DIVERSION OF ADULT SALMON BY AN ELECTRICAL FIELD

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United States Department of the Interior, Fred A. Seaton, Secretary
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DIVERSION OF ADULT SALMON BY AN ELECTRICAL FIELD

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ABSTRACT

An electrical weir consisting of a line of hanging electrodes and a submerged ground line has proved satisfactory for the diversion of adult salmon. The electrical field is created by 110-volt, single phase, 60-cycle, alternating electrical current available from most commercial sources.

The optimum operating conditions for a weir of this type require minimum stream velocity within the electrical field of 3 feet per second, minimum barrier voltage of 0.5 volts per inch, and minimum field length of 10 feet with a voltage gradient which may vary within the range of from 0.3 to 0.7 volts per inch in the effective field.

Adult salmon, once conditioned to the electrical stimulus, may be diverted from their normal migration path into an alternate route by the electrical field. With adequate water velocities and voltage gradients the electrical weir is a positive barrier to the upstream migration of adult fish. Downstream migrant salmon fingerlings pass through the weir with impunity.

The weir is generally applicable to the varying conditions encountered in salmon streams of the Pacific Coast.

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INTRODUCTION

The artificial propagation of salmon, unlike that of trout, is dependent, entirely, on the entrapment of wild fish as a source of eggs. Because of this dependency, the trapping and retention of the adult fish until maturity is one of the primary problems in salmon culture. The problem becomes particularly acute in some species of salmon where the interval between the upstream and spawning migrations may be as long as three or four months. Unless natural holding facilities such as lakes exist which cause the fish to remain concentrated until the spawning migration, the salmon must be captured on the upstream migration to prevent dispersal throughout the river system.

The confinement of the fish until maturity creates still another problem. The use of stream impoundments has proved unreliable because they are subject to the vagaries of seasonal stream flows which may destroy or bypass the retaining racks and permit the escapement of the entire spawning stock. A loss of such magnitude can be catastrophic to a program of artificial propagation for the production potential for an entire year may be lost. Artificial holding areas with controlled water supplies have proved much more reliable for the retention of the fish. With at least a partial solution to the impoundment problem available, actual diversion of the adult migration either into traps or into artificial holding areas becomes the critical factor in the procurement of the fish.

Conventional methods for diversion of salmon employ mechanical barriers of one sort or another to halt upstream progress of the fish and force them to seek another route. Such barriers usually impede stream flow and either become ineffective or are destroyed at high water stages. They are costly to install and difficult to maintain under most conditions and cannot be classed as positive barriers.

In the search for a positive method of diversion the use of an electrical field has been at least partially explored. Until the problem of sea lamprey control in the Great Lakes developed, the primary interest in the use of electrical barriers was for the diversion of downstream migrants. The history of these early experiments has been reviewed by Holmes (1948). The Great Lakes Fishery Investigations of the U. S. Fish and Wildlife Service, faced with the problem of controlling the sea lamprey, explored the possibilities of electrical fields both for the diversion of upstream migrants and as lethal devices. The results of these experiments using alternating current were reported by Applegate, Smith, and Nielsen (1952) and using direct current by McLain and Nielsen (1953). The conclusion drawn from these investigations was that an electrical field created by 110-volt, 60-cycle, alternating current was the most effective method for the diversion of upstream migrants.

The results of these investigations were utilized in the development of an electrical barrier for the diversion of adult salmon. Upon the recommendation of Mr. Bernard R. Smith of the Great Lakes staff, the alternating current field created by a single row of hanging electrodes and a ground line was selected as the most suitable for the stream conditions to be encountered at the Salmon-Cultural Laboratory. This installation, with some alteration, has been tested since 1953 as a method for the diversion of adult salmon. It has been found to be a positive barrier and an excellent method for the diversion of adult salmon. This report will be concerned with a general description of this type of weir, the factors influencing its efficient operation, the reaction of salmon to the electrical field, and the application of the weir in salmon culture.

DESCRIPTION OF THE WEIR

The requirements of an electrical field for the diversion of adult salmon differ considerably from those for the trapping and destruction of sea lamprey. Salmon, being larger, are more sensitive to an electrical field and therefore require a lower minimum voltage to provide a positive barrier. Because they are larger the momentum acquired before entering the field is greater and the field must have a greater depth if the fish are not literally to coast through the field even after they are immobilized. An electrical field for the diversion of salmon, therefore, should be of greater depth and less intensity than for lamprey control.

