Scale and Effectiveness Validation of Electrical Barriers in Service

More than 70 Smith-Root-designed electrical barriers and guidance systems have been installed across the globe. Use of electricity to guide and block fish is not a new concept; alternating current (AC) barriers have been used since the 1930's and are still in use in some small rivers and streams today. The first generation of Smith-Root electrical barriers in the late 1980's built upon the principles of electrofishing and utilized safe and economical levels of pulsed direct current (DC).

Smith-Root electric barrier are custom-designed for each situation and, as such, includes a wide variety of barrier geometries, waveforms, and field strengths. For example, power output can vary from 30 W (at the Lake Seminole Fish Pond drain barrier in Georgia) to 3.85 MW at the three combined barriers in the Chicago Sanitary and Ship Canal in Illinois. In short, the objective of each barrier and guidance system is what drives the system design.

Appendix 1 presents the 44 electric barriers and guidance systems Smith-Root has designed and installed since 1999. The owners of many of these facilities elect to have Smith-Root conduct annual (or more frequent) maintenance inspections, which include verification of the electrical field in the facility, electrical tests of the pulse generators, and other facility inspection duties. These return visits to active facilities give Smith-Root the opportunity to assess the ongoing effectiveness of the electric field. The field measurements for three of these barriers are given in Figures 1 through 3. The figures demonstrate the consistency of the electrical field strength within the barrier over time. While water quality characteristics and depth are variable, the pulse generators are able to adjust to these external factors and maintain minimum voltage gradients in varying conditions. Further discussion of the mechanisms for maintaining voltage gradients in variable conditions is presented in separate report in this series.

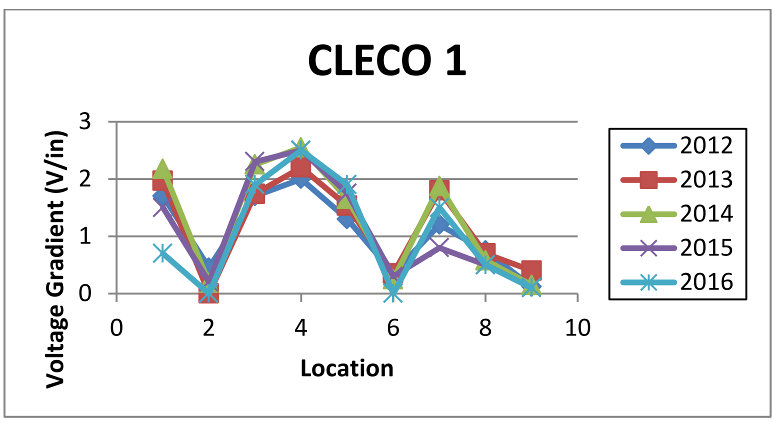

Figure 1. Measured voltage gradient at nine locations within and outside of the CLECO 1 electrical barrier in St. Landry, Louisiana.

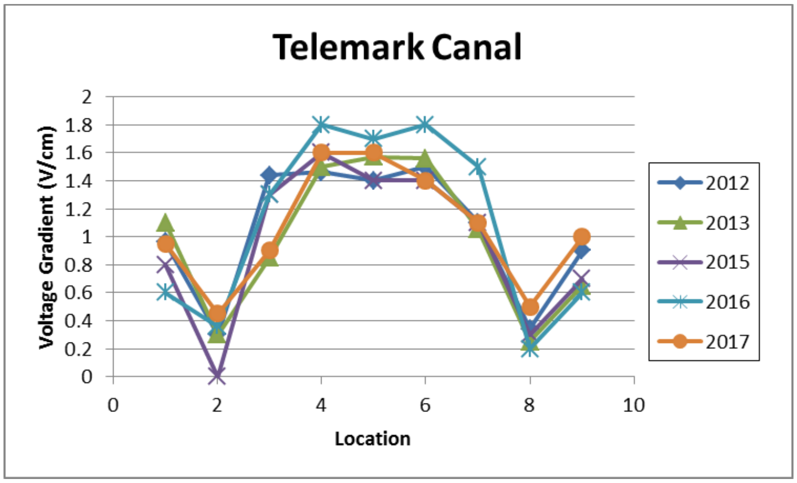

Figure 2. Measured voltage gradient at nine locations within and outside of the Kjeldal Lock/Telemark Canal electrical barrier in Telemark County, Norway.

