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PASSAGE OF MIGRANT FISH AT DAMS

PASSAGE OF ADULT SALMONIDS THROUGH PIPES

by

Emil Slatick

Fish-Passage Research Program
U. S. Bureau of Commercial Fisheries
Seattle, Washington

INTRODUCTION

Pipes are potentially useful as transportation channels for migrating adult salmonids. Fish passages through difficult areas at dams might be less costly if pipe passageways were substituted for conventional concrete structures. Another potential application includes the use of pipes to extend fishways exits beyond the immediate influence of spillway gates.

Fish passage characteristics of pipes may be similar to existing fish facilities. In Washington, Oregon, and California darkened fishways and channels up to 500 feet long are in use. Some have lighting systems, but most are operated in the dark. Laboratory tests indicated that steel-head trout made faster fishway ascents in a darkened fishway than during a lighted condition (Long, 1959).

The objective of this study was to explore factors affecting passage of adult salmonids through pipes. The first year of a 2-year study included exploratory work on 100-foot sections of 1-foot and 3-foot-diameter pipes. In the second year, we tested a 270-foot long, 2-foot-diameter pipe with two 180-degree turns and a 90-foot section of 1-foot-diameter pipe. Water velocities, light conditions, and entrance conditions were tested to establish criteria for the passage of salmonids in pipes.[1]

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[1] Tests are still in progress, so findings are not complete at this writing.

EXPERIMENTAL EQUIPMENT

Laboratory

This experiment was conducted at the Fisheries-Engineering Research Laboratory located on the Washington shore of Bonneville Dam. A detailed description of the laboratory is given by Collins and Elling (1960).

Description of Pipes

This study was done during the 1963 and 1964 field seasons with a different installation each season.

The initial installation in 1963 was comprised of two 100-foot lengths of smooth surface pipe with diameters of 1 and 3 feet (Fig. 1) and an approach, introduction, and exit pool (Fig. 2). The pipes were level and the centerline of both pipes was at the same elevation. Hinged doors (Fig. 3) were placed at both ends of the pipes, enabling either pipe to be used independently. The weir in the exit pool was provided with a finger trap to prevent fish from falling back into the system after completing passage (Fig. 3). Water velocities in the pipes were controlled by regulating the head on the pipes with stoplogs in the introductory and exit pools. There was no interior lighting within the pipes in the 1963 study.

The installation in 1964 (Fig. 4) consisted of two pipes, one 2-foot-diameter pipe 270 feet long with two 180° bends (Fig. 5) and a 1-foot-diameter straight pipe 90 feet long. Both pipes had smooth surfaces. The pipes were level with the same centerline elevation and separate introductory and exit pools. This permitted simultaneous use of both pipes with a different water velocity in each pipe.

Hydroscopes (Fig. 6) were used for visual observations and were placed at the entrances and exits of both pipes. The exit area of the 2-foot-diameter pipe (Fig. 6) contained a wire fyke and a luminescent light panel directly below the hydroscope. Electronic detectors (points 1 through 8, Fig. 7) wired to a time-event operations recorder were used to provide a record of the fish passage through various sections of the system.

Lighting

General lighting in the open pool areas of the laboratory was provided by 1,000-watt mercury-vapor lights spaced at 6-foot intervals 6 feet above the water surface. This provided a light intensity comparable to light conditions in the main Bonneville fishway during a bright, cloudy day.

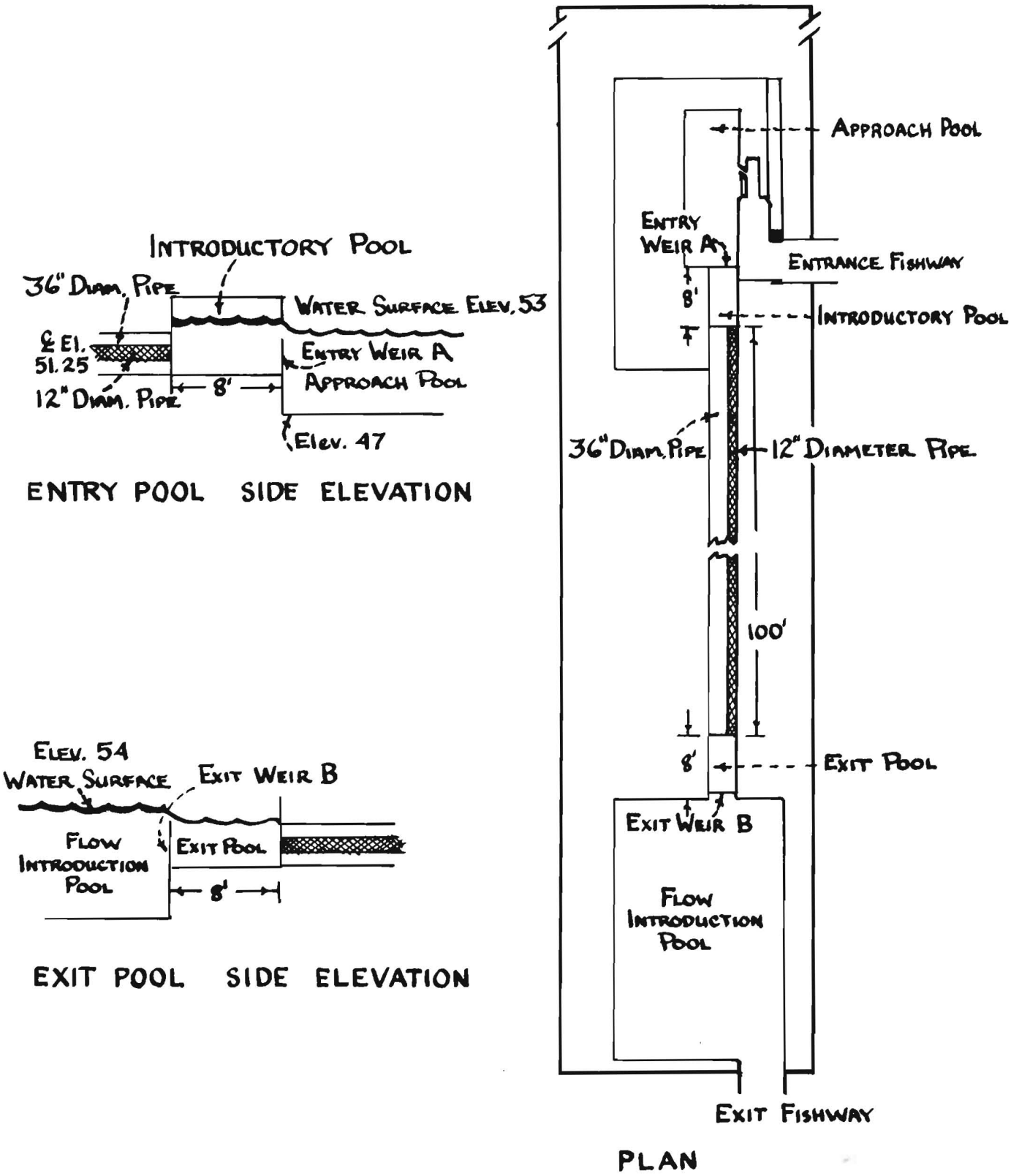

Figure 1.--Plan and side elevation views of 1-foot- and 3-foot-diameter pipe installation.

