EFFECT OF WATER VELOCITY ON THE FISH-GUIDING EFFICIENCY OF AN ELECTRICAL GUIDING SYSTEM

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ABSTRACT

The study was performed in 1962 in a diversion of the Yakima River near Prosser, Wash. Massive structures for regulating the water velocity, producing the desired electrical field, and collecting the guided fish were installed. Evaluation facilities consisted of rotary drum screens to divert all fish that escaped past the electrical field to an inclined-screen trap. The fish tested were wild, downstream-migrating fingerlings of chinook salmon, *Oncorhynchus tshawytscha;* coho salmon, *O. kisutch;* and rainbow or steelhead trout, *Salmo gairdneri.* The variables were three water velocities, three species, and four test periods.

Fish-guiding efficiency tended to decrease with increasing water velocity. The guiding efficiencies of the electrical system at water velocities of 0.2, 0.5, and 0.8 (m.p.s.) meter per second were, respectively, 84.2, 54.2, and 50.2 percent for chinook salmon; 82.4, 47.8, and 42.8 percent for coho salmon; and 69.9, 40.2, and 44.8 percent for rainbow or steelhead trout. The guiding efficiency achieved was, thus, highest with chinook salmon, intermediate with coho salmon, and generally lowest with rainbow or steelhead trout.

The use of electricity to guide juvenile salmon and trout migrating downstream may be feasible in certain environments where the water velocity does not exceed 0.3 m.p.s. but does not appear practical for use in most rivers and streams.

One of the major problems facing fishery agencies in the Pacific Northwest is that of providing an efficient and economically feasible method of guiding juvenile salmon and trout past areas potentially dangerous to fish. The need is particularly acute in river systems affected by high dams and large, deep storage reservoirs. Recent studies (Durkin, Park, and Raleigh, 1970) indicate that under certain conditions many juvenile migrants fail to pass through large reservoirs, implying that if natural runs are to be perpetuated, downstream migrants must be guided and collected at the head of a reservoir or in its tributaries.

Various methods of guiding fish, including the use of electricity (Holmes, 1948; Andrew, Kersey, and Johnson, 1955), louvers (Bates and Vinsonhaler, 1957), and of lights and air bubbles (Brett and Alderdice, 1958) have been tested with varying degrees of success. Mason and Duncan[1] described experiments using the electrical guiding principle in which they successfully diverted about 90 percent of the juvenile migrants. Their experiments, however, were in water velocities of less than 0.3 m.p.s. Because the physical conditions at the upstream end of large reservoirs may vary considerably, a guiding system for the collection of juvenile salmon must operate efficiently under a variety of flow conditions.

The purpose of the present study was to determine the effect of three water velocities—0.2, 0.5, and 0.8 m.p.s.—on the fish-guiding efficiency of an electrical guiding system operating under field conditions.

EXPERIMENTAL SITE

Requirements of the experimental site were: ample flows that could be controlled, readily available electric power, sufficient downstream migrants to carry out the tests, and a convenient system for assessing the total outmigration. A section of the Chandler Canal (fig. 1), a diversion of the Yakima River near Prosser, Wash., met these requirements.

The Chandler Canal is about 2.4 m. deep, 19.8 m.

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[1] Mason, James E., and Rea E. Duncan, Development and appraisal of methods of diverting fingerling salmon with electricity at Lake Tapps. Bur. Commer. Fish., Biol. Lab., Seattle, Wash. Manuscript.

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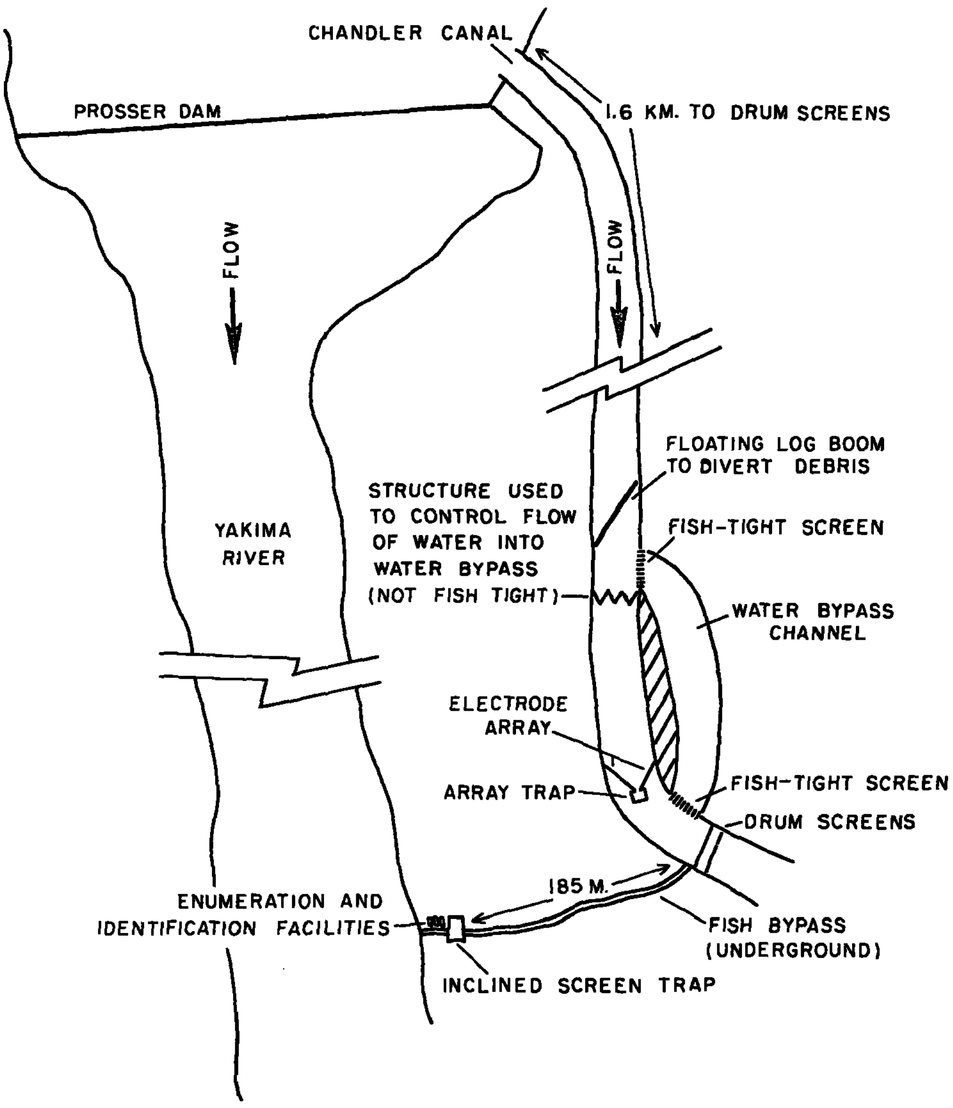

FIGURE 1.—Diagrammatic sketch of experimental site.

wide, and 14.5 km. long; it normally carries a flow of 28.3 to 34.0 c.m.s. (cubic meters per second). The banks have a 60° slope. The bottom consists primarily of sand and silt with some areas of small gravel. The water velocity is relatively uniform because large obstructions are lacking.

The entrance to the canal is not screened; juvenile fish migrating down the Yakima River have easy access, especially during periods of low water when a large portion of the river is diverted into the canal. To salvage these fish, the Bureau of Sport Fisheries and Wildlife operates rotary drum screens and a fish bypass system about 1.6 km. downstream from the canal intake. The experimental site consisted of a 439-m. section of the canal just upstream from the drum screens.

VELOCITY CONTROL STRUCTURES

Stoplogs, shunting panels, and screens were manipulated to effectuate and maintain the desired water velocities (0.2, 0.5, and 0.8 m.p.s.). Figure 2 is an aerial photo of the velocity control structures. A trash boom at the upstream end of the experimental site diverted floating debris to the bank where it was collected for disposal. Just downstream from the boom, flows could be diverted to the water-bypass channel (B, fig. 2),

