CZES Coastal Zone and Estuarine Studies

DEVELOPMENT OF A SYSTEM FOR PROTECTING JUVENILE SALMONIDS AT THE SECOND POWERHOUSE AT BONNEVILLE DAM — PROGRESS 1976

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Final Report of Research
Financed by
U.S. Army Corps of Engineers
(Contract No. DACW57-76-F-0512)

and

NOAA
National Marine Fisheries Service
Northwest and Alaska Fisheries Center
Division of Coastal Zone and Estuarine Studies
2725 Montlake Boulevard East
Seattle, Washington 98112

June 1977

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INTRODUCTION

In 1976 the NMFS conducted studies at Bonneville Dam and the Pasco Biological Field Station as part of the continuing research program to develop an improved fingerling protection system for the Bonneville Second Powerhouse. Major goals of this research program include the following: (1) developing design and operating criteria for submerged orifices that will efficiently pass fingerlings from gatewells into a safe bypass and (2) developing methods that are less costly and more efficient than the traveling screen systems currently in use for guiding fingerling salmonids out of turbine intakes and into intake gatewells. Research conducted in 1976 addressed both of these major goals. At Bonneville Dam, we tested the effectiveness of several designs of submerged orifices for passing fish out of gatewells and began tests with naturally migrating fish to determine their swimming attitude (buoyancy) as they enter the turbine intake. At the Pasco Field Station, in a special oval flume, we began preliminary studies of trash rack configurations designed to guide fish vertically.

SUBMERGED ORIFICE STUDIES

Efficient and safe passage of fingerling salmonids from intake gatewells to a bypass leading around the dam has been difficult to achieve at most main-stem dams on the Columbia and Snake Rivers. The submerged orifices commonly employed to provide fish with egress from gatewells have been underdesigned resulting in delay of fish within the gatewells which leads to descaling of fish and other problems.

The fish passage efficiency (FPE) of submerged orifices may be reduced by the presence of a fish-guiding device in the turbine intake. The fish-guiding device increases the flow of water through the gatewell and the associated turbulence interferes with the FPE of the orifices. In addition, the vertical barrier screen, installed in the gatewell to prevent guided fish from reentering the turbine intake, will eventually cause descaling to fish that are exposed to the screen for an extended period of time. Because both the fish-guiding device and the vertical barrier screen are necessary features of the bypass system, our research was directed toward reducing the delay of fish in gatewells by increasing the FPE of the orifices.

The research conducted at Bonneville Dam in 1976 addressed the problem of increasing FPE of submerged orifices by developing better orifice design and operating criteria. If passage efficiencies of 90% or more could be achieved in spite of increased flows and turbulence within the gatewell, caused by a fish-guiding device in the intake, delay of fish within the gatewells would be minimal. It follows that if delay were minimized, descaling would be reduced.

METHODS AND PROCEDURES

Studies of submerged orifices were conducted in gatewell 9-B at the Bonneville First Powerhouse. Figure 1 illustrates the equipment employed. A caisson installed in the gatewell was equipped with two separate compartments to serve as water passages from the gatewell to the ice sluice. Slide gates on each compartment accommodated orifices

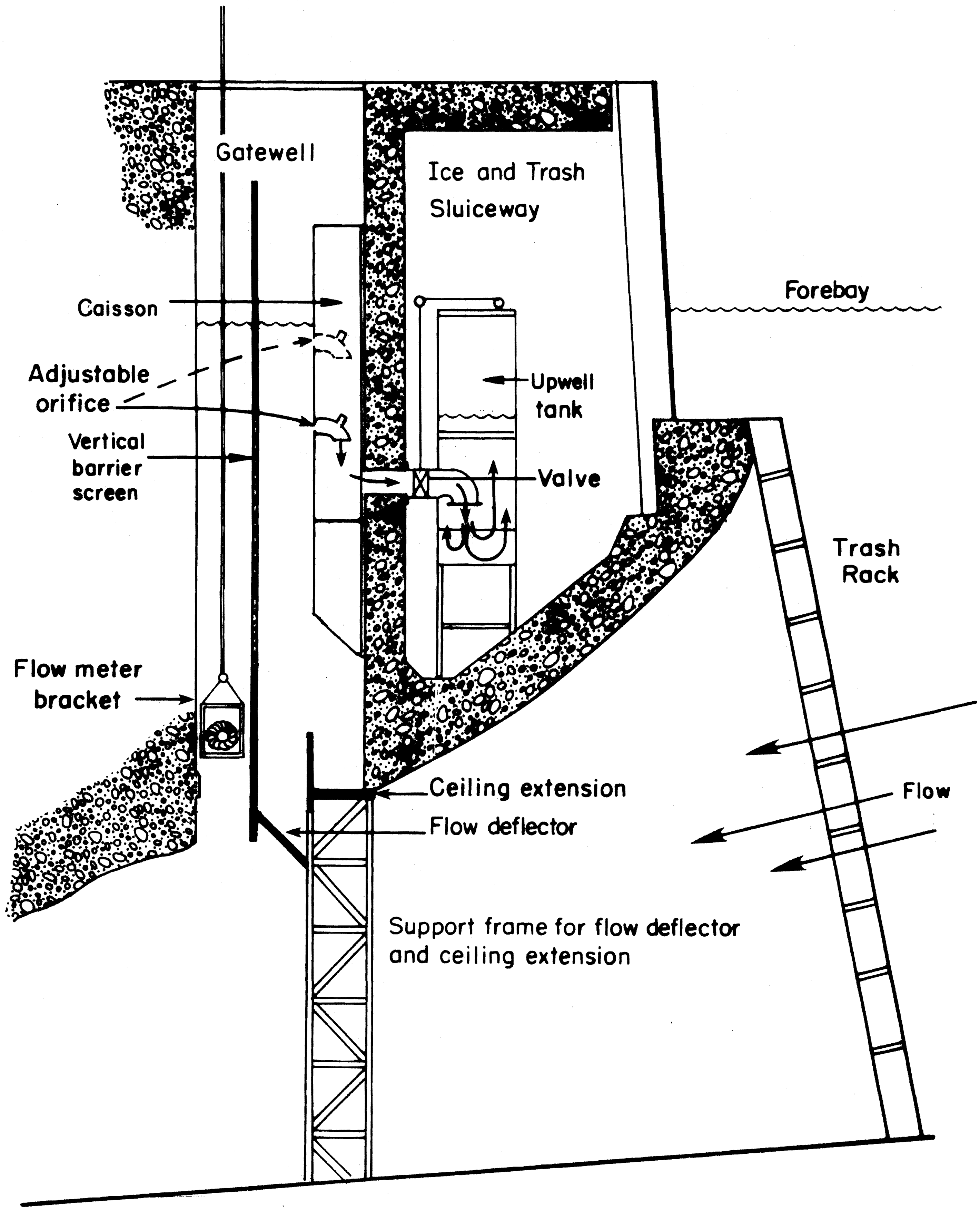

Figure 1.--Equipment used in the turbine intake gatewell 9-B and in the ice sluice at Bonneville Dam to measure fish passage efficiency (FPE) of submerged orifices of various designs.

of any size and shape desired. Vertical adjustment of the slide gates allowed positioning of each orifice at any submergence below the water surface within the gatewell to a maximum depth of 8.5 feet when the elevation of the forebay surface was held at 76.5 feet above MSL.