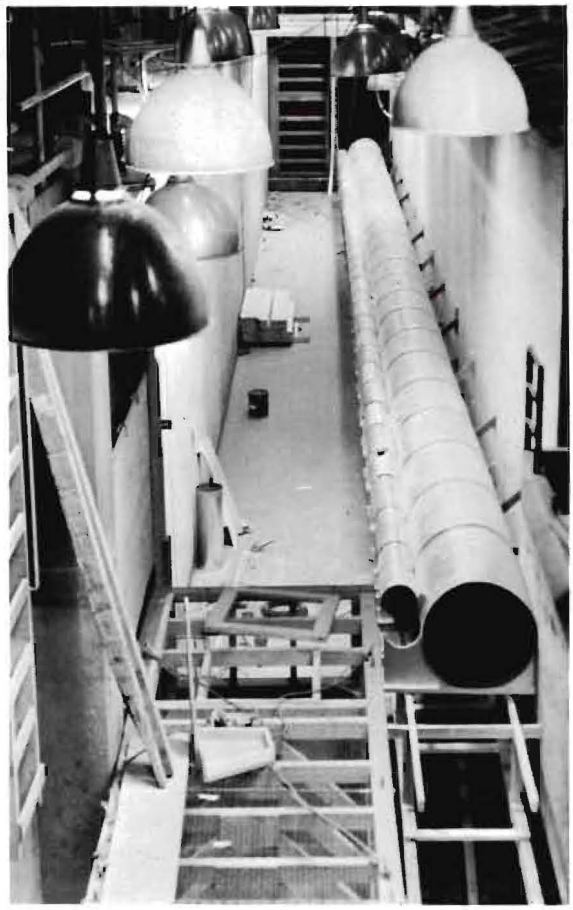

Figure 2.--Installation of the 1- and 3-foot-diameter pipes in the laboratory.

Figure 3.--Exit pool for 1-foot- and 3-foot-diameter pipes. Hinged doors are above pipe openings. Finger trap is attached to stoplog in foreground.

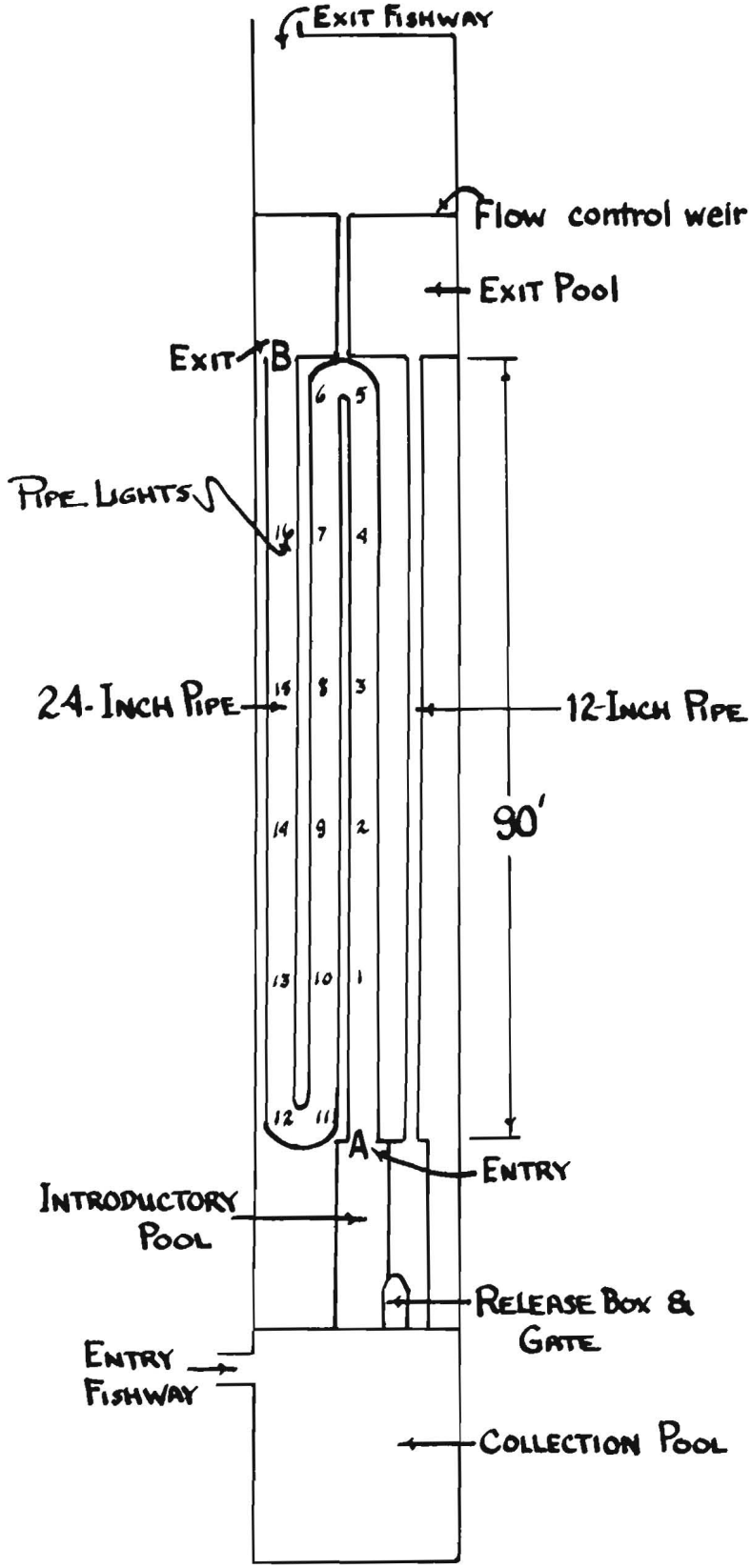

Figure 4.--Diagrammatic plan view of laboratory showing pipe arrangement. Pipe lights are at numbered points 1 through 16.

Figure 5.--Plexiglass window for viewing fish as they enter 2-foot-diameter pipe. One of the 180° turns is shown on right.

