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Laboratory Evaluation of a Denil-Type Steeppass Fishway with Various Entrance and Exit Conditions for Passage of Adult Salmonids and American Shad

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*ABSTRACT—This research was designed to determine the feasibility of using a Denil-type fishway as part of a system to trap marked adult salmon and trout ascending a pool-and-overfall fishway at Little Goose Dam on the Snake River. Several entrance and exit situations were tested along with two methods (hollow weir and a pool) of supplying water to the Denil. Water supplied directly to the Denil through a hollow weir provided the best passage conditions for chinook salmon (*Oncorhynchus tshawytscha*), sockeye salmon (*O. nerka*), steelhead trout (*Salmo gairdneri*), and American shad (*Alosa sapidissima*). Salmonids and shad readily entered and ascended a Denil fishway when the downstream end was submerged to a depth of 2.5 feet (0.7 m). Chinook salmon, coho salmon (*O. kisutch*), and steelhead trout readily passed through a Denil steeppass fishway that was 50 feet long (15.2 m) and positioned at a slope of 28.7 percent.*

INTRODUCTION

Denil steeppass fishways (Ziemer, 1962) have been used successfully in Alaska (Ziemer, 1965) to pass adult migrating pink salmon (*Oncorhynchus gorbuscha*), sockeye salmon (*O. nerka*), and coho salmon (*O. kisutch*). This type of fishway has the advantage of being portable, is relatively inexpensive, and can pass a substantial number of fish per unit of time.

Experiments on slopes of Denil steeppass fishways[1] at the Fisheries-Engineering Research Laboratory at Bonneville Dam indicated that salmonids ascending pool-and-overfall fishways in the Columbia and Snake Rivers would also pass through a Denil fishway.

The National Marine Fisheries Service (NMFS) (formerly the Bureau of Commercial Fisheries) has been conducting research for several years in an effort to find solutions to the complex fish passage problems caused by dams on the Columbia and Snake Rivers. Since 1968 considerable effort has been centered on transportation experiments designed to determine whether collecting juvenile salmonid migrants at upstream dams and transporting them downstream around hazardous areas, such as turbines at dams, might be a feasible method of reducing losses during downstream migration. Evaluation of these studies is based on returning adults.

To properly evaluate these experiments, an automatic system was needed to detect and separate wire-tagged (Jefferts et al., 1963) adult salmon during ascent of a fishway. Durkin et al. (1969) described and tested a prototype system at Minter Creek Hatchery, and Ebel et al. (1973) used this system successfully in the fish ladder at Ice Harbor Dam to evaluate a transportation experiment. A basic requirement of the detection system is that the fish must pass the detector head at a velocity of about 1.0 m/s. This can be achieved in a conventional fishway by directing the fish to an auxiliary steeppass which requires ascent to a height above the primary fishway. On reaching the apex of the steeppass, the fish descend a chute which discharges them past the detector head at the required velocity. Untagged fish are returned directly to the primary fishway, whereas tagged fish are automatically deflected into a holding trap.

Another transportation experiment is presently in progress at Little Goose Dam on the Snake River, and a comparable automatic detection and separation system was needed for pickup of wire-tagged adult salmon. Although the detection and collection system used at Ice Harbor incorporated a steeply sloped pool-and-overfall fishway, space limitations in the fishway at Little Goose Dam precluded use of a pool-type fishway. However, previous experiments at the Fisheries-Engineering Research Laboratory on slopes of Denil steeppasses indicated that a Denil fishway would be suitable for adaptation at Little Goose Dam.

Before installing the Denil in the fishway at Little Goose Dam, we needed to know its effect on fish passage. Therefore, in 1971, we conducted experiments with the Denil fishway to determine the best entrance and exit conditions and to assess the affect on fish passage through the Denil when placed in a prototype 1-on-10-slope, pool-and-overfall fishway. This information is described herein and was used in the final design of the automatic detection and separation system installed at Little Goose Dam.

EQUIPMENT AND PROCEDURES

This study was conducted at the Fisheries-Engineering Research Laboratory located at Bonneville Dam on the Columbia River (Collins and Elling, 1960). The laboratory is an enclosed rectangular flume 180 feet (54.9 m) long, 24 feet (7.3 m) wide, and 24 feet (7.3 m) deep, located adjacent to the Washington shore fish ladder on the

[1]Weaver, C.R. Progress Report No. 154 for January through March 1969. Research on fishway problems conducted at the Fisheries-Engineering Research Laboratory at Bonneville Dam under Contract No. DA-35-026-25142 with the U.S. Fish and Wildlife Service (Biol. Lab., Seattle, Wash.). 8 p. (Typescript.)

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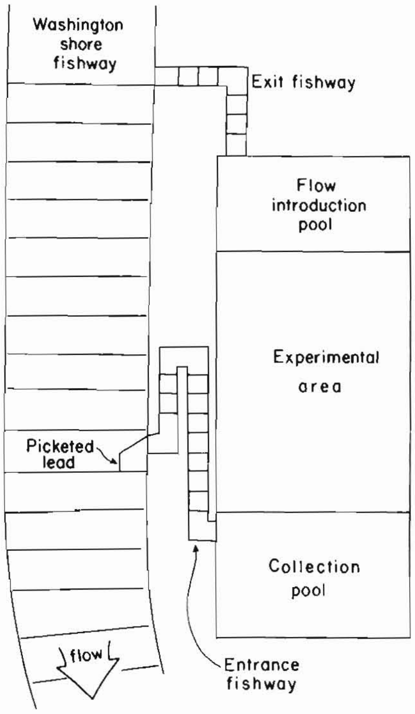


Figure 1.—Plan view of Fisheries-Engineering Research Laboratory showing relationship to the Washington-shore fishway at Bonneville Dam.

