A GUIDELINE FOR PORTABLE DIRECT CURRENT ELECTROFISHING SYSTEMS

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ABSTRACT

Anode current appears to be a good electrical measure of electrofishing effects with less current required as the water conductivity decreases. A simple guideline table listing minimum required current and suggested anode sizes for various voltages was assembled to effectively fish typical Wisconsin streams with portable direct current systems. Actual stream tests of conductivity (micromhos/cm) and generator voltage must be available in order to select the correct size anodes. The power required for effective electrofishing depends on water conductivity, size and number of anodes, water depth and stream size. A table of suggested power levels is included.

Means of attaining the required current are discussed. In general, large electrodes have lower resistance and thus permit larger currents at a given voltage. The cathode should always be as large as possible and the anodes selected to meet stream conditions and generator ratings. The output voltage of any generator drops as current is taken from the machine and this voltage drop can cause a serious loss of effectiveness in some generators under heavy loads. Current per anode is reduced as the number of anodes fed from a single generator is increased even if the generator voltage is constant. Quantitative results illustrating these effects are included.

CONTENTS

INTRODUCTION

There are many factors which influence the effectiveness of direct current electrofishing equipment. Among these are the electrical parameters of the equipment, water conductivity, width and depth of the stream or river, water clarity, water temperature, current, species of fish being sought and the skill and experience of the operators. At the present time the direct current electrofishing equipment used in Wisconsin is quite inflexible, offering only slight opportunity during electrofishing operations to adjust for the various factors which influence the performance of the equipment.

The objectives of this study were to determine the extent of equipment variation and techniques currently in use; to attempt to clarify the purely electrical parameters that influence electrofishing performance; and to provide a basis for the proper electrical utilization of electrofishing equipment and a better understanding of the capabilities of this method for capturing fish.

BASIC ELECTROFISHING SYSTEM

A basic hand–held direct–current electrofishing system includes the following:

(1) Power source: usually a direct–current, engine–driven generator. The ability to control the output voltage is desirable but not mandatory. The electrical rating (kilowatts) of the power source must be chosen in relation to the size of the streams or rivers to be fished (number of anodes) and the range of water conductivity likely to be encountered.

(2) Cathode: normally as large as can be conveniently handled in the particular stream conditions encountered. Often the bottom of the boat used to carry the power source is used as the cathode, but other arrangements are also possible.

(3) Anodes: normally one or more loop–shaped electrodes on insulated handles. The shape of the electrode is not of primary importance so long as it is basically loop or spherical in shape rather than long and slender (cylindrical). The size and number of anodes must be chosen to match the generator characteristics and meet stream conditions.

(4) Metering: normally a voltmeter and an ammeter to determine the electrical output and thus enable determination of the extent to which the system meets the requirements of the stream conditions.

(5) Safety switches: normally a low–voltage relay system to enable operators to quickly disconnect the electric power in case of emergency.

To achieve optimum performance, the various parts of the electrofishing system must be chosen to complement each other and to meet or exceed the requirements imposed by the stream conditions to be encountered.

NATURE OF THE PROBLEM

In principle, the function of an electrofishing system is to produce a sufficient electrical stimulus in fish near the anode to elicit forced swimming (electrotaxis) toward the anode and hence easy capture. Work done on electric shock phenomena in humans has shown that the electrical variable most easily correlated to the sensible shock effect is the current (Dalziel and Lee, 1968). Similar conclusions regarding electrofishing effects are indicated by the work of Cuinat (1967) and by our own observations in the field. Regardless of the means by which a current is established, then, it seems reasonable to assume that similar electrofishing effects will be attained at a given level of current through a fish.

Following this line of reasoning, the primary function of the electrofishing generator and electrode system is to set up a sufficient electric current in the water to permit establishing the required minimum current in fish near the anode. The voltage and the number or size of anode to be used are therefore important parameters in establishing the current; but it is the current which is responsible for the desired response in the fish. This is a very important first concept in terms of understanding the relationship between the various electrical parameters of an electrofishing system.

Based on this concept, there exists some minimum value of current per anode required to affect fish out to a specified distance from the anode. This minimum current will depend upon the desired range, fish species, water temperature and other factors affecting the physiology of the fish, water conductivity, and probably other less obvious factors. Of these factors, water conductivity is of special importance since it becomes very difficult to attain significant electrode currents in low conductivity water. Fortunately, less anode current is required when the conductivity is low because the fish then becomes a relatively better path for current and more of the anode current concentrates in the fish.

Clearly what is needed is information regarding what these minimum current levels are over a range of values of the various factors. From a practical point of view, the best method of obtaining such information is from actual electrofishing experience and this is the approach followed here.

SURVEY METHODS

During the latter part of the 1969 season and through most of 1970, personnel of the Wisconsin Department of Natural Resources were asked to fill out a brief questionnaire describing their experience after each electrofishing effort. A copy of the form used is included as Appendix A.

Fifty fully completed forms were collected from fifteen different persons (some of the equipment in use did not have adequate electrical instrumentation to permit acquiring the necessary electrical data and completing the form). In addition, we made five field trips to obtain firsthand experience and acquire electrical data. The data covered a range of water conductivity from 50 to 450 micromhos/cm and included results using three different types of generators.

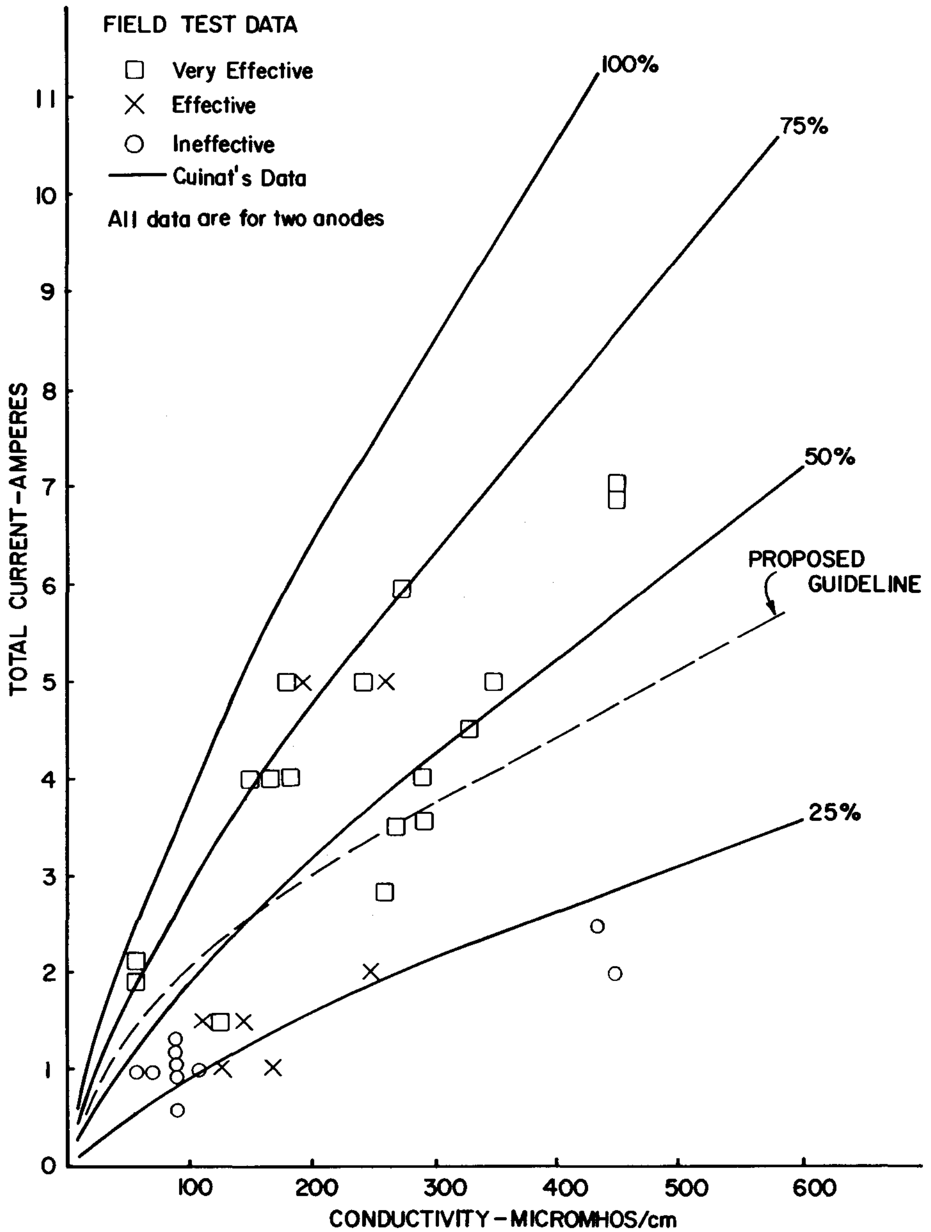

FIGURE 1. Required current for effective stream shocking with direct current using two anodes.

SURVEY RESULTS

Electrofishing Effectiveness

Figure 1 presents the operators' evaluations of electrofishing effectiveness as a function of water conductivity and total electrofishing current. The data are presented for a two–anode electrofishing system since this was the most common system employed. Also presented on this figure are the data from Cuinat (1967) regarding the current used in electrofishing in his department. Both Cuinat's data and the Wisconsin data refer to the capture of trout in typical trout streams and small rivers. Cuinat's data are reported as producing "effective fishing", which he explains as permitting a satisfactory statistical estimate of population in two sweeps of the stream. The approximate range of capture is given as 4 to 7 feet. The Wisconsin data are much more subjective and rely on the experience of the operator to give an evaluation of the effectiveness.