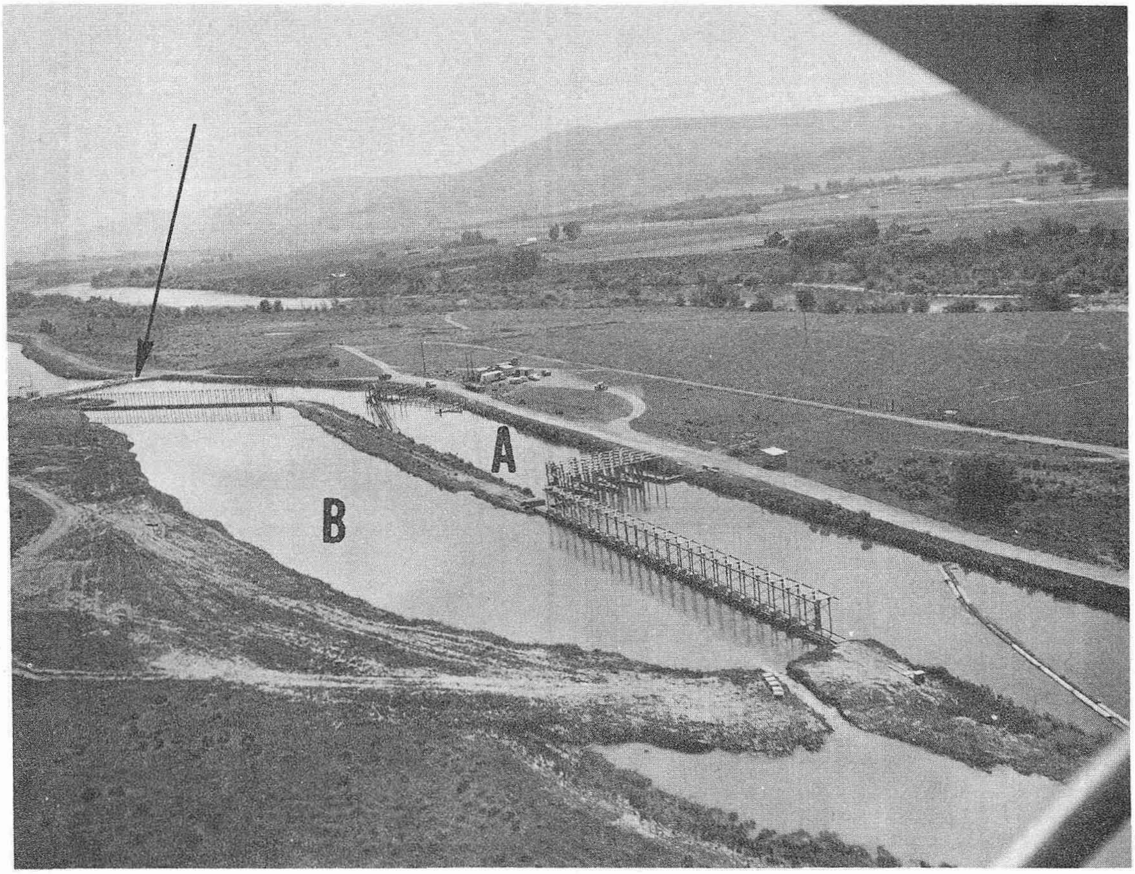

FIGURE 2.—Physical facilities of experimental fish-guiding site at Prosser, Wash. Waterflow is from right to left. Experimental canal (A) had V-type electrode array, an array trap, and a water-velocity control structure to divert excess flow through water-bypass channel (B). The water-bypass channel was screened at both ends to prevent entry of fish. Arrow points to rotary drum screens used to evaluate fish-guiding efficiency of electrical field created by electrode array. Yakima River is in background.

which was excavated adjacent and parallel to the Chandler Canal.

The bypass channel was about 1.2 m. deep, 288 m. long, and 64 m. wide. It carried the excess flow when reduced velocities were desired in the experimental canal. Both ends of this bypass channel were screened to prevent entry of fish (fig. 3). Each screen support structure consisted of a wooden framework, 72 m. long and 3 m. high, equipped with guides to accommodate 69 individual screens. Each screen was about 0.9 m. wide, 3 m. high, 3.2 mm. thick, and constructed of perforated steel plate. The perforations were 6.4 by 25.4 mm. ovals that provided a 46 percent opening. A traveling hoist on an overhead I-beam was used to lift the screens for cleaning. Each screen bay was fitted with a double set of guides so that a second screen could be installed before the first was removed.

The screen support structure at the entrance to the water-bypass channel was also equipped with guides to accommodate stoplogs. The stoplogs, constructed of concrete, were about 0.9 m. long, 0.6 m. high, and 5.1 cm. thick. An overhead hoist, similar to that used for lifting the screens, was used to raise and lower these stoplogs.

Another structure, at the upstream end of the main experimental canal and just downstream from the entrance to the water-bypass channel, was also used to help regulate the water velocity (fig. 4). This structure was constructed in the form of four V's joined together (VVVV) and was placed in the experimental canal at 90° to the flow. The structure was connected to each bank by earth-filled wooden abutments. The sides of each V were equipped with guides to accommodate 15 solid plywood panels. An overhead hoist raised or lowered

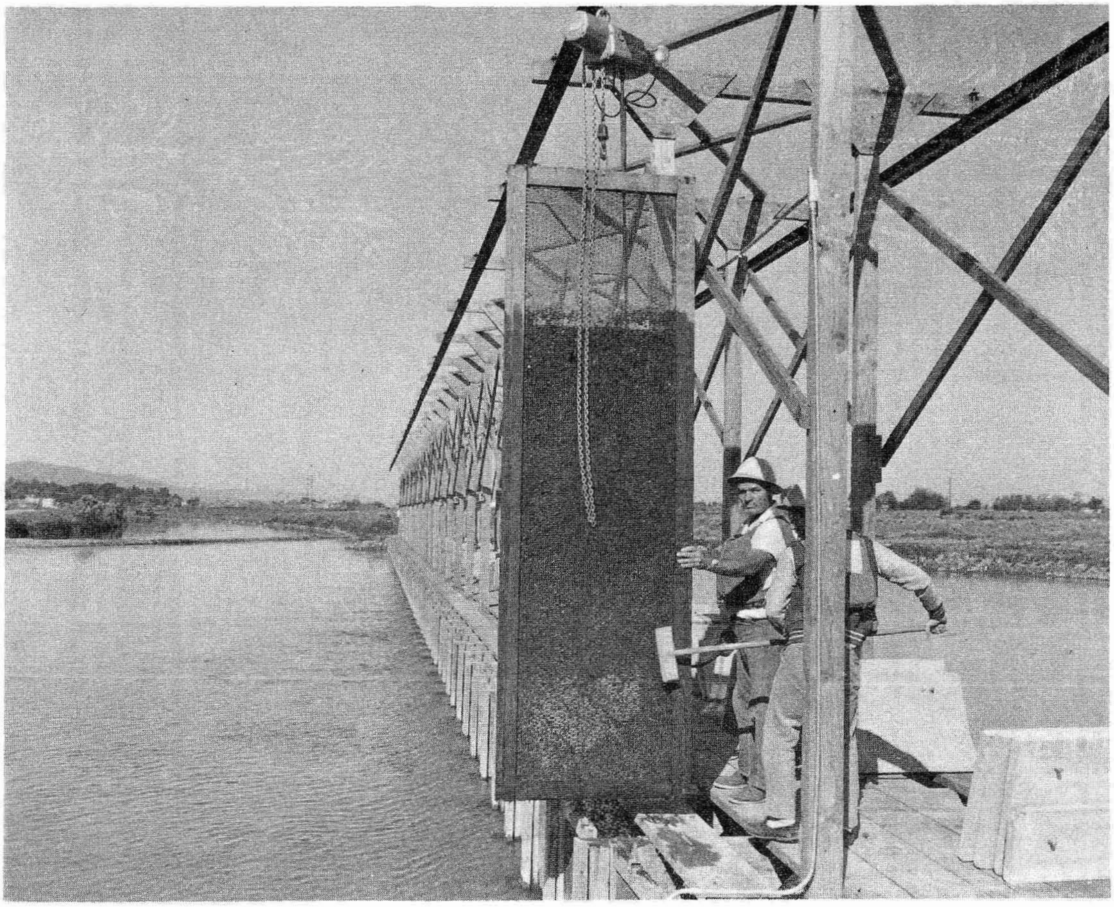

FIGURE 3.—Screen support and velocity control structure at entrance to water-bypass channel. Screen is raised for cleaning. Several concrete stoplogs are stacked in lower right foreground.

the panels. By installing various numbers of these plywood panels and adjusting the stoplogs in the velocity control structure at the entrance to the water-bypass channel, we could divert water to regulate the flow. At the slowest velocity tested—0.2 m.p.s.—the flow was about 7.4 c.m.s.; at 0.5 m.p.s. it was 22.2 c.m.s.; and at 0.8 m.p.s., 37.1 c.m.s. The three test velocities were average velocities and were maintained by routine cleaning of the screens. Actual water velocities varied about ±0.06 m.p.s. from the desired test velocities.

ELECTRODE ARRAY AND ELECTRICAL CONDITIONS

The angle of the electrode array to the waterflow and the electrical conditions of the array were held constant during the entire experiment. The array consisted of three rows of vertically suspended electrodes forming a 30° V (fig. 5). Because the electrode array trap was constructed nearer the right bank, looking downstream, and both legs of the array extended upstream at about a 15° angle to the flow, the legs were not exactly the same length. The left leg was 45.7 m. long, and the right leg 30.5 m. The electrodes were supported on the surface by a wooden framework and on the bottom by wooden dowels. One dowel extended from the bottom of each electrode and was driven into the sandy canal bottom about 10 cm. These dowels helped to keep the electrodes vertical at the higher water velocities and also insulated them from the canal bottom. The electrodes were 3-m. lengths of steel pipe with an outside diameter of 5.1 cm. The distance between the rows of electrodes in each leg of the array was 1.2 m. from the upstream row to the middle row and 0.6 m. from the middle to the downstream row. Spacing between the electrodes was 0.6 m. (fig. 6).