The two water passages in the caisson connected to separate 18-inch diameter ports drilled through the concrete wall separating the gatewell and ice sluice. Each port was equipped with air operated valves, and water passing through each port entered an individual riser affixed to an inclined plane screen and trap. Thus, fish passing through each port remained separated. The elevation of the risers and traps could be adjusted to control hydraulic head and, thus, the volume of water passing through the orifice.

The manner in which the orifices were installed resulted in flow characteristics comparable to sharp-edged orifices for which rating curves were developed by the North Pacific Division Hydraulic Laboratory, Army Corps of Engineers, Bonneville Dam.

The gatewell was equipped with a vertical barrier screen. The screen was located about 4 feet from the caisson, a distance approximating the intended position of the screen in the gatewells of the Bonneville Second Powerhouse. The upper and lower portions of the screen were closed with baffles. The resulting screen was 16 feet high and 21 feet wide--the maximum possible screen area available in the gatewells of the Bonneville Second Powerhouse as presently designed.

A flow deflector was installed in the turbine intake to simulate the presence of a fish guiding device immediately below the gatewell. Flows entering the gatewell were estimated by measuring water velocities in a balanced grid pattern on the downstream side of the vertical barrier screen.

Individual tests lasted 22 to 24 hours beginning about 4;00 p.m. Traps were emptied and the fish identified and counted hourly throughout the test period. At the beginning and end of each test, fish were removed from the gatewell by dipnetting. Fish removed at the start of a test were disregarded; those removed at the end of a test were counted and identified. Intermittently, samples of fish from the traps and those taken by dipnetting the gatewell were examined to determine the percent of fish having missing scales.

The relative merit of the various experimental orifices was determined by comparing their FPE. FPE is defined as the percentage of fish entering the gatewell during the test that passed out through the submerged orifices before completion of the test. Those fish that remained in the gatewell at the end of a test plus the fish removed from the traps were taken as the total number of fish that entered the gatewell during the test. The number of fish removed from the orifice traps, expressed as a percentage of the total number that entered the gatewell, is the FPE.

Previous research at McNary Dam showed that submerged orifices were most efficient when the gatewell was darkened and the orifices were back-lighted, i.e., with light directed toward the discharge of an orifice illuminating the orifice from downstream as viewed by fish within the darkened gatewell. During the entire season of testing, gatewell 9-B was darkened by means of a plywood cover, and backlighting of the orifices was provided.

The test program considered diameter, submergence, and hydraulic head for two equal orifices in gatewell 9-B. In addition, we conducted tests with a single orifice in operation and with two types of overfall weirs.

Testing began on May 6 and terminated June 29. Tests from May 6 through May 13 were conducted without the flow deflector in place. Tests from May 13 through June 29 were conducted with the flow deflector in place.

FISH PASSAGE EFFICIENCY OF SUBMERGED ORIFICES AND OVERFALL WEIRS

Table 1 provides the FPE for each test completed during the field season. The average FPE for each species or race was used to determine whether the submerged orifices, as designed and operated, were adequate. For our purposes, we selected a FPE of 90% to determine adequacy. By definition, therefore, satisfactory submerged orifices were required to have a FPE of 90% or more for all species and races of fish tested. If the FPE was less than 90% for any species or race tested, the submerged orifices used for that test were judged inadequate.

We conducted a statistical test to obtain a measure of the reliability of the test data in denoting adequacy or inadequacy of the orifices when using the 90% FPE as the cut-off point. We calculated the mean and variance of FPE using only data where orifice passage for 2 or more tests resulted in a FPE of 90% or greater and provided that numbers of each species and race were 30 fish or more per test.

Table 1.--Submerged orifice tests showing orifice information, numbers of fish per test, and percentage orifice passage by species, Bonneville Dam, 1976.

Orifice condition							Test results										
							Spring Chinook		Fall Chinook		Steelhead		Coho		Sockeye		All species combined
Date	No.	Diameter (inches)	Sub-mergence (feet)	Head (feet)	Q (cfs)	Vel. (fps)	No. of fish	Passage efficiency %	No.	%	No.	%	No.	%	No.	%	%
5-6	2	18	5	5	19.3		134	99.3	55	100	70	98.6	133	95.5	23	95.6	
5-7	2	18	5	5	19.3		180	97.7	15	100	90	97.7	256	100	28	96.4	
5-8	2	18	5	5	19.3		192	99.4	1252	99.9	87	98.9	238	100	43	97.6	
5-9	2	18	5	5	19.3		147	100	611	99.8	155	99.4	463	100	37	100	
Weighted average								99.1		99.9		98.8		99.4		97.7	99.5
5-10	2	8	5	5	3.8		96	77.1	57	96.5	71	71.8	217	97.2	14	71.4	
5-11	2	8	5	5	3.8		138	75.5	49	93.9	162	66.0	454	97.1	37	70.3	
5-12	2	8	5	5	3.8		145	85.5	27	96.3	166	75.9	388	97.9	27	88.9	
Weighted average								79.7		95.5		71.2		98.2		76.9	88.0
Flow deflector installed for subsequent tests																	
5-13	1	8	5	5	3.8		95	56.2	2	25.0	113	74.3	91	66.4	20	69.0	58.2
5-13	Overfall weir			8½	3.8		74	43.8	6	75.0	39	25.7	46	33.6	9	31.0	26.8
5-15	2	12	5	5	8.6	18	236	96.2	63	96.8	305	91.5	295	97.6	53	92.5	
5-16	2	12	5	5	8.6	18	274	94.9	50	100	420	89.8	279	98.9	147	92.5	
5-17	2	12	5	5	8.6	18	233	95.3	30	100	386	88.9	203	97.0	140	97.9	
Weighted average								95.4		98.6		89.9		97.9		94.7	94.1
5-18	2	10	2	2	3.8	11	154	83.8	39	100	153	62.7	164	94.5	58	84.5	
5-23	2	10	2	2	3.8	11	90	67.8	2044	69.5	137	59.9	152	78.9	67	73.1	
Weighted average								77.9		70.1		61.4		87.0		78.4	72.0

