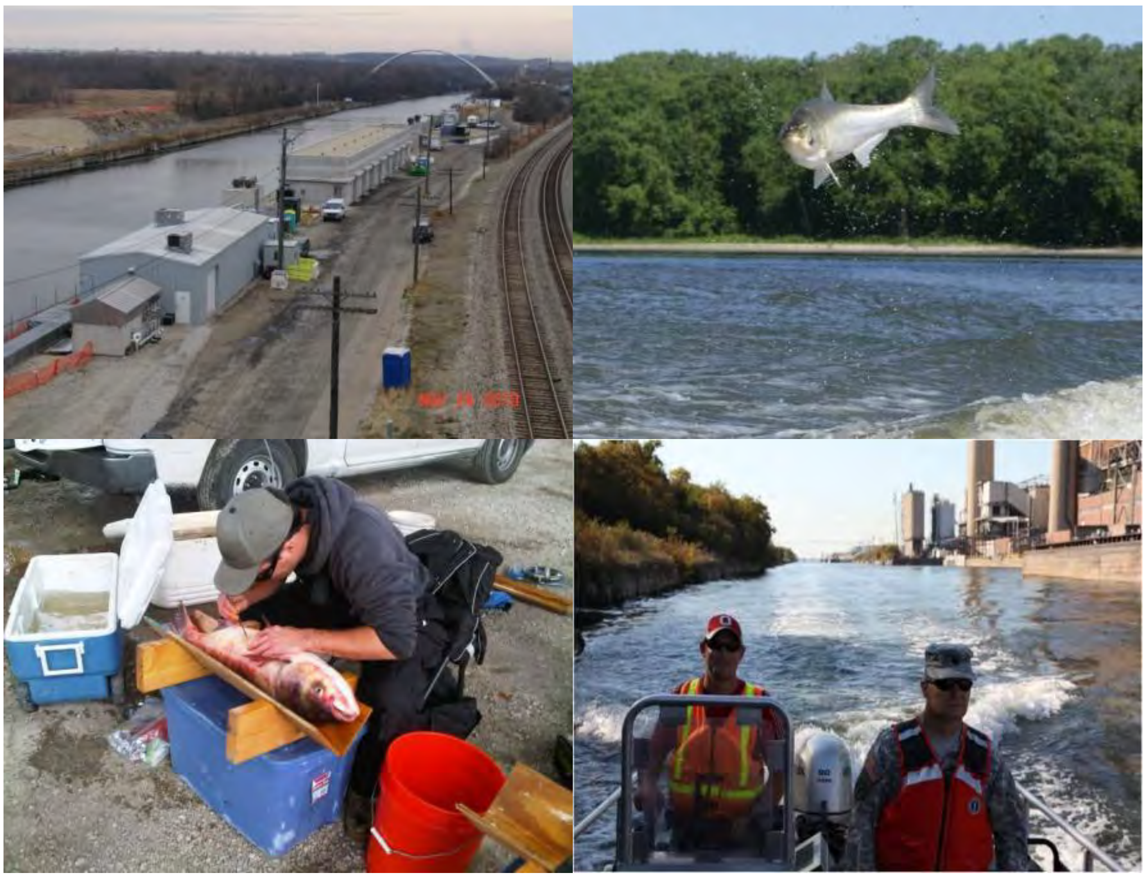
Dispersal Barrier Efficacy Study

Efficacy Study Interim IV, Chicago Sanitary and Ship Canal Dispersal Barriers Risk Reduction Study



June 2019

US Army Corps
of Engineers
Chicago District

Executive Summary

The U.S. Army Corps of Engineers (USACE) was authorized in Section 3061(b)(1)(D) of the Water Resources Development Act of 2007, P.L. 110–114 (WRDA 2007) to conduct a study of a range of options or technologies for reducing impacts of hazards that may reduce the efficacy of the Electric Dispersal Barrier located on the Chicago Sanitary and Ship Canal (CSSC), hereafter referred to as the Efficacy Study. The Electric Dispersal Barrier was designed to reduce the risk of upstream movement of fish from the Mississippi River to the Great Lakes drainage basins via the CSSC. It consists of two electric barriers, Barrier I (Demonstration Barrier) and Barrier II. Barrier II contains two independently operated components, Barrier IIA and Barrier IIB. These barriers comprise the Electric Dispersal Barrier System.
As Asian carp have moved steadily northward up the Illinois River, the threat of these species gaining access to Lake Michigan and the rest of the Great Lakes has become generally recognized by many in the environmental community and among numerous federal, state and local government agencies as having potentially significant ecological and economic consequences, although many uncertainties remain about the ability of Asian carp to establish in the Chicago Area Waterway System (CAWS) and the Great Lakes.

USACE and its agency partners are not waiting to develop one comprehensive approach for near-term solutions. Rather, in order to address the increasing sense of concern surrounding the movement of Asian carp close to Lake Michigan, and consistent with the Asian Carp Action Plan released annually by the inter-agency Asian Carp Regional Coordinating Committee (ACRCC), the Efficacy Study is being conducted in a series of interim studies as the USACE identifies potentially implementable technologies and actions to deploy in support of this multi-agency effort. To date, the USACE has completed four Efficacy Studies, Interim I, Interim IIA, Interim III and Interim IIIA. Recommendations from three of the four studies have been implemented including the construction of the Des Plaines and Illinois and Michigan (I&M) Canal Bypass Barriers, modification of Barrier II operating parameters, and the installation of fish screens on sluice gates at two lake-front controlling works.

A qualitative risk assessment was conducted by the barriers Project Delivery Team (PDT) in order to identify the level of risk associated with each failure mode for the Electric Dispersal Barrier System and evaluation of potential measures to reduce that risk. Potential failure modes were identified in prior Efficacy Studies, and include the following failure modes: bypass of the barriers via interbasin connections; movement and release by people or animals; inadvertent movement by vessels; failure of the barriers to perform effectively; and other miscellaneous risks. The systematic analysis of the failure modes provided the barriers PDT with an opportunity to quantify risks associated with a particular failure mode, potential mitigation measures, and an assessment of residual risk when mitigation measures were implemented.

The results of the Risk Assessment are documented in a Risk Register, which provides a vehicle for the USACE to focus efforts on critical areas of risk reduction, to increase the efficacy of the Electric Dispersal Barrier System. Previous Interim Efficacy Studies utilized an interim risk reduction approach developed for Dam Safety projects. This study is utilizing a more detailed risk-based process. Summaries of the first four Efficacy Studies follow.

(1) *Interim I*, *Dispersal Barrier Bypass Risk Reduction Study and Integrated Environmental Assessment* –This interim report was approved by the Assistant Secretary of the Army for Civil

Works (ASA (CW)) on 12 January 2010 to construct measures to prevent Asian carp from bypassing the Electric Dispersal Barrier System during flood events on the Des Plaines River and through culverts in the I&M Canal. The USACE awarded a construction contract on 21 April 2010 for the construction of the bypass barrier. Construction of the bypass barrier was completed in October 2010.

(2) Interim IIA, *Electrical Barrier Optimal Operating Parameters: Phase A, Laboratory Research and Safety Tests*–This interim report provided an evaluation of tests conducted to determine the optimal operating parameters and recommended an increase in the operating parameters of Barrier II to those believed to more effectively deter very small fish. Based on this report, the operational settings were changed in October 2011 operations.

(3) Interim III, *Modified Structures and Operations, Chicago Area Waterways Risk Reduction Study and Integrated Environmental Assessment*–This interim report presented an evaluation of the potential for risk reduction that might be achieved through potential changes in the operation of the CAWS structures, such as locks, sluice gates, and pumping stations in consultation with the multi-agency working group. This report included an assessment of operational changes that could be implemented as needed by agencies that are responsible for fish population management efforts such as electrofishing, spot piscicide application, or intensive commercial fishing efforts by the U.S. Fish and Wildlife (USFWS) and Illinois Department of Natural Resources (IDNR). This report was approved by the ASA (CW) on 13 July 2010. Installation of the sluice gate screens at the Chicago River Controlling Works at Chicago Harbor Lock and at the Controlling Works at T.J. O'Brien Lock and Dam was completed in January 2011.

(4) Interim IIIA, *Fish Deterrent Barriers, Illinois and Chicago Area Waterways Risk Reduction Study and Integrated Environmental Assessment*–This interim report investigated and evaluated additional deterrent measures within USACE authority that could be quickly employed to potentially reduce the risk of Asian carp dispersing into the Great Lakes. This report focused on evaluating measures that applied readily available fish deterrent and guidance technologies at key locations in the CAWS and downstream in the Illinois Waterway (IWW). This analysis was initially included in the scope of Interim III, but was cycled out to consider fielding a developing technology that was thought to be quickly deployable and relatively inexpensive. This report was approved by the ASA (CW) on 13 July 2010.

(5) *Interim IV*, *Chicago Sanitary and Ship Canal Dispersal Barriers Risk Reduction Study*–This report incorporates by reference the previously completed interim reports, documents the preliminary results of ongoing testing and analysis related to the Electric Dispersal Barrier Project, includes a systematic Risk Assessment of identified barrier failure modes, and identifies ongoing risk reduction efforts for the Electric Dispersal Barrier System. This report documents the efforts of the ACRCC, and various working groups to address the risks posed by Asian carp to the Great Lakes. The *Efficacy Study Interim IV* also includes a discussion of improvements to the Electric Dispersal Barrier System that have been completed by the USACE since the enactment of WRDA 2007 that serve to increase the performance of the system and reduce risk associated with barrier failure modes. The *Efficacy Study Interim IV* also includes updates on other efforts to increase the efficacy of the Electric Dispersal Barrier Project and further reduce risk related to potential bypasses of the project by Asian carp. These updates include work by the USACE, as well as other federal and state agencies as part of the ACRCC. Additional topics

include monitoring and response actions, environmental deoxyribonucleic acid (eDNA) monitoring; other potential modes of transit including ballast water; and commercial harvesting. Additionally, an update regarding Dual Frequency Identification Sonar (DIDSON) used by the USFWS in conjunction with USACE to study the behavior of fish near the Electric Dispersal Barriers is provided.

(6) Interim V, Chicago Sanitary and Ship Canal Dispersal Barriers Risk Reduction Study-The goal for the Efficacy V study is the optimization of barrier operations. This study will build upon the risk analysis in the Interim IV report. As part of the Interim V study, a future with project scenario will be forecasted for the Electric Dispersal Barrier System. A key component of the operational analysis is the identification of a minimum fish total length target. The target will be established through the use of existing research from both laboratory and the field, known ecological and biological requirements of Illinois River Asian carps, and possibly an expert elicitation. Once a minimum fish total length target is established, residual risks of barrier bypass mechanisms from Efficacy IV will be reviewed in light of the size classes of Asian carp being targeted. Mitigation strategies for remaining risk and planned barrier improvements will be considered and specific measures identified. Cost estimates and benefits (reduction in risk) will be assigned to each mitigation measure and a cost effectiveness/incremental cost analysis will be performed to identify potential combination of measures that are cost effective/best buy alternatives. The analysis will be used to develop a recommended plan for implementation which will include a lifecycle management plan. This lifecycle management plan will review options for replacement and maintenance of systems components with the goal of reducing risk of system failure while optimizing resources.

In all cases, permanent solutions to the interbasin transfer of Asian carp and other aquatic nuisance species of concern are more appropriately evaluated in the longer term Great Lakes and Mississippi River Interbasin Study (GLMRIS). The Project Management Plan and current information about GLMRIS can be found at http:// www.glmris.anl.gov. More information on GLMRIS is contained in *Section 3.1 - Introduction*, of this study.

Due to the nature of the threat related to the Asian carp, interim risk reduction analyses were conducted following the USACE process—as described in USACE EC 1110-2-6064, *Interim Risk Reduction Measures (IRRMs) for Dam Safety*—to rapidly implement interim measures to mitigate unacceptable risks for the first three Efficacy Studies. While this expedited process was designed to evaluate dam structures, its concepts are applicable to other circumstances that require expedited development of solutions to reduce risk. The analysis identified five potential failure modes, and then an analysis of alternatives was conducted to reduce risk and/or consequences associated with the failure modes. Three of the four Interim Studies resulted in the implementation of recommendations by the USACE.

This study presents a significant amount of technical information regarding the Electric Dispersal Barrier System including a discussion on testing related to barrier operations and barrier safety. The report also includes very detailed information on some key ongoing evaluations related to Monitoring and Response Actions and a compilation of key actions ongoing with other ACRCC member agencies. This report does not include a recommendation requiring approval of the Secretary prior to implementation.

Dispersal Barrier Efficacy Study

Interim IV, Chicago Sanitary and Ship Canal Dispersal Barriers, Risk Reduction Study

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CHAPTER 1 – Introduction

1.1 - Study Purpose

The U.S. Army Corps of Engineers (USACE) was authorized in Section 3061(b)(1)(D) of the Water Resources Development Act of 2007, P.L. 110–114 (WRDA 2007) to conduct a study of a range of options or technologies for reducing impacts of hazards that may reduce the efficacy of the Electric Dispersal Barriers located on the Chicago Sanitary and Ship Canal (CSSC), hereafter referred to as the Efficacy Study. The Electric Dispersal Barriers were designed to prevent fish from spreading between the Mississippi River and the Great Lakes drainage basins via the CSSC. The Electric Dispersal Barriers are one control technology in a broad interagency effort to prevent Asian carp establishment in the Great Lakes.

The first dispersal barrier was authorized in 1996 as a demonstration project under Section 1202(i)(3) of the Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990, P.L. 101–646, as amended by Section 2(e)(3) of the National Invasive Species Act of 1996, P.L. 104–332 (codified at 16 U.S.C. § 4722(i)(3)), and the Demonstration Barrier has been in operation since April 2002. The second dispersal barrier was initially implemented by Section 1135 of WRDA 1986, P.L. 99–662, as further authorized by Section 345 of the District of Columbia Appropriations Act of 2005, P.L. 108–335. Barrier II is a set of two barriers, Barrier IIA and Barrier IIB. Barrier IIA has been in operation since April 2009, Barrier IIB has been operational since April 2011. Section 3061(b)(1)(A) of WRDA 2007 authorized USACE to upgrade and make the Demonstration Barrier permanent, and stated that the barriers should be operated and maintained as a system to optimize effectiveness. Currently all barriers are operated simultaneously during normal operations. When completed, the combination of these barriers, designed to function together, will be operated to prevent interbasin transfer of fish between the Mississippi River and Great Lakes drainage basins, particularly the northerly movement of two species of Asian carp as much as technologically possible.

Although the Electric Dispersal Barrier System is designed to prevent fish from spreading between the Mississippi River and the Great Lakes basins, the current species of concern are the Asian carp (Cypriniformes: Cyprinidae). Asian carp have the potential to damage the Great Lakes and confluent large riverine ecosystems. Two species of Asian carp, Bighead Carp (*Hypophthalmichthys nobilis*) and Silver Carp (*H. molitrix)*, have become well established in the Mississippi and Illinois Rivers exhibiting exponential population growth in recent years. Certain life history traits have enabled Bighead and Silver Carp to achieve massive population numbers soon after establishing a presence in these areas.

The USACE is implementing a four-pronged strategy to address threats posed by Asian carp. The strategy is consistent with the *Asian Carp Action Plan* developed annually by the Asian Carp Regional Coordinating Committee (ACRCC). An organization chart of the ACRCC is shown in Figure 1.

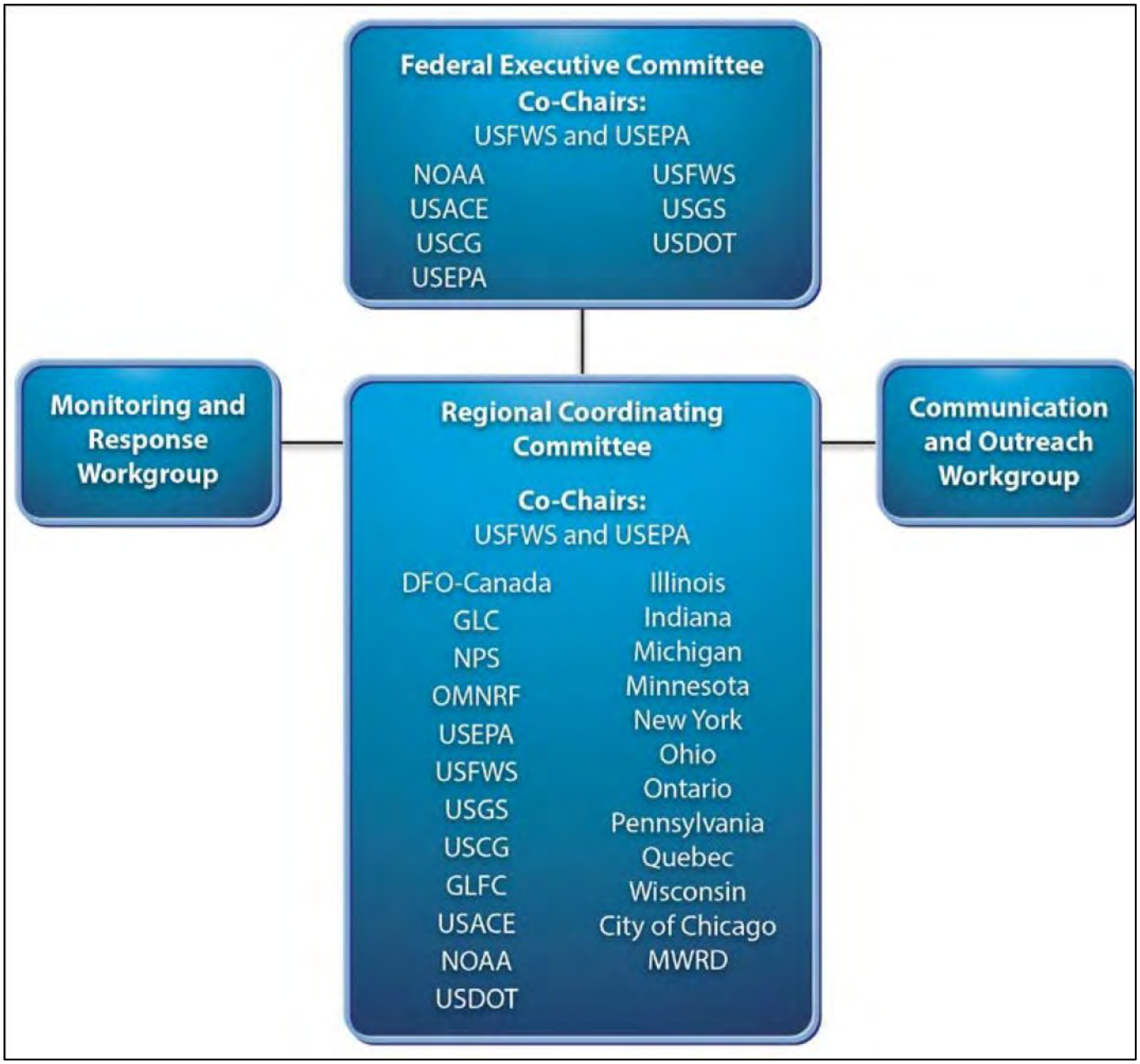


Figure 1 – ACRCC Member Agencies Organization Chart

Operating within this framework, USACE:

(1) operates electric barriers in the water just outside of Chicago;
(2) studies the barriers' effectiveness and make adjustments, as necessary;
(3) participates in extensive monitoring of the waterways and continue research on monitoring tools; and
(4) conducts GLMRIS looking at options and technologies to prevent the transfer of aquatic nuisance species of concern between the Great Lakes and Mississippi River basins.

The Efficacy Study is being conducted and documented in a series of interim studies and associated reports:

- Interim I*, Dispersal Barrier Bypass Risk Reduction Study and Integrated Environmental Assessment*–This interim report was approved by the Assistant Secretary of the Army for Civil Works (ASA(CW)) on 12 January 2010 to construct measures to prevent Asian carp from bypassing the Electric Dispersal Barrier System during flood events on the Des Plaines River and through culverts in the Illinois and Michigan (I&M) Canal. Construction of the bypass barrier and I&M Canal blockage was completed in October 2010.

- Interim IIA*, Electrical Barrier Optimal Operating Parameters: Phase A, Laboratory Research and Safety Tests*–This interim report provided an evaluation of tests conducted to determine the optimal operating parameters and recommended an increase in the operating parameters of Barrier II to those believed to more effectively deter very small fish. Based on this report, the operational settings were changed in October 2011.

- Interim III, *Modified Structures and Operations, Chicago Area Waterways Risk Reduction Study and Integrated Environmental Assessment* –This interim report presented an evaluation of the potential for risk reduction that might be achieved through potential changes in the operation of the CAWS structures, such as locks, sluice gates, and pumping stations in consultation with the multi-agency working group. The report included an assessment of operational changes that could be implemented as needed by agencies that are responsible for fish population management efforts such as electrofishing, spot piscicide application or intensive commercial fishing efforts by the U.S. Fish and Wildlife (USFWS) and Illinois Department of Natural Resources (IDNR). As part of the Interim III Study, a risk assessment was facilitated by the USFWS, and included representatives of numerous federal and state agencies, including USFWS, USGS, USACE, and IDNR. The results of the risk assessment are included in the Interim III report. This report was approved by the ASA (CW) on 13 July 2010. Installation of the sluice gate screens at the Chicago River Controlling Works at the Chicago Harbor Lock, and the Controlling Works at the Thomas J. O'Brien Lock & Dam was completed in January 2011.

- Interim IIIA, *Fish Deterrent Barriers, Illinois and Chicago Area Waterways Risk Reduction Study and Integrated Environmental Assessment*–This interim report investigated and evaluated additional deterrent measures within USACE authority that could be quickly employed to potentially reduce the risk of the Asian carp dispersing into the Great Lakes. This report focused on readily evaluating measures available fish deterrent and guidance technologies that could be deployed at key locations in the CAWS and downstream in the Illinois Waterway (IWW). The study included an evaluation of numerous fish deterrents including acoustic barriers, strobe barriers, bubble barrier, electric barriers and combined technology barriers. This analysis was initially included in the scope of Interim III, but was cycled out to consider fielding a developing technology that was initially thought to be quickly deployable and relatively inexpensive. The report included a recommendation for a two year demonstration of a combined acoustic-bubble-strobe fish deterrent. This report was approved by the ASA (CW) on 13 July 2010.

- *Interim IV*, This report incorporates by reference the previously completed reports, documents the results of ongoing testing and analysis related to the Barriers Project, includes a systematic Risk Assessment of identified barrier failure modes, and identifies upcoming risk reduction efforts for the Barriers Project. This report documents the efforts of the Asian Carp Regional Coordinating Committee (ACRCC), and various working groups to address the risks posed by Asian carps to the Great Lakes. The *Efficacy Study Interim IV* also includes a discussion of improvements to the barriers that have been completed by the USACE since the enactment of WRDA 2007 that serve to increase the performance of the project and reduce risk associated with barrier failure modes. The *Efficacy Study Interim IV* also includes updates on other efforts to increase the efficacy of the barriers and further reduce risk related to potential bypasses of the project by Asian carp. These updates include work by the USACE, as well as other federal and state agencies as part of the Asian Carp Regional Coordinating Committee (ACRCC). Additional topics include: monitoring and response actions, eDNA monitoring; other potential modes of transit including ballast water; and commercial harvesting. Additionally, an update regarding Dual Frequency Identification Sonar (DIDSON) used by the USFWS in conjunction with USACE to study the behavior of fish near the Electric Dispersal Barriers is provided.

- Interim V, Chicago Sanitary and Ship Canal Dispersal Barriers Risk Reduction Study-The goal for the Efficacy V study is the optimization of barrier operations. This study will build upon the risk analysis in the Interim IV report. As part of the Interim V study, a future with project scenario will be forecasted for the Electric Dispersal Barrier System. A key component of the operational analysis is the identification of a minimum fish total length target. The target will be established through the use of existing research from both laboratory and the field, known ecological and biological requirements of Illinois River Asian carps, and possibly an expert elicitation. Once a minimum fish total length target is established, residual risks of barrier bypass mechanisms from Efficacy IV will be reviewed in light of the size classes of Asian carp being targeted. Mitigation strategies for remaining risk and planned barrier improvements will be considered and specific measures identified. Cost estimates and benefits (reduction in risk) will be assigned to each mitigation measure and a cost effectiveness/incremental cost analysis will be performed to identify potential combination of measures that are cost effective/best buy alternatives. The analysis will be used to develop a recommended plan for implementation which will include a lifecycle management plan. This lifecycle management plan will review options for replacement and maintenance of systems components with the goal of reducing risk of system failure while optimizing resources.

The USACE and other federal, state and local agency partners continue to evaluate options and cycle out concepts as they are ready for evaluation and potential implementation based on thorough analyses, review, approval and any necessary future authorization needs. These options have independent utility, potentially each providing ways to impede Asian carp range expansion, and can be considered in separate decision-making processes. Ultimately, any implemented measures are expected to complement each other to provide a comprehensive solution, pending further assessment of a possible permanent solution.

In collaboration with federal, state and local agencies as well as nongovernmental entities, USACE conducted a feasibility study of the long-term options and technologies that could be applied to prevent or reduce the risk of aquatic nuisance species (ANS) transfer between the Great Lakes (GL) and Mississippi River (MR) basins through aquatic pathways, where aquatic pathways are defined as natural and manmade hydraulic connections between the Great Lakes and Mississippi River basins. The Great Lakes and Mississippi River Interbasin Study (GLMRIS) provides a thorough and comprehensive analysis of these Aquatic Nuisance Species (ANS) controls. The GLMRIS Report was released in January 2014 and contains eight alternatives, each with concept-level design and cost information, and evaluates the potential of these alternatives to control the transfer of a variety of ANS. The options concentrate on the Chicago Area Waterway System (CAWS) (**Figure 2**) and include a wide spectrum of alternatives ranging from the continuation of current activities to the complete separation of the Great Lakes and Mississippi River basins. A copy of the report and summary information can be found at http://glmris.anl.gov/glmris-report/.

Based on an agency assessment informed by public input following release of the GLMRIS Report, the Assistant Secretary of the Army (Civil Works) concluded that a formal evaluation of potential control options and technologies near Brandon Road Lock and Dam to prevent the movement of ANS from the Mississippi River Basin to the Great Lakes Basin was an appropriate next step. The GLMRIS – Brandon Road Draft Integrated Feasibility Study and Environmental Impact Statement – Will County, IL (Draft GLMRIS-BR Report) evaluates options and technologies near the Brandon Road Lock and Dam site in Will County, Illinois, near Joliet, to prevent the upstream transfer of aquatic nuisance species (ANS) from the Mississippi River Basin into the Great Lakes Basin, while minimizing impacts to existing waterway uses and users. The GLMRIS-BR Report is scheduled for completion in early 2019.

This report presents the results of the Efficacy Study Interim IV as well as encompassing the previous Efficacy Studies. The Efficacy Study Interim IV consists of five (5) parts including a main report and three (3) appendices with figures and tables. The Interim Efficacy Studies are referenced in this report, but available in their entirety at http://www.lrc.usace.army.mil. The Interim IV Efficacy Study Report is structured as follows:

- Main Report
- Appendix A–Hydrology and Hydraulics
- Appendix B–Planning Information and Risk Register

Figure 2 – Map of the CAWS with Key Points of Interest.

1.2 - Study & Implementation Authorities

Several statutory authorities are relevant to the measures considered in this report. The first is Section 3061(b)(1)(D) of the Water Resources Development Act of 2007 (P.L. 110–114) which is a study authority only. This authority does not authorize implementation of any Efficacy Study recommendations. The second authority is from Section 1039(c) of the Water Resources Reform and Development Act of 2014, P.L. 113–121 which provides authority to implement recommendations from the Interim Efficacy Reports. These two authorities are:

WRDA 2007 SEC. 3061. CHICAGO SANITARY AND SHIP CANAL DISPERSAL BARRIERS PROJECT, ILLINOIS.

(a) TREATMENT AS SINGLE PROJECT.—The Chicago Sanitary and Ship Canal Dispersal Barrier Project (in this section referred to as "Barrier I"), as in existence on the date of enactment of this Act and constructed as a demonstration project under section 1202(i)(3) of the Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990 (16 U.S.C. 4722(i)(3)), and the project relating to the Chicago Sanitary and Ship Canal Dispersal Barrier, authorized by section 345 of the District of Columbia Appropriations Act, 2005 (Public Law 108–335; 118 Stat. 1352) (in this section referred to as "Barrier II") shall be considered to constitute a single project.
(b) AUTHORIZATION.—
(1) IN GENERAL.—The Secretary, at Federal expense, shall—
(A) upgrade and make permanent Barrier I;
(B) construct Barrier II, notwithstanding the project cooperation agreement with the State of Illinois dated June14, 2005;
(C) operate and maintain Barrier I and Barrier II as a system to optimize effectiveness;
(D) conduct, in consultation with appropriate Federal, State, local, and nongovernmental entities, a study of a range of options and technologies for reducing impacts of hazards that may reduce the efficacy of the Barriers; and
(E) provide to each State a credit in an amount equal to the amount of funds contributed by the State toward Barrier II.

WRRDA 2014, SEC. 1039(c)

(c) PREVENTION, GREAT LAKES AND MISSISSIPPI RIVER BASIN.—

(1) IN GENERAL.—The Secretary is authorized to implement measures recommended in the efficacy study authorized under section 3061 of the Water Resources Development Act of 2007 (121 Stat. 1121) or in interim reports, with any modifications or any emergency measures that the Secretary determines to be appropriate to prevent aquatic nuisance species from dispersing into the Great Lakes by way of any hydrologic connection between the Great Lakes and the Mississippi River Basin.

(2) NOTIFICATIONS.—The Secretary shall notify the Committees on Environment and Public Works and Appropriations of the Senate and the Committees on Transportation and Infrastructure and Appropriations of the House of Representatives any emergency actions taken pursuant to this subsection.

Section 1039(c) of WRRDA 2014, P.L. 13–121, authorizes the Secretary of the Army to implement measures recommended in the efficacy study directed by Section 3061(b)(1)(D) of the WRDA 2007, or in interim reports, with any modifications or any emergency measures the Secretary determines to be appropriate to prevent aquatic nuisance species from dispersing into the Great Lakes by any hydrologic connections between the Great Lakes and the Mississippi River Basin.

The Explanatory Statement accompanying the Consolidated Appropriations Act of 2016, P.L. 114–113, (Congressional Record, December 17, 2015, at H10056), directed USACE to establish formal emergency procedures, including rapid response protocols, monitoring, and other countermeasures, that are appropriate to prevent Asian carp from passing beyond the Brandon Road Lock and Dam. These procedures were established in coordination with the USFWS and in consultation with the Asian Carp Regional Coordinating Committee, and approved by the Assistant Secretary of the Army for Civil Works (ASA(CW)) on May 20, 2016.

1.3 - Study Area Background

Prior to development, the Chicago and Calumet Rivers were large wetland complexes that flowed sluggishly east towards Lake Michigan. The Des Plaines River naturally flowed west into the Mississippi River drainage. There were periods of high flow when the Des Plaines River changed its course and flowed into the Chicago and Calumet Rivers due to the relatively flat topography of the region. Two regional high points in the landscape, located near Mud Lake and Saganashkee Slough functioned as hydraulic divides. Sporadically, most often during spring floods, Mud Lake and the Saganashkee Slough would overflow into the West Fork of the South Branch of the Chicago River near Kedzie Avenue and the Little Calumet River near Blue Island. This overland flow provided a temporary connection between the Great Lakes and Mississippi River drainage basins. The intermittent natural connection was made permanent in 1848 with completion of the Illinois and Michigan (I&M) Canal (Figure 3). The dimensions of the original I&M Canal were 60-feet wide at the surface, 36-feet wide at the base, and 6-feet deep. In the spring of 1849, the Little Calumet River was connected to the I&M Canal via a 40-foot wide and 4-foot deep Calumet Feeder Canal, which was constructed through the Saganashkee Slough. The I&M Canal was replaced by the much larger Chicago Sanitary and Ship Canal (CSSC). The I&M Canal is no longer in operation as a navigation channel, but is intermittently connected and serves as a conduit for local storm water conveyance.

Construction of the CSSC was initiated in 1892 and completed in 1900. The permanent connection between the Lake Michigan and the Mississippi River drainage was established with the completion of the CSSC. On the Calumet River, the USACE removed sandbars and built piers at the mouth of the river from 1870 to 1882. The Calumet River connecting Lake Michigan and Lake Calumet was straightened between 1888 and 1896, and between 1899 and 1916 the Calumet River was dredged to a depth of 16 feet. The Calumet-Saganashkee (Cal-Sag) Channel was constructed through the Saganashkee marshland, a vast and unique dolomite prairie, between 1911 and1922. With the final phase of these modifications, and the connection of the Cal-Sag Channel and the Calumet River, the Calumet Region's drainage was reversed, and in 1961, the Calumet River was completely reversed by the construction of the Thomas J. O'Brien Lock and Dam (L&D) near the original confluence with Lake Michigan.

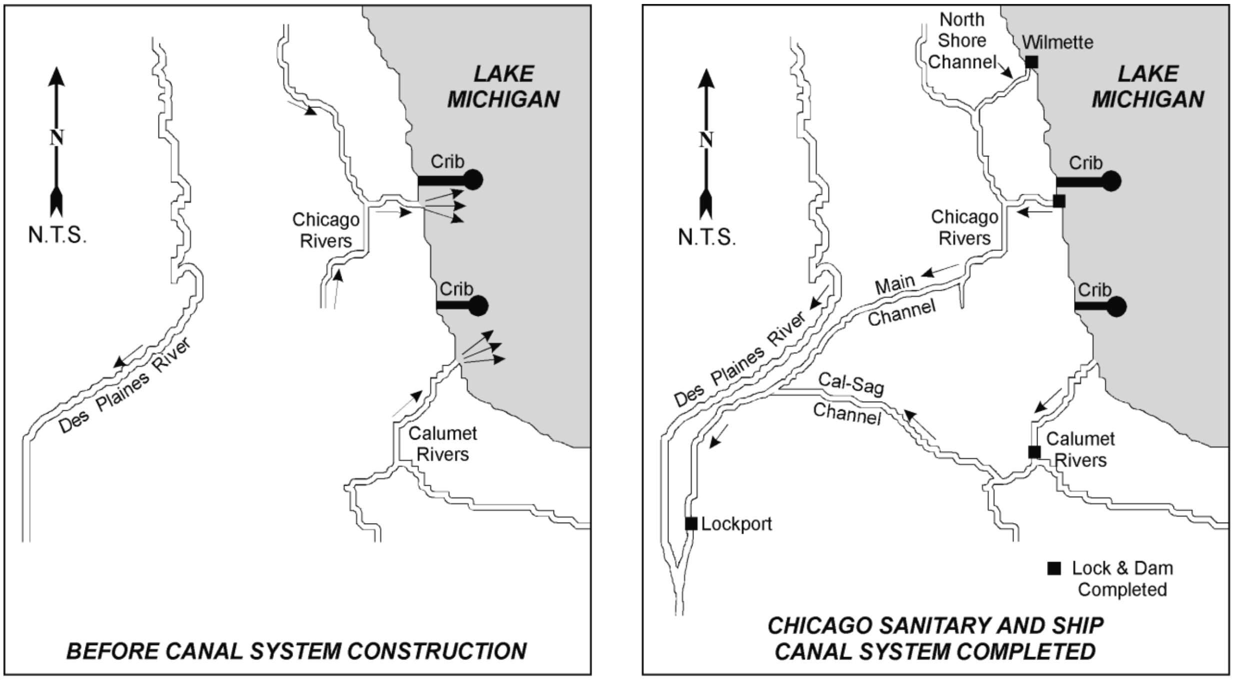


Figure 3 – Development of the Chicago Area Waterways.

Since the creation of the canal system, combined sewer overflows, treated Water Reclamation Plant (WRP) effluent, low dissolved oxygen concentrations, high ammonia concentrations and other constituents found in the waterway formed an effective "barrier" not only to colonization of the canal by native pioneer species, but to introduced species as well. Significant improvements in water quality over the last two decades have allowed the aquatic conditions in the canal to become suitable for tolerant native and introduced species, which both share pioneering attributes.

There was interbasin transfer of aquatic species between the Mississippi River and the Great Lakes naturally in the past after various glaciation and major flood events, which inherently drives speciation and biogeography; however the man-made connection in conjunction with non-native species introduction poses a great threat to these processes. This species transfer gained wide attention in the early 1990s when the introduced eastern European Round Goby *(Neogobius melanostomus)* and the Atlantic Slope White Perch *(Morone americana)* were found in southern Lake Michigan.

In an effort to contain their range expansion, the Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990, P.L. 101–646, as amended by the National Invasive Species Act of 1996, P.L. 104–332, authorized the Assistant Secretary of the Army for Civil Works (ASA (CW)) to examine potential methods to create an aquatic nuisance species dispersal barrier in the CSSC. In November 1997, Congress appropriated $500,000 to begin work on the project. In April 2002, the Demonstration Electric Barrier was turned on with the goal of reducing interbasin transfer of fish between the Great Lakes and Mississippi River basins nearly 140 years after the permanent connections were established. The Electric Dispersal Barrier Project located at river mile 296.25 in the CSSC was to be the first stop gap measure to prevent the spread of aquatic nuisance species (ANS) species between the Mississippi River and Great Lakes Basins.

Unfortunately, the Round Goby and White Perch dispersed faster than anticipated and were well past the Demonstration Barrier site before construction was completed. However, the decision to construct the barriers was prudent since a new threat was emerging from the Mississippi River system—the Silver and Bighead Carp.

A number of government and non-governmental organizations led by the USFWS contributed to the *Management and Control Plan for Bighead, Black, Grass, and Silver Carps in the United States*, dated October 2007. Due to heightened concern about the target species in the Great Lakes, the Asian Carp Regional Coordinating Committee (ACRCC), comprised of federal and state agencies, was formed in 2009 and the members of the ACRCC are working collaboratively to bring their particular authorities and knowledge together to reduce the threat of Asian carp establishment in the Great Lakes. The group developed the Asian Carp Action Plan (previously called the Asian Carp Control Strategy Framework) (referred to hereafter as the Action Plan) annually to document actions already undertaken and to identify potential courses of action to be implemented in both the near and short term. The actions outlined in the Framework, such as ongoing Asian carp monitoring efforts and research by our multi-agency partners, provide the context for the analysis in this report. The most recent Action Plan is available on the ACRCC website (http://www.asiancarp.us).

The Action Plan is designed to establish the need for participating agencies to act urgently to apply full authorities, capabilities and resources to prevent Asian carp from becoming established in the Great Lakes; to integrate and unify the impending actions of the participating agencies; and to facilitate cooperation by additional agencies. It also serves to identify lead agencies for particular actions.

1.4 - General Study Area

The study area includes the IWW and the CAWS (Figure 4). Specifically, the study area includes reaches of the CSSC, lower Des Plaines River, I&M Canal, Cal-Sag Channel, Calumet River, Little Calumet River, Grand Calumet River, Chicago River, South Branch Chicago River, North Branch Chicago River and North Shore Channel. The study area is in all or part of Cook, Du Page, Lake and Will Counties in the metropolitan Chicago area in Illinois, and in Lake County, Indiana. The Electric Dispersal Barriers Project is located at river mile 296.25, roughly 0.2 miles or 1300-feet upstream of the 135th Street Bridge in Romeoville, IL (Figure 10). The Electric Dispersal Barriers Project site lies in the southeast ¼ of the southwest ¼ of section 35, T37N R10E, Lockport Township, in Will County. The CAWS as defined for this study includes the waterways in both Illinois and Indiana, and extends for approximately 128 river miles from Lockport Lock and Dam north and east to Lake Michigan via both natural and man-made channels.

Figure 4 – Chicago Area Waterways and Upper Illinois Waterway

1.5 - Existing Projects

Illinois Waterways

The Illinois Waterways, including the CAWS, provide a direct hydraulic connection between Lake Michigan and the Mississippi River. The CAWS is comprised of 128 miles of canals and modified streams located within Cook and Will Counties in Illinois and Lake and La Porte Counties in Indiana. The CAWS includes the Chicago, Des Plaines, and Illinois Rivers, plus numerous canals, in particular the CSSC, the Cal-Sag Channel and the tributaries in an area extending from the metropolitan Chicago area to the Lockport vicinity. As mentioned above, part of the CAWS system is the Chicago River with its two main branches (North Branch and South Branch).

Natural flow regimes in the CAWS were modified through a series of engineered projects to establish the existing configuration of the waterways. Modifications occurred over the past 100 or more years to accommodate the needs of regional and local interests. Modifications included channel construction, lock and dam construction, and operation and maintenance activities. Presently, operation and maintenance of the waterway includes, but is not limited to the following: ensuring sufficient water levels in pools behind the dams; operation of locks for navigation; dredging in certain areas to maintain channel depth for navigation; and clearing and snagging to keep the channel clean for navigation and storm water conveyance. The formal authorization for the USACE to perform operation and maintenance activities on the Illinois Waterway was provided in the Rivers and Harbors Acts of 1927, 1930, and 1935, (P.L. 69–560, 71–520, and 74–409).

The portion of the I&M Canal linking Lake Michigan to the Illinois River was completed in 1848. In 1900, the upper end of the I&M Canal was replaced as far south as Lockport by the CSSC which, in addition to providing sanitation, was available for navigation. In Section 107 of the Energy and Water Development Appropriation Act of 1982, Pub. L. No. 97–88, 95 Stat. 1135, 1137 (1981), Congress transferred operation and maintenance responsibility for the CSSC to the USACE. See also Supplemental Appropriations Act of 1983, Pub. L. No. 98–63, 97 Stat. 301, 311 (1983) (extending authority to the Chicago Lock).

In 1922, the Metropolitan Water Reclamation District of Greater Chicago (MWRD) completed the construction of the Cal-Sag Channel for the purpose of preventing the pollution of Lake Michigan by reversing the flow of the Calumet River. The CAWS connects to the Illinois Waterway which is completely navigable with a minimum depth of nine feet over its stretch of 350-miles for commercial navigation to near Alton, IL. The physical components of the navigation system are the eight sets of locks, seven with accompanying dam structures, and the navigation channel.

Water is diverted from Lake Michigan for a number of purposes including water supply, water quality and navigation makeup. Diversions for water quality and navigation makeup are necessitated by the reversal of the Chicago River and the construction of controlling works along the lakefront. The diversion of water from Lake Michigan is closely regulated by the Illinois Department of Natural Resources (IDNR). Currently, the Lake Michigan diversion accountable to the state of Illinois is limited to 3,200 cubic feet per second (cfs) over a forty-year averaging period. The measurement of the quantity of Lake Michigan diversion water and the method for accounting are specified in a U.S. Supreme Court Decree in *Wisconsin v. Illinois*, 388 U.S. 426 (1967), *amended by* 449 U.S. 48 (1980), and in a 1996 Memo of Understanding (MOU) between the U.S. Department of Justice and eight states bordering the Great Lakes. The USACE is responsible for computing the annual Illinois Lake Michigan diversion and preparing an annual diversion report for IDNR.

Chicago Lock – The Chicago Lock, also known as the Chicago Harbor Lock, is situated at the mouth of the Chicago River. This lock is the primary controlling mechanism of the Illinois Waterway separating Lake Michigan from the Chicago River. The current lock was designed and built by the Sanitary District of Chicago (now the Metropolitan Water Reclamation District of Greater Chicago). The Chicago Lock is operated and maintained by USACE.

The Chicago Lock complex is comprised of a lock chamber, concrete guide walls, and a lock control house. The lock chamber measures 600-feet long, 80-feet wide, and 22.4-feet deep and is equipped with two sets of rotating double-leaf sector gates (one set at each end). An unusual aspect of the Chicago Lock is its use of sector gates, a gate type normally used in tidal reaches of rivers and canals. Sector gates resemble traditional miter gates, except each gate is shaped like a pie-sliced sector of a cylinder oriented to rotate about a vertical axis. This form of lock system does not utilize valves, sluices or culverts. Also located at the Chicago Lock is the Chicago River Controlling Works (CRCW). The CRCW consists of two sets of four sluice gates. Each gate has a 10′ x 10′ opening.

The Chicago Lock/CRCW has three primary functions. First it serves as a hydraulic gateway between the Chicago River and Lake Michigan. Used by more than 40,000 commercial and recreation vessels a year, this is the second-busiest navigational lock in the United States. The lock and CRCW also play a role in reducing pollution, by letting controlled quantities of lake water into the Chicago River for water quality purposes. Lastly, the lock and CRCW function as flood control through the discharge of floodwaters from the Chicago River into the lake during periods of extreme high water.

T.J. O′Brien Lock and Dam – The Thomas J. (T.J.) O′Brien Lock and Dam (L&D) is located 326.0 miles above the confluence of the Illinois River with the Mississippi river at Grafton, Illinois. It is approximately 35 miles upstream of the Lockport L&D, in the southeastern portion of Chicago. T.J. O′Brien is located seven miles southwest from the entrance to Lake Michigan along the Calumet River. The facility is a unit of the Inland Waterway Navigation System operated and maintained by USACE, and is one of eight such facilities between Chicago and Versailles, Illinois. It is composed of a navigational lock, fixed dam, and controlling works. The T.J. O′Brien Lock and Dam were authorized by the Rivers and Harbors Act of 1945, P.L. 79-14, and the Rivers and Harbors Act of 1946, P.L. 79-525.

T.J. O'Brien lock is a low-lift sector gate lock. It provides a maximum lift of five feet for traffic passing from Lake Michigan to the Calumet River. The lock chamber is 1,000-feet long by 110-feet wide. There are also two sets of sector gates weighing 216 tons each at both the river and lake ends. The controlling works consist of four large vertical slide gates (10 feet square) located near the center of the dam to regulate water flow. The dam is 296.75 feet long. T.J. O′Brien L&D and controlling works control the movement of water between Lake Michigan and the Calumet River while maintaining navigation. The controlling works are used for flood control and water quality diversion similar to the Chicago Harbor Lock and CRCW.

Lockport Lock and Dam – The Lockport L&D is located 291.0 miles above the confluence of the Illinois River with the Mississippi River at Lockport, IL. The complex is two miles southwest of the city of Lockport, Illinois on the CSSC. The lock opened in 1933. The lock is 110 feet wide by 600 feet long. Maximum vertical lift is 42.0 feet; the average lift is 39 feet. It averages 22.5 minutes to fill the lock chamber; 15 minutes to empty.

Lockport Lock was one of five locks designed and partially constructed by the state of Illinois over a period from 1923 to 1930. The complex was about 97 percent complete when construction was turned over to the federal government due to state financial difficulties. The USACE controls the navigation lock at Lockport. The Lockport Dam consists of the MWRD lock, powerhouse and associated controlling works. The dam serves the multiple purposes of power generation, flood control, and navigation. The USACE has no ownership of the controlling works; however, it has the responsibility to maintain the foundation, piers, dolphins and all the concrete at the Lockport Controlling Works and the gravity structure at the dam. The Lockport Controlling Works is located 2 mi upstream of the Lockport Powerhouse and connects the CSSC to the Des Plaines River. The Lockport Controlling Works' primary purpose is to control flooding by allowing overflow relief for the CSSC into the Des Plaines River; its secondary purpose is to maintain CSSC's elevations for navigation. In addition, activities at the controlling works are also coordinated with downstream powerhouse activities to maximize electricity production. The Lockport Controlling Works consists of seven operational vertical lift sluice gates, 20 foot high by 30 foot wide, which the MWRDGC opens 6 to 10 times per year.

Brandon Road Lock and Dam – Brandon Road L&D is located 286 miles above the confluence of the Illinois River with the Mississippi river at Grafton, Illinois. The complex is located 27 miles southwest of Chicago; 2 miles southwest of Joliet, Illinois, near Rockdale. The lock opened in 1933 and was one of five locks designed and partially constructed by the state of Illinois over a period from 1927 to 1930. The complex was about 70 percent complete when construction was turned over to the federal government due to state financial difficulties. The lock is 600 feet long, 110 feet wide. Nominal lift is 34 feet with an average 19-minute lock chamber fill time; 15-minute emptying time.

The dam is 2,391 feet long (exclusive of fixed embankment and river wall). It contains 21 operational Tainter gates (50 feet wide by 2 feet, 3-1/2 inches high), six sluice gates (7 feet, 9 inches wide x 8 feet, five inches high, bulkheaded closed), and 16 pairs of 16 feet high by 15 feet wide headgates (eight operational, eight bulkheaded closed). The height of the pool and discharge past the dam are controlled by the 21tainter-type crest gates which hold the normal pool 27 inches above the crest of the dam.

Wilmette Pumping Station – The Wilmette Pumping Station is located on the North Shore Channel, approximately 1500 feet from the open waters of Lake Michigan, and is operated and maintained by the MWRD. The pumping station controls the movement of water between Lake Michigan and the North Shore Channel. The pumping station is also used for flood control and water quality diversions. The Wilmette Pumping Station, constructed in 1910, consists of a pump house and a large sluice gate. The pump house forms a part of the structure of the Sheridan Road Bridge over the North Shore Channel in the City of Wilmette. The sluice gate, located on the channel side south of the pump station, was the primary hydraulic component to control the diversion of water from Lake Michigan, but it is mainly used for reverse flow now due to concerns regarding Asian carps. The original sluice gate was 32 feet wide by 16 feet high. The pump house historically included four pumps, housed in individual bays fronted by trash racks, with flap gates at the downstream end of each bay to prevent backflow.

The Wilmette Pumping Station underwent a two-phase major rehabilitation that was completed in 2014.

- Phase 1, 2012: MWRD removed and rebuilt the old 250 cfs pump, and modified three of the pump tunnels with gates to facilitate reverse flow to Lake Michigan. Phase 1was completed in 2013

- Phase 2, 2013: MWRD removed the 16' x 32' sluice gate, and replaced it with three smaller gates with approximately equivalent flow capacity. After the new gates were put in service, a new 150 cfs variable speed pump was installed to serve as the primary diversion pump. The old, rehabilitated 250 cfs pump was put back in service as a backup pump. The two remaining pump tunnels will be used during floods if additional reverse flow capacity is needed.

Locks and Controlling Works of the Chicago Area Waterways

Lockport Lock and Powerhouse, Lockport Controlling Works, Chicago River Controlling Works (CRCW), O'Brien Lock and Dam, and Wilmette Pumping Stations serve as controlling points to maintain proper water levels in the Chicago Waterway System to facilitate navigation and prevent flooding. Facilities at CRCW, O'Brien Lock and Dam and Wilmette Pumping Station also control the flows entering to the waterway system from Lake Michigan, whereas Lockport Lock and Powerhouse and Lockport Controlling Works control the flows leaving the system at the downstream end. Figures 5 through 9 show major structural components at Lockport Lock and Powerhouse, Lockport Controlling Works, CRCW, O'Brien Lock and Dam, and Wilmette Pumping Station, respectively.

Figure 5 – Lockport Lock and Powerhouse, CSSC RM 291.

Figure 6 – Lockport Controlling Works, CSSC RM 293.2.

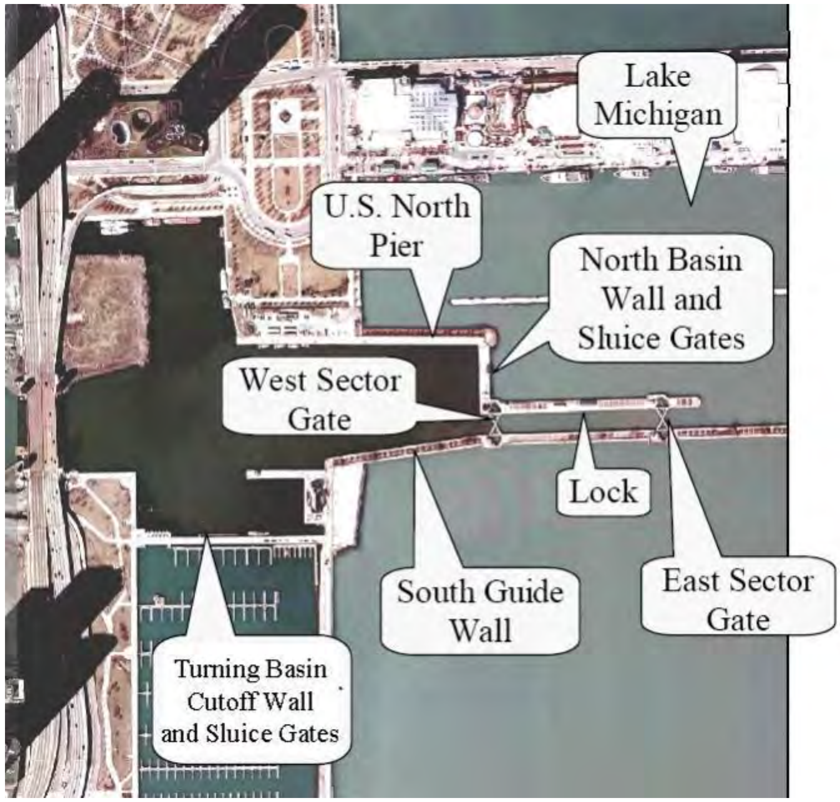


Figure 7 – Chicago River Lock and Controlling Works, RM 327.2.

Figure 8 – O'Brien Lock and Dam, Calumet River mile 326.4.

Figure 9 – Wilmette Pumping Station.

Lock facilities at Lockport and O'Brien are owned and operated by the USACE. The MWRD built the Chicago Lock but transferred all responsibility for the facility, including operation and maintenance, to USACE in June 1984. The MWRD owns and operates the facilities at Lockport powerhouse, Lockport Controlling Works, Wilmette Pumping Station, and the sluices gates at CRCW. As an exception, the Corps owns the sluice gates at the O'Brien Lock and Dam, and operates these sluice gates under the direction of MWRD per a 1966 agreement between these two agencies. Under the 1966 agreement, and an additional 1984 agreement, the Corps and MWRD coordinate their lock and controlling work operations in response to storm water, water quality and water diversion conditions.

The MWRD canal operation control center in downtown Chicago monitors the operating conditions and river stages of these facilities on the Chicago Waterway System. Under normal conditions, water levels in most parts of the system are like a flat pool. When the MWRD receives a rainstorm forecast from their consultant, they start allowing more flows to pass to the downstream portion of the system. This is achieved by passing more flow through the turbines and opening the sluice gates in the Lockport Powerhouse. In response to the increase of flow at Lockport, the canal water level is lowered—most at Lockport, and less away from Lockport. This operation is often referred to as *canal drawdown*. Canal drawdown serves two purposes: first, it evacuates water in the canal system preparing for the anticipated large runoff to come; and secondly, it creates a steeper hydraulic gradient in the canal system that allows flood water to move out of the system faster. With very large rainstorm events, sluice gates at Lockport Controlling Works, located about two miles upstream from Lockport Lock and Powerhouse, will also be opened to divert additional water to the adjacent Des Plaines River.

During significant rainstorms characterized by heavy and intense precipitation, the conveyance and storage of the canal system may become inadequate to handle flood waters. Under this condition, sluice gates at CRCW, O'Brien Lock and Dam and Wilmette Pumping Station need to be opened. Water will be reversed from the waterway to Lake Michigan by gravity. During the most severe rainstorm events, the locks at CRCW and O'Brien Lock and Dam also need to be opened in addition to the sluice gates. This reversal of flow is called *backflow*.

Other Structures and Outfalls – The remainder of the Illinois Waterway has 5 additional navigation structures which include the Dresden Island Lock and Dam (RM 271), the Marseilles Dam (RM 246), the Starved Rock Dam (RM 230) Peoria Dam (RM 158), and the LaGrange Dam (RM 80).

There are two major types of outfalls into the CAWS: Water Reclamation Plants (WRP's)/industrial discharge outfalls and Combined Sewer Overflow (CSO) outfalls. There are four WRP's that discharge into the CAWS; they are Stickney, North Side, Calumet and Lemont. Normal long term (firm) capacity and short-term (peaking) capacity for each of the four plants is as follows: Stickney 1200 mgd and 1400 mgd; North Side 333 mgd and 450 mgd; Calumet 354 mgd and 430 mgd; and, Lemont 2.3 mgd and 4 mgd. The permitted industrial discharge outfalls return the non-contact cooling, treated process water, and wastewater back to the waterway. The CSO outfalls relieve overload of the sewer network and the waste water treatment plants primarily during major storm events. There are more than three hundred CSO outfalls owned by the City of Chicago, MWRD, and local municipalities in northeastern Illinois. Not all outfalls into the CAWS are permitted.

Table 1 shows the historical records of backflow at the CRCW from 1949 through 2017. No backflows were observed in 2018. Historically, most flow reversal events occurred during the summer months. Twenty-five events have occurred at the CRCW since record-keeping began. Fifteen events have occurred since 1986, and nine out of these fifteen events involved lock opening, denoted in the table by an "L" superscript.

Table 1 – Historical Records of Backflow at CRCW.

Date	Million Gallons(MG)	Date	Million Gallons(MG)
10/9-10/10/54 ^{L}	970	7/17-7/18/96	519
7/14/57 ^{L}	2,260	2/20-2/22/97	1,947
9/14/61 ^{L}	718	8/16-8/17/97	402
8/17/68 ^{L}	533	8/2/01 ^{L}	833
8/26/72	59	8/22/02 ^{L}	1,296
4/18/75	1,130	9/13-9/14/08 ^{L}	5,438
6/30/77	297	7/24/10 ^{L}	5,703
7/21/80	184	7/23/11 ^{L}	1,716
8/7/82	83	4/18-4/19/13 ^{L}	6,105
12/2-12-3/82	248	6/30-7/1/14 ^{L}	362
8/13-8/14/87 ^{L}	986	6/15-6/16/15 ^{L}	996
5/9-5/10/90	208	10/14/17 ^{L}	2456
11/27-11/28/90	86		

Table 2 shows the historical records of backflow at O'Brien Lock and Dam since 1965. Nine backflow events have occurred since record-keeping began at the O'Brien Lock and Dam. Five events have occurred since 1986, and three of these events involved lock opening, denoted in the table by an "L" superscript.

Table 2 – Historical Records of Backflow at O'Brien Lock and Dam

Date	Million Gallons (MG)
12/24-12/25/65 [L]	898
5/12/66 [L]	1,152
6/13/81	377
12/2/-12/3/82	124
11/27-11/28/90	224
7/17-7/18/96	1,032
2/20/-2/22/97 [L]	1,458
9/13-9/14/08 [L]	2,669
4/18-4/19/13[L]	3,017.4

Table 3 shows the historical records of backflow at Wilmette Pumping Station since 1986. Backflow at Wilmette Pumping Station is more frequent than that at the other two lakefront controlling works, with twenty-eight backflow events occurring from 1986 through 2017. No backflow events were observed in 2018.

Table 3 – Historical Records of Backflow at Wilmette Pumping Station.

Date	Million Gallons (MG)	Date	Million Gallons (MG)
10/3/86	53	9/13-9/14/08	2,942
8/13-8/14/87	971	12/27-12/28/08	461
8/25-8/26/87	18	2/26-2/27/09	79
8/3-8/4/89	52	3/8/09	143
5/9-5/10/90	289	6/19-6/20/09	192
8/17-8/18/90	10	7/24/10	764
11/27-11/28/90	154	5/29/11	107
2/20-2/22/97	775	7/23/11	504.3
8/16-8/17/97	157	4/18-4/19/13	1,429.2
6/13/99	10	6/30-7/1/14	162.8
8/2/2001	140	6/15-6/16/15	167.2
8/31/2001	75	7/24/16	34.01
10/13/01	91	10/14/2017	289.8
8/22/02	455		
8/23-8/24/07	221		

Chicago Sanitary & Ship Canal, Demonstration Barrier

The CSSC's first dispersal barrier (Demonstration Barrier) was implemented as a demonstration project, and consists of an array of electrodes which were installed on the channel bottom of the CSSC (see Figure 10). When power is provided, a pulsing electrical field is created within the water that repels fish in order to prevent or reduce the dispersal of fish between the Great Lakes and the Mississippi River drainage basins. The Demonstration Barrier is located approximately at river mile 296.25 at Romeoville, IL, and was activated in April 2002. It currently operates at a maximum in-water field strength at the water surface ($IWFS_0$) of 1 volt per inch (V/in), 5 pulses per second (Hertz), and each pulse 4 milliseconds (ms) in duration.

Chicago Sanitary & Ship Canal, Dispersal Barrier II

The second dispersal barrier (Barrier II) on the CSSC is also an electrical field barrier, but includes design improvements identified during monitoring and testing of the Demonstration Barrier. Barrier II consists of two independently operated permanent barriers, IIA and IIB.

Barrier IIA and Barrier IIB each consist of two sets of electrified arrays of 5″ x 5″ steel bars ("electrodes") that rest on concrete supports on the channel bottom and run across the width of the canal. Jacketed copper cables are fastened to the ends of the submerged electrodes.

The cables travel up individual boreholes to copper bus bars. The bus bars connect to electrically operated polarity switches and then to the output of electronic pulse generators ("pulsers"). A large capacitor array stores an electrical charge that the electronic switch sends in short repetitive pulses of DC voltage to the electrodes. These capacitor arrays receive DC power from rectifiers. The rectifiers receive incoming electrical utility power and convert it from alternating current (AC) to direct current (DC). There are three rectifiers, one for each of the three pulsers. Two pulsers are needed to energize each of the two electrode arrays, while the third pulser is a spare that can be pressed into service by operation of the appropriate polarity switch. Parasitics are conductive materials that were also installed in the canal to limit the extent of the electric fields generated by the barriers to the areas designed for fish deterrence. The parasitics are not connected to any electrical source on land. They are passive features that act as "sinks" for electricity in the water. Since parasitics are made of highly conductive material, electrical current in the water flows into the parasitic. Placing parasitics upstream & downstream of the barrier electric field reduces the amount of electricity from a barrier that extends beyond the parasitics.

Barrier IIA was activated in April 2009 at the same settings as the Demonstration Barrier. These settings were increased in August 2009 to $IWFS_0$ = 2 V/in, 15 Hz, and 6.5 ms in response to eDNA monitoring results that suggested Asian carp were closer to the barriers than earlier believed and research information indicating the new parameters were more effective for smaller Asian carp.

Barrier IIB was activated in April 2011 at Barrier IIA's settings, and Barrier IIA was placed into warm standby mode. From April 2011 to December 2013 the standard operating protocol was to operate either Barrier IIA or Barrier IIB with the other inactive, but in a warm standby state from which it could be quickly activated. The operating protocol was changed in January 2014, when both Barrier IIA and Barrier IIB began to operate simultaneously to provide increased redundancy.

The operating parameters for both Barrier IIA and Barrier IIB were changed to $IWFS_0$ = 2.3 V/in, 30 Hz, 2.5 ms in October 2011 after research indicated these parameters should be even more effective for deterring Asian carp. Since then the pulse parameters have been changed multiple times in response to further research results and concerns about interference with a nearby railroad crossing signal. The current operating parameters for both Barrier IIA and Barrier IIB are 2.3 volts per inch, 34 Hz, 2.3 milliseconds. Further information on the effectiveness of barrier operating parameters is contained in *Chapter 5, Effectiveness of the Barriers*. The Electric Dispersal Barrier System is the fourth largest power user among all USACE projects.

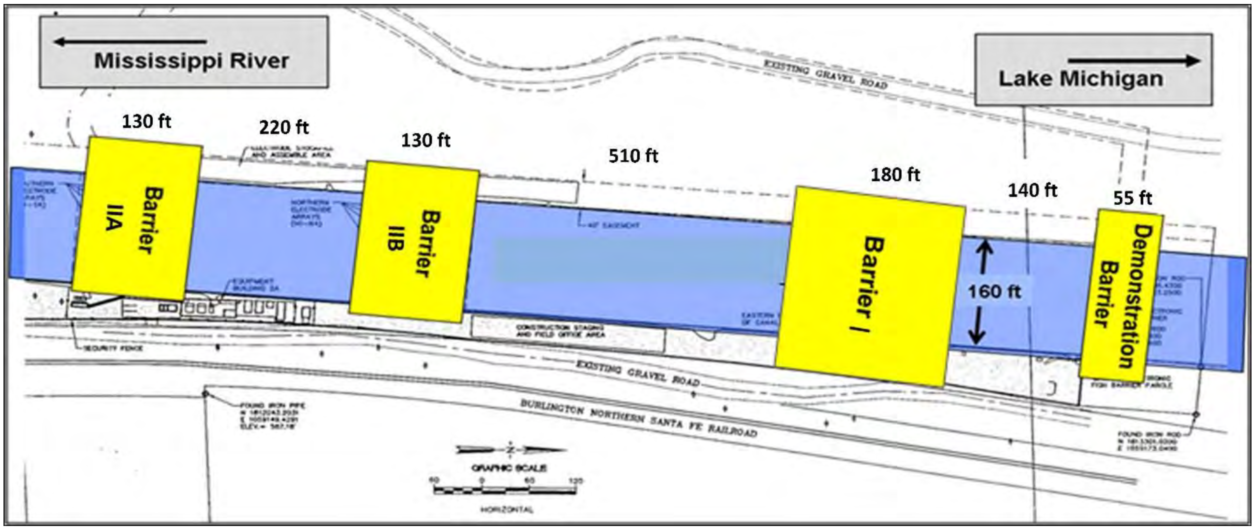


Figure 10 – Schematic of Electric Dispersal Barriers Project.

<u>Permanent Barrier I</u>

WRDA 2007 authorized USACE to upgrade and make permanent the Demonstration Barrier, also known as Barrier I. The new barrier is referred to as Permanent Barrier I. Permanent Barrier I will have the highest power capability of any of the barriers. Construction is currently underway. Further information on Permanent Barrier I is contained in *Chapter 6, Permanent Barrier I*.

CHAPTER 2 –Study Area Environment

This chapter includes a description of the resources within the study area and a description of waterway operations and the operations of the controlling works for water quality diversion and flood risk management.

2.1 - Physical Resources

Climate

The climate of the project area is typical of northeast Illinois and may be classified as humid continental, characterized by warm summers, cold winters, and daily, monthly, and yearly fluctuations in temperature and precipitation. The study area is in the continental region of the U.S. National Weather Service data collected from the area around Chicago report daily mean temperatures of 24.9° F in winter and 71° F in summer. Coldest average monthly temperatures range from daily lows and highs of 14° F and 30° F respectively, in January. July is the warmest month with an average daily low of 63°F and an average high of 84° F.

Mean annual precipitation is 36.57 inches with the majority of the precipitation occurring April through October. Accumulated annual snowfall averages 46.2 inches for the study area. Wind speed averages 11 to 12 miles per hour. Early spring floods may occur when snow accumulations extend into a period of increasing temperature that results in melting. If this occurs when soils are already saturated or still frozen, and given the amount of impervious surfaces within the study area, runoff increases dramatically. The start of the growing season, as defined for agricultural purposes, usually occurs from late April to early May, but in natural areas there may be blooming plants in ground water discharge zones as early as the last week in January, although most native organisms start their annual growth after cultivated and non-native species. The first frost typically occurs between late September and mid-October, with the frost free season ranging from 158 to 178 days.

Also of some concern are the potential future effects of climate change on the land and water resources of the Great Lakes region. Current science-based predictions indicate that climatic changes in this region will likely include higher mean temperatures in summer and winter, with measurably less average annual rainfall, but more intensive rainfall events when they do occur. Higher summer air temperatures would generate greater rates of evaporation from the CAWS, and potentially less mean overland and tributary flow into the waterway system. This would tend to lead to lower water levels in the CSSC and potentially higher water temperatures, which may impact the effectiveness of the Barrier System by making the water less conductive to electrical current (see *Section 4.8 - Ground Currents*). However, higher annual temperatures also raise the threat of migration northward of warm-weather aquatic species, as the warmer water conditions may be more hospitable to migration and may make a particular temperature sensitive species more active, speeding their range expansion.

Decreases in winter and summer precipitation could also endanger general aquatic ecosystems and lessen groundwater supplies to the CSSC. Ongoing research is supporting the observed trend toward more regionally-intense storm and rainfall events, primarily during seasonal transition periods in the fall and spring. The potential threat to the CSSC and the Barrier System is the increased intensity of rainfall events that would increase the risks of flash flooding in the

CAWS, increasing the likelihood of backflows, and increase the potential for Asian carp to be flushed through the Barrier System by record-high flows.

Air Quality

The Chicago Metropolitan area, including the study area, is a non-attainment area for both ozone (and ozone precursors) and particulates (with a diameter less than 2.5 microns). Existing air quality data are available for Cook, DuPage, Lake and Will counties from the USEPA Air Data database. Although the trends show overall improvement over the last 10 years, individual measurements and monitoring stations still have measurements that exceed the national standards. The existing air quality should be considered marginal, but improving over time.

