THE ELECTRICAL RESISTIVITY METER IN FISHERY INVESTIGATIONS

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United States Department of the Interior, Fred A. Seaton, Secretary
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THE ELECTRICAL RESISTIVITY METER IN FISHERY INVESTIGATIONS

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ABSTRACT

A portable resistivity (or conductivity) meter is easily used in fishery investigations to obtain rapid and precise measurements of the electrical resistance (or conductance) of waters. These measurements can be used to estimate the total dissolved solids content of waters, to facilitate the selection of appropriate gear for efficient electrofishing, and to determine the velocity, stretch-out, dilution, and effective range of a solute over miles of a stream in conjunction with chemical reclamation operations. Applications of resistivity measurements on Appalachian streams are discussed.

THE ELECTRICAL RESISTIVITY METER IN FISHERY INVESTIGATIONS

INTRODUCTION

An electric resistivity (or conductivity) meter is an instrument which deserves wider use in fishery research and management because of its multiple applications. An inexpensive, portable meter has been employed in research on southeast trout streams in the following ways: (1) in making easy and rapid estimates of the total dissolved solids in streams; (2) in facilitating the selection of proper AC and DC electrofishing gear for various waters; and (3) in measuring the velocity, stretch-out, dilution, and effective range of a solute over miles of a stream in conjunction with chemical reclamation operations.

There are a number of new or improved instruments on the market which were developed for industrial, soils, and limnological work and are lightweight, compact, line- or battery-powered, vacuum tube, Wheatstone bridges. Included are instruments which are applicable in fishery investigations in the laboratory and field. Models are equipped with visual or audio indicators or both. Some meters indicate resistivity in ohms, microhms, or megohms; others indicate conductivity in mhos, micromhos, or megmhos. Conductivity is the reciprocal of resistivity and it is of little consequence whether measurements are obtained in ohms or mhos since they can easily be converted from one to the other.

The resistivity meter that we have used during the past four years on trout streams is a Model RC-7, portable, battery-powered unit manufactured by Industrial Instruments, Inc. This instrument with its 6-volt A battery and 108-volt B battery weighs 25 pounds. It is equipped with a "tuning-eye" null indicator which permits readings to be made quickly and easily. It measures resistivity (resistance in ohms of a centimeter cube of any substance) over a range of 0 . 2 to 2,500,000 ohms and its rated accuracy range is ± 1 percent of the reading except at extreme ends of the scale. Immersion electrodes for liquids are incorporated into a flexible tube dip cell and the model used on clear, soft water trout streams has a cell constant of 0.1. Any instrument, however, capable of measuring resistivity or conductivity over a wide range with reasonable accuracy could be used in fishery work. Most have the advantage in that only a few moments are needed to obtain a reading.

METHODS

The measurement of resistivity or conductivity with a suitable meter is a simple procedure but one which varies somewhat with the type of meter. Specific instructions are provided with meters and they should be followed to insure accuracy in measurements. Since our meter indicates resistivity of water samples, we have elected to express all results and interpretations in terms of resistivity (specific resistance) rather than convert measurements to the reciprocal, conductivity (specific conductance).

The temperature of the water is taken and recorded each time a measurement of resistivity is made since it influences resistivity significantly and in an inverse direction. The relationship between the two is considered linear for all practical purposes and amounts to a 2-percent decrease in resistivity with each centigrade degree increase in temperature (Gustafson and Behrman 1939). It is desirable therefore in comparing the resistivities of various waters to correct the actual measurements to a selected, standard temperature. It is common practice in limnology and in industry to correct measurements of resistivity or conductivity to 77° F. (25° C.). Haskell (1954) presented a formula for the correction of resistivity at one Fahrenheit temperature to another as follows:

$$\frac{R_1}{R_2} = \frac{4 + T_2}{4 + T_1}$$

in which R = resistivity

T = temperature in degrees F.

APPLICATIONS OF RESISTIVITY MEASUREMENTS

Relationship of resistivity to dissolved solids

Measurements of electrical resistivity have been utilized by industry for many years as rough empirical indices of the total dissolved solids content of waters (Gustafson and Behrman, 1939). The principal solids in non-turbid fresh waters are Ca, Mg, Na, K, Cl, SO_4, HCO_3, and SiO_2. All but the SiO_2 are major electrolytes. Rodhe (1949) noted that the combined total concentration of electrolytes may vary greatly fron one body of freshwater to another but that the proportions of specific electrolytes in each body tended to be remarkably similar. Welch (1948) recognized that a measure of total electrolytes can be obtained by measuring the electrical resistance of a sample of water. He added that any measurement of the electrolyte content of a body of water is of considerable importance in limnological practice since, other things being equal, the richer the water in electrolytes the greater the biological productivity.

