An Introduction to "Electrofishing with Power v1.4"

This program would not be possible without the significant contributions made to electrofishing theory and application by A. Lawrence Kolz, James B. Reynolds, James Boardman, Jan Dean, and Steven Miranda.

The purposes of this program are primarily to calculate needed power, voltage, or amperage required for successful electrofishing and to estimate if your particular unit will supply the needed outputs. Other important features aid in improving equipment efficiency via electrode design (estimating electrode resistance), calculating the power, voltage, and current demand on a unit given a proposed electrode configuration and conductivity, deriving applied power density and voltage tables that allow development and maintenance of desired effective field sizes; exploring patterns and dynamics of electric fields, listing selected fish threshold power densities, estimating battery discharge time, and referencing specifications of various equipment types.

***Power Goal* Tab**

The purpose of this tab is to calculate power, voltage, or amperage needed to effectively electrofish across a range of water conductivities based on data provided by the biologist. Outputs are provided in three tables and associated graphs. The upper table requires inputs of volts and current. The middle table is used if you have a voltmeter or a calibrated voltage dial only. The bottom table needs only current from an ammeter. If your unit does not have metering, then you must apply external metering (e.g., a clamp ammeter) to monitor outputs when electrofishing.

Inputs: The upper gray box is used for inputs (water conductivity, volts) and some outputs (duty cycle, power, electrode resistance). Not all input boxes need to be entered. Most cells have comment boxes that explain the component.

Example 1.

You were out boat electrofishing using AC in 250 µS/cm water. Successful electrofishing occurred at minimum settings of 336 V and 6.34 amps (from metering). Enter 250 in water conductivity, 336 V_{rms} and 6.34 I_{rms}. The power (rms) is automatically calculated (2,130 Watts) as is equivalent electrode resistance (Req) of 53.0 Ohms.

Example 2.

You were boat electrofishing using pulsed DC in 325 µS/cm water. Successful electrofishing occurred at minimum settings of 395 V and 7.5 I. Enter these values, water conductivity, Volts in "Volts peak" and current in "Amps peak". Peak power is calculated for you at 2,963 peak watts. Total electrode resistance is figured at nearly 53 Ohms. Suppose further that you dialed in a duty cycle of 24%. Enter that number at 0.24 into "Duty Cycle (from instrumentation)". "Power (PDC average is calculated as 711 average Watts. Now instead, let's say we do not know duty cycle directly but have pulse width and frequency of the pulsed direct current. For instance, assume you used a 4 millisecond pulse width at a 60 pulse per second frequency. Enter these numbers. Note that "Duty Cycle (calculated)" now displays 0.24 or 24% duty cycle.

The next box is an optional area to record gear specifications from the manufacturer.

The final input box regards power transfer to the fish. You must enter a fish conductivity for the species or fish assemblage of interest. Values for freshwater fish ranging between 100 and 150 μS/cm are found in the literature. From the entered fish conductivity and the minimum power required to successfully electrofish in your particular situation, the mismatch ratio, power correction factor, and power needed at matched conditions are calculated. For example, enter 115 μS/cm for fish conductivity while keeping your settings of 395 peak Volts and 7.5 peak amps from example 2 above. The mismatch ratio comes up at 2.83, the PCF at 1.29, and the power needed at match conditions at 2288 watts.

Outputs: The output section consists of three tables and associated graphs, linked to the inputs section (water conductivity, volts, amps, and fish conductivity). These tables are electrical output goals (power, Volts, or Amperes) across water conductivities, based on the minimum settings required for successful electrofishing and assumed fish conductivity.

The uppermost table is used when volts and amps are recorded from equipment metering. The most important output is the power goal with associated Volts and Amps at each water conductivity. You can change water conductivities to any you wish.

Example 1.

You were successfully electrofishing at a minimum 395 V and 7.5 Amps in a water conductivity of 325 μS/cm. The assumed fish conductivity is 115 μS/cm. If not done so already, enter the Volts, Amps, and water conductivity in the upper box. Then enter 115 for fish conductivity into the lowest-most box in the inputs. Once done, the lowest input box and the three tables/graphs will be populated with numbers. As a check, in the top output table, 2708 watts are required at 50 μS/cm, 2467 watts at 200 μS/cm, and 4598 watts at 675 μS/cm. On the far right, note the shape of the "Power Goals vs. Water Conductivity graph. The bottom of the curve is near 115 μS/cm, the condition where water and fish conductivities are the same, resulting in the least amount of power required for capture. Now suppose you are interested in the power needed at a low water conductivity of 25 μS/cm. Click on the 50 μS/cm box and replace with 25. The power goal should change to 3899 watts.

