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A main goal of Reclamation is the delivery of water and power. However, these water delivery systems could affect endangered and protected fish species. Electric fish barriers could control the movement of fish and divert them away from these structures, thereby protecting them from adverse outcomes. Literature research revealed that electric fish barriers could cause electrical interference on nearby structures and electrical systems. This potential for electrical interference not only could cause corrosion on nearby structures but also create interference issues with cathodic protection systems. This project evaluated the effect of the electrical field generated by the electric fish barrier located at the East Portal of Gunnison Tunnel in Gunnison, Colorado on a temporary test structure.

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Final Report No. ST-2020-1722-01

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Acronyms and Abbreviations

AC	Alternating Current
CP	Cathodic Protection
CSE	Copper/Copper-Sulfate Reference Electrode
DC	Direct Current
ICCP	Impressed Current Cathodic Protection
Reclamation	Bureau of Reclamation

Measurements

ºF	degrees Fahrenheit
A	amperes
cfs	cubic feet per second
cm	centimeters
ft	feet
Hz	hertz
in	inches
m	meters
min	minutes
ms	milliseconds
mV	millivolts
sec	seconds
V	volts
V_{CSE}	volts versus copper/copper-sulfate reference electrode
W	watts

Executive Summary

Electric fish barriers are utilized on some structures to divert or control the movement of select species of fish. These barriers are used to prevent fish from moving upstream or downstream in certain situations, such as preventing target fish from entering a canal or tunnel inlet from a river. Barriers can be designed in an effort to completely prevent the passage of most types of fish into an area or used in the prevention of certain, typically invasive, species of fish from entering a body of water. Power requirements and the strength of the electric field depend on the type and size of fish being controlled. The current type, length, and amount also alter the field strength.

While these barriers may be effective in controlling the movement of species of fish, they do pose several possible hazards including; electric shock hazards, adverse impacts to non-target species, limitations to boat traffic, increased collection of debris (for surface suspended electrodes), and the potential for increased corrosion rates on nearby structures. For this reason, monitoring of the barriers and safety precautions must be employed.

The focus of this project was investigating the potential effects that electric fish barriers may have on nearby metallic structures. Barriers may cause stray current corrosion on nearby structures and the interaction between an electric barrier and cathodic protection system has never been examined.

Testing performed on the electric fish barrier system at Gunnison Tunnel East Portal in Gunnison, Colorado showed that the barrier did not have a major influence on the structure-to-water potential of a temporary test structure. Based on these results it can be concluded that the electric fish barrier at the Gunnison Tunnel does not have a significant effect on the corrosion rate of the gate or log boom. It is also safe to assume that electric fish barriers under similar operational conditions would not have an influence on the corrosion rate of a permanent structure in their vicinity. However, any possible effects would still need to be evaluated if an electric barrier system with higher current output is installed at a Reclamation facility.

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Introduction

Electric fish barriers are one form of a non-physical barrier used to control the movement of fish. These barriers use alternating current (AC), direct current (DC), or pulsed DC to prevent fish from entering a specified location (e.g. tunnel, canal, turbine), encourage movement into a certain area (e.g. fish ladder, fish hatchery), or prevent invasive species from entering a body of water. This technology may be useful in protecting fish while limiting impacts to the passage of boats or collecting debris compared to physical fish barriers. This project will assess the potential for electrical barriers to cause electrical interference with nearby structures, thereby causing corrosion.

Project Background

How Electric Barriers Work

Also known as aquatic electrical barriers, the systems are very similar to impressed current cathodic protection (ICCP) systems. Both pass an electrical current through water between conductive anodes and cathodes, creating an electric field. However, the intent of the fish barrier is to cause a physiological reaction in the aquatic species, whereas the intent of cathodic protection (CP) is to prevent a structure from corroding. The amount of current that passes through the fish is dictated by the relative conductivities between the fish and the water, creating the following potential reactions: avoidance, electrotaxis (forced swimming), electrotetanus (muscle contraction), electronarcosis (muscle relaxation or stunning), or death [1].

These barriers consist of an array of electrodes connected to a power source; pulse generators are also required for pulsed DC barriers. The electrical field lines generated during a current release typically run parallel to the direction of flow and the fish are oriented head-to-tail fin along the maximum voltage gradient [2,3]. Figure 1 shows a fish parallel with the electric field lines causing a voltage drop across the fish. As fish approach the barrier, they will become part of the electrical circuit and experience increasing field intensities [2]. While fish will generally turn around and swim away from the electric barrier, fish that continue through the barrier the electric current overwhelms their sense of orientation resulting in rheotaxis [2,4]. Rheotaxis is when fish align themselves perpendicular to the current to avoid a continued passage of current through their body and results in the fish being swept downstream. The range of threshold voltage gradients that produce tetany in freshwater fish was determined to be between 0.05 and 5.5 V/cm (0.127 to 13.97 V/inch) [2,3,5].

