Potential for Warping and Arcing at Proposed Menasha Lock Electrical Barrier

INTRODUCTION

Fish are uniquely sensitive to electrical currents because their muscle control is based on electrical impulses through their nervous system, and because they inhabit a conductive environment. Electrical barriers and guidance systems make use of this sensitivity. Electrical barriers involve electrical current passing from one submerged electrode (or series of electrodes) to another. When a fish is within the field, they become part of the electrical circuit with some of the current flowing through its body. This induces reactions ranging from behavioral modification to full tetany, depending on the strength of the current, voltage gradient, and pulse duration and frequency they receive.

The proposed electrical barrier at Menasha Lock is what is referred to as a “bottom-mounted barrier.” This is a bit of a misnomer because electrodes would be attached to the vertical side walls of the barrier as well as the bottom. A bottom-mounted barrier allows boat traffic to proceed without obstacles while halting migration of fish through the barrier. The question to be answered in this report is what happens to the electrical field when a boat passes through the barrier? The answer depends on the size of the boat and the material it is made out of. Three-dimensional modeling is used to model the distortion of the electrical field in some of these situations.

ELECTRICAL FIELD BACKGROUND

In the absence of voltage electrical current does not flow. Electrical sources generate a voltage on a circuit and cause electrons to flow in the circuit. How many electrons flow is dependent on the voltage on the circuit and the total conductivity of the circuit. For example, a circuit with 10 volts (V) applied and a load with a total conductivity of 1 siemen (S) would have 10 amps (A) of current flowing in it. If the same 10 V were applied to a circuit that had a total load conductivity of 0.0005 S, or 500 µS, then there would be 0.005 A, or 5 mA, flowing in it.

Circuits can be made up of many different types of conductors, loads and sources. In a fish barrier, the sources are called pulse generators (or pulsers). The conductors are the wires and electrodes in the water, and the load is the water and anything in the water.

Fish normally orient parallel to the flow of water with their heads into the flow. Electric fields oriented parallel to flow are effective in stopping fish from moving upstream. The amount of electricity a fish absorbs from the water depends on its length and its orientation in the water. Electric fields oriented in other directions – i.e. perpendicular to flow or from the top of the water column to the bottom, do little to affect fish behavior because fish spend little time oriented in these directions.

BOAT USE AT MENASHA LOCK

Prior to the closure of Menasha Lock, detailed records of boat lockages at Menasha Lock were not kept. However, Smith-Root talked to the FRNSA Locks Manager Jim VanBoxtel who provided general information about the boats that used the lock prior to the closure. In summary:

- The lock is open mid-May to October 1.

- The average usage is about 1500 boats per year.
- Of the 1500 boats, about 35% are metal (conductive) hull boats, and 65% are fiberglass (non-conductive) hull boats.
- With the exception of work barges, the range of boat lengths is 14' to 32'.
- 75% of the boats that use the lock are 14'-18' in length.
- With the exception of work barges, most, if not all, of the boats longer than 18' are constructed of fiberglass.
- Personal watercraft make up about 5% of all boats that use the lock. Of this 5%, about half are self-propelled (canoe and kayak), and half are motored (jet ski or wave runner).
- The self-propelled personal watercraft currently have a path to portage around the lock when it is closed.

In addition to the pleasure craft that use the lock, there are occasional lockages of work barges. Mr. VanBoxtel said the DNR currently allows the work barges to use the locks up to 10 passes per year (one direction is considered one pass). 2 days before each pass, DNR treats the lock with rotenone. Prior to the lock closure, the usage of the lock by work barges was highly variable and depenedent on construction needs. Sometimes there was no barge lockage for two years, and other times there were more than 10 lockages per year.

Tom Radtke, the owner and GM of Radtke Contracting in Wisconsin, gave Smith-Root details on their work barges. In summary:

- They have 5 work barges.
- All 5 barges are made of steel.
- Four are used most often and are of nearly identical size: 32-ft wide by 115-ft long, 4-ft high (2-ft draft and 2-ft freeboard).
- The fifth is less commonly used and is differently sized: 30-ft wide by 100-ft long, 6-ft high (4-ft draft and 2-ft freeboard)
- They have two tug boats. One is 12-ft wide by 30-ft long, and the other is 16-ft wide by 45-ft long.
- When the shorter, 30-ft tug boat is used, both boat and barge can fit into the lock together.
- When the longer, 45-ft tug boat is used, the barge and boat must go through the lock separately. When that happens, the barge is pushed into the lock (regardless of direction) by the tug, and then pulled out of the lock by workers on each side of the lock with 20-ft push poles.
- Other methods can be used by Radtke Contracting to move the barge out of the lock if needed, such as use of paddles or a small motor.