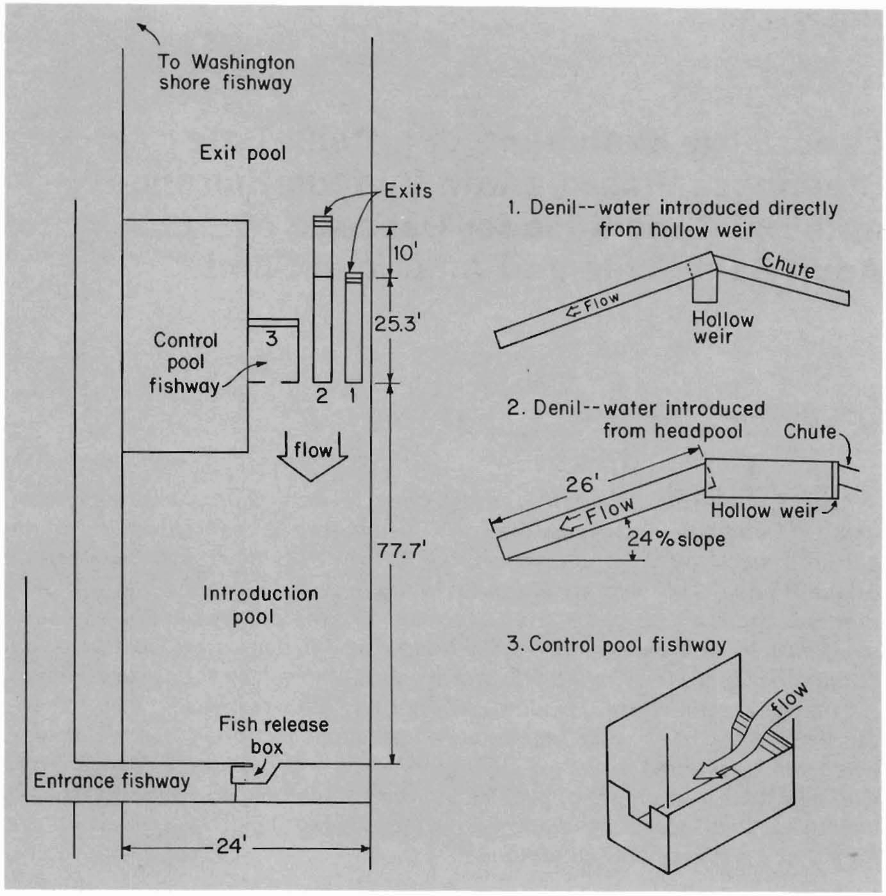


Figure 2.—Plan view of experimental area used for tests of entrance and exit conditions of Denil-type fishways.

north bank of the river (Fig. 1). Fish were diverted from the ladder and observed as they passed on their own volition through experimental conditions in the laboratory. After attaining the upstream pool they reentered the ladder and continued their migration over the dam. Fish were not handled at any time.

Illumination throughout the tests was provided by 1,000-watt, mercury-vapor lights, spaced at 6-foot (1.8-m) intervals and placed 6 feet (1.8 m) above the water. These lights provided an intensity of illumination comparable to that in the main Bonneville fishway on a bright, cloudy day.

The laboratory provided the capability for testing the performance of fish over a range of operational conditions in the Denil fishway. Figure 2 is a plan view of the experimental area within the laboratory. Facilities in this area consisted of a submerged release box, a large introductory pool and—depending on the experiment—a Denil fishway, a pool-and-overfall fishway, or both.

Fish used in these experiments entered the experimental area through the release box where an observer ascertained size and species. The fish then passed through the introductory pool, through one of the experimental fishways, and into an exit pool from which it reentered the Washington shore fishway and continued its ascent over the dam.

The experimental structures consisted of a Denil fishway and a pool-and-overfall fishway. The Denil fishway used in this study was a steeppass model A described by Ziemer (1962). This is an aluminum flume made of 10-foot (3.1-m) long sections that are 22 inches (0.5 m) wide by 27 inches (0.7 m) high and contain internal baffles for control of water velocity (Fig. 3). Clearance within the baffles (open area) is 14 inches (0.35 m) by 22 inches (0.6 m). Sections were bolted together to achieve length of ladder required for testing. During the experiments the Denil was completely filled with water and carried a flow of approximately 5.5 cfs (0.16 m^3).

A simple control fishway used in these tests was positioned adjacent to the Denil structure and consisted of a single pool having dimensions identical to those in the auxiliary pool-type fishway at Ice Harbor Dam. The pool

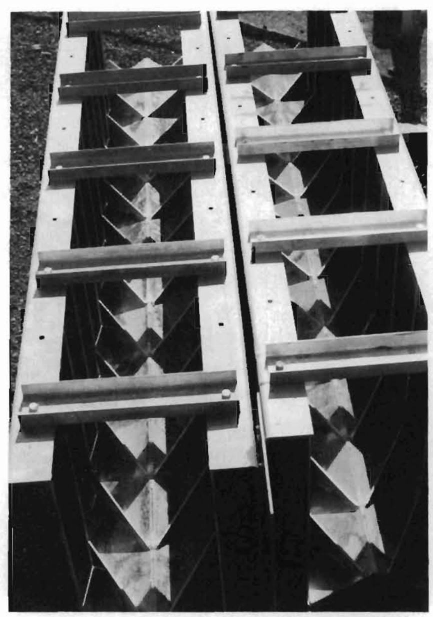


Figure 3.—Sections of model A Denil fishways.

