranging from 11.4 to 13.6 f.p.s., July 19-28, 1961. All Fish Tested Passed Through Flume.

Mean Velocity	Number of Fish Tested	
	Chinook	Steelhead
F.p.s.		
11.4	50	112
12.6	50	80
13.2	6	8
13.6	20	52

In the course of the velocity studies, supplemental observations were made on shad (Alosa sapidissima). Some shad ascended the 84-foot flume in velocities of 6 and 8 f.p.s. At higher velocities (11.4 to 13.6), there appeared to be an inverse relationship between velocity and swimming distance (Table 6).

Table 6 - Performance of Shad in Water Velocities of 11.1 to 13.4 f.p.s., July 18-28, 1961

Date	Water Velocity	Distance Covered in Feet			
		Mean		Maximum	
			Number of Fish		Number of Fish
July 21	11.4	27.2	62	54	1
22	11.4	29.2	193	59	1
23	11.4	32.0	160	65	2
24	11.4	30.5	107	59	1
25	11.4	29.9	30	60	1
25	12.6	19.1	18	30	2
26	12.6	24.8	29	43	2
27	12.6	24.8	25	44	2
18	13.2	18.8	72	35	2
19	13.2	18.8	126	40	1
28	13.6	11.7	15	20	1

5. TRANSPORTATION CHANNEL WATER VELOCITY

Exploratory experiments indicated that a transportation channel water velocity less than the accepted standard of 2 f.p.s. might be satisfactory for passage of fish. A study was then conducted to compare fish passage at a water velocity of 1 f.p.s. with passage at the standard of 2 f.p.s.

The channel was 4 feet wide by 91 feet long and was operated at a water depth of 6 feet. The timing zone was about 100 feet long, as it included a short introductory area in addition to the channel. Fish were timed individually.

Two tests were run with chinook, and one each with sockeye and steelhead. Passage times were about the same at each velocity (Fig. 11), but differences in passage times between species were noted. The similarity in passage times suggests that the lower water velocity of 1 f.p.s. in a transportation channel might be as satisfactory for fish passage as the standard of 2 f.p.s.

6. PASSAGE OF SALMONIDS THROUGH PIPES

Discussion

Since pipes are potentially useful as transportation channels for migrating adults salmonids, studies were conducted to explore factors affecting passage of fish through pipes. The work included tests on the effect of light, water velocity, transition zones, depths of flow, and pipe diameter on fish passage.

Experimental equipment included straight pipes about 100 feet long, 1, 2 and 3 feet in diameter, and a 270-foot long pipe, 2 feet in diameter having two 180° bends (Fig. 12). Only the long pipe was lighted inside. Lights were 75-watt floodlights spaced 7 feet apart on the straight portions of the pipe (Fig. 13). Fish were timed individually through the pipes.

Results

Varying water velocity, in the range of 1 to 4 f.p.s., did not affect passage of chinook, sockeye or steelhead in 2-foot and 3-foot diameter pipes. In a 1-foot diameter pipe, sockeye and steelhead moved through the pipe slower at the lower velocities and a 1 f.p.s. velocity in a 1-foot diameter pipe was not suitable for chinook.

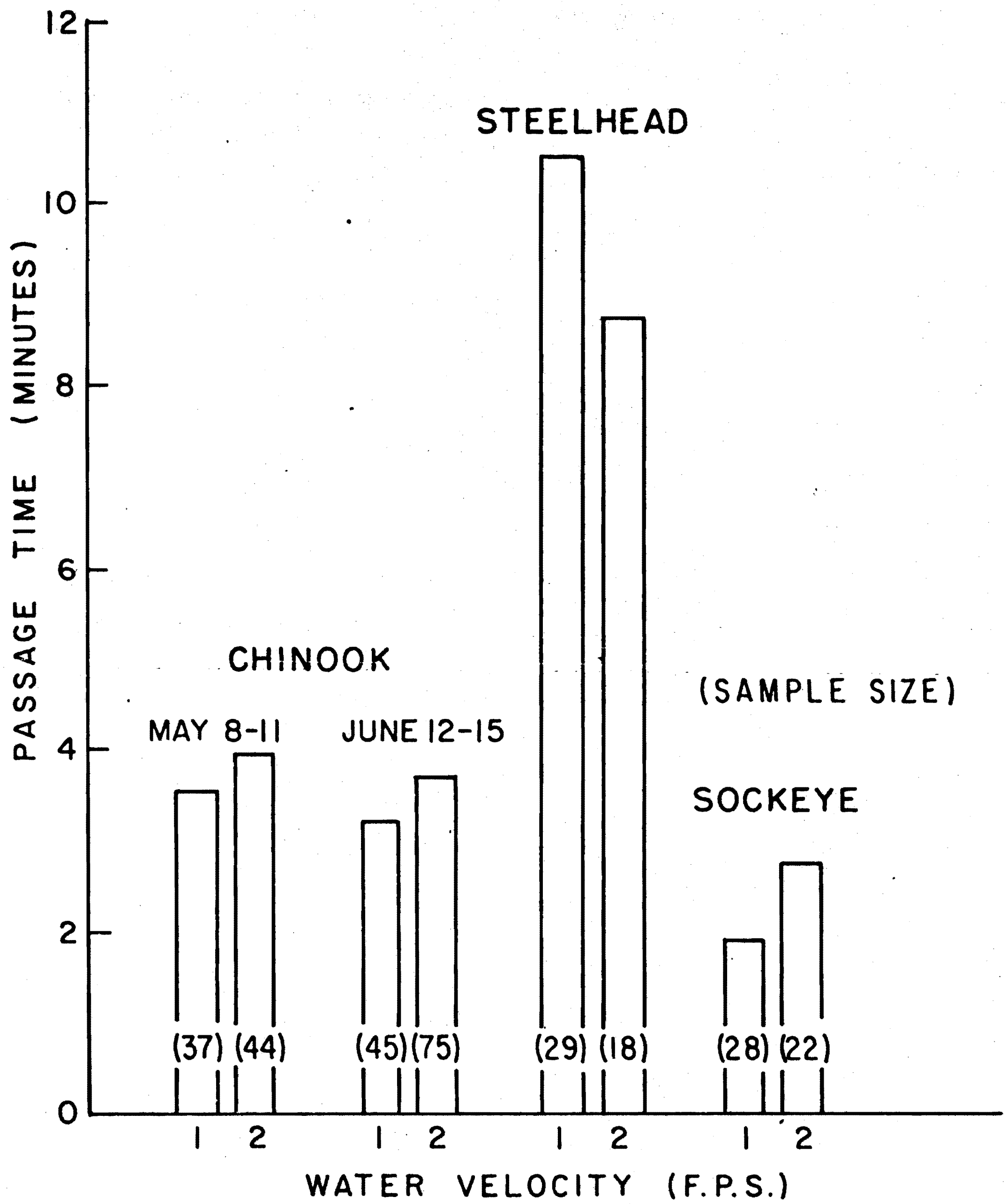

Figure 11 - Median passage times of chinook salmon, sockeye salmon and steelhead trout in a transportation channel having water velocities of 1 and 2 f.p.s. (1962).

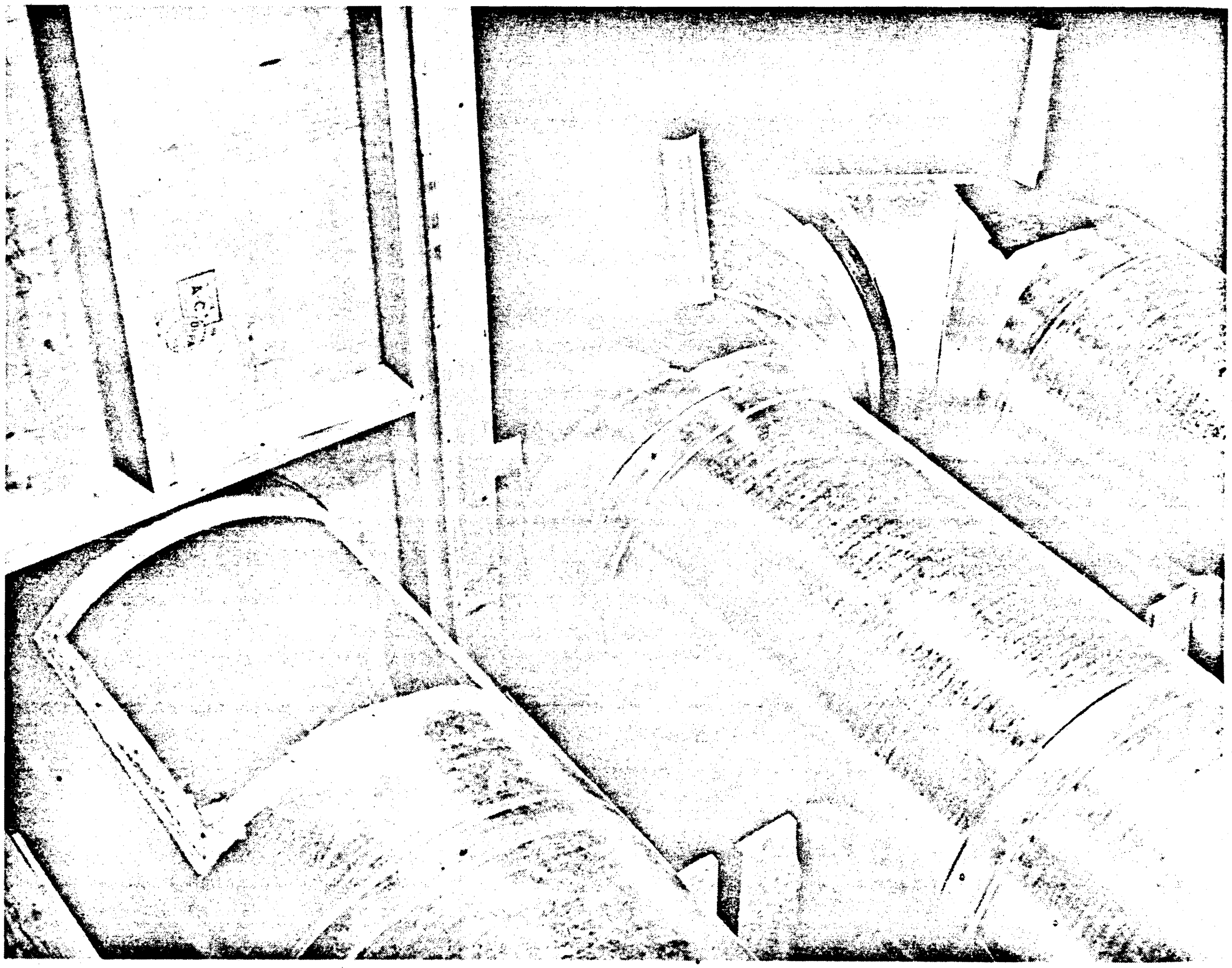

Figure 12 - Plexiglass window for viewing fish as they enter 2-foot-diameter pipe. One of the 180° turns is shown on right.

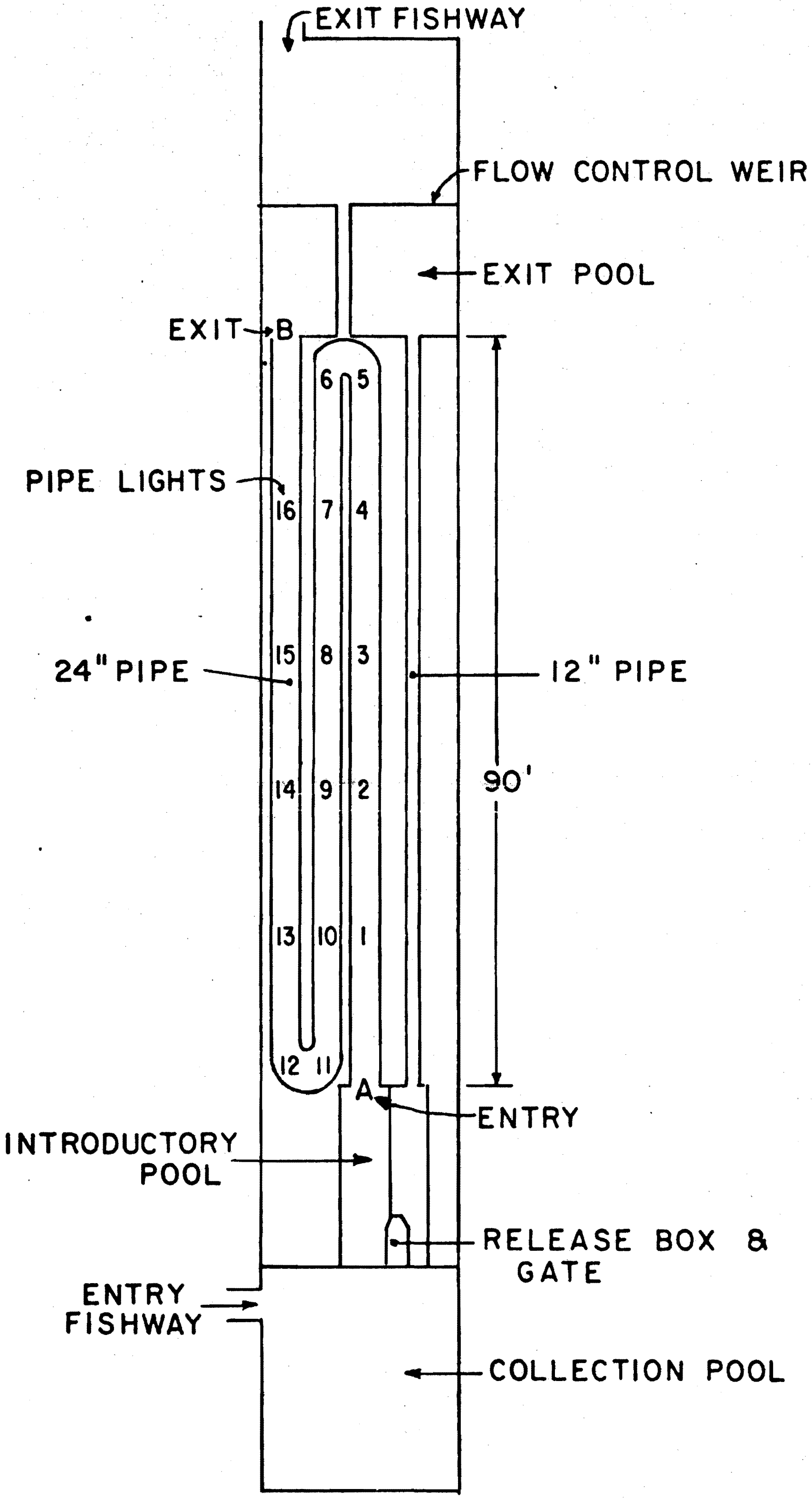

Figure 13 - Diagrammatic plan view of laboratory showing pipe arrangement. Pipe lights are at numbered points 1 through 16.

A truncated cone, used as a transition zone from pool to pipe, made the 1-foot-diameter pipe more acceptable to chinook, sockeye and steelhead but had no effect on entry into the 2-foot-diameter pipe. These cones were 10 feet long, 3 feet in diameter at the downstream end, and tapered to fit the pipes at the upstream end.

Light speeded passage of steelhead through the 270-foot long pipe more than it speeded passage of chinook, coho and sockeye (Table 7). Summer-run chinook moved through the pipe faster under a darkened condition than a lighted one. Conversely fall chinook moved faster under a lighted condition than a darkened one. Sockeye and coho also moved faster through the pipe under a lighted condition than under a darkened one.

A capacity study was conducted to determine the number of salmonids that could be passed through a 2-foot-diameter straight pipe 90 feet long. In the test involving the greatest number of fish, about 12 fish per minute passed through the pipe for a 60-minute period, and 15 fish per minute during the peak 20-minute period. Species composition was about 52 percent chinook, 41 percent steelhead and 7 percent coho.

Table 7 - Passage of Salmonids Through a 2-Foot-Diameter Pipe 270 Feet Long Under Dark and Light Conditions, 1964

Date	Species	Median Passage Time			
		Dark		Light	
		Number of Fish	Minutes	Number of Fish	Minutes
June 25-28	Chinook	39	7.8	25	11.8
Aug. 28-31	Chinook	31	10.0	62	5.5
July 12-15	Sockeye	45	8.5	41	6.8
Sept. 8-11	Coho	24	11.1	17	7.2
July 17-20	Steelhead	22	24.6	52	7.0

In a test comparing passage under full and partially full conditions, chinook and steelhead moved through the 270-foot long pipe faster when the pipe was only partially filled with water than when it was completely filled. When partially filled, water depth was about 20 inches, leaving a 4-inch air space.

7. RESPONSE OF SALMONIDS TO VERTICAL AND HORIZONTAL RECTANGULAR ORIFICES

Discussion

The objective of this study was to determine whether a vertical or a horizontal orifice is the most satisfactory for fish passage and if orifice depth affects use of the orifice. A pair of 2-by-5-foot rectangular orifices were installed at the junction of two channels with the collection pool (Fig. 14). The orifices could be installed in either vertical or horizontal positions, and at 3- and 9-foot depths (on the centerline). A 1-foot head was maintained on the orifices, giving a flow of about 49 c.f.s. through each.

Eight test conditions were used in this experiment. Conditions A, B, C and D (Fig. 15) provided for a direct comparison of the proportion of fish utilizing vertical and horizontal orifices at deep and shallow positions. Conditions E, F, G and H tested the effect of orifice depth on use of horizontal and vertical orifices, respectively.

Results

A total of 3,390 chinook, 9,522 steelhead and 787 coho were tested. A majority of chinook and steelhead entered the vertical orifice rather than horizontal orifice at deep and shallow settings (Conditions A, B, C and D); this utilization was statistically significant at the deep setting. A majority of chinook and steelhead entered shallow orifices rather than deep ones (Conditions E, F, G and H), and this difference was statistically significant when orifices were horizontal. Coho responses to the test conditions were the same as chinook and steelhead with one exception -- more coho entered the deep vertical orifice than the shallow one.

8. COUNTING STATION DESIGN

Discussion

A preliminary study was made to explore means of improving fish counting methods at dams on rivers where turbidity is a problem. A submerged observation chamber served as a counting station. A vertical light panel 4 feet square was installed in a watertight enclosure so that the distance between the light panel and counting station could be varied from 1 to 4 feet (Fig. 16). Fish passed the counting area between the light panel and observation window.

Results

Individual tests were conducted with the light panel set 1, 2, 3 and 4 feet from the viewing window. Secchi disk readings ranged from 2.0 to 2.8 feet during the tests. In general, counts and identification of species were quite accurate at the 1- and 2-foot settings. Identification of species was not always possible at the 3- and 4-foot settings.