Geology

Bedrock located within the project area is primarily composed of dolomite and limestone with small amounts of shale present. The bedrock is covered by up to 300 feet of an unconsolidated formation comprised of clay, silt, sand, and gravel. Much of the material was directly deposited as glacial till and outwash from melting glaciers. The very young glacial geology of the region plays a significant role in the hydrology that drives the local ecosystems.

The project area lies entirely within the Central Lowland Province. Comprising the province is the Great Lake Section and the Till Plains Section. The Great Lake Section is composed of the Wheaton Morainal Country and the Chicago Lake Plain. The Wheaton Morainal Country is characterized by broad flat expanses spotted with steeply sloping Wisconsinan-age moraines and till plains that are approximately parallel to the Lake Michigan shoreline. The Chicago Lake Plain is approximately the area that is now metropolitan Chicago. It is relatively flat, glacio-lacustrine deposit formed by the slow moving waters of glacial Lake Chicago. Elevation ranges from 400 to 900 feet above sea level. The Till Plains Section is composed of the Bloomington Ridged Plain, with land surface elevation ranges from 585 to 855 feet above sea level.

Soils

The US Department of Agriculture Soil Surveys of Cook, DuPage, and Will Counties, Illinois describe 28 soil series found on the study area; twelve of the soil classes are hydric. Muskego and Houghton Mucks, which is a group of nearly level depressional areas composed primarily of herbaceous organic material over coprogenous deposits, is the only soil association. The 28 soil series encompass four soil orders: Alfisols, Entisol, Histosol, and Mollisols. Alfisols form in semiarid to humid areas and are typically found under hardwood forest cover. They have a clay-enriched subsoil and relatively high native fertility.

The soil series included under Alfisols are Blount, Fox, Ozarkee, and Wauconda. The Entisol soil order is characterized by having no diagnostic soil horizons. Most of the soils within this order are unaltered from their parent material. The only soil series included under the Entisol order is Orthents. Soil comprised primarily of organic materials characterizes the Histosol soil order. For Histosol soils to be present, aquic conditions or artificial drainage must exist. The Muskego and Houghton soils are the only series included under the Histosol soil order. Finally, the largest order is the Mollisols including the Ashkum, Barrington, Channahon, Drummer, Faxon, Grundelein, Harpster, Joliet, Kane, Kankakee, Mundelein, Rockton, Romeo, and Sawmill soil series. The Mollisols form typically under grassland cover in semi-arid to semi-humid areas. These soils are characterized by a deep, high organic matter, nutrient-enriched surface soil. Prime farmlands do not occur along or on the project footprint.

In some locations within the counties, significant disturbance to the native soil profile are the result of development. The Electric Dispersal Barriers, and support buildings are located along the CSSC in very disturbed areas. While some native soil remnants remain, most of the soils within the Project can be characterized as urban.

Land Use

Pre-settlement land cover of the study area was primarily prairie, with pockets of rare dolomite prairie and wetland depressions. Along the riparian zones of the Des Plaines River and confluent streams, hardwood forest most likely occurred. The riparian zones of the Chicago and Calumet Rivers were much different than the Des Plaines River. These two river systems flowed through vast marshes and more often than not, had an undefined channel.

Today, land use within the CAWS basin is generally urban with extensive industrial development. Basin stakeholders include the City of Chicago and 31 suburban municipalities. Flow in the CAWS is dominated by treated wastewater from 5 million residents and an additional industrial load of approximately 4.5 million population equivalents. Land use has been converted from natural undeveloped tracts to industrialized and residential areas with intermittent pockets of highly disturbed forest and wetland. Most of the land adjacent to the rivers and canals is owned by the MWRD; certain parcels are leased to the Cook County and Du Page Forest Preserves and are used for recreational purposes.

General Hydrology

The CAWS in Illinois consists of 78 miles of canals and modified streams. The CAWS consists of the Chicago River, its two main branches (North Branch and South Branch), as well as the Calumet Sag Channel, the CSSC, and the tributaries in an area extending from the metropolitan Chicago area to the Lockport vicinity. It also includes Lake Calumet. To facilitate a reversal of the flow of the Chicago River to divert water from Lake Michigan to the CAWS, the Chicago Sanitary and Ship Canal, the Calumet Sag Channel and the North Shore Channel were constructed over 100 years ago. The diversion and the artificial waterways facilitated navigation and protected the drinking water intakes in Lake Michigan from Chicago wastes. The Little Calumet River North Leg, the Chicago River, the South Branch of the Chicago River and North Branch of the Chicago River downstream from its confluence with the North Shore Channel are natural rivers that have been modified through channelization and widened and deepened.

Chicago's wastewater system was developed with a combined sewer system that accepted both stormwater and sanitary waste. After rainstorms, the capacity of the sewer system became overwhelmed on a regular basis and combined sewer overflows (CSO) occurred. These CSOs are discharged into the CAWS and from the waterway into Lake Michigan during backflow events. To address this problem, the USACE, USEPA and MWRD developed the Tunnel and Reservoir Project (TARP), which included the construction of the Deep Tunnel project and large stormwater reservoirs. The Deep Tunnel consists of 109 miles of tunnels that lie 250 to 300 feet below the Chicago River and are located parallel to it. The first phase of the TARP project or

"Deep Tunnel" project was completed by MWRD in 2006. During periods of heavy rainfall, the TARP project directs combined sanitary waste and infiltrating rainwater into massive tunnels and collection reservoirs where it can be withdrawn for treatment after the rain subsides. Two of the TARP reservoirs have been constructed within the study area: the Thornton Reservoir (2015) and the Stage I of the McCook Reservoir (2018).

Water Quality

The North Shore Channel, North Branch Chicago River, Chicago River, South Branch Chicago River (including the South Fork), Chicago Sanitary and Ship Canal (CSSC), Des Plaines River, Cal-Sag Channel, Grand Calumet River, and Little Calumet River are all currently on the 2018 Final Draft Illinois 303(d) list of impaired waters (Draft dated 11/14/2018). These waters include both natural and man-made waterways which serve as receiving waters for the tributary streams and water reclamation plant effluents, combined sewer overflows, and stormwater runoff, and are therefore of marginal quality. The impairments for these waters vary for both the designated use and for the cause. Polychlorinated biphenyls are listed as a cause of fish consumption use impairment for multiple waterways (Calumet River, Cal Sag Channel, Chicago Sanitary and Ship Canal, Chicago River, North Shore Channel). The source of this contamination is likely a combination of historical sources and current sediment conditions. Other designated use impairments include aquatic life and primary contact recreation. The causes of the impairments vary however mercury, low dissolved oxygen, fecal coliform are common impairments in these waters, and these causes are linked to the urban environment including atmospheric deposition and discharges of combined sewage and low quality stormwater to the rivers.

2.2 - Biological Resources

Riverine Habitat

Chicago Sanitary and Ship Canal – The Chicago Sanitary and Ship Canal (CSSC) in the study area was incised through the native dolomite limestone. Consequently, the aquatic environment is fairly homogeneous, consisting of vertical limestone walls that extend 24–26 feet down to the bottom. These nearly perpendicular walls of the canal offer little or no littoral zone for aquatic species. The walls have crumbled down enough at various locations along the reach that may provide limited littoral habitat for present species. The bottom of the canal is essentially flat with virtually no fine substrates; however, rock or flagstone is present on the bottom of the canal where the vertical walls have been gouged away by barge traffic. There are also intermittent areas of woody debris and detritus that may be used as cover for certain benthic organisms.

Chicago River – The Chicago River serves as a vital transport link between Lake Michigan and the Illinois Waterway. By 1941, the river was transformed into its present configuration. The Main and North Branches of the Chicago River which include a 21-foot deep navigation channel from Rush Street to North Avenue. The South Branch of the Chicago River consists of a 9-foot deep navigation channel that is connected to the Illinois Waterway by the Chicago Sanitary and Ship Canal. The riverine habitat of the Chicago River for the most part consists of a manmade canal of varying depths, with no natural riverine function. The shoreline is retained by concrete, sheet pile or riprap revetment. Physical habitat structure consists of slumping riprap banks, sunken logs and man- made debris.

Des Plaines River – Des Plaines River headwaters begin near Union Grove, Racine County, Wisconsin. It then flows south through the center of Kenosha County, Wisconsin, eastern Lake County, the center of Cook County west of Chicago, the very southeast corner of Du Page County, then south-southwest through western Will County before merging with the Kankakee River to form the Illinois River in Grundy County. Habitats in the project area are varied. Some reaches are lower gradient and exhibit abundant backwater and side stream wetland habitats (near Channahon). Some reaches are higher gradient where the channel braids and exhibits swift currents over bedrock, thus forming many riffles (near Lockport and Romeoville). The Des Plaines River below Lockport is deeper and wider, a result of modification for commercial navigation.

Little Calumet River – Originally a reach of the Grand Calumet River, the 6.1 mile Little Calumet River was widened, straightened, and deepened to accept diverted flows from the Grand Calumet River. The flow of the Little Calumet River was reversed westward into the Calumet-Sag Channel (LimnoTech 2010). The Little Calumet River has a drainage divide occurring east of Hart Ditch. This divide is the point where, in dry weather, all water west of it flows towards Illinois and all water east of it flows towards Lake Michigan via Burns Ditch. During wet weather events, the water on the east side of the divide will flow west towards Illinois.

The Little Calumet River has few vertical dock walls and most of the banks are earthen side slopes. In-stream habitat for aquatic life is available along the Little Calumet River in the form of boulders, logs, brush debris jams, overhanging terrestrial vegetation, and aquatic vegetation. Riparian land use along the Little Calumet River upstream of the Calumet WRP outfall, near Indiana Avenue, is generally urban industrial and commercial. The sediments are up to seven feet deep in this reach and are mostly characterized by sludge and silt deposits, but there are also gravel substrates in the center of the river. Downstream of the WRP, at Halsted Street, land use varies from urban commercial to forest and wetland. Sediments up to three feet deep are relatively heterogeneous, although the substrate is sometimes scoured in the center, exposing bedrock (MWRD 2008). Notable levels of trace metals were detected in sediment samples collected by MWRD in 2007. Water quality in the Little Calumet River is not supportive of the designated Indigenous Aquatic Life and Fish Consumption uses due to elevated concentrations of mercury, PCBs, aldrin, iron, phosphorus, and silver, and low dissolved oxygen concentrations (IEPA 2012).

Grand Calumet River – The Grand Calumet River is comprised of two branches that meet at the southern end of the Indiana Harbor Ship Canal shown in Figure 11. The East Branch of the Grand Calumet River originates at the Grand Calumet Lagoons just east of the United States Steel Gary Works facility, and flows west for approximately ten miles to meet the Indiana Harbor Canal. The West Branch of the Grand Calumet River, located between the Indiana Harbor Canal and the Calumet River, usually flows both east and west, with a watershed divide located in the vicinity of Indianapolis Boulevard, depending on the water level in Lake Michigan. The Indiana Harbor Canal flows north for approximately three miles before turning northeast and flowing for an additional two miles into Lake Michigan (USACE 2004).

The Grand Calumet River has riparian vegetation along its banks which provides habitat for many species of birds and mammals (CDM 2004). The Grand Calumet River is one of 43 Areas of Concern (AOC) on the Great Lakes identified by the USEPA and when listed was the only AOC supporting none of the beneficial use criteria. The legacy pollutants found in the bottom sediments are the greatest contributor to this waterway's impairment. Dredging and capping projects conducted by U.S. Steel Gary Works and USEPA, together with navigational dredging of the Indiana Harbor Canal conducted by USACE, have improved sediment and water quality in this area of concern although additional portions of the river remain to be addressed.

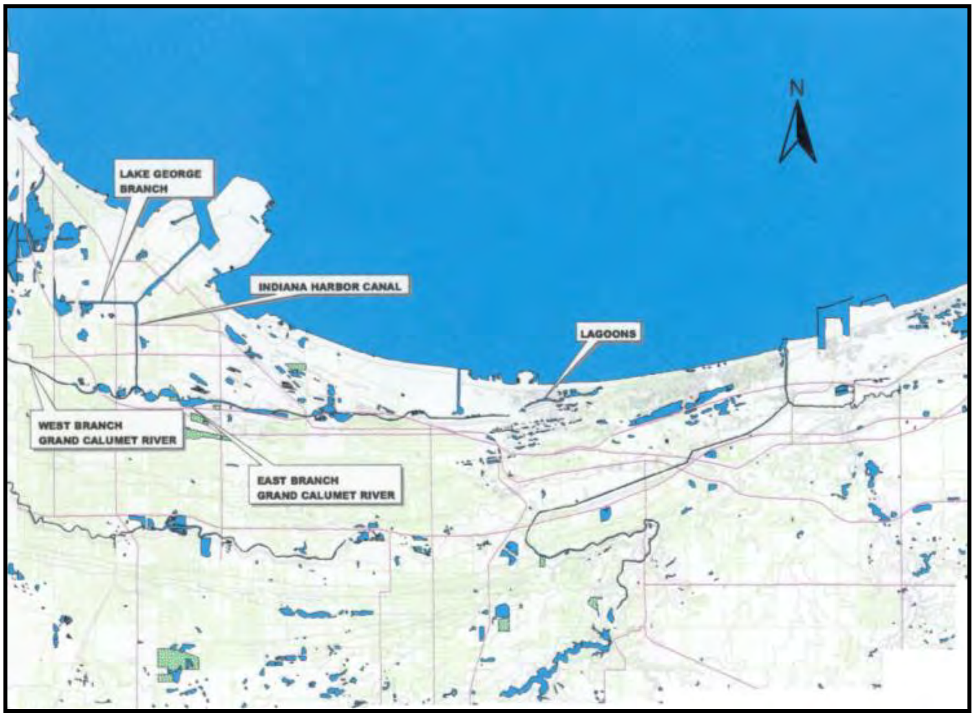


Figure 11 – Grand Calumet River.

<u>Riparian Plant Communities</u>

Generally, these areas are highly disturbed lands with small patches of volunteer plant communities. These sites have the following composition:

Old fields are dominated by Late Boneset (*Eupatorium serotinum*) and Tall Goldenrod (*Solidago altissima*). The woodland tree layer is dominated by White Mulberry (*Morus alba*) and the shrub layer is dominated by Elderberry (*Sambucus canadensis*).

The forested areas are a mixture of wet floodplain forest and mesic woodland with small areas of emergent marsh. The forested areas are dominated by Cottonwood (*Populus deltoides*), Maple (*Acer* sp.*),* and Ash (*Fraxinus* sp.) with a shrub layer dominated by Japanese bush honeysuckle (*Lonicera* sp.). The dominant vine is Riverbank Grape (*Vitis riparia*). The herbaceous layer is represented by mostly Creeping Charlie (*Glechoma hederacea*) and White Snakeroot (*Eupatorium rugosum*). The forested areas are of low quality, typified by low coverage of herbaceous species and dominance of the invasive shrub species (*Lonicera japonica*).

The emergent marsh areas are dominated by a mix of Cattails (*Typha latifolia*) and Common Reed (*Phragmites australis*). Although the cattails are native, their dominance along with the high abundance of Common reed indicates this area is of low quality and is experiencing chronic disturbance.

The riverbanks are wooded with openings dominated by herbaceous species. The herbaceous species are dominated by Reed Canary Grass (*Phalaris arundinacea*), which is a highly invasive species and is typical of wet/mesic disturbed areas. The wooded areas are low quality as well with some larger trees and a shrub layer dominated by Japanese bush honeysuckle and European Buckthorn (*Rhamnus cathartica*), both non-native, highly invasive species.

<u>Aquatic Communities</u>

The aquatic communities and riparian zones of the study area have been marginalized by previous impacts of hydrologic and fluvial-geomorphic modification. A total of 49 species of fish have been collected from the Des Plaines River, CSSC, and I&M Canal: 43 from the Des Plaines River, 19 from the CSSC, and 21 from the I&M Canal. The majority of fish species that occur in the area are ecologically tolerant, meaning they are able to thrive in degraded habitats. Species intolerant to silt and turbid water are found in the Des Plaines River, CSSC, and I&M; however, abundance of these species is low.

Macroinvertebrate species diversity within the CAWS is lower than in the Des Plaines River due to poor habitat (*Appendix B, Table 2*). Fissures in the man-made walls of the canals as well as organic matter inputs provide minimal habitat for invertebrates and other aquatic species. In 1999, the MWRD collected two crayfish species, Rusty Crayfish (*Orconectes rusticus)* and Virile Crayfish *(Orconectes virilis*), from the CSSC. The Rusty Crayfish is introduced from the Ohio River system via the release of unused live fishing bait.

<u>Other Wildlife</u>

Terrestrial wildlife communities on the study area have been degraded due to hydrologic and geomorphic alterations and fragmentation of habitats by industrialization. The majority of the communities are located on sites vegetated with replanted bottomland forest or former industrial parcels. Birds that are associated with these types of habitats and may inhabit the area include marsh birds, nesting and migrant waterfowl and woodland birds. Muskrat (*Ondatra zibethicus*), beaver (*Castor canadensis*), American Mink (*Neovison vison*), North American River Otter (*Lontra canadensis*), and raccoons (*Procyon lotor*) are mammals often associated with bodies of water because they construct their shelters in or near rivers and streams as well as gather food. Aquatic dependent mammals such as these as well as other species of mammals may be found utilizing the study area. In addition, several species of reptiles that are semi-aquatic and feed on stream invertebrates and fish may use the area, as well as certain species of amphibians that utilize wetlands during reproduction.

<u>Natural Areas</u>

Two components of the Des Plaines River preserved greenway are located within one mile of the Barrier System project area. The 95-acre Isle a la Cache County Forest Preserve is located to the west of the project area and the Romeoville Prairie Nature Preserve is located on 314 acres northwest of the project area. These preserves protect forest, prairie, and wetland habitats, and a portion of the Des Plaines River. The Centennial Bike Trail is also located west of the project area. It parallels the Des Plaines River and the CSSC for 11 miles from Romeo Road (135^{th} Street) to the north.

Threatened & Endangered Species

There are ten federally-listed and proposed to be listed species within the study area. There are 76 state-listed species for Will County, Illinois. (Table 4). The high quality, but vulnerable ecosystem at Lockport Prairie, supports three Federally-listed species: the Federally-endangered Leafy Prairie Clover (*Dalea foliosa*) and Hine's Emerald Dragonfly (*Somatochlora hineana*), and the Federally-threatened Lakeside Daisy (*Tetraneuris herbacea*). Lockport Prairie is located near 159^{th} Street adjacent to the Des Plaines River within a few miles of the Barrier System.

In addition, there are numerous state-listed threatened and endangered species potentially occurring within the larger project area (Appendix B, Planning). There are 76 state-listed species within Will County, Illinois, according to the Illinois Natural Heritage Database's Illinois Threatened and Endangered Species by County Distribution List INHD 2016. One state endangered species the Black-Crowned Night Heron (*Nycticorax nycticorax*) has been observed in the study area. Currently, no Black-Crowned Night Heron (*Nycticorax nycticorax*) colonies are identified within the project area. In general, there are approximately 40 plants, 5 reptiles, 2 amphibians, 1 mammal, 9 birds, 8 invertebrates, and 13 fish listed as potentially occurring within project area.

Immediate Aquatic Nuisance Species (ANS) Targets

There are two Asian carp (Cyprinidae) species of concern that are threatening to enter the Great Lakes basin via the CSSC. The following describes the current target ANS.

Bighead Carp

Bighead Carp (*Hypophthalmichthys nobilis*) can grow to a length of 51 inches and weigh up to 88 pounds. This carp feeds by filtering plankton from the water column with its large terminal and upturned mouth. This fish requires large river habitat where it reproduces prolifically and may grow rapidly. Bighead Carp has been identified as a means to remove excess nutrients in wastewater by consuming algae which grow in eutrophic water. Since it can grow to a large size, it has the potential to deplete zooplankton populations; thereby indirectly, adversely impacting all species of larval fishes, planktivorous adult fishes, and native mussels (Unionoida). Bighead Carp are native to Asia, Southern and Central China. Bighead Carp have been spotted in about 18 states in the United States and are established in Illinois within the Mississippi, Illinois and Ohio Rivers. They also can be found in the Cache, Big Muddy, Kaskaskia and Wabash Rivers and in Chain Lake.

Silver Carp

Silver Carp (*Hypophthalmichthys molitrix*) can grow to a length of 41 inches and weigh up to 110 pounds. This freshwater fish is biologically similar to the Bighead Carp and has also been stocked for phytoplankton control in eutrophic water bodies, and is used for food by humans. This fish feeds by filtering phytoplankton, zooplankton, bacteria and detritus from the water column. In great numbers, this fish could consume plankton required by larval fish, invertebrates and native mussels. Silver Carp are native to Asia and can be found in several major Pacific drainages in eastern Asia from the Amur River of Eastern Russia to the Pearl River in China. In North America the species has been documented in Alabama, Arizona, Arkansas, Colorado, Florida, Hawaii, Illinois, Indiana, Kansas, Louisiana, Missouri, Nebraska and Tennessee. In Illinois, it has been found in the Mississippi, Ohio, Cache, Illinois and Wabash Rivers, and several of their tributaries, including the Big Muddy River, Horseshoe Lake, the Cache River drainage, and the Embarras River below Lake Charleston.

Table 4 – Federally listed species potentially occurring with the Study Area

Species	Status	Preferred Habitat
Plants		
Eastern Prairie Fringed Orchid (*Platanthaera leucophaea*)	Threatened	Moderate- to high-quality wetlands, sedge meadow, marsh, and mesic to wet prairie.
Lakeside Daisy (*Hymenopsis herbacea*)	Threatened	Found in dry rocky prairies.
Leafy-prairie Clover (*Dalea foliosa*)	Endangered	Prairie remnants on soil over limestone.
Mead's Milkweed (*Asclepias meadii*)	Threatened	Late successional tallgrass prairie, tallgrass prairie converted to hay meadow, and glades or barrens with thin soil.
Reptiles and Amphibians		
Eastern Massassagua (*Sistrurus catenatus*)	Threatened	Graminoid-dominated plant communities (fens, sedge meadows, peat lands, wet prairies, open woodlands, and shrublands).
Mammals		
Northern long-eared bat (*Myotis septentrionalis*)	Threatened	Hibernates in caves and mines, swarming in surrounding wooded areas in autumn. Roosts and forages in upland forests and woods.
Invertebrates		
Hine's Emerald Dragonfly (*Somatochlora hineana*)	Endangered	Spring-fed wetlands, wet meadows, and marshes. Within Cook County, critical habitat has been designated along the Des Plaines River.
Rattlesnake-master Borer Moth (*Papaipema eryngii*)	Candidate	Undisturbed prairie and woodland openings that contain their single food source, rattlesnake master (*Eryngium yuccifolium*).
Rusty Patched Bumble Bee (*Bombus affinis*)	Endangered	Grasslands and tallgrass prairies, nesting sites (e.g., underground and abandoned rodent cavities or clumps of grasses), and overwintering sites (undisturbed soil).
Sheepnose Mussel (*Plethobasus cyphyus*)	Endangered	Found in large rivers and streams, usually in shallow areas with moderate to swift currents over coarse sand and gravel mixture. Host-specific species with glochidia found only on Sauger in the wild. In the lab, glochidia have successfully transformed on Fathead Minnow (*Pimephales promelas*), Creek Chub (*Semotilus atromaculatus*), Central Stoneroller, and Brook Stickleback (*Culaea inconstans*).

2.3 - Cultural, Archaeological, Economic & Social Resources

Archaeological & Historical Properties

One site in the study area has been listed on the National Register of Historic Places, another has been declared eligible for such a listing, and yet another is potentially eligible. The Illinois and Michigan (I&M) Canal was listed on the National Register of Historic Places by the Illinois State Historic Preservation Agency. The Chicago Lock has been determined to be eligible for the National Register of Historic Places by the Illinois State Historic Preservation Agency based on its historic engineering importance. The T. J. O'Brien Lock and Controlling Works in Chicago were determined to be a noncontributing property to the eligible National Historic Register eligible property "Chicago to Grafton, Illinois Navigable Water Link, 1839-1946". Since then the lock has become over fifty years old, making it potentially eligible for the National Register of Historic Places.

The I&M Canal is the only property within the project area that is both on the National Register of Historic Properties and that extends through all three Illinois counties. The CSSC also extends through all three counties, and although it is eligible for the National Register, it is not currently listed. Within this portion of Cook County, two properties in Western Springs are on the National Register of Historic Properties, the Western Springs First Congregational Church (listed 2006) and the Western Springs Water Tower (listed 1981). Three properties within the Village of Lemont are also listed on the National Register. These are the Lemont Central Grade School (listed 1975), the Lemont Methodist Episcopalian Church (listed 1986), and the St. James Catholic Church and Cemetery (listed 1984). With the exception of the I&M Canal, no properties in this area of Du Page County are listed on the National Register of Historic Properties. Properties listed on the National Register within this portion of Will County include the Red Round Barn (listed 1988) in Romeoville, and the five structures and two historic districts listed within Lockport, Illinois to the south of the project area. There will be no construction within the I&M Canal, and further, all of the other listed properties will be avoided and none will be within any of the selected sites within the project area.

Most prehistoric sites in the Des Plaines River, Chicago and Calumet watersheds occupy high or well-drained ground, in areas unlikely to be affected by any proposed measures; however, the historic occupation of the Des Plaines valley was focused more on water accessibility, putting the majority of historic sites within the floodplain. The region's history has been driven by its location and the developing waterway system. A trading post was established near the mouth of the Chicago River in the 1770's, followed by Fort Dearborn in 1803. Large-scale settlement in this area of northern Illinois only began after the area was ceded by the Potawatomi Indians to the United States Government in 1816 removing the threat of tribal conflict. Settlement was rapid with large numbers of German immigrants establishing farms in the area in the 1820s and 1830s. Chicago was incorporated in 1833 and granted a city charter in 1837. The city grew based on its favorable location between the Great Lakes and the Mississippi River system.

Farming was an early economic driver for the area, with grain and livestock shipped to the markets in Chicago. The first community along this stretch of the Des Plaines River was Lemont. The town was established in 1836 by land speculators gambling on future development stemming from the planned I&M Canal. The community soon served as the agricultural and commercial hub of the region. This area of Illinois experienced rapid population growth based on construction of the I&M Canal from 1837 to 1848. After 1848 Lemont served as a departure point and transit stop for canal traffic. The first railroad was constructed through Lemont in 1854 and the town later developed into a railroad community as canal traffic dwindled. The commercial importance of Lemont faded after 1900 as additional railroads and other transportation links bypassed the town. Lemont's historic buildings and proximity to the I&M Canal National Heritage Corridor have made tourism a major element of the local economy. Recently the town has also developed into a bedroom community for the growing Chicago metropolitan area. Surrounding towns include Lockport, Bolingbrook, Darien, and Romeoville.

The I&M Canal ran 96 miles (155 km) from the Chicago River at the Bridgeport neighborhood in Chicago and joining the Illinois River at LaSalle-Peru, Illinois. It was finished in 1848 and allowed boat transportation between the Great Lakes to the Mississippi River and the Gulf of Mexico. The canal enabled navigation across the Chicago Portage and helped establish Chicago as the transportation hub of the United States, opening before railroads were laid in the area. It ceased transportation operations in 1933. Portions of the canal have been filled. One segment, including a number of engineering structures, between Lockport and LaSalle-Peru, was designated a National Historic Landmark in 1964. Today much of the canal is a long, thin park with canoeing and a 62.5 mile (100 km) hiking and biking trail (constructed on the alignment of the mule tow paths). It also includes museums and historical canal buildings. It was designated the first National Heritage Corridor by the US Congress in 1984.

The CSSC was constructed to divert wastewater away from Chicago by reversing the flow of the Chicago River and directing its flow into the Illinois River drainage. Completed in 1900, the canal was also planned as a replacement for the outdated I&M, thus providing a shipping link between the Great Lakes and the Mississippi Valley. The CSSC is 28-miles long, 24-feet deep, with the width varying between 160-200-feet. The canal was extended to Joliet by 1907. The Cal-Sag Channel connected the CSSC to the Calumet River in 1922. Construction of the CSSC was the largest earth-moving operation that had been undertaken in North America up to that time, and provided important training to a number of engineers who later worked on the Panama Canal. Although not on the National Register of Historic Properties, the system has been named a Civil Engineering Monument of the Millennium by the American Society of Civil Engineers.

The presence of the I&M Canal, and later the CSSC, focused the economy of the project area toward the Des Plaines River valley and the water-based transportation of materials. Industries such as gravel quarries and refineries were developed in the region to take advantage of this transit corridor. Away from the river agriculture dominated the area's economy until recently. This portion of all three counties remained characterized by farms and widely separated small towns until the explosive development of the 1990s and early 2000s reshaped the area into suburban bedroom communities for Chicago.

A summary of Historic Properties for Illinois, the City of Chicago, and Northwest Indiana follows:

Illinois – The three counties in northeastern Illinois contain a large number of historic structures listed in the National Register of Historic Places. Cook County contains 437 individual properties as well as 65 historic districts. DuPage County has 34 individual properties and 4 historic districts on the National Register. Thirty individual properties and 6 historic districts in Will

County are on the National Register. Only a few of these properties are located adjacent to or associated with the waterway.

Chicago – Chicago maintains its own list of City Landmarks and Historic Districts totaling 256 individual structures and 47 historic districts. Many of these landmarks are also on the National Register of Historic Places. Only the city's Ogden Historic District, located directly on the Chicago River, is directly associated with the waterway.

Three properties listed on the National Register of Historic Places could be affected by changes in the operation of the Illinois Waterway. These properties include the structures within the boundaries of the Illinois and Michigan National Heritage Corridor (the Brandon Road Lock & Dam, the T.J. O'Brien Lock, the Lockport Lock, Dresden Island Lock and Dam, the Marseilles Lock, Dam, and Canal, the Starved Rock Lock and Dam Historic District, the I & M Canal, and the Chicago Sanitary and Ship Canal Historic District). The CSSC Historic District consists of three structures (Main Channel, Willow Springs Spillway, and the Lockport Controlling Works), one site (Butterfly Dam Remnant) and one district (Lockport Lock, Dam, and Power House Historic District).

Indiana – Numerous properties in northern Indiana are listed on the National Register of Historic Places. These include 34 individual properties and 6 historic districts in Lake County, 17 individual properties and three historic districts in Porter County, and thirteen individual properties and two historic districts in La Porte County.

Social Setting

The project area extends through portions of three Illinois counties, Cook, DuPage, and Will, as well as Lake County in Indiana. Cook County, Illinois has a racially and ethnically diverse population of 5,294,664 (2008) with a median household income of $73,910.00 (2004) and a median home value of $290,800. DuPage County has a median household income of $105,400 and a median home value of $421,540. For Will County, the median household income is $96,773 and the median home value is $323,900. The portions of all three Illinois counties within the project area are comprised of a number of suburban communities that form a portion of the Chicago metropolitan area with its diverse industrial and commercial base. Racial composition of the three counties is shown in Table 5.

Table 5 – Social Composition of Cook, DuPage and Will Counties.[1]

County	% White	% Black	% Asian	%White (Hispanic)	% White (non-Hispanic)
Cook	65.6	7.7	8	25.5	42.3
DuPage	80.3	5.2	12.1	14.4	67
Will	79.8	12.0	5.9	17.5	63.6

[1] Source. US Census; http://quickfacts.census.gov/cfd/states/17/17197.html

The Electric Dispersal Barriers project is located within the Village of Romeoville in Will County. The project is located adjacent to the CSSC in an area that has been heavily disturbed by past industrial development and usage. The project is situated next to a Burlington Northern-Santa Fe RR (BNSF RR) line, including a signaled crossing at 135th Street. Three residential structures are located in the adjacent parcels. The predominant land use in the vicinity of the Barrier System is commercial/industrial.

Commercial Navigation

The Chicago Sanitary and Ship Canal (CSSC) and the Calumet-Sag Channel (Cal-Sag) are the primary navigation channels that make up the Chicago portion of the Illinois Waterway also known as the Chicago Area Waterway System (CAWS). Commercial navigation provides the most cost-effective mode of transit for commodities required by several industries. The movement of these goods via the waterway contributes to both the regional and national economies. In addition to the industries that utilize the coal, iron ore and other commodities, the inland waterway industries are responsible for activities such as waterway transportation and support activities such as cargo handling, loading and unloading, terminal operations, as well as the transport of goods to and from the waterway via truck and rail. The five year average annual tonnage for the CSSC and the Cal-Sag are 25 million tons and 10 million tons respectively. To avoid double counting, the annual tonnage estimates for these navigation channels should not be summed for the CAWS.

Normally, commercial navigation is the most efficient form of transit because it takes fewer resources to move bulk commodities via waterways than by land modes such as truck and rail. While the difference between land route and waterway costs varies based on the distance between the shipment origin and destination, the economic benefit of utilizing the waterway is dependent on its relative savings to land routes. Maintaining navigable channels by dredging and lock maintenance procedures contributes to the efficiency of using waterborne transportation versus truck or rail to transport goods. Maintaining navigation is also a best practice for the environment. The transit of goods by rail and truck would consume more energy, with truck traffic requiring the most energy. Truck traffic is also a greater source of primary air pollutants, which would affect regional air quality. Moving goods by barge also reduces traffic and wear and tear on area roadways.

Recreation

The undeveloped nature of large portions of the Des Plaines River Valley, the CSSC, and the Cal-Sag Canal makes this area a popular destination for outdoor sports including bird watching, hunting, fishing and boating. The Calumet Sag region also includes a number of recreational opportunities including boat launches, forest preserves and other natural areas. Area waterways are utilized extensively during warm weather months by recreational vessels.

Hazardous, Toxic and Radioactive Waste (HTRW)

No HTRW issues have been identified at the Barrier System. Separate HTRW assessments were conducted for various portions of the project including for Permanent Barrier I, Barrier II, and in support of multiple real estate actions. These assessments are included in the project documentation as a series of reports dating from 2000 through 2016.

Chapter 3 – Asian Carp Management Strategy

3.1 - Introduction

As previously noted, the USACE is implementing a four-pronged strategy to address the threat posed by Asian carp. Operating within this framework, USACE:

(1) operates electric barriers in the water just outside of Chicago;
(2) studies the barriers' effectiveness and make adjustments, as necessary;
(3) participates in extensive monitoring of the waterways and continues research on monitoring tools; and
(4) conducts GLMRIS looking at options and technologies to prevent the transfer of aquatic nuisance species of concern between the Great Lakes and Mississippi River basins.

Barrier Operations

A significant number of analyses have been undertaken to evaluate barrier operations from two perspectives: effectiveness and safety. The analyses include laboratory and field scale testing, as well as in-situ evaluations of the barriers in operation mode. Critical evaluations considered issues including: ground current, person in the water, and metal hull effects. Detailed discussions on these critical aspects of barrier operations are contained in *Chapter 4, Safety Considerations and Operational Impacts* and *Chapter 5, Effectiveness of the Barriers*, respectively.

Monitoring & Response

The members of the ACRCC Monitoring and Response Work Group (MRWG) have continued monitoring of the CAWS for the presence of Asian carp through traditional, as well as non-traditional means. Traditional monitoring utilizes tools such as fish nets and electro-shockers. Additional methods employed by the MRWG include monitoring fish movement with telemetry, various hydroacoustic technologies, and utilizing environmental DNA (eDNA) to attempt to define the leading edge of the Asian carp population in the CAWS. Summaries of ongoing field data collection for electrofishing, telemetry and eDNA efforts are contained in *Section 3.2, Interagency Monitoring Activities*. A summary of response actions executed by the ACRCC in response to monitoring data is contained in *Section 3.3, ACRCC Response Actions*.

Efficacy Studies

The Efficacy Study is being completed through a series of reports, some of which proposed Interim Risk Reduction Measures that have been implemented. In addition to the ongoing analyses related to barrier effectiveness and barrier safety, the USACE team completed a risk assessment and developed a risk register to further consider the failure modes and to consider risk mitigation measures that would address the hazards and improve the efficacy of the Barrier System. The risk assessment is discussed in *Chapter 7, Risk Assessment*.

GLMRIS

The USACE is currently conducting the Great Lakes and Mississippi River Interbasin Study (GLMRIS). GLMRIS is investigating the options and technologies available to prevent the spread of ANS between the Great Lakes and Mississippi River basins via aquatic connections. The USACE initiated the study in 2009, commenced scoping activities in accordance with the National Environmental Policy Act (NEPA) for the study in 2010, and, to date, has released twenty-nine (29) interim products as part of GLMRIS.

Legislation set forth in Section 1538 of the Moving Ahead for Progress in the 21st Century (MAP-21) Act, Public Law 112–14, directed the Secretary of the Army (Secretary) to expedite the completion of the GLMRIS study report authorized by Section 3061(d) of Water Resources Development Act (WRDA) 2007 and, if the Secretary determines a project is justified in the completed report, to proceed directly to project preconstruction engineering and design (PED). Further, Section 1538 directed the Secretary to complete the GLMRIS report no later than 18 months after the date of enactment of MAP-21 and to submit an interim report to the Committees on Appropriations of the House of Representatives and Senate, the Committee on Environment and Public Works of the Senate and the Committee on Transportation and Infrastructure of the House of Representatives, no later than 90 days after the date of enactment of MAP-21 (October 5, 2012). In completing this report, the Secretary was directed to focus on methods to prevent the spread of ANS between the Great Lakes and Mississippi River basins, such as through hydrological separation, while focusing that analysis on specifically named watersheds associated with the CAWS. In addition, Section 1538 directs the efficient use of funds to complete the study. The Interim Report was provided to Congress on 3 October 2012. The GLMRIS Report was provided to Congress on January 6, 2014.

The GLMRIS Report provided Congress and other stakeholders with an array of alternatives. The GLMRIS Report identified several alternatives to address the problem of interbasin transfer of ANS, but full implementation of several of the alternatives would require a substantial investment of time and money. Given the potential urgency of the threat and in response to a growing consensus, the Secretary determined that further investigation of an interim measure was an appropriate next step. The Brandon Road Lock and Dam provided singular advantages for further study.

In 2015 USACE initiated work on the GLMRIS-Brandon Road Feasibility Report and integrated Environmental Impact Statement to evaluate alternatives for controlling upstream transfer of ANS from the Mississippi River Basin into the Great Lakes Basin through the CAWS, and the impacts of those alternatives on waterway uses and users. The purpose of this study is to evaluate structural and nonstructural options and technologies near the Brandon Road Lock and Dam to prevent the upstream transfer of ANS from the Mississippi River Basin into the Great Lakes Basin while minimizing impacts on existing waterway uses and users. For this study, "prevent" means the reduction of risk to the maximum extent possible, because it may not be technologically feasible to achieve an absolute solution.[1]

[1] Defining the term "prevent" to mean reducing the risk to the maximum extent possible is entirely reasonable. *Michigan v. U.S. Army Corps of Engineers*, 911 F. Supp. 2d 739, 766 (N.D. Ill. 2012), aff'd, 758 F.3d 892 (7th Cir. 2014).

In addition, establishing a one-way control point for ANS of concern could lead to new long-term solutions to prevent two-way species transfer. This scope of this study is to evaluate alternatives with the goal of preventing the upstream transfer of ANS, incorporating input from Federal, state, and local agencies and nongovernmental stakeholders. This study does not examine downstream aquatic transfer of ANS from the Great Lakes Basin to the Mississippi River Basin, nor does it examine aquatic transfer of ANS along the remaining basin divide or ANS transfer through nonaquatic pathways.

The GLMRIS-BR alternatives were purposely formulated to prevent the interbasin movement of ANS that swim (i.e., fish), float (i.e., fish eggs or larvae and plant fragments), or foul/hitchhike on vessel hulls (i.e., hull fouling crustaceans or plants attached to vessels). Three species were identified that are representative of the aforementioned modes of transport: Bighead Carp (*Hypophthalmichthys nobilis*), Silver Carp (*H. molitrix*), and *A. lacustre*. Although the GLMRIS-BR alternative evaluation was conducted specifically for these three species, the alternatives formulated are adaptable for future ANS that use these transport mechanisms.

The Draft Final Feasibility Report identified a Federal interest in preventing the upstream transfer of ANS from the Mississippi River Basin to the Great Lakes Basin through the Chicago Area Waterway System in the vicinity of the Brandon Road Lock and Dam through the planning period of analysis. The No New Federal Action (No Action) Alternative and five Action Alternatives were carried forward for analysis. The Recommended Plan is the Technology Alternative – Acoustic Fish Deterrent with Electric Barrier, which includes the following measures: (1) nonstructural activities, (2) acoustic fish deterrent, (3) air bubble curtain, (4) engineered channel, (5) electric barrier, (6) flushing lock, and (7) boat launches.

In November 2018, The Great Lakes and Mississippi River Interbasin Study – Brandon Road Final Integrated Feasibility Study and Environmental Impact Statement – Will County, Illinois was released for State and Agency Review. The report and supporting documentation are available at: https://www.mvr.usace.army.mil/Missions/Environmental-Protection-and-Restoration/GLMRIS-BrandonRoad/.

3.2 - Interagency Monitoring Activities

Monitoring

As Asian carp populations have progressed steadily northward up the Illinois River, the threat of these species gaining access to Lake Michigan and the rest of the Great Lakes has become a concern to many in the environmental community as well as among federal, state, and local government agencies. There is a potential for significant ecological and economic consequences should reproducing populations of Asian carp become established in the CAWS, Lake Michigan, and in the other Great Lakes. The presence of Asian carp in the Great Lakes could cause declines in abundances of native and stocked fish species and studies suggest that conditions in areas of the Great Lakes may be suitable for the feeding and reproduction of Asian carp (Kolar et al. 2005; Cooke, Hill 2010; Murphy & Jackson 2013). Although there are uncertainties as to the level of environmental and economic impact, federal and state partners are taking action now to reduce the risk that a sustainable population of Asian carp could threaten the Great Lakes.

The USACE is one of several agencies that has helped monitor for the presence of Asian carp within the CAWS and upper Illinois Waterway (IWW). The USACE is a member of the Monitoring and Response Work Group (MRWG). The MRWG was established by the ACRCC and is co-led by the Illinois Department of Natural Resources (IDNR) and the Great Lakes Fishery Commission (GLFC). Guided by the ACRCC Action Plan, the MRWG was assigned the task of developing and implementing a Monitoring and Response Plan (MRP) for Asian carp that were present or could gain access to the CAWS. The MRP has been released annually since the establishment of the MRWG in 2010.

The 2018 MRP includes 26 individual project plans detailing tactics and protocols to identify the location and abundance of Asian carp in the CAWS, lower Des Plaines River, and upper Illinois River, and initiate appropriate response actions to address such findings (MRWG 2018). As part of the MRPs, the USACE has participated primarily in projects listed as monitoring and barrier effectiveness evaluations. USACE supported monitoring projects include:

1) Fixed Site Monitoring Upstream of the Dispersal Barrier (2010-2011),
2) eDNA Monitoring in the CAWS and Upper Des Plaines River (2009 to 2013),
3) Fixed Site Monitoring Downstream of the Dispersal Barrier (2011 to present), and
4) Seasonal Intensive Monitoring Upstream of the Dispersal Barrier (2013 to present).

Barrier effectiveness evaluations that the USACE has participated in include:

1) Telemetry,
2) Small Fish Telemetry,
3) Dual Frequency Identification Sonar (DIDSON), and
4) Fish-Barge Interactions.

Current findings and results of the projects USACE has participated in are examined below and in *Chapter 5, Effectiveness of the Barriers*.

Electrofishing

The USACE has performed fixed site electrofishing, as part of the MRWG Monitoring and Response Plan (MRP), since 2010. USACE has concentrated electrofishing efforts on habitats located downstream of the Electric Dispersal Barriers. These efforts supplement the existing efforts downstream of the barriers as outlined in the 2011 through 2018 MRPs. Objectives of the study are to 1) assess the risk of aquatic nuisance species to challenge the Electric Dispersal Barriers and 2) track the leading edge of Asian carp.

In 2011, electrofishing surveys were conducted monthly from June through November in the Lockport (Figure 12) and Brandon Road (Figure 13) pools. Each survey consisted of eight fixed sites that were electrofished for 15 minutes each. All fish were collected, counted, and identified to species before being released. A total of 3336 fish comprising 24 species were captured in the lower Lockport pool while 2419 fish comprising 32 species were collected from the Brandon Road pool. Species richness was greater overall and from month to month in the Brandon Road pool while total abundance of fishes was greater in the lower Lockport pool. Gizzard Shad (*Dorosoma cepedianum*) dominated the majority of fishes caught comprising approximately 84% of the total catch. During 2011, no live Asian carp were captured or observed over the course of the sampling season; however, two dead Silver Carp were observed on barge decking below Lockport Lock.

The USACE electrofishing survey in 2012 continued sampling at the downstream fixed sites within the Lockport and Brandon Road pools and was conducted monthly for a total of six trips from March through November. Sampling was conducted by the IDNR July through September due to USACE equipment malfunction. For the six sampling events completed, a total of 3006 fish comprising 29 species were collected from the lower Lockport pool while 1486 fish comprising 39 species were collected from Brandon Road pool. Similar patterns in the catch between the two pools persisted from the previous year with Gizzard Shad composing the majority of the catch and Common Carp being the second most common. Three state threatened Banded Killifish (*Fundulus diaphanus*) were captured within the Lockport pool in October and November as water temperatures dropped and dissolved oxygen was on the rise. While no Bighead or Silver Carp were captured or observed within the fixed site electrofishing runs, one Grass Carp (*Ctenopharyngodon idella*) was captured just downstream of the Lockport Lock. Additional non-native species to the Great Lakes captured from both pools throughout the year include White Perch (*Morone americana*), Oriental Weatherfish (*Misgurnus anguillicaudatus*), Goldfish (*Carassius auratus*), Common Carp (*Cyprinus carpio*), Round Goby (*Neogobius melanostomus*), Threadfin Shad (*Dorosoma petenense*) and Skipjack Herring (*Alosa chrysochloris*).

In 2013, the USACE continued participation in Asian carp monitoring with electrofishing surveys. Based on results from the previous years, monitoring effort was decreased upstream of the Dispersal Barrier System and re-allocated downstream. As a result, four fixed sites and four randomly generated sites were sampled bi-monthly from March through November in both lower Lockport and Brandon Road Pools. A total of 32 electrofishing trips resulted in 14,433 fish captured across both lower Lockport and Brandon Road pools. Lockport consisted of 7,921 fish comprising of 26 species and 2 hybrids while Brandon Road consisted of 6,512 fish comprising of 41 species and 2 hybrids. Gizzard Shad where the most abundant species captured in both pools followed by Emerald Shiner (*Notropis atherinoides*), Common Carp, and Pumpkinseed

(*Lepomis gibbosus*). No Silver or Bighead Carp were observed or captured in Brandon Road or Lockport pool in 2013, however five Grass Carp were captured in Brandon Road pool and one was captured in Lockport pool.

In 2014, electrofishing effort was further increased downstream of the Electric Dispersal Barrier by adding four additional random sites resulting in a total of four fixed sites and eight random sites within each of lower Lockport and Brandon road pools. Despite the increased effort, the number of trips remained 32 as in 2013. A total of 4,082 fish comprised of 30 species and one hybrid group were captured in Lockport pool and 4,976 fish from 37 species and two hybrid groups were captured in Brandon road pool. Similar to previous years, the majority of the fish captured consisted of Gizzard Shad followed by Common Carp, Threadfin Shad, and Emerald Shiners. No Silver or Bighead Carp were observed or captured in Lockport or Brandon Road Pools in 2014.

Electrofishing protocols in 2015 remained the same as 2014 in Lockport and Brandon Road pools, however there were only 22 days of electrofishing trips. The difference in days was due to IDNR's determination that electrofishing was not needed during the months of the seasonal intensive monitoring events. As a result of the reduced effort, 2,067 individual fish comprised of 26 species were captured in Lockport Pool and 2,166 individual fish from 33 species and one hybrid group were captured in Brandon Road pool. Gizzard Shad, Common Carp, Emerald Shiner and Largemouth Bass were the most common species captured in Lockport and Brandon Road Pools. No live Silver or Bighead Carp were observed or captured in Lockport or Brandon Road Pools in 2015.

In 2016, protocols within Lockport and Brandon Road Pools remained unchanged. However, IDNR that USACE, Chicago District conduct one day of targeted electrofishing in Dresden Island pool per month. Targeted sites in Dresden Island pool consisted of areas that are most likely to hold Asian Carp. In general, the sites included side channel and backwater habitats to better understand how Asian Carp are using the pool and assist in the removal of them within the northern edge of their range. A total of 30 trips of electrofishing were conducted in Lockport and Brandon Road pools in 2016, which consisted of a total of 360 15-min fixed and random site surveys. A total of 68 15-min targeted electrofishing surveys were conducted in Dresden Island pool. A total of 5,788 individuals from 28 species and 1 hybrid group were captured in Lockport and Brandon Road pools. An additional 2,922 individuals from 56 species and 3 hybrid groups were captured in Dresden Island pool. A total of 7 Asian Carp were captured in Dresden Island pool by USACE electrofishing crews. Combined, Gizzard Shad, Threadfin Shad, Smallmouth Buffalo, Largemouth Bass, and Bluegill were the most common species captured.

There were no changes to the fixed, random, and targeted site electrofishing protocols for monitoring in the Lockport, Brandon Road, and Dresden Island pools in 2017. A total of 24 electrofishing trips to the Lockport and Brandon Road pools occurred from 4 April through 20 November 2017. A total of 4604 individual specimens were collected from the Lockport pool representing 30 species and one hybrid group. Another 3281 specimens were collected from the Brandon Road pool representing 39 species and 3 hybrid groups. No Asian carps were collected or observed from the Lockport or Brandon Road pools. There were a total of five trips to the Dresden Island Pool in 2017 from April to November. Dresden Island pool was not sampled as part of targeted sampling efforts in August, September, or October due to alternative monitoring activities. Efforts within the Dresden Island pool resulted in the capture of 1262 specimens representing 38 species. One Bighead Carp and four Silver Carp were captured within the Dresden Island pool in 2017 through targeted electrofishing surveys.

Figure 12 – Fixed site electrofishing locations in the lower Lockport pool.

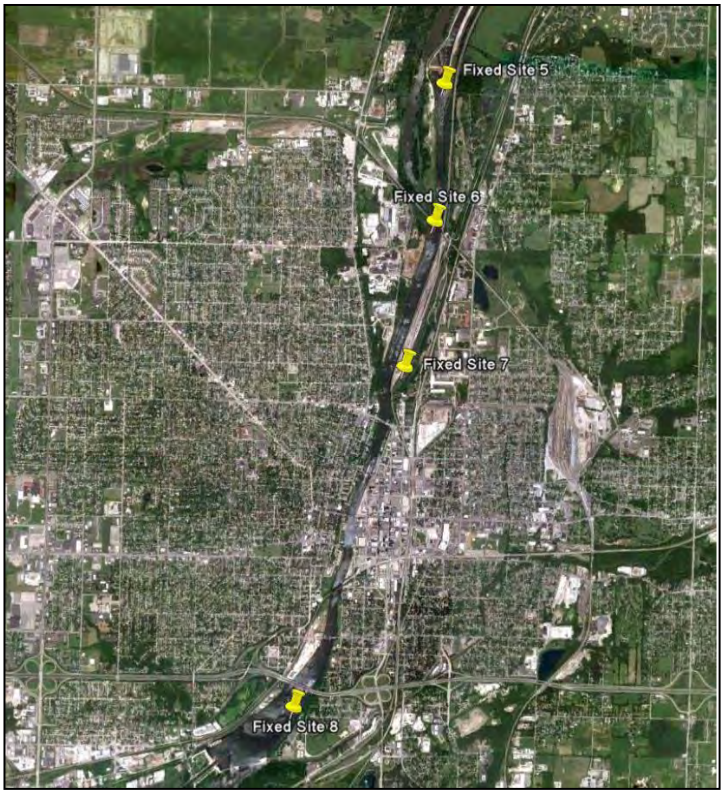


Figure 13 – Fixed site electrofishing locations in the Brandon Road pool.

<u>Ultrasonic Telemetry</u>

In 2010, the USACE ultrasonic telemetry monitoring project set out to: 1) determine if fish are able to challenge and/or penetrate the Dispersal Barrier System; 2) investigate the ability of Asian carp to navigate through lock structures in the upper Illinois River, lower Des Plaines River, and CAWS; 3) determine the location of the leading edge of the Asian carp population front; and 4) examine responses of adult and small fish to the barriers (ACRCC MRWG 2012). The project involves surgically implanting individually coded ultrasonic transmitter tags in Bighead Carp, Silver Carp and surrogate species and then monitoring movements with a series of stationary and mobile hydrophones. The results for tagged Asian carp are discussed here. Results for use of tagged surrogate species to test the effectiveness of the barriers are presented in *Section 5.6, Field Studies Investigating Effectiveness of the CSSC Barriers*.

During 2010, 17 Bighead Carp were tagged in the Dresden Island pool (ACRCC MRWG 2012). During 2012, 60 Asian carp from the Marseilles and Dresden Island pools were targeted for telemetry tag implantation; however, Asian carp during tagging events were only captured within the Marseilles pool. Within the Marseilles pool, 15 Silver and 16 Bighead Carp were tagged and released on the week of 15 October 2012.

No Asian carp were observed to pass upstream into the Brandon Road pool. With the exception of the one Bighead Carp detected at the Brandon Road lock within the Dresden Island pool, all Asian carp have remained in the lower portions of that pool near the mouth of the Kankakee River. Additionally, only one of the tagged Asian carp within the Dresden Island pool traveled downstream into the Marseilles pool approximately 10 miles before returning to the Dresden

Island pool five days later. Tracking data on these Asian carp indicate strong schooling patterns and dispersal from their release point. All tracked fish were observed either within backwater areas or on the shoreward side of small islands.

In April 2013 an additional 25 Asian carp were tagged—20 Bighead, 3 Silver, and 2 hybrid. These fish were captured in Rock Run Rookery (RRR), a connected backwater to the Dresden Island pool, five were released within RRR and the remaining 20 were released in the main river channel. Telemetry mobile tracking was completed in the Dresden Island Pool on 23 April following a significant flooding event. Only 7 of 25 tagged Asian carp were tracked within the pool and all below the release points. The majority of detections occurred near the mouth of the Kankakee River. Three additional tagged Bighead Carp were detected at the mouth of the DuPage River as it connects with the Des Plaines River. In addition, 17 out of the 25 Asian carp were detected within or near RRR throughout 2013. Many fish moved in and out of RRR, migrating between the backwater habitat of RRR and the confluence of the Kankakee River. One bighead detected at RRR was also observed to pass into the Marseilles pool and continue all the way down to the Marseilles Lock. Analysis from 2013 also demonstrated that Asian carp are more active during the spring and summer months and display diel variations in movement with most movement occurring at crepuscular (dawn and dusk) and night time periods.

Eight more Asian carp—3 Silver and 5 Bighead—were tagged in 2014. After 2013 it became apparent that Asian carp are using the confluence of the Kankakee and RRR more frequently than other areas within the Dresden Island pool. Environmental data (flow and temperature) was acquired through USGS Surface-Water Data website (http://waterdata.usgs.gov/nwis/sw) to determine when Asian carp were using the two different areas. Analysis demonstrated that Asian carp were using the Kankakee during increased flow when temperatures were within the preferred range for spawning (18° to 30° C). The data also suggested that RRR is used as habitat during low flow and at colder temperatures. Some fish seemed to overwinter at RRR, but still made several trips to and from the Kankakee River during high flows. Surprisingly, Asian carp are leaving RRR and heading downstream during high flows rather than upstream which is most common of a riverine species. As of December 2014, only two tagged Asian carp have been detected near the Brandon Road Lock and Dam. This data suggests the leading population front is still located within the Dresden Island Pool.

Approximately 106 tags were placed into surrogate fish species (Common Carp) and Asian Carp in 2015. In terms of barrier efficacy, two main goals were assessed. USACE continued to investigate whether or not fish downstream of the barrier can penetrate the Electric Dispersal Barrier System. Of the 69 total tagged Common Carp downstream of the barrier, 24 of them were detected around the Vemco Positioning System around the Electric Dispersal Barrier System. During the time of study, none of the 24 detected fish were able to penetrate the Electric Dispersal Barrier System. USACE also released fish with depth sensors to determine how fish behave within the Electric Dispersal Barrier System and how they behave in terms of water depth as they approach the barrier. All fish released between IIA and IIB died very quickly. In general, fish utilized the whole water column while approaching the electric field. One fish was released upstream of Barrier IIB and passed downstream through the barrier and survived as USACE continued to receive detections on several receivers downstream of the Electric Dispersal Barrier System. Additional tags placed into Asian Carp were used to look at movement patterns and differences between Common Carp surrogates. Mean distance traveled per day was higher in Asian Carp ((mean ± SD) 0.71± 0.39) than Common Carp (0.51 ±0.45), but was not significantly different. In 2015, USACE observed tagged Asian Carp further upstream on the Kankakee River than previous years. A total of 85 detections from 12 Asian Carp were detected on a receiver just downstream of the Wilmington Dam in Wilmington, Illinois. The Kankakee River was at flood stage for a much longer time frame than previous years and this may have accounted for the increased detections. Overall, telemetry data suggests that the population front for Asian Carp continues to be similar to prior sampling years.

A total of 25 new acoustic tags were placed in surrogate fish in 2016, resulting in a total of 215 active tags for some portion of 2016 from Dresden Island Lock and Dam to the Electric Dispersal Barrier. A total of 75 tags in Lockport pool below the Electric Dispersal Barrier were active at some point throughout 2016. No tagged fish were detected upstream of the Electric Dispersal Barrier in 2016. In attempt to determine how fish are using various habitats an analysis of location and residency times were conducted to determine where fish are located at various part of the year within Lockport Pool. USACE was able to determine that fish are most frequently located at or adjacent to fixed electrofishing sites, validating that our electrofishing sites are appropriate locations for sampling. In addition, USACE determined that a majority of tagged fish were detected just downstream of the Electric Dispersal Barrier but had low residency time, meaning they don't stay near the barrier for long and return back downstream. In terms of Asian Carp telemetry in Dresden Island, several new receivers were placed to learn more about the frequency of use in the Kankakee River. Two receivers were placed upstream of Wilmington Dam and one was placed just upstream of the confluence of the Kankakee and Des Plaines Rivers. No tagged Asian Carp were detected upstream of Wilmington Dam. The receiver just upstream of the confluence had over 50% of the total detections for all of Dresden Island Pool. The receiver is near shallow vegetated habitat, side channel habitat, backwater habitat (harbor slips) and close to an outfall from the I&M Canal. These habitat types may be an attractant to Asian carp, and the placement allows for fish to be detected as they move from the upper portion of the pool to the lower pool as well. Further investigations of fish detections at this station showed fish that tended to move through the area with only a few detections, other fish seemed to stage in the area for several days before moving up or downstream, and some fish appeared to use the area for a majority of the year and make minor movements into the Kankakee or upstream before returning to the area.

Eight Asian carp within the Dresden Island pool and 25 surrogate Common Carp were implanted with new transmitters in 2017 bringing the total number of fishes tagged to 590 since 2010. As of December 2017, there have been over 28.2 million detections of these tagged fishes within the Lockport, Brandon Road, and Dresden Island pools. This data has helped verify movement patterns, increase catch efficiencies of alternate gear types, and has demonstrated the effectiveness of the Electric Dispersal Barrier System to deter large bodied fishes. Data collected from 2017 has highlighted seasonal patterns of habitat use by surrogate Common Carp within the Lockport and Brandon Road pools as well as Asian carps within the Dresden Island pool. Inter-pool movement data was summarized in the Interim Summary Report (MRWG 2017) of the MRP findings reporting only 11 passages of Common Carp through the Brandon Road Lock. There have been five upstream and six downstream passages at Brandon Road accounting for 13% of the total inter-pool movements. Lockport passages accounted for 57% of all inter-pool movement with over 75% of that movement in the downstream direction. Many fishes within the Lockport Pool below the barriers are transferred downstream through the Lockport Controlling Works flood control structure in addition to the lock chamber. Detection data of Asian carp within the Dresden Island pool in 2017 indicated similar habitat use patterns as previous years and no change to the gradient of detections along the river system with successively fewer detections as you move upstream. There were two Bighead Carp detected within the approach channel to Brandon Road Lock in 2016 and another in 2017. There have been no Asian carp detected within the lock chamber at Brandon Road and detections within the vicinity continue to be rare.

eDNA

As part of a comprehensive review in the fall of 2008, USACE assessed the full suite of methods available to locate and monitor Asian carp as they migrated up the Illinois River. These fish sampling tools were evaluated for their ability to deliver a high level of confidence that USACE could locate the leading edge of Asian carp populations. USACE concluded that the available tools, principally netting and electrofishing conducted primarily by partner agencies, could effectively locate Asian carp when the populations are high, but they were not necessarily effective in locating the fish when population numbers are low. Because this type of a populations leading edge is generally comprised of a few individuals, traditional sampling methods do not provide a good indication of their presence, and consequently additional technologies were investigated.

Researchers at the University of Notre Dame were the first to apply a technique, environmental DNA (eDNA) analysis, locally in an aquatic system for an invasive species. Environmental DNA (eDNA) analysis is presently the most sensitive technology available to detect the possible presence of Silver and Bighead Carps in the aquatic environment (Jerde et. al., 2011). In this method, water samples with suspended solids are taken from waterways (with many containing fish feces, scales, and other tissue with DNA). Please refer to Figure 14 for the general location of waterways sampled. The suspended solids are removed and then tested using DNA technology to identify the DNA markers of a target species, in this case, Silver and Bighead Carp, and the results are then reported. In August 2009, identification of Asian carp DNA in the Brandon Road pool, just over 6 miles downstream of the Electric Dispersal Barrier, triggered the Corps' decision to increase the electrical output of Barrier IIA from 1 volt per inch, 5 hertz, 4 milliseconds to 2 volts per inch, 15 hertz, 6.5 milliseconds, although live Bighead and Silver Carp had not been visually identified in that location.

In 2009, the University of Notre Dame led eDNA monitoring efforts. Following a period of negative results of tests for Asian carp DNA above the Electric Dispersal Barrier, on November 17, 2009 Asian carp DNA was detected in the Cal-Sag Channel and Calumet River near the O'Brien Lock. The detection was in three areas ranging from 10 to 30 miles upstream of the Electric Dispersal Barrier. An intensive fishing effort followed and although over 1,000 fish were caught near the O'Brien Lock, none of them were the target Asian carp species. Detection of Asian carp DNA was reported north of the barrier near the Wilmette Pumping Station and lakeward of the O'Brien Lock during the 2009 field season.

Beginning in the fall of 2010, eDNA monitoring was transitioned from the University of Notre Dame. The USACE assumed a lead role for eDNA monitoring, responsible for coordinating sampling, processing samples, and posting results. The U.S. Fish and Wildlife Service (USFWS) and IDNR became responsible for collecting samples. Under the direction of the MRWG's Monitoring and Response Plan (MRP), eDNA monitoring was a surveillance tool used to monitor for the genetic presence of Bighead or Silver Carp, and used as part of a comprehensive set of methods to assess and identify where more efforts were needed to prevent self-sustaining populations of Asian carp from establishing in the Great Lakes.

Objectives of the 2010 eDNA monitoring effort were: 1) sample the Des Plaines River to determine whether Asian carp DNA is present in the Des Plaines River, which may indicate an increased risk of Asian carp bypassing the Electric Dispersal Barrier during Des Plaines River flooding and 2) sample for Asian carp DNA in close proximity to barriers leading to Lake Michigan to determine whether Asian carp DNA is accumulating below structures that impede fish passage into Lake Michigan.

As part of regular weekly eDNA monitoring, a total of 958 water samples were collected and analyzed along with 51 control samples during the 2010 season. Seven samples tested positive for Silver Carp DNA and four samples tested positive for Bighead Carp DNA in reaches above the Electric Dispersal Barrier. The mean temperature for samples testing positive for Asian carp DNA was 17.3ºC (Standard Deviation (SD) $\pm$ 4.27), while the mean temperature for samples testing negative was 16.2ºC (SD$\pm$5.28). Mean channel depth for samples testing positive for Asian carp DNA was 4.59 m (SD$\pm$2.94), while mean depth for samples testing negative was 4.7 m (SD$\pm$2.98). Total sampling effort for the 2010 season was 240 estimated person-hours spent in the collection and filtering of 1,458 liters of water collected throughout the CAWS.

In late 2011, the Asian Carp Regional Coordinating Committee (ACRCC) funded a study to better understand eDNA. This study was referred to as the eDNA Calibration Study (ECALS). The main purpose of ECALS was to improve the application of the eDNA methodology to assess and mange uncertainty. ECALS investigated alternate sources of Asian carp DNA, improved existing genetic markers and investigated the relationship between the number and distribution of positive eDNA samples with the density of Asian carp populations. The results of this study would allow the agencies to better interpret eDNA results, as well as investigate ways to make the eDNA process more efficient (decrease processing time and cost). The ECALS report is available for download at https://www.asiancarp.us/ecals.html.

In 2011, eDNA monitoring continued to be led by the USACE, USFWS, and IDNR. As per the 2011 MRP released by the MRWG, use of the eDNA methodology was to continue to aid in the monitoring for the presence of Asian carp in the CAWS. Objectives for the 2011 eDNA monitoring were: 1) determine whether Asian carp DNA is accumulating in Lake Calumet and below structures that impede fish passage into Lake Michigan, 2) detect Asian carp DNA in areas targeted for rapid response actions as a measure of the effectiveness of conventional gear or rotenone removal efforts, 3) determine the instantaneous distribution of Asian carp DNA in the CAWS, 4) monitor for the presence of Asian carp DNA in other strategically important areas, such as the upper Des Plaines River below Hofmann Dam, confluence of the CSSC and Calumet-Sag Channel, and the Lockport pool of the Chicago Sanitary & Ship Canal (CSSC) immediately upstream and downstream of the Electric Dispersal Barrier. The focus on Lake Calumet was the result of prior eDNA results, the capture of a live Asian carp in Lake Calumet in 2010, and the suitability of the habitat in Lake Calumet for Asian carp.

As part of regular weekly monitoring, a total of 1,865 water samples were collected and analyzed along with 93 control samples during the 2011 field season. Twenty (20) samples tested positive for Silver Carp DNA and zero (0) samples tested positive for Bighead Carp DNA in reaches above the Electric Dispersal Barrier. The mean temperature for samples testing positive for Asian carp DNA was 22.2ºC (SD+5.32), while the mean temperature for samples testing negative was 22.8ºC (SD+3.98). Mean channel depth for samples testing positive for Asian carp DNA was 3.0 m (SD+2.61), while mean depth for samples testing negative was 3.41 m (SD+2.46). Total sampling effort for the 2011 season was 697 estimated person-hours spent in the collection and filtering of 3,730 liters of water collected throughout the CAWS.

Also during 2011, the USACE took part in the eDNA "Snap-Shot" strategy proposed as part of the 2011 MRP. The goal of the strategy was to test the viability of the assumption that a small number of Asian carp (or some other contributing source of genetic material) were causing eDNA positive results in different locations of the CAWS. The USACE, USFWS, IDNR and USEPA provided support for this effort that occurred October 25 through October 27 and concluded eDNA sampling for the 2011 field season. As part of the snap-shot event a total of 684 water samples were collected and analyzed along with 36 control samples. All of the water samples were collected above the Electric Dispersal Barrier in the CAWS. Sixteen (16) samples returned positives for Silver Carp DNA while zero (0) samples returned positives for Bighead Carp DNA. Temperature and depth information were recorded for each sample collected; however, four of the sampling locations on 25 October had only depth recorded due to temporary equipment failure. The mean temperature for 16 samples testing positive for Asian carp DNA was 13.0ºC (SD+1.55), while the mean temperature for 664 samples testing negative was 13.9ºC (SD+3.10). Mean channel depth for 16 samples testing positive for Asian carp DNA was 3.8 m (SD+2.80), while mean depth for 668 samples testing negative was 3.9 m (SD+2.88). Sampling effort for the snapshot was 183.5 estimated person-hours spent in the collection and filtering of 1,482 liters of water.

In 2012, eDNA monitoring continued to be led by the USACE with support from USFWS, and IDNR. As per the 2012 MRP released by the MRWG, use of the eDNA methodology was to continue to aid in the monitoring for the presence of Asian carp in the CAWS. Objectives for the 2012 eDNA monitoring were: 1) determine whether Asian carp DNA is present in strategic locations in the CAWS to help guide Rapid Response actions; and 2) detect Asian carp DNA in areas targeted for rapid response actions as a measure of the effectiveness of conventional gear or rotenone removal efforts.