Example 2.

The middle table applies when only voltage and water conductivity were taken at the electrofishing trial site. Let's assume you only had a functional Voltmeter on your electrofishing boat. In the upper input table, delete the 7.5 "Amps peak" entry and keep or enter 325 μS/cm into the water conductivity box. In the voltage goal table (middle output table), you should have voltages of 396 V at 325 μS/cm, 350 V at 575 μS/cm, and 325 V at 1000 μS/cm. Note the voltage pattern in the graph at right. Voltage demands increase dramatically at water conductivities below 100 µS/cm.

Example 3.

The lowest table generates current goals, used when only amperage and water conductivity were taken at the electrofishing trial site. Let's assume you only had a functional ammeter on your electrofishing boat. In the upper input table, delete the 395"Volts peak" value, reenter 7.5 into "Amps Peak", and keep or enter 325 µS/cm into the water conductivity box. Only the amperage goal table (lowest output table) is populated. In the amperage goal table, you should have amperages of 3.66 I at 100 µS/cm, 8.35 I at 375 µS/cm, and 12.19 I at 600 µS/cm. Note in the right graph that current increases linearly with conductivity.

***Operating Capacities* Tab**

Tools in this tab assist you in estimating the maximum power, Volts, and current you can expect from your gear under specified water conductivities. If you have developed a power goal chart (or voltage or current goal charts) in the *Power Goals* tab, then you can compare the outputs needed to successfully electrofish with the output capacities of the equipment. Can the equipment supply the required levels of power, voltage, and current to successfully electrofish?

Inputs: Enter the manufacturer's specifications for your model. These may be found in the manual, on the manufacturer's website, or you may have to call the company and ask. At least for backpack units, the amperage peak maximum is not as important as power and voltage information. Provide electrode resistance, water conductivity that you plan to electrofish, and duty cycle. See the comment red triangles for additional instructions.

The gray *Outputs unadjusted by capacity limitations*: box contains intermediate calculations that you can ignore.

Outputs: This box exhibits your estimated maximum outputs expected from your equipment at the water conductivity of interest. On the far right is the comparison box. This box lists your equipment estimated maximum outputs. You enter the required outputs for successful electrofishing from the *Power Goals* tab. At the bottom of the box, the answer "Yes" or "No" appears- yes indicates your equipment has the needed capacity, no indicates that your gear does not.

Finally, the lowermost section of the worksheet contains inputs for a graph that displays the operating range of your unit and the required electrical outputs for successful electrofishing.

Example 1.

You have an electrofishing boat that you used in to determine successful electrofishing in 325 µS/cm using pulsed DC at 24% duty cycle, 60 pps. The voltage setting was 395 V peak, the current was 7.5 peak amps, and the power was 2,963 peak Watts. The information was entered into the *Power Goals* tab and a power goal chart was derived. You assumed a fish conductivity value of 115 µS/cm. For the boat's power supply, you have a 5,500 Watt generator. The control box specifications are: pulsed DC, 4800 Watt average, 45 I peak, and 600 V peak. You use a 5,500 Watt generator because, under load, the generator will not be able to maintain a 5,500 Watt output (runs around 85 – 90% of capacity).

In the *Operating Capacities* tab, enter 4,800 for the "Maximum output power…", 600 for the "Voltage peak maximum", and 45 for the "Amperage peak maximum…". Enter the total resistance of your electrodes (53 Ohms), duty cycle (24%), and the ambient water conductivity you wish to electrofish in the future (in this example, 625 µS/cm). The most your gear can do electrically is estimated as 380 V peak, 44.77 I peak, 17,000 Watts peak, and 4,080 Watts average. These values (except for average Watts) automatically appear in the box to the right ("Can your unit deliver…?"). Go back to the power goal chart in the *Power Goals* tab, get the values for peak Watts (4,357), peak voltage (354), and peak amps (12.61) needed to successfully electrofish, and then enter them into the "Outputs needed…" section of the "Can your unit deliver…?" (*Operating Capacities* tab). Now check the responses under "Does your equipment have the capacity?" section. The answer is "Yes" for peak Watts, Voltage, and amperage. So, you are good to go with this equipment in 625 µS/cm water.