While there is a significant scatter in the Wisconsin data, the trend is quite clear. Roughly speaking, the operators reported effective or very effective electrofishing whenever the current approached about 50% of the current reported by Cuinat. Ineffective fishing was reported only when the current was significantly less than this. No Wisconsin data even approached Cuinat's 100% curve except one point at a conductivity of 60 micromhos/cm. This was a test run in which we used a special high–voltage (470 volts) power source and a very large (16-inch diameter) anode. The results in this case were judged very effective and the catching range was estimated to be at least 6 feet. No injury to fish was observed.

In order to have some specific dividing line between ineffective and effective electrofishing, the dashed line on Figure 1 was drawn rather arbitrarily at roughly twice the level of the highest data points reported as ineffective. There are a few points below this curve which were reported as effective. However, all points above the curve were reported as very effective (with two exceptions which specifically noted difficulty with deep water). The dashed curve (Fig. 1) will be used in this report as defining the minimum required current for effective electrofishing.

Proposed Guideline

The proposed guideline is redrawn in Figure 2 with the area below the minimum required current curve shaded and labeled as ineffective. Since none of the Wisconsin data reported any significant cases of fish mortality, an upper bound curve has been established by using twice the single electrode current from Cuinat's data. The area above this upper curve is also shaded and labeled as potentially harmful to fish. In reality, Cuinat's data really suggest that at or below this curve no significant danger exists to fish. It is likely that one could go considerably above this curve without danger to fish. However, quite high voltages and large amounts of power are required to reach above this curve and it probably represents a realistic upper bound for portable equipment.

The unshaded area in Figure 2 thus represents the region in which one can expect effective electrofishing with portable equipment in typical Wisconsin trout streams. The "midline" is simply a line halfway between the other two curves and is strictly for purposes of judging where a point lies relative to the upper and lower curves. In general the larger the current, the greater will be the catching range. Thus, when greater range is necessary (as in deep water) one should try to approach or even exceed the upper curve. In very small streams, currents below the lower curve may be sufficient. It is important to remember that these curves are somewhat arbitrary and that electrofishing effectiveness is not something that changes abruptly as a specific value of current. The curves are intended only to outline a general range of values that will yield acceptable values.

No field data were available for conductivities below 50. The guideline curve was sketched in this region by following the trend of Cuinat's data which tend to approach zero current at conductivities of zero. Since Cuinat's report does not indicate actual data below a conductivity of 25, the lower portion of the curve is speculative. Since it is very difficult to attain even small currents at these low conductivities with reasonable voltage levels, it is likely that data points in this region will be more indicative of attainable levels of current rather than necessary or desirable levels. Additional ex-

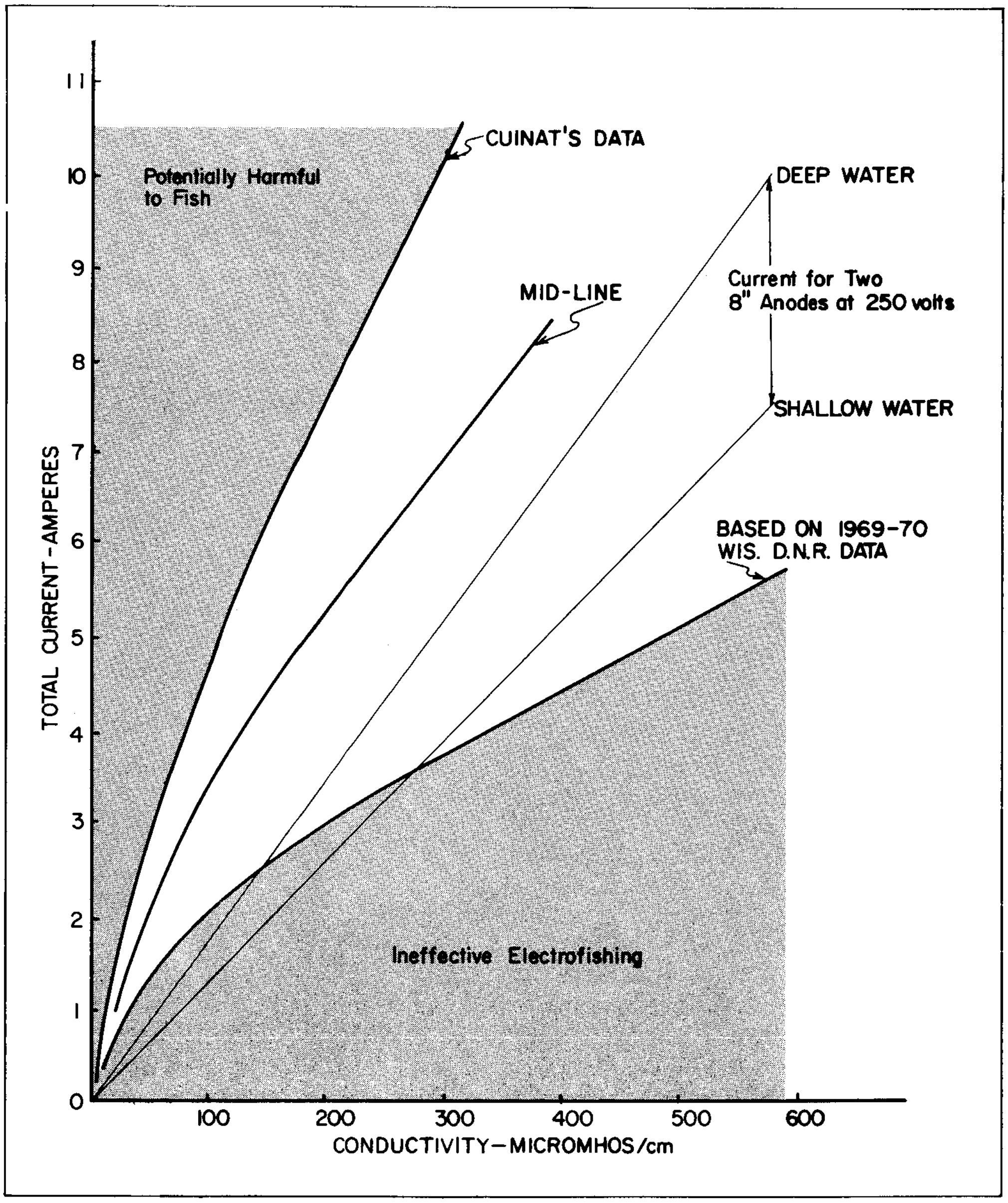

FIGURE 2. Proposed guideline for stream shocking with direct current using two anodes.

perimental work is needed over the entire range of conductivity but is especially important at very low values.

Water Depth and Bottom Conductivity

In addition to the overall judgment of electrofishing effectiveness, the field survey provided additional information on other aspects of the problem. A number of forms indicated acceptable electrofishing results except when deep water was encountered. This is to be expected since greater range is required in deep water, and, unfortunately, the lower electrical resistance associated with an anode deeply immersed is likely to cause a reduction in voltage due to generator loading and a net reduction in range. This occurs even though the anode current will actually increase because the current now must spread in all directions (including upward toward the surface) and hence there may actually be less current in the region below the anode where the fish are likely to be located. Since most of the electrofishing done in Wisconsin is in small shallow streams, most of the remainder of this report will be concerned with this type of situation. Equal success in deep water will require larger currents, approximately twice as much to maintain the same effective range as in shallow water.

Best results are generally obtained in sandy or rocky bottom streams since the bottom conductivity of such streams is usually low. Thus most of the current will remain in the water where it is useful. If the stream is also quite shallow, the current will essentially spread in only two dimensions and the effective range will be increased. As the stream deepens or the bottom material becomes highly conductive, the range will decrease for a given current. Under these conditions it will generally be necessary to use currents well above the minimum on the curves in Figure 2.

Generator Waveform

One other factor which was again observed during the field tests was the inhibiting effect of high frequency ripple in the generator output. This can occur in generators which produce alternating current and convert to direct current electronically. If this ripple is too large, the desired forced—swimming response is severely inhibited. The fish appear quite sluggish and tend to become stunned as they approach the anode. If the water current is large, this can cause very poor electrofishing since the fish are overcome by the current and do not approach close enough to be easily captured. The remedy for this problem is a simple electrical filter to remove the ripple.

Electrode Resistance

With a guideline for the required current available, attention can be turned to means for obtaining this current with portable equipment. In general, the current is determined by the ratio of the generator voltage and the total circuit resistance $I=V/Rt$ where the circuit resistance includes the effects of the cathode and the anodes. It is possible in the type of system being treated to consider each electrode as a separate unit and finally combine the resistances to obtain the total resistance. This is permissible because the resistance of each electrode is associated with what happens within the first few feet near the electrode. At greater distances the current is so spread out that the water acts as a conductor of nearly zero resistance by comparison to the near zone of each electrode.

In general, the resistance of an electrode depends upon its shape and size and upon the conductivity of the water. The variation is a simple inverse linear relation with respect to water conductivity but is rather complex with respect to size and shape. In general, however, the larger an electrode, the smaller will be its resistance. Appendix B contains a discussion of electrode resistance and a set of curves which permit calculating resistances from the known geometry and water conductivity.