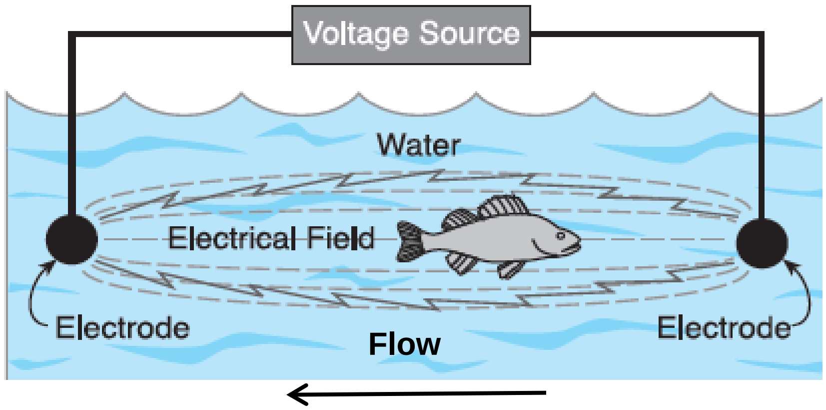

Figure 1. Electric field lines shown parallel to fish between two electrodes. [6]

Types of Barriers

An electric fish barrier is created with a series of evenly spaced electrodes, alternating between anodes (positive electrodes) and cathodes (negative electrodes) [7]. These electrodes can be arranged in a horizontal (Image 1a) or vertical (Image 1b) configuration in the waterway. Vertical hanging electrodes create a more uniform electric field over water depth. However, the vertically hanging electrodes are susceptible to debris buildup, icing, and limiting boat passage. Horizontal electrode arrangements submerged in the water perpendicular to the flow do not impede flow, but they may exhibit a weaker electric field towards the surface of the water in deeper water bodies.

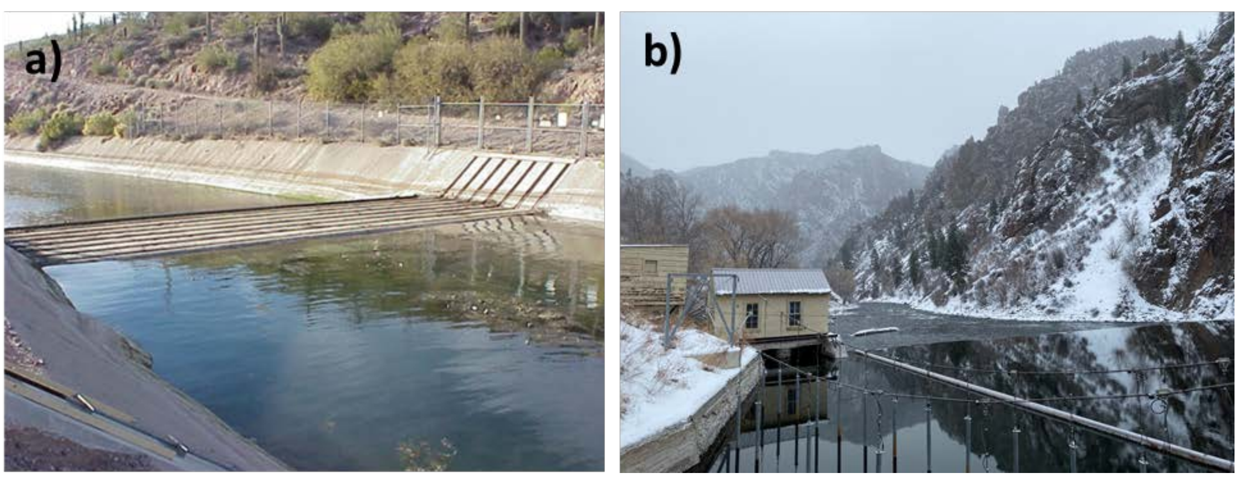

Image 1. Photo a) shows the fish barrier at Granite Reef Dam on the Salt River, consisting of railroad iron electrodes bottom-mounted to the concrete deck. The barrier is considered 100% effective at blocking the upstream movement of Colorado River striped bass and grass carp [8]. Photo b) is the fish barrier at the East Portal of the Gunnison Tunnel which uses vertically placed electrodes.

Problem

Can electric fish barriers cause corrosion issues on nearby structures (e.g. gates or log booms)?