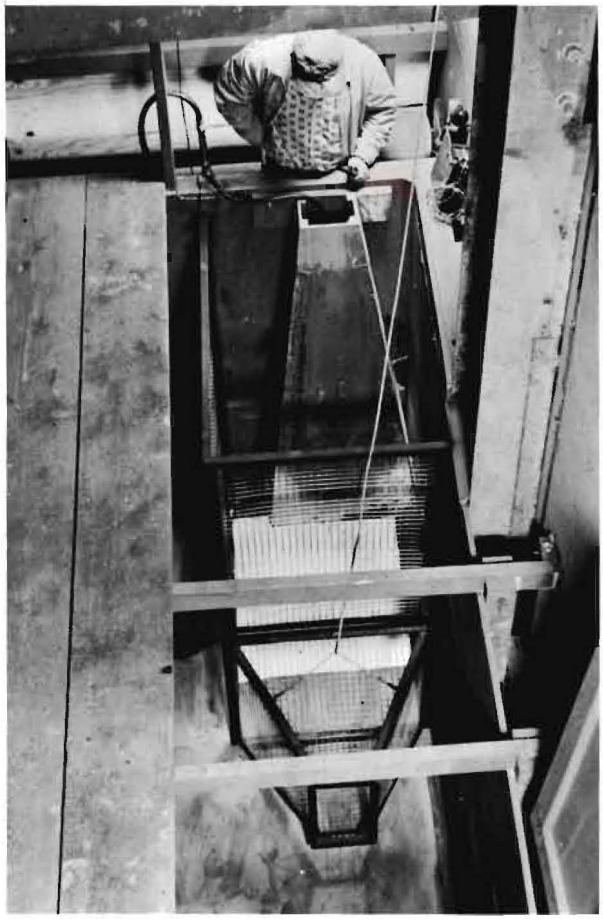

Figure 6.--Exit pool of 2-foot-diameter pipe system. Hydroscope for viewing fish is in center below observer. Exit fyke with removable funnel is in foreground.

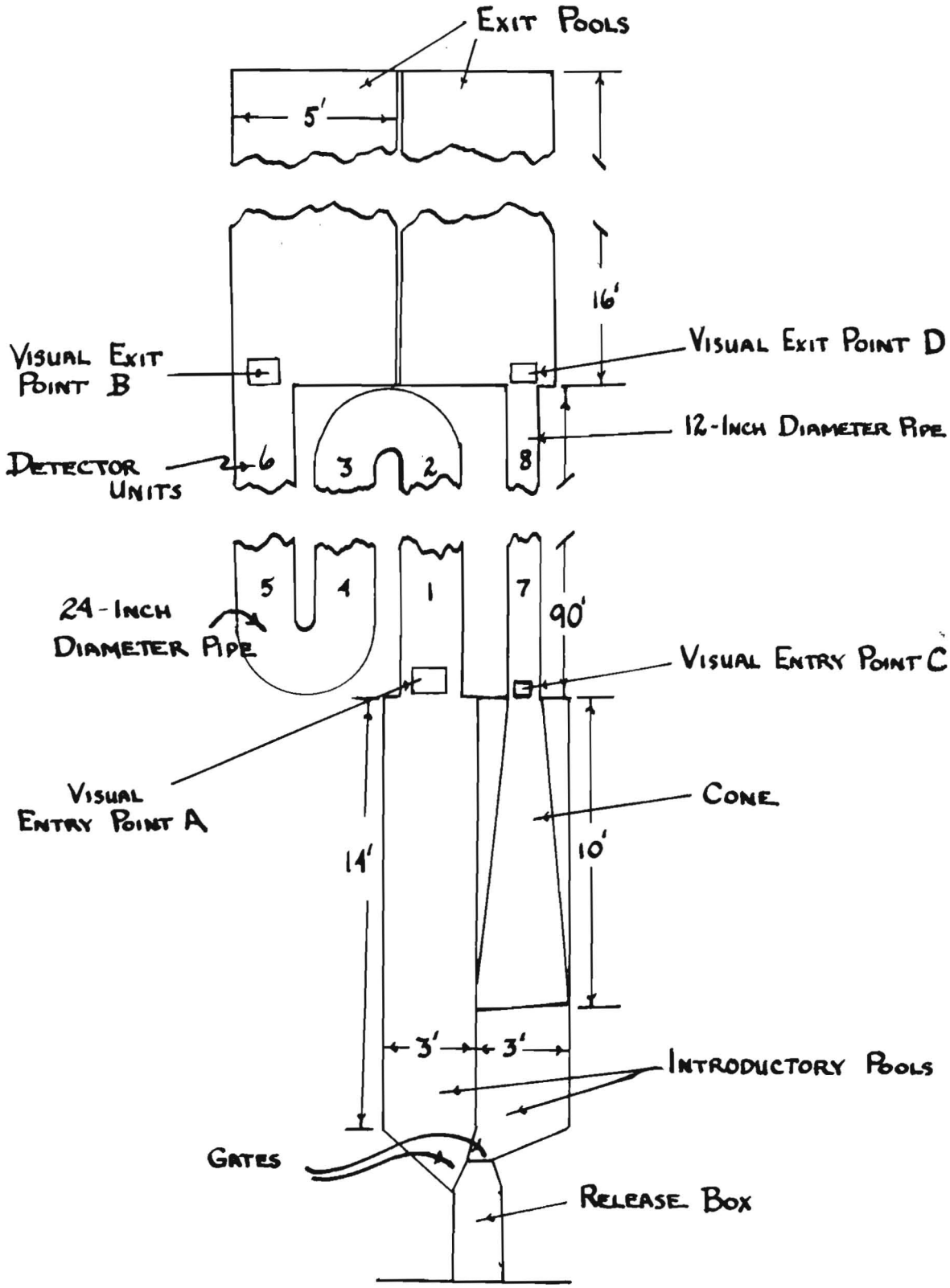

Figure 7.--Plan view showing physical features of pipe installation. Electronic detectors are at numbered points 1 through 8.

Illumination for the interior of the 2-foot-diameter pipe was provided by 75-watt flood lamps. The head of the lamp protruded 1 inch into the top of the pipe (Fig. 8). In a dry pipe, the flood lamps produced an average light intensity of 321 foot-candles measured on the bottom of the pipe below the light source. The lighting array consisted of 16 units spaced 17 feet apart on the straight sections of the 2-foot pipe (Fig. 4).