Our measurements and calculations and the results of the field survey yielded sufficient information to evaluate electrode resistances under actual field conditions (Table 1). The results for deep water are actual measured values on test electrodes. The results for shallow water and the cathode resistance values are obtained from the field survey forms. The anode resistance in actual use averaged about 160% of the measured value for deep water and this is the basis for the resistance values given for shallow water. The total resistance for one anode is simply the sum of the anode and cathode resistances. For two anodes, it is assumed the anodes are operated far enough apart not to interact. This permits combining the two anode resistances in parallel, and since the two are equal this results in an equivalent resistance equal to one half of the single anode value. The total resistance for two anodes is thus one half the anode resistance plus the cathode resistance.

To attain large currents, it is necessary to keep the total circuit resistance small. In particular, since the cathode need not be actually carried by the operator it should be as large as possible to reduce its resistance.

TABLE 1
Average Electrode Resistance, with Conductivity, 400 micromhos/cm, and Cathode size, 7ft x 2.5 ft Rectangular Plate

Anode Size (Inches)	Cathode Resistance (ohms)	Anode Resistance (ohms)		Total for One Anode (ohms)		Total for Two Anodes (ohms)	
		Deep	Shallow	Deep	Shallow	Deep	Shallow
8 x ¼	15	40	64	55	79	35	47
12 x ¼	15	28	44	43	59	29	37
16 x ¼	15	22	35	37	50	26	32

The cathode resistance in the table is the smallest value. The cathode resistance of 15 ohms, however, becomes almost half of the total resistance when two 16-inch anodes are being used. This indicates that a considerable improvement in performance can be attained by enlarging the cathode when using two large anodes.

Operating Characteristics

The electrode resistance data permit determination of the current resulting from operation at a particular voltage level. These results can be plotted on the same axis as the earlier graphs and the required voltage and/or electrode system needed to attain the required current at a particular water conductivity can be determined. Since the electrode resistance varies linearly with water conductivity, the current for a given voltage and electrode system is also linear with respect to water conductivity. The performance lines are therefore straight lines on the current vs. conductivity graphs and are easily drawn in. A series of these performance curves are presented here illustrating the effects of various changes in system parameters.

Anode Size. The range of current associated with different anode systems at a voltage of 250 volts is shown in Figure 3. This figure illustrates the effect water depth has on the current supplied by an otherwise fixed system. Since the guideline is based on data for shallow streams, the operating lines are drawn for shallow water in the remainder of this report.

While the current is greater in deep water, it is likely the fishing effectiveness would be lower for the reasons stated earlier. For example, the line for an 8-inch anode exceeds the current guideline curve down to a conductivity of 260. The upper 8-inch line (for deep water) is actually above the guideline down to a conductivity of 140, but it is unlikely that effective electrofishing in deep water would be possible much below a conductivity of 450. In deep water the guideline should be exceeded by about a factor of two to assure effective electrofishing.

The curves of Figure 3 are drawn for loop anodes where the diameter of the anode material itself is taken as 0.25 inch. If larger

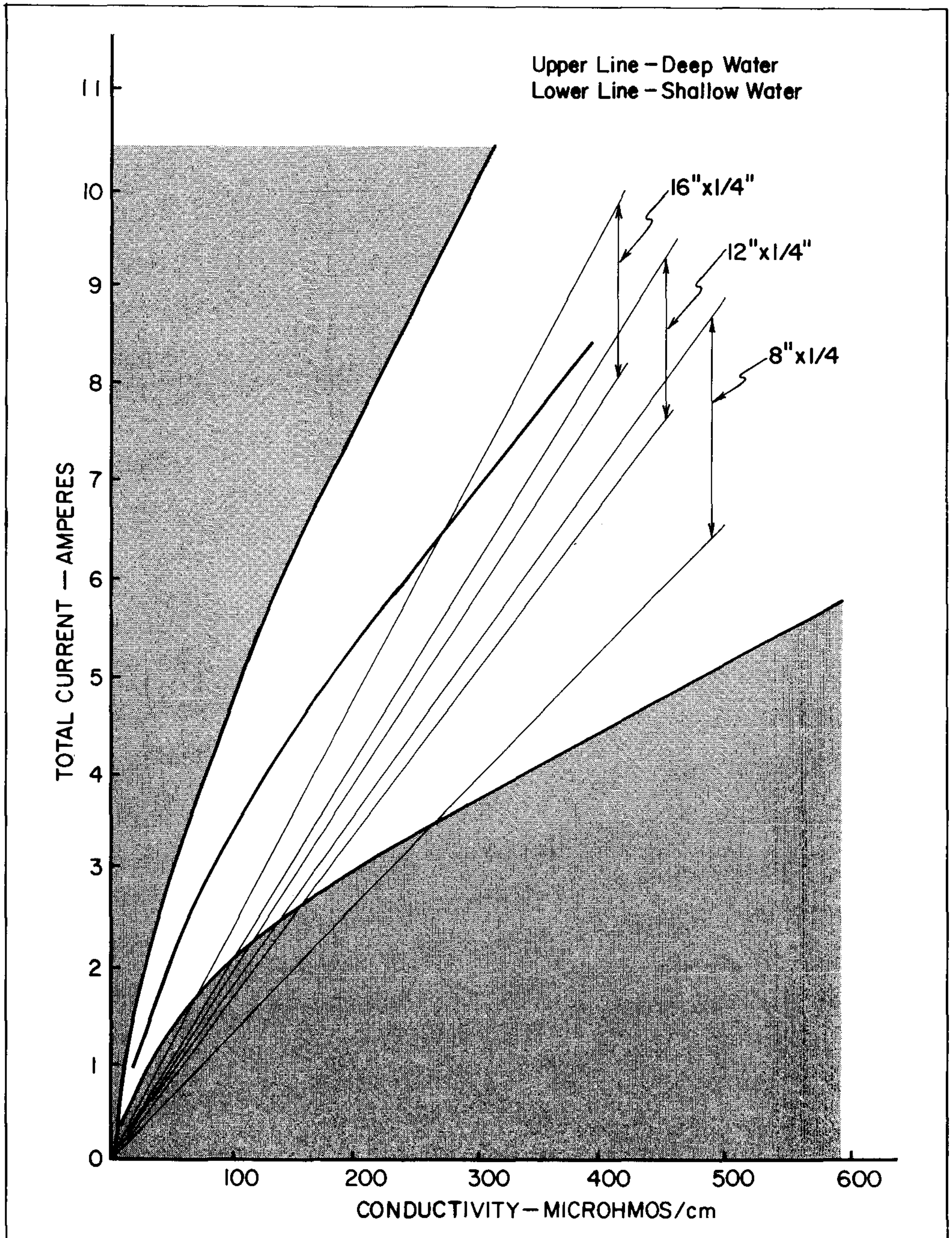

FIGURE 3. Effect of varying anode size using two anodes at 250 volts.