Refinements in the resistivity method of estimating dissolved solids in samples of waters have been reported by Rossum (1949) and Sylvester (1958). Sylvester demonstrated the straight line relationship between conductivity and total solids in non-turbid waters of the Columbia River Basin and presented a formula for basin streams whereby any single conductivity value (micromhos at 25° C.) minus 50 can be multiplied by 0.74 to give the approximate value of the total solids (mg./l).

The motivation to improve the resistivity method for determining the concentration of solids resulted from the fact that the old method required the evaporation of 1 liter samples of water, heating and then weighing the residue - a method which is very slow and subject to great errors. In contrast, the resistivity of a water sample can be rapidly and precisely metered. The developments cited above warrant consideration in fishery investigations since field men engaged in extensive surveys can convert measurements of resistivity to estimates of total solids or electrolytes in lakes and streams. The results can serve as tentative indices of biological productivity and permit classification, ranking, or other comparisons of the waters. Applications of resistivity measurements can be made in more intensive surveys to obtain qualitative and quantitative estimates not only of total solids and total electrolytes but total hardness, non-carbonate hardness, and concentrations of specific electrolytes.

Rodhe (1949) observed that among bodies of freshwaters there may be local peculiarities, particularly in geochemical and climatic conditions, which might give certain waters a different electrolyte composition from the general, world wide "standard composition". It is advisable that fishery investigators test representative waters of their regions to determine if the accepted relationship between resistivity and total dissolved solids exists in them.

The waters studied by Rossum, Rodhe, and Sylvester ranged from soft to brine. Sylvester indicated, however, that his curve and formula for the conductivity-solids relationship was of little value where conductivity was less than 150 micromhos. The linear relationship was therefore tested with data collected on 133 clear, soft water streams in western North Carolina in which conductivities were less than 150 micromhos. Complete chemical analyses for these streams were included in a study of mountain watersheds made by the North Carolina Department of Conservation and Development (1950, 1951, and 1953). The measurements of total dissolved solids and conductivity for the streams were grouped according to toal hardness determinations (3-7, 8-12, 13-17 .... 38-42 ppm). Conductivities and total dissolved solids in each group were then averaged and the products used in the line equation $y = a + bx$, where $y = \text{TDS}$[1/] and x = conductivity at 77° F. The resulting equation was: $\text{TDS} = 7.02 + 0.72$ (conductivity in micromhos), with a standard error of $\pm$ 2.0 ppm.

A comparison of the measured, grouped values of conductivity and TDS with the values calculated for same from the equation shows close agreement (table 1). The small disparities in measurements might be attributable to errors made in the evaporation technique. The line drawn from

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[1/] TDS hereafter used to denote total dissolved solids the calculated values is straight and shows that the conductivity-solids relationship applies also in these soft waters (fig. 1).

In confirmation, the measured values of TDS in 75 additional analyses made in North Carolina soft water streams at high and low levels of flow and at warm and cold temperatures were compared with values calculated from the equation. The range of measured conductivity was 14.1 to 101.1 microhmos and range of measured TDS was 14 to 82 ppm. The average difference between measured and calculated values of TDS was 3.54 ppm which is within the standard error of ± 2.0 ppm. The differences ranged from 0 to 17 ppm, but inspection of the analyses showed that the greatest disparities occurred where the water samples contained a considerable amount of organic matter which does not ionize.

The estimation of TDS in soft water, nonturbid, trout streams in the Appalachian Mountains has been expedited by the preparation of a reference table in which TDS contents in ppm have been calculated for resistivities of 10,000 to 115,000 ohms and conductivities of 90.9 to 8.7 micromhos (table 2). A measurement of either resistivity or conductivity is corrected to 77° F. (25° C.) and then referred to the table to obtain an estimate of TDS.

It is advisable to accumulate a series of resistivity measurements for a given stream under a variety of water conditions in order to compute an average TDS content. In general, the concentration of TDS varies inversely with water levels in streams, as shown in a list of 22 observations made at a gauging station on Little River in Great Smoky Mountains National Park (table 3). The average of the TDS estimates was 17.1 ppm and they ranged from 15.3 to 19.1 ppm. The estimates were greatest when water levels were low in August 1956, and were smaller when near flood levels occurred in early February 1957. Larger differences may occur, however, in other streams at various water levels.

One of the water samples taken from the gauging station on Little River was analyzed by a U.S.G.S. laboratory and the TDS, measured as residue after evaporation at 180° C., was 16 ppm. The resistivity of the sample at 77° F. was 74,000 ohms which by reference to table 2 indicated a TDS estimate of 16.7 ppm. This close agreement is typical of those obtained in checks made of measured and estimated TDS contents of southern Appalachian streams.