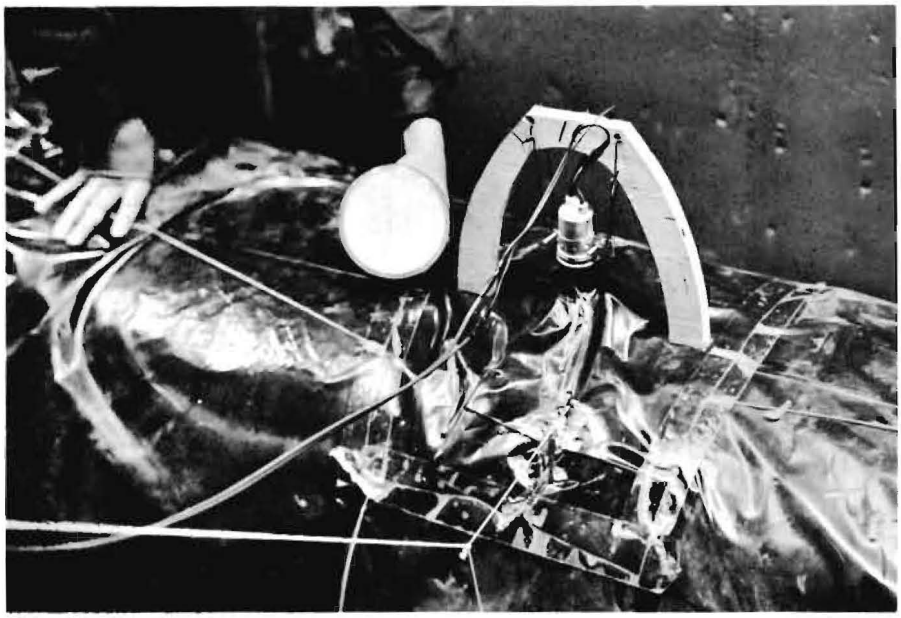

Figure 8.--Installation of 75-watt flood lamps on the 2-foot pipe system. Head of lamp shown at left is the portion inserted into the pipe.

Transition Zones

Tests with two types of light transition zones were made in the 3-foot-diameter pipe during the 1963 season. The first was the normal light condition used throughout the season which gave an abrupt transition from the lighted introductory pool (Fig. 1) to the dark pipe at the downstream end, and from the dark pipe to lighted exit pool at the upstream end. The second condition, obtained by putting plywood covers on the introductory and exit pools, gave a gradual light transition from lighted entry weir A to the dark pipe on the downstream end, and from the dark pipe to lighted exit weir on the upstream end.

Truncated cones were used for transition zones between the introductory pools and pipes in 1964. These were placed on the downstream ends of the 1-foot- and 2-foot-diameter pipes, The cone on the 1-foot diameter pipe tapered down from a 3-foot to a 1-foot diameter, and the cone on the 2-foot-diameter pipe tapered from a 3-foot to a 2-foot diameter. Both cones were 10 feet long and took up a greater part of the introductory pool, which was 14 feet long. The pipes were unlighted except for a minimal amount of light entering through the ends of the pipes.

PROCEDURE

Timing

A time-event operations recorder was employed to record passages through the test area. Observers at the release, entry, and exit points were equipped with push button switches to transmit information on fish passage to the recorder, where the information was transcribed onto an operations sheet.

As it was not possible to see the fish as they entered the 1-foot- and 3-foot-diameter pipes during the 1963 test season, the timing zone extended from the downstream weir of the introductory pool to the upstream weir of the exit pool (A to B, Fig. 1). The timing zones used in 1964 were somewhat more precise. Introductory pool passage times (release box to point A, Fig. 4) and pipe passage times (A to B, Fig. 4) were obtained. An arbitrary timing period of 45 minutes was used. If a fish had not gone through the pipe in 45 minutes, timing was stopped and another fish started.

Release of Fish

Fish entered a relaease box where species and size was ascertained. The fish were then released into the introductory pool of the selected pipe system. Only one fish was used at a time.

Experimental Design

Variations of a Latin square experimental design were used in this study.

RESULTS

This study on the passage of salmonids through pipes included effects of water velocity, pipe diameter and length, transition zones, and light on passage of fish. Chinook salmon (Oncorhynchus tshawytscha), sockeye salmon (Oncorhynchus nerka), and steelhead trout (Salmo gairdneri) were used in these experiments. Results to date are as follows:

Effect of Velocity

Tests measuring the effect of water velocity on passage of salmonids through pipes were conducted in 1-, 2-, and 3-foot-diameter pipe systems. Water velocities ranged from 0.5 to 4 feet per second (f.p.s.).

Three-Foot-Diameter Pipe, 1963

Spring chinook were tested in the 3-foot-diameter pipe under water velocities of 1 and 2 f. p. s. Summer chinook, sockeye salmon, and steelhead trout were tested in water velocities of 0. 5, 1, and 2 f. p. s.

Spring chinook. --Mean and median passage times during two test periods (April and June) in water velocities of 1 and 2 f. p. s. are given in Table 1. The results showed that fish passage was slightly slower in the higher water velocity, but the difference was not significant. On the basis of numbers completing passage within the 45-minute time period, however, the higher velocity condition appeared to have a slight advantage (80 percent passage under 1 f. p. s. and 88 percent under 2 f. p. s.).

Summer chinook. --Passage (Table 1) was slowest at the . 5 f. p. s. water velocity and fastest at 1 f. p. s. The median passage time obtained at the water velocity of 1 f. p. s. was significantly faster than the passage times obtained at both , 5 and 2 f. p. s. , but from a practical standpoint, the difference was slight. The percentage of chinook completing passage within the time limit was about the same at all three water velocities used.

Sockeye. --Sockeye passage (Table 1) was slowest at the water velocity of , 5 f. p. s. and fastest at 1 f. p. s. Median passage times at three velocities, however, did not differ significantly. Also, the percentages of fish completing passage within the time limit were about the same at all velocities.

Steelhead--Steelhead passage (Table 1) was fastest at the water velocity of 1 f. p. s. and slowest at 2 f. p. s. The median passage time at 1 f. p. s. was significantly less than those obtained at 0. 5 and 2 f. p. s. Passage time at the 0. 5 f. p. s. velocity was significantly less than that at the 2 f. p. s. velocity. Percentages of fish completing passage within the time limit were 84 percent of 0. 5 f. p. s. 61 percent at 1 f. p. s. , and 41 percent at 2 f. p. s

One-Foot Diameter Pipe, 1963

Preliminary tests with chinook salmon were made under water velocities of 1, 2, 3 and 4 f. p. s. in the 1-foot diameter pipe (Table 2). At a water velocity of 1 f. p. s. , the 1-foot diameter pipe proved unacceptable to spring chinook. Of nine fish, only one went through the pipe readily; the rest remained in the approach and introductory pools. Several went through the pipe after a few hours, but the 3-foot pipe had to be opened to pass the remainder.

