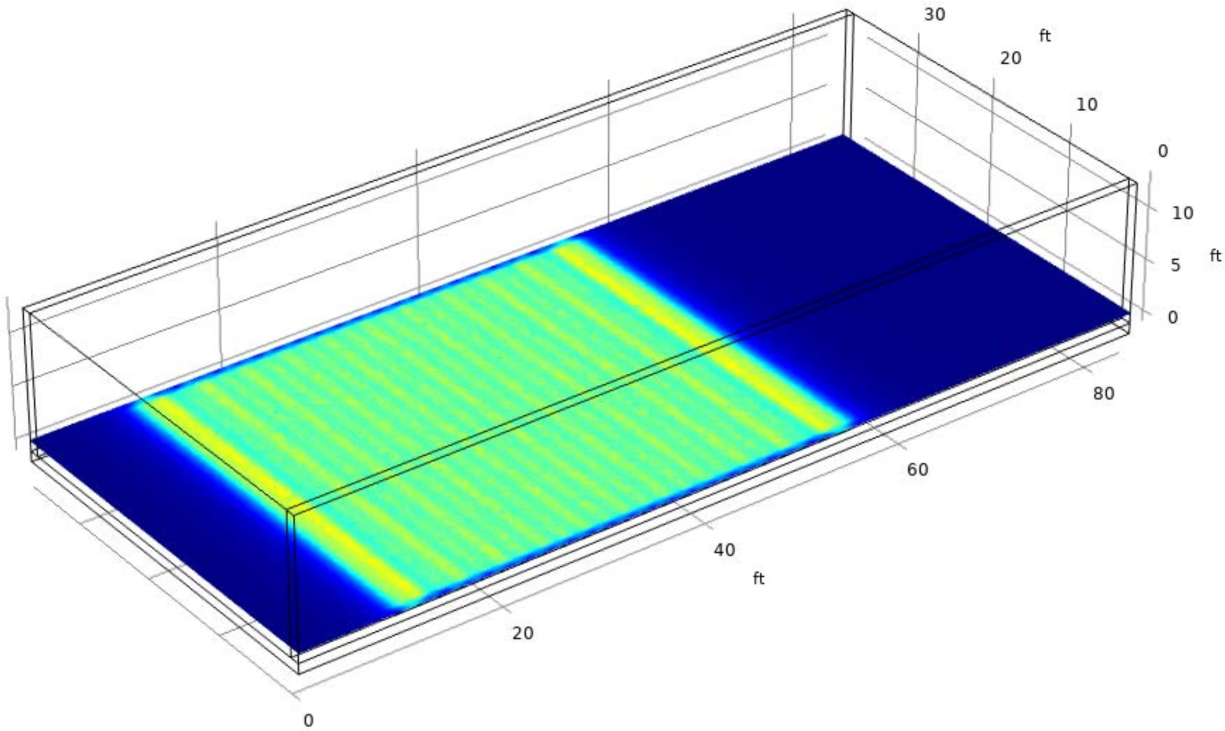
Menasha Lock Electric Fish Barrier 60% Design DRAFT Electrical Field Simulation Report



Prepared for Fox River Navigational System Authority

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1. INTRODUCTION

Menasha Lock is situated on the outlet of Lake Winnebago in Menasha, Wisconsin, and is the upstream-most lock on the Fox River Navigational System. The first lock was built at the site in 1856. The current lock was constructed in 1970, and underwent repairs in 2014. The lock, constructed of concrete and steel and 144 feet long by 35 feet wide, has a total lift of 9.7 feet. The lock and most of the area surrounding the lock is owned by the Fox River Navigational System Authority (FRNSA); the dam on the southwest side of the lock is owned and operated by the U.S. Army Corps of Engineers (USACE). A small excavated boat access channel on river right (looking downstream) exists about 140 feet downstream of the lower lock gates; this basin is privately owned and is often used by personal watercraft owners to put in and take out their boats and for portage around the lock. Lake Winnebago is upstream of the lock, and downstream of the lock the reach of the Fox River is known as Little Lake Butte Des Morts.

In September 2015, FRNSA closed the lock to comply with the Wisconsin invasive species rule (Wisconsin Administrative Code chapter NR40) due to the presence of the invasive Round Goby (*Neogobius melanostomus*) in Little Lake Butte Des Morts. FRNSA has since contracted the team of Smith-Root, Aptum Inc., and OMNNI Associates to develop a 60% design for an electric fish deterrent system downstream of Menasha Lock. The purpose of the deterrent system is to use a pulsed DC electric field to create an impassable barrier to fish to prevent their egress into Menasha Lock.

