DIFFUSION WATER VELOCITY -- ITS EFFECT ON SALMONID PASSAGE THROUGH A TRANSPORTATION CHANNEL

by

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October 1964

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

INTRODUCTION

Diffusion water, also termed attraction water or auxiliary water, is the water flow that is added to a fish facility through a floor or wall diffusor. It is needed to maintain prescribed flows in the enlarged sections of the fish ladders, fish collection channels, and fishway entrances.

Design features, size, and operation of auxiliary water systems vary considerably, but all exhibit certain basic similarities. Water for these systems flows by gravity from the forebay of the dam or is sometimes pumped directly from the tailwater into the auxiliary water system and transported through open channels or closed systems. Regardless of supply, energy must be dissipated to insure that there is no excessive turbulence or velocity in auxiliary water supplied to the fishway. An elaborate system at Bonneville Dam includes facilities with a design capacity of 1,600 cubic feet per second (c.f.s.). Figure 1 (from the Annual Fish Passage Report, North Pacific Division, U.S. Army Corps of Engineers, 1950) shows part of a system supplying a segment of the Washington shore fishway and collection bay.

The presently accepted criteria for gross diffusion water velocities are 0.25 feet per second (f.p.s.) through a floor diffusor and 0.50 f.p.s. through a wall diffusor (Clay, 1961). 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. Both floor- and wall-type diffusors were studied. If higher velocities than those presently accepted do not appreciably deter fish passage, then smaller diffusors could be used in new fishways. Smaller diffusors would be less costly to build and maintain.

This report presents results of experiments in 1961, 1962, and 1963. The floor diffusion work was done in the first year and wall diffusion was studied in the following 2 years.

EXPERIMENTAL EQUIPMENT

All experimental facilities and apparatus were housed in the Fisheries-Engineering Research Laboratory, described fully by Collins and Elling (1960). 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 0.50 to 2.00 f.p.s. through the wall diffusor.

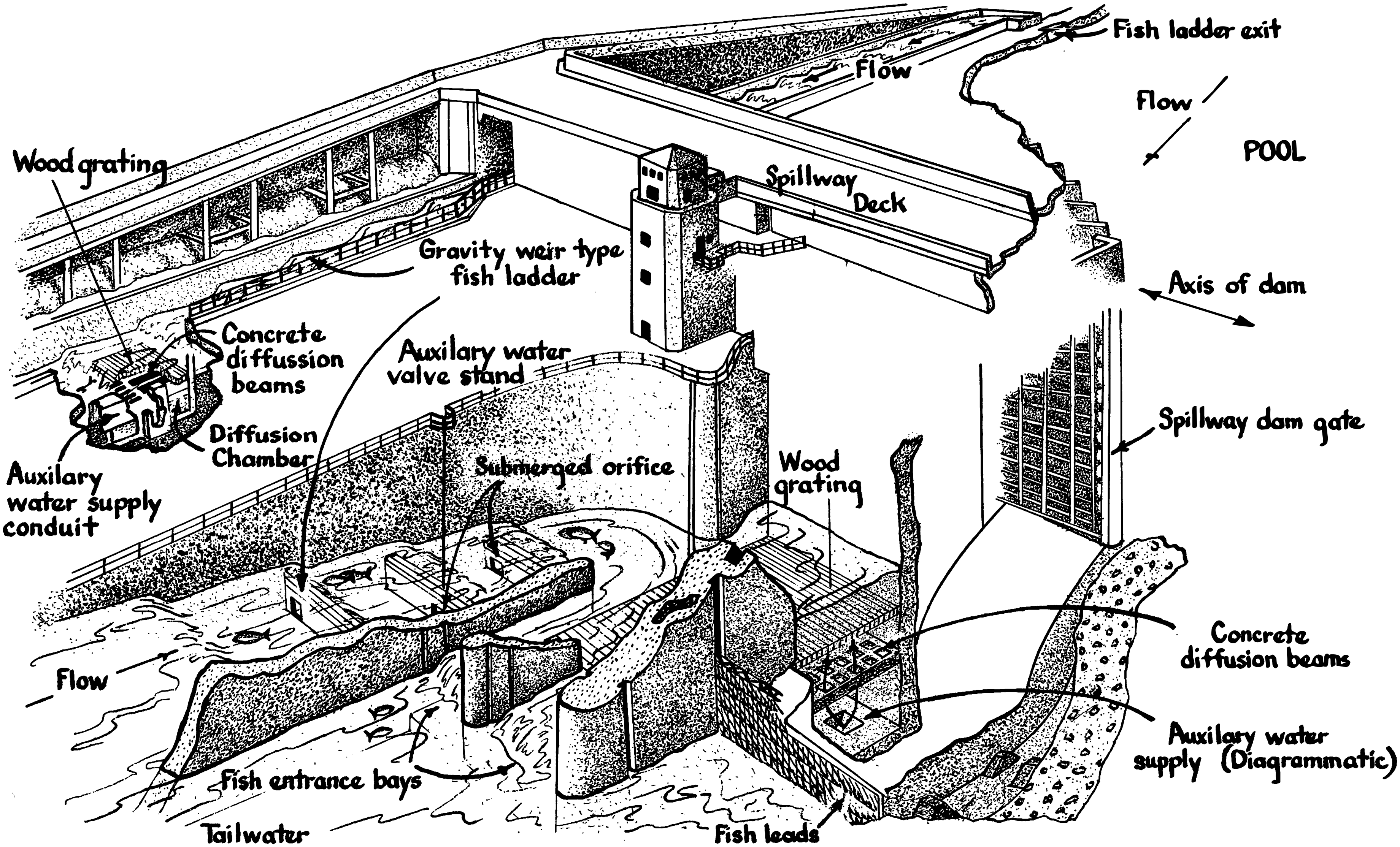


Figure 1.--Diagrammatic view showing dam, fishway, and diffusion water chamber.

Transportation Channel

The basic channel (fig. 2) was 4 feet wide by 91 feet long exclusive of a short introductory area. Water depth was 6 feet, and velocities upstream of the diffusion area were maintained at approximately 2 f.p.s. During the floor diffusion study, the approach section downstream of the diffusor was designed to permit adjustments in width of the channel as additional volumes of water were supplied through the diffusor. Thus, the approach area could be widened (figs. 2 and 3) from 4 to 5½ feet and then to 7 feet as the discharge was increased. This facilitated control of flows in the downstream section of the channel, maintaining a velocity approximately comparable to that (2 f.p.s.) in upper section of the channel.

The exit grill (fig. 4) was simply a section of pickets angled at 45 degrees from the floor to lead fish toward the surface and within view of the observers. Water depth over the grill was 9 inches.

During experiments with the wall-type diffusor, we made several changes in the experimental area (fig. 5). Only one observation chamber was used at the diffusion area, since the wall diffusor was placed in the space formerly occupied by the other unit. Another viewing chamber was installed adjacent to the exit area. The diffusor was placed in the same general location in the channel except that it now formed part of the channel wall (fig. 6). During the 1962 tests, the exit grill consisted of a picketed lead that guided fish to within a foot of the observer at all depths (fig. 7). In 1963 this exit was further modified by increasing the exit slot to 2 feet and installing a lighted background panel (fig. 8).

Velocities in the channel above the wall diffusor were maintained at approximately 2 f.p.s. Because of structural limitations, the width of the approach channel (downstream of diffusor) remained at 4 feet in all tests. Hence, the established transportation flow (2 f.p.s.) increased in proportion to the amount of diffusion water that was added. Under this condition, velocities in the approach channel ranged from about 2 to 4 f.p.s. in the various tests. Weaver (1963) has shown that various species of salmonids ascend channels at varying speeds in relation to the water velocity, but for purposes of these tests, the minor change in velocity would not be expected to alter the passage time more than a few seconds.

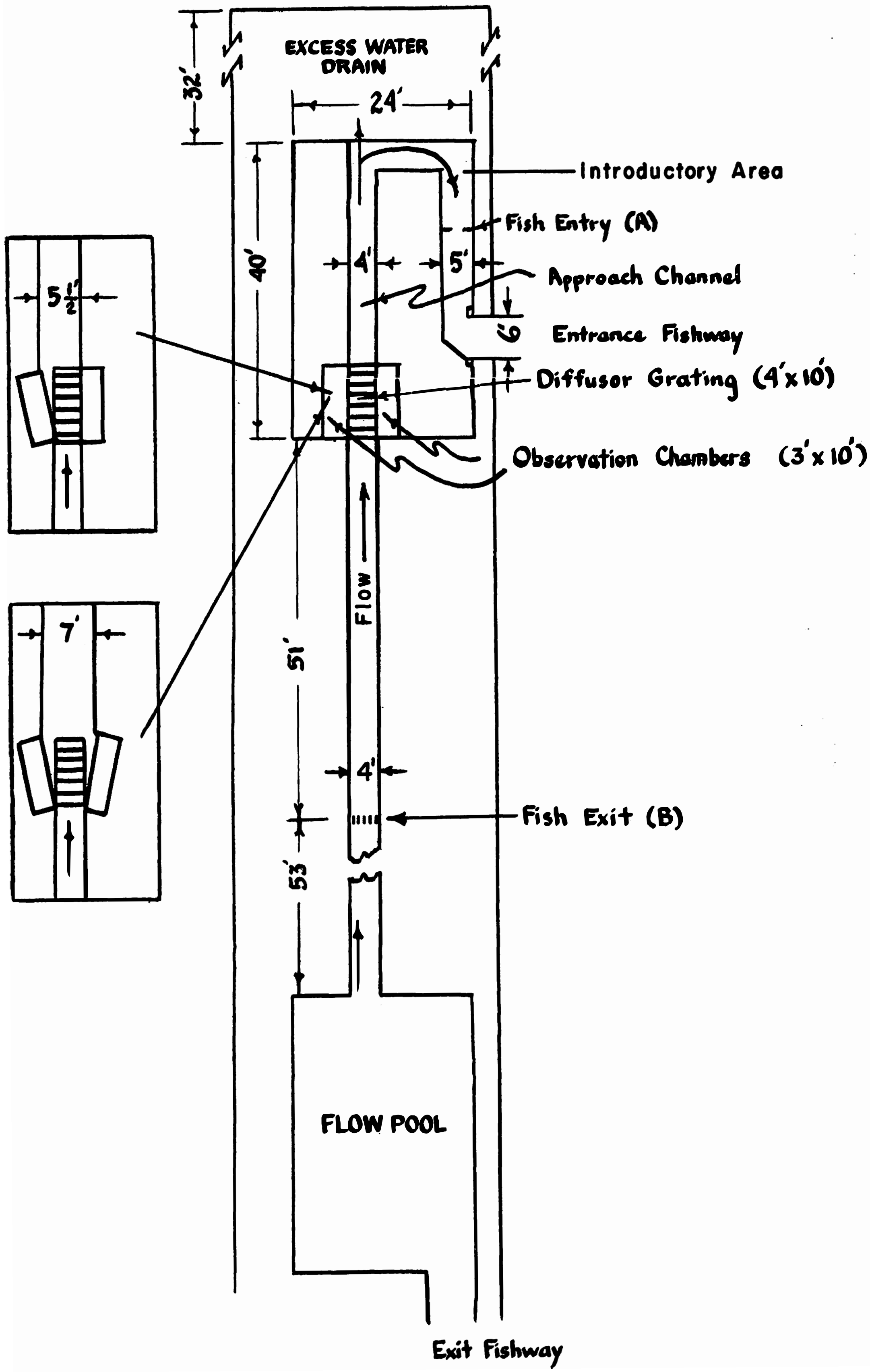


Figure 2.--Plan view of experimental area for testing response of salmonids to gross diffusion velocities from a floor diffusor. Insets show modifications in approach channel width.