Table 1 Continued

5-19	2	10	4	4	5.3	16	143	79.0	19	84.2	178	70.8	71	94.4	73	91.8	
5-22	2	10	4	4	5.3	16	72	84.7	2888	89.9	115	79.1	100	95.0	32	100	
		Weighted average						80.9		89.8		74.1		94.7		94.3	88.4
5-20	2	10	6	6	6.5	19	164	97.0	290	93.4	153	94.8	139	99.3	95	100	
5-24	2	10	6	6	6.5	19	123	99.2	2139	97.5	119	89.9	131	99.2	78	98.7	
		Weighted average						97.9		97.0		92.6		99.3		99.4	97.0
5-21	2	10	7.5	7.5	7.3		140	92.8	1760	94.5	151	95.4	140	98.6	70	91.1	
5-25	2	10	7.5	7.5	7.3		69	100	485	98.4	79	96.2	106	98.1	37	94.6	
		Weighted average						95.2		95.4		95.7		98.4		96.3	96.0
5-26	2	10	6	4	5.3	16	90	81.1	856	95.1	89	87.6	129	85.3	29	76.3	
5-28	2	10	6	4	5.3	16	79	100	107	95.0	119	93.0	64	96.8	13	100	
		Weighted average						89.9		95.1		90.9		91.7		78.6	92.3
5-27	2	10	6	2	3.8	11	40	95.0	224	95.1	84	85.7	33	93.9	19	78.9	
5-29	2	10	6	2	3.8	11	61	95.1	48	100	90	96.6	46	100	4	100	
		Weighted average						95.0		96.0		91.4		97.5		82.6	94.2
5-30	S	10	6	6	6.5	19	72	88.8	68	94.1	56	91.1	17	100	13	100	
6-1	S	10	6	6	6.5	19	45	80.0	51	98.0	66	74.2	48	97.9	21	90.5	
		Weighted average						85.5		95.8		82.0		98.5		94.1	89.7
5-31	N	10	6	6	6.5	19	34	94.1	30	93.3	66	84.8	66	98.5	18	88.8	
6-2	N	10	6	6	6.5	19	28	92.9	68	97.1	79	87.3	50	88.0	26	84.6	
		Weighted average						93.5		95.9		86.2		94.0		86.4	91.2
6-4	2	10	4	6			28	100	33	91.0	47	93.6	20	95.0	14	100	95
6-5	2	10	8.5	6	6.5	19	17	70.6	55	94.5	40	95.0	21	95.2	11	81.8	
6-6	2	10	8.5	6	6.5	19	11	100	51	96.0	24	87.5	13	84.6	6	100	
6-7	2	10	8.5	6	6.5	19	18	72	24	87.5	41	95.1	13	100	6	100	
6-8	2	10	8.5	6	6.5	19	22	90.9	21	100	36	86.1	11	81.8	11	90.9	
6-9	2	10	8.5	6	6.5	19	16	100	32	100	18	94.4	10	100	8	100	
		Weighted average						85.7		95.6		91.8		94.0		92.9	92.5

Table 1 Continued.

6-10	2	Overfall weir		1.9	6.5		19	36.8	11	45.5	15	66.7	9	44.4	11	27.3	
6-11	2	" "		1.9	6.5		20	60.0	19	78.9	24	100	15	73.3	9	77.8	
6-11 to 6-14	2	" "		1.9	6.5		44	77.2	49	85.7	56	85.7	30	76.7	15	73.7	
6-14 to 6-16	2	" "		1.9	6.5		37	83.7	35	85.7	43	88.3	26	88.5	14	85.7	
		Weighted average						70.0		80.7		81.1		76.3		67.3	77.9
6-17	2	10		6	6.5	19	47	61.7	22	86.4	17	94.2	11	81.8	12	50.0	
6-18	2	10	2	6	6.5	19	30	70.0	29	89.7	27	92.6	18	72.2	7	57.1	
6-3	2	10	2	6	6.5	19	33	87.9	38	97.4	38	97.4	20	90.0	7	100	
		Weighted average						71.8		92.1		95.1		81.6		65.4	83.1
6-18 to 6-22	2	12	4	3			97	93.8	46	97.8	50	100	22	90.9	30	96.7	
6-22 to 6-25	2	12	4	3			88	86.4	44	93.2	18	94.4	6	100	10	100	
6-25 to 6-29	2	12	4	3			231	90.0	38	97.4	9	100	19	84.2	15	100	
		Weighted average						90.1		96.1		98.7		89.4		98.2	92.7

Applying these statistics we can state with 90% confidence that orifices deemed adequate would pass 95% of the fish over an extended period of 24-hour tests.

Another important criteria used to select one set of orifice design and operating criteria over another was the hydraulic head required to achieve adequate FPE in relation to the submergence. Where head must exceed submergence, construction of the prototype becomes more difficult and costly. In general then, orifice diameters that produce adequate FPE with heads that do not exceed submergence are considered superior.

Figure 2 summarizes data in Table 1 where, except as noted, two or more tests of paired orifices were conducted. The figure portrays the adequacy of various orifice design and operating characteristics using a 90% FPE as the cut-off point.

Tests with the 18-inch and 8-inch diameter orifices were conducted prior to installation of the flow deflector (Table 1, May 12). All other tests were conducted with the flow deflector in place. FPE for the 18-inch orifices at 5 feet of submergence and head was nearly 100 percent. The 8-inch orifice, however, had low FPE's and was judged inadequate.

Most of the testing was conducted with 10-inch diameter orifices. From Figure 2 we see that at submergences of 6 feet or more, hydraulic head required to achieve adequate FPE need not exceed submergence. At a submergence of 4 feet, however, a hydraulic head of 6 feet was required and at a submergence of 2 feet, even a head of 6 feet was not sufficient to achieve an adequate FPE.

