EXPLORATORY RESEARCH ON GUIDING JUVENILE SALMON

by

Daniel W. Bates

October 1964

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

INTRODUCTION

Many years of research have been devoted to the problem of protecting young salmon and steelhead from destruction in rivers, streams, and canals subject to hydroelectric or irrigation developments. This has included studies, to name just a few, on the practicability of using such guiding devices as electricity (Holmes, 1948; Andrew, Kersey, and Johnson, 1955; Pugh and Monan, 1962); light (Fields, 1957); odors, traveling cables, differential velocities, and electricity (Brett and Alderdice, 1958); sound (Moore and Newman, 1956); and louvers (Bates and Vinsonhaler, 1956, and Ruggles and Ryan[1/]). The task of safeguarding each of the five species of Pacific salmon (*Oncorhynchus*) as well as steelhead (*Salmo gairdneri*) has not been simplified, because each year the complex of dams and irrigation projects becomes even more intricate.

Where effort has been made to collect downstream migrants at high-head dams, collection has been accomplished within the forebay adjacent to the dam. This applies to all high-head dams in the Columbia Basin, such as Brownlee in the Snake, Pelton in the Deschutes, North Fork in the Clackamas, and Mayfield in the Cowlitz. At Brownlee, a $3.5 million system composed of a deep, river-wide seran net and three "skimmers" on floating barges to trap downstream migrant salmon and steelhead was unsuccessfully used for 4 years. It has since been removed, but not replaced.

Another approach to downstream migrant collection at high-head dams has been used at Mayfield Dam on the Cowlitz River, where the total powerhouse flow of 12,000 c.f.s. is screened through a louver system (fig. 1).

As there is some question as to both the ability of the juvenile migrant to pass through reservoirs and the effectiveness of the migrant collection system at these high-head dams, biologists are currently carrying out investigations on these particular problems. One such study is being conducted in the Brownlee Reservoir. Present observations indicate that the downstream migrant is beset by many problems in its effort to find a way through the 57-mile-long reservoir. The evidence indicates that the length of a reservoir may be one of the factors limiting successful downstream migration.

1/ Ruggles, C. B. and D. Ryan. An investigation of louvers as a method of guiding juvenile Pacific salmon. Canadian Fish Culturist (in press).

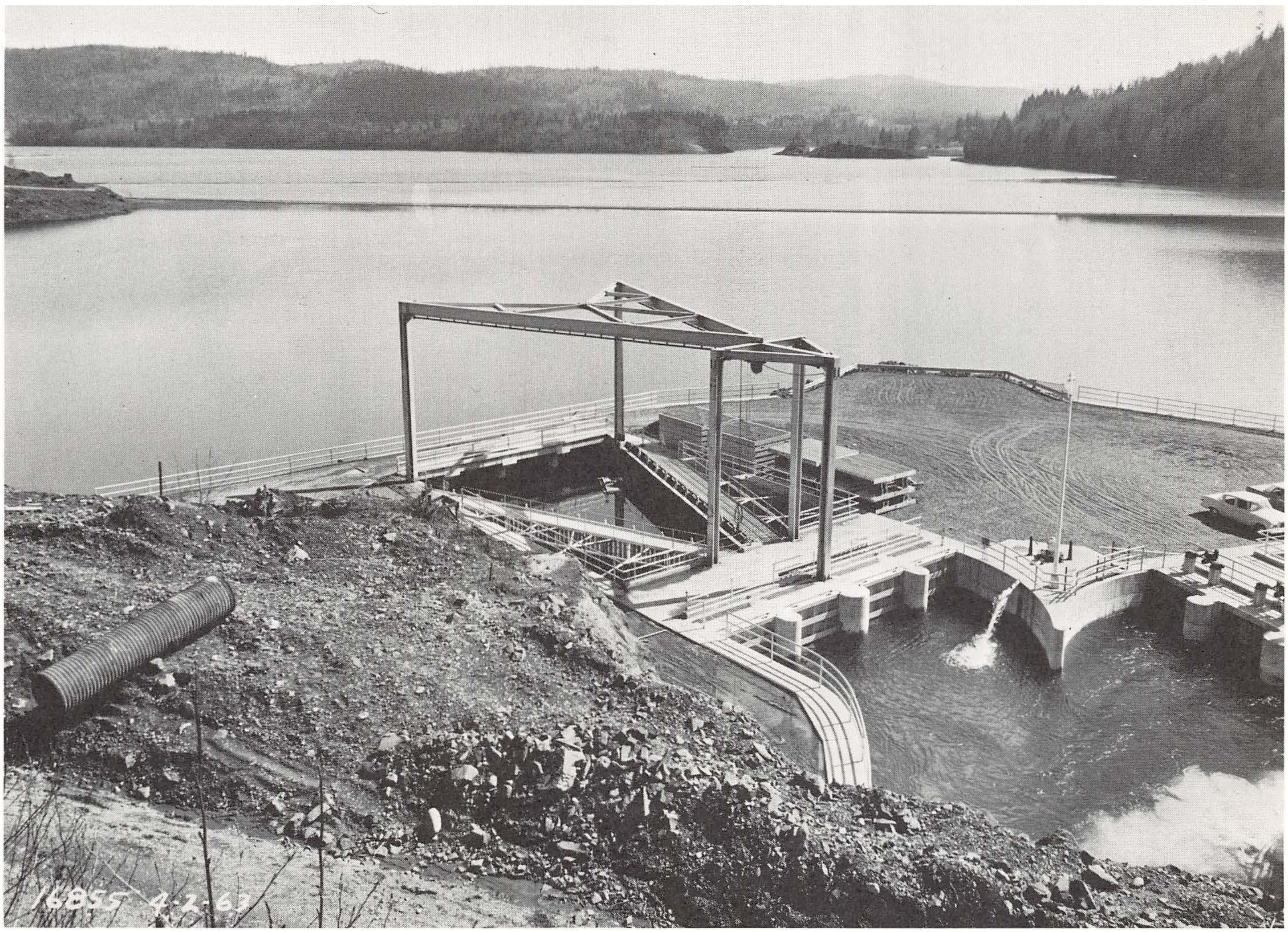

Figure 1.--Mayfield Project. Looking toward intake and trash rack, north louver structure. Fish bypass is located at juncture of louver "V." Partial view of south louver structure appears on right.

In view of the problems associated with migrant collection in the forebays of large, deep reservoirs, the scope and scale of research on methods for the collection of young migrants from rivers, streams, and canals above the reservoir have been expanded. Such studies, if successful, would eliminate the loss of migrants in reservoirs. Once collected above the reservoir, juvenile migrants could then be safely transported around the dam.

In approaching the problem, we recognized that although young salmon make regular and often precisely timed migrations (Hoar, 1953), the mechanics of the movement and behavior patterns which accompany these migrations are still undetermined. Young fish obviously respond to particular stimuli. If nature can supply such stimuli, it would be logical to employ artificial stimuli to guide the young fish into safe routes of passage. But the questions of choice and techniques and how these should be applied require investigation. The purpose of this paper is to describe some of these investigations.

Flow Deceleration Experiment
(University of Washington, 1963)

Introduction

Biologists have observed the outflow of water from fyke nets, particularly in debris-laden water where the effective open area between the mesh is reduced through clogging. When clogging occurs, entrance velocities are reduced and fish collecting efficiencies drop materially. It has been presumed that such fish response is due to the deceleration of flow immediately ahead of the net. Bates and Vinsonhaler (1956) have made observations of fish avoidance of velocity conditions existing at the entrance to a louver bypass where the bypass velocity is lower than the velocity of approach--a hydraulic condition similar to that in the clogged fyke-net example. An interesting behavior pattern has been demonstrated by stream-reared juvenile steelhead (Bates[2/]) where such a velocity relationship exists. These young fish, having stopped in their downstream movement at the entrance to the bypass, have been observed to rise and drop vertically in what would appear to be a search for a more favorable velocity condition.

2/ Bates, Daniel W. Additional studies on louver efficiency in deflecting downstream migrant steelhead. Manuscript in preparation (1964).

Extensive field studies have been carried out at Tracy, California, to determine the most efficient ratio of approach-to-bypass velocity to use in making the final collection of fish as they conclude their deflection along the louver line (Bates, Logan, and Pesonen, 1960). The results of this study (corroborated by Ruggles and Ryan[1/]) indicate that guiding efficiency for most juveniles increases with bypass accelerations up to about 145 percent of the approach velocity. The guiding efficiency dropped significantly when the bypass velocity decelerated from 100 percent of the mean approach velocity to 80 percent. Other biologists working on the problem have noted this response to velocity decelerations (Brett and Alderdice, 1958).

On the basis of these earlier experiments, we decided that there was sufficient justification for proceeding with an exploration of the feasibility of utilizing this response at the University of Washington Hydraulic Laboratory.