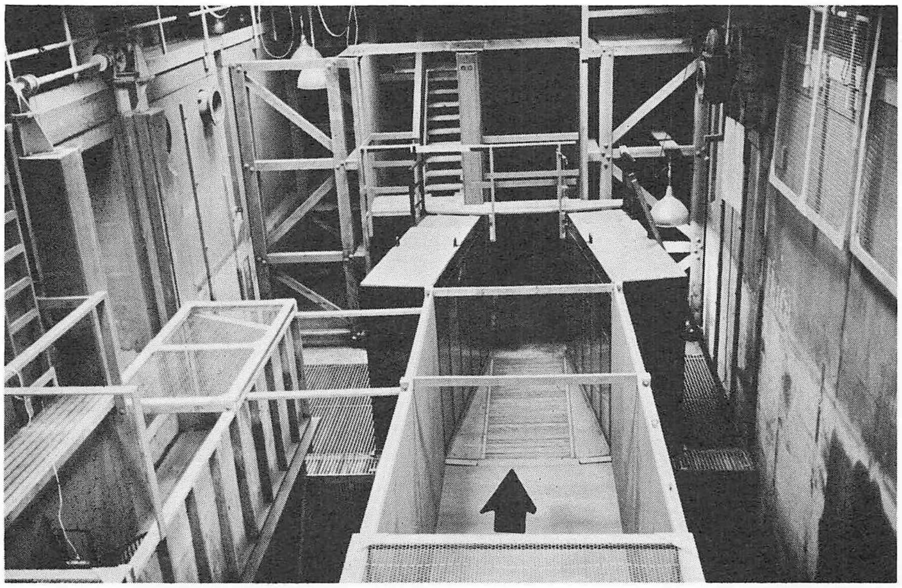


Figure 3.--Floor diffusor (arrow) with adjacent observation chambers. Approach channel walls (foreground) are set to give a 7-foot channel width.

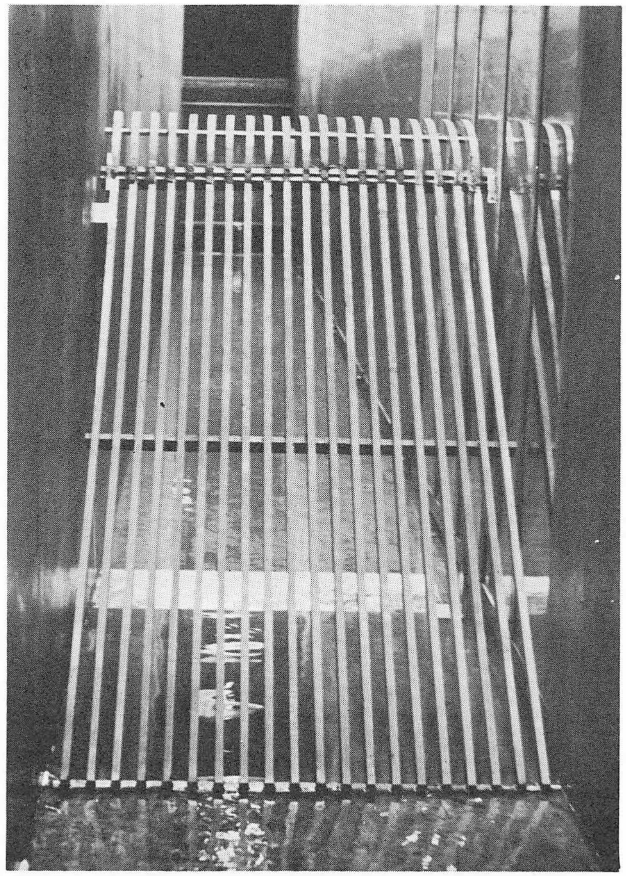


Figure 4.--Sloping grill at exit of the transportation channel leads fish to surface within view of counters.

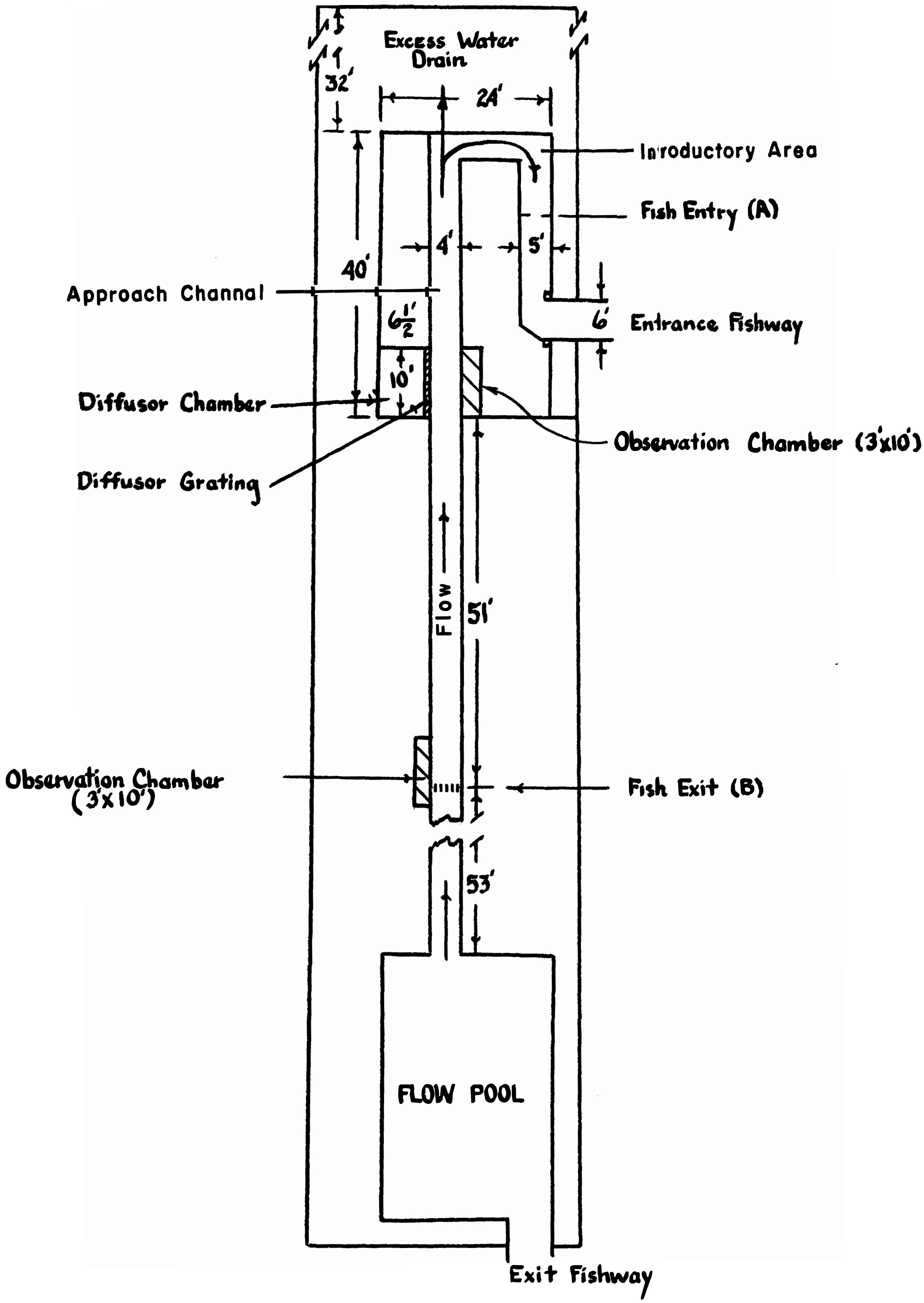


Figure 5.--Plan view of experimental area for testing response of salmonids to gross diffusion water velocities from a wall diffusor.

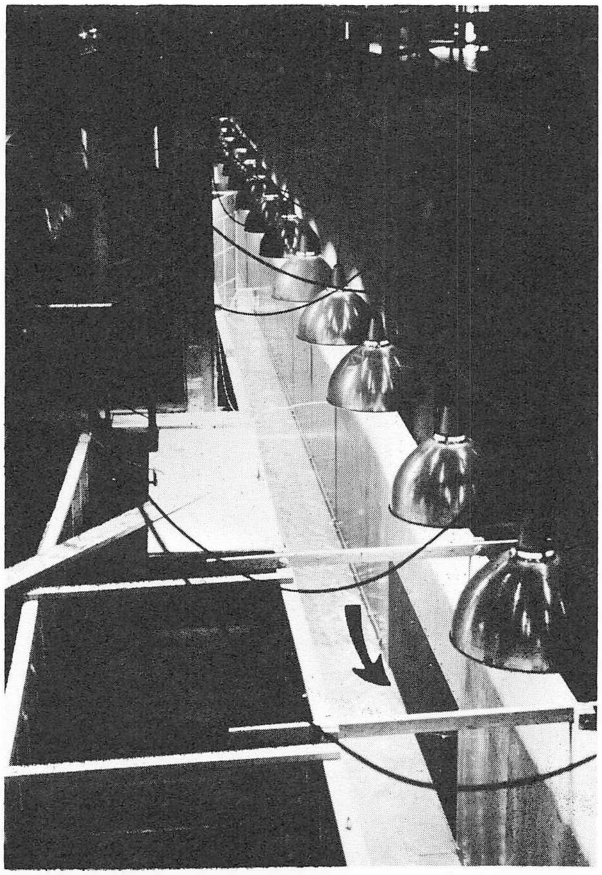


Figure 6.--The 4- by 10-foot wall diffusor (arrow) in the 4-foot wide transportation channel. Exit grill is visible at upper end of channel.

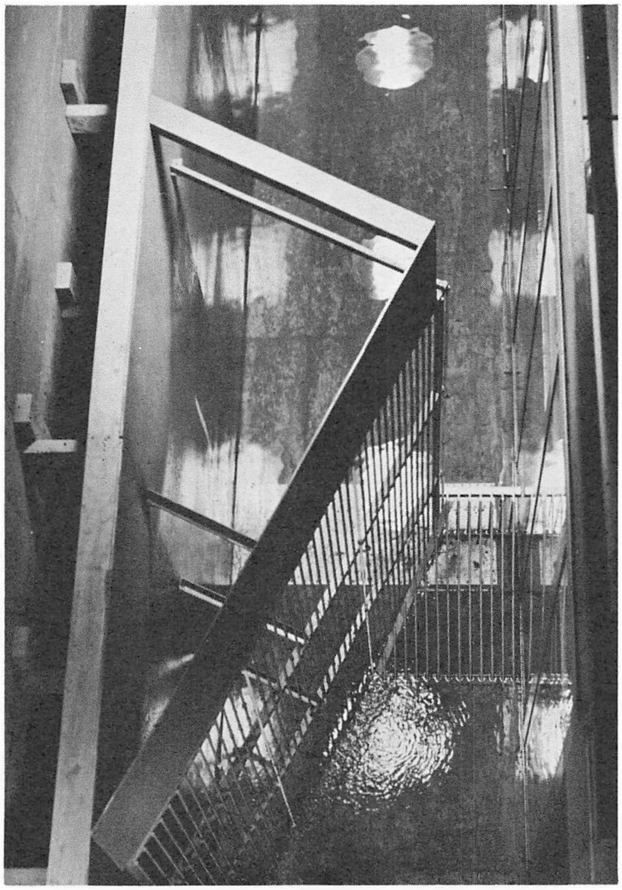


Figure 7.--Exit grill used in 1962 wall diffusor tests. Picketed lead guides fish to the 1-foot wide exit slot within view of counters in the observation chamber (right).

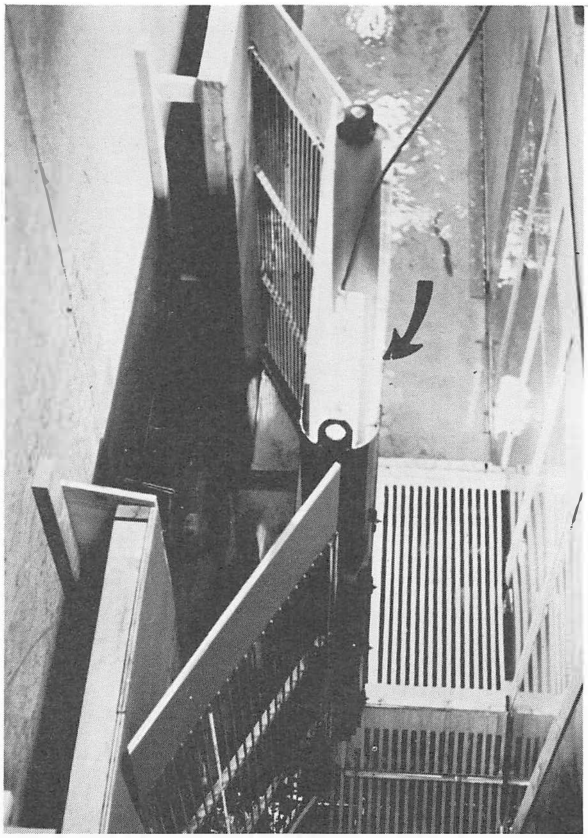


Figure 8.--Exit grill used in the 1963 wall diffusor tests. Fish pass through the 2-foot wide exit slot between the observation chamber (right) and light panel (arrow).

