Chicago Sanitary and Ship Canal Aquatic Nuisance Species Dispersal Barriers

P. Moy, University of Wisconsin Sea Grant Institute
C.B. Shea, U.S. Army Corps of Engineers, Chicago District
J.M. Dettmers, Illinois Natural History Survey, Lake Michigan Biological Station
I. Polls, Ecological Monitoring and Assessment
U.S. Army Corps of Engineers, Chicago District
111 North Canal Street, Suite 600
Chicago, IL 60606
charles.b.shea@usace.army.mil

ABSTRACT

The Chicago Sanitary and Ship Canal (Canal) is a man-made waterway that forms a hydraulic connection between the Illinois River and Lake Michigan. As aquatic invasive species use the Canal to move from Lake Michigan to the Illinois River and vice versa, they prey on native species and compete for food, living space, and spawning areas. The National Invasive Species Act (NISA) of 1990, Section 1202 as amended in 1996, authorized the U.S. Army Corps of Engineers to conduct a demonstration project to identify an environmentally sound method for preventing and reducing the dispersal of non-indigenous aquatic nuisance species through the Canal. The Corps formed an Advisory Panel, consisting of people from U.S., state, and regional agencies; environmental groups; Canal users; and researchers, to evaluate potential methods to restrict movement of aquatic species through the Canal. An electric barrier was selected, constructed, and activated on April 9, 2002. The demonstration barrier continues to operate today. Based on monitoring of the demonstration barrier, a second more permanent barrier has been designed and is currently under construction.

THE ILLINOIS RIVER – LAKE MICHIGAN HYDRAULIC CONNECTION

The Chicago Sanitary and Ship Canal (Canal), is a man-made waterway that is part of the Chicago Waterway System. It connects the Chicago River and the DesPlaines River (Figure 1), thereby providing a hydraulic connection between the Illinois River and Lake Michigan basins (Figure 2). The Canal was constructed in the late 1800s to convey sewage away from Lake Michigan and to provide a navigational corridor between the Illinois River and the Great Lakes. Historically, the water quality of the Canal was so poor that pollution limited the cross-basin transfer of aquatic organisms. Significant improvements in water quality since the early 1970s now allow the Canal to form a two-way corridor for the passage of aquatic invasive species between the Illinois River and Lake Michigan.

In the early 1990s, zebra mussels (*Dreissena polymorpha*) quickly spread from the Great Lakes to the Mississippi River via this route. In 1999, the round goby (*Neogobius melanostomus*) moved from Lake Michigan into the lower Des Plaines River and in 2004 a specimen was found by the Illinois Natural History Survey in the Illinois River near Peoria, Illinois. There is grave concern regarding the potential for movement of Asian carps (bighead *Hypophthalmichthys nobilis*, silver *Hypophthalmichthys molitrix* and black carp *Mylopharyngodon piceus*) from the Mississippi River into the Great Lakes via the Canal.

