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PROGRESS REPORT

NO. 1

FURTHER EXPERIMENTS WITH AN ELECTRIC SCREEN FOR DOWNSTREAM-MIGRANT SALMON AT BAKER DAM

BY

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PARTICIPATING ORGANIZATIONS

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ABSTRACT

Experiments undertaken at Baker Dam in 1955 to determine the effectiveness of a large-scale electric screen for guiding downstream-migrant salmon were continued at this dam in the spring of 1956. An electric screen 200 feet long and 50 feet deep energized with direct current was placed across the forebay of the dam and a by-pass trap, much larger than the one used in 1955, was provided at the crest of the dam. The type of electric screen used in these experiments was again found to be ineffective. A webbing barrier only 15 feet deep placed across the forebay in the same location as the electric screen was much more effective. The by-pass used in these experiments was quite effective in collecting fish during darkness but was ineffective during daylight.

ACKNOWLEDGMENT

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FURTHER EXPERIMENTS WITH AN ELECTRIC SCREEN
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INTRODUCTION

A previous experiment conducted at Baker River Hydroelectric Plant in 1955 to measure the effectiveness of a prototype electric screen for guiding downstream-migrant sockeye salmon (Oncorhynchus nerka) and coho salmon (O. kisutch) showed that a "galvanotropic screen" that had been very successful in small-scale experiments at Cultus Lake in 1953 and 1954 was not effective in the forebay of this dam (Andrew, Kersey and Johnson, 1955). In the 1955 experiment with a prototype screen certain problems were encountered that were not evident in the small-scale experiments; the fish were temporarily stopped by the screen but were not guided to the by-pass exit as they had been in previous small-scale experiments. Another problem was that of providing an effective by-pass that fish would enter without delay. The by-pass used at Baker in 1955 was of the same type as one that had been very effective in the experiments at Cultus Lake but it was inadequate in the forebay of Baker Dam. Large schools of fish accumulated in the area upstream from the entrance but did not readily enter the by-pass. A third problem was that the vertical distribution of the fish was changed after they encountered the electric screen. Increases in the proportion of fish migrating through the tunnel when the electric screen was operating indicated that many fish were guided to the deeply submerged tunnel intake by the electrified zone.

The marked difference between the results obtained at Cultus Lake and those obtained at Baker Dam demonstrated some limitations of laboratory and small-scale experiments as a means of predicting the practical guiding efficiency of an electric screen in a large, deep forebay. Therefore, it was considered important that subsequent investigations be conducted at the prototype level.

In 1956, these experiments were continued at Baker Dam. An electric screen was installed across the forebay to prevent fish from passing over the spillway and to divert them to a by-pass at the crest of the dam. Nets and traps were installed below the dam and a sampling procedure was used to calculate the numbers of fish passing over the spillway and through the tunnel. The effectiveness of the screen was then determined by comparing the catches in the by-pass trap with computed spillway and turbine escapements.

The objectives of the investigations were: first, to make a qualitative study of the reactions of fish to this type of electric screen in a deep reservoir; second, to determine some of the requirements of an efficient by-pass; and third, to measure the overall efficiency of the electric screen and by-pass. The present report describes the results of this investigation.

DESCRIPTION OF EXPERIMENTAL FACILITIES

The electric screen used in this experiment was of the same design as that used in 1955 but was located in a different area in the forebay. In 1955, the electric screen was installed across the forebay from a point near the center of the dam to a point on the east shore. The arrangement of the electric screen and by-pass was designed to take into account the natural horizontal distribution of fish in the forebay; the by-pass was located in the main path of the migration along the west or shaded shore and the electric screen was placed on the other side of the forebay to deflect the small numbers of fish migrating downstream along the east shore. It was considered that this would be the most efficient arrangement for guiding the fish in the forebay of Baker Dam. However, in 1956, it was considered advisable, for experimental purposes, to place the electric screen across the main migration route on the west or shaded shore of the forebay in order to increase the proportion of fish encountering the electric screen, thereby providing more opportunity for observing their reactions.

This screen was 200 feet long and 50 feet deep and consisted of vertical electrodes in two parallel rows spaced two feet apart. In each row the electrodes were 1/8-inch diameter galvanized iron wires, hung vertically at intervals of one foot along a single $\frac{1}{4}$-inch diameter copper conductor supported by cork floats. The screen extended upstream and across the forebay from a point near the center of the dam to within 35 feet of the west shore (Figure 1). The gap between the end of the screen and the shore, where the water was shallow, was blocked off by a webbing barrier appropriately shaped and weighted to fit the contours of the bottom and provide a seal with the shore regardless of fluctuations in the forebay elevation.

The electric screen was energized with direct current, a stimulus found to be very effective for guiding sockeye migrants in small-scale experiments at Cultus Lake. Energy, obtained from a 75-kilowatt direct current generator located on the east shore of the forebay, was supplied to the electrodes by a pair of feeder lines leading out from the generator and attached to the midpoint of the electric screen.

The by-pass consisted of a floating channel located immediately upstream from a spillway gate near the center of the dam, as shown in Figure 1. This channel, constructed of plywood and painted black, was