Floor Diffusor

The floor diffusor (figs. 9 and 10) was centered in the transportation channel between two observation chambers. The 4- by 10-foot opening was covered with a grating of 1- by 4-inch dressed lumber spaced 3/4 inch apart and set flush with the transportation channel floor at a 45° angle. About 5 feet below the grating, two rows of baffles were used to dissipate the force of water jetting from the valve box (fig. 10). The valve box and stepped concrete floor were part of the laboratory water supply facilities, whereas the remaining units were temporarily constructed for the experiment.

Water for the diffusor was introduced through a 2-foot metering orifice placed in the 3-foot supply pipe (fig. 10). Maximum flow at the diffusion box was slightly greater than 50 c.f.s., which gave a maximum gross velocity of 1.25 f.p.s. through the diffusor grating.

Wall Diffusor

The wall diffusor (fig. 11) was placed flush against the wall of the transportation channel. The diffusor grating was 4 feet high and 10 feet long, the bottom edge being even with the floor of the channel. Dressed 1- by 4-inch lumber was used for the grilling. Individual slots were spaced 3/4 inch apart and angled at 45° downstream.

In 1963, the grating was modified to obtain a gross velocity of 2 f.p.s. Since the maximum quantity of water was limited to approximately 50 c.f.s., the size of the grating was reduced to 2½ by 10 feet to produce the desired maximum diffusion velocity. The grating was built of 3/16 by 3-inch steel spaced 1 inch apart at 45° angle facing downstream. The bottom edge of this grating remained flush with the channel floor.

PROCEDURE

Diffusor Operation

Auxiliary water flow to the diffusion chamber was controlled by two supply valves and measured by a differential manometer (fig. 12) which registered the pressure difference between the upstream and downstream sides of the metering orifice (figs. 10 and 11). By referring to a calibration chart, the manometer reading was readily converted to c.f.s. flowing into the diffusion water chamber. The volume of water required for each test velocity was predetermined in relation to the gross

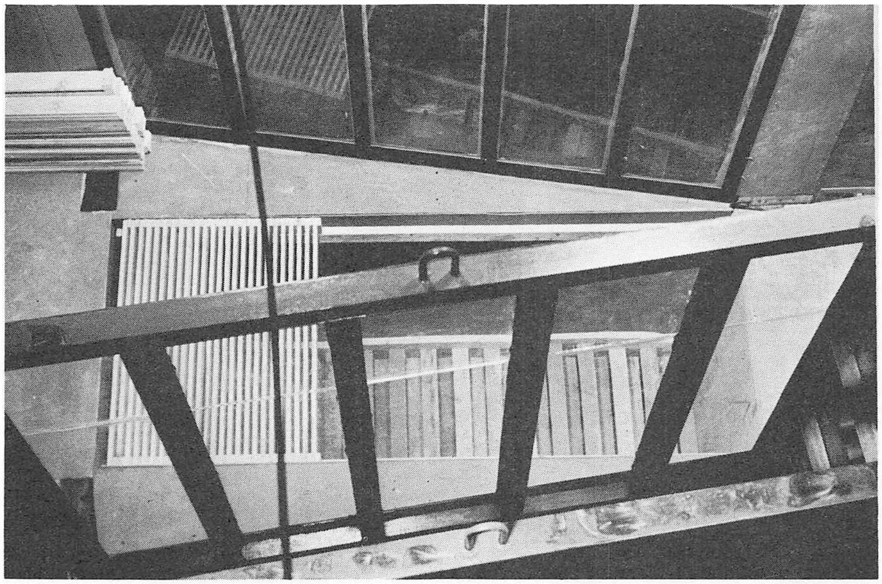


Figure 9.--Looking down on the 4- by 10-foot floor diffusor. Portion of grating has been removed to show internal baffle arrangement. Steel viewing chambers with plexiglass windows adjoin diffusion area.

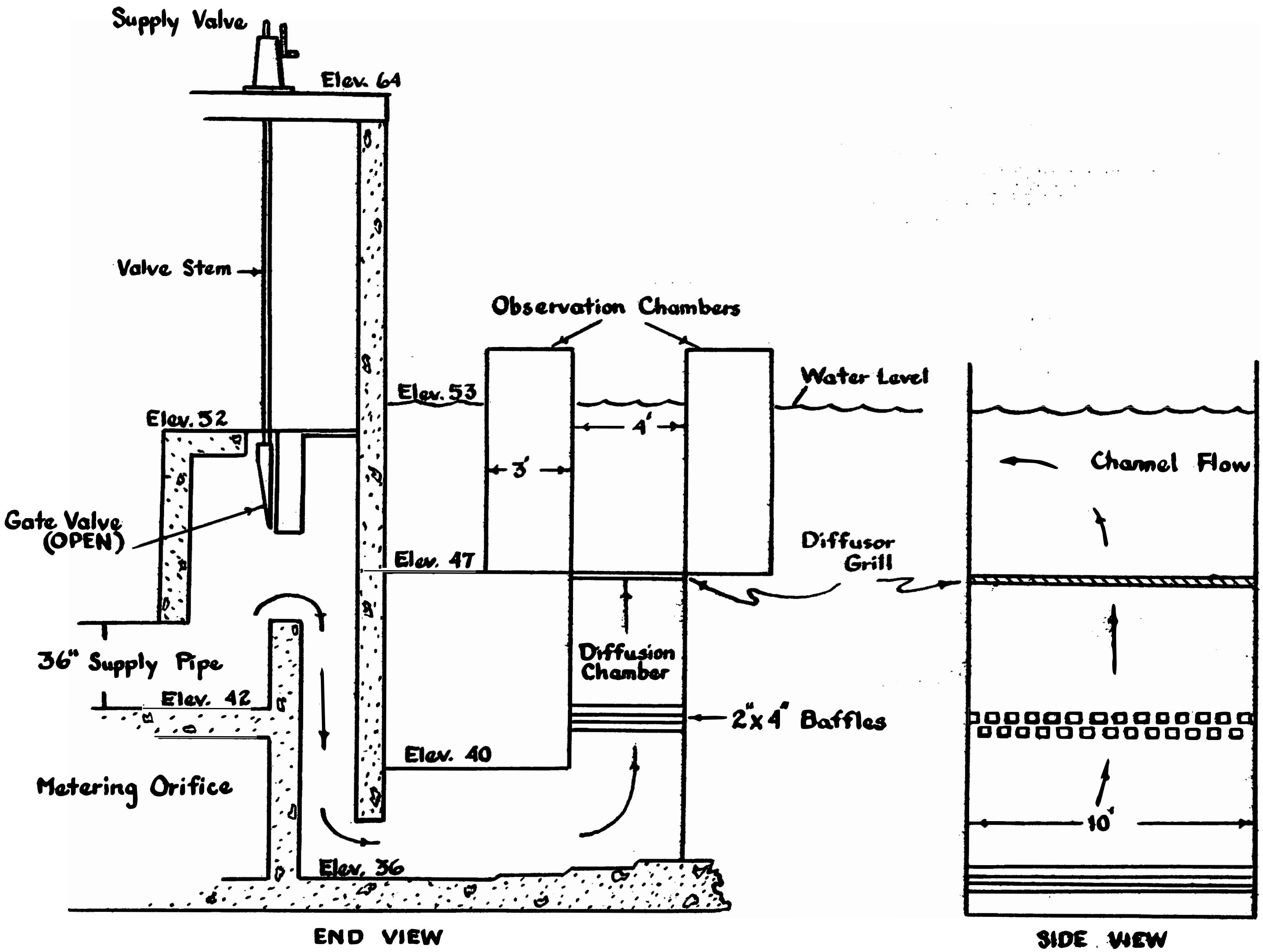


Figure 10.--Sectional views showing floor diffusor, water supply system, and observation chambers.

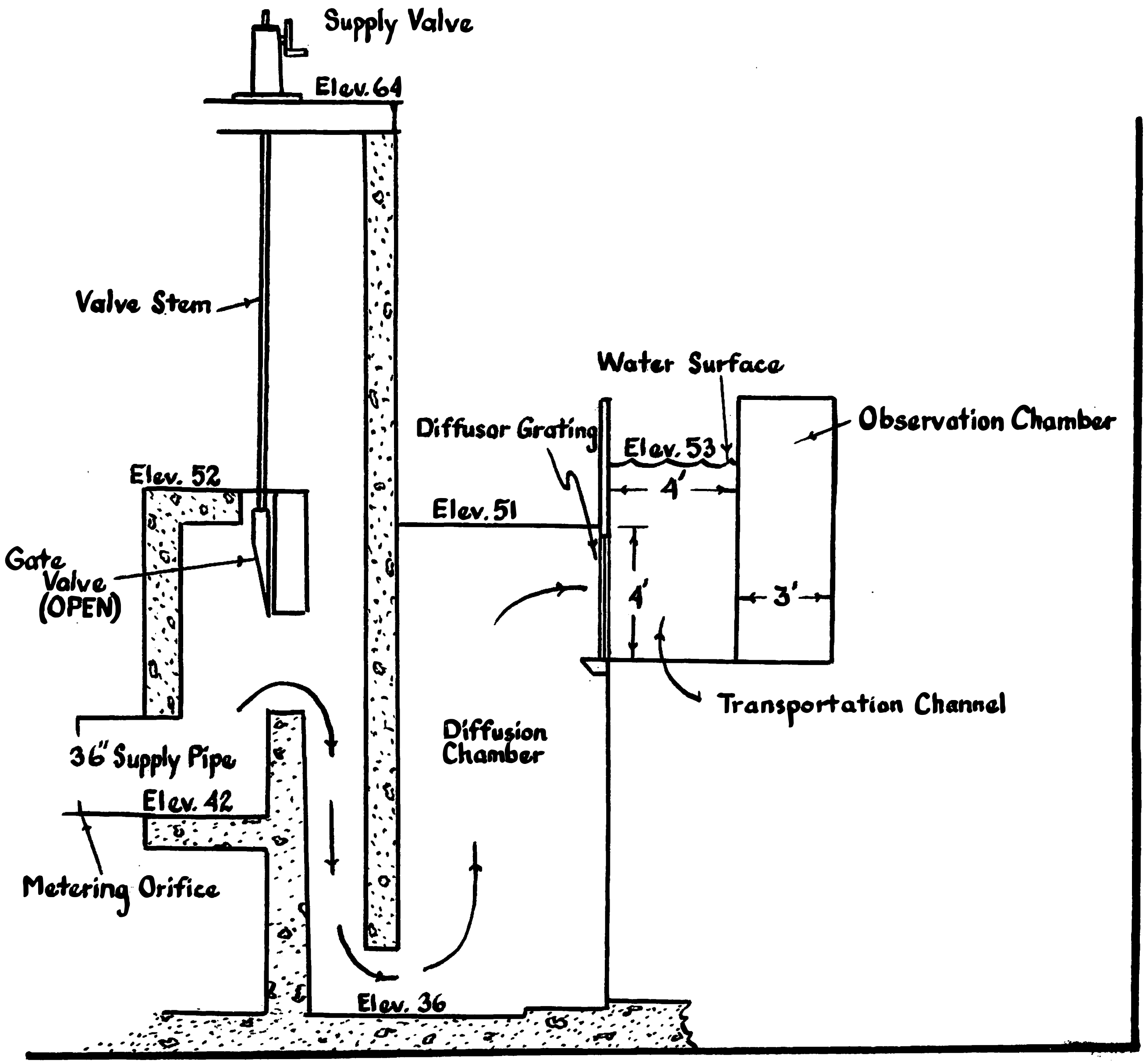


Figure 11.--Sectional view showing wall diffusor, water supply system, and observation chamber.