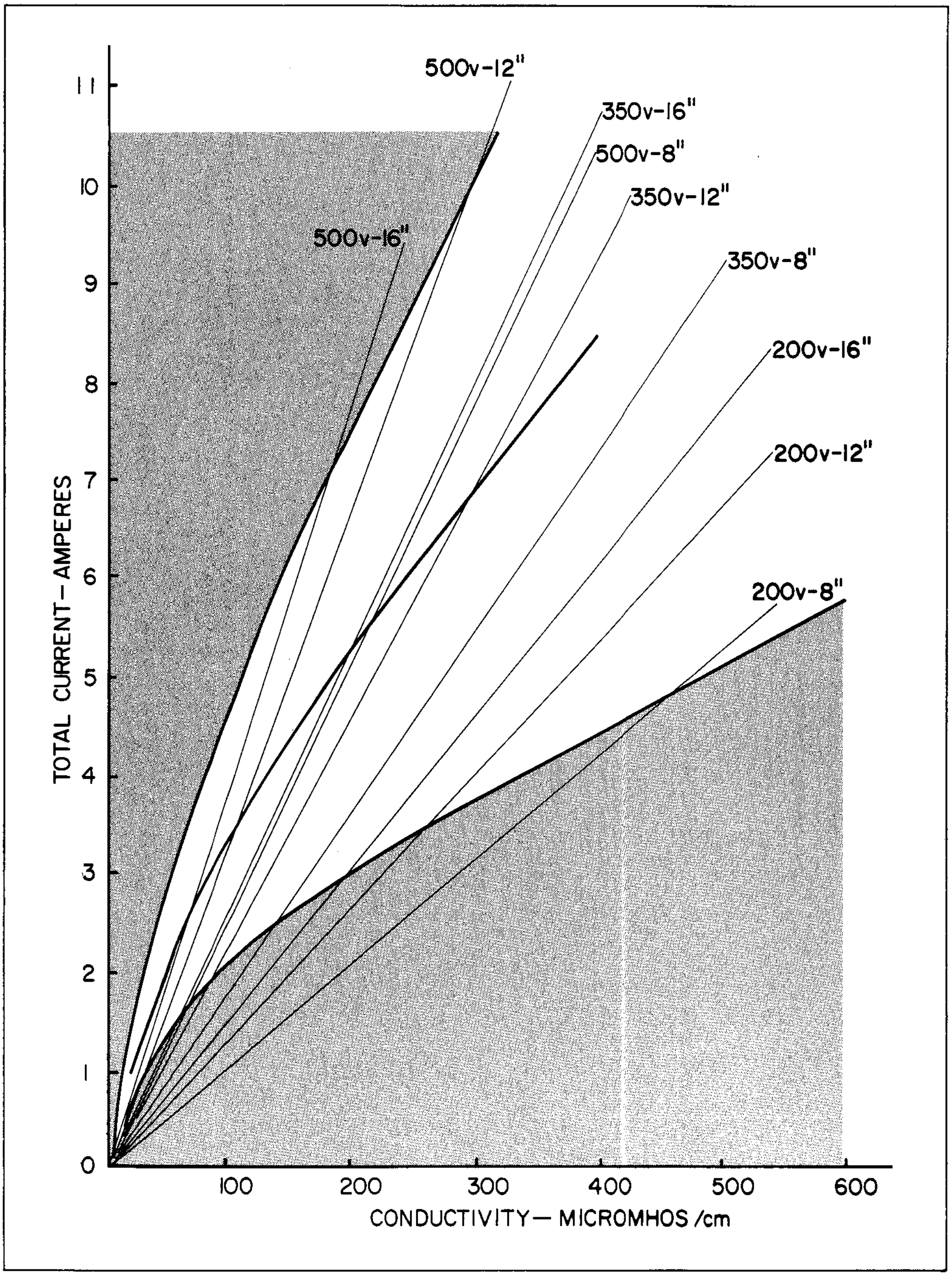

FIGURE 4. Effect of varying anode size and voltage using two anodes in shallow water.

diameter material is used to form the loop, the anode resistance is reduced but the reduction is small compared to the increase in weight of the anode. Table 2 illustrates the relative importance of changing loop diameter and loop material diameter using an 8- x 0.25-inch loop as a base to obtain normalized resistance values.

Thus, for example, increasing the diameter of the loop material of an 8-inch anode from 0.25 to 0.50 inches results in only a 12% reduction in resistance. Since the larger anode will be very much heavier and have much greater resistance to movement through the water, it does not seem desirable to use the larger–diameter loop material. Much greater reductions in electrical resistance are achieved by increasing the diameter of the loop and this is the recommended procedure. The values in Table 2 are calculated values based on the material contained in Appendix B.

TABLE 2
Normalized Anode Resistance With Loop Electrodes

Diameter of Loop (inches)	Diameter of Loop Material (inches) 0.25	0.375	0.500
8	1.0	0.93	0.88
12	0.71	0.67	0.63
16	0.55	0.52	0.50

Voltage and Anode Size. Figure 4 illustrates the effect of changes in voltage and anode size. This is a very significant set of curves, for it is possible to read off the lowest conductivity which can be effectively fished with a given anode size and voltage. All that is necessary is to note the conductivity at the point where the operating line intersects the guideline curve. As examples, the lowest water conductivity for effective electrofishing with 8-inch anodes at 200 volts is 450, while the corresponding value for 16-inch anodes at 400 volts is 25. It is possible to build up a table of recommended operating conditions from a figure such as this, and this is done in a later section.

Cathode Size. The effect of using a larger cathode is shown in Figure 5. This effect is not associated with a change in water depth, but with an increase in the size of the cathode and the corresponding reduction in the cathode resistance. The increased current resulting from the change will therefore produce an increase in electrofishing effectiveness. Note that the effect is largest with the 16-inch anodes, since the cathode resistance is a larger fraction of the total resistance with the large electrodes.

In general, the largest possible cathode should be used in any direct current electrofishing system. In systems where the bottom of the boat carrying the generator supports the cathode, the cathode size might be increased by attaching one or more flexible electrodes to the original cathode and allowing them to drag behind the boat. The effectiveness of these added cathodes will increase as their length is increased. However, it is probably not advisable to use more than two such added cathodes, since their effectiveness decreases from interaction if they are close together.

An alternative to using a cathode mounted on the boat carrying the generator is to simply place a large cathode in the stream and work upstream from this point to the extent permitted by the length of wire available. This approach has the advantage of permitting quite large cathodes to be used since size is not restricted by the requirements of portability. Also, more than one electrode can be used to form the cathode. If this is done, the two electrodes should be placed far enough apart to avoid interaction; a distance several times the maximum dimension of either electrode is sufficient. Plates, grids of wires, or rolls of screen material could be used for the electrodes. The disadvantage of this approach is the necessity to periodically return and pick up the cathode electrodes and move to a new location. Unless the stream is extremely small it should be possible to work to 100 feet or more from the cathode location without excessive voltage drop in the stream or wires supplying the anodes. In very low conductivity streams this method may offer significant advantage by permitting use of large anodes to obtain the necessary current.

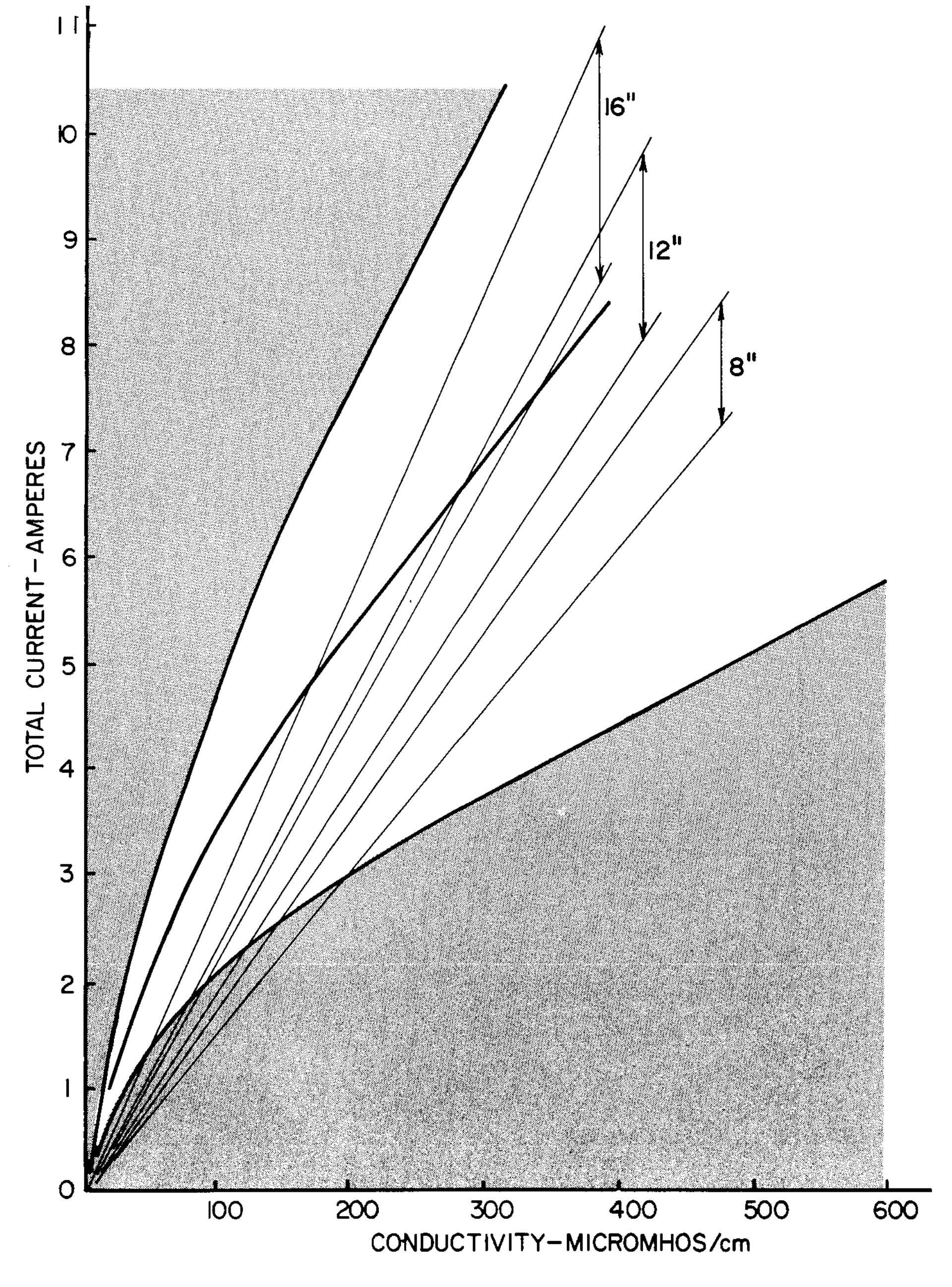

FIGURE 5. Effect of doubling effective cathode size using two anodes in shallow water at 300 volts.

