## Power Analysis Workup of Office Electrofishing Boat

Northern Chub* electrofishing field study

**Date:** November 10, 2012
**Location:** Yankee Creek, Virginia
**Water conductivity:** 207 µS/cm
**Crew:**

**Electrofishing boat:** 2 booms (anodes) with 6-dropper Wisconsin arrays, droppers approximately 3/8 inch diameter (Smith-Root SAA-6 Spider Adjustable Array), dropper submergence depth approximately 3'; 16' hull (non-painted) wired as cathode containing a bow cathode skirt separately wired; powered by a 7.5 GPP.

**Purpose:** To field test electrical waveforms found in lab studies to be effective in causing capture-prone responses in northern chubs. Waveform type and frequencies were: PDC 30 pps (pulses per second), PDC 120 pps, and AC 60 Hz. The secondary objective was to determine boat electrode resistance and perform a system power analysis.

**Design:** Trial run each waveform to determine threshold (minimum) settings that result in successful electrofishing (acceptable capture-prone responses). **Note that GPP units do not have sufficient controls to determine thresholds so these estimates are likely high. Once threshold settings are determined, apply a simple random sampling design, assigning a total of five 3-minute sampling runs to each waveform. Current is on continuously from beginning of the run to the 3 minute time limit. Response variable is catch-per-unit-effort (CPUE). Waveform resulting in highest CPUE will be considered most effective.

<u>Trial runs to determine threshold settings for power standardization</u>

**Conditions:** higher water, maybe two feet higher than typical; a lot of aquatic vegetation

*Waveform #1*: 30 pps, Percent of Range 60%, 170 V setting

> Some attraction, good gizzard shad immobilization; other taxa captured largemouth bass, American eel, not bad on sunfish. Conclusion: not completely satisfactory, turn up power.
> Peak Volts: 145 V

***Northern Chub is a hypothetical species**

*Waveform #2*: 30 pps, Percent of Range 80%, 340 V setting

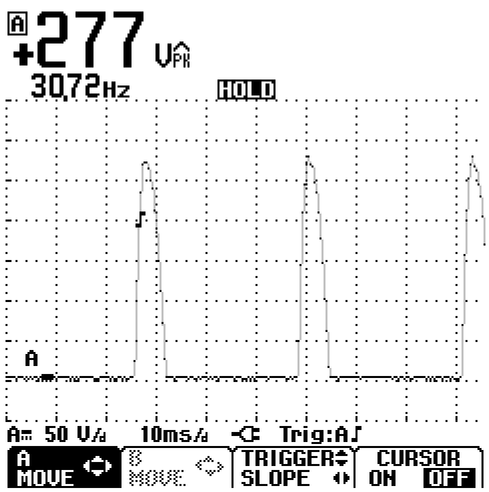
Some attraction, good immobilization of small fishes (including cyprinids), some taxis and good immobilization of white perch, very effective on that species; a Chub was immobilized (no attraction observed) and netted; fish seemed to come to surface with more of an attraction to the general anodic field more so than the anodes themselves.

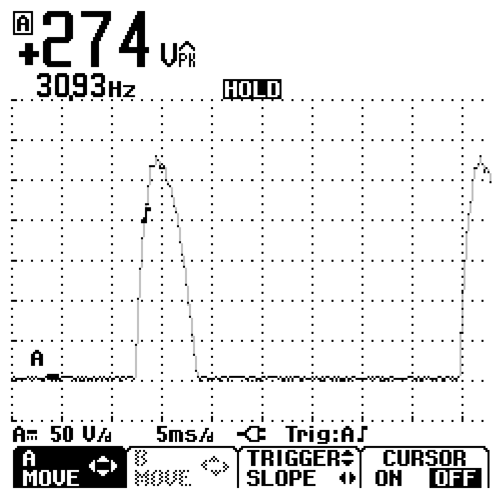
Peak Volts: not measured since immediately adopted 100% of range to increase duty cycle to the maximum of ~13%.

**Waveform selected:** to maximize duty cycle to 13%, waveform selected was

**30 pps, 100% Percent of Range, 340 V setting**

**Scopemeter readings of this waveform:**




Peak Voltage: 278 V

Peak Power: $278^2/12.15$ = **6361 Watts** (note: the 12.15 Ω boat electrode resistance determined later)

Peak Current: 6361/278 = 22.9 amps

Frequency: ~30 pps

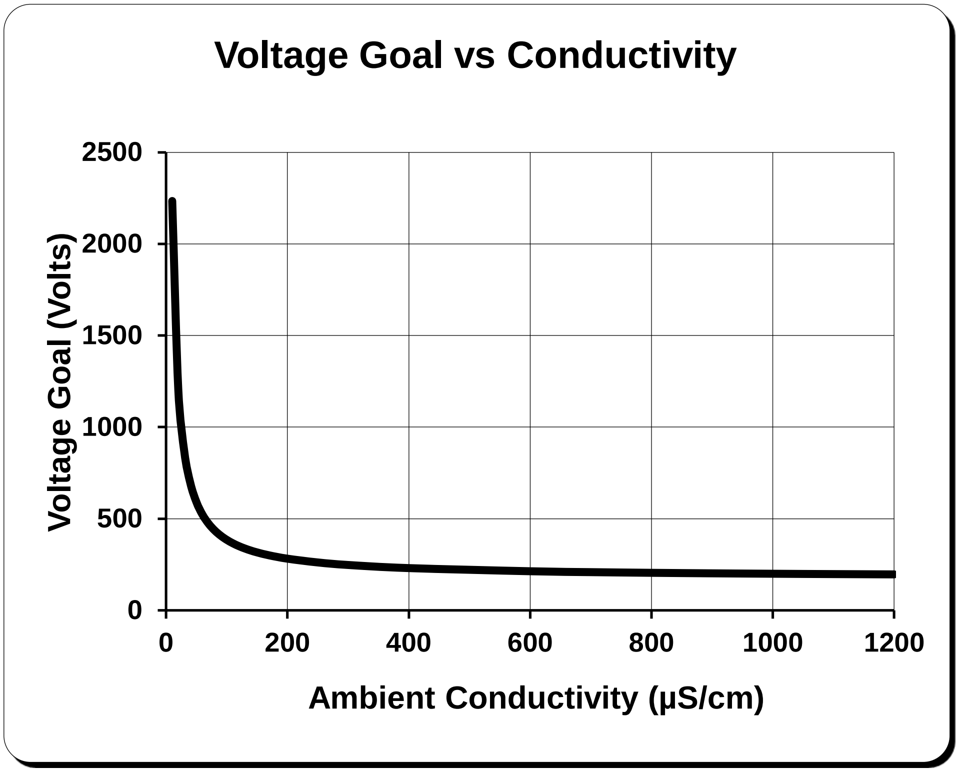
Pulse widths: 6.4 ms (base), 4.4 ms (50% of pulse amplitude)

Duty cycle: 13.2% (pulse width @ 50% of pulse amplitude)

