Barrier System Response to Changes in Water Quality

INTRODUCTION

Water quality is an important factor in electrofishing and in deterrence of fish. Of water quality parameters, the parameter that has the highest impact on effectiveness of using electricity in water is conductivity (also referred to as specific conductance). The ease of collecting “spot measurements” of water conductivity is fairly high, and as a result there are multiple data sets of repeat collections of water conductivity at specific locations throughout the Fox River.

Cursory inspection of the water conductivity data reveals that water conductivity in the Fox River is highly variable. The variability of this water quality parameter can, in turn, affect the efficacy of in-water electrical fields, such as the proposed electrical fish deterrent system at Menasha Lock. The issue of how an electrical barrier is affected by changing water conductivity is addressed in detail in this report.

OHM’S LAW AND POWER TRANSFER THEORY

Documentation of the use of electricity to capture fish can be found as far back as a British patent granted to Ishan Baggs. The earliest known research conducted on the effectiveness of fishing with electricity was after World War I (McMillan 1928). The science of inducing behavioral response in fish using electricity was advanced in the 1950’s and 1960’s, culminating in the important text book “Fishing with electricity” (Vibert 1967).

The basic principle of how power is distributed in an electrical barrier is described by Ohm’s Law, which states that the current through a conductor between two points is directly proportional to the voltage across the two points. The expression of Ohm’s Law is $I = V / R$ where I is current, V is voltage, and R is resistance. In an electrical barrier, resistance is provided by the water between two electrodes. Water conductivity is an expression of the water’s capability to pass electrical current. The equation for resistance is $R = d / (c*A)$, where d is length of material, c is conductivity, and A is cross-sectional area. When length and area are held constant, an increase in water conductivity decreases the resistance of the water. Taking this relationship back to Ohm’s Law, when voltage is held constant, a decrease in resistance of water will increase the current in the circuit. These two equations are essential in predicting what will occur when the water conductivity in an electrical barrier increases or decreases.

In 1989, a paper on power transfer theory (Kolz 1989) led to a sharp increase in electrofishing efficiency. This concept is also the basis for the operation of electrical deterrence and guidance systems. Power transfer theory, in short, is the concept that the power transferred to a fish is a function of the ratio between the conductivity of the water and the conductivity of the fish. As the difference between the relative conductivities increases, the efficiency of the system decreases. Thus power needs to be adjusted as a function of conductivity. Power, with the typical unit of watts, is simply the product of current (in units of amps) and voltage (in units of volts).

In the case of an electrical barrier, a target voltage gradient is prescribed for an area, and electrical power, with characteristics of voltage and current, is delivered to the electrodes to generate the prescribed electrical field. The power needed to deliver this prescribed voltage gradient is dependent on the water conductivity. When conductivity changes, the power needed to maintain the prescribed voltage gradient changes by a known factor. An excellent discussion of the science behind this relationship can be found in a blog post by Dr. Jan Dean (2016). The curve in Figure 1 is taken from this blog post. The curve shows maximum efficiency around 115 µS/cm, which is the accepted average conductivity of a fish (Miranda 2009). When water conductivity is higher than 115 µS/cm, more power output is needed to maintain the prescribed voltage gradient. This is accomplished by increasing the current, measured in amps, of the output.

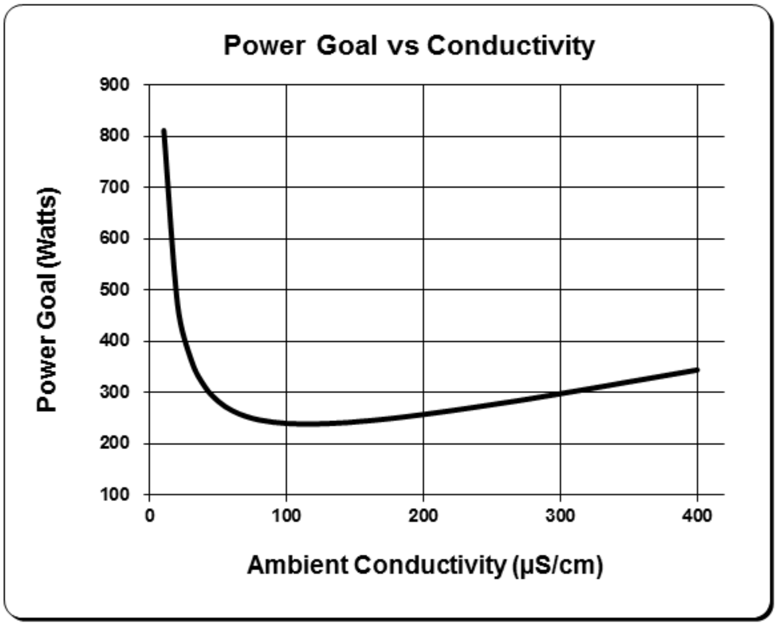

Figure 1. Electrofishing power output goal as a function of water conductivity (Dean 2016).

WATER CONDUCTIVITY AT MENASHA LOCK

Smith-Root gathered previously-collected water quality data from several sources near the Menasha Lock. The summarized information for the two nearest sources is given in Table 1.

Table 1. Water quality data collection stations and sources near Menasha Lock.