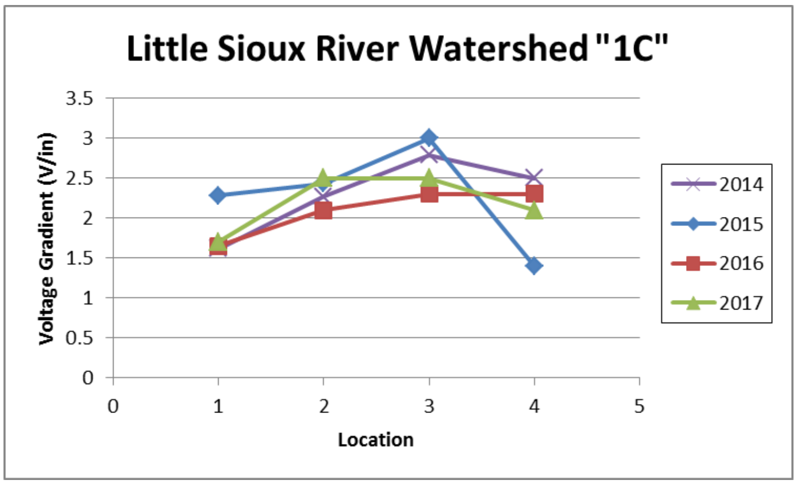

Figure 3. Measured voltage gradient at four locations within and outside of the Little Sioux River Watershed "1C" barrier near Worthington, Minnesota.

We also summarize several studies that have been conducted on installed fish barriers. All of the barriers studied are still in operation and effectively deterring upstream migration of fish.

Case Study 1 — Bottom-Mounted Electric Barrier to Deter/Guide Upstream-Moving Fish in a Hydropower Tailrace

Location – Geneva, Switzerland

Year of study – 2008

The effectiveness of a hydropower, tailrace electric barrier was evaluated in a technical report for a power generation facility at Vessy (near Geneva), Switzerland by GREN Biologie (2009). The electric deterrence array was installed in 2008, in the tailrace of this twin-turbine, annual 3 GWh hydroelectric generating station owned by Centrale Hydroelectrique de Vessy (Figure 4). During October 2008, 339 brown trout were brand-marked and released downstream of the barrier in an attempt to assess the electric barrier's efficiency at preventing fish movements into the powerhouse. The consultant's technical report (in French) was translated and approved by the power authority. Key points from their report include the following results:

"The fish, which moved upstream using a migration route situated along the left bank, did not enter the tailrace and were effectively guided along the bed of the River Arve. In fact, whether these fish were fall trout or spring barbels, a comparison of fish actually present in the tailrace to the catch in the traps of both fishways shows that the electric barrier played its role perfectly and migrating spawners did not have a propensity to wander (at a higher rate) into the tailrace."

"None of the 339 brand-marked trout put into water of the River Arve in mid-October 2008 … just downstream of the plant … were found in the tailrace one month later, while in this interval 16 of the brand-marked trout were passed by the two fishways. These results confirmed that the electric barrier demonstrated good efficiency in helping to move branded trout upstream and that none ended up becoming trapped at the foot of the hydroelectric plant."

"Despite the capacity of the tailrace to provide fish habitat, very few fish were found during electrofishing. The effectiveness of the electric barrier system explains the insignificant presence of fish observed in the tailrace compared to the much higher fish numbers found in the River Arve at a point directly proximal to the hydropower station."

Figure 4. The tailrace electrical deterrence array at the Vessy (Switzerland) hydroelectric power plant. A series of seven electrode cables can be seen housed within the special, non-conductive concrete slab that was installed to run across the river bottom from left to right bank, thus providing full deterrence capabilities across the entire stream without being affected by floating debris. The barrier successfully deterred fish from moving upstream from the River Arve into the tailrace and powerhouse.