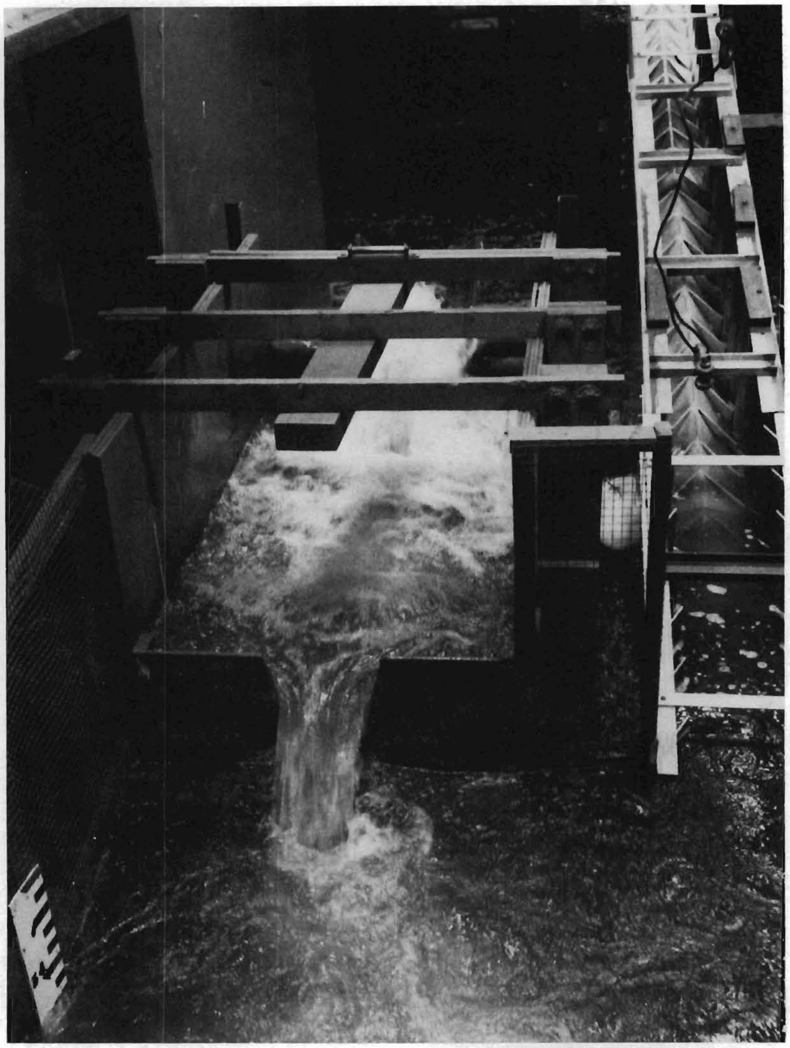


Figure 4.—The control pool-type fishway in operation. Structure on the right is an unwatered Denil fishway.

was 4 feet (1.2 m) wide, 8 feet (2.4 m) long, and 6 feet (1.8 m) deep. Water entered from a hollow weir at the upstream end and filled the pool to a depth of 3.7 feet (1.2 m). Discharge from the pool was through a notched weir (Fig. 4) and totaled 2.5 cfs (0.07 m^3).

Due to poor visibility at the entrance into the Denil fishway (caused by turbidity and large amounts of entrained air in the water), fish could not be enumerated as they entered. Instead, fish were timed as they entered the introductory pool and as they exited over the hollow weir at the upstream end of the Denil fishways. Timing of fish in the control, pool-and-overfall fishway was from time of release until entry to the fishway. Thus, passage times recorded for the test conditions (Denil) were for transit through the entire system, whereas those for the control (pool-type fishway) covered only the period from release into the system to entry of the fishway.

A time-event recorder was used to log fish passage through the test area. Observers at the release and exit points activated push-button switches to transmit information to the recorder. This information was then transcribed onto an operations sheet.

Our study consisted of a series of tests which can be grouped into three categories. The first series evaluated various entrance and exit conditions of the Denil fishway and also compared fish passage in the Denil fishway system with that in the pool-and-overfall fishway. The second series was concerned with assessments of fish passage in a selected Denil system installed in a prototype 1-on-10-slope fishway. The third series involved evaluations of fish passage through a 50-foot (15.2-m) long Denil fishway.

Two experiments were conducted to determine the effect of entrance conditions on fish passage through a Denil fishway system. In the first we evaluated three types of entrance conditions, and in the second we compared the response of fish presented with a choice of entering a Denil or pool-type fishway. The Denil fishway in these tests was 26 feet (7.9 m) long and inclined at a slope of 24 percent.

Entrance conditions tested included the following:

1. Downstream end of the Denil submerged to the top of the entrance of the Denil fishway (Fig. 5A) with wire mesh leads (Fig. 6) at the entrance to guide fish into the fishway.
2. Same as number 1 except that downstream end was extended 10 feet (Fig. 5B) so that top of Denil entrance was submerged 2.5 feet (0.8 m). Screened sides were added to this submerged section to retain fish within confines of the Denil fishway, and space bars in the submerged section were removed to facilitate fish passage into the fishway.
3. No lead or side screens at entrance to Denil. With these screens removed, fish could proceed 10 feet (3.1 m) farther upstream until they were stopped by the upstream barrier screen (Fig. 5C).

In the second experiment on entrance conditions, a Denil-type fishway and the control pool were offered simultaneously to determine the preference of salmonids and shad when offered a choice of entering a Denil fishway or a pool-and-overfall fishway (Fig. 7).

Tests of exit conditions for fish passage through the Denil fishway systems were concerned with the means by which water was discharged into the Denil fishway and effects of these water supply systems on fish passage. Three exit conditions were examined for their effect on fish passage. In addition, passage through the Denil systems was compared with that in the control pool-and-overfall fishway. Exit conditions tested in replicate included the following:

1. Flow from hollow weir (Fig. 8) discharged directly into Denil fishway. Standing water depth at the upstream end of the weir was from 10