Corrosion

The definition of corrosion is the deterioration or degradation of a material (usually a metal) as a result of a chemical or electrochemical reaction with its environment. A refined metal, such as steel, will be converted into a more chemically stable form such as iron oxide (rust). While this process is not limited to steel, steel is a common material used for gates, stranded ropes, and log booms, which are often components of structures in areas where a fish barrier may be installed. Corrosion changes the useful properties such as strength, and also results in material loss, affecting the operational capabilities of a structure.

Cathodic protection (CP) systems are used to mitigate or control the rate of corrosion of a metal. One type of CP is called impressed current cathodic protection (ICCP), also referred to as active CP. This form of CP utilizes an external power source to supply DC to an impressed current anode, thereby reducing the corrosion rate of a metal by negatively polarizing the cathodes to the same potential as the anodes on the surface of the metal.

Electrical Interference

Electrical interference is defined as "any detectable electrical disturbance on a structure caused by a stray current where a 'stray current' is defined as a current in an unintended path" [9]. Although DC from an ICCP system is often the source of the interfering current, it can also originate from any electrical system that uses the earth or water intentionally or inadvertently as a current path. As a result, the pulsed electric barriers employed on various structures may be a source of interfering current.

Sources of Electrical Interference

Stray currents can be transmitted through the concrete apron when multiple pulsators release an output simultaneously [10]. This current can then flow through the ground or water, creating a ground current. These stray currents may flow to and from nearby structures and electronics if they are in the same electrolyte (water) or connected electrolytes (e.g. water-to-soil). At points where the stray current enters the structure, the potential of the structure will be made more negative, providing partial cathodic protection. However, corrosion may occur when the potential becomes more positive where the stray current leaves the structure.

If the possibility for stray current interference exists and there are no mitigation measures in place, accelerated corrosion may occur. Stray currents on other buried or submerged structures are typically considered when designing and operating CP systems. Design features used to minimize the risk include anode bed location and installation of additional CP systems.

Previous Work Performed

U.S. Army Corps of Engineers Chicago Sanitary and Ship Canal Electric Barriers

The U.S. Army Corps of Engineers (USACE) has installed three electric barriers on the Chicago Sanitary and Ship Canal to prevent invasive Asian carp from moving into the Great Lakes. Power output at this location is high due to requirements for electrical parameters, high water conductivity, and large width and depth of the canal. The electric barriers have resulted in a significant amount of interference and potential corrosion issues on Enbridge line 6A pipeline, Barrier Building IIB foundation rebar, a fence, and a traffic signal at a railroad crossing [10]. Stray current flowed through the ground and created a ground current with nearby structures and electronics. This was the reason cited for the malfunction of a traffic signal at a nearby railroad crossing [10] and the fences at the facility. Current monitoring of the electrical potential and corrosion of many structures nearby has thus far not determined any detrimental electrical potential or heightened corrosion on the nearby pipeline but did affect the railroad light nearby as well as concern in regards to the fence [10]. A more detailed discussion about the USACE electric fish barriers is presented in MERL-2015-70 [11].

Data Collection and Analysis

Technical Approach and Methods

Test Facility

The facility used for test purposes was the electric fish barrier at the East Portal of the Gunnison Tunnel (installed in 2012) in Colorado in order to determine if an electric fish barrier operating at a more "typical" output would have a large effect on a nearby metal structure. The barrier at the East Portal, shown in Image 2, was installed to alleviate the population risk to the Gold Medal trout fishery due to the irrigation canal and hydroelectric facility [12].

Prior to installation of the electric barrier, fish survival was thought to be low during tThe typical low and intermittent flows (100 cfs twice a month for 24 hrs to 48 hrs) through the tunnel in the winter months. However, a slow constant flow for one winter resulted in a much larger number of fish in the canal than expected due to survival of the entrained fish [13]. The electric fish barrier was installed to discourage the brood stock fish from entering the canal [12]. The electric fish barrier as observed in Image 2d was installed in a vertical arrangement to prevent spawning sized fish from entering the tunnel. Image 3 shows a corroded stranded rope used to anchor the log boom, however this was most likely due to galvanic corrosion caused from using dissimilar metals.