The 60% design of the electric deterrent system features a concrete slab and vertical walls with flush-mounted steel electrodes, connecting wires, and control equipment that produce the deterrent electrical field. The concrete structure would be situated immediately downstream of the existing Menasha Lock (Figure 1). The existing steel wingwalls would be disconnected from service, and the barrier structure would extend at the same 35-ft minimum width downstream.

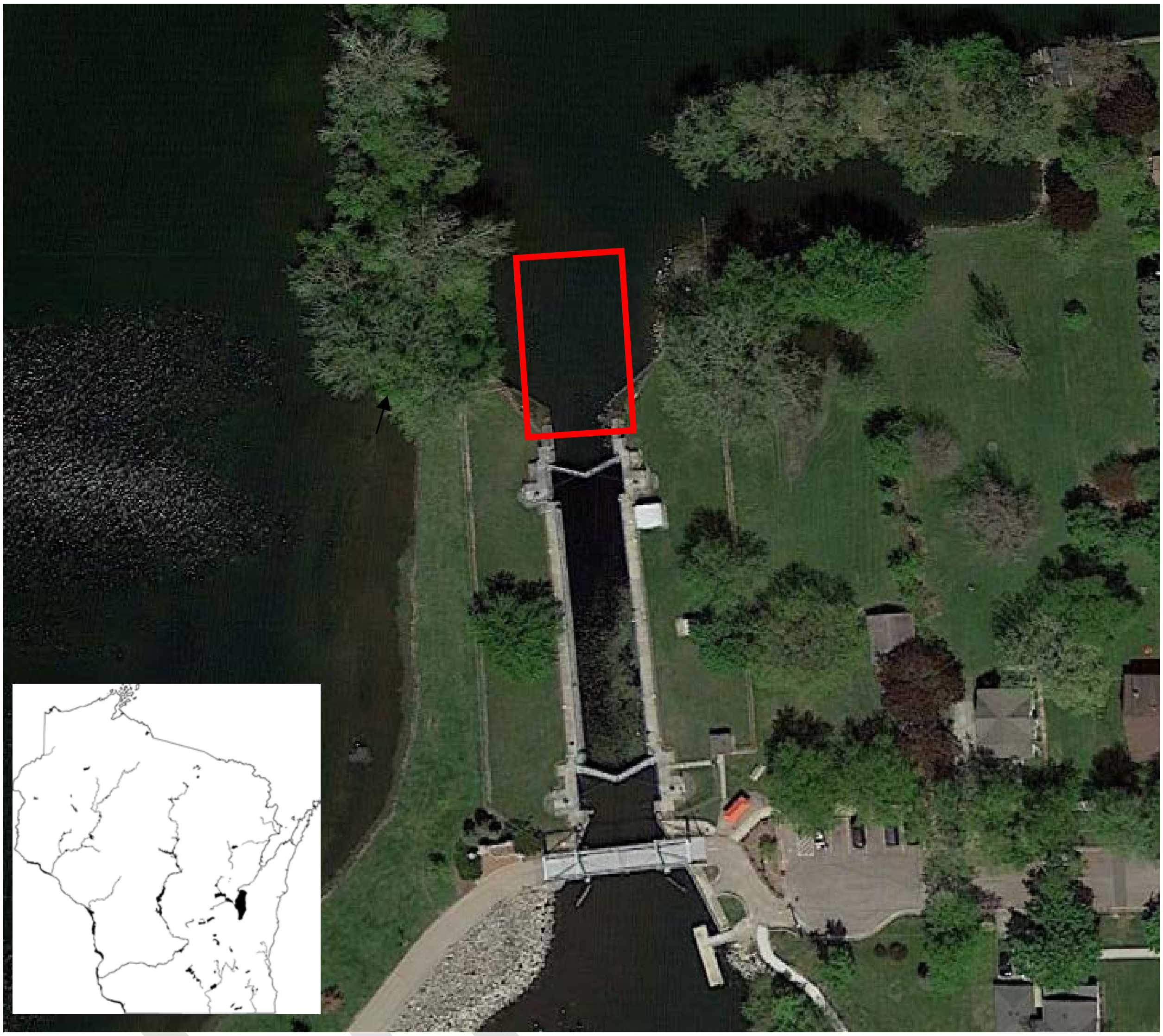

Figure 1. Proposed Location of Menasha Lock Electric Fish Barrier (Source: Google Earth; inset: State Cartographer's Office, University of Wisconsin-Madison)