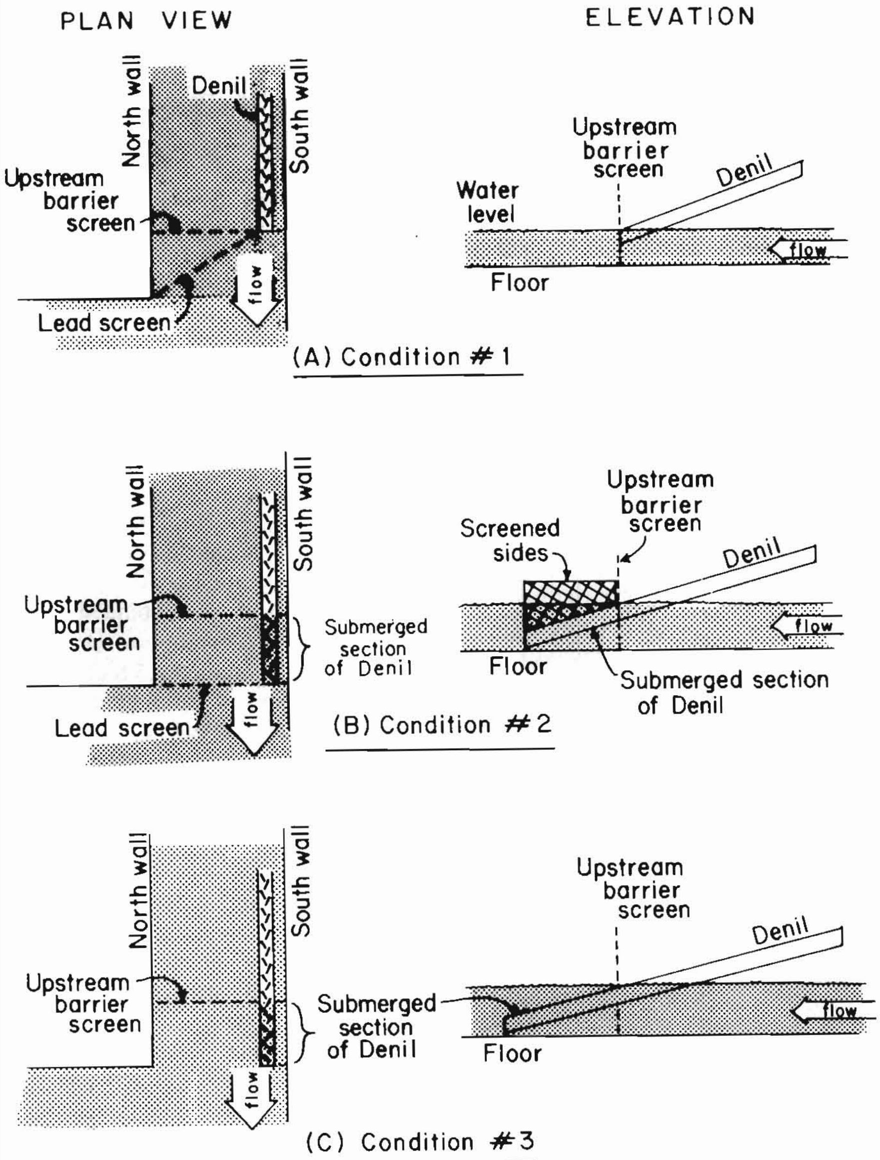


Figure 5.—Plan and side view of experimental area showing position of Denil for entrance condition tests.

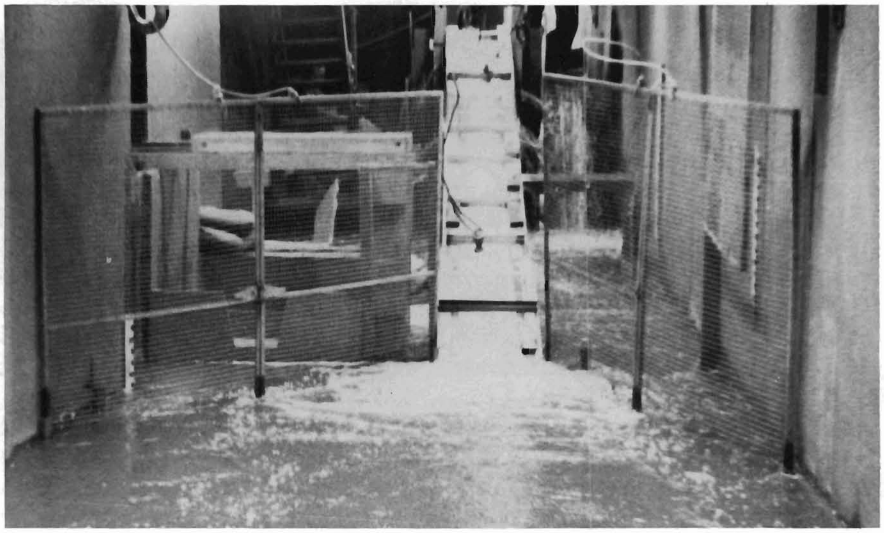


Figure 6.—The Denil fishway in operation with wire mesh lead screens situated to guide fish to the entrance of the fishway.

to 12 inches (0.25 to 0.31 m); most of the water entered the Denil, but a small quantity spilled into the chute to sluice fish back to water level of the laboratory exit pool. Fish swam through the Denil, over the top of the hollow weir, and their momentum carried them directly into the chute (Fig. 9).

2. Flow to Denil fishway from a headpool supplied by water plunging from a hollow weir at upstream end of pool. Headpool dimensions were 10 feet (3 m) long by 2 feet (0.6 m) wide by 5 feet (1.5 m) high. Fish passed from Denil to headpool and then over hollow weir into chute. Plexiglas[2] windows on a sidewall provided a view of the fish during passage through the pool. Water depth in headpool was 3 feet (0.9 m); flows passed over lip at downstream end of pool and into Denil fishway.

3. Same conditions as in 2 above except that an inclined grill was installed on downstream face (Fig. 10) of the hollow weir. Water supplied to the laboratory and used in the hollow weirs during tests was by gravity flow from the Bonneville Dam forebay.

Tests involving the installation of a Denil fishway within a section of a 1-on-10-slope fish ladder (Fig. 11) were done to determine the effect on fish passage. Water supplying the Denil and various structural modifications within the pool fishway that were necessary to install the Denil could disrupt fish passage. The Denil fishway in these tests was 30 feet (9.1 m) long and inclined at a slope of 28.7 percent. Flow to the Denil was supplied through a hollow weir. Three operating conditions (Fig. 12) were tested to determine which would be preferable for use at Little Goose Dam. They were:

1. Gravity flow to the Denil steeppass from source outside the pool-type fishway. This condition caused a 0.2-foot (6.1-cm) rise in pool levels downstream from the Denil. (In the above tests, weir 545 immediately downstream from the Denil was removed to provide a long approach pool to the entrance of the steeppass.)

[2]Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

Figure 7.—Simultaneous operation of Denil fishway (right side) and control pool-type fishway (left side). Portion of introductory pool in foreground.

2. Flow to the Denil steeppass pumped from the 1-on-10 fish ladder. No change resulted in water level of pools downstream from the Denil (in the above tests, weir 545 immediately downstream from the Denil was removed to provide a long approach pool to the entrance of the steeppass).

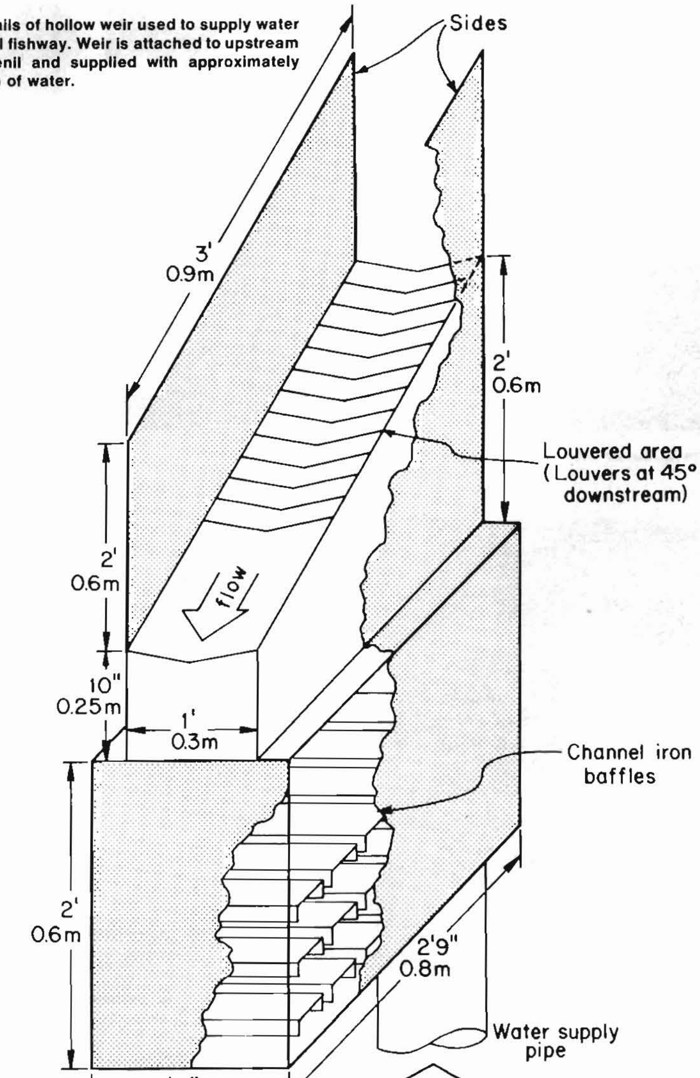
3. Same as condition one except that a stub weir (half-height) was installed in the pool-and-overfall fishway immediately downstream from the Denil. A capacity test was conducted under this condition to determine the maximum number of fish that would pass through the Denil fishway system.