Example 2.

You have an electrofishing boat used primarily for assessing largemouth bass (*Micropterus salmoides*) populations in reservoirs. The pulsator capacities are 4800 average Watts output, 600 peak Volts maximum, and 45 Amps peak maximum. The total resistance of the boat electrode system is 69 Ohms at 100 µS/cm. From a pilot study, you found out that approximately 3,500 Watts peak (310 V and 11.3 Amps) is need for successful electrofishing of largemouth bass at 250 µS/cm ambient water conductivity. The waveform was pulsed DC, 50 pulses per second with a 4 millisecond pulse width (20% duty cycle). You adopt a fish conductivity value of 115 µS/cm, taken from the literature.

A couple reservoirs in your management region have high conductivities, around 1900 µS/cm. You want to determine if spending money for converting your pulsator to a 72 Amp peak maximum option would be worthwhile.

First, go to the *Power Goals* tab. Under inputs, enter:

250	for "Water Conductivity"
310	for "Volts peak"
11.3	for "Amps peak"
4	for "Pulse width (msec)"
50	for "Frequency (pps)"
115	for "Assumed or Known Fish Conductivity"

A power goal chart is calculated. As a check, the chart should indicate that 3,3039 Watts is needed for successful electrofishing at 100 µS/cm, and about 3,024 Watts are needed at match conditions (115 µS/cm).

Go to the *Operating Capacities* page. Scroll to the table at the bottom and you'll see that the water conductivities, power goals, and electrode resistances have been copied automatically from the *Power Goals* page. Most of the values for "Maximum Power Output 1" have been manually entered already for you (as a time saver). These values are the maximum power that a unit with the specifications you are using can generate at given water conductivities. Later, we'll address the power output numbers under "Maximum Power Output 2". The high capacity graph to the right displays a smooth blue line that plots the power goals for successful electrofishing by water conductivity. The white circles plot your equipment's maximum output across water conductivities. At water conductivities where the equipment output (white circle) exceeds that needed for successful electrofishing (line), your unit can generate the required power. When the opposite is true (power goal exceeds maximum power output), your gear can not generate the needed power. We will get to the black circles later, but they represent a gear with different specification(s).

Scroll up to the inputs box. These values are your equipment specifications. Enter:

4800 for"Maximum output power (average Watts)"
600 for "Voltage peak maximum"
45 for "Amperage peak maximum"
69 for "Total electrode resistance @ 100 μS/cm
skip ambient water conductivity for now
20 for "Duty cycle"

The total electrode resistance standardized at 100 μS/cm can be obtained by the electrode resistance calculator on the *Power Goals* tab or you can scroll down on this tab and find the electrode resistance that corresponds to 100 μS/cm water conductivity (69 Ohms). Now, for entering the ambient water conductivity value in the inputs box, scroll down to the table. You'll see that the values for "Maximum power Output 1", that is, the maximum power that your machine can generate at the particular water conductivity, has been left blank for the 25, 50 and 75 μS/cm water conductivities. These water conductivities correspond to electrode resistance values of 276, 138, and 92 Ohms.

Scroll to the right to the high capacity graph. You'll note that there are no data points plotted for x-axis coordinates 276, 138, and 92. Now, let's fill the maximum power output values in. Go back up to the inputs box and enter 25 for the ambient water conductivity. 1304 Watts peak appears in the "Power peak maximum" cell (outputs box) Type in 1304 into the cell under "Maximum Power Output 1" that is on the same row as 25 water conductivity. Follow the same process for water conductivity values of 50 (= 2609 Watts) and 75 (= 3913 Watts). After entering these values, scroll to the graph at right.

To determine the successful electrofishing range based on water conductivity, inspect the graph (or look back at the table) to see where the white circles cross the blue line. The two intersection points are at about 100 Ohms (low water conductivity) and at 5 Ohms (high conductivity) on the w-axis. To find the water conductivity range of successful operation, you can use the calculator just below the graph. Input 100 into "Ohm value from X-axis". The answer comes out to 69 μS/cm water conductivity. Now for the upper range limit, plug-in 5 into "Ohm value from X-axis". The water conductivity value is 1380 μS/cm. Thus the successful electrofishing range of your gear with a 45 Amp peak maximum is 69 – 1380 μS/cm.