2. EXISTING CONDITIONS AND PROPOSED ELECTRIC FISH BARRIER

Menasha Lock existing conditions

The Menasha Lock is built in an earth fill dam that separates the Menasha Channel of Lake Winnebago from Little Lake Butte Des Morts (Fox River). The lock and the land immediately surrounding it is owned by FRNSA, and the dam is operated by USACE. Immediately downstream of the lock, wingwalls connect the lock structure to the surrounding banks. An excavated boat access channel is in place about 110 feet downstream of the lock structure on river right; a small, vegetated peninsula separates the approach to the lock from the main Little Lake Butte Des Morts channel for about 200 feet on river left. The lock and surrounding area is shown in Figure 1.

Based on hourly water level data at a gauge station on the Fox River at Fritse Park in Menasha for the period 11 October 2011 through 30 June 2017, the range of water surface elevations was 736.07 to 740.16 (NAVD88 vertical datum). Comparing this to the lock floor elevation, the maximum depth was about 12.4 feet.

Data exists for water conductivity (specific conductance) at several locations on the Fox River. The closest and most relevant data set is collected by Wisconsin Department of Natural Resources at the Lake Winnebago dam outlet (Sta. No. 713002). Conductivity measurements were evaluated for the period January 1979 to November 2018 (N=303); the average conductivity measurement was 375 µS/cm, with a standard deviation of 44.

Proposed fish deterrent system

The proposed layout of a deterrent system to deter upstream movement of Round Goby utilizes 23-2"x1" flat bar mild steel electrodes that span the floor of a concrete slab. The electrode array starts about 120-ft downstream of the lower lock gates and span upstream approximately 45-ft; the electrodes are spaced 2-ft on center.

The Round Goby deterrent system is situated within a larger concrete barrier structure. The structure includes a 36-ft wide slab and vertical walls of height approximately 13.5-ft. The structure dimensions are intended to allow the electrical field to be expanded in the future if other invasive fish invade the Fox River. The concrete barrier structure is cast with Insulcrete™, a concrete mix that is more electrically resistant than standard concrete. A schematic of the barrier layout used in the electrical field simulation is shown in Figure 2.