An idealized plan for installation of the diversion weir is shown in figure 1. This perspective drawing shows the hanging electrodes upstream from the parallel ground line and both forming an angle at the entrance to a fish ladder. Concrete abutments have been used to constrict the stream flow, to eliminate the normal tapered stream bank and to ensure a uniform, high velocity flow within the electrical field.

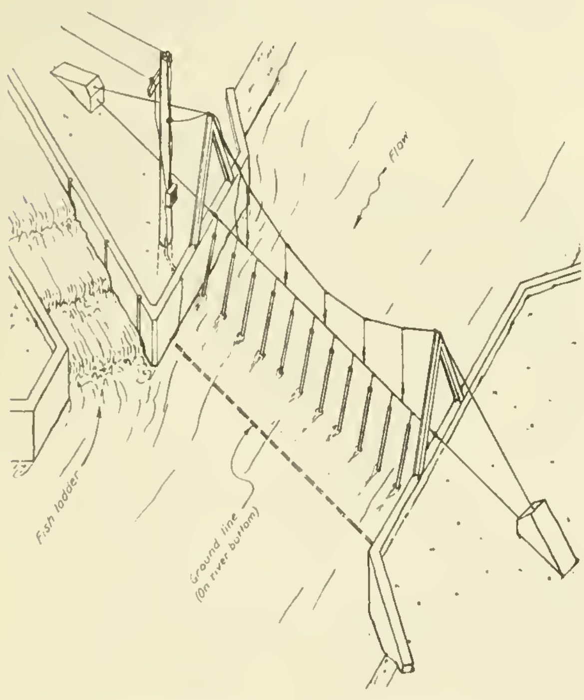


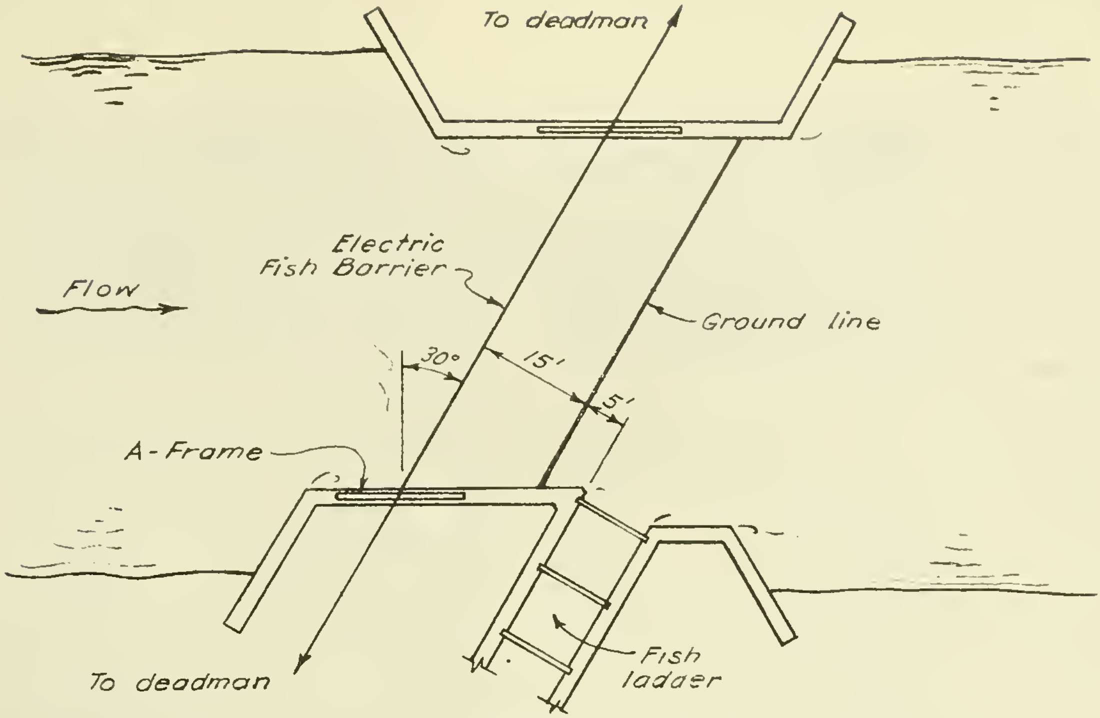
Figure 1.--Perspective drawing of idealized electrical weir installation with concrete abutments to constrict river flow. Fish ladder at left leading to retaining area.

The plan view of the installation and actual detailed dimensions and materials used are shown in figure 2. It is suggested that no alterations be made either in materials specified, type of installation, or dimensions given, in weirs which do not exceed 200 feet in length. Particular attention is directed to the method for attaching the pipe electrodes to supporting cables and to the anchoring and recessing of the ground line. These are areas in which difficulties were encountered and for which satisfactory solutions have been developed.