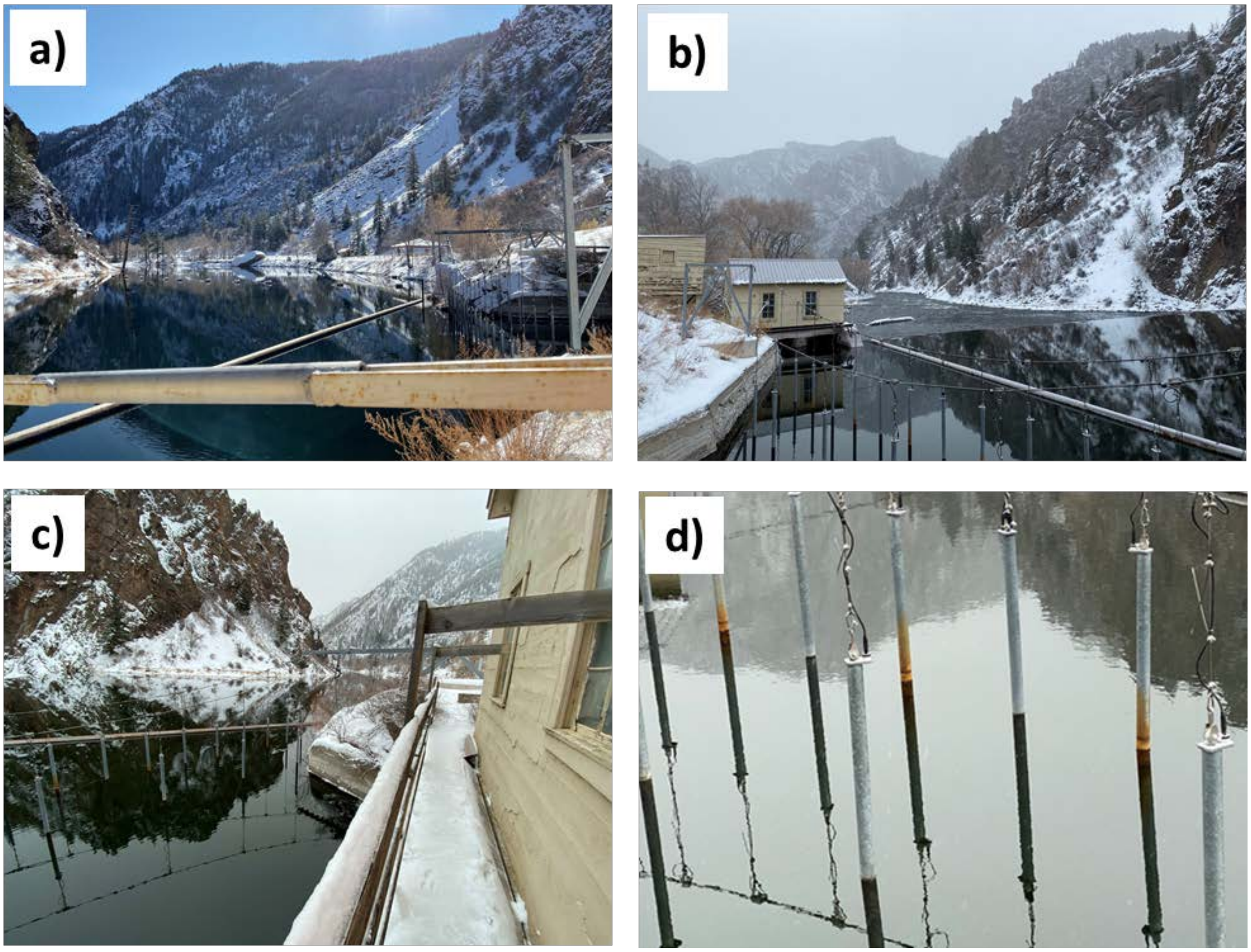

Image 2. The electric fish barrier installed at the East Portal of Gunnison Tunnel. Photos a) through c) show the fish barrier and log boom from various orientations. Photo d) clearly shows the vertical arrangement of the electrodes.

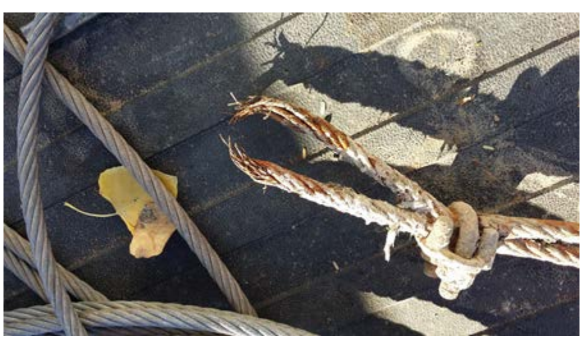

Image 3. Corrosion of log boom stranded wire anchor rope located at the Gunnison Tunnel's East Portal.