The ranges of resistivities and estimates of TDS contents were examined in selected trout streams in the southern and northern Appalachian Mountains (table 4). In Great Smoky Mountains National Park, resistivities at 77° F. in 24 streams ranged from 13,700 ohms in Abrams Creek to 111,900 ohms in Indian Creek and TDS ranged from 59.8 to 13.4 ppm respectively. That the difference in TDS contents of Abrams and Indian Creeks is biologically significant has been shown in observations of their fauna. For example, the growth rate of trout in Abrams Creek is greater than in other streams listed whereas it is poorest in Indian Creek. (King 1942). Abrams contains not only a greater density of fish and bottom organisms but also a greater variety of species than does Indian Creek.

Among the streams of Shenandoah National Park, Big Run, Rapidan River, and Staunton River have estimated TDS contents of 20 ppm and Chamberlain (1950) rated their food grade as I (413 to 586 pounds per acre). Piney Run has 27.5 ppm of TDS and a food grade of IA (826 pounds per acre). Gooney Run has 28 ppm TDS and a food grade of IAA (1,037 pounds per acre). Other factors such as temperature, gradient, scouring, and stability of flow also affect stream productivity but the importance of total dissolved solids is unmistakable and an estimate of same facilitates ranking the stream.

Corrected resistivities and estimates of TDS in 10 streams of White Mountains National Forest ranged from 30,000 ohms and 31 ppm in Ellis River to 90,400 ohms and 15 ppm in Cutler Branch. No data are available, however, to demonstrate the biological significance of the difference in the TDS contents. The list does show that the high resistivity-low dissolved solids condition prevails also in the northern Appalachians.

Table 1:- Average, measured and calculated values for conductivity and total dissolved solids in 133 North Carolina streams which were grouped according to their total hardness contents. The calculated values were derived from the line equation: $y = 7.02 + (0.72)(x)$, where y = total dissolved solids and x = conductivity.

Conductivity (micromhos at 77°F.)		Total dissolved solids (parts per million)	
Measured	Calculated	Measured	Calculated
19.2	19.1	21	21
32.7	32.8	30	31
53.9	53.9	44	46
63.5	63.4	53	53
78.1	78.1	66	63
93.8	93.9	75	75
92.8	92.8	76	74
107.3	107.3	81	84

Table 2:- Concentrations of dissolved solids in ppm calculated for selected levels of resistivity.

Resistivity (77°F.)	Conductivity (micromhos at 77°F.)	Total dissolved solids (ppm)
10,000	90.9	72.5
12,500	80.0	64.6
15,000	66.7	55.0
17,500	57.1	48.2
20,000	50.0	43.0
22,500	44.4	39.0
25,000	40.0	35.8
27,500	36.4	33.2
30,000	33.3	31.0
32,500	30.8	29.3
35,000	28.6	27.6
37,500	26.7	26.2
40,000	25.0	25.0
42,500	23.5	24.0
45,000	22.2	23.0
47,500	21.1	22.2
50,000	20.0	21.4
52,500	19.0	20.7
55,000	18.2	20.1
57,500	17.4	19.5
60,000	16.7	19.0
62,500	16.0	18.5
65,000	15.4	18.1
67,500	14.8	17.7
70,000	14.3	17.3
72,500	13.8	16.9
75,000	13.3	16.6
77,500	12.9	16.3
80,000	12.5	16.0
82,500	12.1	15.7
85,000	11.8	15.5
87,500	11.4	15.2
90,000	11.1	15.0
92,500	10.8	14.8
95,000	10.5	14.6
97,500	10.3	14.4
100,000	10.0	14.2
102,500	9.8	14.1
105,000	9.5	13.9
107,000	9.3	13.7
110,000	9.1	13.6
112,500	8.9	13.4
115,000	8.7	13.3

Table 3:- Fluctuations in water level, temperature, resistivity, and estimated total dissolved solids in Little River, Great Smoky Mountains National Park, as determined in a series of seasonal observations.