<u>*Case*</u>

<u>Study 2 – Deterrence/Guidance of Upstream-Moving Anadromous Fish at a Hydropower Tunnel Outlet</u>

Location – Helle, Norway

Year of study – 2014

In 2013, a Smith-Root designed vertical electrode barrier system was installed at the outlet of the power tunnel at the Rygene Power Plant on Nidelva (River Nid) in southern Norway (Figure 5). The purpose of the barrier was to deter upstream-migrating Atlantic salmon and sea trout from migrating up the power tunnel in favor of continuing up Nidelva to the fish ladder at Rygene Dam. When operation of the barrier began in 2014, the power plant owner commissioned a study of the effectiveness of the barrier. The study authors installed video cameras inside the power tunnel immediately upstream of the barrier, and in the fish ladder at Rygene Dam. A comparison of the numbers of fish that passed the cameras at the two locations was made to determine the efficiency of the electric barrier.

During the 131-day study period in 2014, a total of 10 migratory fish passed the cameras inside the power tunnel. This represents 0.7% of the total anadromous run that year, leading to a 99.3% efficiency rate for the electric barrier. The study authors concluded "the electric fish barrier therefore functioned as intended" in 2014.

While 100% deterrence wasn't achieved at this location, it is important to note that 100% deterrence was not the objective of the system. The objective of the system was to create a substantial reduction in the number of misdirected anadromous fish. The tunnel exit is logistically a difficult location, requiring construction directly into a bedrock outcrop. The maximum length of the barrier (from downstream to upstream parallel with the outlet flow) is about 5 m, and the Atlantic salmon in Nidelva can grow to lengths of 1 m, for a barrier length to body length ratio of 5:1. In contrast, the barrier length to body length for the proposed Round Goby barrier at the Menasha Lock is around 100:1. This difference reflects the difference in the objective of the barrier – the objective of the Nidelva barrier is to substantially reduce upstream passage in the tunnel, while the objective of the Menasha Lock barrier is to prevent all upstream passage.