The barrier is designed to prevent the spawning sized fish from entering the tunnel and has been successful. The barrier has prevented 26-71% of all spawning sized fish with zero fish larger than 16 inches and only four larger than 12 inches passing through the barrier during the first two years of operation [12,14]. The output data from the last inspection date performed on August of 2019 by Smith-Root, Inc. is included in Table 1 and the output data from the system recorded during the site visit in January of 2020 is presented in Table 2. During the inspection performed by Smith-Root, Inc. the field strength readings between the electrode pairs in the east electrode array were measured and presented in Table 3. The field strength between the east electrode array and the electrodes in the west array were measured by Smith-Root, Inc. and are included in Table 4. The field strength at various distances from the east electrode array between the east electrode array and the log boom were measured by Smith-Root, Inc. and are included in Table 5. The locations of the electrode arrays in relation to the log boom and tunnel inlet gate at Gunnison Tunnel are shown in Image 4.

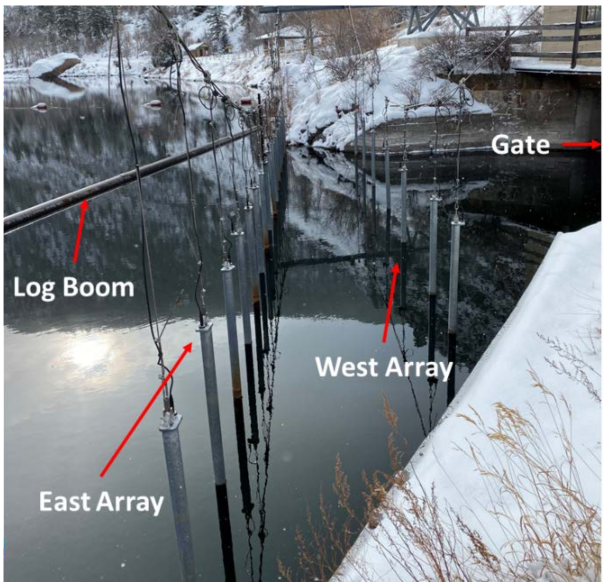

Image 4. Locations of the electrode arrays in relation to the tunnel inlet gate and the metallic log boom at the East Portal of the Gunnison Tunnel.

Table 1. Operational information from inspection performed by Smith-Root, Inc. on 8/27/2019 [15].

Device	Status	Waveform	Voltage	Current	Power	Temp
Pulser #1	Master	5 ms / 2.5 Hz	97 V	24 A	57 W	88 ºF
Pulser #2	Slave	5 ms / 2.5 Hz	99 V	21 A	50 W	89 ºF
Pulser #3	Slave	5 ms / 2.5 Hz	98 V	20 A	49 W	89 ºF

Table 2. Operational information from site visit performed by Reclamation in January 2020.

Device	Status	Waveform	Voltage	Current	Power	Temp
Pulser #1	Master	5 ms / 2.5 Hz	98 V	41 A	49 W	53 ºF
Pulser #2	Slave	5 ms / 2.5 Hz	99 V	36 A	44 W	56 ºF
Pulser #3	Slave	5 ms / 2.5 Hz	98 V	35 A	42 W	52 ºF

Table 3. Field strength readings between east electrode pairs from inspection performed by Smith-Root, Inc on August 27th, 2019 [15].

Electrode Pairs in East Electrode Array		Field Strength (V/in)
#1	#2	1.30
#2	#3	0.72
#3	#4	0.50
#4	#5	0.73
#5	#6	0.80
#6	#7	0.70
#7	#8	0.70
#8	#9	0.80
#9	#10	1.40
#10	#11	0.90
#11	#12	0.80
#12	#13	0.83
#13	#14	0.85
#14	#15	0.50
#15	#16	0.50
#16	#17	0.90

Table 4. Field strength readings between east array of electrodes to west electrodes from inspection performed by Smith-Root, Inc on August 27th, 2019 [15].

East Array to West Electrode		Field Strength (V/inch)
East	#18	1.0
East	#19	1.1
East	#20	1.26
East	#21	1.1
East	#22	1.2
East	#23	1.2
East	#24	1.0

Table 5. Field strength readings at various distances from east electrode array between the electrode array and the log boom collected during the inspection performed by Smith-Root, Inc on August 27th, 2019 [15].