Description of Experimental Apparatus

To develop the desired flow deceleration conditions, a plastic model as illustrated in figure 2 was constructed and installed in a specially prepared test flume at the University. This model contained five separate canals measuring 5 inches wide, 12 inches long, and 6 inches deep--each offset to provide a deflection angle of 30^{o}. The most downstream canal was used as a bypass.

The results of this work indicated that the velocity conditions could be secured (fig. 3), but only in part, and that there was insufficient velocity variation to consider application under actual field conditions. For this reason the project was temporarily set aside.

Resume

Based on hydraulic studies conducted in the laboratory, it was concluded that physical limitations made the extension of this design impractical.

Flow Acceleration Experiments Using Vertical Wedges, Model I (Carson Behavioral Flume, 1963)

Introduction

Following the limited success achieved in the study of the flow decelerator, we decided to direct our next investigation

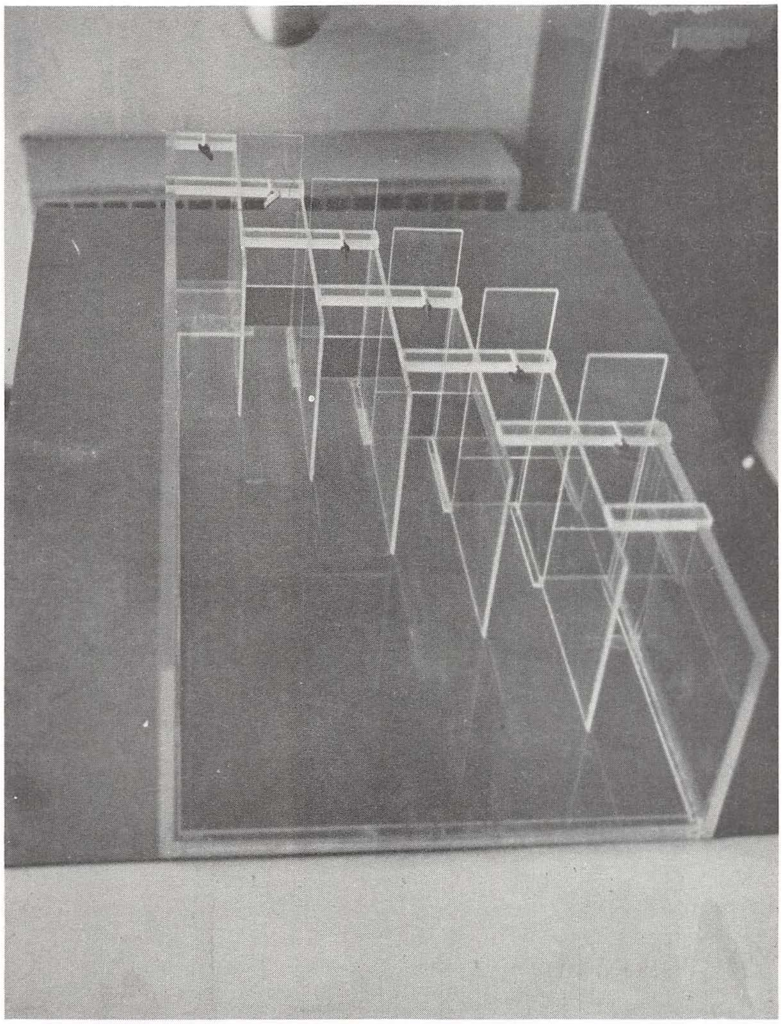

Figure 2.--Plexiglass flow decelerator hydraulic model used to study flow control methods.

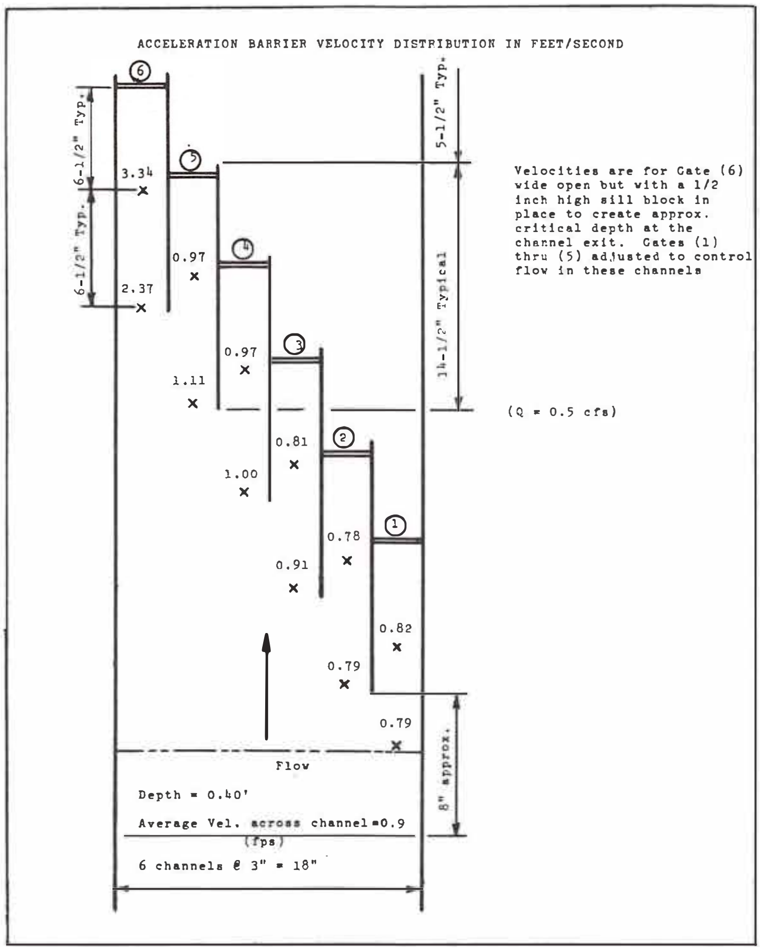

Figure 3.--Plan view sketch of the flow decelerator showing the optimum velocity relationships which could be achieved in the hydraulic model.

toward the opposite condition--the acceleration of flow. To achieve this condition, the velocity of approach would be caused to increase rapidly over relatively short lineal distance and, additionally, the canal would be gradually restricted in width up to a specific point over a specified distance. A distinction should be made here concerning the difference in this design to that of a conventional and rectangular bypass where there is no restriction or change in bypass width throughout the system. Although an acceleration of velocity exists in this type of bypass, the rate of acceleration is considerably different, and it is this difference which causes fish to accept the rectangular bypass and reject the wedge-type bypass.

Description of Experimental Apparatus

A small wooden trough measuring 5 feet long, 2 feet deep, by 1 foot wide was constructed and installed in the Carson behavioral flume. (See "Behavioral Flume at Carson," appended.) Wedges were attached near the downstream end of the trough along each side. The taper of each wedge started at the upstream end, gradually flaring out into the trough, a distance of 3 inches over a lineal distance of 8 inches. Trough width at point "A" (fig. 4) measured 12 inches, but only 6 inches at point "B."

The flow through the wedges (fig. 5) suggested that since the area was being reduced, there would be a uniform acceleration along the wedges. However, as the flow equations were solved for the acceleration, it became apparent that the acceleration depended upon the initial velocity squared and the distance from the beginning of the wedge. The acceleration at the end of the wedge might easily be five or ten times that at the beginning of the wedge. If the response of the fish is to be attributed to an acceleration effect, the comparison of responses between different wedges should be related to the acceleration curves for the wedges.

Test Procedure

Trough velocity during the experiment was maintained at 1.8 feet per second, which was generally 0.2 to 0.4 foot per second under the sustained swimming speed of the young hatchery-reared (3 to 4 inches in length) chinook salmon.

Only observations on response were made, and no attempt was made to determine any type of efficiency in remaining above point "A" (fig. 4). During any one study, only five fish were introduced into the canal immediately upstream from point "A."