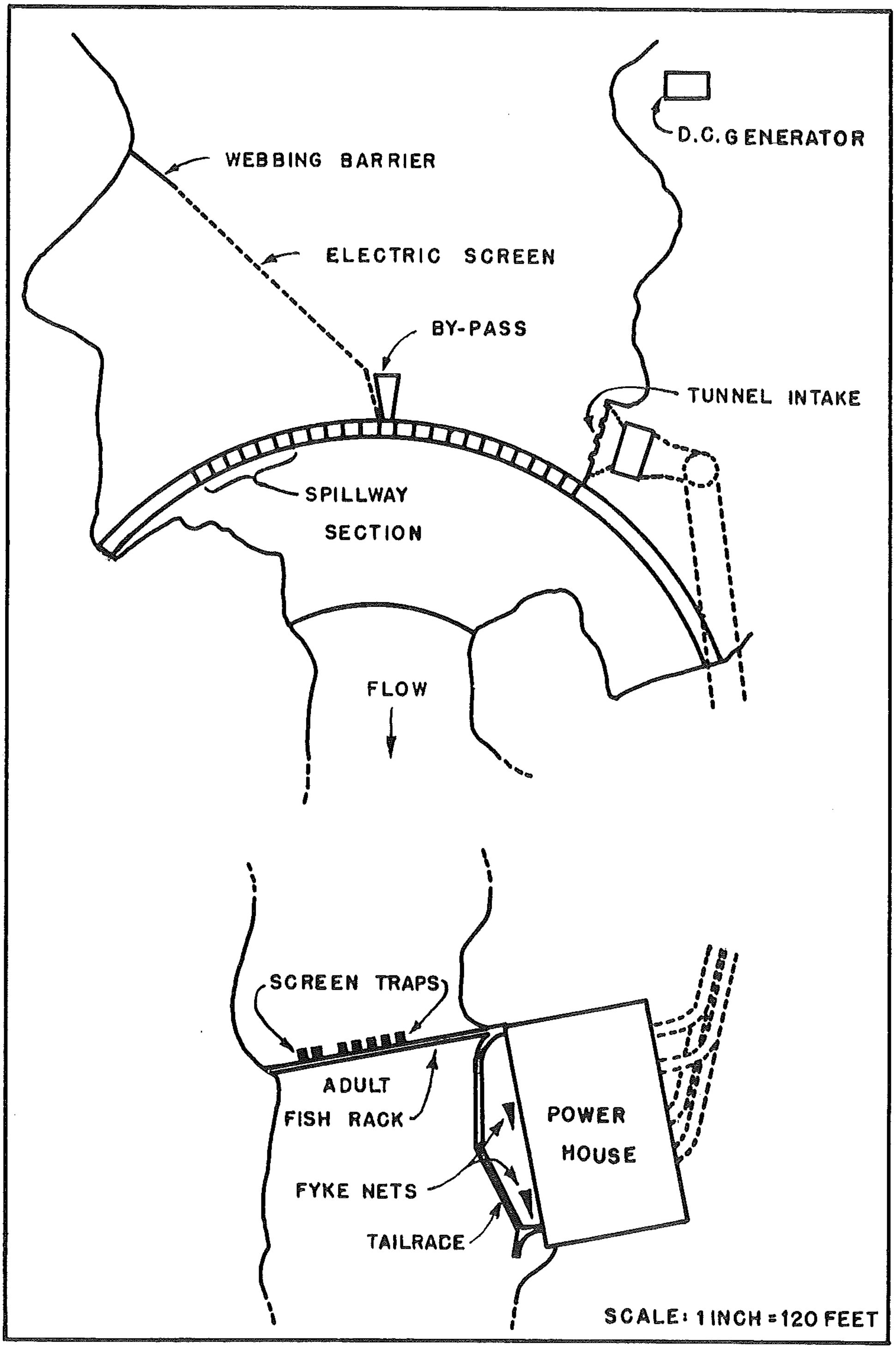

Figure 1. Experimental facilities at Baker Dam, 1956.

32 feet long with a 16-foot square opening at the upstream end and an 8-foot wide by 12-foot deep opening at the downstream end (Figure 2). Trapping facilities placed in this by-pass channel consisted of a vertical panel of $\frac{1}{4}$-inch-mesh wire screen across the mid-section of the channel with an 8-foot wide by 6-foot deep opening at the water surface and a sloping wire screen projecting downstream from this opening to a plywood collecting compartment. The water depth over the sloping screen at the entrance to the collecting compartment varied from 7 to 10 inches. The collecting compartment and all screens were painted black so as to be less perceptible to the fish. The downstream end of the by-pass channel was connected to a large wooden gate having a 7-foot square opening near the top. This gate, which was 17 feet deep and 10 feet wide, ran in guides on the upstream face of the dam and was raised and lowered to follow fluctuations in the forebay elevation. Water was drawn through the by-pass channel and the wooden gate by opening the spillway gate immediately downstream from these structures and the flow was controlled by regulating the size of opening of the spillway gate. The amount of flow was systematically changed to determine its effect on the by-pass efficiency. A reverse-polarity electric screen[1] was installed across the entrance of the by-pass in an attempt to attract fish into the by-pass and also to stop those that entered from swimming back out. Submerged spotlights located near the upstream end of the by-pass were also used in an attempt to attract fish into the entrance. The details of the reverse-polarity screen and the submerged spotlights will be described later.

[1] At Sweltzer Creek in 1954 it was found that when two rows of electrodes, placed across a flume, were energized with direct current or interrupted direct current with the cathode row upstream and the anode row downstream, fish that encountered this screen were forcibly drawn downstream and were unable to swim back upstream through the energized electrodes.