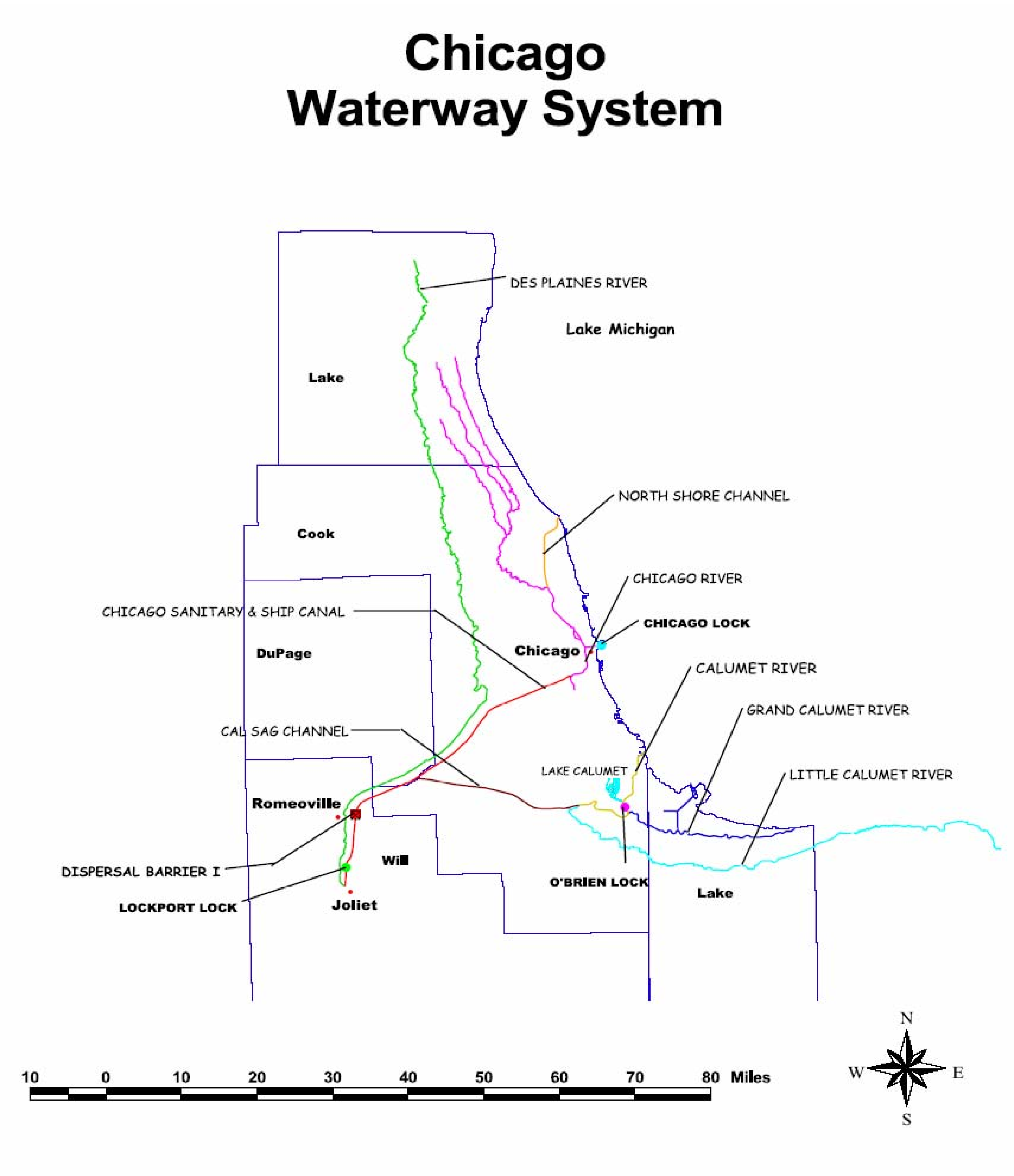

Figure 1. The Chicago Waterway System's Connections with Lake Michigan and the DesPlaines River (Via the Chicago Sanitary and Ship Canal).

Figure 2. The Chicago Waterway System's Connection to the Illinois River Basin.

INVESTIGATION OF POTENTIAL BARRIER METHODS

Dispersal Barrier Advisory Panel

The National Invasive Species Act (NISA) of 1990, Section 1202 as amended in 1996, authorized the U.S. Army Corps of Engineers to conduct a demonstration project to identify an environmentally sound method for preventing and reducing the dispersal of non-indigenous aquatic nuisance species through the Canal. In the fall of 1996 the Chicago District assembled a Dispersal Barrier Advisory Panel (Advisory Panel) to evaluate potential barrier methodologies. Experts on the physiology and behavior of aquatic species were invited to participate on the Advisory Panel to provide technical advice on the feasibility and likely effectiveness of potential barriers. Representatives of the businesses and other groups that use the Canal were also invited to participate to insure that social and economic impacts of potential barriers were considered. More than 50 international, Federal, state, regional, municipal, commercial, academic, and environmental groups or agencies have participated in the Advisory Panel (Table 1). Active participation in the Advisory Panel has varied somewhat as the focus of the demonstration project changed.

Table 1. Participants on the Dispersal Barrier Advisory Panel.

Federal	State
U.S. Army Corps of Engineers	Illinois Department of Natural Resources:
- Chicago District	- Illinois Natural History Survey
- Rock Island District	- Department of Natural Resources
- Waterway Experiment Station	- Office of Water Resources
U.S. Fish and Wildlife Service	Illinois Environmental Protection Agency
U.S. Environmental Protection Agency	Illinois Pollution Control Board
- Great Lakes National Program Office	Minnesota Dept. of Natural Resources
- Water Division	Michigan Dept. of Natural Resources
U.S. Geological Survey	Wisconsin Dept. of Natural Resources
- Biological Resources Division	Mississippi Interstate Conservation
U.S. Coast Guard	Resource Association
International	
International Joint Commission	Consulate General of Canada
Great Lakes Fishery Commission	University of Windsor
Regional, Municipal, Industrial & Academic	
Illinois International Port Authority	Illinois-Indiana Sea Grant College Program
Illinois River Carriers Association	University of Wisconsin Sea Grant Institute
University of Michigan	University of Illinois
Loyola University	Smith-Root, Inc.
Great Lakes Sportfishing Council	Midwest Generation
Metropolitan Water Reclamation District	Commonwealth Edison
Ecological Monitoring and Assessment	Lake Michigan Federation
City of Chicago Dept. of Environment	Great Lakes Protection Fund
Northeast Midwest Institute	Great Lakes Commission
Habitat Solutions	Friends of the Chicago River

