Erie Canal

Aquatic Invasive Deterrent Study

Prepared for:

BuroHappold and
New York Power Authority

Prepared by:

RESOURCE CONSULTANTS INC.

15250 NE 95th Street
Redmond, WA 98052

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EXECUTIVE SUMMARY

Aquatic Invasive Species: Background

An aquatic invasive species (AIS) is a waterborne organism that causes ecological or economic harm in a new environment where it is not native. Where AIS flourish, they can negatively impact native species, sometimes re-engineering the aquatic food web that native species are dependent upon. They can be a nuisance to boaters and water users by fouling screens and intakes, and clogging pipes and engines. AIS can also have a negative economic impact on revenue from recreational boating, fishing and related hospitality and tourism industries and pose a threat to property values and the regional quality of life.

Aquatic species invasions can be facilitated when naturally separated watersheds become connected through human interventions. The Erie Canal did this, and as Canal water quality has improved over the decades and become more hospitable for many species, it inadvertently created both habitat and dispersal pathways for AIS, connecting five major New York State (NYS) watersheds to both the Great Lakes and the Atlantic Ocean via New York Harbor.

Many invasive species have made their way into the state this way, such as water chestnut, a plant that forms thick nets that challenge navigation and lower property values, and zebra mussels, which create million-strong colonies, siphoning the nutrients from the water that native mussels need to survive while clogging water conveyance infrastructure. The threats from AIS are vast and varying, with new threats at the doorstep (such as in the Mississippi River Basin but not yet the Great Lakes/NYS including, most famously, Asian carp) as well as further away but recognized threats (for example, species moving around in global maritime shipping but not yet taken hold in the US).

Approach and Outreach Efforts

New York State has already taken great steps to combat invasive species; there is an Invasive Species Council, and a Comprehensive Management Plan. Partnerships for Regional Invasive Species Management (PRISMS) have been established and are actively engaged in invasive species management. With the *Reimagine the Canals* initiative, the Canal Corporation and its parent agency, New York Power Authority (NYPA), have begun evaluating how they might use canal infrastructure to help mitigate threats posed by current and future AIS. To this end, NYPA, alongside R2 Resource Consultants, engaged dozens of DEC scientists, lake association representatives, NGOs, research organizations, and academics to better understand the greatest AIS threats, existing mitigation efforts, and potential deterrents.

This study report is the product of these efforts and a commissioned scientific analysis undertaken to identify potential alternatives to stop AIS transport via the Canal. Two main tenets of the study were to employ an approach that considered “all AIS species” and to consider alternatives to protect not just against known AIS threats, but also unknown ones that may present themselves in the future. Further, the analysis was not designed to address impacts on navigation, recreation or broader ecosystems associated with these alternatives.

Deterrent (Barrier) Technologies

To accommodate an “all AIS species” approach, the AIS threats to the Canals were categorized into different groups, depending on how they move. For example, some can swim or crawl on their own (“unassisted dispersers”), but others latch onto boats or equipment (“hitchhikers”). Thirty-six potential deterrents were considered, representing three broad categories: (1) physical deterrents; (2) chemical treatments; and (3) behavioral deterrents; they were evaluated based on 22 different criteria. After considering a variety of factors (effectiveness, cost, risk), six deterrent technologies types were advanced for more detailed analysis and inclusion into the Alternatives.

1. **Hydrologic separation:** Stopping flow of water by permanently closing certain canal infrastructure (guard gates, locks).
2. **Canal boat wash program:** A combination of a boat lift, inspection and wash station specifically targeted at detection and elimination of “hitchhikers.”
3. **High temperature/steam washing:** A component of a boat wash program.
4. **Pressure washing:** A component of a boat wash program.
5. **Screens:** Barrier screens, which allow water to pass through but prevent movement of many AIS species and life stages.
6. **Bio-Acoustic fish fence (BAFF):** A patented behavioral deterrent, which uses air, sound, and light to deter fish species, in particular Asian carp, from passing.

Alternatives and Recommendation

Three alternatives, comprised of multiple deterrent technologies from the list above, were developed and analyzed. **Alternative 1: Protect the Hudson** was developed to meet the objective of hydrologically separating and prevent movement of AIS between the Great Lakes and Hudson River basins. The objective of **Alternative 2: Watershed Divide** is to diminish the probability of AIS using the Canal for eastward passage from Lake Erie and Lake Ontario and westward passage from the Hudson River, as well as for movement between the three central watersheds: Finger Lakes, Oneida, and Oswego. The objective of **Alternative 3: Key Watershed Protection** is similar but reduces the probability of AIS passage from Lakes Erie and Ontario to the Finger Lakes and Oneida Lake; it also provides added protection to the Upper Mohawk River from the Hudson River.

Based on a comparison of likely effectiveness, cost, and permitting feasibility, **Alternative 2: Watershed Divide** is the recommended alternative. This alternative would prevent waterborne transport through the Erie Canal of all AIS from the Great Lakes to the Hudson; from Lake Erie to the Finger Lakes; and from the Hudson to Oneida Lake, the Finger Lakes and the Great Lakes. In addition, it provides added protection for AIS moving out of Lake Ontario and Lake Erie into the western Erie and Oswego Canal.

Alternative 2: Watershed Divide consists of:

1. **Hydrologic separation at Rochester** (West Guard Lock) to protect the Finger Lakes and Oneida Lake from invasive species in the Western Canal;
2. **Hydrologic separation at Rome** (West Guard Gate and Lock E21) to protect the Mohawk and Hudson River Estuary from any threats in the Canal from the West;
3. **Replacement of lock operation in Oswego** (Locks O7/O8) **with a boat lift/wash station** to prevent threats moving from Lake Ontario to Oneida Lake and the Finger Lakes;
4. **Installation of a Bio-Acoustic Fish Fence (BAFF) at Lockport/Pendleton**, to deter Asian carp, which may leave Lake Erie via the Niagara River, from entering the Canal.

This alternative includes hydrologic separation at both western and eastern portions of the canal. Hydrologic separation is the most effective deterrent available for all species and life stages of AIS (adults, larva, seeds, eggs, etc.). Disconnecting the Canal pathway at discrete locations and restoring natural drainage areas would stop the direct water transport of AIS across watersheds and promote containment, allowing focused control efforts to be undertaken for previously-established populations within separate watersheds.

Hydrologic separation is not, however, technically feasible on the Oswego Canal due to high flows. Instead, this alternative includes a boat wash and inspection station at Locks O7/O8 for additional protection against invaders from the Great Lakes. This alternative would thus be effective for all current and future aquatic invasive species.

1. STUDY SCOPE

The overarching goal of this study was to develop conceptual network alternatives for stopping the dispersal of aquatic invasive species (AIS) via the Erie Canal. Additionally, key goals related to the protection of individual water bodies were identified and included the Hudson River Estuary, the Finger Lakes, and Lake Champlain. The study scope included identifying and assessing barrier technologies, their potential effectiveness as deterrents to AIS dispersal via the Erie Canal, associated costs, operational constraints, and overall feasibility.

Where AIS flourish, they can negatively impact native species, sometimes re-engineering the entire aquatic food web that native species are dependent upon. They can be a nuisance to boaters and water users by fouling screens and intakes, and clogging pipes and engines. AIS can also have a negative economic impact on revenues from recreational boating, fishing and related hospitality and tourism industries and pose a threat to property values and the regional quality of life.

We employed a collaborative decision-making framework to assess and identify the most promising deterrent technologies, and these were built into several networked alternatives. The networked alternatives were compared using an effectiveness analysis, preliminary cost estimates, and identification of permitting needs and challenges, and one alternative was recommended by the study team for further development and implementation. It is important to note that time frame of this assessment included immediate interruption of movements for species already present in the system, as well as prevention of future aquatic species invasions.

2. PROJECT BACKGROUND

The State of New York (NYS) Canal System is comprised of four Canals: the Oswego, the Champlain, the Cayuga-Seneca, and the Erie. The Erie Canal is the longest of the four Canals. The entire NYS Canal System includes 57 locks, 19 guard gates, 10 movable dams, 20 upland reservoirs, feeder canals, and other forms of supporting water control infrastructure (Figure 2-1). The original Erie Canal was completed in 1825, was enlarged in 1918 to accommodate barges, and spans approximately 363 miles from Buffalo east to the confluence of the Mohawk and Hudson rivers near Albany. The other three canals within the NYS Canal System connect to the Erie Canal and thus, provide hydrologic connection across five major watersheds (Figure 2-2).

Figure 2-1. The New York State Canal System with infrastructure and flow direction.

The Erie Canal was developed to provide a water route for shipping between New York City and the Great Lakes. Rail and road transport have since become the primary modes of transporting goods, and today the Erie Canal System is used primarily by recreational boaters with very little, localized commercial vessel traffic. In addition to boating, the Erie Canal currently provides water for hydropower production, and is used by municipalities, farms, and industrial users.

Along with the construction of the NYS Canal System came the destruction of natural physical barriers that separated watersheds and major waterbodies in NYS. By breaching these barriers, the Canal System created new hydrologic connectivity that provides many different pathways for the movements of aquatic plants and animals between the Great Lakes, the Hudson River, and many inland waters in NYS.

Figure 2-2. Watersheds intersected by the Erie Canal

Flow in the Erie Canal is complex and bifurcates at the Canal divide near Rome, NY (Figure 2-1). The Erie Canal begins near where Tonawanda Creek flows into the Niagara River. There, the Canal captures Lake Erie basin water and flows eastward to the Oswego Canal, intersecting with the Genesee River at Rochester. Leaving Rochester and flowing east, the Erie Canal entrains Genesee River water. The Cayuga-Seneca Canal flows out of the Finger Lakes to the north and joins the Erie Canal west of Port Byron. This section of the Erie Canal flows in a northeasterly direction, then turns to the north near Syracuse and drains through the Oswego Canal into Lake Ontario. The high point in the Erie Canal is near Rome. At the confluence with the Mohawk River, flows split and run both east and west. Water is captured from the upper Mohawk River/Delta Reservoir and the flow is split in Rome with the vast majority of the water flowing to the east along the Mohawk River until it joins the Hudson River in Waterford. A very small portion of the water, limited to the water required to lock vessels at Lock E-21, flows to the west, through Oneida Lake and into the Oswego Canal. This flow occurs only during the navigation season.

The Erie Canal provides multiple, bi-directional pathways for new, non-native plant and animal species to move once introduced to a connected waterbody. Several species, such as round goby, zebra mussels, and spiny water flea, are thought to have arrived in North American waters via ballast water discharged from ocean going vessels from around the world. Once established, they have spread from the Great Lakes across NYS. Other species, such as Blueback Herring, are native but historically were limited in distribution; Blueback Herring were naturally distributed in the Lower Hudson River, but have expanded up the Mohawk River and are thought to have invaded Lake Ontario via the NYS Canal System.

AIS have different ecologies and spread via different dispersal mechanisms. They can be active swimmers or crawlers, passive dispersers and/or “hitchhikers,” or organisms that obtain a “free ride” to a new location in small pockets of water on other organisms or in vessels, or directly attach themselves to another organism or vessel. Because of the different dispersal modes, and different lifecycle timeframes of the various aquatic species that may use the Erie Canal, different barrier technologies, as well as their effectiveness and feasibility, needed to be considered in order to develop an effective networked barrier solution to the spread of AIS.

2.1. Study Area

This study focused on the Erie Canal between Lake Erie and the Hudson River, along with hydrologically connected canals including the Oswego and Cayuga-Seneca Canals. There is an ongoing independent study that will assess and identify a proposed solution to deter the movement of AIS through the Champlain Canal (Figure 2-1).

3. EVALUATION OF SUITABLE DETERRENTS

3.1. Review and Synthesize Existing Information

In preparation for developing potential alternatives for AIS deterrence, R2 staff reviewed existing available literature to identify and characterize the ecology of AIS species of concern in the Great Lakes and NY, and to identify appropriate deterrent technologies that have been used throughout the world.

3.1.1. Summary of NYS Priority AIS

As of summer 2019, 213 non-native aquatic species have been documented in the Great Lakes basin, and an additional 81 species are on the watch list for potential future invasion (National Oceanic and Atmospheric Administration [NOAA] 2018). Substantial numbers have also been reported for other water bodies bordering the state of New York, with 122 non-native aquatic species in the Hudson River, 87 in the State Lawrence River, and 50 in Lake Champlain (Lake Champlain Basin Program [LCBP] 2018).

To independently evaluate the dispersal mechanisms and potential deterrence of such large numbers of species would be time-consuming and would not likely improve any analysis or potential control mechanisms; thus we grouped the species into “guilds” for this alternatives analysis. In addition, many non-native species have not been associated with negative social, economic, or environmental impacts. AIS are non-native species that have demonstrated rapid population growth and aggressive spread, and have the potential to cause harm to the ecosystem, the economy, and/or human health. For this assessment, we focused on the top priority AIS species of concern, as identified from: (1) Species included in the Council of Great Lakes Governors Least Wanted List; (2) AIS with a ranking of “Very Highly Invasive” in Appendix B of the New York State AIS Management Plan; and (3) Species recommended for inclusion by New York State Department of Environmental Conservation (NYSDEC) staff and/or regional AIS experts. The 36 priority species of concern that were identified were still too numerous to evaluate individually.

Guilds are commonly used in ecological research as means to group flora and fauna with similar ecology when constructing an operational framework for the role of species in ecosystems. Guilds are typically made up of a group of species that share similar life history traits and behavioral adaptations. Many of these AIS share similar pathways for introductions and, therefore, may have similar methods for control. Grouping AIS of similar taxa into guilds based on their dispersal mechanisms was useful for deterrent design and effectiveness modeling.

A total of 36 priority species of concern were selected to represent 7 ecological guilds. This included 14 fish species, 12 invertebrate species, and 10 plant/algae species (Appendix A1). In order to categorize the 36 species into appropriate guilds, a literature review of the ecology, reproduction, life history, habitat requirements, means of dispersal, potential pathways of introduction, and current and experimental control applications was completed for each species. The assumption was made that the guilds would cover the ecology and control measures needed to address not only priority species of concern but also a sufficiently broad range of dispersal mechanisms to represent any new aquatic species that may try to disperse via the Erie Canal. Complete summaries of the literature review for each guild are located in Appendix A1.

3.1.1.1. Fish Species

Fish species were broken up into two guilds: unassisted dispersal and assisted dispersal. Unassisted dispersals fish guild included White Perch (*Morone Americana*), Alewife (*Alosa pseudoharengus*), Tench (*Tinca tinca*), Sea Lamprey (*Petromyzon marinus*), and Bighead Carp (*Hypophthalmichthys nobilis*). Bighead Carp represented four Asian carp species. This guild was comprised of fishes that are generalists and have the capacity to establish populations in a variety of habitats across a broad geographic range and variable environmental conditions. These species actively invade new waterways by upstream and downstream swimming. Assisted dispersals were made up of fish species whose introduction into new waterways have primary been a result of hitchhiking by either ballast and live-well water discharges or by species who lay their eggs on vegetation and are transported between waterways when boats, motors, and trailers are not cleaned of plants. Species in the assisted dispersals guild include Eurasian Ruffe (*Gymnocephalus cernua*), Monkey Goby (*Neogobius fluviatilis*), Round Goby (*Neogobius melanostomus*), Freshwater Tubenose Goby (*Proterorhinus semilunaris*), and Stone Moroko (*Pseudorasbora parva*).

3.1.1.2. Invertebrate Species

Invertebrates were broken down into three guilds: crayfish, molluscs, and pelagic invertebrates. The crayfish guild was composed of red swamp crayfish (*Procambarus clarkia*), common yabby (*Cherax destructor*), and marbled crayfish (*Procambarus virginalis*). Crayfish differed from the other two invertebrate guilds primarily because of their ability for independent mobility up and down streams and even overland travel. The molluscs guild was made up of zebra mussel (*Dreissena polymorpha*), quagga mussel (*Dreissena rostriformis bugensis*), golden mussel (*Limnoperna fortune*), Asian clam (*Corbicula fluminea*), New Zealand mudsnail (*Potamopyrgus antipodarum*), and Faucet snail (*Bithynia tentaculata*). The pelagic invertebrates guild included fishhook waterflea (*Cercopagis pengoi*) and killer shrimp (*Dikerogammarus villosus*). Species in these guilds both utilized hitchhiking as a primary vector to invasion. Both molluscs and pelagic invertebrates species transfer resting eggs and larvae on boats and ballast water of ships. Molluscs have also achieved rapid dispersal throughout the Great Lakes and major river systems due to the passive drifting of the larval stage (the free-floating or “pelagic” veliger).