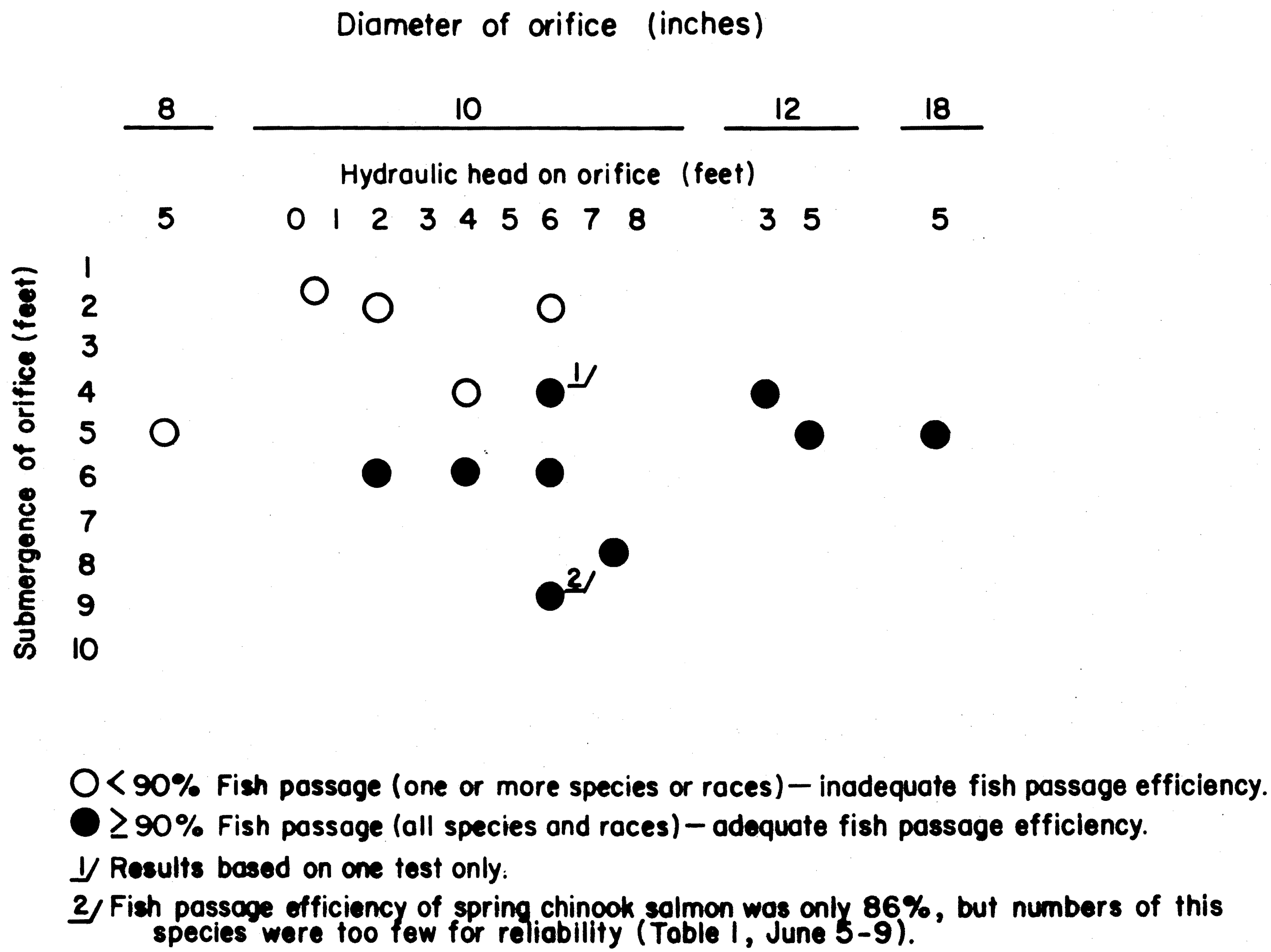

Figure 2.--Summary of submerged orifice tests showing adequacy of various design and operational characteristics using 90% FPE as the cut-off point.

We subsequently tested 12-inch diameter orifices to determine if adequate FPE could be achieved at the shallower submergences. It is clear from Figure 2 that at the 4-foot submergence two 12-inch orifices were superior to two 10-inch orifices; only 3 feet of hydraulic head was required to achieve adequate FPE with the 12-inch, but 6 feet was required with the two 10-inch orifices.

We also conducted tests to determine if overfall weirs could be employed in place of submerged orifices. During the 24-hour test terminating on May 13 (Table 1), we compared an 8-inch diameter orifice at a submergence and head of 5 feet and an overfall weir having a head of 8.5 inches. Both the orifice and the weir passed 3.8 c.f.s. of water. Together they passed 85% of all the fish; however, the overfall weir passed only 26.8% of the fish.

From June 10 to 16, two equal overfall weirs were tested. This time, the weirs were designed to maximize the depth over the weirs; the weir length was reduced to 10 inches and the depth to 1.9 feet. The water volume passed by each overfall weir was 6.5 c.f.s., equal to the water passed by one 10-inch orifice at a submergence and head of 6 feet. Because only small numbers of fish were entering the gatewells by this date, we found it necessary to lengthen the tests to 48 hours and, finally, to 72 hours (Table 1) to obtain adequate numbers of each species and race. In spite of the fact that tests of longer duration bias the data in favor of a higher FPE, the overfall weirs proved to be inadequate; the highest FPE was only 81% (steelhead trout).

With the objective of developing operational criteria that could result in reduced water consumption by a prototype fingerling protection system, we examined the possibility of operating only one orifice at a submergence that appeared to be optimum. From Figure 2, a depth of 6 feet appears to be the shallowest of an undescribed range of depths that will produce the highest FPE for any pair of orifices. From May 30 to June 2 (Table 1) we conducted two tests using only the south orifice and two tests using only the north orifice at a depth of 6 feet. The average FPE for steelhead trout was inadequate for both the south (82%) and the north (86.2%) orifices. However, because of the superior performance shown by two 12-inch orifices at a depth of only 4 feet (June 18 to 29 tests), a single 12-inch diameter orifice may prove to be adequate for all species and races at depths of 6 feet and possibly more. Time did not permit such tests to be made in 1976.

DIEL FISH PASSAGE

The timing of the passage of fish is important to many aspects of the day-to-day operation of a fingerling protection system. Disruption of the operation of the system, often required for various reasons, can result in a minimum impact on the fish runs if the disruption can be timed to occur when the fewest fish are in the system. Consequently, we attempted to obtain data on diel passage for all species and races.

Throughout the field season, the orifice traps were usually tended hourly, 24 hours a day, whenever tests were being conducted. To portray diel passage, we used orifice trap catches during those tests in which the FPE for the species or race of concern was 90% or greater. Using this criteria, we believe delay between the time the fish entered the gatewell and the time they exited (to enter the trap) was minimal. Therefore, the diel passage information not only applies to passage of fish through the fingerling protection system, but closely approximates the timing of fish passage through the turbines.

Figures 3 to 7 portray the diel passage of fish by species in 2-hour increments over a 24-hour period. Passage of spring chinook salmon, steelhead trout, and coho salmon was greatest during the hours of darkness, whereas passage of fall chinook salmon and sockeye salmon was more evenly distributed over the 24-hour period.

Taking all species and races into account, the normal working hours of 8:00 a.m. to 4:00 p.m. coincide with minimum fish passage. However, the 4-hour period from noon to 4:00 p.m. had the lowest rate of movement, ranging from a maximum of 9.4% of the sockeye salmon to a minimum of 1.3% of the coho salmon.

We conclude from this data that disruption of operation of the fingerling protection system would have the least impact on passage of all species if it occurred during normal working hours, and that for disruption periods of 4 hours or less, the least impact would occur during the afternoon. This holds true for all species and races examined.