Date	Water level index (inches)	Water temperature (°F.)	Resistivity (thousands of ohms) Measured	Resistivity (thousands of ohms) Corrected to 77°F.	Estimated total dissolved solids (ppm)
1- 2- 57	...	36	128.0	63.2	18.4
1-17- 57	...	32	142.0	63.1	18.4
1-24- 57	42	40	124.0	67.4	17.7
1-30- 57	44	48	116.0	74.5	16.5
2- 4- 57	51	52	126.0	87.1	15.3
2- 7- 57	45	52	118.0	81.6	15.8
2-14- 57	37	42	138.0	78.4	16.2
2-21- 57	32	44	127.0	75.3	16.5
2-28- 57	32	50	110.0	73.3	16.8
3- 6- 57	30	45	122.0	73.8	16.7
3-21- 57	31	41	133.0	73.9	16.7
3-30- 57	29	43	128.0	78.3	16.6
4- 4- 57	31	55	104.0	75.8	16.5
5- 3- 57	32	58	98.0	75.0	16.6
5-10- 57	28	57	100.0	75.3	16.6
5-23- 57	27	61	80.0	64.2	18.2
7- 8- 57	27	69	84.0	75.7	16.5
7-24- 57	24	72	74.0	69.4	17.4
8- 3- 57	22	72	72.0	67.6	17.7
8- 7- 57	22	72	69.0	64.7	18.1
8-15- 57	22	72	68.0	63.8	18.3
8-21- 57	22	68	71.0	63.1	18.4
8-29- 57	20	76	63.0	62.2	18.6
11-27-57	41	46	134.0	82.7	15.7

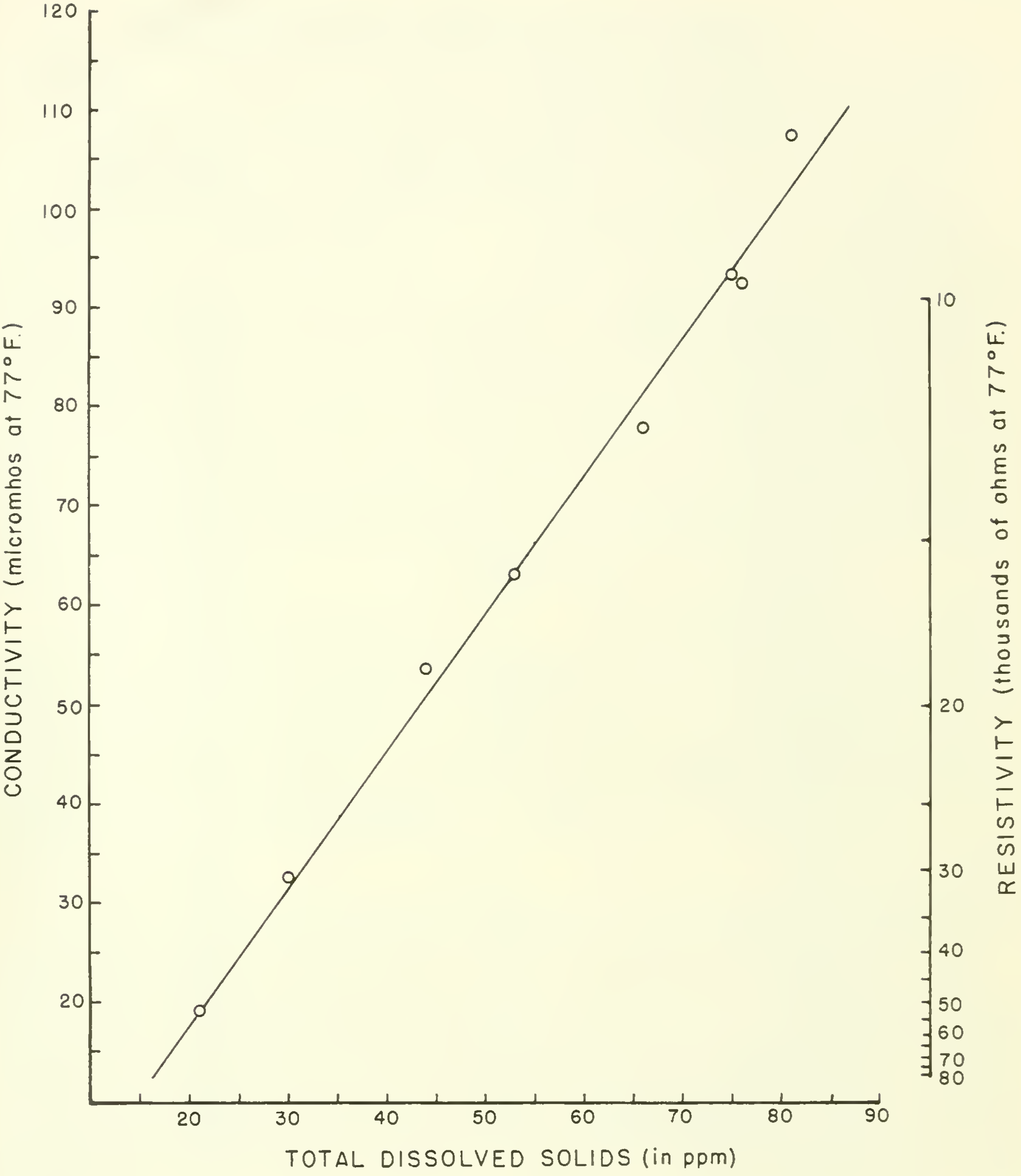

Figure 1:- The relationship of conductivity and resistivity to total dissolved solids in non-turbid streams of the southern Appalachian Mountains. Plotted points represent averages of grouped measurements made on 133 streams.