3.1.1.3. Plant Species

Plants species were broken into two guilds: fragmentation and floating. The fragmentation plant guild was made up of Brazilian elodea (*Egeria densa*), Hydrilla (*Hydrilla verticillata*), Curly waterweed (*Lagarosiphon major*) Parrot-Feather (*Myriophyllum aquaticum*), Eurasian watermilfoil (*Myriophyllum spicatum*), Starry stonewort (*Nitellopsis obtusa*), and Curly-leaf pondweed (*Potamogeton crispus*). These submerged invasive aquatic plant species reproduce largely through fragmentation. Fragmentation is a type of vegetative clonal propagation that provides intermediate- to long-distance dispersal. Fragments are formed by the mechanical breakage of the plant stem by disturbances in the water, such as those generated by boats, swimmers, animals, and wave action. The floating plant guild was made up of species with leaf structures that float on the surface of the water. The entire plant or the floating structure can easily become dislodged by wind, current action, boats, or swimming fauna. This mechanism allows the plant to drift throughout a waterbody into new, previously unreachable locations. Species in this guild included European frogbit (*Hydrocharis morsus-ranae*), Water soldier (*Stratiotes aloides*), and Water chestnut (*Trapa natans)*.

3.1.2. Summary of AIS Deterrent Technologies

Our review of available literature identified 37 potential deterrent technologies that have been implemented in aquatic systems around the world and/or are currently under development in the US. The deterrent technologies were categorized as follows: 24 physical, 6 chemical, 5 biological and 2 outreach related (Appendix B2). Potential application for addressing the different species guilds presented in 3.1.1 were identified and both known advantages and disadvantages of individual technologies were noted. A summary table was used to inform the team brainstorming described below in Section 3.2.

3.2. Brainstorming and Matrix Development

The first step in our evaluation of potential deterrent technologies was to conduct a brainstorm workshop with an internal team composed of Canal experts and aquatic scientists. During this brainstorm workshop, we identified potential deterrent technologies and developed criteria that would be used to evaluate them. Discussion also ensued about the ability of deterrent technologies to be implemented in the near- or long-term, and how specific technologies could be integrated with existing Canal infrastructure. The output of the brainstorm was then put into a numerical matrix tool, a Pugh Matrix, for grid analysis.

The grid analysis is valuable as a tool for developing a mutual understanding of each technology concept, understanding values and differing perspectives of team members, and for optimizing the deterrent concepts. This method promotes creative thinking and helps remove personal judgments from decisions. It also helps diverse stakeholders understand each other's values and issues, and provides a quantitative technique to rank multi-dimensional options. The quantitative rankings have a rationale and are consistently applied so that they provide a test of sensitivity of objectives and project features. Clarifying criteria and any substantial differences in scoring are discussed among the team to develop a clear, common understanding of options, definitions, and assumptions. The Pugh Matrix provided a framework for discussion, understanding, and consensus-building (Appendix B).

3.2.1. Select Components

The first step in building a matrix is to select measures for comparison. The AIS guild summaries (Section 3.1.1) provided a literature-based review of potential deterrent and control technology options, including known measures of effectiveness. The team of experts also reviewed summaries of potential deterrent technologies that had been compiled (Section 3.1.2). This review included technologies under consideration for Champlain Canal and the Chicago Sanitary and Ship Canal. In addition, team members shared their professional experience at other similar projects. Through the brainstorming workshop and technical discussions, 30 deterrent technologies were reviewed and incorporated. The technologies included physical, chemical, and biological deterrents (Appendix B3).

3.2.2. Develop Criteria

The second step in building the evaluation matrix was to define the criteria that would be used to evaluate each deterrent technology. Criteria were discussed during the brainstorming and were refined during matrix scoring to eliminate redundancies. Thirty-six criteria were developed and categorized under the umbrellas of: effectiveness, risk, operations and maintenance needs, and cost. A detailed description of the evaluation criteria is provided in Appendix B1. For scoring, each criterion was a positive attribute and could be considered an objective of the concept.

Criteria were also weighted relative to each other. Weighting was based on professional opinion and experience with similar facilities or effectiveness of similar species. The criteria had different levels of importance and were weighted appropriately on a scale of zero to ten. To facilitate differentiation of deterrents, we stipulated that the average weight for each category of criteria had to equal five.

3.3. Conduct Evaluation

The third step in the grid analysis was to score how well each deterrent technology satisfied each criterion. Six experts independently scored each technology using a ten-point (zero to ten) scale. Differences among individual scores due to difference in available information, the experience of individual team members, or differences in understanding of the technology or criteria prompted additional conversation. Individual scores were then adjusted, and the description of each alternative or criteria was modified as necessary to reflect a common understanding.

For each deterrent technology and criterion combination, a final score was attained by averaging scores given by individual team members. Each final score was then multiplied by the weightings previously assigned to criterion to generate weighted scores and these were summed across criteria to generate and overall score for each technology. Deterrent technology scores were then normalized so that each one was reported as a percent of the highest ranked technology. Totals were compared graphically (Figure 3-1). We emphasize that the entire process was used as a means for communication, mutual understanding, and optimization of concepts, rather than to simply calculate a final score.

Developing weighted scores for each deterrent technology highlighted the strengths and weaknesses of each. Hydrologic separation was the highest scoring deterrent technology with a score of 100. Other technology concept scores are expressed as a percent of the top score and ranged from a low of 58 for electric barriers to 85 for a canal boat wash steward program (Figure 3-1). Technologies with a score greater than 70 were further considered when developing networked deterrent alternatives. However, as described below in Section 3.6, several of these technologies were eliminated due to fatal flaws at the time of this report. Thus, a total of six deterrent technologies were advanced for the development of networked alternatives (Figure 3-1):

7. Hydrologic separation
8. Canal boat wash program
9. High temperature/steam washing
10. Pressure washing
11. Screens
12. Bio-acoustic fish fence (BAFF)

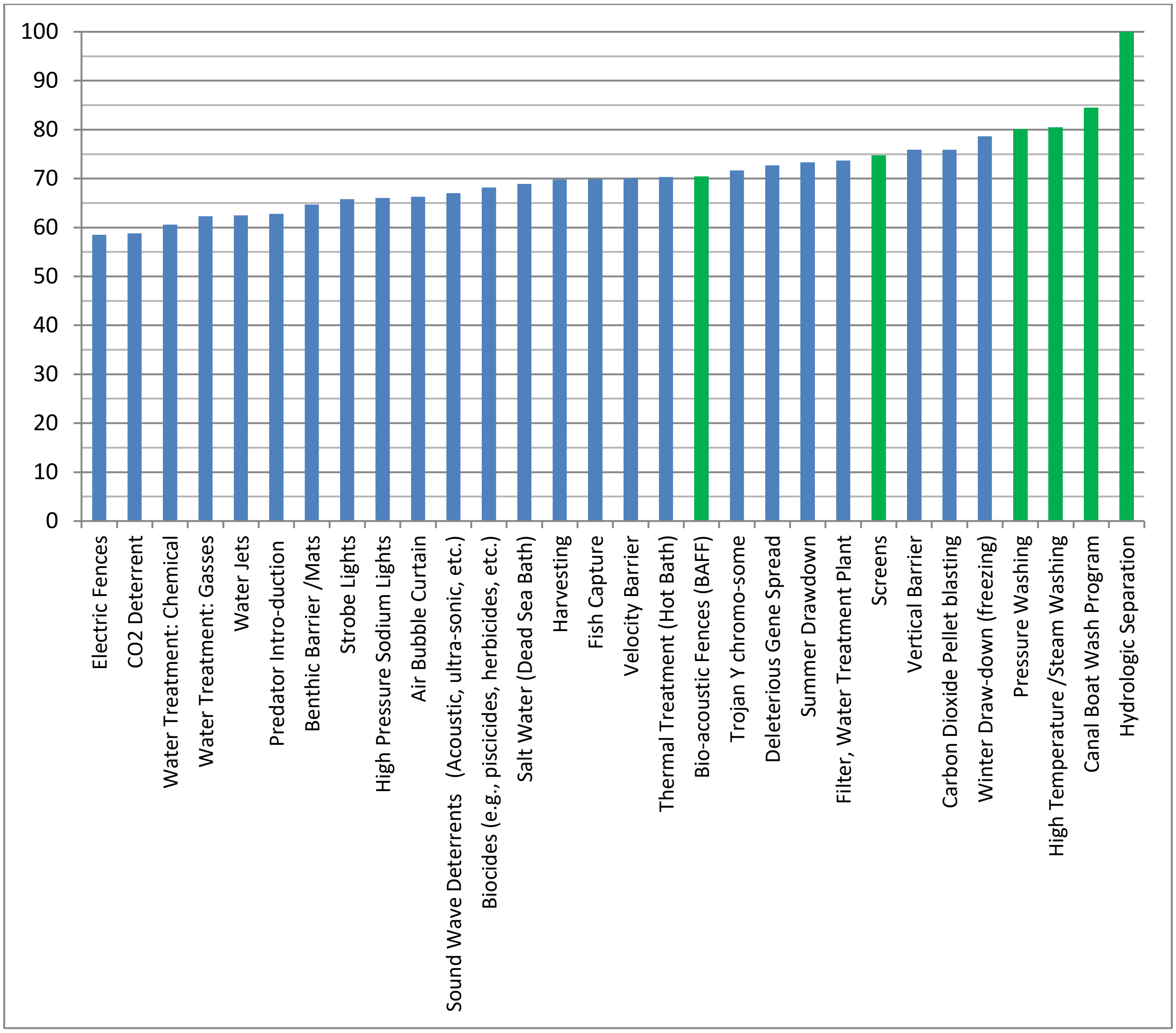

Figure 3-1. Normalized scores for deterrent technology concepts evaluated in the Pugh Matrix by the internal expert team.

3.4. Agency/Stakeholder Outreach

Agency and stakeholder outreach was conducted from May through September of 2019. Initially, outreach consisted of telephone interviews with regional AIS experts who provided input on invasive species of concern along with potential technologies and criteria for use in the evaluation of deterrents. R2 reached out to 16 experts and received positive responses for follow up discussions from 12 (Table 3-1). The general themes that emerged from these interviews are captured below.

- A general consensus that NYS Canal System poses risk of spread of invasive species to a majority of the inland water bodies of NYS.
- Costs should consider potential avoided costs with proposed barriers in place (e.g., money not spent to respond to damage done by AIS).
- Need to protect the Hudson River against Great Lake invasives and keep Hudson River invasives from reaching the Great Lakes.
- Efforts should focus on the most destructive species; for example, while the banded mystery snail is an AIS and is abundant in surveys, it fills a niche in the food web but does not structure the system, making it functionally redundant in the food web and therefore not one of the most destructive species.
- Need to consider unintended ecological consequences to NYS aquatic ecosystems and inland fisheries.
- The Champlain AIS barrier effort being undertaken by the U.S. Army Corps of Engineers is in its study phase; hydrologic analysis is ongoing and a list of priority controls is being refined.
- Finger Lakes contain several invasives that are not ubiquitous throughout the rest of the Canal and should be contained (hydrilla, milfoil, starry stonewart, fishhook waterflea, etc.).
- There may be no control that will be effective for some species.
- Electric barriers are not effective enough.

R2 staff also participated in meetings with regional AIS experts. R2 participated in a NYSDEC-hosted meeting on invasive species to gain additional perspective on a broader range of concerns shared by scientists actively engaged with AIS efforts throughout NYS. R2 convened a focused meeting with NYSDEC and Lake Champlain Basin Program staff on July 23rd to discuss the approach for evaluation of deterrent technologies and present preliminary results. A follow-up meeting to coordinate with DEC regional Fisheries Managers was held on August 1st. Lastly, on September 24, 2019, R2 staff participated in a focus group discussion with DEC scientists as well as representatives from PRISMs, lake associations, and academia in which the scope and preliminary outputs of the study were presented and discussed.

Table 3-1. AIS experts engaged in telephone interviews and meetings May – September, 2019.

Expert	Organization
Mr. Robert Breault	USGS
Mr. Lindsay Chatterton	The Nature Conservancy, AIS Director
Ms. Aimee Clinkhammer	NYSDEC
Ms. Katherine Czajkowski	NYSDEC
Ms. Judy Drabecki	NYSDEC, Deputy Commissioner
Ms. Frances Dunwell	NYSDEC, Hudson Estuary-Coordinator
Ms. Jean Foley	NYSDEC
Ms. Heather Gierloff	NYSDEC, Hudson Estuary-Habitat
Ms. Jennifer Tufano Grillo	Cayuga Lake Watershed Network
Mr. Stuart Gruskin	The Nature Conservancy, Chief Conservation and External Affairs Officer
Ms. Kristen Holeck	Cornell Biological Field Station, Shackelton Point
Mr. Steve Hurst	NYSDEC Inland Fisheries, Bureau Chief
Mr. Gregg Kenney	NYSDEC, Hudson Estuary-Fisheries
Ms. Sandra Keppner	USFWS, Northeast Region AIS Coordinator
Ms. Kristin King	Western NY PRISM
Ms. Hilary Lambert	Cayuga Lake Watershed Network
Dr. Jacqueline Lendrum	NYSDEC
Ms. Andrea Locke	Western NY PRISM
Mr. Matt Marko	NYSDEC
Dr. Cathy McGlynn	NYSDEC Invasive Species, AIS Coordinator
Ms. Meg Modley	Lake Champlain Basin Program, Director
Ms. Kathy Moser	Open Space Institute, Senior Vice President for Parks and Policy
Dr. Steven Pearson	NYSDEC
Dr. Rick Relyea	Rensselaer Polytechnic Institute
Ms. Emily Sheridan	NYSDEC
Mr. Ian Smith	Finger Lakes Institute
Dr. AJ Smith	NYSDEC
Mr. Matt Snyder	Oneida Lake Association
Ms. Gwendolyn Grace	Capital/Mohawk PRISM
Mr. Josh Thiel	NYSDEC
Mr. Eric Wiegert	NYSDEC
Mr. Rob Williams	SLELO PRISM

3.5. Technologies Suitable for Consideration in Networked Alternatives

3.5.1. Hydrologic Separation

Hydrologic separation within the Erie Canal could potentially be achieved through permanent closure of Canal features, such as locks or guard gates. Hydrologic separation would stop the flow in the Canal in both directions, preventing direct water transport of AIS at the location of separation.

Discrete guard gates could be permanently closed to achieve separation, and the edges sealed with concrete or other measures to stop all surface flow and seepage through the gate. Specific measures to develop the seal details could be addressed on a site-specific basis depending on the existing guard gate design and configuration. Specific decommissioning measures could also be addressed on a site-specific basis, ranging from total removal to welding mechanical drive trains shut and securing the mechanical equipment from the public. There could be opportunities to showcase the mechanical equipment for public recreation or other uses.

Hydrologic separation at locks would require similar permanent closure of both upstream and downstream miter gates associated with each lock. Once closed, the gates would be sealed shut (with concrete or other measures) and the miter gate operating equipment decommissioned. Additionally, all conduits (fill and drain portals, conduits, pipes, storm drains, etc.) used to fill and drain the locks would be permanently sealed – again to prevent any aquatic vector (i.e., connection) between the upstream and downstream sides of the locks. Measures to seal these conduits would include permanently closing valves, and adding concrete fill or welded steel plates at strategic locations within the fill and drain systems. From a future maintenance and decommissioning perspective, filling the entire or a substantial length of the conduit with concrete would produce a permanent closure and seal to create the hydrologic separation.