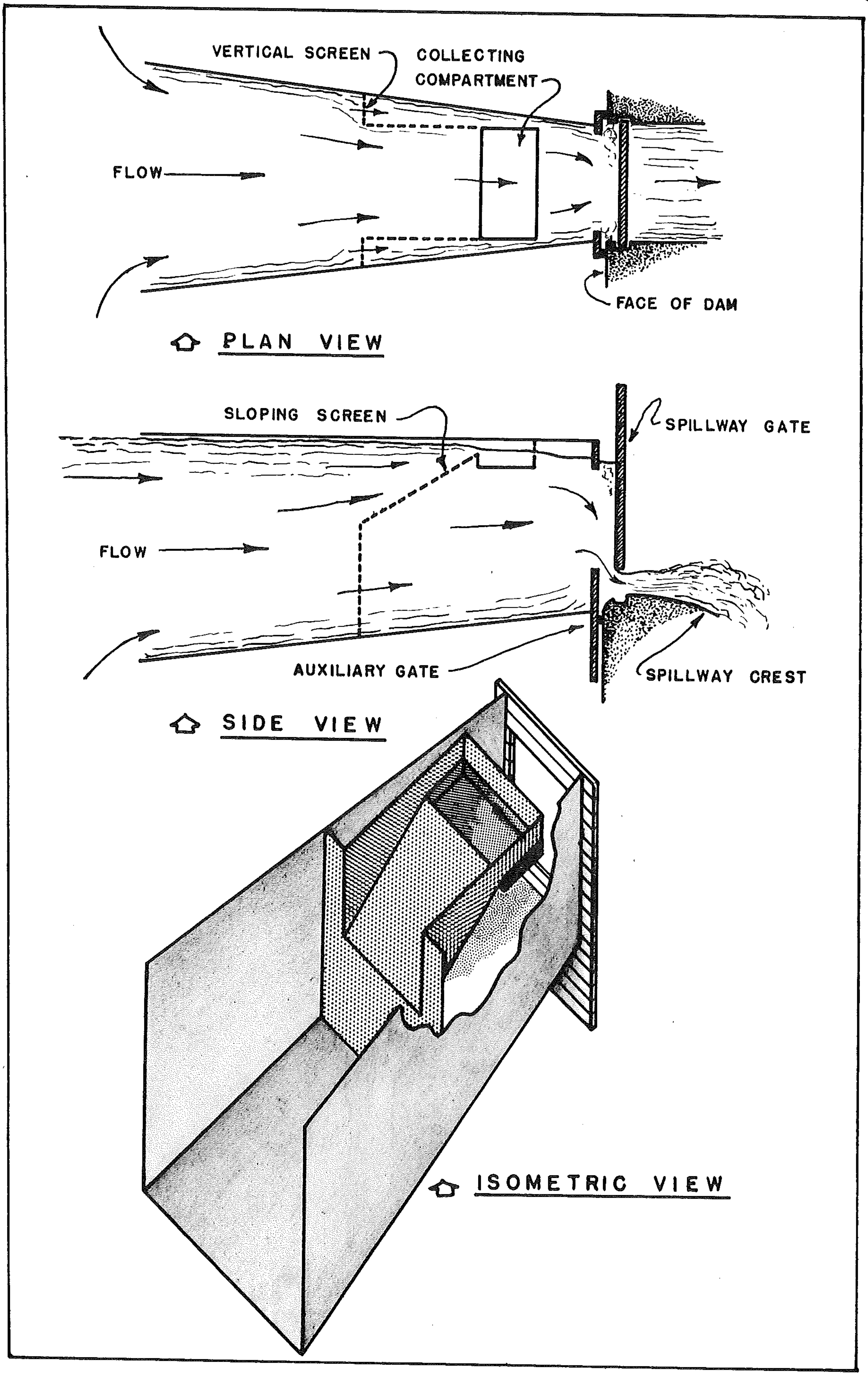

Figure 2. By-pass channel used at Baker Dam, 1956.

To enumerate the migration over the spillway, seven screen traps were placed on the inclined upstream face of an adult fish rack located in the river below the dam (Figure 1). These traps were rectangular boxes 8 feet long, 4 feet wide and 8 inches deep with $\frac{1}{4}$-inch-mesh screen bottoms and wooden sides. They were mounted on casters which ran in grooved tracks on the face of the adult fish rack. As shown by the 1955 experiments, these traps caught a representative proportion of the fish passing over the spillway.

To enumerate the migration through the tunnel and turbines two webbing fyke nets were installed in the tailrace of the power plant. One of the nets was 6 feet square at the upstream end and the other was 5 feet square.

The efficiency of the enumeration gears was determined by the rate of recapture of marked fish released over the spillway and through the tunnel. The fish were marked by an electric tattooing machine. Releases over the spillway were made by pouring groups of approximately 100 fish from a bucket into the fast-flowing water upstream from an open spillway gate. Fish were released into the tunnel by lowering groups of fish enclosed in a weighted bag down an air vent connecting with the upstream end of the tunnel. A quick upward pull on the lowering rope opened the bag and released the fish.

COMPUTATION OF MIGRATION RATES

The number of fish released and the number of each group recovered are shown in Tables 1 and 2. Only coho were used in the releases because not enough sockeye were available for this purpose. Releases over the spillway

TABLE 1

RECOVERY RATES OF MARKED COHO RELEASED OVER THE SPILLWAY

Number of Spillway Gates Open	Number Released	Number Recovered	Per Cent Recovered
1	106	2	1.89
	108	2	1.85
	109	4	3.67
	102	2	1.96
	105	0	0
	110	1	0.91
	unweighted average		1.71
	weighted average		1.72
2	100	5	5.00
	100	3	3.00
	100	5	5.00
	109	6	5.50
	106	5	4.72
	109	3	2.75
	unweighted average		4.33
	weighted average		4.33

TABLE 2

RECOVERY RATES OF MARKED COHO
RELEASED THROUGH THE TUNNEL

Number Released	Number Recovered	Per Cent Recovered
113	10	8.85
111	15	13.51
111	9	8.11
	unweighted average	10.16
	weighted average	10.15

were made at the one- and two-gate spill conditions and it was noted that the recovery rate with one gate of spill was lower than that obtained at the two-gate spill condition; a result previously observed in the 1955 experiment. The numbers of fish migrating over the spillway were computed separately for the one- and two-gate spill conditions based on the weighted average recoveries at each of these conditions. The migration over the spillway during times when more than two gates were spilling could not be determined because at this condition the water level upstream from the rack was too high to permit operation of the traps.

Although the recovery rates of marked fish in the tailrace fyke nets showed considerable variation, the weighted average recovery rate of 10.15 per cent was similar to that obtained for fyke nets placed in the same locations in the 1955 experiments and this value was used as the best estimate for enumerating the tunnel migration. Such a small number of the migrating fish passed through the tunnel in relation to the number passing over the spillway that even if the calculated recovery rates were considerably in error, the percentage distributions of fish captured in the by-pass and migrating over the spillway and through the tunnel would not be appreciably affected.