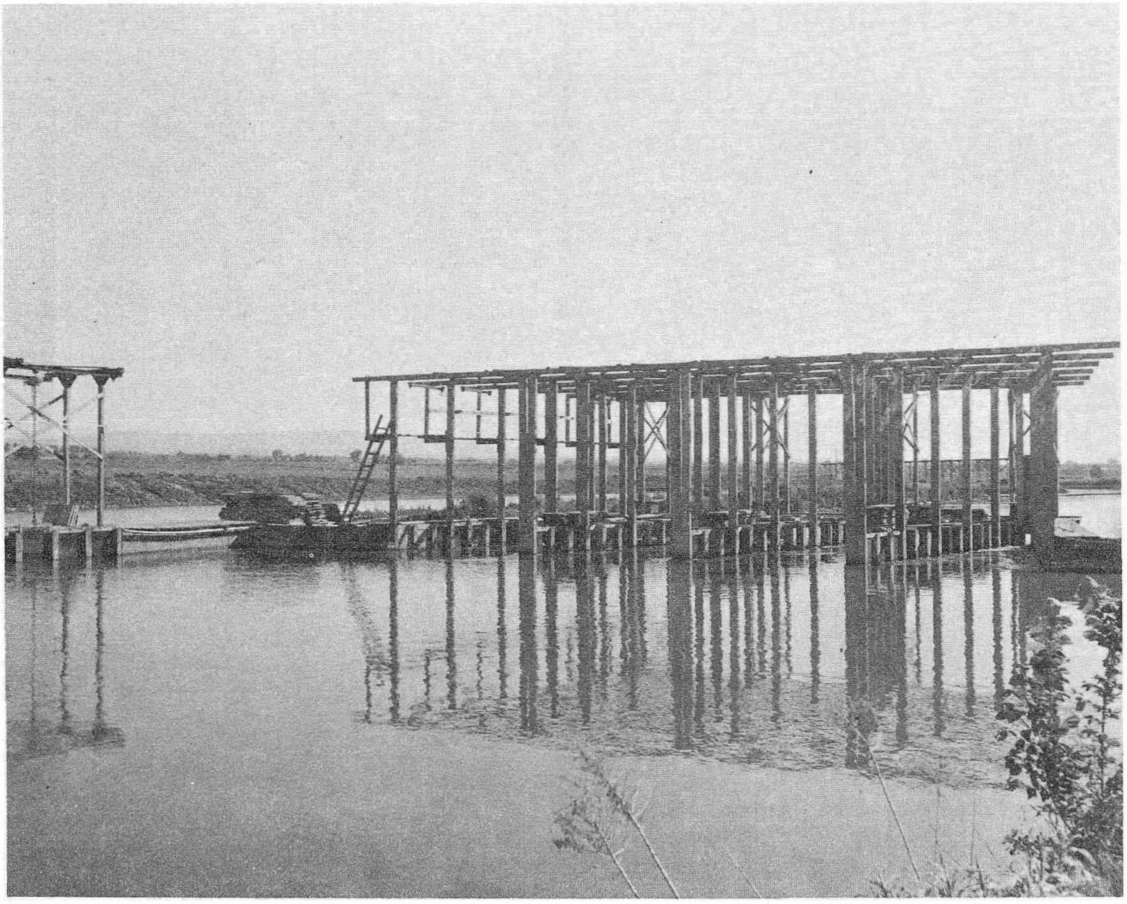

FIGURE 4.—Velocity control structure at upstream end of main experimental canal.

The electrodes were wired to make a total of five groups (fig. 7); when energized, each group produced an electrical field. The applied voltage to all of the electrodes was the same; hence, the voltage gradient created by the electrode arrangement and wiring pattern was higher on the downstream side than on the upstream side of the array. Figure 8 is an analog gradient plot of an electrical field created by one pulse at one specific location on the left side of the electrode array. The plotting interval is 10 percent of the applied voltage. Only one pulse of the five-pulse cycle is illustrated, but it is representative of the electrical fields produced with each pulse, because the wiring pattern was uniform with respect to electrode spacing.

The electrodes were energized with d.c., square-wave pulses, supplied by interrupting the output of a d.c. generator with sequential switching equipment (Volz, 1962). Figure 9 shows a block diagram of this equipment. The pulse amplitude was 125 volts, the duration 20 milliseconds, and the frequency 15 pulses per second. Because the electrodes were wired in five groups and the groups pulsed sequentially, each group was actually energized only three times per second (total pulse frequency divided by number of electrode groups). These electrical conditions had been tested in previous guiding experiments and had proved to be non-injurious to fish (Pugh, 1962).

Table 1 shows the pulsing sequence of the electrode array. When the first pulse was delivered, the electrodes connected to pulse supply cable 1 became positively energized and all the electrodes in the downstream row (pulse supply cable 6) became negatively energized. On the second pulse, the electrodes connected to pulse supply cable 2 became positively energized and the electrodes in the downstream row became negatively energized. This succession of pulses continued through pulse supply cables 3, 4, and 5. When the fifth pulse had been

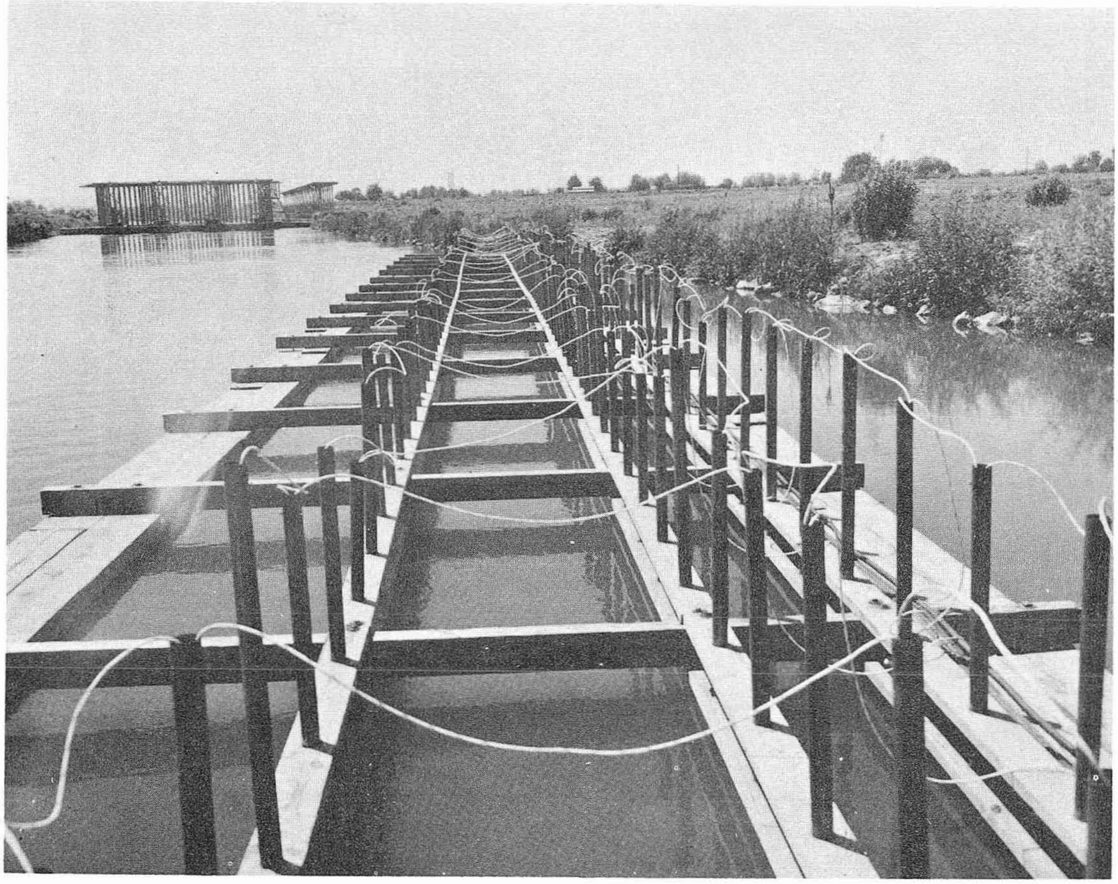

FIGURE 5.—One leg of electrode array.

delivered, the cycle was complete and the sequential pulsing equipment switched automatically to start the second cycle. During the second and each succeeding cycle, the electrodes were energized in exactly the same manner as they were during the first cycle.

Although the polarity of the electrodes was not alternated, we experienced very little electrolysis. Once the desired electrical conditions had been set into the sequential switching equipment, the gear functioned automatically and dependably for the duration of the experiment.

TABLE 1.—*Pulsing sequence and polarity of the electrode array*

Pulse supply-cable (number)	Pulsing sequence and polarity					
	Pulse 1	Pulse 2	Pulse 3	Pulse 4	Pulse 5	Pulse 1 (second cycle)
1	(+)	0	0	0	0	(+)
2	0	(+)	0	0	0	0
3	0	0	(+)	0	0	0
4	0	0	0	(+)	0	0
5	0	0	0	0	(+)	0
6	(–)	(–)	(–)	(–)	(–)	(–)

The purpose of a sequentially pulsed field, sweeping in the direction of the array trap, was to take advantage of any electrotactic effect that the electrical energy might produce. Although the electrode array and electrical conditions in this experiment were designed to divert the fish by stimulating an avoidance response at the periphery of the electrical field, it is known that when fish penetrate a pulsed d.c. electrical field of sufficient intensity they are stimulated to propel themselves in the direction of the positive pole or anode (Haskell, MacDougal, and Geduldig, 1954).