East Array to Log Boom Distance	Field Strength (V/inch)
30 cm	0.4
50 cm	0.0
100 cm	0.0
150 cm	0.0

Test Procedure

In order to determine if the electric fish barrier at the East Portal affected a nearby metal structure, a small portable test apparatus was used. The test apparatus, shown in Image 5, consisted of an expanded metal cylinder which acted as the structure in the vicinity of the electric fish barrier. As shown in Image 5 the steel cylinder was held together with stainless pipe clamps and housed a copper/copper-sulfate (CSE) reference electrode on the inside. A cable with a copper clamp was attached to the cylinder providing the electrical connect for measurement purposes. The mixed-metal makeup of the apparatus affected the native potential, but the purpose of testing was to determine a change in potential of the structure, so the mixed-metal native potential was not an issue. The potential of the structure was measured utilizing a voltmeter and recording the structure-to-water potential as referenced to a CSE reference electrode.

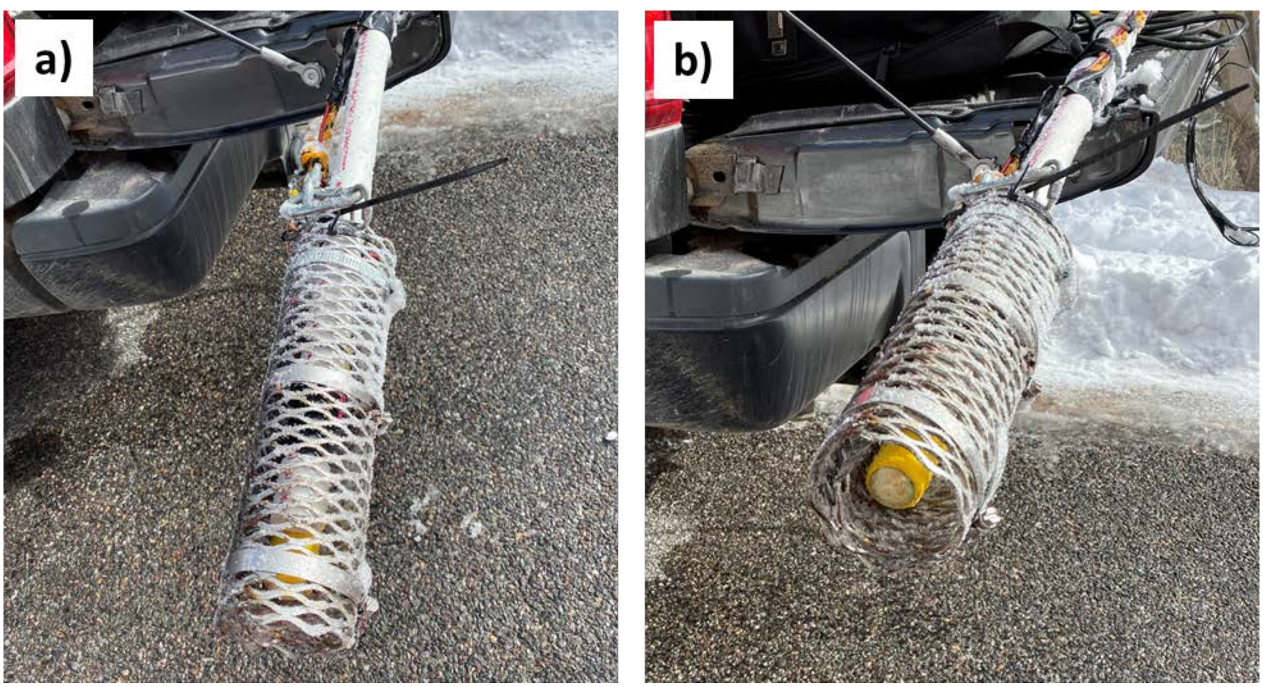

Image 5. The test apparatus was made of an expanded steel sheet cylinder, stainless steel pipe clamps, copper clamp for the cable connection to the cylinder, and a CSE reference electrode on the inside of the cylinder. The test structure was attached to a PVC pole to place the structure at different locations.

The test apparatus was attached to a PVC pole to accurately place the temporary structure and prevent shifting or moving during the test. A photo of the immersed apparatus is shown in Image 6a and b.