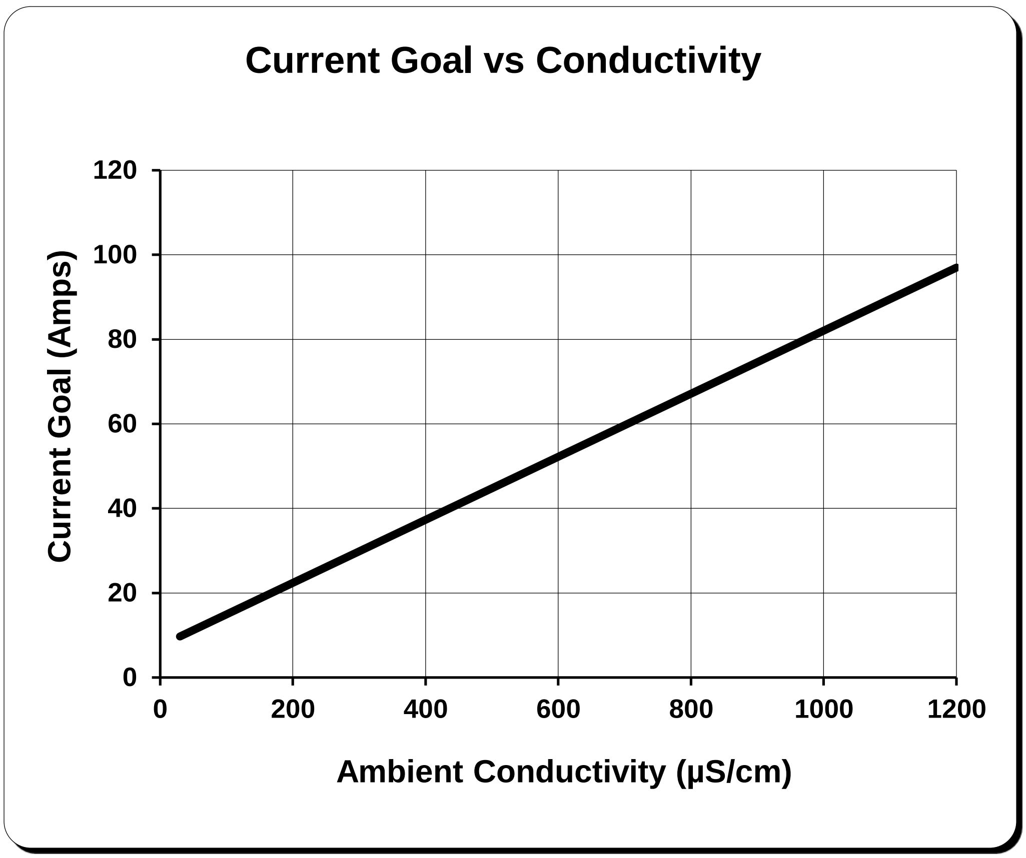
Note: Despite low loading on the generator (6361 Watts x 0.13 = 827 average Watts), the output was only 278 Volts instead of 340 Volts (82% of setting). Martinez and Kolz (*2009. Evaluating the Power Output of the Smith-Root GPP 5.0 Electrofisher to Promote Electrofishing Fleet Standardization. North American Journal of Fisheries Management 29:570–575*) found actual outputs much lower than dial settings by a 5.0 GPP across a large range of water conductivities.  Thus, it is difficult to say that the Office boat GPP is malfunctioning.

## Power standardization tables for 30 pps, 13% duty cycle-

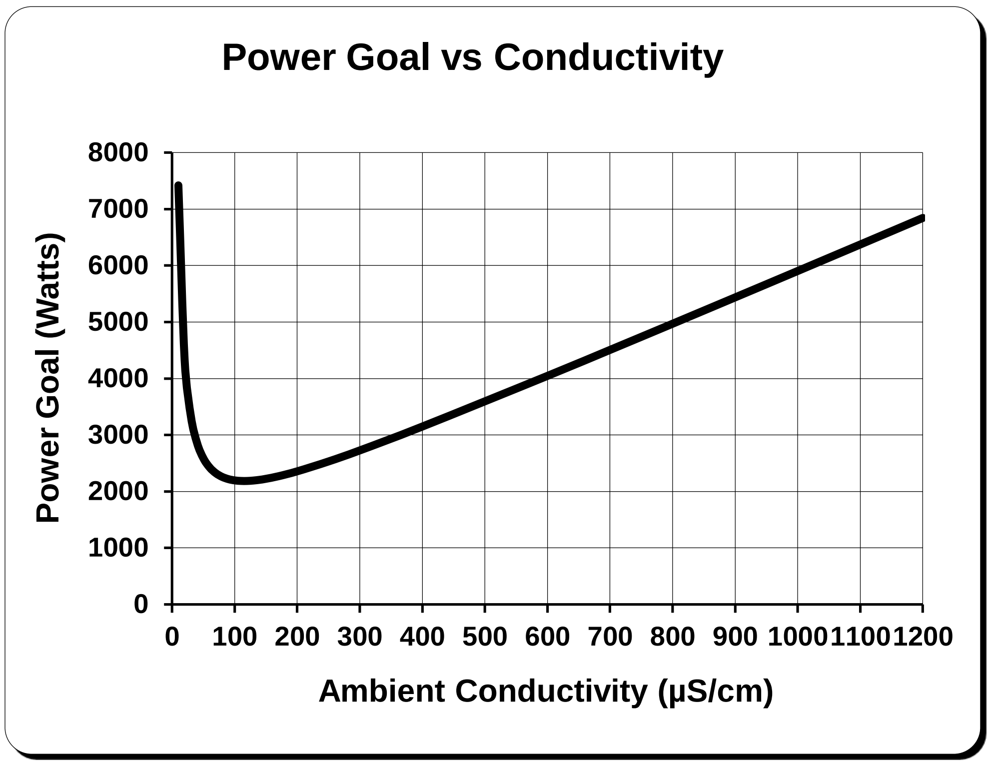
| Conductivity | Voltage goal |
|---|---|
| 30 | 864 |
| 40 | 693 |
| 50 | 590 |
| 60 | 521 |
| 70 | 472 |
| 80 | 436 |
| 90 | 407 |
| 100 | 384 |
| 110 | 366 |
| 120 | 350 |
| 130 | 337 |
| 140 | 326 |
| 150 | 316 |
| 170 | 300 |
| 200 | 281 |
| 250 | 261 |
| 300 | 247 |
| 400 | 230 |
| 600 | 213 |
| 700 | 208 |
| 800 | 204 |
| 900 | 202 |
| 1000 | 199 |
| 1100 | 197 |
| 1200 | 196 |



| Conductivity | Amp goal |
|---|---|
| 30 | 9.7 |
| 40 | 10.4 |
| 50 | 11.2 |
| 60 | 11.9 |
| 70 | 12.7 |
| 80 | 13.4 |
| 90 | 14.2 |
| 100 | 14.9 |
| 110 | 15.7 |
| 120 | 16.4 |
| 130 | 17.2 |
| 140 | 17.9 |
| 150 | 18.6 |
| 170 | 20.1 |
| 200 | 22.4 |
| 250 | 26.1 |
| 300 | 29.8 |
| 400 | 37.3 |
| 600 | 52.2 |
| 700 | 59.7 |
| 800 | 67.1 |
| 900 | 74.6 |
| 1000 | 82.1 |
| 1100 | 89.5 |
| 1200 | 97.0 |



| Conductivity | P goal |
|---|---|
| 30 | 8900 |
| 40 | 7628 |
| 50 | 6915 |
| 60 | 6482 |
| 70 | 6209 |
| 80 | 6036 |
| 90 | 5930 |
| 100 | 5870 |
| 110 | 5845 |
| 120 | 5844 |
| 130 | 5864 |
| 140 | 5898 |
| 150 | 5945 |
| 170 | 6068 |
| 200 | 6301 |
| 250 | 6768 |
| 300 | 7291 |
| 400 | 8421 |
| 600 | 10820 |
| 700 | 12050 |
| 800 | 13290 |
| 900 | 14537 |
| 1000 | 15788 |
| 1100 | 17043 |
| 1200 | 18300 |




Power standardization tables (voltage, current, or power) have as assumptions (1) that water conductivity is the primary efficiency factor and, when conductivity changes, varies in its influence on efficiency and (2) that if other significant efficiency factors are operating, their influence on efficiency is constant across water conductivities. For example, if the presence of submerged vegetation reduces catchability, then vegetation lowers catchability by the same proportion regardless of water conductivity. In practice, sampling boundaries are often imposed on competing efficiency factors, e.g., we only sample in water bodies with vegetation percent coverage between 10 – 40%.