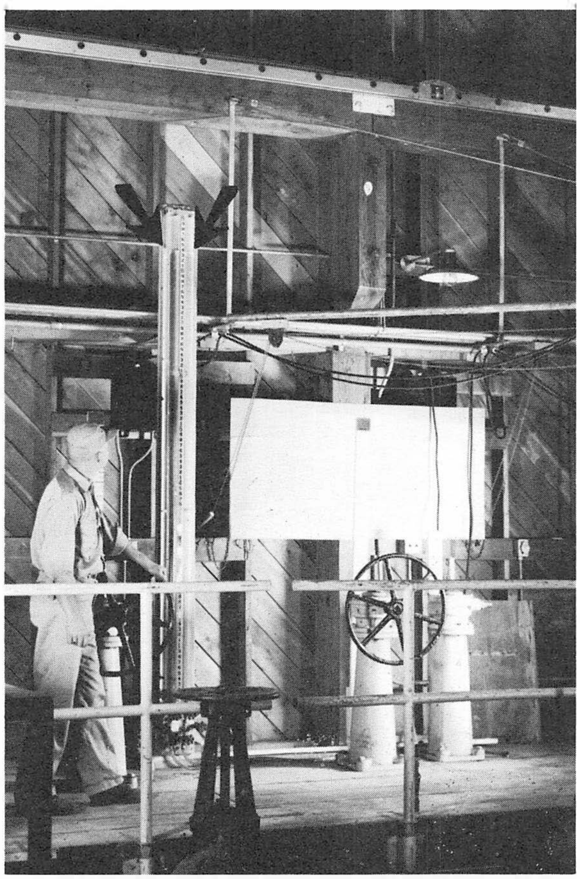


Figure 12.--Diffusion water supply valves and manometer (right of operator). View shows opposing water columns (arrows) at same height, indicating that no water is passing through diffusor. Differences in height of water columns give pressure reading which is converted to flow (c.f.s.).

area of the diffusor. For example, a gross diffusion velocity of 1 f.p.s. would require a discharge of 40 c.f.s. through a 4- by 10-foot diffusor. The manometer was checked frequently, and occasional minor adjustments of the water supply were necessary to compensate for slight forebay fluctuation of the dam. Water level in the test channel was controlled by regulating intake from the flow introduction pool and by adjusting the laboratory drain valve.

Release of Fish

Test fish entered the laboratory from the main fishway on their own volition and were released individually into the experimental area from a release compartment (fig. 13). During their passage through this compartment, each fish was classified by species. Usually a fish was not released until the previous individual had passed through the experimental area.

At the end of each day, the entrance fishway was closed and the release box was opened to allow fish remaining in the fishway to pass through the laboratory and back to the main fishway. During 1962 and 1963, a special bypass channel was installed in the laboratory to permit the unimpeded passage of all fish not needed for experimental purposes. This channel was attached to the side of the release box and extended to the upper end of the laboratory where fish could continue their migration without unnecessary delay.

Fish Timing and Observations

Individual salmonids were timed through a 100-foot timing zone (A to B in figs. 2 and 5). All passage times were registered on a commercial time-event recorder. Observers were stationed at the start and end of the timing zone and transmitted the respective entry and exit times to the recorder. This information was then transposed from the time-scaled tape to a daily operations sheet.

Observations on the behavior of salmonids were made in the vicinity of the diffusor and at the exit of the channel. Two submerged observation chambers were used. These were placed at convenient areas in the test channel as previously noted.

Experimental Design

Statistical treatment of the data was based on a Latin square design, but application and sampling technique varied slightly between years.

Figure 13.--Release compartment at entry gate. Fish ascend entrance fishway (screened section in background) and are released individually into the test area (foreground).

The various gross diffusion velocities that were compared in the floor diffusor studies included combinations of 0.0, 0.25, and 0.50 f.p.s. (approach channel 4 feet wide); 0.0, 0.25, 0.50, and 0.75 f.p.s. (approach channel 5½ feet wide); and 0.0, 1.00, and 1.25 f.p.s. (approach channel 7 feet wide). Usually five salmonids of each available species were tested under each diffusion velocity before changing to the next trial condition.

During the wall diffusion experiments, test velocities were changed daily according to the experimental design, and as many salmonids as possible were tested in a given trial. In the 1962 tests, a 4 by 4 table was used in comparing the response of salmonids to gross diffusion velocities of 0.25, 0.50, 0.75, and 1.00 f.p.s. A 5 by 5 table was used in 1963 for velocities of 0.0, 0.5, 1.0, 1.5, and 2.0 f.p.s.

RESULTS

Floor Diffusor Tests--1961

This study was made to determine the effect of floor diffusion water on the passage of salmonids in a transportation channel. Spring chinook, fall chinook, and steelhead trout were used. Gross diffusion velocities tested were 0.25, 0.50, 0.75, 1.00 and 1.25 f.p.s., with 0.0 f.p.s. (no diffusion water) as a control.

Additional studies were made on effect of entrained air on passage of chinook in a channel and on the response of chinook and steelhead to a diffusor without protective grating.

Performance.--Median passage times of spring-run chinook salmon under the control and various test conditions are given in table 1. These data show that the addition of diffusion water, regardless of magnitude, delayed the passage of fish. There is evidence of an increased delay at each successive increase in diffusion velocity, except at the highest level tested (1.25 f.p.s.).

Median passage times of fall-run chinook (tables 2 and 3) followed a pattern similar to that for the spring chinook. Introduction of diffusion water at any velocity caused a delay in passage, and this delay was not consistently correlated with diffusion velocity. Mean passage times generally reflected the same trends as the median times.

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, 1964.

Gross diffusion velocity	Sample size	Mean passage time 1/	Sample size	Median passage time
F.p.s.	Number	Minutes	Number	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

1/ Based only on fish for which complete times are available.

Passage times of steelhead (tables 2 and 3) at the various diffusion velocities also showed that introduction of diffusion water at any velocity caused a delay in passage. Steelhead passage times under the different diffusion velocities varied widely, and there did not appear to be any direct correlation between passage time and diffusion velocity.

Behavior.--Observations on the behavior of chinook and steelhead were categorized according to the number of times each fish was seen over the diffusion area (fig. 14). Clearly, there was a definite increase in activity when diffusion water was introduced into the channel. In general, activity appeared to increase as the diffusion flows increased. Typically there was considerable to-and-fro movement, which suggests that fish sensed the diffusion water and made repeated passes over the diffusor to investigate the source. The fish, however, always remained parallel to the floor; i.e., they did not attempt to probe into the diffusor grill. Spring-run chinook salmon often assumed a stationary position at the upstream end of the diffusor with only their caudal area extending back over the grillwork.

Effect of air on passage.--An experiment on effect of entrained air on passage of fish in a channel was conducted with spring chinook. The air was introduced through the diffusion chamber and welled up into the channel, creating considerable turbulence (fig. 15). Fish were timed through the channel under two conditions--with and without air introduction. Median passage times (table 4) show that air had no effect on fish passage in the channel.

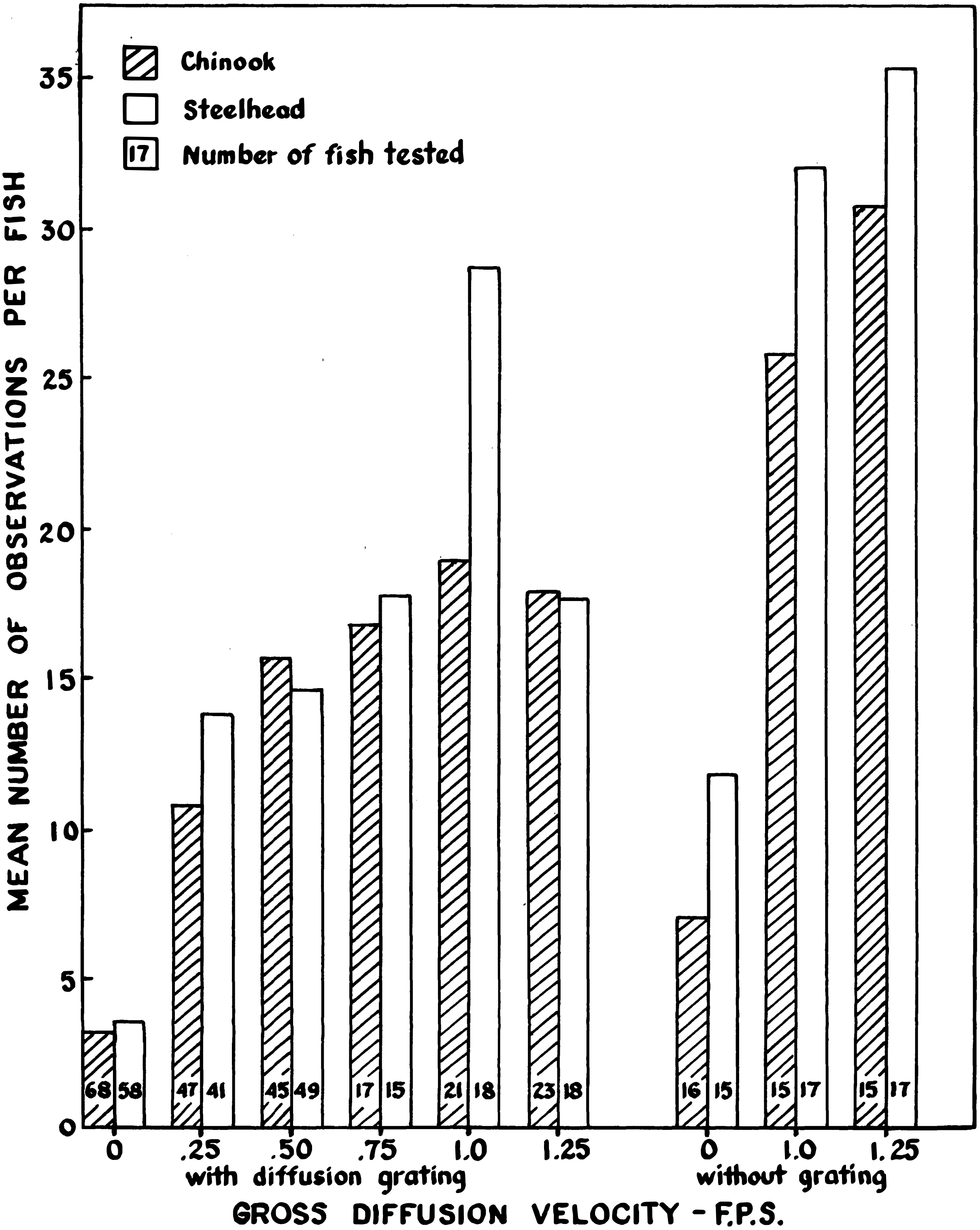
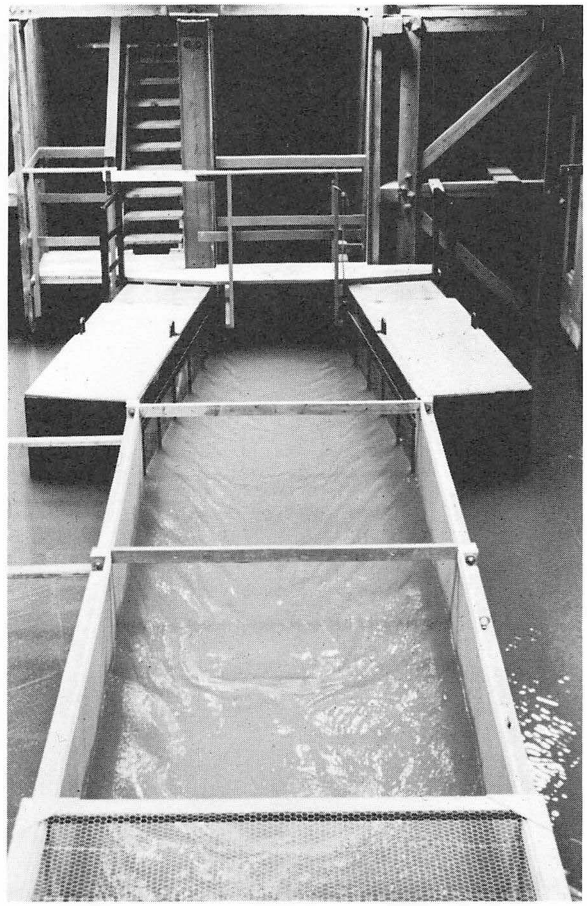


Figure 14.--Mean number of times individual fish appeared over diffusion areas under diffusion velocities ranging from 0 to 1.25 f.p.s., August and September 1961. Sample size given within bars.