Tests to measure effect of water velocity on fish passage were then conducted with velocities of 2 and 4 f. p. s. for chinook salmon, and with water velocities of 1, 2, and 4 f. p. s. , for sockeye salmon and steelhead trout.

Table 1. Passage times of chinook salmon, sockeye salmon, and steelhead trout through a 3-foot-diameter pipe system with water velocities of 0.5, 1, and 2 f.p.s., 1963.

Species and dates	Passage time by water velocity in pipe: 0.5 f.p.s. velocity n	Mean[1] Minutes	n	Median Minutes	1 f.p.s. velocity n	Mean[1] Minutes	n	Median Minutes	2 f.p.s. velocity n	Mean[1] Minutes	n	Median Minutes
Spring Chinnok:												
April 19	-	------	-	-------	20	5.4	21	2.0	--	------	-	------
April 20	-	------	-	-------	--	---	--	---	14	5.0	15	3.5
April 29 and May 2	-	------	-	-------	26	4.6	30	2.5	--	------	--	------
April 30 and May 1	-	------	-	-------	--	--	--	---	28	6.1	30	3.6
Summer Chinook:												
June 9, 12	-	------	-	-------	31	3.8	33	3.2	--	------	--	------
June 10, 11	-	------	-	-------	--	---	--	---	27	6.2	28	3.9
June 22, 23	17	7.6	19	4.7	--	-	--	---	--	------	--	------
June 21, 24	-	------	--	-------	12	3.6	12	---	--	------	--	------
Sockeye:												
June 22, 23	19	5.3	20	4.5	--	---	--	---	--	------	--	------
June 21, 24	--	-----	--	-----	23	3.7	26	2.7	--	------	--	------
July 5, 8	--	-----	--	-----	47	3.8	50	2.8	--	------	--	------
July 6, 7	--	-----	--	-----	--	---	--	---	35	5.6	37	3.7
Steelhead:												
July 23, 28	21	5.2	25	4.8	--	---	--	---	--	------	--	------
July 24, 26	--	-----	--	---	14	3.8	23	2.9	--	------	--	------
July 25, 27	--	-----	--	---	--	---	--	---	7	5.2	17	26.0

[1] Based on fish for which complete times are available.

Table 2. --Passage times of spring chinook salmon ascending 100 feet of 1-foot-diameter pipe at water velocities of 1, 2, 3, and 4 f. p. s. Test period, April 15-24, 1963.

Water velocity in pipe	1 F. p. s.	2 F. p. s.	3 F. p. s.	4 F. p. s.
Mean passage time[1] (minutes)	6. 0	12. 5	11. 3	12. 3
Sample size.....	1	10	16	19
Median passage time (minutes)	Over 45	24. 1	10. 1	14. 2
Sample size.....	9	20	21	25
Lower limit of median[2].....	10. 0	12. 2	5. 7	7. 8
Upper limit of median[2].....	Over 45	Over 45	29. 1	21. 7

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

[2]95 percent confidence intervals about the median.

Spring chinook. --Median and mean passage times in the two test periods are given in Table 3. In general, the passage times indicate that chinook moved faster at 4 f. p. s. than at 2 f. p. s. The percentage of fish passing through the pipe within the time limit (45 minutes) indicates that the high velocity is more attractive to fish, (70 percent at 2 f. p. s. and 82 percent at 4 f. p. s.).

Summer chinook. --Chinook passage times (Table 3) were less at the water velocity of 4 f. p. s. than at 2 f. p. s., but the difference was not statistically significant. The percentage of fish completing passage within the time limit (45 minutes) was greater at the higher velocity--65 percent as compared to 58 percent.

Sockeye. --Sockeye passage (Table 3) was fastest when the water velocity was 4 f. p. s., but passage at 2 and 4 f. p. s. and slowest at 1 f. p. s. Passage times at 1 f. p. s. were significantly slower than those at 2 and 4 f. p. s., but passage at 2 and 4 f. p. s. did not differ significantly. Percentages of fish completing passage within the time limit at the 1, 2, and 4 f. p. s. water velocities were 46, 78, and 85 percent, respectively.

Steelhead. --Performance of steelhead was somewhat different than that exhibited by both chinook and sockeye which had their fastest passage at the highest water velocity.

Steel head passage (Table 3) was fastest when the water velocity was 2 f. p. s. and slowest at 1 f. p. s. Median passage times at the water velocities of 2 and 4 f. p. s. were significantly less than that under a velocity of 1 f. p. s. There was no significant difference between the passage times obtained at the water velocities of 2 and 4 f. p. s. Percentages of fish completing passage within the time limit were as follows: 44 percent at 1 f. p. s., 86 percent at 2 f. p. s., and 79 percent at 4 f. p. s.

Two-Foot Diameter Pipe, 1964

The effect of water velocity on fish passage was examined in a 2-foot diameter pipe in 1964. Water velocities of 1, 2, and 3 f. p. s. were used in all experiments except for the summer chinook, which were tested at only the 1 and 3 f. p. s. velocities.

Spring chinook. --The test periods covered the peak and the end of the spring migration. Results of the initial experiment covering the peak of the run (April 23 to May 1) shown in Table 4. Median passage times at the water velocities of 2 and 3 f. p. s. were significantly less than the time at a velocity of 1 f. p. s. There was no significant difference between the passage times at water velocities of 2 and 3 f. p. s. The percentages of chinook completing passage at the 1, 2, and 3 f. p. s. velocities were quite similar (86, 82 and 85 percent, respectively).

Table 3. --Passage times of chinook salmon, sockeye salmon, and steelhead trout through a 1-foot-diameter pipe system with water velocities of 1, 2, and 4 f. p. s., 1963.