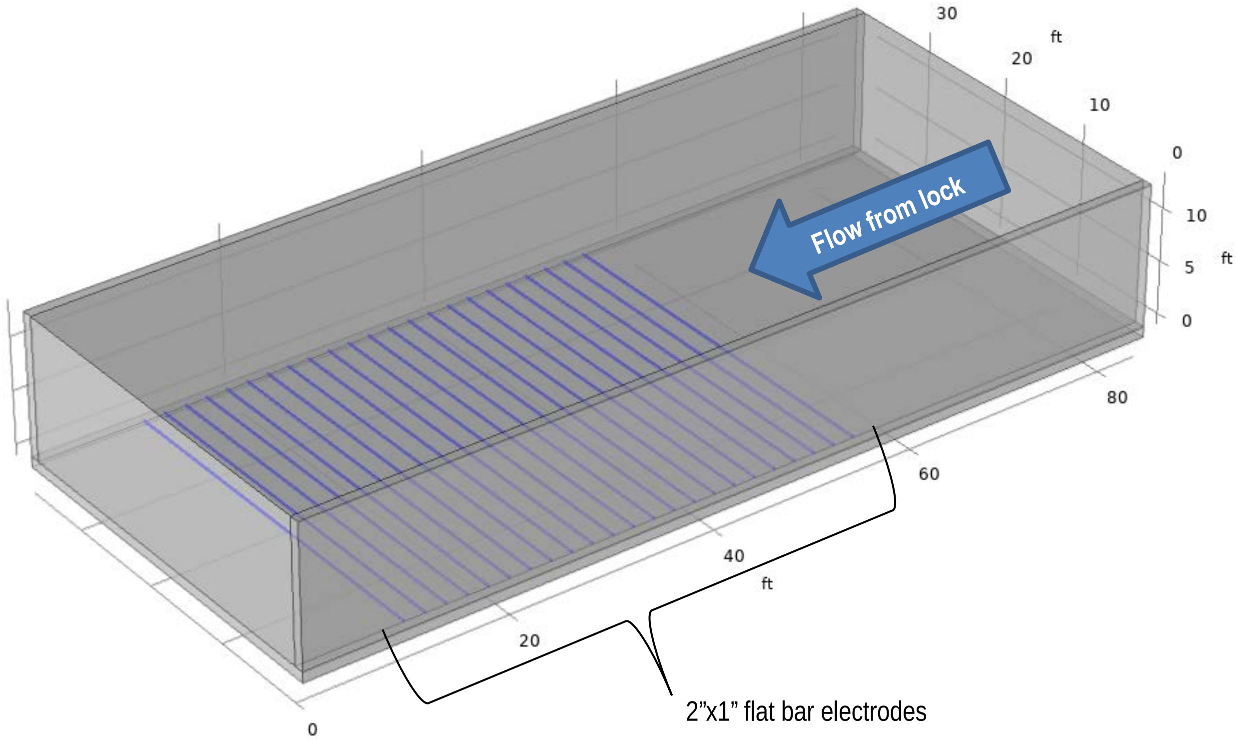

Figure 2. Schematic of Menasha Lock Barrier 60% Design Layout

3. METHODOLOGY

Electrical simulations of the 60% design deterrent system layout were performed using 3D physics software to determine the optimal power and voltage settings to achieve this purpose. The software simulates the electrical field in and around the barrier, and considers all constructed features including the barrier geometry, depth of flow in the channel, and the specific conductance of the barrier slab, river/lake bed, river water, and the adjacent soil.

Model Background and Setup

The electric field was simulated using COMSOL Multiphysics software. Each site is modeled within COMSOL using a simplified representation of the site which eliminates most features and surfaces that will not be in contact with the electric field. The surfaces that are in contact with the electric field have been somewhat simplified as required for the analysis. Given the barrier layouts, design water depth, water conductivity, and the strategy of deterring the predominantly benthic Round Goby while allowing the possibility to modifiy the barrier in the future to deter other fish species, it was decided to create a benthic barrier on the downstream side of a barrier structure utilizing 23 steel bar electrodes with recesses in the concrete intended to allow future modification and expansion of the barrier. The spacing and quantity of electrodes was determined based on initial simulations and successes with previous barrier installations.

Assumptions

The following assumptions were made for this analysis:

- Surface water conductivity: 509 µS/cm (assumed; see analysis below)
- Insulcrete™ conductivity: 7 µS/cm
- Soil conductivity: 20 µS/cm (assumed; see analysis below)
- Maximum depth: 13.43 feet; target voltage gradient to 1 foot (~30 cm) above barrier floor

Soil conductivity was not directly measured at the project site; the value was based on an assumption using common material conductivities associated with electrical grounding data. Geotechnical logs of the test boring taken at the project site show the underlying soil is predominantly sand with some gravel (OMNNI Associates 2019; boring logs provided by OMNNI Associates, 11/5-7/2018). Moist, sandy clay soils have an electrical resistivity approximately 150 Ω·m (Fluke Corporation 2013). The conductivity of Insulcrete™ at previous installations was measured using procedures similar to the ASTM C1760 testing methodology.

Water conductivity was assumed at 509 µS/cm for the electrical field model. This value is 3 standard deviations from the mean (Wisconsin DNR station 713002, Fox River at Lake Winnebago Outlet; n=303), and captures 99.85% of the measured data set. This value is considered conservative and is intended to capture most of the environmental conditions expected at the barrier site. In the case this value is exceeded in the field, the Smith-Root pulse generators will require additional output power to maintain the voltage gradient in the water.

<u>Simulation</u>

A steady-state electric field simulation was run using COMSOL Multiphysics 5.2 to simulate the electric field at the water level for the input parameters described above. Voltage potentials were applied to each electrode and conductivities were applied to all features and surfaces.

The goal of the simulation is to achieve the prescribed voltage gradient at a point 1-ft above the bottom of the barrier floor. Considering the burst speed of adult Round Goby, it is advised that this prescribed voltage gradient be maintained for at least 30 feet. In bottom-mounted deterrent systems, a point at the top of the target water depth is where the field strength will be the lowest. The desired outcome of the simulation is to determine the power output needed to generate the selected deterrent voltage gradient at the top of the target water depth (1 foot above the barrier floor) for a sufficient length parallel to water flow. Simulations are run in COMSOL until this desired outcome is achieved.

The target voltage gradient for Round Goby used in the COMSOL simulations was 2.54 V/in at 1-ft above the barrier floor. The rationale for selection of this target voltage gradient is provided in previous Smith-Root documents submitted to FRNSA (Smith-Root 2017; Burger and Johnson 2018).