The final design selected for installation at Little Goose Dam required two 50-foot (15.2-m) long Denil fishways. To achieve that length in the laboratory, we added a 20-foot (6.1-m) section to the downstream end of the existing steeppass. This placed the bottom of the downstream end of the Denil on the floor of the laboratory. Water depth at the approach to the Denil was, therefore, only about 2.5 feet (0.7 m).

Fish used in these tests are designated as spring-, summer-, and fall-run salmonids and American shad (*Alosa sapidissima*). Spring runs consisted of chinook salmon (*O. tshawytscha*) and steelhead trout (*Salmo gairdneri*); summer runs consisted of chinook salmon, sockeye salmon, and steelhead trout; fall runs consisted of chinook salmon, coho salmon, and steelhead trout. Other species of fish which passed through the Denil fishways included suckers (*Catostomus* sp.); northern squawfish (*Ptychocheilus oregonensis*); and Pacific sea lamprey (*Entosphenus tridentatus*).

Fish used in the first series of experiments on entrance and exit conditions consisted of spring- and summer-run salmonids and American shad. These fish were actively migrating adults and ranged in size from 8 to 39 inches (20 to 100 cm). Our test procedure was to release 25 chinook salmon and any other fish which voluntarily entered the test area during the time the chinook entered. Then the release of fish was stopped and 1 h was allowed for the fish to pass through the test area. This arbitrary time limit was established so

Figure 8.—Details of hollow weir used to supply water directly to Denil fishway. Weir is attached to upstream end of the Denil and supplied with approximately 5.5 cfs (0.16m³) of water.



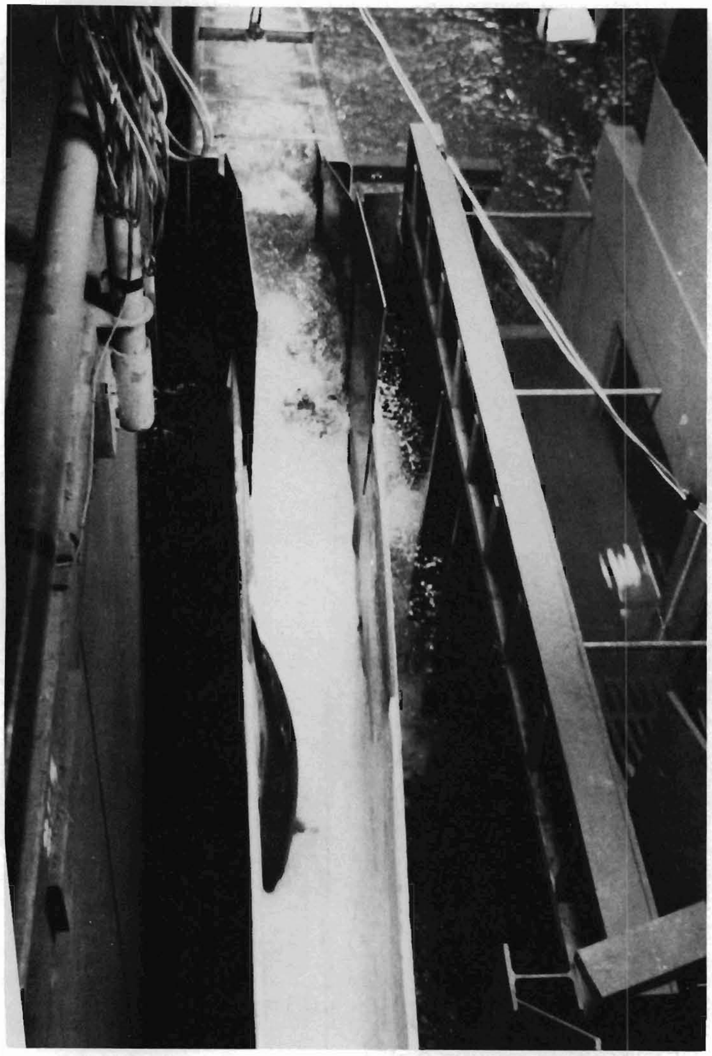


Figure 9.—Adult salmon after passing apex of hollow weir slides down to base water level.

Figure 10.—Headpool showing inclined wooden grill on downstream face of hollow weir (center). Hollow weir without grill and without headpool on right.

Figure 11.—Flow conditions in mockup of Denil fishway in 1-on-10 slope fish ladder. In lower foreground is a portion of the introductory pool; in the center are two fish ladder pools downstream from the Denil. Entrance to the Denil fishway is at upper right. Picket lead for directing fish to Denil appears on left of entrance to Denil.

that excessive time would not be spent on fish that failed to pass through the test facility.

Our second series of tests with the Denil fishway in a prototype 1-on-10-slope fish ladder was conducted with fall-run fish. The procedure was to release fish for 2 h and allow 1 h for the fish to pass through the test area. Fish for the capacity test were collected below the test area for 6 h; then a large gate was opened allowing the massed fish free entry into the test area. The same procedure as above was used in regard to time limits.

For the third series of tests where fish passage through a 50-foot (15.2-m) long Denil was examined, we also used fall-run salmonids. Fish were released into the test area as rapidly as available for 1 h and 15 min, after which 1 h was allowed for the fish to pass through the test area.