Species and dates	Passage times by velocity in pipe											
	1 f. p. s.				2 f. p. s.				4 f. p. s.			
	n	Mean[1]	n	Median	n	Mean[1]	n	Median	n	Mean[1]	n	Median
		Minutes		Minutes		Minutes		Minutes		Minutes		Minutes
Spring chinook:												
April 26, 27	-	--------	-	-------	15	10.6	21	15.8	-	-------	-	------
April 25, 28	-	---------	-	-------	-	-------	-	-------	22	11.0	26	9.8
May 7, 10	-	--------	-	-------	17	12.5	25	15.2	-	-------	-	-----
May 8, 9	-	--------	-	-------	-	-------	-	-------	14	8.4	18	9.2
Summer chinook:												
June 6, 7	-	--------	-	-------	11	16.5	19	25.7	-	------	-	-----
June 5, 8	-	--------	-	-------	--	----	--	----	13	11.9	20	13.8
Sockeye:												
June 25 & July 1, 3	13	17.2	28	36.1	--	----	--	----	--	------	--	-----
June 26, 29 & July 4	--	-------	--	------	29	12.9	37	17.9	--	------	--	-----
June 27, 30 & July 2	--	-------	--	------	--	----	--	----	35	8.4	41	8.4
Steelhead:												
July 17 & 22	7	9.7	16	35.5	--	----	--	----	--	------	--	-----
July 18 & 20	-	-------	--	------	30	7.2	35	7.2	--	------	--	-----
July 19 & 21	-	-------	--	------	--	----	--	----	23	11.1	29	13.5

The second test period covered the end of the spring migration (May 11 to 19). Though there was no significant difference between the median passage times at the three velocities tested, chinook did travel slightly faster in the 3 f. p. s. velocity (Table 4). Percentages of fish completing passage within the time limit at the velocities of 1, 2, and 3 f. p. s. were 88, 69, and 79 percent, respectively.

During both test periods, willingness of the chinook to enter the pipe from the introductory pool appeared to be directly related to the preveiling velocity; i. e., the higher the velocity, the more rapid the entry.

Summer chinook.--Median passage time of chinook in the 3 f. p. s. water velocity was significantly less than the time obtained at 1 f. p. s. (6.9 and 10.4 minutes respectively, Table 4). Passage time through the introductory pool was about the same under both water velocities. A slightly larger percentage of chinook completed passage within the 45-minute time limit at the 1 f. p. s. water velocity than at the 3 f. p. s. velocity (92 and 87 percent, respectively).

Sockeye. --Median passage times through the pipe under water velocities of 1, 2, and 3 f. p. s. were 5.8, 7.9, and 6.5 minutes respectively (Table 4). Passage through the introductory pool was about the same at all three velocities tested. The percentages of sockeye completing passage within the time limit at water velocities of 1, 2, and 3 f. p. s. were 93, 79, and 89 percent respectively.

Steelhead. --There was no significant difference in median passage times through the 2-foot pipe at water velocities of 1, 2, and 3 f. p. s. (20.3, 16.9, and 19.8 minutes respectively, Table 4). Passage times through the introductory pool were about the same at all three velocities used. The percentage of fish completing passage through the pipe system within the time limit was 65, 68, and 59 percent of velocities of 1, 2, and 3 f. p. s. respectively.

Effect of Pipe Diameter

The experiment was designed to determine the effect of pipe diameter on the passage of chinook, sockeye, and steelhead. Passage times through the 1-foot and 3-foot-diameter pipes (A to B, Fig. 1) were used to measure the effect of pipe size on fish passage.

All three species of salmonids tested gave essentially the same results. Median passage times (Table 5) in the 3-foot-diameter pipe system were significantly shorter than those in the 1-foot-diameter pipe system. Over 90 percent of the fish tested completed passage in the 3-foot diameter pipe, whereas only 61 percent passed through the 1-foot diameter pipe.

Table 4. --Passage times of chinook salmon, sockeye salmon, and steelhead trout ascending 270 feet of 2-foot-diameter pipe at water velocities of 1, 2, and 3 f. p. s. Pipe system included two 180° bends. April-July, 1964.

Species and date	Passage time by velocity in pipe: 1 f. p. s. n	1 f. p. s. Mean[1]	1 f. p. s. n	1 f. p. s. Median	2 f. p. s. n	2 f. p. s. Mean[1]	2 f. p. s. n	2 f. p. s. Median	3 f. p. s. n	3 f. p. s. Mean[1]	3 f. p. s. n	3 f. p. s. Median	Lower limit median[2]	Upper limit median[2]
		Minutes		Minutes		Minutes		Minutes		Minutes		Minutes	Minutes	Minutes
Spring chinook														
April 23, 26, 30	30	12.3	42	13.0	--	-------		-------	--	-------	--	------	7.3	16.2
April 25, 28, May 1	--	----	--	----	41	8.7	50	8.2	--	-------	--	------	5.8	12.2
April 24, 27, 29	--	----	--	----	--	-------	--	-------	46	8.2	54	7.7	6.3	11.6
May 11, 14, 18	45	10.9	51	10.6	--	-------	--	-------	--	-------	--	------	7.6	13.6
May 13, 16, 19	--	----	--	----	20	11.5	29	12.8	--	-------	--	------	6.5	37.6
May 12, 15, 17	--	----	--	----	--	-------	--	-------	34	9.4	43	8.8	6.5	14.2
Summer chinook														
June 24, 23	24	12.3	26	10.4	--	-------	--	-------	--	-------	--	------	5.5	18.7
June 22, 25	--	----	--	----	--	-------	--	-------	27	7.8	31	6.9	5.2	9.8
Sockeye														
July 4, 6, 9	40	8.1	43	5.8	--	-------	--	-------	--	-------	--	------	5.2	8.3
July 5, 8, 11	--	---	--	---	41	8.2	52	7.9	--	-------	--	------	6.1	14.4
July 3, 7, 10	--	---	--	---	--	-------	--	-------	47	7.8	53	6.5	5.5	8.4
Steelhead														
July 21, 23, 26	22	13.6	34	20.3	--	-------	--	-------	--	-------	--	------	11.7	45+
July 22, 25, 30	--	----	--	----	26	14.3	38	16.9	--	-------	--	------	11.5	40.3
July 20, 24, 27	--	----	--	----	--	-------	--	-------	20	17.1	34	19.8	15.6	45+

[1] Based on fish for which complete times are available.

[2] 95 percent confidence intervals about the median.

Table 5. --Passage times of chinook salmon, sockeye salmon, and steelhead trout through 1-foot- and 3-foot-diameter pipe systems at a water velocity of 2 f. p. s., 1963.

Species and dates	Passage time by pipe diameter: 1-foot pipe n	1-foot pipe Mean[1]	1-foot pipe n	1-foot pipe Median	3-foot pipe n	3-foot pipe Mean	3-foot pipe n	3-foot pipe Median	Lower limit of median[2]	Upper limit of median[2]
		Minutes		Minutes		Minutes		Minutes	Minutes	Minutes
Spring chinook:										
May 3, 6	10	11. 1	19	25. 1	--	-----		-----	7. 2	45+
May 4, 5	--	---	--	----	33	5. 6	34	3. 2	2. 4	5. 8
Summer chinook:										
June 13, 16	13	12. 2	20	14. 7	--	----	--	-----	8. 8	34. 8
June 14, 16	--	----	--	----	24	5. 4	26	3. 3	2. 1	6. 4
Sockeye:										
July 10, 11	8	8. 2	13	15. 6	--	---	--	---	4. 4	45+
July 9, 12	--	---	--	----	26	4. 2	28	3. 0	1. 9	4. 4
Steelhead:										
July 10, 11	8	9. 7	12	16. 1	--	---	--	----	2. 5	45+
July 9, 12	--	---	--	----	23	3. 9	24	3. 3	2. 6	4. 3

[1] Based on fish for which complete times are available.