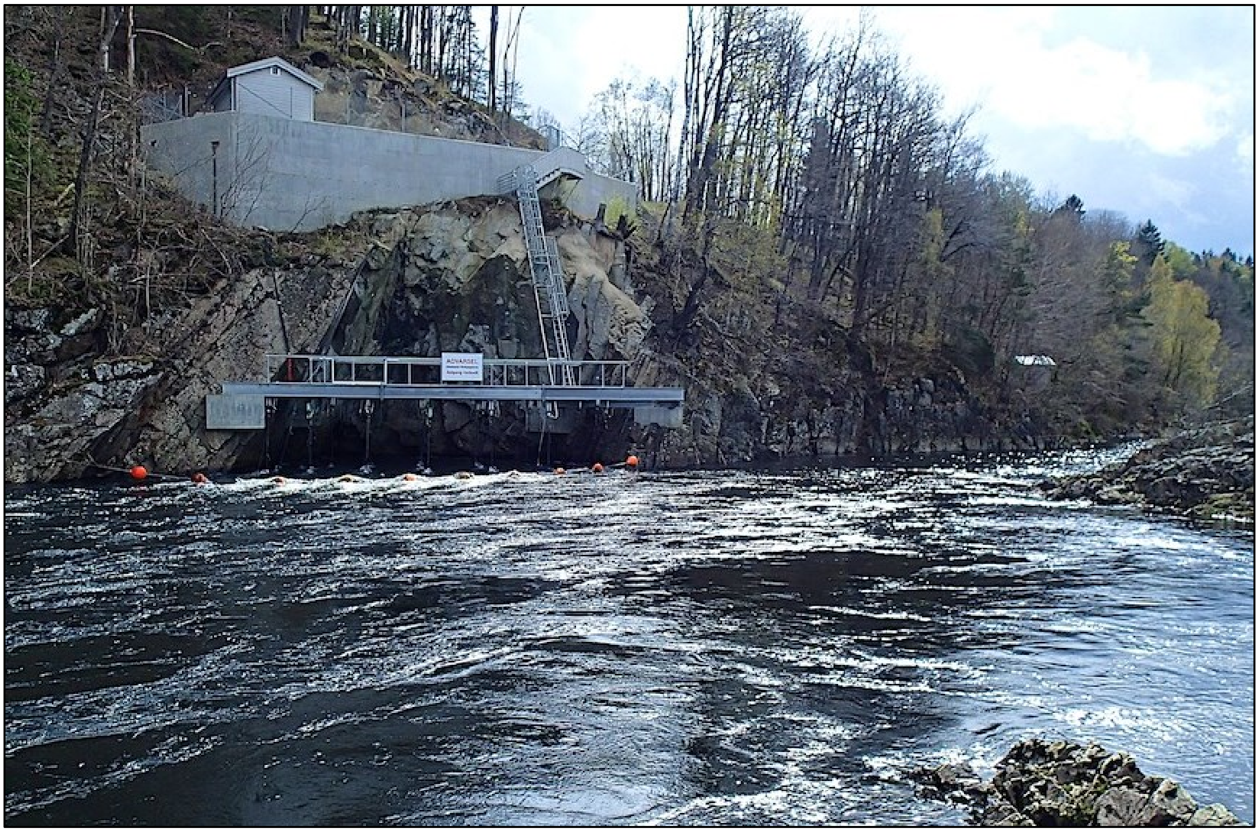

Figure 5. The electrical barrier at the outlet of the Rygene Power Plant power tunnel on Nidelva in southern Norway. Three vertical rows of electrode cables are affixed to the overhead steel structure and the tunnel floor, presenting the electrical deterrent field uniformly at all depths in the water column. The barrier has been demonstrated to successfully deter anadromous fish from migrating upstream in the power tunnel, allowing them to continue their upstream migration in the river channel.

Case Study 3 – Deterrence of Upstream-Moving Fish in the Chicago Sanitary and Ship Canal

Location – Romeoville, Illinois

Year of study – 2004

The world's largest electric fish barrier system was first installed in the Chicago Sanitary and Ship Canal in the early 2000's (Figure 6). This Canal is 60 m wide and up to 9 m in depth, having water velocities up to 0.8 m/s and reverse flows of about 0.3 m/s. There are presently three, bottom-mounted electrode arrays installed in the Canal (each spanning its full width and depth) with plans to add a fourth in the near future. The project's goal is to ensure that invasive carp species do not reach or colonize the Great Lakes. Post-installation studies of barrier effectiveness used common carp species as surrogates. Of the 130 tagged and released downstream of the original demonstration barrier, only one transmitter was located upstream of the barrier during the study; a single transmitter that never changed position, suggesting a dead fish swept upstream by a passing barge.