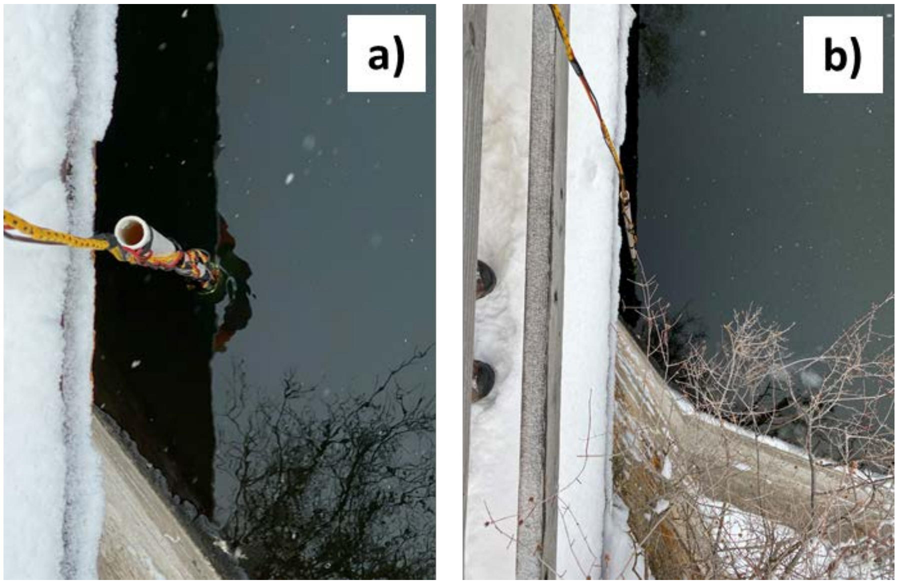

Image 6. Photo of immersed test apparatus. The temporary structure is on the submerged end of the PVC pole which was used for electrode placement and prevent excessive movement during the test.

Test Results

To determine the native potential of the temporary structure, measurements were made in the basin downstream of the closed gates shown in Image 2b approximately 150 ft from the electric fish barrier electrode array. The native potential after one hour was a stable -0.321 V_{CSE}. The test apparatus was placed in five different locations at various distances from the electrode array, including between electrodes. Potentials were then measured on the temporary structure over the course of an hour. The five locations and distances from the east array are labeled in Image 7 and listed below:

- #1 was in front of the gate and approximately 20 feet from the east array,
- #2 was in front of the gate and approximately 15 feet from the east array,
- #3 was along the concrete wall 12 feet from the east array,
- #4 was between two anodes in the east array approximately 1.5 feet from each electrode,
- #5 was along the wall approximately 25 feet from the end of the east array.

Image 7. The five different locations where structure-to-water potential were measured are shown in the photos.

The structure-to-water potentials measured on the temporary structure at the five locations is presented in Table 6. The structure was immersed in the water for an hour while the potentials were recorded periodically to show the effect of the electric fish barrier.

Table 6. Structure-to-water potentials measured on the temporary structure at the five different locations. At each location, the test apparatus was immersed for an hour and measurements were made periodically. Measurements are displayed in V_{CSE}.

Time	Voltage at Test Location (V_{CSE})				
	#1	#2	#3	#4	#5
0 sec	-0.700	-0.107	-0.103	-0.110	-0.150
5 sec	-0.275	-0.157	-0.275	-0.221	-0.200
10 sec	-0.292	-0.201	-0.330	-0.285	-0.257
30 sec	-0.301	-0.305	-0.340	-0.320	-0.306
45 sec	-0.315	-0.344	-0.348	-0.322	-0.315
1 min	-0.330	-0.345	-0.350	-0.327	-0.327
2 min	-0.341	-0.359	-0.355	-0.330	-0.334
5 min	-0.351	-0.361	-0.361	-0.334	-0.344
10 min	-0.353	-0.362	-0.362	-0.336	-0.349
20 min	-0.362	-0.364	-0.362	-0.341	-0.350
30 min	-0.360	-0.365	-0.363	-0.343	-0.349
45 min	-0.364	-0.365	-0.361	-0.344	-0.351
60 min	-0.364	-0.366	-0.358	-0.343	-0.349

Discussion

The results from the structure-to-water potentials measured show little to no effect from the electric fish barrier on the potential corrosion rate of the temporary structure at this facility. After an hour, the structure-to-water potentials measured at all five locations were only 30 to 40 mV more negative than the native potential measured in the basin, as shown in Table 6.

Electric barrier systems with larger current output, such as at Chicago Sanitary and Ship Canal, do show impacts on nearby metallic structures. However, this may not occur on a Reclamation structure since the systems which would be employed for Reclamation applications would likely require less current output. As shown in Table 5, the field strength is 40 V/ms at 30 cm from the east electrode array and decreases quickly with increasing distance from the electrode array. The log boom sees little to no effect from the field.

The only observed issue from the electric barrier system at the East Portal of the Gunnison Tunnel was the increased amount of corrosion present on every other electrode, as shown in Image 8. A portion of the electric fish barrier electrodes at the east portal, shown in Image 8a, indicates that every other electrode is exhibiting corrosion. Some electrodes do not exhibit corrosion but do show organic growth, as shown in Image 8b. Images 8c and d show significant amount of corrosion on an electrode, including corrosion tubercles on the surface of the electrode in Image 8d.