[2] 95 percent confidence intervals about the median.

Effect of Light

Passage time through the 2-foot-diameter pipe (A to B, Fig. 4) was used to measure the effect of light on fish passage. During the experiments, a water velocity of 3 f. p. s. was maintained in the pipe. Summer chinook, sockeye, and steelhead were tested.

Summer chinook. --Median passage times of summer chinook (Table 6) in the lighted pipe were significantly greater than those in the dark pipe (11. 8 and 7. 8 minutes respectively).

Sockeye. --Sockeye passed through the pipe slightly faster (6. 8 and 8. 5 minutes, respectively) when the pipe was lighted than when it was dark (Table 6), but the difference was not statistically significant. Median passage times through the introductory pool (release box to A, Fig. 4) were about equal under the two light conditions and appeared to be unaffected by the light conditions in the pipe.

Steelhead. --Steelhead moved through the pipe at a significantly faster rate (7. 0 and 24. 6 minutes, respectively) when the pipe was lighted than when it was dark (Table 6). Median passage times through the introductory pool were about the same at both light conditions.

Transition Zones

Two studies were made to assess the effect of a transition from pool to pipe on fish passage. The first, with the 3-foot-diameter pipe, used abrupt and gradual light changes at the pipe entrance. The second, with the 1-foot- and 2-foot-diameter pipes, used truncated cones on the pipe entrances.

Light

Experiments under the two light transitions were conducted with summer chinook, sockeye, and steelhead. Under both light conditions, water velocity in the pipe was 2 f. p. s. The respective median passage times of chinook and sockeye were virtually indentical (Table 7) under the two light conditions. Steelhead also showed little difference in performance under the two conditions.

Most of the fish completed passage through the system regardless of the prevailing light transition.

Truncated Cones

The effect of a cone-type transition on fish passage through a pipe system was measured by comparing passage times under two conditions--(1) with the cone attached to the pipe entrance and (2) without the cone. Two passage times were obtained--passage through the introductory pool and passage through the pipe.

Table 6. --Passage times of chinook salmon, sockeye salmon, and steelhead trout through a 2-foot-diameter pipe 270 feet long under light and dark conditions. The pipe system included two 180° bends.

Species and dates	Passage time by lighting condition									
	Dark				Light				Lower limit of median[2]	Upper limit of median[2]
	n	Mean[1]	n	Median	n	Mean[1]	n	Median		
		Minutes		Minutes		Minutes		Minutes		
Summer chinook:										
June 25, 28	37	9.1	39	7.8	--	----	--	----	4.8	9.8
June 26, 27	--	---	--	---	18	13.4	25	11.8	7.1	43.7
Sockeye:										
July 12, 15	44	9.2	45	8.5	--	---	--	----	6.3	10.2
July 13, 14	--	---	--	---	39	7.8	41	6.8	5.6	8.8
Steelhead:										
July 17, 20	12	12.4	22	24.6	--	---	--	----	10.0	45+
July 18, 19	--	----	--	----	51	8.4	52	7.0	6.2	8.3

[1] Based on fish for which complete times are available.

[2] 95 percent confidence intervals about the median.

Table 7. --Passage of times chinook salmon, sockeye salmon, and steelhead trout in the 3-foot diameter pipe system with a change in light transition from pool to pipe, June & July 1963.

	Passage time by type of transition							
	Abrupt light change				Gradual light change			
Species and dates	n	Mean[1]	n	Median	n	Mean[1]	n	Median
Chinook:								
June 17 & 20	32	6.3	35	4.6	--	----	--	----
June 18 & 19	--	---	--	---	30	6.2	34	4.5
Sockeye:								
July 13 & 16	10	4.0	11	2.7	--	---	--	----
July 14 & 15	--	---	--	---	14	3.8	14	2.8
Steelhead:								
July 13 & 16	29	3.4	31	3.0	--	---	--	---
July 14 & 15	--	---	--	---	21	5.1	24	3.7

[1]Based on fish for which complete times are available.

Spring chinook. --Spring chinook were tested under water velocities of 4.3 f.p.s. in the 1-foot-diameter pipe and 3 f.p.s. in the 2-foot-diameter pipe. Introductory pool passage times (median), with and without the cone on the 1-foot pipe, were .8 and 9.6 minutes, respectively (Table 8). Therefore, chinook salmon entered the 1-foot-diameter pipe far more readily when a cone was used for a transition zone from pool to pipe. Chinook moved through the pipe at about the same rate under the two entrance conditions.

In the 2-foot-diameter pipe system, the introductory pool passage times (median), with and without the cone on the pipe, were 1.1 and 2.3 minutes, respectively (Table 9). This indicates that the cone had only a slight effect on fish entry into the larger pipe. Passage times through the pipe section did not differ significantly under the two entrance conditions.

Summer chinook. --Summer chinook were tested under water velocities of 3 f.p.s. in both the 1-foot- and 2-foot-diameter pipes. The results were quite similar to those obtained previously with spring chinook. The median passage time through the introductory pool (Table 8) was significantly less when the cone was on the 1-foot-diameter pipe than when it was off (.8 and 4.8 minutes, respectively). The rate of passage through the pipe was unaffected by the entrance conditions, being quite similar under both conditions.

In the 2-foot diameter pipe system, summer chinook passed through the introductory pool in about the same time at both entrance conditions (0.6 and 0.5 minutes, respectively) with and without the cone (Table 9), thus indicating that the cone did not materially aid summer chinook in entering the pipe. Median passage times through the pipe, with and without the cone were 6.5 and 7.0 minutes, respectively. The difference was not significant.

Sockeye. --Both the 1-foot- and 2-foot-diameter pipe systems were operated with a water velocity of 3 f.p.s. Median passage time through the introductory pool of the 1-foot-diameter pipe system (Table 9) was significantly less with the cone on the pipe than without the cone (0.6 and 15.9 minutes, respectively). However, once sockeye entered the 12-inch pipe, passage times through the pipe were the same under both entrance conditions.

These results indicated that the cone greatly facilitated the entrance of sockeye into the 1-foot pipe. Further evedence is noted in the percentage of fish entering the pipe with and without the cone on the end. Forty-four sockeye entered the introductory pool with the cone on the pipe, and all went into the pipe within the 45 minute time limit. Twelve sockeye entered the introductory pool without the cone on the pipe, but only six fish went into the pipe within the time limit.