The initial purpose of the Advisory Panel was to assist the Corps in identifying the most promising barrier method or methods for preventing and reducing the dispersal of aquatic nuisance species through the Canal. The evaluation completed is described below. Since a demonstration barrier was constructed, the Advisory Panel has continued to meet at least twice each year to evaluate the performance of the demonstration barrier, discuss potential ways to improve it, and provide advice on the construction of a second permanent barrier.

Barrier Characteristics and Constraints

To identify a barrier method, the Corps and Advisory Panel first developed a list of characteristics for an “ideal” aquatic nuisance species barrier, and then identified constraints and obstacles imposed by uses of the Canal. All parties agreed that an ideal dispersal barrier would not interfere with current uses of the canal, including water flow, sanitary discharges, and navigation. It was also agreed that a barrier must be cost-effective, environmentally friendly, use available technology, and operate continuously. Additional characteristics are listed in Table 2. Limitations to barrier development were that the barrier could not interfere with commercial navigation, could not restrict the conveyance of Chicago’s wastewater, and could not affect the volume of water diverted from Lake Michigan. Additional obstacles to barrier development included permitting and safety issues.

Table 2. List of Characteristics of an Ideal Aquatic Nuisance Species Barrier.

Cost effective	Long-term effectiveness	Broad spectrum
Continuous operation	Fail safe	Redundant
Protect public health	Minimal downstream effect	Currently available technology
Quick to implement	Applicable to other systems	Environmentally sound

Barrier Alternatives

The various barrier approaches considered by the Corps and the Advisory Panel are listed in Table 3. Several barrier approaches (screens, dams, and lock closure) were not considered because of wastewater discharges and navigational constraints. For example, closure or physical impediments would adversely affect the movement of barges and boats through the Canal. This could slow the transportation of goods or require off-loading and reloading with resultant increases in shipment costs. Closure of the Canal would redirect Chicago's wastewater to Lake Michigan, potentially tainting the water supply for the Chicago Metropolitan area. Operational changes were considered to be possible long-term options, but not feasible in the short term.

Table 3. Approaches Considered for an Aquatic Invasive Species Barrier in the Chicago Sanitary and Ship Canal.

Physical/Mechanical	Waterway Operations	Biological	Chemical
Filtration	Reverse flow	Pathogens	Chlorine
UV light	Canal redesign	Parasites	Nitrogen
Thermal	Close near-lake locks	Predators	Ozone
Electricity			Piscicide
Electromagnetic			
Bubble screen			
Acoustic			
Low dissolved oxygen			

The large volume of water in the Canal makes filtration or treatment with UV light infeasible. The biological effect of electro-magnetic fields is unknown. At the start of the project, bubble screens and acoustic barriers were not considered effective based on available technology and existing research. Reducing the dissolved oxygen concentration in the Canal is possible, for example through the application of nitrogen. With current technology, however, this alternative would be quite expensive ($250,000 per day). Other options to reduce the oxygen concentration could not keep the oxygen concentration at levels effective against all fish species.

Thermal treatments—for example, using hot water discharges from power generating stations—were not considered because the heated water would tend to rise to the surface of the Canal, reducing the full water-column effectiveness. Another constraint on using thermal effluents is that local power generating stations do not produce power continuously, so the thermal plume would be intermittent. A dedicated power generator would be required to continuously heat the water and produce an effective thermal plume.

Biological controls, such as pathogens and parasites, are long-term approaches that would require an extensive research and approval period before field application could be considered. Predators could be stocked in the reach between a two-barrier system; however, it is unlikely that these predators would remove all invasive organisms. Also, if water quality was reduced in the inter-barrier reach, the predators may be unable to tolerate the poor conditions.

Chemical piscicides were considered as a stop-gap approach, for use only in an emergency or for a short time frame. Obtaining permits for chemical control would be much more difficult than for a physical or behavioral barrier. Due to the Canal flow and volume of water involved, the cost of chemical control would be very high.