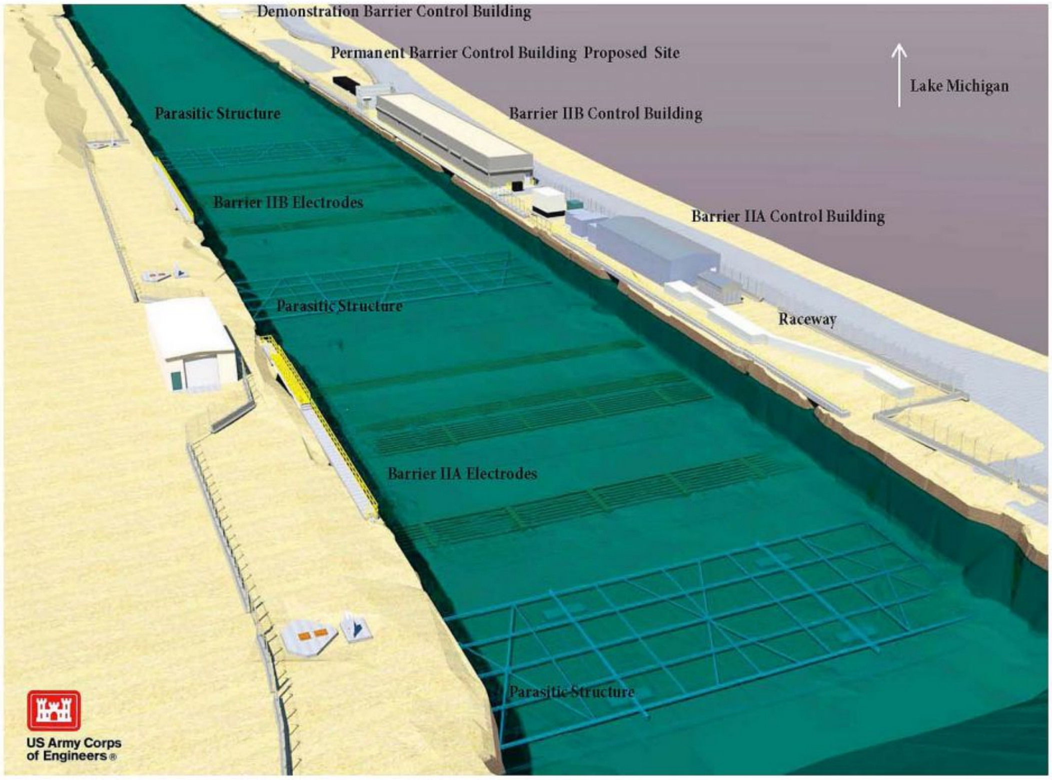

Figure 6. Schematic of a portion of the electrical barriers in the Chicago Sanitary and Ship Canal near Chicago, Illinois. These barriers are the "last line of defense" against Asian carp, present in the canal and the Des Plains River, establishing a population in the Great Lakes. Since the installation of the first barrier in the canal in 2002, Asian Carp have not advanced their population beyond this series of barriers.

Other Findings: A host of additional published studies and reports have evaluated the effectiveness of electric barriers in either blocking or guiding the movements of fish for various resource management-related needs. Several are annotated here for possible future examination and reference:

- Maceina et al. 1999 (Grass Carp Containment Goal): "After the electric barrier was in place, no verified escapes occurred."
- Swink 1999 (sea Lamprey Blockage Goal): "No unmarked and none of the 1,194 tagged sea lamprey were found above the electric barrier."
- Savino et al. 2001 (Downstream Guidance Evaluation): "The only marked Round Goby found below the electric barrier were dead."
- Verrill and Berry 1995 (Invasive Carp Blockage Goal): "None of 1,600 tagged fish were among the 3,367 examined above the barrier."

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APPENDIX

List of Smith-Root barriers constructed since 1999

Year Constructed	Project Name	Project Type	Location	Client
2017	Mill Pond Dam Removal Temporary Electrical Barrier	Temporary main channel barrier	Sullivan Creek Metaline Falls, Washington	Seattle City Light
2016	Franciolini Power Plant Electrical Guidance System	Downstream guidance	Fiume Ecino Ancona, Italy	ENEL SpA
2015	Illinois Lake “Site 6C”	Main channel barrier	Illinois Lake outlet Round Lake, Illinois	Minnesota Department of Natural Resources
2015	Goose Creek Electrical Barrier	Main channel barrier	Goose Lake outlet Albert Lea, Minnesota	Shell Rock River Watershed District
2015	Albert Lea Lake Outlet Electrical Barrier	Lake outlet barrier	Shell Rock River Albert Lea, Minnesota	Shell Rock River Watershed District
2014	Rygenefossen Hydroelectric Outlet Tunnel	Tailrace barrier	Nidelva Arendal, Norway	Agder Energi
2014	Little Sioux River Watershed “Site 1C”	Main channel barrier	Agricultural ditch Brewster, Minnesota	Minnesota Department of Natural Resources
2013	Lost Island Lake Electric Barrier	Lake inlet barrier	Lost Island Lake Ruthven, Iowa	Iowa Department of Natural Resources
2013	Lake Okoboji Outlet Electric Barrier	Lake outlet barrier	Lower Gar Lake Milford, Iowa	Iowa Department of Natural Resources
2012	Gunnison Tunnel Electric Barrier	Downstream guidance	Gunnison River Montrose, Colorado	Delta-Montrose Electric Association
2012	Telemark Canal	Canal barrier	Kjeldal Lock canal Telemark County, Norway	County Governor of Telemark
2011	Mountain Bayou Lake Electric Barrier	Lake barrier	Mountain Bayou Lake Bunkie, Louisiana	CLECO
2011	Rainey Creek Electric Barrier	Main channel barrier	Rainey Creek Swan Valley, Idaho	Idaho Department of Fish and Game
2011	Chicago Sanitary & Ship Canal Electric Dispersal Barrier 2B	Main channel barrier	CSSC Romeoville, Illinois	U.S. Army Corps of Engineers