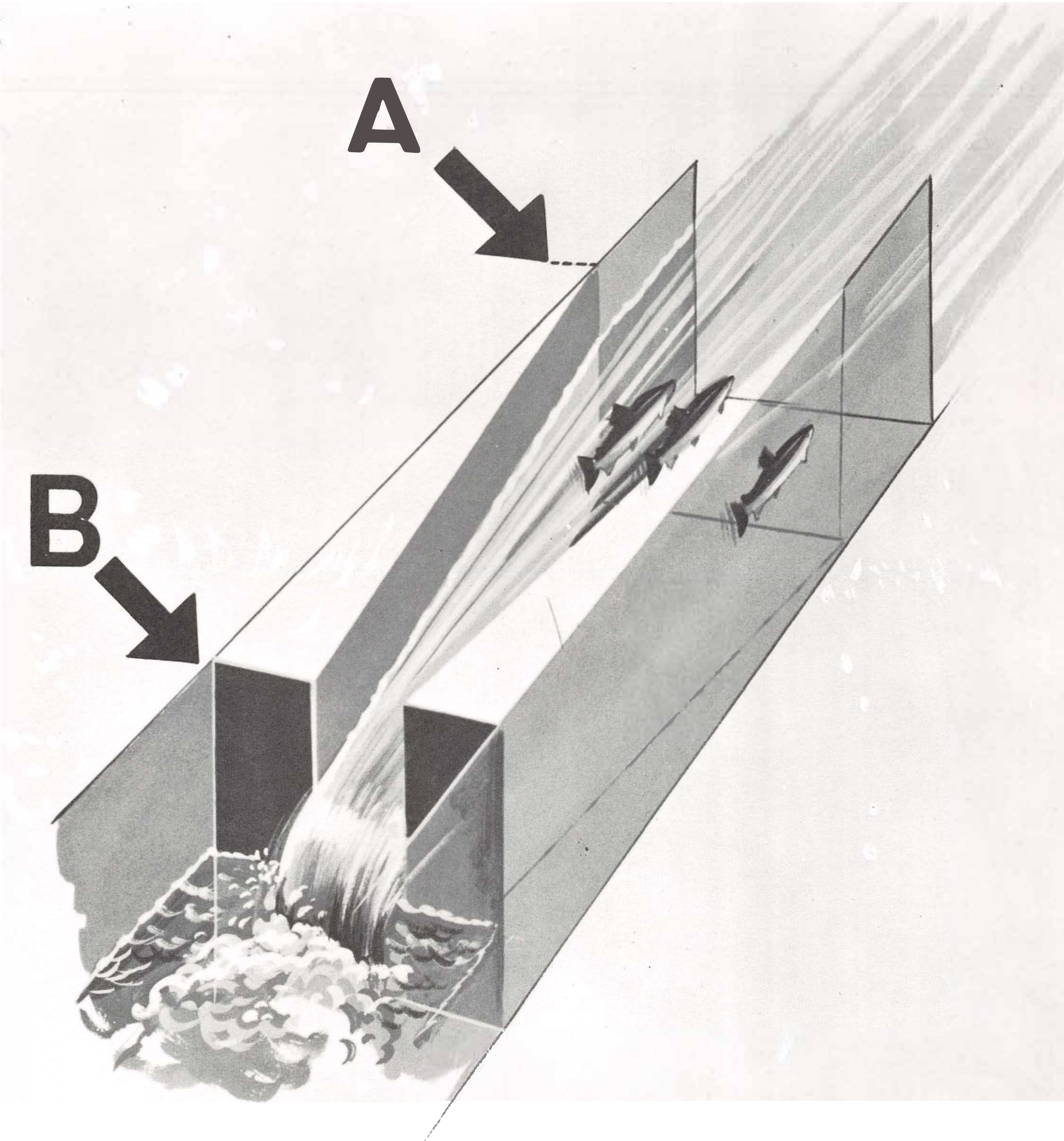

Figure 4.--Diagrammatic sketch of the flow accelerator, model I, showing wedges extending into the canal and the upstream point of flow acceleration (broken line).

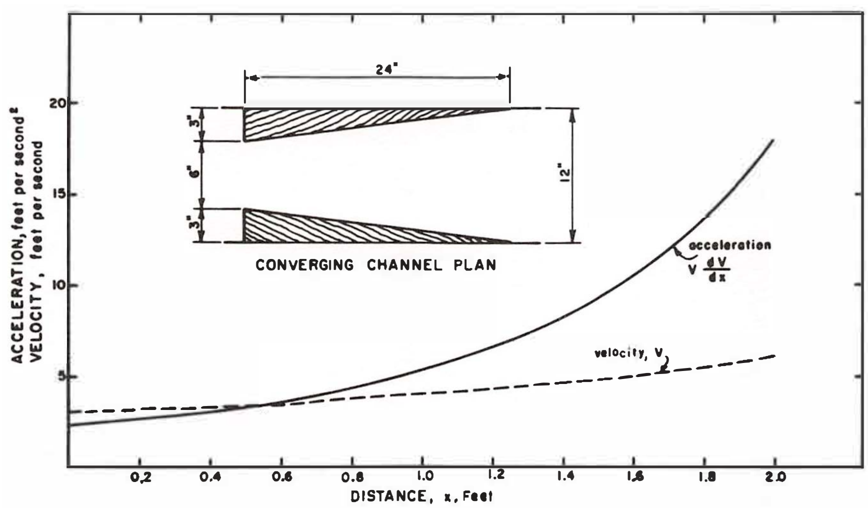

Figure 5.--Relation between velocity and acceleration plotted against the distance.

Observations

The young migrants moving downstream tail first from the upper portion of the small trough would stop in their downstream movement just as the tail portion of their bodies reached the imaginary line at point "A." On occasion, some of these fish continued downstream past "A" until they reached the area of higher velocities near point "B"; then they darted rapidly upstream, resuming their original positions between point "A" and the screen. As they maneuvered up and downstream in this area, always heading into the flow, they seldom allowed themselves to drop downstream past point "A." Also, being bounded by the flume walls, the fish were limited in their choice of movement. Fish having once rejected movement downstream past point "A" could thereafter seldom be forced downstream beyond this point.

To answer the question as to the role of vision in the response to the flow accelerator, co-workers Niggol and Gerold[3/] in 1962 carried out a series of experiments dealing with this matter.

Several hundred hatchery-reared juvenile chinook and silver salmon were blinded and held for testing. The response of these fish to the acceleration of flow was identical to that of fish with vision, indicating in this case that primary orientation was not visual, but essentially a sensory response to flow differentials.

Discussion

The pattern of behavior to the flow accelerator was similar, irrespective of species used. Of significance was the positive avoidance response by the blind fish to the unseen velocity change. The initial success in the use of this particular type of barrier was sufficient to warrant consideration of an installation composed of several acceleration barriers placed on an angle to flow to provide the downstream migrant a facility on which to guide.

3/ Niggol, Karl, and M. Gerold. Notes on the reaction of blinded fingerling salmon. Manuscript in preparation (1964).

Flow Acceleration Experiments Using Vertical Wedges, Model II (Carson Behavioral Flume, 1963)

Introduction

Following the experimental success achieved in the previous study utilizing the stimulus of flow acceleration, we decided to concentrate further investigation on a series of flow accelerators positioned on such an angle to the direction of flow that a deflection of fish could be accomplished.

Again, the intent here was to detect, where possible, unquestionable indications of acceptable deflection rather than to search for subtle differences of behavior.

Considering the use of hatchery fish, we have made no attempt to treat the data for all their statistical possibilities. One prevalent problem in this regard was that hatchery fish would swim rapidly downstream headfirst and pass through the installed facility at any open point. It was estimated that 10 to 15 percent of all fish released behaved in this particular manner.

Description of Experimental Apparatus

For the next series of experiments, the flow accelerator, modified to provide fish-deflecting capabilities (figs. 6 and 7), was installed in the behavioral flume. The assembly, consisting of five individual sets of double wedges, was placed within the behavioral flume on approximately a 25° angle to flow. Each set measured 12 inches in width at the opening, tapering to a width of 6 inches over a distance of 9.5 inches. The 1-foot-wide bypass was placed near a plexiglass view window to allow observations of fish response to certain portions of the accelerator barrier and the bypass. Velocity control was maintained at the downstream end of the flume through placement of stoplogs. Approach velocities ranged from 1.2 feet per second to 2.4 feet per second in increments of 0.2 foot per second. For all tests and all approach velocities, a ratio of approach to bypass velocity of 1.0 to 1.4 was maintained. Throughout the experiments, water depth was held generally at 18 inches.