Single-phase, 110-volt, alternating current is used in this installation. The ground line is connected to the grounded side of the electrical circuit and the electrode cable to the activated side. No pulsation other than the normal 60 cycles is introduced.

The electrode cable must be well above the maximum high water level to allow for free passage of floating debris at flood stages of the river. The electrodes themselves should be of sufficient length to protrude above the maximum high water level and to penetrate two-thirds of the minimum low water depth. In the idealized installation no feather-edged stream bank exists due to the abutments which constrict the stream flow. In some situations, specifically where low stream banks preclude the constriction of the flow by use of abutments, the electrodes must extend into shallow water to establish a positive barrier. Under such conditions a one-inch clearance above the stream bottom is the minimum practicable. Unless the stream bottom is of uniform depth, which is highly improbable except when a concrete apron is constructed, the pipe electrodes must be cut to conform to the bottom contour with allowance made for the desired clearance. Numbering the electrodes will facilitate their installation each year.

The principal differences between this type of installation and the "type B" structure recommended by Applegate, Smith, and Nielsen (1952) are the substitution of flexible cable for channel iron in the mounting of the electrodes and the lengthening of the field from 8 to 15 feet. The substitution of cable for channel iron allows the electrodes to become free swinging in all directions. Although the field is erratic close to the electrodes it becomes stabilized within a distance of four feet below the electrodes. Such construction lightens the structure, simplifies the installation, and lowers the cost. The lengthening of the field is necessary because it reduces the voltage within the field and increases the length of the barrier.



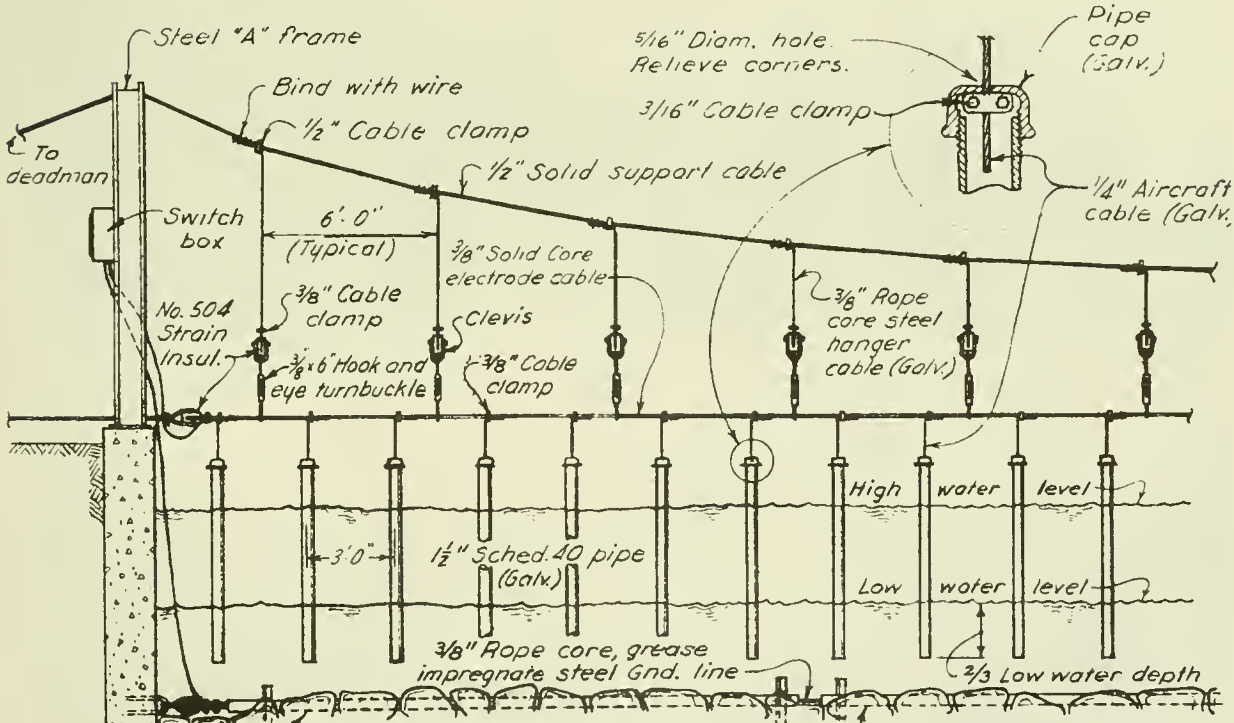


Figure 2.--Specifications of electrical weir. A. Plan view giving general dimensions; B. Detail of electrode and ground line installations.