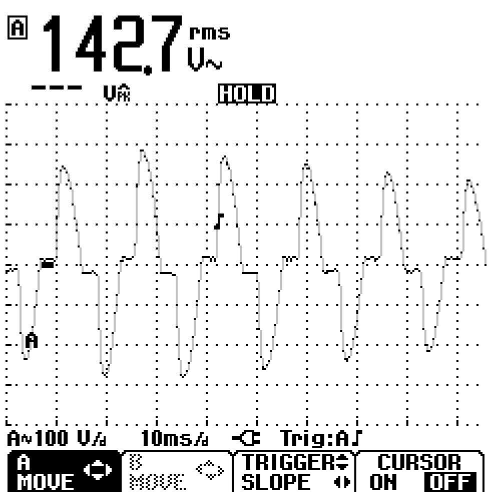
*Waveform #3*: Alternating current (AC), 60 Percent of Range, 170 V setting
No fish observed

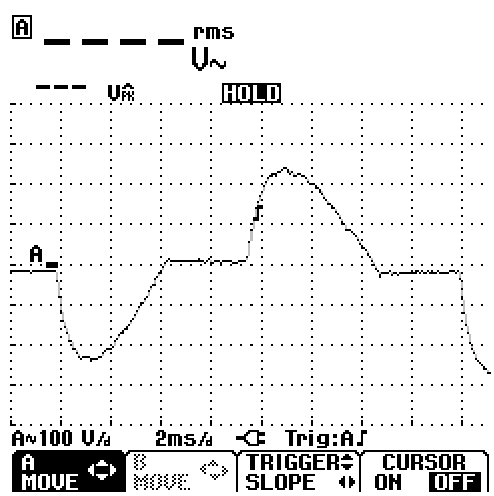
*Waveform #4*: AC, 40 Percent of Range, 240 V setting
Large Chub netted, small eel, largemouth bass

*Waveform #5*: AC, 60 Percent of Range, 240 V setting
Very successful electrofishing, all sizes of sunfish, cyprinids, yellow perch; effective on white perch

**Waveform Selected: AC, 60 Percent of Range, 240 V setting**

**Scopemeter readings of this waveform:**



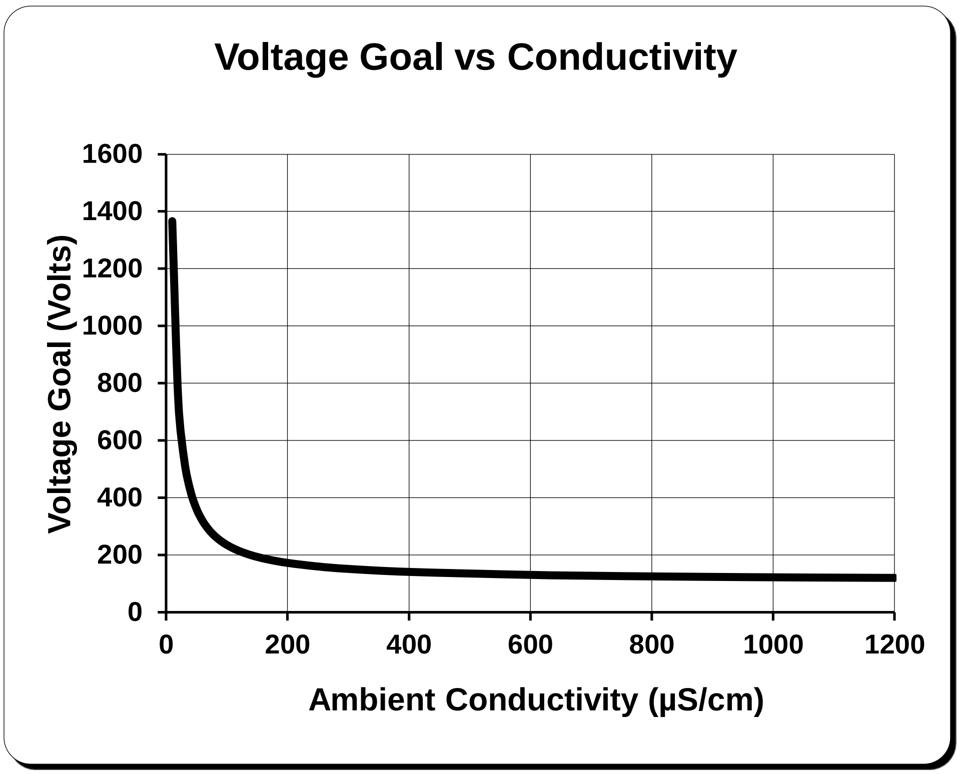




Peak Voltage: 230 V
Peak-to-Peak Voltage: 475 V
Peak Power: $230^2$/12.15 = **4394 Watts**
Peak Current: 4394/230 = 19.1 amps
Frequency: 60 Hz
Duty cycle: 3.6 ms pulse width/8.3 ms period [positive pulse width and period]= 44%

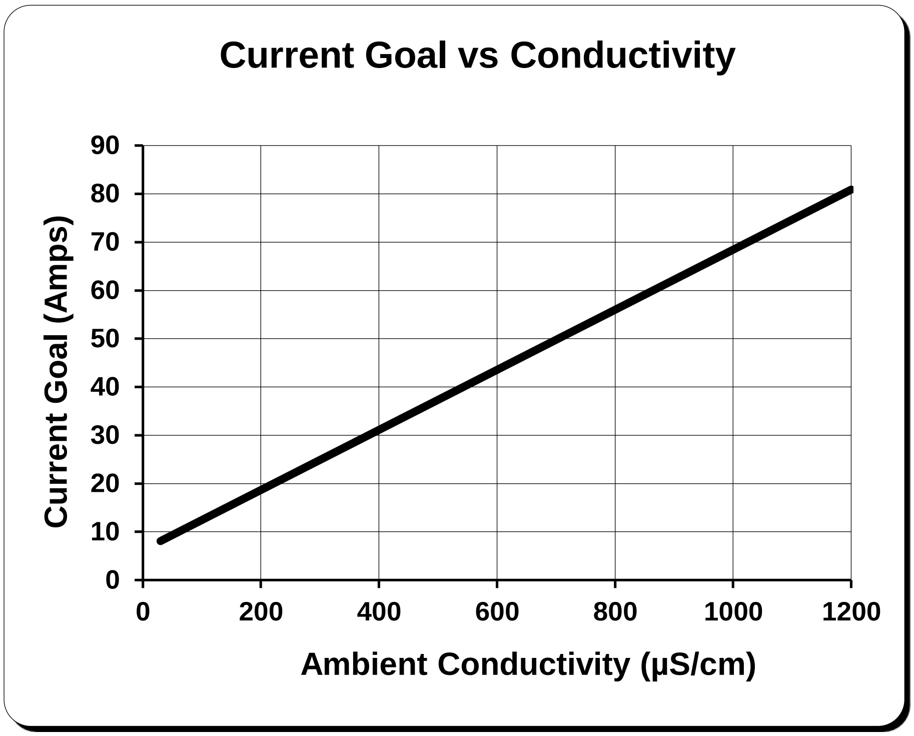
Note: The peak voltage is varying across cycles, possibly generating a constant, repeating pattern. Thus, it is uncertain to know which pulse to measure. A peak voltage of 230 V is an approximate average. This instability may be indicative of equipment malfunction since the loading was not excessive.