Table 4:- The resistivities and estimated contents of total dissolved solids of selected trout streams in Great Smoky Mts. National Park (Tenn. and N.C.), Shenandoah National Park (Va.), and White Mts. National Forest (N.H.).

Name of stream	Resistivity at 77° F. (thousands of ohms)	Estimated total dissolved solids (ppm)
GREAT SMOKY MTS. NP		
Abrams Creek	13.7	59.8
Anthony Creek (lower)	20.4	42.4
Anthony Creek (upper)	96.3	14.5
Big Creek	56.2	20.0
Cataloochee River	80.0	16.0
Chasteen Branch	71.8	17.1
Cosby Creek	57.8	19.4
Deep Creek	81.1	15.9
Forge Creek	100.1	14.2
Indian Creek	111.9	13.4
Jakes Creek	81.8	15.8
Little Pigeon River	81.9	15.7
Lynncamp Prong	91.2	14.9
Mill Creek	88.6	15.1
Mingus Creek	106.0	13.8
Noland Creek	83.8	15.6
Oconaluftee River	77.4	16.4
Porters Creek	73.3	16.8
Raven Fork	84.7	15.5
Roaring Fork	69.4	17.4
Rough Creek	72.4	16.9
Straight Fork	73.0	16.9
Taywa Creek	106.5	13.8
Twenty-mile Creek	78.5	16.1
West Prong Little Pigeon	50.4	21.3
SHENANDOAH NP		
Big Run	53.3	20.5
Gooney Run	34.0	28.0
Hogcamp Branch	48.2	22.0
Jeremys Run	31.6	30.7
Jordan River	33.2	28.7
Lands Run	26.3	34.5
Moorman River, North Fork	39.7	25.1
Pass Run	21.8	39.8
Piney Run	35.2	27.5
Rapidan River	55.0	20.1
Staunton River	57.9	19.4
Thornton River, North Fork	29.0	32.3
Thornton River, South Fork	33.8	28.4
White Oak Canyon Run	45.9	22.8
WHITE MTS. NF		
Cold Brook	32.8	29.0
Cutler Branch	90.4	15.0
Ellis River	30.0	31.0
Moose River	31.1	30.3
Nineteen-mile Brook	57.4	19.5
Oliverian Brook	42.8	23.9
Peabody River	39.2	25.5
Swift River	40.9	24.6
Upper Ammonoosuc River	42.8	23.9
Wildcat River	46.9	22.5

The significance of resistivity in electrofishing

A measurement of resistivity at once informs an operator of electrofishing gear whether AC or DC power can be used, whether 115, 230, or more volts are required, what type of electrode systems can be employed efficiently, and whether or not salt is needed to reduce the resistivity to a workable level. Since natural waters vary greatly in resistivity from one lake or stream to another, and vary within a given body of water with temperature and water levels, a measurement at the time of electrofishing insures the proper selection of gear and indicates roughly the efficiency of collecting which can be expected. This use of resistivity measurements not only contributes to a general improvement of electrofishing operations but permits the results of such fishing in different bodies of water or in the same bodies under various conditions to be more validly compared.

Resistivity also indicates the type of water as very soft (over 17,000 ohms), soft (8,000 to 16,600 ohms), medium hard (4,300 to 7,700 ohms), hard (1,100 to 4,200 ohms), and very hard (less than 1,000 ohms) (table 5). These types are usually defined in terms of total hardness (U.S.D.A., 1955) but are related here to resistivity and conductivity to assist in evaluating the performance of electrofishing gear in various waters.

There has been considerable misunderstanding among fishery workers regarding the reported performance of soft water or hard water electrofishing gear due to the fact that the terms soft or hard were used arbitrarily rather than according to the total hardness standard. Thus some types of gear which have been reported effective in soft water were actually tested in medium hard water and they fail to function in true soft water. Further confusion can be avoided only by typing water and gear by the standard rather than relatively.