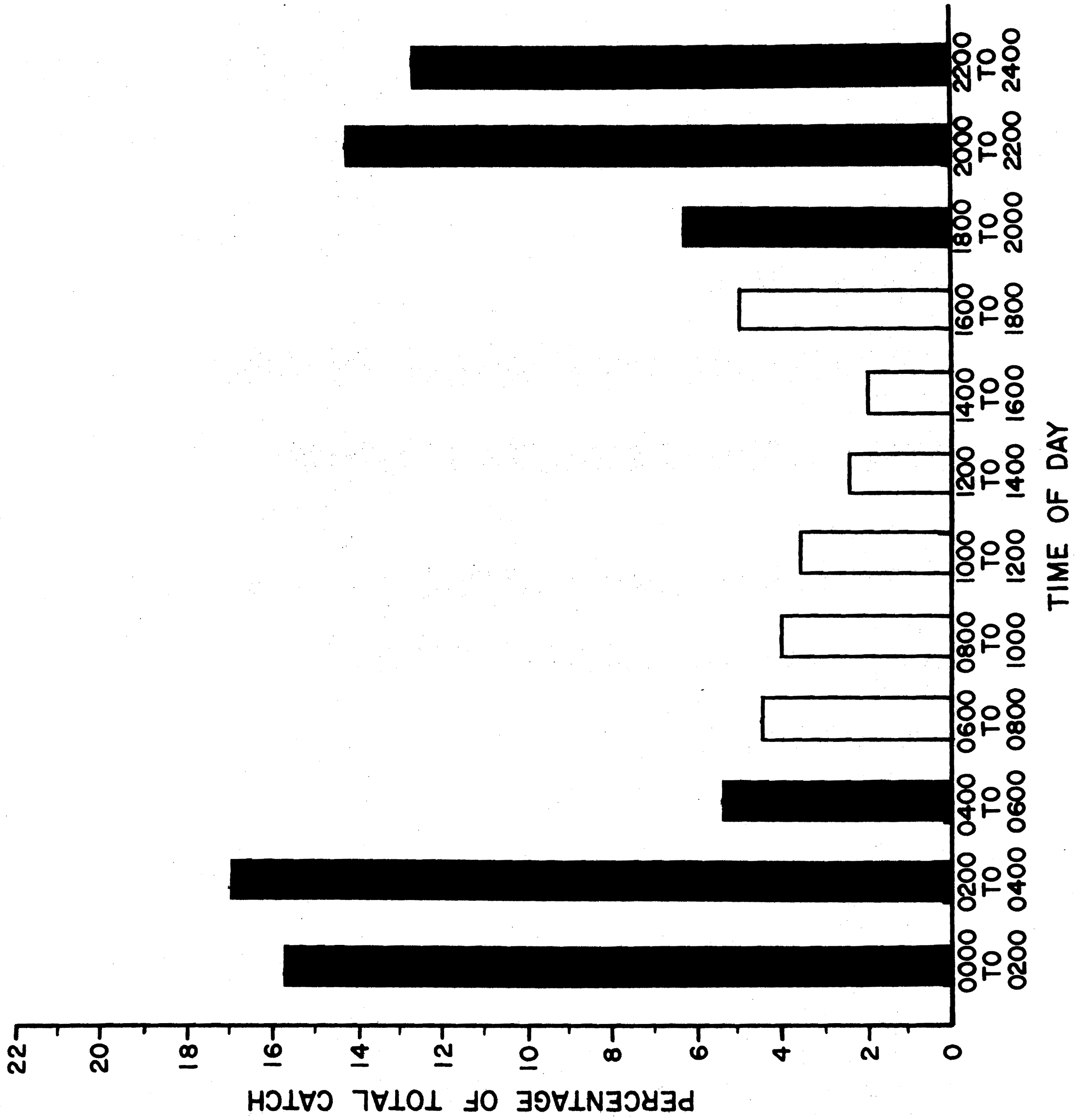

Figure 3.--Diel passage of spring chinook salmon smolts out of gatewells equipped with submerged orifices having a fish passage efficiency of at least 90%. Percentages are weighted averages of three 24-hour tests.