EFFICIENCY OF ELECTRIC SCREEN

Tests were conducted during daylight and darkness with different voltage gradients to determine the effectiveness of the screen. Tables 3 and 4 show the combined data. The catches in the by-pass trap and the estimated escapements over the spillway and through the tunnel are shown as percentages of the total number of fish migrating from the reservoir during each set of experimental conditions.

TABLE 3

CONTROL AND TEST DISTRIBUTIONS OF SOCKEYE
UNDER VARIOUS EXPERIMENTAL CONDITIONS

	DAYLIGHT			DARKNESS			
Voltage on Electrodes	0 (Control)	72	96	0 (Control)	48	72	96
One-gate Spill							
No. of tests	1	1					
No. of fish	481	412					
% Through tunnel	2.10	0					
% Over spillway	97.50	100.00					
% In by-pass trap	0.40	0					
Two-gate Spill							
No. of tests	6	1		2	1	2	1
No. of fish	514	25		229	224	388	77
% Through tunnel	3.88	0		0	0	10.30	0
% Over spillway	95.74	100.00		96.94	98.66	88.92	96.10
% In by-pass trap	0.38	0		3.06	1.34	0.78	3.90

TABLE 4

CONTROL AND TEST DISTRIBUTIONS OF COHO
UNDER VARIOUS EXPERIMENTAL CONDITIONS

	DAYLIGHT			DARKNESS			
Voltage on Electrodes	0 (Control)	72	96	0 (Control)	48	72	96
One-gate Spill							
No. of tests	1	1		2			
No. of fish	2317	294		1198			
% Through tunnel	0	0		2.50			
% Over spillway	99.10	100.00		78.46			
% In by-pass trap	0.90	0		19.04			
Two-gate Spill							
No. of tests	6	1		3	1	2	1
No. of fish	2426	26		2183	707	1362	597
% Through tunnel	0.41	0		1.85	11.18	13.06	8.20
% Over spillway	99.14	96.20		84.28	79.35	70.34	57.60
% In by-pass trap	0.45	3.80		13.87	9.47	16.60	34.20

During both daylight and darkness most of the fish used the spillway as an exit from the forebay regardless of whether the electrodes were energized or not. When the electrodes were energized during darkness with 48, 72, and 96 volts respectively, there was a progressive decline in the percentage of fish passing over the spillway and a progressive increase in the percentage of fish entering the by-pass. This result was more pronounced for coho than for sockeye. The highest percentage of fish was caught in the by-pass when the electrodes were energized with 96 volts. However, a comparison of the proportion of fish caught in the by-pass with the proportion caught in control tests (power off) indicates that the electric screen was not very effective at <u>any</u> of the conditions tested. It was also observed, as in previous experiments, that many of the fish sounded when they encountered the electrified area as shown by the increased migration through the tunnel during "power on" periods.

The electric screen and by-pass were far less efficient during daylight than during darkness. The maximum proportion of migrating fish caught in the by-pass when the electric screen was operating was about four per cent during daylight and about 34 per cent during darkness. However, a comparison of control tests conducted during daylight with those conducted during darkness shows that the by-pass was not effective during daylight. Therefore, although it appears that the efficiency of the electric screen decreased during daylight, the difference in results obtained between daylight and darkness might be due entirely to the marked reduction in the effectiveness of the by-pass during daylight.

The relative proportions of sockeye and coho using the various exits from the reservoir are shown in Figure 3. It can be seen that the electric