Station No.	Source	Gauge Name	Start Date	End Date	N	Min Sp. Cond.	Max Sp. Cond	Mean Sp. Cond.
						µS/cm	µS/cm	µS/cm
04084422	USGS	Little Lake Butte Des Morts at Menasha, WI	10/18/1989	11/17/1992	9	306	404	358
713002	Wisconsin DNR	Fox River – Lake Winnebago Outlet	3/30/2015	3/28/2018	49	317	513	402

The DNR data set has been collected regularly since March 2015 at Fritze Park. The proximity of this data set and the recent and ongoing collection dates make it the most relevant data set for monitoring water conductivity at Menasha Lock. A statistical analysis of the 49 measurements at this station returns a mean conductivity of 402 µS/cm with a standard deviation of 41.6. The range of collected values is almost 200 µS/cm, with a minimum observed value of 317 and a maximum observed value of 513 µS/cm.

The range of values is rather large. Simulations, to be described later in this document, evaluated water conductivities +/- 3 standard deviations from the mean, 277 and 527 µS/cm, which is expected to encompass 99.7% of the observed water conductivity at Menasha Lock. An additional simulation with environmental water conductivity of 600 µS/cm is also evaluated.

SMITH-ROOT BP-1.5 POW PULSE GENERATORS

Smith-Root BP-1.5 POW pulse generators are designed to deliver a pulsed DC current to the water column at a constant, prescribed voltage. In order to maintain this voltage, the output power needs to be adjusted to the environmental water conductivity in the barrier vicinity. This is achieved through a continuous feedback loop that adjusts output current as a function of water conductivity, maintaining the output voltage constant.

While the BP-1.5 POW pulse generators can operate independently, they are typically connected to a fish barrier telemetry and control system (FBTCS) that compiles the input and output of each pulse generator connected to the system and provides a remote or on-site user interface. In addition, the FBTCS is capable of integrating outside monitoring data, such as a water conductivity meter or water level sensor, and can automatically send instructions to the pulse generators when user-defined thresholds are met.

SENSITIVITY ANALYSIS

Using a general purpose finite element analysis software, COMSOL Multiphysics, Smith-Root conducted a sensitivity analysis of a potential Menasha Lock electrical field and, holding constant all other factors, evaluated the required power output at several water conductivities.

The result of the voltage gradient as a function of water depth is shown in Figure 2. The distance in the table is in units of feet below the water surface; the purple line is at the bottom of the barrier and the dark blue line is at the water surface. Because the power output from the BP-1.5 POW pulse generators hold voltage output constant, the results of this graph do not change with water conductivity.

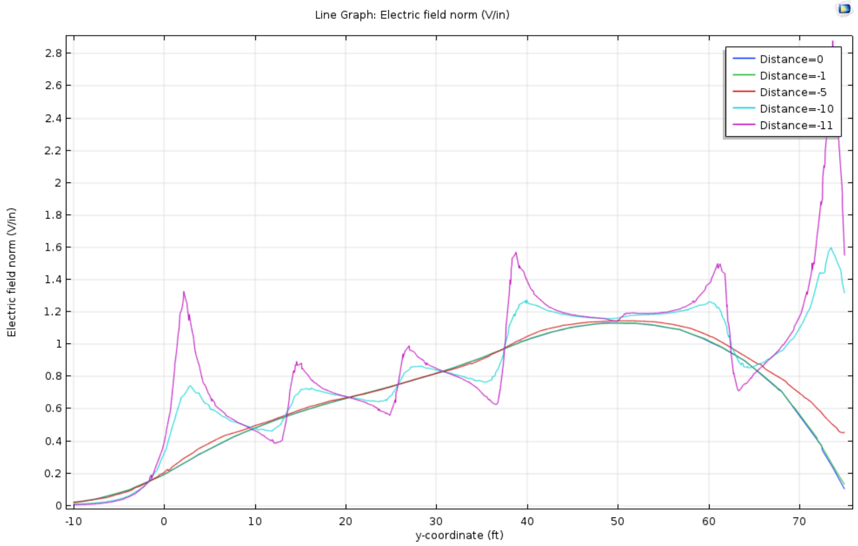

Figure 2. Characteristic COMSOL model output for Menasha Lock with multiple water conductivities.

While output voltage is constant, output current and power change as environmental water conductivity changes. This relationship is predicted by Ohm's Law, and the model output shows a generally linear relationship between conductivity, current and power, as is expected. The results are presented in Table 2.

Table 2. COMSOL model output for Menasha Lock barrier at various simulated water conductivities.

Simulated water conductivity	**Peak output voltage**	**Peak output current**	**Output power at 100% duty cycle**	**Output power at 5% duty cycle**
(µS/cm)	**Volts (V)**	**Amps (A)**	**Watts (W)**	**Watts (W)**
277 µS/cm	900	266.7	36,781	1,839.1
402 µS/cm	900	327.4	53,093	2,654.7
527 µS/cm	900	428.0	69,404	3,470.2
600 µS/cm	900	486.8	78,928	3,946.4

CONCLUSION

The conductivity component of water quality in Little Lake Butte Des Morts is relatively inconstant, thus the question of how an electrical barrier can handle a conductivity range of more than 200 µS/cm is certainly relevant. Ohm's Law and the power transfer theory describes how the electrical pulse, generated by the Smith-Root pulse generators, is distributed in the water within the electrical barrier and subsequently to fish that enter the barrier. In general, an increase in conductivity results in the pulse generators automatically increasing the output power in order to maintain the constant voltage in the electrical barrier. When the ambient conductivity always exceeds 115 µS/cm, as does the water of Little Lake Butte Des Morts, the limiting factor then becomes high values of conductivity. Thus, an electrical barrier system at the Menasha should be designed to function with the highest anticipated water conductivity in Little Lake Butte Des Morts. This maximum value of anticipated water conductivity is a variable that will be confirmed with Wisconsin DNR prior to the completion of system design.

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