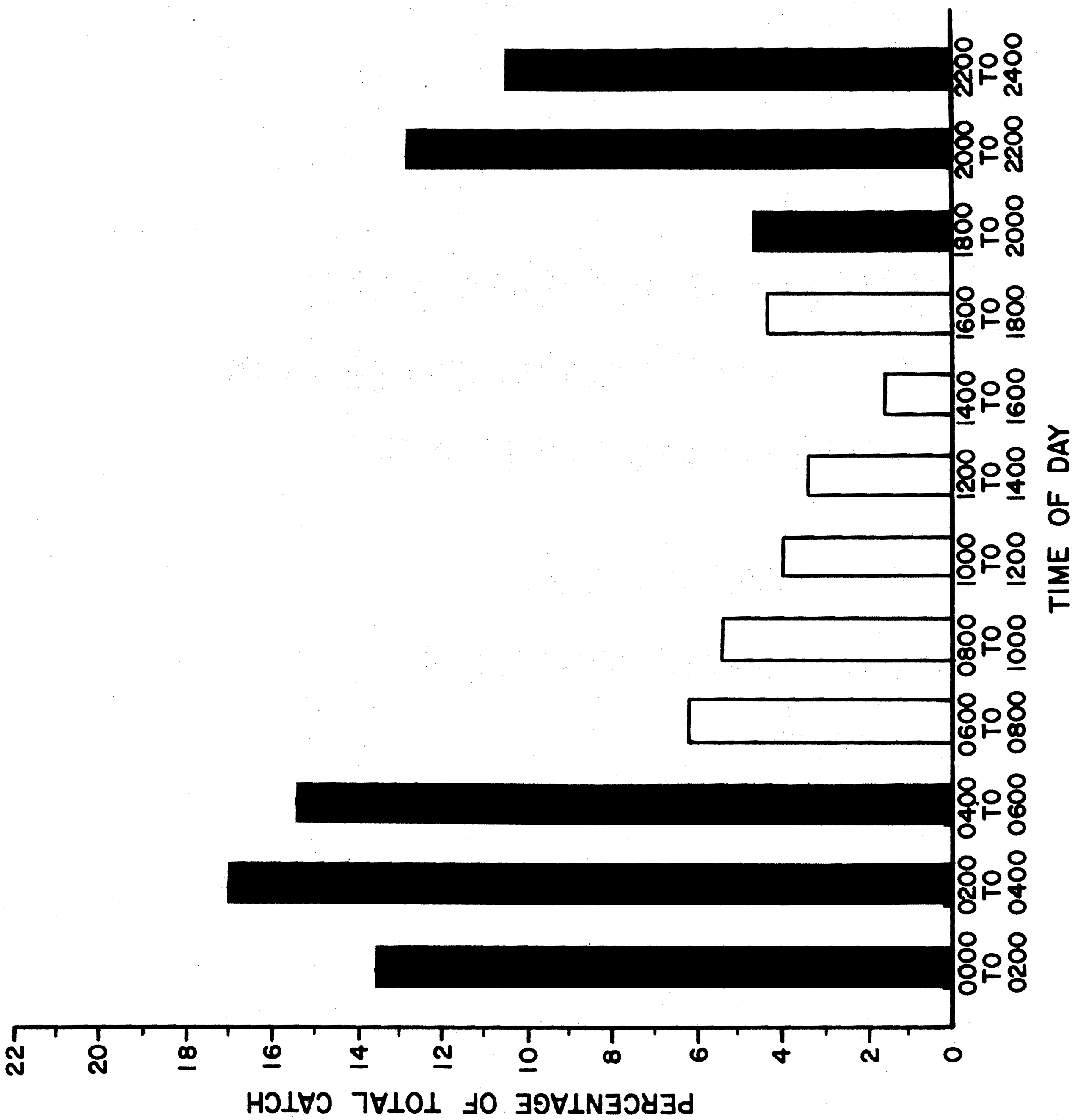

Figure 4.--Diel passage of steelhead trout smolts out of gatewells equipped with submerged orifices having a fish passage efficiency of at least 90%. Percentages are weighted averages of three 24-hour tests.

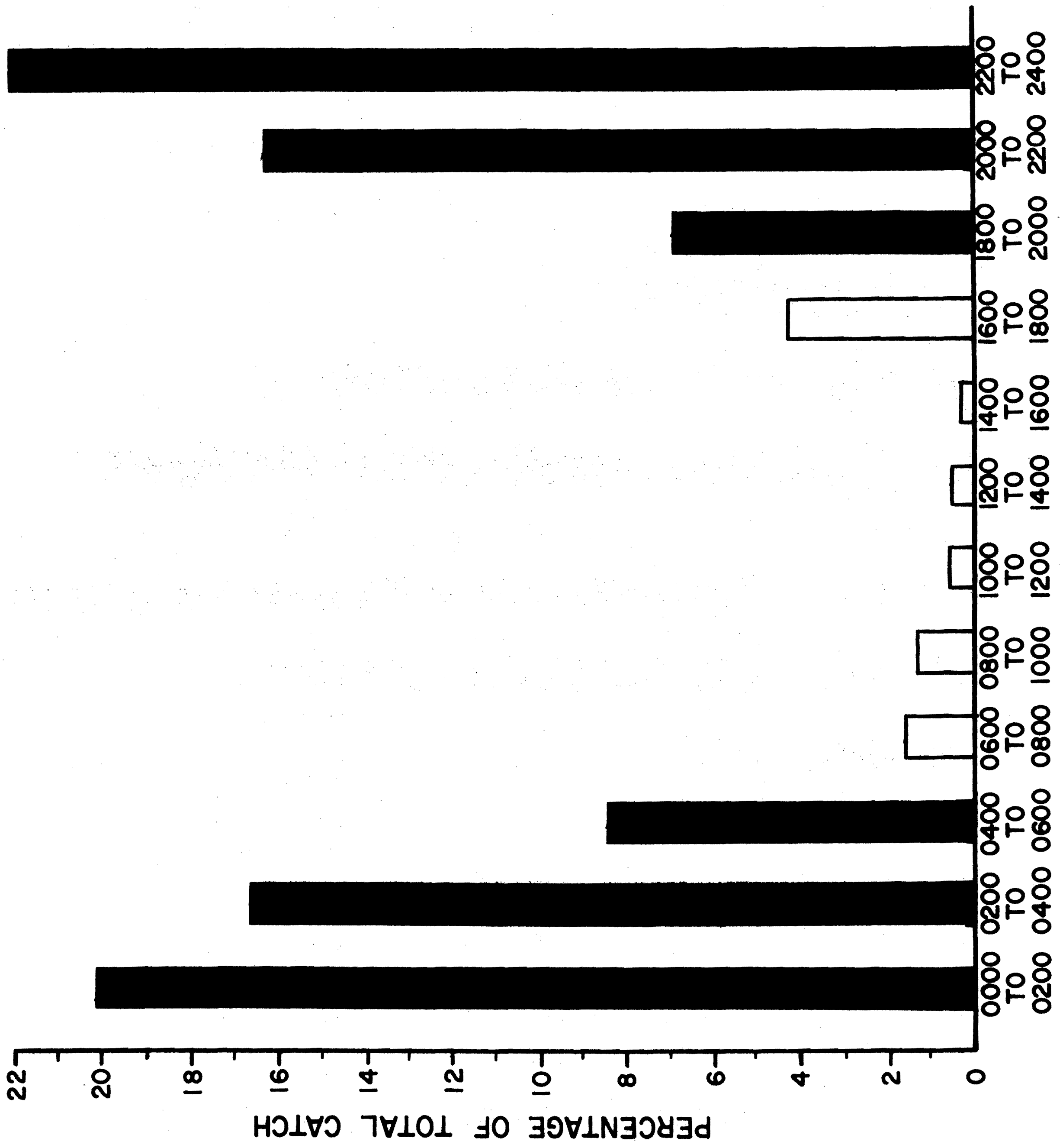

Figure 5.--Diel passage of coho salmon smolts out of gatewells equipped with submerged orifices having a fish passage efficiency of at least 90%. Percentages are weighted averages of three 24-hour tests.