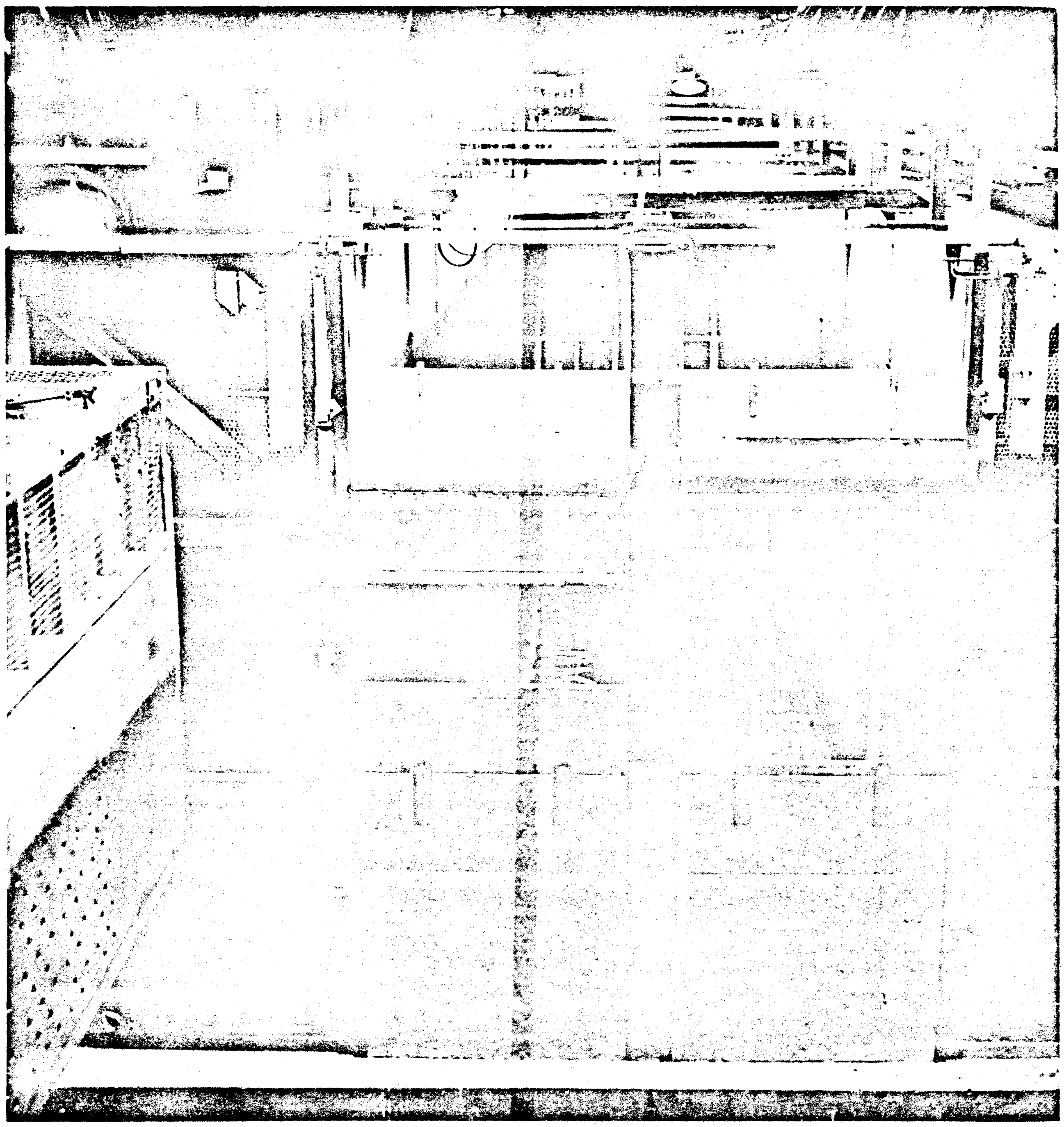

Figure 14 - Test area unwatered to show horizontal (left) and vertical (right) orifice choice condition at the shallow setting--centerline of orifice 3 feet below water surface.

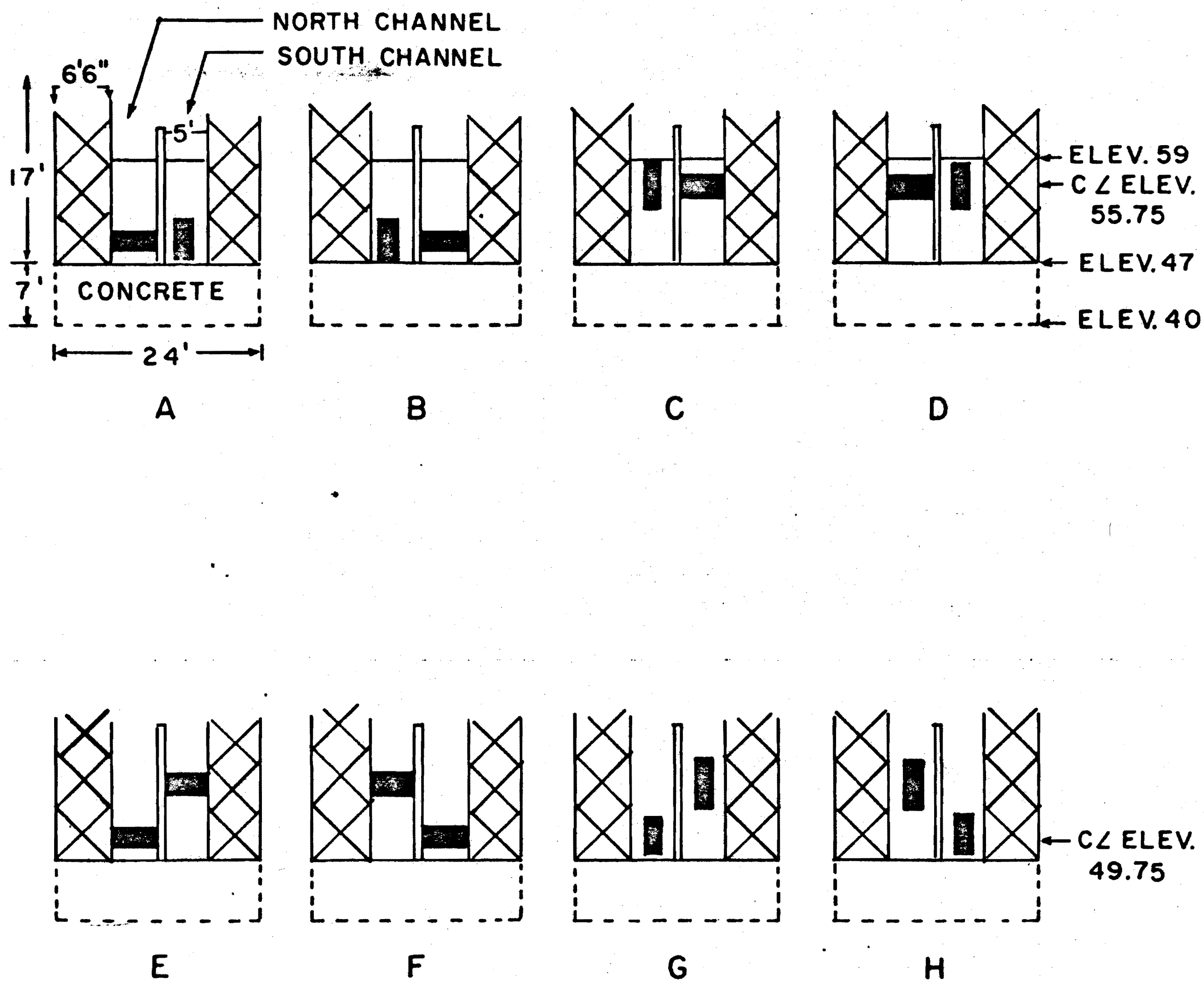

Figure 15 - Sectional views showing eight test conditions used in orifice study.

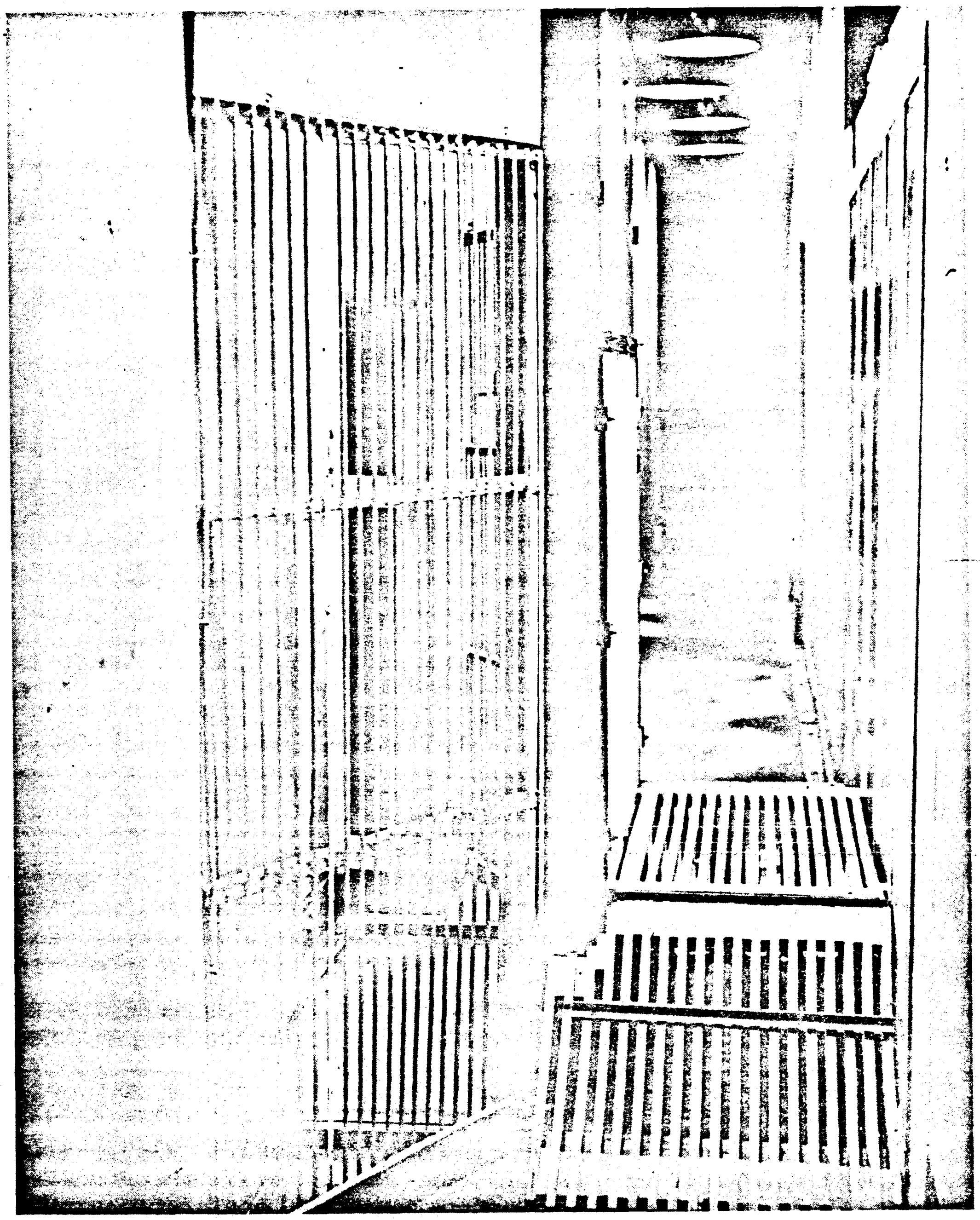

Figure 16 - Installation used in counting station design study. Submerged observation chamber (right) and lighted panel (center) are set 2 feet apart.

9. FISH SEPARATION STUDIES

Discussion

There is a growing need for knowledge on methods of separating species or populations of fish in relation to water resource development. For example, the loss of spawning grounds due to inundation by impoundments is becoming a serious problem in the Columbia River system. Fisheries agencies seek to segregate the displaced spawners from other stocks bound for upriver spawning areas and use these fish for artificial propagation. In other instances it may be necessary to transport adult stock around reservoirs. If there is more than one tributary system to a reservoir, the individual races must be segregated before they are placed in their respective spawning streams. On occasion, some of the less desirable species (carp, suckers, etc.) become a problem in fishways or need to be controlled to reduce competition or predation on the more prized species. Sorting out the so-called scrap species could be a decided benefit to salmonids.

Studies were conducted on the possibility of separating a race of chinook during the spawning migration by use of home-stream water, on mechanical separation of chinook salmon stocks distinguished by color differences, and on separation of resident fishes from salmonids in fishway situations.

The separation with home-stream water was based upon the hypothesis that during their spawning migration, chinook salmon home upon some distinctive quality in the water imparted from their home stream. The race of chinook studies was the one destined for Spring Creek Hatchery, about 25 miles above Bonneville Dam. Adult chinook passing through the laboratory were offered a choice of entering one of five similar channels (Fig. 17). Flow in each channel was about 3.6 c.f.s. or 1,620 gallons per minute (g.p.m.). During control tests, flow and composition of water in the channelswere identical. During experimental tests, about 11 g.p.m. of Spring Creek water was introduced into one of the channels. This water was hauled by tank truck from Spring Creek Hatchery. After making a choice of channels, both test and control fish were tagged and released.

Results

The response of the Spring Creek fish to the choice array was determined from tagged fish arriving at the hatchery. A total of 565 chinook were subjected to the choice condition and subsequently tagged and released. Of the 42 fish recovered at Spring Creek, 17 were tagged during control tests and 25 during tests when Spring Creek water was being added into Channels 3 and 4. A comparison of the response of the fish during test and control conditions (Fig. 18) indicates that Spring Creek chinook were not attracted when Spring Creek water was introduced. Further studies would appear to be warranted, however.

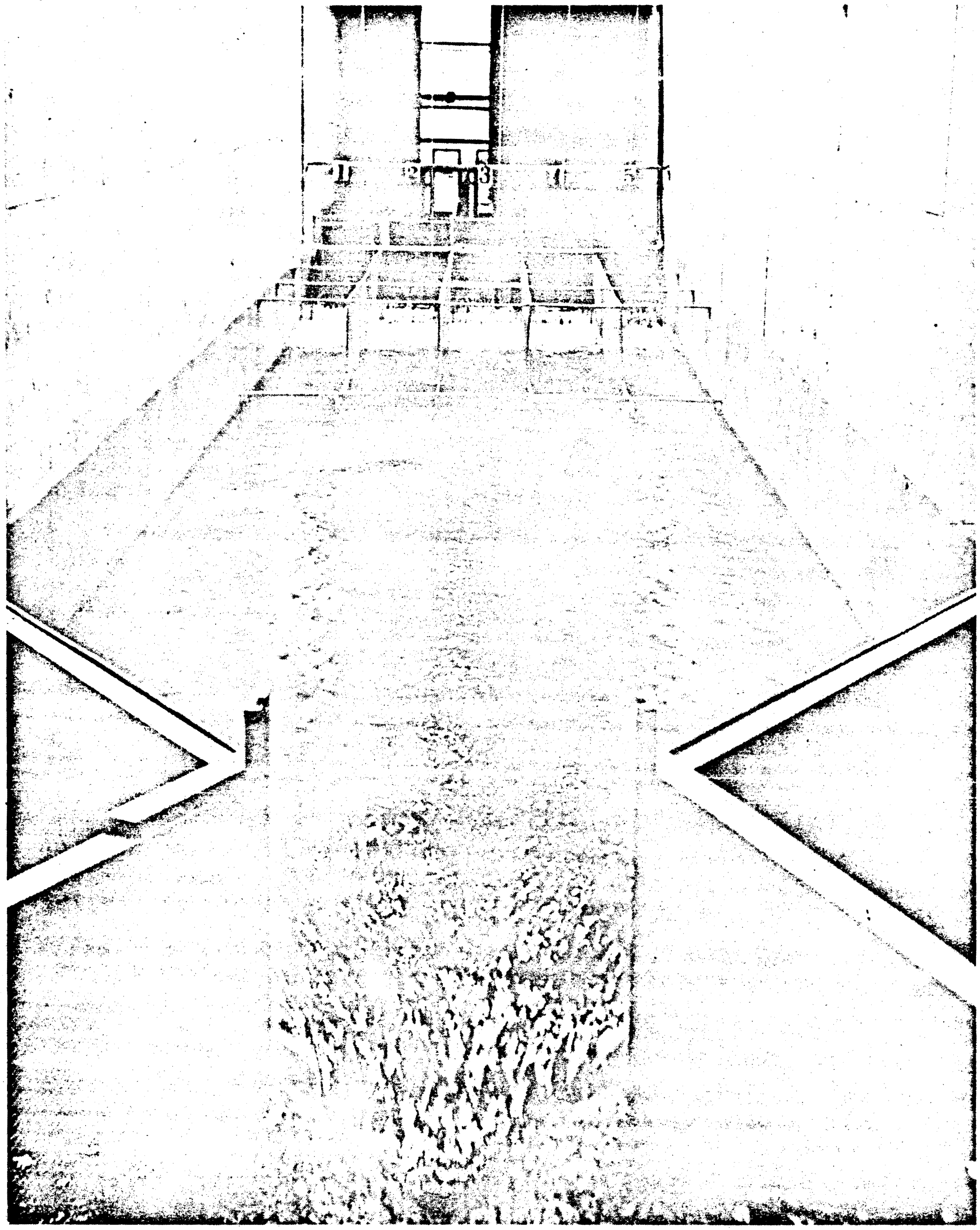

Figure 17 - Choice area, channels and holding pens (in darkened area) with Spring Creek water being introduced into Channel #3. Note chinook salmon just below entrance to Channel #2. Vertical ropes in background are used to operate drop screens at entrance to holding pens.

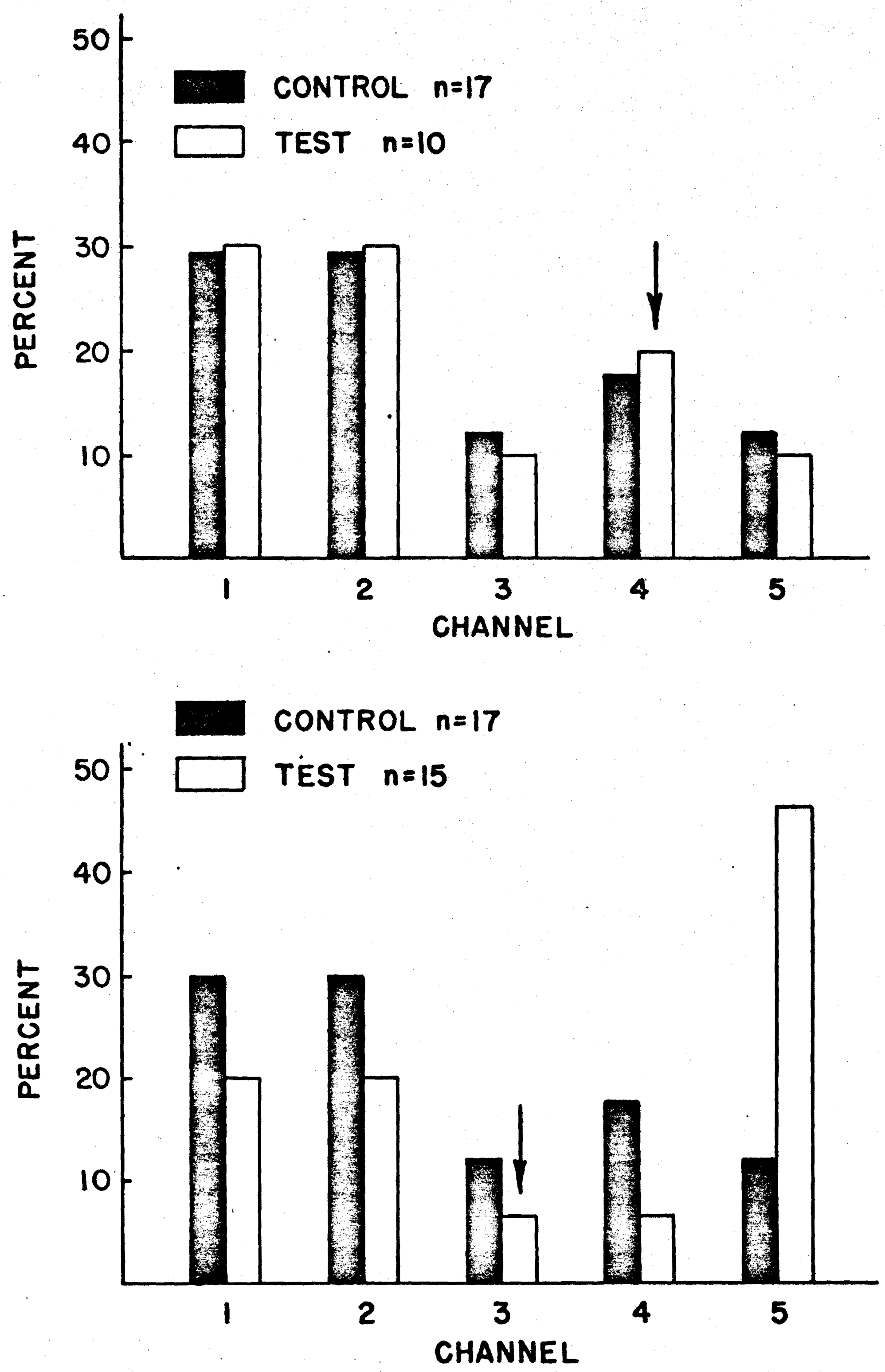

Figure 18 - Results of tests at Bonneville on the response (proportions entering each channel) of Spring Creek chinook salmon to home stream water. Arrows indicate channel carrying added amounts of Spring Creek water under test conditions.

Segregation on the basis of skin coloration (light or dark) required that fish go over a false weir onto a slide (Fig. 19). An operator then deflected the fish into the proper channels according to skin color as they descended the slide. A second sorter (Fig. 20) appeared to be more satisfactory than the first one tested. Results demonstrated that this was a practical method for separating chinook on a basis of skin color or for separating species--provided the operator was competent and experienced.