# Power standardization tables for AC, 60 Hz, 44% duty cycle-

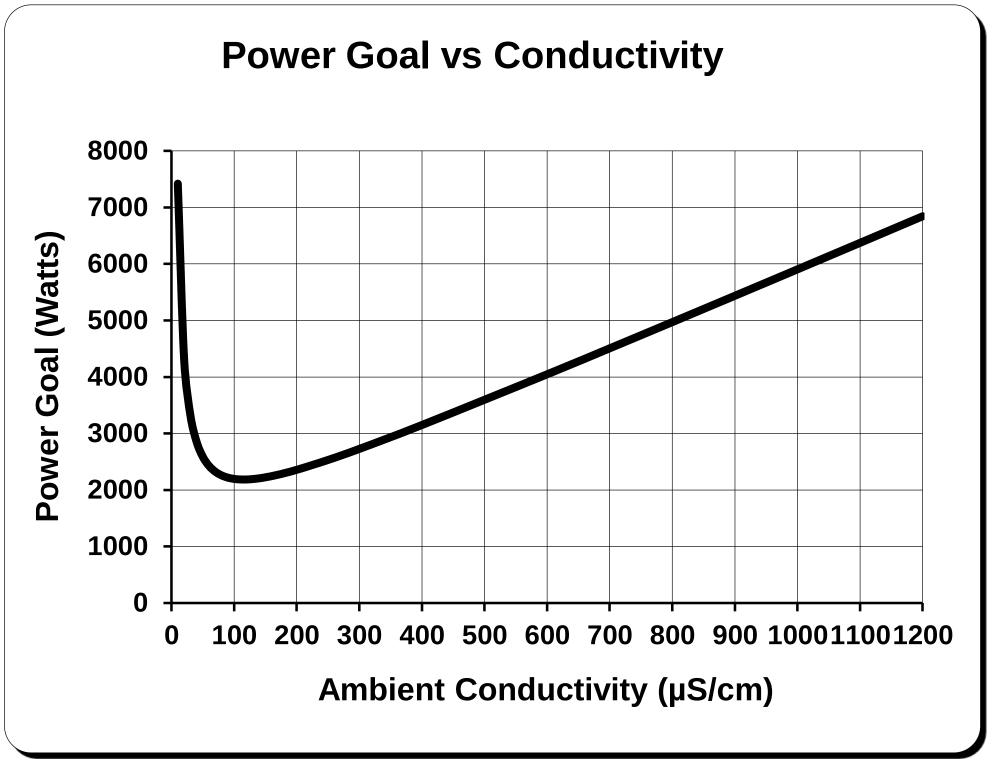
| Conductivity | V goal |
|---|---|
| 30 | 715 |
| 40 | 573 |
| 50 | 488 |
| 60 | 431 |
| 70 | 391 |
| 80 | 360 |
| 90 | 337 |
| 100 | 318 |
| 110 | 302 |
| 120 | 290 |
| 130 | 279 |
| 140 | 269 |
| 150 | 261 |
| 170 | 248 |
| 200 | 233 |
| 250 | 216 |
| 300 | 205 |
| 400 | 190 |
| 600 | 176 |
| 700 | 172 |
| 800 | 169 |
| 900 | 167 |
| 1000 | 165 |
| 1100 | 163 |
| 1200 | 162 |



| Conductivity | Amp goal |
|---|---|
| 30 | 8.1 |
| 40 | 8.7 |
| 50 | 9.3 |
| 60 | 10.0 |
| 70 | 10.6 |
| 80 | 11.2 |
| 90 | 11.8 |
| 100 | 12.4 |
| 110 | 13.1 |
| 120 | 13.7 |
| 130 | 14.3 |
| 140 | 14.9 |
| 150 | 15.6 |
| 170 | 16.8 |
| 200 | 18.7 |
| 250 | 21.8 |
| 300 | 24.9 |
| 400 | 31.1 |
| 600 | 43.6 |
| 700 | 49.8 |
| 800 | 56.0 |
| 900 | 62.2 |
| 1000 | 68.4 |
| 1100 | 74.7 |
| 1200 | 80.9 |



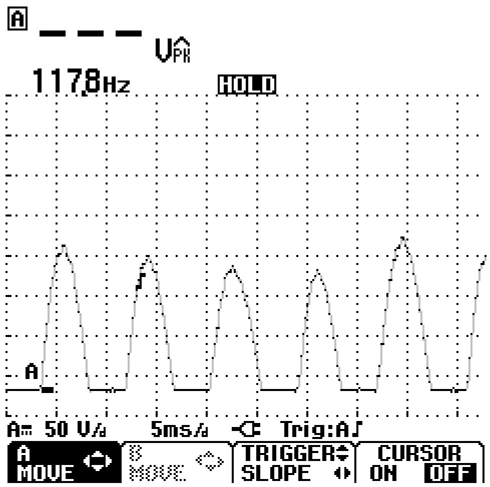
| Conductivity | P goal |
|---|---|
| 30 | 6148 |
| 40 | 5269 |
| 50 | 4777 |
| 60 | 4478 |
| 70 | 4289 |
| 80 | 4170 |
| 90 | 4096 |
| 100 | 4055 |
| 110 | 4037 |
| 120 | 4037 |
| 130 | 4050 |
| 140 | 4074 |
| 150 | 4107 |
| 170 | 4191 |
| 200 | 4352 |
| 250 | 4675 |
| 300 | 5036 |
| 400 | 5817 |
| 600 | 7474 |
| 700 | 8324 |
| 800 | 9181 |
| 900 | 10042 |
| 1000 | 10906 |
| 1100 | 11773 |
| 1200 | 12641 |