4. RESULTS

Figures 3-5 shows the electric field strength in a plane perpendicular to the electrodes at the barrier centerline under the design flow conditions. The downstream end of the barrier is on the left; water would flow from the lock from right to left (as depicted in Figure 2). Figure 3 shows an oblique view of model output at the barrier floor; Figure 4 shows the output 0.5 foot (15.2 cm) above the barrier floor; and Figure 5 shows the output 1 foot (30.5 cm) above the barrier floor. Electrical field values that exceed the prescribed voltage gradient of 2.54 V/in are shown in red, orange and yellow.

In bottom-mounted electrode barriers, a fish traveling through the barrier at several depths would encounter different voltage gradients and also at different longitudinal locations within the barrier. Figure 6 is a conceptualization of potential fish travel paths, and the resulting line graphs that show voltage gradient within the barrier is given in Figure 7. The high voltage gradients shown by the blue line represents those along a theoretical path 0.5 foot above the top of the barrier floor and the electrode; the results are also shown by the green line 1.0 foot above the floor and the red line 1.5 feet (45.7 cm) above the floor.

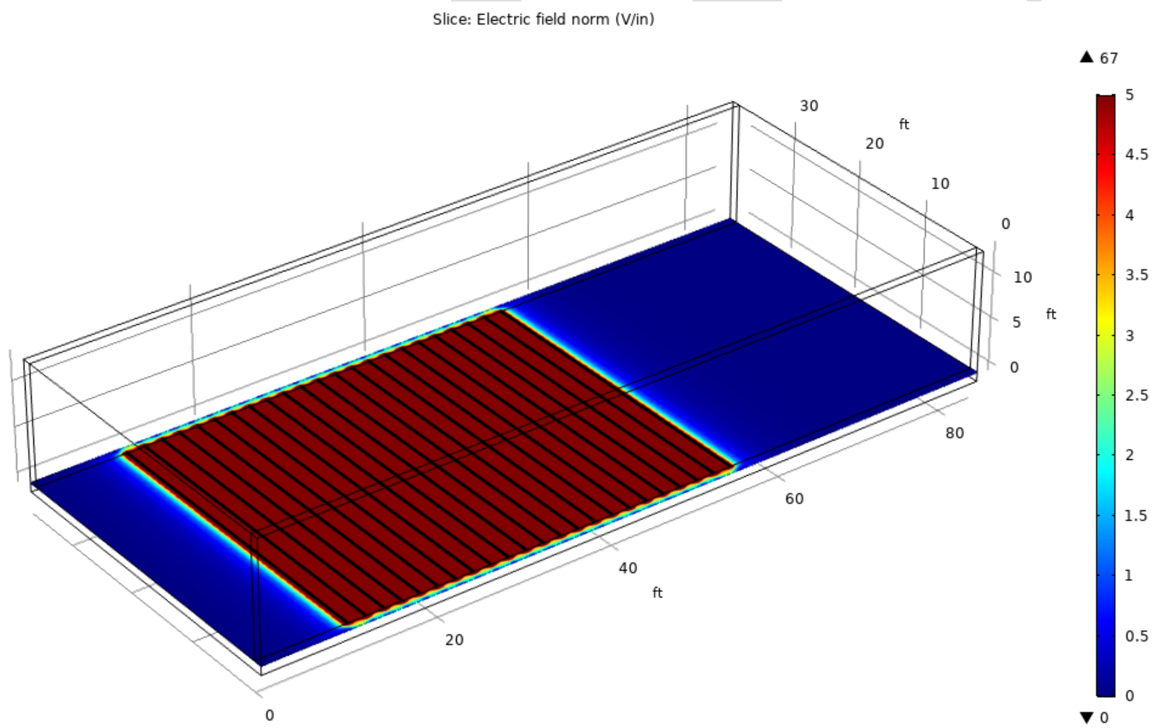

Figure 3. Electric Field Density in Menasha Lock Barrier at Barrier Floor.