As part of regular weekly monitoring, a total of 1,196 water samples were collected and analyzed along with 64 control samples during the 2012 field season. One-hundred fifty-three (153) samples were positive for Silver Carp DNA and four (4) samples were positive for Bighead Carp DNA in reaches above the Electric Dispersal Barrier. The mean temperature for samples testing positive for Asian carp DNA was 20.0ºC (SD+4.46), while the mean temperature for samples testing negative was 22.3ºC (SD+4.08). Mean channel depth for samples testing positive for Asian carp DNA was 2.9 m (SD+2.69), while mean depth for samples testing negative was 2.5 m (SD+2.38). In addition, dissolved oxygen concentration, mean conductivity, and pH data were collected. Mean dissolved oxygen concentration for samples testing positive for Asian carp DNA was 6.19 mg/L (SD+3.18) while mean DO for samples testing negative was 7.88 mg/L (SD+2.74). Mean conductivity for samples testing positive for Asian carp DNA was 519.61 µS/cm (SD+237.68) while mean conductivity for samples testing negative was 532.15 µS/cm (SD+285.75). Finally, mean pH for samples testing positive for Asian carp DNA was 7.71 (SD+0.37) while mean pH for samples testing negative was 7.84 (SD+0.41). Total sampling effort for the 2012 season was 428 estimated person-hours spent in the collection and filtering of 2,420 liters of water collected throughout the CAWS.

In 2013, the USFWS assumed responsibility of coordinating sampling and filtering in the field (Fish and Wildlife Conservation Offices; FWCO) and laboratory analysis (Whitney Genetics Lab; WGL) (MRWG 2013b). Environmental DNA sampling was used as a surveillance tool to monitor for the genetic presence of Bighead Carp and Silver Carp, complementary to traditional methods of sampling. However, the resulting data were no longer used as a trigger for response actions. Instead, objectives for eDNA sampling in 2013 were to: 1) determine whether Asian carp DNA is present in strategic locations in the CAWS and if it could be used to inform status of Asian carp; and 2) detect Asian carp DNA in areas that have been monitored since 2009 to maintain annual data collection which may inform future work in the CAWS. Comprehensive sampling in the CAWS occurred in June and November 2013. A total of 417 samples along with 23 control samples were collected and analyzed upstream of the Electric Dispersal Barriers. The June event had 18 positive detections for Silver Carp and the November event had three (3) positive detections for Silver Carp. There were no positive detections for Bighead Carp during either sampling event (MRWG 2013b).

In 2014, the FWS continued responsibility of coordinating sampling and filtering in the field to meet the following two objectives outlined in the 2014 Monitoring and Response Plan (MRWG 2014a): 1) monitoring Asian carp DNA in strategic locations in the CAWS could be used to inform status of Asian carp; and 2) detect Asian carp DNA in areas that have been monitored since 2009 to maintain annual data collection which may inform future work in the CAWS. During 2014, the FWS conducted two comprehensive eDNA sampling events that took place in the CAWS at four regular monitoring sites. A total of 456 water samples were collected and analyzed. For the June comprehensive sampling event, the FWS detected Silver Carp eDNA in seven (7) water samples and detected one Bighead Carp eDNA in water samples. For the October comprehensive sampling event, the FWS detected Silver Carp eDNA in 23 water samples and detected no Bighead Carp eDNA. Additionally in 2014, the FWS began using new markers for Bighead Carp and Silver Carp. These markers were designed to reduce false negative results by being less sensitive to inhibition (qPCR). FWS also used cPCR, the technique used to analyze samples from 2009 to 2013, as a comparison for qPCR results. In 2014, there were 17 cPCR detections and 30 qPCR detections for Silver Carp from 456 water samples. For Bighead Carp there were zero cPCR detections out of 228 water samples (samples not analyzed via cPCR for Bighead Carp during October because there were no qPCR detections) and one1 qPCR detection out of 456 water samples (MRWG 2014b).

USFWS completed one eDNA sampling event in 2015. A total of 240 samples were collected upstream of the Electric Dispersal Barriers. All 240 samples came back negative for both Bighead and Silver Carp DNA. In addition to upstream of the Electric Dispersal Barriers, FWS analyzed 720 samples from Lockport Pool to Marseilles Pool to potentially help inform the current status of Asian Carp within the CAWS. No Positive samples for Silver Carp, Bighead Carp, or Both species were recorded in Lockport or Brandon Road Pools. A total of 18 positive samples were observed in the Dresden Island Pool and Kankakee River while 49 positive samples were detected in Marseilles. These data support the observed gradient of Asian Carp populations across the pools. It is important to mention that during one of the sampling trips in Marseilles, fish were observed spawning and yet less samples came back positive than the previous sample date. eDNA continues to help provide surveillance, but further refinement is needed to maximize the tool.

USFWS also completed one eDNA sampling event upstream of the Electric Dispersal Barriers in 2016. A total of 240 water samples were collected and analyzed from four monitoring sites. The results indicate that one positive detection for both species of Asian Carp DNA was found. In addition to the upstream sampling event, two sampling events occurred downstream of the Electric Dispersal Barriers from lower Lockport to the upper half of Dresden Island Pool and in portions of the Kankakee River. A total of 248 samples were collected prior to spawning activity in April and after spawning activity in September. One sample was positive for Silver Carp DNA I April and no positive samples were found in September. Continued eDNA sampling is planned to continue to maintain vigilance and changes in the status quo as it may provide evidence for a change in Asian Carp populations.

Two eDNA sampling events occurred within the CAWS upstream of the Electric Dispersal Barrier System in 2017 for total of 520 individual water samples. The first 240 water samples were collected during a planned comprehensive monitoring event at four fixed sites which are annually sampled. The following 280 water samples were collected in June 2017 following the capture of a single Silver Carp within the Little Calumet River upstream of the Electric Dispersal Barriers approximately 9 miles from Lake Michigan and just downstream of the T.J. O'Brien Lock and Dam (see Section 3.3 ACRCC Response Actions for further details on Asian carp detected within the Lockport pool). There were zero positive detections for Bighead and Silver Carp following processing and analysis of the collected water samples. An additional two eDNA sampling events occurred within the Dresden Island pool in May and September 2017 with 276 water samples collected in each event to improve the interpretation of results along an active invasion front of these invasive species (MRWG 2017). Approximately 3% of samples returned positive results in May (n=8) and 6% in September (n=17).

Currently, eDNA is used only to provide an indicator of the presence of Asian carp DNA. The current state of the science does not answer such important questions as whether the DNA came from live or dead carp or why the DNA might be present at any given location. The USACE, in coordination with other stakeholders, has and continues to conduct additional studies (i.e., eDNA Calibration Study) to determine what eDNA tells about Asian carp presence in the field. The eDNA Calibration Study (ECALS) https://www.asiancarp.us/ecals.html. Further discussion on interagency response actions is contained in *Section 3.3, ACRCC Response Actions*.

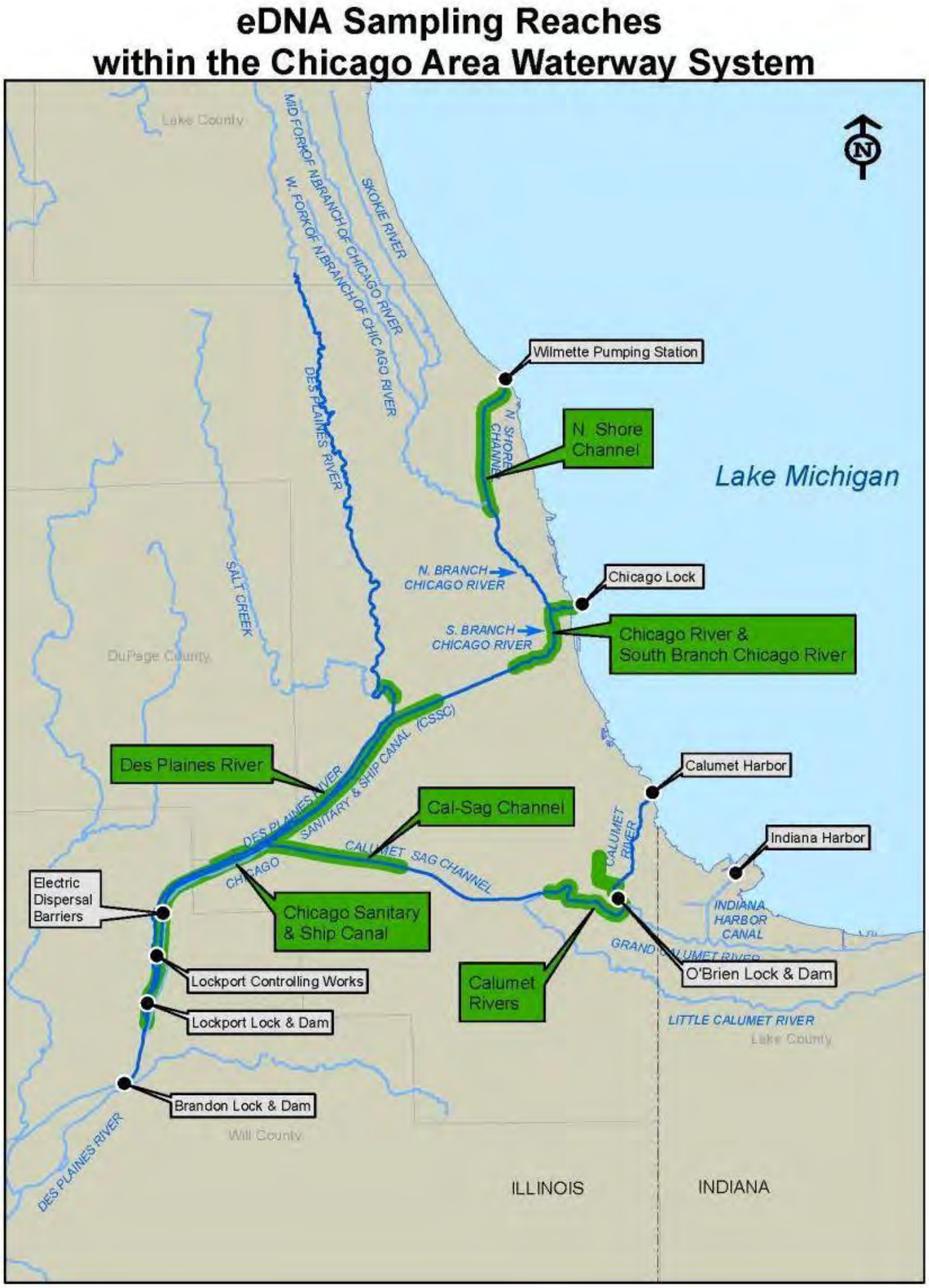


Figure 14 – CAWS Sampling Locations, eDNA.

3.3 - ACRCC Response Actions

Members of the MRWG, including staff from USACE, IDNR and USFWS completed eleven response actions with conventional fishing gears and rotenone in the CAWS upstream of the Dispersal Barrier from 2010 to 2011. All responses, with the exception of the June 2010 response action, were triggered by eDNA monitoring results. The June 2010 intensive, collaborative action was in response to a live Bighead Carp captured in Lake Calumet during routine fixed site monitoring in that area.

The MRWG estimated that over 9,700 person-hours were spent to complete 111 hours of electrofishing, set 31.8 miles of trammel/gill net, treat 2.5 miles (173 acres) of river with rotenone, make four 800-yard long commercial seine hauls, and deploy four tandem trap nets equal to 22.5 net-days of effort for the 2010-2011 response actions. Across all response actions and gears, agency staff sampled over 108,057 fish representing 52 species and 2 hybrid groups. No Bighead or Silver Carp were captured or observed during response actions, nor were positive detections for Asian carp DNA reported from eDNA samples taken immediately before conventional gear and rotenone sampling. (MRRWG 2010, 2011a, 2011b). Post-processing of the Bighead Carp captured in Lake Calumet in 2010 indicated that it was a six year old fish which had originated in the Illinois River and then moved to or was transported to Lake Calumet or Lake Michigan early on in its life (ILDNR 2010). The above described effort includes the multi-agency response with traditional gears such as electrofishing, seines, trammel/gill nets, and traps which were deployed following the capture of the Bighead Carp. No additional Asian carps were captured or observed in that

The MRWG completed five response actions in 2012: North Shore Channel, Chicago River and three response actions in Lake Calumet. Rotenone was not used during 2012 response actions. These response actions were labor intensive and employed extensive sampling effort targeting any Asian carp that might be present in the waterway. An estimated 1,630 person-hours were spent on 2012 response actions. Total effort for all responses in 2012 was 59 hours of electrofishing (250 transects), 18.4 miles of trammel/gill net (180 sets), 1.4 miles of commercial seining (3 hauls), 7.6 trap net-days, 19.1 hoop net-days, and 3.6 pound net-days. Across all actions and gears in 2012, 29,818 fish were collected representing 53 species and 2 hybrid groups. Gizzard Shad, Bluegill and Common Carp were the numerically dominant species sampled. No Bighead or Silver Carp were captured or observed during any of the response actions in 2012. In addition, MRWG team members examined 5,731 Gizzard shad young-of-year and found no Asian carp. Three of the five response actions were triggered by three consecutive positive eDNA detections for Bighead and/or Silver Carp within a particular location.

Beginning in the 2013 sampling season, the MRWG proposed a new framework to guide management decisions on response actions in the CAWS where eDNA would no longer be a response trigger. As calibrations studies on eDNA technology continued to identify alternate vectors for eDNA into the CAWS besides a live fish and identified further uncertainties associated with interactions between environmental variables and the persistence, detection rate and degradation rates with eDNA, it was determined that only a live capture or observation by a credible source of Asian carp would trigger a response action by the MRWG.. In order to be vigilant and ensure monitoring actions are still in place upstream of the barriers, a seasonal intensive sampling plan was developed which mimicked response actions at fixed and random sites. These seasonal intensive sampling events are conducted twice each year, once in the spring and once in the fall. Each event consists of two weeks of effort including but not limited to collection techniques such as pulsed DC-electrofishing, trammel and gill nets, deep water gill nets and a commercial seine.

A description of various gear used during monitoring and response actions follows:

Gillnet - A passive capture device in which fishes are captured by becoming wedged or tangled in a single panel of netting.
Hoop net - A passive capture device consisting of mesh-covered hoops and funnel-shaped throats for capturing fishes a fish can easily find its way into the net through the funnels, but not out of it.
Block net - A net used to enclose an area that is being samples by electrofishing, seining, or other active sampling methods. Block nets prevent movement of fish in or out of an area while sampling.
Fyke net - A passive capture device in including a lead net that directs fishes into a trap that contains funnels. A fish can readily find its way into the trap through the funnels, not out of it.
Pound net – A passive capture device, similar to a trap net, but often at a larger scale. Typically pounds nets are composed of a series of nets that are staked upright within the water column with a lead line to draw fish into a small entrance. The design is such that fish can enter easily and is difficult to find a way out. At the back of the net structure is a rectangle "pound" that fish can be herded into and removed by fishermen.
Seine - An active capture deice used in fisheries work consisting of a panel of netting that is pulled through the water to capture the target animals.
Trammel net - A passive capture devise used in fisheries that entangles organisms in two or three panels of netting.
Trawl - A type of net that is generally triangular with a pocket at one end that is towed through the water to capture fish.
Trap nets - A passive capture device used in fisheries that contains either rectangular frame that stabilize the net or floats and stakes that hold the net open. The netting is arranged so that a fish can readily fish its way into the trap but not out of it. Lead lines are usually present.

During 2015, agencies within the MRWG came together again to discuss future response actions in areas below the Electric Dispersal Barriers not specifically addressed in prior year plans. The result was the addition of an Upper Illinois Waterway Contingency Response Plan. The purpose of the plan is to outline the process and procedures that ACRCC member agencies will follow in response to a change in Asian carp conditions from the Starved Rock Lock and Dam to Lake Michigan. This plan specifically addresses the Starved Rock, Marseilles, Dresden Island, Brandon Road and Lockport pools. The plan is designed such that response actions may be triggered not only by range expansion of adult Asian carp upstream of the barrier but also upstream of previously known invasion fronts. The plan also addresses significant changes to population sizes in already invaded areas, new locations of juvenile and larval stage Asian carp, and areas of newly discovered reproductive activity. Response action tools are listed for a variety of different situations which could trigger a response. A communication strategy is outlined along with a decision making process. There are many different situations that could change the status of Asian carp population dynamics within the Upper Illinois Waterway, thus the Contingency Response Plan allows for flexibility and adaptability in the range of response actions. The Contingency Response Plan was incorporated into the 2016 MRP as Appendix J (MRWG 2016).

There were no monitoring reports from the field in 2016 which triggered a response action as outlined in the Contingency Response Plan in its first year of practice. The intent of the contingency response plan is to be a working document and it was integrated into the 2017 MRP (MRWG 2017) with minor revisions. In 2017, acoustic telemetry was added to the Contingency Response Plan as possible supporting evidence that could elicit a response action from the MRWG. Additionally, it was realized that the Contingency Response Plan provided a stable structure for communication and reporting of planned events that may require multi-agency support such as maintenance events at the Electric Dispersal Barriers requiring a shutdown. This was the case in the winter of 2016-2017 during construction work at the barriers to replace submerged electrodes at Barrier IIB. Barrier IIA was required to be powered down during dive work at Barrier IIB in March to support the construction work and the Demonstration Barrier was the sole electric barrier in operation. The MRWG action agencies were able to use the Contingency Response Plan as a template for collaborating to ensure risk of Asian carp presence at the barriers remained low during the planned shutdown and that an alternative barrier to fish passage was in place. A four speaker acoustic deterrent array was deployed by USGS with help from the US Army Corps of Engineers just downstream of the barriers. Additionally, USFWS and ILDNR were able to increase monitoring efforts utilizing netting, electrofishing, and hydroacoustic surveys in the Lockport pool during that same timeframe. Lessons learned will be applied and integrated into future Monitoring and Response Plans.

A Silver Carp was subsequently captured during the Seasonal Intensive Monitoring effort on 22 June 2017 in the Little Calumet River downstream of the T.J. O'Brien Lock and Dam. This physical capture of an Asian carp upstream of the Electric Dispersal Barrier System triggered a response action as outlined within the Contingency Response Plan. Another two weeks of intensive sampling followed from 26 June to 7 July 2017. Response actions included electrofishing, trap (fyke) nets, a Great Lakes pound net, commercial netting efforts, and the use of an electrified paupier net boat. Extensive sampling occurred using each of these gears for a total of 2054 person hours of effort resulting in the capture of 22,156 fish representing 52 species and 6 hybrid groups (MRP 2017). Six Grass Carp were removed from the Lake Calumet and Calumet River locations but no additional Bighead or Silver Carp were captured or identified.

3.4 - Summary of Other Asian Carp Initiatives

Summary of Selected Initiatives in Illinois

In order to address the impact of the Asian carp that already exist within the Illinois River below the Electric Dispersal Barrier System, commercial fishermen have been employed to decrease the density of Asian carp in these areas thereby lowering the number of fish that attempt to expand their range to infiltrate the Great Lakes. The ACRCC prioritized this action in June 2010, and commercial fishing crews have removed 3,078 tons of Asian carp in the stretch of the Upper Illinois River between Dresden Island and Marseilles pools through 2017. This Barrier Defense Asian Carp Removal Project has been incorporated into the annual MRP with slight variations from year to year to account for lessons learned from previous efforts.

A comprehensive monitoring and response plan for the Upper Illinois River was developed to systematically determine the distribution and abundance of Asian carp in the waterway and to define the leading edge and reproduction locations of those populations. In addition, the State of Illinois signed an agreement with a Chinese meat processing facility for the annual purchase of up to 50 million pounds of Illinois River Asian carp for consumption in China, creating 180 direct and indirect jobs. IDNR began collaborating with the Illinois Department of Commerce and Economic Opportunity (IL DCEO) for the development of an Asian Carp Training, Certification, Incentives, and Market Development Program. The program, intended for commercial fishermen, began in 2011.

A key strategy for optimizing the mass removal of Asian carps at and near the leading edge of the invasion front utilizes the Chinese Unified Fishing Method (UFM). The UFM addition to the Barrier Defense Asian Carp Removal Project was a result of international collaboration between the State of Illinois and representatives from the Chinese delegation and universities. The UFM has been employed since 2016 as part of the Monitoring and Response Plan and has contributed to nearly 100 tons of Asian carp removal in the Marseilles and Dresden Island pools (MRWG 2018).

Excerpts from Interim Summary Reports (ISR) and Monitoring Response Plans (MRP) with regards to Unified Fishing Method

2016 ISR: Hydroacoustic sampling was also conducted in the Hanson Material Services West Pit in the Marseilles Pool before and after the unified fishing method in spring 2016 to assess its effectiveness at reducing Asian carp abundance. Marseilles Pool densities increased from 2012 – 2014 and remained stable in 2015 before undergoing a 62% decrease in 2016. This decrease is likely attributable, at least in part, to the increased harvest efforts occurring throughout Marseilles Pool in 2016, particularly the unified fishing method. The unified fishing method took place in the Hanson Material Services West Pit during spring 2016; however, fall densities were lower throughout most sites in Marseilles Pool.

2017 ISR: A second and third deployment of the Chinese Unified Fishing Method (method of slowly driving fish to areas where they are more easily captured) to remove Asian carp were performed, with approximately 60,000 pounds of fish removed by IDNR in the Hanson Material Services pit in the Marseilles Pool of the Illinois River, and 240,000 pounds of fish by USGS and partners at Creve Coeur Lake in Missouri.

2018 MRP: Optimization of Mass Removal Techniques - This project will use a variety of methods to evaluate the efficacy of mass harvest techniques for removing Asian carp, including the Unified Fishing Method. This project will develop and evaluate herding and containment methods tailored to Asian carp and local conditions to improve the efficiency of mass harvest efforts. It will also aim to identify locations where aggregations of Silver Carp are common based on environmental conditions.

The 2018 Asian Carp Action Plan recognizes management based contracts that can be issued to increase removal efforts in the lower Illinois River. The MRP describes the suite of tools needed to successfully achieve its objectives. One of the tools demonstrating success within our Barrier Defense strategy is the Chinese Unified fishing method. This method of fishing has identified additional efficiencies to improve prescribed removal activities generally using existing harvest tools and techniques in more coordinated ways. To date this method has successfully removed nearly 100 tons of Asian carp and has been used in Marseilles and Dresden Island pools, and will be applied more broadly in the Upper IWW during 2018. Understanding how other technical solutions (e.g. underwater speakers, electricity) increase capture rates will continue to be explored in 2018.

Further, a series of evaluations on the effectiveness of commercial harvesting activities were completed by Dr. James Garvey of Southern Illinois University for the MRWG (MRWG 2012). Additional studies were conducted in 2014 and 2015 with some updates to the 2012 studies. Summaries of the evaluations are contained below.

Monitoring Asian Carp Population Metrics and Control Efforts: Preventing Upstream Movement in the Illinois River by James E. Garvey, David C. Glover, Marybeth K. Brey, Wesley Bouska, Greg Whitledge; Southern Illinois University at Carbondale.

Summary: The object of the study is to summarize population dynamics of Asian carp within the Illinois River. Baseline biomass data was gathered in 2011 using trammel nets, electrofishing, and split-beam hydroacoustics. In addition, Silver and Bighead Carp were tagged to track movements. Preliminary results indicate that:

- Upstream movement is linked to flooding;
- Contracted fishing in Marseilles is causing a decline, but high immigration is offsetting these impacts;
- Based on microchemistry, fish in the upper Illinois River are originating from the lower Illinois River or the middle Mississippi River;
- Experimental harvest in the lower Illinois River coupled with poor recruitment has caused a decrease in Asian carp densities, and,
- Commercial harvest will be difficult without economic incentives and upper Illinois River harvesting will depend on government sponsored fishing.

Chapter 1: Remote Sensing Transects at the Barrier, by David C. Glover and James E. Garvey; Southern Illinois University at Carbondale

Summary: This chapter outlines the methodology used during fish clearing events when barrier maintenance is required. Essentially, SIUC conducts three transects within the barrier array, immediately analyzes the data, and provides the number of fish >12″ within the barrier.

USACE, IDNR, and USFWS use that data to focus in on specific areas to remove fish from between the barriers. In addition, the study outlines recommendations for future work which includes finding morphological characteristics via hydroacoustics that can be used for species specific identification. In addition, SIUC and USFWS will be cooperatively experimenting with different frequency hydroacoustics to incorporate into statistical modeling for Asian Carp detection.

Chapter 2: Evaluating the efficacy of upstream harvest of Asian carp, by David C. Glover, Marybeth K. Brey, and James E. Garvey; Southern Illinois University Carbondale

Summary: SIUC tagged 320 fish within the Hanson Material Service Corporation east pit within the Marseilles pool. The objectives were to try estimate the population size of Asian carp, immigration and emigration rates, and exploitation rates within a backwater in Marseilles. Through a mark-recapture study an estimated exploitation rate of 76% was determined over a 20 week period. The study suggests that even with such high exploitation rates, fishermen cannot outpace immigration until August. However, emigration from the Hanson pit was low, making fish susceptible to harvest. Overall, harvest may be most useful during late fall and winter when immigration into the backwater is low.

Chapter 3: Standardized sampling on the Illinois River by David C. Glover, Wesley Bouska, Marybeth K. Brey, and James E. Garvey; Southern Illinois University Carbondale

Summary: Standardized sampling (electrofishing and trammel netting) of Asian carp was carried out to determine demographic responses of Asian carp to commercial fishing and length- specific proportion of Asian carp relative to other species to use for hydroacoustics. A reduction of 33% in catch of Silver Carp was observed from 2011 to 2012; however catches in Bighead Carp were not different. Length at age was significantly smaller in 2012 within the Alton reach. In addition a shift from equal sex distribution in 2011 to 17% more males occurred in 2012 and no age-1 fish were found in 2012. These demographics can help establish impacts of commercial fishing and other environmental factors on Asian carp. The authors state that it appears they are seeing immediate changes due to size selective harvest, but remain cautiously optimistic and that populations need to be monitored continuously.

Chapter 4: Hydroacoustic estimate of Asian carp abundance, size distribution, and biomass in the Illinois River by David C. Glover and James E. Garvey; Southern Illinois University at Carbondale

Summary: The objective of the research was to provide Asian carp biomass and size distributions from the confluence of the Illinois and Mississippi to Brandon Road lock and dam. Approximately 2,306 nautical miles of acoustic surveys were conducted. These data still have to be analyzed, but the authors mention that this method appears to work well for finding Asian carp as they would often observe jumping Silver Carp. In addition, they have successfully used the hydroacoustics to locate schools of Asian carp for the Barrier Defense Asian carp Removal Project.

Chapter 5: Asian Carp Movement in the Illinois River by Marybeth K. Brey and James E. Garvey; Southern Illinois University-Carbondale

Summary: The objective was to investigate movement at large and fine scales using telemetry data and correlate movement with varying environmental data. No fish were observed moving upstream in Starved Rock, Marseilles, or Dresden Island. Fish in Starved Rock show strong site fidelity with 40% of the fish not moving outside of the pool. Three fish moved downstream through Starved Rock lock and dam. Movement was high in Marseilles with most movement occurring in and out of the Material Services pits. Three fish tagged in Dresden Island remained in the pool and one moved downstream into Material Services pit.
Dr. James Garvey also developed a summary evaluation of impacts of commercial harvesting on the population of Asian carps on the Illinois River for the ACRCC. A summary of the findings presented in that evaluation follow.

Fishing Down the Bighead and Silver Carps: Reducing the Risk of Invasion to the Great Lakes
Garvey et al. 2012

Summary: The study covered a myriad of objectives that focused on conducting a comprehensive estimate of fish assemblages within the Illinois River. Hydroacoustics, telemetry, and other sampling techniques were used to conduct this massive project. The following are key findings from this research.

- Of the tagged fish, approximately 30% moved from the Mississippi River into the Illinois River during high flow events. Therefore, the authors suggest increased flows are a cue for Asian Carp movement.
- Through the use of environmental chemical signatures, the authors found that 72% of Silver Carp and 100% of Bighead Carp sampled originated within the Illinois River. This means that there is successful reproduction occurring within the Illinois River.
- With the use of hydroacoustic surveys, an estimated 2,800 Asian carp per river mile with an estimated weight of 4,666 lbs of Asian carp/ river mile were determined. This estimate was made from Peoria Lock and Dam to the confluence of the Mississippi. Based on these estimates per mile, the authors predict a total of 3.1 million pounds of Asian Carp exist within the lower Illinois River and that is likely an underestimate since they only scanned the main channel.
- Silver Carp made up 90% of the total density and Bighead made up 70% of the total biomass.
- Asian carp made up 63% of the total biomass and 100% of the fish over 16 inches in the lower Illinois River.
- Asian carp body condition was low compared to previously reported data, which may suggest fish are reaching maximum capacity within the river.
- The authors report the interest both locally and overseas for the development of an Asian carp market, but infrastructure is lacking.

Results of the study suggest overharvesting of Asian carp to control the population will be difficult because these fish are resilient unless all size classes are targeted simultaneously.

Identifying Movement Bottlenecks and Changes in Population Characteristics of Asian Carp in the Illinois River. Ruairi MacNamara, Marybeth K. Brey, James E. Garvey, Greg Whitledge, Matt Lubejko, and Andrea Lubejko; Southern Illinois University-Carbondale.
Jahn Kallis and David Glover, The Ohio State University
Jim Lamer; Western Illinois University

Chapter 1: Standardized sampling on the lower Illinois River by Ruarii MacNamara, Matt Lubejko, Andrea Lubejko, Marybeth K. Brey, and James E. Garvey; Southern Illinois University-Carbondale

Summary: The study investigated population metrics of Asian carp. Data from 2014 suggest that Silver Carp relative abundances increased to levels similar to 2011 and comprised primarily of 2009 year class. Peoria pool continues to have the greatest catch per unit effort (CPUE). In addition, 380 age-0 Asian carp were captured demonstrating strong recruitment in 2014. Condition and gonadal somatic index (GSI) were higher in 2014 than previous years. Genetic testing resulted in 31.8% and 28.8% of the Asian carp population consist pure Silver Carp and Bighead Carp, respectively.

Chapter 2: Hydroacoustic population estimates of Asian carp in the Illinois River by Ruairi MacNamara, James E. Garvey; Southern Illinois University at Carbondale

Summary: Data obtained from 2012 and 2013 demonstrated high biomass (43.8-65.6%) of Asian carp populations in the upper reaches of the Illinois River. Abundances and biomass decreased between years by 32.5-54.8% and 53.5-60.6%, respectively. These decreases may be a result of commercial fishing activities in the Illinois River. Over 2000 nautical miles of hydroacoustic surveys were conducted in 2014 and the data is still being analyzed.

Chapter 3: Asian carp movement in the Illinois River by Marybeth K. Brey, James E. Garvey; Southern Illinois University at Carbondale

Summary: Tagged fish within the Illinois River had 8.3% detection rate in 2014. Detections in the lower river and upper river (Starved Rock Lock and Dam) demonstrate differences in movement patterns. Fish in the lower river tended to move as far as the Peoria Pool and then return back downstream and moved further distances more quickly. Fish in the upper river tended to move downstream more frequently and took longer amounts of time while moving. No tagged fish have been observed moving upstream through the Starved Rock Lock and Dam. Tagged fish in the Hanson Material Services pits, a well-known area where Asian carp congregate, moved into the main channel in mid-May during increased flows and when water temperature reached 18° C. The amount of fish moving in and out of the HMS pits was not as common as previous years and may be due to the increase river stage throughout 2014.

Chapter 4: Spatially explicit population model by Jahn Kallis, David Glover; The Ohio State University

Summary: The objective of the study is to develop an age-structured simulation model to predict Asian carp abundance in each of the seven pools of the Illinois River for the next 25 years. The model statement has been coded in the statistical program R, but additional data and sub-models for growth, movement, annual survival, spawner-recruit are needed. The model was formed to allow updating as new parameters become available. The overall model is still under development at this time.

Bigheaded carps (Hypophthalmichthys spp.) at the edge of their invaded range: using hydroacoustics to assess population parameters and the efficacy of harvest as a control strategy *in a large North American river. MacNamara et al. 2016. Biological Invasions 18(3): 3293-3307.*

Summary: The study investigated the effectiveness of commercial harvest of bigheaded carps from 2012 to 2015 in the upper Illinois River (Starved Rock, Marseilles, and Dresden Island pools) through the use of hydroacoustics. The data demonstrate a reduction in localized populations up to 64.4% with immigration rates that quickly resulting in a rebound of the population within a few weeks. The hydroacoustic data between 2012 and 2013 suggested a 40% decline in the total of bigheaded carps throughout the upper Illinois River with populations remaining stable for 2013 and 2014. Data of note from the study show a decrease of 68% in bigheaded carps in Dresden Island from 2012 and 2014. While this data suggests that commercial harvest appears to be successful in managing bigheaded carps, the study also suggests that strong age-class and successful recruitment may provide challenges to effectively managing the populations of bigheaded carps in the upper Illinois River.

U. S. Coast Guard Investigation of Barge Tanks

Survivability of Asian Carp in Barge Tanks in the Illinois River. United States Coast Guard, Acquisition Directorate, Research and Development Center, Department of Homeland Security. March 2012.

Summary: The USCG conducted a study to assess the potential for early life stage of Asian carp (egg and larvae) to become entrained in ballast water, and whether eggs and larvae could survive in the ballast water tanks, and survive single passage through a tank dewatering pump. The study was conducted on the Illinois River in the LaGrange Reach in June 2011 with the Illinois Natural History Survey (INHS).

The study was conducted on larval stages between 11–13 days after a spawning event. Larval fish included primarily gizzard shad with a small sample of Asian carp. Younger larval stages and eggs were not evaluated in this study. The study found that larval stages of fish (including Asian carp) could be entrained in ballast water tanks and survive containment for periods as long as 144 hours. However, the study did demonstrate very high mortality (low survivability) for larval fish, including Asian carp during a single passage through a ballast water pump

U. S. Geological Survey, Selected Investigations

Water (Hydro) Gun

USGS conducted a combination of controlled experiments in a research pond complex in late 2012 to evaluate the effectiveness of pulse-pressure waves emitted from either a 1-cubic inch or 120-cubic inch water gun, at deterring the movement of Asian carp. In 2013 USGS completed further fish behavioral testing in research ponds with acoustically-tagged Silver Carp, Bighead Carp, and four native fishes. Refined pressure mapping of 80-cubic inch guns was also completed in research ponds. Field trials were completed in July 2013 to evaluate water guns as a deterrent barrier within a connecting chute between the Illinois River and a mining pit.

In August 2013 USGS completed an integrated pest management experiment and demonstration. An algal feeding attractant was applied in the mining pit for an extended period of time. A water gun barrier was then deployed to bisect the pit and the water guns were fired continuously for almost three days. Commercial fishers were deployed east and west of the water gun barrier to collect fish. Data analysis for all of the water gun research is ongoing.

The ongoing research will address current unknowns:

- What is the optimal operating sequence and pulse pressure configuration to establish an acoustic barrier for both large and small carp?
- For how long and at what distance will carp remain out of the area during and after the cessation of pulse pressure application?
- How will carp respond in different environments such as in the Chicago Sanitary and Ship Canal (CSSC) or around lock structures which would be considerably noisy due to anthropogenic activities, "masking" the acoustic noise created by the pulse pressure technologies?
- Validation of the minimum gun size, operating pressure and gun discharge frequency needed to alter the behavior of carp under field conditions.

In 2014, USGS investigated the behavioral responses of tagged wild Asian carp to the firing of the water gun at the Hanson Material Services (HMS) West Pit. An array of real time telemetry receivers were placed throughout the HMS west pit and 184 fish were tagged and released. Water gun firing began two weeks after releasing the tagged fish. The data obtained from the trial is limited due to a series of malfunctions with the water gun and/or compressors. However, the study indicated that shallower water helps attenuate the pressure gradient, which may allow fish to penetrate the barrier.

Another portion of the 2014 study was looking at the potential impacts of high pressure waved on native mussel species. Three species of native mussels with varying shell densities where placed in cages and were exposed to 100 firings of the water gun. All mussels were x-rayed and then placed in a tank supplied with a shellfish diet to record post study mortalities. No mussels displayed any shell damage and all survived to the end of the 30 day trial.

Additional detailed discussions on the USGS's hydro gun investigation are contained in the Monitoring and Rapid Response Plan for the Upper Illinois River and Chicago Illinois Area Waterways System. (MRRWG 2012, MRRWG 2013 and, MRRWG 2014).

After several years of research, USGS decided in 2015 to stop investigating the use of Hydro Guns as a fish deterrent. It was determined that the technology was not reliable and it did not effectively deter fish.

U.S. Geological Survey, Selected Asian Carp and CAWS Publications 2009-2015

Response of Bighead Carp and Silver Carp to Repeated Water gun Operation in an Enclosed Shallow Pond

Romine, J.G., Jensen, N., Parsley, M.J., Gaugush, R.F., Severson, T.J., Hatton, T.W., Adams, R.F., and Gaikowski M.P., 2015, Response of Bighead Carp and Silver Carp to repeated water gun operation in an enclosed shallow Pond, North American Journal of Fisheries Management 35(3): 440-453.

Summary: The Bighead Carp *Hypophthalmichthys nobilis* and Silver Carp *H. molitrix* are nonnative species that pose a threat to Great Lakes ecosystems should they advance into those areas. Thus, technologies to impede Asian carp movement into the Great Lakes are needed; one potential technology is the seismic water gun. We evaluated the efficacy of a water gun array as a behavioral deterrent to the movement of acoustic-tagged Bighead Carp and Silver Carp in an experimental pond. Behavioral responses were evaluated by using four metrics: (1) fish distance from the water guns (D); (2) spatial area of the fish's utilization distribution (UD); (3) persistence velocity (V_p); and (4) number of times a fish transited the water gun array. For both species, average D increased by 10 m during the firing period relative to the pre-firing period. During the firing period, the spatial area of use within the pond decreased. Carp were located throughout the pond during the pre-firing period but were concentrated in the north end of the pond during the firing period, thus reducing their UDs by roughly 50%.

Overall, V_p decreased during the firing period relative to the pre-firing period, as fish movement became more tortuous and confined, suggesting that the firing of the guns elicited a change in carp behavior. The water gun array was partially successful at impeding carp movement, but some fish did transit the array. Bighead Carp moved past the guns a total of 78 times during the pre-firing period and 15 times during the firing period; Silver Carp moved past the guns 96 times during the pre-firing period and 13 times during the firing period. Although the water guns did alter carp behavior, causing the fish to move away from the guns, this method was not 100% effective as a passage deterrent.

Location and Timing of Asian Carp Spawning in the Lower Missouri River

Deters, J.E., Chapman, D.C., and McElroy, B., 2012, Location and timing of Asian carp spawning in the Lower Missouri River, Environmental Biology of Fishes, Online First, July 2012.

Summary: The objectives of the study were to determine 1) if Asian carps spawn in tributaries or confluences of tributaries; 2) if they have diel (multiple) spawning cycles; and, 3) if they only spawn in a few confined locations. These questions were answered by deploying an ichthyoplankton net at 6 tributaries in the Missouri River between river miles 350 and 200. Three samples were taken at each location during periods of increased flow. One sample was collected within the tributary and at one-half mile (1 km) above and below the confluence of the tributary. Spawning locations and times were estimated based on developmental stages, temperature, and water velocity. The results of the study suggested that Asian carp do not spawn within tributaries in any substantial quantity, that spawning occurred mostly during the day, and that spawning occurred throughout the study area within the Missouri River with spawning activity mostly occurring in areas with high river sinuosity.

Binational Ecological Risk Assessment of Bigheaded Carps
Cudmore, B., Mandrak, N.E., Dettmers, J.M., Chapman, D.C., and Kolar, C.S., 2012, Binational ecological risk assessment of bigheaded carps, DFO Canadian Science Advisory Secretariat, Research Document 2011/114. 57p.

Summary: An ecological risk assessment was conducted for both Bighead and Silver Carp by Fisheries and Oceans Canada. They defined the CAWS as being the most likely point of entry due to the proximity of Asian carp populations. The assessment estimated that Bigheaded carps will spread to other lakes within 20 years. Ideal habitat would be found in Lake Erie, Lake St. Clair, and high productivity embayments of the other lakes. The most surprising finding from the assessment predicts a probability greater than 50% of successful spawning with approximately 10 females and 10 males in the basin of a single Great Lake.

Developmental Rate and Behavior of Early Life Stages of Bighead Carp and Silver Carp
http://pubs.er.usgs.gov/publication/sir20115076
Chapman, D.C., and George, A.E., 2011, Developmental rate and behavior of early life stages of Bighead Carp and Silver Carp, U.S. Geological Survey Scientific Investigations Report 2011-5076. 11p.

Summary: The objective of the study was to classify early life stages of Bighead and Silver Carp under controlled environmental variables. Eggs from each species were allowed to develop under two different temperature treatments. Images were taken from each stage of development for each species. In general, both Silver and Bighead Carp developed quicker at the warmer temperature treatment and strong vertical swimming was observed immediately after hatching. These data can be used to help calculate spawning location and stage in wild fish under known environmental conditions.

Thermal and Hydrologic Suitability of Lake Erie, and its Major Tributaries for Spawning of Asian Carps http://www.sciencedirect.com/science/article/pii/S0380133011002516. Kocovsky, P.M., D.C. Chapman, and J.E. McKenna. 2012. Journal of Great Lakes Research 38(1):159-166.

Summary: The objective of this study was to model whether Lake Erie and its tributaries were suitable for the spawning of Silver, Grass, and Bighead Carps. Eight tributaries were analyzed for spawning suitability and included the Raisin, Maumee, Portage, Sandusky, Huron, Vermilion, Black, and Grand Rivers. Thermal and hydrologic data from 1991-2009 were obtained from municipal water intakes and USGS stream gage resources, respectively. These data, combined with length of undammed river, were used to predict summer water temperatures and velocity to determine if egg incubation time and river length were suitable for spawning of Asian Carp. The results show that most rivers provide the right temperatures for incubation and proper river length for hatching success. The Maumee, Sandusky, and Grand Rivers were more suitable for Asian Carp spawning, while the Black Huron, Portage, and Vermilion Rivers were less suitable.

This research provides insight on the potential threat of establishment of Asian carp establishment within Lake Erie.

Molecular Responses Differ Between Sensitive Silver Carp and Tolerant Bighead Carp and Bigmouth Buffalo Exposed to Rotenone, http://pubs.er.usgs.gov/publication/fs20103033
Amberg, Jon J.; Schreier, Theresa M.; Gaikowski, Mark P. 2012, Fish Physiology and Biochemistry, 38: 1379 - 1391

Summary: This study investigated physiological differences of rotenone sensitivity in Silver carp, Bighead Carp, and Bigmouth Buffalo. The first part of the study contrasted concentrations of rotenone in the plasma of Bigmouth Buffalo and Silver Carp. The data demonstrated that silver carp are much more sensitive to rotenone since all Silver Carp were dead after 6 hours of exposure, while some Bigmouth Buffalo were still alive after 12 hours. The second part of the study focused on the physiological differences between Bighead and Silver Carp. Several genes that are associated with detoxification and oxidative stress were measured after exposure to rotenone. The results show varying amounts of expression on a few genes, which may suggest each species has different mechanisms for detoxifying rotenone, which has been seen in other species. In addition, differences in oxidative stress biomarkers were observed. These differences appear to be important in determining rotenone tolerant and intolerant species.

Invasive Asian Carps of North America
Chapman, D.C., and Hoff, M.H., eds., 2011, Invasive Asian Carps of North America, Bethesda, Md., American Fisheries Society Symposium 74, 266 p.

Summary: Invasive Asian Carps of North America is a collection of manuscripts from a wide variety of biologists and professionals within the fisheries science field. The book outlines the history, biology, status, and reviews current research on Grass, Black, Bighead, and Silver Carp.

Verification of Ploidy and Reproductive Potential in Triploid Black Carp and Grass Carp
Papoulias, D.M., Candrl, J., Jenkins, J.A., and Tillitt, D.E., 2011, Verification of ploidy and reproductive potential in triploid carp and grass carp, in: Chapman, D.C. and Hoff, M.H., eds., http://pubs.er.usgs.gov/publication/70003922. Invasive Asian Carp in North America, American Fisheries Society Symposium: Bethesda, American Fisheries Society, Symposium 74, p. 251-266.

Summary: Grass Carp and Black Carp are important for controlling nuisance vegetation and snails, respectively. However, they are considered invasive species and reproduction must be prohibited to prevent their spread. One way to prevent reproduction is by making organisms triploid (more than two sets of chromosomes). This study had three objectives which included: verification of the accuracy of ploidy determination based on nuclear size; determination of the growth and survival of juvenile Black Carp; and, examination of the development of gonads from triploid and diploid of Black and Grass Carp. The verification process demonstrated that field techniques used by managers had an error rate of 0.25%, indicating that this technique is very accurate. Black and Grass Carp grew and survived well in Missouri ponds, which demonstrates a potential for establishment within the state. In addition, both triploid Black and Grass Carp had some level of normal functioning reproductive cells. In conclusion, the authors indicate there is a small chance that diploid carp could make it through the screening process and that further reproductive studies are needed to determine if triploids could produce viable offspring.

Significant Genetic Differentiation Between Native and Introduced Silver Carp (Hypophthalmichthys molitrix) Inferred from mtDNA Analysis. Li, S.F., Xu, J.W., Yang, Q.L., Wang, C.H., Chapman, D.C., and Lu, G. 2011. Environmental Biology of Fish 92:503-511.

Summary: The study investigated the genetic differences between three native populations (Amur, Yangtze, and Pearl Rivers) and two introduced populations (Mississippi and Danube Rivers) of Silver Carp. Mississippi River populations were most closely related to native Silver Carp populations of the Yangtze and Amur Rivers which are located in Central and Northern China, respectively. The relatedness of the Mississippi River populations to northern populations within the native range of Silver Carp may be important for calculating the risk of invasion within the Great Lakes. Since these are more related to fish from colder latitudes, they may be more successful at establishing throughout the Great Lakes basin.

Tools for Assessing Kinship, Population Structure, Phylogeography, and Interspecific Hybridization in Asian Carp Invasive to the Mississippi River, USA: Isolation and Characterization of Novel Tetranucleotide Microsatellite DNA Loci in Silver Carp Hypophthalmichthys molitrix. King, T.L., M.S. Eackles, and D.C. Chapman. 2011. Conservation Genetic Resources. 3(3):397-401.

Summary: The manuscript investigates specific DNA markers (microsatellite loci) for Silver Carp and then compares them across other invasive carp species (Bighead, Grass, and Black Carp) to determine evolutionary relationships. Twenty-five markers met the criteria of uniqueness, length, and adequate flanking regions for PCR primer development. These markers were deemed sufficient to provide "unique genotypes, determine kinship relationships, differentiate populations and species, estimate effective population size, and provide demographic perspectives for control." In addition, the manuscript mentions the current use of these markers to determine hybridization of Silver and Bighead Carp, gene-flow between populations, and demographic status of sub-populations. The goal of future research is to use this information to characterize invasive carp populations and better understand their movement and source via genetic material in order to effectively control/manage for these invasive carp.

Effect of Water Hardness and Dissolved-Solid Concentration on Hatching Success and Egg Size in Bighead Carp. Chapman, D.C. and Deters, J.E., 2009. Transactions of the American Fisheries Society, 138(6): 1226-1231

Summary: The object of the study was to determine if water hardness and dissolved solid concentration had an impact on hatching success and egg size in Bighead Carp. In some studies, soft water has been shown to cause eggs to burst and this relationship could provide important information for understanding the potential spread of Bighead Carp. To test their hypothesis, the authors placed Bighead Carp eggs into a wide range of hardness and dissolved solid concentrations. The results indicated that the varying hardness levels had no significant impact on hatching rate or egg size. Therefore, it is important to re-consider hardness as a limiting factor of the spread of Bighead Carp.

A Comparison of Complete Mitochondrial Genomes of Silver Carp Hypophthalmichthys molitrix and Bighead Carp Hypophthalmichthys nobilis: Implications for their Taxonomic Relationship *and Phylogeny.* Li, S. F., Xu, J. W, Yang Q. L., Wang, C. H., Chen Q., Chapman, D. C., and Lu G. 2009. Journal of Fish Biology 74:1787–1803

Summary: Debates on whether Bighead and Silver Carp are within the same genus or should be separated into two separate genera due to differences in morphological characteristics have occurred. To put the debates to rest, the study did a comprehensive genetic comparison using mitochondrial DNA. There were variations between the two genomes, but both were very similar. Transfer RNA genes were 98.8% similar, the control region (D-loop) were 89.4% similar, and the protein–coding genes were 94.2% similar. The study concludes that based on these findings, Silver and Bighead Carp are members of the genus *Hypophthalmichthys*.

Fright Reaction and Avoidance Induced by Exposure to Conspecific Skin Extracts in Invasive Bighead and Silver Carps. Little, E. E.; Calfee, R. D.; Fabacher, D. L.; Sanders, L. 2011, Invasive Asian Carps in North America, American Fisheries Society Symposium, 74: 215 – 226

Summary: The study investigates the use of skin extracts from both Bighead and Silver Carp as a deterrent. Abrasion or cuts to the outermost cells of fish release an alarm substance that individuals can detect and react to in an appropriate manner. In the first part of the study, fish were placed into tanks and the alarm substance extract was administered. Behavioral responses were then observed and recorded. These responses included freezing (remain motionless) and overall decrease in activity. When the alarm substance was added, an increase in freezing behavior and decreases in feeding and other activity were observed. However, the behavioral responses decrease through time either from dilution or possibly habituation. Another portion of the study used a counter-current chamber and found that young juvenile Bighead and Silver Carp spent less time in areas of the chamber where the alarm substance was present. Fish moved away from the source of the alarm substance as long as it was continuously added. These data demonstrate the possible use of alarm substances to deter Asian carp, but more research will be needed to find effective application procedures.

Comparison of Index Velocity Measurements Made With a Horizontal Acoustic Doppler Current Profiler and a Three-Path Acoustic Velocity Meter for Computation of Discharge in the Chicago Sanitary and Ship Canal near Lemont, Illinois. 2012. Jackson, P.R., Johnson, K.K., and Duncker, J.J., U.S. Geological Survey Scientific Investigations Report 2011-5205.

Summary: The USGS stream gage at Lemont is important for monitoring flow within the CAWS. The study compares two methods for monitoring flow: a horizontal acoustic Doppler current profiler (H-ADCP) and a three-path acoustic velocity meter (AVM). The study concluded that H-ADCP is a suitable replacement to the AVM because it requires a smaller sample volume and is more reliable than the AVM. However, the study indicates that one weakness to the H-ADCP is that it has high uncertainty with the measurements.

Determination of the acute toxicity of isoniazid to three invasive carp species and rainbow trout in static exposures. 2015 Schreier, Theresa M. & Terrance D. Hubert. U.S. Geological Survey Open-File Report 2015-1101.

Summary: Three invasive fishes of considerable concern to aquatic resource managers are the *Hypophthalmichthys nobilis* (Bighead Carp),*Hypophthalmichthys molitrix* (Silver Carp), and *Ctenopharyngodon idella* (Grass Carp), collectively known as Asian carps. There is a need for an effective chemical control agent for Asian carps. Isoniazid was identified as a potential toxicant for grass carp. The selective toxicity of isoniazid to grass carp was verified as a response to an anecdotal report received in 2013. In addition, the toxicity of isoniazid to Bighead Carp, Silver Carp, and *Oncorhynchus mykiss* (Rainbow Trout) was evaluated. Isoniazid was not toxic to grass carp at the reported anecdotal concentration, which was 13 milligrams per liter. Isoniazid (130 milligrams per liter) was not selectively toxic to Bighead carp, Silver carp, or Grass Carp when compared to Rainbow Trout.

Application of the FluEgg model to predict transport of Asian carp eggs in the Saint Joseph River (Great Lakes tributary). 2015. Garcia, Tatiana, Elizabeth A. Murphy, Patrick R. Jackson, and Marcelo H. Garcia. Journal of Great Lakes Research.

Summary: The Fluvial Egg Drift Simulator (FluEgg) is a three-dimensional Lagrangian model that simulates the movement and development of Asian carp eggs until hatching based on the physical characteristics of the flow field and the physical and biological characteristics of the eggs. This tool provides information concerning egg development and spawning habitat suitability including: egg plume location, egg vertical and travel time distribution, and egg-hatching risk. A case study of the simulation of Asian carp eggs in the Lower Saint Joseph River, a tributary of Lake Michigan, is presented. The river hydrodynamic input for FluEgg was generated in two ways—using hydroacoustic data and using HEC-RAS model data. The HEC-RAS model hydrodynamic input data were used to simulate 52 scenarios covering a broad range of flows and water temperatures with the eggs at risk of hatching ranging from 0 to 93% depending on river conditions. FluEgg simulations depict the highest percentage of eggs at risk of hatching occurs at the lowest discharge and at peak water temperatures. Analysis of these scenarios illustrates how the interactive relation among river length, hydrodynamics, and water temperature influence egg transport and hatching risk. An improved version of FluEgg, which more realistically simulates dispersion and egg development, is presented. Also presented is a graphical user interface that facilitates the use of FluEgg and provides a set of post-processing analysis tools to support management decision-making regarding the prevention and control of Asian carp reproduction in rivers with or without Asian carp populations.

Asian carp behavior in response to static water gun firing. 2013. Layhee, Megan J, Jackson A. Gross, Michael J. Parsley, Jason G. Romine, David C. Glover, Cory D. Suski, Tristany L. Wagner, Adam J. Sepulveda, & Robert E. Gresswell. U.S. Geological Survey Fact Sheet 2013-3098.

Summary: The potential for invasion of Asian carp into the Great Lakes has ecological and socio-economic implications. If they become established, Asian carp are predicted to alter lake ecosystems and impact commercial and recreational fisheries. The Chicago Sanitary and Shipping Canal is an important biological conduit between the Mississippi River Basin, where invasive Asian carp are abundant, and the Great Lakes. Millions of dollars have been spent to erect an electric barrier defense in the canal to prevent movement of Asian carp into the Great Lakes, but the need for additional fish deterrent technologies to supplement the existing barrier is warranted. Scientists with the U.S. Geological Survey Northern Rocky Mountain Science Center are examining seismic water gun technology, formerly used in oceanic oil exploration, as a fish deterrent. The goal of the current study is to employ telemetry and sonar monitoring equipment to assess the behavioral response of Asian carp to seismic water guns and the sound energy it generates.

Hydraulic and water-quality data collection for the investigation of Great Lakes tributaries for Asian carp spawning and egg transport suitability. 2013. Murphy, Elizabeth A. & P. Ryan Jackson. U.S. Geological Survey Scientific Investigations Report 2013-5106.

Summary: If the invasive Asian carps (Bighead Carp *Hypophthalmichthys nobilis* and Silver Carp *Hypophthalmichthys molitrix*) migrate to the Great Lakes, in spite of the efforts to stop their advancement, these species will require the fast-flowing water of the Great Lakes tributaries for spawning and recruitment in order to establish a growing population. Two Lake Michigan tributaries (the Milwaukee and St. Joseph Rivers) and two Lake Erie tributaries (the Maumee and Sandusky Rivers) were investigated to determine if these tributaries possess the hydraulic and water-quality characteristics to allow successful spawning of Asian carps. To examine this issue, standard U.S. Geological Survey sampling protocols and instrumentation for discharge and water-quality measurements were used, together with differential global positioning system data for georeferencing. Non-standard data-processing techniques, combined with detailed laboratory analysis of Asian carp egg characteristics, allowed an assessment of the transport capabilities of each of these four tributaries. This assessment is based solely on analysis of observed data and did not utilize the collected data for detailed transport modeling. All four tributaries exhibited potential settling zones for Asian carp eggs both within the estuaries and river mouths and within the lower 100 kilometers (km) of the river. Dams played a leading role in defining these settling zones, with the exception of dams on the Sandusky River. The impoundments created by many of the larger dams on these rivers acted to sufficiently decelerate the flows and allowed the shear velocity to drop below the settling velocity for Asian carp eggs, which would allow the eggs to fall out of suspension and settle on the bottom where it is thought the eggs would perish. While three rivers exhibited these settling zones upstream of the larger dams, not all settling zones are likely to have such effects on egg transport. The Milwaukee River exhibited only a short settling zone upstream of the Grafton Dam, whereas the St. Joseph and Maumee Rivers both had extensive settling zones (>5 km) behind major dams. These longer settling zones are likely to capture more eggs than shorter settling reaches. All four rivers exhibited settling zones at their river mouths, with the Lake Erie tributaries having much larger settling zones extending more than 10 km up the tributaries. While hydraulic data from all four rivers indicated settling of eggs is possible in some locations, all four rivers also exhibited sufficient temperatures, water-quality characteristics, turbulence, and transport times outside of settling zones for successful suspension and development of Asian carp eggs to the hatching stage before the threat of settlement. These observed data indicate that these four Great Lakes tributaries have sufficient hydraulic and water-quality characteristics to support successful spawning and recruitment of Asian carps. The data indicate that with the right temperature and flow conditions, river reaches as short as 25 km may allow Asian carp eggs sufficient time to develop to hatching. Additionally, examining the relation between critical shear velocity and mean velocity, egg settling appears to take place at mean velocities in the range of 15–25 centimeters per second, a much lower value than is generally cited in the literature. A first-order estimate of the minimum transport velocity for Asian carp eggs in a river can be obtained by using mean flow depth and river substrate data, and curves were constructed to show this relation. These findings would expand the number of possible tributaries suitable for Asian carp spawning and contribute to the understanding of how hydraulic and water-quality information can be used to screen additional rivers in the future.

Development of a Fluvial Egg Drift Simulator to evaluate the transport and dispersion of Asian carp eggs in Rivers. 2013. Garcia, Tatiana, P. Ryan Jackson, Elizabeth A. Murphy, Albert J. Valocchi, Marcelo H. Garcia. Ecological Modelling 263: 211-222.

Summary: Asian carp are migrating towards the Great Lakes and are threatening to invade this ecosystem, hence there is an immediate need to control their population. The transport of Asian carp eggs in potential spawning rivers is an important factor in its life history and recruitment success. An understanding of the transport, development, and fate of Asian carp eggs has the potential to create prevention, management, and control strategies before the eggs hatch and develop the ability to swim. However, there is not a clear understanding of the hydrodynamic conditions at which the eggs are transported and kept in suspension. This knowledge is imperative because of the current assumption that suspension is required for the eggs to survive. Herein, FluEgg (Fluvial Egg Drift Simulator), a three-dimensional Lagrangian model capable of evaluating the influence of flow velocity, shear dispersion and turbulent diffusion on the transport and dispersal patterns of Asian carp eggs is presented. The model's variables include not only biological behavior (growth rate, density changes) but also the physical characteristics of the flow field, such as mean velocities and eddy diffusivities. The performance of the FluEgg model was evaluated using observed data from published flume experiments conducted in China with water-hardened Asian carp eggs as subjects. FluEgg simulations show a good agreement with the experimental data. The model was also run with observed data from the Sandusky River in Ohio to provide a real-world demonstration case. This research will support the identification of critical hydrodynamic conditions (e.g., flow velocity, depth, and shear velocity) to maintain eggs in suspension, assist in the evaluation of suitable spawning rivers for Asian carp populations and facilitate the development of prevention, control and management strategies for Asian carp species in rivers and water bodies.

Validation of eDNA surveillance sensitivity for detection of Asian carps in controlled and field experiments.2013. Mahon, Andrew R. Christopher L. Jerde, Matthew Galaska, Jennifer L. Bergner, W. Lindsay Chadderton, David M. Lodge, Margaret E. Hunter, Leo G. Nico. PloS ONE. 8 (3).

Summary: In many North American rivers, populations of multiple species of non-native cyprinid fishes are present, including Black Carp (*Mylpharyngodon piceus*), Grass carp (*Ctenopharyngodon idella*), Bighead Carp (*Hypophthalmichthys nobilis*), Silver Carp (*Hypophthalmichthys molitrix*), Common Carp (*Cyprinus carpi*o), and Goldfish (*Carassius auratus*). All six of these species are found in the Mississippi River basin and tracking their invasion has proven difficult, particularly where abundance is low. Knowledge of the location of the invasion front is valuable to natural resource managers because future ecological and economic damages can be most effectively prevented when populations are low. To test the accuracy of environmental DNA (eDNA) as an early indicator of species occurrence and relative abundance, we applied eDNA technology to the six non-native cyprinid species putatively present in a 2.6 river mile stretch of the Chicago (IL, USA) canal system that was subsequently treated with piscicide. The proportion of water samples yielding positive detections increased with relative abundance of the six species, as indicated by the number of carcasses recovered after poisoning. New markers for Black Carp, Grass Carp, and a Common Carp/Goldfish are reported and details of the marker testing to ensure specificity are provided.

Detection of environmental DNA of Bigheaded Carps in samples collected from selected locations in the St. Croix River and in the Mississippi River. 2013. Amberg, Jon J., S. Grace McCalla, Loren Miller, Peter Sorensen, Mark P. Gaikowski. U.S. Geological Survey Open-File Report 2013-1080.

Summary: The use of molecular methods, such as the detection of environmental deoxyribonucleic acid (eDNA), have become an increasingly popular tool in surveillance programs that monitor for the presence of invasive species in aquatic systems. One early application of these methods in aquatic systems was surveillance for DNA of Asian carps (specifically Bighead Carp (*Hypophthalmichthys nobilis*) and Silver Carp (*H. molitrix*)) in water samples taken from the Chicago Area Waterway System. The ability to identify DNA of a species in an environmental sample presents a potentially powerful tool because these sensitive analyses can presumably detect the presence of DNA in water even when the species is not abundant or are difficult to catch or monitor with traditional gear. Prior to research presented in this report, an initial eDNA surveillance effort was completed in selected locations in the Upper Mississippi and St. Croix Rivers in 2011 after the capture of a Bighead Carp in the St. Croix River near Prescott, WI. Data presented in this report were developed to duplicate the 2011 monitoring results from the Upper Mississippi and St. Croix Rivers and to provide critical insight into the technique to inform future work in these locations. We specifically sought to understand the potential confounding effects of other pathways of eDNA movement (e.g., fish-eating birds, watercraft) on the variation in background DNA by collecting water samples from (1) sites within the St. Croix River and the upper Mississippi River where the DNA of Silver Carp was previously detected, (2) sites considered to be free of Asian carp, and (3) a site known to have a large population of Asian carp. We also sought to establish a baseline Asian carp eDNA signature to which future eDNA sampling efforts could be compared. All samples taken as part of this effort were processed using conventional polymerase chain reaction (PCR) according to procedures outlined in the U.S. Army Corps of Engineers Quality Assurance Project Plan with minor deviations designed to enhance the rigor of our data. Presence of DNA in PCR-positive samples was confirmed by Sanger sequencing (forward and reverse) and sequences were considered positive only if sequences (forward and reverse) of ≥150 base pairs had a match of ≥95% to those of published sequences for Bighead Carp or Silver Carp. The DNA of Bighead Carp and Silver Carp was not detected in environmental samples collected above and below St. Croix Falls Dam on the St. Croix River, above and below the Coon Rapids Dam and below Lock and Dam 1 on the Upper Mississippi River, and from two negative control lakes, Square Lake and Lake Riley. The DNA of Silver Carp was detected in environmental samples collected below Lock and Dam 19 at Keokuk, Iowa, a reach of the river with high Silver Carp abundance. The portion (68%) of environmental samples taken below Lock and Dam 19 that were determined to contain the DNA of Silver Carp was similar to that reported in the scientific literature for other abundant species. The DNA of Bighead Carp, however, was not detected in environmental samples collected below Lock and Dam 19, a reach of the river known to have Bighead Carp. Previous reported detections of the DNA of Silver Carp in samples collected in 2011 were not replicated in this study. Additional analyses are planned for the DNA extracted from the samples collected in 2012. Those analyses may provide additional information regarding the lack of amplification of Bighead Carp DNA and the lengths of the sequences of Silver Carp DNA present in samples taken below Lock and Dam 19. These additional analyses may help inform the use of eDNA monitoring in large, complex systems like the Mississippi River.

ECALS: loading studies interim report July 2013. Klymus, Katy E. Catherine A. Richter, Duane C. Chapman, and Craig Paukert. ACRCC Interim Report. 2013.

Summary: Silver Carp (*Hypophthalmichthys molitrix*) (SVC) and Bighead Carp (*H. nobilis*) (BHC) have impacted waters in the US since their escape. Current chemical controls for aquatic nuisance species are non-selective. Development of a bioactive micro-particle that exploits filter-feeding habits of SVC or BHC could result in a new control tool. It is not fully understood if SVC or BHC will consume bioactive micro-particles. Two discrete trials were performed to: 1) evaluate if SVC and BHC consume the candidate micro-particle formulation; 2) determine what size they consume; 3) establish methods to evaluate consumption of filter-feeders for future experiments. Both SVC and BHC were exposed to small (50-100 μm) and large (150-200 μm) micro-particles in two 24-h trials. Particles in water were counted electronically and manually (microscopy). Particles on gill rakers were counted manually and intestinal tracts inspected for the presence of micro-particles. In Trial 1, both manual and electronic count data confirmed reductions of both size particles; SVC appeared to remove more small particles than large; more BHC consumed particles; SVC had fewer overall particles in their gill rakers than BHC. In Trial 2, electronic counts confirmed reductions of both size particles; both SVC and BHC consumed particles, yet more SVC consumed micro-particles compared to BHC. Of the fish that ate micro-particles, SVC consumed more than BHC. It is recommended to use multiple metrics to assess consumption of candidate micro-particles by filter-feeders when attempting to distinguish differential particle consumption. This study has implications for developing micro-particles for species-specific delivery of bioactive controls to help fisheries, provides some methods for further experiments with bioactive micro-particles, and may also have applications in aquaculture.

Use of eyeballs for establishing ploidy of Asian Carp. 2011. Jenkins, Jill A. & R. Glenn Thomas. North American Journal of Fisheries Management 27: 1195-1202.

Summary: Grass Carp (*Ctenopharyngodon idella*), Silver Carp (*Hypophthalmichthys molitrix*), and Bighead Carp (*H. nobilis*) are now established and relatively common in the Mississippi and Atchafalaya rivers. Commercial fishers of Louisiana's large rivers report recurrent catches of Grass Carp, and the frequency of Bighead Carp and Silver Carp catch is increasing. Twelve Black Carp (*Mylopharyngodon piceus*) were recently captured from the Mississippi and Atchafalaya River system, and 10 were analyzed for ploidy. By using the methods described herein, all 10 fish were determined to be diploid. Such correct identifications of ploidy of feral Asian carp species, as well as other species, would provide science-based information constructive for meeting reporting requirements, tracking fish movements, and forecasting expansion of species distribution. To investigate the postmortem period for sample collection and to lessen demands on field operations for obtaining samples, a laboratory study was performed to determine the length of time for which eyeballs from postmortem black carp could be used for ploidy determinations. Acquiring eyes rather than blood is simpler and quicker and requires no special supplies. An internal DNA reference standard with a documented genome size, including erythrocytes from diploid black carp or Nile Tilapia (*Oreochromis niloticus*), was analyzed simultaneously with cells from seven known triploid Black Carp to assess ploidy through 12 d after extraction. Ploidy determinations were reliable through 8 d postmortem. The field process entails excision of an eyeball, storage in a physiological buffer, and shipment within 8 d at refrigeration temperatures (4 C) to the laboratory for analysis by flow cytometry.

Reproductive condition and occurrence of intersex in Bighead Carp and Silver Carp in the Missouri River. 2006. Papoulias, D.M., D. Chapman, & D.E. Tillitt. Hydrobiologia 571 (1): 355-360.

Summary: Little is known about the reproductive biology of the exotic Bighead Carp (*Hypophthalmichthys nobilis*) and Silver Carp (*Hypophthalmichthys molitrix*) in the Missouri River. In order to fill this gap in understanding, herein is described the reproductive condition of these Asian carps. Evidence is presented which indicates that Bighead and Silver Carp in the Missouri River have a protracted spawning period that extends from early spring through fall and some individual Bighead and Silver carp are spawning multiple times during a reproductive season. Although Bighead and Silver carps are successfully maturing and spawning in the Missouri River some reproductive abnormalities such as intersex, atresia, and sterility were observed. Knowledge of the reproductive activity of these invasive carps may be useful to resource managers tasked with their control. Furthermore, the reproductive abnormalities observed should be considered when evaluating the environmental condition of the Missouri River relative to supporting a healthy fish fauna.