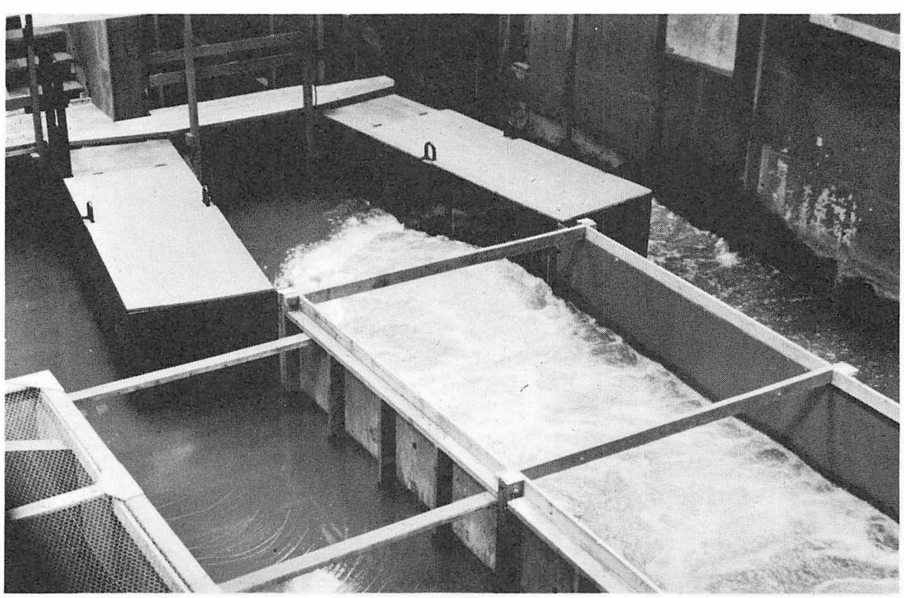


Figure 15.--Diffusion area and transportation channel with air being introduced through the diffusor (bottom) and without air (top).

Table 2.--Effect of floor diffusion (range--0.0 to 0.50 f.p.s.) on the passage of chinook salmon and steelhead trout in a transportation channel, August 25-31, 1961.

Gross diffusion velocity	Sample size	Mean passage time 1/	Sample size	Median passage time
		Chinook		
F.p.s.	Number	Minutes	Number	Minutes
0.0	30	2.0	32	1.9
.25	30	6.3	32	3.6
.50	28	6.5	30	4.3
		Steelhead		
0.0	31	3.5	31	2.0
.25	27	7.8	30	7.1
.50	30	7.3	34	6.5

1/ Based only on fish for which complete times are available.

Table 3.--Effect of floor diffusion on the passage of chinook salmon and steelhead trout in a transportation channel. Passage times compared under gross diffusion velocities of 0.0 to 1.25 f.p.s., September 1-14, 1961.

Gross diffusion velocity	Sample size	Mean passage time 1/	Sample size	Median passage time
		Chinook		
F.p.s.	Number	Minutes	Number	Minutes
0.0	37	3.6	38	2.6
.25	11	9.2	15	10.6
.50	12	17.4	15	17.7
.75	13	13.1	15	14.4
1.0	15	8.4	16	6.3
1.25	12	10.4	18	17.0
		Steelhead		
0.0	28	11.2	29	3.0
.25	10	9.8	10	7.7
.50	12	15.0	15	20.7
.75	14	12.1	15	11.8
1.0	13	14.7	16	19.3
1.25	16	9.0	17	8.5

1/ Based only on fish for which complete times are available.

No grating on diffusor.--Another experiment was made to evaluate the effect of removing the diffusor grating on fish passage. Gross diffusion velocities were 0, 1, and 1¼ f.p.s. Removal of the grating created a 4½-foot depression in the floor of the channel. A wire-mesh screen was placed over the diffusion baffles to prevent the fish from entering inner areas of the chamber.

Table 4.--Comparison of chinook salmon passage in a transportation channel under aerated and non-aerated conditions, May 19-24, 1961.

Test condition	Sample size	Mean passage time 1/	Sample size	Median passage time
	Number	Minutes	Number	Minutes
With air	20	6.1	21	3.4
Without air	21	6.8	21	3.5

1/ Based only on fish for which complete times are available.

The results (table 5) show that a considerable delay in passage occurred when diffusion water was added.

Observations from the viewing chamber demonstrated that it would be impractical to operate diffusion systems without gratings. Both chinook and steelhead sounded into the diffusor even when no water was introduced. Steelhead were more inclined than chinook to enter the diffusor with no auxiliary flow; steelhead rarely passed the diffusor without sounding. The number of times fish were seen in the diffusion area (fig. 14) appears to be correlated with diffusion velocity. Also, both steelhead and chinook were more active in the vicinity of the diffusor when the grating was removed than when it was in place. Steelhead were slightly more active under all conditions than chinook.

Wall Diffusor Tests--1962

Tests during April, May, June, and July included spring- and summer-run chinook salmon, sockeye salmon, and steelhead trout. A 16-day Latin square experimental design included a 4-day operation at each diffusion velocity--.25, .50, .75, and 1.00 f.p.s. Median and mean passage times of salmonids were used to evaluate performance under the four diffusion

Table 5.--Passage times of chinook salmon and steelhead trout in a transportation channel with floor diffusor grating removed. Diffusion velocities were 0.0, 1.00 and 1.25 f.p.s., September 15-20, 1961.

Gross diffusion velocity	Sample size	Mean passage time	Sample size	Median passage time
F.p.s.	Number	Minutes	Number	Minutes
		Chinook		
0.00	14	3.3	16	3.0
1.00	9	9.6	15	17.1
1.25	12	14.1	15	17.4
		Steelhead		
0.00	13	7.0	15	6.2
1.00	13	15.2	17	19.4
1.25	15	17.4	17	17.4

velocities. Tests for significance were based on the 95 percent confidence intervals about the median (Dixon and Massey, 1957). Behavior patterns under the respective diffusion velocities were also compared.

Performance.--Tests with spring- and summer-run chinook salmon extended from April 17 to July 1 (table 6). These showed that passage times varied only slightly within the 0.25 to 0.75 f.p.s. range of diffusion velocities. At 1.00 f.p.s., passage times increased markedly. The difference between passage times at 1.00 f.p.s. and at the lower diffusion velocities (0.25 - 0.75 f.p.s.) was statistically significant in the April and June tests. Seasonal differences in passage times were noted but the effects of diffusion remain consistent over the course of the test period.

The June 24 to July 9 tests with sockeye salmon encompassed the peak of the run. Mean and median passage times under the various diffusion water velocity conditions (table 7) show that the fastest passage was achieved at the 0.50 f.p.s. diffusion velocity. The difference between the passage time at 0.50 f.p.s. and that at .75 f.p.s. was statistically significant. There appeared to be little difference between the passage times at diffusion velocities of 0.25, 0.75 and 1.00 f.p.s.

Table 6.--Effect of wall diffusion on the passage of chinook salmon in a transportation channel. Passage times compared under gross diffusion velocities of 0.25 to 1.25 f.p.s., April 17 to July 1, 1962.

Gross diffusion velocity	Sample size	Mean passage time 1/	Sample size	Median passage time
F.p.s.	Number	Minutes	Number	Minutes
April 17 - May 2				
0.25	137	5.4	138	3.7
0.50	181	4.5	186	3.4
0.75	132	5.4	136	3.6
1.00	107	6.5	114	4.9
May 12 - 27				
0.25	42	10.7	45	9.3
0.50	41	11.9	48	9.9
0.75	36	11.6	40	7.4
1.00	45	11.8	49	11.2
June 16 - July 1				
0.25	43	9.8	46	6.8
0.50	44	12.1	50	9.8
0.75	29	11.0	35	12.7
1.00	23	16.8	30	20.7

1/ Based on fish for which complete times are available.

Table 7.--Effect of wall diffusion (0.25 to 1.00 f.p.s.) on the passage of sockeye salmon in a transportation channel, June 16 to July 9, 1962.

Gross diffusion velocity	Sample size	Mean passage time 1/	Sample size	Median passage time
F.p.s.	Number	Minutes	Number	Minutes
0.25	35	10.9	39	9.1
0.50	39	8.2	42	4.9
0.75	34	12.1	42	11.2
1.00	38	12.1	42	9.9

1/ Based only on fish for which complete times are available.

The effect of wall diffusion on steelhead passage time was similar to that on sockeye. Median passage times at velocities of 0.25, 0.50, and 1.00 f.p.s. did not differ, but at a velocity of .75 f.p.s., the passage was slower (table 8). A comparison of mean passage times indicates there is a breaking point between 0.50 and 0.75 f.p.s., with passage at 0.25 and 0.50 f.p.s. being faster than passage at 0.75 and 1.00 f.p.s.

Behavior.--Observations of fish in the vicinity of the diffusor and at the exit point during the wall diffusor study were tabulated as follows: (1) the number of times each fish was seen in the vicinity of diffusor, (2) behavior of the fish when seen in vicinity of diffusor, and (3) the number of turnbacks at the exit point.

The mean number of observations per fish in vicinity of wall diffusor is shown in figure 16. Test periods for chinook are shown separately and for all periods combined. The apparent increase in number of times chinook were seen as the season progressed is explained in part by a decrease in water turbidity as the season advanced; i.e., the fish were more readily observed in the clearer water later in the season. Using number of observations per fish as a measure of activity, there appears to be a positive correlation between diffusion velocity and fish activity. Sockeye and steelhead differed slightly from chinook in that there appeared to be two levels of activity--limited at 0.25 and 0.50 f.p.s., and moderate activity at velocities of 0.75 and 1.00 f.p.s.