WHEN A CONDUCTIVE BOAT ENTERS THE ELECTRICAL FIELD

When a large metallic object such as a boat or barge enters the electric field, it begins to attract the electric field in the water as it crosses the first electrode. Metal is a conductor, and steel is over 200,000 times more conductive than the water at Menasha Lock, so a metallic hull is much more effective at conducting electricity than water. While electricity will flow through all paths available, it shows a preference for the path with the highest conductivity – also known as the path of least resistance. As the metallic hull moves further into the barrier and across multiple electrodes, the strength of the electric current (in amperes) drawn from the pulse generators increases. This happens because the metallic hull presents an easier path for electric current than does the water between the electrodes. The current strength will continue to increase until the entire metal hull is over the barrier, and then as the hull begins to leave the barrier the current strength will begin to decrease back to normal.

During this scenario, the voltage being supplied by the pulsers does not change. However, the electric field near the metallic hull does. This is caused by the increase in electrical current flowing from an electrode through the water to the metallic hull and then back through the water to the return electrode for that pulse generator. The defining principle for this effect is Ohm's Law: V=I*R, where V is voltage, I is current, and R is resistivity. Resistivity is the inverse of conductivity, so when conductivity increases the resulting current also must increase in order to keep voltage constant.

The substantially increased conductivity of the metallic hull causes the orientation of the electric field in the water to change direction as a metallic hull moves across the electrical barrier. The fields perpendicular to the metallic hull increase in intensity, while the field parallel to the hull decreases in intensity. Also, a steel hull that is over 200,000 times more conductive than the surrounding water creates very little voltage change from one end of the hull to the other. As a result, the overall intensity of the field with a metallic hull in the barrier is higher, but the direction of the electric field changes so that the barrier is less effective in the immediate vicinity of the metallic hull while the boat is over the barrier. This effect is shown in Figure 1, a plan view of the electric barrier with a theoretical metallic hull barge, represented by the rectangle outline, in the center of the barrier. The colors represent the voltage in the water at a depth of 4 feet below the surface and 1 foot below the bottom of the barge (which was given a theoretical 3-ft draft in the model).

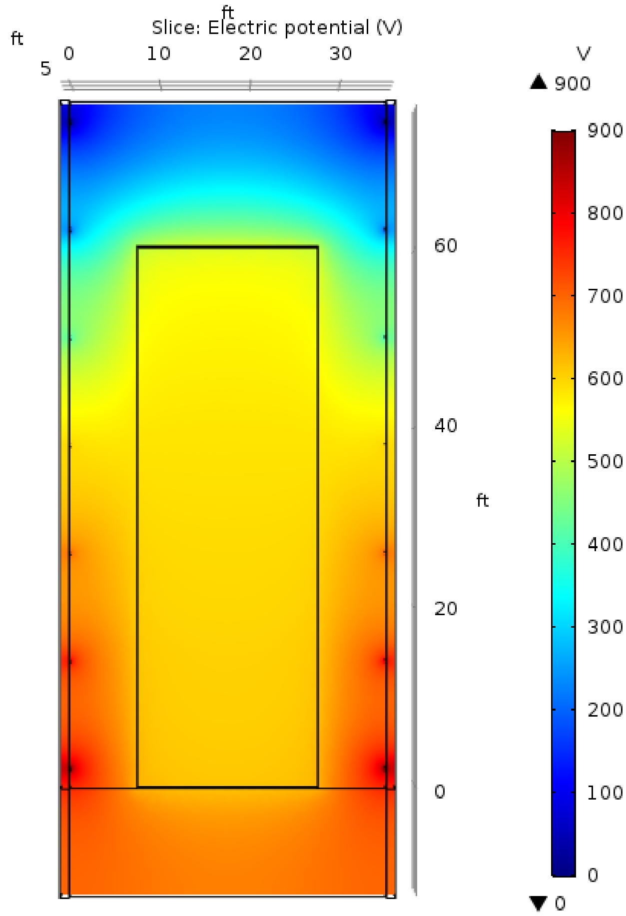

Figure 1. Voltage map (plan view) at depth 4 ft below surface (8 ft above bottom) with theoretical 60-ft by 20-ft metallic hull barge with a 3-ft draft.

The effect of the metallic hull on the electric field in the water decreases with distance from the hull. This is a key point for a barrier that is operated to deter migration of Round Goby, which migrate within 30 cm (0.98 ft) of the bottom of a channel. In the Menasha Lock barrier, the effect of the metallic hull with a 3-ft draft is abated a few feet below the bottom of the hull. Figure 2 shows the voltage potentials returning to normal at a depth of 5 feet above the floor (left, 4 feet below the hull) and unaffected at a depth of 2 feet above the barrier floor (right, 7 feet below the hull). As mentioned previously in this report, the work barges that typically use the Menasha Lock have a 2-ft draft.