A dry reach of Canal would enhance hydrologic separation by increasing the distance of non-hospitable habitat between wetted reaches of Canal. This would help to minimize the possibility of crawlers or hitchhikers finding alternative overland routes around the separation. To achieve a dry reach of Canal would require closure of two separate Canal features and draining the Canal between them. If the intended dry reach cannot be completely drained, fill could be used to raise the Canal floor or to create smaller dry reaches between intermittent wetlands.

Additional measures to prevent overland-dispersing AIS could enhance the effectiveness of hydrologic separation and may include smooth vertical surfaces and/or fill material placed near the closures to discourage them, such as crayfish. Additional management options for the dry reach include (1) sand wedges to filter water at specific locations (2) grading and fill material in low spots, and (3) adding additional walls or geomembranes in the dry or filled reaches to prevent inflow/backflow of water. Depending on the location, consideration for flooding that would overwhelm the measures described above should be considered and addressed. If the intervention were to be implemented at a location where flooding could render the closure measures ineffective, the intervention could be augmented by the use of dikes, the raising of existing infrastructure walls or the addition of Canal slopes.

3.5.2. Boat Lift and Wash

Boat inspection and washing was identified to eliminate the invasive species transmission vector used by hitchhiking plants and molluscs that can attach to vessels, pelagic invertebrates, and even small-bodied benthic fishes that hide in mussel beds when boats become heavily encrusted. This measure would also address invasive hitchhiker species that stow away in water associated with vessel engine cooling systems, ballast tanks, bilges, live-wells, bait buckets, as well as fish and boating equipment or anchor lines that are used in the water. The measure would include the transporting of a vessel around a lock or gate via a boat lift, an inspection, cleaning, sanitizing, re-inspection, and certification that the vessel is clean. The inspection and cleaning station would be isolated from the Canal System so AIS that are removed and collected could be properly disposed of or treated prior to cleaning process water being returned to the Canal or watershed.

Boat lifts are commonly used by the boating industry to launch, dry dock and/or repair boats. They are commercially available in sizes to accommodate up to 40 tons and can be custom-designed and fabricated to larger sizes. For the Canal System, design specifications for a boat lift to accommodate the vessel inspection and cleaning would be based on anticipated vessel sizes to be lifted at each site, the number of boats to be lifted (peak number per day), the required transport distance, and desired inspection station processing time.

The lift would hoist the boat/boats in a sling or bed out of the Canal and transport the vessel on wheels, rail, or truck bed overland around the closed lock and back to the Canal on the other side. Launch piers with floating docks would allow passenger ingress and egress, as well as temporary boat mooring. Depending on the type of boat, the owner may be required to start and idle the engine in a certified clean flushing basin for a specified time (likely 2 to 4 minutes) to flush the engine. The operators would then lift the boat from the chamber and move it to the upstream side of the station to be lowered into the river. Passengers could then re-board. The time necessary to transfer, inspect, and decontaminate boats would vary, and would be defined by variables such as staffing levels, vessel size, vessel type, vessel material and condition, propulsion system, ballast and live-well provisions/configuration, equipment, and bilge configuration. At this phase of the study, a goal of approximately 30-60 minutes would seem to be desirable for the total process. For vessels in extremely contaminated condition, a pre-inspection or secondary, more thorough decontamination station could be required, or the vessel could simply not be allowed to enter the next watershed. Based on a review of vessels currently passed through the Erie Canal System, inspection/treatment stations could be developed to accommodate boats as large as 60 feet in length, 17-foot beam, and 40 tons. Additional facilities could be necessary to address commercial traffic such as the current gravel barges that utilize the Champlain Canal System, or closure to those vessels could require other transport means such as rail or truck for that traffic.

Many states are adopting boat inspection and wash stations to combat the spread of AIS, and different types of boat cleaning and wash units are being used throughout the country to aid in the prevention of the spread of invasive species from waterbody to waterbody. Decontamination procedures and protocols vary among programs, and the intention of any Erie Canal boat wash program would be for it to be adaptively managed and flexible to account for the known existing invasive species, as well as the future invasion of plants and animals that may have different treatment tolerances. The following recommendations are a summary of detailed step-by-step manuals developed by the Minnesota Department of Natural Resources (2018) and the Vermont Department of Conservation (2018).

Boats would be visually inspected for AIS during entrance and exit inspections before and after the wash procedure. Any plants and animals detected during the visual inspection should be physically removed by hand, if possible, and properly disposed of by the inspector. Treatment of exterior surfaces of the watercraft including the hull and deck would entail a high pressure (1,800 psi), hot water (140^{o} F, 60^{o} C) wash designed to achieve at least 10 seconds of exposure time on all exterior surfaces. The pressure wash wand nozzle type, distance from the surface, and hot water flow rates would be further specified to assure proper treatment. Low-pressure hot-water application may be appropriate on carpeted areas, decals, electrical connections, gimbal area on the inboard/outboard engine, interior compartments, transducers, and depth sounders and their wiring. The application wand should be kept close to the hull as water temperature decreases approximately 15 to 20^{o} F per foot of distance when sprayed from a power nozzle.

As noted in the introduction to this section, interior watercraft compartments including bilge compartments, ballast/water holding tanks, wet wells, live wells, bait wells, and any other compartments that could hold standing water would be drained and treated with hot water. This process could proceed as follows:

- Start the decontamination by having the boat operator open all interior compartments that need to be decontaminated and remove plugs.
- Use a laser thermometer and measure the temperature at the through-hull discharge port for each compartment.
- Flush each compartment until the exit temperature of the water reaches 120° F for a minimum of 30 seconds. If the boat is equipped with a discharge (bilge) pump, have the boater turn on the discharge pump for the compartment, and run hot water through the pump system until discharge water reaches 120° F for at least 30 seconds.

All watercraft engines have some type of cooling system that typically contains water when not in use. An engine flush should be performed to remove high-risk standing water that may still be inside of a motor that was not fully drained. For an engine flush, hot water would be supplied to the intake openings with appropriate fittings on the water intake (*clamp-style motor muffs, "Fake-a-Lake" muffs for inboards, etc.).* The boat operator would then be asked to start the motor and run the engine in neutral while hot water is flushed through the engine until the water temperature is 140°F for 120 seconds when measured by a laser thermometer at the discharge port(s). Both inboard and outboard engines with an open loop cooling system would be treated. Where fittings cannot be accommodated, boats could be held in a heated pool of contained water and run in a similar manner.

Based upon a visual inspection, onboard equipment including anchors, mooring and anchor lines, personal flotation devices, swim platforms, inflatables, down-riggers, planing boards, water skis, wake boards, ropes, ice chests (used for bait or for holding fish), fishing gear, bait buckets, and stringers may also need to be treated with hot water. Live bait containers would be inspected and the boat operator would be required to provide proof of purchase from a certified commercial bait dealer. Bait inspection and decontamination prevents the potential transfer of AIS in water found in a bait well or bucket. Receipts must accompany bait, and strict step-by-step procedures must be followed if the bait receipt is older than seven days. If the bait is from out of state, the bait is not permitted and must be disposed of.

A reliable water source is necessary for the boat wash system operations. Water should come from a freshwater source - preferably from a municipal water supply or filtered/treated water either reclaimed onsite or, in the case of the one-way boat transfer/wash, sourced from the receiving water (upstream). The wash station would be designed with a reclaim/filtration system and/or wastewater containment and disposal system. Containment may include a tank or pad for wastewater, a vacuum or sump pump mechanism for water recovery and, in some instances, a multistage filtration system for recovered water. AIS that are physically removed must be properly euthanized and disposed of following appropriate permitting procedures.

3.5.3. Bio-Acoustic Fish Fence (BAFF)

A BAFF is a multi-stimulus non-physical fish barrier that combines strobe lights, an air bubble curtain, and sound to behaviorally deter fish from entering a waterway. However, not all BAFF systems are the same and do not have equal performance. The BAFF deterrent we identified for consideration was patented and manufactured by Fish Guidance Systems Ltd. (United Kingdom) and consists of a bottom-mounted array of sound projectors (speakers), which are carefully positioned within a gas diffusion system supplied by a shore-based compressor such that the sound produced by the projectors becomes “trapped” (modified in a manner that produces a steep gradient) within the gas stream. To further increase the effectiveness of the BAFF system, we propose adding a 2 hz SILAS light system (a commonly-employed combination). The BAFF/SILAS system typically uses target sounds and produces a wall of sound with illuminated bubbles to produce a distinct sensory field that fish can follow and avoid. Providing a well-defined multi-component sensory field(s) that fish can discern has been key to its success at numerous locations, and it is typically installed at an angle for use as a deterrent.

An experimental BAFF/SILAS system is currently being field tested to guide Asian carp away from a lock entrance on the Cumberland River (KY; Figure 3-2), and another system was determined to be successful in guiding juvenile Chinook Salmon away from an irrigation diversion on the San Joaquin River (CA). In terms of its structure, large experimental BAFF systems consist of modular sections of sound and light projector arrays and an air or gas diffuser system arranged along the river bottom following the riverbed contour.

The acoustic stimulus of the BAFF is generated by sound projector arrays (SPAs). SPAs consist of an onshore power supply, signal generator, and signal control/amplifier units that are linked by cable to underwater electromechanical transducers, or ‘sound projectors’ (Figure 3-3). The sound system and strobe light flash rate can be tuned to known sensitivities of target fish species. The manufacturer uses audiogram and behavioral studies to determine the most effective sound frequency range for target fish species. The characteristics of the acoustic signals of the BAFF are proprietary (Fish Guidance Systems Ltd, Southampton, UK), but are typically within the 20-2000 Hz frequency range and use frequency or amplitude sweeps. The sound level inside the bubble curtain may be as high as 170 dB re 1µPa, typically decaying very rapidly to 5% of this value within 0.5-1.0 m from the bubble sheet (Bowen et al. 2012).

The primary function of the bubble curtain is to contain the sound generated by the SPAs. Bubble curtains are generated by passing compressed air (~0.2 bar pressure) or gas into a uniformly perforated rubber pipe running along the base of the BAFF. Air flow rates are typically around 2.0 liters per second per 1-meter length of barrier. An air compressor capable of an operating pressure up to 7 bar is used to regulate the bubble curtain air supply at the pressure required to open the pores in the air curtain hose. This air demand works out to a rate of 130 standard cubic feet per minute (scfm) from a compressor rated for 100 pounds per square inch gage (psig) for every 100-feet of barrier.

The SILAS™ light system is composed of synchronized linear LED strobe light arrays. The light arrays are aligned vertically such that the beam projects onto the rising bubble curtain creating a visual stimulus (Figure 3-2). The strobe lights are powered from a power supply accumulator, a unit that accumulates energy until it is discharged to a bank of strobe lights; the flash rate is triggered from a signal generator. The exact power rating for the strobe lights and the wavelength of the light are proprietary (Fish Guidance Systems Ltd, Southampton, UK). Up to 120 amps (115 volts, alternating current) of an inductively rated power supply is required to run a BAFF light and sound generating system. Onshore, a small trailer or building is required to house the air compressors, control units, signal generators, and amplifiers.

Figure 3-2. Construction of the Bio-Acoustic Fish Fence at Barkley Dam, Kentucky. Waterproof power cables, sound transducers, and LED light bars are visible *(photo courtesy of Kentucky Department of Fish and Wildlife Resources*).

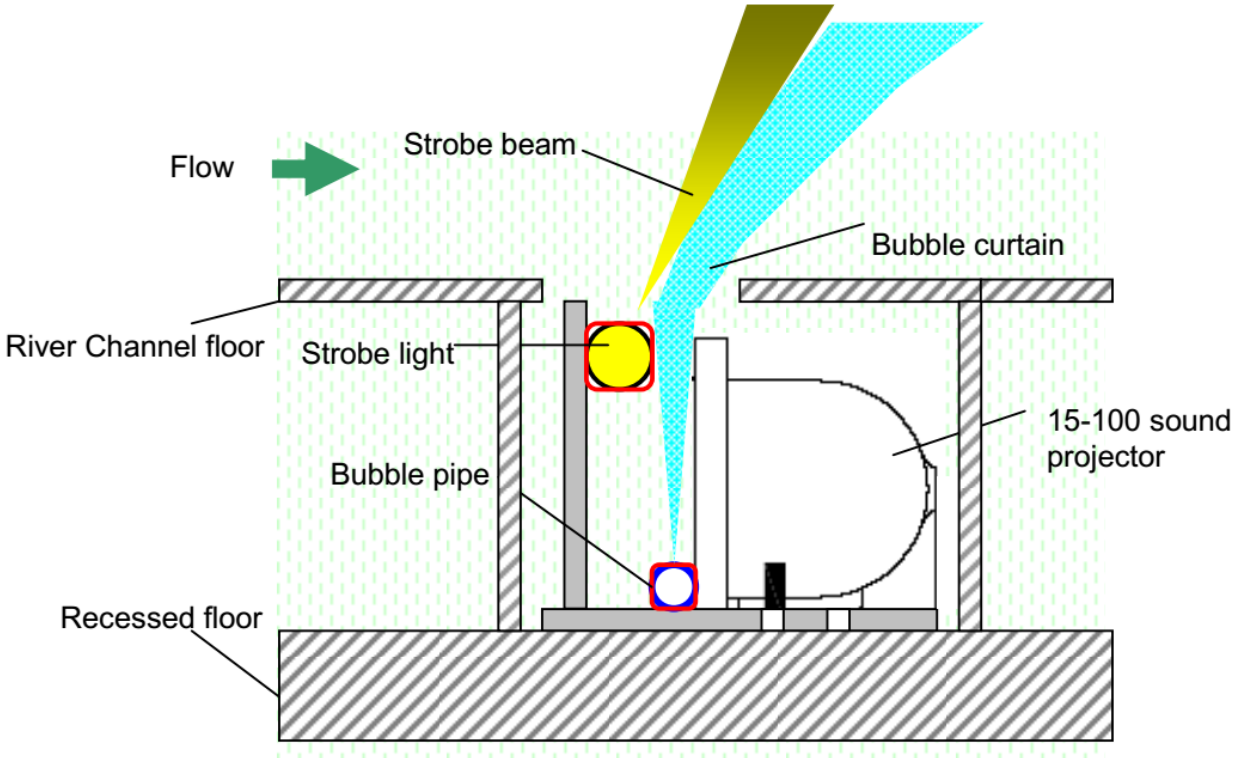

Figure 3-3. Schematic of Bio-acoustic Fish Fence (BAFF) combining multiple stimuli to create a non-physical fish barrier/guidance structure (figure from Bowen et al. 2009).

3.5.4. AIS Barrier Screen

A barrier screen can be an effective deterrent for numerous types and sizes of AIS. The AIS barrier screen would include appropriate screen size to deter the target fish species and life stage sizes. As a starting point for a reasonable approach, screen material (stainless steel profile bar, wedge wire, or Hydrolox™ plastic belt screens for example) can be based on juvenile (fry) salmonid criteria per NOAA Fisheries latest screening criteria (NMFS 2011). With an active cleaning system, the criteria allows a maximum 0.4 fps (feet per second) approach velocity for fish screens, which is based on the ability of juvenile salmonid fry to not become impinged. Maintaining an approach velocity below 0.4 fps is also an important factor in keeping the screens cleaning. An approach velocity of 0.2 fps is recommended to prevent injury to small fish and ensure maintenance of a clean screen condition. Self-cleaning systems, including traveling belt screens (using Hydrolox™ plastic belt screens for example), or stainless-steel profile bar or wedge wire screens with external or internal brushes, pressure water backwash, or air burst systems are all viable options for initial consideration.

Table 3-2 provides a summary of published larval fish entrainment reductions based on screen slot size, using wedge-wire or profile-bar screen. This information can be considered with site-specific criteria where AIS barrier screens are considered, such as design flow, depth, and orientation.

Table 3-2. Larval fish exclusion size and entrainment reduction with various wedgewire screen slot sizes.