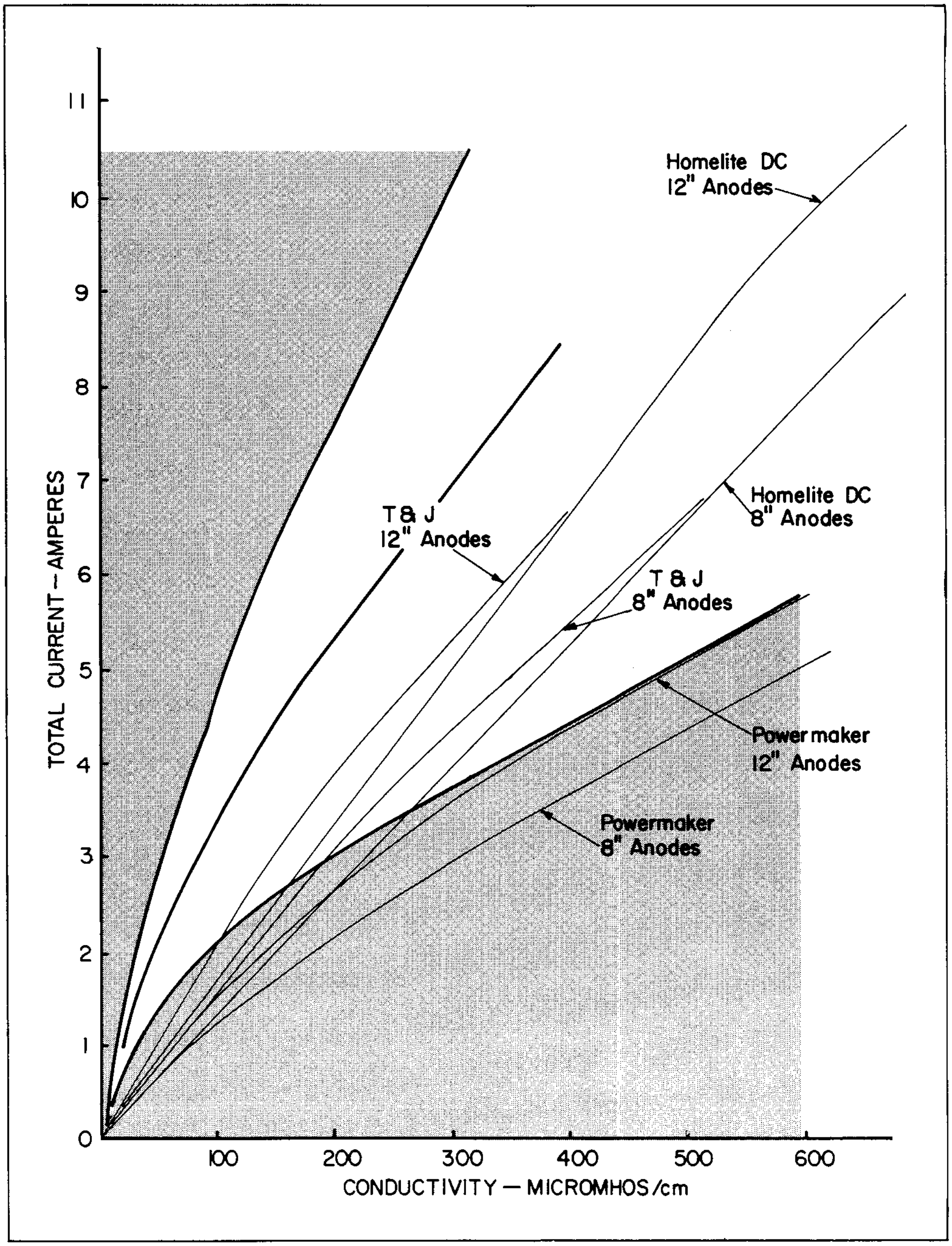

FIGURE 6. Effect of generator characteristics on fishing efficiency using two anodes in shallow water.

Generator Characteristics. The performance curves presented in the preceding figures are straight lines because they are drawn for a constant voltage. In any real generator the output voltage drops as the generator is placed under load. First there is an internal electrical voltage drop which increases as the current increases, and second, placing a load on the engine causes the engine speed to drop. The amount of this voltage reduction (or voltage regulation, usually expressed in percent) depends on the type of generator, the quality of the speed governor on the engine, the condition of the engine, and to some extent on the size of the generator.

Figure 6 illustrates for three different types of generators the effect of this reduction in voltage as the generator is loaded. The obvious effect is a bending of the operating line to the right and down as the conductivity of the water increases. This bending is a direct result of the reduced generator voltage as the output current increases. Two different anode sizes are illustrated for each generator.

The shape of the characteristics are quite different for the three machines. Since these characteristics can have significant effects on electrofishing effectiveness, a brief description of the machines and a discussion of the rating and limitations are included here.

(1) Homelite D.C. Generator (Model 24D230)

Rating: 230 volts, 10.9 amperes, 2500 watts
No Load Voltage: 264 volts
Voltage Regulation: 14.8%

This is a conventional DC Shunt Generator. Machines of this type are typically relatively heavy, and have good voltage regulation and smooth (ripple free) output voltage. The characteristic (Fig. 6) for 8-inch anodes is very nearly a straight line since the change in voltage is small. With 12-inch anodes some bending is evident in the characteristic, but it is nearly negligible. For practical purposes this machine can be considered to be a constant voltage machine. The rating of the machine is sufficient to supply two 12-inch electrodes up to a conductivity well over 600 (even higher with 8-inch electrodes). Effective fishing down to a conductivity of approximately 160 is possible with 12-inch anodes.

(2) **Powermaker AC–DC Generator (Model EAD–1250)**

Rating: 115 volts, 10 amperes, 1150 watts
No Load Voltage: 260 volts
Voltage Regulation: 126%

This is a single–phase, 400 hz, AC generator with a permanent magnet field, and a rectifier to produce DC. Machines of this type are characterized by lightweight, high–voltage regulation, and high ripple content in the DC output voltage. Filtering is necessary for electrofishing applications. The characteristic on Figure 6 is curved because of the large change in voltage (from 260 down to about 130 volts). This machine actually has too low an output voltage to be effective in electrofishing as can be seen on Figure 6. Because the voltage is so low, the machine never approaches its rated load current of 10 amperes and much of the output capability is wasted. Use of a transformer to increase the voltage of this machine (on the AC side since transformers only function with AC power) could significantly improve the electrofishing performance.

(3) **T & J Generator (Model 1736 DCV)**

Rating: 125/250 volts, 7 amperes, 1750 watts
No Load Voltage: 320 volts
Voltage Regulation: 28%

This machine is a 3-phase, 60 hz wound field generator with a 12-diode double bridge rectifier (to obtain two output voltages) to produce the DC output. A machine of this type is characterized by moderate weight, moderate to low regulation, and moderate ripple in the DC output. By virtue of its higher no–load voltage and moderate regulation, this machine has the best electrofishing characteristics of the three machines shown in Figure 6. With 12-inch anodes this machine should produce effective electrofishing down to a conductivity of approximately 100. However, the machine reaches its full rated output of 7 amperes at a conductivity of approximately 400. To fish above this conductivity, 8-inch anodes (or *one* 12-inch anode) would be necessary. In these high conductivity waters, the Homelite

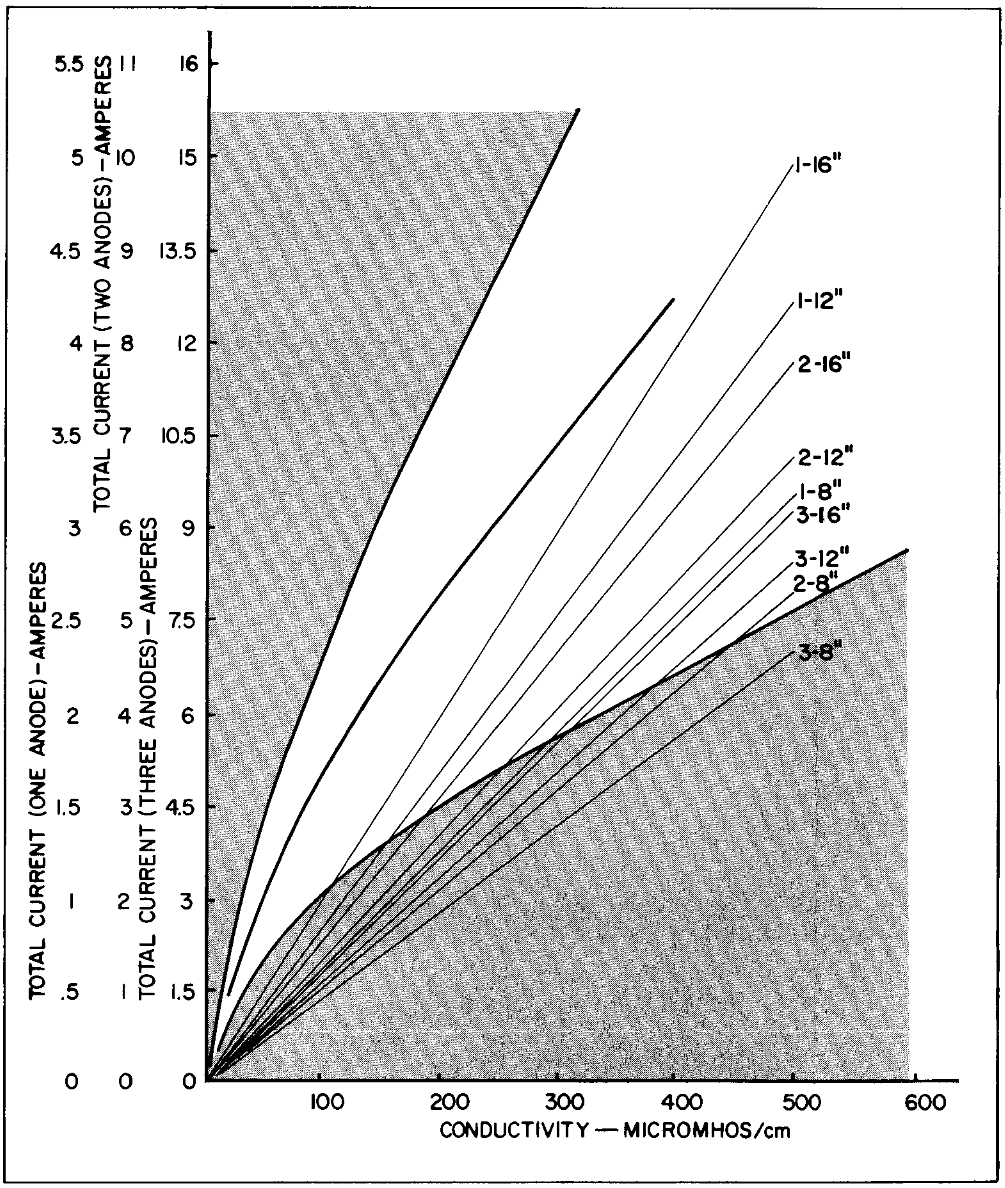

FIGURE 7. Effect of varying the number of anodes in shallow water at 200 volts.