Test Procedure

By dip-netting, fish were secured from the raceways, placed in buckets, and carried to the holding tank placed at the upstream end of the flume. The fish were then held for a period

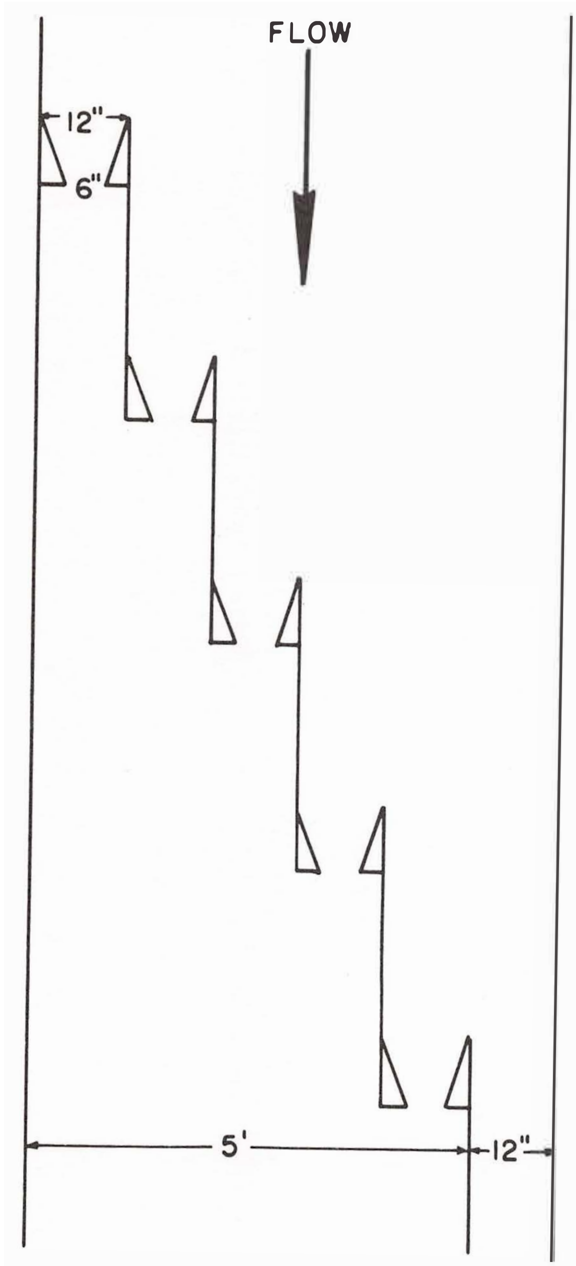

Figure 6.--Diagrammatic sketch (plan view) of the model II flow accelerator showing the individual accelerators formed on a 20° angle to flow.

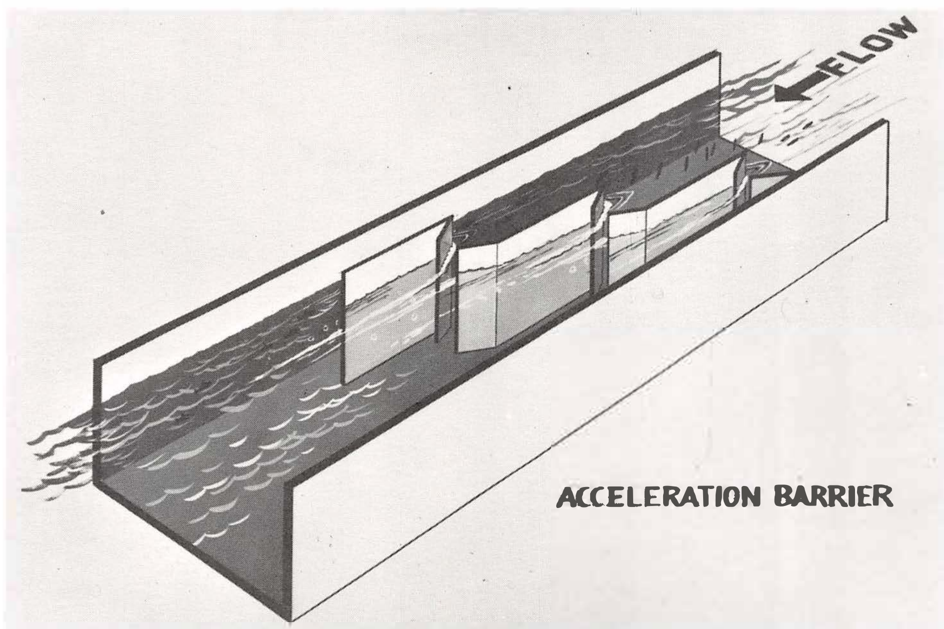

Figure 7.--Diagrammatic sketch of the flow accelerator, model II, showing a series of individual accelerators formed on a 20° angle to flow.

of 15 to 30 minutes to allow time for them to adjust to their new environment. To record fish behavior toward the various deflection devices, motion pictures were taken periodically.

Results

The results secured from the acceleration of flow created by vertically positioned wedges demonstrated that a relatively high level of deflection was possible (table 1). Young spring salmon were observed changing their direction of downstream movement in front of the barriers, moving along the entire line, and ultimately entering the bypass. In most cases, several fish would hold at the entrance to each barrier. These fish could not be driven through, even after considerable effort.

A change in the length of wedges from 9.5 to 6.7 inches did not result in any significant variation in efficiency (table 2). However, this modification of wedge lengths was relatively small. The exceedingly rapid rate at which these fish could readjust their direction of movement was surprising. This readjustment is particularly noteworthy considering the fact that as hatchery fish they never had any prior experience in avoiding obstructions, particularly at high velocities.

Discussion

One of the great disadvantages of this particular barrier design is that each individual barrier entrance creates a pocket into which a considerable number of fish will gather and hold. More desirable would be a design eliminating all pockets but providing a continuous guiding line along the complete length of structure.

Flow Acceleration Experiments Using Horizontal Wedges, Model I (Carson Behavioral Flume, 1963)

Introduction

Due to the formation of objectionable pockets created by the vertically positioned wedges, which tended to restrict the continuous downstream movement of fish along the face of the structure, a redesign was considered necessary.

Description of Experimental Apparatus

To eliminate the above problem of holdup and yet apply the principles of a flow barrier which had been developed, it was decided to place the wedges on a horizontal plane rather than a

Table 1.--Percentage deflection using vertical velocity accelerator at a deflection angle of 20°. Wedge openings tapered from upstream width of 12 inches to downstream width of 6 inches over a lineal distance of 9.5 inches, Carson behavioral flume, 1963.

Date	Time	Velocity	Recapture: Trap 1 bypass	Recapture: Trap 2	Deflection
April		F.p.s.	No.	No.	Percent
12	1020	1.2	270	94	74.1
12	1150	1.2	282	45	86.2
18	1400	1.6	210	123	63.0
18	1615	1.6	235	54	81.3
23	2105	1.8	318	120	72.6
23	2135	1.8	315	51	86.0
23	2200	2.0	234	50	82.3
24	2330	2.0	255	24	91.3
24	0910	2.2	233	21	91.7
24	1350	2.2	165	27	85.9
24	1415	2.4	196	18	91.5
				Avg.	81.2

Table 2.--Percentage deflection using vertical velocity accelerator at a deflection angle of 20°. Wedge openings tapered uniformly from upstream width of 12 inches to downstream width of 6 inches over a lineal distance of 6.7 inches, Carson behavioral flume, 1963.

Date	Time	Velocity	Recapture: Trap 1 bypass	Recapture: Trap 2	Deflection
April		F.p.s.	No.	No.	Percent
24	1630	1.8	255	27	90.4
24	1710	1.8	225	57	79.7
24	2100	1.8	289	45	80.7
24	2210	1.8	321	48	87.2
				Avg.	84.8

vertical. uch a design would provide a continuing structure along which the young fish might deflect. The new deflector (fig. 8) consisted of two horizontal wedges placed 90^{o} to the direction of flow (no guidance provided in this first model) and installed within a 5-foot-long trough having an 18-inch depth and a 1-foot width. This in turn was positioned parallel to flow within the larger behavioral flume. The wedges which were installed near the downstream end of the trough were 3 inches high and 9 inches long, with a clear spacing of 6 inches at the downstream end. The upstream end of the small trough was screened to retain the test fish.

Although results of the initial work provided responses similar to those secured with the vertical wedges, the uppermost wedge, being made of wood, restricted observation to the extent that it was considered necessary to replace it with glass. In doing so, the length of the upper wedge was increased from 9 inches to 22 inches. At a water depth of 15 inches, point "A" of the upper wedge extended several inches upstream and beyond point "A" of the bottom wedge as shown in part "a" of figure 9.

Test Procedure

Following the pattern of procedure developed for observation of fish response to the vertical wedge design, a series of observations were made in the case of the horizontal wedges, using five juvenile chinook salmon each time. These were introduced by dip-net into the upper portion of the test trough. After a 10-minute period, those remaining were collected and returned to their respective hatchery raceway. A new group was then introduced.

Results

Although the precise hydraulic effect of having the leading edge of the upper wedge extend several inches beyond the leading edge of the lower wedge is not completely understood, there was no question as to its effectiveness. Fish were not stopped in their downstream passage. In an effort to eliminate this condition, the long glass wedge was taken out and cut to a 9-inch width to correspond in length with the lower wooden wedge as shown in part "b" of figure 9. Following this, and on retesting, the original favorable fish blocking effectiveness was obtained. No deflection efficiencies were maintained, since this test design did not provide for fish deflection possibilities, having been placed 90^{o} to flow. Under this condition, the fish had no alternative than to move either upstream or downstream or to hold their position.