Age, growth, and gonadal characteristics of adult bighead carp, Hypophthalmichthys nobilis, in the lower Missouri River. 2002. Schrank, S.J. & C.S. Guy. Environmental Biology of Fishes 64 (4): 443-450.

Summary: Bighead Carp were introduced into Arkansas in 1973 to improve water clarity in production ponds. Bighead Carp subsequently escaped aquaculture facilities in the early 1980's and dispersed into the Mississippi and Missouri rivers. The first documentation of Bighead Carp reproduction in the Mississippi River system was in 1989. The population has increased in the Missouri River as is evident in their increased proportion in the commercial harvest since 1990. The effect of this exotic planktivore on native ecosystems of the U.S. has not been examined. Basic biological data on Bighead Carp (*Hypophthalmichthys nobilis*) in the Missouri River are needed to predict potential ecological problems and provide a foundation for manipulative studies. The objectives of this study were to assess age, growth, and gonadal characteristics of Bighead Carp in the Missouri River. Adult Bighead Carp in our sample varied from age 3 to age 7 and length varied from 475 to 1050 mm. There was a large variation in length at age, and overall Bighead Carp exhibited fast growth. For example, mean back-calculated length at age 3 was 556 mm. The sample was dominated by Bighead Carp from the 1994 year class. There was no difference in gonad development (i.e., gonadal somatic index, egg diameter) between winter and spring samples. Length of male Bighead Carp and GSI were not significantly correlated; however, females exhibited a positive linear relationship between length and GSI. In each ovary, egg diameter frequencies exhibited a bimodal distribution, indicating protracted spawning. Mean fecundity was 226 213, with a maximum fecundity of 769 964. Bighead Carp in the Missouri River have similar life history characteristics to Asian and European populations. They have become well established in the Missouri River and it is likely that range expansion and population density will increase.

Chapter 4 – Safety Considerations and Operational Impacts

4.1 - Introduction

There are several safety concerns related to operation of the barriers: the potential of the electrified water to generate sparking within or between barges or other vessels, the potential risks that the electrified water poses to people who contact it, potential risks created by on-land ground currents, potential risks from exposure to airborne electromagnetic fields, and electrical hazards to which workers on site may be exposed. Operation of the barriers also has other potential side effects such as accelerated corrosion of metal in the vicinity and interference with other nearby electronic equipment. These safety concerns and operational impacts must be understood and considered when potential changes in barrier operations to improve efficacy are evaluated.

This chapter summarizes the testing and results of all studies completed to date on potential safety hazards and other side effects. More detailed information on the studies is available in the previously published reports cited in *Chapter 10, References and Glossary of Terms,* of this document. Figure 15 provides an overview of the barrier systems for reference.

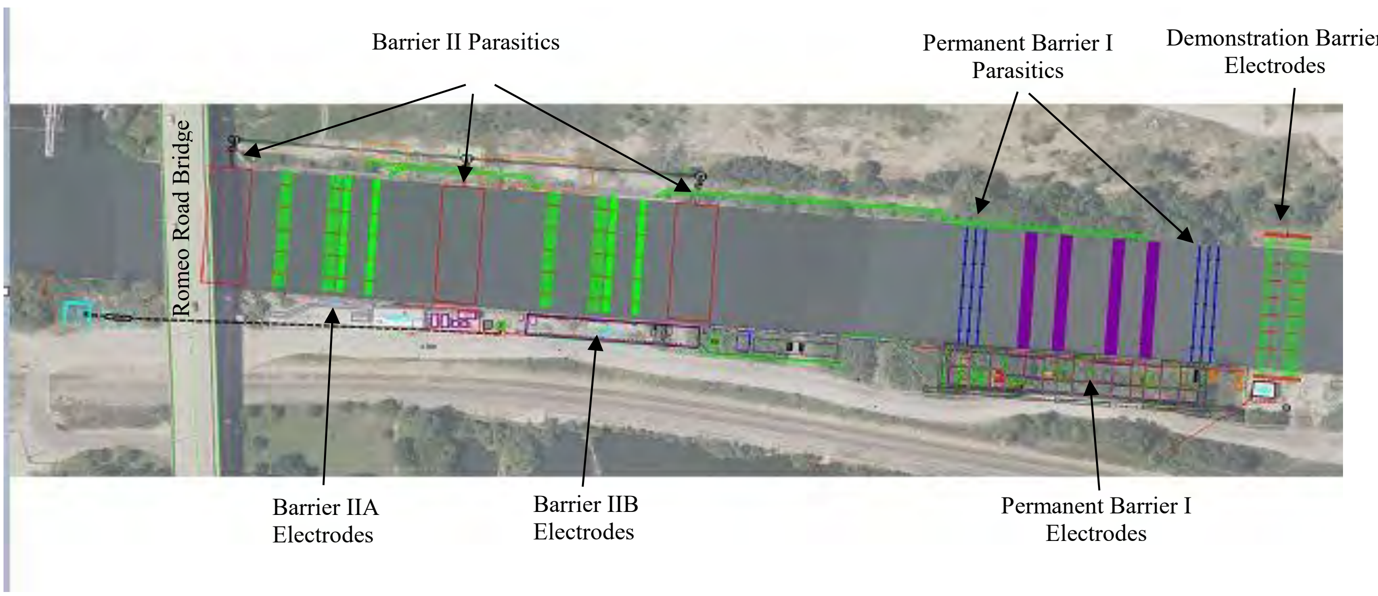


Figure 15 – CSSC Barrier System Electrode Arrays and Parasitics

4.2 - In-Water Testing Overview

In January and March of 2005 testing was completed with various barge configurations to determine the potential for sparking within and between vessels due to the operation of the Demonstration Barrier (USACE Construction Engineering Research Laboratory, 2005). The results indicated that sparking could occur within barge tows that are connected with soft lines, between unconnected barges, or between barges and metal structures on land. Based on this testing, the U.S. Coast Guard established a Regulated Navigation Area (RNA) in the vicinity of the barriers (33 C.F.R. § 165.923). Barrier IIA was under construction at this time and the extent of the RNA was defined to include the location of Barrier II as well as the Demonstration Barrier. Testing was also completed in to evaluate human health risks associated with contacting the electrified water (USACE Construction Engineering Research Laboratory, 2006a).

Construction of Barrier IIA was completed in the spring of 2006. Testing was then begun to define the extent and magnitude of the electric field generated by Barrier IIA, evaluate the potential of Barrier IIA to create sparking between metal hulls, and evaluate the potential physiologic effects a person in the electrified water would experience. Initial measurements in April 2006 of the strength and extent of the electric field generated by Barrier IIA showed that the field extended south of the Romeo Road bridge. This generated concerns that the field would negatively impact barge operations in a fleeting area located immediately south of the bridge. Tests were completed in which a barge tow was bumped into a barge moored in the fleeting area. Sparking did occur between the contacting barges. Therefore, physical and operational changes were evaluated to reduce the electric field beyond the RNA (USACE Construction Engineering Research Laboratory, 2006b).

It was determined that placing electrically conductive material in the canal between Barrier IIA and the southern end of the RNA would reduce the electric field extent. In May 2006 a grounding system consisting of interconnected steel blast mats was constructed on the canal bottom between Barrier IIA and the Romeo Road Bridge. These mats were located where the southernmost parasitic structure, which later replaced them, is on Figure 15. With the blast mat system in place, additional testing was completed in May and June 2006. This additional testing involved measuring the extent and strength of the electric field while varying barrier operating parameters and the way the blast mats were grounded. These measurements identified several operating configurations that were most successful at reducing the spread of the electric field beyond the RNA (USACE Construction Engineering Research Laboratory, 2006b).

In February 2007 additional tests were completed to determine if the grounding system had reduced sparking potential in the fleeting area and, if so, to identify an optimal operational configuration for Barrier IIA. The "bumping" test completed in 2006 was repeated for several operating configurations and no sparking was observed. Other tests were done that simulated the making up of a tow in the fleeting area. No sparking attributable to operation of Barrier IIA was observed during the simulated fleeting operations (USACE Construction Engineering Research Laboratory, 2007). These tests were completed with Barrier IIA operating at 5 pulses per second (a frequency of 5 hertz (Hz)) with each pulse 4 milliseconds (ms) long and maximum in-water field strengths at the water surface ($IWFS_0$) of 1, 1.5, and 2 Volts/inch (V/in).

The February 2007 testing showed that operations outside the RNA would not have an increased risk of sparking with Barrier IIA operated at those parameters. However, there were still concerns about longer tows that could be partially within the RNA and partially outside of the RNA during transit over Barrier IIA, specifically whether sparking would occur if a tow long enough to simultaneously span the active electrodes of Barrier IIA and the fleeting area south of the RNA collided with moored barges in the fleeting area. It was also still necessary to examine the electrical effects on a long tow transiting the RNA when both Barrier IIA and the Demonstration Barrier are operational. The additional concern would be that exposure to two different electric fields at opposite ends of the tow could lead to increased voltage potential differences within the tow. Additional testing to evaluate these long tow scenarios was completed in April 2008 (USACE Construction Engineering Research Laboratory, 2008).

USACE contracted with the U.S. Navy Experimental Diving Unit (NEDU) to analyze the data obtained from Barrier IIA field strength data collected in April 2006 and evaluate the potential physiologic effects that are likely to occur if a person were immersed near the energized Barrier IIA. NEDU published the results of their evaluation in June 2008 (U.S Navy Experimental Diving, 2008).

Prior to August 2009, the Demonstration Barrier and Barrier IIA were operating at 1 V/in $IWFS_{0,}$ 5 Hz, 4 ms. USACE is engaged in an ongoing research program to identify the most effective combination of electric field strength, pulse frequency, and pulse duration for deterring all sizes of carp. After environmental DNA (eDNA) monitoring indicated that Asian Carp may have dispersed closer to the barrier system than previously thought, the operating parameters at Barrier IIA were increased in August 2009 to levels recommended based on the research completed at that time: 2 V/in $IWFS_{0,}$ 15 Hz, 6.5 ms. A series of additional in-water tests were completed in August and September 2009 to evaluate impacts of this change in operating parameters (USACE Construction Engineering Research Laboratory, 2011a).

Construction of Barrier IIB was substantially complete in December 2010. This included placement of three steel frames on the canal bottom to serve as parasitic structures to limit the spread of the electric field from Barriers IIA and IIB (see Figure 15). By that time the ongoing research on optimal operating parameters had identified 2.3 V/in $IWFS_{0,}$ 30 Hz, 2.5 ms as most effective for deterring smaller sizes of Asian carp. Additional safety tests were completed in February and June 2011 to evaluate the risks of operating at these newer proposed operating parameters and of operating Barriers IIA and IIB simultaneously (USACE Construction Engineering Research Laboratory, 2011b).

All of the in-water testing was completed in coordination and cooperation with the U.S. Coast Guard. The Coast Guard restricted through-traffic in the canal during all testing. All barges used in testing were fully loaded to achieve maximum hull exposure underwater. The following sections summarize the results of testing to evaluate the effects of the in-water electrical fields on potential for sparking (*Section 4.3, Evaluation of Sparking Potential*), other potential damage to vessels using the canal (*Section 4.4, Other Potential Damages to Vessels*), humans immersed in the electrified water (*Section 4.5, Evaluation of Risks Posed by Human Immersion in the Electrified Water*), and shock hazards for people in contact with objects in the electrified water (*Section 4.6, Other Electrical Hazards for Mariners*).

4.3 - Evaluation of Sparking Potential

Studies have been done to evaluate whether the electrified water created by Barrier IIA increases the possibility of sparking occurring:

- Within a single vessel
  - When metal objects contact the deck or on-board structures/equipment
  - Between the engine drive shaft and engine block
- Between a vessel and a grounded on-land object

- Between the components of a barge tow
  - When one barrier is operating
  - When multiple barriers are operating
- Between barges during fleeting operations outside the RNA
- Between two unconnected vessels or tows
  - When both are within the RNA
  - When one is partially within the RNA and one is not

Sparking can occur when there is a large electrical potential difference between objects. So to minimize the chance of sparking, vessel hulls should be at nearly equal potentials.

USACE is confident that the results of the sparking potential tests are independent of weather conditions. The measurements collected indicate that the voltage potential differences generated between metal objects in the vicinity of the barrier are not great enough to initiate the breakdown of air due to a high voltage. Therefore, arcing does not occur between two objects that are close, but not touching. The sparking observed in the sparking potential tests only occurred after two barges touched and then separated; this type of sparking is analogous to striking an arc in electric welding or the contacts of an electrical switch opening. When two metal objects at different electric potentials are brought together, the differing potentials result in an electric current flow between the objects. When the objects are separated, the current continues to flow, ionizing and heating the air between the objects. When the distance becomes too great for the electric potential to maintain the arc, the current is limited by the circuit resistance or power supply, or if the electric potential is removed, current flow stops.

In the case of barges, localized heating results in melting of steel and tiny metal particles are emitted from the barge. This is the observed sparking. This sparking is independent of the weather conditions because it is initiated by the two objects touching and separating, and the process of ionizing air via this mechanism is independent of temperature and humidity. The heat generated by this sparking process is much greater than the temperatures on the canal and will rapidly evaporate any moisture in the air.

<u>Sparking Potential within a Single Vessel</u>

In January 2005 experiments were completed to determine if a barrier electric field would lead to increased possibility of sparking on board a vessel. A towboat was positioned over the Demonstration Barrier, and USACE and the Coast Guard moved throughout the boat touching a handheld metal rod to metal equipment and fixtures. No sparking was observed. This confirmed that the electricity is distributed only on the outside of the boat hull as predicted by electrical law (the Faraday Cage Effect).

In March 2005 an additional experiment was done to measure electrical continuity between the engine drive shaft and engine block of a typical towboat. While a towboat was stationary over the Demonstration Barrier, the electrical resistance between the engine drive shaft and engine block was measured. The electrical resistance between the drive shaft and block was 0.2 ohm. This indicated that the engine block, transmission, and drive shaft are electrically continuous. Therefore, sparking between the drive shaft and engine block is unlikely.

For both of these experiments the Demonstration Barrier was operating at 1 V/in $IWFS_0$, 5 Hz, 4 ms. These experiments did not need to be repeated at Barriers IIA and IIB because the results will hold true for any electrical field in the canal water and any metal-hulled vessel.

In 2009 testing was completed to examine sparking potential on a non-metallic hulled vessel traversing Barrier IIA (USACE Construction Engineering Research Laboratory, 2011a). The possibility of igniting gasoline stored on a non-metallic hulled vessel was of particular interest. Barrier IIA was operating at 2.0 V/in $IWFS_0$, 15 Hz, 6.5 ms. Digital multi-meter probes were connected to the rudder of the wooden hull boat and the fuel tank which was not electrically bonded to it. The voltage potential was continuously recorded while the vessel traversed the RNA.

Baseline measurements were made outside the RNA. The voltage potentials within the RNA were compared with the baseline measurements and examined for significant increases while operating within the RNA. A maximum voltage of 3.8 volts was recorded which is not much greater than the noise maximum of 2.5 volts and well below the commonly used threshold of 9 volts. Therefore there is no ignition hazard for gasoline stored on board a non-metallic hull vessel traversing Barrier IIA. It can safely be assumed that if there is no hazard for Barrier IIA at these operating parameters, then there would be no hazard for Barrier IIB at the same operating parameters. Based on expert judgment, USACE believes that the results would be similar for operating parameters of 2.3 V/in $IWFS_0$, 30 Hz, 2.5 ms and other similar pulse durations and frequencies. Therefore, for both metal-hulled and non-metallic hulled vessels, traversing the barriers while the barriers are at operating parameters used to date does not increase the risk of sparking potential within the vessel.

Sparking Potential between a Vessel and a Grounded On-Land Object

Testing was completed in January 2005 to measure the voltage difference between a vessel above the Demonstration Barrier and the earth ground adjacent to the canal. One test lead was connected to a barge on a tow transiting over the barrier and a second test lead was connected to a grounded fence around the Demonstration Barrier complex. The peak voltage difference between the barge and earth ground exceeded 80 volts. Thus, if a vessel or tow were to attempt to moor to a grounded conductive structure, such as a metallic bollard, cleat, or fence, on land in the vicinity of the barriers using wire rope there is a significant risk of sparking.

This test was done with the Demonstration Barrier operating at 1 V/in $IWFS_0$, 5 Hz, 4 ms. It was not repeated at the other barriers or at other operating parameters because the result would be similar for any electric field in the water of the same strength and the voltage potential differences would be even larger for higher electric field strengths. There is potential for sparking if any mooring is attempted within the electric fields generated by the barriers. A prohibition on mooring is one of the requirements of the RNA. Also, USACE has removed all mooring structures, including cleats, bollards and capstans that were within the RNA due to previous land uses.

Sparking Potential between the Components of a Barge Tow

When One Barrier Is Operating

In January 2005 tests were done to measure the voltage potential difference between the components of a tow with two barges in series while it passes over the Demonstration Barrier. Separate tests were done with the barges connected by soft lines and wire rope.

With the barges connected by soft lines, the maximum voltage difference between the two barges approached 250 volts as the tow moved over the barrier. This level of voltage potential difference creates a significant risk of sparking. No sparking was observed during transit. However, while making a tow with soft lines for the experiments, sparking between barges was observed. One barge was moored slightly downstream of the Demonstration Barrier while the other barge and towboat were over the barrier. Sparking was created when a metal tool used for connecting the barges was used to bridge the barges. As the tool was scraped across one of the barge surfaces, sparks were created. Sparks were also observed when the hull corners of the roped barges made contact. This confirms that sparking is a definite possibility between barges connected with soft lines.

With the barges connected by wire rope, the maximum voltage difference between the two barges was less than 0.1 volt. The maximum voltage difference between the towboat and the barge it was directly contacting was less than 0.15 volt. These low potential differences indicate sparking is extremely unlikely within a tow where the barges are in series and connected by wire rope. No sparking was observed during testing. Note that the maximum voltage potential difference for the barges connected with wire rope was more than three orders of magnitude less than the maximum voltage potential difference measured for the barges connected with soft lines.

In March 2005 similar testing was done at the Demonstration Barrier for a tow where the barges were in parallel. These tests were only done with wire rope connections. The maximum observed voltage potential difference was approximately 3 volts. No sparking was observed. Although the maximum potential difference was higher than for the series configuration with wire rope, it is still low enough to make sparking unlikely. Also note that the maximum potential difference is still nearly two orders of magnitude less than the maximum potential difference measured for the series configuration with soft lines.

These tests show that sparking within a tow is extremely unlikely if each component of the tow remains electrically connected to all neighboring components of the tow. Electrical connectivity could occur in a tow connected by soft lines if the metal hulls remain in continuous contact with one another. However, if the soft lines are loose enough to allow the hulls to separate and come back together again, sparking between the hulls is a significant possibility. Connecting a tow with wire rope is much safer as it insures continuous electrical connectivity within the tow. Thus, there is an RNA requirement that tows be made up with wire rope. There is also an RNA requirement prohibiting the making or breaking of tows within the RNA. During making or breaking of tows there are times when the tow components are not electrically connected to one another and, therefore, the risk of sparking could be high.

The 2005 tests were done with the Demonstration Barrier operating at 1 V/in $IWFS_0$, 5 Hz, 4 ms. Similar tests to quantify maximum voltage potential differences over the other barriers have not been completed because the principle that tow components must be electrically connected to all neighboring tow components is assumed true for any electric field in the water. However, during other tests done over Barrier IIA sparking was generated by dragging a wire rope connected to a towboat over an adjacent barge that was connected to the towboat by soft lines. No sparking was observed between components of a tow at Barrier IIA when the components were connected by wire rope.

When Multiple Barriers Are Operating Concurrently

Multiple tests have been completed to determine if operation of more than one barrier at the same time increases the potential for sparking to occur between the components of a tow. The additional concern when multiple barriers are operating would be that exposure to different electric fields at different locations along the tow could lead to increased voltage potential differences within the tow. The longer the tow, the more likely it is to be exposed to electricity from multiple barriers simultaneously. Therefore, the tests have been done for the longest tow that is used on this segment of the CSSC, a tow five barges long.

Tests with a long tow and multiple barriers operating were first done in April 2008 with the Demonstration Barrier and Barrier IIA both operating at 1 V/in $IWFS_0$, 5 Hz, 4 ms. Similar tests were completed in 2009 with the Demonstration Barrier operating at 1 V/in $IWFS_0$, 5 Hz, 4 ms and Barrier IIA operating at 2 V/in $IWFS_0$, 15 Hz, 6.5 ms. Additional long tow tests were completed in February 2011 with Barrier IIA operating at 2.3 V/in $IWFS_0$, 30 Hz, 2.5 ms and Barriers IIA and IIB operating together in various combinations of 2 V/in $IWFS_0$, 15 Hz, 6.5 ms and 2.3 V/in $IWFS_0$, 30 Hz, 2.5 ms. During all of the 2011 long tow tests the Demonstration Barrier was operating at 1 V/in $IWFS_0$, 5 Hz, 4 ms.

For each operating scenario three or four test runs were completed alternating between upstream and downstream travel. During each test run the entire tow traveled from south of the Romeo Road Bridge to north of the aerial pipeline or vice versa. All parts of the tow were always made up with wire rope.

The maximum voltage potential differences between the barges ranged from 3.5 to 5 volts in 2008, 4.7 to 9.3 volts in 2009, and 3.8 to 6.0 volts in 2011. These low voltage values between barges indicate good electrical contact between the barge pairs. The measurements for all the test scenarios are below levels of concern and there is a low probability of sparking between barges.

The maximum voltage potential difference between the towboat and the barge next to it was approximately 9 volts in 2008, 23 volts in 2009, and 36.6 volts in 2011. The maximum potential difference between towboat and barge is greater than between barges because this can be a higher electrical resistance connection. The towboat has rubber bumpers that the barge is pulled up against, so the sole electrical connection is the wire cabling. In addition to the wire cables, barges have the additional steel-to-steel contact of their hulls. However, even though the measured voltages between towboat and barge are higher than between barges, there is still a low probability of sparking because the barge is winched very tightly to the towboat. Sparking occurs when electrical contact is broken which would be very unlikely between towboat and barge.

As long as all the components of the tow are electrically connected and are tightly bound together there is very little potential for sparking within a barge tow. This doesn’t vary significantly between all the various operating scenarios tested. Even for the higher voltage operating scenarios, the measured voltage potential differences are below levels of concern.

Sparking Potential between Barges during Fleeting Operations

As discussed earlier, when Barrier IIA was first activated and tested it was discovered that the electric field spread beyond the RNA at a level that led to sparking in the fleeting area south of the Romeo Road Bridge. After the blast mat grounding system was constructed and optimized, testing was completed in February 2007 to confirm that operation of Barrier IIA would not lead to increased sparking potential in the fleeting area. Three scenarios were evaluated for sparking potential while assembling tows in the fleeting area: connecting barges in series, connecting barges in parallel, and inserting a single barge into a tow.

For each scenario, the moving tow was placed in close proximity to the moored barge that it was to contact. The tow then slowly made contact with the moored barge and slowly moved away. These contacts are called "bumps" in this report. At least two bumps were completed for each scenario. For each scenario Barrier IIA was operated at 5 Hz, 4 ms and both $IWFS_0$ = 1 V/in and $IWFS_0$ = 2 V/in. In addition, bumps were completed for each scenario with Barrier IIA off to obtain a "background" comparison. The Demonstration Barrier was always in continuous operation at 1 V/in $IWFS_0$, 5 Hz, 4 ms. During the making and breaking of contact, USACE, the Coast Guard, and tow company personnel were positioned to look for sparking between barges. No sparking was observed for any of the bumps with Barrier IIA operating at an $IWFS_0$ of either 1 V/in or 2 V/in. This showed that Barrier IIA could be operated at these parameters without creating an increased risk of sparking to make or break tows in the fleeting area.

When the Barrier IIA operating parameters were increased in August 2009 to 2 V/in $IWFS_0$, 15 Hz, 6.5 ms, the "bumping" tests in the fleeting area were repeated at those operating parameters. The Demonstration Barrier remained in operation at 1 V/in $IWFS_0$, 5 Hz, 4 ms. For each scenario there were six bumps with key personnel positioned to look for sparking during each contact and separation for each test. No sparking was observed by any personnel during the initial testing which took place during the day. However, review of video footage taken by the US Coast Guard during testing did provide evidence for sparking during one test. As a result, the US Coast Guard requested that the tests be repeated during night time when ambient light was less likely to interfere with observation of sparks.

The night testing was done with a different contact point between the barges as shown in Plate 4. This test configuration was repeated with the northern end of the stationary barge located near Bollard 1, Bollard 2, and Bollard 3. Four to seven bumping runs were completed at each location. No sparking occurred at Bollard 1 or Bollard 3, but sparking was observed in two of five bumps at Bollard 2. Combining the day and night testing, sparking was observed in 5.88% of the test barge impact events with Barrier IIA operating at 2 V/in $IWFS_0$, 15 Hz, 6.5 ms. The series, parallel, and insertion tests were repeated again in 2011 with Barrier IIB also in operation. The test results for various combinations of operating parameters at Barriers IIA & IIB are summarized in Table 6. Throughout all of these tests the Demonstration Barrier remained in operation at 1 V/in $IWFS_0$, 5 Hz, 4 ms. The northernmost stationary barges in these tests were moored at Bollard 2. Overall in the 2011 testing, sparking was observed on 1.9% (1/52) of the series mooring tests, on 0% (0/49) of the parallel mooring tests, and on 38% (18/48) of the insertion tests.

The fleeting area where all this testing took place has been used to load coal from a large outdoor coal stockpile into open-top barges. Therefore, USACE conducted research to identify the potential for any sparking generated by fleeting operations to lead to a fire or explosion of the coal in the barges and near the dock. Since the sparking does not occur near the coal itself, ignition of the coal dust would be the pathway for a hazard. However, a literature review indicated that it is highly unlikely that sparking will ignite coal dust unless it occurs in a confined area. Therefore, although operation of the barriers may increase the likelihood of sparking occurring during fleeting operations (no sparking was observed during background tests with Barriers IIA and IIB not operating), there is no detrimental impact from the sparking.

Table 6 – Barge Fleeting Operations Sparking Potential Test Results

Operating Parameters		**Sparking Observations**		
Barrier IIA	**Barrier IIB**	**Series**	**Parallel**	**Insertion**
2.0 V/in, 15 Hz, 6.5 ms	Off	0/6	0/6	0/6
2.3 V/in, 30 Hz, 2.5 ms	Off	1/6	0/6	0/7
Off	2.0 V/in, 15 Hz, 6.5 ms	0/6	0/6	4/6
Off	2.3 V/in, 30 Hz, 2.5 ms	0/6	0/4	0/2
2.0 V/in, 15 Hz, 6.5 ms	2.0 V/in, 15 Hz, 6.5 ms	0/12	0/12	7/12
2.0 V/in, 15 Hz, 6.5 ms	2.3 V/in, 30 Hz, 2.5 ms	0/12	0/13	5/12
2.3 V/in, 30 Hz, 2.5 ms	2.3 V/in, 30 Hz, 2.5 ms	0/12	0/12	6/12

It should also be noted that the company that operates the coal stockpile discontinued shipping coal via barge in 2012. At this time the fleeting area is no longer in use. It is unknown if or when shipping of coal or any other loading or unloading of barges in the fleeting area will resume.

Sparking Potential between Two Unconnected Vessels or Tows

In January 2005 tests were also done to determine the possibility of sparking between unconnected barges moving in the vicinity of one another over Barrier I. During these tests the Demonstration Barrier remained in operation at 1 V/in $IWFS_0$, 5 Hz, 4 ms. In the first test one barge was moored approximately 40 feet downstream from the Demonstration Barrier. Electrical potential measurements were made between the fixed barge and a moving barge while a tow passed over the barrier. The maximum measured voltage potential difference was over 300 volts. As discussed earlier, this potential difference is not high enough to lead to sparking if the barges do not contact one another. However, if elements from separate tows were to scrape against one another in the barrier region, the possibility of sparking is substantial.

In the second test of unconnected barges in January 2005, one barge was moored approximately 40 feet downstream from the Demonstration Barrier and a tow was maneuvered toward the moored barges until head-to-head contact was made. The voltage potential difference between the two barges decreased with decreasing distance, but not to zero. Instead, as the distance decreased to the point where they were virtually touching, the potential difference remained in excess of 40 volts. This represents a worst-case condition that almost assures sparking. Indeed, sparking was clearly visible between the barges in the field tests.

Similar tests to quantify maximum voltage potential differences over Barriers IIA and IIB have not been completed because collisions directly over active barriers operating at higher electric field strengths would also have a high risk of generating sparking. These tests led to RNA requirements prohibiting passing and making or breaking of tows within the RNA.

Tows which are long enough to have one end near or directly over a barrier while the other end could collide with barges in the fleeting area create another concern. If the tow is configured with wire rope as required, the electrical connectivity will lead to an electric charge on the barge at the head of the tow, even though that barge is no longer over a barrier. As noted earlier, initial tests completed in April 2006 after completion of Barrier IIA indicated that sparking could occur in this type of scenario. These tests were done using a tow one-barge long with the towboat located under the Romeo Road bridge. After placement of the blast mat system, the same tests were repeated in 2007 and no sparking was observed.

In April 2008 a similar test was completed, but with a tow two barges long so that the northern end of the tow was directly over Barrier IIA when the collisions occurred. The position of the moving tow was varied to see if the location between the sidewalls of the canal made a difference in the results. Eleven test runs were completed with varying positions of the moving tow and the entire tow made up with wire rope. During each test run, the barges were bumped together a minimum of three times. Sparking was not observed during any of the test runs.

Additional tests for collisions between a downbound tow two barges long and a barge in the fleeting area were completed in August and September 2009 with Barrier IIA operating at $IWFS_0$ = 2 V/in, 15 Hz, 6.5 ms. Sparking occurred on every test in this scenario.

Additional testing was performed in 2011 for longer tows (five barges long) and with Barrier IIB in operation. For all testing the barges moored at the fleeting area were at bollard 2 and southward. The tow passed over the electrode arrays of Barrier IIA and Barrier IIB while approaching the fleeting area. During the collision tests, observers saw sparking on 100% (36/36) of the tests when Barriers IIA and IIB were operating in any combination of $IWFS_0$ = 2 V/in, 15 Hz, 6.5 ms and $IWFS_0$= 2.3 V/in, 30 Hz, 2.5 ms, on 100% (8/8) of the tests when only IIB was operating at either $IWFS_0$ = 2 V/in, 15 Hz, 6.5 ms or $IWFS_0$= 2.3 V/in, 30 Hz, 2.5 ms, and none (0/6) of the tests when only Barrier IIA was operating at $IWFS_0$= 2.3 V/in, 30 Hz, 2.5 ms.

This testing shows that sparking is possible if a moving tow collides with a barge moored in the fleeting area. There is increased risk of sparking when a tow is spanning both Barriers IIA and IIB with both operating (versus only IIA operating). As noted earlier, this isn't a significant concern for coal barges in the fleeting area. However, it is a concern if the moving tow is carrying flammable or explosive cargo. Barges that carry such cargo are known as red flag barges. Based on this testing the RNA requires vessels containing any red flag barges to have a bow boat. A bow boat is an extra towboat on the bow of the tow. The extra towboat is to assist in navigating without colliding with anything. Although fleeting operations are currently not occurring at the docks immediately south of the barriers, this rule is still in effect.

4.4 - Other Potential Damages to Vessels

Corrosion

In 2005 tests were completed in order to evaluate whether the fish barrier increased corrosion rates of metal hulls, hull voltage buildups were determined by measuring the electrical potential difference between reference electrodes mounted on the corners of the barges and the steel hull adjacent to the electrode (USACE Construction Engineering Research Laboratory, 2005). The measurements were made during several passes over the Demonstration Barrier by the tow. The Demonstration Barrier was operating at $IWFS_0$ = 1 V/in, 5Hz, 4ms. Calculations indicate that the average for all hull-to-cell values was less than -0.057 volts. This confirmed that the hull-to-electrode corrosion potentials have a near perfect "net zero" value, meaning that the pulsed fish barrier electrical signal results in effectively inducing an AC signal during the cycle of the tow entering, passing over, and leaving the barrier. Thus, so long as the tow is electrically connected while entering, passing through, and continuing beyond the barrier by at least several hundred feet, the vessels will be at the same voltage eliminating the possible current flow which is necessary for corrosion. No long-term corrosion effects should be of concern for tows passing through the fish barrier. No further testing of this parameter was conducted at the other barriers because the results suggest that corrosion will not be an issue regardless of operating scenarios.

In 2011 testing was completed to determine whether the barge hull corrosion rates of barges moored in the fleeting area south of the bridge changes with barrier operation (USACE Construction Engineering Research Laboratory, 2011b). The barge was fully loaded to achieve maximum hull exposure underwater. Tests were conducted for multiple barrier operating scenarios for Barriers IIA and IIB at the middle bollard (Bollard 2) at the mooring facility. Hull voltage potentials were measured between a copper/copper sulfate ($Cu/CuSo_4$) reference electrode immersed in the CSSC water at the stern corner on the starboard side of the moored barge and the steel hull. These tests were conducted at the same time as the sparking potential tests discussed earlier in this report.

The highest measured corrosion potentials were 360 -mV on the southeast corner of the barge with Barriers IIA and IIB operating at $IWFS_0$ = 2V/in, 15 Hz, 6.5ms and 380 -mV on the southeast corner of the barge with Barriers IIA and IIB operating at $IWFS_0$ = 2.3V/in, 30Hz, 2.5ms. These test results indicate minimal corrosion activity. There is no indication that barrier operations will lead to accelerated corrosion of the barges at the mooring facility.
Since there is no concern for long-term corrosion potential for either barges passing through the barrier area or moored at the mooring facility, it can be concluded that there is no additional risk of barge corrosion as a result of the tested barrier operations.

Electrical Equipment Damage on Vessels

For a metal-hulled vessel the in-water electricity will be distributed only on the outside of the boat hull (the Faraday Cage Effect). On-board equipment will therefore not be exposed to any electricity from the water.

Testing to determine if the electronic equipment (navigation, propulsion, control etc.) on a non-conductive hulled vessel could be impacted by the barriers was completed in 2009. The test was conducted on an operating scenario with the Demonstration Barrier operating at $IWFS_0$ = 1V/in 5 HZ, 4.5ms and Barrier IIA at $IWFS_0$ = 2 V/in, 15 Hz, 6.5ms. The probe from a digital multi-meter was connected to the 12 volt DC electrical system (battery output and power input to electronic radio). Measurements were taken of the voltage waveform while operating outside of the barrier for 1 minute for reference.

The voltage at the monitoring points was then measured continuously while the vessel passed over Barrier IIA. The frequency spectrum of the source voltage was examined for barrier induced power quality problems. The voltage spectrum should show an increase in the 15 Hz or 5 Hz frequency component if the barrier was adversely affecting the power quality. The 15 Hz frequency component (5 Hz frequency component of Barrier I) was not significantly increased when traversing Barrier IIA (I), indicating that the barrier pulses had no effect on the power quality. It can be concluded that if Barrier IIB were operating (with IIA off) at these same parameters, the results would be similar. The barriers have no effect on the power quality of a non-conductive hull vessel. This conclusion is supported by the fact that USACE has never received any reports of equipment malfunctions or irregularities from any vessel traversing the barriers.

4.5 - Evaluation of Risks Posed by Human Immersion in the Electrified Water

USACE collected data on in-water electric field strengths and wall contact potentials at Barrier IIA in April 2006. USACE then contracted NEDU to analyze the data to determine the potential physiological effects likely to occur if a person were immersed in the CSSC in the vicinity of an energized barrier. The most likely sources of such an immersion would be an individual falling into the water from a barge, towboat, or recreational boat or from the land at the canal's edge. The discussion below on risk posed by immersion is taken from NEDU's June 2008 report (U.S. Navy Experimental Diving Unit, 2008).

<u>Risk Posed by Immersion</u>

The analysis of the effect of the Barrier IIA electric field on humans immersed in the CSSC is complex. While many studies of the effects of electrical shocks to animals and humans are published, almost all investigate bodies in air, not immersed in water, and with single current burst shocks from alternating current. The CSSC Dispersal Barriers generate rapid pulses of direct current. In addition, the situation at the barrier includes many continuously changing environmental and physiological variables.

NEDU's approach was to identify and characterize the worst-case conditions and to apply several different analytical techniques to estimate body currents. Several safety standards and codes then were extrapolated to evaluate the potential harmful effects of these body currents. The goal was to bound the problem and to estimate the order of magnitude of risk for serious physiological effects.

Key information on the significant cumulative effect of repetitive short-duration DC shocks on the heart - information not available until the May 2007 revision of the IEC Technical Specification on the effect of electric current on humans and livestock - greatly increased the expected probability of ventricular fibrillation (cessation of heartbeat). The IEC Technical Specification (International Electrotechnical Commission, 2007) reports that pulses of current that are separated by less than the period of a normal heartbeat can have cumulative effects that lead to ventricular fibrillation even though the effect of each individual pulse would not alone lead to ventricular fibrillation. The threshold for ventricular fibrillation applicable to a second pulse within the period between heartbeats can be as low as 65% of the threshold current for a single pulse. Each succeeding pulse reduces the threshold current by another ~35%, until a minimum threshold of ≤10% of the single pulse threshold is reached. Since a person immersed in the CSSC at Barrier IIA will experience at least 5 pulses per second (at the Demonstration Barrier, more at Barriers IIA and IIB) , the value of the threshold current for inducing ventricular fibrillation is ≤10% of the threshold current for a single pulse.

The NEDU report compared voltage gradients measured within the CSSC at Barrier IIA while the barrier is operating at 4 or 5 pulses per second with a pulse width of 4 milliseconds and a maximum in-water field strength of 1 V/in to electric shock safety standards and to other scientific studies and concluded that currents in a person immersed in the water could be life threatening. At a minimum, the shock effects could render an immersed person unable to maintain personal flotation or to assist in their own rescue. In the worst case, ventricular fibrillation could be induced. The probability of ventricular fibrillation being induced is greater than 50% and the risk of strong muscular contractions and difficulty breathing is even higher. These physiologic effects could result in death in a relatively short time. The most severe risk would be death from ventricular fibrillation or from asphyxia (due to either paralysis of the chest muscles or inability to remain afloat). Once removed from the electric field, if breathing cessation is less than about three minutes and ventricular defibrillation is not required, individuals may require pulmonary resuscitation to survive the exposure, but normally they can recover with no long-term physiological effects. When removed from the electric field, an individual suffering fibrillation does not spontaneously recover; emergency medical treatment including defibrillation must be administered within a few minutes of initiation of fibrillation or death will result.

The NEDU report didn't address the risks of operating parameters $IWFS_0$ = 2 V/in, 15 Hz, 6.5 ms and $IWFS_0$ – 2.3 V/in, 30 Hz, 2.5 ms as they had not been identified as likely for use at the time the report was completed. However, the approach developed by NEDU can be applied to other operating parameters and USACE has used it to analyze risks posed as the operating parameters at Barriers IIA and IIB have changed over time.

In 2009 when the Barrier IIA operating parameters were increased to $IWFS_0$ = 2 V/in, 15 Hz, 6.5 ms the electric fields generated in the water were measured and analyzed to identify areas where it may be hazardous for people to be in the water (USACE Construction Engineering Research Laboratory, 2011a). The results are shown on Plate 5. The Demonstration Barrier was also in operation at $IWFS_0$ = 1 V/in, 5 Hz, 4 ms. The areas highlighted in yellow are where strong involuntary muscular reactions can occur. The areas highlighted in red are where there is a probability of ventricular fibrillation being triggered.

Once Barrier IIB was operational similar measurements and analyses were completed for various operating combinations of Barriers IIA and IIB with the Demonstration Barrier remaining in operation at $IWFS_0$ = 1 V/in, 5 Hz, 4 ms (USACE Construction Engineering Research Laboratory, 2011b). These results are shown in Plates 6 and 7.

Additional testing was completed in the summer of 2011 by the U.S. Coast Guard (Black & Veatch, 2010). The primary purpose was to focus on the ability to provide safe rescuer response actions to assist a person in water (PIW). As part of this study a test was completed to measure the expected worst-case electrical current flowing through the chest area of a PIW exposed to electric fields immersed in the CSSC. Plates 8 and 9 include the range of harmful effects for all three barriers operating at the same time. A summary of the detailed testing methodologies and results are included in the report.

As one would expect, higher operating voltages and more barriers operating simultaneously both increase the area in the canal that is potentially dangerous.

Additional Risk Posed by Contact

The discussion immediately above assumes the immersed person is floating, swimming, or treading water without contacting anything other than the water. Once an immersed person touches or otherwise contacts a structure, such as a canal wall or a boat, the current induced in their body may change. This could change the risks to which the person is exposed. Therefore, it is also necessary to evaluate the physiologic effects of an immersed person contacting a physical structure, since during a rescue attempt the victim at some time will be in contact with the water and the canal wall, another structure, or a boat. NEDU used the same approach used to evaluate risk from immersion to evaluate contact voltage potentials measured by USACE for several scenarios.

A test was completed at the Demonstration Barrier in January 2005 to determine the voltage potential difference between a reference electrode floating in the water above the barrier and the system ground for the barrier. This situation represents a worst-case possibility that would occur if the rescue of an immersed person was being attempted using a metal ladder, cable, or chain electrically connected to a ground. The Demonstration Barrier was in operation at 1 V/in $IWFS_0$, 5 Hz, 4 ms. In such a situation, the current flow induced in the person has a greater than 50% probability of inducing ventricular fibrillation (U.S. Navy Experimental Diving Unit, 2008).

Another test was completed at the Demonstration Barrier in March 2005 to determine the voltage potential difference between a reference electrode floating in the water and a towboat as the electrode was pulled toward the towboat. This was intended to simulate a person being pulled to the hull of the towboat. Again the Demonstration Barrier was in operation at 1 V/in $IWFS_0$, 5 Hz, 4 ms. The maximum voltage potential difference between the electrode and hull occurred when the electrode was near the boat, indicating that a significant current could be generated in an immersed person upon contact with the boat. This current would have a 5 to 50% probability of inducing ventricular fibrillation (U.S. Navy Experimental Diving Unit, 2008).

The two described tests completed at the Demonstration Barrier were not repeated at Barriers IIA and IIB because the risks would still be present. However, site-specific tests were done at Barrier IIA with Barrier IIA operating at $IWFS_0$ = 1 V/in, 5 Hz, 4 ms to measure the contact currents generated by contacting the canal walls at seven locations above and near the barrier. The measured contact currents with the walls of the canal near Barrier IIA were low enough that they should not cause any serious physiological health effects (U.S. Navy Experimental Diving Unit, 2008).

Measurements of contact currents generated by contacting the canal walls at locations above and near the Demonstration Barrier also were low enough that they should not cause serious health effects (U.S. Navy Experimental Diving Unit, 2008). The canal walls are composed of rock. The contacts in the 2005 tests were with an electrical grounding system and a metal hull. Thus, the risks associated with contact appear to vary depending on the electrical conductivity of the object being touched and the extent to which the touched object is grounded.

In July 2011 the U.S. Coast Guard completed tests focused on assessing potential conditions that would be encountered during an attempt to rescue a person from the electrified water. Experimental efforts focused on measuring electrical current flow through a simulated human rescuer under various touch-point conditions from both a rescue vessel in the water and from the west bank of the canal simulating a shore-side rescue.

The Coast Guard's data analysis showed that on-water rescuers could be exposed to dangerous electrical currents. Under no circumstances should a rescuer enter or immerse any part of their body directly into the electrified water. Additionally, a rescuer on shore could encounter significant electrical currents and could put themselves in danger. Touch-point current with the CSSC bank showed that the magnitude of electrical current hazard strongly related to the electrical resistance to the grounding point. The observed conditions during the July 2011 data collection period were relatively dry (mid-summer), and earth conductivity may change throughout the year due to amounts and frequency of precipitation. Maximum electrical currents were shown to occur when a metallic grounding point was established, either via sign post, fence post, or other embedded metallic object.

Rescue Procedures

In general, non-conductive or resistive materials, such as rubber, plastic and fiberglass, are effective in reducing the electrical current risk to a rescuer, so long as rescuers understand the electrical current paths, and take actions to avoid or minimize them. A fiberglass-hulled vessel provides good protection for rescuers if precautions are taken to avoid touching metallic items on the vessel that are in contact with the water, such as the motor or motor brackets and over-the-side ladders or railings. A rescuer should not make contact with any PIW in the electrified area unless the rescuer is electrically isolated from the PIW. Any attempt at rescue in electrified water conditions is inherently hazardous. The following are safety recommendations for vessel rescue:

- Use a non-metallic-hulled rescue vessel for attempting rescue of a PIW in the barrier zone. If rescuers must use a metallic hull, do not allow the metallic hull to make direct contact with the PIW.
- Use a non-conductive tether to prevent a rescuer from inadvertently entering the water.
- Use dielectric materials, including poly line, non-conductive rescue hooks, and lineman's gloves, to provide a safer means of making contact with a PIW. Use them to keep all rescuer body parts from making contact with the water or with the PIW while the PIW is in the electrified zone.

As with rescue from a vessel, a potential rescuer on shore must take many of the same precautions, including use of non-conductive equipment and isolation materials, and avoidance of contact with metallic objects such as fence posts, sign posts, or electrical boxes which were shown during testing to provide a low-resistance ground path for electrical current, thus creating a higher risk of shock hazard. The following are the recommendations for rescue from shore:

- If unable to assist the PIW from a vessel, use a polypropylene throw-rope and life ring to reach the PIW from shore.
- Use a non-conductive tether to prevent a rescuer from inadvertently entering the water.
- Protective equipment, including use of dielectric materials, should always be employed for rescues from the CSSC bank.

All potential rescuers should be provided a base level of electrical safety training that emphasizes circuit awareness, the risks associated with electricity and water, specific attention to variations in rescue conditions in the CSSC electrified area, and deleterious effects of even extremely low currents on individuals with implanted electrical devices. A memorandum of agreement (MOA) has been signed by the USCG, USACE, MWRD, the Village of Romeoville, the Village of Lemont, and Citgo Refinery, Lemont to set forth notification and coordination procedures for response actions in the event of an emergency situation within the vicinity of the barriers.

Each of the barriers has emergency stop switches on the wall that are easily accessible from the barrier's control area (which contains a workstation with the computers that control and monitor the barrier). There is one stop switch for each pulser at the barrier. They are toggle switches. The stop switch must be in the on position before the pulser can be activated and will immediately turn off the pulser, thereby immediately stopping power to the water, when turned to the off position.

There are video cameras located throughout the site, including cameras that provide views of the canal. Any camera can be viewed on monitors at the control workstation in any of the barriers. In addition, the Barrier IIA and Barrier IIB control workstations, which is where operators are based, have marine band radios that are continuously on and scanning for transmissions from local vessel traffic. If any USACE employee or USACE contractor responsible for barrier operations becomes aware of a person immersed in the water between the Romeo Road bridge, approximately 80 feet downstream of Barrier IIA and the aerial pipeline arch approximately 600 feet upstream of the Demonstration Barrier, they shall immediately shut down barrier operations using the emergency stop switches. They will then call 911 to report the situation. If a person is immersed in the water of the CSSC within ¼-mile north of the pipeline arch and any of the emergency responders party to the MOA inform the Corps that they will be unable to remove the person from the water prior to their entering the electrified area, USACE employees or operations contractors are also to shut down barrier operations.

The USACE and/or contractor staff on site will try to minimize the amount of time the barriers are shut down. Once all immersed people are no longer in the electrified area, the operation of the barriers will be resumed immediately. If possible, the staff on site will only shut down the minimum number of barriers necessary to avoid exposing an immersed person to electrified water. However, shutdown of all barriers is authorized if deemed necessary.

If the barrier is shut down for a person in the water, the Monitoring and Response Workgroup will evaluate the need to initiate a response action to address the possibility that Asian carp moved upstream through the barriers during the shutdown.

4.6 - Other Electrical Hazards for Mariners

Shock Hazard at Fleeting Area

Testing has been completed to determine whether there is a shocking hazard for the personnel working with the barges in the fleeting area located south of the Romeo Road bridge (USACE Construction Engineering Research Laboratory, 2011a and 2011b). These tests measured the voltages and currents between fixed barges in the fleeting area and the dock. A 500-Ω resistor was used for the current measurements. The 500-Ω resistance simulates the body's impedance from hand to foot. The hand to foot shock potential is referred to as the touch potential. The tests were completed for various combinations of Barriers IIA and IIB operating at $IWFS_0$ = 2 V/in, 15 Hz, 6.5 ms and $IWFS_0$ = 2.3 V/in, 30 Hz, 2.5 ms. The barges used in testing were moored at the #2 and #3 bollards. Bollard #2 is approximately 470 feet downstream from the southern-most end of Barrier IIA. Bollard #3 is approximately 200 feet downstream for the #2 bollard.

Both peak voltage and current measurements were significantly lower at Bollard #3. At Bollard #2 the maximum peak current was 17 mA and the maximum peak voltage was 11.2 Volts. These measurements are in the DC-2 range of the IEC Publication 60479-1 (International Electrotechnical Commission, 2007), whereby "Involuntary muscular contractions likely, especially when making, breaking or rapidly altering current flow but usually no harmful electrical physiological effects."

It should also be noted that the company that operates the coal stockpile discontinued shipping coal via barge in 2012. At this time the fleeting area is no longer in use. It is unknown if or when shipping of coal or any other loading or unloading of barges in the fleeting area will resume.

Shock Hazard to Personnel on Vessels

For a metal-hulled vessel the in-water electricity will be distributed only on the outside of the boat hull (the Faraday Cage Effect). Therefore, unless a person on board comes in direct contact with a conductive object that is directly in contact with the water there is no risk of shocking due to traversing over the barriers.

Testing to determine the possibility of electric shock to occupants touching two non-electrically bonded metal objects as they traversed the barriers was completed in 2009 (USACE Construction Engineering Research Laboratory, 2011a). The testing was completed on a non-metallic hulled vessel with Barrier I operating at $IWFS_0$ = 1V/in 5 HZ, 4ms and Barrier IIA at $IWFS_0$ = 2 V/in, 15 Hz, 6.5ms. Electrical resistance was measured between various metal objects on board but not electrically connected to one another. A digital multi-meter probe was connected to the pairs of un-bonded metallic objects tested above and the vessel ground. Voltage potential differences were measured using the following resistor values: 100, 500, and 1,000 ohms. The resistor values are meant to model the resistance of occupants within the vessel. The voltage wave forms across the resistors at the monitoring points were recorded continuously while the vessel passed over Barrier IIA. For all measurement channels and resistances there was no difference between the voltages measured while over the barrier and while not over the barrier. Therefore, the potential for shock for people in non-metallic hulled vessels traversing the barriers is also not increased provided the person does not make contact with a conductive object in the water.

4.7 - Regulated Navigation Area and Safety Zone

On January 26, 2005 the United States Coast Guard (USCG) published a Regulated Navigation Area (RNA) on the CSSC in the vicinity of the barriers as a temporary final rule. The RNA became permanent on January 1, 2006 (33 C.F.R. § 165.923). The USCG has modified the RNA at times to improve its effectiveness. The most current version became effective in August 2018.

The RNA is currently defined as all waters of the CSSC located between mile marker 295.5 and mile marker 297.2, and established the following guidelines.

- Vessels must be greater than 20 feet in length.
- No personal watercraft of any kind (i.e., jet skis, wave runners, kayaks, row boats, etc.) is permitted to transit the RNA.
- Vessels engaged in commercial service, as defined in 46 U.S.C. 2101(5), may not pass (meet or overtake) in the RNA and must make a SECURITE call when approaching the RNA to announce intentions and work out passing arrangements.
- Commercial tows transiting the RNA must be made up with wire rope or appropriate alternatives to ensure electrical connectivity between all segments of the tow.
- All vessels are prohibited from loitering in the RNA.
- Vessels may enter the RNA for the sole purpose of transiting to the other side and must maintain headway throughout the transit. All vessels and persons are prohibited from dredging, laying cable, dragging, fishing, conducting salvage operations, or any other activity, which could disturb the bottom of the RNA.
- Except for law enforcement and emergency response personnel, all personnel on vessels transiting the RNA should remain inside the cabin, or as inboard as practicable. If personnel must be on open decks, they must wear a USCG approved personal flotation device.
- Vessels may not moor or lay up on the right or left descending banks of the RNA.
- Towboats may not make or break tows if any portion of the towboat or tow is located in the RNA.
- All vessels are required to transit at no wake speed but still maintain bare steerageway.

All vessels are also prohibited from transiting the RNA with any non-potable water on board if they intend to release that water in any form within or on the other side of the safety zone. Non-potable water includes, but is not limited to, any water taken on board to control or maintain trim, draft, stability, or stresses of the vessel. It also includes any water taken on board due to free communication between the hull of the vessel and exterior water. Vessels with non-potable water onboard are permitted to transit the RNA if they have taken steps to prevent the release, in any form, of that water in or on the other side of the RNA. Alternatively, vessels with non-potable water onboard are permitted to transit the RNA and discharge the water on the other side if they obtain the permission of the USCG. Discharges that may be approved include plans to dispose of the water in a biologically sound manner or water that based on accepted testing methods does not contain potential live Silver or Asian carp, viable eggs, or gametes. The USCG has also investigated the potential for Asian carp eggs and larvae to become entrained in barge tanks, and whether eggs and larvae could survive in the ballast water tanks, and survive single passage through a tank dewatering pump. Further information is included in *Section 3.4, Summary of Other Asian Carp Initiatives,* of this report.

4.8 - Ground Currents

Operation of the barriers also causes safety concerns and operational impacts for people and equipment not in contact with the electrified water. The electrified water is in direct contact with the rock walls and bottom of the CSSC. Some electricity passes from the canal into the rock causing electrical currents under the ground surface in the vicinity of the barriers. USACE has been studying the potential impacts of these ground currents near the barriers since February 2009.

<u>Shock Hazards from Ground Currents</u>

When a person walks on the ground adjacent to the fish barrier along the bank of the CSSC, he or she is essentially walking on ground that has elevated voltage gradients when compared to a remote reference point. When a person bridges the gap between two electric potential gradients of different levels, current may flow through the person, equalizing the potentials. The magnitude of the current to which the human is exposed is the result of the person's resistance and the difference between the two electric gradients. The Institute of Electrical and Electronics Engineers (IEEE) defines the following types of electric potential exposures for a human:

- Touch Potential: The potential difference between the ground potential rise and the surface potential at the point where a person is standing while at the same time having a hand in contact with a grounded structure.
- Reach Potential or Metal-to-Metal Touch Potential: The difference in potential between metallic objects or structures that may be bridged by direct hand-to-hand or hand-to-feet contact. Most reach potentials are present where there is a possibility for a person to be touching two conductive grounded structures at the same time. Reach potentials include: between metallic hand rails, between chain link gates that are not electrically bonded, between permanent grounded and temporary fences, and between metallic signage and fencing.
- Step Potential: The difference in surface potential experienced by a person bridging a distance of 1 meter with the feet without contacting any grounded object.

The degree of shock hazard and the threshold levels of current that can be tolerated by human beings depend on many factors. The possibility of shock from lower voltages is the most difficult to assess. The degree of shock hazard depends on factors such as the voltage level and duration of human exposure, human body weight, human skin conditions, and the path and magnitude of any current conducted by the human body. The magnitude of current conducted by the human body is a function of the internal impedance of the voltage source, the voltage impressed across the human body, and the electrical resistance of the body path. This resistance also depends on the contact resistance (e.g., wet or dry skin, standing on dry land or in water), and on the current path through the body (e.g., hand-to-foot, hand-to-hand, etc.).

Eight incidents of people being shocked in the vicinity of the barriers likely due to ground currents have been reported since 2009. None of these incidents have resulted in any reported injuries.

USACE has developed a Long Term Monitoring Plan for earth surface potentials. The plan includes monitoring methods, locations to monitor, and safety precautions to employ during monitoring. Measurements are collected monthly and when barrier operating parameters change, there are physical changes to the barriers, or there is significant new construction by neighbors. A database is being maintained to determine characteristics of the earth surface potential gradients. The voltage data includes step potentials, touch potentials, and reach potentials used to assess personnel safety concerns. This database is being used to develop a framework for long term data monitoring and to draw conclusions regarding the causes of voltage in the ground near the barriers. The database is also being used to develop ways to manage or mitigate the influence of earth surface potentials. There have been three remote earth measuring events to evaluate ground potential rise for operation of Barrier IIA, IIB, and to evaluate the impact of site grounding. There have been several surveys of the adjacent railroad to evaluate touch potential and to evaluate the impact of site grounding.

Field measurements of earth surface potential may vary at any specific location over time due to changes in barrier operations and environmental conditions. However, certain locations are known to have relatively high voltages. USACE staff and neighbors, as applicable, have been informed of these locations and steps are taken as possible to mitigate the risk. Throughout the project site, mitigation measures have included warning signs, placing of metal mesh or dielectric mats on the ground to equalize potentials, and covering of conductive materials with non-conductive paints or other coverings, such as plastic sleeves on poles and plastic covers on bolts. A summary of known high voltage locations, magnitudes, and mitigation measures can be found in the Fish Barrier Ground Current Summary and Monitoring Plan (USACE Chicago District, 2015). USACE is in the process of replacing fencing on adjacent property owners' land with non-conductive fencing in areas that have shown a history of stray voltage impact.

As expected, ground currents in the vicinity of the barriers are increased when Barrier IIA and Barrier IIB are operating concurrently. The effects of the additional barrier dissipate as the distance from the CSSC increases. Some local values near the barriers show an increase of up to 100 percent when both barriers are operational, while others do not show a measurable increase when both barriers are operational.

Testing in February 2011 testing showed that when barges are passing over the barriers the ground currents decreased, creating lower earth surface potential gradients. Comparison of testing points showed a slight decrease in step and touch potentials when barge traffic was in the CSSC. While this was not the case for every comparison point, the majority had this trend.

The electric energy in the ground varies due to weather conditions, the soil/rock resistivity, water resistivity, and other factors. Because of these factors, there was not a clear distinction between the risks with Barriers IIA and IIB operating at $IWFS_0$ = 2.0 V/in, 15 Hz, 6.5 ms versus $IWFS_0$ = 2.3 V/in, 30 Hz, 2.5 ms. However, in general the electrical potentials are higher nearer to the CSSC under all operating scenarios and higher when both Barriers IIA and IIB are operating simultaneously. Further evaluation of the testing results obtained during 2010 and 2011 was completed to compare the relationship between the independent variables of CSSC water conductivity, power, water level, air temperature, and humidity on the dependent variable voltage. This analysis showed that there is a correlation between water conductivity and temperature parameters and voltage. Essentially the trends show that in the winter months, the temperature drops and water conductivity rises. Additional power is needed to produce voltages necessary on the CSSC surface to offset the higher conductivity. This correlates to higher current readings in the ground.

Touch and reach potential at the neighboring railroad tracks has been of particular concern. Mitigation by covering or replacing the rails with non-conductive materials isn't possible and railroad workers do need to contact the rails at times. Measurements recorded in 2010 and 2014 showed that the touch potential from the east and west rails to earth 10 feet away exceeded the threshold for inducing ventricular fibrillation in some locations immediately adjacent to active barriers. The largest measurements were adjacent to Barrier IIA. In the spring of 2014 a grounding grid was placed underground south of Barrier IIA. The grid consisted of a 10 foot (ft) x 10 ft copper wire grid buried parallel to the ground surface. Additional grounding was installed in the fall of 2015 and the spring of 2016. The grounding in 2015 and 2016 entailed installing ground rods at depth of 30 – 50 ft at a spacing of 20 ft and connecting these ground rods to the barrier grounding system. In the fall of 2015 the 10 ft x 10 ft grid was continued to connect Barriers IIA and IIB, and in the spring 2016 a 10 ft x 10 ft grid was added to the west side. Measurements taken after the installation of the grounding grid indicate the touch potential to the rails has been reduced adjacent to the barrier reduced by approximately 80 percent. However, directly adjacent to the barriers reading exceed the fibrillation touch potential threshold. Permanent Barrier I was constructed with 50 ft ground rods installed at 20 ft spacing to reduce the spread of stray current.

Fifteen (15) feet from the rails, a counterpoise system was installed in the fall of 2015 to reduce the amount of voltage that reaches the railroad tracks. The system consists of a 3,000-foot long bundle of copper wires buried approximately one-foot deep parallel to the ground surface in a trench located fifteen feet west of the westernmost rail. The wire bundles were connected to five-feet deep copper-bonded ground rods located every 100 feet along the alignment of the wires. The counterpoise extended from approximately 350 feet north of the Demonstration Barrier to approximately 1,400 feet south of Barrier IIA. Though the counterpoise was not effective at reducing touch potentials, the grounding adjacent to the barriers described above was highly effective.

Railroad Crossing Signal Interference

The road adjacent to the barriers crosses over a railroad track approximately 250 feet south of Barrier IIA. Ground current from the barrier can interfere with the crossing signal creating false drops of the crossing gates (i.e., the signal causes the gates to go down when there is no train coming). This is both an operational impact and a safety concern. The concern is that when the gates drop but no train is coming, people may drive around the gates. Accidents could occur if a train does come down the line shortly after the false drop occurs or if people get in the habit of ignoring the gates because they don't believe a train is coming.

The signal interference wasn't observed when Barrier IIA was operating at $IWFS_0$ = 1 V/in, 5 Hz, 4 ms or when Barriers IIA and/or IIB operated at $IWFS_0$ = 2 V/in, 15 Hz, 6.5 ms. The interference was initially identified when the $IWFS_0$ = 2.3 V/in, 30 Hz, 2.5 ms operating parameters were first used in October 2011. The majority of the false drops subsided after Smith Root Inc. corrected a grounding problem at the barriers on October 31, 2011. Pulser 3 of Barrier IIB had been grounded to the in canal blast mat during Barrier IIB construction in 2010 and had not been disconnected. This created a large electric field that was believed to be the primary cause of the signal interference that occurred after switching to 30 Hz in October of 2011.

However, despite the grounding correction, periodic signal interference continued to occur. USACE hired consultants with signal expertise to investigate the situation and several reports have been published (CCC; 2011a, 2011b, and 2012)). The consultants concluded that much, if not most, of the signal malfunctions could be addressed by developing a stable pulse train between the two barriers and between the pulses of the given barrier. This constant pulse repetition frequency would then result in fewer false drops. They then proceeded to model and recommend pulse configurations that would result in minimal railroad interference. USACE presented these results to BNSF and on January 31, 2013 met with BNSF to discuss remediation options. As a result of this meeting, BNSF agreed to change the signaling device to a more robust device and USACE agreed to stabilize their barrier operating pulse train. USACE contracted with Smith Root Inc. to perform the pulse synchronization and the pulse synchronization, which was completed in Jan 2014. BNSF proceeded to replace their HXP 3 signal with a HXP 4 on September 11, 2014. BNSF also changed the operating frequency of their signal from 156 Hz to 430 Hz.

The changes made by USACE to synchronize the pulses and by BNSF to replace the signal and change the operating frequency didn't alleviate signal interference. It was calculated that certain pulse durations and frequencies were less likely to result in crossing signal interference. On October 30, 2014 the pulse parameters for Barriers IIA and IIB were changed to 34 Hz, 2.3 ms because these parameters seemed likely to avoid signal interference and are supported by research that they are effective at fish deterrence. These parameters seemed to be operating with minimal interference with the railroad signal.

However, a heavy snowfall in early February 2015 was followed by other snow events. Thaws resulted in runoff of road salt into the CSSC, producing higher water conductivities. These higher water conductivities increased the power demand on the barriers. The power demand eventually exceeded the capacity of the barriers and the operating parameters were automatically reduced, referred to as "folding back" of parameters, to a sustainable power level. When this occurred, significant and sustained interference with the railroad crossing signal began to occur. BNSF felt the ongoing interference was an unacceptable safety issue and close the crossing to vehicle traffic. The crossing remained closed for approximately six weeks, creating site access limitations for USACE and a neighboring business.

In an attempt to solve this problem, the voltage at the barriers was reduced and the impact of a variety of different pulse parameters was evaluated. The $IWFS_0$ was reduced to 1 V/in on February 25, 2015 and was increased in steps over the spring. The reduction in voltage was considered acceptable because

- monitoring wasn't indicating a presence of Asian carp near the barriers;
- any Asian carp present would be highly likely to be a larger fish and larger fish can be deterred by lower voltages;
- fish activity is lower when the water temperature is colder; and
- preliminary results of ongoing research indicate electric barriers are more effective in colder water temperatures.

More information on the effectiveness of barrier operating parameters can be found in *Chapter 5, Effectiveness of the Barriers*, of this report. On June 1 the voltages at Barriers IIA and IIB were returned to early February 2015 levels. After trying several alternatives, the pulse parameters were returned to 34 Hz, 2.3 ms on June 8, 2015.

Occasional periods of signal interference have been observed since June 8, 2015 and research on possible causes is continuing. Also, although the closest crossing has been the principle area of concern there are three other crossings within approximately 3, 000 to 11,600 feet of the barriers. Two of them have previously experienced at least some interference from the barriers.

At present, provided the pulse frequency of 34 Hz and pulse duration of 2.3 ms is maintained, the railroad signals show minimal to no interference. The barrier is now programmed to permit maintaining these parameters even when the barrier reaches its power threshold. However, in order to stay within the barrier power constraint, the voltage is automatically lowered.

Corrosion of Structures by Ground Currents

Another concern created by ground currents is their potential to accelerate corrosion of metallic structures on land in the vicinity of the barriers, such as piping, concrete reinforcing steel, and fence posts. This is commonly referred to in industry as "stray current". The stray current pattern consists of a pick-up of stray current from the earth at one or more locations and the subsequent discharge of stray current to the earth at one or more locations. When a current transfers from a metallic structure to earth, it must do so via an oxidation reaction that converts electronic current to ionic current. On an iron or steel structure without cathodic protection, the oxidation reaction is usually the dissolution (corrosion) of the metal. The corrosion of the metal items is limited to the areas where the electrical potentials can be detected.

In addition to testing for shock hazards, the initial ground current investigations of 2010 also evaluated potential corrosion impacts (Black & Veatch, 2010). With the addition of Barrier IIB further corrosion investigations were completed in 2011 (Black and Veatch, 2011a and 2011b). The field testing investigations included evaluating potential impacts at neighboring businesses to the north and south, three nearby residences to the east, a petroleum pipeline that passes through the area, the Barrier IIA building foundation/slab, the Romeo Road bridge piers, the railroad rails to the east, and the local electrical distribution network.

Testing in 2010 showed very low presence of ground currents from the barriers on the properties of the businesses. These areas have only minor underground systems subject to corrosion and with the low ground current present corrosion was not a concern. Further testing was completed in June 2011 with Barrier IIB in operation. The 2011 testing confirmed no adverse risk for corrosion on their facilities.

There are three residences in the vicinity of Barrier IIA. Potential impacts to these residences were a major focus of the 2010 testing. Water well pumps, propane tanks, and pipes were evaluated. The water well pumps were found to be corroding at an accelerated rate, likely because of barrier ground currents. At the time of the well pump failures, the solution to stop the failures was to disconnect the neutral ground from the well pump. Since that time ComEd has installed an isolator between the utility and residential service and disconnected the customer side neutral line from adjacent customers. These actions taken by ComEd should mitigate for corrosion of well pump. However, the owner has chosen to leave the well pumps disconnected from the neutral line as an added precaution against pump failure.

Propane tanks at two of the nearby residences as well as on the BNSF property have been upgraded to reduce risks from stray currents. The lines to the tanks were replaced with non-metallic lines and the tanks are supported on non-metallic sleepers. This effectively isolates the tanks from ground. As an added precaution non-conductive pads for the tank filler to stand on and signage to alert the propane tank filler of special precautions to take when filling these tanks have been installed.

The only metallic piping system into the three houses is a cast iron pipe from the house to the septic tank at one of the houses. The cast iron pipe was inspected and no visual signs of corrosion were observed on the exposed piping. However, pipe to soil potential measurements indicated that the piping is discharging current and therefore corroding.