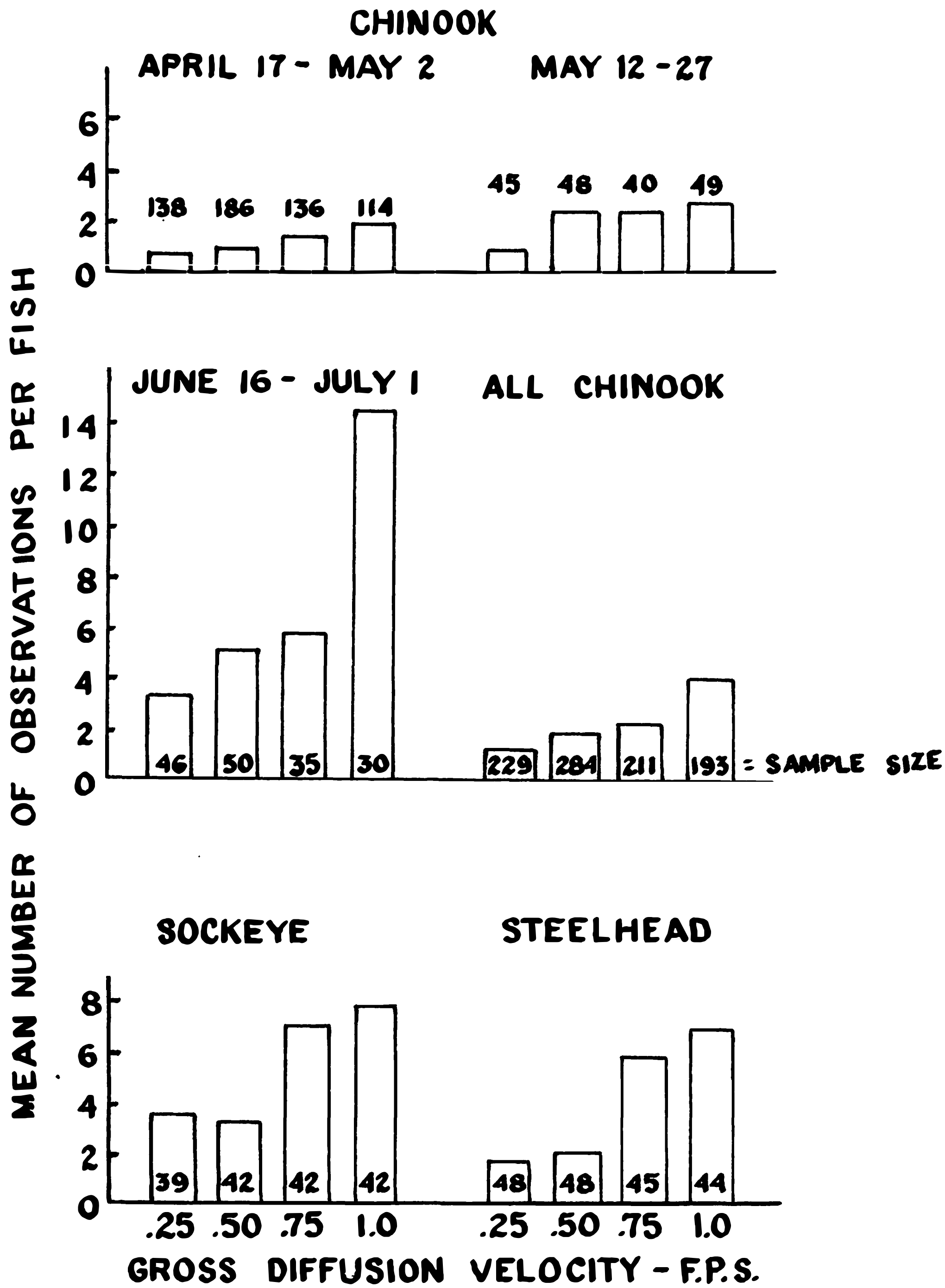


Figure 16.--Mean number of observations per fish in vicinity of wall diffusor, 1962. Sample sizes are listed in bars.

Table 8.--Effect of wall diffusion (0.25 to 1.00 f.p.s.) on the passage of steelhead trout in a transportation channel, July 14-29, 1962.

Gross diffusion velocity	Sample size	Mean passage time 1/	Sample size	Median passage time
F.p.s.	Number	Minutes	Number	Minutes
0.25	43	8.0	47	7.0
0.50	48	9.7	49	5.7
0.75	40	12.0	44	11.7
1.00	37	11.5	43	7.6

1/ Based only on fish for which complete times are available.

The behavior of the fish in the vicinity of the diffusor was reduced to three patterns: (1) movement upstream past the diffusor, (2) movement downstream past the diffusor, and (3) incomplete passage--fish remained in diffusion area for varying intervals. Figure 17 shows these patterns for chinook by a percentage occurrence at each velocity. Generally, an increase in diffusion velocity did not appear to affect behavior patterns of chinook within the individual tests. There was some increase in the occurrence of the type 3 pattern (incomplete passage) during the third period (June 16 to July 1). This could have been related to improved visibility; i.e., stationary fish were readily observed in the clearer water prevailing at this time.

Behavior patterns of steelhead and sockeye in the vicinity of the diffusor (fig. 18) approximated those of the chinook during the June period. Steelhead showed some evidence of an increase in the type 3 pattern as diffusion velocity increased.

Explanation is given for the fact that percentage of downstream movement was almost always greater than percentage of upstream movement. Inasmuch as all fish had to make one trip more upstream than downstream to pass through the channel, the fish must have moved upstream close to the diffusor (where they could have passed unobserved) and downstream close to the observation chamber.

The mean number of turnbacks at the exit point is given in figure 19. This aspect of behavior was studied to determine if there was some relation between the diffusion

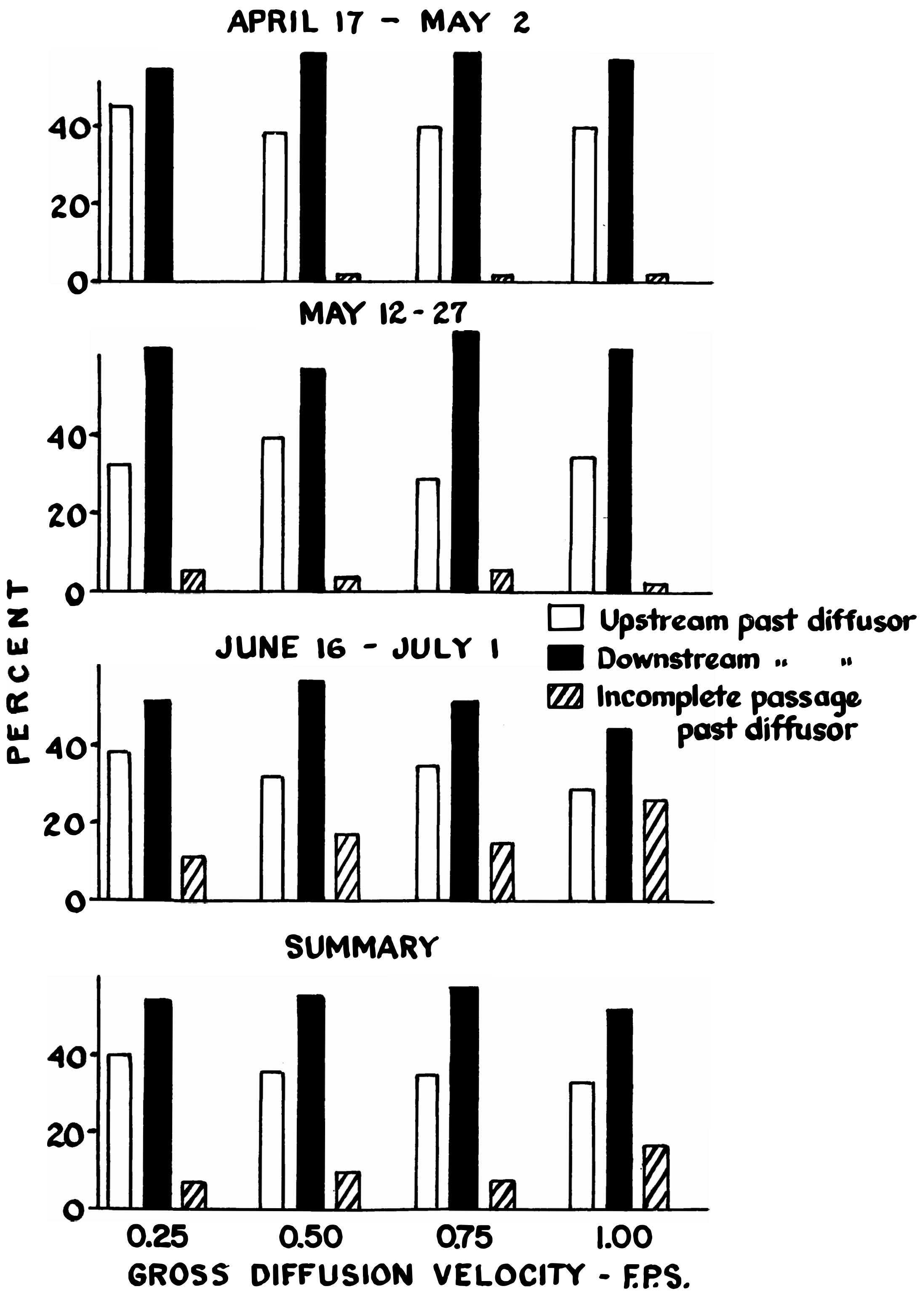


Figure 17.--Behavior patterns of chinook salmon in vicinity of wall diffusor by percentage occurrence, June and July 1962.

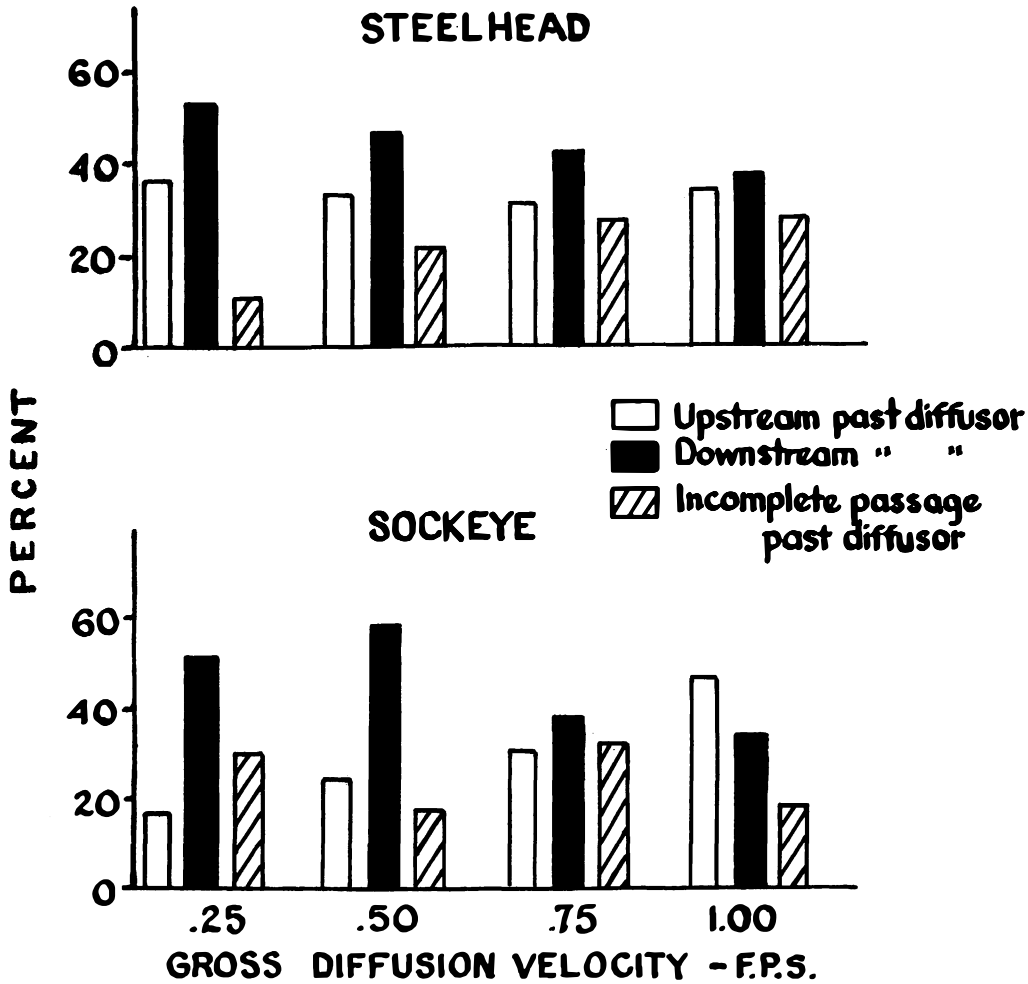


Figure 18.--Behavior patterns of steelhead trout and sockeye salmon in vicinity of wall diffusor by percentage occurrence, June and July 1962.