ARRAY TRAP

The array trap was at the downstream end of the electrode array. It was constructed with a 6.4 m.-wide entrance so that the effective electrical fields created by the converging legs of the elec-

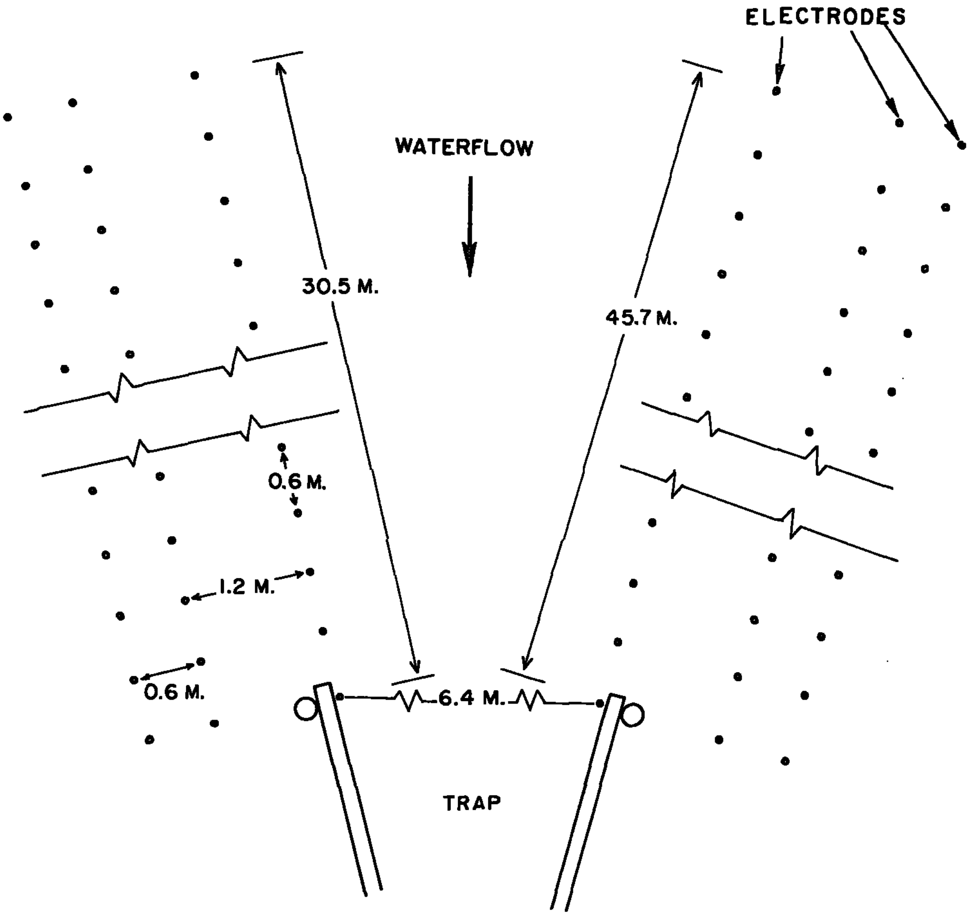

FIGURE 6.—Electrode array with spacing of electrodes as indicated.

trode array would not overlap and prevent the entry of fish. Observations indicated that the electrical field did not affect fish swimming more than 0.9 to 1.2 m. away from the electrodes; hence, any fish migrating in an area about 4.0 m. wide in the middle of the canal were able to enter the array trap without being visibly affected by the electrical energy.

The trap entrance occupied 34 percent of the cross-sectional area of the canal. Measurements showed that when the water velocity in the canal was 0.2 m.p.s., the trap screened about 33 percent of the flow. At higher water velocities the hydraulic head on the trap lead-in screens increased and some water tended to flow upstream around the end of the screens rather than through them. Consequently, the trap screened only about 29 percent of the flow at a water velocity of 0.5 m.p.s. and about 25 percent at 0.8 m.p.s.

The trap lead-ins, converging at a 30° angle (fig. 10) extended downstream from the trap entrance to the trap throat. Each of these lead-ins was 11.6 m. long and consisted of 11 screens of the same design and construction as those used in the velocity control structure at the entrance to the water-diversion channel. An overhead lifting device facilitated the cleaning of the screens. The trap throat was 0.5 m. wide by 2.4 m. deep. It was equipped with guides to accommodate a gate that could be closed when the trap was being emptied.

The trap holding area was about 3 m. wide, 3 m. long, and 2.4 m. deep. It was equipped with a metal brail that was divided into four sections by wooden separators (fig. 11) to facilitate the removal of captured fish. The brail was lifted by a wire rope attached to an electric winch.

EVALUATION FACILITIES

Facilities for evaluating the fish-guiding efficiency of the electrical system were about 150 m.

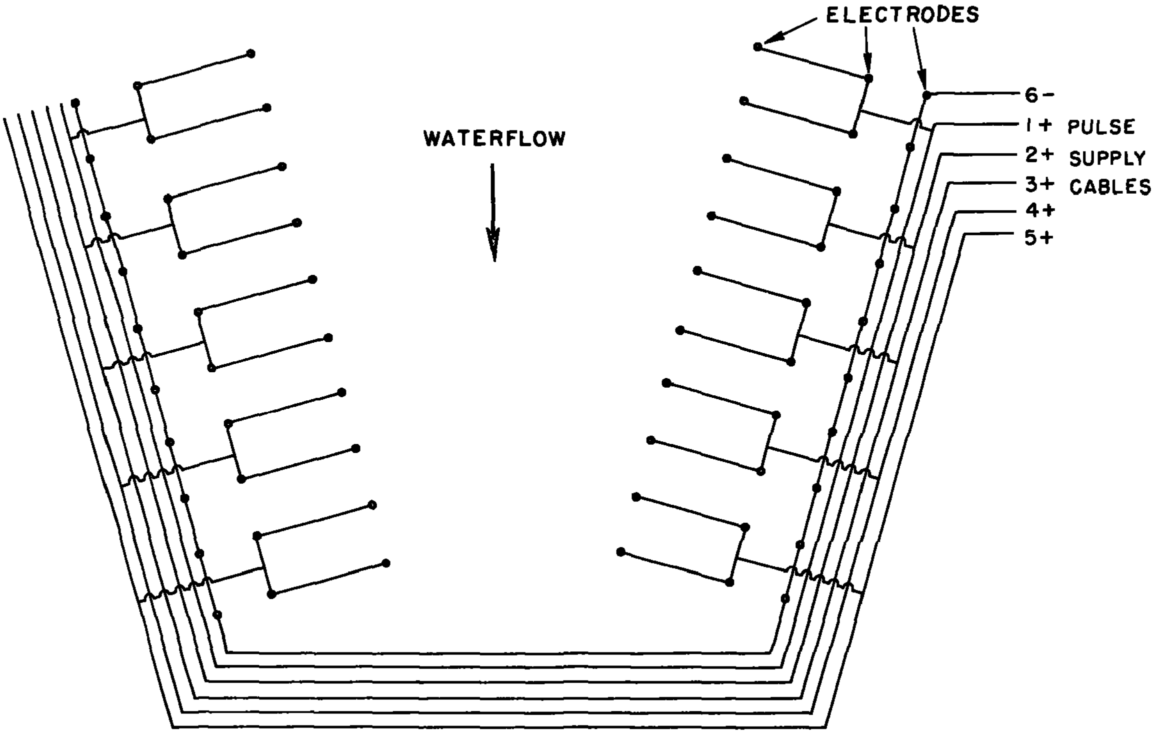

FIGURE 7.—Wiring pattern of electrode array.

downstream from the electrode array trap. All fish escaping past the electrode array were stopped by revolving drum screens (fig. 12), which diverted them to an underground bypass leading to an inclined-screen trap. Four wooden troughs adjacent to the inclined-screen trap held the captured fish while they were being counted and identified. These troughs were 20.3 cm. deep, 22.9 cm. wide, and 167.6 cm. long (fig. 13). Each was divided into three sections by removable screen partitions and fitted with an overflow standpipe at one end. A constant flow was fed to the troughs from a headbox upstream from the inclined-screen trap. The troughs were placed so the end with the standpipe was above an open flume which carried water from the inclined-screen trap to the Yakima River.

EXPERIMENTAL DESIGN

The variables tested were three water velocities (0.2, 0.5, and 0.8 m.p.s.), four test periods (variations among the test periods were due to uncontrollable environmental changes such as temperature, turbidity, and water resistivity), and three species of fish—chinook salmon, *Oncorhynchus tshawytscha;* coho salmon, *O. kisutch;* and rainbow-steelhead trout, *Salmo gairdneri.*[2] Table 2 shows the sequence of tests. The effect of each water velocity on the fish-guiding efficiency of the electrode array was tested once during each period. The experiment ran 50 days (April 21 to June 9, 1962); testing was continuous except for a 1-day interruption due to power failure during an electrical storm.

The effect of each of the three water velocities on the fish-guiding efficiency of the electrical system was determined by comparing the number of individuals of each of the three species of fish captured in the electrode array trap during a specific test period with the total number of the same species taken by the array trap plus the inclined-screen trap during that period.

Water conditions in the experimental canal were checked periodically. Velocity was measured every 2 hours with a Gurley current meter (No. 622–E)[3] at the downstream end near the middle of the

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[2] The term rainbow-steelhead trout, as used in this paper, includes both seaward migrants and residual members of the species.

[3] Trade names referred to in this paper do not imply endorsement of commercial products by the Bureau of Commercial Fisheries.