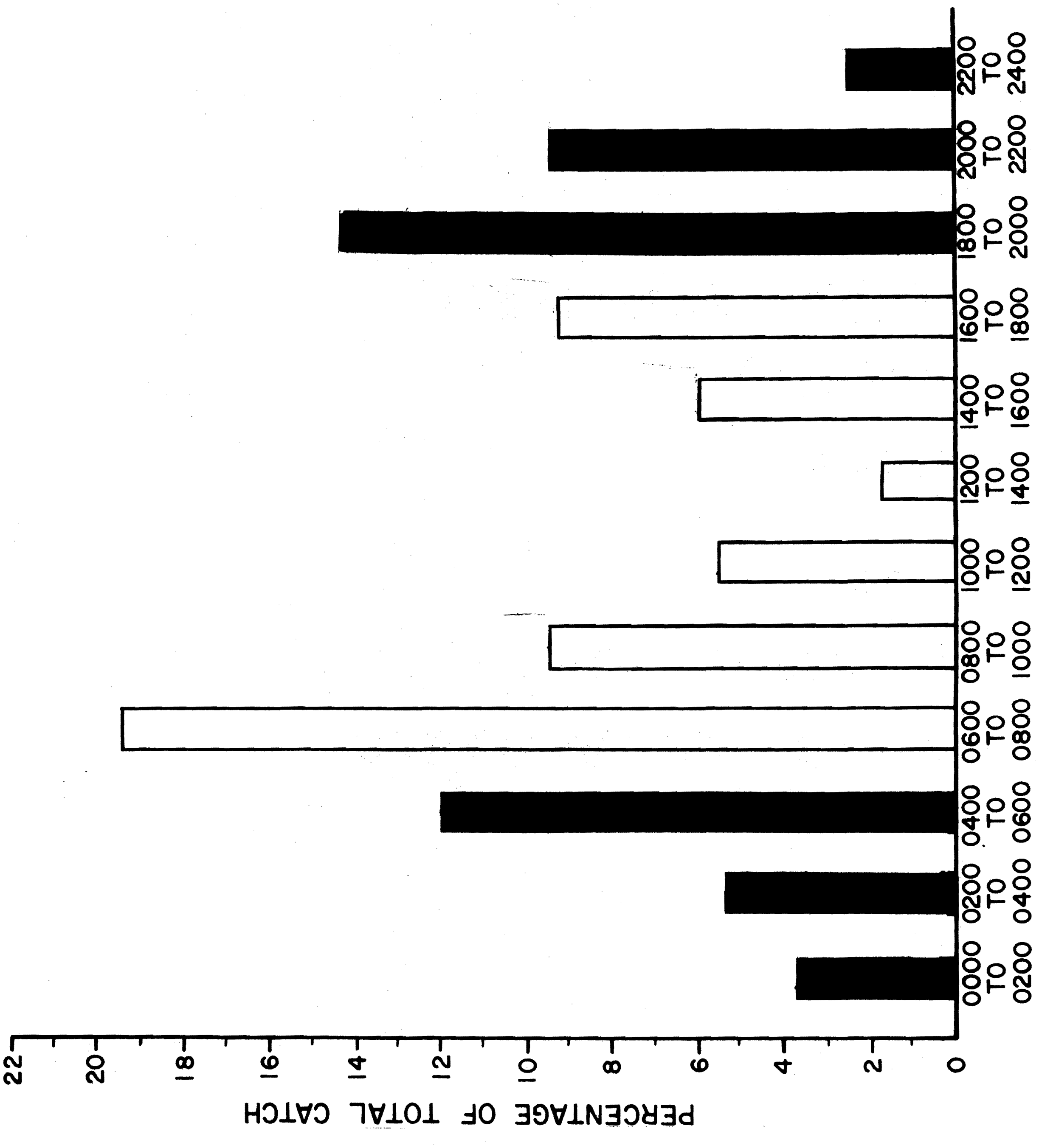

Figure 6.--Diel passage of fall chinook salmon smolts out of gatewells equipped with submerged orifices having a fish passage efficiency of at least 90%. Percentages are weighted averages of three 24-hour tests.

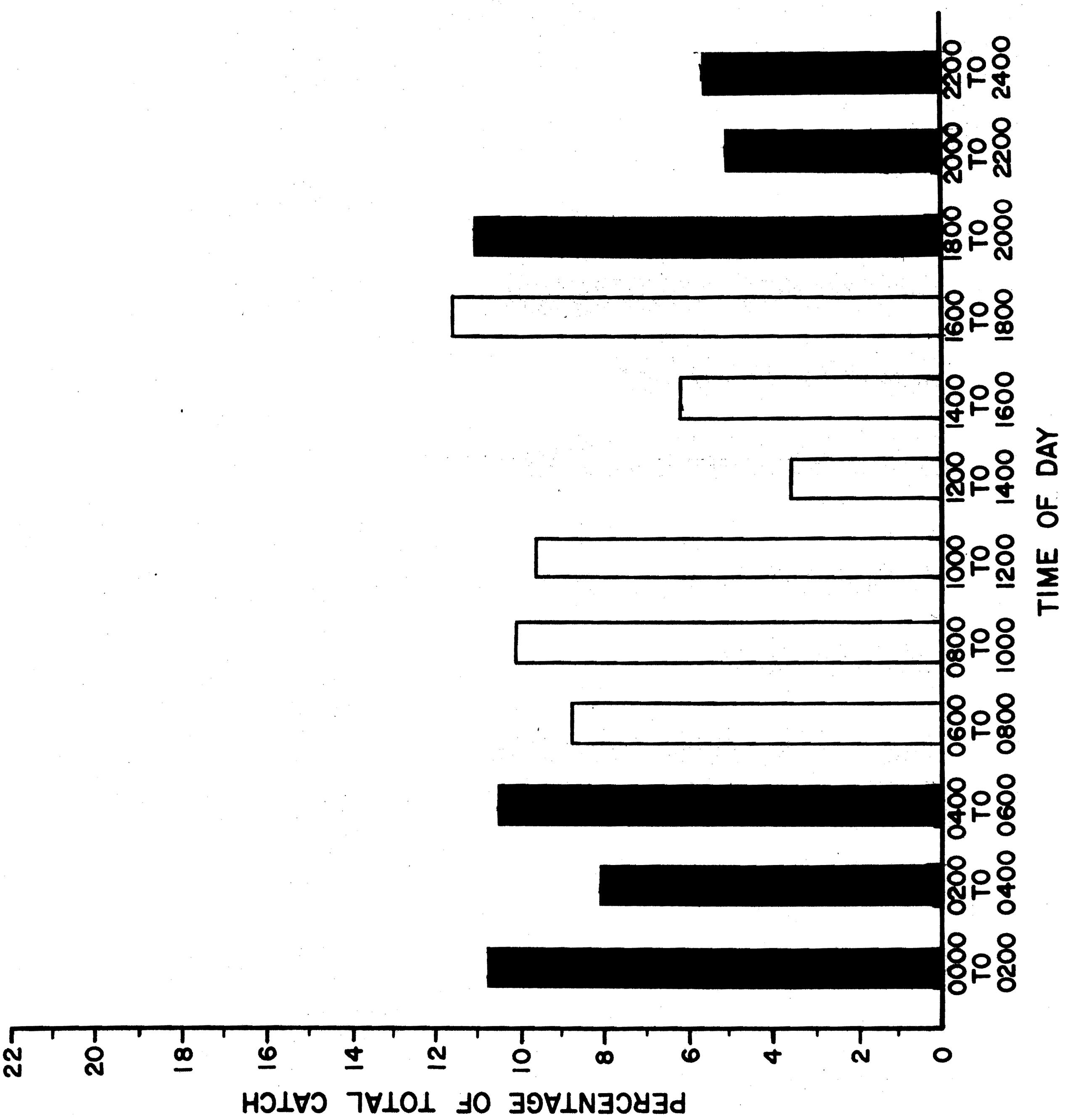

Figure 7.--Diel passage of sockeye salmon smolts out of gatewells equipped with submerged orifices having a fish passage efficiency of at least 90%. Percentages are weighted averages of three 24-hour tests.