The Entiat diversion weir, as shown in figure 3, differs from the idealized structure in that there are no abutments, and wooden "A" frames have been substituted for steel. The cost of materials for this 175-foot weir when it was installed in 1953 was $800. The installation itself was made by laboratory labor and required 200 man hours. The entire yearly maintenance cost including placement and removal of electrodes for seasonal operation is represented by less than 16 man hours of labor. The electrical demand varies with the number of electrodes submerged and the depth to which they are submerged. At low water stages of the river with approximately 32 feet of electrodes submerged the demand was 300 watts. At medium high water with 56 feet of electrodes submerged, the demand was 450 watts.

The power demand of the Entiat weir is considerably less than that of the Great Lakes weirs. This difference may be explained by the lower conductivity of the stream bottom at the Entiat weir site. Another contributing factor to a lower power demand as the stream depth increases, is the use of free swinging electrodes. The water velocity through the weir varies from 3 feet per second at low water stages to 10 feet per second at flood levels. As the depth of water increases the length of submerged electrodes does not increase accordingly because the current velocity forces the lower ends of the electrodes downstream and away from a vertical position. In figure 4 the amount of deflection is clearly demonstrated. Although the length of the electrical field is shortened the strength of the field is increased. No salmon has been able to pass through the field at any water stage of the river.

Figure 3.--The Entiat electrical weir looking upstream. Fish ladder to holding ponds at upper left. Ground line may be seen on bank between electrode line and fish ladder.

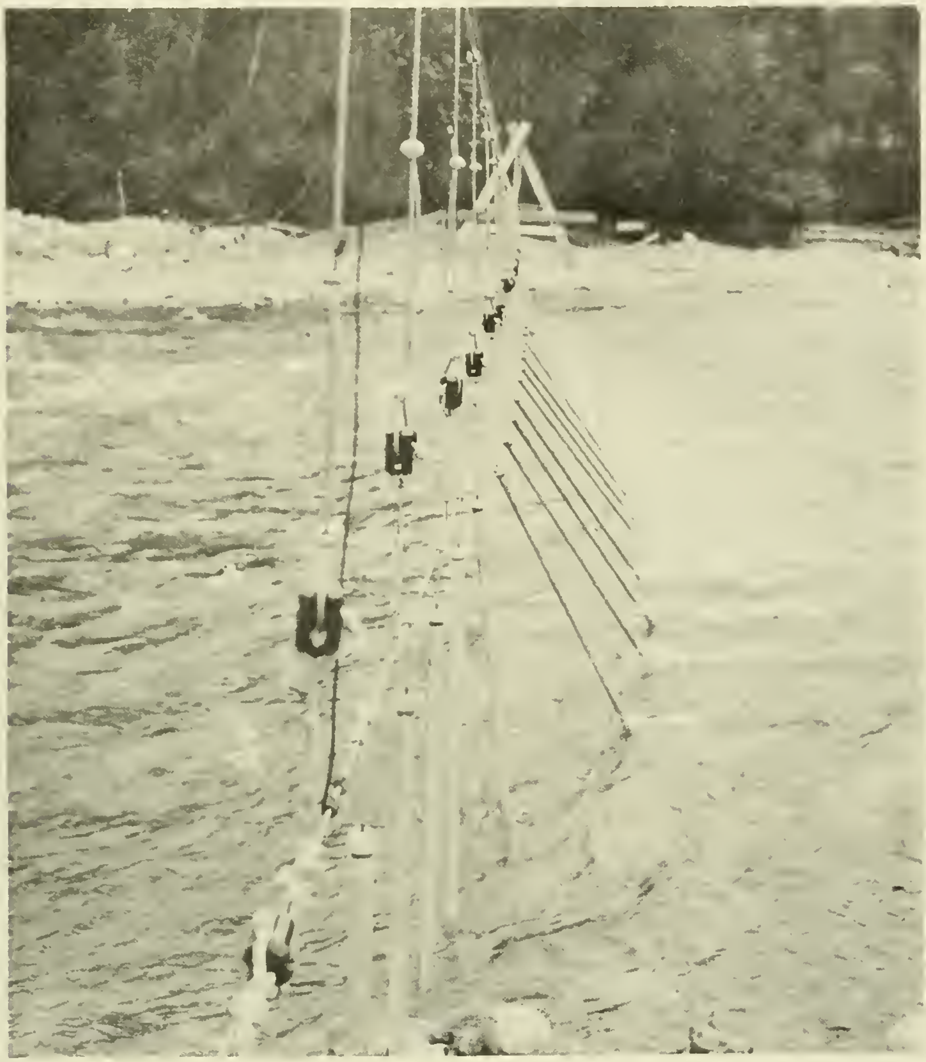


Figure 4.--View of electrode line showing deflection of electrodes from vertical position caused by water velocity at medium high-water stage of river.