The separation of resident species from salmonids was done in a typical fishway pool (Fig. 21). Perforated plates and gratings were used to sort out the smaller resident fish as they passed through the orifice. The larger salmon were diverted over the overfall. The most successful separation was made with a perforated plate having 2-1/2 inch diameter holes. About 61 percent of all suckers passing up the fishway were diverted and trapped using this plate. All of the salmonids went over the weir.

10. CURRENT RESEARCH

Studies undertaken during fiscal year 1966 season include investigation of (a) the response of adult migrating salmonids to changes in water temperature; (b) the effect of pipe length and light on passage of salmonids through pipes; and (c) the mechanics of fingerling collection in turbine intakes.

Response of adult salmonids to changes in water temperature will be determined by subjecting them to a choice of two channels having different water temperatures. Heating equipment will raise the temperature of 2 c.f.s. about 2° C. above river temperature and cooling equipment will cool a like amount about 1.6°C.

Effect of pipe length and light on fish passage will be determined in a circular "endless" pipe in which the willingness of fish to swim long distances will be examined. Electronic detectors will be used to record passage through the pipe.

It has been noted at Bonneville and other dams that juvenile salmonids collect in turbine intake gate slots. This general area represents a potential collection site for downstream migrants. A scaled down version of a turbine intake has been built in the laboratory. It consists of a sloping conduit with risers spaced along the axis (Fig. 22). Fish are introduced into the conduit where they are subject to an increasing pressure change as they descend. Studies are now in progress to measure the response of chinook fingerlings to this pressure change and to explore methods of enhancing collection of fish in the riser. Methods of attracting fish out of the risers into a bypass will also be investigated.

Figure 19 - Sorter used in first test on mechanical separation of chinook salmon on basis of coloration. Fish have just gone over false weir and are starting down slide.

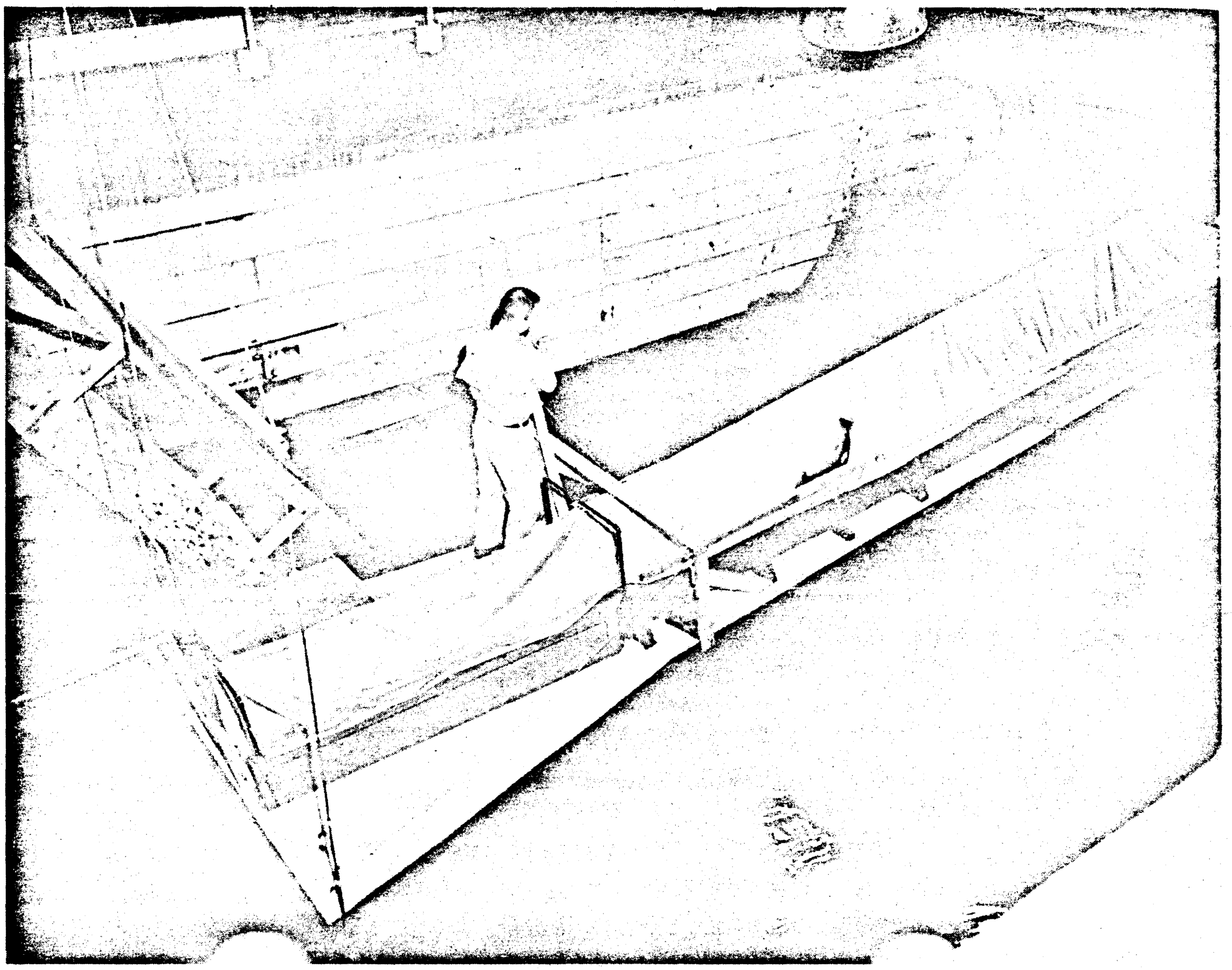

Figure 20 - Another sorter tested in mechanical separation of chinook. Lever in hand of operator moves lower end of slide to divert fish into proper channel.

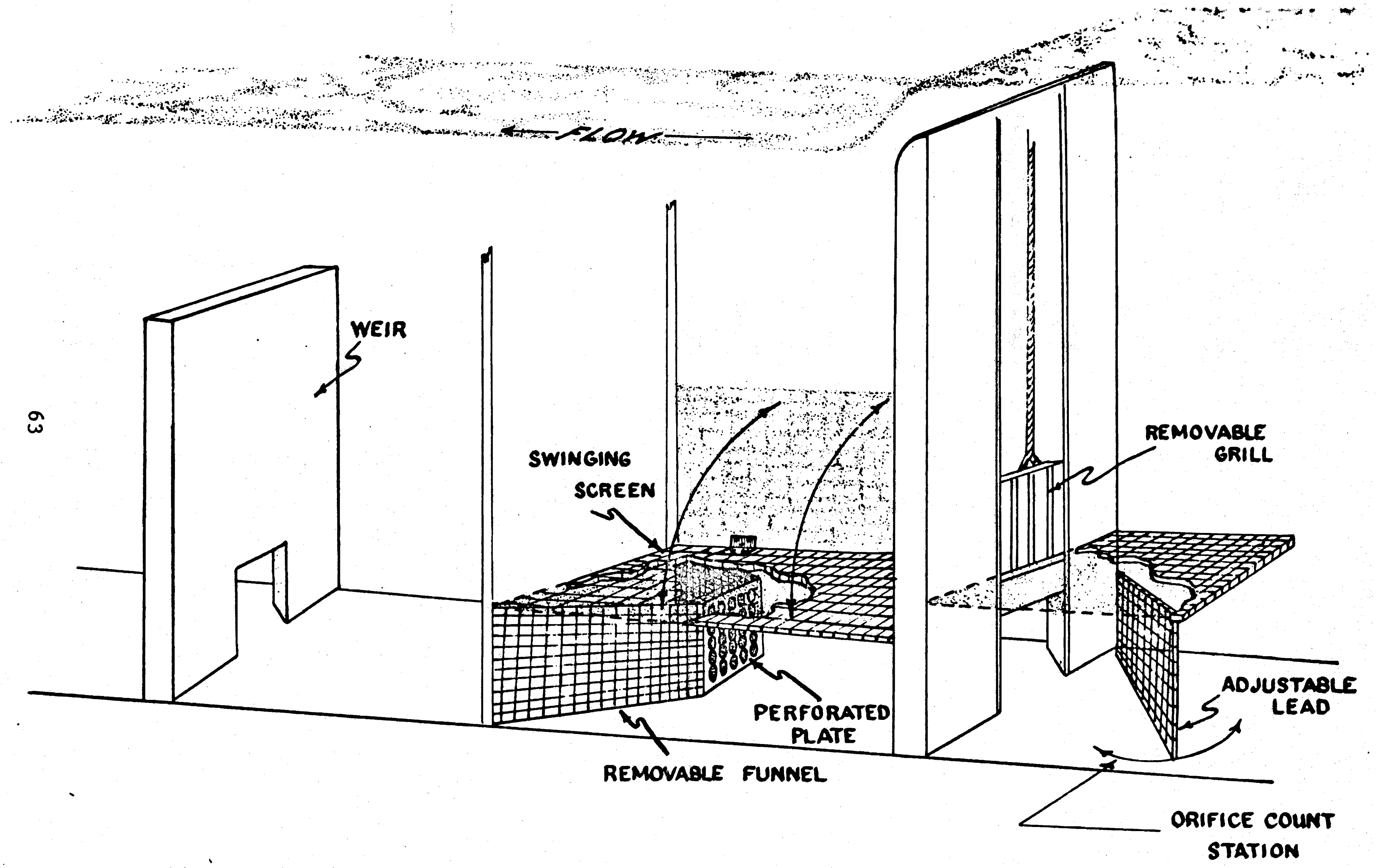

Figure 21 - Simulated fishway pool showing orifice and sorting devices used in study on separating resident fishes from salmonids.

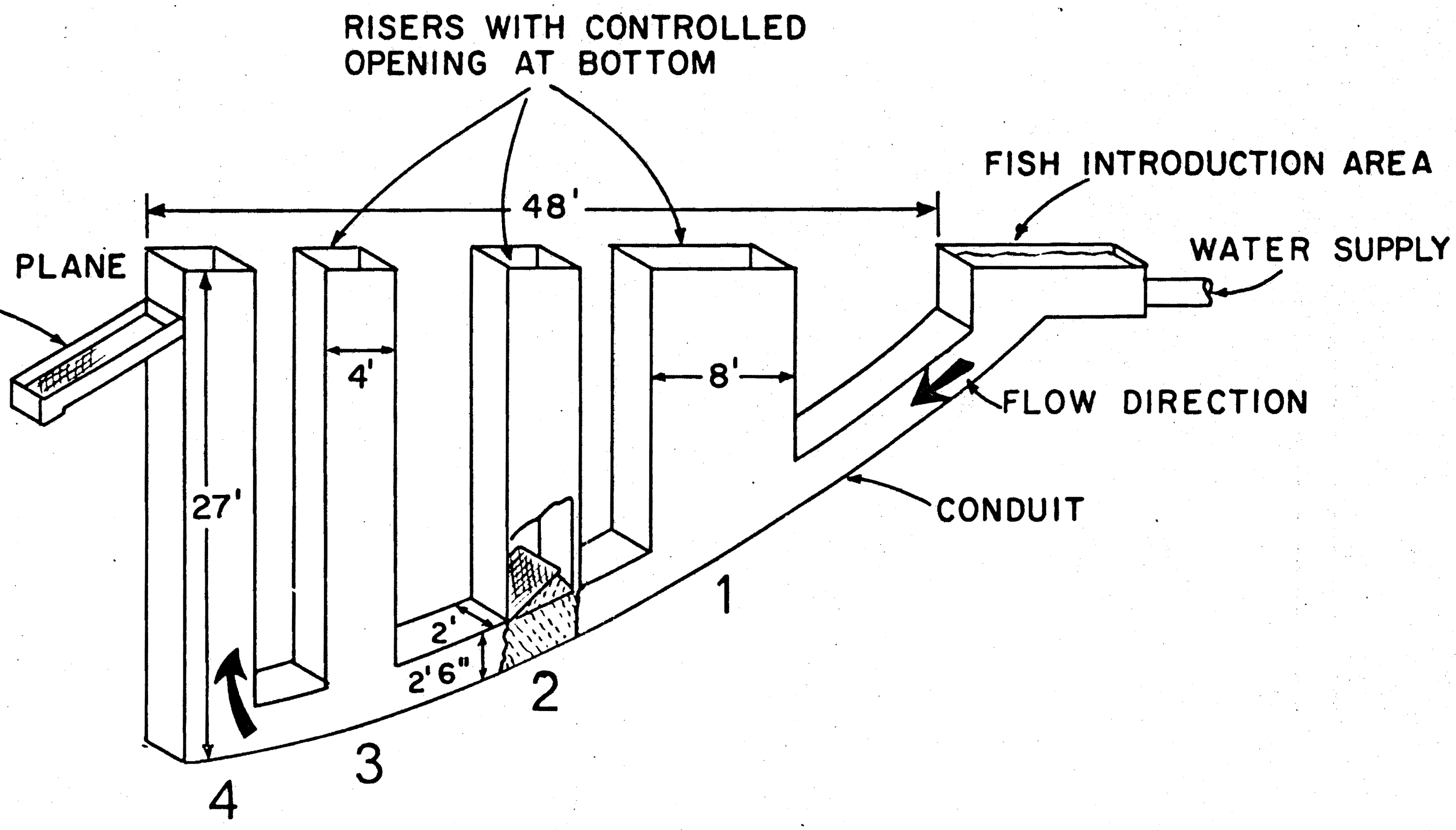

Figure 22 - Experimental device for study of response of salmonid fingerlings to pressure changes encountered in turbine intakes.

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   Effect of Water Velocity on Passage of Salmonids in a Transportation Channel.

2. GAULEY, JOSEPH R. and CLARK S. THOMPSON
   Diffusion Water Velocity - Its Effect on Salmonid Passage Through a Transportation Channel.

3. LONG, CLIFFORD W.
   Effect of Light on Orientation and Rate of Movement of Adult Salmonids in a Channel.

4. SLATICK, EMIL
   Passage of Adult Salmonids Through Pipes.

5. THOMPSON, CLARK S.
   Effect of Flow Pattern on Performance and Behavior of Salmon in Fishways.

6. THOMPSON, CLARK S., WILLIAM S. DAVIS and EMIL SLATICK
   Response of Migrating Adult Salmonids to Vertical and Horizontal Rectangular Orifices at Two Depths.

7. WEAVER, CHARLES R. and CLARK S. THOMPSON
   Evaluation of the 1-on-10 Slope Fish Ladder at Ice Harbor Dam.

8. GAULEY, JOSEPH R. and CLARK S. THOMPSON - 1963
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   Passage of Salmonids Through a Darkened Fishway. U. S. Fish and Wildlife Service, Special Scientific Report - Fisheries No. 300, 9 pp.

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    Observations on the Swimming Ability of Adult American Shad (Alosa sapidissima). In press. Transactions of the American Fisheries Society, Vol. 94.

RESEARCH ON FISHWAY PROBLEMS
MAY 1960 TO APRIL 1965

Joseph R. Gauley, Charles R. Weaver and Clark S. Thompson
U. S. Bureau of Commercial Fisheries

INTRODUCTION

The increasing number of water use projects in the Columbia River system poses a constant threat to the anadromous fishery resource by obstructing the natural migratory routes of these fish. Fish passage facilities are normally provided in these circumstances, and considerable planning is often necessary to achieve the safest and most efficient conditions for fish. In line with these needs, the U. S. Army Corps of Engineers has sponsored a program of fisheries engineering research to secure design criteria for such structures.

The Fisheries-Engineering Research Laboratory at Bonneville Dam was completed as a part of the above program and has been operated continually since 1955 by the Bureau of Commercial Fisheries under contract to the Corps. The primary aim of research at Bonneville has been to provide basic knowledge of the behavior, abilities and requirements of fish in fish passage situations. Major emphasis has centered on seeking means of reducing the cost of fish passage facilities without impairing their efficiency. The laboratory has contributed materially to fishway design criteria in several areas, resulting in major savings in construction and operational costs. This report summarizes research conducted during the second 5-year period (May 1960-April 1965) of operation.

INVESTIGATIONS

1. FISHWAY SLOPE

Discussion

Earlier studies on fishway slopes at the Fisheries-Engineering Research Laboratory demonstrated that a slope steeper than 1-on-16 was suitable for fish passage if proper hydraulic conditions were maintained. This work led to further development and testing by the Corps of Engineers Hydraulic Laboratory and ultimately resulted in the design of the 1-on-10 slope ladder for Ice Harbor Dam on the Snake River. Evolution of this ladder initially included development of suitable hydraulic conditions by model studies at the Hydraulic Laboratory. This was followed by study of fish passage in a full scale 6-pool section of the ladder in the Fisheries-Engineering Research Laboratory. The final stage was reached when the prototype ladder was tested during its first year of operation at Ice Harbor Dam.

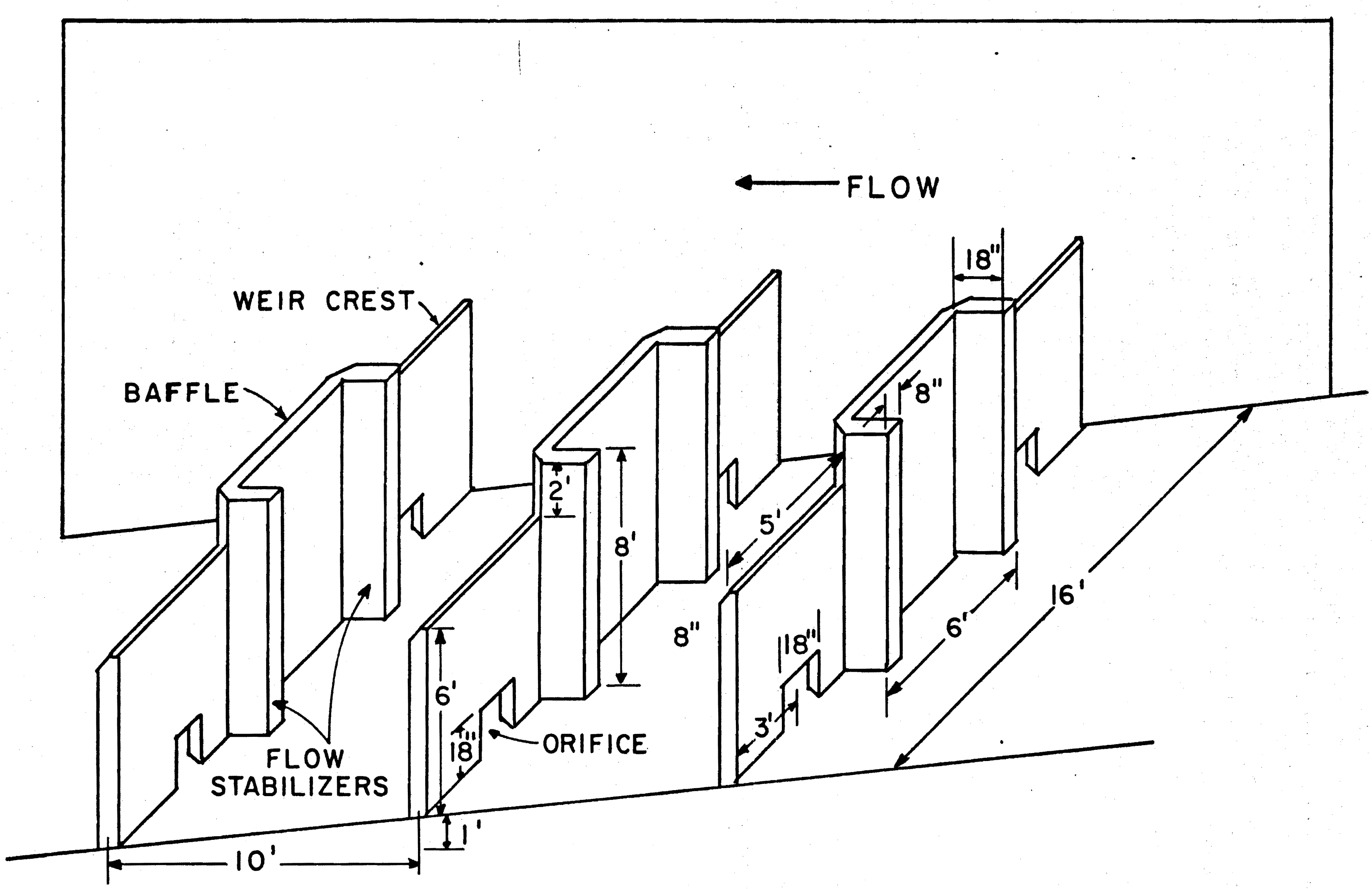

Figure 1 - Pool and Weir Dimensions of the Ice Harbor Fishway Design

The new 1-on-10 slope fishway is a pool-and-overfall type with submerged orifices, flow stabilizers and a non-overfall section in the middle of each weir (Fig. 1). There is a 1-foot rise between pools, and average water depth under normal operating conditions is 6.5 feet. The fishway tested in the laboratory was constructed of wood so that it could be modified to produce a variety of test conditions.

a. Laboratory Evaluation. Performance and behavior of chinook salmon (*Oncorhynchus tshawytscha*), sockeye salmon (*Oncorhynchus nerka*), coho salmon (*Oncorhynchus kisutch*), and steelhead trout (*Salmo gairdneri*) were evaluated under normal operating conditions of the fishway. Tests were also conducted with a half-width fishway (Fig. 2), orifice flows only (non-overfall flow), overfall flow only, and higher than normal flow. Three weir crest designs--McNary type, The Dalles type, and plane-surface ogee type--were tested. Underwater viewing facilities were provided for observing fish behavior and hydraulics.