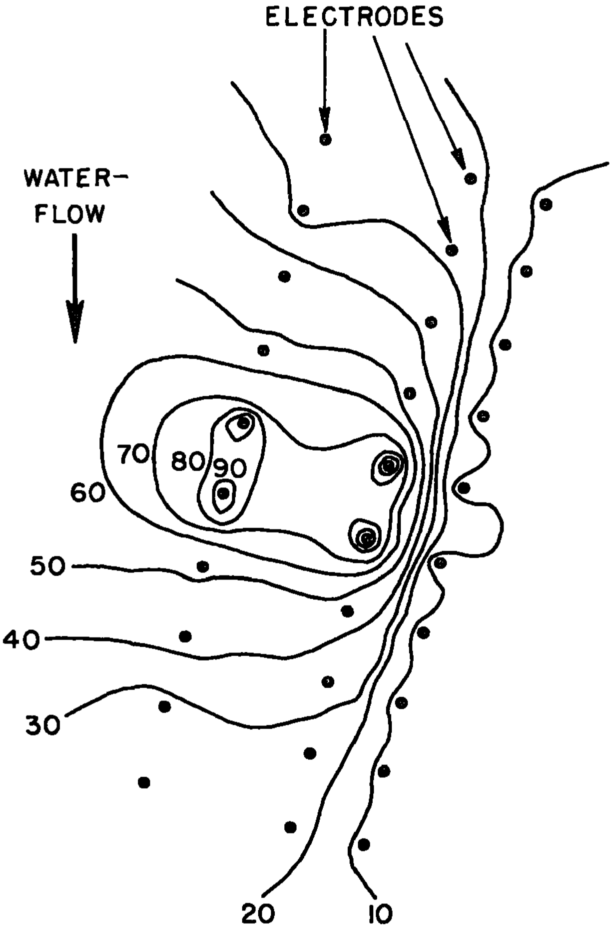

FIGURE 8.—Electrical field created by one pulse at one specific location on the left side of the electrode array. (Lines connect points of equal potential; numbers show percentage of the applied voltage.)

canal. Water temperature was taken three times daily (6 : 00 a.m., 2 : 00 p.m., and 10 : 00 p.m.) with a standard mercury thermometer. The average water temperature was 14.4° C. (range 11.1 to 20.0° C.). Turbidity and resistivity were also measured three times daily. Turbidity averaged 15.6 parts per million silica dioxide (range 10.0 to 26.0 p.p.m.), and the average water resistivity was 5,535 ohm cm. (range 4,290 to 7,400 ohm cm.).

To minimize the escape of fish from the array trap, the catch was removed every 2 hours (e.g., 2 : 00 p.m., 4 : 00 p.m.). Fish could not escape from the inclined-screen trap; therefore, it was checked less frequently—at 4-hour intervals (e.g., 4 : 00 p.m., 8 : 00 p.m.). This schedule was followed throughout the experiment, even during periods of maintenance and stoplog manipulation, to ensure that fish were not delayed in their downstream migration. Fish captured in the array trap were transported in an aerated tank to the holding troughs adjacent to the inclined-screen trap where they were counted and identified. Movable partitions within the troughs made it possible to count and identify the fish without handling. The fish were released, after the data from each group had been recorded, by removing standpipes from the troughs and allowing the water and fish to drain into the bypass flume. From the flume, the fish could re-enter the Yakima River. Fish captured in the inclined-screen trap were also identified, counted, and released into the Yakima River.

TABLE 2.—*Sequence in which different water velocities were tested during four test periods*

Test periods	Dates (1962)	Water velocities		
		M.p.s.	*M.p.s.*	*M.p.s.*
I	April 21–May 3	0.5	0.8	0.2
II	May 3–May 16	.2	.5	.8
III	May 16–May 28	.8	.2	.5
IV	May 28–June 9	.5	.8	.2

EXPERIMENTAL PROCEDURE

Before beginning each test, we obtained the desired water velocity by manipulating the concrete stoplogs in the velocity control structure at the entrance to the water-bypass channel and the plywood panels in the velocity control structure in the main canal. This operation required about 8 hours.

Each control test (power off) was started at 4 : 00 p.m. The array trap and the inclined-screen trap were cleared of fish before the start of the test and then emptied at regular intervals for the duration. The control test lasted 40 hours (until 8 : 00 a.m. on the second day after the experiment started). The 8 hours following the control test (8 : 00 a.m. to 4 : 00 p.m.) were used primarily for maintenance and cleanup. At 4 : 00 p.m., when the maintenance period ended, the electrode array was energized according to preset electrical conditions. These conditions were monitored during the entire power-on test by means of a calibrated oscilloscope. The power-on test lasted 40 hours (until 8 : 00 a.m. on the second day after the array was energized); the sequential switching equipment was then turned off and the stoplogs and plywood

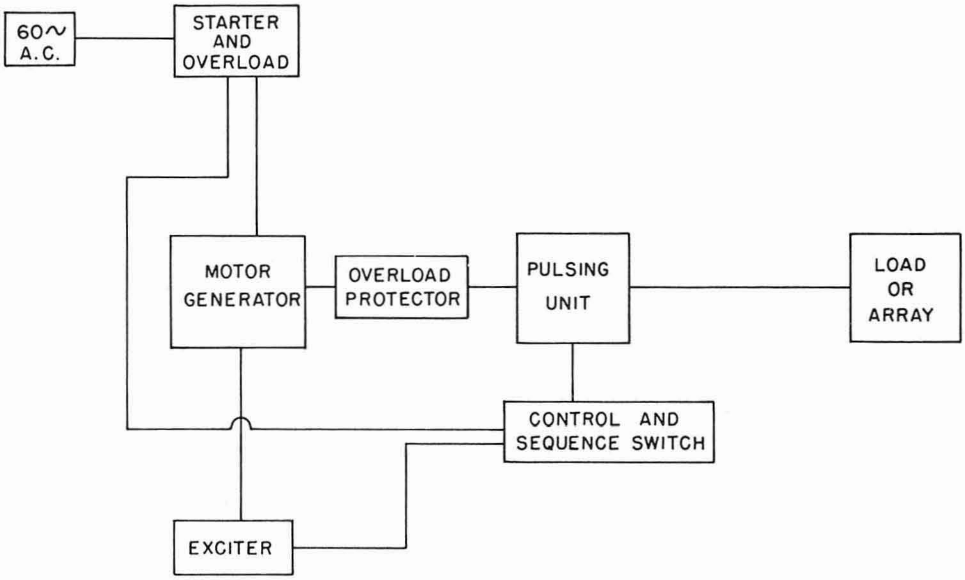

FIGURE 9.—Block diagram of sequential switching equipment used to supply d.c., square-wave pulses.

FIGURE 10.—Lead-in screens and throat (arrow) of array trap.

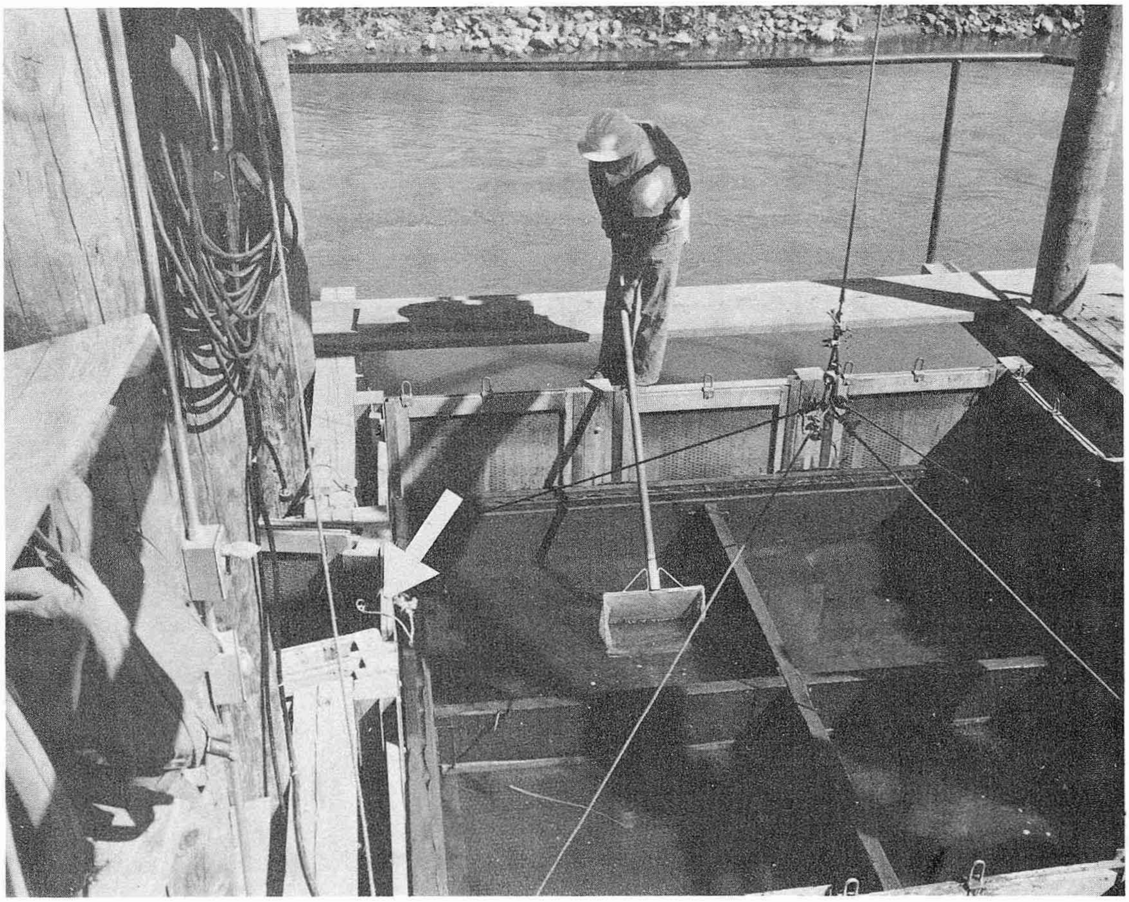

FIGURE 11.—Electrode array trap with throat closed (arrow) and sectioned brail raised.

panels manipulated to create the desired water velocity for the next test. This procedure was followed for the duration of the experiment. Each complete test took 96 hours: stoplog adjustment, 8 hours; control period, 40 hours; maintenance, 8 hours; and power-on, 40 hours.