The next step to address whether modifying your pulsator to increase its current capacity to 72 Amp peak will be worthwhile. Remember, you had a couple reservoirs having a conductivity of about 1900 μS/cm. The black circles represent the condition of your unit with a

72 Amp peak capacity (power data under the “Maximum Power Output 2” column). For practice, we’ll fill in two additional data points. Return to the input box toward the top of the page and replace 45 peak Amps with 72. For ambient water conductivity, enter 800 (8.6 Ohms). The maximum power output should be 19200. Enter 19200 into the cell in the “Maximum Power Output 2” column that corresponds to 800 µS/cm. Next enter 900 for the ambient water conductivity and repeat the process. That will join the black circles to the white circles.

Now the question, how much more operating capacity will I gain if I increase maximum peak current to 72 Amps? By inspection of the graph and table, the black circles cross the power goal line at a resistance of about 3.1 Ohms. Using the converter, 3.1 Ohms translates to 2,225 µS/cm. Thus, by going with a higher current capacity, given the other gear specifications, the effective electrofishing range increased from 69 – 1380 µS/cm to 69 – 2,225 µS/cm. Since your high conductivity lakes now are included in the successful electrofishing range of the 72 Amp equipment, it would be worthwhile to purchase the high current option.

Finally, the maximum power output values can all be changed to accommodate any equipment you wish to evaluate. The lower capacity graph (below the higher capacity graph) has a different scale for low power units as backpack shockers.

Electrode Resistances **Tab**

This page is useful for estimating electrode resistances and resulting power or amperage demand on your equipment at various water conductivities. Results from this tab can allow preliminary evaluation of electrode systems at the design phase. Questions that can be addressed include which electrode designs result in increased power output, which designs might result in too high a power demand for your equipment, and how is available power allocated percent-wise between anode and cathode. Electrode resistances are listed for some electrodes and electrode systems (anode and cathode). Resistances also may be obtained by theoretical and empirical calculations. Once you have a total (equivalent) electrode resistance for your gear, you can estimate the power demand given an applied voltage within a specified water conductivity. Please note that it is preferable to make your own electrode resistance measurements of your gear (see electrofishing course manual or Kolz (1993)).

Example 1.

You have a boat electrofisher that has a painted hull. You have not measured the resistance of your system but you’re interested to see if removing the paint from the hull would result in increased electrical performance. Under “Electrode Resistance In-water Measurements (standardized to 100 uS/cm)” list, go to the section under “Equivalent (Total) Resistances (anode & cathode sets)”. Find the boat electrofisher with a painted hull. The standardized total resistance of that particular boat was 74 Ohms. Scroll up and to the right and find the “Calculating Power Demand on Equipment” box. Enter 74 in the “System equivalent resistance…” line, 500 for “Water Conductivity…”, and 360 for ”Voltage applied…”. The system equivalent resistance is automatically calculated for the new conductivity at 14.8 Ohms. The amp draw is 24.32 and the peak power comes out at 8757 Watts.

Now, go back to the electrode list, and find the boat system with a non-painted hull (40 Ohms). Scroll back to the calculating power demand box and replace 74 with 40, keeping the other inputs the same. This time, the amperage draw is much more, 45 amps, and the peak power possible is 16,200 Watts. By removing the paint from the hull, you can get approximately 85% more power. Obviously, a lower resistance electrode system is capable of putting out much more power. If you have the power capacity in your generator/control box, then removing the paint allows your equipment to function effectively over a wider range of water conductivities.

Next, let's work with the theoretical and empirical equations for determining electrode resistance. Returning to the top of the tab, the theoretical equation for electrode resistance is located in cell E24. The inputs are primary electrode dimension (K) and the shape factor ratio (γ), adjusted for ambient water conductivity. Scroll to the left and the graph found there contains values for functions of gamma. These values are entered into theoretical resistance calculations for three electrode shapes (Novotny 1990). The primary dimension, K, has much more influence on electrode resistance than does the shape factor. That said, the section of particular interest for us is to the right, past the table of *f*(gamma) values for various electrodes. Under the section entitled "Single Electrode Resistance by Calculation…", there are four electrode shapes listed (includes a cylinder shape). To use the theoretical equations for estimating the resistance of a particular electrode of a given shape, you only need to enter electrode dimensions.

Example 2.