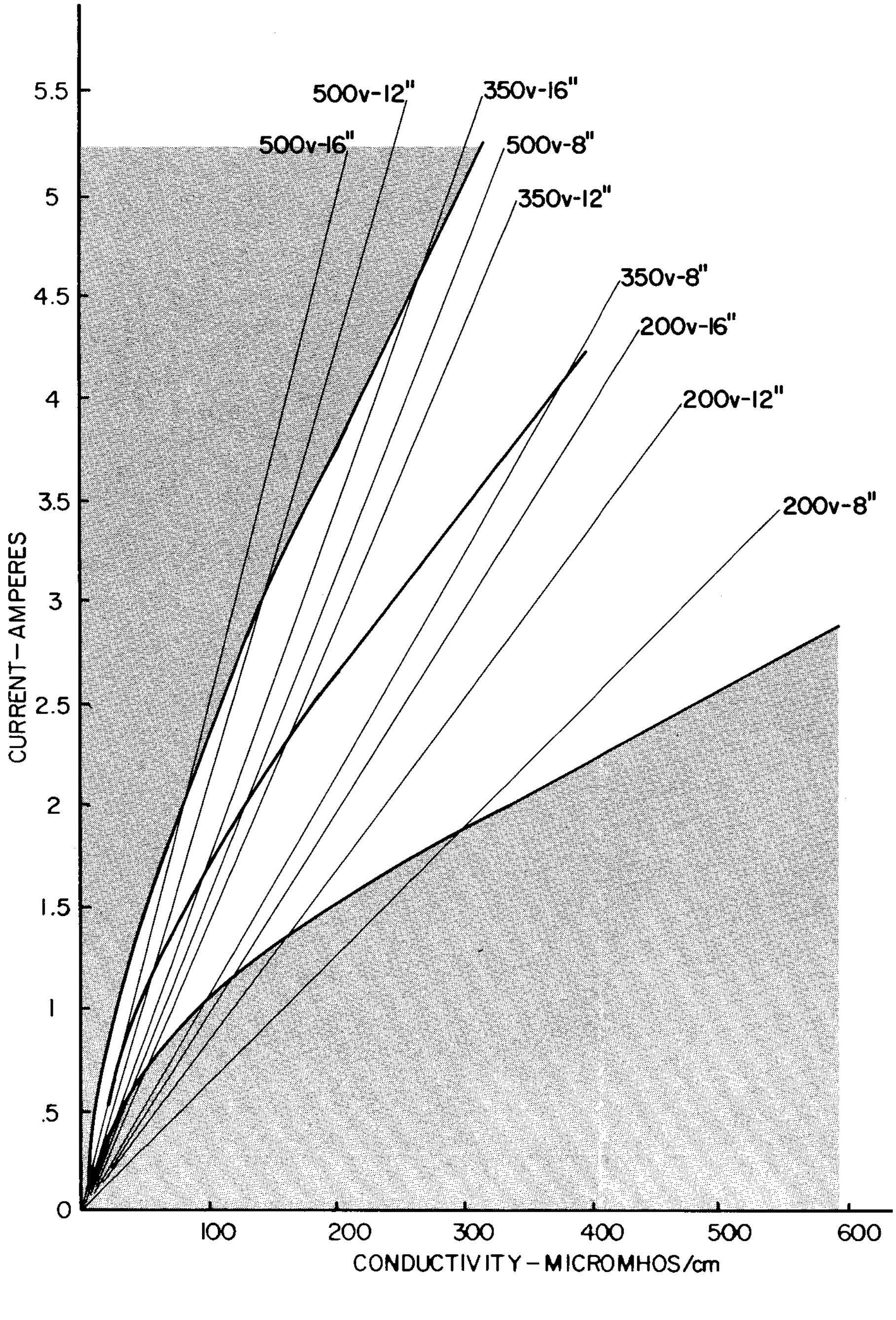

FIGURE 8. Effect of varying anode size and voltage using one anode in shallow water.

machine would be the better choice because of its larger current rating.

One- and Three-Anode Operation. Operating with one anode instead of two will increase the current in the remaining anode for a fixed value of voltage. This results in an increased catching range for that anode and increased effectiveness if stream conditions do not require the cooperative efforts of two operators with two anodes. The increased current is a result of a reduced voltage drop around the cathode because less total current must pass through the cathode resistance. Exactly the opposite result is true if three anodes are used instead of two.

The magnitude of this effect is illustrated in Figure 7. This figure has three different current scales on the ordinate which correspond to the three cases of one, two, or three anodes. The straight line operating characteristics are labeled with the number and the size of the anodes. For each of these lines, the current must be read on the corresponding current scale. However, if it is assumed that each anode is operated independently, then for equal effectiveness each would require the same current per anode. The straight line characteristics may then be directly compared and the guideline characteristic applies equally to each line.

Examination of Figure 7 reveals, for example, that a single 8-inch anode will be about as effective as any one of three 16-inch anodes operated simultaneously from a single generator (at the same voltage). If it is now recognized that because of the voltage drop in the generator, the voltage available to drive the three anodes would be less than that available to drive the one smaller anode, it can be seen that the single small anode may be very much more effective than any one of the three large anodes. This can be a very significant factor in situations which demand increased effectiveness (deep water, for example) and considerable improvement may be attained by operating with only one anode in these situations. Of course, one large anode will result in more current and better electrofishing than one small anode, and hence the most effective mode of operation for any system is to use one large anode and as large a cathode as possible.

Figure 8 illustrates the operating characteristics for various voltages and anode sizes for operation with a single anode. By comparing this figure to Figure 4, it is possible to estimate the increase in effectiveness associated with single anode vs. two anode operation. One 16-inch anode at 350 volts should permit effective electrofishing down to a conductivity of 30. The corresponding minimum conductivity for two 16-inch anodes at 350 volts is 60 (Fig. 4).

Power Requirements. By using the electrode resistance data given in Table 1, it is possible to compute the electric power required to attain a specific current at a specific water conductivity. Since this power must be supplied by the generator, the required generator size can be obtained from such computations.

Table 3 presents the results of a series of computations for a range of water conductivities. For each conductivity the power required to just meet the minimum required current guideline and reach the midline curve on Figure 2 is given. In an approximate sense, these two values may be interpreted as the minimum power required for shallow water electrofishing and for deeper or larger stream applications respectively. On this basis a 1000-watt generator is sufficient for shallow streams up to a water conductivity of 500 micromhos/cm, whereas about 4000 watts would be necessary in larger streams. The other entries in the table will allow generator rating estimates for other water conductivities. The table also shows an additional advantage of larger electrodes in terms of the power required. Larger electrodes require less power to supply the same current because of their lower resistance.

For operation with a single anode, the power required is less than 50% of the table value since the power loss in the cathode resistance is less at the smaller cathode current. Calculations indicate that about 40% of the table value is needed with only one anode. For three anodes, approximately 180% of the table value will be required.

In selecting a generator for electrofishing applications attention must be given to both the power and voltage ratings of the machine. Tables 1 and 3 and Figures 4 and 8 will permit appropriate selection for various ranges of water conductivity. The guideline table presented in the next section will also be of value in this regard.

TABLE 3
Power Requirements Using Two Anodes

Conductivity (micromhos/cm)	Minimum Power (watts) With Anode Size (inches):			Midline Power (watts) With Anode Size (inches):		
	8	12	16	8	2	2
500	1000	800	690	4000	3100	2700
400	910	720	620	3500	2700	2360
300	860	680	580	3100	2400	2100
200	790	620	540	2500	2000	1700
100	830	650	560	2200	1700	1500

GUIDELINE TABLE

TABLE 4
Proposed Guidelines for Stream Shocking with DC Current and Two Anodes

Conductivity (micromhos/cm)	Minimum Required Current (amperes)	Maximum Current (amperes)	Voltage/Anode Size (diameter in inches) 200	250	300	350	400	450	500
500	5.2	15.2	8,12	8	-	-	-	-	-
450	4.8	14.2	12	8	-	-	-	Generator Overloading	-
400	4.4	12.8	12,16	8,12	8	-	-	-	-
350	4.0	11.5	12,16	A	8,12	8	-	-	-
300	3.7	10.2	12,16	A	A	8,12	8	8	-
250	3.3	8.8	16	12,16	A	8,12	8,12	8	8
200	2.9	7.5	16	12,16	A	A	8,12	8,12	8
150	2.5	6.3	-	16	12,16	A	8,12	8,12	8,12
100	2.1	4.7	-	-	12,16	12,16	A	A	8,12
80	1.8	4.0	-	-	16	12,16	12,16	A	A
60	1.5	3.2	-	Ineffective	-	16	12,16	12,16	12,16
40	1.2	2.5	-	Electrofishing	-	-	16	16	12,16
20	0.8	1.5	-	-	-	-	-	16	16

Notes: A represents 8; 12; 16

1. For electrofishing with one anode, the minimum required current is 50% of the table value.
2. For electrofishing with three anodes, the minimum required current is 150% of the table value.
3. The indicated anode sizes at various voltages are only suggestions–in all cases the current should be within the specified range and be within the rating of the generator being used.
4. Best results will be attained with as large a current per anode as can be supplied within the specified range. Current per anode can be increased by
   a) increasing voltage
   b) using larger anodes
   c) using fewer anodes
   d) enlarging cathode

For use in the field a curve of the minimum required current (Fig. 2) is less convenient than a table of values. Furthermore, the various lines showing operating characteristics would be difficult to use in the field. To overcome these limitations, a guideline table has been prepared (Table 4).