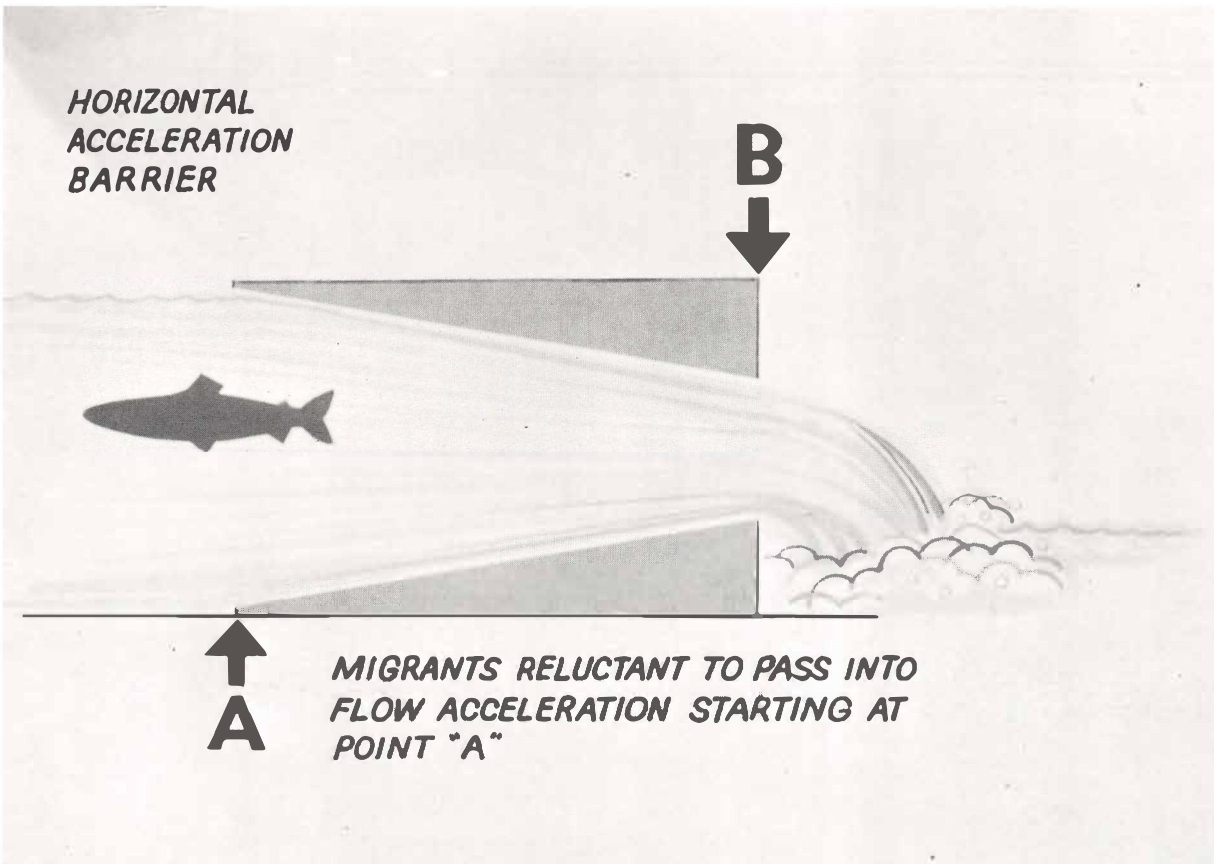

Figure 8.--Diagrammatic sketch of horizontal flow accelerator showing wedges extending into the canal and the upstream point of flow acceleration at point "A."

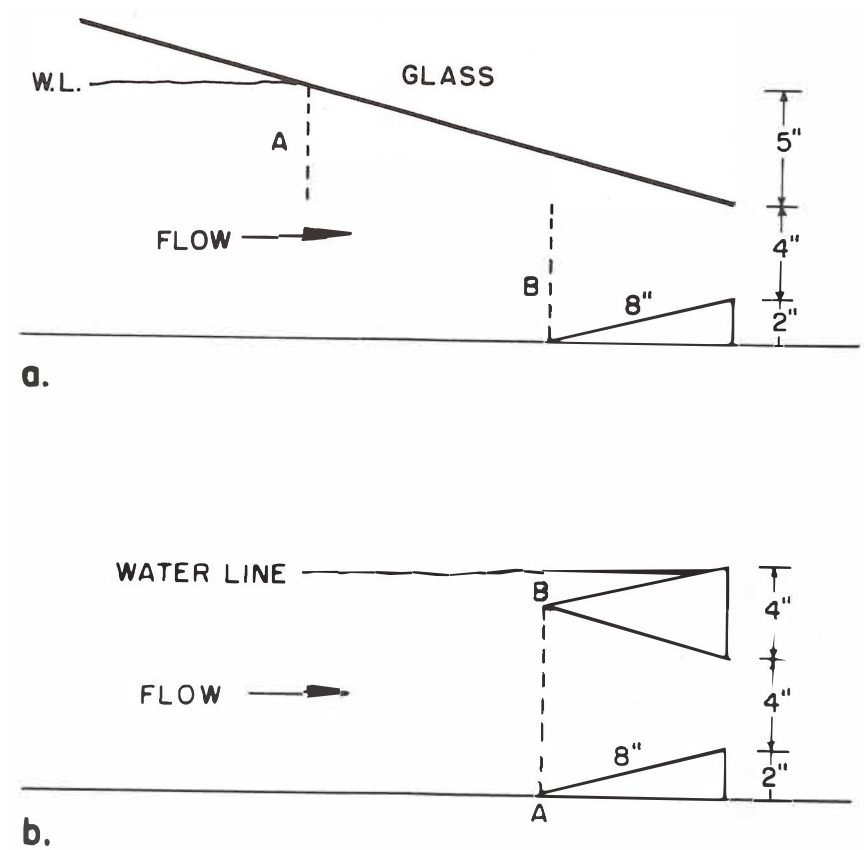

Figure 9.--Part a. Cross section of the horizontal wedge where point "A" is some distance upstream from point "B." Part b. Cross section of horizontal wedge illustrating correct position of point "B" in relation to point "A."

Resume

The basic experimental horizontal accelerator barrier, when placed 90° to flow, did show considerable potential for blocking the downstream passage of young fish.

Flow Acceleration Experiments Using Horizontal Wedges, Model II (Carson Behavioral Flume, 1963)

Following considerable measure of experimental success secured with flow acceleration created by a single unit of horizontal wedges placed 90° to flow, it was decided to redesign for a complete horizontal barrier placed on such an angle to flow as to provide for fish deflection.

Description of Experimental Apparatus

The new horizontal flow accelerator, measuring 14.6 feet in length, was placed in the 6-foot-wide canal on a 25° angle to flow (fig. 10). The individual "V" styled wedges tapered from the upstream point to a height of 6 inches over a length of 9 inches. The clear vertical distance between wedges was adjustable. The structure was designed to accommodate a water depth of 2 feet. A 1-foot-wide bypass placed near the observation window was provided at the downstream end of the horizontal barrier.

Test Procedure

As in previous tests, the fish were dip-netted from the raceways, placed in containers, and carried to the holding tank into which they were placed. Here they were held for a 30-minute adjustment period. Although the approach velocities were generally modified for each test, they did range from a minimum of 1.5 feet per second up to a maximum of 3.4 feet per second.

Two specific series of tests were conducted. The first utilized an opening of 8 inches and 2 inches, respectively, between wedges at the upstream and downstream points, and the second utilized openings of 9 inches and 3 inches.

Results

The guiding efficiencies of the horizontal wedges (table 3) were considerably less than those achieved earlier with the vertical wedges, irrespective of either a daytime or a nighttime condition. A number of blind fish were tested, with efficiencies no better than those secured with fish having full vision.

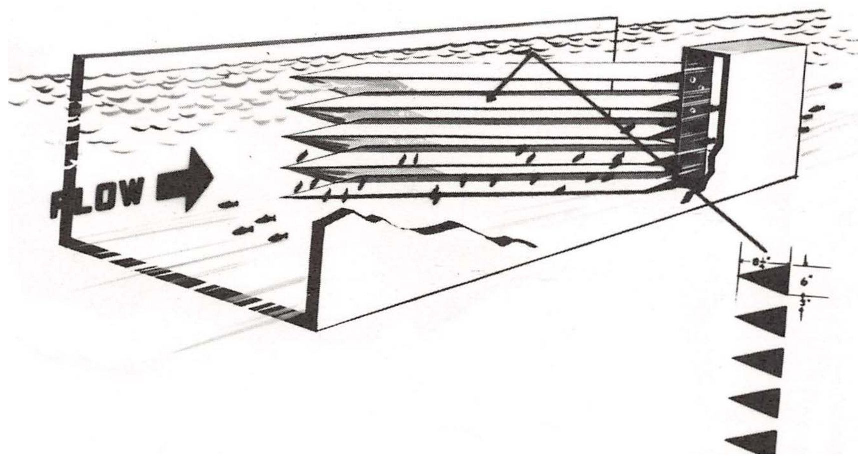

Figure 10.--Diagrammatic sketch of the horizontal accelerator barrier, model II, and bypass.