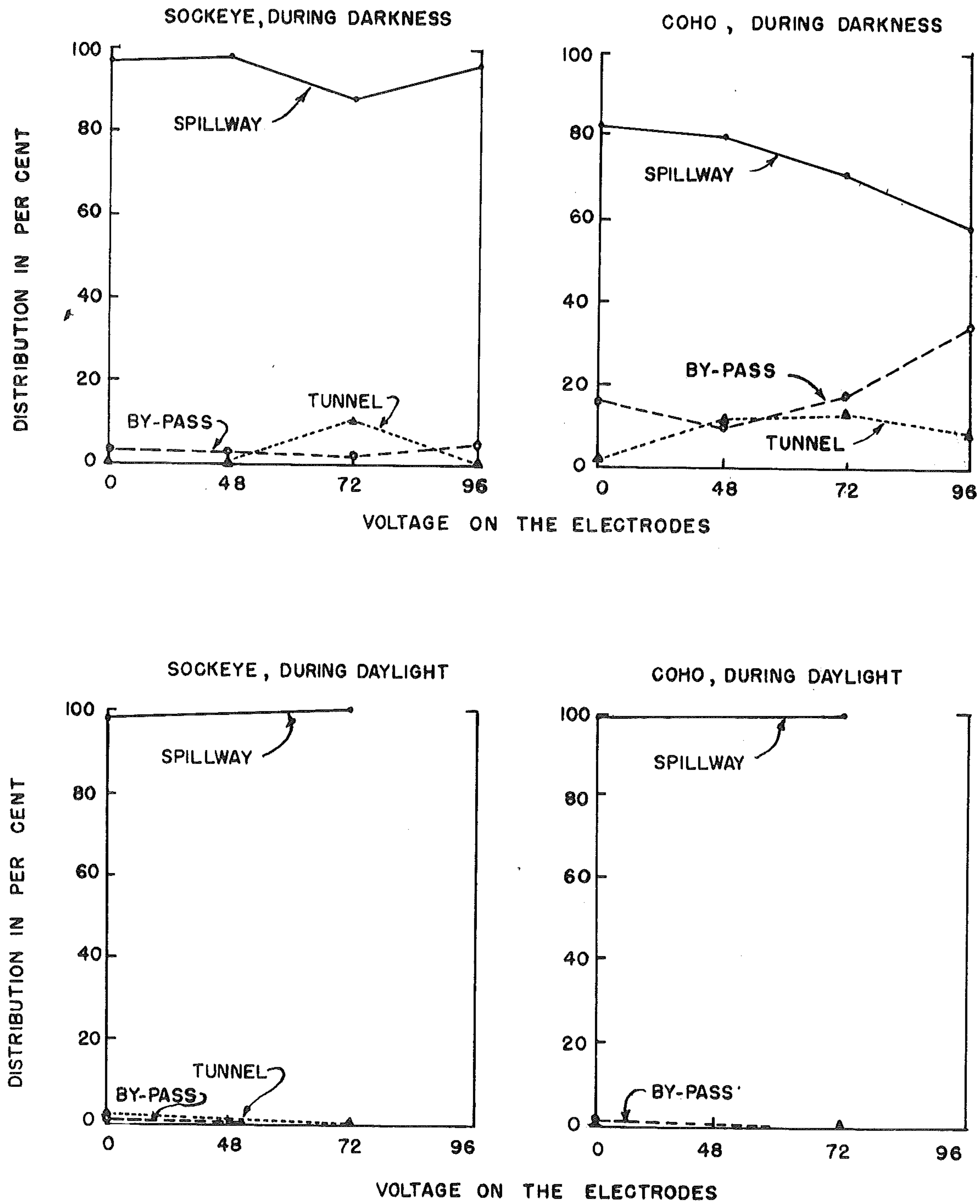

Figure 3. Percentage distribution of sockeye and coho over the spillway, through the tunnel, and in the by-pass trap during spillway discharges of one and two gates.

screen was more effective in diverting coho than sockeye. When the screen was energized with 96 volts during darkness the proportion of coho using the by-pass was 34 per cent, a substantial increase over the 14 per cent using this exit during control tests. During this same "power on" test the proportion of sockeye caught in the by-pass was only four per cent, which was not significantly different from the three per cent that used the by-pass during control tests. The difference in results between sockeye and coho apparently was not caused by a difference in vertical distribution since nearly all of the sockeye and coho used surface exits during control tests. However, this difference might have resulted from a difference in size between sockeye and coho; the coho being considerably larger than the sockeye. The mean fork length of a sample of 324 coho was 4.13 inches with a range of 3.18 to 5.63 inches whereas the mean fork length of a sample of 63 sockeye was 3.49 inches with a range of 2.99 to 4.29 inches. Since previous experiments had shown that the voltage gradient required to produce galvanotaxis increased as the length of the fish decreased, the voltage gradient that deflected a proportion of the coho was probably less effective in deflecting the smaller sockeye.

Although the efficiency of the electric screen appeared to improve as the applied voltage was increased, it should be noted that the maximum voltage used in these experiments was far higher than that required to produce efficient galvanotropism in small-scale tank experiments conducted with native sockeye and coho at Baker Dam in 1954. These small-scale experiments were conducted to determine whether fish would exhibit a galvanotropic reaction in the low-conductivity water at Baker Dam and also to determine the intensity of the stimulus required. The specific resistance of the water was varied between 3,150 ohms per inch-cube (similar to Cultus Lake water) and 12,300 ohms per inch-cube (Baker River water) and it was found that the voltage gradient required to produce galvanotropism had to be raised as the resistivity of the water was increased. In water with a specific resistance of 3,150 ohms per inch-cube, the voltage gradient required to cause all of the fish to move to the anode was 1.75 volts per inch. When the specific resistance of the water was 12,300 ohms per inch-cube, a voltage gradient of 2.5 volts per inch was required. From these results, it was calculated that the required voltage between electrode rows spaced two feet apart in water with the same resistivity as at Cultus Lake was 42 volts, which agreed very closely with the actual applied voltages of 40 and 48 found to be very effective for guiding fish at Cultus Lake. Higher voltages caused severe immobilization.

On the basis of this information, therefore, the optimum applied voltage for an electric screen of the same design operating in the high-resistivity water at Baker Dam was calculated to be 60 volts (nominal voltage gradient of 2.5 volts per inch). The small-scale experiments also showed that the degree of immobilization increased very rapidly as the voltage gradient was increased above the observed optimum value. For instance, when the voltage gradient was 2.5 volts per inch approximately 20 per cent of the fish became immobilized after an exposure of 5 seconds in the electrified zone whereas when the voltage gradient was increased to 3.0 volts per inch 65 per cent of the test fish were immobilized.

Therefore, it was considered that 96 volts (nominal voltage gradient of 4.0 volts per inch), the maximum voltage applied to the electric screen in the 1956 experiments, was much higher than the optimum voltage for successful guiding. When exposed to this high voltage gradient, the fish probably suffered severe immobilization so that the indicated efficiency of the electric screen and by-pass could be erroneous. The indicated increase in the efficiency of the electric screen at the high voltages might have been caused by a decrease in the availability of fish to the traps in the river below the dam because of immobilization and settling out of dead or injured fish in the forebay.

REACTION OF FISH TO ELECTRIC SCREEN

From experiments conducted at Baker Dam in 1955 it was apparent that fish reacted differently to an electric screen located in deep turbid water in a forebay than to a similar screen operating in a clear shallow stream. In the experiments at Cultus Lake the fish migrated downstream in relatively compact schools and when they encountered the electric screen several of the members at the leading edge of the school entered the electrified area but quickly darted out, thereby deflecting the main school. Occasionally some of the fish passed through the electrified zone but generally they returned upstream through the electrified zone and rejoined the school. Although fish made frequent attempts to pass through the barrier, the schools remained intact and followed downstream along the upstream face of the screen to the by-pass. At Baker a different reaction was indicated. A proportion of the migrating fish were temporarily stopped by the energized electrodes but apparently they did not remain on the fringe of the electrified area and follow along the screen to the by-pass. A further undesirable reaction was the tendency for fish to change their vertical distribution when they encountered the electrified area so that they descended in the forebay and some entered the deeply submerged tunnel intake.