COMPOSITION OF CATCH

Most of the test fish were wild, downstream migrants of the Yakima River system. One-hundred twenty-nine thousand juvenile salmon and trout were captured. About 50 percent were chinook salmon, 32 percent coho salmon, and 18 percent rainbow-steelhead trout. The chinook salmon belonged to age-groups 0 and I and had average fork lengths of 89 and 133 mm., respectively. The coho salmon were age-group I fish and averaged 131 mm. The rainbow-steelhead trout were age-group I and older and had a mean length of 198 mm.

EFFECT OF TEST VARIABLES ON EFFICIENCY OF FISH-GUIDING AND COLLECTING

Preliminary analysis indicated that the electrode array and array trap collected a relatively high percentage of fish, even during the power-off (control) conditions. To distinguish between the fish-collecting efficiency of the total guiding system (electrode array and array trap) with the power on and the actual fish-guiding efficiency of the electrode array and electrical field alone, the experimental results are presented in three sections: (1) electrode array energized plus array trap—percentage of fish collected by the electrode array and array trap with the electrode array energized, (2) electrode array nonenergized plus array trap—percentage of fish collected by the electrode array and array trap under control conditions, and (3) electrode array energized without

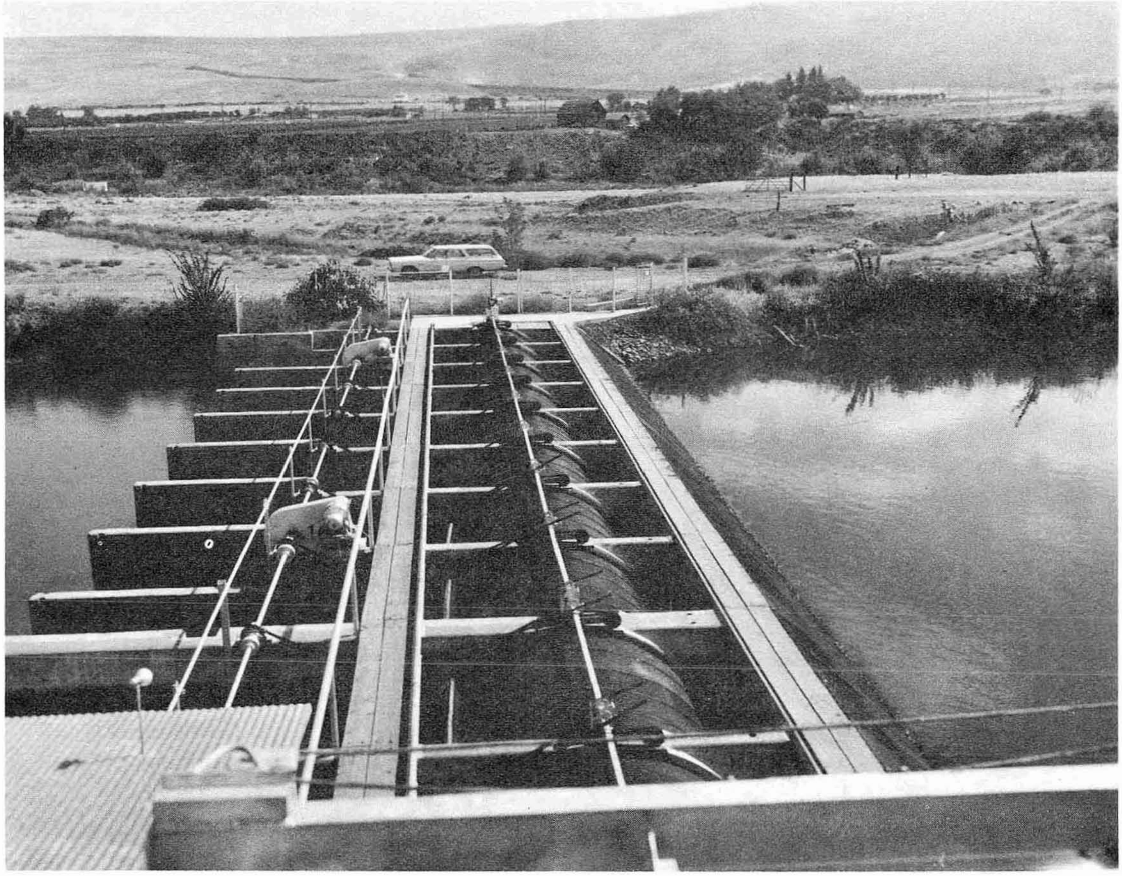

FIGURE 12.—Revolving drum screens used to divert fish that escaped past the electrode array to an inclined-screen trap.

array trap—percentage of fish actually guided by the electrode array and the electrical field created by the electrode array. Details of the methods used to compute these fish-guiding and collecting efficiencies are discussed below.

ELECTRODE ARRAY ENERGIZED PLUS ARRAY TRAP

Table 3 shows the fish-collecting efficiency of the electrode array and array trap with the power on for each test velocity and test period, by fish species. These efficiencies (in percentages) were computed by dividing the total number of each species of fish captured in the electrode array trap during a specific power-on period by the sum of this number plus the number of fish of the same species captured in the inclined-screen evaluation trap during the same power-on period, and multiplying the quotient by 100.

TABLE 3.—*Fish-collecting efficiency (in percent) of the electrode array and array trap, with the electrode array energized, for each water velocity, test period, and fish species*

Velocity	Test period	Species		
		Chinook salmon	Coho salmon	Rainbow-steelhead trout
M.p.s.		*Percent*	*Percent*	*Percent*
0.2	1	88.2	82.0	71.3
	2	81.2	82.8	74.3
	3	78.2	86.0	75.9
	4	93.9	82.0	64.1
	Average	85.4	83.2	71.4
.5	1	77.1	77.9	43.3
	2	79.7	82.3	64.2
	3	72.6	60.5	59.8
	4	39.9	24.6	28.9
	Average	67.3	61.3	49.0
.8	1	88.2	76.2	74.9
	2	87.5	75.5	70.2
	3	86.4	76.1	72.2
	4	57.3	59.4	49.5
	Average	79.8	71.8	66.7

The mean fish-collecting efficiency for the electrode array and array trap with the power on was highest at a water velocity of 0.2 m.p.s.; intermediate at 0.8 m.p.s.; and lowest at 0.5 m.p.s. (fig.

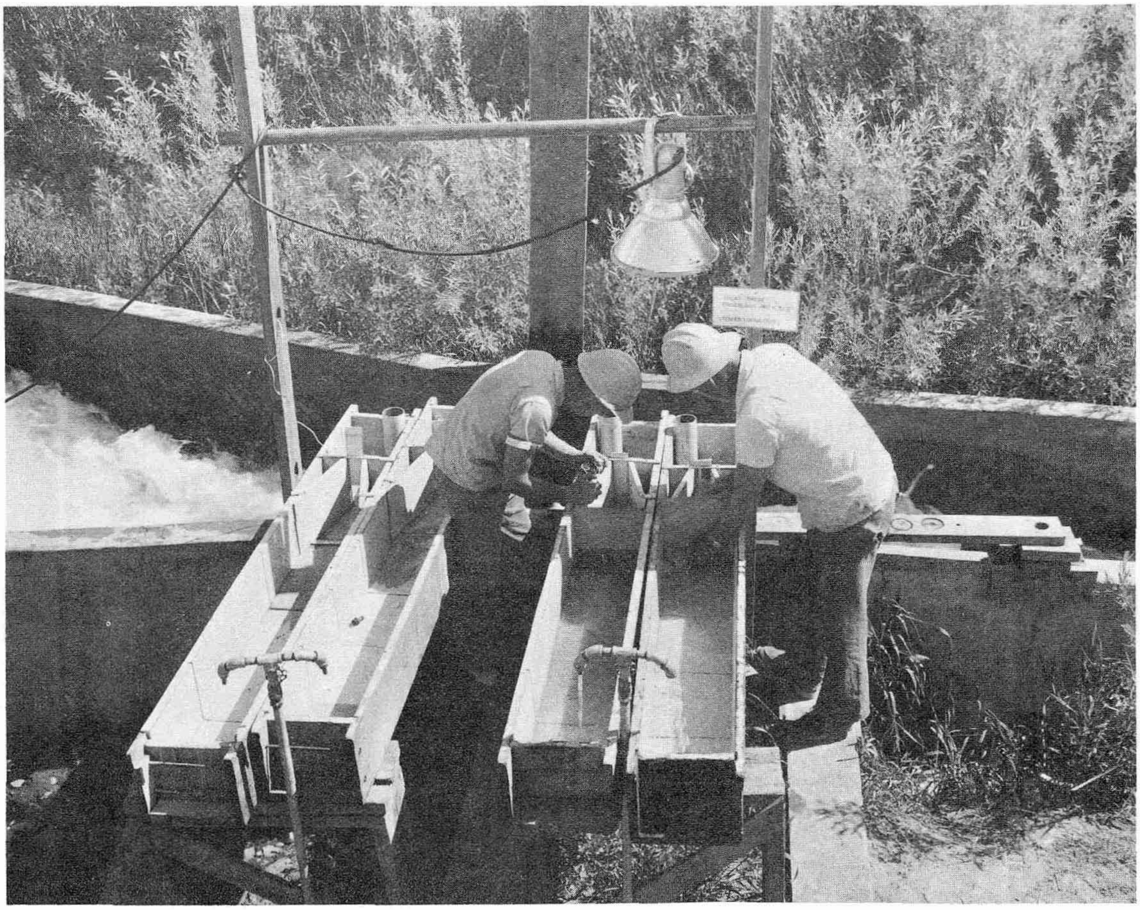

FIGURE 13.—Troughs for counting and identifying salmon and trout.