The simplest input is for the sphere electrode. Assume you are electrofishing with a 27.7 cm diameter sphere in a water conductivity of 250 µS/cm. Enter 27.7 under ""Diameter (cm)". the K factor is calculated as is the function (gamma). For spheres, the function (gamma) is a constant. Scroll further to the right. The sphere resistance at the water conductivity conditions (250 µS/cm) is listed as 23.0 Ohms. The standardized resistance (to that resistance in a water conductivity of 100 µS/cm) is 57.5 Ohms. Under the tab's electrode list, the measured resistance for a 27.7 cm sphere was 55 Ohms. These values are in very close agreement. Theoretical calculations for a sphere may be the most accurate.

Example 3.

You are considering different designs for a backpack electrofisher. One design has a hand-held ring anode with a rattail (long cylinder) cathode. The dimensions of the ring are 28 cm overall diameter (K) and a stock diameter of 0.95 cm; the rattail is 155 cm long (submerged metal) with a 0.49 cm diameter. Under the "Single Electrode Resistance by Calculation…" section, enter 0.95 for the ring diameter and 28 for the "Diameter hoop (cm)". Select any water conductivity since we are going to use the standardized values only. Note the standardized ring resistance is 97.1 Ohms.

Next, enter 0.49 for "Diameter (cm)" and 155 for length of the rattail electrode. Let's assume a distance of 182 cm (6') between electrodes. At that distance, the ring and rattail fields are essentially independent. The standardized result is 67.9 Ohms. So, the total system resistance of one ring anode and a rattail cathode of the stated dimensions is 97.1 + 67.9 = 165 Ohms. The ratio of anode resistance to total system resistance is 97.1/165 = 0.59 or 59%. Thus, 59% of the available power is allocated to the anode (where you do your electrofishing). Only 41% of the power is going to the cathode.

If the calculated values for the ring (97.1 Ohms) and for the rattail (67.9 Ohms) are compared to measured values found in the list, the theoretical is quite a bit less than measured. This is due to boundary effects of the water surface and stream or pond bottom on the measured resistance values, conditions not accounted for by the theoretical. However, the resistance ratio of anode to total resistance for determining power allocation between electrodes may be very similar to the ratio from measured values and hence valuable for electrode design decisions.

Example 4.

You wish to get an estimate of the resistance of your boat hull that you have wired as an electrode (cathode if using DC). The boat hull is not painted, and is 550 cm x 122 cm (18' x 4'). Find the flat plate electrode shape, enter 550 in "Length (cm)" and 122 in "Width (cm)". The standardized resistance is 8 Ohms. Since only one side of the plate (bottom of boat) is in contact with the water, double the resistance value from 8 to 16 Ohms. This value falls in the range of unpainted 550 cm length boat hulls (see under "Electrode Resistance In-water Measurements…").

Beaumont and Lee (2005) developed a regression equation from resistance measurements taken on various ring hoop diameters. They found the material diameter unimportant. Beaumont and Lee's empirical equation is incorporated under the "Singe Electrode Resistance by Calculation…" section.

Example 5

Let's come ring resistance values calculated by the theoretical and the empirical equations. Under "Single Electrode Resistance by Calculation (equations from Novotny 1990)", find the ring electrode shape. Enter 1 for the "Diameter (cm)", 30 for the "Diameter hoop (cm)", and a water conductivity of your choosing. The standardized resistance (at 100 µS/cm) is 91.0 Ohms as made by theoretical calculation.

Now go to the "Single Electrode Resistance by Calculation (equation from Beaumont & Lee 2005)" section and input 30 for the "Diameter hoop (cm)". Scroll to the right and you'll see that the standardized resistance by empirical equation is 114 Ohms. The empirical result is about 25% larger than the theoretical. Beaumont and Lee (2005) found an average of 23% higher empirical readings from the theoretical and attributed this discrepancy to boundary effects.

It is important to note that you are after a "nominal" electrode resistance, not an absolute. Moving from deeper to shallower water can substantially change the electrode resistance. Beaumont and Lee (2205) found that electrode resistances at 50 cm (1.6') depth were only 70% of the electrode resistance at the water surface. The key is to deploy electrodes in water depth and bottom type similar to typical conditions electrofished, and use the nominal resistance values for electrode power allocation calculations and for an estimate of power demand on the equipment.

The final section of this tab ("Equivalent Resistance of Electrode Array:…") calculates total or equivalent electrode resistance of your system measured at a specified ambient water conductivity.