Although the end results of the reactions of fish to the electric screen were indicated by the measured proportions of fish passing through the various exits from the reservoir, the series of reactions that led to the selection of these exits could not be observed. The water upstream from the dam was so turbid that fish could be observed only when they were within about three feet of the water surface. Therefore, another method of observing their reactions was required.

Observations made in 1955 by the United States Fish and Wildlife Service using an echo-sounding device ("Sea Scanar") were helpful in determining the vertical distribution of fish in the forebay (Trefethen, 1955). Individual schools of fish were located and kept under observation for periods as long as one hour. The positions of fish schools in relation to the position of the electric screen were indicated on a calibrated screen and the depths of the schools could be determined by simple calculations. The results obtained in these trials suggested the possible usefulness of this device.

In 1956, a Minneapolis-Honeywell "Sea Scanar" (Model 1 B, modified) was installed in the forebay of Baker Dam in an attempt to locate and follow schools of fish and to determine their reactions to the electric screen. This device, a high-frequency sonar system, utilized the passage of transmitted and reflected sound energy through water as a means of determining the location of underwater objects. It consisted of three major components: a submersible transducer, a transmitter-receiver, and an indicator. The transducer, supplied with energy from the transmitter, sent out a narrow diverging beam of high-frequency sound energy through the water. Part of this energy, upon contact with underwater objects in the path of the beam, was reflected back and picked up again by the transducer. The position of the reflecting object was shown as a visible spot of light on a cathode-ray tube. A screen located in front of this tube and calibrated in distances and angles was used to plot the position of the object in relation to the known location of the transducer. The direction of the transmitted beam could be varied through any horizontal angle, either automatically or manually, within a range of 240 degrees in combination with any downward tilt from 0 to 90 degrees. The ranges provided were from zero to 100, 200 and 400 feet.

This equipment was operated for considerable lengths of time throughout the experimental period and the transducer was tried in several different locations in the forebay. At all times clear images of the dam, the electric screen, and the shoreline were obtained. Positions of large metal objects suspended at various depths from a boat in different areas of the forebay were also easily located but despite the success obtained with similar equipment in 1955, the movements of fish schools could not be followed with this equipment during the 1956 experiment. Apparently the effectiveness of this equipment for detecting fish was governed to a large extent by the size and compactness of schools and since the number of sockeye migrating from the reservoir each day was considerably less than in 1955 the fish may not have been concentrated in large enough schools to be easily detected. The coho, although present in greater numbers than the sockeye, were probably not observed because of their less pronounced schooling tendency.

EFFICIENCY OF WEBBING BARRIER

The use of a shallow webbing barrier in place of the electric screen clearly demonstrated the ineffectiveness of the latter. In this experiment the webbing barrier was placed across the forebay in the same location as the electric screen. It consisted of a piece of $\frac{1}{2}$-inch stretched-mesh cotton webbing 200 feet long suspended from the water surface to a depth of 15 feet. With this net in place during darkness and one spillway gate open downstream from the barrier, the percentage of fish caught in the by-pass trap was considerably higher than when the electric screen was operating and was far greater than the percentage caught in the by-pass during controls. This is illustrated in Table 5.

Although this barrier was only 15 feet deep and there were openings at both ends through which fish could escape, it was far more efficient than the electric screen, which was joined to the bank at one end and to the dam at the other end and extended to a depth of 50 feet.

EFFICIENCY OF BY-PASS

The by-pass described earlier was different from that used at Baker in 1955. In 1955, the by-pass consisted of an inclined-screen trap constructed on the downstream side of a spillway gate. The entrance to this by-pass was a narrow orifice 7 feet 3 inches wide and 6 inches deep with the top edge submerged to a depth of 20 inches. The discharge was 24 cubic feet per second. The rapid acceleration of water at the by-pass entrance appeared to frighten the fish and only those members of a school that were crowded into the high approach velocities close to the orifice were captured in the by-pass trap. The addition of a reverse-polarity electric screen at the entrance to the trap did not aid in attracting fish into the by-pass and modification of the entrance so that it operated as an overflow weir, which almost doubled the discharge, did not appear to have any effect on the efficiency. Similarly, a surface current directed towards

TABLE 5

DISTRIBUTION OF COHO PASSING THROUGH VARIOUS EXITS DURING DARKNESS

Type of Deflector	Per Cent in By-pass	Per Cent Over Spillway	Per Cent Through Tunnel
		One-gate Spill	
Control (no deflector)	19.04	78.46	2.50
Webbing Barrier	68.20	31.80	0
		Two-gate Spill	
Control (no deflector)	13.87	84.28	1.85
Electric Screen			
48 volts	9.47	79.35	11.18
72 volts	16.60	70.34	13.06
96 volts	34.20	57.60	8.20

the by-pass from a pump located in the forebay did not appear to increase the by-pass efficiency. It was considered that the low discharge through this by-pass was not sufficient to attract deflected fish and that the rapid acceleration of water at the by-pass entrance frightened them.

The by-pass installed in 1956 was operated with about ten times the discharge used in 1955. It was designed to extend the influence of flow farther upstream and provide attraction over a greater distance. The by-pass entrance was made large to permit low approach velocities and the sides and bottom of the by-pass converged towards the downstream end to produce a gradual acceleration of water in the direction of the fish collecting compartment. With the by-pass operating at a discharge of 265 cubic feet per second the water velocity at a point 16 feet upstream from the by-pass was approximately 0.2 feet per second which gradually increased to a mean velocity of 1.1 feet per second at the by-pass entrance and further increased to a maximum of 2.0 feet per second at the entrance to the collecting compartment.