Tests were carried out using individual fish in the fishway, groups of mixed species, and capacity type concentrations which were similar to group releases, but involved larger numbers of fish.

Passage times were obtained to assess performance of fish ascending the ladder under various operational conditions. A comparison of passage times of salmonids under half-width and full-width fishway conditions shows that chinook made significantly faster ascents under the half-width fishway condition than under the full-width condition, but that sockeye and steelhead performed about the same under either condition. Capacity tests were conducted in the half-width fishway. Several trials were run of which the largest group tested in a 1-hour period numbered 1,371 fish. However, the numbers of fish available were considered insufficient to demonstrate that capacity of the fishway had been reached. During the passage of these large groups, there was no evidence that movement of fish was impeded.

In a comparison of weir crests, McNary and plane-surface ogee crests appeared to improve hydraulic conditions and hasten fish passage slightly when they were used in lieu of a Dalles-type crest specified in the original design.

Observations were made on effect of various flow conditions on the passage of fish. Chinook and steelhead made significantly faster ascents under an overfall and orifice flow condition when the head on the weir was increased from 0.95 foot to 1.20 feet. With the orifices closed both species made significantly slower ascents when the head on weir was increased from 0.95 foot to 1.20 feet. Steelhead and chinook accepted this condition quite readily and ascended the fishway without difficulty. Preference for overfall or orifice passage appeared to vary seasonally with chinook and steelhead, but sockeye favored the overfall. Carp, suckers and squawfish favored the orifice, and shad the overfall.

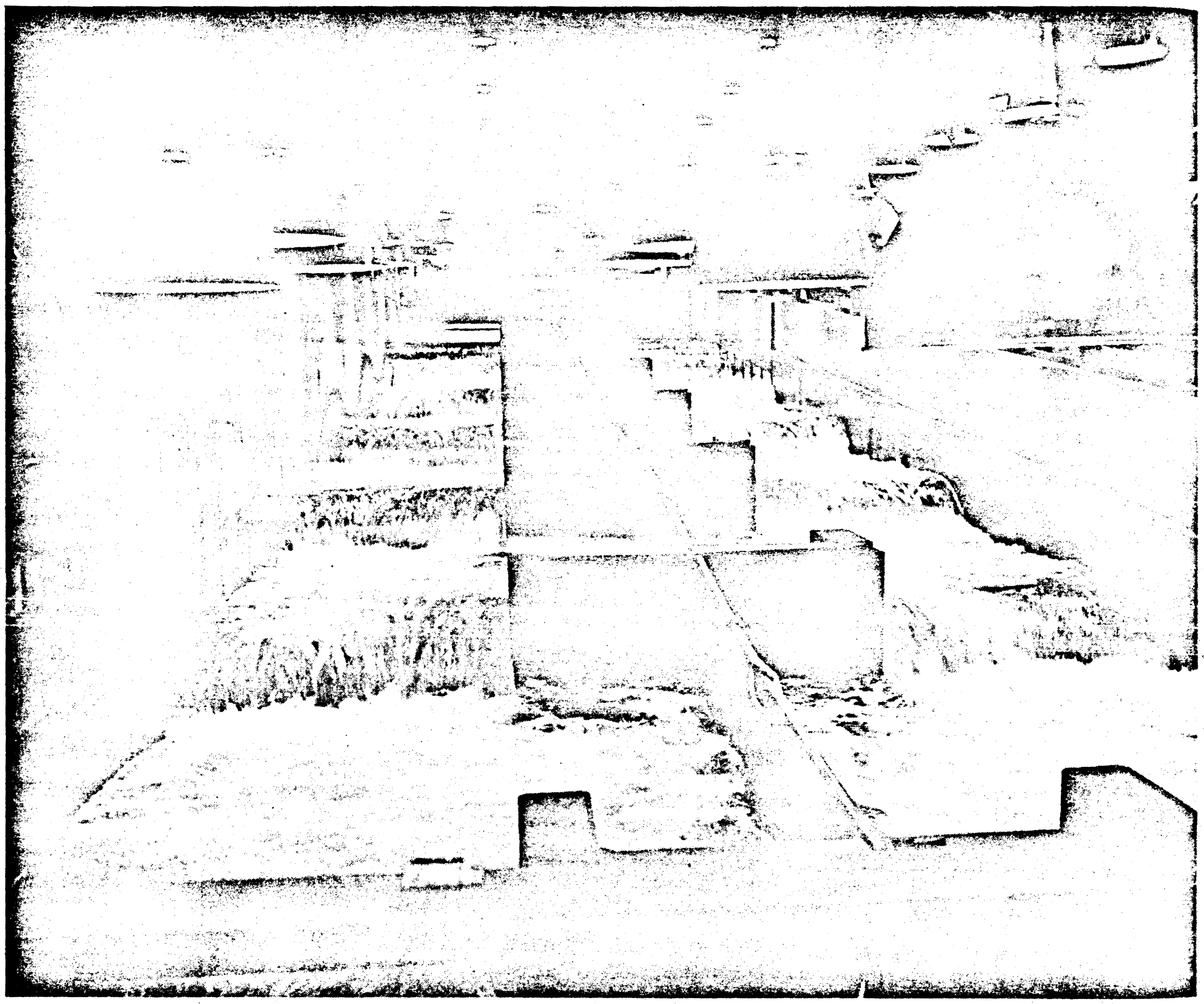

Figure 2. - Ice Harbor Design Fishway Showing Divider Wall in Center to Produce Half-Width Condition.

In brief, the laboratory studies indicated that the 1-on-10 slope fishway would be as suitable for passage of fish as the conventional 1-on-16 slope fishways now in use on the Columbia River.

b. Field Evaluation. The field evaluation of the 1-on-10 slope Ice Harbor design fishway was conducted from May 10 to October 5, 1962, at Ice Harbor Dam on the Snake River. Fish passage facilities at the dam consist of two pool-and-overfall fish ladders: (1) a 1-on-16 slope fishway, 24 feet wide of conventional design (Fig. 3), and (2) a 1-on-10 slope fishway 16 feet wide usually referred to as the Ice Harbor design (Fig. 4).

The objective of the evaluation was to determine if the new 1-on-10 slope fishway would satisfactorily and safely pass salmonids over the dam. This was done by comparing performance of fish ascending the 1-on-10 slope fishway with performance of fish ascending the 1-on-16 slope fishway. Criteria employed in comparing performance of fish in the two ladders included: (1) Proportions of fish successfully negotiating comparable sections of the two ladders during a given period; (2) Rates and patterns of movement through comparable test sections (same or similar number of pools); and (3) Fallback activity (downstream passage within the test area).

Observations were made within a 74-pool test area in each ladder. Temporary partitions were installed longitudinally throughout the test area dividing each ladder into a test and bypass side. Only the test side was employed in the study. Count stations installed at several different elevations within the test area (Fig. 5) provided means of comparing the performance of fish as they ascended various segments of the test areas in each ladder.

Relatively few salmonids failed to complete the test section in either ladder during the individual test periods. Comparisons of salmonid passage patterns at count stations encompassing comparable test sections indicated similar patterns of movement in the 1-on-10 slope and 1-on-16 slope ladders. Passage times based on the time at which 50 percent of the salmonids had crossed each counting station indicated that there was little difference in the rates at which salmonids ascended the entire test area of the two ladders. Average passage times for the 74-pool test section were 1.36 minutes per pool in the 1-on-10 slope ladder and 1.41 minutes per pool in the 1-on-16 slope ladder. Observations of fallback (downstream passage) activity of salmonids during the tests failed to demonstrate any abnormal occurrences in the 1-on-10 slope ladder.

Incidental observations of the behavior of suckers (*Catastomus sp.*), squawfish (*Ptychocheilus oregonensis*), and carp (*Cyprinus carpio*) revealed their performance in both ladders was characterized by consider-

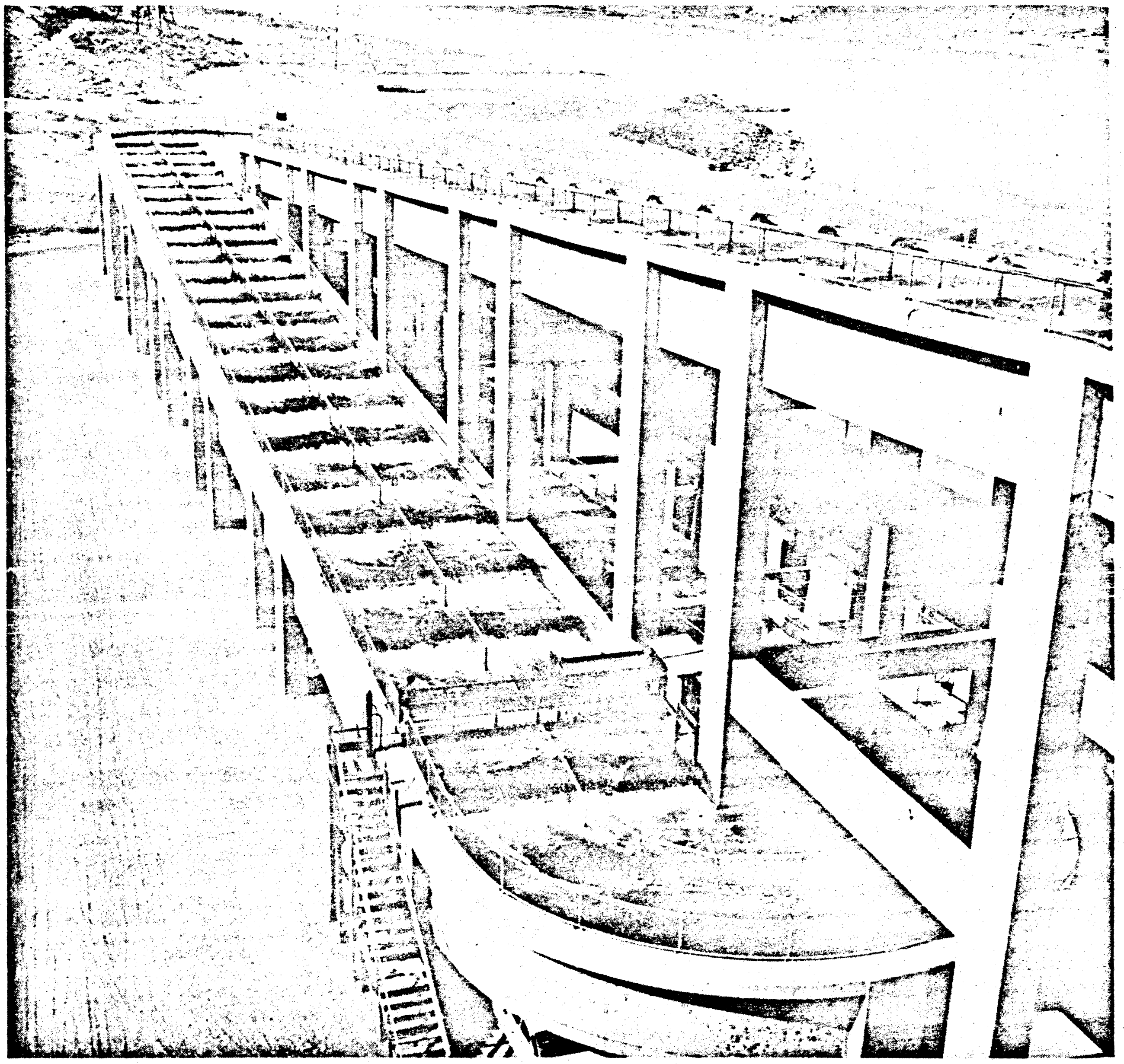

Figure 3 - South Shore 1-on-16 Slope Fish Ladder Showing the Divider Screen and Count Stations for Weir Elevations 380 (to right of bridge) and 381 (on the bridge).

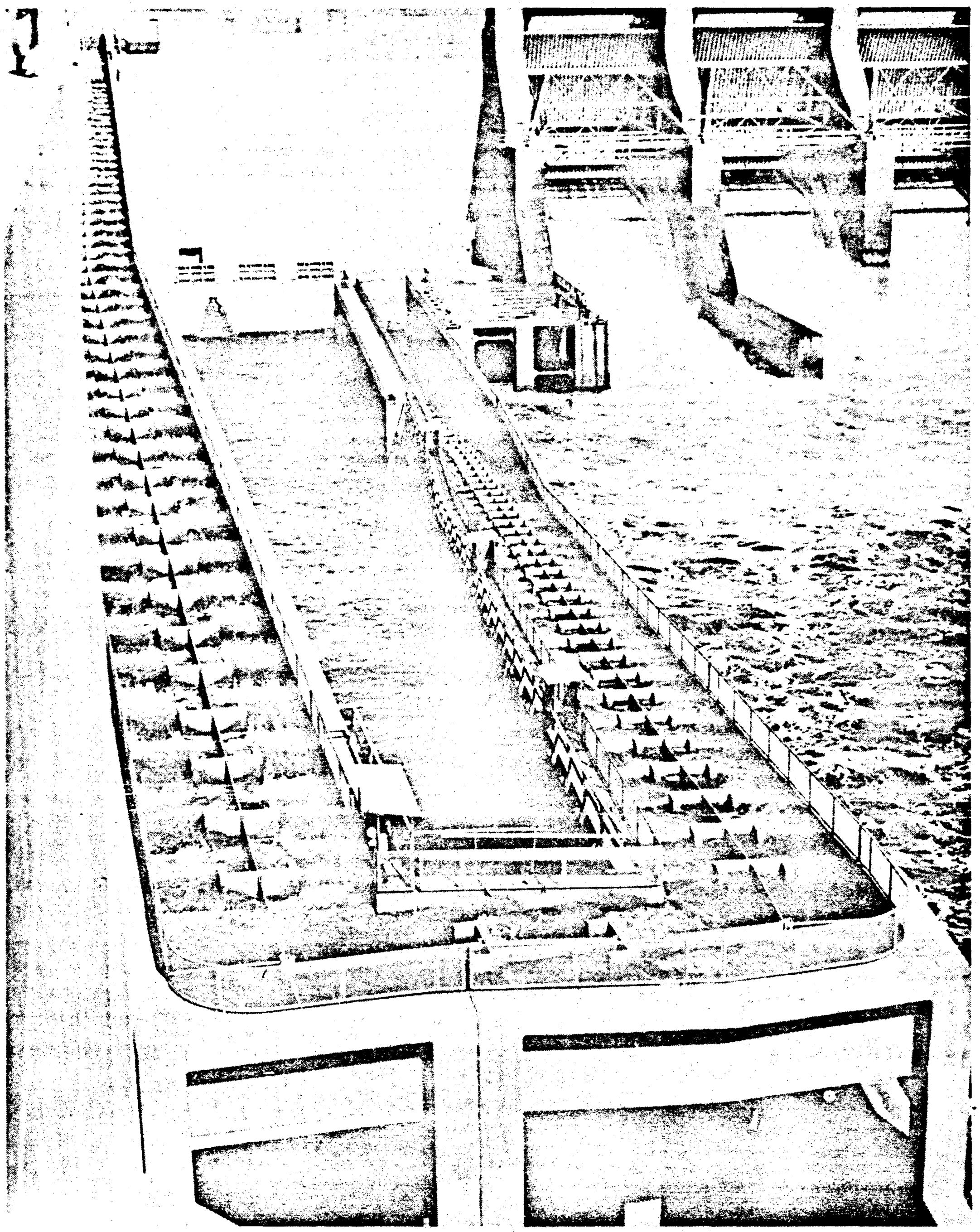

Figure 4 - North Shore 1-on-10 Slope Fish Ladder Showing the Timber Divider Wall and Location of the Five Count Stations. The Uppermost Count Station (Elevation 433) is Barely Visible at the Upper Left Corner.

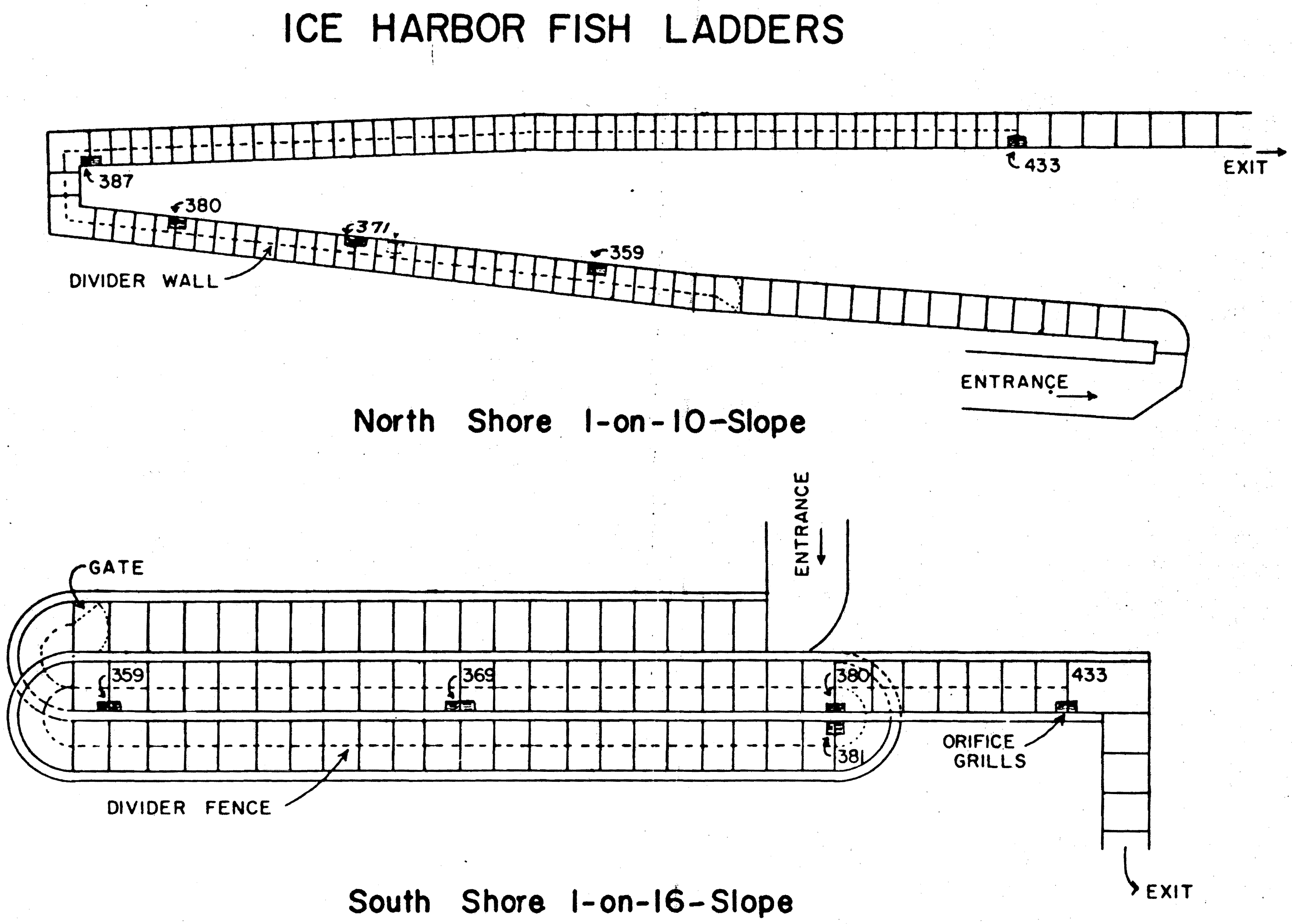

Figure 5 - Ice Harbor Fish Ladders Showing Locations of Count Stations.

able fallback activity and a much slower rate of passage than salmonids. There was no indication that these fish encountered more difficulty in the 1-on-10 slope ladder than in the 1-on-16 slope ladder.