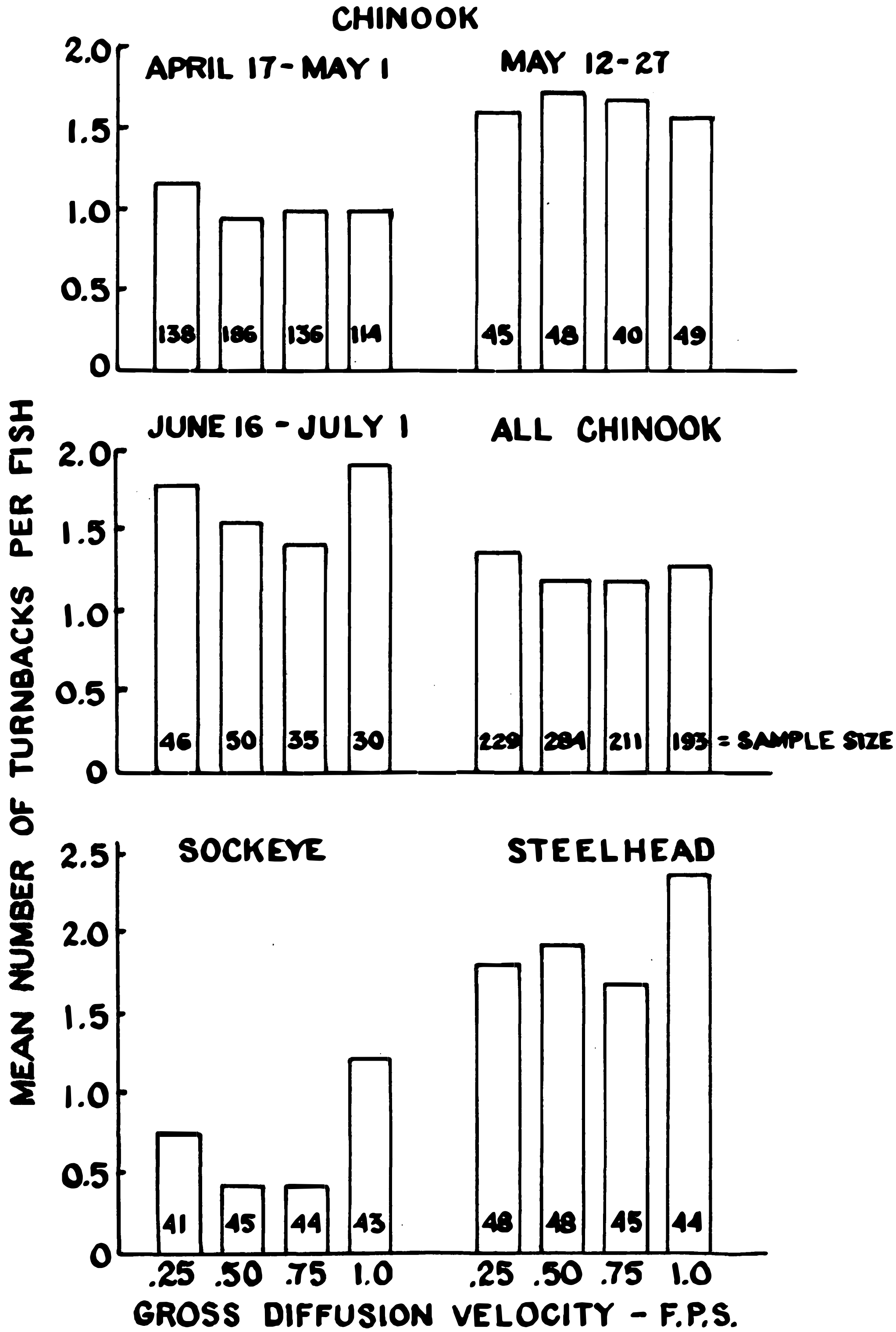


Figure 19.--Mean number of turnbacks at exit point by chinook salmon, sockeye salmon, and steelhead trout during wall diffusor study, 1962. Sample sizes are listed on individual bars.

condition and the tendency of the fish to return back downstream after reaching the exit point, which was some 50 feet upstream of the diffusor. Evidence that chinook salmon were more prone to turn back at the higher diffusion velocities than at the lower appears lacking. In the case of steelhead and blueback, there was some indication of an increasing tendency to turn back at the highest diffusion velocity (1.0 f.p.s.).

Wall Diffusor Tests - 1963

For these tests the diffusor opening was reduced in size in order to extend the gross diffusion water test velocities to 2.0 f.p.s. The wooden grillwork in the diffusion grating was replaced with steel plate 3/16-inch thick. This was done to reduce the high jet velocities that would have resulted with wooden grating. Gross diffusion velocities of 0.5, 1.0, 1.5, and 2.0 f.p.s. were included in the test schedule. Control tests (no diffusion) were also run. The Latin square experimental design was based on a 5-day operation at each of the five settings. Evaluation of the effects on fish passage was similar to that in previous test series, and tests for significance were based on the 95 percent confidence intervals about the median.

Performance.--Chinook salmon tested during two periods, April 15 to May 9 (spring run) and June 8 to July 3 (summer run), once again showed that the introduction of diffusion water caused a delay in passage time (table 9). As in previous tests the median and mean statistic showed that passage time increased as the diffusion velocities increased. During April and May, median passage times of chinook salmon at 0.5 and 1.0 f.p.s. do not differ significantly from each other. Passage times at 1.5 and 2.0 f.p.s., however, differed significantly from each other and were also significantly longer than passage times at 0.5 and 1.0 f.p.s. Results of tests on the summer run were comparable to the earlier trials at 0.5 and 1.0 f.p.s. Although median times at 1.5 and 2.0 f.p.s. did not differ significantly from each other, both times were significantly slower than those at 0.5 f.p.s.

Sockeye salmon passages were generally faster than those of chinook, but the effects of diffusion water were similar--that is, passage was slower as diffusion water velocities increased (table 10). The one exception from previous results with chinook was that passage time did not increase as diffusion increased from 1.0 to 1.5 f.p.s. Median passage times at 1.0 and 1.5 f.p.s. were both significantly slower than passages under the 0.5 f.p.s. velocity, but the actual time difference was roughly only .4 minute. Median passage times at 2.0 f.p.s. were significantly greater than those at lower diffusion velocities.

Table 9.--Effect of wall diffusion (gross velocity--0.0 to 2.0 f.p.s.) on the passage of chinook salmon in a transportation channel, April 15 to May 9 and June 8 to July 3, 1963.

Gross diffusion velocity	Sample size	Mean passage time 1/	Sample size	Median passage time
F.p.s.	Number	Minutes	Number	Minutes
		April 15 - May 9		
0.0	238	3.2	239	2.4
0.5	208	4.4	211	3.2
1.0	139	5.4	143	3.4
1.5	146	6.3	151	5.2
2.0	102	7.8	105	6.8
		June 8 - July 3		
0.0	111	3.9	112	2.1
0.5	90	6.7	93	3.7
1.0	70	7.7	73	4.5
1.5	62	8.5	64	5.9
2.0	71	9.5	72	6.8

1/ Based only on fish for which complete times are available.

Steelhead trout appeared to be only slightly affected by the addition of diffusion water (table 11). The median passage time at zero diffusion velocity was significantly less than any of the passage times obtained when diffusion water was added, but from a practical standpoint, the actual differences were slight. None of the median passage times at 0.5, 1.0, 1.5, and 2.0 f.p.s. differed significantly from each other.

Behavior.--Movements of fish at the wall diffusor and exit point were tabulated in the same manner as in the 1962 tests.

The mean number of observations per fish (fig. 20) demonstrated that activity of both spring and summer chinook in the vicinity of the diffusor increased with the introduction of diffusion water, especially at velocities of 1.5 and 2.0 f.p.s.

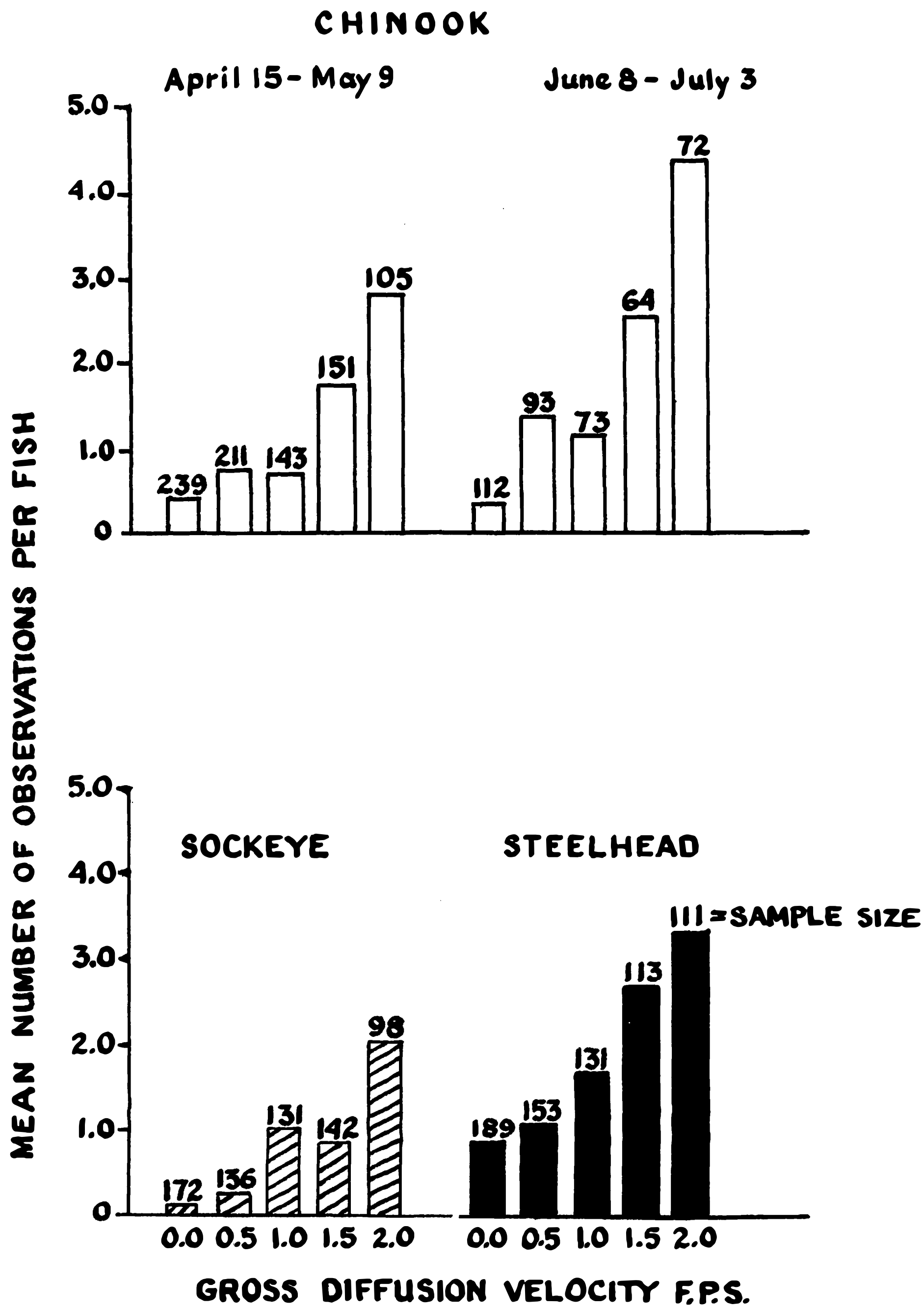


Figure 20.--Mean number of observations per fish in vicinity of wall diffusor, 1963.

Table 10.--Effect of wall diffusion (gross velocity--0.0 to 2.0 f.p.s.) on the passage of sockeye salmon in a transportation channel, June 18 to July 13, 1963.

Gross diffusion velocity	Sample size	Mean passage time 1/	Sample size	Median passage time
F.p.s.	Number	Minutes	Number	Minutes
0.0	172	2.4	172	1.4
0.5	132	3.4	136	1.9
1.0	130	5.3	131	2.4
1.5	137	4.3	142	2.3
2.0	94	6.3	98	4.6

1/ Based only on fish for which complete times are available.

Table 11.--Effect of wall diffusion (0.0 to 2.0 f.p.s.) on the passage of steelhead trout in a transportation channel, July 1963.

Gross diffusion velocity	Sample size	Mean passage time 1/	Sample size	Median passage time
F.p.s.	Number	Minutes	Number	Minutes
0.0	188	4.0	189	2.2
0.5	152	5.3	153	2.7
1.0	128	5.6	131	2.8
1.5	112	5.5	113	3.4
2.0	108	5.7	111	2.7

1/ Based only on fish for which complete times are available.

The greater number of observations per fish on summer chinook may be an actual increase, but could have resulted from a decreased turbidity which made it possible to see the fish at a greater distance from the viewing chamber. Observations on sockeye and steelhead (fig. 20) showed activity pattern similar to those of the chinook. Sockeye were relatively inactive at diffusion velocities of 0.0 or 0.5 f.p.s., but activity increased somewhat when diffusion velocities reached 1 f.p.s. and above with further increased activity at 2 f.p.s. Steelhead activity appeared to be directly correlated with diffusion velocity.