Since the initial discovery of concerns at the residences, USACE has implemented mitigation measures to effectively reduce corrosion potentials including additional grounding, plastic piping, shielding and insulation, and an isolation transformer. The corrosion in the water wells was thought likely to be due to voltage coming in through the utility neutral line. USACE worked with ComEd, the local electrical utility, to separate the homes from the adjacent customers on the secondary side and from the primary neutral with a 650 Volt lightning arrestor. A new transformer was installed to feed nearby commercial customers: canal lights, bridge lights, railroad signals and a warehouse. The existing transformer, which once supplied various customers, including those listed above, now only supplies the three residential properties. This isolates the residences so they are not connected to the barrier in any way. These measures have effectively mitigated the concern for corrosion on metallic items at the nearby residences.

A slight signature of barrier pulsing was observed on the petroleum pipeline in 2010 testing. However, potential measurements indicated that the piping was meeting the criteria for cathodic protection at all of the locations tested. Based on this it was concluded that the Demonstration Barrier and Barrier IIA were not having any adverse corrosion effects on the pipeline at the locations tested. However, data collected in February 2011 suggested that operation of Barrier IIB increased the electric potentials in the soil around the pipeline, which could increase the probability of corrosion. Further testing conducted in August 2011 indicated that this concern was unwarranted and the pipeline wasn't being influenced by stray currents from the barrier (Black & Veatch, 2011c).

However, the pipeline owner raised concerns in 2012 that further testing had not been completed since the Barrier II operating parameters were changed to $IWFS_0$ = 2.3 V/in, 30 Hz, 2.5 ms in October 2011. Additional measurements collected in July 2012 indicated corrosion could again be a concern. Further field testing was completed in December 2012 to evaluate the utility neutral as a pathway for voltage onto the pipeline. However, disconnecting the utility neutral didn't help and might actually increase the impact on corrosion. USACE is currently working with the pipeline owner to install additional test stations and corrosion monitoring equipment to evaluate the corrosion rates on the pipeline. USACE has met with the pipeline company, provided the results of the investigations, and outlined a plan to monitor. In 2016 testing equipment that included IR drops, ER probes, corrosion coupons were installed. A separate data collection contract with Black & Veatch was awarded in 2016. Because of a contract modification requiring bringing power to the site, the completion has been delayed. However, baseline data is expected to be collected prior to turning on Permanent Barrier I.

A study in 2010 indicated that the rebar in the Barrier IIA building foundation was under the influence of the barrier currents and corrosion was occurring. However, another investigation completed in November 2013 showed that the IIA rebar wasn't undergoing voltage shifts that would indicate corrosion. However, the rebar in the Barrier IIB foundation did show voltage shifts that indicate corrosion. The potential for foundation corrosion was considered in the design of Permanent Barrier I with epoxy coated rebar installed in the foundation slabs.

Initial attempts in 2010 to make electrical connection to the Romeo Road bridge footing rebar through the bridge beams and expansion joints were not successful. A plan was developed in coordination with the Village of Romeoville to access the rebar for testing by limited drilling through the bridge piers. This testing was completed and the results did indicate some stray current activity on the bridge pier rebar (Romeoville Bridge Stray Current Report, 2011). The potentials do not indicate any significant corrosion of the vertical rebar or loss of adherence of the rebar sampled. However, the report recommended that grounding be installed around six of the bridge piers to minimize the soil electrical gradients adjacent to the piers and minimize the possibility of any significant rebar corrosion. USACE completed installation of this grounding in October 2013.

Rail-to-soil potential measurements performed on the railroad tracks in 2010 indicated the presence of the fish barrier pulsing. However, the rails are not in intimate contact with the earth due to the wooden tie and rock ballast construction. Based on this there does not appear to be a corrosion issue with the rails due to the barrier. This result was confirmed through further testing in June 2011 with Barrier IIB in operation.

Transference of Voltage on the Utility Network

One of the lessons learned during the ground current investigation is that voltages can be transferred to the utility network. The utility that serves Barrier IIA contains a neutral line that is connected to pole grounds in the vicinity of the fish barriers. It is through this neutral line that voltages can be picked up and transferred to neighboring customers. Testing of the electrical distribution network was completed in 2011. Measurements were taken as far as a mile away on various utility infrastructures. Areas investigated were a museum, multiple light poles, a neighboring petroleum refinery, residential neighborhoods, and local restaurants. The results showed that the spread of this voltage is limited to the immediate vicinity of the fish barriers. In general, the most significant voltages have dissipated to the west of Centennial Park to the west and to the Citgo entrance to 135th Street to the east. Monitoring to the north has not been as comprehensive as to the west and east. The analysis of information showed no indication for possible corrosion concern on the utility network. To address touch potential to utility poles, non-conductive covers were installed in 2017.

4.9 - Electric and Magnetic Fields

The electrical equipment at the barriers generates airborne electric and magnetic fields. Electric fields are created by differences in voltage potential. Magnetic fields are created by flow of electric current. The strength of these fields decreases with distance from the source. The potential health effects of exposure to these types of fields are a significant topic of research and discussion. For example, there has been media coverage of whether living or working regularly near high voltage power lines or frequent use of cellular phones has detrimental health effects due to electric and magnetic fields. One of the key characteristics of electric and magnetic fields are their frequency. The CSSC Electric Dispersal Barriers operate at what are considered extremely low frequency (ELF).

USACE has researched whether the electric and magnetic fields generated by operation of the barriers may be unhealthy for either workers on site or members of the general public that visit or pass by the facilities. Federal Occupational Health (FOH) was engaged by USACE to complete on-land measurements of electric and magnetic fields at the Demonstration Barrier and Barrier IIA in November 2009 and March 2010. At that time Barrier IIA was operating at $IWFS_0$ = 2 V/in, 15 Hz, 6.5 ms and the Demonstration Barrier was operating at $IWFS_0$ = 1 V/in, 5 Hz, 4 ms. Further measurements were collected by FOH in February 2011 with Barrier IIB in operation. The 2011 measurements were collected both on land and from on the decks of boats in the canal over the barriers. During this 2011 testing the operating parameters of Barriers IIA and IIB were varied in different combinations of $IWFS_0$ = 2 V/in, 15 Hz, 6.5 ms and $IWFS_0$ = 2.3 V/in, 30 Hz, 2.5 ms. The Demonstration Barrier remained in operation throughout at $IWFS_0$ = 1 V/in, 5 Hz, 4 ms.

While FOH had expertise in obtaining the measurements, there were still questions about how to interpret the data as to effects on human health and safety. A contract was awarded in 2012 to retain the services of a team from the Electric Power Research Institute (EPRI) EPRI completed a thorough analysis of the entire fish barrier site in 2013 and have found minimal concerns with compliance to standard IEEE C95.6-2002 for pulsed magnetic and electric fields generated by the operation of the Demonstration Barrier, Fish Barrier IIA, or Fish Barrier IIB (EPRI 2013). Data collected during the investigation was compared to the exposure limits defined in that standard and the following conclusions were found:

- There were no pulsed electric fields (DC) or 60-Hertz (AC) magnetic fields measures during the investigation that exceeded the IEEE Standard for Controlled Environments (i.e., trained workers).
- There were no pulsed magnetic fields measures over the canal water in either fiberglass or metal boats that exceeded the IEEE Standard for the General Public.
- There were eight (8) points across five (5) locations on the site at which the pulsed magnetic fields (DC) exceeded the IEE limit for the General Public. However, these locations are not accessible to the public. These elevated readings were localized and only in a space very close to the surface of electrical equipment. They are in locations that personnel are not typically in during normal site activities and are not accessible for head and torso exposure. These locations do not exceed the limits for Controlled Environments (i.e., trained workers).

USACE has restricted access by both workers and visitors to the locations which exceed the General Public standards.

4.10 - Electrical Equipment Hazards to Workers

Arc flash evaluations are periodically completed at the Barriers. The most recent evaluation of all barriers was completed in 2017 (Tetra Tech, 2017). This was done to evaluate equipment safety and make adjustments as needed to protect personnel. It should be noted that the results of the arc flash evaluations are independent of the operational parameters of the barriers. Changing operational parameters does not impact these analyses.

The arc flash hazard scenarios were evaluated to develop arc flash labels and select appropriate personal protective equipment (PPE) to be worn when working within the flash protection boundary. Service or maintenance work should only be performed when equipment is de-energized or the proper protective equipment is in place. The recommended PPE is based upon the hazard risk category levels from the arc flash incident energy calculations. The PPE recommendations are taken directly from NFPA 70E. Arc flash labels have been provided for each piece of electrical equipment to identify incident energy levels, arc flash boundary distances, and any PPE required.

Studies of the potential for electrical equipment at Barriers IIA and IIB to explode or catch fire were also completed in 2010 (USACE Protective Design Center, 2010). It should be noted that the operation of the capacitors is completely independent of the operational scenarios for all of the barriers; therefore, the hazard potential is the same for all operational scenarios.

The primary hazard in the Electric Dispersal Barrier buildings is the electrical equipment containing large capacitors. A failure of a capacitor can cause fire, air blast pressure, and fragment hazards to personnel. The report calculated that the probability of a capacitor failure is 3.1x10-4 (or 0.031%) with a 95% confidence level. Furthermore, the analysis performed in the report calculated an air blast pressure of less than 5 psi. In comparison, the Department of Energy allows a limiting pressure to 5 psi for personnel protection. Therefore the air blast hazard is minimal. The calculated blast pressure will not cause either the buildings or the pulser cabinets to fail and create a safety hazard from structural collapse.

The report goes on to make recommendations to mitigate the identified hazards. The report recommends that flammable materials not be stored in the pulser rooms and personnel are kept out of pulser rooms during operation to address the concerns of fire and fragment hazards. These recommendations are being followed in the IIA & IIB buildings. They will also be made part of Permanent Barrier I operation.

The report also found that a minimum 0.075-inch thick steel plate or equivalent barrier is required as an enclosure to contain fragments resulting from a potential failure. All the existing enclosures or cubicles in the IIA and IIB buildings have sufficient protection. Any fragments would not perforate the building IIA enclosure walls, building IIB blast doors or dampers, building IIB personnel or exterior double doors, or the wall or roof of either building IIA or IIB. However, fragments could perforate the IIA capacitor enclosure filter cover, but would not have enough kinetic energy to perforate the walls, roof, or doors of building IIA. However, fragments perforating the filter cover which could be a hazard if any personnel were inside the IIA building at the time of a blast. The Permanent Barrier 1 building design incorporated the findings of the report in order to have sufficient protection from fragments and air blasts. The pulser room is fitted with a clean agent fire suppression system to contain any fire hazard that might occur.

4.11 - Conclusions

There are inherent risks associated with the operation of the Electric Dispersal Barrier System in the CSSC. There is no way to reduce the electric field in the water to completely eliminate the potential for sparking between vessels or the health risks posed by human immersion without compromising the ability of the barriers to effectively stop the movement of invasive fish species. However, these risks can be greatly reduced if canal users obey the RNA and behave carefully near the barriers.

There is no risk at the barriers of increased sparking potential for on-board activities when a vessel is in the electrified water. There is a significant risk of sparking between vessels that make contact within the electric field and are not otherwise electrically connected to one another. There is also a significant risk of sparking if something conductive on a vessel within the electric field contacts a grounded object on land. However, these risks are minimized by complying with the RNA requirements prohibiting mooring, passing, and making or breaking tows and requiring transiting tows to be made up with wire rope.

The proximity of the fleeting area south of the Romeo Road Bridge to Barrier IIA creates additional concerns for sparking potential. However, the fleeting area is not currently used.

Tests were also completed to evaluate the voltage potential differences that would develop within a long tow made up with wire rope if it transited the area with multiple barriers in operations concurrently. There is no significant additional risk of sparking within a tow transiting over multiple barriers operating versus the risk of transiting with only one barrier operating.

The health risks of human immersion can best be reduced by avoiding human contact with the electrified water. It is not possible to control the behavior of all individuals, but it is possible to make every effort to ensure that canal users are aware of the location of the barriers, the risks they pose, and the importance of staying out of the water. To achieve this awareness, large signs have been erected along the waterway. USACE also supports US Coast Guard efforts to reach out to boaters and to publicize the location and safety concerns of the barriers.

There are also potential safety risks and operational impacts created on land due to ground currents. Since electric energy will always be present underground when the barriers are operated, the probability of adverse impacts from ground currents cannot be reduced to zero. Mitigation of the adverse impacts has been managed and the probability of the adverse impacts has been lowered. To mitigate for adverse impacts to people, USACE has installed non-conductive fencing all around the site, reduced the conductive metal items around the site, installed multiple mitigation features at the nearby residences, and has electrical safety precautions in place at the site. All of these have been effective in reducing the electrical shock risk due to ground currents.

Investigation of the potential health risks of airborne barrier-generated electric and magnetic fields has shown that these fields do not exceed standards for general public exposure in any areas accessible to the general public and do not exceed standards for controlled environments (i.e., environments accessed by trained workers) at any location.

All electrical equipment has been assessed for arc flash hazards and appropriately labeled. All operations and maintenance personnel have received NEC and NFPA 70E training.

There is a very small chance of capacitor failure leading to an explosion and fire within the barrier pulsers. At Barrier IIA the pulsers are enclosed in casings that should contain fragments and fire except for the possibility that fragments could perforate the enclosure roof. At Barrier IIB the pulsers are located in blast-proof rooms that are inaccessible to personnel when the pulsers are operating.

Efforts to identify and mitigate against safety hazards are ongoing.

Chapter 5 – Effectiveness of the Barriers

Barrier effectiveness ("efficacy"), the ability of the barriers to deter the movement of fish, is influenced by technical, environmental, and biological factors. These factors are described below. A number of laboratory and field studies have been completed to evaluate the effectiveness of the CSSC Electric Dispersal Barriers and more are underway. A summary of these studies and their findings is also presented here. The factors that influence effectiveness of the barriers are presented below.

5.1 - Technical Factors

Electrical Operating Parameters

Effectiveness of the electrical barriers for reducing the risk of passage of Asian carp is strongly influenced by the operational protocol employed. The barrier electric fields are generated by rapid pulsing of DC applied to the electrodes on the canal bottom. The electrical operating characteristics that can be controlled are the voltage (amplitude) and the frequency and duration of the DC pulses. The energy output from voltage (amplitude), frequency, and duration of the pulsed DC applied to the submersed electrodes are directly reflected in the waterborne electric field. The field strength of the waterborne electric field [measured as the voltage per unit distance (V/in)], is directly proportional to the voltage applied to the electrodes. The rate at which the waterborne electric field pulses [measured in cycles per second (Hz)] and the pulse duration [measured in milliseconds (ms)], matches the pulses of the DC applied to the electrodes.

Field Orientation

The orientation of the electric field (direction of electric current flow) employed by the barriers can strongly influence the probability of immobilizing fish penetrating the field. The electric barriers on the CSSC utilize cross-channel bottom mounted electrodes. In general, the strength of the electric field increases with proximity to the electrodes in both vertical and horizontal aspects. The direction of electric current flow is parallel with the direction of water current flow on the CSSC. Fish swimming upstream experience the greatest electrical exposure (greatest body-voltage) when oriented parallel to the direction of electrical current flow, the upstream-downstream direction.

The electric field orientation is critical during times of both low and high water velocities. Under conditions of zero or minimal flow fish have the opportunity to turn perpendicular to the direction of electric current flow and minimize electrical exposure while still progressing upstream. These conditions could be experienced at times in the CSSC. As the velocity of water flow increases, the need for Silver and Bighead Carp to be aligned parallel with the direction of flow increases as each fish attempts to progress upstream or maintain its position. Thus, the need to align in the direction of water flow, which is the direction of maximum electrical current flow and electrical exposure, will compete with the need to minimize body-voltage, which is accomplished by turning to the side. Fish turning to the side, away from alignment with the direction of flow will be swept downstream. Thus, it is expected that in flowing water these competing motivations will result in a repeated action where fish align parallel with the directions of water and electric current flow and swim upstream, where upon reaching some point of discomfort they will turn to the side in an attempt to minimize body-voltage and be swept back downstream, where in the less intense electric field they will re-align with the directions of water and current and swim back upstream. Based on outcomes from the laboratory experiments on operating parameters described below, it is expected that these actions will occur in small Bighead Carp (2 to 3 inches) at the downstream margin of the high electrical field, and in large fish at the edge of the low electrical field.

Field Size and Distribution

The size and distribution (shape) of the waterborne electric fields generated by the barriers are determined by the characteristics and placement of the electrodes and the electric energy applied. The distribution of field strength for Barriers IIA and IIB, which have the same electrode placements, is characterized by two lobes: a low-field that is wide and occurs downstream and a high-field which is narrower and occurs upstream. The Demonstration Barrier has only one lobe and covers a shorter distance upstream to downstream in the canal. See Figures 16, 17, 18, and 19 for graphic representations of typical barrier electric field strengths.

The worst case scenario of fish swimming near the water surface is based on responses of fish to the shape of the electric field. While effects were not directly measured, anecdotal observations led scientists to hypothesize that the shape of the electric field will tend to guide fish toward the water surface. Fish motivated to swim upstream and similarly motivated not to exceed some electrical threshold for *in vivo* stimulation will follow the equipotential boundary to the surface where the electrical field is weakest. This approach to breaching the barrier, may allow fish swimming at the surface to penetrate more deeply into the field.

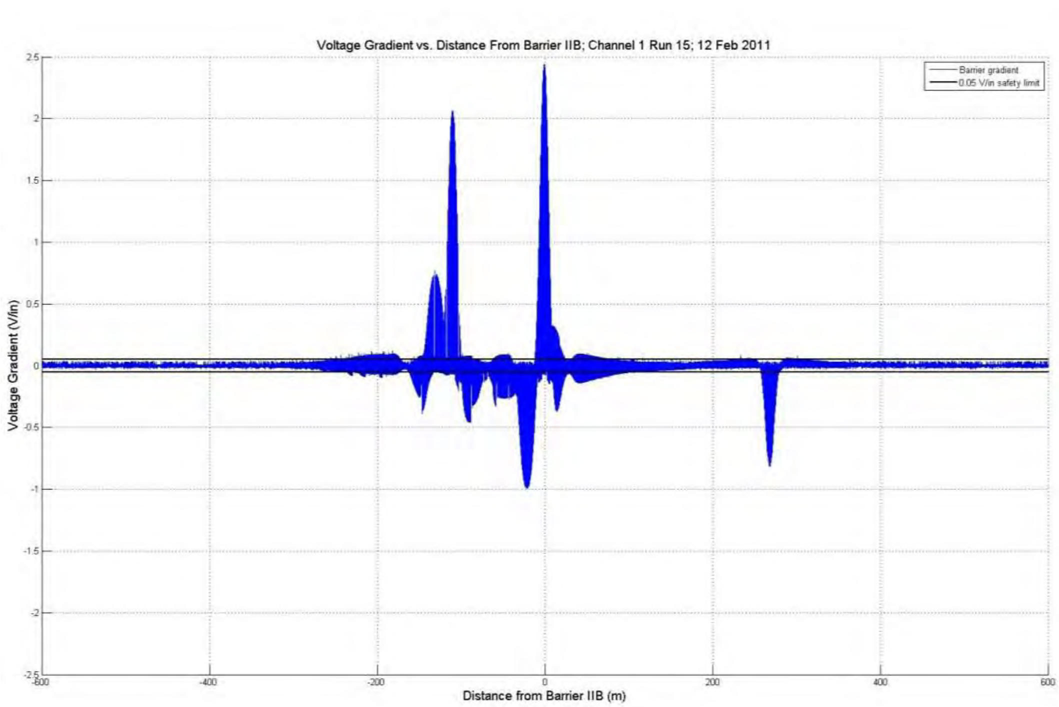


Figure 16– An electric field strength plot geo-referenced with respect to the center of the high field of Barrier IIB.

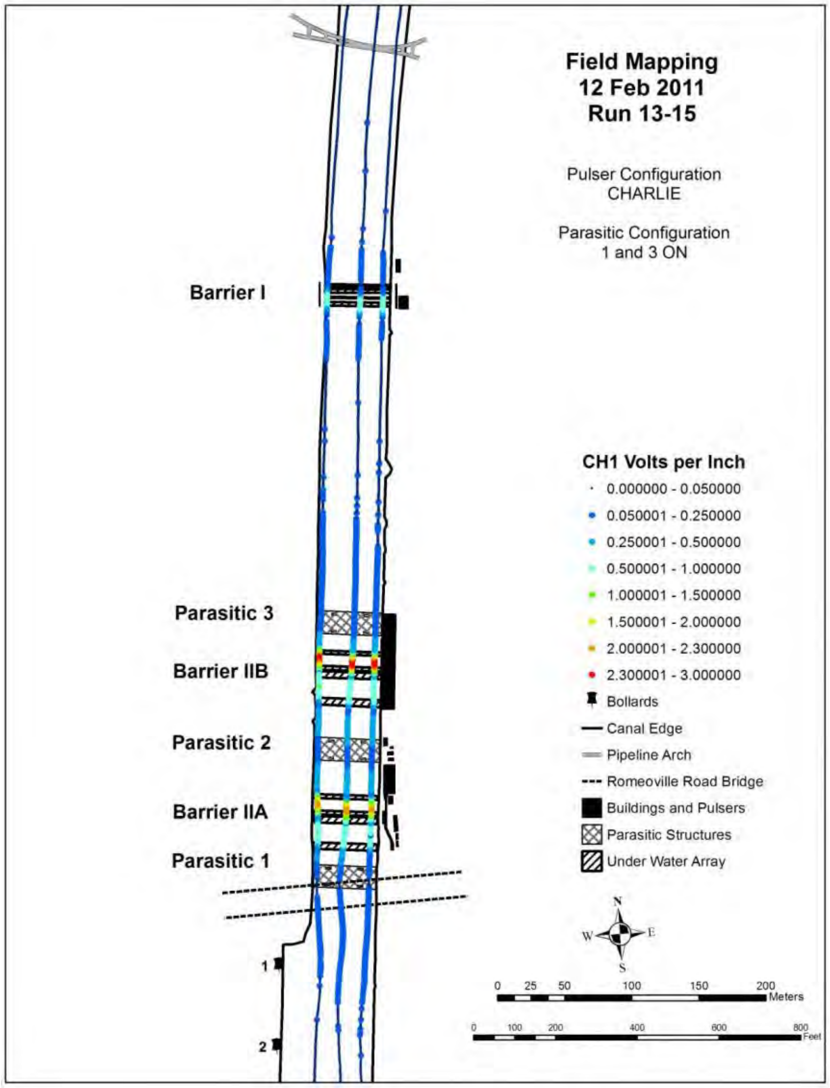


Figure 17– A plan view electric field strength plot.

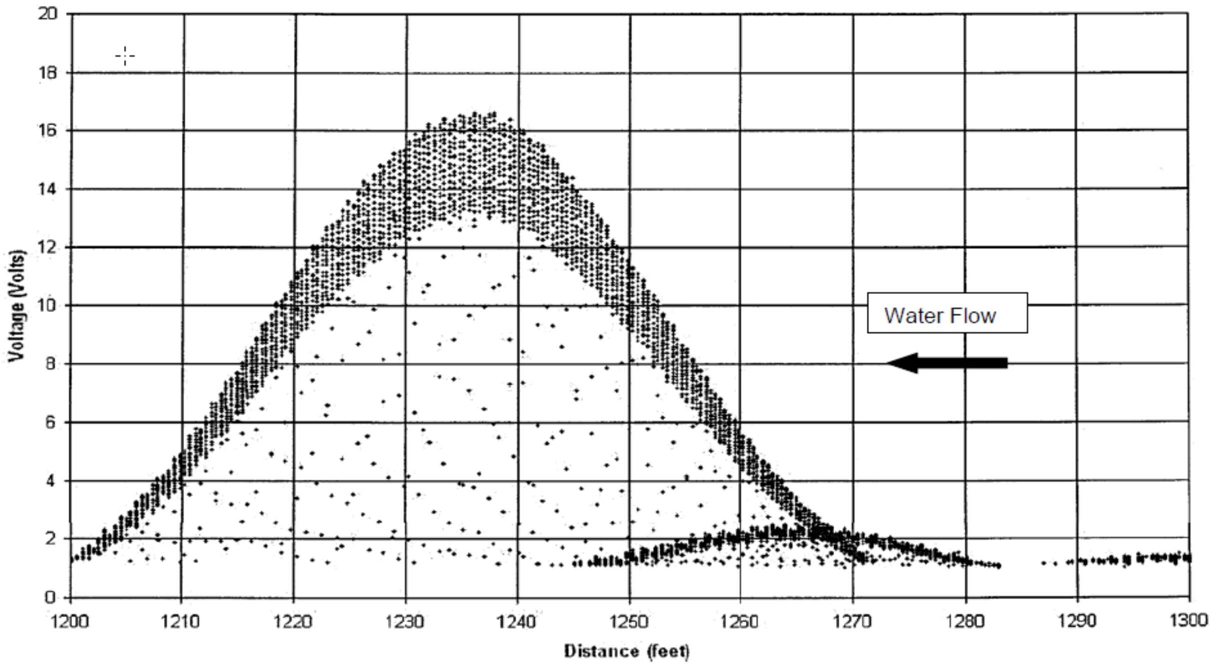


Figure 18– Example of distribution of electric field generated by the Demonstration Barrier at the water surface.

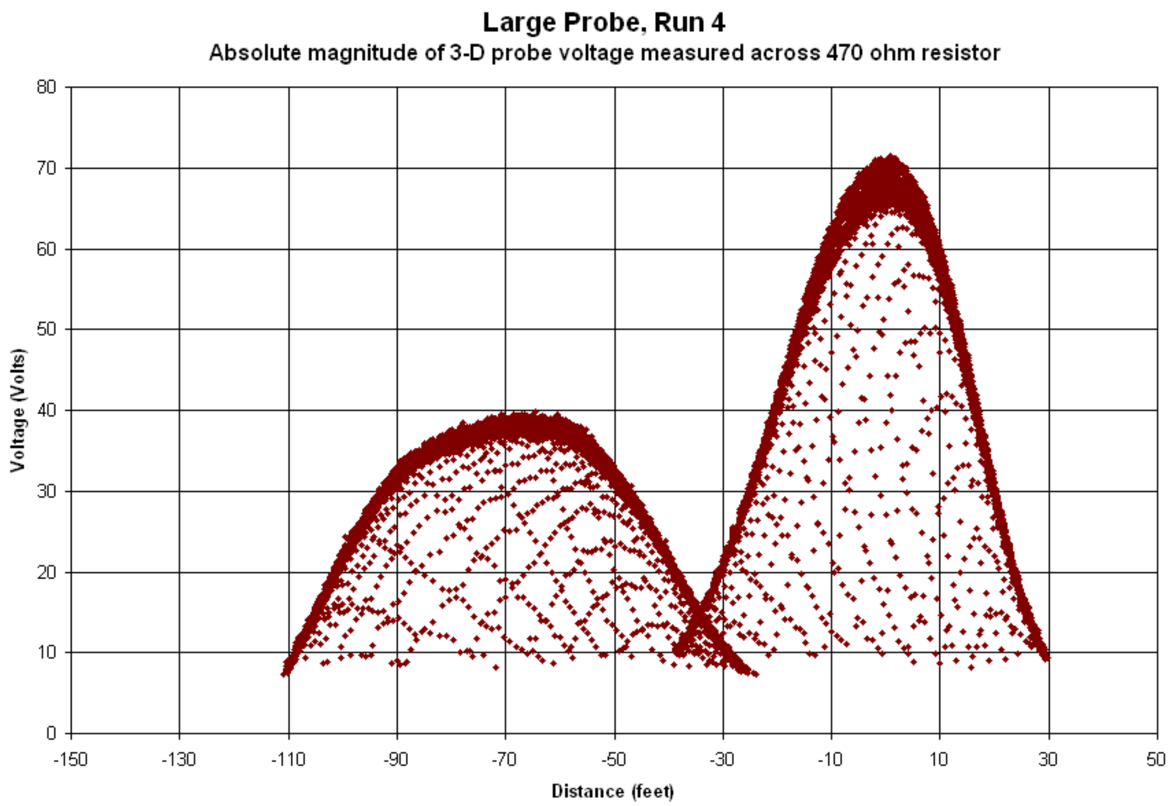


Figure 19 – Example of distribution of electric field generated by Barrier IIA or Barrier IIB at the water surface. Water flow would be from right to left. The wider but lower voltage part

of the field is referred to as the low field. The narrower but higher voltage part of the field is referred to as the high field.

5.2 - Environmental Factors

Environmental factors that influence the probability of breaching the electric barriers by fish include water conductivity, water velocity, water depth, habitat, and vessel traffic in the canal. The effects of water conductivity and velocity were directly tested in laboratory experiments and findings are reported below. The effects of water depth and habitat were not directly measured in any of the experiments, though important information regarding both can be inferred from the experiments. Laboratory and field studies of the potential impacts of vessel traffic are ongoing and described below.

<u>Water Conductivity</u>

Water electrical conductivity is a measure of the net motion of the charged ions present. Measurements of water conductivity are temperature dependent. Specific conductivity, conductivity adjusted to a temperature of 77°F (25°C), which reflects the ion content of water as thermal effects are removed, is typically reported. Ambient water conductivity, the water conductivity at the ambient temperature, reflects electrical conductivity and determines the electrical "load" experienced by the barrier power systems.

Water conductivity in the CSSC is an important environmental factor affecting barrier operation and efficiency as it influences the transfer of electrical energy from water to fish known as the Power Transfer Theory (Koltz, 1989). When conductivity of water in the CSSC increases the power demand on the electrical barrier increases as well, and the efficiency of electric energy transfer from waterborne field to flesh of fish decreases. More simply put, barrier effectiveness decreases when water conductivity is high. The decrease in energy transfer efficiency is determined by the difference in conductivity between the waterborne field and flesh of fish. When water is more conductive than are fish, current tends to flow through the water and around the fish per *Murphy, B.R., and D.W. Willis, 1996, Fisheries Techniques, Second Edition, American Fisheries Society, Bethesda, Maryland* (Murphy and Willis 1996). In a matched condition, where water conductivity equals fish conductivity, the maximum amount of power density (i.e. energy/volume/time) applied to the water is transferred to the fish (Murphy and Willis 1996). In the mismatched condition, not all of the power applied to the water is transferred to the fish (Murphy and Willis 1996). To address this, the power system for the barrier is a constant voltage system and it automatically compensates for fluctuations in conductivity in the CSSC by adjusting the electrical current output in order to maintain an effective output voltage.

Analysis of specific water conductivity measures collected near the barriers between October 1998 and April 2010 showed specific conductivity of water in the CSSC was between 489 to 4,697 µS/cm (micro Siemens per centimeter). Variation in specific conductivity was seasonal, ranging between 3,049 and 4,697 µS/cm from December to March, and between 489 and 1,940 µS/cm for the rest of the year. Specific conductivity measurements were then adjusted with water temperature readings to estimate ambient water conductivity, these new values ranged between 388 and 2,551 (852 ± 261; 95% CI 843 – 862) µS/cm. Mean ambient conductivity varied significantly among months of the year, but was greatest in February and least in September. Spikes in conductivity can occur during winter months when large amounts of runoff containing road salt enter the CSSC.

Water Velocity

The water velocity in the CSSC can have a critical impact on the effectiveness of the barriers. Under conditions of zero or minimal flow, fish have the opportunity to turn perpendicular to the direction of electric current flow and minimize electrical exposure while still progressing upstream. These conditions could be experienced at times in the CSSC. As the velocity of water flow increases, the need for fish to be aligned parallel with the direction of flow increases as each fish attempts to progress upstream or maintain its position. Thus, the need to align in the direction of water flow, which is the direction of maximum electrical current flow and electrical exposure, will compete with the need to minimize body-voltage, which is accomplished by turning to the side. Fish turning to the side, away from alignment with the direction of flow will be swept downstream when water velocity is high. It should be noted however that Asian carp are rheotactic, meaning that they are attracted to increased water velocities and will swim into flowing water in the upstream direction. This may translate to an increased probability of Asian carps approaching and challenging the CSSC Electric Dispersal Barriers but the barrier efficacy would increase.

Velocity data is collected by the USGS near Lemont, IL as part of the Lake Michigan Diversion Accounting program overseen by USACE. Data were collected between November 2006 and January 2010 by the USGS and analyzed. The majority of flow velocities within this portion of the CSSC ranged between 0.5 to 0.75-ft/s and result from "normal" power generation at the Lockport Powerhouse. Also common, but to a lesser degree, were flow velocities ranging between 3.5 to 4.0-ft/s which are thought to be a result of rapid drawdown events in the canal. A third range of velocities between 2 to-3ft/s were also observed. These are thought to be associated with flows resulting from lockages and/or operational changes in power generation (Jackson et al. 2012).

Negative flow velocities have also been measured at the Electric Dispersal Barrier System in which the canal water is moving in the northward or upstream direction toward Lake Michigan. This may be caused by powerhouse or lock operations restricting flow into the Brandon Road pool or more locally at the Electric Dispersal Barrier System due to elevated cooling water intake operations at the coal fired power plant immediately downstream. Stream flow monitoring stations within the CSSC near Lemont, IL (USGS 05536890; https://waterdata.usgs.gov/usa/nwis/uv?05536890) have documented the duration, frequency, and magnitude of these reverse flows within the CSSC. In addition to these full water column reverse flow events, southerly winds may generate a negative velocity confined to the surface of the canal. USACE worked with USGS to have a surface velocity radar installed at the Electric Dispersal Barrier location in order to more fully understand the frequency and magnitude of these wind-driven return flows at the surface. Acoustic Doppler techniques used in other areas of the waterway and historically at the barriers are limited to predicting the full water column average flow velocity and were unable to characterize any difference at the surface. This surface velocity radar station was installed in 2016 and has been collecting data at nine cells across the canal streamwise to provide an average surface velocity. It is important to understand how often this occurs as the efficacy of the Electric Dispersal Barrier System depends on a downstream, southerly flow to carry incapacitated fish away from the Great Lakes and back downstream of the barriers. A preliminary review of a limited data set indicates that the risk of reverse flow is greater than anticipated. Additional data is currently under analysis with results to be provided to USACE managers which will help reduce uncertainty around this risk variable. Results and recommendations will be provided in a future Efficacy Study.

Water Depth

While the effect of water depth at the Electric Dispersal Barriers has not been directly tested, the significant influence of ultimate field strength on probability of immobilization demonstrated in the tests with operational protocols provides indirect evidence that barrier effectiveness may be influenced by changes in depth of the CSSC. The electric barriers in the CSSC employ bottom-mounted electrodes. The strength of the electric field increases with proximity to the electrodes in both vertical and horizontal aspects. Water depth in the CSSC is regulated via drawdowns in anticipation of precipitation events. During drawdowns, the strength of the electrical field at the surface may increase as water depth decreases. Subsequently, field strength may decrease at the water surface of the electrical barriers during periods of increased depth, requiring compensation of barrier output to maintain effectiveness in order to reduce risk of breaching by Asian carp. Such a decreased effectiveness, if significant, could be countered by adjusting the operational settings of the barriers during high water periods. Channel depth at the barriers typically ranges between 24 and 29 feet.

Water Temperature

Water temperatures of the CSSC measured at Lockport Lock, 5.1 miles downstream of the electric barriers from Aug 1998 - Aug 2014 were observed as low as 2.3° C in the winter months and as high as 34.8° C at the peak of summer. A plot of water temperatures is shown in Figure 20. As discussed in the above sections, water temperature can have an indirect role in barrier efficacy through the effects of water conductivity but it can also directly affect barrier efficacy through physiological effects to the fish. Studies on the effects of temperature on barrier efficacy are currently ongoing at the ERDC Environmental Laboratories research facility. Preliminary results have been provided on Bighead Carp from two size classes with mean total lengths of 76 and 101 mm (3-4 inches) at water temperatures of 10°C and 27°C. While a final report will verify the findings, initial results have identified several statistically significant differences in fish behavior to the electric field at these two temperatures. The relationships between the high and low temperatures were also found to be consistent across the two size classes of fish tested.

Fish tested at higher temperatures experienced loss of posture and immobility at significantly higher voltage gradients than those tested at low temperatures. Once immobility was induced, recovery periods for both size classes were longer for those fish tested at lower temperatures. These general trends indicate an inverse relationship between barrier efficacy and temperature; the barrier effectiveness increases at low canal temperatures in the winter and begins to decrease with increased temperatures in the summer. This preliminary analysis of temperature effects coincides with DIDSON observations in 2012 of small fish penetrating the high field of Barrier IIB in the upstream direction. The fish observed in those videos were measured at 3 to 4 inches in total length at temperatures near 27°C.

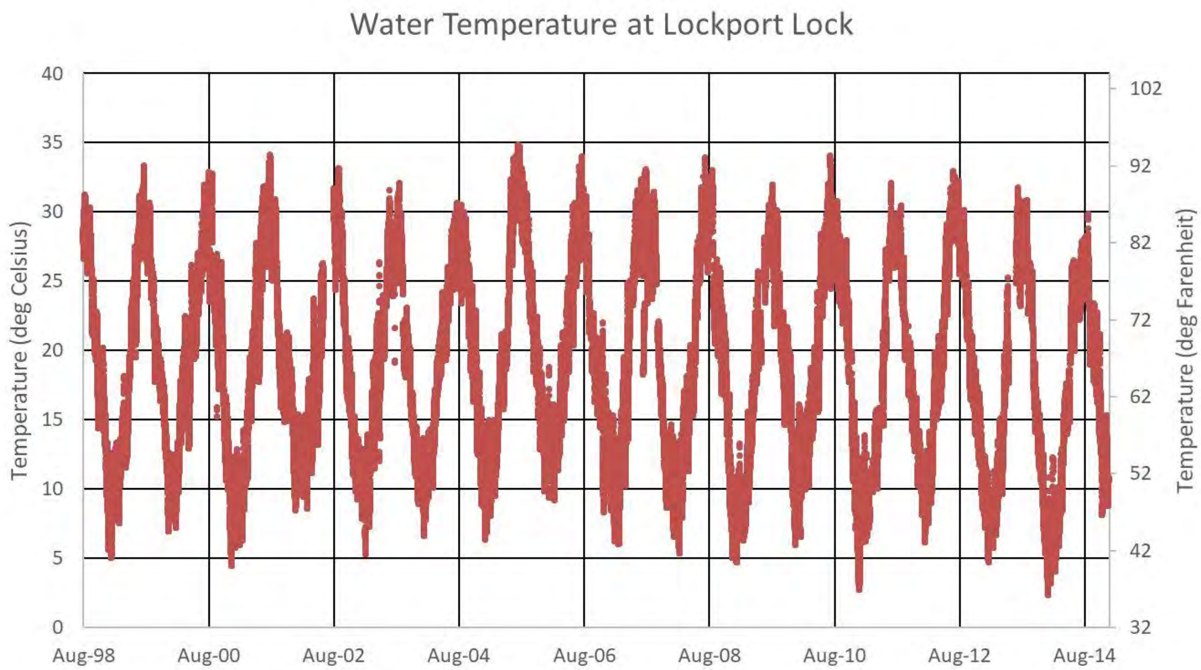


Figure 20 - Canal water temperatures recorded at Lockport Lock from August 1998 through August 2014.

Habitat in the Chicago Sanitary and Ship Canal

The desirability of habitat near the barriers will influence the number of fish in the vicinity of the barriers and the desire of the fish to press upstream through the barriers. More fish in the area could lead to more fish progressing upstream if the barrier is for some reason inactive or ineffective. Habitat within the safety zone surrounding the barriers is limited. Cut limestone vertical walls line the canal throughout the safety zone creating a deep, straight channel. The canal floor presents an irregular bathymetry causing intermittent pockets of sediment to collect in depressions with exposed rock in higher areas. Canal water velocity is also variable and may change daily as river stage is controlled by the Metropolitan Water Reclamation District. High flow events occur during drawdown events of the canal in preparation of forecasted storms. Sparse vegetation can be found growing near the water's edge from the walls of the canal but is intermittently removed for maintenance and improved visibility. No submerged vegetation is located within the safety zone and limited submerged cover may be provided by impinged debris or limestone rock piles sloughed from the canal walls. A specific habitat concern in the immediate vicinity of the barriers is the irregularity of the canal walls throughout the lengths of the barriers. The walls aren't smooth and contain a large number of notches, cracks, and crevices of various sizes spaced sporadically along the east and west banks of the safety zone. These may afford small fish protection from water current flow and the electric field, allowing fish to recover from electrical exposure negating any cumulative effects of low gradient electrical exposure. Although small bodied fishes have been collected from these irregularities within the low fields of Barriers IIA and IIB, no fishes have been observed to utilize the same type of habitat within the high fields.

5.3 - Vessel Traffic in the CSSC

The movement of vessels, particularly large barge tows, can impact barriers effectiveness in two major ways. First, the movement of vessels through a relatively confined waterway, as the CSSC is near the barriers, can create water motions throughout the waterway and in the immediate vicinity of the tow hull itself. If the induced water motions are powerful enough, they could potentially push or pull a fish through an electrified field regardless of the effect the electricity has on the fish. This entrainment of fishes may occur in return flows along the sides of the canal or between the junction of barge hulls where a raked bow meets another barge or the tow. This is of particular concern for fish that might be rendered unconscious, but not killed, by exposure to the electricity. This may be especially noticed in between barge hulls where the metal hulls provide a shelter to the fish from the electric field. Such fish could potentially pass through a barrier via vessel-induced water currents and then return to consciousness on the other side.

Another concern is the impact of metal-hulled vessels on the in-water electric field strength. Since the metal hulls are conductive, they have the potential to alter the shape and magnitude of the electric field. A joint USFWS and USACE field experiment was completed Findings show that field strength may increase at some areas while decreasing in others. The primary direction of the electrical field was also observed to change intermittently beneath the metal hulls. There is concern that these changes may be detected by fishes near the barriers and actively utilized for passage. Both of these concerns are discussed further in *Section 5.6, Field Studies Investigating Effectiveness of the CSSC Barriers*, below.

5.4 - Biological Factors

Biological factors influencing the ability of fish to breach the Electric Dispersal Barriers include fish species, size, behavior, and swimming ability as it relates to the duration of exposure.

Fish Species

Significant differences in vulnerability to electrical stimulation have been demonstrated between dissimilar fish species. In extreme cases the response can be manifested as electrical stimulus leading to immobilization in one species but flight in another. Currently, the primary species of concern for the CSSC Barriers are Bighead and Silver Carp. In the laboratory experiments described below, the difference in vulnerability between Silver and Bighead Carp of similar size was not evaluated. However, the morphological and taxonomic differences between Bighead Carp and Silver Carp are relatively subtle. Thus, differences in response to electrical stimulation between these species are also expected to be subtle; and therefore, results of experiments with Bighead Carp are cautiously assumed to be relatively applicable to Silver Carp of similar size and vice versa.

Fish Size

Fish size is an important biological factor of barrier effectiveness. Immobilization rate for fish encroaching upon the barriers is dependent upon the size of the fish. It is well known that reactions of fish to electrical exposure are size dependent. The longer a fish is, the greater the electrical gradient that develops across the fish and the more vulnerable it is to electrical exposure. This phenomenon of larger fish having lower thresholds of response to a given electric field than smaller fish is significant. The intensity of the electric field necessary for an electric barrier to be effective is dependent on the size of the fish that the barrier is intended to deter.

Fish Behavior

Electric barriers are regarded as behavioral technologies that function by inducing avoidance and immobilization responses in fish to block passage or direct movement (Operational Protocols Report 2011). Fish behavior will change in response to different levels of electrical field strengths. The likelihood that fish will continue to probe or challenge the barrier once initially encountering it is dependent on a variety of behavioral motivations.

Fish behavior was evaluated in the laboratory studies determining the effectiveness of various combinations of electrical parameters that are described below. During simulations of electrical exposure, fish behavior was monitored and the following four responses to electrical stimulus were reported: (1) first response; (2) flight; (3) immobilization; and (4) righting.

First response was categorized as the initial reaction to the presence of the electric field, which typically included rapid starts, distinctive twitches of the head or tail, or brushing against the side or bottom of the tank. Flight was characterized by the onset of rapid (frantic) non-directed swimming. Flight often transitioned to swimming from side-to-side in the tank (body-voltage minimizing behaviors), forced swimming while righted and forced swimming with loss-of-equilibrium. Immobilization was characterized by the complete cessation of swimming motions and was typically accompanied by loss-of-equilibrium. Righting was recorded as the resumption of upright orientation by fish previously losing equilibrium while immobilized.

Fish Swimming Ability

The effects of swimming speed on probability of breaching the electrical barriers was not directly tested by USACE in the operating parameters laboratory studies, but was a consideration in the simulations of encroachment. Swim speed is an important factor since the duration of electrical exposure to fish swimming through the waterborne electric fields in the CSSC will be determined by how quickly or slowly fish swim through the field. Thus, the minimum duration of electrical exposures experienced by fish swimming through barrier field is determined by fish swimming speed coupled with size of the electric field. It is hypothesized that longer exposure periods would increase the probability of immobilization in encroaching fish, and shorter exposure periods would decrease the probability of immobilization. This hypothesis will be tested in future planned studies.

5.5 - Laboratory Studies Investigating Effectiveness of the CSSC Barriers

Optimal Operating Parameters

The initial operating settings for the Demonstration Barrier were $IWFS_0$ = 1 V/in with a pulse frequency of 2 Hz and a pulse duration of 2 ms based on the prior experience of the contractor that designed the barrier. After a telemetry transmitter passed through the barrier in April 2003 (see Section 5.6 for further details on the telemetry program), the operating parameters were changed to $IWFS_0$ = 1 V/in, 5 Hz, 4 ms. Barrier IIA was set at the same parameters when it was first activated in April 2009.

In 2009 USACE began a research program to better identify the optimal operating parameters for the barriers. Several stages of research have been completed and additional work to investigate other questions that have since arisen is ongoing. The research effort is being completed by the Environmental Laboratory at the USACE's Engineer Research and Development Center in Vicksburg, MS.

2009-2010 Testing

During the first stage of operating parameter research begun in 2009, five studies evaluating barrier effectiveness were completed: a pilot study on small Silver Carp, a follow-up study assessing risks of breach by small Bighead Carp, two separate studies evaluating the influence of water conductivity and water velocity on risk of breach of the barriers by small Bighead Carp, and a final study evaluating volitional challenge of electric fields by small Bighead Carp. These tests are summarized here and described in detail in the report *Influence of Electrical Characteristics, Water Conductivity, Fish Behavior, and Water Velocity on Risk for Breach by Small Silver and Bighead Carp,* dated March 24, 2011.

In the pilot study with juvenile Silver Carp, the effectiveness of various operational protocols for preventing fish passage at Barrier IIA was evaluated. Wild caught juvenile Silver Carp between 5.4 and 11 inches were subjected to various electrical treatments over a cumulative exposure of 24 seconds which mimicked what would be received by fish penetrating the electric field of

Barrier IIA. The effects of 10 unique operational protocols were evaluated with the efficiency of immobilization, first response to electrical stimulation and flight behaviors being the primary outcomes of interest. During these tests ambient water conductivity was 687-765 µS/cm. All of the fish (100%) in each of the treatments utilizing DC pulses of 15 Hz were stunned at field strengths within the output capabilities of Barrier IIA. In addition, for treatments applying pulses of DC at 15 Hz there was an inverse relationship between effective field strength and pulse duration, where greater field strength was required to incapacitate fish when using pulses of shorter duration. The operational protocol of 2.0 V/in, 15Hz, 6.5ms, was demonstrated to be the most effective protocol for preventing passage of Silver Carp 5.4 to 11 inches in length. In August 2009, the USACE began employing this protocol at Barrier IIA. These operating settings were also used at Barrier IIB when it began operation in April 2011. The Demonstration Barrier has remained at its previous settings because it doesn't have the capacity to operate at higher levels.

In a follow-up study, simulations of encroachment into the electric field of Barrier IIA by small Bighead Carp 2.0 to 3.0 inches in length were conducted in a controlled environment to again evaluate the effectiveness of various combinations of electrical parameters for inducing passage-preventing behaviors. In this experiment, simulations of encroachment were based on the hypothesized worst case scenario for preventing passage of the targeted fish:

(1) encroaching fish were small,
(2) encroaching fish were swimming at the surface of the CSSC,
(3) fish penetrating the electric barrier continued upstream despite receiving electrical stimulus,
(4) very low or no water current, and,
(5) fish traversed the barrier at maximum swimming speeds.

The ambient conductivity of water in the swim tunnel was maintained between 1,913 and 2,040 (1,996 ± 36) µS/cm. The strength of the electric field was varied over time to mimic the electrical exposure that fish traversing the electrified zone of Barriers IIA or IIB would experience when swimming at the surface of the CSSC. The two distinct lobes characterizing the electric field of Barrier IIA, the downstream low field and the upstream high field, were represented in the exposures (Figure 19).

Based on the simulations, pulse-frequency, field strength, and pulse-duration were significant individual indicators of immobilization, suggesting efficiency of the electric barriers on the CSSC will be strongly influenced by the operational protocol employed. Incapacitation of Bighead Carp in the simulations was increased with operational protocols employing pulse-frequencies of 25 or 30 Hz. Operational protocols applying DC pulsed at 15 Hz or less were relatively unsuccessful at inducing immobilization of small Bighead Carp. Immobilization of fish was significantly increased by the operational protocol of 2.3 V/in, 30 Hz, 2.5 ms compared to the protocol effective for immobilizing small Silver Carp in the pilot study.

Controlled experiments evaluating effects of water conductivity on the effectiveness of Barrier IIA for immobilizing small Bighead Carp 1.7 to 2.8 inches were carried out between October and November 2009. Bighead Carp were exposed to 2 ms pulses of DC, cycling at 30 Hz, and ultimate field strength between 2.0 V/in and 3.8 V/in depending on water conductivity. The strength of the electric field was varied over time to simulate the electrical exposure experienced by fish traversing the electric field of Barrier IIA at the surface of the CSSC. The range of field strength associated with the "low-field" was consistent among the treatments. The exposure period was calibrated to a swimming speed of 1.6 ft/s (50 cm/s), with simulations of 88 seconds in duration, an exposure thought to be the worst-case scenario as duration of exposure was minimized. Simulations of encroachment were conducted on individual fish (20 fish per treatment) in water with ambient conductivity of approximately 20, 40, 100, 150, 500, 1,000, 2,000, and 4,000 µS/cm.

Simulations in water with conductivity of 100-4,000 µS/cm and applying operational protocols of 2.0 – 2.3 V/in field strength, a pulse-frequency of 30 Hz, and pulse-duration of 2 ms, resulted in 80-100% of fish being immobilized. Thus, the effectiveness of Barrier IIA will be relatively constant, with respect to water conductivity in the CSSC, when applying operational protocols with this level of output. It should be noted, however, that barrier effectiveness will likely decrease should ambient water conductivity in the CSSC exceed 4,000 µS/cm.

Simulations of encroachment upon the electric field of Barrier IIA by small Bighead Carp (1.7 – 3.7 inches), under various conditions of water flow, were carried out in March and April, 2010. Fish were exposed to homogeneous electric fields that changed in field strength over time to mimic the exposure of fish swimming through the Barrier IIA field at the surface of the CSSC. A total of 440 Bighead Carp, with 20 fish per treatment group, were used in the experiment. The ability of fish to maintain position in the barrier was found to be inversely related to water velocity, where maintaining position during the exposures was significantly reduced when water velocity was 0.72 ft/s or 0.49 ft/s compared to when it was 0.23 ft/s. Overall, when current velocity is greater than 0.49 ft/s the probability that fish might breach a barrier is reduced. This is because an increase in water current flow reduces the rate of forward progress of fish challenging the electric field, increasing the amount of exposure time.

The motivation for fish to challenge the barrier field under conditions of no or very low water flow is uncertain, but this is a worst-case scenario for preventing breach, as fish penetrating the field can orient perpendicular to the direction of electric current flow to reduce body voltage without being swept back downstream by water currents. Positive rheotaxis (motivation for swimming upstream into water current flow) was absent in small Bighead Carp in water flowing at 0.1 ft/s, but was present at a velocity of 0.2 ft/s in the experiment on volitional behavior and at 0.23, 0.49, 0.72 ft/s in the experiment on effects of water velocity. Thus, the probability that small Bighead Carp might challenge the barrier field may be increased when water current velocity on the CSSC is ≥ 0.23 ft/s. Countering this increased probability of challenge is the condition that water current velocity potentially reduces the probability of breaching by sweeping fish that attempt to minimize body-voltage back downstream, forcing increased periods of alignment with the direction of electric current flow, by magnification of deleterious effects of electroshock on swimming capabilities, and through the effects of electroshock associated with increased exposure duration.

The effectiveness of the 2.3 V/in ultimate field strength, 30 Hz pulse frequency, and 2.5 ms pulse duration operational protocol, shown to more effectively immobilize encroaching small Bighead Carp under conditions of no or minimal flow, is expected to be enhanced in flowing water, further reducing probability of breach of the barrier field. With additional research, parameters of specific operational protocols could be reduced under increased flow without loss of barrier efficiency.

The experiment on volitional challenge of waterborne electric fields was the primary study for evaluating fish behavior. In this experiment, fish exhibited positive rheotaxis at water velocities of 0.20 ft/s and consistently swam upstream into the flow of water. Fish were clearly able to detect the edge of the electric field and, therefore, could avoid entering the field and any further interaction with it.

However, it was common for fish immobilized during encroachment upon the field to again challenge the electric field upon righting. Fish typically swam as a group where separated individuals often retreated from the field and sought cover. In many cases, however, fish did challenge and interact with the electric field as individuals, often attempting to rejoin with individuals or the group as it penetrated the field. Larger fish often became immobilized during attempts to follow smaller fish through the field. There is potential for behavioral differences between fish experiencing electrical stimulation in groups versus those as individuals.

The behavior of small Bighead Carp challenging the downstream margin of the electric field indicate it prudent to assume that these fish will not avoid the high-field of Barrier IIA but will likely penetrate the high-field to the extent that they can. The optimum operational scenario for the barrier should be adequate to stun the smallest fish of the targeted size.

The experiment on volitional challenges again showed that the probability that small Bighead Carp successfully traverse the electric field was significantly reduced with the operational protocol of 2.3 V/in, 30 Hz, 2.5 ms compared to the protocol shown effective for small Silver Carp in the pilot study, 2.0 V/in, 15 Hz, 6.5 ms.

From the experiment on volitional challenge of waterborne electric fields by small Bighead Carp, it should be noted that fish maintaining position at the origin of the field swam upstream through the apparatus immediately when the field was de-energized. Similar responses may occur on the CSSC when the barriers are de-energized on purpose or accidentally; fish holding position in the field, or at the margin of the field, can be expected to resume upstream progress immediately upon de-energizing of the field.

Based on the results of the four studies that followed the original pilot study, the operating parameters at Barriers IIA and IIB were changed in October 2011 to were $IWFS_0$ = 2.3 V/in with a pulse frequency of 30 Hz and a pulse duration of 2.5 ms.

2013 Testing

Additional research on optimal operational protocols was begun in 2013. While the operating parameters currently used at Barriers IIA and IIB were proven effective in the previous research, discovery of operating parameters that require less electrical energy while maintaining barrier effectiveness would reduce operating costs. Therefore, further experiments were begun to compare other operating parameters to those in use. Previous testing didn’t include pulse frequencies higher than 30 Hz because of concerns about the ability of the equipment at the barriers to operate at higher frequencies. After the equipment capabilities were confirmed, frequencies up to 60 Hz were used in the testing. Electrode polarity configurations were also examined to address the concern of galvanotropisms and galvanotaxis, where fish direct themselves parallel to electric current lines and swim toward an electrode, increasing risk for breach of the barriers. Results from the testing on both the reverse polarity and additional optimal operating parameters are discussed below.

In the additional operating parameters testing, fifteen different sets of operating parameters with different pulse frequencies and pulse durations that reduce the operating duty cycle were examined. A total of 59 fish were used for each of the 15 different sets of operating parameters as well as in the control set of operating parameters that were then in use (2.3 V/in, 30 Hz, 2.5 ms; N=944). Small sizes of live Bighead Carp (M=104; SD=9; Range = 73 to 141 mm total length) were used and typically demonstrated graded behavioral responses including first response, flight, loss of posture, and the key outcome variable, immobility. Each set of parameters was evaluated to determine the *a priori* standard of 95% reliability at a 95% level of confidence for induction of immobility (95/95). The 95/95 standard was achieved with 14 of the 16 sets of electric field (EF) parameters tested, including the control set. Pulse frequency, duty cycle, and fish length were shown to be influential factors in probability for induction of immobility in the low-field. When applying the control set of EF parameters the predicted probability for induction of immobility in the low-field was 0.91 for fish 140 mm total length. When applying pulse frequencies ≥ 35 Hz at 7.5% duty cycle or pulse frequencies ≥ 50 Hz at 6.0% duty cycle, the predicted probability for induction of immobility in the low-field was ≥ 0.95.

Risk (probability) of immobility at any given time in the simulation compared to the control set increased ~150% when applying 45 Hz, 7.5% duty cycle, 46% when applying 50 Hz, 7.5% duty cycle, about 110% when applying 55 Hz, 7.5% duty cycle, and 45% when applying 60 Hz, 7.5% duty cycle or 6.0% duty cycle. Fish size was demonstrated to be an influential factor in the probability, and timing, of the induction of immobility; risk for immobility at any given time in the simulation increased by approximately 6% per mm of fish length. Combined, these findings demonstrated the efficacy of the sets of the EF parameters in creating electrified zones that this size of invasive Bighead Carp cannot swim through and suggested that optimal results may be obtained using the 45 Hz, 1.65 ms set of parameters (Holliman, 2014a).

In the reverse polarity trials, reliability demonstration testing was conducted on two sets of EF parameters (pulse frequency, pulse duration: 30 Hz, 2.50 ms; 60 Hz, 1.25 ms), at two levels of water conductivity (1,300µS/cm, 2,000 µS/cm), and four electrode polarity configurations, using small sizes (106.2 ± 9.0 mm total length) of live Bighead Carp. A total of 1,280 fish were used across the 16 sets of experimental factors, 80 fish were used with each combination of experimental factors to evaluate an *a priori* standard of 96% reliability at a 95% level of confidence (96/95). This standard was only achievable by a combination of the experimental factors if immobility was induced in all 80 fish. A second reliability standard of 99% reliability at a 95% level of confidence was stipulated *a priori* for the combinations of EF parameter set and water conductivity (i.e., data pooled across electrode configuration), which was achievable only if immobility was induced in all 320 fish.

Fish typically demonstrated graded behavioral responses (i.e., first response, flight, loss of posture, immobility) during the testing. The induction of immobility was the key outcome of interest. The 95/95 reliability standard was achieved with 15 of the 16 combinations of electrode configuration-EF parameter set-level of water conductivity, including three of the four electrode configurations applying 30 Hz, 2.50 ms. These were the EF parameters that were applied in the electrified zones on the CSSC at the time of the study. The Cathode-Anode, Cathode-Anode; 30 Hz, 2.50 ms;2,000 µS/cm combination of experimental factors induced immobility in 79 of 80 fish, resulting in the conservative estimate for reliability of 0.94. There were no meaningful differences among the electrode configurations in the patterns of onset of the behavioral endpoints. When data were pooled across electrode configuration the 99/95 reliability standard was met for the EF parameter set-level of water conductivity combinations. The exception was 30 Hz, 2.50 ms, 2,000 µS/cm, which achieved a reliability of 0.985. Probability of induction of immobility, at any given time in the simulations, was not influenced by electrode configuration.

Automated video-tracking markedly advanced the analysis of the behaviors exhibited by fish in the simulations of encroachment by more objective quantification of activity, locomotion, and movement. Locomotion and activity of fish was demonstrated to be markedly diminished by exposure to the high-field, while path tortuosity increased, compared to that in the low-field. Fish demonstrated a significantly greater use of space adjacent to the cathode during exposure to the low-field and greater use of space adjacent to the anode during exposure to the high-field.

The combined findings demonstrated the efficacy of the sets of the EF parameters in creating electrified zones that this size of invasive Bighead Carp cannot swim through, at two-levels of water conductivity. The findings also suggest that during periods of high risk for challenge of the electrified zones by these small sizes of Bighead Carp, optimal results may be obtained with the downstream most electrodes of the low field-array employed as the cathode and the downstream most electrode array of the high field-array employed as the anode (Holliman, 2014b).

Research into the problem of barrier operation interfering with the neighboring railroad signal, (see Section 4.8) identified pulse frequency and duration combinations that would minimize interference. One of those combinations was 34 Hz, 2.3 ms which was very similar to one of the fourteen sets of EF parameters that met the 95/95 standard in the 2013 testing, 34 Hz, 2.2 ms. Increasing the pulse duration from 2.2 to 2.3 ms does not negatively impact the fish deterrence capability because more power is actually delivered to the water. Therefore, the operating parameters for Barriers IIA and IIB were changed from 2.3 V/in, 30Hz, 2.5 ms, to 2.3 V/in, 34 Hz, 2.3 ms in October 2014. After incidences of railroad signal interference in February 2015, the impact of several other operating parameters was analyzed at IIA and IIB in the spring of 2015. However, pulse parameters were returned to 34 Hz, 2.3 ms in June 2015. These have remained the pulse parameters since then. These specific pulse parameters were used in scenarios in the laboratory testing completed since 2013 and their effectiveness has been confirmed.

2014 -2018 Testing

As operation of the barriers continued and results from the completed operating parameters research were reviewed, a variety of other topics for research were identified and the scope of the research was significantly expanded. Additional topics studied included testing of deterrence of smaller fish, impacts of water temperature, further testing of volitional challenges, and testing of Gizzard Shad as a surrogate species. No final reports have yet been published on these studies, but all data collection is done and final reporting will be completed in 2019. A summary of major results based on communications with the research team is presented below.

Additional testing similar to the 2013 operating parameters was completed using smaller sizes of Bighead Carp and Silver Carp, which hadn't been used in testing since the original pilot study. Bighead carp sizes tested ranged from 60 to 90 mm (approximately 2.3 – 3.5 inches) in total length. Silver carp sizes tested ranged from 80 to 120 mm (approximately 3.1-4.7 inches). Tests were conducted at 20^0 C and 1,300 µS/cm for each of four electrode polarity configurations. The targeted 95/95 reliability standard was met by numerous sets of electric field parameters capable of being produced at Barriers IIA and IIB. Fish size was shown to be a significant factor in the induction of passage preventing behaviors (Holliman, in progress). Further testing was conducted on Bighead Carp from 25 to 50 mm (approximately 1-2 inches) in total length. Tests were conducted at 20^0 C and 1,300 µS/cm. A maximum surface voltage of 1.06 V/cm (2.7 V/inch) and an 11% duty cycle (presently 2.3 V/inch and 7.8%) was necessary to approach the 95/95 reliability goal for induction of immobility in these very small fish (Holliman, in progress). Barriers IIA and IIB aren't currently capable of operating at these levels.

Extensive testing has been done to further evaluate the influence that water temperature, conductivity, and rate of water flow have on the reliability of electric field parameters for inducing passage-preventing behaviors in targeted sizes of Asian carp. These tests have shown that water temperature has a significant impact on barrier effectiveness. Operating parameters necessary to immobilize fish at winter water temperatures (test done at 10^0 C) are significantly lower than operating parameters necessary to immobilize fish at summer water temperatures (tests done at 25 - 30^0 C) (Holliman, in progress). Previous tests were primarily done at an average water temperature of 20^0 C.

Given the increased effectiveness of the barriers in colder water and the decreased fish activity in colder water, the USACE has begun to implement winter operating parameters. Once the seven-day rolling average water temperature in the canal drops below 10°C, the electric field strength at Barriers IIA or IIB is reduced to $IWFS_0$ = 1.7 V/in and only one of those two barriers is operated. The other is placed in a warm standby status, in which it will automatically be activated if the other loses power for any reason. An $IWFS_0$ = 1.7 V/in in 10°C water will immobilize fish greater than or equal to approximately three inches in total length (Holliman, in progress). The winter operating parameters reduce wear and tear on equipment and operation and maintenance costs at a time when the risk of fish passage is significantly lower. The field strength is returned to $IWFS_0$ = 2.3 V/in and both IIA and IIB are operated simultaneously again after the seven-day rolling average water temperature in the canal exceeds 10°C.

In 2014, ERDC built a 9,500 gallon fiberglass, oval-shaped continuous raceway flume with an accompanying model Electric Dispersal Barrier System to accommodate more extensive volitional testing. Subsequent testing of volitional challenge of model electric fields for Barriers IIA or IIB indicate that carp continue to challenge the barrier after making initial contact, small fish can breach and linger in the low field, schooling behavior influences movement towards the high field, and fish immobilized by the high field tend to sink towards the electrodes resulting in death (Holliman, in progress).

Gizzard Shad are a native species often observed near the barriers and are used as surrogates in the telemetry tracking studies. Therefore, testing was done to evaluate how similarly Gizzard

Shad behave in the laboratory tests versus Asian carp. Tests were conducted at 20^0 C and 1,300 µS/cm. Small sizes of Gizzard Shad were shown to be a conservative surrogate for small sizes of Bighead Carp because the probability of immobility was greater in Bighead Carp compared to Gizzard Shad (Holliman, in progress).

Effectiveness of Current Operating Parameters at Barriers IIA and IIB

Based on the results of the laboratory testing described above and the need to minimize interference with the neighboring railroad signals, since June 2015 the standard operating parameters for Barriers IIA and IIB have been $IWFS_0$ = 2.3 V/in with a pulse frequency of 34 Hz and a pulse duration of 2.3 ms. The laboratory research indicates these parameters will immobilize fish at a minimum of standard of 95% reliability at a 95% level of confidence of approximately 2.5 inches or greater total length at a water temperature of 10°C, 4 inches or greater total length at 20°C, and 5.5 inches or greater total length at 30°C. The maximum water temperature that can be expected within the CSSC in summer months is 30°C. The winter operating parameters of $IWFS_0$ = 1.7 V/in with a pulse frequency of 34 Hz and a pulse duration of 2.3 ms will immobilize fish of approximately 3 inches or greater total length at a water temperature of 10°C (Holliman, in progress).

Entrainment of Fish by Vessels

The Coastal and Hydraulics Laboratory of the Engineer Research and Development Center (ERDC-CHL) in Vicksburg, MS evaluated the potential modes that Asian carp (Bighead or Silver Carp) could be transported past the Electric Dispersal Barrier System by commercial navigation traffic. (Bryant et al. 2016[A]). The commercial navigation vessels of interest are referred to as "tows" and consist of various numbers of barges and a pusher boat referred to as a "towboat". The purpose of this study was to evaluate different barge configurations, barge drafts, vessel speeds, and relative position in the channel to identify potential mechanisms for movement of Asian carp.

Objectives

The objectives of this study were to:

- Develop an understanding of the different mechanisms associated with commercial navigation that could contribute to fish passage at the barrier.
- Quantify the potential movement of fish for each mechanism.
- Explore ways to minimize or eliminate the potential for movement past the barrier.

. The study used model fish that cannot swim and were passively transported with the current. Therefore, the study did not include fish behavior, which is an important factor in studying transport. The study assumed that the fish are stunned by the electric barrier and become incapacitated.

Near-Field Flow Definitions and Potential Modes of Transport

The identification of different mechanisms that could transport Asian carp requires an understanding of the hydrodynamics around the tow. Vessel speed and tow configuration are primary factors that affect the possible entrainment and transport of fish through the electric barriers. As an example, a tow traveling at the recommended no-wake speed of 4 mph will traverse Barrier IIA or IIB in only 22.2 sec and the high field (highest voltage section of IIA or IIB) in 6 to 7 seconds. A short description of the important water motion and entrainment mechanisms are presented in Figure 21 and described in this section.

Return Velocity (A) – When a vessel moves through a waterway, the hull displaces water forcing the flow alongside and beneath the vessel opposite to the direction of the vessel. The flow moving opposite the direction of the vessel is referred to as return flow or return velocity. In a channel as small as the CSSC, return velocity tends to be relatively uniform over the entire cross section including the area beneath the hull of the tow. For downbound tows, return velocity is opposite the ambient flow.

Bow Wave (B) - Directly ahead of the tow, the rectangular shape of the barge (plan view) creates a bow wave that sets water in motion in the same direction as the tow. If the channel is not too deep relative to the draft and if the tow is traveling at high enough speed, the bow flow extends over the full depth but is significantly greater at the surface than at the bed. The bow flow is greater for square end barges than the more streamlined raked barges.

Propeller Jet (C) - The propeller jet generates strong currents and turbulence resulting in a complex flow field behind the tow. At full speed the flow speed exiting the propellers can range up to 30 ft/sec and extend over the depth of the water column. For lower speeds, typical of the CSSC, the propeller jet is much weaker and may not reach the bed. For these lower speeds, near bed velocities under the propeller jet are dominated by the wake flow (D) and are in the same direction as the tow. For all propeller speeds, outside the width of the propeller jet but behind the barges, the wake flow is the dominant mechanism and the current is in the same direction as the tow.