Examples of the importance of resistivity in electrofishing were provided by trials on trout streams in Great Smoky Mountains National Park and at the Leetown (W. Va.) Fish-Cultural station. The resistivities of many of the park streams tested were over 50,000 ohms and it was found that the Petty-type alternate-polarity electrode system with 230 volts AC furnished the best, and in many cases the only results in electrofishing (Petty 1955; Lennon and Parker 1957). An experimental DC apparatus with pulsed 230-volt current produced results at resistivities up to 50,000 ohms. Paddle-type electrodes with 230 volts AC and straight DC apparatus with 230 volts failed completely. In contrast, Leetown Run had a resistivity of 2,400 ohms and paddle-type electrodes with 115 volts AC, or straight DC apparatus with 115 volts worked very well. Pulsed DC at 230 volts in a soft water, electrode system worked well but was obviously too powerful. The soft water, alternate-polarity electrode systems with 115 and 230 volts AC not only overloaded the generator but killed a large proportion of the fish taken. Obviously the latter system which worked better than others at 50,000 or more ohms was unsuitable in hard water at 2,400 ohms.

Resistivities in park streams commonly range over 100,000 ohms in winter and the efficiency of the 230-volt, alternate-polarity electrofishing gear decreases as resistivities increase. Blocks of stock salt are employed to reduce the resistivities to a range of 30,000 to 40,000 ohms, a range which is easy to achieve and at which the electrogear functions efficiently (Lennon and Parker, 1959).

The resistivities measured on selected streams in association with electrofishing operations have ranged from 10,000 to 207,000 ohms in Great Smoky Mountains National Park, from 31,000 to 114,000 ohms in Shenandoah National Park, from 2,300 to 4,850 ohms in Jefferson and Berkeley Counties, W. Va., from 22,000 to 122,000 ohms in Coos and Carroll Counties, N. H., and from 20,000 to 41,000 ohms in Kennebec, Lincoln, and Washington Counties, Me. (table 6). Those listed were not corrected to a standard temperature since they represent the prevailing condition under which electrofishing was conducted.

It has been our experience that no one electrode system, nor voltage level, nor type of electric power (AC or DC) performs efficiently over this wide range of resistivities. It is desirable, therefore, to have two or more electrode systems, two or more types and levels of voltage,

Table 5:--Types of fresh water classified according to total hardness with approximate ranges of conductivity and resistivity for each type.

Type of water	Total hardness (CaCO in ppm)	Conductivity (micromhos at 77° F.)	Resistivity (ohms at 77° F.)
Very soft	4 - 14	14 - 58	71,400 - 17,000
Soft	15 - 49	60 -124	16,600 - 8,000
Medium hard	50 - 99	130 -234	7,700 - 4,300
Hard	100 -199	235- 895	4,200 - 1,100
Very hard	over 200	over 900	less than 1,000

as well as blocks of stock salt available. In situations where two systems work equally well at a certain resistivity, one system may have advantages over the other in rough, deep, or turbid waters.

The electrode systems, power types, and voltage levels listed in table 6 are not necessarily the only ones which perform adequately in streams but they demonstrate that different gear is required in soft or hard waters. In some instances, the performance of a particular type of gear may be improved by minor alterations in the spacing of electrodes or by increasing or decreasing the number or surface areas of electrodes. Measurements of resistivity provide a guide for making the proper adjustments. Also, it should be noted that winter temperatures in the streams listed would cause substantial increases in resistivities. It would be necessary then to employ salt blocks in many of them to reduce the resistivities to workable levels.

The fact that the design of electrofishing gear must be related to the resistivity of the water cannot be overemphasized. The selection of various types of electrogear without reference to resistivity accounts for the frequent failures encountered, especially in very soft waters. Partial collections of fish made with inappropriate gear can be even more unfortunate since they may be interpreted as representative. The use of a resistivity meter is an easy and economical way to avoid such difficulties.

The resistivity meter in reclamation of streams

The resistivity meter greatly facilitated the successful reclamation of two trout streams with rotenone in Great Smoky Mountains National Park in 1957. Indian Creek is small and its flow was 22 cfs at the time that 7.5 miles of mainstream and tributaries were reclaimed. Abrams Creek is larger and its flow was 92 cfs when 14.6 miles of mainstream plus tributaries were reclaimed.

Among the problems encountered in the reclamation projects were these: (1) accurate determinations of the total rotenone were required since the material not only had to be backpacked into remote areas but toxicity downstream from the reclaimed areas had to be controlled; (2) the rates of stretch-out and dilution of the toxic bolt as it moved downstream had to be determined so that strengthening stations could be located and approximate supplies of rotenone cached; (3) the velocity of the bolt downstream had to be measured so that the limited crew could be properly disposed to maintain the bolt at desired concentration and to collect fish in daylight and dark; and (4) the above determinations had to be related to various rates of stream flow since water levels in these streams are subject to rapid and large fluctuations. Further the rotenone in Indian Creek had to be detoxified as it reached the downstream limit of the reclamation area. It was necessary, therefore, to know the total stretch-out of the bolt as it moved through the 4.5-mile section of mainstream so that detoxifi tion with $KMNO_4$ would be complete. On Abrams Creek, it was very important to State and industrial cooperators that the bolt of rotenone reach the mouth of the stream at a specified hour. Consequently its velocity through the 14.6-mile section of stream had to be determined for several possible water levels.