Example 6.

You have a backpack system with an anode of 80 Ohms (at 200 µS/cm) and a cathode having a resistance of 57 Ohms. Enter the water conductivity that measurements were taken in

(200 µS/cm), the anode 1 resistance of 80 and cathode of 57. The standardized equivalent resistance of your electrode system is 274 Ohms.

Example 7.

Your electrofishing boat has two boom electrodes (anodes if DC) with the hull wired as the other electrode (cathode if DC). Each anode has a resistance of 95 Ohms in 50 µS/cm water. The hull has a resistance of 36 Ohms in 50 µS/cm water. What is the total (equivalent) resistance of your boat electrofisher standardized to 100 µS/cm? Enter 50 for "Ambient water conductivity (µS/cm)", and under "2 Anodes & 1 Cathode" enter 95 for anode 1 resistance, 95 for anode 2, and 36 for cathode 1 resistance. The equivalent resistance of all electrodes (2 anodes + 1 cathode) is 42 Ohms at 100 µS/cm. Now, what is the power allocation between anodes and cathode? Scroll down to the "Percent Power Allocation Among Electrodes" box. You can either enter the values for electrode resistance at 50 µS/cm or at 100 µS/cm, just use the same water conductivity for all electrodes. Here, we'll use electrode resistance values in 50 µS/cm. Enter 95 for both "Anode 1 resistance" and "Anode 2 resistance". Leave anode 3 and 4 blank. The result should be 47.5 Ohms for anode total resistance. Now, enter 36 for "Cathode 1 resistance", leaving "Cathode 2 resistance" blank. Cathode total resistance is, of course, 36 Ohms. Electrode system total resistance is calculated at 83.5 Ohms, with 56.9% of the power going to the anodes and 43.1% of the power going to the cathode.

***Battery Time Calculations* Tab**

This tab allows you to estimate battery discharge time using DC and pulsed DC currents. One of the important relationships you'll find is how lower duty cycle results in longer battery time. You'll need to know your equipment's total electrode resistance, battery capacity under 1 amp load, and the battery Peukert's number. The battery values can be obtained from the manufacturer or calculated. The page has more explanations in several cell comments.

Example.

You are using an LR-24 backpack electrofishing unit with a 12 amp-hour battery supplied by Smith-Root, Inc. From the *Electrode Resistances* tab, select 284 Ohms for the total electrode resistance at 100 µS/cm. You plan to electrofish using a DC waveform in a water conductivity of 312 µS/cm, using 400 Volts. Under the "Battery Specifications" section (*Battery Time Calculations* tab), note that for the 12 Amp-hour battery used for the LR-24, the Peukert's number is 1.25 and the battery capacity is 10.59.

Scroll to the right. Under "Amp calculation for DC:", enter 312 for water conductivity, 284 for electrode equivalent resistance, and 400 for DC volts. The "DC amps" value is 4.39. Now, scroll to the left and use the calculator. Enter 1.25 for Peukert's Number, 4.39 for current draw, and 10.59 for battery capacity. The battery life (100% discharge) is 100 minutes.

Another option is to use 50% duty cycle pulsed DC. Scroll back to the right. This time, use the "Average amp calculator for pulsed DC:" section. Enter 312 for water conductivity, 284 for standardized electrode total resistance, 400 for Volts peak, and 0.5 for duty cycle. The pulsed DC average amps now is 2.20. Enter 2.20 into the battery life calculator, keeping the other inputs the same. Battery discharge time has increased to 237 minutes. Next try 24% duty cycle. You'll find that the battery life is further extended to 598 minutes.

Electric Fields **Tab**

This tab introduces the topic of electric fields in water generated by a few electrode shapes (i.e., sphere, cylinder, and ring). The spherical and cylinder electrode fields are described by the use of theoretical and empirical equations, whereas the ring electrode field is derived from field measurement data.

Inputs (for theoretical and empirical equations, on left side of tab):

water conductivity, voltage applied, standardized (at 100 µS/cm) total electrode resistance, and electrode dimension(s). If you do not know the gear standardized electrode resistance, then scroll to the right and enter peak Volts and peak amps from your metering.

Outputs (for theoretical and empirical equations, on left side of tab):

Current applied to electrodes, equivalent (total) resistance of electrode system, and the voltage gradients and power densities at given distances away from the electrode. The field characteristics (voltage gradient and power density by distance) is provided in tabular and graphic forms.