DESCALING

Sub-lethal injuries to fish within the fingerling protection system are often associated with loss of scales. The extent of the scale loss and the severity of the associated abrasion presumably determines whether a fish will ultimately survive or perish. At the present time, descaling is used merely as an indicator of undesirable conditions. In general, conditions that cause descaling in even minor degrees are to be avoided or corrected when possible.

Descaling of fish within the gatewell is most likely to be caused by contact with the vertical barrier screen. The extent and severity of such contact is dependent upon the volume of water passing through the gatewell (and vertical barrier screen) and the time fish require to find and exit from the gatewell via the submerged orifices. Consequently, greater volumes of water and more turbulent flows may be tolerated in the gatewell when the FPE of the submerged orifices is very high.

Intermittently throughout the season we examined for descaling samples of fish taken from the traps (those fish successfully exiting from the gatewell) and all the fish remaining in the gatewell at the end of a test (residuals).

In general, the incidence of descaling among the trap caught fall chinook salmon was always less than 1%, but the incidence of descaled steelhead trout ranged from a low of 2% to a high of 20%. The higher rates of descaling, however, were associated with trap settings that allowed the stronger swimming fish, such as steelhead trout, to remain within the water passages of the orifice-trap system for extended periods of time. We believe the higher rates of descaling experienced by the steelhead trout were due directly to the delay of the fish within the water passages of the orifice-trap and not due to contact with the barrier screen within the gatewell. However, further tests are needed to verify this belief.

The incidence of descaling among fish remaining in the gatewell at the end of a test was as high as 25%, and all species and races were affected. However, these fish represented not more than 10% of the total population for those tests in which FPE for all species and races was 90% or better. Consequently, a descaling incidence of 25% of the residuals is in fact only 2.5% of the total population. The higher incidence of descaled fish among the ≈10% of the fish population that failed to exit from the gatewell by the end of the test is not unexpected. However, in terms of the total population, the impact of a high incidence of descaled residuals is very small.

Research scheduled for 1977 will employ modified equipment that will enable us to clearly determine the cause or source of descaling and the level of incidence associated with the cause.

RECOMMENDED FUTURE RESEARCH

Research will be continued in 1977 to answer the following questions:

1. What is the minimum and maximum submergence and head required on two 12-inch orifices to produce a FPE of 90% for all species and races over a 24-hour period?

2. What is the minimum and maximum submergence and head required on a single 12-inch orifice to produce a FPE of 90%?

3. With optimum hydraulics now established for submerged orifices, is it necessary to darken the gatewell and backlight the orifices?

4. Using incidence of descaled fish as a criteria, can we reduce the present 90% FPE cut-off point in determining the adequacy of submerged orifices, or should the cut-off point be increased?

VOLITIONAL FISH-GUIDING STUDIES

The development of a method for diverting fish out of turbine intakes and into turbine gatewells that is as effective but less costly than the methods in current use is a major goal of our research program to develop a fingerling protection system for the Bonneville Second Powerhouse. Our initial approach is to explore the possibility of utilizing a portion of the basic structure that, with modification, will serve two functions. Currently we are studying the feasibility of redesigning the trash racks so they will not only protect the turbines from trash, but also guide fish vertically and concentrate them near the ceiling of the turbine intake. The idea is based on previous observations indicating that fish passing through turbine intakes are negatively buoyant and assume a tail-down swimming attitude (videotape observations at Little Goose Dam, 1973). We hypothesize that a fish in a tail-down attitude will ascend toward the ceiling of the intake if it is stimulated to swim against the flow. A specially designed trash rack could produce such a stimulus. Once a higher percentage of the fish passing through turbine intakes are concentrated near the ceiling, it should be possible to employ a much smaller fish-guiding device than the present traveling screen. Development of such a guiding device is the next logical step of our research.

Research leading toward the development of a trash rack to vertically guide fish is divided into two parts: (1) field studies to determine the swimming attitude (buoyancy) of smolts at any depth immediately upstream from the turbine trash racks at Bonneville Dam and (2) laboratory studies to test several trash rack designs under carefully controlled conditions at the Pasco Biological Field Station.

Research in 1976 was limited to the design and construction of special test equipment and the development of the necessary procedures for its use. By the time the equipment was built and adequate procedures were worked out, natural smolts were no longer available. Consequently, testing was deferred until 1977. A description of the equipment and the results of testing will be covered in our report for 1977.

SUMMARY

1. In 1976 field and laboratory studies to develop a fingerling protection system for the Bonneville Second Powerhouse involved studies to define orifice design and operational characteristics that are highly efficient in passing smolting fingerlings out of intake gatewells and into a fingerling bypass, determine swimming attitude (buoyancy) of deep traveling smolts, determine if trash racks can be designed which will induce smolting fingerlings to swim against the flow

entering turbine intakes, determine when disruption of the fingerling protection system would have the least impact on migrating fish, and determine by measuring rates of descaling, whether orifices with a given FPE are acceptable.

2. In studies employing two submerged orifices to pass fish efficiently out of gatewells, we varied orifice diameter, submergence, and hydraulic head. Based on previous research, the gatewell was always darkened and the orifices were always backlighted; i.e., light was presented from the downstream side of the orifice entrance. Orifice diameters tested were 8-, 10-, 12-, and 18-inches.

Two criteria were used to determine the adequacy of a pair of orifices in passing fish out of gatewells; (1) fish passage efficiency should equal or exceed 90% for all species and races of fish (for tests of 24-hour duration), and (2) hydraulic head should not have to exceed submergence of the orifices.

Initial tests showed that 8-inch orifices were inadequate and that 18-inch orifices were over-adequate. Most of the subsequent tests were conducted with 10-inch orifices. The results with 10-inch orifices showed that at the shallower submergences (4 feet, for example) 10-inch orifices required that the hydraulic head exceed the submergence in order to achieve 90% FPE. On the other hand, the 12-inch orifices did not. We therefore tentatively concluded that two 12-inch orifices were superior to two 10-inch orifices and would probably prove adequate over a larger range of submergences than two 10-inch orifices.

3. By studying the diel passage of smolts through the collection system, it was determined that if the system needed to be shut down for maintenance, etc. it could be done with the least impact on fish passage if it was done between the hours of noon and 4:00 p.m.

4. Descaling of smolts was not a serious problem in the system as long as a high FPE was maintained.

5. Equipment was designed and tested and procedures were developed for studying the swimming attitude of fish and the effectiveness of specially designed trash racks in guiding fish, but testing was deferred until 1977.

6. Further studies will be conducted in 1977 to confirm results obtained in 1976 with one and two orifices and to extend the results to include more data at the extreme submergences, e.g., at depths less than 4 feet and greater than 8.5 feet. Improved methods will be employed to isolate sources of descaling, which then will be used to help determine if the 90% FPE cut-off point should be raised or lowered.