Recommended Barrier Approach

The Corps and the Advisory Panel decided that an electric barrier was the most promising type of aquatic invasive species barrier for the following reasons.

- Electric barriers had previously been proven effective on a smaller scale at fish hatcheries and in smaller bodies of water.
- An electric barrier would not impede the flow of water or the movement of boats within the Canal.
- Electric barriers can repel fish without killing them.
- An electric barrier would not degrade overall environmental quality in the canal.

It was recognized that an electric barrier would not be selective; that is, it would affect both native and invasive species. However, this was considered acceptable because the barrier would not be lethal and there are no native species that migrate through the Canal.

DEMONSTRATION BARRIER DESIGN AND CONSTRUCTION

After selecting the electric barrier technology, the Corps identified a location in the Canal for the demonstration. The location had to be south of the Canal's junction with the Calumet-Sag Channel; not conflict with commercial navigation uses, including fleeting areas; have electrical service available; and allow for an equipment enclosure accessible by land. After a field survey and coordination with barge companies, the electric barrier was located at River Mile 296.5 in the Canal. At this location the Canal has a shore-to-shore width of approximately 160 feet and is approximately 25 feet deep.

Design and construction of the demonstration barrier was contracted to Smith-Root, Inc. of Vancouver, Washington. Construction of the barrier began in March 2001 and the barrier began operation on April 9, 2002. The barrier consists of on-shore electrical equipment and underwater cable electrodes. The on-shore electrical equipment includes transformers and pulsers (Figure 3). This equipment receives incoming alternating electrical current from the local electrical utility, steps it up to the desired voltage, and converts it from an alternating to a direct pulsing current. The pulsing current is conveyed to the underwater electrodes via cables that pass through diagonal borings that open into the canal just above the canal bottom. This eliminates the need to mount any electrical connections on the canal sidewalls. The electric field is imparted to the water via twelve cable electrodes that rest just above the canal bottom on concrete supports. The cable electrodes are spread over approximately 54 feet of the canal bottom upstream-to-downstream. Each cable electrode is a bundle of six or seven 1.5-inch diameter steel cables. Some of the cables serve as cathodes and some as anodes and the water becomes the conducting medium for the electric field. If power from the electric utility is lost, a diesel back-up generator will start automatically and restore power to the barrier within a matter of seconds.