14). The decrease in fish-collecting efficiency between 0.2 and 0.5 m.p.s. and the increase at 0.8 m.p.s. suggests that fish-guiding efficiency decreased as the water velocity increased, but that perhaps: (1) the electrodes created hydraulic conditions that diverted more fish into the array trap at a water velocity of 0.8 m.p.s. than at 0.5 m.p.s. or (2) that the fish-holding efficiency of the array trap was higher at 0.8 m.p.s. than at 0.5 m.p.s. It was not possible within the scope of this research to determine the effect of the hydraulic conditions created by the electrodes on the fish-guiding efficiency of the electrical system, nor was it possible to determine conclusively the holding efficiency of the array trap at each of the three test velocities. Because salmon and trout populations of the Yakima River at the time of this experiment were so critically low, we deemed it inadvisable to handle, mark, and delay the number of migrating salmon and trout required to determine accurately the efficiency of the array trap in retaining fish.

General observations, however, indicated that fish could escape from the array trap at all test velocities but that fish-holding efficiency was higher at 0.5 m.p.s. and at 0.8 m.p.s. than at 0.2 m.p.s. Therefore, during the power-on tests, some fish were probably guided into the array trap by the electrical system but, because they were not removed immediately, they were able to escape by swimming back upstream into the canal. Consequently, all of the fish-guiding and collecting efficiencies reported here for the low and middle water velocities are probably lower than the actual efficiencies achieved. Those reported for the highest water velocity, 0.8 m.p.s., are probably more accurate than those for the lower velocities, but even these values are doubtless below the actual values achieved.

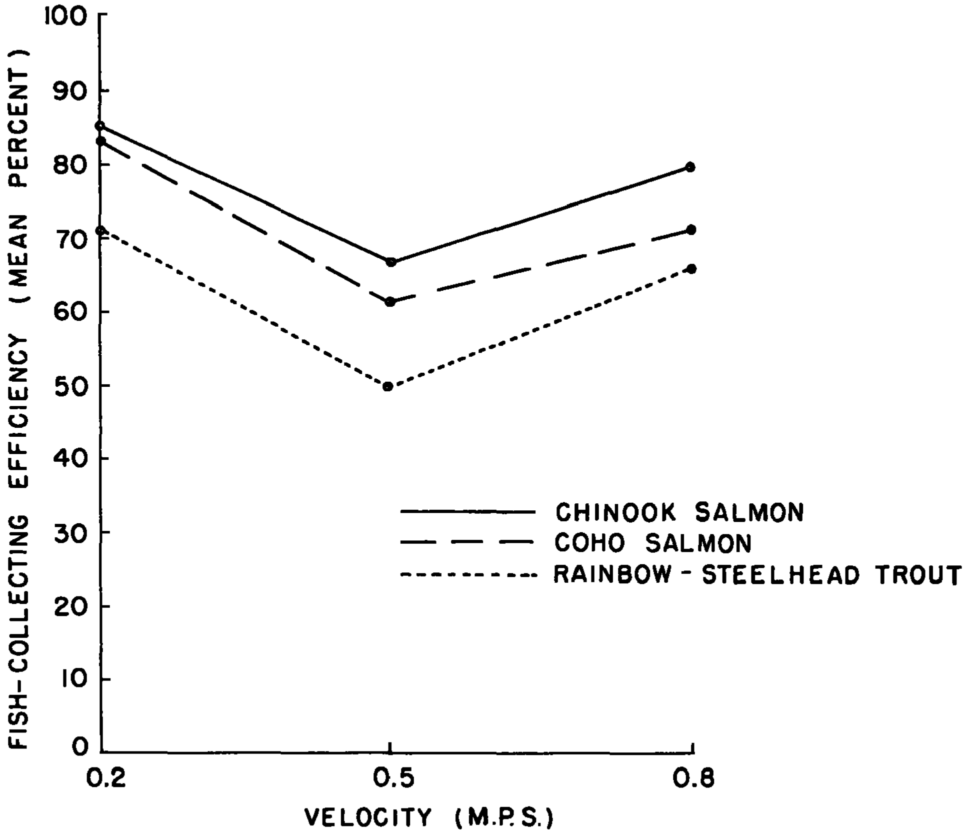

FIGURE 14.—Fish-collecting efficiency (mean percent) of the electrode array and array trap, with the electrode array energized, for each water velocity and fish species.

Figure 14 shows that the mean fish-collecting efficiency was highest for chinook salmon, intermediate for coho salmon, and lowest for rainbow-steelhead trout.

Examination of table 3 shows that at the 0.2 m.p.s. velocity, the results were about the same in the fourth test period as in the first three. At the middle and high water velocities, however, the fish-guiding and collecting efficiencies were substantially lower during the fourth test period than during the first three. To determine the reason for this decrease, we considered such factors as the size of fish, timing in the migration period, environmental fluctuations, possible malfunctions of the electronic equipment, and underwater damage to the electrode array trap. None of these factors, however, were sufficiently different from previous conditions to provide an explanation for the lower fish-guiding efficiencies. (It should be noted that the sudden unexplained failures in fish guidance at the middle and high water velocities did not occur at 0.2 m.p.s., which was the last velocity tested during the fourth test period—see table 2.)

ELECTRODE ARRAY NONENERGIZED PLUS ARRAY TRAP

We calculated the fish-collecting efficiency of the electrode array and array trap with the power off (table 4) for each test velocity and test period, by fish species, by the same method used to determine the fish-collecting efficiency of the electrode array and array trap with the power on. The catches compared were those made under control conditions. Figure 15 shows that the fish-collecting efficiency (mean percent) of the electrode array and array trap with the power off increased for all three species as the velocity increased. This increase in fish-collecting efficiency with increasing velocity during tests with the power off substantiates one or both of our previous hypotheses that: (1) the electrodes created hydraulic conditions at the higher water velocities that diverted fish into

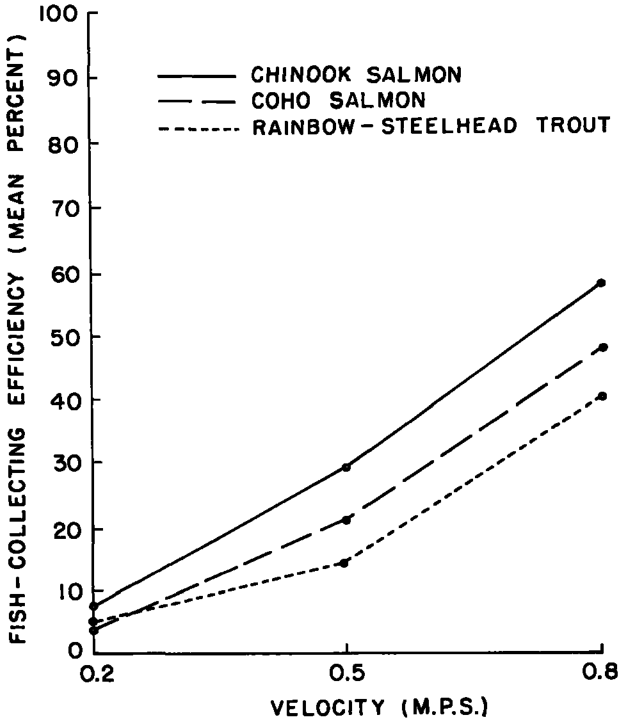

FIGURE 15.—Fish-collecting efficiency (mean percent) of the electrode array and array trap during the control conditions (power off) for each water velocity and fish species.

the array trap or (2) the fish-holding efficiency of the array trap increased with increased water velocity. In general, the rank of the species in relation to fish-collecting efficiency of the electrode array and array trap was the same as during the power-on test; chinook salmon ranked first, coho salmon second, and rainbow-steelhead trout third.