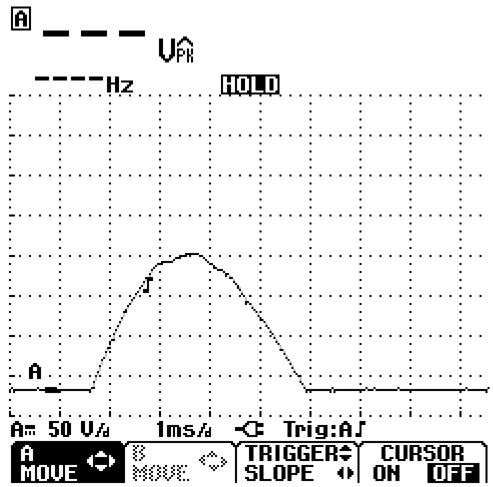


**Waveform selected: 120 pps, 40 Percent of Range, 1000 V**

*(Setting used historically for electrofishing Northern Chubs)*

**Scopemeter readings of this waveform:**



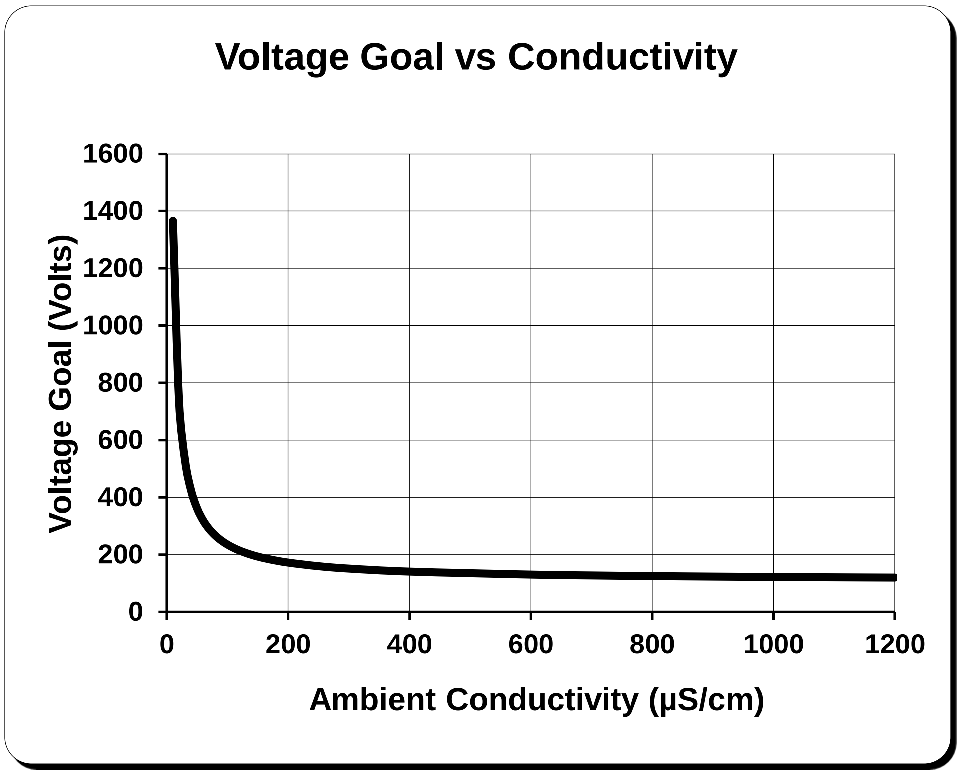

Peak Voltage: 170 V
Peak Power: $170^2$/12.15 = **2379 W**
Peak Current: 2379/170 = 14.0 amps
Frequency: ~120 pps (actually 118 pps)
Pulse widths: 4.2 ms (base), 3.0 ms (50% of pulse amplitude)
Duty cycle: 35% (pulse width @ 50% of pulse amplitude)

Note: Despite low loading on the generator (2379 Watts x 0.35 = 833 average Watts), the output was only 170 Volts instead of 1000 Volts per the dial setting. Martinez and Kolz (2009) found dramatic reduction of power output on the 1000 V setting of a 5.0 GPP in 400 µS/cm water. In addition, the waveform is variable, having the appearance of a repeating pattern. Due to these two observations, suggest using a lower voltage setting to increase power and possibly reduce variation in pulse height. Again, difficult to say if the GPP control box is malfunctioning.

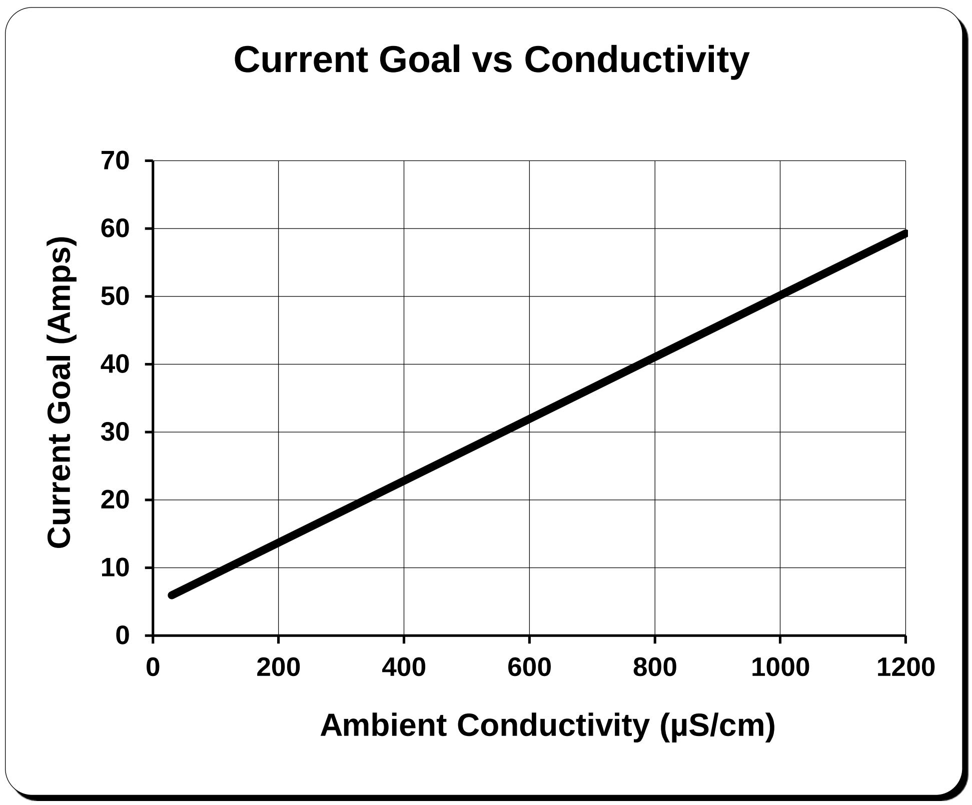
Unlike the process we followed for PDC 30 pps and AC 60 Hz, we didn't thoroughly test the 120 pps waveform for threshold (voltage range and percent of range settings) and probably should in the field next time

# Power standardization tables for 120 pps, 35% duty cycle-

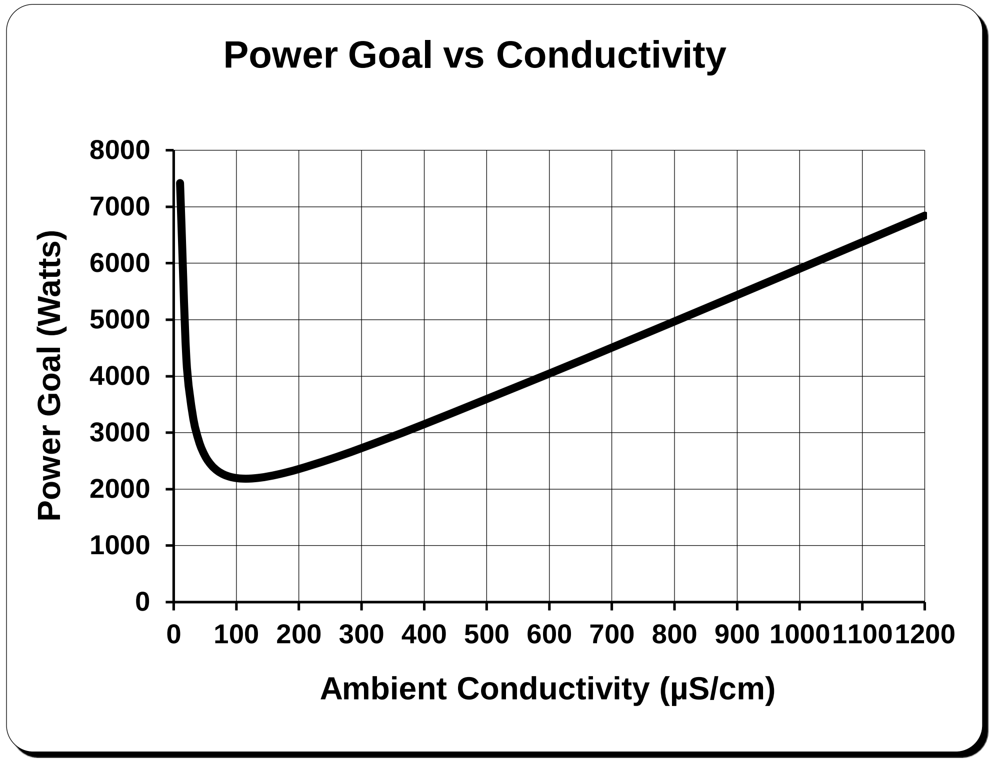
| Conductivity | V goal |
|---|---|
| 30 | 528 |
| 40 | 423 |
| 50 | 361 |
| 60 | 319 |
| 70 | 289 |
| 80 | 266 |
| 90 | 249 |
| 100 | 235 |
| 110 | 224 |
| 120 | 214 |
| 130 | 206 |
| 140 | 199 |
| 150 | 193 |
| 170 | 183 |
| 200 | 172 |
| 250 | 160 |
| 300 | 151 |
| 400 | 141 |
| 600 | 130 |
| 700 | 127 |
| 800 | 125 |
| 900 | 123 |
| 1000 | 122 |
| 1100 | 121 |
| 1200 | 120 |