Evaluation of fish performance was made by comparing passage time and the proportion of fish completing passage within a given time period. The statistic "median elapsed time" was used to compare passage time of groups of fish passing through the fishways. This was determined by subtracting the time of the median fish at the release box from the time of the median fish at the exit of the Denil fishways. Timing through the control structure was determined by subtracting the time of the median fish at the release box from time of the median fish entering the control pool.

SALMONID PERFORMANCE IN DENIL FISHWAYS

Salmon and steelhead trout entered and passed through all fishway systems examined. Differences in performance of fish were observed, however, among the various entrance and exit conditions.

Effect of Entrance Conditions

The use of fishway entrance leads and the submergence of the Denil entrance affected the passage of summer salmonids through a Denil fishway system. When offered a normal Denil entrance condition (Denil not submerged but fishway leads provided), 96 percent of the salmonids passed through this system in 12 min (Fig. 13). When summer salmonids were offered the submerged Denil entrance provided with fishway lead screens, they accepted and passed through the Denil but at a slower rate of speed. The median elapsed passage time increased to 27.5 min.

When the fishway lead screen and screened sides on the submerged portion of the Denil were removed, the proportion of fish entering and passing through the Denil fishway during the test period decreased; only 75 percent of the summer salmonids passed through the Denil fishway system (Fig. 13) and the length of time required to enter and pass through the test facility increased to 37 min. Obviously, the lead screen and screened sides were beneficial in enhancing the entrance to the Denil fishway.

Response of spring and summer salmonids presented with a choice of entering a Denil or a pool-type fishway was very clear-cut. Seventy percent of the spring salmonids chose the Denil and 30 percent chose the pool-and-overfall fishway (Fig. 14). When summer salmonids were offered this choice, 97 percent selected the Denil and only 3 percent entered the pool fishway.

These results are very similar to those obtained by Fulton et al. (1953) at Dryden Dam on the Wenatchee River. The Denil used by Fulton had 40 percent more flow than his pool-type fishway. Enumeration of the fish run showed that 89 percent of the salmonids chose the Denil and 11 percent chose the pool-type fishway.

The Denil we used carried 55 percent more water than the pool fishway. If we combine our spring and summer salmonid passage data, the results indicate that 95 percent of the salmonids chose the Denil and only 5 percent selected the pool-type fishway.

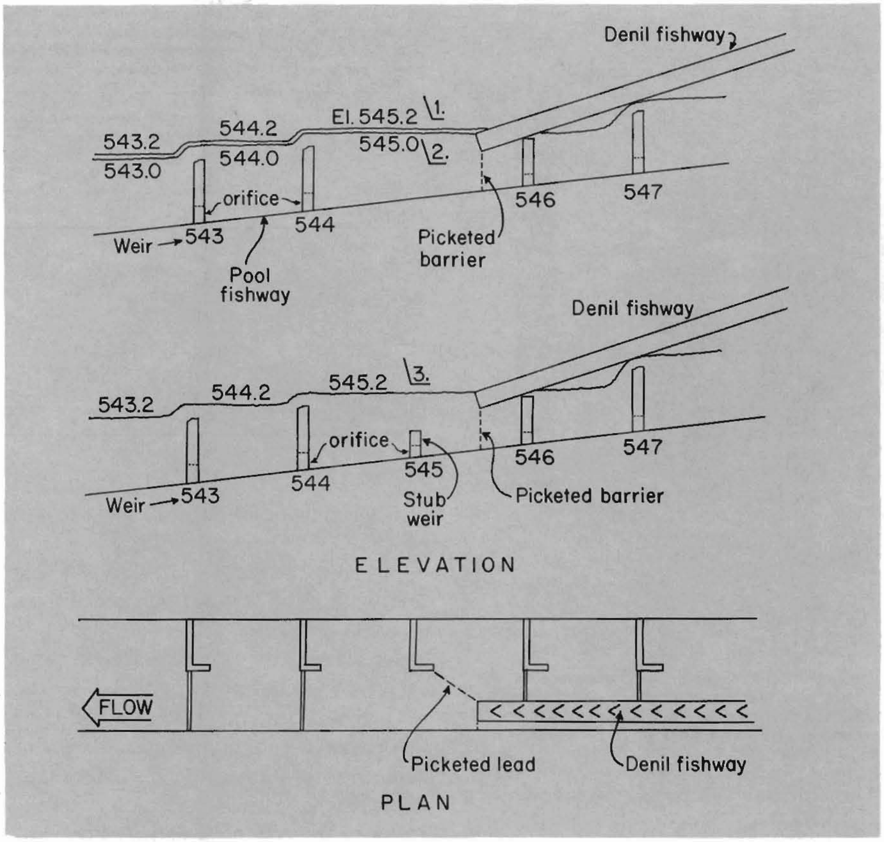


Figure 12.—Plan and elevation views of prototype fishway. Plan view illustrates the layout of three test conditions. Elevation view shows the location of the Denil in the pool fishway.

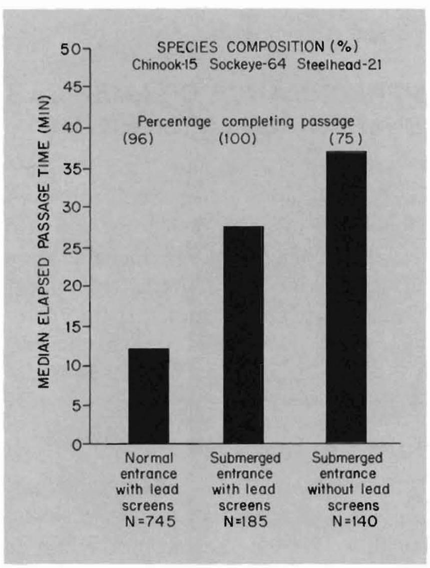


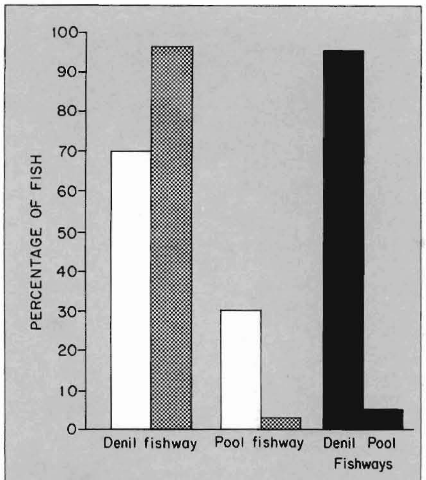
Figure 13.—Effect of entrance conditions of Denil fishways on passage time of summer-run salmonids through a Denil fishway.