The minimum and maximum values of current have been read from the guideline curves on Figure 2. The acceptable anode sizes which could be used at the given voltages have been determined and tabulated. Where no entry exists in the table, no suitable anode size is available (of the three considered). The entire table is set up for two–anode systems but can be applied to one- or three-anode systems by applying notes 1 and 2 at the bottom of the table.

In use, the operator would measure or make his best estimate of the actual water conductivity (not the value corrected to some nominal temperature). By entering the table at the nearest listed conductivity, the minimum required current is determined. Knowing the voltage available from the generator to be used, the operator could then move across to the appropriate voltage column and note the anode sizes which are recommended. Normally, the largest size recommended should be selected if maximum effectiveness is desired. With the anodes connected and the generator operating, the output current and voltage should be noted (the anodes should be in the water 6 to 10 feet apart). If the current is within the generator rating and above the required minimum, the selected system could be used immediately. However, if the current is significantly below the generator rating and larger anodes are available, it might be advantageous to shut down and install the larger anodes. To fully utilize the generator being used, the largest possible current within the rating of the generator should be the desired goal since *effectiveness is greater with larger currents.*

The upper right-hand entries of the table are blank because at these high conductivities the generator is likely to be overloaded (a maximum current of approximately 8 amperes was used in establishing the table). Since the ratings of generators vary, it might well be possible to operate in this region of the table with some of the larger generators available. Following the procedure outlined above would lead to this naturally by starting with 8-inch anodes and moving to larger ones after measuring the current.

At low conductivities it becomes increasingly difficult to force enough current into the water to attain effective electrofishing. The entries in the lower left of the table are blank wherever the current will not exceed the guideline values. In situations where the stream conditions and available generator voltage result in a table entry which is blank, the operator should expect poor results if electrofishing is attempted. In very small streams, results may be reasonably good even below the recommended minimum current. Operation with only one anode or use of anodes even larger than 16 inches will help in these limiting situations.

Few data are available at very low conductivities, resulting in speculative guidelines under those conditions. There is little reason to expect any severe bending of the guideline curve at these low conductivities since experimental work has indicated that the body conductivity of fish is of the order of 500 micromhos/cm or more (Monan and Engstrom, 1963). Thus, the low end of the curve is in the region where the water is many times less conductive than the fish and rapid variations in required current would not be expected. Additional field test data are needed in this low conductivity region.

OTHER CONSIDERATIONS

There are many nonelectrical factors which affect the performance of electrofishing equipment. The minimum required current guidelines presented in this report must be interpreted as pertaining to situations similar to the field test conditions upon which the guidelines are based. In particular, most of these data were obtained on shallow streams (less than 24 inches deep) and involved only brook and brown trout. The suggested current levels for deeper waters are speculative and other species, particularly warmwater fishes, should be expected to have different levels of susceptibility to electric currents.

Water temperature in the field tests varied between approximately 48° and 70° F. There were insufficient data to permit any conclusions regarding the effect of this parameter. The dominant effect of water temperature is probably reflected in its physical effect on water conductivity, but there may well be a physiological influence on the susceptibility of fish to an electric current.

In general, application of the minimum current guideline to situations involving other fish species, deep water, or extremes of temperature or water current should be viewed as a starting point only. If fish response is not adequate, increasing the anode current by one of the means discussed is indicated. Additional field tests are needed to evaluate the importance of some of these factors.

Finally, the skill and experience of the operators will have a significant effect on performance. An experienced crew, cooperatively employing two or more anodes to direct fish movements and take advantage of natural barriers and holding areas in a stream can markedly increase the effectiveness of any electrofishing system.

SUMMARY

1. **Minimum required current.** The current is a good electrical measure of electrofishing effects. In general, less current is required as the water conductivity decreases. A guideline indicating the minimum current required for effective electrofishing can be established by actual stream tests. (Figs. 1 and 2, Table 4).

2. **Water depth and stream size.** Deep water and large streams will require larger currents to produce effective electrofishing. Approximately twice the current indicated as the minimum in Table 4 is required in deep water to maintain effectiveness.

3. **Electrode resistance.** Large electrodes have lower resistance and thus permit larger currents at a given voltage. The cathode should always be as large as possible. Anode size must be selected to obtain the maximum current without overloading the generator. (Figs. 3, 4, 5, Tables 1 and 2).

4. **Generator characteristics.** The output voltage of any generator drops as current is taken from the machine. The amount of this reduction depends upon the type of generator and can be very great in some machines. This reduction in voltage can cause a serious loss of effectiveness if generators are heavily loaded. (Fig. 6).

5. **Number of anodes.** The current per anode is reduced as the number of anodes fed from a single generator is increased, even if the generator voltage is constant. Maximum current per anode (and hence maximum effective range) is attained when using one anode. (Figs. 7 and 8).

6. **Power requirements.** The power required for effective electrofishing depends on water conductivity, size and number of anodes, and water depth and stream size. Approximately 1000 watts should be satisfactory for two anodes in small streams up to a water conductivity of 500 micromhos/cm. (Table 3).

7. **Guideline.** A simple guideline table listing the minimum required current and suggested anode sizes for various voltages is available. (Table 4).

APPENDIX A: Stream Shocker Survey Form

Date____________________

Operators____________________________ Stream____________________________________

____________________________ County____________________________________

Conductivity Reading__________________ micromhos/cm at _____________°F

Make of Generator__________________________ conservation #___________________________

Electrical performance:

1. Open circuit (both electrodes out of water) _________________________volts
2. One electrode operating __________ volts ______________amps
3. Two electrodes operating _________ volts ______________amps
4. Three electrodes operating _______ volts ______________amps
5. On "Powermaker" generators - was filter used? Yes_____ No_____
6. Describe any special electrical equipment employed______________________________

   ____

If other than standard electrodes were used, give details ____________________________

____

Fishing Performance:

1. Describe stream conditions (rough approximate average width and depth and water clarity) ____

   ____

   ____

   ____

2. Describe fishing effectiveness (how well were fish held at electrode, were any fish injured, how well did system function in deeper water, etc. Give your qualitative judgment of over-all effectiveness compared to other similar stream electric fishing____

   ____

   ____

   ____

   ____

3. Other Comments: ____

   ____

   ____

APPENDIX B : Theoretical Determination of Electrode Resistance

The physical laws which govern the current distribution and resistance of an electrode immersed in a conducting medium are the same as those governing the static electric field and capacitance of a charged body. Since many of the electrode shapes employed in electric fishing are simple geometric shapes for which the capacitance has been determined, this analogy permits rapid evaluation of the resistance of these electrode systems.

In most direct current electric fishing systems the anode and cathode are separated by a distance which is large compared to the electrode dimensions. For such systems the electrodes do not interact and it is possible to consider each electrode separately. The total resistance of the electrode system is then obtained by properly combining the separate resistances—for example, for a single anode, single cathode system, the two resistances are simply added to obtain the total resistance. In cases where the electrode spacing is comparable to the electrode dimensions, the system must be treated as a single unit to obtain the correct system resistance. Such closely spaced systems are not treated here.

The Resistance Equation

For a single electrode far removed from the return electrode and submerged far below the water surface, the resistance can be expressed in the form

$$R = \frac{\rho}{D} f\left(\frac{d}{D}\right) \quad \text{(ohms)}$$

where

ρ = resistivity (ohm-cm)

D = principle dimension (cm)

d = secondary dimension (cm)

$f(\frac{d}{D})$ = function of dimensionless geometric ratio which accounts for the particular geometry of the electrode

This formulation is exact for an electrode infinitely far removed from the water surface and bottom and becomes an approximation as these boundaries approach the electrode.

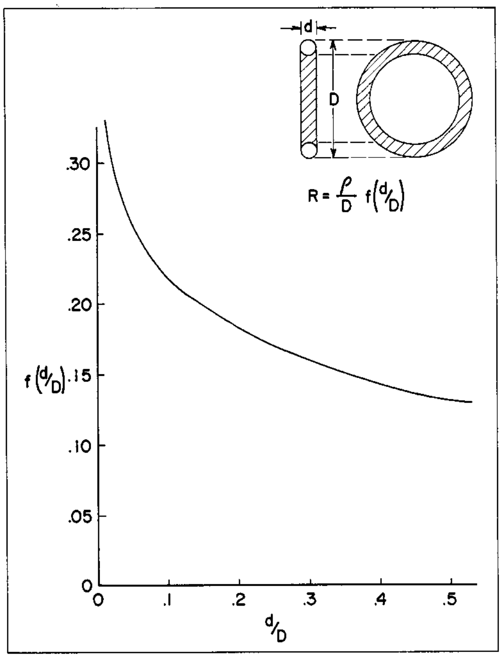

FIGURE 9. Resistance in ohms of a ring electrode.