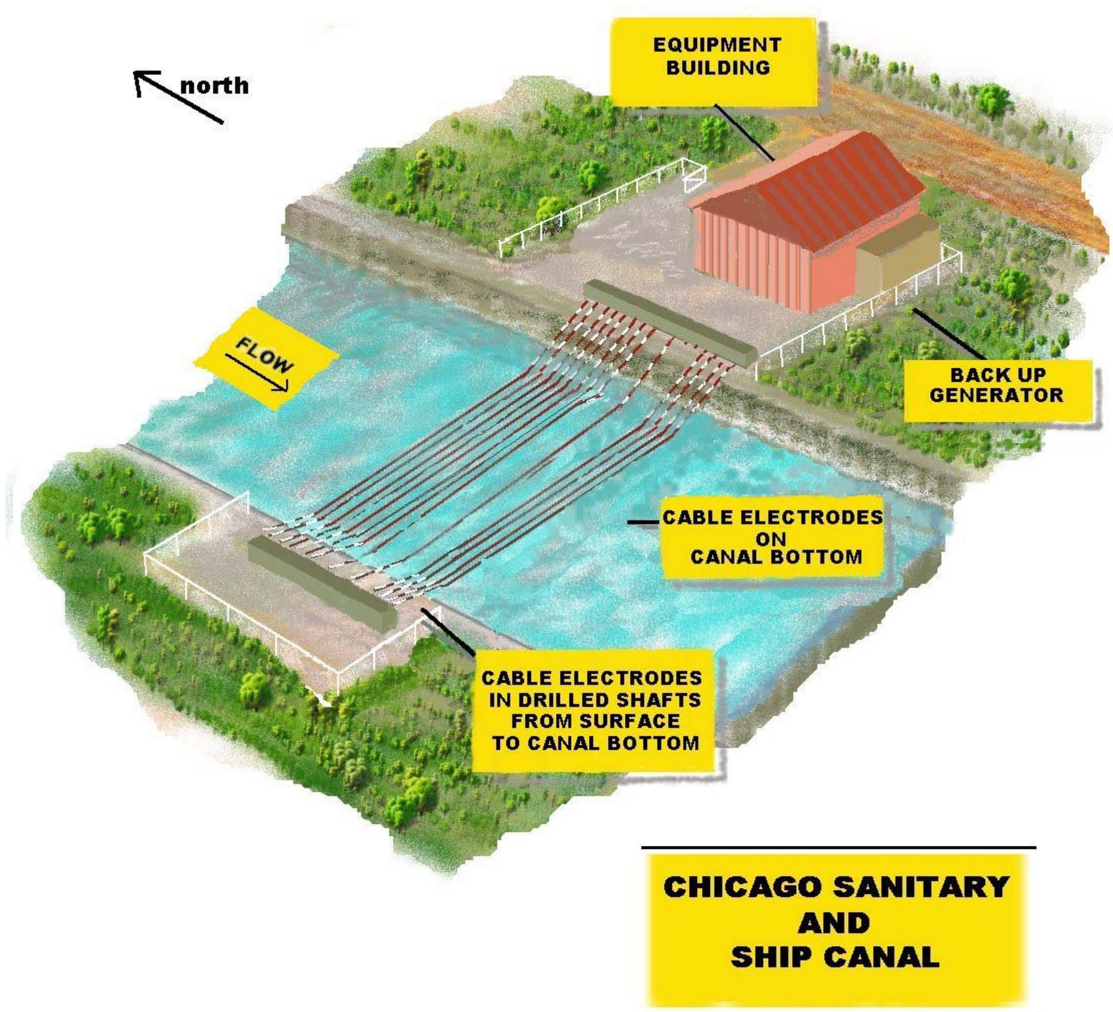

Figure 3. Illustration of the demonstration barrier.

The duration of the pulses is only several milliseconds long and the frequency is approximately four or five pulses per second. The duration and frequency of the pulses can be varied to optimize effectiveness of the barrier. The electric field is graduated so that it is weaker at the upstream and downstream edges and stronger in the center; it is designed to deter fish rather than stun them. As a fish swim into the field, it feels increasingly uncomfortable. When the sensation is too intense, the fish turns back in the direction from which it came.

The effect of the electric field extends from the electrodes on the bottom of the Canal to the water surface. The electrode array is comprised of benthic and full water-column electrode pairs. One set of electrodes forms a focused benthic array to target bottom-dwelling fish like the round goby. The other set of electrodes targets fish higher in the water column.

Demonstration Project Costs

Project planning and design cost approximately $900,000 and construction cost approximately $1,800,000. Since construction, operation and maintenance of the demonstration barrier has cost approximately $800,000. This includes continuous monitoring of operation, inspecting and maintaining the equipment, and an average monthly electrical cost of approximately $2,000. In addition, the biological performance monitoring efforts have cost approximately $600,000.

RESULTS OF OPERATING AND MONITORING THE DEMONSTRATION BARRIER

Operation and Maintenance

The durability and reliability of the electrical components that generate and modulate the electric pulses have been good. The system was shut down in the first month of operation when a steel cable from a vessel fell across the electrode array. No damage occurred, and divers were used to remove the debris. The steel cable electrodes in the barrier array have an anticipated service life of three to five years. This limited service life is primarily due to corrosion of the steel. One of the steel cables has become ineffective, apparently as a result of a metal object resting on the cable and shorting it out. Redundancy in the electrode array has allowed the barrier to continue to repel fish. Loss of electrodes due to falling objects or corrosion is a significant maintenance concern.

Biological Monitoring

Biological monitoring is being used to evaluate the effectiveness of the demonstration barrier on fish. Since 2002, radio-acoustic transmitters have been surgically implanted in 118 locally-captured common carp (*Cyprinus carpio*). These fish, all greater than 15 inches in length, were released in the Canal downstream of the barrier.

Remote sensing at the barrier and periodic field tracking of the tagged common carp have shown that only one tagged fish has crossed the barrier. This occurred in April 2003. The position of the fish's radio tag, has not changed since the fish was discovered upstream of the barrier, which suggests the fish is dead or has expelled the tag. It was subsequently determined that the tagged fish that passed through the barrier crossed at the same time a barge was passing through the array. Based on this observation, it seemed plausible that the barge may have compromised the fish's ability to avoid the electric field or that the barge altered the effectiveness of the barrier field. To test this hypothesis, a research project was implemented to quantify the effect of barges on the electric field. The results are discussed below.