Screen Slot Size (mm)	Fish Exclusion size (length, mm)	Ichthyoplankton Entrainment Reduction (%)[c]
0.5	4.6-6.6[a]	80
0.75	7[b]	77.1
1	9[b]	67.6
1.75	16[b]	34.6[d]
3	24[b]	15.8
4	No data	7.8
6	No data	1.8

a. fish exclusion length is the range of average length for Centrarchids, Clupeids, and Cyprinids based on field evaluation (McDonald and Karchesky 2010)

b. fish exclusion length based on estimated proportion of 0.5 for goby larvae (Tenera 2013)

c. based on the probably of entrainment for larvae of 15 taxonomic categories of fish, extrapolated to the size at which the larvae are no longer susceptible to entrainment, 20–25 mm (Tenera 2013)

d. entrainment reduction based on 2mm slot spacing

3.6. Technologies Not Used in Networked Alternatives

Twenty-six deterrent technologies were evaluated, scored and considered, and ultimately were not advanced for development of networked alternatives due to their low scoring and/or a fatal flaw in one or more category (Table 3-3). Initially, all the deterrent technologies that scored greater than 70 during the evaluation were considered as having merit for use in developing networked deterrent alternatives. However, several of these higher scoring technologies were determined to have fatal flaws with respect to near term implementation (Trojan Y Chromosome, Deleterious Gene spread), were redundant with Canal operation and or another technology (Summer and Winter Drawdown, Vertical Barrier), or there remained much uncertainty associated with feasibility (Water Treatment Plant, Carbon Dioxide Pellet Blasting). Thus, these higher scoring technologies were eliminated from further consideration in building alternative solutions. Several other technologies that received scores of 70 or less during the evaluation were eliminated as stand-alone deterrents, but were adopted for use in combination with other technologies. For example, air bubble curtains, strobe lights, and acoustics were eliminated when considered individually, but are all components of a BAFF. While electric barriers have been considered a promising technology in the past, application in the Chicago

Sanitary and Ship Canal has demonstrated uncertainty regarding their effectiveness for deterring fish when implemented in a navigable waterway (Parker et al. 2015a; Parker et al. 2015b). In addition, this technology has high-perceived human risk.

Table 3-3. Summary of AIS deterrent technologies evaluated and not advanced

Dot size indicates low (small), medium (medium), and high (large) composite scoring for four categories: effectiveness, cost, operations and maintenance, and risk. High scores for cost, O&M and risk indicate low cost, low O&M, and low risk.

Deterrent Technology	Effectiveness	Cost	O&M	Risk
Air Bubble Curtain	•	●	●	⬤
Benthic Barrier/Mats	•	•	●	⬤
Biocides	●	•	•	•
Carbon Dioxide Pellet Blasting	●	●	•	●
CO_2 Deterrent	•	•	•	●
Deleterious Gene Spread	•	•	●	•
Electric Fences	•	•	•	•
Filter, Water Treatment Plant	⬤	•	•	●
Fish Capture	•	•	●	⬤
Harvesting	•	●	⬤	⬤
High Pressure Sodium Lights	•	⬤	●	⬤
Predator Introduction	•	⬤	●	●
Salt Water	●	•	●	•
Sound Wave Deterrents	•	⬤	●	●
Strobe Lights	•	⬤	●	⬤
Summer Drawdown	●	⬤	⬤	●
Thermal Treatment	●	•	●	●
Trojan Y Chromosome	⬤	•	●	•
Velocity Barrier	●	●	●	●
Vertical Barrier	●	⬤	⬤	●
Water Jets	•	●	●	●
Water Treatment: Chemical	●	•	•	•
Water Treatment: Gasses	●	•	•	●
Winter Drawdown	●	⬤	⬤	⬤
Key	*Lower Score* • → ● → ⬤ *Higher Score*			

4. DEVELOPMENT OF INITIAL NETWORKED ALTERNATIVES

The study goal was to develop a few networked alternatives for comparison of their potential to deter the spread of AIS through the NYS Canal System. The following sections describe each alternative and include the goal of the alternative, the locations of deterrents, and a description of each deterrent.

4.1. Networked Alternative 1: Protect the Hudson

The objective of Alternative 1 is to hydrologically separate the Great Lakes and Hudson River basins (Figure 4-1). Hydrologic separation between the Lake Ontario and Hudson River watershed basins would eliminate the waterborne vector of AIS transmission between these two key basins.

4.1.1. Hydrologic Separation at Summit of Erie Canal

Guard Gate 7 (G7) is located near Rome, NY, just to the west of the confluence of the Mohawk River and the Erie Canal. Rome is the summit (or high point) for the Erie Canal, with a water surface elevation of 420.4 feet between Locks E20 and E21. Guard gates G7 and G8 sit between these two locks in the summit pool. Permanently closing the Canal to flow at the summit would create a hydrologic barrier and would eliminate AIS water dispersal at this location.

The Mohawk River flows from north to south and was impounded (restricted/contained) by the construction of Delta Dam, which created Delta Reservoir, located to the north of the Erie Canal near Rome. As shown on Figure 4-1, water from Delta Reservoir feeds the Mohawk River and drains towards the south and into the Erie Canal where it merges with the Canal just east of G7 at the summit of the Canal between locks E20 and E21. During the navigation season, a small portion of the water that is associated with navigation lockages flows into the Canal toward the west to Oneida Lake and the Oswego River basin. Recreational traffic use varies greatly from a minimum of 2 lockages (2 vessels) per day to a maximum of 17 lockages (26 vessels) per day in either direction.

Most of the Mohawk River flow discharges through several spillways along the Canal to the Mohawk River channel on the south side of the Erie Canal, which primarily flows to the east. The Erie Canal and the Mohawk River channel then flow in parallel towards the east between Rome and Frankfort where they rejoin. Under current operations, the majority of the water in the Mohawk River and Erie Canal flows east toward the Hudson River.

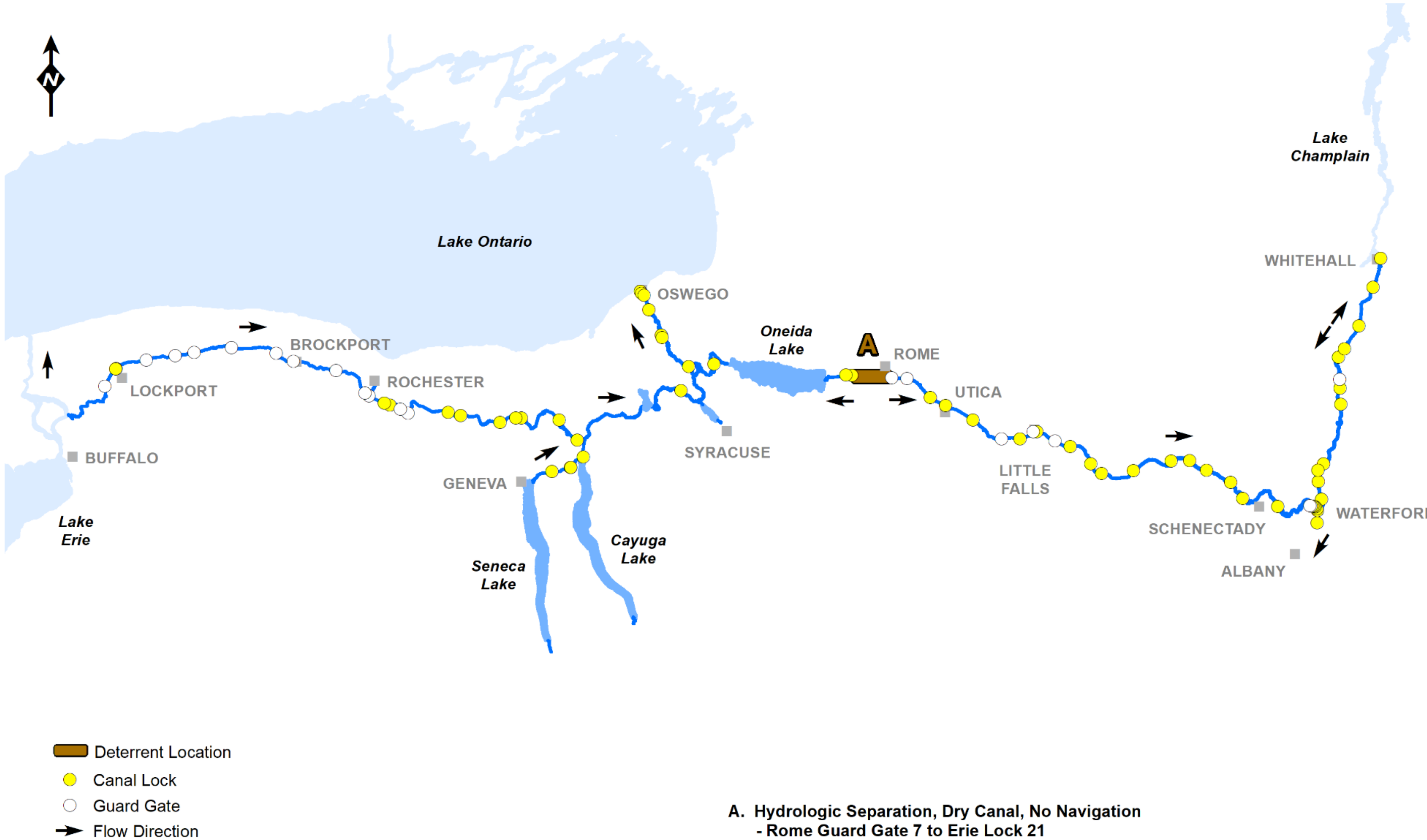

Figure 4-1. A schematic depicting deterrents and changing flow patterns associated with <u>Alternative 1, Protect the Hudson</u>.

During the non-navigation season, the East Rome and West Rome Guard Gates are fully closed. During this period, no water flows to the west of the West Rome Guard Gate and all the flow discharges to the Mohawk River at the spillway associated with the East Rome Guard Gate.

During normal flows, containing the Mohawk River by closing G7 permanently is a feasible means to divide the watershed and would provide for continued Mohawk River source flows to the East. Flows in the Canal to the west of Lock E21 towards Oneida Lake could be provided from local creeks. Effects on Oneida Lake from this changed flow condition are likely minimal, but this observation should be confirmed with future development of this alternative.

Measures to accomplish this are shown on Figure 4-2 and are described below.

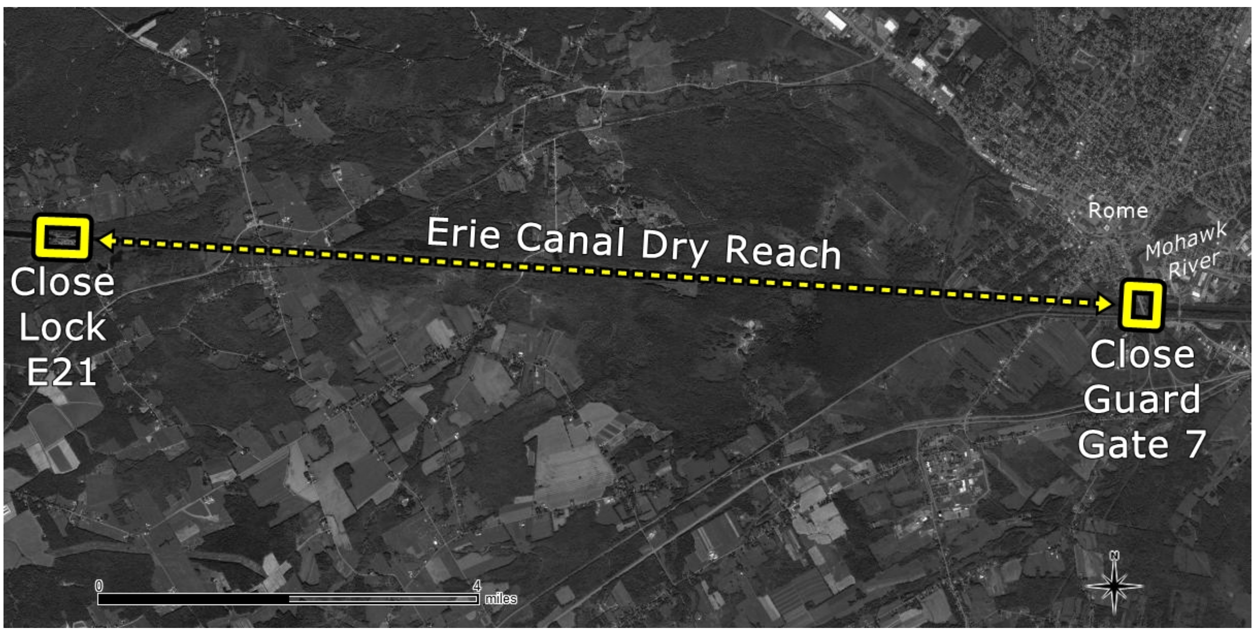

Figure 4-2. Dry Canal reach between closure of Lock E21 and Guard Gate 7.

4.1.1.1. Permanently Close Guard Gate G7

Gate G7 would be permanently closed and sealed to stop all flow and seepage through the gate. This would stop 100% flow of water flowing west at the summit towards Lock 21.

4.1.1.2. Permanently Close Lock E21

Lock E21 would be permanently closed, and the gates and the fill and drain conduits would be sealed to stop all flow, leakage, and associated navigation through the lock.

4.1.1.3. Entrain the Mohawk River

All flows from the upper Mohawk River that enter the Canal just east of Gate G7 would be diverted into the Erie Canal and directed east toward the Hudson River.

4.1.1.4. Permanently Drain the Erie Canal between E21 and G7

Draining the Canal between these structures would create a full AIS barrier to the system, by eliminating flow and by creating physical distance separation between the sections of flowing Canal at the summit. Given that this portion of the Canal is relatively large (~8.25 miles), flows from the north to the south would have to be accommodated with existing culverts and drains under the Canal. The feasibility of effectively draining this Canal should be further examined to determine necessary measures and the ability to convey existing flood flows, and to identify any other concerns relating to the environment or navigation. If draining this entire reach is not feasible, 1,000 feet of the canal just to the west of G7 could be filled and sealed with geomembrane.

4.2. Networked Alternative 2: Watershed Divide

The objective of Alternative 2 is to diminish the probability of AIS using the Erie Canal for eastward passage from Lake Erie and Lake Ontario, westward passage from the Hudson River, as well as containing any AIS within the three central watersheds: Finger Lakes, Oneida, and Oswego. (Figure 4-3).

Water from Lake Erie exits via the Niagara River, flows downslope, and joins the Genesee River. The Genesee River flows into Lake Ontario. The Erie Canal begins in Tonawanda and diverts water from the Niagara River and Tonawanda Creek downslope to the east. Flow in this portion of the Canal only occurs during the navigation season from early May through mid-October. During other portions of the year, the Pendleton Guard Gate is closed, severing the flow of water between the Niagara River down the Erie Canal. The flows in this reach of the Canal are not influenced by rainfall or runoff and are solely based on the amount diverted from the Niagara River for navigation, hydropower, and irrigation.