Effect of Exit Conditions

The best exit condition for passage of both spring- and summer-run salmonids (11.5 and 12.0 min, respectively, Table 1) was provided by the Denil fishway with flow supplied directly from a hollow weir. In contrast, passage into the control (pool) fishway took longer (73 and 86 min for spring- and summer-salmonids, respectively). The proportions of salmonids completing passage ranged from 100 percent in the Denil to 73 percent in the control fishway.

Evaluation of Prototype Denil Fishway Installation

There was little difference in the passage times of fall-run salmonids through the Denil fishway under the three simulated operating conditions tested in a section of a pool fishway.



Number and type of fish	SPECIES COMPOSITION (%) Chinook	Sockeye	Steelhead
□ 27 Spring run	86	—	14
▨ 294 Summer run	17	63	20
■ 321 All fish	23	57	20

Figure 14.—Response (i.e., percentage of the total number of fish that entered each fishway) of salmonids presented with a choice of entering a Denil or a pool-type fishway.

The median elapsed passage times under the two conditions with the first downstream weir completely removed were: 17.7 min with an outside water source and 14.0 min with pumped water. The median elapsed passage time with the outside water source and a half weir downstream of the Denil was 11.5 min (Fig. 15).

The best passage situation (Denil fishway supplied by an outside water source and a half weir downstream) was used to examine the fish-passing capacity of a Denil fishway with prototype dimensions. Four hundred and two fish passed through the Denil during the capacity test. Peak passage for a 20 min period averaged 11 fish per min, and peak passage for a 1 min period was 19 fish per min (Table 2). Thus, we estimated that the fish-passage capacity of the proposed installation would most likely fall within a range of 650 to 1,140 fish per hour during peak passage times.

Effect of a 50-foot (15.2-m) Long Denil on Fish Passage

Extending the Denil fishway an additional 20 feet (6.1 m) for a total length of 50 feet (15.2 m) had no adverse affect on passage efficiency. The results of three separate tests using fall-run salmonids indicated median elapsed

Table 1.—Comparison of fish passage in the Denil fishway facility with that in the control (pool fishway). Passage times and proportions completing passage in the Denil structure include fish performances from time of release (into introductory area downstream from fishway) to exit from the fishway. Those for control include only movement from time of release until entry to the control pool.

	Spring-run salmonids			Summer-run salmonids		
Test condition	No. of fish	Median passage time (min)	Completed passage (%)	No. of fish	Median passage time (min)	Completed passage (%)
Source water directly to Denil—from hollow weir	132	11.5	100	745	12.0	96
Source water to Denil—from headpool						
Without grill	59	34.0	86	312	30.0	100
With grill	69	33.0	95	330	21.0	99
Control (pool fishway)	67	50.0	73	345	47.5	86

passage times of 4.0, 6.5, and 10.2 min (Table 3). The proportions of fish completing passage through the test area within the test period ranged from 90 to 93 percent.

As a result of this experiment, two Denil fishways were installed in the pool-type fishway at Little Goose Dam as part of an automatic detector-separator system in 1972. The Denil fishways have been used successfully for 3 years and pass fish without any apparent injuries or noticeable delay. During this time approximately 160,000 adult migrating salmon and 110,000 steelhead trout have ascended and passed through the Denil fishways.

PERFORMANCE OF AMERICAN SHAD IN DENIL FISHWAYS

The response of shad to the entrance and exit conditions of the Denil used during the first series of tests was also examined. The timing of shad migration at Bonneville Dam precluded an examination of shad response to the prototype Denil that was tested in the fall; thus data regarding their response to the prototype are lacking.

Effect of Entrance Conditions

Entrance conditions affected the passage of shad through a Denil fishway system. Under the normal entrance

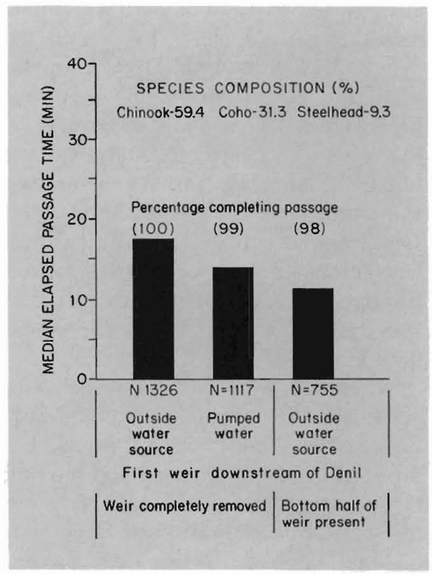


Figure 15.—Comparison of median elapsed time and proportions of fall-run salmonids passing through a Denil fishway system placed in a 1-on-10 slope pool and overfall fishway under three simulated operating conditions.

conditions (with only the entrance to the Denil submerged and fishway lead screens present), 32 percent of the shad passed through the system in 47 min. When the entrance was submerged to a depth of 2.5 feet (0.8 m) and was equipped with screened sides and fishway leads, 61 percent of the shad entered and passed through the Denil fishway system in 54 min. Removal of

Table 2.—Summary of a fish passage test to determine capacity of a prototype fishway installation containing a 30-foot (9.1-m) long Denil fishway set at a slope of 28.7 percent, 13 September 1971.

	Numbers of fish passed				Species composition (%)		
Total no. fish entered	Total passage (1 h)	60-min period (avg. per min)	Peak 20 min period	Peak 1 min period	Chinook salmon	Coho salmon	Steelhead trout
412	402	6.7	10.8	19	54	27	19

Table 3.—Passage times and the proportions of three groups of fish which ascended a 50-foot (15.2-m) long Denil fishway with a slope of 28.7 percent, 16 September 1971.

Test group	No. of fish entering fishway	No. of fish exiting fishway	Completed passage (%)	Median elapsed passage time (min)	Species composition (%)		
					Chinook salmon	Coho salmon	Steelhead trout
1st	69	62	90	6.5	43	42	15
2nd	86	80	93	4.0	55	34	11
3rd	83	76	92	10.2	44	41	15

the lead screens and screened sides on the submerged portion of the Denil decreased the proportion of fish entering and passing through the Denil fishway during the test period. When this was done, only 20 percent of the shad passed through the Denil fishway. Obviously, the submerged entrance with lead screens and screened sides was beneficial in enhancing entrance to the Denil fishway for shad.

Response of shad when presented with a choice of entering a Denil or a pool-type fishway was also obvious. Of the 109 shad introduced into the test area, 35 (32 percent) entered and passed through the Denil; none entered into the pool-type fishway.