Table 6:- The resistivities and electrofishing gear effective on selected eastern streams. The types of gear are indicated as follows: I - alternate-polarity, II - paddle-type, III - straight direct current, and IV - pulsed direct current. Voltages are listed for each type. Salt blocks, if used, are indicated by 's'.

Place and Stream	County	Type of Water	Principal game fish	Water temp. (°F.)	Resistivity (thousands of ohms)	Appropriate electrogear
GREAT SMOKY MOUNTAINS NATIONAL PARK						
Abrams Creek	Blount	soft	Rainbow trout	70	15.0	I-230,IV-230
Anthony Creek	"	"	" "	51	10.0	I-230,IV-230
Big Creek	Haywood	very soft	" "	40	110.0	I-230,s
Cataloochee River	"	" "	" "	50	120.0	I-230,s
Deep Creek	Swain	" "	" "	49	124.0	I-230,s
Forge Creek	Blount	" "	" "	47	159.0	I-230,s
Indian Creek	Swain	" "	Brook trout	44	207.0	I-230,s
Jakes Creek	Sevier	" "	Rainbow trout	47	125.0	I-230,s
Little Pigeon River	"	" "	" "	44	138.0	I-230,s
Lynncamp Prong	"	" "	" "	48	142.0	I-230,s
Noland Creek	Swain	" "	" "	49	128.0	I-230,s
Oconaluftee River	"	" "	" "	57	93,0	I-230,s
Raven Fork	"	" "	" "	44	140.0	I-230,s
Straight Fork	"	" "	" "	47	116.0	I-230,s
Twenty-mile Creek	"	" "	" "	49	120.0	I-230,s
SHENANDOAH NATIONAL PARK						
Big Run	Rockingham	" "	Brook trout	40	92.0	I-230,s
Gooney Run	Warren	" "	" "	51	50.0	I-230,s
Hogcamp Branch	Madison	" "	" "	36	114.0	I-230,s
Jeremys Run	Page	" "	" "	38	61.0	I-230,s
Jordan River	Rappahannock	" "	" "	52	48.0	I-230,IV-230,s
Lands Run	Warren	" "	" "	52	38.0	I-230,IV-230,s
Moorman River,N.Fk.	Albemarle	" "	" "	49	67.0	I-230,s
Pass Run	Page	" "	" "	53	31.0	I-230,IV-230,s
Piney Run	Rappahannock	" "	" "	53	50.0	I-230,s
Rapidan River	Madison	" "	" "	38	111.0	I-230,s
Staunton River	"	" "	" "	63	70.0	I-230,s
Thornton River,N.Fk.	Rappahannock	" "	" "	52	42.0	I-230,IV-230
Thornton River,S.Fk.	"	" "	" "	52	49.0	I-230,IV-230,s
White Oak Canyon Run	Madison	" "	" "	56	62.0	I-230,s
WEST VIRGINIA						
Back Creek	Berkeley	hard	SM bass	59	4.9	II-115,III-115&230,IV-115&230
Evitts Run	Jefferson	"	Rainbow trout	56	2.9	II-115,III-115&230,IV-115&230
Leetown Run	"	"	" "	61	2.5	II-115,III-115&230,IV-115&230
Mill Creek	Berkeley	"	" "	60	2.3	II-115,III-115&230,IV-115&230
Opequon Creek	Jefferson	"	SM bass	59	2.5	II-115,III-115&230,IV-115&230
Potomac River	"	"	Rainbow trout	60	3.2	II-115,III-115&230,IV-115&230
Rocky Marsh Creek	"	"	" "	58	2.5	II-115,III-115&230,IV-115&230
Shenandoah River	"	"	SM bass	60	2.5	II-115,III-115&230,IV-115&230
Turkey Run	"	"	Rainbow trout	63	2.4	II-115,III-115&230,IV-115&230
NEW HAMPSHIRE						
Androscoggin River	Coos	very soft	Rainbow trout	68	39.0	I-230,IV-230
Chickwolnepy Stream	"	" "	Brook trout	63	36.5	I-230,IV-230
Cold Brook	"	" "	" "	55	45.0	I-230,IV-230
Cutler Branch	Carroll	" "	" "	56	122.0	I-230,s
Ellis River	"	" "	" "	60	38.0	I-230,IV-230
Horne Brook	Coos	" "	" "	60	40.0	I-230,IV-230
Moose River	"	" "	Rainbow trout	64	37.0	I-230,IV-230
Nineteen-mile Brook	"	" "	Brook trout	58	75.0	I-230,s
Oliverian Brook	Carroll	" "	" "	59	55.0	I-230,s
Peabody River	Coos	" "	Rainbow trout	65	46.0	I-230,IV-230
Stearns Brook	"	" "	Brook trout	60	43.0	I-230,IV-230
Swift River	Carroll	" "	" "	68	46.0	I-230,IV-230
Upper Ammoosuc River	Coos	" "	" "	59	44.5	I-230,IV-230
Upper Ammoosuc,W.Br.	"	" "	" "	59	55.0	I-230,s
Wildcat River	Carroll	" "	" "	69	52.0	I-230,s
MAINE						
Machias River	Washington	" "	Atlantic salmon	78	41.0	I-230,IV-230
Machias River,E.Br.	"	" "	" "	71	35.0	I-230,IV-230
Mopang Stream	"	" "	" "	84	41.0	I-230,IV-230
Mopang Stream,W.Br.	"	" "	" "	69	41.0	I-230,IV-230
Narraguagus River	"	" "	" "	77	32.0	I-230,IV-230
Pleasant River	"	" "	" "	73	38.0	I-230,IV-230
Schoodic Stream	"	" "	" "	70	35.0	I-230,IV-230
Sheepscot River	Lincoln	" "	" "	69	27.0	I-230,IV-230
Sheepscot River,W.Br.	Kennebec	" "	" "	65	20.5	I-230,IV-230