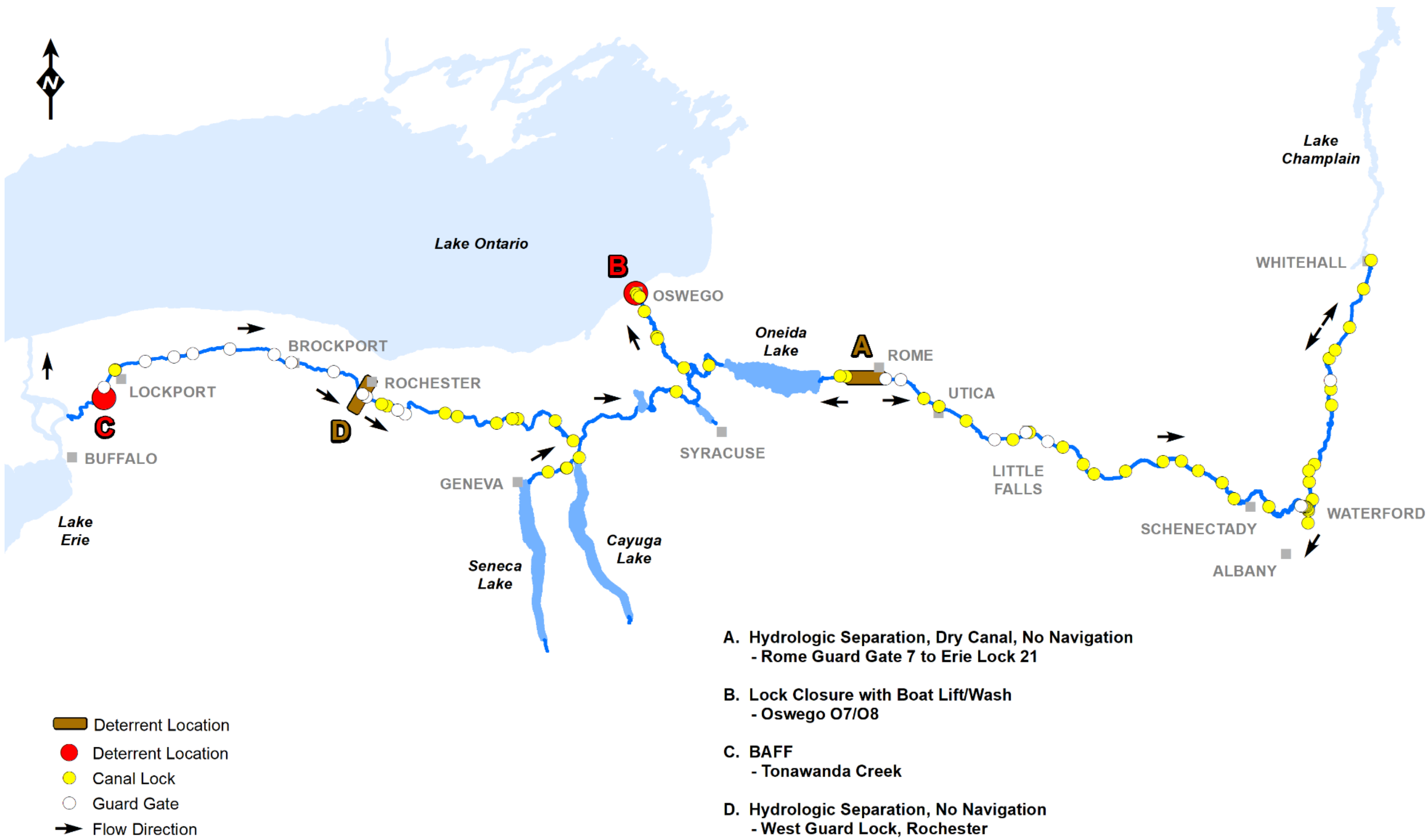

Figure 4-3. A schematic depicting deterrents and changing flow patterns associated with <u>Alternative 2, The Watershed Divide</u>.

4.2.1. Bio-Acoustic Fish Fence (BAFF) at Tonawanda

As the first point of control between Lake Erie and the Erie Canal, a robust AIS deterrent at this location would reduce the movement of AIS, and in particular, fish species, from Lake Erie via flow into the Canal (Figure 4-3). Because Niagara River water flows into the Canal, installation of the BAFF system would help actively discourage aquatic species from leaving Lake Erie and entering the Canal.

In order to be most effective, the BAFF system should be located upstream (west) from Lock E35 (the first lock to the east from Lake Erie) and as close to the Niagara River as possible to help guide fish away from the Canal. A possible location is shown near the confluence of Tonawanda Creek as shown in Figure 4-4 that provides an alternate flow field for fish to move into rather than stay in the Canal. This barrier would be about 250-feet in length, which would require 325-scfm of compressed air and a 14-kW power load for light and sound generation.

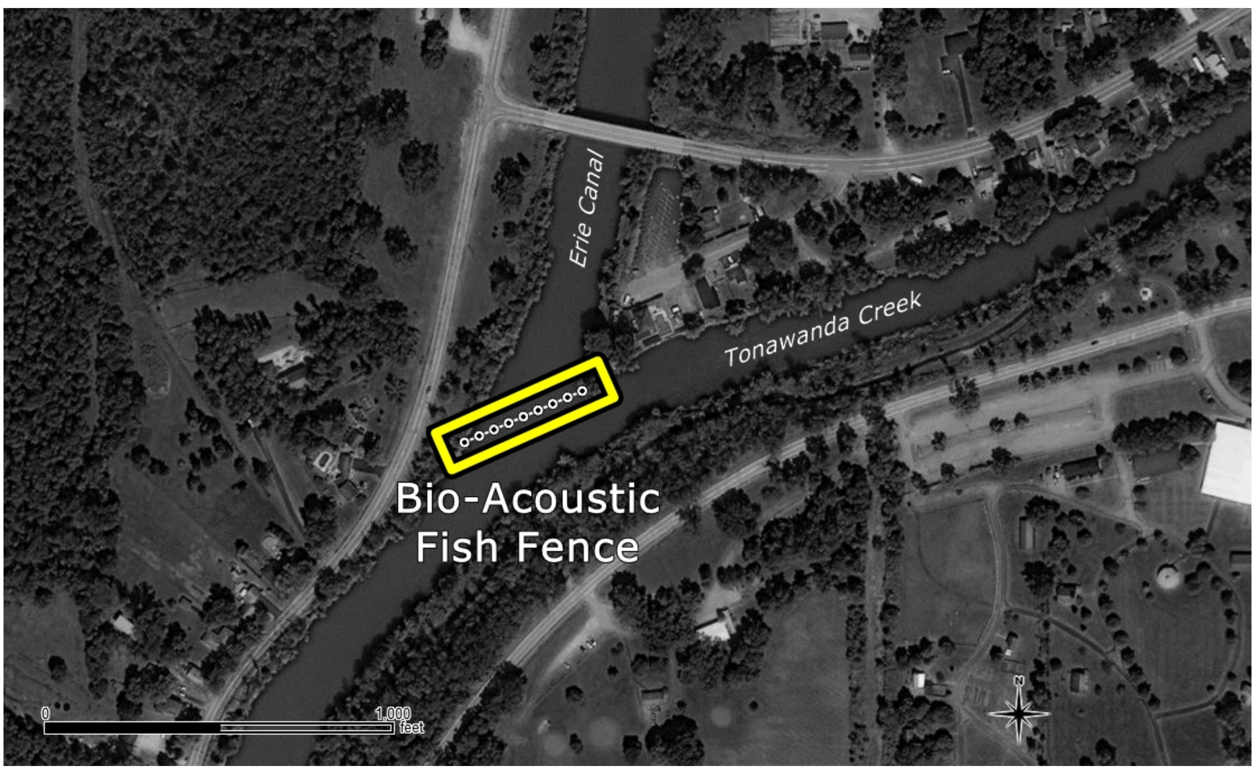

Figure 4-4. BAFF location near Tonawanda Creek at western entrance to Erie Canal.

4.2.2. Hydrologic Separation at Rochester Guard Gate

The West Guard Gate (RM 261.02) is located 0.35 miles west of the crossing of the Genesee River (Figure 4-5). The West Guard Gate is located along the flattest section of the Erie Canal with a water surface delta of 2.3 ft over the 64.3-mile segment between the Lockport (E34-35) and Rochester (E33) locks and dams. The water surface elevation at the West Guard Gate is approximately 513 feet. The West Guard Gate is generally opened during the navigation season; however, it is closed when high flows are observed along the Genesee River to prevent the high flows from impacting the static canal to the west of the Genesee River. The West Guard Gate is fully closed at the end of the navigation season and remains closed until the western Erie Canal is refilled in early May of the following year.

The West Guard Gate at Rochester would be permanently closed and sealed to stop 100 percent of water flowing east down the Erie Canal and from Lake Erie via the Niagara River and eliminate the hydrologic connection between the Western Erie Canal and the Genesee River and the Erie Canal to the east of Rochester, NY. The closure of the West Guard Gate would maintain water for hydropower, irrigation, and local navigation in the Canal between Tonawanda and Rochester. With the closure of the West Guard Gate, the Genesee River (RM 260.7) would then provide a source of water for the Canal east of Rochester.

Figure 4-5. Close Rochester West Guard Gate

4.2.3. Cease Lock Operations on Oswego Canal, Lock O7/O8

The Oswego River is formed upstream of Phoenix, NY by the confluence of the Seneca River and the Oneida River and flows northwest into Lake Ontario. Locks O7 and O8 operate in series and are located in Oswego, NY (Figure 4-6), with Lock O8 being the most downstream near the inlet to Lake Ontario. The flows in the Oswego River are dynamic from rainfall and runoff from the 5,100 square mile watershed. USGS Gage #04249000 Oswego River has recorded an average annual flow that ranges from 2,200 cfs (cubic feet/second) up to 12,000 cfs typically in the spring, with a maximum measured flow of 37,000 cfs. Navigation season flows in August-September are much lower, typically in the range of 2,200 to 3,000 cfs. Flows through Locks O7 and O8 are static, and are only associated with navigation lockage flows during the navigation season.

High water levels in Lake Ontario do not backwater above Lock O8, and the variation of Lake Ontario water levels does not have any impact on flows from the Oswego Canal. The flows over the Varick Dam, adjacent to Lock O7, are not influenced by the downstream water level as flows are hydraulically controlled by the upstream water levels based on the free-flowing ogee spillway (an “S” shaped spillway). Lock O8 operates independently of the downstream water level; the downstream water operation level is set to the downstream (Lake Ontario) water level.

Navigation use is primarily for recreational traffic, and daily use varies greatly from a minimum of two lockages per day (two vessels) up to a maximum of 20 lockages per day (with up to 18 motorized vessels and 268 kayaks for example during Oswego Harborfest on 8/18/2018). The peak traffic occurs during Oswego Harborfest festival: as the festival starts, most of the navigation is to the north, and when the event ends, most of the navigation traffic is to the south (upstream). At other times, lockages occur in both upstream and downstream directions with no specific rationale for direction.

Closing Locks O7 and O8 would prevent upstream migrating fish and AIS species from swimming or being conveyed upstream from Lake Ontario via lockages. Locks O7 and O8 would be permanently closed and the gates sealed to stop all flow and leakage through the lock. Alternatively, these gates could simply be permanently closed, without any other measures, as leakage through the gates would not provide a vector for upstream migrating AIS species due to the vertical height between the locks (10.4 feet at Lock O8, and 14.4 feet at Lock O7).

To maintain recreational navigation through this active corridor, this measure would require self-powered boat lifts at each end and trucking with a lowboy trailer and cradle over approximately 3000-feet between the locks. The boat lifts would require a structure to allow them to travel out over the water adjacent to the closed lock and back to shore to lower the boat onto the trailer. Other facilities would include an inspection station and portable wash system as described in Section 3.5.2 to help contain AIS hitchhikers attempting to move upstream out of Lake Ontario. The wash system could include a generator to power a water heater, pressure washing pumps, and waste pumps. The water generated from the cleaning process might be directed back into the lake. This system would not handle commercial barge traffic, as boat lifts for such large vessels would be a tremendous undertaking and changing freight transport to rail or truck would be more cost-effective.

Because there is so much flow moving down the Oswego Canal, there is no effective means to eliminate AIS vectors moving downstream into Lake Ontario. However, it appears that the existing vertical barriers at the two dams upstream of Locks O7 and O8 likely prevent upstream migrating fish from entering the Oswego Canal. Preventing fish from swimming upstream through the locks would provide a strategic control point for upstream migrating AIS species into the Oswego Canal.

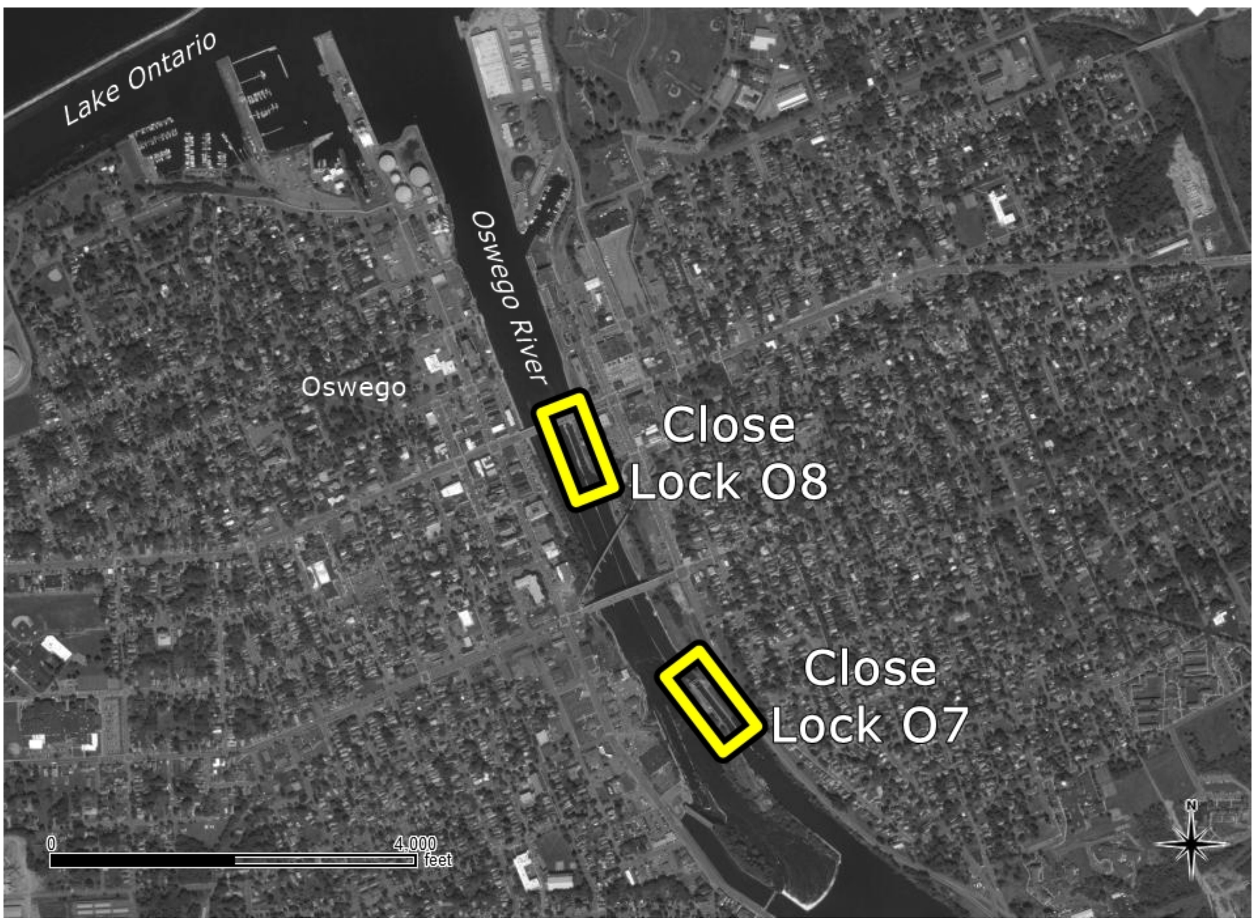

Figure 4-6. Close Locks O7 and O8.

4.2.4. Hydrologic Separation at Summit of Erie Canal

Hydrologic separation at Rome is the same measure proposed for Alternative 1 and is described in Section 4.1.1.

4.3. Networked Alternative 3: Key Watershed Protection

The objective of Alternative 3 is to reduce the probability of AIS passage from Lakes Erie and Ontario via the Erie Canal to the Finger Lakes, Oneida Lake, as well as from the Hudson River to the Upper Mohawk River. Figure 4-7 provides a schematic of this alternative. Measures to accomplish this include:

4.3.1. Bio-Acoustic Fish Fence (BAFF) at Tonawanda

The Bio-Acoustic Fish Fence (BAFF) at Tonawanda is the same measure proposed for Alternative 2 and is described in Section 4.1.2.1.

4.3.2. Cease Lock Operations at Macedon (Lock E30) and Install Fish Barrier Screen at Macedon Bypass Channel

The Genesee River intersects the Erie Canal near Rochester, between the East and West Rochester Guard Gates, about 4 miles west of Lock E33. Although no data are available on the mixing of flows, it appears that the Genesee River flows capture Canal flows from the west and heads north to Lake Ontario. A portion of the Genesee River flow is then diverted east into the Erie Canal downslope toward Macedon, NY where Lock E30 is located. This reach of the Erie Canal only flows during the navigation season. Flows at Lock E30 range from 20 cfs up to 200 cfs with an average of 100 cfs, and are regulated through the Macedon Bypass Gates, to the south of Lock E30. East of Lock 30, the Erie Canal continues east downslope toward the junction with the Seneca River.