Results

On the basis of preceding results, it was concluded that the 1-on-10 slope ladder will provide adequate passage for the number and species of fish it may be expected to accommodate at Ice Harbor Dam. Since little difference could be detected between performance of salmonids in the two ladders, there is no reason to doubt that a 1-on-10 slope ladder could pass salmonids as efficiently as a conventional 1-on-16 slope ladder designed to accommodate the same number of fish.

2. DIFFUSION WATER VELOCITY

Discussion

Diffusion water, also termed attraction water or auxiliary water, is the water flow that is added to a fish passage facility through a floor or wall diffusor. It is needed to maintain prescribed flows in the lower ends of fishways, in fish collection channels, at fishway entrances, and occasionally in other sections of fishways where depth and width increase.

The presently accepted criteria for gross diffusion water velocities are 0.25 feet per second (f.p.s.) through a flood diffusor and 0.50 f.p.s. through a wall diffusor. The primary objective of this study was to determine the effect of various gross diffusion water velocities on the passage of salmonids in a transportation channel. If higher velocities than those presently accepted do not appreciably deter fish passage, then smaller diffusors could be used in new fishways with a resultant savings in construction and maintenance costs.

Test facilities consisted of a fish transportation channel into which auxiliary water was added from either a floor- or wall-type diffusor. Diffusion water velocities ranged from 0.25 to 1.25 f.p.s. through the floor diffusor and from 0.25 to 2.00 f.p.s. through the wall diffusor. The channel was 4 feet wide by 91 feet long exclusive of a short introductory area (Fig. 6). Water depth was 6 feet, and velocities upstream of the diffusion area were maintained at approximately 2 f.p.s. The installation for the floor diffusor was essentially the same for the wall diffusor (Fig. 7) except that the former discharged up through the bottom of the channel.

The effect of diffusion water velocity on fish passage was determined by timing individual fish through the channel (A to B, Fig. 6). A Latin Square design was used in conducting the experiments with some variation in design between years.

Median and mean passage times of spring chinook (Table 1) show that the addition of diffusion water at any velocity through the floor diffusor delayed the passage of fish. This was also true of fall chinook and steelhead. A comparison of median passage times of chinook through

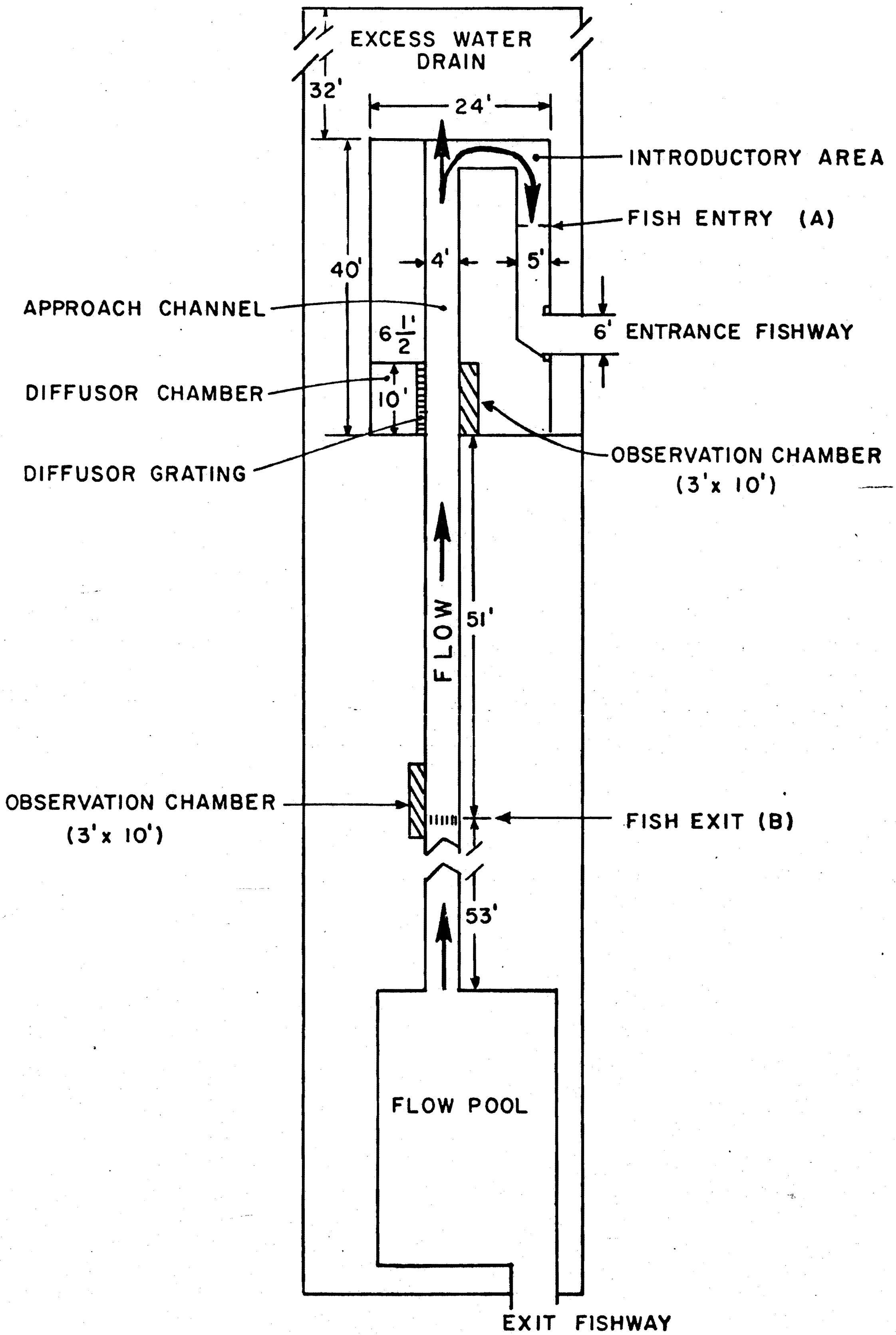

Figure 6 - Plan view of experimental area for testing response of salmonids to gross diffusion water velocities from a wall diffusor.

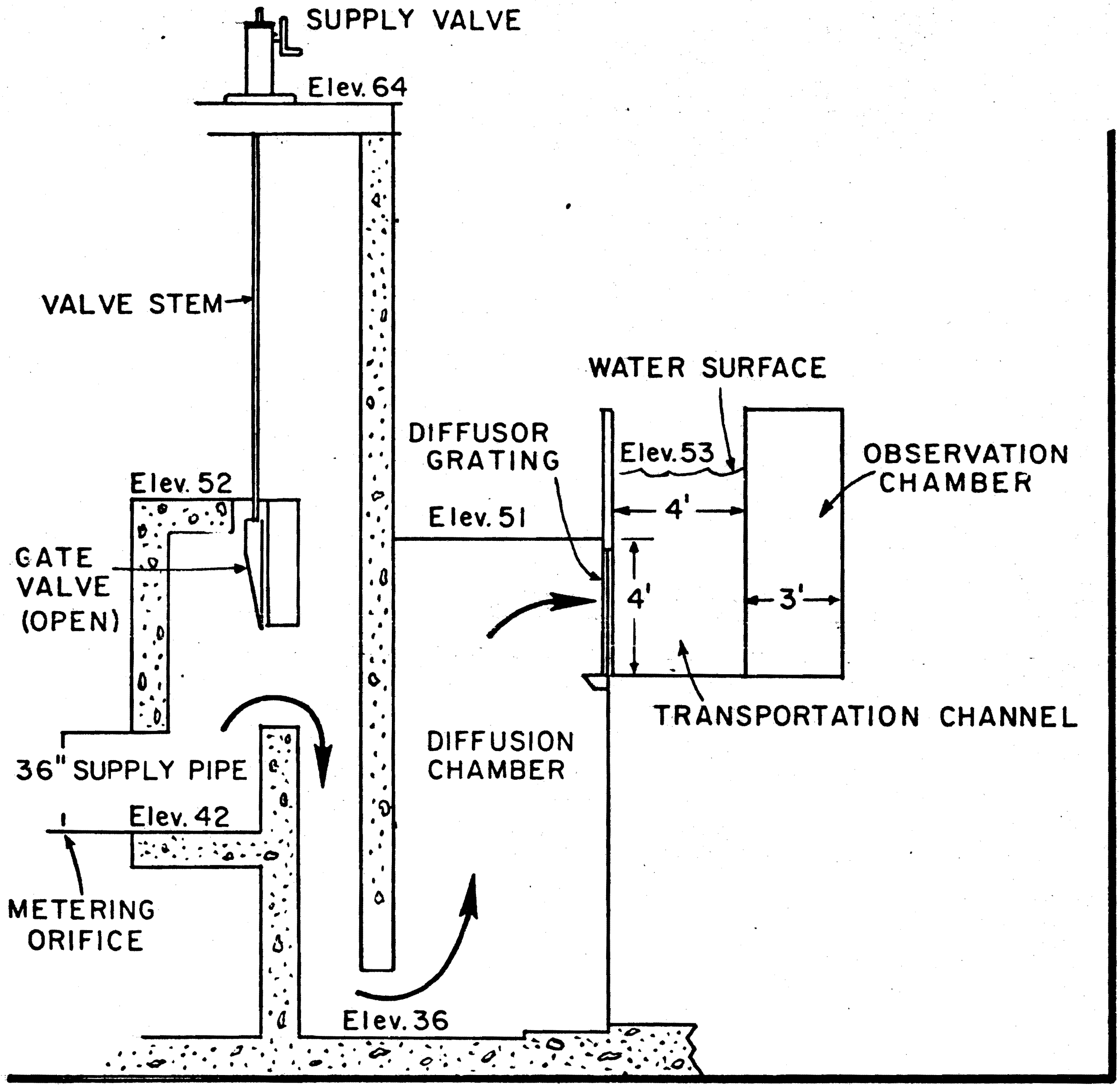

Figure 7 - Sectional view showing wall diffusor, water supply system and observation chamber.

the channel with and without entrained air in the water (Fig. 8) demonstrated that air had no effect on fish passage. Operation of the diffusor without a grating indicated that this might not be practical as both chinook and steelhead entered the diffusor opening even when no water was flowing out.

Table 1 - Mean and Median Passage Times of Chinook Salmon in a Transportation Channel with Gross Floor Diffusion Velocities of 0.25 to 1.25 f.p.s., May 2-23, 1961

Gross Diffusion Velocity F.p.s.	Sample Size Number	Mean Passage Time Minutes	Sample Size Number	Median Passage Time Minutes
0.00	19	9.9	20	4.1
0.25	18	13.2	20	9.7
0.50	17	11.9	20	10.6
0.75	18	17.2	20	15.9
1.00	16	17.4	20	19.4
1.25	16	10.3	20	10.4

Results

Wall diffusor tests were conducted in 1962 using velocities of 0.25, 0.50, 0.75, and 1.00 f.p.s. and in 1963 using velocities of 0.00, 0.50, 1.00, and 2.00 f.p.s. Passage times of chinook, sockeye and steelhead in 1962 under the various diffusion velocities did not differ greatly, except that passage time increased slightly at the 1.00 f.p.s. velocity. Passage times of chinook, sockeye and steelhead in 1963 (Table 2) demonstrated that an increase in passage time occurred as gross velocity increased. From a practical standpoint, however, there was little difference in passage times under the velocities tested.

The tests with floor and wall diffusors demonstrated that introduction of diffusion water at any velocity slowed the passage of salmonids through the channel, and there was a general tendency for passage times to increase at the higher velocities. It appears, however, that the standards for floor and wall diffusors (0.25 and 0.50 f.p.s. respectively) could be increased 100 percent without creating an appreciable delay in fish passage.

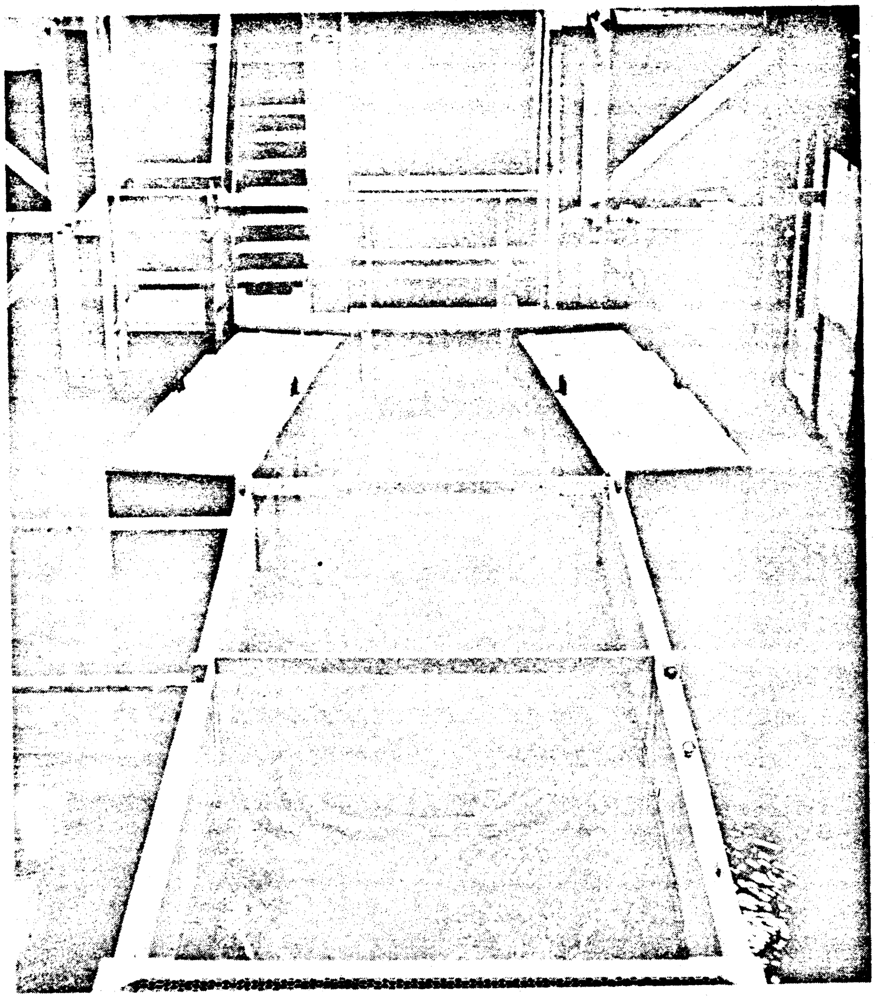

Figure 8 - Diffusion area and transportation channel with air being introduced through the diffusor (bottom) and without air (top).

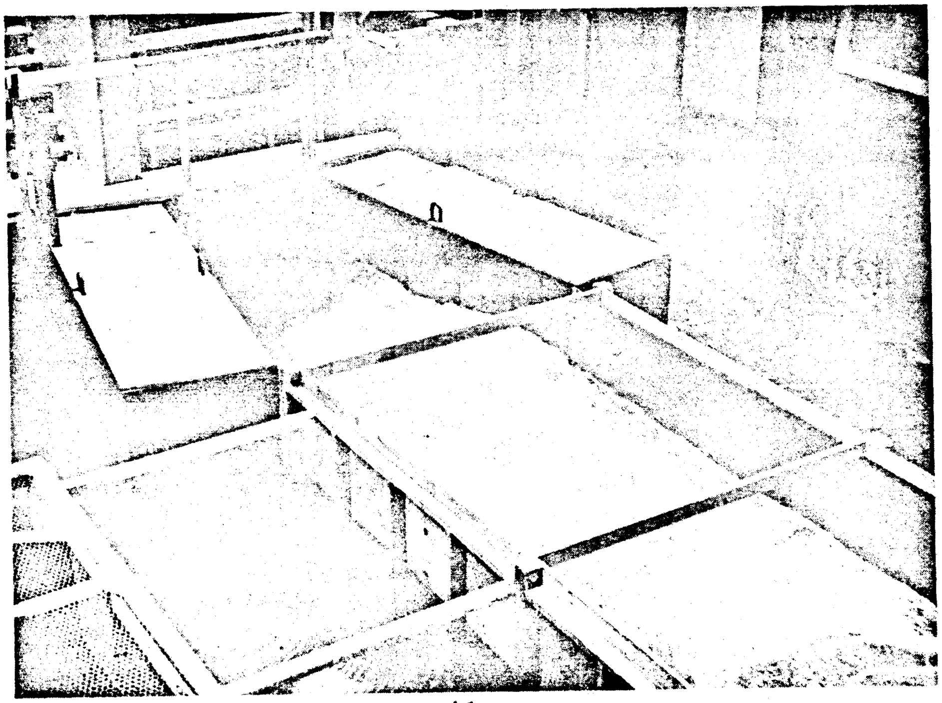

Table 2 - Effect of Wall Diffusion (Gross Velocity 0.00 to 2.00 f.p.s.) on the Passage of Chinook Salmon, Sockeye Salmon and Steelhead Trout, 1963.

Species and Date	Gross Diffusion Velocity	Sample Size	Mean Passage Time	Sample Size	Median Passage Time
	F.p.s.	Number	Minutes	Number	Minutes
Chinook	0.0	238	3.2	239	2.4
	0.5	208	4.4	211	3.2
April 15	1.0	139	5.4	143	3.4
to	1.5	146	6.3	151	5.2
May 9	2.0	102	7.8	105	6.8
Sockeye	0.0	172	2.4	172	1.4
	0.5	132	3.4	136	1.9
June 18	1.0	130	5.3	131	2.4
to	1.5	137	4.3	142	2.3
July 13	2.0	94	6.3	98	4.6
Steelhead	0.0	188	4.0	189	2.2
	0.5	152	5.3	153	2.7
July 4	1.0	128	5.6	131	2.8
to	1.5	112	5.5	113	3.4
July 20	2.0	108	5.7	111	2.7

3. ATTRACTION OF FISH

Discussion

Studies conducted in 1957 demonstrated that a majority of chinook and steelhead, when given a choice between channels with a "high" and a "low" velocity (Fig. 9), would select the channel with the higher velocity. Additional studies were made in 1961 to examine the response of sockeye salmon to opposing velocity conditions and to consider the effects of quantity as well as velocity of the water. Sockeye salmon responded in the same manner (Table 3) as the chinook and steelhead in the earlier tests, i.e., they generally showed a preference for the higher velocity.