Demonstration Barrier Limitations

Three weaknesses have been identified in the demonstration barrier's design. The one tagged fish that passed through the barrier made the passage at the same time a barge tow was crossing over the barrier. Research of this incident identified two ways that boat traffic may facilitate passage through the barrier. First, the turbulence and physical displacement of water created by boats could potentially push or pull a fish across the barrier against its will. The potential for such an "unintentional" passage can be greatly reduced by having a longer barrier field or having multiple distinct electric fields.

The passage of metal-hulled boats over the demonstration barrier also has a negative effect. The metal hulls absorb some of the electricity in the water, thus weakening the electrical field in the immediate vicinity of the hull. The “dead spots” of weaker field can be reduced or eliminated by using a stronger electrical field and by changing the number and spacing of the electrodes on the canal bottom.

The Illinois Department of Natural Resources has completed independently funded trough tests of Asian carp behavior near electrical barriers of a similar strength as the demonstration barrier. Their studies have documented good performance in repelling large bodied fish, but have shown that fish less than five inches in length may be able to swim through such an electrical field when the fish are near the water surface. The larger the fish, the more surface area the electric field has to affect, so small fish feel the effect of the field less than large fish. A higher voltage is required to insure deterrence of fish less than five inches in length.

The safety of the barriers for boat traffic and people is being carefully monitored. The absorption of electricity by metal hulls can lead to the potential for sparking between metal hulls in certain circumstances. As a result the U.S. Coast Guard has promulgated regulations that prohibit mooring, passing, and making or breaking of barge tows in the vicinity of the barrier. Previous incidents where people have contacted the electrified water from other electrical barriers in other waterways have produced no injuries. However, people should avoid contacting the water at the demonstration barrier site. Site-specific research on health impacts if a person accidentally fell in the water is ongoing.

BARRIER II

The dispersal barrier demonstration project has shown that an electric barrier can prevent the dispersal of fish via the Canal. As a result, the State of Illinois asked the Corps to begin a permanent electric barrier project under the Corps’ Continuing Authorities Program Section 1135. The request was approved and the permanent dispersal barrier (Barrier II) became a specifically authorized project in October 2004 with the President’s signing of Section 345 of H.R. 4850. Construction of the permanent barrier is currently underway.

Barrier II will be an electric barrier similar to the demonstration barrier, but will include design improvements identified during monitoring and testing of the demonstration barrier. Specifically, the second barrier will include two underwater arrays of electrodes located approximately 220 feet apart. Each array will cover approximately 130 feet of the canal length. This spacing will make it unlikely that fish can be carried through both arrays by currents and turbulence created by boat traffic. The number (84) and spacing of the electrodes was designed, based on computer modeling, to create a more complex electrical field that eliminates the possibility of weak spots being created by metal hulls. All of the electrodes in the second barrier are solid steel billets to provide increased protection against corrosion and extend service life to approximately 20 years. The entire system will be capable of creating a higher voltage electric field than the demonstration barrier.

The cost for planning, design, and construction of Barrier II is estimated to be $9.1 million. The Corps of Engineers is providing 75% of the project cost. The Illinois Department of Natural Resources – Office of Water Resources (IDNR-OWR) is the non-Federal sponsor for Barrier II and is providing the majority of the remaining 25% of the project cost. The IDNR-OWR has received contributions of about $70,000 from each of the other seven Great Lakes states.

CONCLUSIONS

Electrical barriers currently appear to be a reliable technology to repel fish without killing them, degrading the surrounding environment, or disrupting navigation. Acoustic and bubble screen barriers, which also satisfy those three criteria, appear to be promising alternatives to electrical barriers and are being considered for use in the Mississippi River. Future barrier projects should evaluate using these technologies to augment electrical barriers or as an alternative barrier technology.

An electric barrier alone is not the complete answer to eliminating the movement of aquatic invasive species through the Canal. Organisms that are strong swimmers can sense the adverse conditions created by the electric field and return in the direction from which they came. But plants, planktonic organisms, and eggs could simply float through the barrier and life forms attached to boat hulls, such as zebra and quagga mussels, could be carried through the electric field. Thus, it is obvious that methods that deter fish may not be effective against all aquatic organisms and that a diversity of barrier approaches will ultimately need to be employed to entirely eliminate the movement of aquatic invasive species through the Canal.

In 2003 the City of Chicago and the United States Fish and Wildlife Service co-hosted an Aquatic Invasive Species Summit. The summit proceedings recommended pursuing hydrologic separation of the Illinois River and Lake Michigan basins. Though preliminary evaluation of this option, funded by the Alliance for the Great Lakes, is underway, the practicality and cost-effectiveness of such a separation would have to be evaluated in a Corps feasibility study before such a proposal could be implemented.