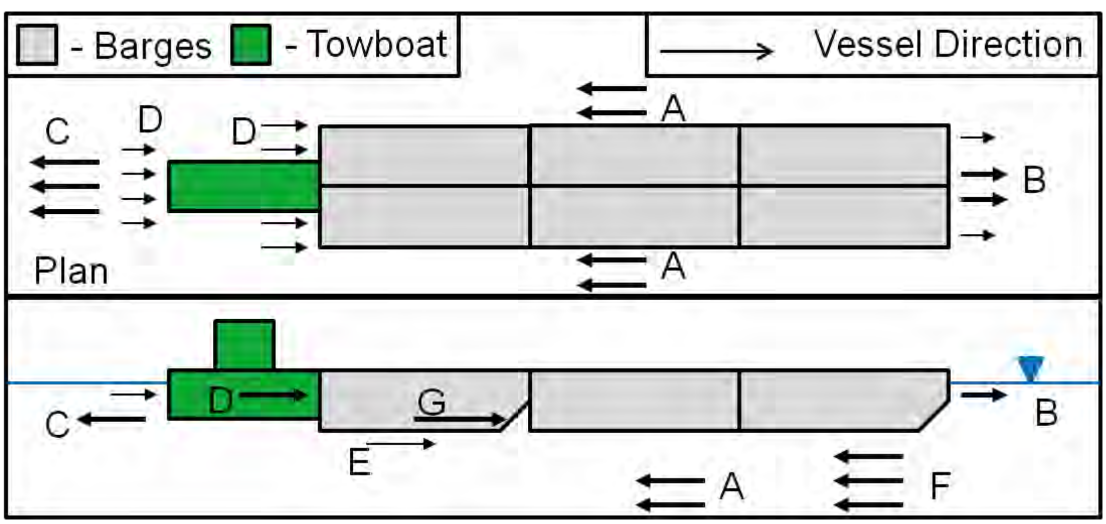


Figure 21– Water motions around tows moving left to right in confined channels. A = return velocity, B = bow wave, C = propeller jet, D = wake flow, E = flow in boundary layer along hull, and G = displacement flow at bow between hull and channel bottom having short duration.

Wake flow (D) - Directly behind the stern is the wake zone, where a reverse pressure gradient is produced causing the surface flow to move in the direction of the tow at about the same speed as the tow. The abrupt change in geometry between the last barge and the towboat likewise produces a barge wake zone and associated eddies that are carried along with the tow. For a typical 2-wide barge configuration, the barge wake is symmetric on either side of the towboat. Debris and other particles can be trapped in the wake zones and carried for long distances.

Vessel Boundary Layer (E) – Moving vessels develop a turbulent boundary layer due to the no slip condition at the hull. The size and strength of this boundary layer depends on the vessel speed, hull roughness, channel geometry and the CSSC discharge. The no slip condition causes the current adjacent to the hull to move at the same speed and direction as the tow.

Displacement Velocity (F) - Displacement flow is only present beneath the bow of the barges and is relatively uniform over the distance between the hull and the bed.

Barge Junctions (G) - The junction of two raked barges or the junction of a square-end barge and a raked barge forms a protected area with weak, closed circulation. Water in these recesses may form an eddy that is similar in diameter to the barge draft. As with the wake flow, the exchange of water, debris, and fish in and out of this recess is controlled by the barge speed, local geometry, Reynolds number, and floating object characteristics.

With the exception of the return velocity (A) and propeller jet (C) these flows move in the direction of the tow. Particles, such as the model fish used in this study, become trapped in these zones and are passively transported with the tow. Another important aspect of model fish movement by these mechanisms is their likelihood of occurrence. The return velocity acts over the entire cross section and every fish adjacent to or beneath the tow will feel its effect. Therefore, the probability for fish movement via the return velocity is high. For other mechanisms such as the pocket between barges (G) or the wake corners (D) at the towboat/barge junction, only some of the model fish enter these zones and the likelihood is less. Once a model fish enters either a barge junction (G) or a wake corner (D), the distance the fish travels depends on the time required for the fish to get flushed from the eddy.

Physical Model

The section of the CSSC near the electric barriers is an approximately 160 feet wide by 30 feet deep straight rectangular channel. To replicate conditions in the CSSC, the ERDC has a model test facility equipped with a 10 feet wide by 4 feet deep rectangular flume and an effective length of about 500 feet. During test runs the water depth in the flume was maintained at a height so that the width: depth dimensions corresponded to canal depths between 25 and 28 feet to simulate various scenarios. In addition, ERDC has a remote controlled towboat that is scaled based on the USACE MV Benyaurd having twin open wheel propellers. The model towboat is 6.8 feet long by 1.6 feet wide. Six plexiglass model barges were constructed to facilitate flow visualization of fish movement beneath the barges. The model barges were drafted to the desired 9 feet by adding lead ingots. Four of the barges had a rake configuration (sloped surface) on one end the other two had square ends on both ends of the barge. Based on the CSSC width, available model towboat size, and available model barge size, a scale ratio of 1:16.7 was selected to model the CSSC. The 500-foot flume scales to a length of about 1.5 miles allowing for adequate distance for model tows to reach cruising speed before reaching the test section. The test section includes the electric barrier and is equipped with glass sidewalls for viewing flow conditions adjacent to and beneath the tow.

When tows are southbound on the CSSC, they reach the barrier before they reach the fish that are south of the barrier, whereas northbound tows reach the fish before they reach the barrier. For initial testing, the flume was painted with a 130-foot wide test section. After initial testing a model representation of Barriers IIA and IIB was included along with additional wall and bed roughness to better approximate the canal's roughness. Figure 22 is a picture of the model channel with Barriers IIA and IIB installed.

Scale effects are anything that makes the model not act like the full scale because the size of the model is different from the full scale. Care has been taken to account for these scale effects while keeping the Froude number dynamic similitude. A full explanation of the scale effects are not presented here but will be available in the final report.

Results

Figures 23 through 26 demonstrate the model fish transport for the various mechanisms discussed previously. Modes of transport include the return current (A), the barge wake (D), the prop wash (C), the barge/towboat boundary layer (E) and barges and towboat junctions (G). Figure 23 shows four snapshots of model fish moving along the bottom in the boundary layer caused by the return current (A). Above each snapshot the corresponding model time, t_m, and prototype time, t_p, is given. This mechanism moves any fish along the bottom or channel walls in a direction opposite the tow and is important for southbound tows. The vessel is moving left to right in the four snapshots, but the model fish, surrounded by the red circle, are moving in the opposite direction. The model fish move 66.8 ft (prototype) in 54.4 seconds (prototype).

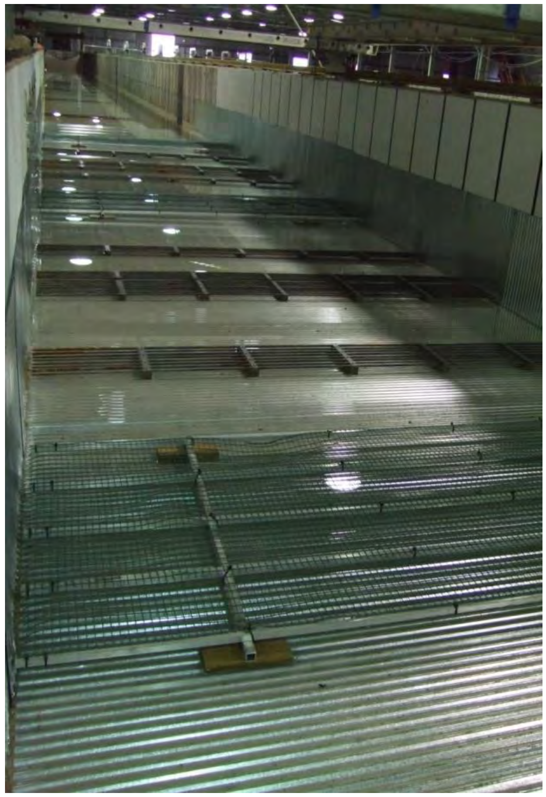


Figure 22– Model of CSSC with Barriers IIA and IIB at ERDC.

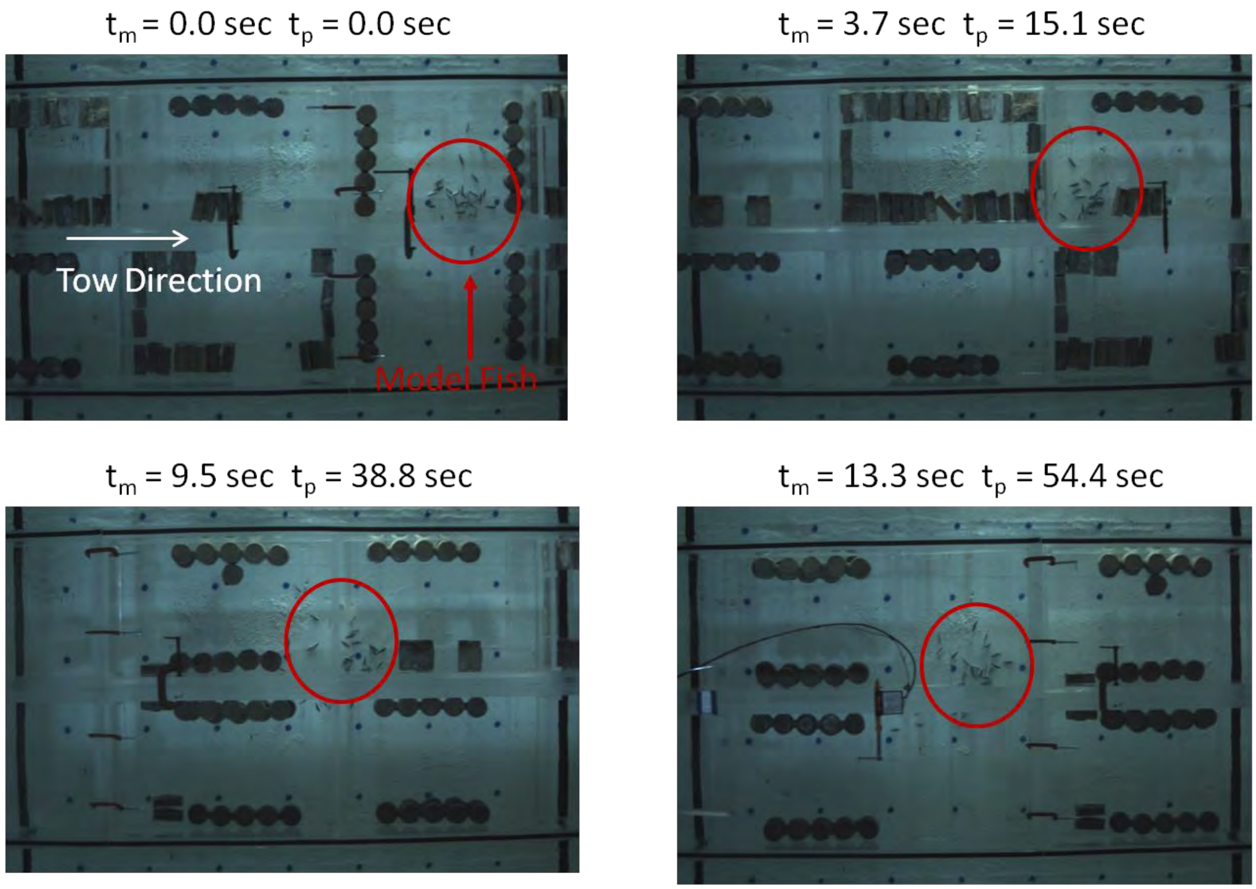


Figure 23– Snapshot showing the transport of model fish in the return current (A) as the barge passes overhead with corresponding model and prototype time.

Figure 24 shows model fish, highlighted by the red circle, moving with the tow in the barge wake (D). The tow direction in this picture is towards the bottom left corner. This mode of transport is effective at moving model fish in the same direction as the tow. Figure 25 shows model fish being carried within the barge boundary layer (E). The tow is moving right to left with the fish being pulled along. This mode of transport is not as efficient due to mixing and the intermittency of boundary layer vortex structures that can eject the fish. Another effective mode is the junction between barges as shown in Figure 26. In this series of snapshots the tow moves forward into the page as the model fish are suspended beneath. The black box represents the barge junction (G) region of the tow configuration. As the tow moves over the model fish (red circle) they become entrained in the junction area and are carried in the same direction as the tow. The snapshots show the model fish being transported 100.2 ft (prototype) in 36.8 seconds (prototype). Once the model fish become entrained in the vortex, they tend to remain trapped for long periods of time resulting in efficient transport.

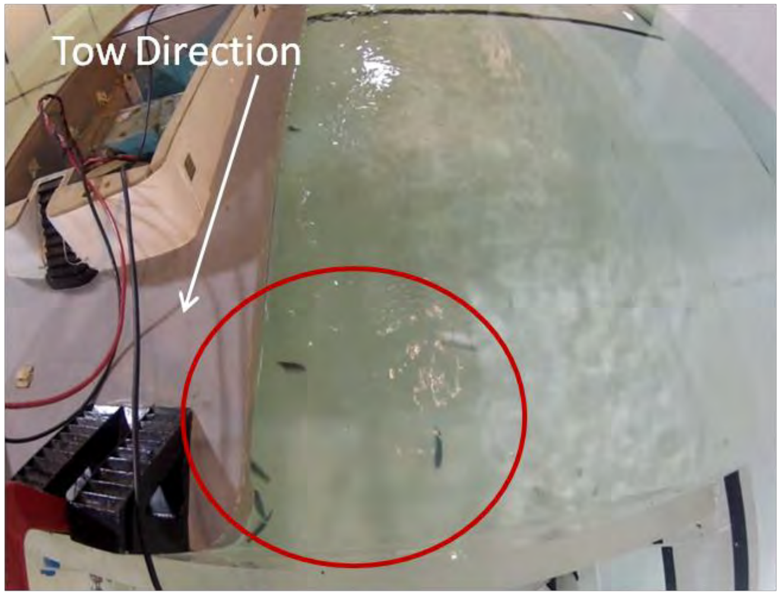


Figure 24– Snapshot showing the transport of model fish in the barge wake (D).

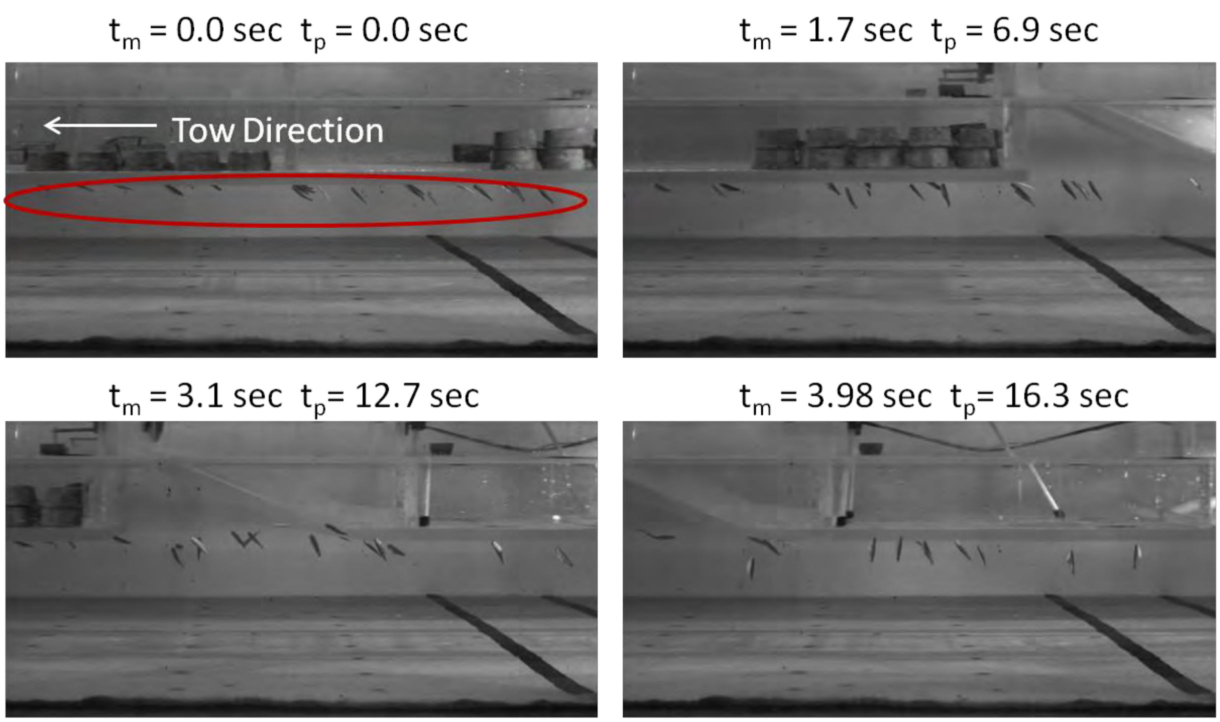


Figure 25– Snapshot showing the transport of model fish in the barge boundary layer (E) and entrainment of some of the model fish between two barges with corresponding model and prototype time.

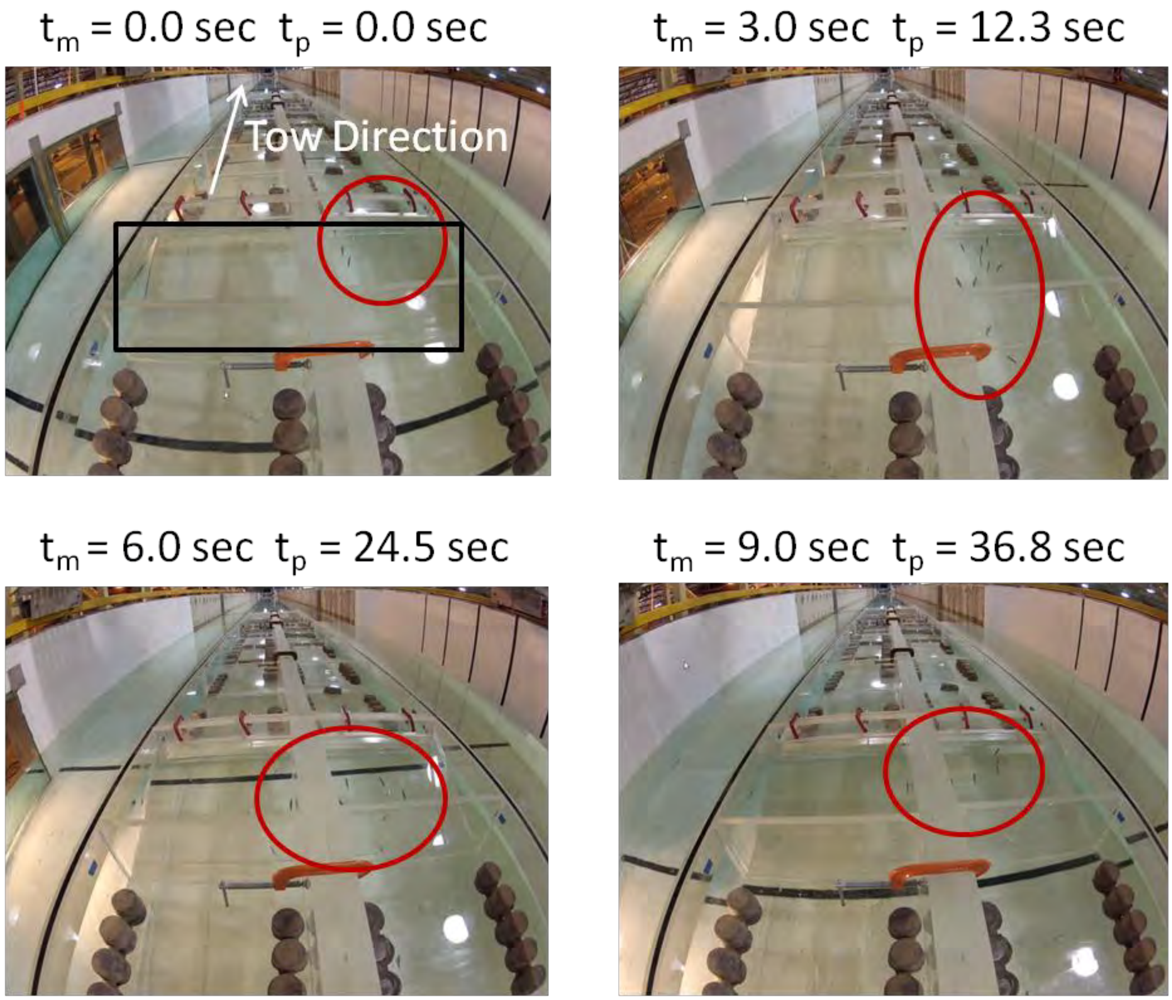


Figure 26– Snapshot showing the transport of model fish in the junction between a raked barge and a square barge (G) with corresponding model and prototype time.

The study results show that for southbound traffic, the return velocity (A) was most relevant for model fish transport. Northbound traffic can transport fish through four modes. The bow wave (B) transported model fish short distances. The barge boundary layer (E) transported model fish far enough to potentially cross an electric barrier. The wake flow (D) and entrainment within voids in the barge configuration (G) had the most significant impact. They were shown to be capable of transporting model fish much longer distances than the length of the electric fields generated by the barriers. None of the barge tow configurations or speeds attempted entirely eliminated the transport of model fish across distances greater than the length of the electric fields.

Follow up testing was conducted in 2015 and early 2016 using the same physical model flume at the Coastal Hydraulic Laboratory described above. This follow up testing addressed several mitigation measures that would lessen the risk of barrier bypass via barge or water current entrainment. This testing involved engineered solutions such as various configurations of nozzles placed on the waterway bottom generating upward-facing water jets that could be used to clear entrained fish from barge voids or in areas of entrained water. The testing also addressed operational solutions such as tow-barge maneuvers within the safety zone over the

Electric Dispersal Barriers, speed limitations, or controlling canal discharge to maintain a minimum flow velocity in the downstream direction. A final report by Bryant et al (2016[B]) provides two potential mitigation actions for fish entrainment.

Analyses of results indicate the following:

- Southbound barges creating a reverse flow in the upstream direction may be mitigated by imposing a lower vessel speed limit or maintaining an increased downstream flow velocity.
- Northbound barges creating entrainment opportunities to carry fishes over the barriers in the upstream direction may be mitigated through the use of water jets in conjunction with reduced speed limits. Higher vessel speeds mean that the barges pass more quickly over the water jets, reducing the exposure time to the flushing action and therefore reducing the effectiveness of fish removal.

5.6 - Field Studies Investigating Effectiveness of the CSSC Barriers

Since the initial activation of the Demonstration Barrier in April 2002, a variety of field studies of barrier effectiveness have been conducted.

Tagging of Common Carp

The first field studies were completed by the Illinois Natural History Survey (*Does the Electric Fish Barrier Work? Update for the Illinois River Coordinating Council*, Dr. Richard Sparks, 2 March 2009). In 2003 the INHS team began tagging Common Carp (*Cyprinus carpio*) with combined radio and acoustic transmitters and releasing them immediately downstream of The Demonstration Barrier. Fixed hydrophones and antenna were placed along the canal walls in the area to detect the transmitters. A tracking boat periodically confirmed locations and found transmitters that were beyond the range of the fixed stations. The transmitters had a battery life of 400 days.

From 2003 to 2009, 130 tagged common carp were released downstream of the Demonstration Barrier. 15 tagged fish were released between the Demonstration Barrier and Barrier IIA in September 2008. Only one of the transmitters passed through the Demonstration Barrier. This occurred in April 2003. At the time the Demonstration Barrier had been operating at $IWFS_0$ = 1 V/in, 2 Hz, 2 ms. These operating parameters had been selected based on the barrier contractor's previous experience with other electric barriers. After the passage occurred, the operating parameters were changed to $IWFS_0$ = 1 V/in, 5 Hz, 4 ms. The tag that crossed the barrier did so at the same time a barge tow was crossing over the barrier. This led to concerns that the barge tow may have in some way facilitated the movement through the electric field. The 2003 metal hull study described in the next section was initiated because of this incident.

In September and October 2008, three tagged fish traversed Barrier IIA in the downstream direction. One of the tagged fish traversed Barrier IIA before a severe rain storm on 13 September and other two after the storm. The storm increased water flow velocities in the canal to 5 ft/sec, which exceeds the sustained swimming speed of common carp.

Since 2010, 162 Asian carp have been collected and tagged from the Dresden Island and Marseilles Pools in the IWW while 447 fish of surrogate species have been collected and tagged from the Lockport and Brandon Road Pools closer to the barriers. Tagged surrogate fish have been released above and below the barrier; however, no tagged Asian carp have been released upstream of the previously known leading population front (Rock Run Rookery, Des Plaines River, RM 281.5). Tagged fish deployment at the Electric Dispersal Barriers has varied in the species, total length, and deployment methods to account for potential bypass mechanisms identified by outside projects. Potential bypass mechanisms include small fish (less than 4 inches) challenging the barriers as well as barge interactions causing entrainment through the barriers.

Barrier efficacy was assessed by observing both long range and fine scale movements of tagged fishes within the pools below and above the barriers. Long range movements of these fish were assessed by a network of 11 stationary VR2W receivers strategically place up and downstream of the Electric Dispersal Barriers (n=6 upstream and n=5 downstream), 4 receivers in the Brandon Rd pool, and 12 in Dresden Island pool (includes 2 in the Kankakee River). These receivers were placed at the lock entrance, in high quality habitat, in proximity to the Electric Dispersal Barriers and at the confluence of the CSSC and the Cal-Sag Channel. Receiver data was analyzed for individual fish detections that would indicate an upstream or downstream passage through the Electric Dispersal Barriers. Bi-monthly mobile tracking utilizing the VR100 supplemented the stationary receiver data.

At the Electric Dispersal Barrier System, 8 VR4 receivers were originally located around the arrays of Barriers IIA and IIB. These receivers were able to provide a two dimensional fish position in relation to the barrier. In the Lockport pool, 148 surrogate fish have been released of which there have been two observations of tagged fish released below the Barriers that were later detected upstream. These tags were not detected on receivers in proximity to the Barriers. Further investigation suggests that these tags may have been transported by barge entrainment although it has not yet been verified. No tagged fish have been observed to swim through an active electric barrier field in the upstream direction to date.

Battery life in the VR4 receivers expired in the 2016 sampling season. The Vemco Positioning System (VPS) supported by the VR4 receivers had provided sufficient data to assess the performance of the Electric Dispersal Barrier System up to that point. It was decided to discontinue use of the VPS as a means of generating fine-scale movement fish tracks in the vicinity of the barriers and instead rely on the larger VR2 receiver system and broad-scale tracking to assess barrier efficacy for tagged fish. VR2 receivers are maintained at stationary locations up and downstream of the barriers each sampling season and a skeleton network is maintained year-round. This allows sufficient monitoring of tagged fish below, at, and above the Electric Dispersal Barrier System. A VPS may be established at the Electric Dispersal Barrier System again once Permanent Barrier I is brought online. This will allow researchers to assess the new barrier performance as well as any behavioral changes the tagged fish community may experience in relation to the new electric field.

<u>Barge Testing Studies</u>

<u>2003 Testing</u>

As a result of the April 2003 incident where a tagged common carp crossed the Demonstration Barrier when a barge tow was crossing the barrier, an investigation of the possible effect of barge hulls on the electric field was completed in fall 2003. In this study a barge tow was metered to measure the electric field in the water in close proximity to the metal hulls while the tow passed over the barrier. In addition, fish were suspended in cages along the sides of the barges and the behavior of the fish as they passed over the barriers was observed.

The study showed that the electric field in the water was weakened in the immediate vicinity of the metal hulls at some locations. The available electric field measurements suggested that there may be areas around the barges where no electric charge was present. While it is not clear whether or not fish are able to navigate around barges, the area of reduced electrical field could provide a way for a fish in close proximity to a barge to cross the barrier without being deterred.

The information from the 2003 study was used in the design of Barriers IIA and IIB. The number and spacing of the electrodes was altered from that used at the Demonstration Barrier. The electrodes at both Barriers IIA and IIB were designed to have two independently-pulsing arrays (the two lobes referenced earlier in this chapter) to create a more complex electric field that could potentially reduce any reductions in electrical field during barge passage over the barriers.

2012 Testing

In 2012 the Construction and Engineering Research Laboratory (CERL) of ERDC and the Chicago District completed further testing to determine the effects of passing barges on the field strength of the barriers. Testing was completed in two phases. The first, completed in June 2012, consisted of three dimensional (3-D) field mapping at depths up to 16 feet below the surface without any conductive vessels in the water. This phase provided the baseline, or control, for the testing that occurred later in 2012.

The second phase, completed in July and October 2012, utilized two instrumented barges and a tow vessel under contract with USACE. The barges were instrumented in a dry dock facility with several 3 dimensional voltage probe arrays in various locations. The testing included measurement of the electric field strength at the voltage probes as the barges traversed the barriers. The barge tow configuration and the operating parameters of Barriers IIA and IIB were varied to simulate different scenarios. This phase of testing was designed to test the effect of barges in the barrier zone on the electrical field in the water.

The U.S. Fish and Wildlife Service (USFWS) also participated in the second phase. During the July testing USFWS placed fish in cages mounted on a barge hull in various locations and video recorded their behavior as the barge traversed the barriers. The October work included more tests with caged fish and some tests with free swimming fish that were tagged with an external float and released between the barges in a tow. The fish used were locally caught fish including common carp, gizzard shad, and freshwater drum. No Asian carp were used in the testing.

The June 2012 testing was completed using a Boston Whaler and a specially designed sensor array (Figure 27). The array had 3-D sensors located at depths of 2, 6, 12, and 16 feet below the water surface. This provided continuous data at water depths comparable to the predicted water depths of the arrays on the instrumented barges.

Electrical data were continuously collected at a rate of 8000 samples per second as the boat traversed the barriers from the Romeo Road Bridge to the pipeline arch. This extends the data-collection region well beyond the Demonstration Barrier to the north and Barrier IIA to the south. Geo-positional data were taken concurrently with the voltage and current measurements during field mapping to allow them to be geo-referenced. A minimum of ten passes — two passes along five transect paths spread across the canal were taken to allow for data interpolation throughout the barrier zone.

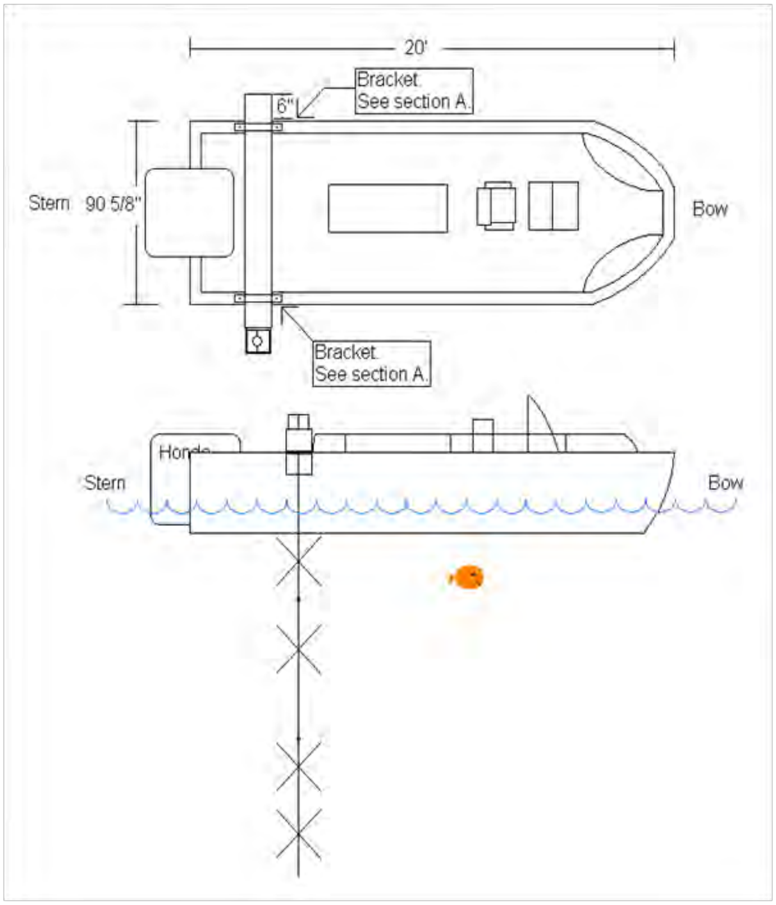


Figure 27 – Schematic of the Boston Whaler and probe array.

A typical voltage gradient plot from this testing is shown in Figure 28. The y-axis of the plot shows the voltage gradient of the field in units of volts/inch. The x-axis is distance in units of meters. The plot is geo-referenced to the center of the high field of Barrier IIB. The plot shows all three electrical component directions: Y (red) is along the canal (upstream-downstream), X (Yellow) is transverse (wall-wall), and Z (blue) is through the depth of the water. The two red peaks on the left of the plot show the field gradient of the Barrier IIA and IIB high fields. The inverted red peak on the right shows the field gradient of the Demonstration Barrier. Note that the Y axis is the dominant field axis for the barriers, and is the measurement used to describe their operation (e.g. 2.3 volts/inch). The total vector magnitude may be calculated by taking the cube root of all three measurements cubed. The total vector magnitude represents the maximum field strength potential in the ideal orientation and is generally higher than the field strength measured in any of the three fixed orientations.

Geo-referenced electrical data collected in this effort was projected into a GIS format to determine the location of field strengths and weaknesses. These maps not only provided the baseline for comparison to later runs but were also used to generate safety zone maps in preparation of Barrier I construction.

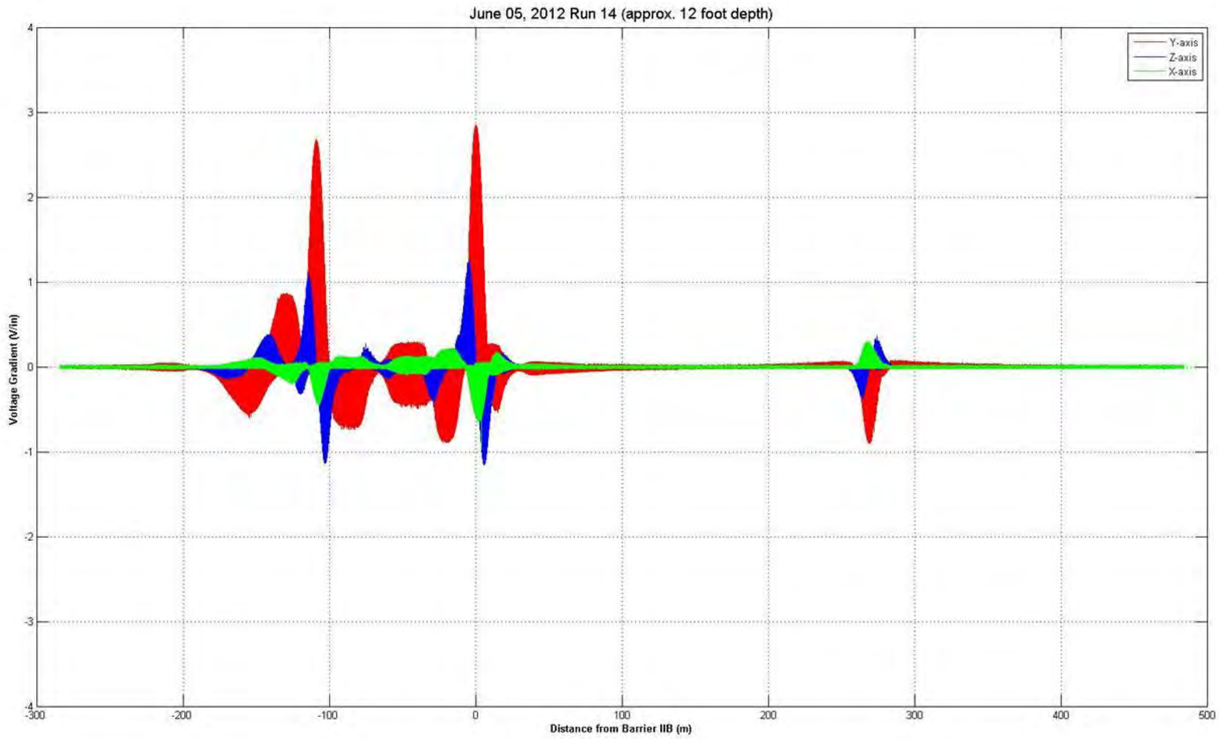


Figure 28 – Typical 3-D electric field mapping plot.

For the July and October testing, a total of forty-six 3-dimensional sensors were designed and fabricated at ERDC-CERL and welded to the barges in dry dock. Each array contained three sensors spaced 1 foot, 2 feet, and 3 feet from the surface of the barges (Figures 29 and 30). A pair of arrays was suspended within the wedge of the rake barge to measure the electric fields within this area (Figure 31). During testing, electrical field data was collected on up to 24 channels at a sampling rate of 8000 samples per second. These readings are geo-referenced using GPS receivers mounted to the forward and aft areas of the instrumented barge. The combined electrical and geo-positional data was used to determine the strength and direction of the electrical field around the barges throughout the barrier zone. Testing occurred with the barges in multiple configurations (Figure 32) to simulate tow configurations regularly utilized by shipping companies.

Figure 29 – 3 Dimensional probe arrays along the bottom edge of rake barge in dry dock.

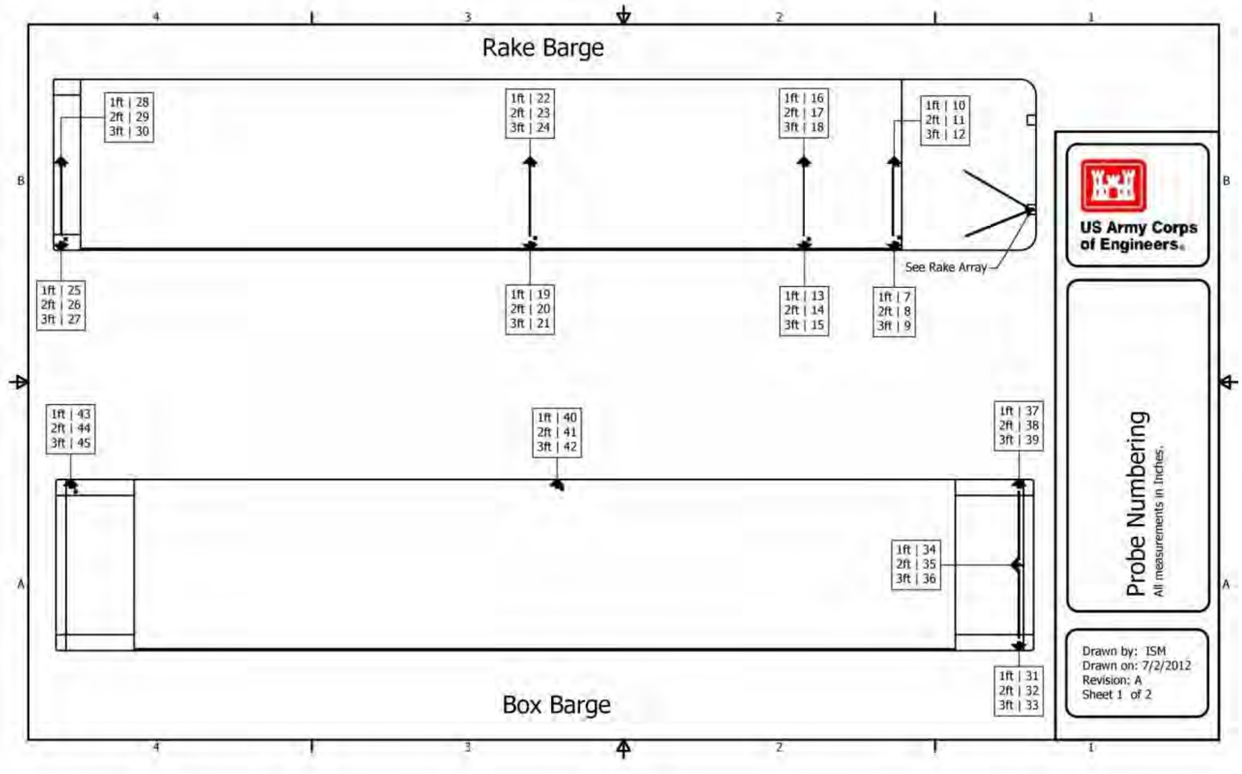


Figure 30 – Sensor array locations and numbering for the rake and box barges.

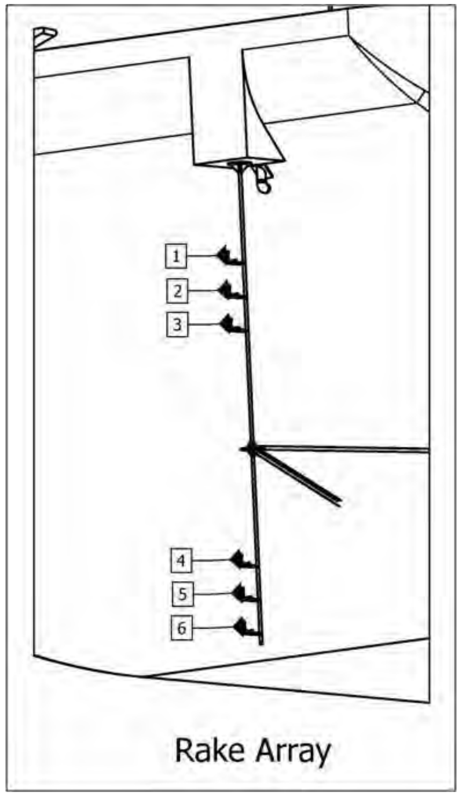


Figure 31 – Rake array locations and numbering.

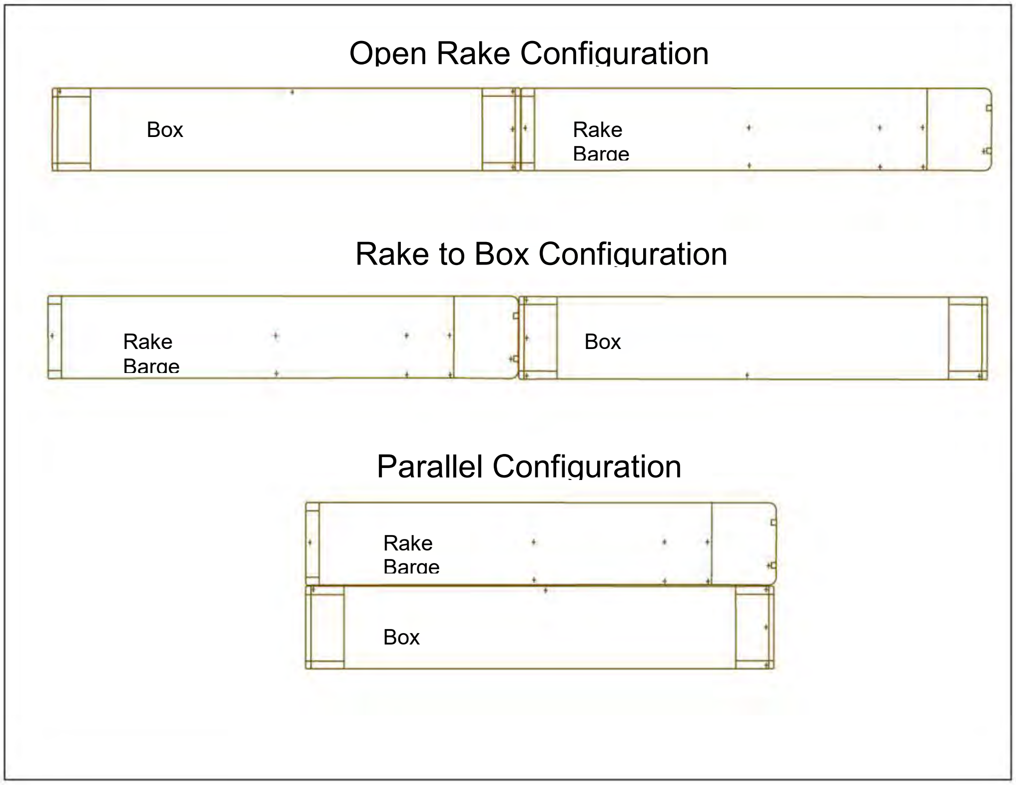


Figure 32 – Barge Testing Configurations

Several tests were conducted in July using barge configurations where the rake section of one barge was not connected directly to the flat backed box section of another barge (open rake or parallel configurations). A typical voltage gradient plot from open rake barge testing in the series connection is shown in Figure 33. This plot was taken from Probe 22 which was spaced at 1 foot from the bottom of the center of the rake barge. When compared to the field mapping plot from Figure 28, it can be seen that the electric field gradient is significantly distorted due to the presence of the barges. The overall magnitude is much higher, and the dominant electric field component is in the Z direction as opposed to the Y direction, normal to the surface of the barge. (Note: only Barrier IIB was operational during this testing.)

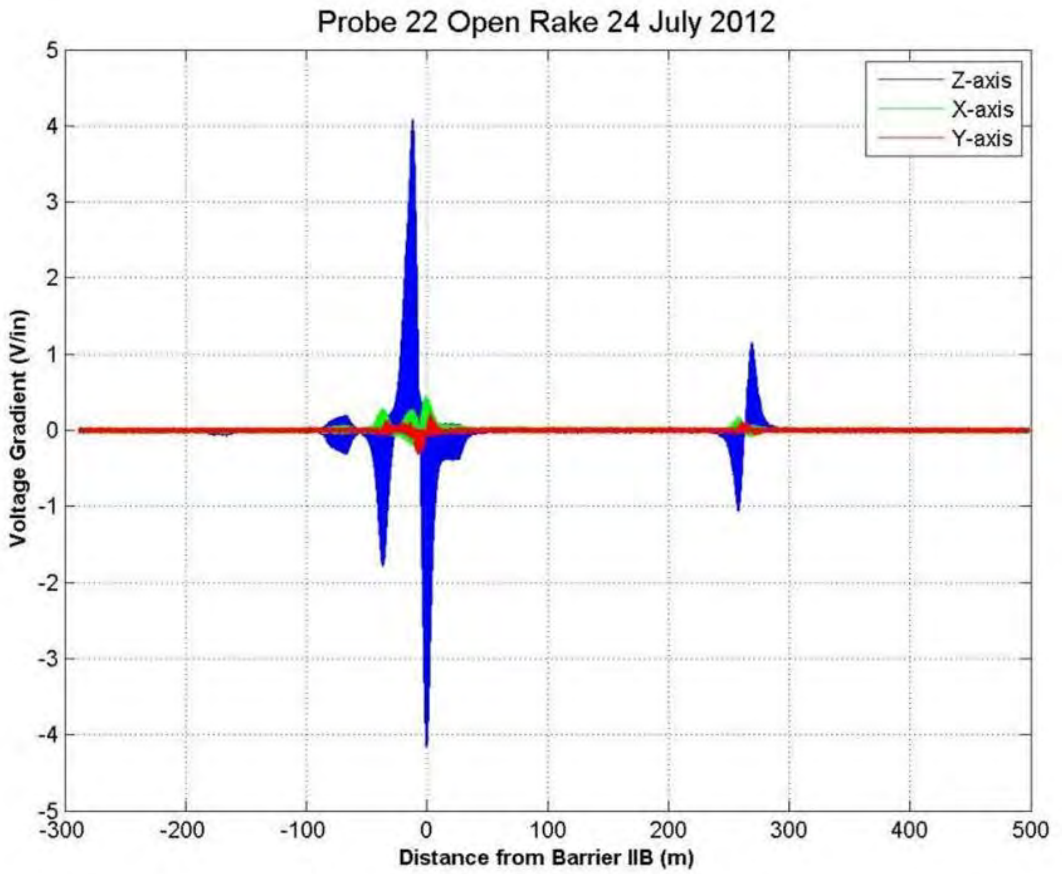


Figure 33 – Typical electric field plot from the bottom of rake barge in the open rake (series) barge configuration.

It wasn't feasible to place caged fish on the bottom of barges. However, caged fish were placed off of the side of the barges during the open rake configuration tests. All of those caged fish were incapacitated when they passed over Barrier IIB.

The rake array probes provide information on the electric field strength in the water beneath the rake. Figure 34 shows a vector magnitude plot of the electric field at probe 1 near the water surface in the rake as the barges passed over operating Barrier IIB (centered at 0 on the x-axis) and the Demonstration Barrier (centered around approximately 270 m on the x-axis). This shows increased field strength near the surface of the water. With typical peaks of 2.3 Volts/inch and 1 Volts/inch when no barges are passing, the peaks measured from the rake section of a passing barge were 3.7 Volts/inch and 1.4 V/inch.

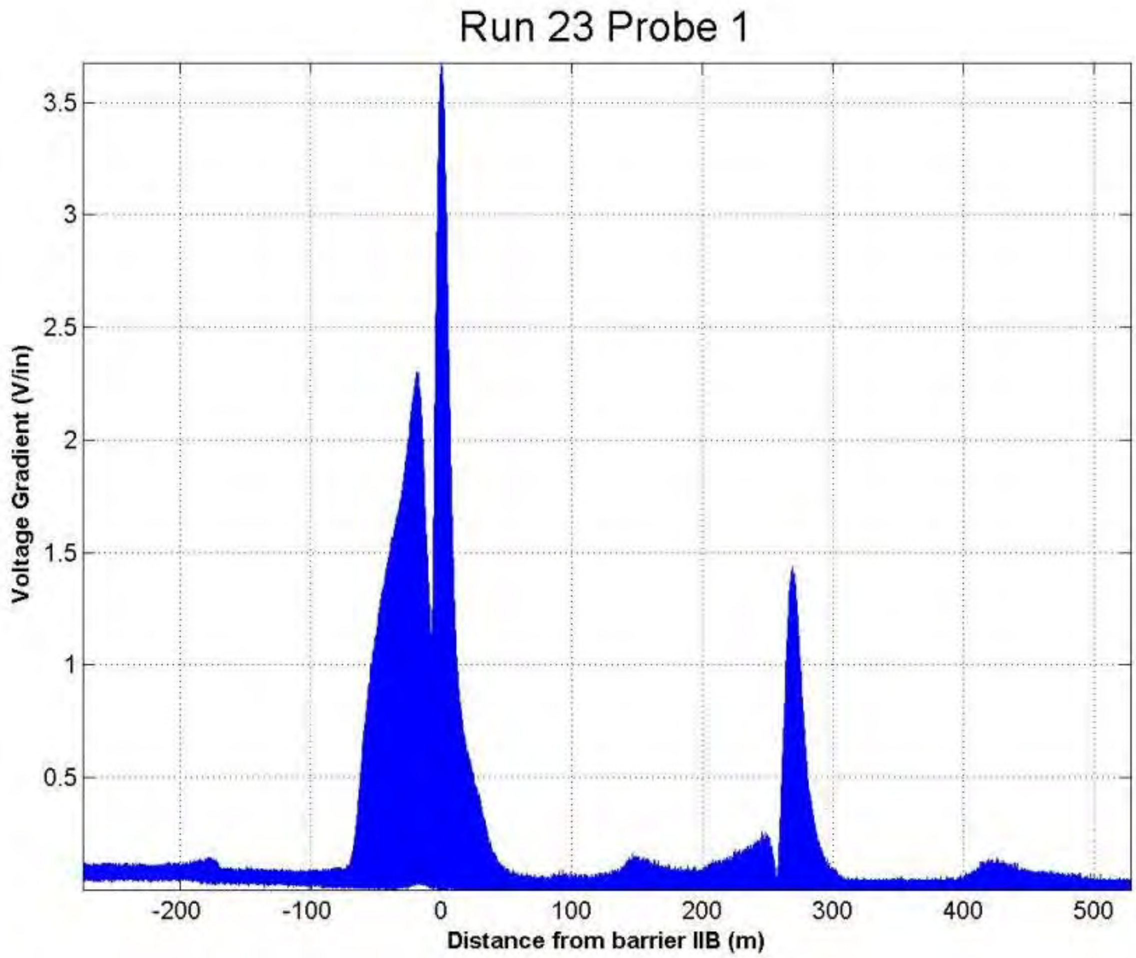


Figure 34 – Vector Magnitude field strength measurements over Barrier IIB and the Demonstration Barrier from the open rake section of an instrumented barge.

Caged fish were placed in the water beneath the rake during some test runs in series configuration or at the stern of the barges in the parallel configuration. All of the caged fish located beneath the "open" rake in series or at the stern in parallel were incapacitated when they passed over Barrier IIB. However, feral mosquitofish (*Gambusia* spp.; not stocked by USFWS) were observed being entrained in the stern position of the parallel barge configuration.

Other testing in July included the barge configuration where the rake section on an instrumented barge is connected to the box section of another barge as depicted in Figure 35. As seen in the figure, the rake and box barges are connected together using steel cables allowing a good electrical connection between them. In this case, the water beneath the rake is partially enclosed by the bow rake.

Figure 35 – Instrumented barges in the Rake to Box configuration during testing.

The 3-D voltage gradient at Probe 22 is shown in Figure 36. This can be directly compared to the voltage in the same location with the open rake configuration (Figure 33). The distortions in the electric field gradient at the bottom center of the rake barge are very similar in both configurations. The voltage gradient is increased, and the Z-field (depth) component is dominant. The overall magnitudes are similar between the two.

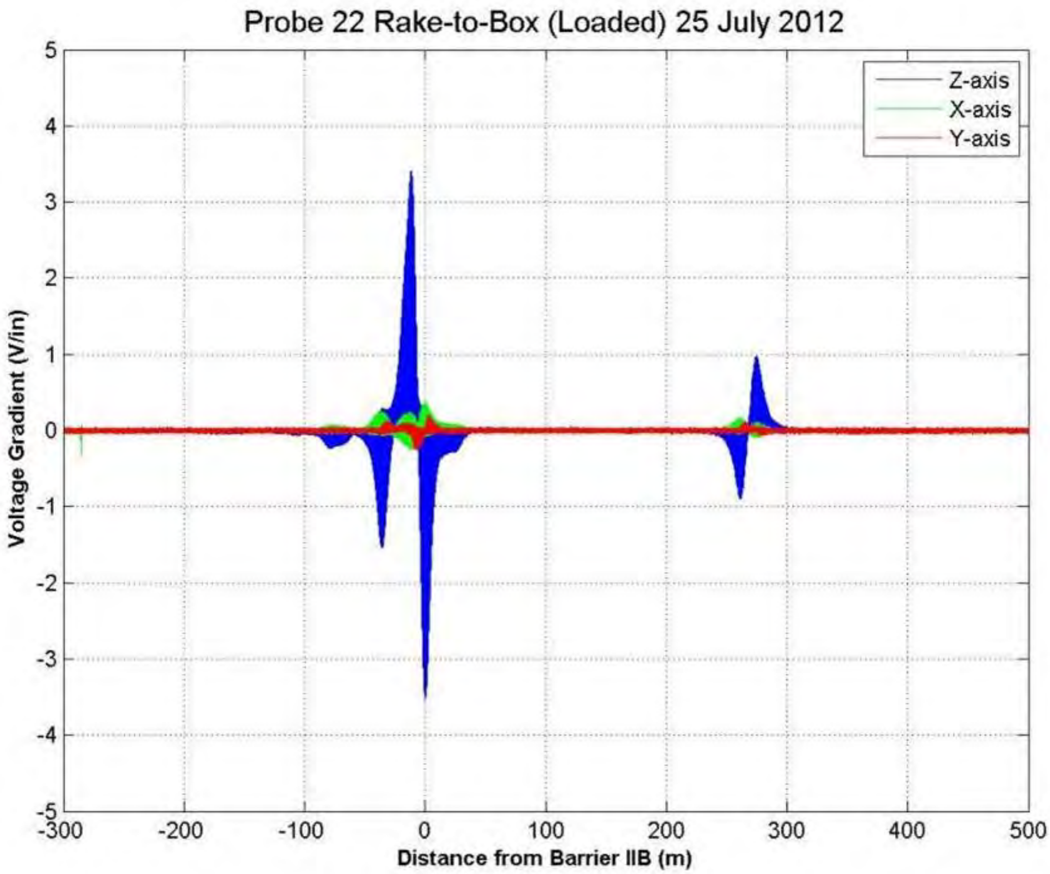


Figure 36 – Typical electric field plot from the bottom of rake barge in the rake-to-box barge configuration.

Figure 37 is a plot of the voltage gradient vector magnitude in the water under the rake (Probe 1) in the rake-to-box configuration. Two peaks are visible at the Barrier IIB high field. The field strength measured while passing over the high field of Barrier IIB (0 on the x-axis) is 0.15 Volts/inch rather than the typical peak of 2.3 Volts/inch when no barges are present. This represents a very significant reduction in the electric field strength within the water beneath the rake for this barge configuration. The Demonstration Barrier electric field is not discernible within the noise of the measurement.

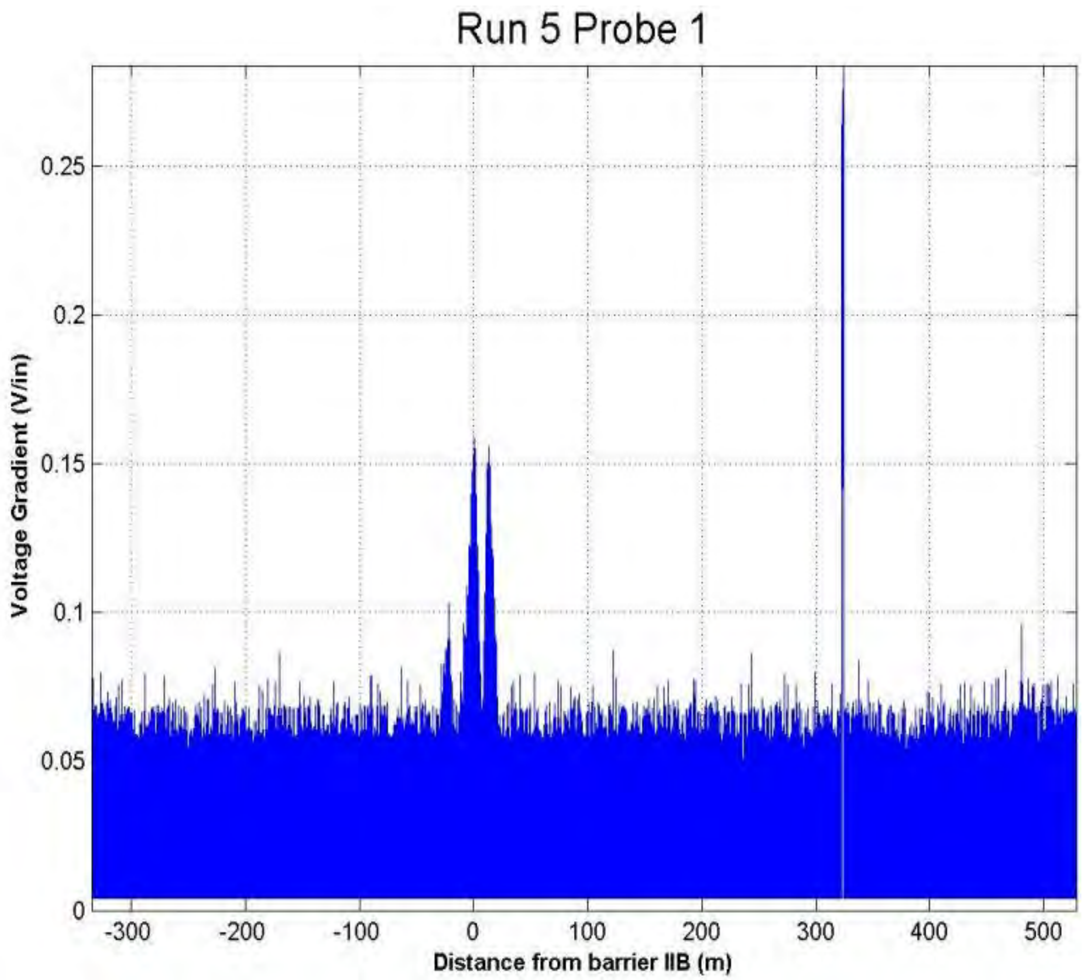


Figure 37 – Field strength measurements over Barrier IIB and the Demonstration Barrier from beneath the rake section of an instrumented barge connected to the box section of another barge. (Note: The line at approximately 320 m is due to radio interference during testing.)

Caged fish were placed beneath the rake in multiple rake-to-box configuration test runs. One of thirty-six caged fish pulled across the barriers under the rake in this configuration was incapacitated. In addition, during the October testing seventy-five gizzard shad tagged with external floats were dropped into the area beneath the rake in a rake-to-box configuration immediately before the barge tow began to traverse the barriers. All three barriers were operating during these tests. Most of the tagged fish quickly exited the rake area, but seven crossed at least one barrier staying within the rake area, two crossed both Barriers IIA and IIB, and one crossed all three barriers. It is unknown whether these fish chose to stay in the rake area or were for some reason unable to exit it, but they were transported within it over one or more barriers.

The primary objective of the 2012 testing was to determine the effects of passing barges on the electric field gradient. The preliminary data shows that the electric field produced by the barriers in the water is significantly altered by the presence of barges traversing the canal. This alteration is in both magnitude and direction and depends on the configuration of the barges. The key conclusions that can be drawn from the data at this time are summarized below:

- Sensors located along the bottom of the barges measured significantly higher voltage gradients than are measured during routine electric field mapping in a fiberglass hulled boat. The area of low to no electrical field strength reported in the 2003 study wasn't observed in the 2012 testing.
- Sensors located along the bottom of the barges measure a significant distortion in the direction of the electric field. Specifically, it appears that the dominant electric field direction is normal to the surface of the barges. This indicates that the barges are attracting the electric current from the water.
- In an open rake configuration, the electric field in the water beneath the rake is increased in magnitude.
- In a rake-to-box configuration, the electric field in the water beneath the rake is significantly reduced to the point that it is barely measureable.
- All caged fish placed alongside barges or under an open rake were incapacitated when pulled over Barrier IIB or IIA. However, only one of thirty-six caged fish placed under a "closed" rake in a rake- to-box configuration were incapacitated. Also, some fish placed loose under a "closed" rake remained under the rake and traveled over one or more operating barriers.

2013 Testing

In 2013 the Construction and Engineering Research Laboratory (CERL) of ERDC and the Chicago District refined and re-conducted testing to determine the effects of passing barges on the field strength of the barriers. Testing completed in June, July and November included Field Strength Testing from Barges, Far Field Distortion Testing, Measurement of Field Strength in the Notches, and Field Strength measurement during Power Transfer from the Utility to Generator Power.

The electric field mapping conducted in the vicinity of the barge hulls in 2013 was a repeat experiment to the trials conducted in 2012. Repeat experiments were performed to incorporate lessons learned from the previous testing and to increase the spatial coverage of sensors to obtain higher resolution data on areas of interest. These areas included the notch created by a rake barge lashed against a box barge, a rake-to-rake barge configuration and the areas just outside of these created void spaces. Barges were configured in series to create these junctions as well as in parallel. Results from the barge vicinity testing indicate that the presence of barges in the barrier zone significantly distorts the 3-D electric field in magnitude, direction, and polarity as demonstrated in 2012. When a rake barge is up against a box barge, there is a significant reduction in the electric field in the water within the rake void, but not one foot outside of the void. Finally, when barges are present in a series configuration, operating Barriers IIA and IIB simultaneously results in higher voltage readings over each barrier than when one barrier is operating alone.

Instrumentation was also set up along the west bank canal wall on 20 and 21 June 2013 in order to determine if there was any effect to the electric field strength in areas further away from a passing barge. Similar 3-D probes were lowered into the canal within 18 inches from the side wall at depths of 2 feet and 7 feet. Canal electric field strength was recorded on a continuous measurement data logger during the passage of barge traffic. Barges were configured in series in front of the tow boat and pushed through the safety zone of the barriers along the east side, center channel and west side of the canal. Analysis of the data revealed that barges traversing the barrier zone cause distortion in the electric field throughout the water channel and not just in the vicinity of the barges. Field distortion was greatest during the west side channel runs closest to the instrumentation and least distorted during the east side channel runs furthest from the instrumentation. Figure 38 below depicts the reduction of the electric field strength in the y-axis parallel to the canal wall during the passage of the barge on the west side channel run (blue represents 2′ depth and red represents the 7′ depth). Barge passage corresponded to as much as a 40% reduction in field strength at a single point adjacent to the passing barge.

On 17 June 2013, the CERL team performed additional electric field measurements in order to quantify the time of loss of field strength in the water during a transfer of power from utility to generator emergency power. The same instrumentation used for the far field distortion testing described above was utilized for these measurements. Probes were submerged at depths of 2 feet and 7 feet below the surface of the water and measured the electric field strength in the y-axis direction parallel to the canal wall. Results indicated that the field strength in the water dropped off steeply upon discharge of the initial power source regardless if that was utility to generator or generator to utility. Upon initialization of the secondary power source, field strength in the water was reconstituted almost immediately but at reduced voltage gradients that were more gradually ramped back up to the specified target levels (Figure 39). Power transfers between generator and utility power caused a drop in field strength in the water for a period of between 10 and 20 seconds regardless of the direction of power transfer (utility to generator or generator to utility).

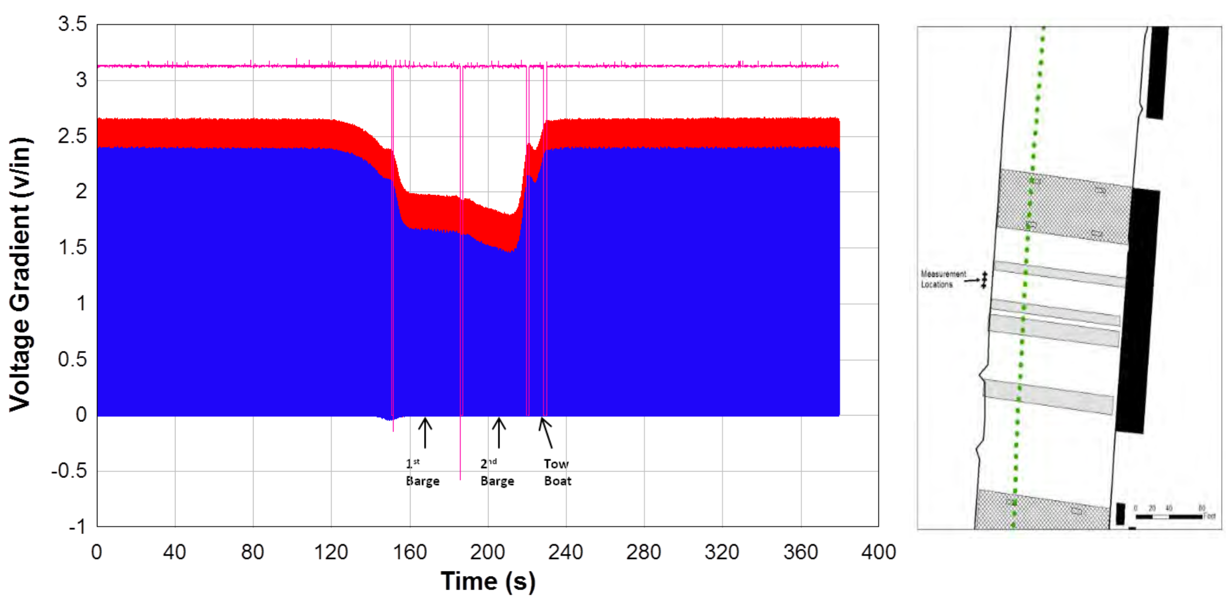


Figure 38 – Far Field Distortion Testing, 20 June 2013 Series Configuration West Wall. Plot shows the envelope of the peaks of the individual pulses at the probe depth of 2′ (blue) and 7′ (red).