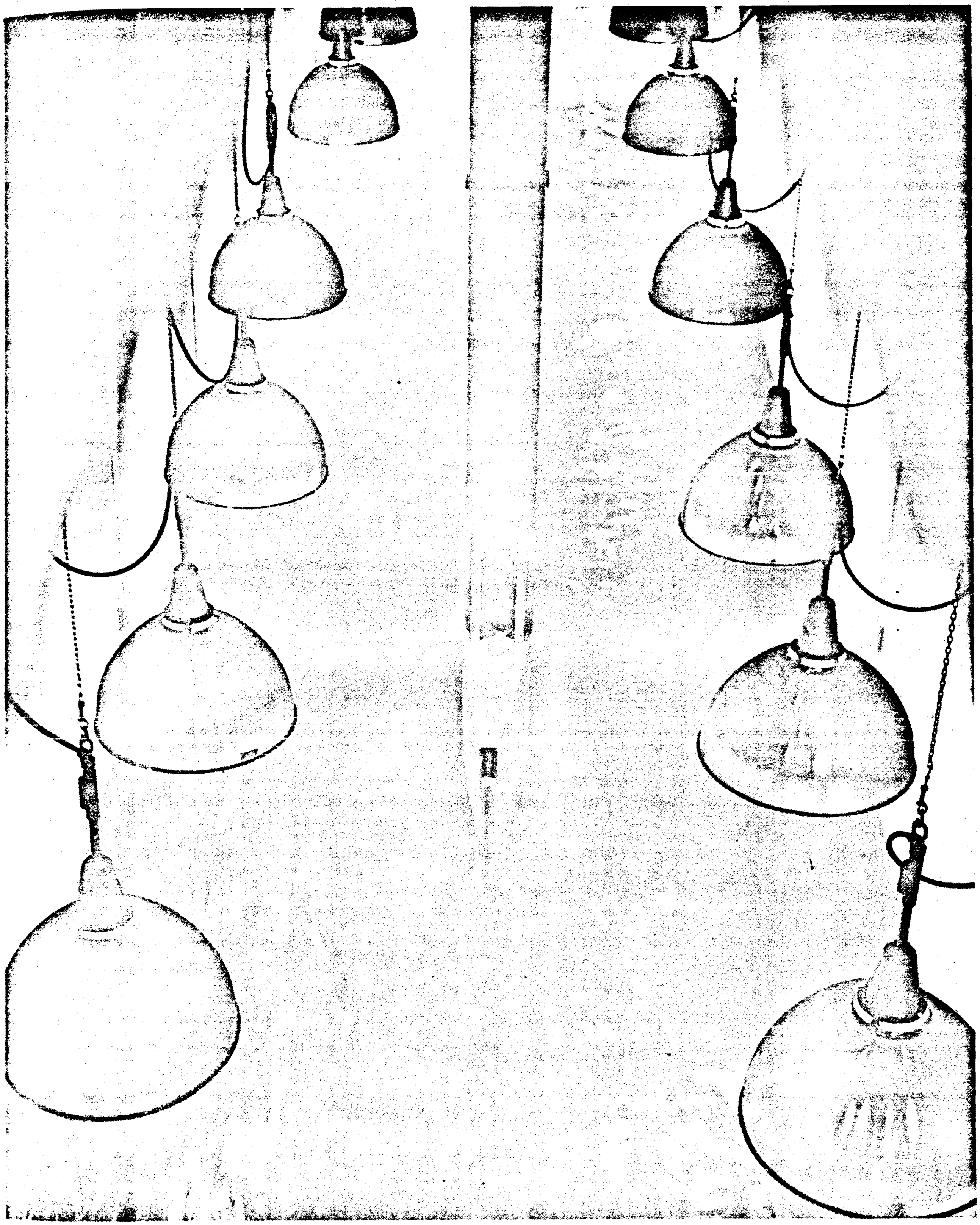

Figure 9 - Choice Area and Two Velocity Channels
(6 f.p.s. in left and 2 f.p.s. in right).

Velocity and quantity of flow were studied to determine if fish selecting a higher velocity were responding to velocity or quantity of flow. Fish were given the choice of entering one of two adjacent channels (Fig. 10) with contrasting velocities. The high-velocity channel was restricted in width so that the quantity of flow from this channel was about the same as that from the low-velocity channel.

Results

The response of chinook and steelhead showed that a majority selected the high-velocity side (Table 4) even though the discharge was the same on both sides.

Table 3 - Response of Sockeye Salmon to a Choice in Water Velocities Ranging from 2 to 8 f.p.s., June 26-July 10, 1961

Test Condition	Number of Fish Selecting Each Channel
North - 6 f.p.s.	11
South - 8 f.p.s.	9
North - 8 f.p.s.	19
South - 2 f.p.s.	1
North - 4 f.p.s.	13
South - 4 f.p.s.	13
North - 2 f.p.s.	10
South - 2 f.p.s.	10
North - 4 f.p.s.	4
South - 6 f.p.s.	16
North - 6 f.p.s.	5
South - 2 f.p.s.	2

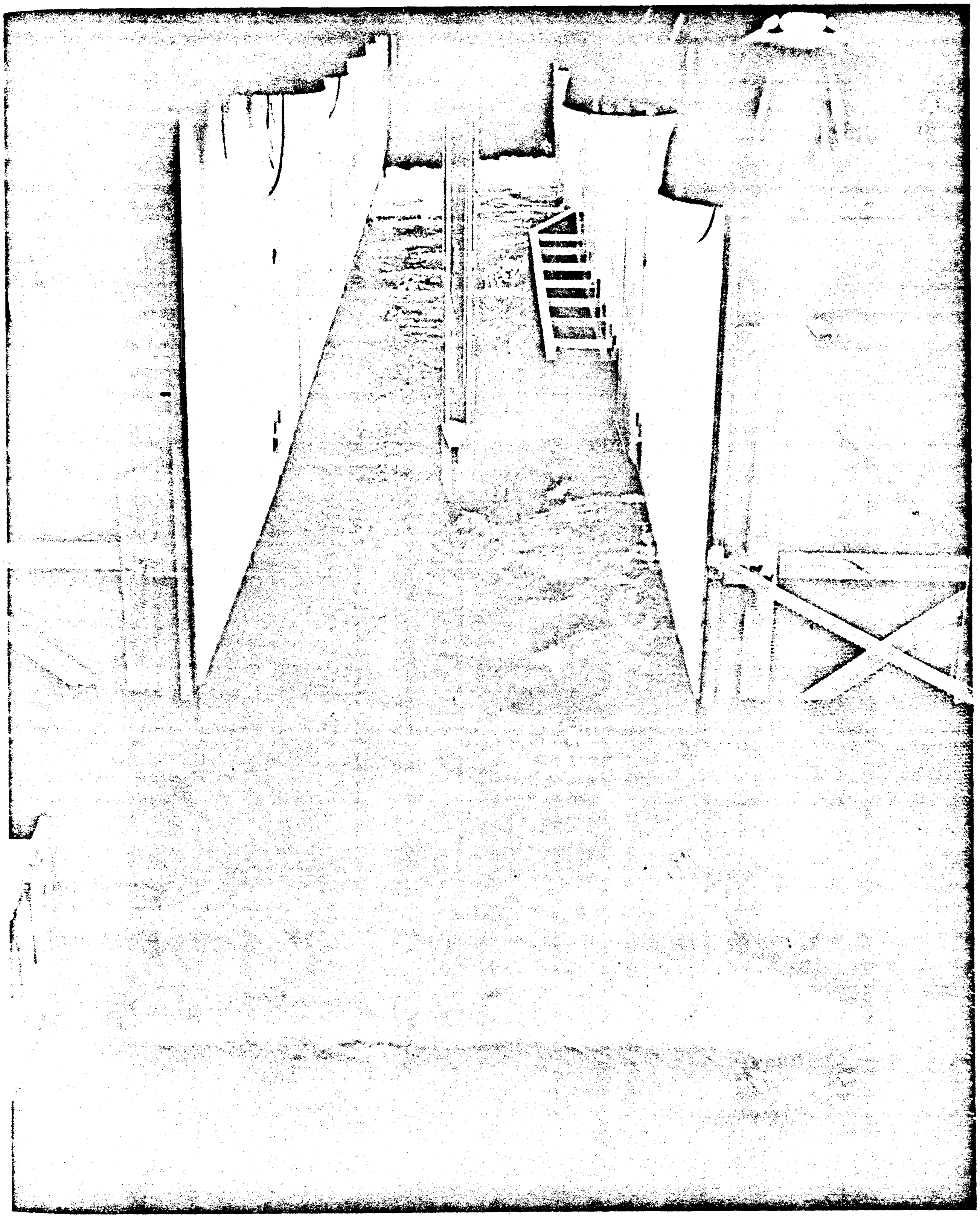

Figure 10 - Channels Used in Quantity vs. Velocity Study. Channel on Left has Greatest Quantity and Channel on Right, Highest Velocity.

Table 4 - Response of Salmonids to Velocity and Quantity of Flow in a Choice Situation, 1961.

Test Date	Number of Fish Selecting Low[1] and High[2] Velocity Channels by Species					
	STEELHEAD			CHINOOK		
	Low Velocity	High Velocity	Total Tested	Low Velocity	High Velocity	Total Tested
8-11	2	5	7	1	1	2
8-12	1	7	8	2	4	6
8-13	5	2	7	1	5	6
8-14	9	13	22	4	15	19
8-15	2	14	16	4	2	6
8-16	8	6	14	2	6	8
8-17	5	6	11	1	3	4
8-18	13	17	30	2	5	7
Total	45	70	115	17	41	58
Percent	39.1	60.9		29.3	70.7	

1/ Velocity 3.34 f.p.s., channel width 5 ft., quantity 32.1 c.f.s.

2/ Velocity 5.97 f.p.s., channel width 2.5 ft., quantity 28.7 c.f.s.

4. SWIMMING ABILITY OF FISH

Studies in 1957 demonstrated that all chinook and steelhead could ascend an 84-foot flume against a velocity of 8 f.p.s., but only 50 percent of the chinook and 91 percent of the steelhead were able to do so when the velocity was increased to 13.4 f.p.s. Studies were then conducted in 1961 to determine the velocity at which performance of chinook began to decline. Tests were carried out at velocities of 11.4, 12.6, 13.2 and 13.6 f.p.s. All of the fish tested (Table 5) were able to ascend the 84-foot flume at these velocities. This suggests that there may be seasonal or racial differences in swimming ability. The 1957 studies were conducted with fall-run chinook and steelhead, and the 1961 tests were conducted with summer-run chinook and steelhead.

Table 5 - Numbers of Chinook Salmon and Steelhead Trout Passing Through an 84-foot Flume in Velocities Ranging from 11.4 to 13.6 f.p.s., July 19-28, 1961. All Fish Tested Passed Through Flume.

Mean Velocity	Number of Fish Tested	
	Chinook	Steelhead
F.p.s.		
11.4	50	112
12.6	50	80
13.2	6	8
13.6	20	52

In the course of the velocity studies, supplemental observations were made on shad (Alosa sapidissima). Some shad ascended the 84-foot flume in velocities of 6 and 8 f.p.s. At higher velocities (11.4 to 13.6), there appeared to be an inverse relationship between velocity and swimming distance (Table 6).

Table 6 - Performance of Shad in Water Velocities of 11.1 to 13.4 f.p.s., July 18-28, 1961

Date	Water Velocity	Distance Covered in Feet			
		Mean		Maximum	
			Number of Fish		Number of Fish
July 21	11.4	27.2	62	54	1
22	11.4	29.2	193	59	1
23	11.4	32.0	160	65	2
24	11.4	30.5	107	59	1
25	11.4	29.9	30	60	1
25	12.6	19.1	18	30	2
26	12.6	24.8	29	43	2
27	12.6	24.8	25	44	2
18	13.2	18.8	72	35	2
19	13.2	18.8	126	40	1
28	13.6	11.7	15	20	1

5. TRANSPORTATION CHANNEL WATER VELOCITY

Exploratory experiments indicated that a transportation channel water velocity less than the accepted standard of 2 f.p.s. might be satisfactory for passage of fish. A study was then conducted to compare fish passage at a water velocity of 1 f.p.s. with passage at the standard of 2 f.p.s.

The channel was 4 feet wide by 91 feet long and was operated at a water depth of 6 feet. The timing zone was about 100 feet long, as it included a short introductory area in addition to the channel. Fish were timed individually.

Two tests were run with chinook, and one each with sockeye and steelhead. Passage times were about the same at each velocity (Fig. 11), but differences in passage times between species were noted. The similarity in passage times suggests that the lower water velocity of 1 f.p.s. in a transportation channel might be as satisfactory for fish passage as the standard of 2 f.p.s.

6. PASSAGE OF SALMONIDS THROUGH PIPES

Discussion

Since pipes are potentially useful as transportation channels for migrating adults salmonids, studies were conducted to explore factors affecting passage of fish through pipes. The work included tests on the effect of light, water velocity, transition zones, depths of flow, and pipe diameter on fish passage.

Experimental equipment included straight pipes about 100 feet long, 1, 2 and 3 feet in diameter, and a 270-foot long pipe, 2 feet in diameter having two 180° bends (Fig. 12). Only the long pipe was lighted inside. Lights were 75-watt floodlights spaced 7 feet apart on the straight portions of the pipe (Fig. 13). Fish were timed individually through the pipes.

Results

Varying water velocity, in the range of 1 to 4 f.p.s., did not affect passage of chinook, sockeye or steelhead in 2-foot and 3-foot diameter pipes. In a 1-foot diameter pipe, sockeye and steelhead moved through the pipe slower at the lower velocities and a 1 f.p.s. velocity in a 1-foot diameter pipe was not suitable for chinook.

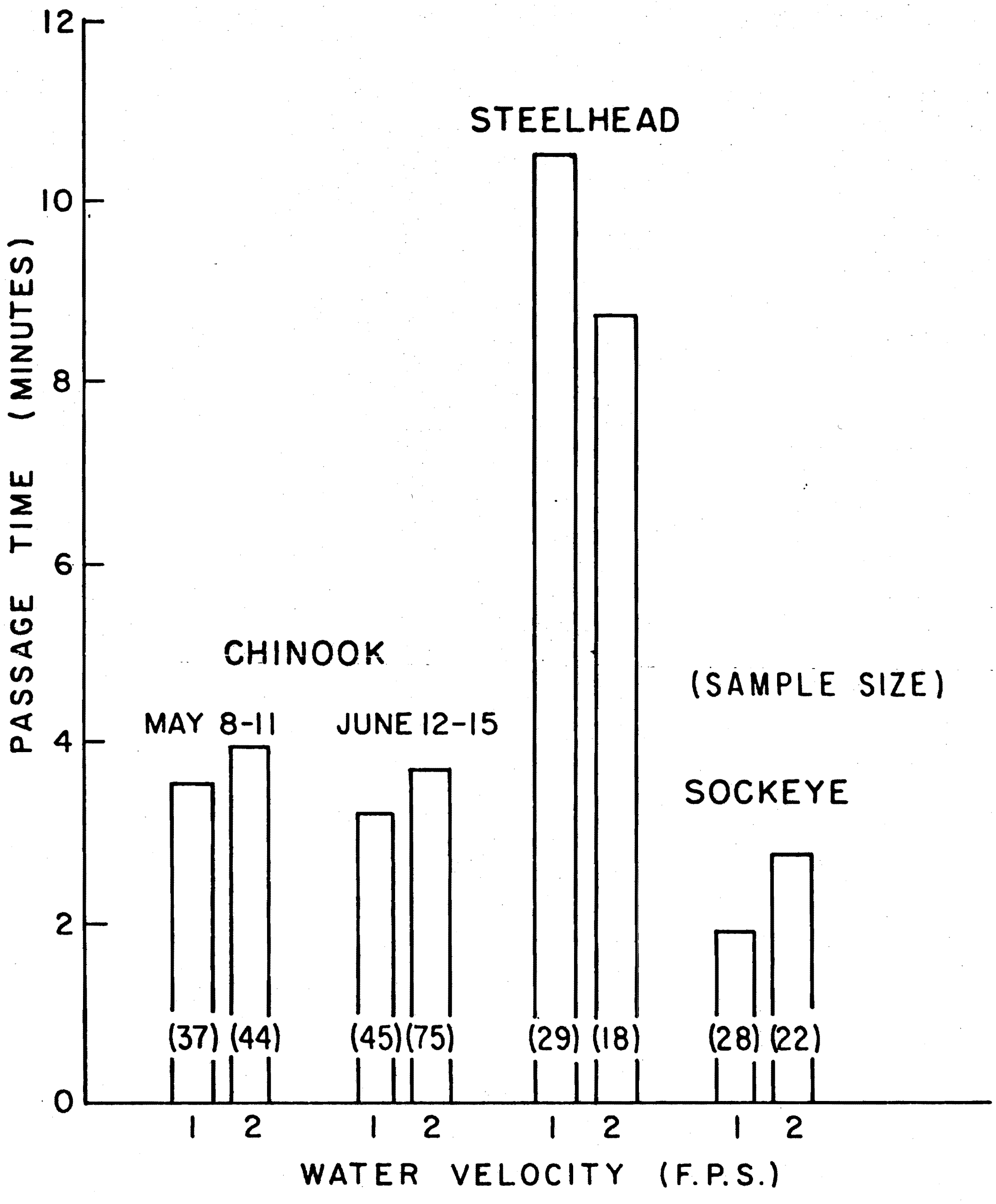

Figure 11 - Median passage times of chinook salmon, sockeye salmon and steelhead trout in a transportation channel having water velocities of 1 and 2 f.p.s. (1962).

Figure 12 - Plexiglass window for viewing fish as they enter 2-foot-diameter pipe. One of the 180° turns is shown on right.

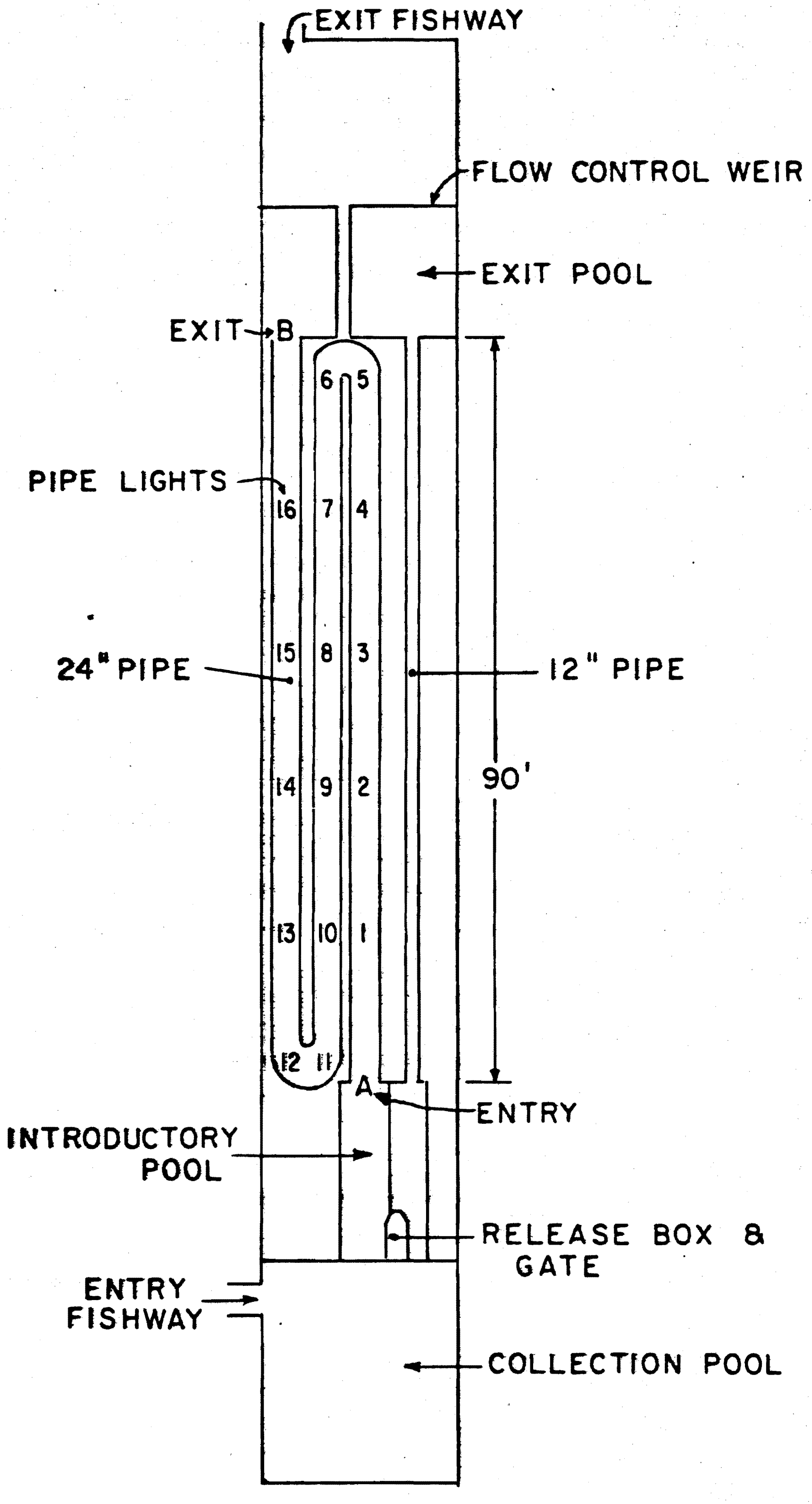

Figure 13 - Diagrammatic plan view of laboratory showing pipe arrangement. Pipe lights are at numbered points 1 through 16.

A truncated cone, used as a transition zone from pool to pipe, made the 1-foot-diameter pipe more acceptable to chinook, sockeye and steelhead but had no effect on entry into the 2-foot-diameter pipe. These cones were 10 feet long, 3 feet in diameter at the downstream end, and tapered to fit the pipes at the upstream end.