| Conductivity | Amp goal |
|---|---|
| 30 | 5.9 |
| 40 | 6.4 |
| 50 | 6.8 |
| 60 | 7.3 |
| 70 | 7.8 |
| 80 | 8.2 |
| 90 | 8.7 |
| 100 | 9.1 |
| 110 | 9.6 |
| 120 | 10.0 |
| 130 | 10.5 |
| 140 | 10.9 |
| 150 | 11.4 |
| 170 | 12.3 |
| 200 | 13.7 |
| 250 | 16.0 |
| 300 | 18.2 |
| 400 | 22.8 |
| 600 | 31.9 |
| 700 | 36.5 |
| 800 | 41.0 |
| 900 | 45.6 |
| 1000 | 50.2 |
| 1100 | 54.7 |
| 1200 | 59.3 |



| Conductivity | P goal |
|---|---|
| 30 | 3329 |
| 40 | 2853 |
| 50 | 2586 |
| 60 | 2424 |
| 70 | 2322 |
| 80 | 2258 |
| 90 | 2218 |
| 100 | 2195 |
| 110 | 2186 |
| 120 | 2186 |
| 130 | 2193 |
| 140 | 2206 |
| 150 | 2224 |
| 170 | 2269 |
| 200 | 2356 |
| 250 | 2531 |
| 300 | 2727 |
| 400 | 3149 |
| 600 | 4047 |
| 700 | 4507 |
| 800 | 4971 |
| 900 | 5437 |
| 1000 | 5905 |
| 1100 | 6374 |
| 1200 | 6844 |



Other PDC settings evaluated:

30 pps, 80 Percent of Range, 500 V setting output = 325 peak Volts
30 pps, 80 Percent of Range, 500 V setting held fish longer than 30 pps, 340 V (at 500 V more fish immobilized but recovery maybe faster at 340 V). Crew concluded that the 30 pps, 340 V setting resulted in fully successful electrofishing and that 500 V setting was above the voltage required.

Overloaded at 30 pps, 55 Percent of Range, 1000 V setting (GPP ammeter = 3.8 "average" amps)

60 pps, 80 Percent of Range, 340 V setting resulted in good immobilization responses, one Chub captured

Other observations:

30 pps seemed to be the most effective waveform; AC possibility not as effective, since the fish were more immobilized in place with less flotation and movement (that is, the fish tended to be immobilized on the bottom or suspended in the water column);

**Field trials:** 15-3 minute trials were conducted. No Chubs were captured. Other species, as white perch, would have been successfully electrofished.

On 12/4/2012, the Office crew did another field trial testing all three waveforms at the same settings. They had a shocking time of one hour per PDC waveform and around 20 minutes for the AC. Water temperature was about 50 degrees F and ambient conductivity between 200 – 300 µS/cm. Crew comments modified for this document: We only caught one fish on AC and we were unhappy with the results. We saw one other Chub we didn't catch. It seems AC is stunning them, but they roll over on the bottom or stay in the middle of the water column. Visibility wasn't great yesterday, but we suspect even when it is good, it will be difficult to see the fish if they aren't near the surface. However, the 30Hz pulsed DC was very successful. Our CPUE for **30 pps was 8.4 Chubs/hr** and for **120 pps was 7.4 chubs/hr**. We covered a lot of area on each of those settings. WeI didn't shock as long with AC but as we mentioned it was fairly unsuccessful. We would say that there wasn't too much difference in Chub reactions between 30 and 120 pps. Both seemed to immobilize Chubs and get them to roll over fairly well. However, what was extremely promising was that for 30 pps we could shock Chubs at least 4' from the cathode array. Now, initially we almost missed a few because the netters weren't watching that far out, but the Chubs were stunned enough I could turn the boat and we'd still capture them. I did not see this happen on 120pps. Our field at 100% on 30pps must be a bit larger (effectively larger anyway) than only 40% at 120pps. Also, it seemed that at 30pps we caught more fish in deeper than normal water (4-5 ft.). That may be because of random chance, but either way it was nice to be able to get fish to the surface from those depths and at typical boat speeds. My only small concern with 30 pps would be that we really hit a lot of small fish pretty hard, while they did recover after a while, in the water they don't recover fast enough to escape the birds. We don't see that kind of reaction from small fish with 120pps. Next summer, if we come across juvenile Chubs, it'll be interesting to see if 30pps will shock them, and then we could potentially quantify the true number of juveniles in a nest. (end comments)

The finding above of lower frequencies hitting fish harder than higher frequencies likely is because the 30 pps frequency is over-powered (applied Watts above threshold) and the 120 pps power level may be at threshold or probably somewhat below threshold. The GPP unit does not allow such fine adjustment. For example, reducing the percent of range knob on the 340 V setting probably will reduce duty cycle too low prior to achieving the threshold voltage. Keeping the duty cycle up (~13%) and reducing applied voltage by moving the voltage setting to 170 V will likely result in voltage well below threshold.

## Boat electrode resistance measurements (standardized to 100 µS/cm):

Waveform used: 30 pps, 340 V setting

| | |
|---|---|
| 6-dropper boom array: | 35 Ω |
| 2 booms in parallel: | 17 Ω |
| Boat hull: | 12 Ω |
| Skirt: | 24 Ω |
| Boat hull/skirt: | 8 Ω |

Configuration:

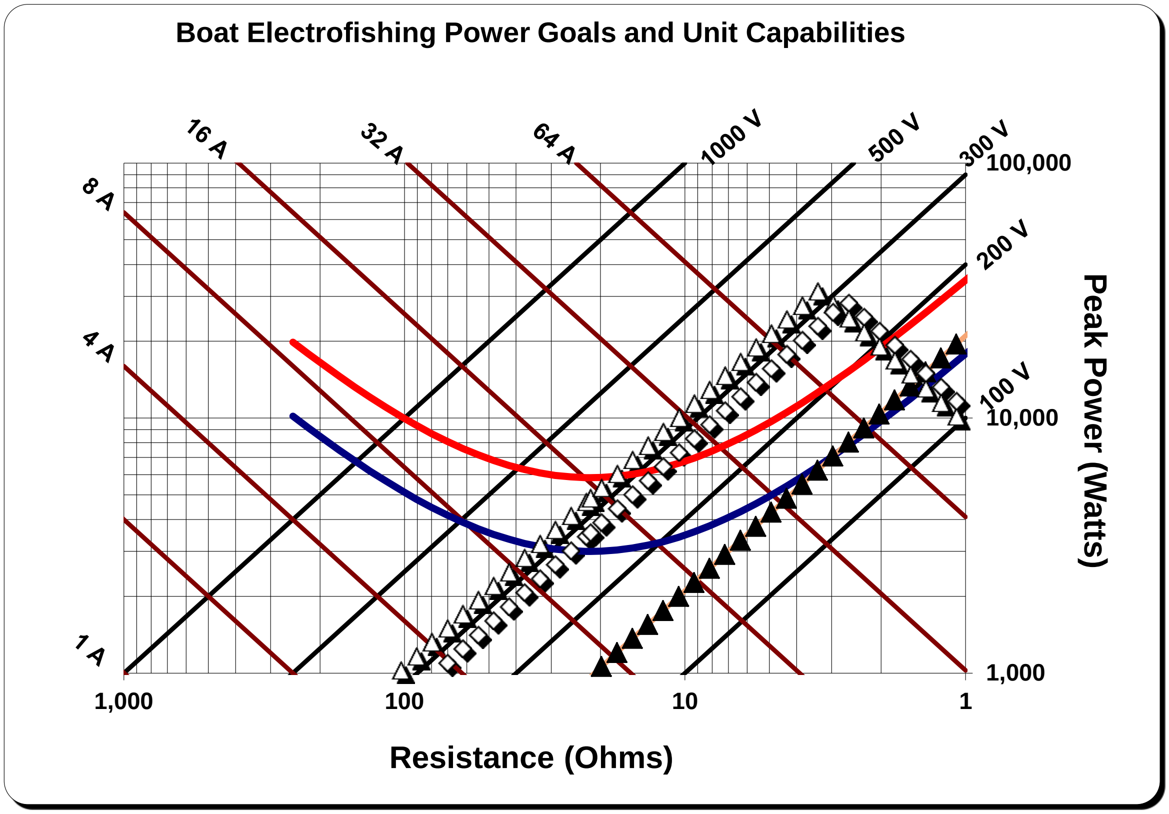
2 boom, hull and skirt independently wired: **25 Ω** (this is the typical electrofishing set-up)