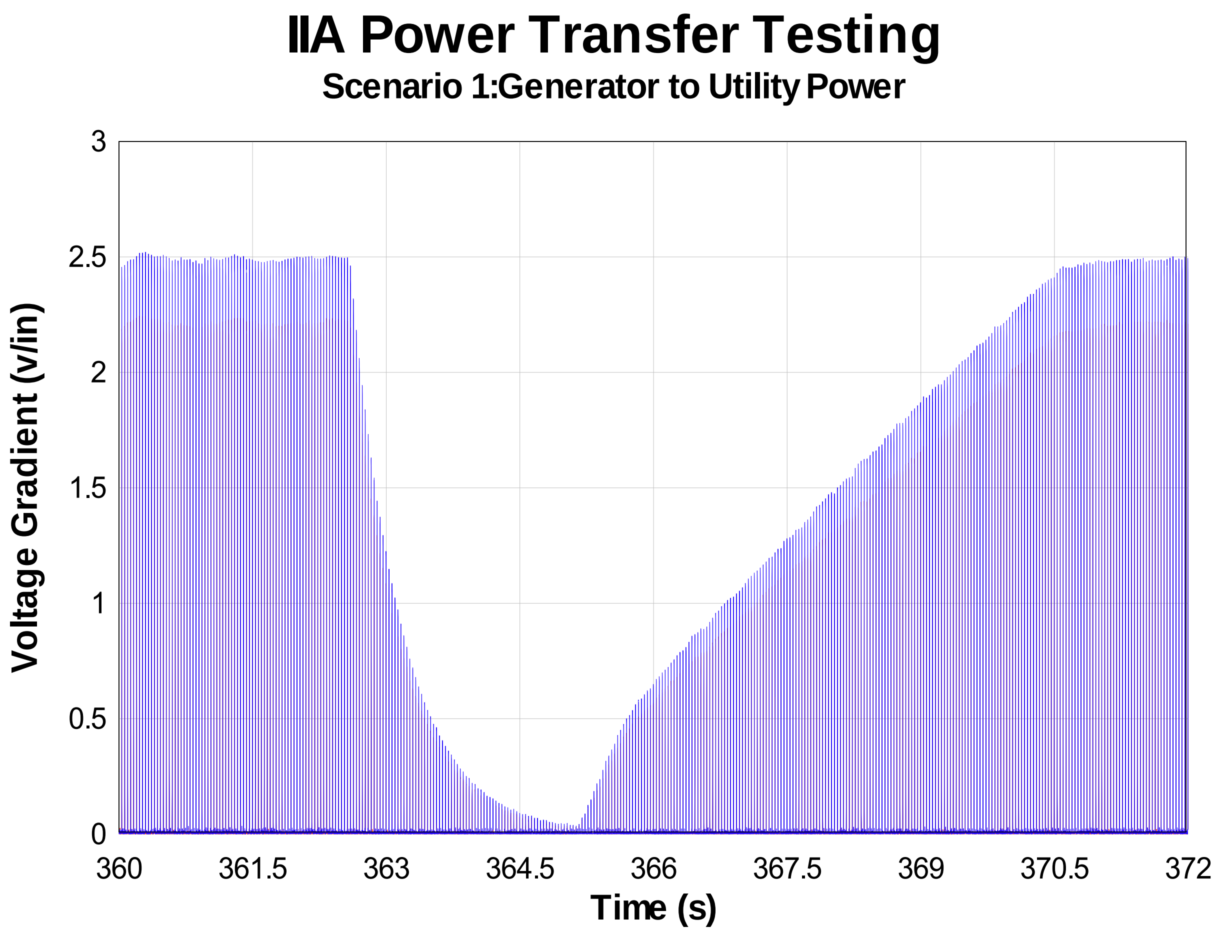


Figure 39 – Barrier IIA Power Transfer Testing plot of voltage gradient vs time at the west bank, 7' below the surface of the water.

2013-2017 Fish-Barge Interaction Trials

After successful evaluation with the unconfined, tethered fish in October 2012, all evaluations in 2013 utilized the tethered fish methodology. Tethered fish were released either directly into the various junction wedges to evaluate the likelihood of entrainment when the fish had the ability to leave under its own volition or they were released in advance of a upstream bound barge to assess the likelihood of entrainment into the junction wedges after a barge strike. All barge configurations evaluated during tethered fish trials, except for rake-to-tow, yielded some percentage of entrainment beyond the electric barriers (Figure 40). Of the 340 Gizzard Shad used during the tethered fish evaluations, 21 breached after direct placement into a junction wedge whereas 20 breached after deployment below the Electric Dispersal Barrier. The 41 Gizzard Shad entrained beyond the Electric Dispersal Barriers ranged in size from 9.9 – 24.7 cm TL (MRWG, 2014; Parker et al, 2015). It should be noted that if fish were found above the Electric Dispersal Barrier but the tether was entangled on the barge, or if any fish entangled their tethers together with other fish tethers, those fish were not recorded as breaching since the entanglement may have facilitated the breach.

In November 2013, tethered fish were released within barge junction wedges below the barriers under three different modes of unconventional navigation techniques to investigate methods of reducing fish entrainment. These methods included having the tow vessel pull rather than push, pushing but stopping below the barriers for 2 minutes before continuing and finally approaching the barriers with a 'zig-zag' pattern to increase flow within junctions. Twenty tethered Gizzard Shad were released upstream of a tow pulling barges at the barrier over three trials which resulted in no entrainment past the barriers. This method was deemed ineffective however for navigation purposes as feasibility for tow captains to use this method in moderate to high flow events is severely degraded and one trial had to be completely aborted for this reason. For the three trials investigating an extended pause below the barriers for 2 minutes, thirty fish were deployed and three were entrained beyond the barriers. The final mitigation technique of approaching the barriers in a 'zig-zag' fashion completed four trials with forty fish. Six of those fish remained within the rake-to-box junction and were entrained beyond the barriers. Of the nine fish entrained beyond the barriers during unconventional navigation, sizes ranged from 21-26.5 cm in total length (MRWG, 2014; Parker et al, 2015).

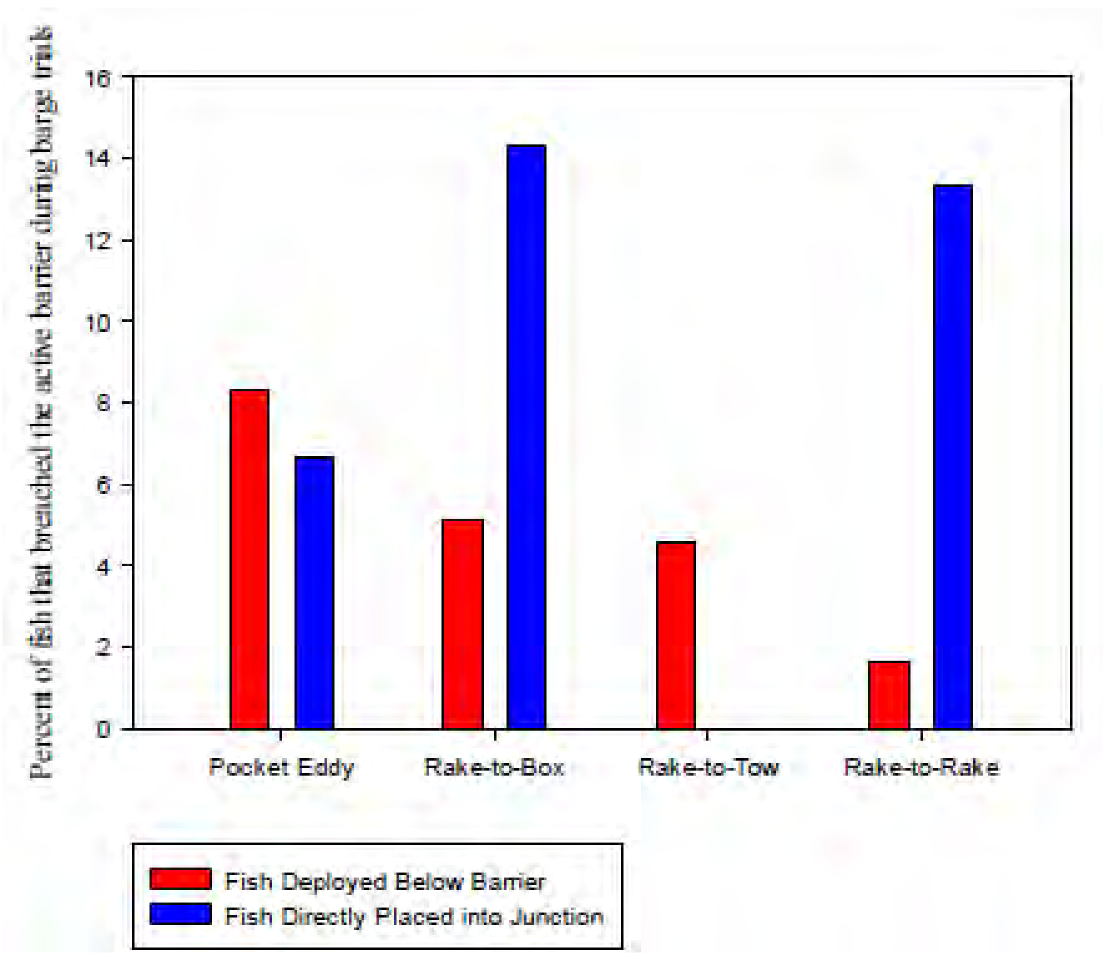


Figure 40 – Percentages of live tethered fish that breached the electric barriers via different barge junction configurations and fish deployment methodologies (MRWG, 2014).

In 2013, Ultrasonic telemetry was identified as an alternative method to assess fish reaction to commercial vessels in situ. Internally implanted transmitters were used to address the concern that externally tethered fish may have reduced swimming capabilities due to drag on the tether or bobber-marker. USACE biologists implanted transmitters into 13 large bodied Common Carp averaging 552 mm in total length. The fish were released in two groups of four and one group of five specimens directly into the box-to-rake barge junction during the approach to the electric barriers in the upstream direction. Later analysis using a telemetry positioning system and mobile tracking indicated that no fish were observed to cross the barriers in the upstream direction. USACE concluded that all fish were able to swim away from the barge junction of their own volition. Although these results differed from those of the USFWS tethered fish testing, differences in fish length and sample size may have played a large roll (MRWG, 2014).

In 2015, USFWS continued work with fish-barge interactions. Detailed results can be found in Davis et al. (2015). In summary, USFWS placed hatchery raised Golden Shiners into the gap of rake to box barge configurations. The fish were uniquely fin-clipped per run and stocked into the rake to box junction at 300 fish per run while the tug was approaching the electric dispersal barrier. Fish were then recaptured using a modified cast net. A mean of 32% of the stocked fish were recaptured after passing through the Electric Dispersal Barrier. Similar trials were conducted at the Brandon Road Lock and Dam. Fish were stocked into the rake to box junction and the barge proceeded to travel through the lock structure. Mean recapture rates ranged between 20.4% and 39.7%. Finally, USFWS investigated the potential transport of Golden Shiners across long distances. Two trials occurred within the Lockport pool with 1000 fish stocked per trial. Two long distance runs within the Lockport Pool consisted of a 3.35 and 4.72 mile run through the Electric Dispersal Barrier and resulted in a mean recapture rate of 26.9%. A single long distance run of 9.6 miles was conducted with 2000 stocked fish. This run consisted of traveling through Lockport Lock and the Electric Dispersal Barrier. Recapture rates were 3.8%. These results demonstrate the potential for barge mediated transport through lock structures as well as the Electric Dispersal Barrier.

Results from 2015 provided further continuation of fish-barge interaction studies in 2016. A multi-agency team consisting of FWS, USGS, and USACE conducted a study to determine how a decrease in electrical measurements at the surface and hydrodynamic forces provide potential passage of fish at the Electric Dispersal Barrier. A summary of the study suggests that the upstream passage of small fish is possible when barges move downstream at the Electric Dispersal Barrier. Return currents in the upstream direction created by the barges moving downstream, in concert with decreased surface electrical measurements, can successfully move small fish passed the Electric Dispersal Barriers. For more detail on the study, please see Davis et al. 2017.

This multi-agency team of researchers returned to the CSSC for additional testing in 2017 with the goal of field testing two mitigation strategies. These two concepts were designed to address return currents generated by upstream tow movements and direct entrainment of fishes surrounding the barge hulls. Return current mitigation tested a range of controlled ambient canal velocities in partnership with the MWRDGC in an effort to maintain a downstream canal flow during a downstream tow passage. A contracted tow was utilized to study the effect of various canal flow velocities, multiple barge configurations, and various tow speeds on the likelihood of inducing a return current and subsequent fish passage. While increasing ambient flow velocities in the canal reduced the probability of return flow in conjunction with downstream tow passage, it was not sufficient on its own in preventing small fish passage. Further mitigation of the reduction in voltage gradient which occurs during barge transit over the Electric Dispersal Barrier System may be warranted to help reduce small fish passage (Davis and Shanks, 2018).

The 2017 trials also tested a field-scale prototype of the water jet array developed by the Coastal Hydraulic Laboratory designed to flush entrained fishes from barge and tow junctions. This water jet system was designed to mimic the laboratory testing discussed in Section 5.5 Laboratory Studies Investigating Effectiveness of the CSSC Barriers – Entrainment of Fish by Vessels. The water jet manifold used in the 2017 testing was installed on the CSSC bottom downstream of the Electric Dispersal Barrier System with three jet nozzles directing a controlled flow velocity at an upstream angle toward the water surface. The contracted barge was instructed to pass over the disrupted water column while marked fish were released into the barge junction gaps. Various tow speeds and water jet velocities were studied for efficacy in clearing entrained fish. Preliminary results indicated that ejection velocities within the junction gaps increased as the tow transited over the water jets. Initial observations indicated the water jets were capable of flushing a portion of the small marked fish from the junction gap however complete removal of all marked fish did not occur (Davis and Shanks, 2018).

<u>Tethered Fish</u>

In June, 2009, the Illinois Natural History Survey (INHS) carried out a study where bluegill, common carp, largemouth bass, white suckers, green sunfish and other types of fish were tethered to a float and allowed to pass downstream through the Barrier IIA electric field (Ruebush et. al, January 2010). With Barrier IIA operating at 1.0 V/in, 5 Hz, 4 ms, 3 of 11 fish were incapacitated and 8 of 11 passed through the electric field unaffected. In November, 2009, with the strength of the electrical field at Barrier IIA increased to 2.0 V/in, 15 Hz, 6.5 ms, 20 of 20 fish were incapacitated immediately or a few seconds after passing through the field. It was noted that fish less than 4 inches in length took longer to become incapacitated.

In 2011 and 2012, U.S. Fish and Wildlife Services (USFWS) used Gizzard Shad (*Dorosoma cepedianum*) as a surrogate species emulating small Asian Carp attempting to traverse the barrier. They were placed in a non-conductive PVC frame cage lined with a 0.95-cm bar monofilament mesh. Fish behavior was recorded within and outside of the electric barrier and assessed for each year. The caged fish were pulled either mid channel through the entire barrier array, along the western wall of the canal within the array, or through a non-electrified control area downstream of the array system.

In summer of 2011 the operating parameters of the electric barriers were such that the voltage at the surface measured 0.79 V/cm, canal temperature was an average of 24.2 °C, and average conductivity was 0.74 mS/cm. A total of 270 small Gizzard Shad were pulled through the barrier while at these conditions and of those 3% did not become incapacitated (n=4 through mid-channel and n=4 along west wall). The median incapacitation distances were 66 m and 73 m respectively for fish moved through the mid-channel and along the wall of the canal.

In 2012 the operating parameters of the electric barrier were such that the voltage at the surface measured 0.91 V/cm and fish were pulled through the same locations over the barriers during each of the four seasons. The reactions and distance to incapacitation of the fish varied widely depending on the types of conditions (conductivity, location, type of boat, fish size, temperature), but at some point all fish that moved through the barriers were incapacitated at this setting. The biggest influences were the size of the fish and the temperature. With larger fish and cooler temperatures, incapacitation occurred at a shorter distance inside the barriers (sooner) than it did with smaller fish at warmer temperatures (summer and fall).

Ultrasonic Telemetry

In 2010, the USACE ultrasonic telemetry monitoring project set out to: 1) determine if fish are able to challenge and/or penetrate the Electric Dispersal Barrier System; 2) investigate the ability of Asian carp to navigate through lock structures in the upper Illinois River, lower Des Plaines River, and CAWS; 3) determine the location of the leading edge of the Asian carp population front; and 4) examine responses of adult and small fish to the barrier (ACRCC MRWG 2012). The project involves surgically implanting individually coded ultrasonic transmitter tags in Bighead Carp, Silver Carp and surrogate species and then monitoring movements with a series of stationary and mobile hydrophones. Telemetry results related to surrogate species and barrier effectiveness are presented below. Telemetry results for tagged Bighead and Silver Carp are discussed in *Chapter 3, Asian Carp Management Strategy*.

Telemetry (Adult Fish)

During 2010, tags were implanted into surrogate species as follows: CSSC/Chicago River above barrier - 20 common carp; Lockport pool above barrier - 18 common carp and 2 freshwater drum; Lockport pool below barrier - 29 common carp; and Brandon Road pool - 1 grass carp, 1 smallmouth buffalo and 17 common carp. (ACRCC MRWG 2012).

In 2011, 47 tags were implanted in adult surrogate species in Lockport pool (43 common carp, 2 mirror carp, 1 freshwater drum, and 1 channel catfish) and 30 tags were implanted in small surrogates (white sucker, green sunfish, pumpkinseed, skipjack herring, largemouth bass, smallmouth bass, crappie, and bullhead) that were released upstream and downstream of the barriers, 14 and 15 respectively with one fish escaping near the surgical site 3.5 miles downstream of the barriers. It should be noted that the smaller sized tags implanted in small fish typically have a much shorter life expectancy than the larger tags used to track large fish. In total, 182 fish were tagged, including 152 adult fish and 30 small surrogate species. Small surrogate species ranged in length from 2.1 to 7.6 inches. Over the course of this monitoring, the Demonstration Barrier and Barrier IIA were operating at 1 V/in, 5 Hz, 4 ms and 2.0 V/in, 15 Hz, 6.5 ms, respectively.

As of October 2011, with 32 stationary receivers tracking movement from the Dresden Island Lock to above the barriers, supplemented by mobile tracking, 3.7 million detections on 75% of the 182 tagged fish indicated no fish have crossed any of the barriers in the upstream direction. There have been 3 observations of tagged common carp moving upstream through the Lockport Lock and 10 occurrences of downstream movement.

The overall goal for the telemetry study in 2012 was to assess the effect and efficacy of the Electric Dispersal Barrier System on tagged fish in the CAWS and upper IWW using ultrasonic telemetry. Table 7 summaries the number, species, and location of all fish tagged from 2010 through 2017.

Data from the 2012 season collected from January through November provided approximately 2.45 million detections from 112 of 176 tagged fish for a 63.64% detection rate. All records indicated that no tagged fish crossed the Electric Dispersal Barriers in either direction during 2012. Positioning data from the Vemco Positioning System (VPS) receiver array around the barriers have shown only four uniquely tagged fish approaching the barriers a total of 18 times through May 2012 (Shanks, 11 Dec 2012). Inter-pool movement was recorded for surrogate species between the Lockport, Brandon Rd, Dresden Island and Marseilles pools. A total of seven individual fish were observed to make the transition from one pool to another with several of these fish moving between pools on multiple occasions. All inter-pool movement occurred at the Lockport and Dresden Island locks with no movement across the Brandon Road lock in either direction. Seven downstream and three upstream passages occurred at the Lockport lock. Only one upstream and three downstream passages occurred at the Dresden Island lock. Similar to 2011 data, the majority of downstream movements occurred during increased flow velocities indicating fish may be flushed through open locks or sluice gates in high flow events.

Telemetry monitoring continued in 2013, resulting in 8.9 million detections from 315 tagged fish by the end of the calendar year. Data analysis concluded that the barriers were effectively preventing the upstream passage of large bodied, adult surrogate fishes (non-Asian Carps tagged in Lower Lockport Pool; i.e. Common Carp). Analysis of surrogate fishes that approached the barrier from the downstream side indicated that Common Carp over at least 381 mm in total length are effectively repelled by electric field strengths as low as .1 to .5 V/in. These voltage gradients are equivalent to electric field strength experienced over the parasitic arrays surrounding the barriers. A number of fish tracked positions are displayed on a map of the barriers in Figure 41 and a map of electric field strengths as measured by ERDC-CERL is provided in Figure 42. Additionally, a positive relationship was found between discharge and the length of time a fish spent challenging the barrier with greater discharges leading to increased time at the barrier. Movements of tagged Bighead and Silver Carp were analyzed within the Dresden Island and Marseilles Pools at the leading edge of the invasion front. It was found that both Silver and Bighead Carp move similarly within the Upper Illinois River system and that these movements rarely extend upstream of the Rock Run Rookery backwater near RM 281.5 in the Dresden Island Pool. Although not enough data was present to clearly describe seasonal behavior patterns in Silver Carp, Bighead Carp were found to be significantly more active within the summer months. Finally, proportions of diel and seasonal movements are related, with the majority of the movement occurring during spring and summer as well as at night and crepuscular diel periods (MRP 2014).

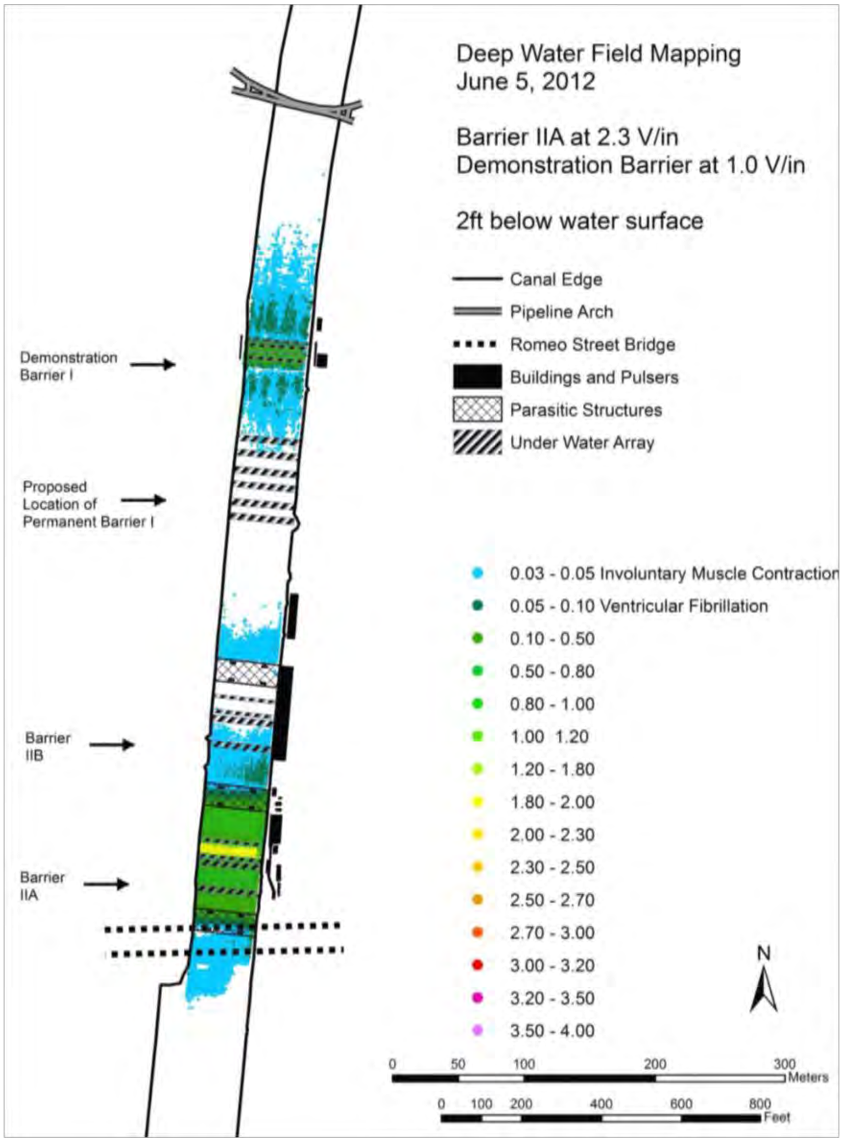


Figure 41 – Electrical field mapping by ERDC-CERL of the Dispersal Barriers indicating an increased electrical field beginning at the parasitic 1 array.

Figure 42 – Typical fish approach displayed as positional data points just downstream of Barrier IIA and indicating that tagged fish are reacting to elevated field strengths over the parasitic array.

There were a total of 15.1 million detections from 432 tagged fish by the end of October 2014. No tagged fish, surrogates or Asian carp, were observed to have swam through the Electric Dispersal Barriers in the upstream direction. There are however two instances of transmitters originally implanted into fish downstream being detected upstream of the barriers. These tags were not detected on receivers at the barriers and the fish in which the tags were implanted were both identified as deceased at their upstream locations. A detailed investigation of plausible modes of transport was initiated. It is possible that these fish were entrained across the barrier safety zone by vessel traffic in the canal which also masked transmissions of the tags during passage via water turbulence and engine noise. The ultimate mode of transport may not come to light and it is also unknown whether the fish had expired prior to or post passage. Asian carp movement at the invasion front had been similar to previous years with the majority of movement observed surrounding the Rock Run Rookery and within the Kankakee River in the Dresden Island Pool. Little movement was detected for Asian carps near the Brandon Road Lock and Dam. However, two Common Carp which were captured in the Brandon Road Pool, subsequently tagged and released within the Dresden Island Pool, were detected moving upstream through the Brandon Road Lock (MRP 2015).

In 2015, the number of tagged fish detections accumulated to a total of 20.2 million detections from 532 fish. No fish were determined to move across the barrier in an upstream direction in 2015. However, one Common Carp did move downstream through the barriers and survived. Additional analysis was conducted on the movement of fish between lock and dam structures. A total of 83 occurrences have occurred since 2010. The majority of the interpool transfers (44) occurred between the Lockport Pool and Brandon Road Pool via the Lockport Lock and/or Controlling Works Spillway. Of the 44 transfers, 31 were in the downstream direction (Lockport to Brandon Road) and 13 in the upstream direction (Brandon Road to Lockport). A total of 10 transfers occurred through the Brandon Road Lock and Dam with 4 moving upstream from Dresden Island and 6 downstream from Brandon Road. It is important to note that all transfers through Brandon Road Lock and Dam occurred by Common Carp. The fish released downstream of the lock were originally captured in the Brandon Road Pool and released downstream in the Dresden Island Pool. In doing so, biologists were able to use the site fidelity of fishes as a way to increase passage and determine how quickly fish are able to navigate through a lock structure. The remaining 29 transfers between pools occurred through the Dresden Island Lock and Dam. A total of 14 upstream transfers and 15 downstream transfers occurred. Continued observations of tagged Asian Carp in 2015 demonstrated similar patterns as in previous years where fish consistently traveled between Rock Run Rookery and the Kankakee River (Figure 43). However, increased flooding on the Kankakee River in 2015 resulted in the furthest upstream movement of Asian Carp in the Kankakee River to date. A total of 85 detections from 12 individual Asian Carp occurred at a receiver near the Wilmington Dam. Additional receivers were placed upstream of the Wilmington Dam to help determine the extent of Asian Carp use in the Kankakee River.

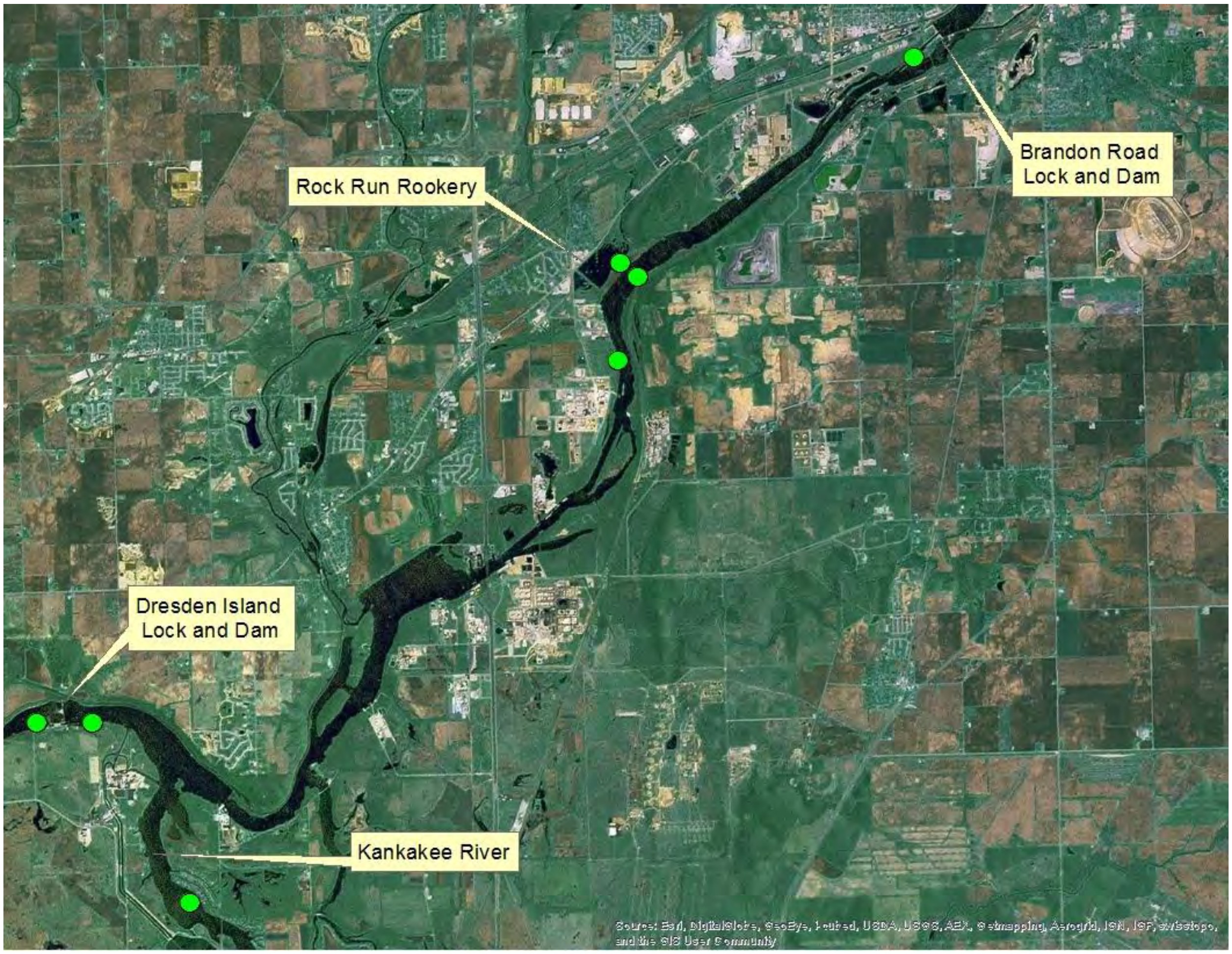


Figure 43 - Map depicting the Dresden Island Pool along with relevant points of reference in regards to Asian carp movement patterns. Green dots represent locations of telemetry receivers.

A total of 28.2 million detections was collected from 597 tagged fish through 2017. No fish were determined to move upstream through the barrier in an upstream or downstream direction. Tagged fish in the Lockport pool were often detected below the barrier, but the fish tended to move back downstream rather quickly. In addition, detections of tagged fish were low in winter months, which may provide additional justification for the implementation of seasonal operational protocols at the Electric Dispersal Barriers. In terms of lock passages, two fish were determined to traverse a lock in 2016. One Common Carp was detected moving upstream through Brandon Road Lock and Dam and one Asian Carp moved downstream through Dresden Island Lock. These movements are determined by looking at time stamped detections on strategically placed receivers upstream, downstream and inside the lock. An additional twelve Common Carp were detected moving downstream from the Lockport pool to the Brandon Road Pool in 2017. Two of these passages occurred through the Lockport Lock while the remaining ten occurred through the Lockport Controlling Works Spillway. Finally, additional receivers were placed in new locations to find finer scale movement patterns of Asian Carp in the Dresden Island Pool. These receivers were focused around the Kankakee River since several fish were detected there in 2015. Specifically, two were placed upstream of Wilmington Dam on the Kankakee River. No Asian Carp were detected on the new receivers in

2016 and they were subsequently removed from the receiver network in 2017. A receiver was also placed just upstream of the Kankakee and Des Plaines River confluence in 2016. At the end of 2017, this receiver had more than 50% of all the total detections in the Dresden Island Pool. The receiver is near shallow vegetated habitat, side channel habitat, backwater habitat (harbor slips) and close to an outfall from the I&M Canal. These habitat types may be an attractant to Asian carp, and the placement allows for fish to be detected as they move from the upper portion of the pool to the lower pool as well. Further investigations of fish detections at this station showed fish that tended to move through the area with only a few detections, other fish seemed to stage in the area for several days before moving up or downstream, and some fish appeared to use the area for a majority of the year and make minor movements into the Kankakee River or upstream before returning to the area (MRWG, 2016b and MRWG, 2017b).

Table 7 - Location and species tagged as part of the 2010-2017 Telemetry Monitoring Plans.

	Lockport Pool Above Barrier								Lockport Pool Below Barrier								Brandon Road Pool							
Species	2010	2011	2012	2013	2014	2015	2016	2017	2010	2011	2012	2013	2014	2015	2016	2017	2010	2011	2012	2013	2014	2015	2016	2017
Common Carp	38			39					29	43		34	25	21	26	25	17			20		18		
Largmouth Bass				24																				
Smallmouth Buffalo										2							1							
Channel Catfish										1							1							
Frashwater Drum	2									1		1												
Total										47		35	25	21	26	25	19			20		18		

	Dresden Island Pool								Marseilles Pool
Species	2010	2011	2012	2013	2014	2015	2016	2017	2012
Bighead Carp	17			20	5	40		6	16
Silver Carp				3	3	10		7	15
BigheadxSilver Hybrid				2		1			
Common Carp					15				
Smallmouth Buffalo			5		8				
Total	17		5	25	31	51		13	31

Telemetry (Small Fish)

A small fish tagging study was implemented as part of the 2011 Telemetry Plan. Twenty-nine small, non-Asian carp fish ranging in size from 2.1 to 7.6 inches were implanted with tags and released immediately upstream and downstream of Barrier IIB. Asian carp were not used to limit the introduction of these species upstream of the current invasion front. Alternate fishes were tracked from June to October 2011 and included the following species: White Sucker, sunfish, bullhead, Largemouth Bass, Skipjack, Common Carp, and crappie. Fourteen fish were released immediately upstream of Barrier IIB and 15 fish were released immediately downstream of Barrier IIB. Fish movements were continuously tracked by stationary receivers that triangulated the position of the fish to give precise location and movement data.

Results indicated that none of the fish released below the Electric Dispersal Barrier System moved upstream. The dominant behavior observed of the fish released below the barrier was short range pacing between Barrier IIB and IIA with intermediate rests near the IIA array. Six of the fourteen fish released upstream of the Electric Dispersal Barrier System did pass downstream through both arrays of Barrier IIB, five moved down into the array of IIB and remained there, and three moved upstream away from the barrier. Preliminary conclusions from the study indicated that the Electric Dispersal Barriers was preventing all upstream passage of tagged fish.

Following an increase of barrier operating parameters to 2.3 V/in in October 2011, fifteen additional small fish had transmitters implanted and released above and below the Electric Dispersal Barrier System during the 2012 field season. Fish species tagged include Green Sunfish (*Lepomis cyanellus*) and Pumpkinseed (*Lepomis gibbosus*) with total lengths ranging from 92 to 132 mm (3.6-5.2 inches). All fish were collected using mini-fyke nets or modified minnow traps from the vicinity just downstream of the barriers. Eight fish were released below the active Barrier IIB and seven fish were released just upstream of Barrier IIB. Mobile tracking data to date indicates no fish crossing the barrier in the upstream direction. Mobile tracking and VPS results of the small fish study on 3-4 October indicated that a majority of the tagged fish (57%) had left the vicinity of the barrier seven days after deployment. As tracking occurred using the mobile VR100 receiver, only 6 unique tag IDs were detected near the barriers indicating the remaining 8 fish were no longer in the study area. Mobile tracking upstream of the barriers did not indicate any upstream passage. All fish movements near Barriers IIA and IIB were recorded by the Vemco Positioning System. Positional data confirmed that there was no upstream passage through the active Barrier IIB from the seven fish released downstream and only two of those fish moved upstream toward the active barrier. Both upstream movements were made by Green Sunfish released downstream of Barrier IIB and approached the barrier on 6 and 7 October. The fish that approached on 7 October (105 mm, 4.13 in) reached the low field before turning back downstream. The fish that approached on 6 October (120 mm, 4.73 in) moved upstream through the low field and then remained between the low and high fields for several hours before losing detections. All seven fish released downstream utilized crevices within the west canal wall at one point during the period of analysis with short range movements into the canal both up and downstream.

Out of the seven fish released upstream of Barrier IIB, two fish moved downstream through both the high and low fields. One of these fish maintained its position along the west bank just upstream of the high field for seven days before moving downstream. Three additional fish moved downstream into the high field where they maintained position for several days before drifting downstream or losing signal. Because of the period of time elapsed while the fish were inside the high field and no indications of upstream movement after that exposure, these fish were assumed to have died within the high field. The remaining two fish did not have positions detected within or below the high field of Barrier IIB.

<u>USFWS Barrier Efficacy Studies: Dual Frequency Identification Sonar (DIDSON) and Caged-Fish</u>

Dual-Frequency Identification Sonar (DIDSON) is an acoustic camera that allows biologists to view fish in aquatic environments and provides real-time, black and white, near-video quality images similar to those of an ultrasound. In 2010, USACE conducted a survey of the electric barriers using DIDSON. Findings indicated the presence of schools of small fish less than six inches above and below the Demonstration Barrier. Some schools appeared to be located directly above this barrier (ACRCC MRWG 2011). Schools of similar sized fish were also observed above and below Barrier IIA. The MRWG’s 2011 Monitoring and Response Plan included DIDSON as a tool to assess the efficacy of the electric barriers as a result of these findings. Later versions of the plan (2012, 2013, and 2014) added projects to study the behavior of caged and tethered fish near barges traversing the barriers as well as feral fish at the high fields. The USACE has provided support to the USFWS DIDSON project since 2011.

2011 Investigation

The intention of using DIDSON technology and caged-fish experiments in 2011 was to assess fish behavior at the Electric Dispersal Barriers. Objectives of the project were to:

1) describe the behavior of various-sized fish (not Asian carp) when subjected to the barriers' electric field; and,

2) use DIDSON surveys to help determine the relative abundance of fish upstream, in, near, and downstream of the electric barriers.

The USFWS began working at the barrier system in June 2011. At that time, Barrier II operating parameters were 2.0 V/in, 15 Hz and 6.5 ms. Work at the barrier system consisted of a two-part study that involved observations of feral fish within the barrier system and caged-fish behavioral trials at the barrier. The USFWS evaluated the abundance and behavior of feral fish near the electric barriers using a DIDSON unit throughout the entire barrier system. (ACRCC MRWG 2012).

During the caged fish studies, groups of five wild-caught Gizzard Shad (*Dorosoma cepedianum*) were placed in cages and allowed to acclimate to in-water conditions for five minutes before testing. Caged fish were then moved through the barrier system at two sites over Barrier II either along the western canal wall or at mid-channel. A third site was considered a control site, which was located at mid-channel outside the zone of electrical influence approximately 100 meters downstream of the barriers. Cage movement parameters (duration, location across the CSSC, and distance traveled) and fish behavior were recorded. Behavioral observations included no response, fright/flight response, incapacitation, and recovery. Observations of caged fish behavior were also made at control sites away from the Electric Dispersal Barriers. Eight of 270 fish averaging 3.6 inches total length pulled through the Electric Dispersal Barrier System during the 2011 study were not incapacitated (Parker et al. 2015).

In-barrier observations using DIDSON were conducted to describe the behavior and determine the abundances of fish within various parts of the Electric Dispersal Barrier System. The sites that were sampled covered the entire gradient of in-water voltages. The USFWS found that fish accumulate below the barrier system and sometimes persistently swim along the electric field and probe the barrier. Smaller fish from 3.6 to 4.9 inches were able to swim far into the electrical field to the area of water containing the ultimate field strength (Parker et al. 2013[B]).

2012 Investigation

The overall goal of the project in 2012 was to add to the body of information on the interaction of fish and Electric Dispersal Barriers by observing fish behavior at the barrier following the change of Barrier II operating parameters to 2.3 V/in, 30 Hz, 2.5 ms pulse length in October 2011. The change was in response to laboratory research completed by ERDC in March 2011 suggesting the previous settings were not as effective on fish between two to three inches in total length (USACE, 2011). Specific objectives of DIDSON monitoring for the 2012 field season were to:

1) describe the behavior of caged-fish when subjected to the electric field of the low and high-intensity fields of Barrier II along a fiberglass-hull boat;
2) describe the behavior of caged-fish when subjected to the electric field of the low and high-intensity fields of Barrier II along a metal-hull boat;
3) describe the behavior of feral fish (i.e., any free-roaming fish) within and around the electric fields;
4) determine the relative abundance of feral fish in the barrier area versus adjacent areas of similar habitat; and
5) describe chemical/physical characteristics of the CSSC throughout different seasons in the event that either caged-fish are observed passing through the barrier or feral fish are observed swimming normally in the barrier.

The 2012 study of feral fish recorded footage from a boat-mounted DIDSON for seven weeks at eight separate sites and ten sub-sites within each site for a total of 80 unique site recordings. USFWS also recorded 800 minutes of footage focusing on the western canal wall directly over the high-voltage barrier arrays.

Caged-fish work continued in 2012 using both fiberglass and aluminum-hull boats. Ten trial runs were completed along the western canal wall and mid-channel over Barrier II and a control site downstream of the Barrier System. One additional day of caged-fish work was completed at mid-channel over the Demonstration Barrier which tested a total of 11 Common Carp (*Cyprinus carpio*) and 2 Freshwater Drum (*Aplodinotus grunniens*).

The 2012 DIDSON data revealed fish abundance below the barriers increases in the summer and fall and declines in the winter and spring. Temperature, conductivity, dissolved oxygen and water velocity showed no meaningful relationship to fish abundance. However, there was an inverse relationship between average fish size and abundance near the barriers, with smaller fish being more abundant and able to penetrate deeper into the barrier arrays. Fish observed closest to the highest electrical field strength were 3.6 to 4.9 in total length (TL) and believed to be Gizzard Shad based on concurrent visual observations of fish at the surface. Caged-fish data showed a marked increase in barrier efficacy when compared to the 2011 trials. At 2.3 V/in operating parameters, all caged-fish were incapacitated when pulled alongside both aluminum and fiberglass hull boats while 8 of 270 fish were not incapacitated in the 2011 trials under the 2.0 V/in parameters. Analysis of the Common Carp and Freshwater Drum pulled through the Demonstration Barrier, which operates at the lower operating parameters of 1.0 V/in , 5 Hertz, and 4 milliseconds, indicated that 6 of 11 Common Carp were not incapacitated but showed avoidance behavior while both Freshwater Drum remained conscious and appeared to swim unaffected through the entire run (MRWG, 2013).

2013 Investigation

In 2013, DIDSON observations by the USFWS continued. However, all of the observations focused on the high fields. The specific objective for the 2013 field season was to describe the behavior of feral fish (i.e. any free-roaming fish) within and around the electric fields.

In-barrier DIDSON observations were continued into the 2013 sampling season with several enhancements to the deployment method designed to improve data reliability. Previous year's in-barrier footage was taken from a single boat-mounted DIDSON. This method presented challenges to biologists when reviewing footage due to unstable images from boat movement as well as a limited area of coverage by the DIDSON's conical view (Parker et al. 2013 [B]).

The area of coverage was increased by adding a second DIDSON, which allowed reviewers a view of the entire high field at Barrier IIB as opposed to only a piecemeal point of view as in the past. Stability of the footage was increased by deploying the double-DIDSON apparatus from the shore using a boom arm. This new deployment method was used in late July and early August to record 72 ten-minute videos along the west bank encompassing the high field and peak electrical field (2.3 V/in) of Barrier IIB. Results indicated that 44 of 72 videos displayed at least one school of small fish (estimated by USFWS from the video footage to be 2-4 inches in total length) breaching the barrier in the upstream direction. Of the 44 videos indicating a breach, 27 videos showed multiple schools breaching the barrier. All breaches observed were in schools with no individual breaches (Parker et al. 2015 [B]).

Although species cannot be determined from the DIDSON footage alone, it is not believed that these fish are Asian carp. Information currently available indicates the best estimate of the closest location of sexually mature, adult Asian carp, necessary to produce the very small fish observed in these experiments, is in the Dresden Island Pool, located between the Dresden Island Lock and Dam (RM 271.5) and the Brandon Road Lock and Dam (RM 286). The upstream limit of the Dresden Island Pool is approximately 10 miles and 2 locks downstream from the electrical barrier (or approximately 41 miles from Lake Michigan). While the furthest upstream spawning event that has been observed by field biologists was one pool downstream, Marseilles Pool, the adult populations within the Dresden Island Pool are sexually mature and capable of reproducing. Because of the lack of an established adult population in the lock pools nearest the electric barriers (Lockport and Brandon Road Pools), and the non-ideal conditions for Asian carp spawning and recruitment near the Electric Dispersal Barriers, current conclusions are that it is unlikely that very small Asian carp are present in either of these pools. Further, current catch data for juvenile Bighead or Silver Carp less than six inches indicates their position to be approximately 62 miles downstream of the Electric Dispersal Barriers, near Ottawa, IL.

2014 Investigation

Additional work in 2014 consisted of deploying two DIDSON units via a telescopic boom lift as previously described. Markers were placed into the water to determine the downstream and upstream limits of the high field. Mechanical issues with one of the DIDSON units caused the USFWS to conduct surveys with only one unit focused on the middle marker of the high field, ensuring the strongest electrical field is in view. For additional data, the USFWS Columbia Fish and Wildlife Conservation Office conducted fish surveys throughout the Electric Dispersal Barrier System in order to characterize the fish community for comparisons with DIDSON footage.

A total of 134 ten minute periods were recorded at the IIB high field with DIDSON technology. No fish were observed crossing the IIB high field. However, several confounding variables impacted the ability of USFWS to obtain comparable data. In 2013, IIB was the only barrier operating during DIDSON collections. In 2014, both IIA and IIB were running resulting in fish stopping at Barrier IIA and preventing their penetration upstream to Barrier IIB. In addition, DIDSON data collections in 2014 were taken at night for the first week of surveys due to diving operations. Lower densities of young of the year fish were observed at the barrier during November 2014 compared to August 2013. These results were expected with the differences in season. Fish sampling by USFWS Columbia confirmed low fish abundances by catching less than ten individuals of Gizzard Shad (Dorosoma cepedianum), Brook Silversides (Labidesthes sicculus), and Creek Chub (Semotilus atromaculatus). Additional details on 2014 DIDSON surveys can be found in the 2014 Asian Carp Monitoring and Rapid Response Plan Interim Summary Report (ACRCC MRWG 2014b).

USFWS continued to utilize DIDSON technology in conjunction with fish-barge interaction trials and barrier efficacy studies from 2015 to 2017 as discussed previously in this section.

Chapter 6 – Permanent Barrier I

The construction of Permanent Barrier I was authorized in Section 3061 of the Water Resources Development Act of 2007 (WRDA 2007), provided below. WRDA 2007 also eliminated the non-federal cost share requirement, thereby making the Chicago Sanitary and Ship Canal Dispersal Barriers Project 100 percent federally-funded.

6.1 - Permanent Barrier I Authority

WRDA 2007 SEC. 3061. CHICAGO SANITARY AND SHIP CANAL DISPERSAL BARRIERS PROJECT, ILLINOIS.

(a) TREATMENT AS SINGLE PROJECT.—The Chicago Sanitary and Ship Canal Dispersal Barrier Project (in this section referred to as "Barrier I"), as in existence on the date of enactment of this Act and constructed as a demonstration project under section 1202(i)(3) of the Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990 (16 U.S.C. 4722(i)(3)), and the project relating to the Chicago Sanitary and Ship Canal Dispersal Barrier, authorized by section 345 of the District of Columbia Appropriations Act, 2005 (Public Law 108–335; 118 Stat. 1352) (in this section referred to as "Barrier II") shall be considered to constitute a single project.

(b) AUTHORIZATION.—

(1) IN GENERAL.—The Secretary, at Federal expense, shall—

(A) upgrade and make permanent Barrier I;

(B) construct Barrier II, notwithstanding the project cooperation agreement with the State of Illinois dated June14, 2005;

(C) operate and maintain Barrier I and Barrier II as a system to optimize effectiveness;

(D) conduct, in consultation with appropriate Federal, State, local, and nongovernmental entities, a study of a range of options and technologies for reducing impacts of hazards that may reduce the efficacy of the Barriers; and

(E) provide to each State a credit in an amount equal to the amount of funds contributed by the State toward Barrier II.

6.2 - Location of Permanent Barrier I

USACE evaluated the location of Permanent Barrier I in 2010. . The evaluation of potential locations for Permanent Barrier I focused on the functionality of the barriers in concert with each other, as well as consideration of operation and maintenance requirements. During a maintenance shutdown of a single barrier, fish would be able to move past the inactive barrier until they encounter the next active barrier. When maintenance is completed and the barrier reactivated, fish could be trapped between two barriers. If the trapped fish are not otherwise removed, then when the next barrier is shut down for maintenance, any surviving fish trapped between the barriers would be free to move upstream. In order to reduce the costs associated with removing fish from between barriers, USACE elected to minimize the distance between barriers.

A second consideration of barrier location was the proximity of the other barriers and the ability to conduct underwater maintenance with divers while a barrier is operational. With the current configuration of Barrier IIA and IIB, it is not safe to dive at IIA with IIB operating or at IIB with IIA operating.

The optimal location for Permanent Barrier I is at the minimum distance required from Barrier II where divers can work at one barrier while other is still operating, and includes the minimal distance between the barriers for fish clearing operations. At this optimal distance, any required maintenance can be completed without shutting down all barriers, and the length of canal for fish clearing before maintenance shutdowns is minimized. Based on all of the above, it was determined the current location of the Demonstration Barrier is nearly the optimal location. The planned location of Permanent Barrier I is shown on Figure 44.

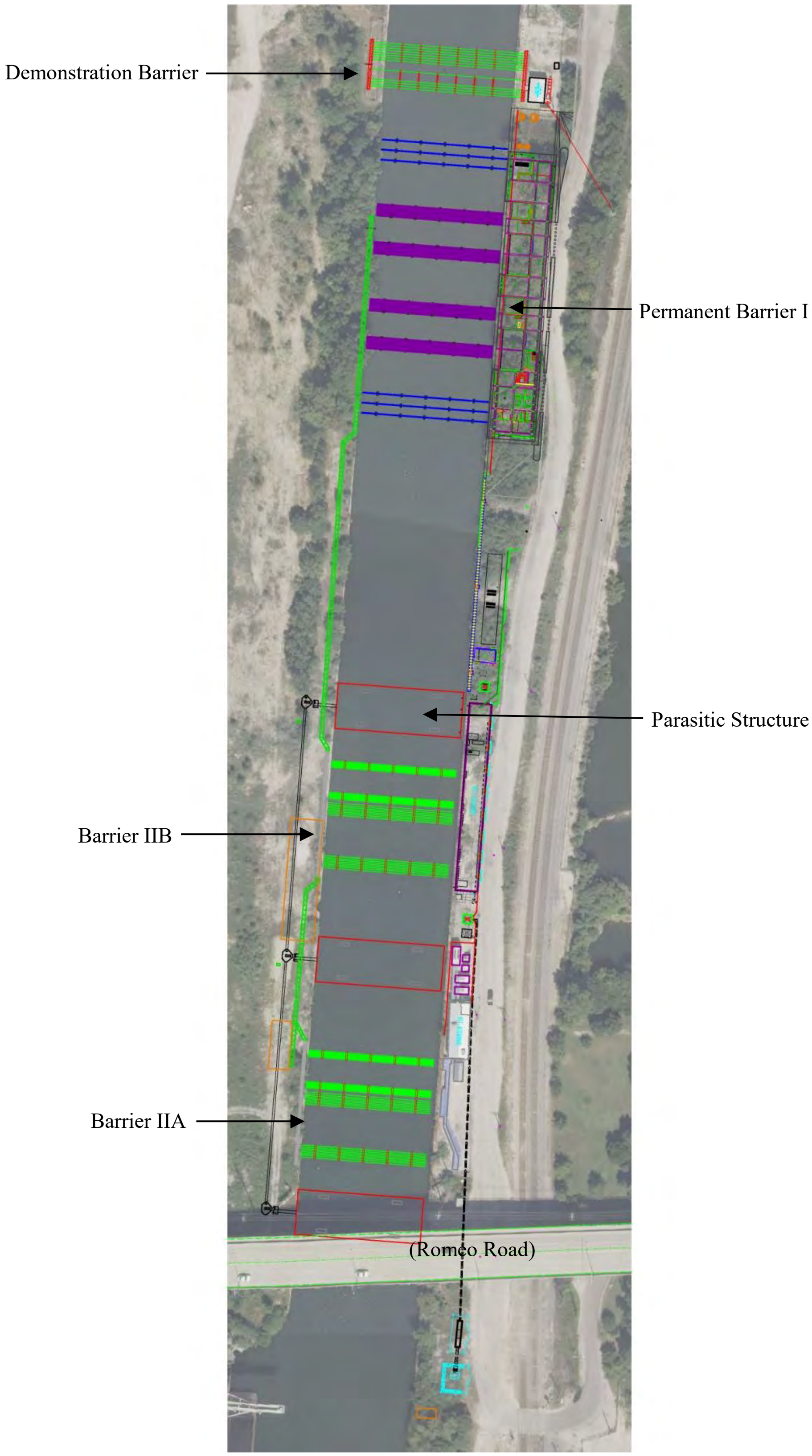


Figure 44 – Permanent Barrier I Project Map

6.3 - Barrier Design Features

USACE considered a number of different types of barriers, including electric barriers, for Permanent Barrier I. The review considered the ANS control technologies published in the "Inventory of Available Controls for Aquatic Nuisance Species of Concern", completed for the GLMRIS Report. The Inventory of Controls was published in April 2012. The purpose of this technical paper was to identify the range of options and technologies available for preventing the transfer of aquatic nuisance species. The review was conducted to determine if other ANS controls might be more effective in combinations with Barriers IIA and IIB than an additional electric barrier. Based on the review of the Inventory of Controls, electric barriers remain the best available solution for preventing the movement of invasive fish upstream through the CSSC. A number of the other technologies are in various stages of R&D, would be very difficult to implement in the CSSC, and/or are not as effective a fish deterrent.

Although Permanent Barrier I will be another electrical barrier, it will have several differences from the existing CSSC barriers. These changes are based on lessons learned from the construction, operation, and maintenance of the other barriers.

6.4 - Power Capacity

Permanent Barrier I will have the ability to generate higher power levels than any of the other barriers. The DC rectifiers that provide electricity to the high field at Barriers IIA and IIB have a capacity of 1.5 megawatts (MW). The rectifiers that provide electricity to the low field at Barriers IIA and IIB have a capacity of 350 kilowatts (KW). The rectifiers for both arrays at Permanent Barrier I are designed to have a capacity of 4.3 MW. The increased power capacity is desired to provide more flexibility to accommodate canal conditions and potential future changes in operating parameters.

The amount of power that must be generated on land to maintain the desired electric field in the water varies with the water conductivity in the CSSC. When the water conductivity is high, more power is needed to maintain the same in-water voltage than when the conductivity is lower. The conductivity in the CSSC varies widely over the year and, for short periods of time, can peak at levels two to three times the average level. Peak conductivities often occur after snow thaws, when it is theorized that large amounts of salt runoff from roadways into the canal.

If the canal conductivity gets too high, Barriers IIA and IIB can reach a point where they don't have enough power to maintain the desired operating parameters. When this occurs, the operating parameters must be "folded back". The barriers automatically reduce power as needed based on a foldback algorithm in the operating programming. As currently programmed, first the pulse duration is gradually reduced to a preset value (currently 1.7 ms). If this doesn't sufficiently reduce power demand, the operating voltage is reduced. Operating parameter foldbacks have occurred at both Barriers IIA and IIB. It is undesirable to reduce the operating parameters from the identified optimal parameters. The larger rectifier design is intended to allow the barrier to operate at a conductivity of up to 2,500 uS/cm without having to fold back any of the operating parameters. Conductivities higher than this are extreme outlier events and, while possible, are highly unlikely.

The additional power capability also provides the ability to accommodate potential future changes in operating parameters. While the existing operating parameters are based on research completed on small Bighead Carp, research on optimal operating parameters is ongoing. There is the possibility that future adjustments to operating parameters could be made to further optimize barrier effectiveness. Barriers IIA and IIB have little, if any, capacity to accommodate any higher operating parameters.

6.5 - In-Water Electrode Arrays

Barriers IIA and IIB both have one low field electrode array and one high field electrode array. On land they have three sets of DC rectifiers and pulsers, one set for the high field array, one set for the low field array, and a third set that can operate either the low field or the high field array. The third set is a backup that can be put into operation if either of the other two are off-line for maintenance. There is a bus bar and switching system that can transfer operation of the arrays between the pulsers and rectifiers.

Permanent Barrier I was designed to have two high field arrays, with the continued operation of the Demonstration Barrier as the low field array. Each set of rectifiers and pulsers for Permanent Barrier I will be directly connected to an array. The switching and bus bar systems at Barriers IIA and IIB have significant maintenance demands and the bus bar system is a major source of air-borne electromagnetic fields that are a potential health and safety concern. Eliminating this type of system should reduce the electromagnetic field (EMF), allow an inactive array to be activated more quickly, and will be simpler from an operations and maintenance perspective.

As with the existing barriers, the electrical field will be imparted to the water via steel electrodes that are secured to the bottom of the CSSC. The electrodes are connected through boreholes to components inside the control building. The electrodes and parasitic structures both consist of 5 in. x 5 in. steel bars resting on 2 ft., 8 in. high concrete blocks on the canal bottom. All of the electrodes and parasitic arrays span the width of the canal and will stand no more than 3 ft., 1 in. off of the canal bottom. The parasitic arrays are situated on either side of the electrode field and help contain the electrical field to the area designed for fish deterrence. The low pool water depth in this location is 19 ft., leaving 15 ft., 11 in. of clearance once the equipment is installed. The in-water structures are not be an impediment to navigation because the required navigation depth at the barriers is 9 ft. from low pool. Boreholes will be drilled diagonally through the surrounding bedrock to connect the electrodes to structures on the canal edge. See Figure 45 for the currently planned layout of the electrodes, parasitic arrays, and control building.

Figure 45 – Plan View of the Permanent Barrier I Design Layout in the Chicago Sanitary & Ship Canal.

6.6 - Redundant Electrical Feeds

Each existing barrier receives utility power from one incoming electrical line. Power from that line goes through one transformer and then is distributed to the sets of DC rectifiers and pulsers. At Permanent Barrier I there is an independent incoming power line and transformer for each array. This will provide independence between the arrays and redundancy in case there are problems with the incoming utility power or on-site equipment on one of the lines.

6.7 - Schedule

The construction of Permanent Barrier I is being completed in stages via multiple contracts. A site preparation contract, completed in October 2013, included clearing and grubbing, site grading, constructing a permanent road with curb and gutters, installation on the west side of the canal of cast-in-place sidewalk with embedded electrical conduits, mast lighting, and appurtenant equipment. A second contract was awarded for installation of the electrodes and parasitics and this work was completed in October 2014. Additional contracts were awarded for construction of the control building and installation of the control gear and backup power systems. The work under these contracts was completed in June 2018. Installation of the incoming electrical utility lines was also completed in 2018. The final major contract, for installation of the electrical equipment and controls for the pulse-generating system, was awarded in September 2018. The awarded contract includes installation of the equipment and controls for one of the two planned electrode arrays because the cost to install both arrays exceeds currently available project funding. There is an option in the contract that could be awarded to complete the second array if additional funding becomes available in the future.

After installation of an array is completed, the barrier must undergo a series of operational and safety tests before it can begin full-time continuous operation. Permanent Barrier I is currently scheduled to begin full-time service with one high field array in 2021. When completed, the building and surrounding property will house transformers, DC power supplies, DC pulse generators, emergency backup generators, equipment cooling systems, lighting, computer control systems, lightning protection, fire suppression and fire alarm systems, and heating, ventilation, and air conditioning equipment.

CHAPTER 7 –RISK ASSESSMENT

7.1 - Qualitative Risk Assessment

Introduction

The Efficacy Study has been conducted through the development of a series of Interim Reports that focused on the Interim Risk Reduction Measures (IRRMs) that would increase the efficacy of the Electric Dispersal Barriers System by reducing the risk associated with identified hazards. For the purpose of the Efficacy Study, the USACE identified five failure modes for the Electric Dispersal Barriers Project that could severely reduce the effectiveness or efficacy of the project in deterring the movement of Asian carp through the CAWS. The five identified failure modes are:

1) Bypass of the barriers via interbasin connections;
2) Movement and release by people or animals;
3) Inadvertent movement by vessels;
4) Failure of the barriers to perform effectively; and,
5) Other miscellaneous risks.

For the Efficacy Study Interim IV, the USACE conducted a risk assessment considering the risks associated with each of the five failure modes identified. The qualitative risk assessment was a systematic review of the likely level of risk associated with each failure mode and evaluation of potential measures that could mitigate the risk associated with the failure mode. Evaluation of the failure modes focused on potential areas of further investigation and mitigation measures to address the functionality of the Electric Dispersal Barriers, as well as measures that could be implemented at other locations within the study area. This approach is consistent with prior interim Efficacy Studies which included recommendations to install a bypass barrier and disconnect other connections (Interim I) and to screen discretionary interbasin flow (Interim III). Evaluation of some failure modes led the team to conclude that actions by other resource agencies may be the primary means to mitigate those risks.

Risk Assessment Process

The USACE developed and reviewed a list of risk areas associated with each identified failure mode. The collaborative review process included the use of documented and ongoing analysis and best professional judgment. As part of this process, USACE reviewed each identified failure mode, and identified the likely level of risk associated with the failure mode and the level of certainty/uncertainty associated with the risk rating.

The risk assessment was conducted at two time steps. The first was the risk perceived at the time the assessment was completed (June 2015) and the final time step considered the likely level of risk after the implementation of any potential additional mitigation measures. USACE utilized existing evidence and professional judgment to evaluate identified risks, mitigation measures, and the effectiveness of those mitigation measures. Through the risk assessment process, USACE documented potential risk reduction measures and remaining risks in a risk register. The register documents ongoing work including improvements to equipment and operations changes and will serve as a means to prioritize future project investigations, design and investments for the project. Further iterations of the risk register may be utilized as more is learned by the investigations and new mitigation measures are identified.

The risk characterization focused on the five potential failure modes and subsequent risk areas listed in the previous section. The team also reviewed additional failure areas that could affect performance, but were not part of the previously defined failure areas. Risk characterizations associated with each failure mode were developed by the team. To characterize the likely level of risk, USACE evaluated the frequency of an event and the opportunity for fish passage if the event did occur, as defined in Figure 46 below. Using this assessment, a risk level was assigned as shown in Figure 47. Where available, USACE cited evidence to support the risk characterization in the risk register.

Frequency of Event:

Very Likely –	Will occur frequently
Likely –	Will occur sometimes
Unlikely –	Will occur rarely
Very Unlikely –	Will almost never occur

Opportunity for Passage if Event Occurs:

Negligible –	Passage is highly unlikely
Low –	Passage is unlikely
Medium –	Passage could intermittently occur
High –	Passage is likely
Certain –	Passage will occur

Figure 46 – Definition of Risk Components

Frequency of Event	*Opportunity for Passage if Event Occurs*				
	Negligible	Low	Medium	High	Certain
Very Likely	2	3	4	5	5
Likely	1	2	4	5	5
Unlikely	0	1	3	3	4
Very Unlikely	0	0	1	2	4

Figure 47 – Level of Risk Determination

Current Risk = risk at time of report
Projected Risk = risk if final mitigation measures are implemented

Figure 48 – Risk Assessment Time Steps

The team reviewed existing risk, potential measures to mitigate that risk, and the probable risk level after implementation of the risk mitigation measure(s) for each identified risk and for each of the two time steps. Where further investigations or studies were needed to determine the nature of each risk area, the team used professional judgment to establish risk level until a clearer risk characterization can be determined. Identified risk mitigation measures include a range of options, some which could be implemented by USACE; others would need to be implemented by other agencies. Agencies with implementation authority were identified where applicable. The results of the risk assessment were documented in the Risk Register Summary (Table 8) and Risk Register (Appendix B, Planning Information). The risk register records specific concerns, discussion and conclusions with respect to the risk, determination of the need for further investigation, identified risk mitigation measures, mitigation results, potential consequences, the likelihood of occurrence and potential impact of each failure mode accompanied by an associated likely risk level defined both by color and numerical value.

There are inherent uncertainties and unknowns in this evaluation process, both regarding the potential impact of Asian carp in the Great Lakes and the efficacy of various measures intended to impede Asian carp range expansion. These problems dictate the need for a strategy that has the flexibility and robustness to develop and incorporate new and better monitoring techniques, methods and tools and to quickly apply them where appropriate.

The presented risk assessment should not be interpreted as an absolute evaluation of the level of risk. The actual risk for any failure mode is dependent on how many fish are present in the immediate vicinity of the barriers. For example, if there is a very large population of fish of concern near the barriers, the risk of fish passage due to any of the failure modes is higher than it is when there are very few of the fish present. Therefore, the actual level of risk posed by a failure mode at any time varies with the fish population pressure. The population pressure is essentially a multiplier that can increase or decrease the risk of passage for each of the failure modes.

The risk characterizations in the risk register should be considered a relative comparison between the failure modes. Whatever the actual fish population present, the modes with higher risk ratings are considered to be more likely to allow passage of fish through or around the barriers than the modes with lower risk ratings.

7.2 - Risk Assessment by Failure Mode

A discussion of each of the five failure modes, and the identified risks is contained in this section. A summary of the identified risk levels for identified potential failure events is presented in Table 8. Detailed discussions of selected areas of risk are contained in *Section 7.3, Interbasin Connections – Permanent Bypass Solution, Des Plaines River*. Documentation of the risk assessment is contained in the risk register located in Appendix B.

Table 8 – Risk Register Summary

Risk Area			Current Risk	Projected Risk
Interbasin Connections	IB-1	Permanent bypass - Des Plaines River	2	2
	IB-2	Permanent bypass - I&M Canal	1	1
	IB-3	Breaching or overtopping of the Lyons Levee	2	2
Movement/Release by People or Animals	MR-1	Direct Release of Fish on the Wrong Side of the Barriers	3	3
	MR-2	Use of Bait Releases Fish on the Wrong Side of the Barriers	4	4
	MR-3	Unintentional Stocking of Fish on the Wrong Side of the Barriers	3	3
	MR-4	Bird or other Animal Transport of Fish to the Wrong Side of the Barriers	1	0
Inadvertent Movement by Vessels	IMV-1	Fish Transport in Ballast or Bilge Water	1	1
	IMV-2	Fish Transport by Vessel Movements	5	5
	IMV-3	Fish Jumping on Vessels	3	2
Barrier Performance Issues	BP-1	Extended Loss of Power to the Pulse Generating Equipment	2	2
	BP-2	Short Duration Loss of Power to the Pulse Generating Equipment	3	1
	BP-3	On-Land Equipment Failure Causing Loss of Power in the Water	3	3
	BP-4	Accidents Causing In-Water Damage that Results in Loss of Power in the Water	2	2
	BP-5	Operation at Less than Optimal Operating Parameters due to Inadequate Knowledge	4	3
	BP-6	Operation at Less than Optimal Operating Parameters due to Inadequate Power	3	2
	BP-7	Operation at Less than Optimal Operating Parameters due to Stray Voltage Concerns	3	3
	BP-8	Operation at Less than Optimal Operating Parameters due to EMF Concerns	2	2
	BP-9	Fish Moving Near the Irregular Canal Sidewalls	4	2
	BP-10	Variations in the Electric Field in the Immediate Vicinity of Metal Vessel Hulls	3	3
	BP-11	Variations in the Electric Field Farther from Metal Vessel Hulls	4	4
Other Risks	OR-1	Person in Water	2	2
	OR-2	Flow Reversal	4	4
	OR-3	Fish Jumping Over the Electrified Water	0	0
Population Pressure	PP-1	Population Pressure		

Population pressure is not counted as a risk itself but may elevate risk levels as popluation varies in proximity to the barriers.
Current Risk = risk at time of report
Projected Risk = risk if final mitigation measures are implemented

Failure Modes IB1-IB3: Bypass via Interbasin connections

Three possible interbasin connections that could allow bypass of the barriers were identified by the PDT. These connections are illustrated on Figure 49. The connections include the Des Plaines River (IB-1), the I&M Canal (IB-2), and the Lyons Levee (IB-3).

Figure 49 – Interbasin Connections and Existing Control Structures within the CAWS.