Effect of Exit Conditions

Exit conditions had a very definite effect on the passage of shad through the Denil fishway systems. Of the four fishway systems tested, the best exit condition for shad passage was provided by the Denil fishway supplied with a direct flow from a hollow weir. Under this condition 32 percent of the shad introduced in the test area entered and passed through the Denil fishway. Their median elapsed passage time was 47 min (Table 4). Although shad passed through the Denil fishway supplied with flow from a headpool, they would not exit the headpool (Fig. 16). Thus, this method of supplying the Denil would not be feasible for passage of shad. Shad failed to enter the pool-type (control) fishway; exit condition of this system therefore had no effect.

Observations of shad behavior in the headpool indicated that shad did not continue upstream principally because of the exit condition created by the weir supplying the pool. This condition was similar to that found in the pool-type (control) fishway. Shad were often seen swimming up to the overfall flow from the weir, where they would assume the typical exit position (as used by salmonids, Fig. 17), and remain in that position for a time. Later they turned and dropped back to the lower downstream half of the headpool and eventually passed back downstream through the Denil.

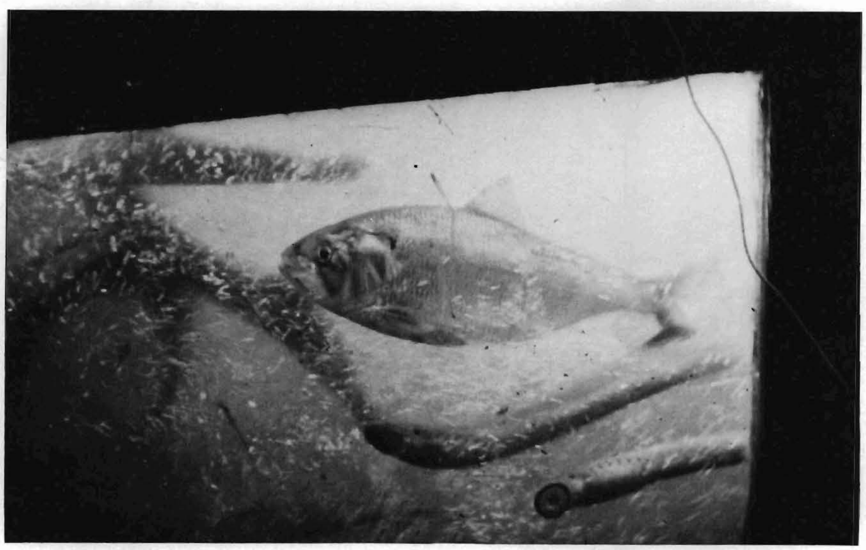


Figure 16.—View of downstream half of headpool through Plexiglas window. Note shad resting in headpool.

Table 4.—Comparison of passage of American shad in the Denil fishway facility with that in the control (pool fishway). Passage times and proportions completing passage in the Denil structure include fish performances from time of release (into introductory area downstream from fishway) to exit from the fishway. Those for the control include only movement from time of release until entry to the control pool.

Test condition	No. of fish	Median passage time (min)	Percentage of fish completing passage
Source of water to Denil from hollow weir	180	47.0	32
Source of water to Denil from headpool	52	84.0	2
Control (pool-fishway)	154	55.0	1

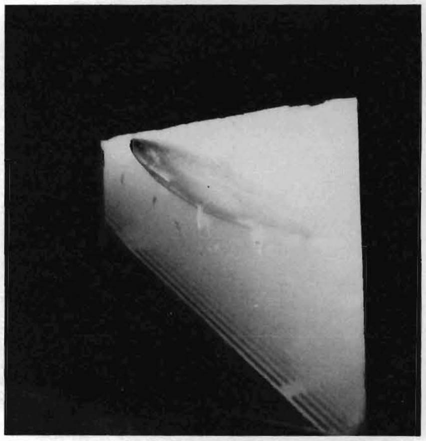


Figure 17.—View of upstream half of headpool through Plexiglas window. Fish in center has assumed a typical exit position in front of the hollow over-flow weir. Wooden inclined grill can be seen in lower left side of window.

Effect of Test Period Duration on Shad Passage

To determine whether the arbitrary 1 h limit was sufficient to assess completed passage by shad, we extended this time limit to 2- and 3-h periods. The results indicated that the length of the test period was one of the limiting factors on the proportions of shad which completed passage through the Denil fishway system. The proportions of shad completing passage through the Denil (with a direct flow from a hollow weir) increased from 32 percent in a 1-h period to 54 percent in a 2-h period and 61 percent in a 3-h period.

Even though the proportion of shad passing through the Denil fishway was considerably less than that of salmonids under all conditions, the tests indicated that shad will enter and ascend a Denil fishway if given sufficient time and the proper entrance conditions.

SUMMARY AND CONCLUSIONS

Tests were conducted at the Fisheries-Engineering Laboratory at Bonneville, Wash., to determine the desirability of using a Denil fishway within a primary pool fishway to direct fish into a tag detection and fish separating system designed to retrieve marked adult salmon and trout containing coded wire tags. Several design arrangements were set up and tested to determine which arrangement would provide the best fish passage with a minimum of delay. These tests included tests on the effect of lead screens, various methods of supplying flow, and length and slope of the Denil.

Initial tests indicated that salmonids and shad entered and passed faster through the Denil fishway with a flow directly from a hollow weir than through the Denil with a flow from a headpool, or through entrance into a pool-and-overfall fishway.

Salmonids and shad readily entered and ascended the Denil fishway when the entrance was submerged to a depth of 2.5 feet (0.8 m); best passage was attained when lead screens were used.

When offered a simultaneous choice between a Denil fishway and a pool-type fishway, the majority of the fish chose the Denil fishway.

Salmon and trout readily entered and passed through a Denil fishway at a 28.7 percent slope when it was placed in a mock-up of a 1-on-10-slope fish ladder of the type used at Little Goose Dam.

A capacity test indicated that 650 to 1,140 adult salmon and trout per hour can pass through a Denil fishway when it is placed in a 1-on-10-slope fish ladder.

Salmon and trout entered and passed through a 50-foot (15.2-m) long Denil fishway with no apparent difficulty.

Entrance and exit conditions were critical to shad passage through a Denil. Shad readily passed through a Denil fishway positioned at a slope of 24 percent when proper entry and exit conditions were provided.

Two 50-foot (15.2-m) long Denil fishways positioned at a slope of 28.7 percent installed at Little Goose Dam on the Snake River have passed approximately 273,000 adult salmon and trout.

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