Flows associated with navigation through Lock E30 are in addition to these controlled flows. The primary navigation use at this lock is for self-skippered canal packet boats, which are rented out by Mid-Lakes Navigation (macedonlanding.midlakesnav.com). Information from NYPA indicates that the use of these boats varies greatly, from 3 Canal packet boats per day on the weekends, to 4 or 5 on Mondays (which are the higher use). Recreational traffic is typically in the range of 8 to 10 vessels per day, with up to 10 lockages per day to accommodate these vessels. During slow periods, lockage rates as low as one lockage per day can occur, mostly for fishing boats.

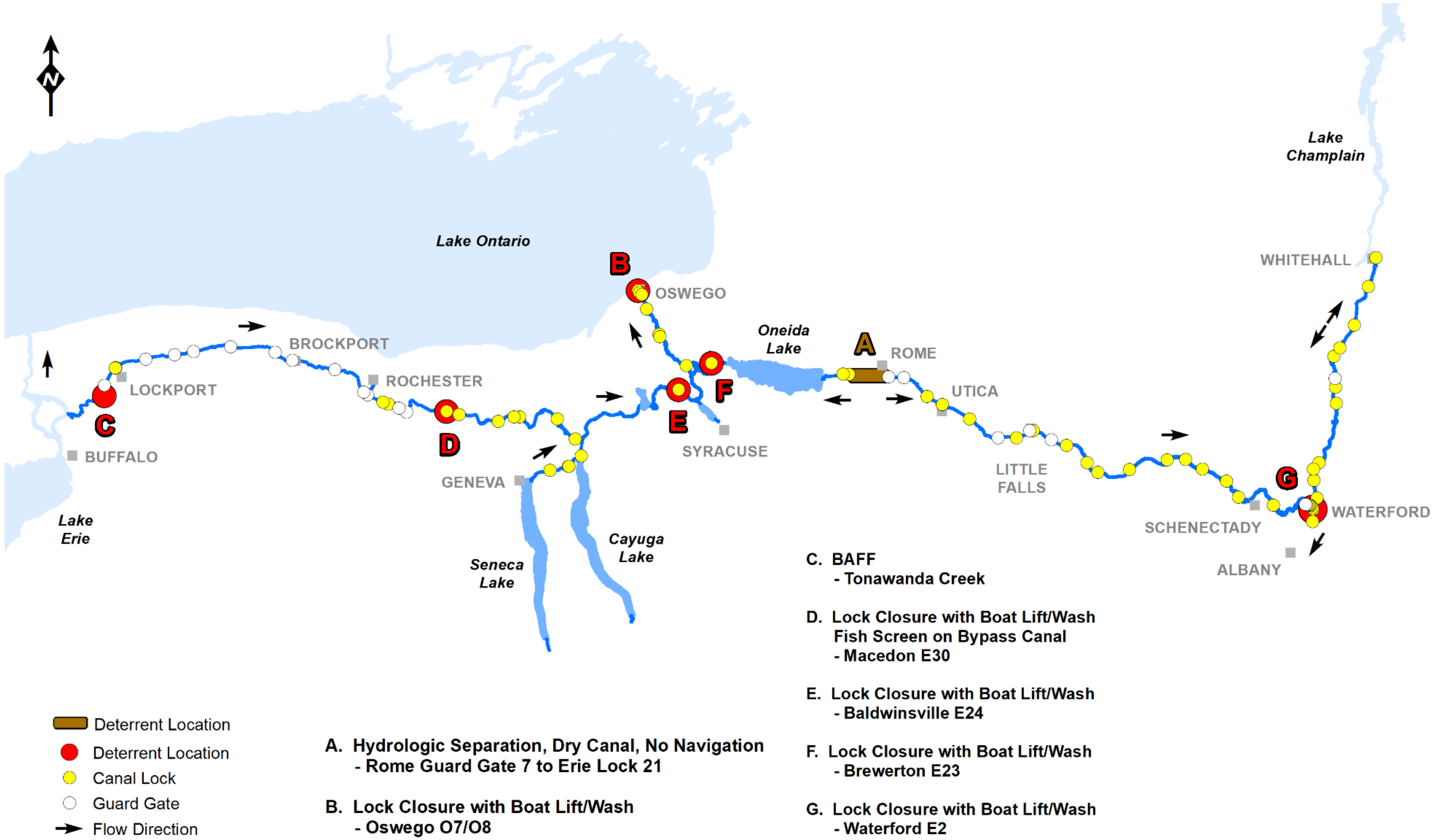

Figure 4-7. **A schematic depicting deterrents and changing flow patterns associated with Alternative 3, Key Watershed Protection.**

4.3.2.1. Cease Lock Operations at E30

Closing Lock E30 would prevent upstream migrating fish and AIS species from swimming or being conveyed upstream via lockages. These gates could simply be permanently closed, without any other measures, as leakage through the gates would not provide a vector for upstream migrating AIS species due to the vertical height between the locks (16.4 feet at Lock E30).

A boat inspection station, washing facility, and recreational boat lift could be deployed at this site with similar equipment as described in Section 4.2.3., with the exception that only one boat lift and no trucking would be needed.

4.3.2.2. Provide barrier screen on bypass channel

A barrier screen on the lock bypass channel to the south of the lock would prevent most AIS from passing this location (Figure 4-8). The barrier screen would need to be self-cleaning to prevent build-up of debris or fouling and keep the screen functioning at capacity within acceptable approach velocity parameters.

Figure 4-8. A barrier screen on the Lock E30 bypass channel.

With an estimated maximum flow of 200 cfs for initial sizing, a series of 8 “Hydrolox” type plastic belt traveling screens with an effective width of 11.5-feet could be used with a depth on the face of the screen of 11-feet. This arrangement would result in an average approach velocity, while operating at 200-cfs, of 0.2-fps. Assuming a Canal and screen depth of 14 feet at Lock E30, a screen length of at least 41 feet would be required using these criteria.

4.3.3. Cease Lock Operations on Oswego Canal, Lock O7/O8

The closure of lock operations on the Owego Canal at Lock O7/O8 is the same measure proposed for Alternative 2 and is described in Section 4.1.2.3.

4.3.4. Hydrologic Separation at Summit of Erie Canal

Hydrologic separation at Rome is the same measure proposed for Alternatives 1 and 2 and is described in Section 4.1.1.

4.3.5. Cease Lock Operations on the Erie Canal at Baldwinsville and Brewerton, Locks E24/E23

Lock E24 is located at Baldwinsville, NY in the portion of the Erie Canal, which overlaps the Seneca River, approximately 11.5 miles upstream from the confluence with the Oswego River. At Baldwinsville, the average annual flow ranges from 1,000 cfs up to 6,000 cfs with a range of 20 cfs up to 18,000 cfs as measured by USGS gage #04237496 Seneca River. A dam is located across the Seneca River with lock E24 located in the bypass channel to the south of the River. Flows in the main stem of the river are regulated by two hydropower facilities located on each end of the dam with combined capacity of 1,500 cfs. The facility to the north has a flow capacity of 600 cfs while the one on the south has a capacity of 900 cfs. Water also flows through lock E24 at Baldwinsville through either leakage or navigation.

Lock E23 is located near Brewerton, NY just downstream of where the Oneida River leaves Oneida Lake. Lock E23 is located on a bypass channel that circumvents a bend in the Oneida River. Caughdenoy Dam, located to the north of Lock E23 on that bend, is used to maintain Oneida Lake water level during the navigation season through the use of 7 Tainter gates in series. The 7 Tainter gates partially open during the navigation season, are fully opened on December 1st, and remain open until after the spring freshet. These bottom-opening gates are not a barrier to fish movement in either direction. The USGS gage at Euclid (USGS Gage #04247000) is representative of current operations, which indicate the average annual flow at this location, ranged from about 2,000 cfs up to about 5,800 cfs, with a minimum and maximum range of zero (or no flow) in May and June, to just over 10,000 cfs.

A boat inspection station, washing facility, and recreational boat lift could be deployed at this site with similar equipment as described in Section 4.2.3 with the exception that only one boat lift and no trucking would be needed.

4.3.5.1. Cease Lock Operations at Locks E24 and E23

At Baldwinsville (Lock E24) and Brewerton (Lock E23), lock operations would be permanently stopped (Figure 4-9), and replaced with boat lifts and vessel washing/check stations to minimize risk of AIS spread from "hitchhikers" on boats traveling inter-basin between the Finger Lakes, Onondaga, and Oneida Lakes. Closing Locks E24 and E23 would prevent upstream migrating fish and AIS species from swimming or being conveyed upstream via lockages. These gates could simply be permanently closed, without any other measures, as leakage through the gates would not provide a vector for upstream migrating AIS species due to the vertical height between the locks (11 feet at Lock E24 and 6.9 feet at Lock E23). A boat inspection station, washing facility, and recreational boat lift could be deployed at this site with similar equipment as described in Section 4.2.3 with the exception that only one boat lift and no trucking would be needed.

Figure 4-9. Close Locks E24 and E23.

4.3.6. Cease Lock Operations on the Erie Canal at Waterford, Lock E2

The only water that flows through the Waterford Flight (i.e., Locks E2-E6) is associated with navigation lockages during the May 1 to November 15 navigation season. Records provided indicate that recreational navigation varies greatly from a minimum of 1 lockage (1 vessel) per day to a maximum of 13 lockages (19 vessels) per day in either direction. On average, approximately 7 lockages occur daily (with 10 vessels). Commercial navigation is limited largely to the General Electric plant's infrequent project cargo needs.

4.3.6.1. Cease Lock Operations at E2

Closing Lock E2 (Figure 4-10) would prevent upstream migrating fish and AIS species from swimming or being conveyed upstream via lockages. These gates could simply be permanently closed, without any other measures, as leakage through the gates would not provide a vector for upstream migrating AIS species due to the vertical height between the locks (33.6 feet at Lock E2). A boat inspection station, washing facility, and recreational boat lift could be deployed at this site with similar equipment as described in Section 4.2.3 with the exception that only one boat lift and no trucking would be needed.

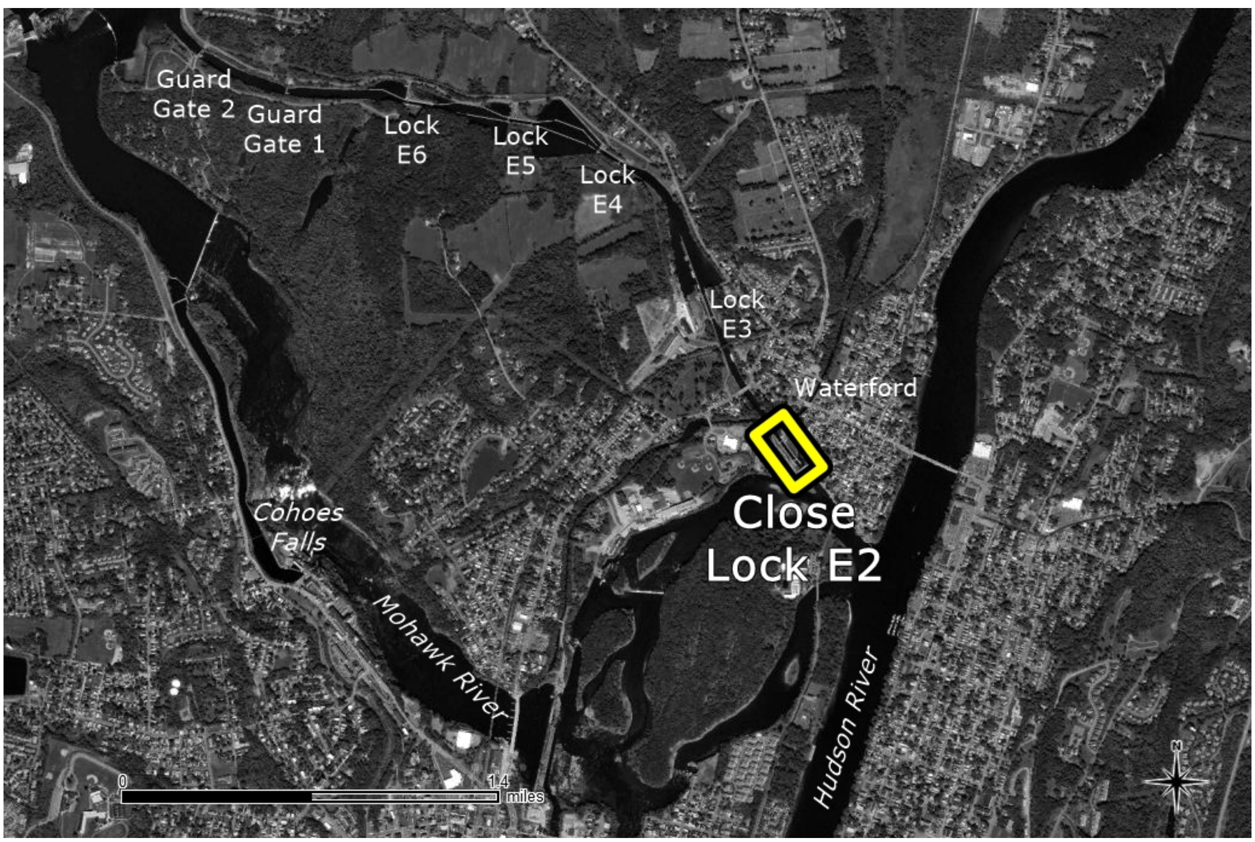

Figure 4-10. Close Lock E2.

5. EFFECTIVENESS ANALYSIS OF NETWORKED DETERRENT ALTERNATIVES

Ultimately, a networked deterrent alternative is effective if it stops the movement of aquatic invasive species (AIS) completely, and no new AIS populations are established in watersheds without current populations. Each AIS is unique in terms of current spatial distribution, population size, habitat requirements, and patterns of movement and population expansion. However, in the interest of achieving a networked deterrent that would successfully deter current and potential future AIS, species-specific characteristics were not used to evaluate effectiveness. Rather, the networked deterrent is termed effective if it stops all types of AIS from using the Erie Canal to move among the four key waterbody groups (Great Lakes, Finger Lakes, Oneida Lake, and the Hudson River) under normal flow conditions. Thus, in order to be 100% effective, the networked deterrent must prevent movement of all AIS along each of the following pathways (Figure 5-1):

1. From Lake Erie/Ontario into Oneida Lake;
2. From Lake Erie/Ontario into the Finger Lakes;
3. From the Finger Lakes into Oneida Lake;
4. From Oneida Lake into the Finger Lakes;
5. From the Hudson River into Oneida Lake; and
6. From Oneida Lake into the Hudson River.

Note that the networked deterrent alternatives have not been designed explicitly to protect the Great Lakes. Also, the potential route from Lake Champlain (assumed connected to the Great Lakes through the St. Lawrence River) into the Hudson River is not included in this effectiveness analysis, as it is under study presently by the U.S. Army Corps of Engineers.

It is important to distinguish between the effectiveness of a networked deterrent and the probability of invasion by AIS, which is not being estimated or reported here. Invasion probabilities would vary substantially by species as well as human interactions with waterbodies, and would require more detailed specific research. The effectiveness analysis methods used to compare across three networked deterrent alternatives and the results of that comparative analysis are summarized in this section; for full details, refer to Appendix C.