Des Plaines River Bypass and I&M Canal (IB-1 and IB-2)

The areas with the highest likelihood of risk in the initial evaluation were the interbasin connections within the vicinity of the Electric Barriers Project. Specifically, overflow between the Des Plaines River and the CSSC and the CSSC and the I&M Canal. These two connections were evaluated in the Interim I Efficacy Study, and interim risk reduction measures were implemented for both of these locations in 2010. Modifications to the Des Plaines River Bypass Barrier were completed in 2011, with the current configuration representing a permanent risk reduction measure. There is currently a barrier operations and maintenance (O&M) plan utilizing regular inspections and repairs to maintain barrier integrity and incorporating lessons learned from any damage from storm events to make improvements. An MWRD overburden project created an even more substantial barrier over some of the most vulnerable stretches of the Des Plaines River Bypass Barrier. Based upon the team's evaluation of the modified Des Plaines River Bypass Barrier, the potential risks associated with that failure mode were significantly reduced from the initial assessment of risk. No additional modifications were considered necessary for the I&M Canal connection. While the risk of this type of failure will remain critical in the event that the mitigations are unsuccessful, the successive improvements to the physical barrier and O&M processes will significantly decrease the likelihood of incident. *Section 7.3, Interbasin Connections – Permanent Bypass Solution, Des Plaines River* contains a detailed discussion on the Des Plaines River Bypass Barrier.

Des Plaines River-Lyons Levee (IB-3)

In April 2013, flooding along the Des Plaines River resulted in an overtopping event at an old levee structure. The Lyons Levee, located in the community of Forest View, was constructed by the MWRDGC in the early 1900s. Floodwaters from the Des Plaines can flow either overland or potentially via the existing storm drainage network to the CSSC. The levee provides protection to residential, municipal and commercial structures, as well as a major north-south route – IL-43 (Harlem Avenue). This overland connection presents another opportunity for Asian carps to bypass the Electric Barriers Dispersal Project and be transported to the CSSC, which has a direct connection to Lake Michigan at the Chicago Harbor. *Section 7.3, Interbasin Connections – Permanent Bypass Solution, Des Plaines River* contains a detailed discussion on the Lyons Levee.

Failure Modes MR1-MR4: Movement and Release by People or Animals

The team identified four ways in which fish could be moved by people or animals and bypass the barriers. These include: direct release by people (MR-1), bait transfers (MR-2), unintentional stocking (MR-3) and bird or other animal transport (MR-4).

Three of the four modes of transfer consist of deliberate or inadvertent movement by people (MR-1, MR-2 and MR-3). In general, movement by people poses a relatively low likelihood of risk, but one that can directly place fish on the wrong side of the barrier and one that may never be fully mitigated. The unintentional transfer via the use of live bait (MR-2) was ranked the highest risk among these because use of live bait is more likely to occur than the others. Some risk reduction can be achieved through vigorous education campaigns and by the implementation and strict enforcement of laws and regulations relating to ownership, transport and release of ANS, including Asian carps. The risk assessment documented ongoing efforts by the USFWS, IDNR and other agencies to address these three risk areas. These efforts include the enforcement and education.

The U.S. Fish and Wildlife Service added the Bighead Carp to the federal injurious wildlife list in 2011. The injurious wildlife listing means that under the Lacey Act it is illegal to import or to transport live Bighead Carp, including viable eggs or hybrids of the species, across state lines, except by permit for zoological, education, medical, or scientific purposes. The Service listed other Asian carps (the Black Carp, Silver Carp, and Large-Scale Silver Carp) as injurious wildlife in 2007. Curbing the interstate transport of live Asian carp promotes the federal government's goal of preventing the carp's spread into new lakes and rivers in the United States, where it can have devastating effects on native species.

Under the Lacey Act, an injurious wildlife listing means the species has been demonstrated to be harmful to either the health and welfare of humans, interests of forestry, agriculture, or horticulture, or the welfare and survival of wildlife or the resources that wildlife depend upon. The penalty for violating the Lacey Act is up to six months in prison and a $5,000 fine for an individual or a $10,000 fine for an organization.

The MRWG has been addressing the need for education and enforcement within the metro region to address releases by people. The Invasive Species Unit of ILDNR Conservation Police has been actively managing their program since 2012. Their success stories are reported in each year's MRP since its inception. The annual MRPs are located at https://www.asiancarp.us. These are the objectives from the 2017 Interim Summary Report which were carried into 2018 and are likely to be adopted for 2019:

(1) Continue to educate and assist Conservation Police Officers regarding invasive species regulations and enforcement techniques.
(2) Monitor the Internet for advertisements of illegal invasive species.
(3) Look for illegal sales or importation of invasive species within the bait industry.
(4) Use the portable environmental DNA testing machines to detect any traces of Asian carp during bait shop and bait truck inspections.
(5) Conduct surveillance operations and random checks of live fish markets.
(6) Carry out fish truck inspections for all live shipments we encounter.
(7) Enforce importation regulations of live aquatic life coming into Illinois.
(8) Complete training relevant towards invasive species investigations.
(9) Represent our agency and the ISU at relevant conferences and joint operations related to invasive species issues.

Each year the Conservation Police make several arrests, initiate new investigations, and issue multiple citations on minor infractions of the laws. Typically, the major issues are related to VHS import permits, release of non-native species other than Asian carp, and infractions of sales or transport without proper documentation or permitting.

Unintentional stocking of fish (MR-3) was addressed in the MRRWG’s 2013 MRP, and continues to be an integral element of the annual plans. The initial effort included monitoring and removal efforts for Asian carp that may have been unintentionally stocked in urban fishing ponds in the Chicago Metropolitan Area. Monitoring with eDNA technology and conventional gears (electrofishing and netting) has previously occurred in local fishing ponds and has detected and removed Asian carp (possibly introduced as contaminants in shipments of stocked sport fish). Revisits of contaminated ponds and further monitoring and surveillance efforts will continue in the Chicago Metropolitan Area including Cook and the collar counties.

A broad range of sampling and removal tools are available to the MRWG action agencies to accomplish the plan objectives outlined above. They include traditional sampling gears (e.g., electrofishing, trammel nets, experimental gill nets, mini fyke or trap nets, larval push nets, trawls, and seines), chemical piscicide (e.g., rotenone) with state and applicable regulatory agency approval, high-tech sonic detection and imaging devices (e.g., ultrasonic telemetry and hydroacoustics, DIDSON, and side-scan SONAR), and newly developed or developing techniques (e.g., eDNA, pneumatic water guns, and attraction pheromones). Whereas many of these gears and techniques are part of on-going monitoring and removal efforts, new tools are continually being added to the MRP as it is periodically revised and new techniques are developed. In many cases, multiple tools are being used to accomplish individual objectives and provide sufficient intelligence to allow for sound management decisions. This strategy of addressing objectives from multiple fronts with a combination of gears and techniques has helped to increase the level of confidence in results provided by monitoring and removal projects to date. In addition, gear evaluations have been on-going (see gear development and evaluation projects below) and have been re-evaluated annually in revised versions of the MRP. Upon completion, these assessments should lead to improved Asian carp monitoring and removal outcomes, better understanding of the effectiveness of in-place barriers built to prevent Asian carp from gaining access to the CAWS and Lake Michigan, and improved interpretation of sampling results.

The potential of fish movement by birds or other animals (MR-4) was considered by the PDT to have a low level of risk because fish generally will not survive being caught by fish-eating birds or other animals even if they are released after initial capture. Reducing the risk of avian or mammal transport even further could be accomplished through the use of repellant measures to deter fish-eating birds or mammals from feeding downstream of the Electric Dispersal Barriers System. Wildlife deterrent systems have been employed at other Corps projects including the Indiana Harbor and Canal CDF.

Failure Modes IMV1-IMV3: Inadvertent Movement by Vessels.

The team identified three ways that vessels could inadvertently transport Asian carp across the barrier: ballast or bilge water (IMV-1), entrainment within water movements created by vessel movement or impingement on the vessel itself (IMV-2), and fish jumping onto vessels (IMV-3).

As discussed in *Section 3.4, Summary of Other Asian Carp Initiatives*, studies on the ability of ballast water to transport live fish (IMV-1) have been conducted by the U.S. Coast Guard in cooperation with other ACRCC member agencies. Recent studies indicate that eggs and larval stages living in ship ballast will not survive being pumped from the vessel to the waterway. USCG has promulgated ballasting restrictions as part of the RNA at the barriers. This should eliminate ballasting on one side of the barrier and discharging on the other side. The risk of transport over the barriers by this means is considered low given the results of the USCG study, the ballasting restrictions in the RNA and the fact that ballasting isn't a common practice for vessels that use the CSSC.

Field and laboratory studies completed to date on the potential entrainment of fish by moving vessels (IMV-2) are summarized in *Section 5.5, Laboratory Studies Investigating Effectiveness of the CSSC Barriers* and *Section 5.6, Field Studies Investigating Effectiveness of the CSSC Barriers*. Further field studies have been completed with analyses of that data underway. The PDT currently considers this to be the mode of transport that is the greatest risk of successfully transporting fish over the barriers. In every test run completed for the model fish in the laboratory flume study and for tethered fish in the field at the barriers, at least some fish were moved across all of the barriers. Changes in barge tow operations, controlled ambient downstream flow velocities of the CSSC, and implementation of water jet flushing systems might be able to reduce this risk, but creation of some flows that might be able to transport fish is inherent in vessel movements. Analyses of the data collected in the field-scale application of water jet technology may assist in determining the efficacy of this mitigation technique and should be further reviewed in the future. Additionally, further research is recommended to identify potential mitigation of return currents generated by the displaced water of a downstream moving tow in conjunction with the metal hull effects to the voltage gradient of the electric field.

It may also be possible for fish to jump onto barges, be carried over a barrier, and then be dislodged back into the water while still alive (IMV-3). This is especially a concern for Silver Carp because they are active jumpers. The risk of fish getting past the barriers by this method is somewhat difficult to define because it is highly dependent on how long the fish is out of the water. However, Asian carp are reasonably tolerant of out-of-water experiences, so some level of risk exists. If monitoring indicates Asian carp are getting closer to the barriers, programs should be initiated to educate barge companies and other boaters on the need to watch for Asian carp on their vessels and to not return them to the waterway on the upstream side of the barriers.

Failure Modes BP1-BP11: Failure of Barriers to Perform Effectively

The Electric Dispersal Barriers have been designed by a team of experts, building upon laboratory and field research and incorporating lessons learned from previous CSSC barriers in each successive barrier. However, despite all of these efforts there is an ongoing risk of malfunction or failure. This failure mode includes risks that fish traverse over the barriers because the in-water electric field doesn't deter them. Eleven possible failure events were identified by the team:

Extended Loss of Power (BP-1);
Short Duration Loss of Power (BP-2);
On-Land Equipment Failure (BP-3);
In-Water Equipment Failure (BP-4);
Operation at Less than Optimal Operating Parameters Due to Inadequate Knowledge (BP-5), Inadequate Power (BP-6), Stray Voltage Concerns (BP-7), or EMF Concerns (BP-8);
Fish Moving Near Irregular Sidewalls (BP-9);
Variations in the Electric Field in the Immediate Vicinity of Metal Vessel Hulls (BP-10); and
Variations in the Electric Field Farther from Metal Vessel Hulls (BP-11).

Extended loss of power to the pulse generating equipment (BP-1), and therefore loss of power in the water, could occur if utility power is lost and the backup generator systems don't operate properly. Frequent testing and exercising of the generators and the recent purchase of a new generator for Barrier IIA make this a relatively low risk. Even when a generator automatically activates correctly there is a short loss of power in the water (BP-2). This is discussed in *Section 5.6, Field Studies Investigating Effectiveness of the CSSC Barriers*. It poses a somewhat higher risk because it is currently unavoidable. However, a UPS system was implemented at Barrier IIA, which eliminates even the short duration loss of power.

If power is continuously provided, there can still be a loss of power in the water if the on-land or underwater equipment fails (BP-3 and BP-4). Failure of the on-land equipment is considered a moderate risk, because even with a regular maintenance program equipment problems have periodically shut down a barrier. The pulse generating equipment includes several major components, each with multiple parts, so there are many potential points of failure. The underwater components are simpler and are rated a somewhat lower risk. However, there is no way to physically shield them from stray objects that may be in the canal without impacting the electric field in the water. If the electrodes or the cabling connecting them to the on-land equipment are damaged, the impact on barrier operations could be significant.

Research on setting the barrier operating parameters at optimal levels for deterring fish was discussed in detail in *Chapter 5, Effectiveness of the Barriers*. Despite all of the effort that has been expended to understand this crucial topic, it is possible that the operating parameters are still not ideal (BP-5). Simply put, we may not know what we don't know about operating parameters. The DIDSON field tests completed by USFWS in the summer of 2013 and discussed in *Section 5.6, Field Studies Investigating Effectiveness of the CSSC Barriers* are an example. The observation of groups of small fish swimming through the high field of Barrier IIB led to additional research on optimal operating parameters for fish even smaller than those previously tested and on the effects of water temperature on barrier effectiveness. The initial results indicate different operating parameters are needed to have a highly effective barrier against fish less than 2 inches in total length and that for a given size of fish barrier effectiveness generally decreases as water temperature increases.

The effect of fish size is very significant when evaluating barrier operating parameters. Larger fish can be deterred by a wider range of operating parameters in a wider range of environmental conditions than smaller fish. The level of risk introduced by the operating parameters used is therefore dependent on the size of the fish being targeted. Assuming smaller fish are a concern, the risk level due to operating at less than optimal operating parameters is high. However, only larger Asian carp, if any, are likely to be challenging the barriers at this time so the current risk level due to possibly using less than optimal operating parameters is moderate. The research program on operating parameters has been extensive and is still ongoing, so this risk will continue to get lower as more research results become available that can guide adjustments to operating parameters.

High water conductivities can cause the power demand required to maintain operating parameters to exceed the power capacity of a barrier. When this occurs, the operating parameters must be reduced (referred to as a foldback). This can lead to operating parameters not at sufficient level versus operating at levels that testing efforts have determined to be optimal parameters (BP-6). This has historically occurred at times at both Barrier IIA and Barrier IIB. This is a seasonal problem because high water conductivities usually occur in the winter because of runoff of road salt into the CSSC. Fortunately fish activity is lower during the winter months and research indicates that the barriers are more effective when water temperatures are lower (see *Section 5.5, Laboratory Studies Investigating Effectiveness of the CSSC Barriers*). Seasonal operating parameters which reduce the applied voltage required to stop fishes have been incorporated into the operational strategy at the barriers during the winter months leading to a reduced frequency of foldback events. Therefore, this is rated as a moderate risk. The risk will be lowered when Permanent Barrier I is activated because it will have a much larger power capacity that is highly unlikely to require power foldback.

As discussed in Section 4.8, Ground Currents, underground stray voltage from the barriers can impact neighboring properties (BP-7). In the winter of 2015 operating voltages had to be substantially reduced to avoid railroad crossing signal interference that led to safety issues for site access. USACE has since programmed the barriers to avoid railroad interference by specifying a constant pulse repetition frequency for both Barriers IIA, IIB and potentially Permanent Barrier I. Additionally, because changes in frequency and pulse width can lead to railroad interference, Barrier IIA and IIB are programmed to prevent changes in these parameters. A counterpoise system and additional site grounding designed to reduce the amount of stray voltage that reaches the railroad tracks was installed in the fall of 2015 and spring of 2016. Similar grounding was installed as part of construction of Permanent Barrier I. These measures should reduce the risk of signal interference.

There were also concerns that EMF impacts could lead to a need to change operating parameters (BP-8). However, the completed EMF study, summarized in *Section 4.9, Electric and Magnetic Fields*, indicated that EMF isn't creating major problems. Therefore, it is unlikely that EMF issues would restrict operating parameters in a way that could allow fish passage.

Another concern is that small fish may be able to utilize any reduced electric field strength near irregularities in the canal walls to pass through the electric fields (BP-9). The concerns are based on observed behavior during laboratory testing in which fish appeared to prefer to stay in a recess in a flume wall. Preliminary field testing has indicated that electric field strength is lower within significant notches in the canal wall. Therefore, this is considered a relatively high risk. Some of the notches in the walls have been filled during various construction projects at the site. A comprehensive program to fill all notches is recommended.

Section 5.6, Field Studies Investigating Effectiveness of the CSSC Barriers, summarized field research on how the presence of metal hulls can alter the in-water electric field. Measurements taken from probes mounted on the hulls showed that the overall magnitude of the electric field strength remains high, although the primary direction changes. Caged fish near barge hulls along the outside of barges were all rendered unconscious in the testing. An identified area of concern was the area underneath a rake bow against a box stern. The electric field strength in this location is significantly reduced and only 1 of 36 caged fish transported over the barriers beneath a rake-to-box connection was incapacitated. However, the electrical field strength in these areas isn't the primary concern. The laboratory testing on transport by barges showed that water in the enclosed area under a rake is very stable and floating objects in that area can be moved along with the barge tow for great distances. Therefore, even if the electrical field could be increased to incapacitate fish, transport in this region is a significant risk. However, this is more a risk due to inadvertent transport by vessels (IMV-2). Fish passage over the barriers due solely to changes in the electric field in the immediate vicinity of hulls (BP-10) is unlikely.

The impact of metal hulls on the electric field farther from the hull (BP-11) is considered a relatively high risk for allowing passage of fish. This is based on the field measurements reported in *Section 5.6, Field Studies Investigating Effectiveness of the CSSC Barriers*, where field strength at the canal sidewall when a barge went by close to the wall indicated a temporary reduction in the field strength of almost 40%.

Failure Modes OR1-OR3: Other Risks

Three other potential sources of risk were also evaluated by the PDT: person in the water (OR-1), flow reversals in the CSSC (OR-2); and fish jumping over the barriers (OR-3).

As discussed in *Chapter 4, Safety Considerations and Operational Impacts*, in the event that a person fell into the water near or at the barriers, a shutdown of one or all of the barriers would be required until a rescue had been affected (OR-1). Depending on the situation, the length of time the electric field is turned off could be significant. Public education and tailored outreach to the local communities and barge operators/personnel could mitigate this risk; however, protection of human life and safety will continue as a priority in barrier operations.

The CSSC is a man-made waterway and current flow within it is managed. Water flow in the CSSC occasionally reverses direction (OR-2). This can be caused by an abrupt shutdown or throttle down of the turbines at the power station located downstream at Lockport Lock & Dam or by wind driving surface flows. Fish could be swept through the barriers during flow reversals. If a fish is rendered unconscious by a barrier and remains afloat, a relatively low reverse flow at the surface could move it across the barrier. Flow reversals caused by power station operations have been analyzed over the past five years by MWRD and USGS, with results indicating that durations long enough to transport a fish far enough to pass the barriers are rare. Wind driven surface flow reversals are more common and USACE personnel have observed floating fish being pushed across an active barrier. This is considered a relatively high risk mode for transport over the barriers because of the frequency of reverse flows and the fact that it would be rare for a fish to be killed by the electric fields at the barriers. A fish that is rendered unconscious and floating by the barriers and is then swept over the barriers from downstream to upstream by a reverse flow would most likely survive. USACE personnel have observed fish, but not Asian Carp, pushed across an active barrier by a reverse flow and then regaining consciousness and swimming away. No mitigation measures have been identified. However, USACE has installed metering at the barriers which will provide better information on how frequently reverse flows occur.

USACE believes that it would be impossible for fish to cross the barriers via one or more jumps out of the water (OR-3). Even Silver Carp are unable to jump over the entire length of the electrode arrays. When electrofishing, Silver Carp are observed to jump when initially sensing the electric field, but then become incapacitated when returning to the electrified water. Therefore, they should not able to cross the barriers in a series of jumps.

Findings of the Risk Assessment

The failure mode identified as having the highest risk for allowing fish past the barriers was inadvertent transport due to entrainment by vessel traffic. The other relatively high risk modes are inadvertent transfer via fishing bait, operation at less than optimal operating parameters due to stray voltage concerns, fish moving near the irregular canal sidewalls, reduction in the electric field due to passing metal hulls, and temporary reverse flows in the canal. Operation at less than optimal operating parameters due to inadequate knowledge of what the optimal operating parameters are could also be a relatively high risk if the fish of concern are less than several inches in length.

USACE can virtually eliminate the risk due to the irregular sidewalls by filling in the larger notches and crevices in the walls. USACE is attempting to reduce the risk due to stray voltage concerns by the ongoing installation of underground engineering controls.

USACE doesn't have authorities to monitor or regulate live bait trade, but other agencies are aware of the risk and are attempting to reduce it.

Ongoing research on optimal operating parameters for smaller fish, including testing in different water temperatures, should provide information to reduce the risk associated with inadequate knowledge.

Currently no solutions have been identified to reduce the risks from reverse flow or the entrainment and electric field risks created by vessel traffic.

7.3 - Interbasin Connections – Permanent Bypass Solution, Des Plaines River

Permanent Des Plaines Bypass (IB-1)

The Interim I Efficacy Study recommended the installation of a hybrid fence-jersey barrier system between the CSSC and the lower Des Plaines River for a distance of approximately 13 miles. The location of the Bypass Barrier, as well as some representative photographs, is shown in Figure 50. The crest elevation of the Bypass Barrier/fence was set at the elevation of the 100-year flood event, plus 3 additional feet. The elevation of the 100-year event was based on the regulatory model, which had not been updated for several decades. Because of the very high level of concern regarding potential populations of Asian carp in the CAWS, the USACE decided to utilize the regulatory models for the Efficacy Study, rather than waiting to complete development of new hydrologic and hydraulic (H&H) models for the lower Des Plaines River.

New numerical hydrologic and hydraulic modeling for the lower Des Plaines River was completed in 2010. Revised water surface profiles were developed for eight storm events for baseline and without project conditions. Further, the Chicago District team developed a Flood Damage Analysis (FDA) model to identify the levels of risk and uncertainty associated with overtopping of the Des Plaines River Bypass Barrier.

A description of the model development, calibration and the results of the scenarios simulated are contained in Appendix A, Hydrology and Hydraulics. The results of the FDA analysis to determine the remaining level of risk and uncertainty are discussed in the next section.

Modifications have been made to the Des Plaines River Bypass Barrier to accommodate requests from resources agencies to reduce the impacts to area wildlife. The long extent of the barrier had inhibited migration of wildlife. The agencies expressed concern that impacts to the migration of listed species might be significant. Modifications completed are discussed below.

Finally, in April 2013, the Chicago area experienced a significant rainfall event. A summary of the flood event, as well as the performance of the Bypass Barrier follows as well.

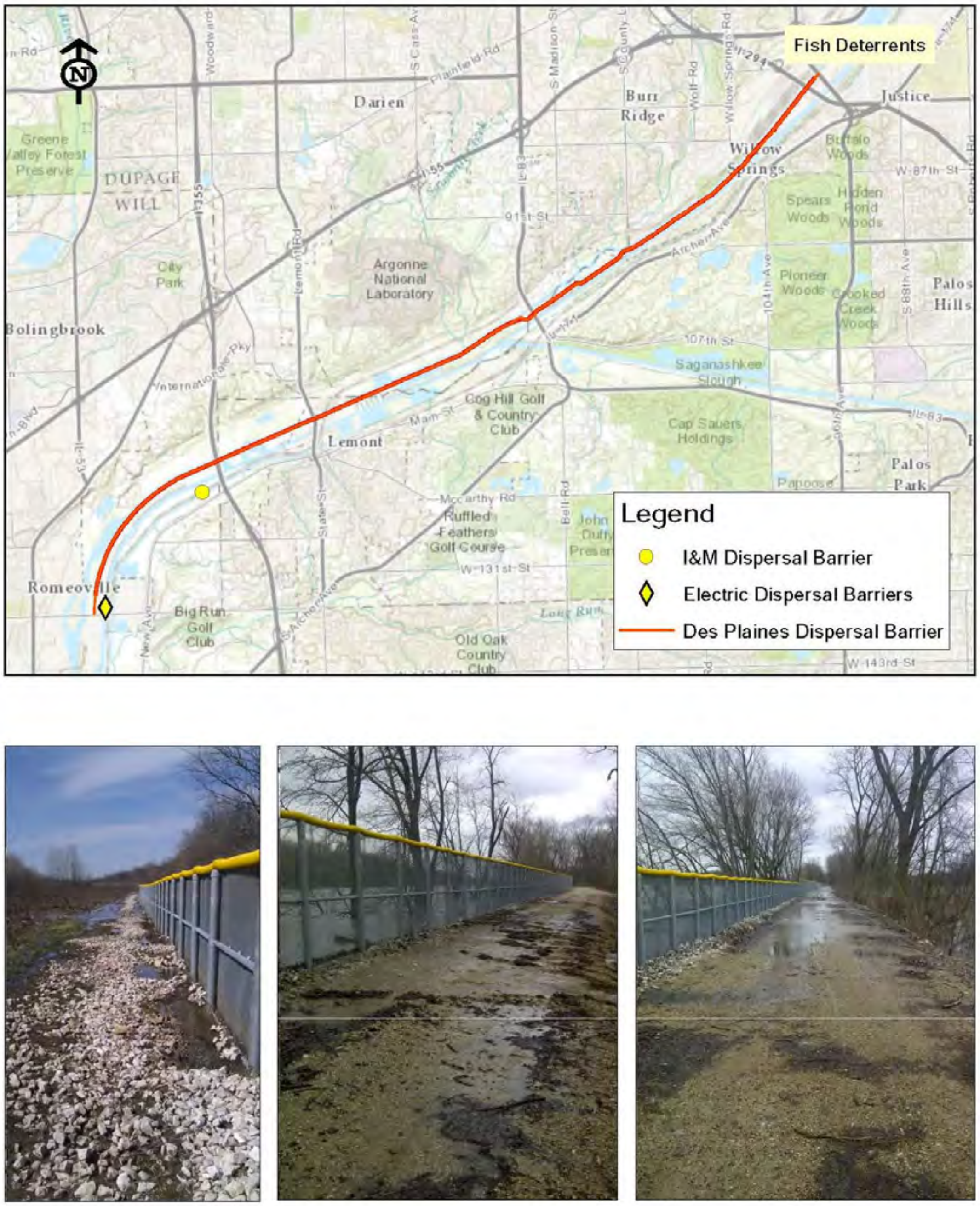


Figure 50 – Des Plaines River Bypass Barrier.

Risk and Uncertainty using FDA

Risk inherently involves the chance of occurrence, uncertainties associated with the risk analysis are quantified and taken into account. As laid out by Engineer Regulation ER 1105-2-101, Risk-Based Analysis for Flood Damage Reduction Studies, risk and uncertainty are intrinsic in water resources planning and design. With advances in statistical hydrology and the availability of computerized analysis tools, such as the USACE - Hydrologic Engineering Center's Flood Damage Analysis (HEC-FDA) model, it is now possible to improve the evaluation of uncertainties in hydrologic, hydraulic, geotechnical and economic aspects of calculations. Through this risk analysis, the team was able to evaluate the overtopping risk associated with the Des Plaines River Bypass Barrier.

The determination of risk and uncertainty must take into account the complex relationships between and uncertainties in key parameters associated with the numerical modeling and evaluation of the hydrologic, hydraulic, geotechnical, and economic information. For this evaluation, the critical parameter considered was the hydraulic or stage uncertainty. More traditional analyses would include evaluation of all four areas of potential uncertainty:

- Hydrologic - The discharge-frequency function describes the probability a given flood will occur. Variables with uncertainties accounted for in the analysis include gage records that are often short or do not exist, precipitation-runoff computational methods that are not precisely known, and imprecise knowledge of the effectiveness of flow regulating structures. Using graphical probability functions, HEC-FDA calculates error bands based upon the input frequency-discharge curve and the equivalent gage period of record.

- Hydraulic - The stage-discharge function describes the water surface elevation for a given flow rate. Uncertainties arise from the use of simplified models to describe complex hydraulic relationships, including simplified geometric data, effects of hydraulic structures, and errors in estimates of slopes and roughness factors. HEC-FDA calculates error bands to the stage-discharge curve based upon a provided error distribution.

- Geotechnical - The geotechnical levee failure function describes levee failure probabilities in relation to channel and protected area water stages. Uncertainties include geotechnical parameters such as soil and permeability values used in the analysis, mathematical simplifications in analysis models, the frequency and magnitude of physical changes or failure events, and the uncertainty of unseen features such as rodent burrows, cracks within the levee, or other defects. Although geotechnical uncertainties are present, the current version of HEC-FDA does not assign error bands around levee failure functions.

- Economic - The stage-damage function describes the amount of damage that may occur for a given flood elevation. Uncertainties include depth/damage relationships, structure and content values, structure locations, first floor elevations, flood duration, flood warning time and the response of floodplain inhabitants. For the Des Plaines River bypass, the PDT did not evaluate the economic impacts of flooding, so there was no further consideration of this parameter for the current analysis.

HEC-FDA performs a Monte Carlo simulation of discharge-probability, stage-discharge, and stage-damage relationships, incorporating their associated uncertainties, to compute a damage-probability function. HEC-FDA uses a Monte Carlo routine to perform numerous (over 30,000) model realizations by randomly selecting values within the specified uncertainty limits for each function.

Identification and classification of the types of uncertainties in the risk and uncertainty analysis method is the key to both quantifying its impact and understanding its implications to the model results. The majority of the model uncertainty can be classified as *natural variability,* resulting from factors such as chance (e.g. flood-frequency curves). Uncertainty derived from measurement limitations or human error is classified as *knowledge uncertainty*.

Natural variability in a hydrologic system is typically quantified by the discharge-frequency relationship. The HEC-FDA methods provided to quantify this relationship are contained in the Graphical Method and the Analytical Method. Due to the complexity of the study and the need to work in both an effective and efficient way, the Graphical Method was selected over the more rigorous Analytical Method.

Knowledge uncertainty is a major factor in this study. Issues of uncertainty in measurements are commonly experienced. For example, prior to the invention of digital thermometers most oral thermometers provided reasonably accurate readings using a graduated scale showing tenths of degrees. Currently, many digital thermometers are available that read to one-hundredth decimal place, a very accurate measurement. Whether that reading is the same after multiple measurements, however, is a matter of the instrument's precision and calibration.

Results of the H&H modeling indicate that the Des Plaines River Bypass Barrier will overtop at approximately 2 feet above the 0.2% chance event. The FDA analysis concluded there is greater than a 97.6 % chance that the Bypass Barrier will not be overtopped for the 0.2% (500-year) event in any particular year at a target stage 1 foot greater than 0.2% event. FDA model results are summarized in Table 14. A safety factor was applied to account for the uncertainty related to measurements and modeling (Target Stage). HEC-FDA has the ability to quantify the uncertainty and report out the conditional non-exceedance probability (CNP). A CNP value will identify the level of confidence that specific location within the design reach could overtop by a particular flood event.

Modifications to the Des Plaines Bypass Barrier

At the request of resource agencies, the Bypass Barrier was modified to include the installation of several gates for seasonal migration of turtles and other wildlife (Figure 51). The gates are open during migration season, but then remain in a closed position for the remainder of the year. In the event rainfall event is forecast that could result in flow through the open gates, USACE crews will be deployed to close all of the gates for the duration of the event. Additional modifications to the Bypass Barrier included scour protection at the ground/fence interface to minimize the potential for transfer of small fish under the fence during a scouring flow event.

Table 9 – Des Plaines Bypass Barrier Results of Risk and Uncertainty Analysis

		Conditional Non-Exceedance Probability (CNP) by Event					
Target Stage	500 YR WSEL	10%	4%	2%	1%	0.40%	0.20%
589.1	588.1	100%	100%	100%	100%	100%	100%

599.8	598.8	100%	100%	100%	100%	100%	99.9%
602.8	601.8	100%	100%	100%	100%	99.5%	97.6%

Figure 51 – Turtle Gate in the Des Plaines Bypass Barrier.

Gates were located in portions of the barrier where the 0.2% flood stage has relatively little chance of overtopping (i.e. 97.6% chance of non-exceedance for the 0.2% flood stage). In order to determine the locations where the Des Plaines River Bypass Barrier could be modified, the design team determined the 0.2% chance flood stage along the study area of the Des Plaines River from the updated Hydrologic and Hydraulic Modeling (See Appendix A). To ensure that design criteria was met a design safety factor of 1 foot was added to the simulated the flood stages for a range of synthetic flood events. Events modeled include the 10%, 4%, 2%, 1%, 0.4% and 0.2% events (10-year, 25-year, 50-year, 100-year, 250-year and 500-year chance exceedance events). Locations for modification must have high enough natural ground elevation relative to the Des Plaines River flood stage that the peak stage for the 0.2% chance stage event would be one foot below the natural ground.

From 2013 to 2015, MWRD excavated a large amount of soil and rock for a project unrelated to invasive species control. MWRD disposed of this excavated material by using it to build a large berm on some of the MWRD property that is traversed by the Des Plaines River Bypass Barrier. The berm is 30 to 60 feet high and 200 to 400 feet wide and buried approximately 7,300 feet of the Bypass Barrier. This substantially increased the ground surface elevation and greatly reduced the risk of flood waters moving to the CSSC in this area. The buried part of the barrier is from approximately 3.5 to5 miles south of the northern end of the Bypass Barrier, within the Village of Willow Springs.

April 2013 Rainfall Event

On April 18-19, 2013 there was a significant rainfall event in northeastern Illinois resulting in high water levels and flooding throughout area waterways, including the Des Plaines River.

There is a USGS gage measuring river stage on the Des Plaines near the areas of bypass concern. The gage in Lemont, IL is located within the Bypass Barrier footprint, approximately 3 miles north of the southern-most end of the Bypass Barrier System. It peaked at record levels on April 19, although this gage has only been in use since 2010.

Overbank flooding out of the Des Plaines River occurred in the vicinity of much of the approximately 13 mile Bypass Barrier. USACE personnel first inspected the Bypass Barrier on April 18 and continued to do so daily through April 22, when waters began to recede significantly. In addition, a team of USACE and U.S. Fish & Wildlife Service biologists conducted surveys along the barrier on April 20 and 21 to look for signs of fish movement in the flood waters.

The jersey barrier sections of the barrier were never overtopped. The fence sections were not overtopped either, but flow through the fence occurred in numerous locations. Water depths at the fence were as high as 3 feet. Overall, the fence held up well, but on April 20 two areas were identified where scour was occurring at places along the base of the fence and unscreened flow was passing below the fence. (Figure 50).

The first location was approximately 3.7 miles south of the northern-most end of the barrier, within the Village of Willow Springs. At this location two adjacent sections of fence panel, each 6.5 feet long, were being undermined. Two 6-feet by 8-feet sections of fence fabric were created and added to the base of those fence panels the afternoon of April 20 as an initial repair. Before the initial repairs were completed, the biologists set three gill nets in the vicinity and did two seine sets down current of the areas were water was flowing under the fence and caught no fish. They spotted two fish while conducting these operations. One appeared to be a common carp, but the other was not identifiable because it moved out of view too quickly. Further inspection on April 21 and 22 indicated that additional areas in this vicinity were undermining. By the end of the event, minor scour was noted along approximately 4,000 feet of fence in this area and six locations within that length developed significant scour beneath the fence. At the worst location, an approximately 31-feet long and 2-feet deep scour hole ran under the fence (Figure 52).

Figure 52 – Flow under the Des Plaines River Bypass Barrier, April 22, 2013.

The second location was approximately 1.25 miles south of the northern-most end of the barrier, near Willow Springs Road and within the Village of Willow Springs. The water level in this area reached more than 1 foot as evidenced by debris along the fence line. The fence was undermined on the upstream (Des Plaines River) side at three locations and scouring on the downstream side of the fence was noted (Figure 53). Repairs at the previously noted location were deemed the first priority on April 20. Since repairs wouldn't happen that day, the biologists set two gill nets at the location with the largest underflow and left them in place until initial repairs could be completed. The only fish caught were five common carp. On April 21 additional fence fabric was placed along the three undermined locations in this area as an initial repair.

Figure 53 – Scour at the Des Plaines River Bypass Barrier near Willow Springs Road, April 20, 2013.

As an initial repair, stone fill was obtained as soon as possible and placed along both the upstream and downstream sides of the fence in all locations where undermining occurred. Figure 54 shows a typical example of this stone placement. All stone placement was completed between April 22 and April 25.

Figure 54 – Placement of stone fill in areas of scour and undermining of the Des Plaines River Bypass Barrier near Willow Springs Road, April 25, 2013.

A further repair was designed and implemented for 1,000 feet of the fence centered on the undermined areas near Willow Springs Road. A 3-feet deep and 18-inches wide concrete wall was added at the base of the fence. A trench 2-feet deep and 6-feet wide (perpendicular to the fence) was dug on the canal side of the fence immediately next to the concrete wall. The bottom and sides of the trench were lined with geotextile fabric. The bottom 6-inches of the trench were filled with 3-inch bedding stone and the top 18-inches were filled with RR-4 stone. Construction of these repairs was completed on June 12, 2013. No additional repairs beyond stone placement were completed for the other area where significant undermining and scour occurred during April 2013 because that area was buried by the berm constructed by MWRD.

USACE will maintain the Des Plaines River Bypass Barrier as well as operating the turtle gates to facilitate migration. The gates will be closed in advance of flooding to minimize the passage of unscreened flow from the Des Plaines River to the CSSC. Based on the performance during the

April 2013 flood event, and planned modifications, the engineered solution appears to be mitigating the risks associated with this pathway. Monitoring will continue.

The Des Plaines Bypass Barrier is to be inspected by USACE operations personnel weekly, after every significant rainfall, and before every predicted significant rainfall if the weather prediction allows sufficient time. The primary focus of the inspections is identification of any damaged concrete barriers, fence sections, or gates; erosion or other threats to the integrity of the barrier base; or excessive vegetation growth. Any identified problems are repaired as promptly as possible. Equipment and materials for repairs, including replacement precast concrete barriers and fence fabric are maintained at the Electric Dispersal Barriers site.

<u>I&M Canal (IB-2)</u>

An interbasin connection between the CSSC and the I&M Canal was identified and analyzed in the Interim I, Efficacy Study. The recommended plan called from the installation of a blockage in the I&M Canal near the hydrologic flow divide. The I&M canal blockage was constructed in 2010, which eliminated the potential interbasin connection for events up to the design event. The location of the blockage is shown in Figure 50. No additional analyses were deemed necessary for this connection based on an analysis of the I&M Canal and tributary areas.IB-2

<u>Lyons Levee (IB-3)</u>

The Lyons Levee (also known as the 47th Street Levee) is located in the city of Lyons, Illinois, which is a southwest suburb of Chicago, along the Des Plaines River in Cook County (Figure 55). The land owner of Lyons Levee is the Forest Preserve District of Cook County, and it is part of Ottawa Trail and Portage Woods. The levee is on the left bank of the Des Plaines River between River Miles 42.7 and 41.9.

The levee is about 4,000 feet long, starting just south of Joliet Road/43rd Street. The levee has an average height of 10 feet, and a maximum height of 12 feet. The lowest portions exist where the levee ties into high ground at Joliet Road and 47th Street and at a railroad bridge. The crest ranges from about 10 to 25 feet wide, with most cross sections around 20 feet. The side slopes have a minimum slope ratio of about 2.5H: 1V and are generally above 3H: 1V.

Figure 55 – Location map for Lyons Levee—47th Street Levee.

Construction information on Lyons Levee was not available and it is unknown exactly when the levee was constructed. The levee has mature trees on the crest and side slopes that have been there for at least 50 years. It was likely constructed about 100 years ago.

The Lyons Levee was identified by the MWRD as a potential connection point between the lower Des Plaines River and the CSSC during their Detailed Watershed Plan (DWP) development for the Des Plaines River. Preliminary analyses indicated that the levee could overtop at less than a 2% chance exceedance event (50-year event). There were also concerns raised about the condition of the structure based on visual inspections. The DWP included an alternative to modify the Lyons Levee through the addition of steel sheet pile. Pumping of interior drainage as well as compensatory storage would be required. Based on the preliminary cost estimate and estimated benefits, the enhancement of the Lyons Levee was not recommended for implementation by MWRD. Estimated costs in the DWP are in excess of $260M, with an estimated benefit to cost ratio (BCR) of 0.03.

A preliminary evaluation performed by USACE indicates that the Lyons Levee could overtop at a 5% chance exceedance event (20-year event). Site visits and further evaluations indicated significant concerns regarding the structural condition of the levee. Throughout the entire stretch of the levee, mature trees, some as big as six feet in diameter are growing at the toe, slope and crest. The unwanted vegetation inhibits inspections, maintenance and emergency response. The root systems may encourage piping through the levee system and impair stability of the levee. If the vegetation is blown over and creates a hole in the levee embankment, the levee could fail due to slope instability, seepage, erosion or scour during a flood event. Photos from a site visit illustrate the overgrown vegetation and other inadequacies of the Lyons Levee (Figures 56-58).

Figure 56 – Lyons Levee at the Lower Des Plaines River.

Figure 57 – Concrete structure in Lyons Levee.

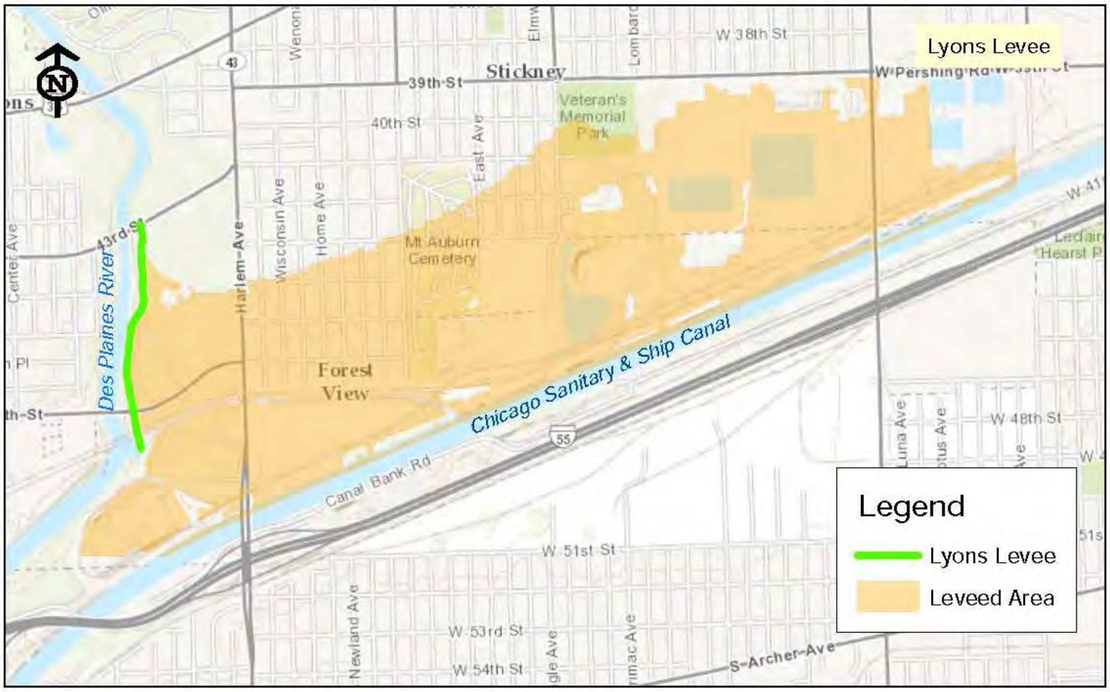
Figure 58 – Lyons Levee with trees along crest and slope.

For the Lyons Levee, preliminary analyses indicate that a significant investment could be required to upgrade the existing levee to address concerns related not just invasive species transfer between the Great Lakes and Mississippi River Basins, but also risks to life, health and safety of the community currently protected by the Lyons Levee.

Summary of April 2013 Rainfall Event

On April 18-19, 2013 there was a significant rainfall event in northeastern Illinois resulting in high water levels and flooding throughout area waterways, including the Des Plaines River. There are two USGS gages measuring river stage on the Des Plaines near the areas of bypass concern. The gage in Riverside, IL is located approximately 1.5 miles north of the Lyons Levee. It peaked on April 18 at a record stage, approximately 0.5 feet higher than the previous record. The event at the Riverside gage was estimated to be a 500-year flood. USACE personnel inspected the area around the Lyons Levee on the morning of April 19. Water from the Des Plaines was overtopping the levee and was at least 1-foot higher than the levee crest. There was extensive flooding and damage in residential and commercial areas east of the levee. Water from flooded areas north of the CSSC was observed flowing over the canal wall and into the CSSC approximately 500 feet east of Harlem Avenue within the Village of Forest View (Figures 59-60). In addition, a culvert approximately 2,300 feet east of Harlem Avenue was observed discharging a significant amount of flow into the CSSC from the north.

When USACE personnel visited the area again on the morning of April 20, no overland flow into the CSSC was occurring. The culvert noted the day before was continuing to discharge a significant flow into the CSSC and a second culvert several hundred feet east of the first was also noted to be discharging a significant flow into the CSSC. The source of the water flowing out of the culverts couldn't be readily identified.



Overtopping of Lyons Levee - April 2013 Flood

Figure 59 – Lyons Levee Vicinity; Levee Overtopping—April 2013.

Figure 60 – Overland flow into the CSSC from the direction of Lyons Levee overtopping.

Post-Flood Activities for Lyons Levee

In its Lower Des Plaines River Detailed Watershed Plan (DWP), the Metropolitan Water Reclamation District of Greater Chicago (MWRDGC) recommended Project DPR-14D, which called for raising the Lyons Levee by 2 to 3 feet to prevent overtopping and reduce flooding during a 100-year storm event. Following the flooding in April 2013, the MWRD's Board of Commissioners authorized DPR-14D for preliminary engineering. Analysis of the recommended project, along with various alternatives to address flooding in Forest View and Stickney was completed by MWRD.

The MWRDGC's plan for the Lyons Levee, included temporary improvements intended to fill in the levee low spots to create additional freeboard. With input from Forest View, and the Cook County Forest Preserve District, a temporary levee improvement targeted raising levee low spots to provide a minimum top of levee elevation of 602.0. This improvement raises the levee crest above the flood stage that occurred during the April 2013 flood event.

After evaluating several options, an earth fill levee crest construction approach was selected for implementation. This method involves constructing a vertical extension of the existing levee using clay material. This includes significant tree clearing and stump removal to key the new material into the existing levee material. The surface of the existing levee will be cleared and grubbed to the extent necessary to expose competent soil. New compacted clay fill will then be placed to establish the target levee crest grade of 602.0. Grass cover will be established on the disturbed portions of the top and side slopes of the new levee material. The fill soils will be placed at 3H:1V slopes minimal. Construction of the temporary levee crest improvements was completed during 2014. (MWRDGC, Lyons Levee Improvement Project 15% Design Stage Study)

The next phase of addressing the overtopping potential at the Lyons Levee was initiated. The Chicago District in partnership with the MWRDGC and the Village of Forest View has started a Section 205, Small Flood Control, Continuing Authorities Program study. The USACE completed a Federal Interest Determination Report 25 September 2015, which initiated the development of a Feasibility Report and Integrated NEPA document for the Section 205 project with MWRD as the non-Federal sponsor.

The feasibility report, Forest View, Illinois, Section 205, Small Flood Risk Management, Detailed Project Report and Integrated Environmental Assessment, was approved on 6 January 2017. The recommended plan includes repair and improvements to the existing Lyons Levee along the entire 4,200 foot alignment, maintaining a crest elevation above the 1% Annual Chance of Exceedance (ACE) flood stage. The levee repairs would maintain a minimum side slope of 3H:1V to ensure levee stability as well as access for maintenance and inspection. A minimum 12 foot crest width would be established along with a 10 foot wide gravel access road along the length of the levee.

Repair and improvement activities would include removal of existing levee encroachments such as trees and placing compacted fill where roots, animal burrows, unmaintained concrete structures, or other encroachments have comprised the integrity of the levee. Additional tree clearing would be completed to allow for construction and maintenance access. At the location of the former spillway, potential seepage and stability concerns would be addressed by driving steel sheetpile on the landward side of the levee and expanding the levee toe to provide a minimum side slope of 3H:1V. The expansion of the tow will fill approximately 0.5 acres of forested wetland. The impacts of this fill will be mitigated by substituting 1.5 acres of wetland resources at a certified wetland bank.

USACE awarded a contract for construction of the project in September 2018.

Similar to the Lyons Levee, is the McCook Levee which is located in the Villages of McCook and Summit, Illinois. While the majority of this watershed drains directly to the Des Plaines River, the drainage area attributed to the McCook Ditch, behind the McCook Levee, is redirected to the CSSC via the Summit Conduit. The McCook Levee was originally constructed around the turn of the 20th century by the MWRDGC, then known as the Sanitary District of Chicago. It is essentially segmented in two sections: the southern portion and the northern portion. Figure 61 highlights the features of the leveed area.

Southern McCook Levee

The southern portion of the levee extends between Lawndale Avenue and the Indiana Harbor Belt Railroad tracks, approximately 3,300 feet south of IL-171. This portion of the levee has several low spots at which the level of protection is lower than the 1% annual chance flood profile as identified by MWRDGC hydraulic modelling. The levee dips down under the IL-171 bridges to allow for clearance of Illinois Department of Transportation (IDOT) maintenance vehicles, which use the top of the levee as an access road to the highway bridges. The levee

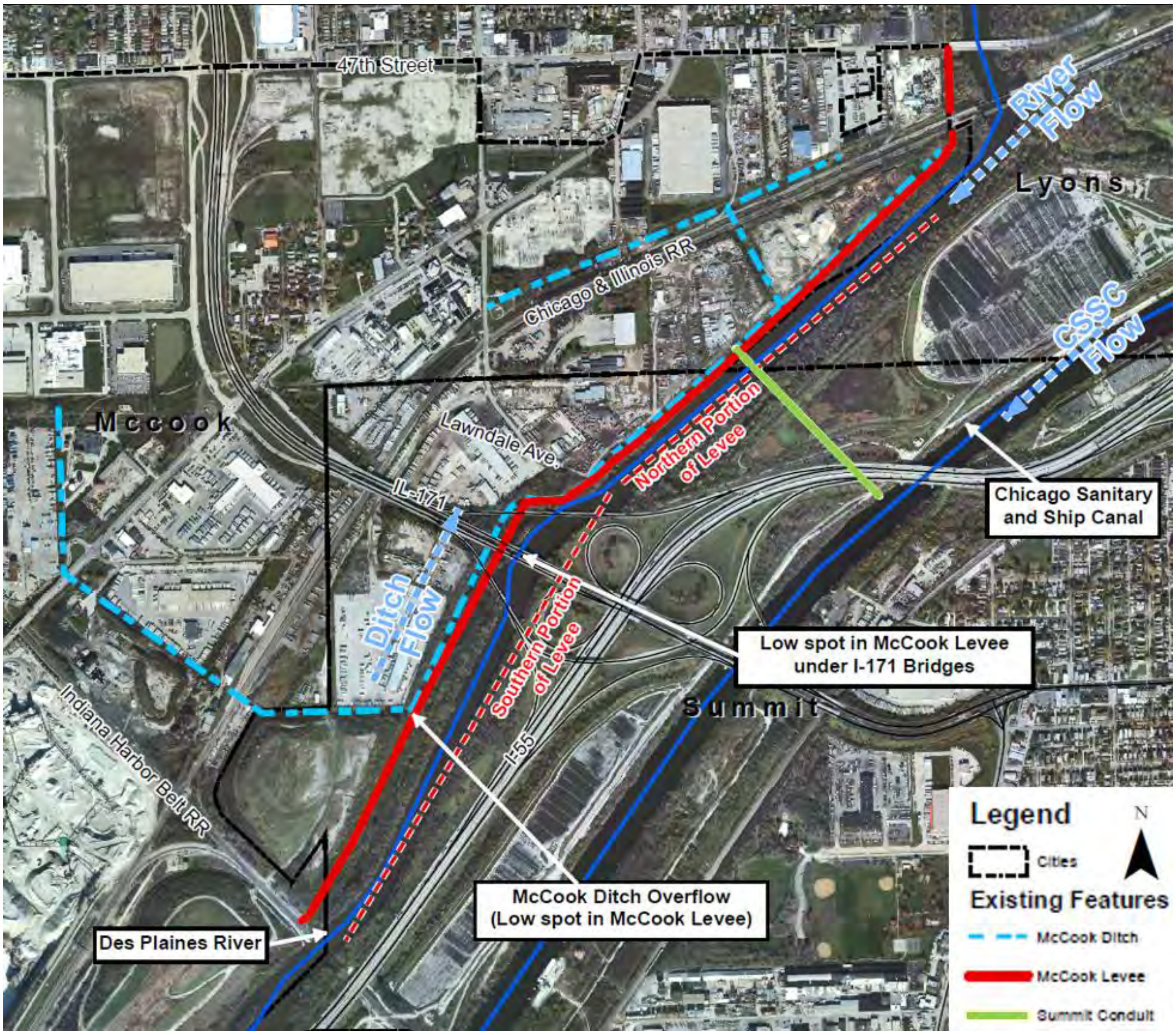


Figure 61 – McCook Levee project area.

also has a low spot approximately 900 feet south of IL-171, which acts as an overland overflow outlet for the McCook Ditch, but also allows for frequent levee overtopping from the Des Plaines River into the ditch. Overtopping at this location can lead to interior flooding behind the levee along the length of the McCook Ditch. MWRDGC estimates that the Des Plaines River has overtopped the McCook Levee at this ditch overflow location at least 17 times since 1948 and at the dip in the levee under the IL-171 bridges 10 times over the same period. In addition to the flooding of structures which may occur from the overtopping of the Des Plaines River Levee, the McCook Ditch and Summit Conduit could provide a path for the ANS in the Des Plaines River to the CSSC above the Electric Barriers at Romeoville.

Northern McCook Levee

The northern portion of the levee extends northeast from Lawndale Avenue approximately 4,100 feet to the Chicago & Illinois Railroad tracks. The levee continues approximately 550 feet north to tie into high ground at 47th Street. In 1979, a section of the levee breached and MWRDGC repaired the damaged portion and drove steel sheet pile along the length of the levee to increase the height of flood protection and to prevent seepage through, but not under, the levee. The top of the levee along this portion is above the 1% annual chance flood profile for the Des Plaines River and there are no known overtopping occurrences since the repairs and elevation were completed in 1979. The area behind this portion of the levee contains several industries which are in danger of flooding, either from breaching or overtopping of the McCook Levee or from the McCook Ditch overbanking as a result of limited outlet capacity via the Summit Conduit.

The Des Plaines River has risen to within 5 feet of the top of the levee at least nine times in the last 30 years. While there hasn't been a levee failure yet, condition of the levee degrades after every flood event. Of particular concern is the riverside slope, which has experienced significant erosion when compared to the as-built cross section. The sheetpile does not extend much deeper than the base of the levee, so as the riverside slope continues to erode, the sheetpile will lose its embedment and could tip toward the river. The seepage path is also significantly shortened. Additionally, during the October 1986 event, several locations were noted for seepage at the landside toe. These seeps were considered minor at the time, but as seepage paths become more developed, the levee can lose additional foundation material and eventually collapse. This seepage was not noted in the recent April 2013 event, however, this was likely due to the landslide ditch being inundated with water from overtopping farther downstream. The additional water on the landside decreased the head differential for the levee, which decreased the likelihood of, or hid, potential seepage issues. If this source of water is cut off from the landside, the seepage risk would greatly increase. Finally, the large trees present on the levee also present a significant risk. As trees continue to grow, they are more likely to fall over, which would take a significant root ball and chunk of levee with them.

A Federal Interest Determination for a CAP 205 project to address the flood risk associated with the McCook Levee was approved on 25 July 2016. USACE completed work on a Feasibility Study in partnership with the MWRDGC with a final feasibility report approved on 5 October 2018. Proposed plans in the study include repair of the northern portion of the levee and hydraulic separation of the southern portion of the McCook Ditch from the northern portion, which would, incidental to the flood risk reduction, reduce the likelihood of ANS movement through the Summit Conduit. A construction contract award is planned for September 2019.

7.4 - Summary and Conclusions

The risk assessment facilitated the development of the risk register to document the risks associated with identified failure modes for the Barriers Project. Further, the risk register documented the effectiveness of ongoing mitigation measures at reducing the risks associated with each of the failure modes. Finally, the team identified future mitigation measures that could be implemented (by USACE or others) to further reduce the risks associated with a project failure mode. The risk register (Appendix B) is a tool that can be used to prioritize modifications to the project that will further reduce the possibility of failure.

Ongoing design, construction, operation and maintenance activities continue to be focused on addressing areas with the highest likelihood of risk associated with barrier operations. The

USACE continues to work with members of the ACRCC and other stakeholders to address the larger range of potential failure modes associated with the project.

CHAPTER 8 –EFFICACY INTERIM IV SUMMARY AND FINDINGS

8.1 - Summary

There are inherent risks associated with the operation of the Electric Dispersal Barrier system in the CSSC. There is no way to reduce the electric field in the water to completely eliminate the potential for sparking between vessels or the health risks posed by human immersion without compromising the ability of the barriers to effectively stop the movement of invasive fish species. However, these risks can be greatly reduced if canal users obey the Regulated Navigation Area (RNA) and behave carefully near the barriers. There are also potential safety risks and operational impacts created on land due to stray voltage in the ground. Investigations on how to reduce this stray voltage are ongoing, but there may not be any practical way to complete eliminate it. Steps have been taken to reduce the risk of exposure to people and other efforts to identify and mitigate against safety hazards are ongoing.

Barrier effectiveness ("efficacy"), the ability of the barriers to deter the movement of fish, is influenced by:

(1) Technical factors including the operating voltage, pulse frequency, and pulse width;
(2) Environmental factors including water conductivity, flow velocity, depth, and temperature; and
(3) Biological factors including fish species, size, and swimming ability.

A wide range of laboratory and field studies have been completed to evaluate the effectiveness of the CSSC barriers and more are underway. A summary of these studies and their findings is presented in *Chapter 5, Effectiveness of the Barriers*.

The available information on environmental and physical conditions of the CSSC, Asian carp management strategy, safety considerations, barrier operating history and procedures, and barrier effectiveness were reviewed to create a risk register. The risk register summarizes potential ways that a fish might be able to successfully get through or around the barriers and ranks the likelihood of breaching or bypassing the barriers. The risk characterizations in the risk register should be considered a relative comparison between the failure modes. The actual risk posed by a failure mode at any time varies with the fish population pressure. The population pressure is essentially a multiplier that can increase or decrease the risk of passage for each of the failure modes. However, whatever the actual fish population present, the modes with higher risk ratings in the risk register are considered to be more likely to allow passage of fish through or around the barriers than the modes with lower risk ratings.

The failure mode identified as having the highest risk for allowing fish past the barriers was inadvertent transport due to entrainment by vessel traffic. The other relatively high risk modes are inadvertent transfer via fishing bait, operation at less than optimal operating parameters due to stray voltage concerns, fish moving near the irregular canal sidewalls, reduction in the electric field due to passing metal hulls, and temporary reverse flows in the canal. Operation at less than optimal operating parameter due to inadequate knowledge of what the optimal operating parameters are could also be a relatively high risk if the fish of concern are less than several inches in length.

8.2 - Next Steps

Monitoring and investigation of the stray voltage in the ground and how to reduce and control it will continue. A contract was awarded in September 2018 to replace fence sections on site that have higher touch potentials with non-conductive fencing and to place further grounding meshes and rods at various areas on site to further reduce shock hazards. These improvements will be completed in 2019.

Several of the larger notches and crevices in the canal sidewalls have been filled as part of completed construction projects. A project will be undertaken to fill the remaining significant notches and crevices to eliminate the risk that they can serve as shelter for fish trying to move through the barriers.

USACE doesn't have authorities to monitor or regulate the live bait trade, but other agencies within the ACRCC are aware of the risk and are attempting to reduce it.

There are currently four areas of continuing study of barrier effectiveness: telemetry monitoring of fish movements near the barriers, impacts of vessel movements, optimal operating parameters, and reverse flows in the CSSC.

Telemetry monitoring is currently planned to continue, provided funding allows, as long as barrier operations continue. The effectiveness of the barriers at preventing fish passage must be continuously confirmed. Therefore, monitoring activities to track fish movements near the barriers, such as telemetry monitoring and/or other tracking activities identified in the future as effective, must always be part of barrier operations. The telemetry program is designed as an adaptable program to be coordinated with the efforts of partner resource agencies such as USGS, USFWS, and ILDNR. The telemetry receiver network may be adjusted in the future to assess new deterrent technologies, supplement other monitoring work, or explore newly discovered barrier weaknesses. The number of transmitters maintained in proximity to the barriers may also be adjusted along with the species of fishes that are targeted for study.

Currently, acoustic telemetry is the only monitoring tool which assesses barrier efficacy 24 hours a day, 7 days a week, 365 days a year. Additional monitoring tools such as physical capture sampling and hydroacoustics are important supplemental techniques to address the deficiencies with acoustic telemetry (i.e. only tracks tagged individuals and is limited to certain size and species of fishes at the barriers location). Reports on results of fish monitoring at the barriers will be prepared on a regular basis, at a minimum annually. If previously unidentified potential threats to barrier effectiveness are identified, additional studies to fully understand the threat and develop mitigation measures may need to be undertaken.

ERDC-CERL is expected to finalize reporting on all of the electrical measurements collected during field barge tow testing within the next year. This field testing report will be used to further assess the dynamics between metal-hulled barges and the water-borne electric field. Understanding this interaction will be crucial to developing a mitigation action to address the vulnerability for fish passage. A follow up report, Efficacy Study Interim V, discussed later in this section, will focus on identifying strategies for addressing the Electric Dispersal Barrier deficiencies acknowledged in this report such as metal-hulled vessel impacts to the electric field.

All planned laboratory tests at ERDC-CHL on inadvertent transport by vessels have been completed and reported. ERDC-CHL has also completed further laboratory research on whether water jets might be able to reduce entrainment by altering the water flow conditions around passing vessels. This laboratory testing showed promising results and a field pilot test of the water jet technology was completed just downstream of the barriers within the CSSC in 2017. Data has been analyzed with a final report currently under review. While preliminary results indicated that the technology had some success at reducing entrainment, it was not 100% successful. The testing did however prove the technology could be implemented at the field scale and highlighted several design issues for future consideration. Additionally, the pilot testing revealed potential in utilizing entrained air or bubble curtains as another mitigation strategy for entrained fish passage. Physical model flume testing has been funded through the Great Lakes Restoration Initiative program for fiscal year 2019. This testing will explore the feasibility of using existing sill bubble curtains at locks as a mitigation technique for removing entrained fish. The testing will investigate the efficacy of compressed air to create an upwelling capable of disrupting the flow structure as a means of clearing entrained fish as well as how the bubbles created act as a deterrent to deter fishes from the entrainment zones of their own volition. The results of this laboratory testing may result in additional future field scale trials to exploit this resource in various locks within the Illinois Waterway.

In addition to USACE activities investigating barge tow entrainment of small fishes, USFWS is also continuing to investigate the probability of entrainment by Asian carps specifically. Testing to date has been primarily completed with surrogate fish species such as Gizzard Shad or with neutrally buoyant passive particles in place of live fishes. USFWS completed a field trial in 2017 within the middle to lower Illinois River using a gradient of Silver Carp sizes stocked within the barge junctions. They then recorded the entrainment rates and distance target fishes were entrained. Follow up studies were completed in the fall of 2018 that allowed for target fishes to be stocked at the front of the test barges to simulate a more natural entrainment scenario where fish have the opportunity to swim away from the barge junctions. The 2018 efforts also studied how entrained fishes reacted to the operation of locking between pools and its impacts to entrainment rates. This field work has been completed, but data analysis is ongoing with results to be reported in calendar year 2019. This work will help further characterize the risk of entrainment of invasive fishes at the CSSC Electric Dispersal Barrier System.

ERDC-EL is currently working to complete all comprehensive final reporting on optimal operating parameters research in 2019. USACE will use the research results to further develop plans for varying operating parameters depending on canal environmental conditions and Asian Carp monitoring data with the objective of minimizing safety risks and operation and maintenance costs while maximizing fish deterrence capability.

USACE successfully collaborated with USGS to design and install a surface velocity radar at the barriers that can record the magnitude and duration of reverse flow events. This new meter is able to track reverse flow events caused by lock and powerhouse operations, natural run-off, and alternative stimuli such as wind speed and direction. This metering system was installed in 2016. Data collected thus far has undergone preliminary review which has indicated that wind driven surface reversals of flow are more prevalent than originally believed. The next step is to analyze the complete dataset to better characterize the risk to barrier effectiveness created by reverse flows. This data will provide an understanding of how passive particles should react to the surface currents and provide an estimate of the potential distance they may be carried. A follow on effort will then design a study which investigates the probability that these reverse currents are able to transport live fish across the active dispersal barriers. This effort may lead to a change in the characterization of this risk and additional investigation of mitigation strategies.

The results of all further studies will be published in one or more additional efficacy study reports. The results will be consolidated in as few reports as possible, but results will not be held unpublished for significant periods of time while waiting for other studies to be completed. An Interim V Efficacy Study was initiated in September 2018. The objectives of this next efficacy study are to attempt to reduce operating and maintenance costs of the CSSC Electric Dispersal Barrier System and to recommend mitigation actions to address the barrier vulnerabilities identified in this efficacy report. Many of the ongoing studies referenced in this report will be included within the Interim V Efficacy Report.

8.3 - District Commander's Certification

I have considered all relevant aspects of the problems and opportunities as they pertain to the efficacy of the Electric Dispersal Barriers Project in relation to the high risk being posed to the Great Lakes by Bighead and Silver Carp in the Illinois Waterway and the Chicago Area Waterways. Those aspects include environmental, social, and economic effects, and the engineering feasibility of operating the Electric Dispersal Barrier System today and into the future; and the authority granted the Secretary of the Army under Section 1039 of WRRDA 2014, P.L. 113-121, to implement findings in the efficacy study, and all relevant authorities relating to the Corps' operation of the Chicago Lock, the O'Brien Lock and system controlling works.

The findings contained herein reflect the information available at this time and current departmental policies governing formulation of individual projects. They do not reflect program and budgeting priorities inherent in the formulation of a national Civil Works construction program nor the perspective of higher review levels within the Executive Branch.

This report has been developed for informational purposes only, and contains no recommendations.

Aaron W. Reisinger
Colonel, U.S. Army
District Commander

CHAPTER 9 – References and GLOSSARY OF TERMS

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GLOSSARY OF TERMS

AC - Alternating Current

AIS - Aquatic Invasive Species

ANS - Aquatic Nuisance species

AOC - Area of Concern

ASA (CW) - Assistant Secretary of the Army for Civil Works

ACRCC - Asian Carp Regional Coordinating Committee

Cal-Sag - Calumet-Saganashkee

CAWS - Chicago Area Waterways

CEQ - White House Council on Environmental Quality

CFS - Cubic Feet per Second

CRCW - Chicago River Controlling Works

CSO - Combined Sewer Overflow

CSSC - Chicago Sanitary and Ship Canal

DC - Direct Current

DIDSON - Dual Frequency Identification Sonar

eDNA - Environmental Deoxyribonucleic Acid

GL - Great Lakes

Hz - Hertz

I&M Canal - Illinois and Michigan Canal

IDNR - Illinois Department of Natural Resources

IHPA – Illinois Historic Preservation Agency

IN - Inch

InDNR – Indiana Department of Natural Resources

IWFS - In-Water Field Strength

IWW - Illinois Waterway

EA – Environmental Assessment

GLFC - Great Lakes Fishery Commission

GLMRIS - Great Lakes and Mississippi River Interbasin Study

HTRW – Hazardous, Toxic and Radioactive Waste

IRRM - Interim Risk Reduction Measure

L&D - Lock and Dam

MAP-21 - Moving Ahead for Progress in the 21st Century Act

MGD - Million Gallons per Day

MRP - Monitoring and Response Plan

MRWG - Monitoring and Response Work Group

MOU - Memorandum of Understanding

MR - Mississippi River

MS - Milliseconds

MWRD - Metropolitan Water Reclamation District of Greater Chicago

NEPA - National Environmental Policy Act

NRHP - National Register of Historic Places

PCB - Polychlorinated Biphenyls

PDT - Project Delivery Team

PED - Planning, Engineering and Design

TARP - Tunnel and Reservoir Project

USACE - U.S. Army Corps of Engineers

USCG - U.S. Coast Guard

USDA - U.S. Department of Agriculture

USEPA - U.S. Environmental Protection Agency

USFWS - U.S. Fish and Wildlife

USGS - U.S. Geological Survey

V - Volt

WRDA – Water Resources Development Act

WRP - Water Reclamation Plant