The distribution of water velocities in the forebay in relation to the water velocities near the by-pass entrance affected the by-pass efficiency. Velocities along the upstream face of the electric screen were considerably lower than those near the by-pass entrance. However, a slight change in the velocity through the electric screen resulted in a change in the by-pass efficiency. With one gate spilling behind the electric screen the mean water velocity at the face of the screen was 0.15 feet per second and at a two-gate spill was 0.2 feet per second. The proportions of fish caught in the by-pass during control experiments at these two spill conditions were 19.04 per cent with a one-gate spill and 13.87 per cent with a two-gate spill.

This by-pass was a definite improvement over that used in 1955. Fish were not observed to accumulate in large numbers and delay at the entrance to the by-pass as they had done in 1955. The mean percentage of fish caught in the by-pass during control experiments in 1955 for the one-gate and two-gate spill conditions were 9.02 and 9.82 per cent respectively, and in 1956 were 19.04 and 13.87. Although the increase in by-pass efficiency was not great it should be emphasized that in 1956 the by-pass was purposely installed in a less favorable location. In view of the difference in location, the increase in by-pass efficiency obtained in 1956 was greater than is indicated by comparing the percentage catches in 1955 and 1956.

The effectiveness of the by-pass used in 1956 was indicated more conclusively in the tests with a webbing barrier in place of the electric screen. These tests showed the by-pass to be quite effective during darkness but it was apparent that only a very small proportion of the fish entered it during daylight.

A series of tests was conducted to determine the effect of flow on the efficiency of the by-pass. In these tests the flow through the by-pass was changed every two hours between discharges of 135, 190, 226 and 265 cubic feet per second and all other controllable conditions were maintained constant. The mean water velocities in the entrance of the by-pass at the above discharges were 0.5, 0.7, 0.9 and 1.1 feet per second respectively. Fish were removed from the by-pass and from the sampling gear below the dam every two hours and the by-pass efficiency was expressed as a percentage of the total number of fish migrating within each two-hour period. Because the range of flows tried in these experiments was not great and because there was considerable variation in the results of tests at each flow condition, no significant difference between the efficiencies at different flows or velocities was indicated.

A reverse-polarity trap located at the entrance of the by-pass channel was operated almost continuously during the period of experiments. This trap consisted of two parallel rows of electrodes two feet apart placed across the entrance of the by-pass and extending from the water surface to the bottom of the channel. Each row was composed of $\frac{1}{4}$-inch diameter iron rods 16 feet long suspended vertically at intervals of one foot. The cathode or negatively charged row was located approximately one foot downstream from the by-pass entrance and the anode row was placed two feet farther downstream.

The by-pass efficiency increased when the reverse-polarity trap was operating. Observations were frequently made in the area upstream from the reverse-polarity trap but few fish were seen in this area and no information was obtained to show that fish were attracted into the by-pass by the energized electrodes. On several occasions fish appeared to be repelled, but comparison of the relative by-pass efficiencies obtained during "power on" and "power off" periods indicated that the reverse-polarity trap increased the by-pass catches. Observations made in the by-pass downstream from the reverse-polarity trap showed that many fish present in this area attempted to swim back out of the by-pass but practically all of them were forced downstream again by the reverse-polarity trap. In several short tests the electrodes were energized with 60-cycle alternating current but this stimulus was less effective in preventing escape than direct current. It was concluded that the reason the by-pass efficiency increased when the reverse-polarity trap was operating was that the fish were prevented from swimming back out of the by-pass once they had entered.

The by-pass efficiency appeared to be further increased by the use of lights during periods of darkness. A subsurface spotlight near the entrance of the by-pass appeared to attract fish towards the by-pass and another light located above the water surface at the center of the collecting compartment induced fish to enter this compartment and tended to keep them confined in this area. The light at the by-pass entrance was a 150-watt spotlight fitted with a reflector. It was located on the center line of the by-pass approximately 4 feet upstream from the reverse-polarity trap and was submerged to a depth of 40 inches with its beam facing upstream and directed downward at an angle of approximately 20 degrees. Guy wires from the light support to the sides of the by-pass prevented excessive vibration of the light in the flowing water. As the water in the forebay was usually very turbid, the beam from the spotlight was not sharply defined; an area of fairly bright but diffuse illumination approximately semicircular in shape was created. This area extended upstream for a distance of about 30 feet but a small amount of light was reflected downstream as well so that the entrance to the by-pass was dimly illuminated.

Opportunities to observe the reactions of fish were restricted by a scarcity of fish in these experiments but, on the basis of the few observations possible, it appeared that the reactions of the fish to the submerged spotlight were similar to those observed in previous experiments at Cultus Lake and Baker Dam. Fish appeared to enter the illuminated area without hesitation and swam towards the main beam of light where they congregated and remained for short periods of time moving back and forth alternately between the bright and dark areas near the light. The spotlight was turned on and off in alternate hourly periods, and more fish were caught when the light was on than when it was off.

In an attempt to eliminate delay and to induce fish to enter the by-pass more readily instead of congregating near the light, a second spotlight was installed. This light, a 75-watt spotlight, was located in the center of the by-pass, 16 feet downstream from the by-pass entrance. It was submerged to a depth of 24 inches with its beam facing upstream and directed downward at an angle of about 20 degrees. No apparent increase in the by-pass efficiency was obtained when this light was used, nor was there any indication that the fish entered the by-pass more readily. Furthermore, those that did enter the by-pass tended to remain in the area surrounding the light instead of moving downstream into the collecting compartment.

A light located above the collecting compartment, on the other hand, improved the efficiency of the by-pass. This light, a 150-watt spotlight, was located directly above the collecting compartment and was suspended 4 feet above the water surface with its beam directed vertically downward. Sheets of plywood were used to confine the light to the collecting compartment. In several tests, in which this light was switched on and off for alternate periods, it was found that more fish entered the collecting compartment when this light was on than when it was off. When the light was first turned on following a period of darkness, very few fish were seen in the collecting compartment but almost immediately those that had accumulated in other areas of the by-pass were attracted into the lighted area and remained there.