2010	Green Lake Electric Barrier	Lake outlet barrier	Green Lake Spicer, Minnesota	Minnesota Department of Natural Resources
2010	Pine Creek Electric Barrier	Main channel barrier	Pine Creek Swan Valley, Idaho	Idaho Department of Fish and Game
2010	Wedge Creek Electric Barrier	Lake inlet barrier	Wedge Creek Albert Lea, Minnesota	Shell Rock River Watershed District
2010	White Lake Electric Barrier	Lake inlet barrier	White Lake Albert Lea, Minnesota	Shell Rock River Watershed District
2009	Fulda First Lake Electric Barrier	Lake outlet barrier	Fulda First Lake Fulda, Minnesota	Minnesota Department of Natural Resources
2009	Mud Lake / Pickerel Lake Electric Barrier	Lake outlet barrier	Pickerel Lake Albert Lea, Minnesota	Shell Rock River Watershed District
2009	Palisades Creek Electric Barrier	Main channel barrier	Palisades Creek Irwin, Idaho	Idaho Department of Fish and Game
2008	Vessy Hydropower Barrier	Tailrace barrier	River Arve Geneva, Switzerland	Services Industriel de Geneva
2006	Arrowwood National Wildlife Refuge Electrical Barrier	Main channel barrier	James River Jamestown, South Dakota	U.S. Fish & Wildlife Service
2006	Chicago Sanitary & Ship Canal Electric Dispersal Barrier 2A	Main channel barrier	CSSC Romeoville, Illinois	U.S. Army Corps of Engineers
2005	Lake Maria Electric Barrier	Main channel barrier	Lake Maria outlet Slayton, Minnesota	Minnesota Department of Natural Resources
2004	Lower Saint Mary Lake	Temporary downstream barrier	Lower St. Mary Lake Babb, Montana	U.S. Bureau of Reclamation
2004	Abernathy Fish Technology Center	Main channel barrier	Abernathy Creek Longview, Washington	U.S. Fish & Wildlife Service
2003	Blackfoot River	Main channel barrier	Blackfoot River Conda, Idaho	Idaho Department of Fish and Game
2003	Karn/Weadock Generating Complex	Cooling water tailrace barrier	Saginaw River Hampton Township, Michigan	Consumers Energy
2003	Quinault National Fish Hatchery	Main channel barrier	Cook Creek Humptulips, Washington	U.S. Fish & Wildlife Service
2003	Eagle Creek National Fish Hatchery	Main channel barrier	Eagle Creek Estacada, Oregon	U.S. Fish & Wildlife Service

2002	Townshend Dam	Main channel barrier	West River Townshend, Vermont	U.S. Army Corps of Engineers
2002	Lake Wohlford Water Intake Barrier	Reservoir water intake downstream barrier	Lake Wohlford Escondido, California	City of Escondido, California
2002	Battle River Generating Station Electrical Barrier	Cooling water tailrace barrier	Battle River Forestburg, Alberta	ATCO Power
2002	Chicago Sanitary & Ship Canal Electric Dispersal Barrier 1	Main channel barrier	CSSC Romeoville, Illinois	U.S. Army Corps of Engineers
2001	Howard Lake	Lake outlet barrier	Howard Lake Howard Lake, Minnesota	Rice Creek Watershed District
2001	Round-Rice Bed Wildlife Management Area	Lake outlet barrier	RRBWMA Garrison, Minnesota	Minnesota Department of Natural Resources
2001	Ocqueoc River	Main channel barrier	Ocqueoc River Ocqueoc Township, Michigan	U.S. Fish & Wildlife Service
2000	Shiawassee River	Temporary downstream barrier	Shiawassee River Argentine Township, Michigan	United States Geological Survey
2000	Quilcene National Fish Hatchery	Main channel barrier	Quilcene River Quilcene, Washington	U.S. Fish & Wildlife Service
1999	Beeston Hydropower Plant	Tailrace barrier	River Trent Nottinghamshire, England	United Utilities
1999	Pere Marquette River	Main channel barrier	Pere Marquette River Custer Township, Michigan	U.S. Fish & Wildlife Service