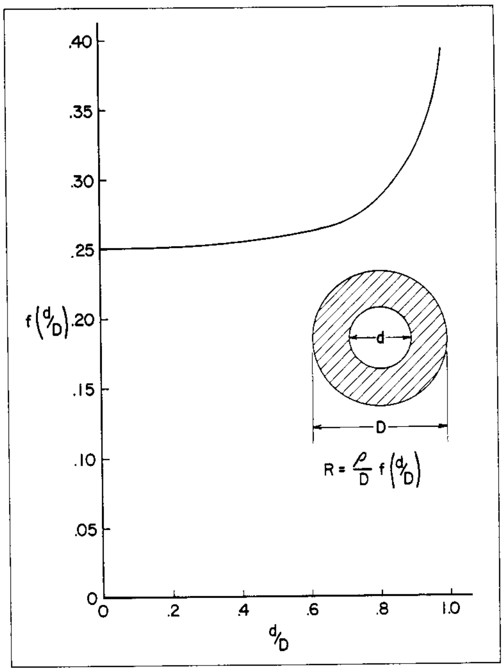

FIGURE 10. Resistance in ohms of a circular disc electrode.

The simplest geometric shape is a sphere for which the principle dimension D is the diameter and no secondary dimension d is needed to describe the geometry. The function f(d/D) is therefore a constant (0.159). Hence, for a spherical electrode

$$R = 0.159 \frac{\rho}{D} \text{ (ohms)}$$

For more complex shapes f(d/D) is not a constant, and a mathematical function or graph is necessary to describe the function.

RESISTANCE OF ELECTRIC FISHING ELECTRODES

Figures 9, 10, and 11 present f(d/D) for ring (Loh, 1959 a and b), disc (Higgins and Reitan, 1959), and rectangular plate (Reitan and Higgins, 1956) electrodes, respectively. The sketch on each figure identifies the principle dimension D and secondary dimension d for each of the electrodes. In each case a wide range of values of d/D is included to permit evaluation of most electrodes encountered in electric fishing.

In addition to direct application in calculating the resistance of a specific electrode, the curves in these figures illustrate a general property which is useful in designing electrodes. This property is associated with the slow variation of the function f(d/D) except at extreme values of d/D. Thus the resistance depends strongly on the primary dimension D and only weakly on the secondary dimension d. Physically, this property results from the tendency of the electric current to concentrate along the edge of the electrode.

As specific examples of this general property with practical significance in electrode design, note that:

1. For ring electrodes the diameter of the ring material is much less significant than the diameter of the ring. See Table 2 in the text for examples.
2. For a given surface area, the resistance of a rectangular electrode increases only 5% as d/D varies from 1.0 (square) to 0.2. A disc with the same surface area will have the same

resistance as a square. Within these limits, then, shape is not an important factor in flat electrodes.

3. For a disc electrode, removal of 50% of the interior surface area (d/D = 0.707) increases the resistance by only 8%. Similar results would hold for rectangular electrodes. Thus, considerable portions of the interior region of flat electrodes can be omitted without significantly increasing the resistance of the electrode.

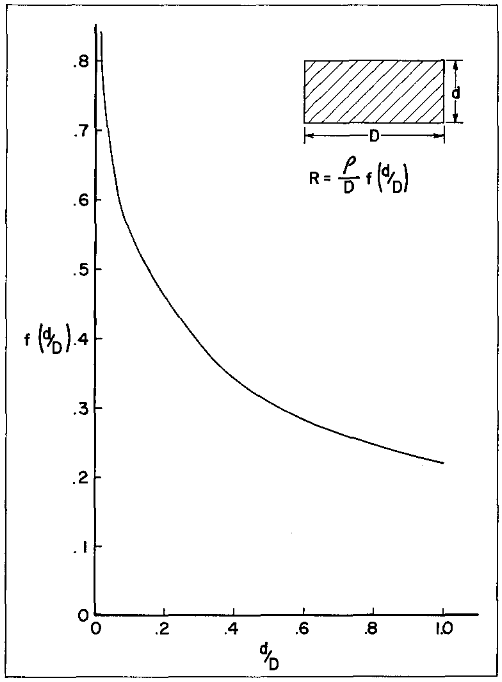

FIGURE 11. Resistance in ohms of a rectangular plate electrode.

EFFECT OF SHALLOW WATER OPERATION

The resistance computed from Figures 9, 10, and 11 is for an electrode very far removed from any boundaries. As the boundaries approach the electrode, the resistance will increase. One limiting case of practical importance is an electrode placed on the water surface in water deep compared to the principle dimension of the electrode. In this case the electrode resistance is exactly two times the value calculated from the figures since exactly one half of the conducting region has been removed. This occurs, for example, when a flat plate electrode fastened to the bottom of a boat is used as a cathode.

When the depth of immersion of the electrode is only several times the principle dimension D, the problem becomes quite complex. For practical calculations it has been found that if the water depth is five or six times the principle dimension D and the electrode is immersed half way, the calculated value will be approximately 10% low. In typical shallow water streams where the water depth is only one or two times the principle dimension, increasing the calculated resistance by 70% has been found to yield satisfactory results.

MULTIPLE ELECTRODE SYSTEMS

For systems with more than two electrodes, the individual electrode resistances can be combined according to the usual laws for adding resistances in series and parallel assuming each electrode is far removed from every other one. Thus for electrodes in series

$$R_s = R_1 + R_2$$

and for electrodes in parallel

$$R_p = \frac{R_1 R_2}{R_1 + R_2}$$

Example

As an illustration of the method the resistance, current, and power of the following system is calculated.

Cathode: 6 × 2 feet flat plate mounted on boat

Anodes: 1 8 × 1/4 inch ring

1 12 × 1/4 inch ring

Generator: 300 volts (assumed constant)

Water Conductivity: 400 micromhos/cm

Solution

Resistivity

$$\rho = \frac{1}{\sigma} = \frac{1}{400 \times 10^{-6}} = 2500 \text{ ohm-cm}$$

Cathode Resistance

D = 6 feet = 183 cm d/D = 0.333

f(d/D) = 0.375 from Figure 11

$$F = \frac{\rho}{D} f(\frac{d}{D}) = \frac{2500}{183} \times 0.375 = 5.1 \text{ ohms}$$

Since only one side of plate is exposed, this value must be doubled; hence

$$R_c = 10.2 \text{ ohms}$$

Anode Resistance - (8 × 1/4 inches)

D = 8 inches = 20.3 cm d/D = 0.031

$f(\frac{d}{D})$ = 0.282 from Figure 9

$$R_8 = \frac{\rho}{D} f(\frac{d}{D}) = \frac{2500}{20.3} \times 0.282 = 34.7 \text{ ohms}$$

Anode Resistance - (12 × 1/4 inches)

$D = 12$ inches $= 30.5$ cm $d/D = 0.021$

$f(\frac{d}{D}) = 0.302$ from Figure 9

$$R_{12} = \frac{\rho}{D} f(\frac{d}{D}) = \frac{2500}{30.5} \times .302 = 24.8 \text{ ohms}$$

Total Resistance

8-inch anode operated alone

$$R_T = R_c + R_8 = 10.2 + 34.7 = 44.9 \text{ ohms}$$

12-inch anode operated alone

$$R_T = R_c + R_{12} = 10.2 + 24.8 = 35.0 \text{ ohms}$$

Both anodes operated in parallel

$$R_T = R_c + \frac{R_8 R_{12}}{R_8 + R_{12}} = 10.2 + \frac{34.7 \times 24.8}{34.7\ 24.8} = 24.7 \text{ ohms}$$

Current and Power - deep water operation

For deep water, multiply all resistances by 1.10

8-inch anode alone

$$I = \frac{V}{R} = \frac{300}{1.1 \times 44.9} = 6.1 \text{ amperes}$$

$$P = VI = 300 \times 6.1 = 1820 \text{ watts}$$

Both anodes

$$I = \frac{V}{R} = \frac{300}{1.1 \times 24.7} = 11.0 \text{ amperes}$$

$$P = VI = 300 \times 11.0 = 3300 \text{ watts}$$

Current and Power - shallow water operation

For shallow water, multiply resistances by 1.70

8-inch anode alone

$$I = \frac{V}{R} = \frac{300}{1.7 \times 44.9} = 3.95 \text{ amperes}$$

$$P = VI = 300 \times 3.95 = 1180 \text{ watts}$$

Both anodes

$$I = \frac{V}{R} = \frac{300}{1.7 \times 24.7} = 7.15 \text{ amperes}$$

$$P = VI = 300 \times 7.1 = 2130 \text{ watts}$$

The current in each anode for this last case can also be determined as follows

$$I_8 = I \frac{R_{12}}{R_8+R_{12}} = 7.15 \frac{24.8}{34.7+24.8} = 3.00 \text{ amperes}$$

$$I_{12} = I \frac{R_8}{R_8+R_{12}} = 7.15 \frac{34.7}{34.7+24.8} = 4.15 \text{ amperes}$$

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