The Entiat weir has been in operation since 1953. In the first season of operation the entire runs of chinook (Oncorhynchus tshawytscha) and sockeye (O. nerka) salmon were diverted into the holding ponds and none were successful in passing through the electrical field. In the years of operation since 1953 portions of the chinook and sockeye runs have been allowed to pass upstream. The weir has been under close observation throughout all periods of its operation and at no time have adult salmon been observed passing through the electrical field. This type of electrical weir has proved entirely practicable for the diversion of adult salmon when certain specific operating conditions are met.

FACTORS INFLUENCING EFFICIENT OPERATION

An alternating current, 60 cycle, electrical field can either kill or severely injure adult salmon under certain conditions. When a salmon penetrates an electrical field with a minimum barrier strength of 0.5 volts per inch and remains within the field more than three minutes it becomes immobilized. Once immobilized, respiration gradually slows until the fish dies. If the fish is removed from the field within three minutes no apparent damage is sustained. The problem is, of course, to remove the immobilized fish from the field before death results. The water velocities within the field offer the only practicable solution to this problem.

Three test installations of this type of weir have been made on the West Coast. In two of these at Entiat and Quilcene, the water velocities and pattern of stream flow within the electrical field have proved adequate. In the third, in the Little White Salmon River, 1 percent of the diverted run was killed within the electrical field. This mortality was caused by an inadequate water velocity along the stream bottom.

At the Little White Salmon weir site the river was constricted into a narrow channel. The surface flow approximated 3 feet per second. The bottom, however, was strewn with large boulders. In this bottom area there was no perceptible current flow. Fish which became immobilized within the field dropped to the bottom and died. At the time of installation the condition was obscured by the fast surface flow.

Two alternatives are available to correct such a condition: the first entails relocating the weir at a more suitable site where bottom contours are more favorable and the second is to alter the bottom contours at the selected site by filling the area with rock to smooth the bottom and reduce the cross sectional area. In this manner both a higher and more uniform water velocity within the electrical field may be attained and mortality eliminated.

The water flow within an alternating current field should have a minimum velocity of 3 feet per second to provide an effective barrier. The maximum velocity is limited by the strength of the installation. In figure 4 the Entiat weir is shown operating at velocities of 10 feet per second. The flow pattern within the electrical field is, also, of particular significance. Eddies contained within the field must be avoided. An immobilized fish caught in an eddy within the field will be killed. Vertical stratification, such as existed at the Little White Salmon weir site, must be eliminated. The stream flow and water pattern requirements within an electrical field must be fulfilled if the barrier is to operate efficiently. Obviously these requirements are as important as the characteristics of the electrical field itself.

The characteristics of an alternating current electrical field as created by the Entiat-type installation present certain problems which must be considered if the weir is to prove an effective barrier and mortality avoided. Two types of voltage gradient exist within this type of weir. The first gradient develops parallel to the electrode line and the second between the electrodes and the ground line. Both of these gradients are of significance in the efficient operation of the weir.

According to McMillan (1929) equipotential voltages develop in concentric rings around the individual electrodes. Adjacent to the electrodes, these voltages are high, in excess of 2 volts per inch, and drop rapidly as the midpoint between electrodes is approached. At a 3-foot spacing between electrodes in weirs of the Entiat type, the volts per inch at the midpoint between electrodes is less than 0.2 volts and is insufficient to immobilize salmon rapidly. As the lines of electrical current flow converge, however, these abrupt gradients decrease until, with 3-foot electrode spacings, a uniform voltage is present approximately 4 feet downstream from the electrodes. This voltage represents the minimum barrier strength of the weir; although higher voltages exist adjacent to the electrodes, much lower voltages exist in closely surrounding areas. The minimum barrier strength required with a minimum water velocity of 3 feet per second is 0.5 volt per inch.