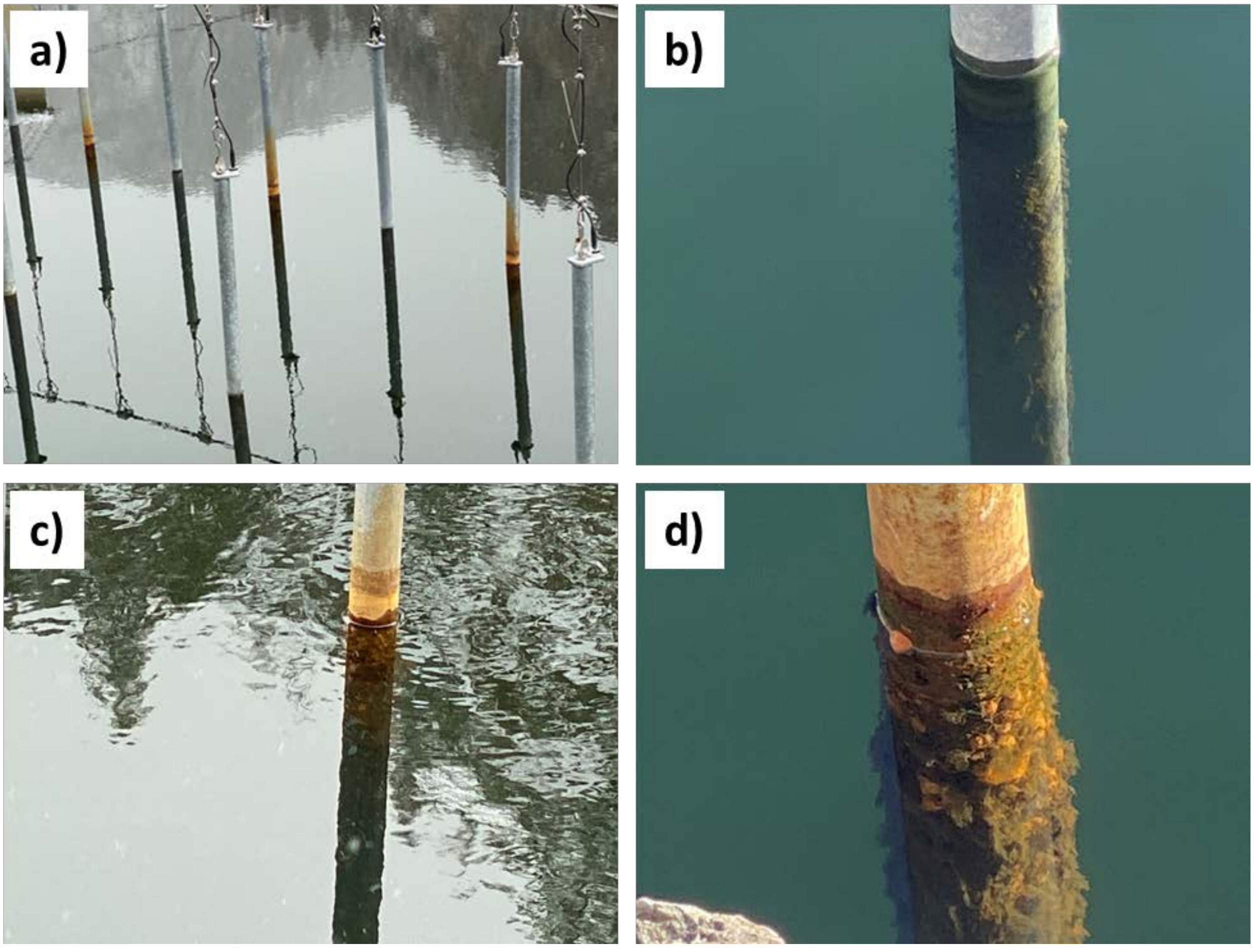

Image 8. Photos of the electric fish barrier electrodes at the East Portal. Photo a) shows a portion of the east array and west array showing corrosion of every other electrode in the east array. Photo b) shows an electrode which is not exhibiting a large amount of corrosion, but which is covered with organic material. Photos c) and d) both show corrosion on the submerged part of the electrode. Note the corrosion tubercles on the surface of the electrode in d).

Conclusions

This project showed that the electric fish barrier system at Gunnison Tunnel East Portal did not have a major influence on the structure-to-water potential of the temporary test structure. Based on these results, it is safe to assume that electric fish barriers under similar operational conditions would not have an influence on the corrosion rate of a permanent structure in their vicinity. However, any possible effects would still need to be evaluated if an electric barrier system with higher current output is installed at a Reclamation facility.

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