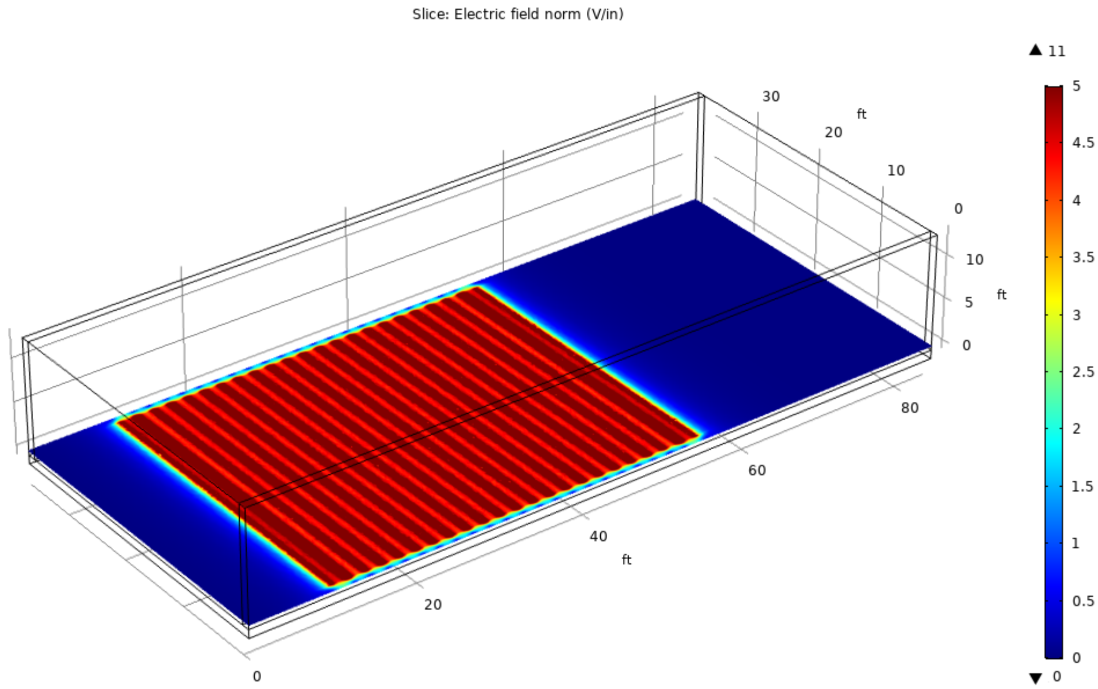

Figure 4. Electric Field Density in Menasha Lock Barrier at 0.5-ft (15.2 cm) Above Floor.

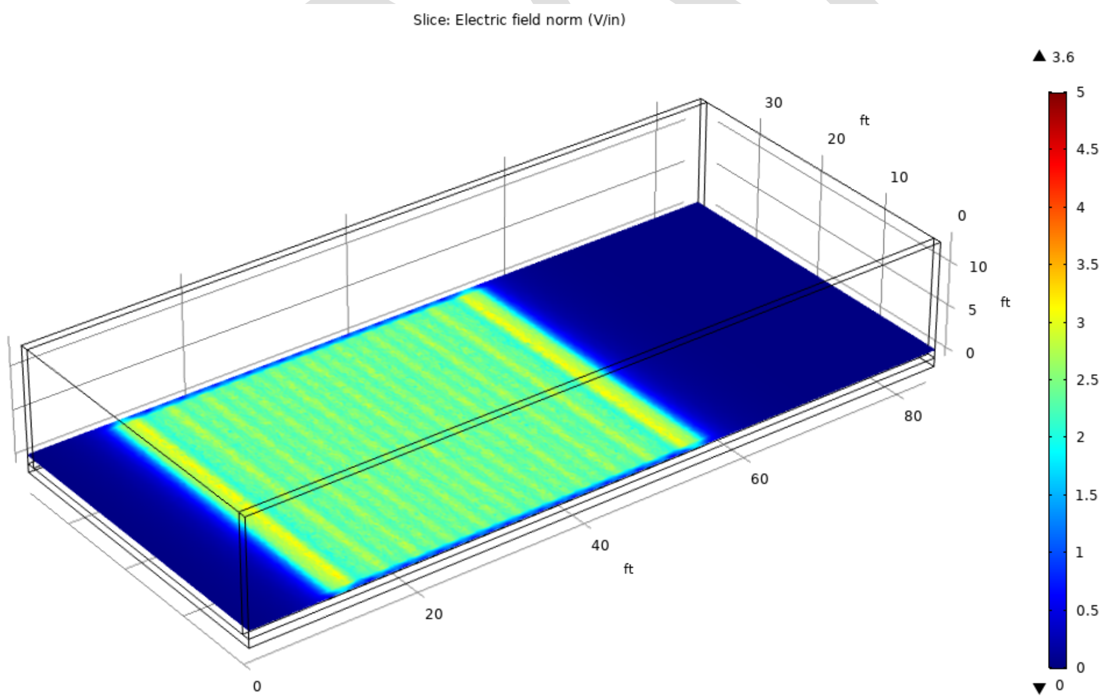

Figure 5. Electric Field Density in Menasha Lock Barrier at 1-ft (30.5 cm) Above Floor.