Percent power to the anodes: 17/25 = **68%**

Conclusions: Very good power allocation to the anodes. Different cathode configurations are options. For example, in an attempt to improve catchability in low conductivity water, the hull could be disconnected, bringing a high intensity cathode (the skirt) into close proximity to the boom anodes (41% power to the anodes).

# Power Analysis

## PDC 30 pps, 60-100 Percent of Range (~10 – 13% duty cycle)




This graph overlays predicted equipment maximum power output over the power goals (blue from Miranda (2009) in Standard Methods) and the red power goal curve from this study. The red power goal curve for 30 pps, 13% duty cycle was based on a threshold power of 6,631 Watts at ambient conditions or 5,847 Watts at matched conditions (115 µS/cm). The symbology is open triangles = 500 V setting (adjusted for actual measured voltage output), squares = 340 V setting (adjusted for actual measured output), and the filled triangles = 170 V setting (adjusted for actual measured output). Note that output from a 4th voltage setting, 1000 V, is not depicted since voltage output was not measured. As a cautionary note, the amperage capacity at each voltage setting is merely a best guess and may be significantly low or high.

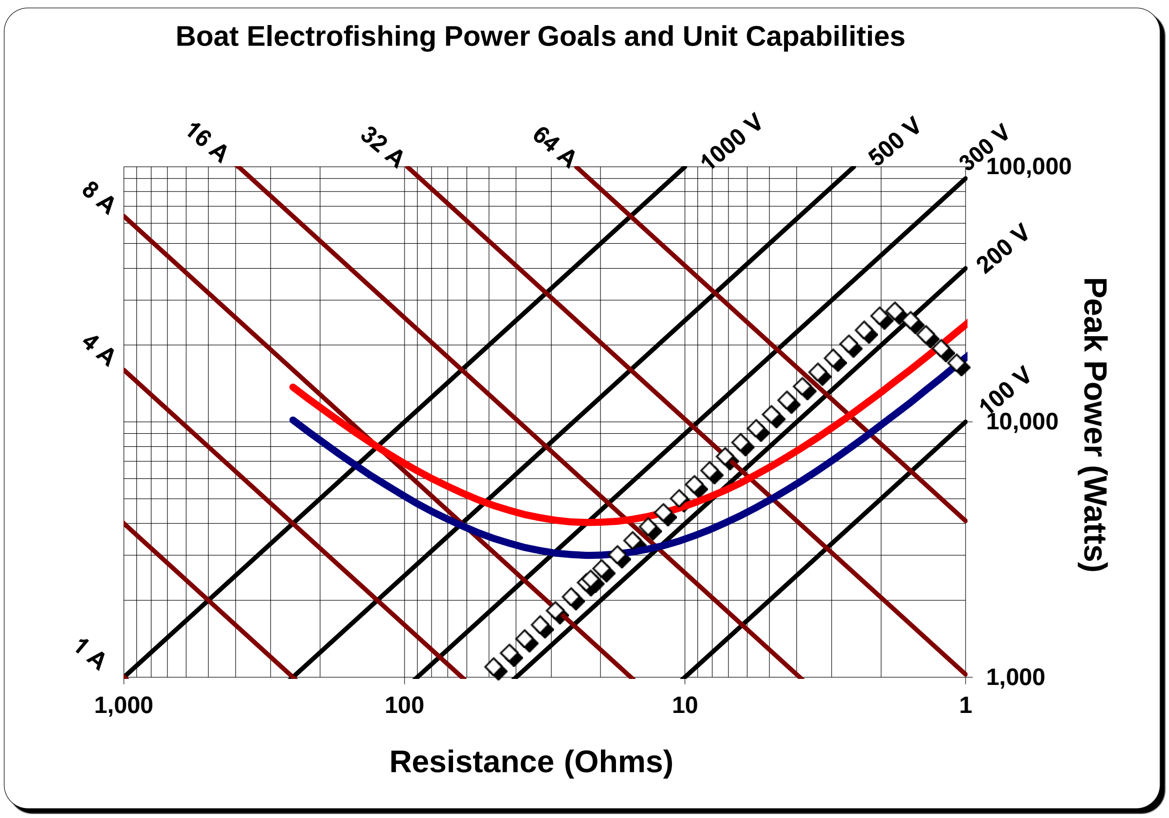
The theoretical range of successful equipment operation is between the intersection points of the red (or blue) power curve and the output symbols. As a conservative measure, since equipment near amperage capacity will often overload and shut-off, we will consider the operating range in high conductivity (= low resistance) at the point where the curve deflects download on the amp limitation.

Resistance refers to boat electrode resistance and is inversely related to water conductivity:

| | |
|---|---|
| 100 Ω = | 25 µS/cm |
| 20 Ω = | 125 µS/cm |
| 12 Ω = | 200 µS/cm |
| 2.5 Ω = | 1000 µS/cm |

The 340 V setting for 30 pps, 100% of range should deliver enough power to successfully electrofish from 200 µS/cm – 1,000 µS/cm. The 1,000 µS/cm upper limit is likely conservative. Lower water conductivities will necessitate switching to the 500 or 1000 V settings. The lowest voltage setting does not deliver the required power to reach threshold power levels in the lower Yankee Creek. The 30 pps waveform required the highest peak power, a finding in agreement with the lab studies. However, the low duty cycle (13%) allows use of 30 pps across expected water conductivities in that section of the Yankee Creek.

## AC 60 Hz, 60 Percent of Range (44% duty cycle)




This graph overlays predicted equipment maximum power output over the power goals (blue from Miranda (2009) in Standard Methods) and the red power goal curve from this study. The red power goal curve for AC, was based on a threshold power of 4,394 Watts at ambient conditions or 4,034 Watts at matched conditions (115 µS/cm). The symbology is squares = 240 V setting (adjusted for actual measured output. As a cautionary note, the amperage capacity is merely a best guess and may be significantly low or high.