Example 1.

You have a 550 cm (18') electrofishing boat with a single 28 cm diameter sphere on a boom. The total resistance of your electrodes is 73 Ohms in 100 µS/cm water conductivity. You don't have a voltage gradient probe/meter but you are interested in getting an estimate of the field extent under different applied voltages. The ambient water conductivity of interest is 200 µS/cm.

For inputs on the upper left of the tab, enter 200 for water conductivity, 100 for voltage applied, and 28 for the diameter of the sphere. Scroll to the right. Enter 73 for the "Equivalent resistance of electrode system at 100 µS/cm.

Return back to the upper left of the tab. Outputs include 2.74 amps of current applied, 37 Ohms equivalent resistance, and the table and graph values for the electric field map. The voltage gradient at 5 cm distance from the sphere is 3.02 V/cm and the corresponding power density is 1824 µW/cm^3. If we estimate that the edge of the effective field is at 0.10 V/cm, then the fish-catching field size is nearly 90 cm from the sphere.

Example 2.

Let's see what increasing the voltage does to the field as defined by the voltage gradients. Double the applied voltage to 200, leaving all else the same. The voltage gradient at 5 cm has doubled to 6.04 V/cm (as have all the other voltage gradients). By a factor of 4, the power density also has increased- to 7295 µW/cm^3. The effective field size has increased to approximately 125 cm from the sphere.

Example 3.

You remove the sphere electrode from your boat and replace it with two booms, each with a cable (cylinder) that is 60 cm long (submersed) and 1.27 cm in diameter. You again are in 200 µS/cm water. This time, you do not know the electrode resistance. You have your boat in an area of the waterbody that you wish to electrofish. You apply power to the electrodes and read the voltmeter (200 V) and ammeter (5.26 amps). From the upper left hand area of the tab, scroll to the right to the "Input of equivalent (total) electrode resistance". Enter 200 for Volts peak applied and 5.26 for Amps peak applied. The result is 76 Ohms standardized. Enter 76 into the "Equivalent resistance of electrode…" box. Scroll back to the left. You'll see that equivalent resistance has been calculated. Enter 60 for the length of the cylinder and 1.27 for the cylinder diameter.

Note that at 5 cm from one of the cylinders, the voltage gradient is 12.39 V/cm and the power density is 30,691 µW/cm^3.

Example 4.

You wish to get an estimate of the distance to the 0.1 V/cm line for your backpack unit when you apply 300 Volts. Your hand-held electrode is a ring and your other electrode is a rattail. The standardized total resistance is about 285 Ohms. In the upper left of the tab, enter 300 for Volts applied. Scroll to the right and enter 285 for the "Equivalent resistance of electrode system…". Go to the middle table "Field patterns described by empirically derived equation for a ring". Find the 0.1 V/cm distance from the ring. You should find it to be close to 90 cm (about 3').

On the far right, another table with graphs describe the field characteristics of an LR-24 backpack electrode system (ring and rattail). The table of the electric field was measured with 194 Volts applied to the electrodes in 55 µS/cm water.

Example 5.

You have a 28 cm x 0.95 cm ring with a 155 cm x 0.49 cm rattail cathode. Water conductivity (ambient) is 125 µS/cm. You are interested in applying 275 Volts. Enter 125 for ambient water conductivity and 275 for new applied voltage. In the table, the column next to the distance column is the original voltage gradients at distance mapped with 194 Volts applied. To the right, the voltage gradient and power density columns describe the field at the new applied voltage (in this case, 275 V). At 61.0 cm from the ring electrode, the voltage gradient is 0.31 V/cm and the power density is 12.16 µW/cm^3.

***Voltage Goals, Field Size* Tab**

Here we are expanding the tools we need to standardize electrofishing by electrical output. We will still need control box metering but we are adding the electric field spatial component. The objective is to maintain a constant desired electric field size for successful and standardized electrofishing across a range of water conductivities. We will develop an applied voltage or amperage chart to guide our output control to maintain the desired constant field size.

If you are interested in improved standardized sampling for fish assemblages or particular fish species, you will need two pieces of information. The first is an estimate of the minimum voltage gradient (or power density) required for the capture-prone response (inhibited swimming, taxis, immobilization) that you are after. The second piece is a judgment on the electric field size needed for successful electrofishing (e.g., 90 cm or 3' in front of the anodes).