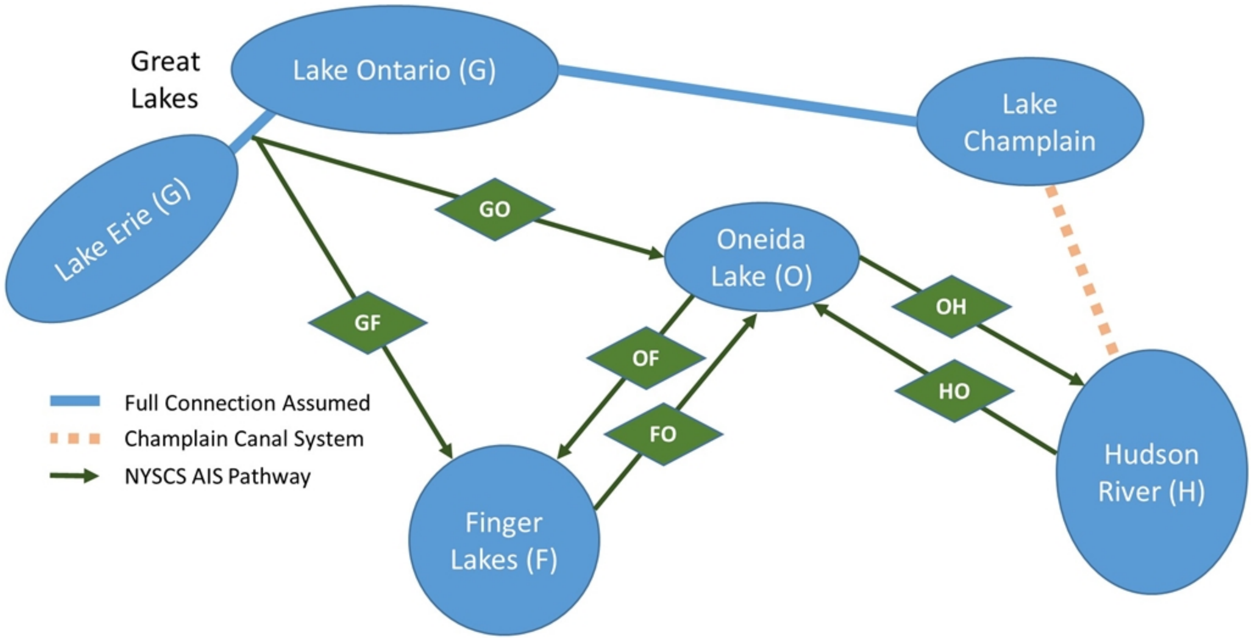

Figure 5-1. Schematic of directional AIS connections that the networked deterrent is intended to stop, labeled with the initials of "from" and "to" waterbody (e.g., Great Lakes to Finger Lakes is GF).

5.1. Effectiveness Model Methods

For each networked deterrent alternative, effectiveness has been defined as the relative decrease in the probability that AIS will use any of the six previously defined pathways over a 25-year time frame, with the deterrents in place. The decrease is relative to the estimated baseline probability of movement. For example, if the probability that AIS can move from the Finger Lakes to Oneida Lake in 25 years is currently estimated to be 50%, but would be 10% under one alternative, the effectiveness would be $100\ x\ \frac{(50-10)}{50} = 80\%$.

The effectiveness analysis is thus a relative comparison of the probabilities that each type of AIS can move through the highlighted segments of the Canal System under each networked deterrent alternative, compared to the current baseline probability. These probabilities were estimated using a probability model, with component parameters based on limited available data. The component parameters contain considerable uncertainty, which has been explicitly considered using a bounding analysis and Monte Carlo simulations (a risk simulation statistical analysis method). For a bounding analysis, most-likely values for individual parameters, such as the probability that a boat wash would remove all hitchhiking AIS from a single boat, are accompanied by reasonable upper and lower uncertainty boundaries. Because of this bounding analysis, the effectiveness results are presented as a range of numbers that account for uncertainty in the results.

For estimating effectiveness, AIS were broken into the following biological groups, which differ with respect to movement methodology and deterrent response:

- Active dispersers – including most lifestages of fishes, crawlers, and lamprey (note that Asian carp were separately considered within this category);
- Passive dispersers – defined by downstream-only movement, includes early lifestages of fishes and lamprey, invertebrates, molluscs, and plants; and
- Hitchhikers – assisted dispersal, which can include some lifestages of fish and lamprey, pelagic invertebrates, molluscs, and fragmenting plants.

Effectiveness results for these groups were then combined into an overall effectiveness estimate based on the proportion of these groups on the "least wanted" AIS list identified by The Great Lakes and St. Lawrence Governors and Premiers.

The following assumptions were made in order to estimate effectiveness.

- Effectiveness is defined in terms of stopping movement among watersheds and does not explicitly account for species that may already be present and/or established within the Canal, or for species entering the Canal from non-Canal sources, e.g., bait bucket or aquarium release.
- Estimates assume AIS are present and entering the Canal System at the start of each pathway. Thus, the effectiveness analysis does not account for differing probabilities of entrance among species or through time, but rather estimates the probability of movement at the time any individuals successfully enter the Canal System.
- Only movement through the entire pathway via one mode of dispersal is considered. Individuals that may change from one dispersal mechanism to another dispersal mechanism within the Canal System are not separately assessed.
- AIS passive dispersal is assumed to occur in a downstream direction only. Because each of the six pathways contains at least one upstream segment that contains upstream filling locks, dams, and/or waterfalls, we assume no current probability of passive dispersal among the four waterbodies.
- Effectiveness was estimated for one-year, then expanded to a 25-year time period. The 25-year time period assumes independence among years and no change in underlying assumptions over time.

5.2. Model Results

The bounding analysis model was run for the three, networked deterrent alternatives described in Section 4. The different types of AIS (Asian carp, other fish, lamprey, crawlers, and hitchhikers) were combined into one overall effectiveness result for each model simulation. The combined results are displayed in Figure 5-2 for each of the six pathways among waterbodies.

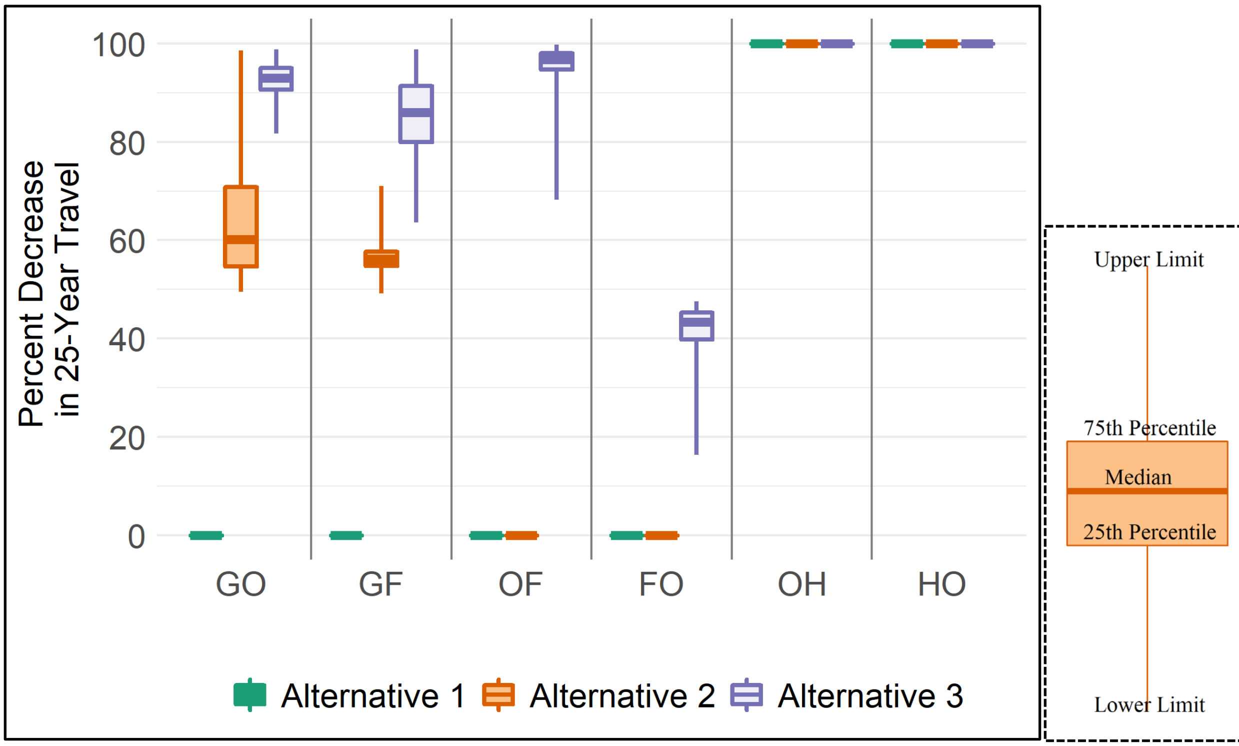

Figure 5-2. Boxplot comparing effectiveness results for three networked deterrent alternatives across six waterbody pathways, for all AIS combined. The boxplots display the median result (50% greater and 50% less), the range with most probability (25^{th} – 75^{th} percentile box), and the full range of possible results based on the Monte Carlo bounding analysis.

Alternative 1 is predicted to be 100% effective for protecting the Hudson River from AIS entering via Oneida Lake, and 100% effective for protecting Oneida Lake and the western Erie Canal System from AIS entering via the Hudson River (Table 5-1). This is the case because the hydrologic separation deterrent near Rome is predicted to stop movement of all AIS through this section in both directions. Alternative 1 offers no deterrents to prevent movement of AIS between the Great Lakes, the Finger Lakes, and Oneida Lake (0% effective).

Table 5-1. Summary of effectiveness results for three networked deterrent alternatives across six waterbody pathways, for all AIS combined

		Pathway Deterrence Effectiveness Estimate (%)					
		GO	GF	OF	FO	OH	HO
Alternative 1	Minimum	0	0	0	0	100	100
	25th Percentile	0	0	0	0	100	100
	Median	0	0	0	0	100	100
	75th Percentile	0	0	0	0	100	100
	Maximum	0	0	0	0	100	100
Alternative 2	Minimum	50	49	0	0	100	100
	25th Percentile	55	55	0	0	100	100
	Median	60	56	0	0	100	100
	75th Percentile	71	58	0	0	100	100
	Maximum	99	71	0	0	100	100
Alternative 3	Minimum	82	64	68	16	100	100
	25th Percentile	91	80	95	40	100	100
	Median	93	86	97	43	100	100
	75th Percentile	95	91	98	45	100	100
	Maximum	99	99	100	48	100	100

Alternative 2 is predicted to be 100% effective for protecting the Hudson River from AIS entering via Oneida Lake, and 100% effective for protecting Oneida Lake and the western Erie Canal System from AIS entering via the Hudson River. In other words, a hydrologic separation deterrent near Rome is predicted to stop movement of all AIS through this section in both directions. In addition, Alternative 2 is estimated to also reduce overall AIS movement from Lake Erie and Lake Ontario into the Finger Lakes by 55-58% and to reduce overall AIS movement from Lake Erie and Lake Ontario into Oneida Lake by 55-71%. Importantly, Alternative 2 is estimated to be 100% effective to prevent Asian carp movement from Lake Erie to the Finger Lakes or Oneida Lake because of the hydrologic separation in Rochester (WGL), and 100% effective to prevent Asian carp movement from Lake Ontario to the Finger Lakes or Oneida Lake because of the closed lock on the Oswego Canal (O7/8). Alternative 2 offers no deterrents to prevent movement of AIS between the Finger Lakes and Oneida Lake (0% effective).

Alternative 3 is predicted to be 100% effective for protecting the Hudson River from AIS entering via Oneida Lake, and 100% effective for protecting Oneida Lake and the western Erie

Canal System from AIS entering via the Hudson River, again due to hydrologic separation near Rome. With deterrents in the western end of the Erie Canal and near Lake Ontario on the Oswego Canal, Alternative 3 is estimated to prevent 80-91% of AIS movement from Lake Erie and Lake Ontario into the Finger Lakes and to prevent 91-95% of AIS movement from Lake Erie and Lake Ontario into Oneida Lake. It is also estimated to prevent approximately 98-99% of Asian carp movement between the Great Lakes and the Finger Lakes and between the Great Lakes and Oneida Lake. Alternative 3 offers additional deterrents to prevent movement between the Finger Lakes and Oneida Lake. It is estimated to reduce AIS movement from Oneida Lake to the Finger Lakes by 95-98% because of the closed lock at Baldwinsville. Alternative 3 is estimated to prevent 40-45% of potential AIS movement from the Finger Lakes to Oneida Lake; deterrence is lower in this reach because actively migrating fish and crawlers can bypass the lock closure at E23 by moving upstream through Caughdenoy Dam's Tainter gates.

6. COST ESTIMATE EVALUATION

This section describes the methods and results of the planning-level cost evaluation for installation and operation of each alternative. Opinions of probable construction costs were estimated for each of the three Networked Alternatives described in Section 4. These costs are intended for comparing the alternatives, and identifying a reasonable planning level capital cost of implementing these alternatives, including design, permitting, and construction costs. Additionally, annual operating and maintenance costs (O&M) are identified for each solution. This information provides a good basis for comparison and cost planning for the future. Due to the complexity of the existing operations and variable conditions at each lock, gate, etc., this study is not addressing any potential cost savings if existing infrastructure were to be decommissioned, which could be substantial given the elimination of future O&M costs at numerous facilities. All costs are quoted in 2019 dollars.

6.1. Capital Cost

The opinions of probable construction cost (OPCC) estimates include the construction cost, plus a contingency and design cost. The cost estimate is largely based on applicable major features of previously constructed projects. This parametric approach is based on a review of available literature, similar or reference projects that are scaled and calibrated to these recommendations, and professional judgement of large, civil infrastructure projects. Other feature costs are estimated based on quantity take-offs and unit pricing (such as soil or concrete fill). The OPCC is developed to the American Association of Cost Engineers International (AACEI) CLASS 5 Cost Estimate, which is generally prepared for screening design concepts. The level of engineering for the CLASS 5 estimate is 0% to 2% complete with an accuracy of -50 to +100 percent. Appendix D provides a breakdown of the cost estimate for each option. The total project cost includes contingency and design work. The contingency and design costs are assumed to be 20% and 25% of the construction cost, respectively, where appropriate, or are simply estimated with professional judgement. The cost estimate includes a range defined by three capital costs including the estimated cost, plus a low and high range cost. The low range is assumed to be 70% of the total cost while the high is 150%.

6.2. General O&M Cost

Operating and maintenance costs are estimated as a percentage of the capital cost. The percentages applied to each of the components are presented in Table 6-1. These costs are associated with the general operating and maintenance of the facility and are used for comparison purposes only.

Table 6-1. General annual O&M cost basis.

Category	Percentage
Structural	1.0%
Mechanical/Electrical	3.0%

6.3. Power Costs

The power costs include the attraction pump power costs and general equipment power costs. Power costs assume continuous operation of the facility over a 12-month period. Power costs are assumed to be 0.13 $/kWh, an average of commercial rates from NYSERDA. The actual provider of power would be National Grid NY or NYSEG.

The comparative costs are presented in Table 6-2, which summarizes the information detailed out in the cost tables presented in Appendix D.

Table 6-2. Summary of Opinion of Probable Construction Costs (OPCCs) and O&M costs for the Networked Alternatives.

Alternative	Capital Cost[1]	Annual O&M Cost[2]
1 – Hydrologic Separation at Summit of Erie Canal	$2.3 m ($1.6 m to $3.5 m)	$13,000
2 – Watershed Divide	$12.0 m ($8.5 m to $18.2 m)	$1,425,000
3 – Key Watershed Protection	$26.5 m ($18.6 m to $39.9 m)	$4,257,000

1 Capital costs rounded to nearest $100,000
2 Annual O&M costs include power costs, and are rounded to the nearest $1,000

7. ENVIRONMENTAL PERMITTING EVALUATION

7.1. Permitting Summary

Each of the three proposed alternatives would require construction in or adjacent to the Erie Canal or adjacent water bodies and would require permits typically associated with in-water work in NYS. The permits associated with the proposed alternatives are triggered by the potential impacts to wetlands, navigation, dredging, and construction of in-water features due to construction associated with the networked alternative concepts (i.e., boat lift). The permits, consultations, and proposed activities that would trigger them are provided in Attachment 1. There are multiple regulations that require similar consultations at both the state and federal level. Where appropriate, this coordination should take place through the use of a U.S. Army Corps of Engineers (USACE) and New York State Department of Environmental Conservation (NYSDEC) Joint Permit Application (JPA) where the necessary application materials are sent to both state and federal agencies to streamline the permitting process.