Table 3.--Percentage deflection using horizontal velocity accelerator at a deflection angle of 20°. Wedge openings tapered uniformly from upstream width of 8 inches to downstream width of 2 inches over a lineal distance of 22 inches, Carson behavioral flume, 1963.

Date	Time	Velocity	Recapture: Trap 1 bypass	Recapture: Trap 2	Deflection
April		F.p.s.	No.	No.	Percent
2	1410	2.0	99	58	63.0
2	1500	2.6	159	63	71.6
2	1540	2.6	207	72	74.1
2	1645	1.8	69	30	69.6
3	0940	1.5	302	257	54.0
3	1020	1.5	226	237	48.8
4	2100	1.8	170	165	50.7
4	2130	1.8	260	341	43.2
4	2215	2.0	197	127	60.8
				Avg.	55.6

Table 4.--Percentage deflection using horizontal velocity accelerator at a deflection angle of 20°. Wedge openings tapered from upstream width of 9 inches to downstream width of 3 inches over a lineal distance, parallel to flow, of 22 inches, Maxwell Canal flume, 1963.

Date	Time	Velocity	Recapture: Trap 1 bypass	Recapture: Trap 2	Deflection
May		F.p.s.	No.	No.	Percent
14	1045	3.0	132	106	55.4
14	1300	3.1	170	146	53.8
14	1700	2.9	71	57	55.4
14	1800	3.0	19	21	47.5
15	0900	3.0	160	182	46.7
15	1005	2.7	98	109	47.3
20	1015	3.4	36	35	50.7
20	2030	3.2	135	152	47.0
22	0645	2.8	72	88	45.0
22	0750	3.0	44	27	61.9
22	1120	3.1	60	51	54.0
22	1240	3.0	47	62	43.1
22	1355	2.9	139	123	53.1
22	1510	2.7	103	63	62.0
				Av .	51.3

Discussion

It was apparent that the particular conditions present in the wedge system when placed at 90° to flow, which were so successful in blocking further downstream passage of the young migrants, were missing in the structure when it was placed on a 25° angle, as evidenced by the reduced deflection efficiencies. One evident difference was the restriction placed on the tendency of fish to swing laterally through the structure placed 90° to flow, whereas the horizontal accelerator barrier seemed to invite such response.

That fish could readily see through the open portions of the wedges may have been the factor contributing to their general willingness to pass through.

During the spring of 1963, the horizontal accelerator barrier was transferred to the Maxwell Canal flume and tested. Results of these tests, shown in table 4, were as unsatisfactory as those secured in the Carson behavioral flume.

Flume Experiments Using Louvers and Pickets (Carson Behavioral Flume, 1963)

Introduction

To secure further information on the response of fish to various forms of stimuli and obstacles, it was decided to determine the factors involved in the specific response of downstream migrants to louvers. This information was also required to permit the biologists to improve present louver design.

As a result of this interest, experiments using blinded fish were carried out by co-workers Niggol and Gerold[3/]. They observed that the blind fish on moving downstream and approaching a line of louvers showed no apparent recognition of the presence of the louvers until they either physically touched the louvers or felt the velocity turbulence existing in between the louver slats. On contacting the louvers with their tail sections, their response was to dart rapidly upstream or, at times, swing laterally away from the louvers. Such response indicated that the blinded fish did not recognize the presence of louvers until actual contact had been made. Yet, by contrast and based on previous experiments with the vertical-accelerator barrier, it was observed that blind fish are most responsive to certain velocity changes.

In general, it appears probable that young fish respond to various deflecting devices by means of visual perception as well as through their capacity to sense and respond to fluctuations of velocity magnitudes, and to both of these in varying degrees dependent on need and the specific conditions existing.

To find out more about the importance of vision as a factor in guiding fish, a new experiment was designed, utilizing triangular pickets placed on a 25^{o} angle to flow, as is done with louvers.

Design of Experimental Apparatus

As will be noted in figure 11, each picket, 2 feet in height, had a 2-inch facing on each of the three sides, with spacing between pickets set as required. The upstream face of each picket was positioned parallel to the entire line of pickets which, in turn, were set on a 25^{o} angle to the direction of flow to assist fish in deflecting. The bypass at the downstream end was 12 inches in width, with approach-to-bypass ratio set for 1 to 1.4. Collection and enumeration took place in the traps at the downstream end of the inclined screen. Fish entering the bypass were physically separated from those passing through the facility. The bypass was positioned within view of the observation window.

Test Procedure

The first and second experiments utilized pickets spaced 2 inches and 6 inches clear, respectively. (See part "a" of figure 12.) In the third experiment, the pickets remained at a clear spacing of 6 inches, but the entire area of the flume immediately downstream from the pickets was "blacked out" to reduce the downstream visibility of the fish through the opening between pickets, as shown in part "b" of figure 12. The "blacking out was accomplished by use of an opaque, black plastic covering. The floor and sidewalls were also covered with black plastic to further darken the interior area. The fourth and final test was the same as number 3, with the exception that the pickets were reset for a clear spacing of 2 inches. Velocities for each of the tests ranged from a minimum of 1.8 to a maximum of 2.2. Fish were collected, held, and released as in previous tests.

Results

As observed in earlier tests, approximately 10 to 15 percent of the fish, apparently through fright, swam headfirst through the facility without any reduction in their swimming speed.

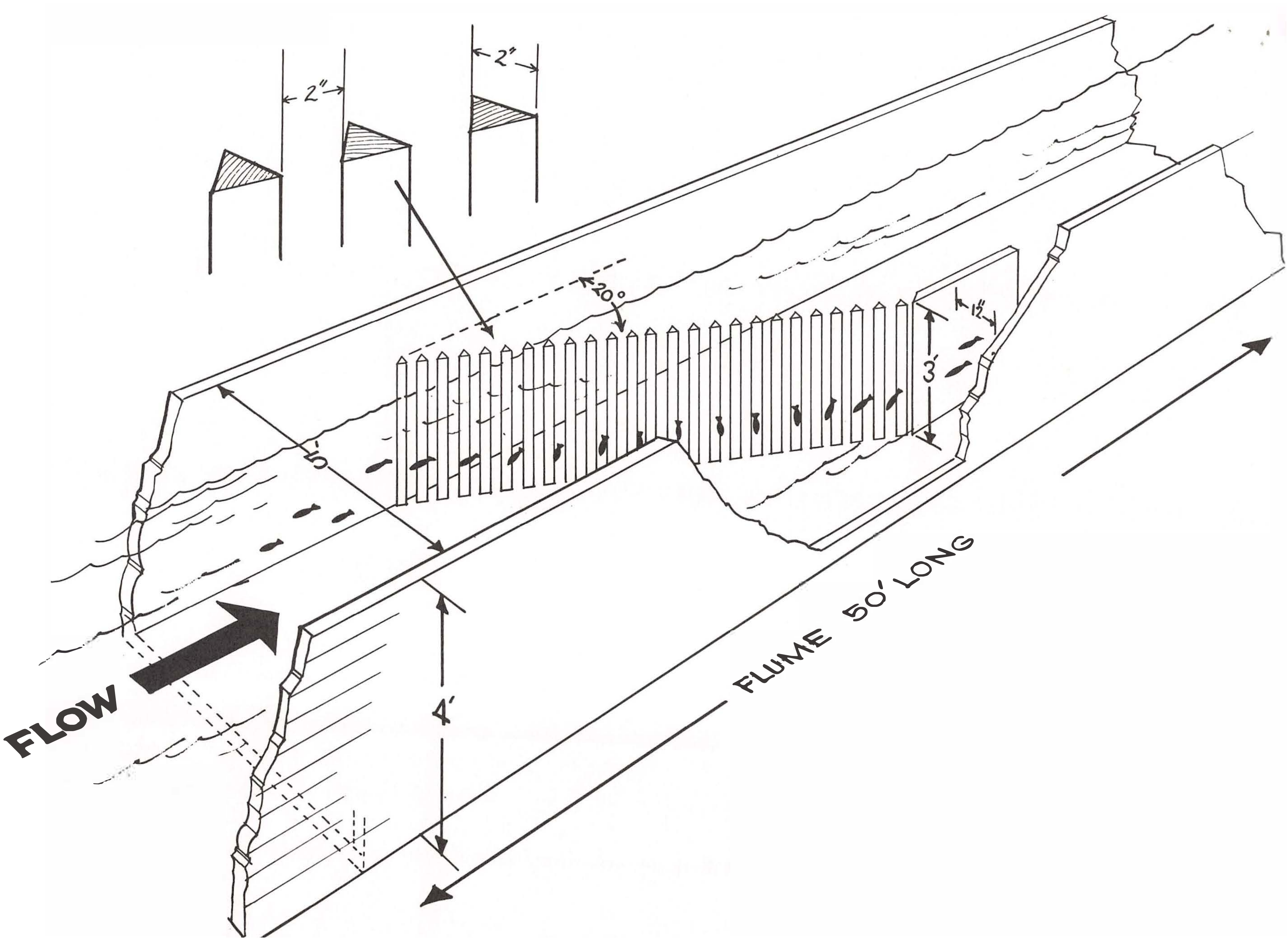

Figure 11.--Diagrammatic sketch of picket deflector with 2-inch clear spacing.