Previous work on the reduction of resistivities in streams with stock salt to improve electrofishing (Lennon and Parker, 1959) indicated that the resistivity meter and salt could be used to solve the problems stated above. An assumption was made that an emulsion of rotenone and a solution of salt would react practically the same in a stream to the factors of stretch-out, dilution, and velocity. It was soon obvious that the resistivity-salt technique was vastly superior to marker dyes since some observations had to be made at night, in turbid waters, in rainy weather, and over long distances. The meter gave precise measurements of salt concentrations in the water under conditions in which malachite green and sodium fluorescein dyes were impossible to measure.

The stretch-out, dilution, and velocity of known amounts of salt over miles of stream were measured according to variations in resistivity. On the basis of repeated trials with various amounts of salt at different water levels and on confirming trials with dyes, the resistivities were related to the concentrations of salt in ppm. For example, a bolt of salt applied in Indian Creek at an average concentration of 8 ppm for 15 minutes required 47 minutes to pass Station I located 100 yards downstream and the maximum concentration was 7.6 ppm for 4 minutes. The bolt reached Station III, 3.5 miles downstream, in 118 minutes and required 110 minutes to pass the station. Its maximum concentration at this point was 1.7 ppm for 4 minutes. The correlation of such data with measurements of stream flow in cfs aided in scheduling each step of the reclamation process and showed the amounts of rotenone needed initially and at strengthening stations downstream to maintain uninterrupted killing concentrations for the required lengths of time.

Observations on the velocity of salt downstream in Abrams Creek at several measured flow rates indicated that a bolt of rotenone would require 20 to 24 hours to pass through the 14.6-mile section. The flow on the date of reclamation was 92 cfs and accordingly, rotenone was introduced at 12:20 P.M. The bolt arrived at the mouth of the stream 23 hours and 40 minutes later, at 12:00 noon, which was precisely the time of arrival specified by State and industrial cooperators. The operation was conducted in an area of difficult access and under stormy weather conditions. The degree of precision and success achieved would not have been possible without the resistivity-salt technique.

Complete details on the reclamation of Indian and Abrams Creeks will be included in a separate report.

SUMMARY

1. The electrical resistance of water is easily and quickly measured in the field with a portable resistivity meter.

2. A straight line relationship exists between resistivity and total dissolved solids in non-turbid, fresh water. The dissolved solids, composed mostly of major electrolytes, influence greatly the biological productivity of water and determinations of same are therefore important to fishery investigators. Measurements of resistivity can be used to estimate the total content of dissolved solids in water within ± 2 ppm. Thus the long and tedious evaporation technique of measuring total dissolved solids is avoided.

3. A measurement of resistivity indicates the softness or hardness of water on a relative scale.

4. The design and selection of electrofishing gear may be related to measurements of resistivity of streams to achieve efficiency and comparable returns in fish collecting. Resistivity dictates the type of electrode system needed the spacing of the electrodes, the type of power, AC or DC; the voltage, 115 or 230; and whether or not salt is needed to reduce the resistivity to a workable level.

5. Determinations of the velocity, stretc out, and dilution of known concentrations of salt in a stream have been made accurately with a resistivity meter under weather and water conditions which, for the most part, ruled out the use of dyes. These determinations on a solute were assumed to apply to emulsions of rotenone and were used successfully in the reclamation of two trout streams.

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