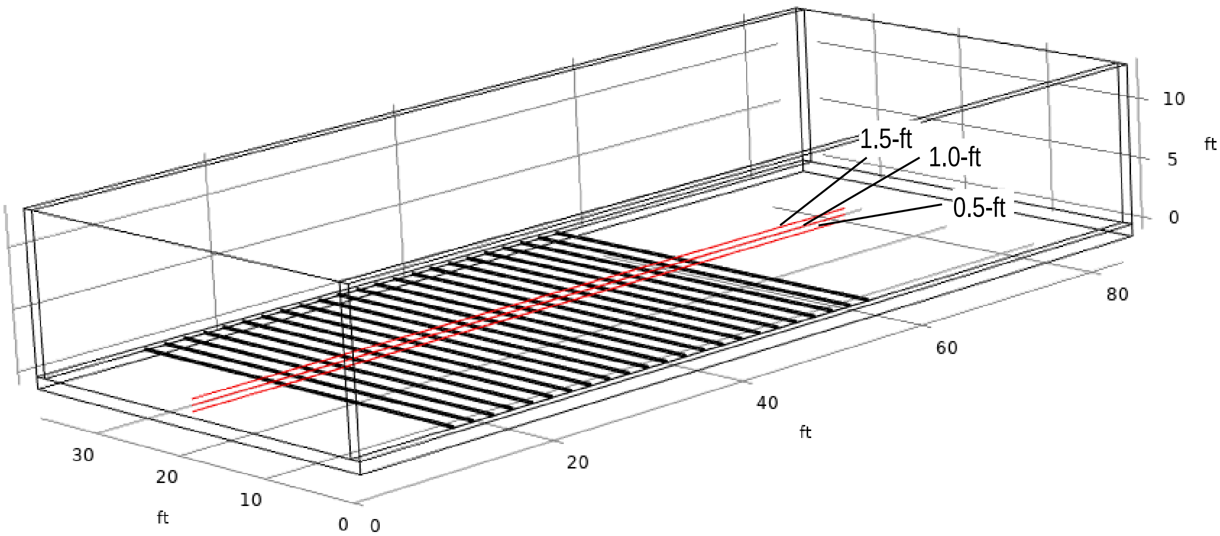

Figure 6. Travel paths for Theoretical Fish in Proposed Menasha Lock Barrier

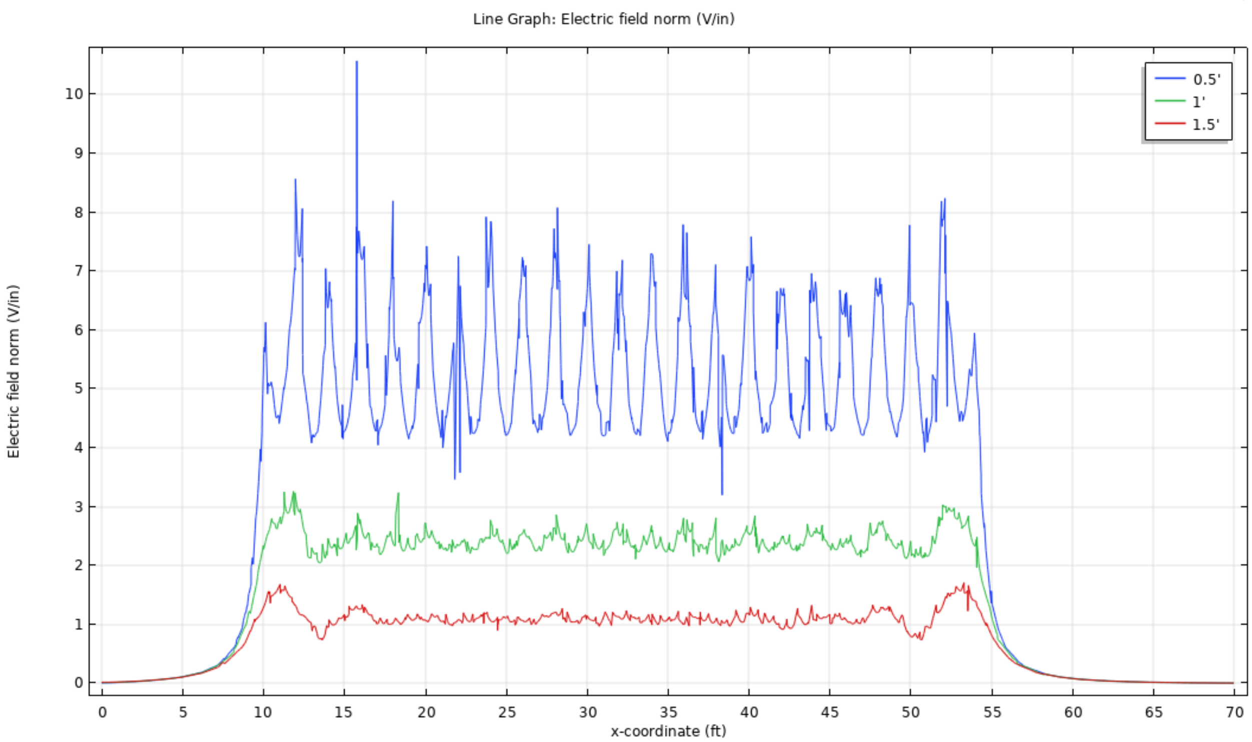

Figure 7. Electric Field Strength for Fish Travel Paths

5. DISCUSSION

Barrier Performance

The proposed Menasha Lock Electric Fish Barrier is designed to deter upstream passage of Round Goby in the bottom 1.0 ft (30 cm) of the open channel barrier. The barrier is designed to be effective in zero flow conditions, and will also be effective when the lower lock gate is open and the lock is discharging water into the barrier.

At the design depth of 1.0 ft, the barrier is designed to present a minimum voltage gradient of 2.54 V/in, a gradient that research and past performance have shown to effectively incapacitate/stun Round Goby. The maximum gradient does not fall below this value at lower depths. Higher voltage gradients can be encountered by a fish that is close to the electrodes on the bottom or sides of the barrier structure.

Voltage gradients exceeding 2.54 V/in gradient is encountered for the shortest length at a point at least one foot above the floor of the electrical barrier; this field strength is expected for a length of about 43 feet. For most of the time, there will be no flow (thus no velocity) in the barrier. A volumetric analysis performed by raSmith (R.A. Smith National, Inc. 2019) predicted an average velocity of 1.2 ft/sec in the 35-ft wide channel immediately downstream of the Menasha lower lock gates when water depth is 6 ft, assuming uniform distribution of flow. This discharge from the lock has the potential to "assist" the barrier performance by not allowing a stunned or incapacitated fish upstream momentum from previous swimming motions; it also will entrain and carry any low-motility Round Goby individuals present in the barrier.

Electrode Life