Light speeded passage of steelhead through the 270-foot long pipe more than it speeded passage of chinook, coho and sockeye (Table 7). Summer-run chinook moved through the pipe faster under a darkened condition than a lighted one. Conversely fall chinook moved faster under a lighted condition than a darkened one. Sockeye and coho also moved faster through the pipe under a lighted condition than under a darkened one.

A capacity study was conducted to determine the number of salmonids that could be passed through a 2-foot-diameter straight pipe 90 feet long. In the test involving the greatest number of fish, about 12 fish per minute passed through the pipe for a 60-minute period, and 15 fish per minute during the peak 20-minute period. Species composition was about 52 percent chinook, 41 percent steelhead and 7 percent coho.

Table 7 - Passage of Salmonids Through a 2-Foot-Diameter Pipe 270 Feet Long Under Dark and Light Conditions, 1964

Date	Species	Median Passage Time			
		Dark		Light	
		Number of Fish	Minutes	Number of Fish	Minutes
June 25-28	Chinook	39	7.8	25	11.8
Aug. 28-31	Chinook	31	10.0	62	5.5
July 12-15	Sockeye	45	8.5	41	6.8
Sept. 8-11	Coho	24	11.1	17	7.2
July 17-20	Steelhead	22	24.6	52	7.0

In a test comparing passage under full and partially full conditions, chinook and steelhead moved through the 270-foot long pipe faster when the pipe was only partially filled with water than when it was completely filled. When partially filled, water depth was about 20 inches, leaving a 4-inch air space.

7. RESPONSE OF SALMONIDS TO VERTICAL AND HORIZONTAL RECTANGULAR ORIFICES

Discussion

The objective of this study was to determine whether a vertical or a horizontal orifice is the most satisfactory for fish passage and if orifice depth affects use of the orifice. A pair of 2-by-5-foot rectangular orifices were installed at the junction of two channels with the collection pool (Fig. 14). The orifices could be installed in either vertical or horizontal positions, and at 3- and 9-foot depths (on the centerline). A 1-foot head was maintained on the orifices, giving a flow of about 49 c.f.s. through each.

Eight test conditions were used in this experiment. Conditions A, B, C and D (Fig. 15) provided for a direct comparison of the proportion of fish utilizing vertical and horizontal orifices at deep and shallow positions. Conditions E, F, G and H tested the effect of orifice depth on use of horizontal and vertical orifices, respectively.

Results

A total of 3,390 chinook, 9,522 steelhead and 787 coho were tested. A majority of chinook and steelhead entered the vertical orifice rather than horizontal orifice at deep and shallow settings (Conditions A, B, C and D); this utilization was statistically significant at the deep setting. A majority of chinook and steelhead entered shallow orifices rather than deep ones (Conditions E, F, G and H), and this difference was statistically significant when orifices were horizontal. Coho responses to the test conditions were the same as chinook and steelhead with one exception -- more coho entered the deep vertical orifice than the shallow one.

8. COUNTING STATION DESIGN

Discussion

A preliminary study was made to explore means of improving fish counting methods at dams on rivers where turbidity is a problem. A submerged observation chamber served as a counting station. A vertical light panel 4 feet square was installed in a watertight enclosure so that the distance between the light panel and counting station could be varied from 1 to 4 feet (Fig. 16). Fish passed the counting area between the light panel and observation window.

Results

Individual tests were conducted with the light panel set 1, 2, 3 and 4 feet from the viewing window. Secchi disk readings ranged from 2.0 to 2.8 feet during the tests. In general, counts and identification of species were quite accurate at the 1- and 2-foot settings. Identification of species was not always possible at the 3- and 4-foot settings.

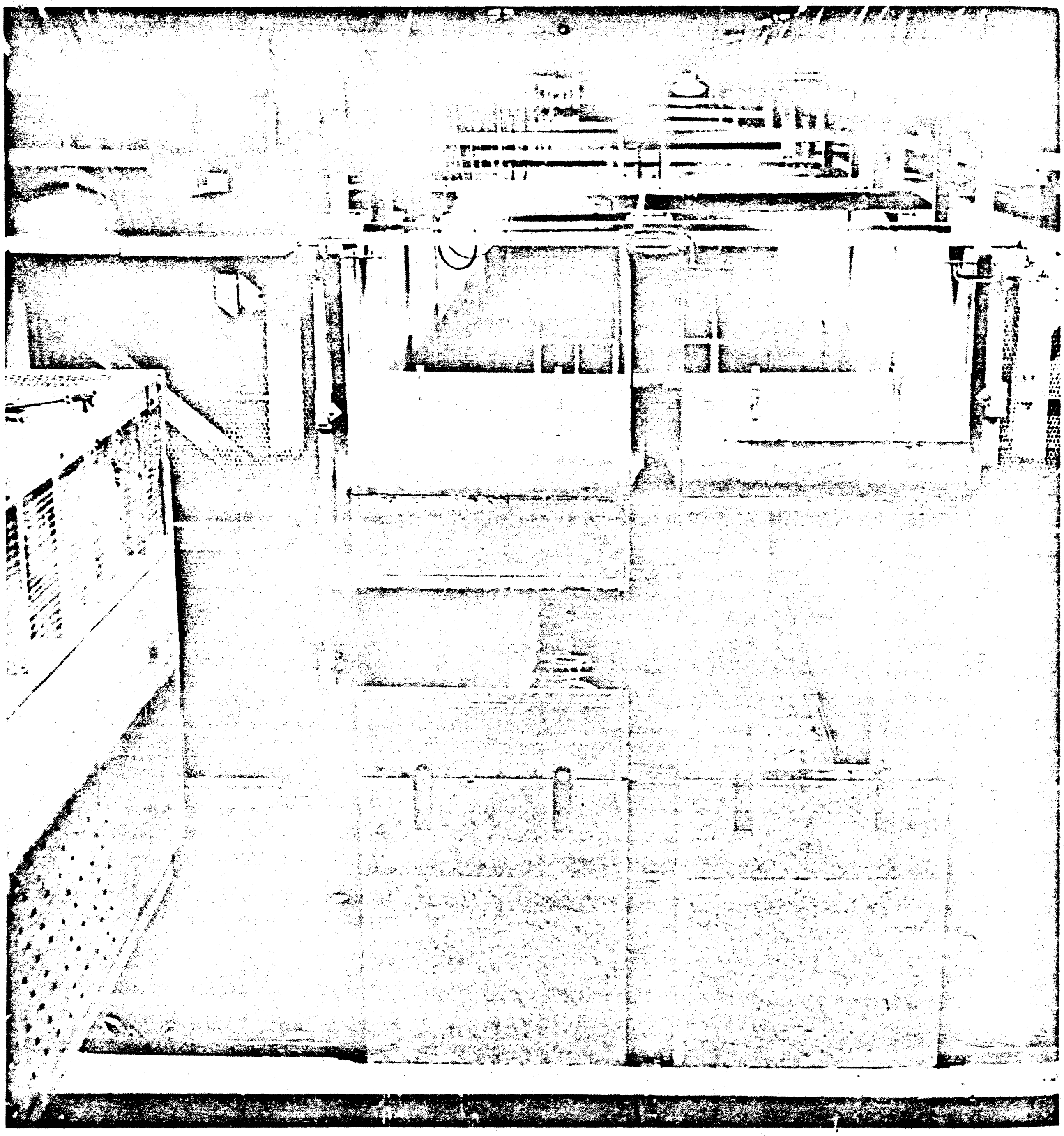

Figure 14 - Test area unwatered to show horizontal (left) and vertical (right) orifice choice condition at the shallow setting--centerline of orifice 3 feet below water surface.

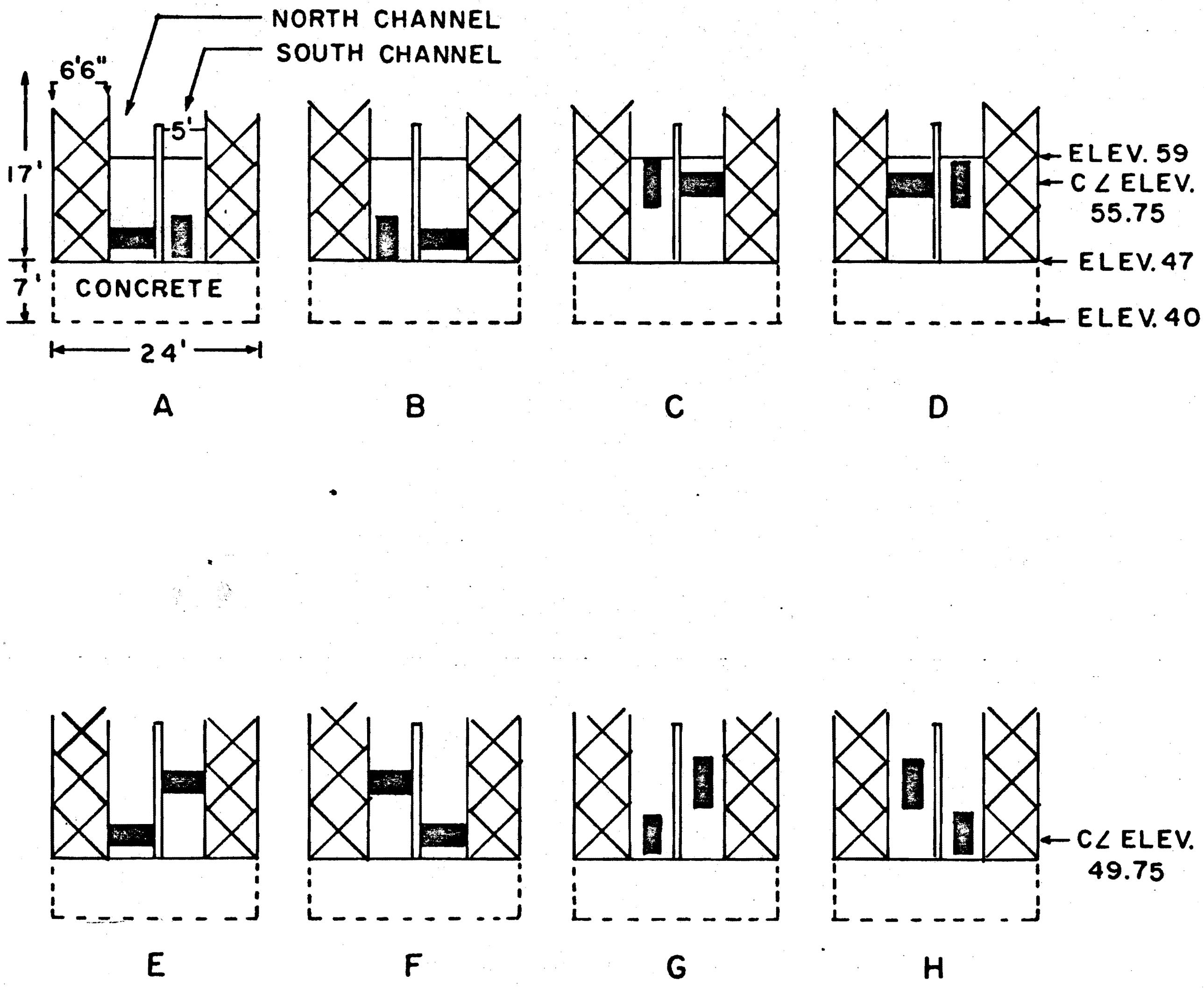

Figure 15 - Sectional views showing eight test conditions used in orifice study.

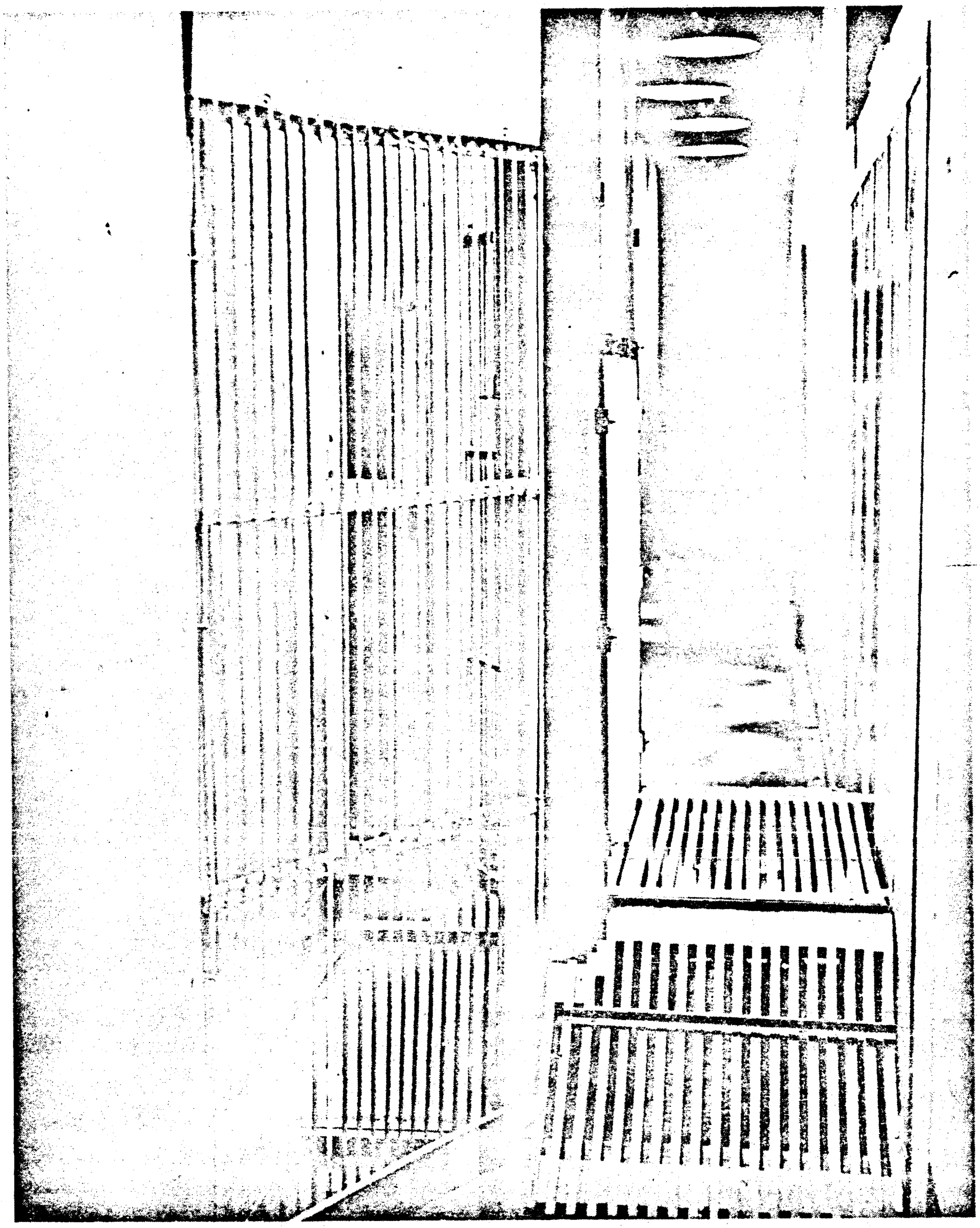

Figure 16 - Installation used in counting station design study. Submerged observation chamber (right) and lighted panel (center) are set 2 feet apart.

9. FISH SEPARATION STUDIES

Discussion

There is a growing need for knowledge on methods of separating species or populations of fish in relation to water resource development. For example, the loss of spawning grounds due to inundation by impoundments is becoming a serious problem in the Columbia River system. Fisheries agencies seek to segregate the displaced spawners from other stocks bound for upriver spawning areas and use these fish for artificial propagation. In other instances it may be necessary to transport adult stock around reservoirs. If there is more than one tributary system to a reservoir, the individual races must be segregated before they are placed in their respective spawning streams. On occasion, some of the less desirable species (carp, suckers, etc.) become a problem in fishways or need to be controlled to reduce competition or predation on the more prized species. Sorting out the so-called scrap species could be a decided benefit to salmonids.

Studies were conducted on the possibility of separating a race of chinook during the spawning migration by use of home-stream water, on mechanical separation of chinook salmon stocks distinguished by color differences, and on separation of resident fishes from salmonids in fishway situations.

The separation with home-stream water was based upon the hypothesis that during their spawning migration, chinook salmon home upon some distinctive quality in the water imparted from their home stream. The race of chinook studies was the one destined for Spring Creek Hatchery, about 25 miles above Bonneville Dam. Adult chinook passing through the laboratory were offered a choice of entering one of five similar channels (Fig. 17). Flow in each channel was about 3.6 c.f.s. or 1,620 gallons per minute (g.p.m.). During control tests, flow and composition of water in the channelswere identical. During experimental tests, about 11 g.p.m. of Spring Creek water was introduced into one of the channels. This water was hauled by tank truck from Spring Creek Hatchery. After making a choice of channels, both test and control fish were tagged and released.

Results

The response of the Spring Creek fish to the choice array was determined from tagged fish arriving at the hatchery. A total of 565 chinook were subjected to the choice condition and subsequently tagged and released. Of the 42 fish recovered at Spring Creek, 17 were tagged during control tests and 25 during tests when Spring Creek water was being added into Channels 3 and 4. A comparison of the response of the fish during test and control conditions (Fig. 18) indicates that Spring Creek chinook were not attracted when Spring Creek water was introduced. Further studies would appear to be warranted, however.

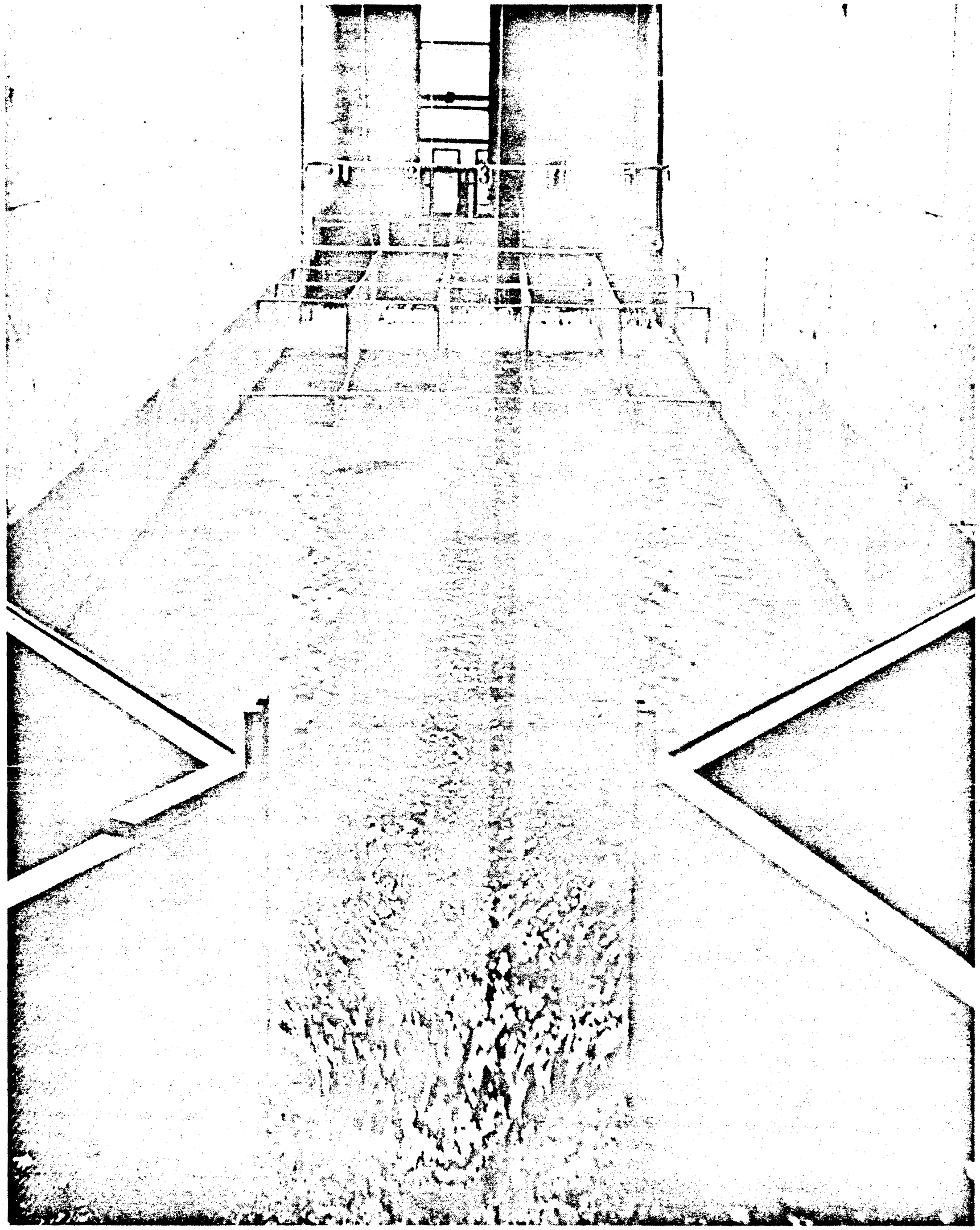

Figure 17 - Choice area, channels and holding pens (in darkened area) with Spring Creek water being introduced into Channel #3. Note chinook salmon just below entrance to Channel #2. Vertical ropes in background are used to operate drop screens at entrance to holding pens.