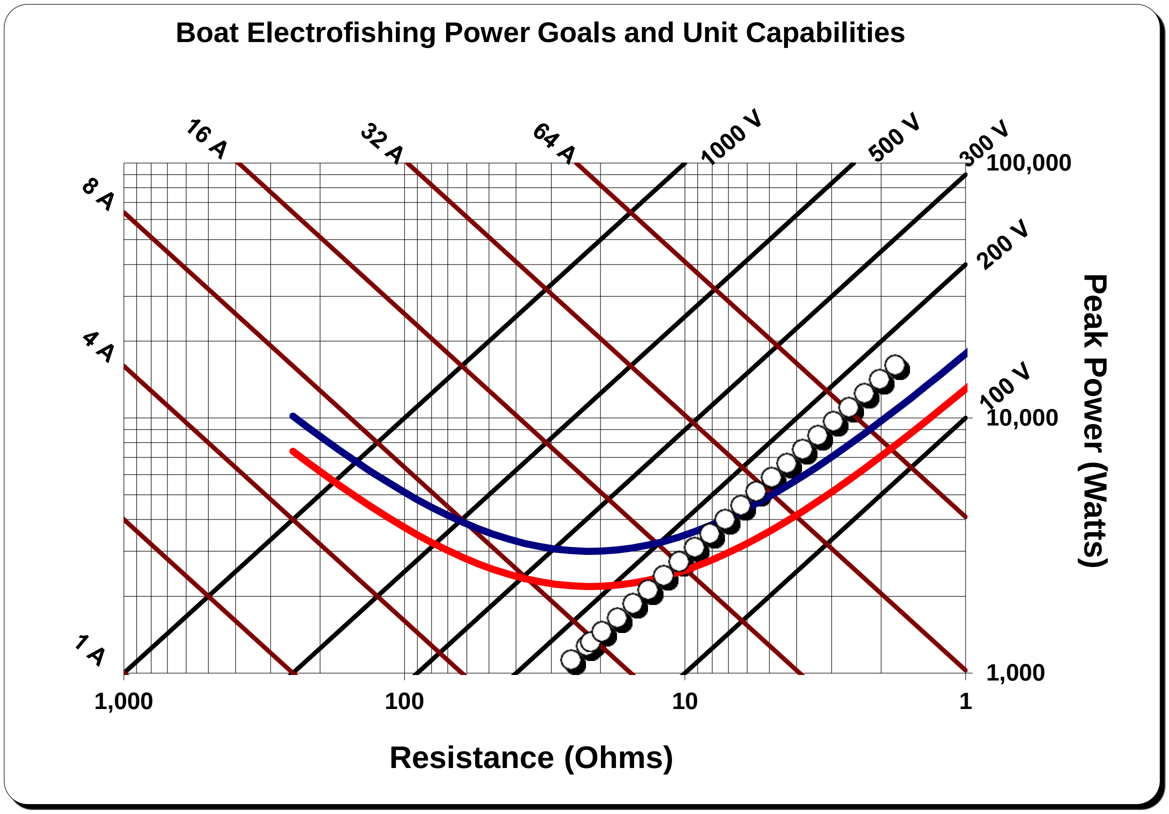
The theoretical range of successful equipment operation is between the intersection points of the red (or blue) power curve and the output symbols. As a conservative measure, since equipment near amperage capacity will often overload and shut-off, we will consider the operating range in high conductivity (= low resistance) at the point where the curve deflects download on the amp limitation.

Resistance refers to boat electrode resistance and is inversely related to water conductivity:

| | |
|---|---|
| 100 Ω = | 25 µS/cm |
| 20 Ω = | 125 µS/cm |
| 12 Ω = | 200 µS/cm |
| 2.5 Ω = | 1000 µS/cm |

The 240 V setting for AC, 60% of range should deliver enough power to successfully electrofish from 200 µS/cm –1,200 µS/cm. Lower water conductivities will necessitate switching to higher voltage settings. This AC waveform setting should cause capture-prone responses (immobilization) across expected water conductivities in that section of the Yankee Creek.

## PDC 120 pps, 40 Percent of Range (36% duty cycle)




This graph overlays predicted equipment maximum power output over the power goals (blue from Miranda (2009) in Standard Methods) and the red power goal curve from this study. The red power goal curve for 120 pps, 36% duty cycle was based on a threshold power of 2,379 Watts at ambient conditions or 2,185 Watts at matched conditions (115 µS/cm). The symbology is circles = 1000 V setting (adjusted for actual measured output. As a cautionary note, the amperage capacity is merely a best guess and may be significantly low or high.

The theoretical range of successful equipment operation is between the intersection points of the red (or blue) power curve and the output symbols. As a conservative measure, since equipment near amperage capacity will often overload and shut-off, we will consider the operating range in high conductivity (= low resistance) at the point where the curve deflects download on the amp limitation.

Resistance refers to boat electrode resistance and is inversely related to water conductivity:

| | |
|---|---|
| 100 Ω = | 25 µS/cm |
| 20 Ω = | 125 µS/cm |
| 12 Ω = | 200 µS/cm |
| 2.5 Ω = | 1000 µS/cm |

Based on the red power goal curve developed during this field trip, the 1000 V setting for 120 pps, 40% of range should deliver enough power to cause successful electrofishing from 200 µS/cm – 1,200 µS/cm. However, this waveform setting results in the only power curve plotted below Mranda's (2009). Given the position of the red power curve and other evidence regarding fish reaction, it is reasonable to think that the 1000 V setting may not be delivering threshold power. Probably, power should be increased somewhat. To accomplish a higher power output, switch to the 500 or 340 V settings. (From the results under the 30 pps waveform, the 170 V setting may not deliver required power). An output study of the various voltage settings with 120 pps should be performed to verify the higher power output capacity of the lower voltage settings.

## Additional Recommendations:

1) Repeat field study on comparing waveform capture efficiencies of PDC 30 pps, PDC 120 pps, and AC next late spring or summer when habitat conditions are representative.
2) Measure outputs of the 7.5 GPP using the 120 pps waveform, across all voltage settings. This will give a more exact indication of actual power output. It also may inform the voltage setting we should use with the 120 pps treatment in the formal field trial. Also test the output of the 30 pps and AC waveforms to see if the GPP is achieving at least predicted threshold voltage or power levels at the ambient conductivity.
3) Measure electric field of the Office electrofishing boat used for Chub sampling.
4) Contact Smith-Root about the variable pulse height patterns with AC and PDC 120 pps to find out if the manufacturer recommends control box inspection for possible malfunction.

Follow-up comment: At some issue here is that we do not have an output analysis across a water conductivity range for the GPP 7.5. That means we have to do some guessing regarding the range of conductivity that can be successfully electrofished by your boat. We do have such an analysis, unpublished as yet, of a GPP 5.0. We did plug in proven capacity numbers for the GPP 5.0 for fishing 30 pps, 13% duty cycle. If we replaced the GPP 7.5 with a 5.0 in your boat, using 30 pps, 13% duty, the effective electrofishing range would be 25 - 735 uS/cm. Going by this result, you need more power capacity to fish in your typically higher water conductivity and it seems a safe assumption that the 7.5 will do that. I also think, given the analysis of the GPP 5.0, that the successful fishing ranges we estimated for the GPP 7.5 are in the ballpark.

One additional note. There is a unsubstantiated claim that taxis with pulsed DC is most likely or most well-developed in a duty cycle range of 20 - 30% In the lab study, we saw good taxis with 30 pps and 24% duty cycle. Due to the control limitations on the GPP, 13% is the maximum duty cycle we can dial in under a frequency of 30 pps. That might explain observations of fish behavior these past two sampling trips where fish tend to move up to the surface of the anodic field without much directional movement to the anode droppers. Still, if what we are seeing is weakly developed taxis, that behavior is very good for capture.