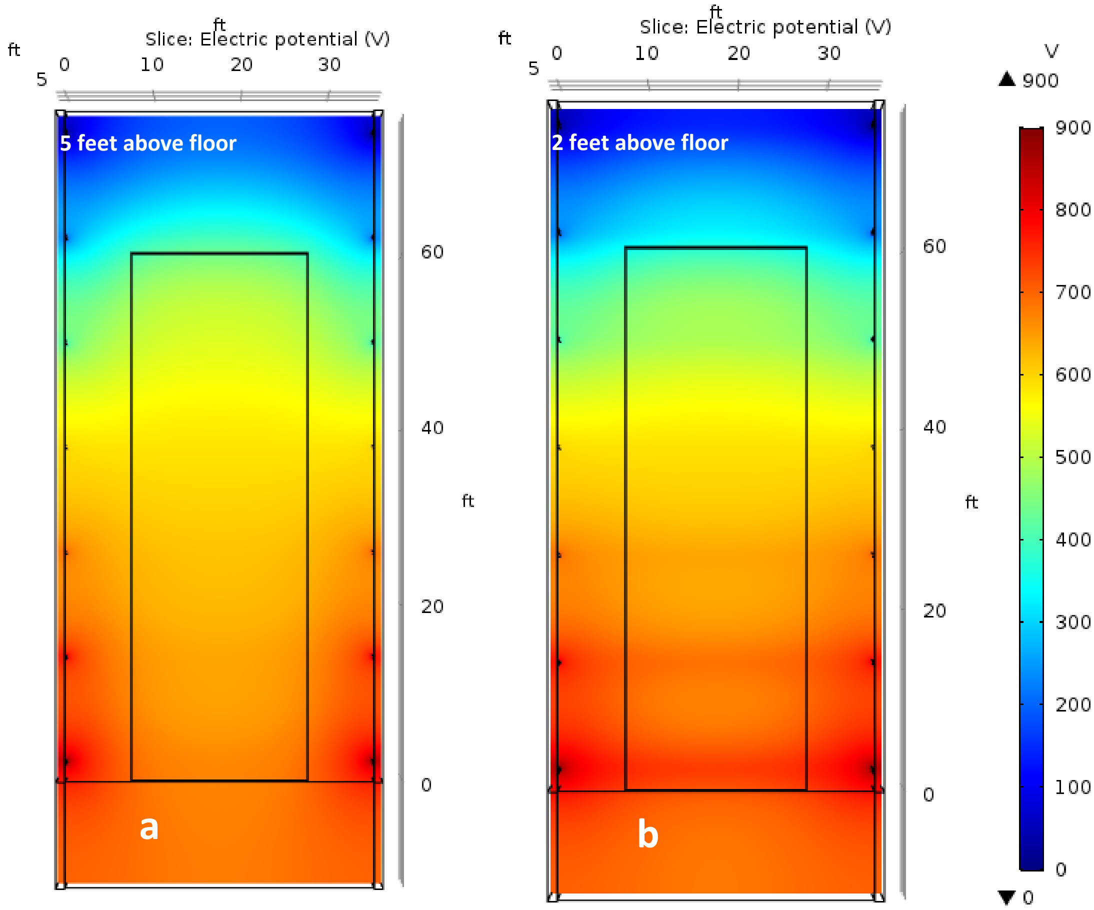

Figure 2. Voltage map (plan view) at a) depth 7 ft below surface (5 ft above bottom) and b) depth 10 feet below surface (2 ft above bottom) with theoretical 60-ft by 20-ft metallic hull barge with 3-ft draft.

The larger the hull, the greater one can expect the effect to be. Small aluminum fishing boats have little effect on the overall field of the barrier, but the effect increases with the size of the boat. For example, metal-hulled boats that draft 2 or more feet of water will have a larger effect than those that draft 2 feet or less. Similarly, a 24-ft metal-hulled boat will have a larger effect than a 16-ft metal-hulled boat. Another factor to consider is the proposed electric barrier includes electrodes running up the sides of the vertical walls. Boats with metal hulls should try to motor through the center of the barrier, as the closer a metallic hull is to the electrodes, the more the hull will affect the electric field. The magnitude of the effect a metallic hull has on a barrier depends on the size of the hull and the distance of the boat from the electrodes on the bottom or the vertical walls of the barrier.