When the plywood shades serving to confine the light to the collecting compartment were moved so that an area immediately upstream was illuminated, several fish present in the collecting compartment swam into the newly lighted area. When these shades were replaced in their original position, the fish returned to the collecting compartment.

DISCUSSION

The results of this study were very similar to those obtained in the experiments at Baker Dam in 1955. These studies have indicated that the electric screen used in these experiments was not effective as a device for guiding downstream-migrant salmon. This screen, which was installed to prevent fish from passing over the spillway, had a very limited effect on the passage of fish through the various exits from the forebay. Although it did act as a barrier to a small proportion of the migrating fish, the majority were only temporarily stopped and after a short delay were able to either penetrate the screen or contrary to their normal migration habits, sound beneath the screen and resume their migration. One objection to this screen was that the fish were not guided along the electrified zone to the by-pass. Another undesirable feature was that fish descended when they encountered the electrodes; many entered the subsurface turbine entrance instead of remaining near the surface and entering the by-pass provided.

The reactions of the fish to this prototype screen were very different from those exhibited in the small-scale experiments. The prototype screen was similar to an electric screen found to be successful at Cultus Lake; the spacing of electrodes, the distance between rows, and the angle of deflection were almost identical. However, the depth of the screen had to be increased for use in the deep forebay at Baker Dam and the voltage applied to the electrodes had to be increased because of the lower conductivity of the water. The low efficiency of the prototype screen could not be attributed to excessive water velocities because the water velocities along the electric screen at Baker Dam were relatively uniform and were lower than those at Cultus Lake.

The space relationships at the two experimental sites, however, were quite different. In the Sweltzer Creek experiments at Cultus Lake, the electric screen was located across a portion of the stream having an average depth of 2.5 feet. Since the maximum depth did not exceed 3.6 feet in this area and the electrodes extended to the bottom of the stream, the vertical distribution of the fish was restricted and the fish were forced to move in a lateral direction in order to avoid the energized electrodes. At

Baker, the electrodes were located in an area where the forebay depth was up to 220 feet so that when fish encountered the electric screen they were not restricted from changing their vertical distribution.

This electric screen extended far deeper than the normal swimming depth of the fish. Rees (1955) showed that under normal conditions 82 per cent of the sockeye and 90 per cent of the coho migrate downstream in the top 15 feet of the forebay of Baker Dam and that very few yearlings are normally present at depths greater than 30 feet. However, many fish were deflected downward by the electric screen and eventually entered the tunnel, the top of which was 85 feet below the surface of the reservoir. It is possible that some fish went under the energized electrodes, and then were attracted back to the surface again by the flow towards open spillway gates. Although the average difference between the mean daily temperatures at the surface of the reservoir and at the tunnel intake was seven degrees Fahrenheit, this temperature gradient did not prevent some fish from using the submerged tunnel as an exit from the reservoir.

The efficiency of the electric screen as a deflector may have been influenced by the turbidity of the water. The turbidity of the water in the forebay might have reduced the tendency of sockeye schools to remain together when they encountered the electrified area. In the clear water at Cultus, compact schools of sockeye were guided along the electric screen with only a few members of the school entering and quickly darting out of the electrified zone. At Baker, the relative numbers of fish using the by-pass and spillway exits and the rate at which fish entered the by-pass suggested that only a small proportion of each school was guided or that the guided schools were very small.

It was stated earlier that one difficulty encountered at Baker Dam was that the fish were not guided along the electric screen to the by-pass. Since it was considered that water velocities through the electric screen in relation to those at the by-pass entrance would have an important influence on the efficiency of the electric screen, the water velocities through this screen were kept at a minimum whereas the velocity at the entrance to the by-pass was considerably higher. To minimize water velocities through the electric screen and maintain them fairly uniform along the length of the screen, the spillway gates immediately adjacent to the west shore were used to discharge surplus water from the reservoir. The flow of water through the by-pass, which at times was as high as 15 per cent of the total surface discharge, produced by-pass entrance velocities seven times greater than those along the electric screen. Although the velocities through the electric screen were very low and there was no danger of fish being swept through the electrified zone by the flow, the fish apparently became dispersed in the forebay when they encountered the electric screen and did not follow along this screen to the by-pass. The webbing barrier, under similar flow conditions, however, provided a lead for the fish and directed them towards the by-pass. Since it is not likely that flow conditions as favorable for guiding fish as those existing at Baker Dam would be encountered at any of the dams that have been proposed for construction on the Fraser River the limitations of this electric screen are obvious.

The improved guiding efficiencies obtained with the shallow webbing barrier suggest that further experiments with similar physical barriers are warranted because this type of barrier might be effective at certain dams where forebay velocities are low and debris is not a problem.

The by-pass used in 1956 was more efficient than the smaller by-pass used in 1955. In spite of the less favorable location of the electric screen in 1956, the by-pass catches during times when the electric screen was energized were about the same as those obtained in 1955. A greater proportion of the fish might have been prevented from passing over the spillway if a number of by-passes had been installed at intervals along the electric screen. However, a more practical solution might be obtained by using a physical barrier and a single by-pass. The improved deflection and guiding obtained with the very shallow and rudimentary webbing barrier during periods of darkness demonstrated the ineffectiveness of the electric screen as a method of guiding downstream-migrant salmon and showed that the by-pass used in these experiments was quite effective in collecting fish during darkness provided they were guided to the by-pass entrance. This by-pass, however, was not effective during daylight.

The electric screen tested at Baker Dam in 1955 and 1956 was ineffective for guiding downstream-migrant salmon even though it was similar to an electric screen found to be very successful in small-scale experiments at Cultus Lake. Electric fish screens being developed by other fisheries agencies using other electrode arrangements and electrical conditions should be thoroughly investigated at the prototype level but further large-scale tests with the type of electric screen used in these studies at Baker Dam seem unwarranted.

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