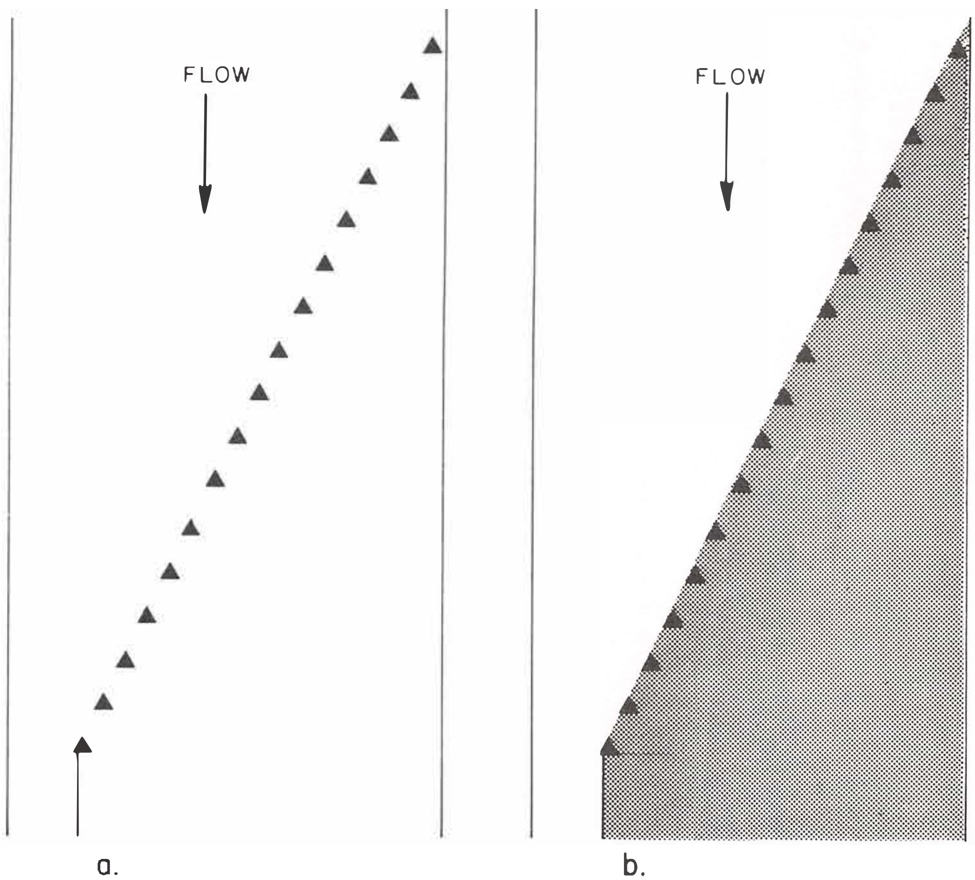

Figure 12.--Part a. Diagrammatic illustration of picket formation and placement. Bypass shown in lower left-hand corner. Part b. Same as "part a" but with the inclusion of the "blacked out" area shown immediately downstream from the pickets.

Deflection efficiencies for all tests were generally unsatisfactory, due to fish swinging laterally between the pickets. Other fish were observed to pass directly tailfirst between the pickets, indicating acceptable flow conditions.

With increased spacing between pickets, visibility improved and flow conditions between pickets became less turbulent, resulting in even greater willingness of the fish to swim through the structure. As a result, deflection efficiencies dropped radically. Although one might have anticipated some guiding effect in this particular case, the data show none. Efficiencies for tests 1 and 2 are summarized on table 5.

The results of tests 3 and 4 (table 6), although not providing a high level of deflection, show the significance of vision as a factor in area avoidance. Another point of interest is the potential shown in the learning process, as illustrated by a group of fish tested during the morning and held over until evening and run a second time (table 6). The results indicate considerable improvement in their ability to deflect. This was illustrated again by a new group tested early one morning and then rerun later that same morning.

Resume

With fish passing unhesitatingly between the pickets as they generally did, it is clear that those stimuli activating fish response to louvers are not present in the picket installation. The results also show that the pickets under certain conditions did provide some guiding, which might be improved through design modification. Use of a picket deflector demonstrated that both vision and the ability to sense changes in flow conditions are important factors to fish as they move downstream.

SUMMARY

The reactions of more than 16,000 juvenile spring chinook salmon (O. tshawytscha) to acceleration, deceleration, and changes in flow rates were tested in a fish behavioral flume constructed at the Carson Fish Cultural Station, Carson, Washington. Based on hydraulic studies conducted in both the laboratory and field on the response of fish to flow deceleration, it was concluded that physical limitations of securing desired flow conditions made application of this plan impractical. The response of fish to flow acceleration created by vertical wedges was found to be effective, with 81 percent of the fish entering

Table 5.--Percentage deflection using different intervals between vertically positioned triangular pickets at a deflection angle of 23^{o}, Carson behavioral flume, 1963.

Date	Time	Velocity	Intervals	Recapture Trap 1 bypass	Recapture Trap 2	Deflection
July		F.p.s.	Inches	No.	No.	Percent
3	1120	1.8	2	159	30	84.1
3	1300	1.8	2	138	42	76.6
3	1345	2.0	2	162	117	58.0
3	2105	2.0	2	207	72	74.1
3	2200	2.2	2	210	75	73.6
8	0905	1.8	6	4	123	3.2
8	0940	1.8	6	11	240	4.4
8	1025	2.0	6	19	265	6.7
8	1110	2.0	6	13	199	6.1
8	1200	2.2	6	12	302	3.8
8	1315	2.2	6	9	276	3.2

Table 6.--Percentage deflection using different intervals between vertically positioned triangular pickets at a deflection angle of 23 with area downstream from pickets "blacked out", Carson behavioral flume, 1963.

Date	Time	Velocity	Intervals	Recapture Trap 1 bypass	Recapture Trap 2	Deflection
July		F.p.s.	Inches	No.	No.	Percent
8	0930	1.8	6	92	140	39.6
8	1010	1.8	6	60	161	27.1
8	1335	2.0	6	108	176	38.0
8	1415	2.0	6	157	201	43.8
8	2105	2.0	6	219	412	34.7
8	2150	2.2	6	178	264	40.3
9	0845	1.8	2	194	130	59.8 a
9	0935	1.7	2	122	106	53.5 c
9	1020	2.0	2	147	53	73.5 d
9	2145	2.0	2	226	75	75.0 b
9	2215	2.3	2	186	90	67.3
9	2255	2.3	2	205	76	72.9

"b" represents a rerun of "a" fish.

"d" represents a rerun of "c" fish.

the bypass when an appropriate combination of approach velocity spacing between wedges and angle of the total facility to flow was employed. Experimental utilization of horizontal wedges placed on an angle to flow did not provide effective cross-canal guiding. Fish exposed to louvers, as well as picket deflectors, demonstrated that vision and sensitivity to changes in flow rate are important factors in their pattern of response.

LITERATURE CITED

Andrew, F. J., L. R. Kersey, and P. C. Johnson.
1955. An investigation of the problem of guiding downstream-migrant salmon at dams. International Pacific Salmon Fisheries Commission, Progress Report No. 8, 65 p.

Bates, D. W., and R. Vinsonhaler
1956. Use of louvers for guiding fish. Transactions of the American Fisheries Society, vol. 86, p. 38-57.

Bates, D. W., O. Logan, and E. A. Pesonen
1960. Efficiency evaluation of the Tracy Fish Collecting Facility, Central Valley Project, California. U.S. Fish and Wildlife Service.

Brett, J. R., and D. F. Alderdice
1958. Research on guiding young salmon at two British Columbia field stations. Fisheries Research Board of Canada, Bulletin No. 117, 75 p.

Fields, Paul E.
1957. Guiding migrant salmon. The Scientific Monthly, vol. 85, no. 1, p. 10-22.

Hoar, W. S.
1953. Control and timing of fish migration. Biological Review, vol. 28, no. 4, p. 437-452.