The second significant voltage gradient develops between the minimum voltage barrier and the ground line and at right angles to the electrode line. The highest uniform voltages per inch are encountered at the voltage barrier and gradually decrease as the ground line is approached. Beyond the ground line the voltage gradient drops abruptly. The length and strength of the field may be varied by the distance between the electrodes and the ground line and the distance between electrodes. With the electrode spacing constant, the greater the distance between the electrode line and the ground line the weaker the field strength will be, but conversely, the longer the effective field. With the distance between electrodes and the ground line constant, the closer the electrodes are spaced the stronger the electrical field will be, the closer the minimum voltage barrier will be to the electrodes, and the more abrupt will be the voltage gradient between the electrode and ground lines. Table 1 demonstrates the effect of three combinations of electrode and ground line spacings on the voltage gradient. The average voltage per inch was derived from a minimum of four readings across the field and represents the minimum voltage, since the readings were taken at points equidistant between electrodes. Although the conductivity of both the water and the stream bottom may vary between locations it is possible to secure the minimum voltage requirement by varying either the electrode or ground line spacing.

In this type of installation the length of the field is as important as the minimum barrier voltage because the fish are not immobilized immediately by low voltages. McMillan (1928) found that voltages between 0.19 and 0.25 volts per inch were required to paralyze adult chinook salmon in 1 minute. A field of this strength would have to be well in excess of 15 feet in length in order to immobilize a fish attempting to move through it. Andrew, Johnson, and Kersey (1956) found that 2.5 volts per inch were required in a 4-foot alternating current field to provide a positive barrier to adult sockeye and pink salmon when the water velocity varied from 1.8 to 2.5 feet per second. At the Entiat weir when stream velocities varied from 3 to 5 feet per second neither sockeye nor chinook salmon were observed to penetrate the electrical field

Table 1.--Voltage gradients created by variations in electrode and ground line spacings

Electrode Spacing	3 feet	3 feet	2 feet
Ground Line Spacing	15 feet	9 feet	14 feet
Distance (in feet) below electrodes	Average volts per inch		
1	0.49	1.03	0.74
2	0.53	0.90	0.74
3	0.61	0.76	0.66
4	0.62	0.64	0.65
5	0.62	0.60	0.57
6	0.62	0.58	0.55
7	0.54	0.50	0.48
8	0.50	0.49	0.44
9	0.43	0.51*	0.43
10	0.43	0.05	0.42
11	0.42		0.41
12	0.46		0.39
13	0.52		0.34
14	0.53		0.34*
15	0.50*		0.11
16	0.10		

* Location of ground line

to a depth of more than 8 feet. In this area they were subjected to voltages ranging from 0.42 to 0.54 volts per inch. With higher stream velocities the depth of penetration was probably less but accurate observation was difficult. The length of the field determines the time of exposure with all other conditions equal. Lesser voltages, therefore, are required as the field length is increased.

Salmon subjected to a voltage gradient of not more than 0.75 volts per inch do not suffer tetanus even though prolonged exposure results in immobilization and eventual death. Higher voltages, however, do cause acute muscular spasms severe enough to dislocate the vertebrae. Surprisingly enough, fish which survive such shocks do not seem to be seriously incapacitated and despite a spinal curvature are capable of swimming effectivelv. It is desirable, however, that severe shock be avoided.

In a weir of the Entiat type, high voltages exist adjacent to the electrodes. At a distance of 6 inches from the electrodes the measurement is 2 volts per inch, but high voltages are of little significance provided the field is of sufficient length and strength to prevent the fish from penetrating far enough to approach the electrodes. In areas of shallow water, under 4 inches in depth, the electrical field is greatly distorted both by diversion of the electrical current through the ground and any unevenness of the stream bottom. In such areas the voltage gradient is more acute and the pattern is erratic. Under these conditions salmon may occasionally penetrate the field to within 1 or 2 feet of the electrodes where they are subjected to voltages sufficiently high to cause vertebral dislocations.

The unfavorable conditions in shallow water areas of the electrical field are usually aggravated by a reduced water velocity. These conditions were corrected at the Entiat site by recessing the ground line to create a faster water velocity and allow the fish free egress from the field. In addition as shallow areas were created by dropping river levels the fish were diverted from these areas by the use of rock dikes. Obviously the use of abutments to constrict the stream flow would eliminate this problem but, in locations where low stream banks make abutments impossible, the use of an electrical weir is not precluded providing the proper precautions are taken.

Large rocks within the electrical field must be avoided for they disrupt both the water velocity pattern and the voltage gradient. High voltages occur in areas adjacent to boulders, and eddies are created behind them. Fish which encounter the high voltage adjacent to a large rock may be stunned and either swept against the boulder or held in the eddy behind it until killed.