Example.

You have a Smith-Root, Inc. LR-24 backpack shocker and you are interested in electrofishing for juvenile bonytail chub (*Gila elegans*) in small streams. The stream you plan to sample has an ambient water conductivity of around 300 µS/cm. From past observations, you assume that an effective field 61 cm or 2' from the anode will allow successful electrofishing. This is a species of special concern, so you wish to minimize immobilizing them but instead use taxis for the capture-prone response.

To begin, for gear inputs in the upper left of the tab, enter 400 for system power, 990 for pulsator V peak, 40 for pulsator I peak, and 285 for standardized electrode resistance. Scroll down to the "Electric Field Maps Measured in the field" section. Enter 300 for the water conductivity of the site to be sampled (95 appears above for the electrode equivalent resistance at the sampling site). Note the table with columns describing a map of the LR-24 electric field at an applied voltage of 194 V. The far left column lists distances from the anode, the next column to the right lists the voltage gradients at 194 V applied, next to the right are columns for voltage gradient and power density at distance from the anode generated by applied voltages you select. (Please observe that below this table is another blank table that you can fill out for your gear electric field map).

Scroll to the right of the field map table. The species name, average length, experimental water conductivity, effective fish conductivity, and waveform have been filled out already for you. The conductivity of the water body to be sampled appears automatically (300) as does the electrode equivalent resistance @ site (95). Just below the waveform entry, there is a row of voltage gradients and power densities. Enter "Taxis" under "Response" and 156 for "Power Density (µW/cm^3). The data comes from the literature, Ruppert & Muth (1997). See references under the "Threshold Power Densities" tab. Now, other values appear in that row, 85 for power density at matched conditions, 96 for power density at site, and 0.56 for target voltage gradient @ site. Previously, you considered a 61 cm effective field extent from the anode sufficient for successful electrofishing. Enter 61 under "Desired Edge of Effective Field (cm)". Scroll to the left and find 61 cm (or near that distance) in the distance column of the field table. Look in the adjacent column to the right (voltage gradient for the original map with 194 V applied). Find the voltage gradient that occurred at a distance of 61 cm from the anode (0.22). Enter 0.22 on the far right of the tab under "Voltage Gradient on Original Field Map that Corresponds with Desired Edge of Effective Field".

Once again, scroll back to the left to the field map table. Above the table, find the "New applied voltage (peak, average, or rms):". Change the voltage applied until the voltage gradient of the new map (3rd column from the left in the table) corresponds to the "Target Voltage Gradient @ site", that is, 0.56 V/cm. The applied voltage to have an effective field extent for taxis is around 495 Volts. This means that to have an effective field size of 61 cm in 300 µS/cm water conductivity, you must apply 495 V. Scrolling back to the right, inspect the "Applied Voltage or Amperage Goals Needed to Maintain Desired Field Size…". This chart indicates, given a particular water conductivity, what voltage must be applied to have an effective field size of 61 cm out from the anode. So, looking at a water conductivity of 300 µS/cm, the applied voltage is 498 Volts. If you went to a water body of 75 µS/cm, the required voltage is 996 Volts; for 150 µS/cm, you'll need 664 Volts; for 425 µS/cm, 449 Volts are required. You'll note that current goals and power density goals across water conductivities are provided as well. Note that you can change the ambient water conductivities in this chart to whatever values and range is important to you.

Threshold Power Densities **Tab**

This tab lists waveforms and minimum power densities (µW/cm^3) required to achieve the indicated response in a variety of fish species and sizes. In some cases, minimum power densities for injury also are recorded. Values are from the literature.

Equipment Specifications **Tab**

This final tab lists manufacturer's specifications for several electrofishing gear models.

Some References-

Kolz, A.L. 1993. In-water electrical measurements for evaluating electrofishing systems. Biological Report 11, U.S. Department of the Interior, Fish & Wildlife Service, Washington, D.C.

Beaumont, W.R.C. and M.J. Lee 2005. The equivalent resistance and power of electric fishing electrodes. Fisheries Management and Ecology 12:37-43.

Novotny, D.W. 1990. Electric fishing apparatus and electric fields. Pages 34 88 *In* I.G. Cowx and P. Lamarque (eds.), Fishing with Electricity, Fishing News Books, Blackwell Scientific Publications, Ltd., Oxford, UK.