Behavior patterns of fish in the vicinity of the diffusor are shown in figure 21. The introduction of diffusion water usually tended to increase downstream movement and the type 3 pattern (incomplete passage) was more prevalent at the highest diffusion (2 f.p.s.).

None of the fish remained in the vicinity of the diffusor for long periods of time. Usually they were in view for only a few seconds. None were observed to turn into the flow from the diffusor.

With spring chinook and sockeye, the mean number of turnbacks (fig. 22) per fish at the exit point appears to be directly correlated with diffusion water velocity; i.e., the higher the velocity the greater the number of turnbacks. Introduction of diffusion water increased the number of turnbacks of summer chinook about the same extent at all velocities. Apparently diffusion water had no appreciable effect on steelhead turnback activity.

DISCUSSION

Application of the findings in these studies should be considered in relation to the size of the test facility. In these experiments, dimensions of the transportation channel were clearly minimal by comparison with large prototype fish facilities on the Columbia River. It is conceivable that the narrow channel and shallow water depth in the laboratory presented an extreme condition and that the effects of diffusion under these close quarters would be more pronounced than might be expected in a more expansive installation. For example, in the laboratory every fish was required to pass in close proximity to the diffusor, whereas in a much larger field facility, fish could pass at a considerable distance from the diffusor and, thus, be less aware of the diffusion flows.

Turning now to the results of these tests, we find that even modest additions of diffusion water in a transportation channel caused a delay to the passage of fish. Although the delay was not always in direct relation to the diffusion velocity, it was generally established that the slowest passage was associated with the higher diffusion velocities in the range tested. How meaningful are these delays from a practical standpoint? In most instances, we have found that a 100 percent increase of established diffusion flow criteria (0.25 f.p.s. for floor diffusor, and 0.50 f.p.s. for wall diffusor) would result in a passage delay of only a few minutes. In our judgment, delays of this magnitude would hardly be of serious consequence.

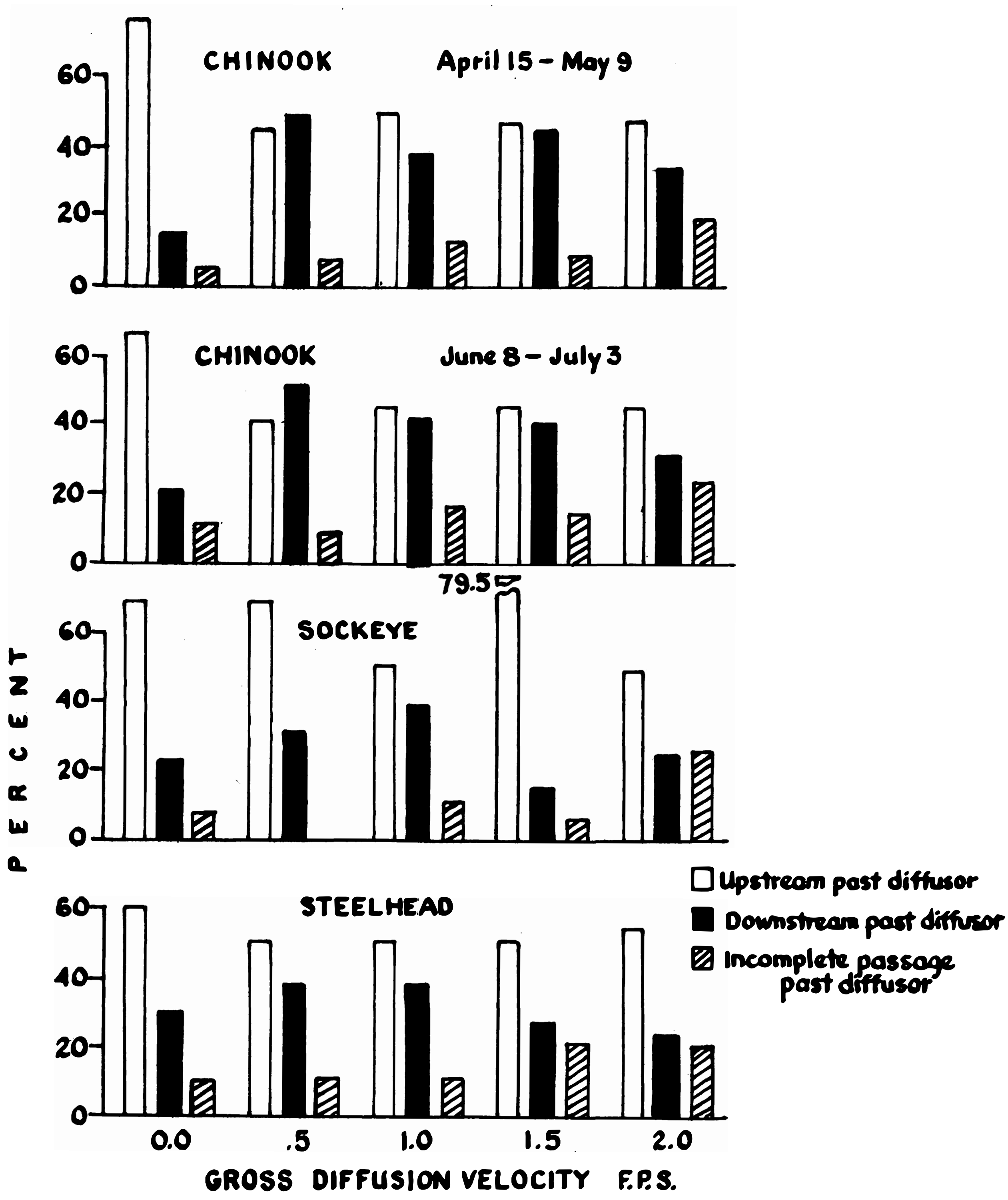


Figure 21.--Behavior patterns of chinook salmon, sockeye salmon, and steelhead trout in vicinity of diffusor by percentage occurrence in 1963.

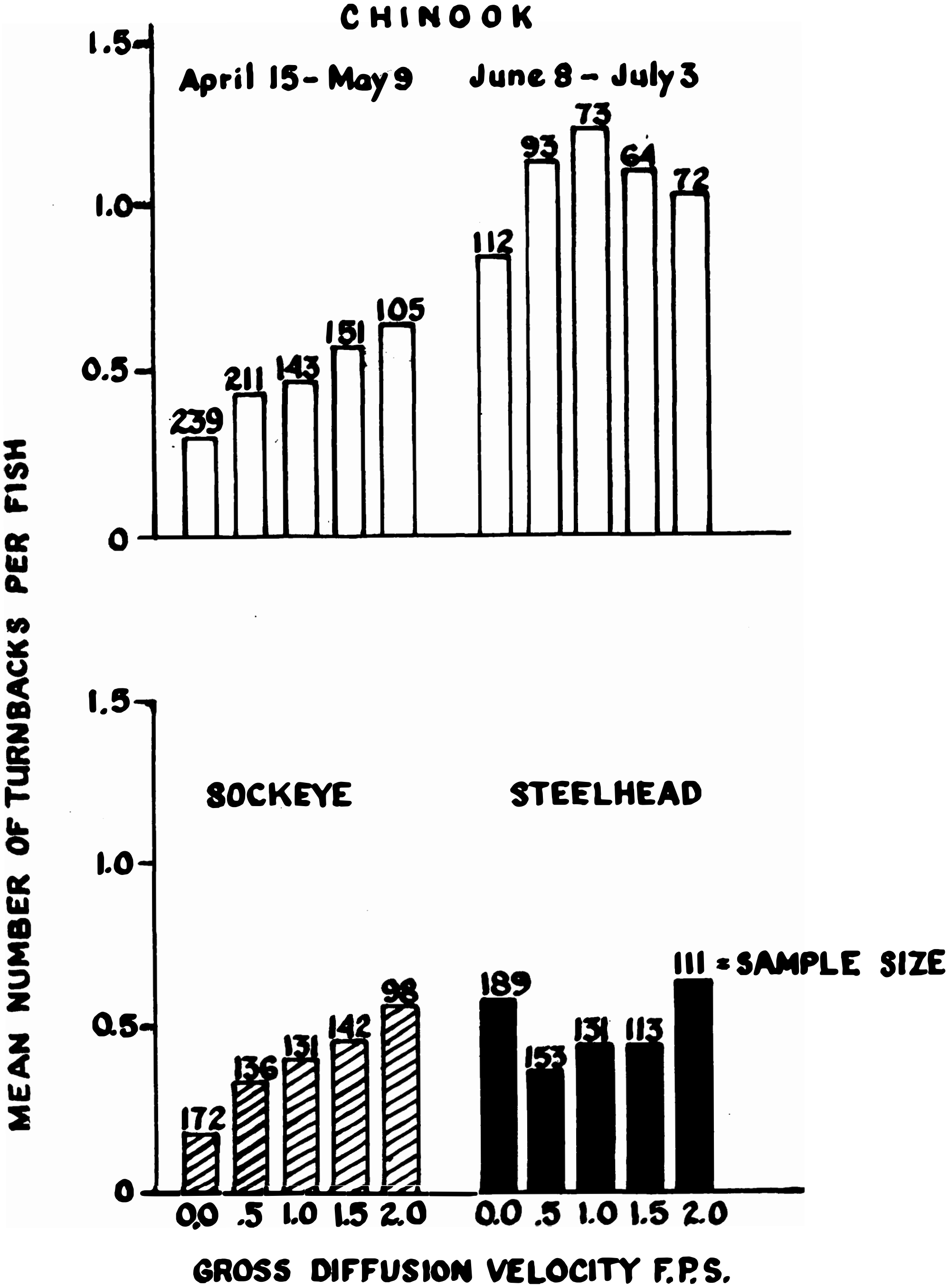


Figure 22.--Mean number of turnbacks at exit point by chinook salmon, sockeye salmon, and steelhead trout during wall diffusor study, 1963.

SUMMARY AND CONCLUSIONS

A study was made to determine the effect of gross diffusion water velocity on passage of salmonids in a transportation channel. The channel was 4 feet wide with a water depth of 6 feet. A floor diffusor was used with velocities ranging from .25 to 1.25 f.p.s. During the first season of the wall diffusor study, velocities ranged from .25 to 1.0 f.p.s., and during the second season, they ranged from .5 to 2.0 f.p.s. A velocity of 0.0 f.p.s. (no diffusion water) served as a control. Passage time and behavior were used to measure the effect of the various diffusion velocities. Chinook salmon, sockeye salmon, and steelhead trout were used. Results and conclusions may be summarized as follows:

Floor Diffusor

1. Introduction of diffusion water at any velocity deterred the passage of chinook and steelhead in a transportation channel.

2. The relationship between diffusion velocity and passage time was not always clear cut, but there was a general tendency for passage times of chinook and steelhead to increase at the higher diffusion velocities.

3. Activity of chinook and steelhead in the vicinity of the diffusor increased at the higher diffusion velocities.

4. The introduction of large masses of entrained air into a channel, will not impede the passage of chinook salmon.

5. It does not appear feasible to operate diffusors without a grating. Both chinook and steelhead entered the diffusor opening when the grating was removed, even when no water was diffused into the transportation channel.

6. A 100 percent increase in the gross floor diffusion velocity (0.25 f.p.s. to 0.50 f.p.s.) will not cause an appreciable delay in fish passage.

Wall Diffusor

1. Introduction of diffusion water at any velocity caused a delay in passage of chinook, sockeye, and steelhead through the transportation channel.

2. There was a general tendency for passage times of chinook, sockeye, and steelhead through the channel to increase as diffusion water velocity was increased.

3. Activity of chinook, sockeye, and steelhead in the vicinity of the diffusor increased at the higher diffusion velocities.

4. Delays in passage with increases in diffusion velocity generally ranged from only a fraction of a minute to several minutes. A 100 percent increase in the gross wall diffusion velocity (0.50 f.p.s. to 1.00 f.p.s.) will not appreciably retard fish passage in a transportation channel.

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