Characteristics of the electrical field created by this type of weir are particularly adapted to the diversion of salmon. The primary requirements of adequate stream velocities and an electrical field of sufficient strength and length to halt the upstream progress of the fish are not impossible to attain in most Pacific Coast streams containing salmon runs. The exact size limitations both as to the length of the weir and the depth of water in which it will operate effectively are not known. The present test installations have been confined to water depths less than 8 feet and to weir lengths under 200 feet.

REACTIONS OF SALMON TO THE ELECTRICAL FIELD

Both chinook and sockeye salmon runs have been under direct observation at the Entiat weir site since 1953. From these observations it has been possible to ascertain the reactions of these species to the electrical field.

Chinook salmon "learn" readily. How many times a fish will penetrate the field is difficult to ascertain because on their first encounter the fish move rapidly downstream for about 200 yards and their individual identities are lost. Observation indicates, however, that after one or more experiences with the weir, chinook recognize and avoid the electrical field. They are sensitive to less than 0.1 volt per inch as indicated by the collection of fish just below the ground line where voltages vary from 0.05 to 0.1 volts per inch. It is at this stage, when they have become conditioned to an electrical stimulus, that the angle lead of the weir becomes effective in directing the fish toward the fish ladder.

This type of electrical field has proved highly efficient in the diversion of chinook salmon. The longest a recognizable fish has been observed in the area of the ground line has been 2 days. In addition no concentration of chinook salmon collected below the weir, indicating that this species was being diverted into the ladder with no appreciable delay. These observations are in sharp contrast to those made at a conventional picket weir installed in exactly the same location in years before 1953. Some of the chinook salmon persisted in fighting the conventional weir for two weeks or longer. As a result concentrations of fish built up below the weir and injuries to the fish, particularly in the head region, were common.

The reactions of sockeye salmon to the electrical barrier have been slightly different from those of chinooks. These fish appear in fairly large schools in deeper parts of the river about 200 yards below the weir. Occasionally a fish will move out of the school and proceed upstream at a high rate of speed. When it enters the electrical field to a depth of from 6 to 8 feet it jumps out of water, reverses its direction, and proceeds as rapidly downstream. Unlike the chinook, the sockeye have never been observed to work along the ground line, yet they move readily into the holding ponds. Whole schools disappear from the river and appear in the holding ponds overnight. Undoubtedly the movement of these fish is directed toward the fish ladder by the angle lead of the electrical field.

Andrew, Johnson, and Kersey (1956) state that an angled electrical field created by a double curtain of electrodes, 4 feet apart between rows and spaced 3 feet apart within rows, had no leading effect on either sockeye or pink salmon. These tests were conducted using direct current and only for 30-minute trial periods. The observations at Entiat indicate little probability that the fish would become conditioned to an electrical stimulus within a 30-minute period. The lack of conditioning, location of the bypass, and the uneven voltage gradient surrounding the electrodes in this experimental installation would make these tests a biased measure of the leading ability of electrical fields. Leading, in this instance, is defined not as an orientation toward one pole of a direct current field but rather as the diversion of the fish away from an electrical field and into an alternate passage.

It has been impossible to demonstrate any deleterious effects from electrical diversion either on the survival until maturation of the adult salmon diverted by the weir or on their resulting progeny. Because all fish procured for artificial propagation since 1953 have been diverted by the electrical field, the only comparisons possible have been with previous years. The many additional variables other than electrical diversion make this a crude measure at best. The survivals of both the adults and fingerling are well within the range encountered in previous operations.

A few females in 1953 and 1954 received sufficient shock to induce spinal curvature. These fish survived to spawning and produced normal appearing eggs. In 1954 the eggs from 2 females were held separately and the viability of the eggs compared with those derived from females which were apparently normal. The survival rate was higher in the eggs from the severely shocked females than in the eggs from the normal fish. Individual variation between females was assumed to be the cause for the differences in survival. Since 1954 no females with spinal dislocations have been observed. The indications are that even severe electrical shock incurred on the upstream migration, when the eggs are at least 2 weeks from maturity, has no deleterious effect on egg viability.

Downstream migrant salmon fingerlings pass through the electrical field of the weir with impunity. According to McMillan (1928), fingerling chinook salmon must be exposed to a gradient of 1.5 volts per inch for 1 minute before they are killed. Voltages of this magnitude occur only in the area immediately adjacent to the electrodes at a maximum distance of not more than 6 inches from the electrodes. Fingerling salmon, 4 to 5 inches in length, have been observed moving freely both upstream and downstream within the electrical field. Only when they approached to within 3 or 4 inches of an electrode were they temporarily stunned. Large whitefish (Prosopium williamsoni), 12 to 14 inches in length, introduced immediately above the electrodes, were immobilized and carried through the field but regained their equilibrium and were swimming normally 10 feet below the ground line. There are no indications that an electrical field of this type has any deleterious effects on the downstream migration of fingerling salmon.