WHEN A NON-CONDUCTIVE BOAT ENTERS THE ELECTRICAL FIELD

When a non-conductive boat enters the electrical field, the boat hull itself does not draw the electrical current as a conductive hull does. Essentially, the boat hull becomes a “void” in the electrical field that is inaccessible to fish because of the solid hull. After the boat passes any point within the barrier, the electrical field returns to normal nearly instantly. The presence of a metal propeller or small metal appurtenance (such as a fish finder transducer) may have a very minor local effect on the field that is not expected to create an opportunity for a fish to avoid the deterrent electrical field.

Through volume displacement, a non-conductive boat passing through an electrical barrier raises the water elevation. Large increases in water elevation can alter barrier effectiveness. However, the rise in water elevation due to volume displacement from a single boat accessing the Menasha Lock is expected to be so miniscule as to be immeasurable, with an equally immeasurable impact on the electrical field.

SUGGESTED SAFETY REQUIREMENTS FOR BOATS CROSSING THE BARRIER

Electrical arcing can occur when two disconnected objects or surfaces at different voltage potentials are connected by a conductive object. In the case of a pulsed DC electrical barrier, current will flow from the object with the higher voltage potential to that with the lower potential.

The combination of voltage and current that would be used for the Menasha Lock barrier, along with the selected waveform, is not an inherently dangerous electrical pulse to healthy humans. However, measures should be taken to eliminate the potential for electrical arcing due to unknown effects to people with heart conditions or pacemakers. In addition, measures should be taken to minimize the potential for people falling into or swimming in the electrical barrier without US Coast Guard-approved personal flotation devices. Physical safety measures such as rub rails, hand rails and fences, etc. will be included in the engineering design of the electrical barrier at Menasha Lock. Policies can also provide further measures of protection; some suggestions for boating policy at the electrical barrier follow:

- People may remain in boats as they cross the electrical barrier as long as they wear a USCG approved PFD.
- While crossing the electrical barrier, people should keep their arms and legs inside the boat and do not contact the water.
- Do not touch the concrete or ground beside the barrier while in or on a boat in the barrier.
- Do not attempt to get on or off a boat in the barrier.
- No metal paddles in the water.
- All metal in contact with the water must be securely bonded to the boat.
- No swimming.
- No fishing (fishing in an active electrical barrier would be a fruitless exercise).
- No craft that encourage limbs in the water, such as inner tubes, paddle boards, and petal boats.
- No metal canoes.
- We strongly recommend no plastic, PVC, rubber, or fiberglass (non-conductive) personal watercraft that can be easily capsized, such as canoes or kayaks.
- No cables or chains in the barrier. The only exceptions commercial barges and tugs where metal cables will reduce sparks between the barge and the tug. No cable or chains hanging off barges or tugs into the water.
- No anchoring.

- Use only polyrope while in the barrier and only if absolutely necessary. Wear heavy rubber gloves with no holes while handling ropes in the barrier. Wet polyrope can conduct electricity.

CONCLUSION

There is a potential for “warping” of the electrical field when metallic hull boats enter the barrier. The impact of the boat on the field – and thus the barrier effectiveness – is dependent on the size of the boat. Most metal-hulled boats that use the Menasha Lock are 18-ft in length or shorter. These types of boats have little to no effect on the operation of the barrier. Non-metallic hulled boats (plastic or fiberglass) have little impact on the effectiveness of the electric barrier, regardless of their length.

Occasionally, large, metal-hulled work barges utilize the Menasha Lock. The barges can currently use the lock under a DNR-approved rotenone treatment program that requires two days of treatment prior to a lockage. Computer simulations indicate that large work barges have the potential for making the voltage gradient equipotential in the immediate vicinity of the barge hull. This means the field would not be effective in deterring a fish that is moving through the barrier alongside and immediately adjacent to the barge. As a fish moves farther away from the barge, the voltage gradient increases. The bottom several feet of the barrier is likely to be unaffected by the passing of a metal-hulled barge above. Round Goby exclusively move along the substrate of a waterbody, utilizing the bottom one foot or less of the water column. Hence it is very likely that allowing barge traffic in the electric barrier would have no negative effect on the deterrence of Round Goby. Further study would need to be conducted to determine the risk of not deterring fish that move higher in the water column when a metal-hulled barge moves through the barrier.

Because of the inherent difference in voltage potential in an electric barrier, there is an opportunity for electrical arcing when a conductive object connects the two potentials. The resulting arc is not dangerous to a healthy human, but it should be a priority to reduce the opportunity of an arc occurring to the greatest extent possible. Physical design elements, incorporated in system design and construction, can be combined with operational and policy elements to reduce or even eliminate the opportunities for arcing to occur at the barrier.