The electric field simulation included the use of 23-2"x1" mild steel electrodes. Under normal operating conditions, the life expectancy of all but a few of these electrodes are all expected to exceed 50 years. A portion of the anodes have a life expectancy of roughly 10 years. The definition of "normal operating conditions" considers the barrier is powered at a 5% duty cycle (e.g. 10 Hz, 5 millisecond pulse width), and is operated up to five months of the year. If the barrier is operated for less than five months, the total power consumption would be lower and the electrode life expectancies should increase. Conversely, if the barrier is operated for longer than five months the electrode life expectancies should decrease. In addition, the calculation assumes a constant water conductivity of 509 µS/cm, while average measured water conductivity at the Lake Winnebago Dam outlet is about 374 µS/cm. Lower water conductivity requires reduced power and current demands, which leads to longer electrode life. The life expectancy calculation assumes 60% loss of mass, continuous operation five months of the year, and does not consider the "environmental" corrosion of the electrodes. Electrode life can be extended roughly equivalent to the increase in mass; for example, service life of an anode would be roughly doubled if a 2"x2" or 4"x1" electrode is installed instead of the designed 2"x1" electrode.

Power Demand

At a 5% duty cycle and with an ambient water quality of 509 µS/cm, the proposed Menasha Lock Electric Fish Barrier is expected to draw approximately 8.79 kilowatts with a peak current of about 80 amps.

6. CONCLUSION

The electrical simulation for this site was created based on conductivity data obtained from the Wisconsin Department of Natural Resources and geometric data associated with the 60% design documents developed by Smith-Root, Aptum Engineering, and OMNNI Associates and submitted to FRNSA on March 15, 2019. Any variations in the actual data versus the assumptions may cause variations between the barrier performance and simulation results.

The initial settings for the proposed Menasha Lock Electric Fish Barrier 1.5 POW Pulsators are as follows:

- Voltage – 200 V; max output 224 V
- Frequency – 10 Hz
- Pulse width – 5.0 ms

Control room circuit breakers should be rated 240 voltts – 20 A.

7. REFERENCES

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