In the 2-foot-diameter pipe system, the median passage time through the introductory pool was .4 minutes under both entrance conditions (Table 9). The sockeye passage times through the pipe of 4.2 and 6.6 minutes (with and without the cone, respectively) were not significantly different. The results indicate

Table 8. --Passage times of chinook salmon, sockeye salmon, and steelhead trout through the 14-foot introductory pool of the 1-foot-diameter pipe system under two entrance conditions, 1964

Species and dates	Passage time by entrance conditions: Without cone on pipe n	Mean[1]	n	Median	With cone on pipe n	Mean[1]	n	Median	Lower limit of median[2]	Upper limit of median[2]
		Minutes		Minutes		Minutes		Minutes	Minutes	Minutes
Spring chinook:										
May 7, 10	20	8.7	27	9.6	--	---	--	-----	3.2	34.6
May 8, 9	--	---	--	---	38	1.4	45	0.8	0.8	1.9
Summer chinook:										
June 29, & July 3	10	5.5	11	4.8	--	---	--	---	3.4	11.5
July 1, 2	--	---	--	---	21	1.4	22	0.8	0.4	2.0
Sockeye:										
June 29 & July 3	6	4.6	12	15.9	--	---	--	---	2.1	45+
July 1, 2	--	---	--	----	44	1.4	44	0.6	0.5	1.0
Steelhead:										
July 31 & Aug. 4, 5	18	6.8	18	3.5	--	---	--	---	1.4	7.8
Aug. 1, 2, 3	--	---	--	---	63	1.9	63	0.8	0.6	1.1

[1] Based on fish for which complete times are available.

[2] 95 percent confidence intervals about the median.

Table 9.--Passage times of chinook salmon, sockeye salmon, and steelhead trout, through the 14-foot introductory pool of the 2-foot-diameter pipe system under two entrance conditions, 1964.

Species and date	Passage time by entrance condition: Without cone on pipe n	Mean[1]	n	Median	With cone on pipe n	Mean[1]	n	Median	Lower limit of median[2]	Upper limit of median[2]
Spring chinook:										
May 7, 10	17	2.6	22	2.3	--	---	--	-----	1.0	3.0
May 8, 9	--	---	--	---	12	2.6	15	1.1	0.6	2.9
Summer chinook:										
June 29, & July 30	11	0.8	11	0.5	--	---	--	---	0.3	1.7
July 1, 2	--	---	--	---	8	.8	--	0.6	0.3	2.0
Sockeye:										
June 29 & July 30	22	1.2	23	0.4	--	---	--	----	0.3	.8
July 1, 2	--	---	--	---	13	1.2	14	0.4	0.2	2.9
Steelhead:										
July 31 & Aug. 4, 5	16	1.2	17	0.7	--	---	--	----	0.4	1.3
Aug. 1, 2, 3	--	---	--	---	23	7.6	24	0.6	0.4	1.0

[1] Based on fish for which complete times are available.

[2] 95 percent confidence intervals about the median.

that the cone on the 2-foot pipe does not improve the entrance condition for sockeye salmon.

Steelhead. --The experiments were conducted with water velocities of 4.4 f.p.s. in the 1-foot-diameter pipe. In the 1-foot-diameter pipe system, steelhead passed through the introductory pool at a significantly faster rate when the cone was on the pipe than when it was not (0.8 and 3.5 minutes, respectively, Table 8). Practically speaking, the rate of passage through the pipe was unaffected by the entrance conditions. Passage times through the 1-foot-diameter pipe with and without the cone were 0.2 and 0.7 minutes, respectively.

In the 2-foot-diameter pipe syste, passage time (Table 9) through the introductory pool was unaffected by the addition of the cone (0.6 and 0.7 minutes, respectively, with and without the cone). Passage time through the 2-foot-diameter pipe was not significantly different under either entrance conditions.

SUMMARY

A study on passage of adult salmonids through pipes was conducted during the 1963 and 1964 migration seasons. Effect of water velocity, light, pipe diameter and length, and transition zones on passage of fish was studied. Passage times through the pipes were used to evaluate the performance of chinook salmon, sockeye salmon, and steelhead trout.

The installations differed during the two seasons. In 1963, two 100-foot lengths of straight pipe, 1 foot and 3 feet in diameter, were used. In 1964, the pipe systems consisted of a straight 90-foot length of 1-foot-diameter pipe and a 2-foot-diameter pipe with a length of 270 feet and having two 180° bends. Water velocities in the pipes ranged from 0.5 to 4.4 f.p.s. Results of the tests follow:

1. Chinook, sockeye and steelhead entered and passed through a 3-foot-diameter pipe more readily than through a 1-foot diameter pipe.

2. In the 1-foot-diameter pipe, using water velocities of 1, 2, and 4 f.p.s., chinook and sockeye entered the pipe and passed through it most rapidly at the 4 f.p.s. velocity; steelhead entered and passed through most rapidly at 2 f.p.s. There was virtually no chinook passage in the 1-foot pipe when the velocity was 1 f.p.s.

In the 3-foot-diameter pipe, using water velocities of 0.5, 1, and 2 f.p.s., chinook, sockeye, and steelhead entered and passed through the pipe most rapidly at the water velocity of 1 f.p.s.

3. In the 2-foot-diameter pipe, using water velocities of 1, 2, and 3 f.p.s., chinook passed through the pipe most rapidly at the 3 f.p.s. water velocity. Sockeye passed through the pipe most rapidly at the 1 f.p.s. water velocity, and steelhead passed through most rapidly at 2 f.p.s.

4. Gradual and abrupt light changes in the introductory pool did not appear to affect fish passage through the 3-foot-diameter pipe system.

5. A truncated cone used as a transition zone from pool to pipe made the 1-foot-diameter pipe more acceptable for entry of chinook, sockeye, and steelhead but had no effect on entry into the 2-foot-diameter pipe.

6. Chinook moved through the 2-foot-diameter pipe more rapidly under a darkened condition than under a lighted condition. Steelhead were the opposite, moving faster under a lighted condition. Light apparently did not affect passage of sockeye.

Conclusions reached are:

1. Salmon and trout will pass through pipes without internal lighting. This includes passageways with 180° bends and lengths up to 270 feet.

2. Of the three species tested (chinook, sockeye, and steelhead), only steelhead appeared to benefit by the addition of lighting in pipes.

3. For practical purposes, a pipe diameter of 2 feet is sufficient for all salmonids. Chinook salmon will not readily enter and pass through a 1-foot pipe unless special transition and velocity conditions are provided.

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