TABLE 4.—*Fish-collecting efficiency (in percent) of the electrode array and array trap during the control conditions (power off) for each water velocity, test period, and fish species*

Velocity	Time period	Species		
		Chinook salmon	Coho salmon	Rainbow-steelhead trout
M.p.s.		*Percent*	*Percent*	*Percent*
0.2	1	6.6	2.4	4.4
	2	10.5	10.2	12.3
	3	5.0	3.7	2.1
	4	5.7	2.8	1.3
	Average	7.0	4.8	5.0
.5	1	29.2	45.0	16.5
	2	30.2	23.6	14.1
	3	23.8	19.1	6.2
	4	30.0	22.0	18.0
	Average	28.3	27.4	13.7
.8	1	58.5	70.5	47.3
	2	56.8	45.2	44.6
	3	64.8	44.2	39.6
	4	58.6	33.0	31.3
	Average	59.7	48.2	40.7

ELECTRODE ARRAY ENERGIZED WITHOUT ARRAY TRAP

Fish-guiding efficiency of the electrode array (power on), without the array trap, is presented in table 5 as percentage differences between the fish-guiding and collecting efficiency of the electrode array and array trap with the power on and the efficiency with the power off. Table 5, however, is only an indication of the actual fish-guiding efficiency of the electrical guiding system. As previously mentioned, fish swimming more than 0.9 to 1.2 m. from the electrodes were not visibly affected by the electrical field created by the electrode array. As the entrance to the array trap was 6.4 m. wide, it was possible for fish migrating near the middle of the experimental canal (i.e., near the middle of the trap entrance) to enter the array trap without having been diverted by the electrical energy. These fish, therefore, were not actually available to be guided by the electrical system. Assuming that the same percentage of fish entered the array trap naturally (i.e., without being guided) during the power-on conditions as during the control periods, we established the following relations to determine the actual fish-guiding efficiency of the electrical system alone:

Let AT_P=Total number of fish captured in the array trap on any given power-on day.
IST_P=Total number of fish captured in the inclined-screen trap on the same power-on day.
AT_o=Total number of fish captured in the array trap on the preceding power-off day.
IST_o=Total number of fish captured in the inclined-screen trap on the same power-off day.
P_E=Percentage of fish guided by the electrical system that were actually available to be guided; i.e., fish that would not have entered the array trap naturally.

$$\text{Then } P_E=\frac{AT_P-\left[\frac{(AT_o)}{(AT_o+IST_o)}(AT_P+IST_P)\right]}{AT_P+IST_P-\left[\frac{(AT_o)}{(AT_o+IST_o)}(AT_P+IST_P)\right]}\times 100$$

Table 5.—*Fish-guiding efficiency (in percent) of the electrode array (power on), without the array trap, for each water velocity, test period, and fish species; values were determined by subtracting percentage of fish collected with the power off from percentage guided with the power on*

Velocity	Time period	Species		
		Chinook salmon	Coho salmon	Rainbow-steelhead trout
M.p.s.		*Percent*	*Percent*	*Percent*
0.2	1	81.6	79.6	67.0
	2	70.7	72.7	62.0
	3	73.1	82.3	74.0
	4	88.3	79.2	63.0
	Average	78.4	78.5	66.5
.5	1	47.9	32.9	27.0
	2	49.5	58.7	50.2
	3	48.7	41.4	54.0
	4	10.0	2.6	11.0
	Average	39.0	33.9	35.6
.8	1	29.6	5.7	27.6
	2	30.7	30.3	25.6
	3	21.6	31.9	32.6
	4	−1.3	26.4	18.2
	Average	20.2	23.6	26.0

Table 6 was prepared from the above formula and shows, by fish species, the adjusted fish-guiding efficiency of the electrical system for each experimental condition. Figure 16 shows the mean percentage fish-guiding efficiency of the electrode array (power on), without the array trap, for each test velocity and species. In general, efficiency was inversely related to velocity—it was highest at 0.2 m.p.s., second highest at 0.5 m.p.s., and lowest at 0.8 m.p.s. Mean guiding efficiency by species was highest for chinook salmon, intermediate for coho salmon, and usually lowest for rainbow-steelhead trout.

QUALIFICATIONS OF COMPUTATION METHODS

Because the inclined-screen trap was several hundred meters downstream from the array trap, a slight delay existed between the time that fish of a particular school or group entered the array trap and the remainder of that school or group entered

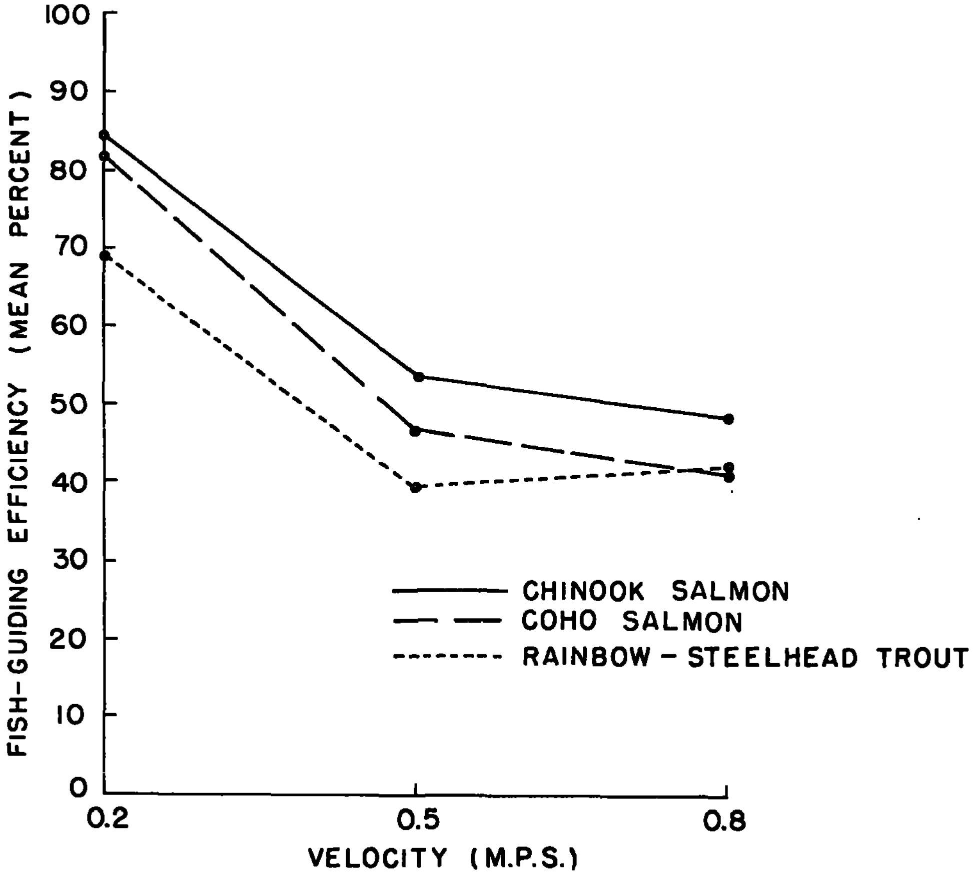

Figure 16.—Fish-guiding efficiency (mean percent) of the electrode array (power on), without the array trap, for each water velocity and fish species.

the inclined-screen trap. Tests to determine the exact time involved in this delay were not conclusive but indicated that the delay was usually less than 4 hours and often even less than 1. Although the array trap was checked every 2 hours and the inclined-screen trap every 4, we computed the fish-guiding and collecting efficiencies by grouping the fish captured in each trap during a 24-hour period and then comparing these totals.

TABLE 6.—*Adjusted fish-guiding efficiency (in percent) of the electrode array (power on), without the array trap, for each water velocity, test period, and fish species*

Velocity	Time period	Species		
		Chinook salmon	Coho salmon	Rainbow-steelhead trout
M.p.s.		*Percent*	*Percent*	*Percent*
0.2	1	87.4	81.5	70.0
	2	79.0	80.9	70.7
	3	77.0	85.4	75.4
	4	93.6	81.5	63.6
	Average	84.2	82.4	69.9
.5	1	67.7	59.8	32.0
	2	70.9	76.8	58.4
	3	64.0	51.2	57.1
	4	14.3	3.4	13.3
	Average	54.2	47.8	40.2
.8	1	71.5	19.2	52.4
	2	71.1	55.3	46.2
	3	61.3	57.1	54.0
	4	−3.1	39.4	26.5
	Average	50.2	42.8	44.8

Consequently, the delay time due to the distance between the two traps affected only the data for the last inclined-screen trap catch in each 24-hour period. Therefore, no lag time was allowed in computing any of the fish-collecting efficiencies. The total number of fish captured in the array trap from 12:00 midnight to the following 12:00 midnight was compared with the total number of fish captured in the inclined-screen trap during the same period. When we analyzed the data to allow for a 4-hour delay (comparing catches in the array trap between 12:00 midnight and the following 12:00 midnight with catches in the inclined-screen trap between 4:00 a.m. and the following 4:00 a.m.) and an 8-hour delay (comparing catches in the array trap between 12:00 midnight and the following 12:00 midnight with catches in the inclined-screen trap between 8:00 a.m. and the following 8:00 a.m.), the results did not modify our major conclusions.

CONCLUSIONS

We have two major conclusions:

1. The fish-guiding efficiency of the electrical system generally decreased as water velocity increased, probably because juvenile salmon and trout may be progressively less able to control their movements as velocity increases.
2. The use of electricity to guide juvenile salmon and trout migrating downstream may be feasible in certain environments where the water velocity does not exceed 0.3 m.p.s., but does not appear practical for use in most rivers and streams.

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