Holmes, Harlan B.
1948. History, development, and problems of electric fish screen. U.S. Fish and Wildlife Service, Special Scientific Report 53, iii + 62. p.

Moore, Harvey L., and H. William Newman
1956. Effects of sound waves on young salmon. U.S. Fish and Wildlife Service, Special Scientific Report, 172 iii + 19 p., 10 figs., 2 tables.

APPENDIX

Behavioral Flume at Carson

A test flume (fig. 13) for the study of fish behavior was constructed at the Carson Fish Cultural Station in Washington, measuring 50 feet in length, 6 feet in width, and 4 feet in depth. At the upstream end, a screened release pen measuring 5 feet in length and 1 foot in width served to retain fish prior to a test. Release of fish could be accomplished through remote control. A brown stain was applied to the interior wall surfaces to minimize light reflection. However, a white paint was applied to the flume floor to facilitate fish observation. An inclined screen of perforated plate was installed at the downstream end of the flume to recapture the test fish. Individual traps were maintained to collect fish and determine deflection efficiency. In most cases, not all released fish would pass immediately downstream; those remaining upstream were not included in the deflection efficiency determinations.

A bypass was generally installed to provide for the collection of all deflected fish. A ratio of 1 to 1.4 or greater between the approach and bypass velocities was maintained. This was necessary to insure the acceptance by fish of the bypass.

A double set of stoplogs controlled the volume of flow passing through the test flume (fig. 14), diverting the stream flow either partially or completely into the flume. Additional velocity control could be secured by positioning stoplogs at the downstream end of the flume. Although an average depth of approximately 24 inches prevailed most of the time, a maximum depth of 48 inches could be created.

Any velocity up to a maximum of 7.5 feet per second, could be secured through appropriate setting of stoplogs. Velocity readings taken throughout the flume indicated a relatively uniform flow. A plexiglass window measuring 6 feet in length and 3.5 feet in height was located at the downstream end of the flume to provide a view window for the biologists.

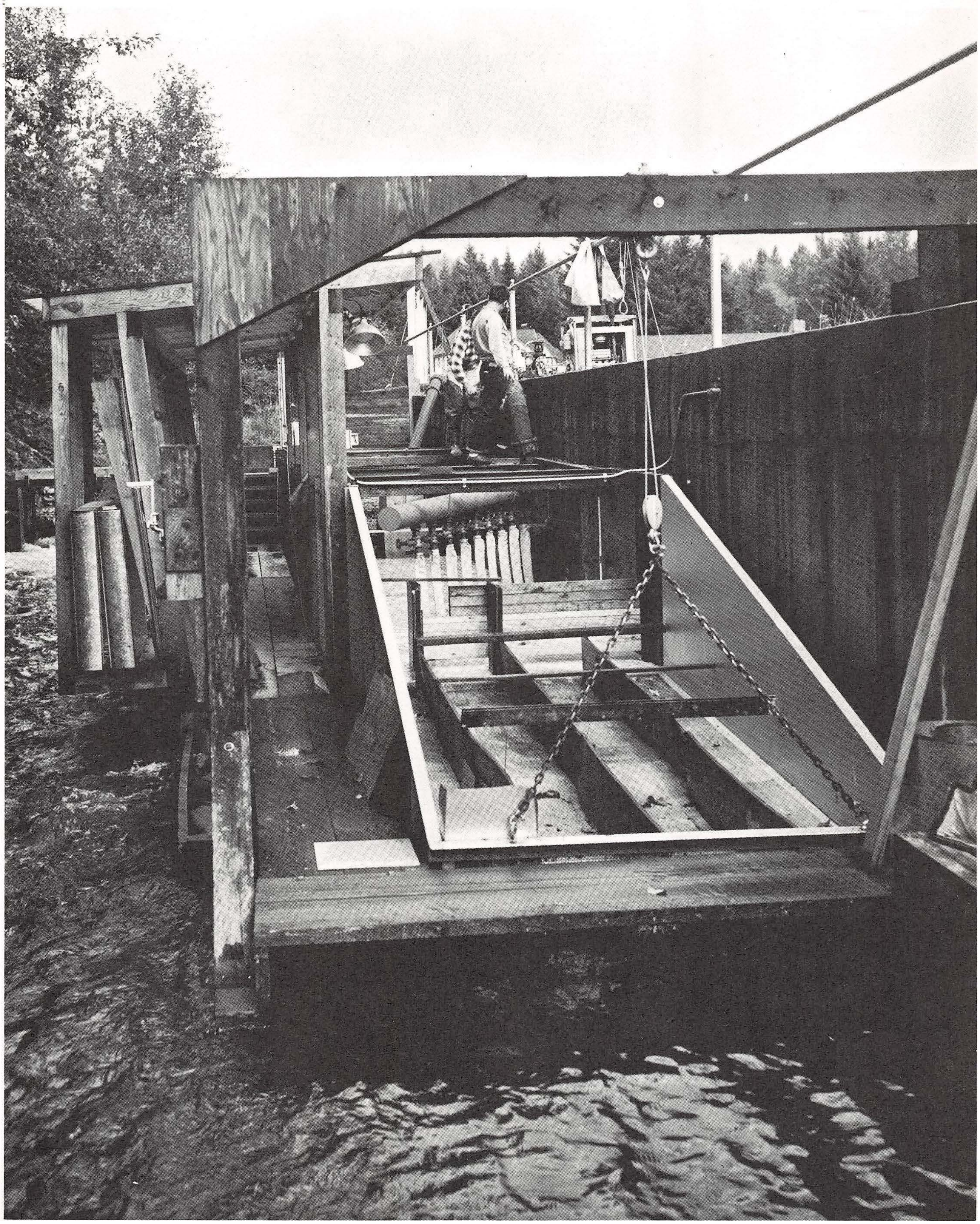

Figure 13.--Looking upstream on the Carson Behavioral Flume. The immediate foreground shows the inclined screens and fish traps.

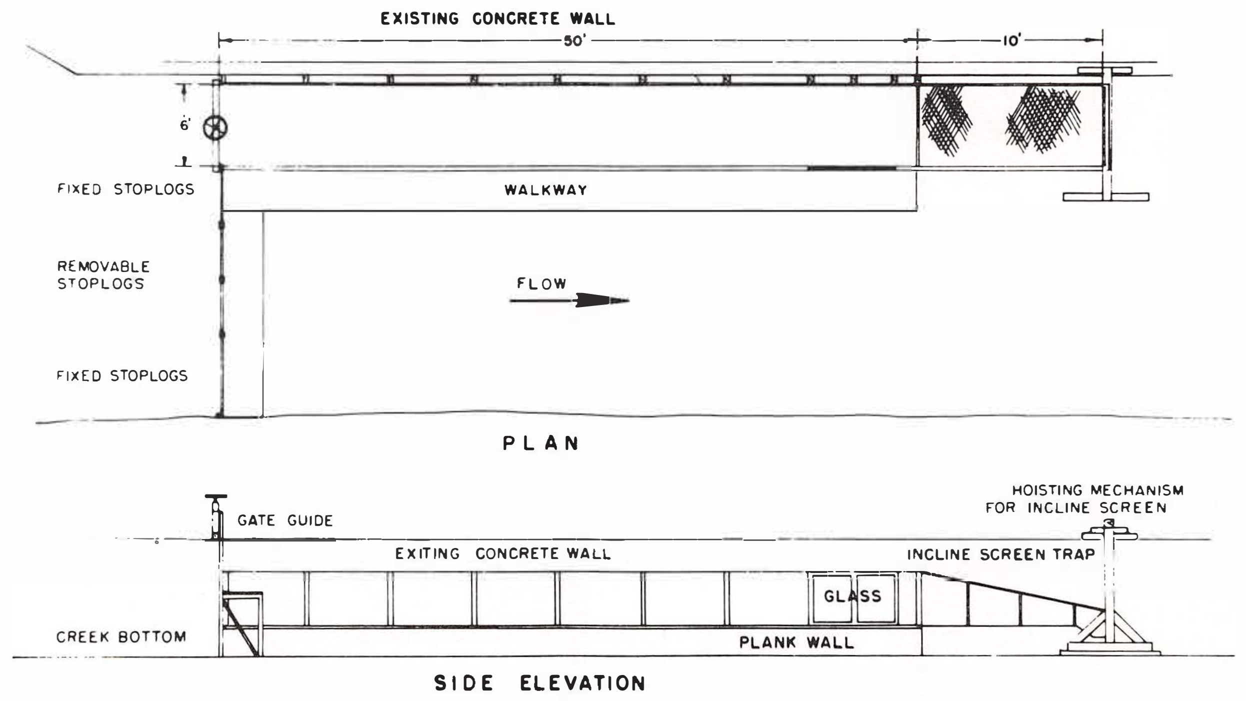

Figure 14.--Plan and elevation views of Carson Behavioral Flume.