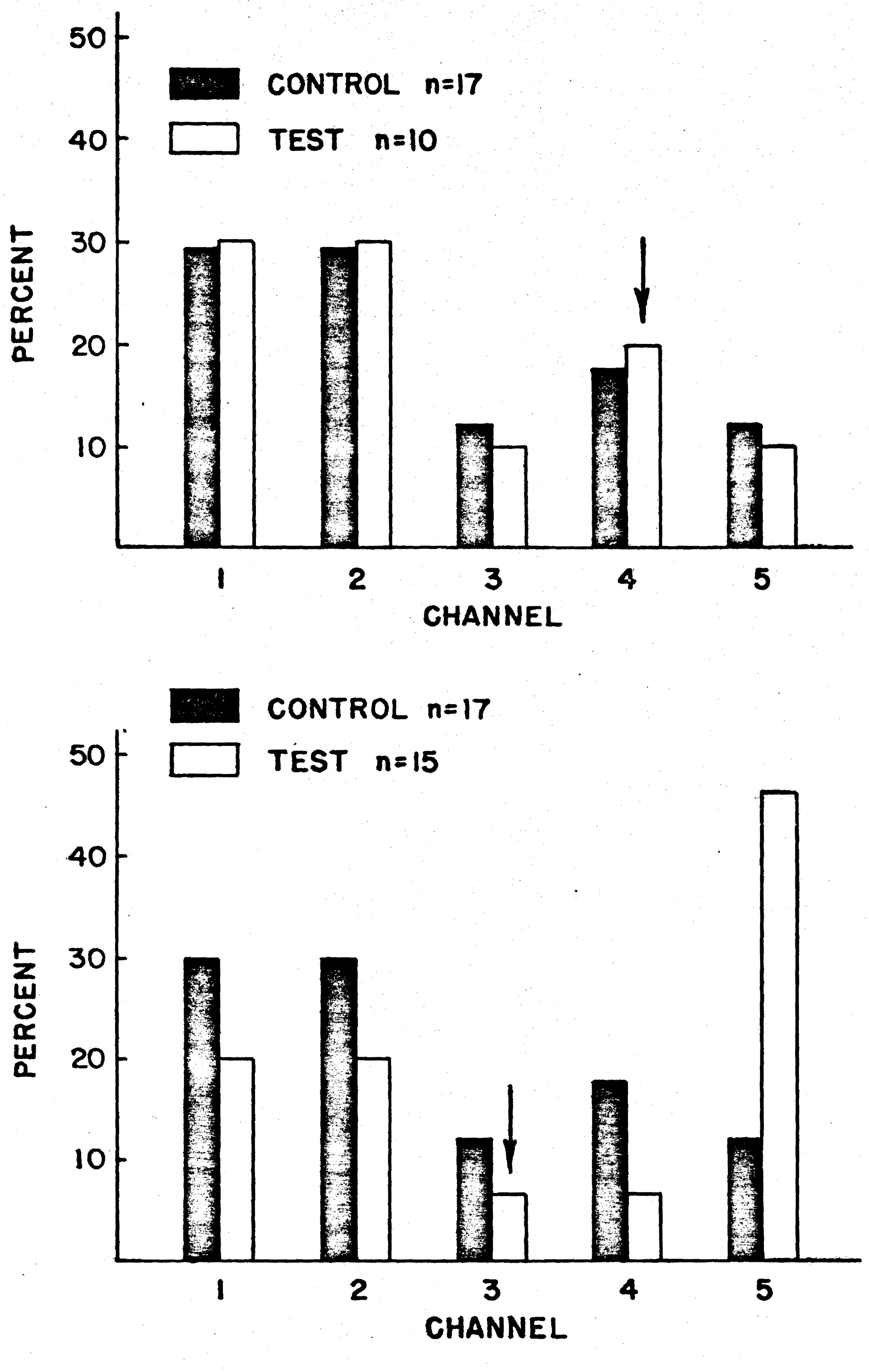

Figure 18 - Results of tests at Bonneville on the response (proportions entering each channel) of Spring Creek chinook salmon to home stream water. Arrows indicate channel carrying added amounts of Spring Creek water under test conditions.

Segregation on the basis of skin coloration (light or dark) required that fish go over a false weir onto a slide (Fig. 19). An operator then deflected the fish into the proper channels according to skin color as they descended the slide. A second sorter (Fig. 20) appeared to be more satisfactory than the first one tested. Results demonstrated that this was a practical method for separating chinook on a basis of skin color or for separating species--provided the operator was competent and experienced.

The separation of resident species from salmonids was done in a typical fishway pool (Fig. 21). Perforated plates and gratings were used to sort out the smaller resident fish as they passed through the orifice. The larger salmon were diverted over the overfall. The most successful separation was made with a perforated plate having 2-1/2 inch diameter holes. About 61 percent of all suckers passing up the fishway were diverted and trapped using this plate. All of the salmonids went over the weir.

10. CURRENT RESEARCH

Studies undertaken during fiscal year 1966 season include investigation of (a) the response of adult migrating salmonids to changes in water temperature; (b) the effect of pipe length and light on passage of salmonids through pipes; and (c) the mechanics of fingerling collection in turbine intakes.

Response of adult salmonids to changes in water temperature will be determined by subjecting them to a choice of two channels having different water temperatures. Heating equipment will raise the temperature of 2 c.f.s. about 2° C. above river temperature and cooling equipment will cool a like amount about 1.6°C.

Effect of pipe length and light on fish passage will be determined in a circular "endless" pipe in which the willingness of fish to swim long distances will be examined. Electronic detectors will be used to record passage through the pipe.

It has been noted at Bonneville and other dams that juvenile salmonids collect in turbine intake gate slots. This general area represents a potential collection site for downstream migrants. A scaled down version of a turbine intake has been built in the laboratory. It consists of a sloping conduit with risers spaced along the axis (Fig. 22). Fish are introduced into the conduit where they are subject to an increasing pressure change as they descend. Studies are now in progress to measure the response of chinook fingerlings to this pressure change and to explore methods of enhancing collection of fish in the riser. Methods of attracting fish out of the risers into a bypass will also be investigated.

Figure 19 - Sorter used in first test on mechanical separation of chinook salmon on basis of coloration. Fish have just gone over false weir and are starting down slide.

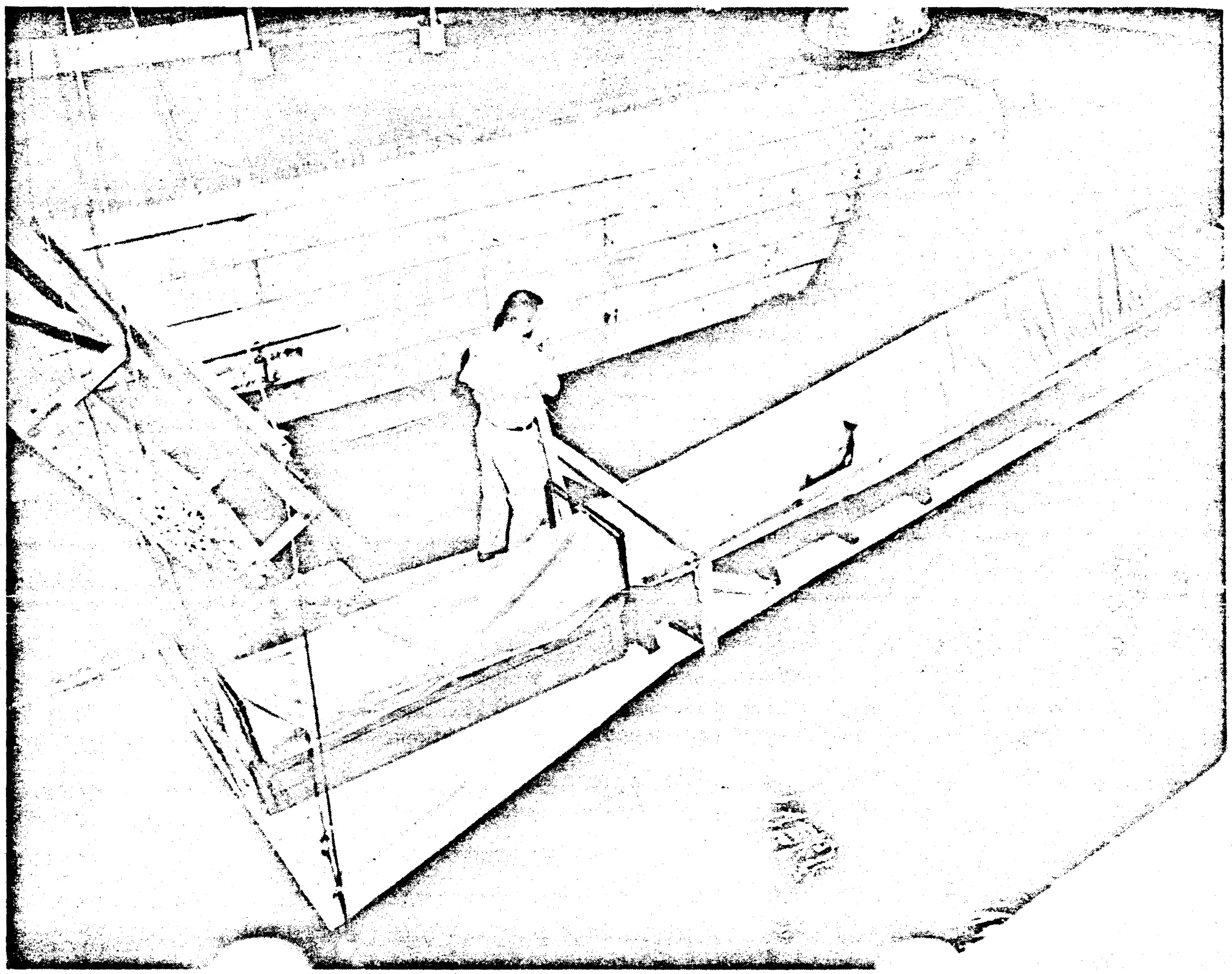

Figure 20 - Another sorter tested in mechanical separation of chinook. Lever in hand of operator moves lower end of slide to divert fish into proper channel.

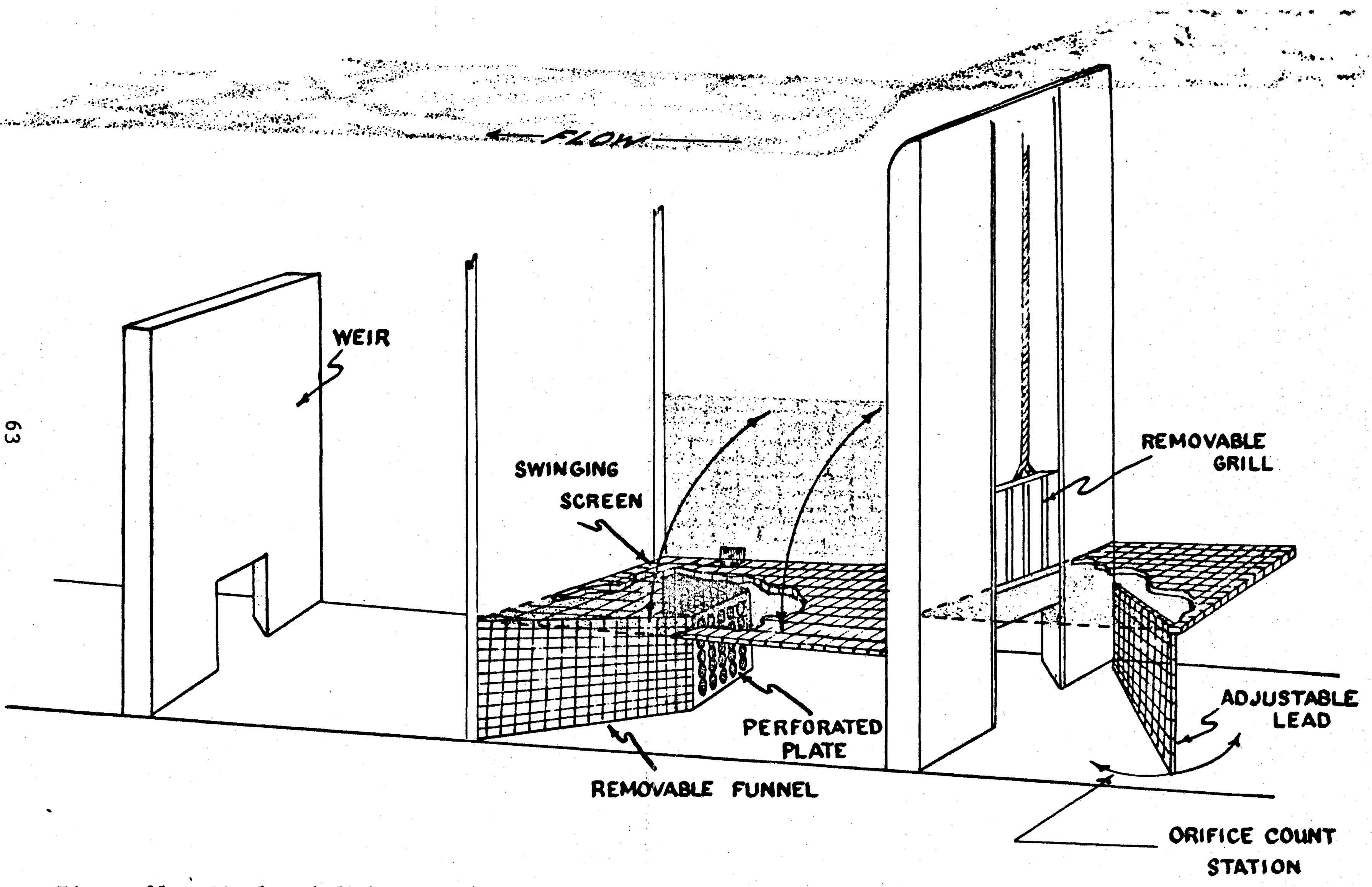

Figure 21 - Simulated fishway pool showing orifice and sorting devices used in study on separating resident fishes from salmonids.

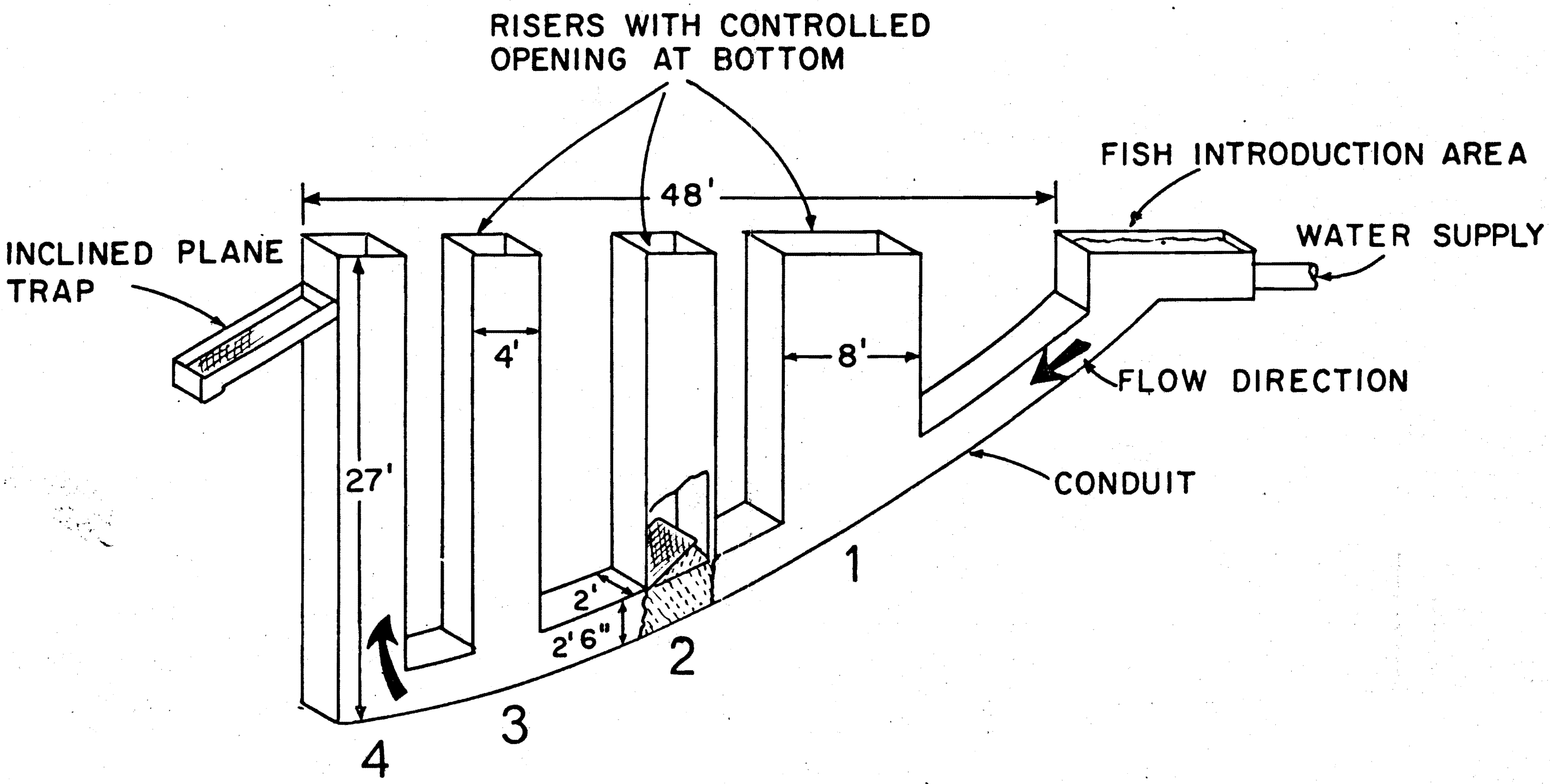

Figure 22 - Experimental device for study of response of salmonid fingerlings to pressure changes encountered in turbine intakes.

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2. COLLINS, GERALD B., and CARL H. ELLING
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1. GAULEY, JOSEPH R.
   Effect of Water Velocity on Passage of Salmonids in a Transportation Channel.

2. GAULEY, JOSEPH R. and CLARK S. THOMPSON
   Diffusion Water Velocity - Its Effect on Salmonid Passage Through a Transportation Channel.

3. LONG, CLIFFORD W.
   Effect of Light on Orientation and Rate of Movement of Adult Salmonids in a Channel.

4. SLATICK, EMIL
   Passage of Adult Salmonids Through Pipes.

5. THOMPSON, CLARK S.
   Effect of Flow Pattern on Performance and Behavior of Salmon in Fishways.

6. THOMPSON, CLARK S., WILLIAM S. DAVIS and EMIL SLATICK
   Response of Migrating Adult Salmonids to Vertical and Horizontal Rectangular Orifices at Two Depths.

7. WEAVER, CHARLES R. and CLARK S. THOMPSON
   Evaluation of the 1-on-10 Slope Fish Ladder at Ice Harbor Dam.

8. GAULEY, JOSEPH R. and CLARK S. THOMPSON - 1963
   Further Studies on Fishway Slope and Its Effect on Rate of Passage of Salmonids. U. S. Fish and Wildlife Service, Fishery Bulletin, Vol. 63, No. 1, pp. 45-62.

9. LONG, CLIFFORD W. - 1959
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