APPLICATION OF THE ENTIAT TYPE ELECTRICAL WEIR

The "type B" electrical weir described by Applegate, Smith, and Nielsen (1952), as modified at Entiat, has a direct application to salmon-cultural operations on the Pacific Coast. The experimental installations have been confined to comparatively small streams, less than 200 feet in width and 8 feet in maximum depth. It is doubtful if this weir could be applied to much larger streams without extensive preliminary testing and probable alteration in design. Most salmon operations, however, are located on tributary streams which do not exceed these limitations. In general, most weir sites are immediately suited or readily adaptable to the requirements of the electrical weir. Although constricted flows at the weir site are highly desirable unavoidable shallows do not preclude the use of the electrical weir if precautions are taken to divert the fish from the extremely shallow areas.

The work of Andrew, Johnson, and Kersey (1956) indicates that 60-cycle alternating current is to be preferred over direct current because it is more economical in operation and no more injurious to salmon. The Entiat-type electrical weir using 60-cycle, 110-volt, alternating current as the energizing source has further demonstrated the applicability of alternating current for the diversion of adult salmon. This type of electrical current is readily available from commercial sources.

Observation indicates that salmon can become conditioned to an electrical field and that once they are conditioned, the weir will lead them into a desired location. Placement of the electrical field at a 30-degree angle to the perpendicular of the stream flow has proved satisfactory for concentrating the fish in the entrance to the fish ladder. The upper end of the fish ladder should be 5 feet below the ground line, as shown in figure 2A so that the fish are collected at the attraction point of the ladder in an area unaffected by the electrical field. The leading qualities of the electrical field make it highly desirable for the diversion of salmon.

In any installation where electricity, at reasonably high voltages, is used there is danger to human beings. The electrical weir installation is no exception. The electrode cable is, of course, electrified and any contact made between the electrode cable and an adequate ground could be dangerous to the person involved. How serious would be the effect should a person fall or be swept into the electrical field has not been ascertained. It is doubtful if the effect would be lethal but it certainly would be unpleasant. With proper precautions, however, working on land around the suspension system presents no problems. It is recommended that the area adjacent to the weir be fenced and warning signs posted to keep the general public away from the electrified area. Figure 3 shows the precautions taken at the Entiat weir site.

The Entiat type weir with its free-swinging, widely-spaced electrodes is particularly adapted to streams which carry large amounts of debris during the trapping period. It requires no maintenance during such periods; this is in sharp contrast to the labor involved in the operation of a conventional picket rack under similar conditions.

SUMMARY

The "type B" electrical weir described by Applegate, Smith, and Nielsen (1952) has been adapted for the diversion of adult salmon on their upstream migration. The electrical field is created between a set of suspended electrodes and a ground line by means of 110-volt, 60-cycle, single-phase, alternating current. For the diversion of salmon, the length of the field has been increased and the voltage gradient reduced, as compared with lamprey-control weirs, by using 3-foot electrode spacings and increasing the distance between the ground and electrode lines to 15 feet. Minor alterations were made also in the type of construction which reduced installation and operating costs.

The factors which influence the efficient operation of the electrical weir are confined principally to two sources, the water velocity and

the voltage gradient. The water velocity within the electrical field should be 3 feet per second or greater if fish mortality is to be eliminated. To provide a positive barrier the minimum barrier voltage should be 0.5 volts per inch with a field length of 10 feet in which the voltage gradient may vary from 0.3 to 0.7 volts per inch.

Adult salmon may be conditioned to an electrical field and the field may then be used to lead and collect the fish for diversion into holding ponds.

Comparisons of survival rates between years of both the diverted adult salmon and their resulting progeny indicate that no measurable difference in survival exists between fish diverted by the electrical field and by a picket weir.

The electrical field offers no barrier or source of mortality to downstream migrant salmon fingerlings. Such fish, 4 to 5 inches in length, move through the field with impunity.

The Entiat type of electrical weir is particularly applicable to salmon-cultural operations where it is desirable to divert the adult fish into holding areas. In comparison with conventional mechanical barriers it is more adaptable to a variety of stream conditions, more economical to install and maintain, and a more positive barrier at all water stages. Tests of this weir have been limited to stream widths of not more than 200 feet and depths less than 8 feet. Its application in larger streams remains to be evaluated.

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