As the projects are being conducted by a state agency, they would require an environmental impact assessment prescribed by 6 NYCRR Part 617 State Environmental Quality Review (SEQR). SEQR is not a permit but rather a self-enforcing program where state and municipal agencies are required to demonstrate that their actions, or the actions they issue permits for, have satisfied the environmental review requirements required under SEQRA. SEQRA reviews are completed in standardized formats, which include the Short Environmental Assessment Form (SEAF), Long Environmental Assessment Form (LEAF), and an Environmental Impact Statement (EIS). Which format is used depends on the size, scope, and potential for significant adverse environmental impacts associated with an action. The SEQR strategy and requirements would be dependent on how the selected network alternative is developed (i.e., multiple projects or one project). If developed as one large project, there is a high potential for an Environmental Impact Statement versus an Environmental Assessment.

7.2. Permitting Challenges

While the proposed action would provide the benefit of preventing the spread of Aquatic Invasive Species (AIS) between the Hudson River and Great Lakes watersheds, challenges may be encountered during the permitting process, which could impact schedule. It is critical to develop a permitting strategy that includes close coordination with design and construction requirements and an agency pre-application meeting. Lack of detail in design and construction requirements (i.e., staging areas) to assess temporary and permanent impacts, when developing the permit application, typically results in extended permitting schedules, additional permit conditions and may result in redesign of the project. In addition, not engaging regulatory agencies for pre-application meetings can impact project design and schedule. A summary of additional permitting challenges is provided below (Table 7-1).

7.2.1. Project Complexity

The Erie Canal covers a large geographic area and spans 338 miles between Waterford, NY and Lake Erie. The three proposed alternatives entail the construction or modification of in water features at 1, 4, and 7 different locations respectively. As additional locations and deterrent measures are incorporated into the cumulative project footprint, the number of stakeholders and complexity of the permitting process would also increase. The alternatives with the fewest number of locations, stakeholders, and potential impacts to the Erie Canal would inherently have a less complex permitting strategy.

7.2.2. Stakeholder Outreach

As part of the regulatory process, there is an associated public review period. As the project has the potential to impact recreational use in the Canal, the development of a public outreach plan is an important step in the permitting strategy.

7.2.3. Historical Significance

The project would include construction within the New York State Barge Canal Historic District, a significant historic property listed in the National Register. There are 563 individual contributing resources that comprise the New York State Barge Canal Historic District, including locks, lockhouses, bridges, dams, storehouses, embankments, spillways, utilitarian buildings, and powerhouses. It is recommended that NY State Historic Preservation Office (SHPO), part of NYS Department of Parks, Recreation and Historic Preservation, and the Erie National Heritage

Corridor, part of the National Park Service, be coordinated and consulted early on in the permitting process to identify ways to avoid or mitigate potential impacts on the New York State Barge Canal Historic District.

Table 7-1. Summary of permitting complexity (dot size increases with increasing complexity).

Challenges	Alternative 1: Protect the Hudson	Alternative 2: Watershed Divide	Alternative 3: Key Watershed Protection
Number of Project Features	•	●	⬤
Number of Municipalities	•	●	⬤
Dredging	•	●	●
In-Water Construction and Impacts	●	●	⬤
Wetlands	•	•	•
Navigation	●	●	⬤
Recreation	•	•	•
Public Outreach	•	●	⬤
Historical Features	●	●	⬤
Visual Impact	•	●	●
Mitigation	•	•	•
Threatened and Endangered Species	•	•	•
KEY	*Less Complex* • → ● → ⬤ *More Complex*		

8. NETWORKED SYSTEM ALTERNATIVES EVALUATION AND RECOMMENDATION

This section describes how the Effectiveness, Cost, and Permitting analyses were used to select a final networked deterrent alternative recommendation.

8.1. Recommended Networked Deterrent Alternative

This study recommends Alternative 2, the Watershed Divide Alternative, be advanced as the best means to stop the movement of AIS through Erie Canal among key waterbodies. A detailed description of the Watershed Divide Alternative is provided in Section 4.2. The following key aspects of the Watershed Divide Alternative support this recommendation.

1. This Watershed Divide Alternative would achieve complete hydrologic separation at two locations along the Erie Canal. Hydrologic separation is the most effective deterrent available for all species and life stages of AIS (adults, larva, seeds, eggs, etc.). Over 150 years ago, the construction of the Erie Canal created an un-natural pathway for water to move between several watersheds. Disconnecting this pathway and restoring natural drainage areas where possible would stop the direct water transport of AIS across watersheds and promote containment, allowing focused control efforts to be undertaken for previously-established populations.

   With implementation of the Watershed Divide alternative, the Mohawk and Oneida watershed would be disconnected, and all flow from the upper Mohawk River would move downstream to the Hudson River basin. A second location for hydrologic separation is at the West Rochester Guard lock; this would disconnect the artificial hydrologic connection between the Oak Orchard-Twelvemile and Genesee watersheds. In combination, these two hard stops in the Canal would prevent waterborne transport through the Erie Canal of all AIS from: 1) the Great Lakes to the Hudson, 2) from Lake Erie to the Finger Lakes; and from the Hudson to Oneida Lake, the Finger Lakes and the Great Lakes.

2. The high flow conditions within the Oswego Canal and into Lake Ontario prevent use of hydrologic separation as an alternative; however, employing a different deterrent at Oswego Canal locks would help stop AIS moving out of Lake Ontario and provide increased protection for the Finger Lakes and Oneida Lake. Thus, this alternative incorporates lock closure at 07 and 08. While the effectiveness analysis conducted showed that additional strategic lock closures with boat wash stations could increase protection for the Finger Lakes and Oneida Lake, this result was driven by

increased effectiveness for deterring AIS fish species introduced into these landlocked waterbodies via other vectors (e.g., overland boats, unauthorized intentional releases) and hitchhiker species specifically. Therefore we are proposing that the lock closure and boat lift and wash station deterrent at Lock O7/O8 be considered a pilot effort. If this deterrent proves effective after implementation, monitoring, and any necessary refinements, this deterrent can be deployed strategically at additional locks, such as those noted in Alternative 3, to further disconnect watersheds and restore natural drainage areas for the purpose of isolating AIS populations.

3. The BAFF/SILAS deterrent component of the Watershed Divide Alternative provides additional protection for 60 miles of the Erie Canal fisheries between Tonawanda Creek and the Genesee River, who would otherwise not be protected by the West Guard Gate at Rochester. The single greatest concern raised during outreach was prevention of invasion by Asian carp from the Great Lakes. The BAFF/SILAS deterrent was selected and placed at the western end of the Canal specifically to address this concern and would help deter carp from ever entering the West end of the Canal. This deterrent would also help protect several western NYS tributaries that support recreational fisheries, including several that support world-class brown trout fishing.
4. Estimated capital and O&M costs for the Watershed Divide Alternative are 53% of the costs of Alternative 3. While they are also nearly 4 times greater than costs of Alternative 1, they provide substantially more protection for more water bodies that are today subject to the action of invasive species.
5. The permitting plan identified that permit complexity for the Watershed Divide Alternative would be slightly less than Alternative 3 and greater than Alternative 1. As indicated in Appendix E, this is related to a less complex USACE permitting for fill and removal at fewer locations.

8.2. Education, Outreach, and Monitoring

Most invasive species are generalist, and it is inherent to their nature to rapidly spread, grow and establish new populations under a wide variety of habitat conditions. In contrast, most native species are more specialized as they have co-evolved with other species over long periods of time and have created a specific niche within that system. Given these general characteristics, it becomes more obvious why, when dealing with invasive species, a focus on prevention is essential. Full eradication of an established invasive population is both costly and, often, infeasible. Preventing the introductions of AIS is the most effective way to prevent harm

(Leung et al. 2002) and generally can be conducted at a fraction of the costs of population control measures. However, once the opportunity for prevention has passed and populations are established, only two options remain: control populations in selected locations and management of human activity. For established populations of AIS, limiting their dispersal, via boating and other vectors, can be a realistic alternative (Vander Zanden and Olden 2008).

The recommended networked deterrent alternative, Watershed Divide, has been designed to minimize the ability of AIS species to spread among key waterbodies using the Erie Canal; this alternative would address the prevention of new introductions and limit the dispersal ability of any AIS that are already present within sections of the Canal or may arrive in the future. Nonetheless, as summarized in the Ecological Summaries of Aquatic Invasive Species Guilds (Appendix A), unauthorized intentional release is likely to continue to all waterbodies. Public engagement is critical to minimize unintentional transport and release of AIS and prevent illegal intentional release. Increasing public awareness through education tools designed to tell the story about AIS invasions and about actions that people can take to prevent AIS introduction and/or reduce their spread of AIS will be key to reversal of the long-term trend of increasing AIS invasions. Furthermore, education and outreach programs specific to stopping AIS in the NYS Canal System would be important tools for engaging the public and mobilizing support of this ongoing effort.

Some approaches to outreach and education that have been used throughout the country include:

- informational website
- signage at entry points
- informational pamphlets, fact sheets, species identification cards
- local public meetings
- local school programs
- clean boat tag or permit programs
- canal stewardship program

Another essential component to AIS deterrence is implementation of a rigorous monitoring program. Monitoring passage at deterrent installations and incorporation of results into adaptive management will be critical to the success of stopping AIS movement in the Canal.

Any Canal deterrent monitoring program should incorporate both an early detection program and systematic sampling. The early detection/monitoring program should involve focused sampling at key locations, including along invasion pathways and on either side of hydrologic separations. The systematic sampling should be set up to evaluate performance of each deterrent and may need to include focused experimental studies to inform operational changes or physical refinements to the installation. For example, early detection monitoring new species from Lake Erie should be conducted on both sides of the BAFF and Hydrologic Separation location at the West Rochester Guard Lock while monitoring invasions from Lake Ontario may involve sampling only upstream at Lock E7 for invasive species known to be present in the lake.

A variety of appropriate methods to study aquatic organisms are available. The use of multiple methods may be necessary to increase cover the diversity of AIS and/or to increase confidence in study results. Applicable methods may include:

- environmental DNA (eDNA),
- settlement samplers,
- entrainment sampling,
- plankton tows,
- rish biotelemetry,
- monitoring through Citizen Science Reporting Programs (e.g., iMapInvasives/iNaturalist).

A canal monitoring program should include an information-sharing component, where data is shared with other monitoring programs operating in NYS as well as received from citizen science reporting programs such as iMapInvasives. It also may be advantageous to coordinate monitoring methods with the various regional monitoring and research programs active throughout NYS (Section 8.3). If the Canal monitoring documents a new invasion or new AIS, the program should take immediate and appropriate actions consistent with the New York DEC Rapid Response for Invasive Species (see: http://www.dec.ny.gov/docs/lands_forests_pdf/isrrprogrampolicy.pdf).

Several potential enhancements or adjustments were identified in the description of the recommended alternative (Section 4.). Results of monitoring efforts should be used to inform decisions about implementing these or other potential adjustments or enhancements at specific deterrent installations. It may be useful to create a performance-modeling tool that uses real data to estimate actualized effectiveness of the networked alternative from a whole-Canal perspective. Understanding the performance of both the independent deterrents as well as any networked solution will be valuable for application of adaptive management principles in the Canal and consideration of future actions that are needed to prevent the use of the Erie Canal by novel AIS that make their way to NY waters.

8.3. Compatibility and Integration with Existing Programs

An existing network of federal, state, university, NGO, conservancy groups, lake associations, soil and water conservation districts, and citizen science initiatives collaborate on AIS monitoring and research in New York State. Regional coordination of AIS preventing, monitoring and control including any Canal-based program will benefit long-term effort at reducing AIS impacts to NYS waters. The following is a brief summary of ongoing monitoring efforts in the region.

New York State Department of Environmental Conservation Invasive Species Comprehensive Management Plan

Efforts at the state level to manage invasive species include the 2003 formation of an Invasive Species Task Force and the 2005 Invasive Species Task Force Report; formation of the Invasive Species Council and Invasive Species Advisory Committee; NYS Invasive Species Research Institute; the invasive species database iMapInvasives; the NYSDEC Bureau of Invasive Species and Ecosystem Health; and the creation of the eight regional Partnerships for Regional Invasive Species Management (PRISM Programs). The New York State Invasive Species Comprehensive Management Plan includes eight initiatives and recommended actions to guide the management activities of State agencies, and to align the priorities of regional and local natural resource managers to State-level actions. (see: https://www.dec.ny.gov/docs/lands_forests_pdf/iscmpfinal.pdf)

New York Invasive Species Research Institute (NYISRI)

The NYISRI is associated with Cornell University. Funding for NYISRI is provided by the Environmental Protection Fund as administered by the New York State Department of Environmental Conservation. (see: http://www.nyisri.org)

New York Sea Grant (NYSG)

New York Sea Grant, a cooperative program of Cornell University and the State University of New York (SUNY) operates an AIS Launch Stewards Program that provides watercraft inspections. In addition to supporting other New York State AIS programs, NYSG's primary focus is on providing educational materials and public outreach an awareness about AIS.(see: https://seagrant.sunysb.edu)

Adirondack Park Invasive Plant Program (APIPP)

APIPP is a program founded by the Adirondack Chapter of The Nature Conservancy (TNC), NYS Department of Environmental Conservation (NYS DEC), NYS Department of Transportation (NYS DOT), and NYS Adirondack Park Agency (APA). APIPP is funded, in part, through the invasive species line of NYS's Environmental Protection Fund as administered by the NYS DEC. In 2018, APIPP collaborated with the Paul Smith's College Adirondack Watershed Institute (AWI), NYS DEC, and other regional partners to advance the fourth year of the Adirondack AIS Prevention Program which staffed boat launch stewards at 51 priority launches and operated 27 regional boat inspection and decontamination stations. APIPP also collaborated with NYS DOT to build a boat inspection and decontamination station at the newly renovated I-87 Northway Adirondack Welcome Center in Glens Falls (Quirion et al. 2018). The new station will service boaters traveling north into the Adirondacks from southern New York waters. In 2018, the APIPP including seventy-three volunteers and two response team members, surveyed 63 Adirondack waterways for aquatic invasive plant species. APIPP's AIS early detection team, staff, and partners conducted zooplankton and sediment sieves sampling in 32 lakes with no new infestations of small-bodied aquatic invasive animals discovered. Mechanical and manual management for AIS infestations is ongoing throughout the Adirondack region by various lake association and municipal partners. (see: http://adkinvasives.com/)

Capital-Mohawk Partnership for Regional Species Management (PRISM)

The Capital-Mohawk PRISM focuses its invasive species monitoring on three Canal Systems (Erie, Champlain, and Feeder) that transect the region, the Hudson River with its three major cargo ports (Albany, Catskill, and Troy), and the Mohawk River, due to its connectivity to the Great Lakes. The Capital-Mohawk PRISM uses citizen science and partners with iMapInvasives to help with early detection. Like other PRISMs, the Capital-Mohawk PRISM operates a watercraft inspection steward program that inspects watercraft at launch sites across the Capital/Mohawk region. In 2018, Capital-Mohawk PRISM also funded a research project entitled "Early detection and range expansion of the invasive bloody-red shrimp, *Hemimysis anomala*, and the round goby, *Neogobius melanostomus* in the Erie Canal and upper Hudson River." Survey techniques included: (1) seining for the presence/absence of round goby and (2) plankton net sampling for bloody-red shrimp at a combination of lock, marina, dock and boat launch sites along the Erie Canal and Hudson River, and (3) a series of goby (predator) and bloody-red shrimp (prey) controlled feeding experiments under different light conditions. (see: http://www.capitalmohawkprism.org/)

Finger Lakes PRISM

The Finger Lakes PRISM currently has a watercraft steward program that inspects watercraft for AIS at popular boat launches at strategic locations in the individual Finger Lakes, the Erie Canal, the Genesee River, and Lake Ontario. The Finder Lakes PRISM also has an annual survey program for early detection rapid response (EDRR) of high priority aquatic invasive macrophytes. (see: http://fingerlakesinvasives.org/)

Lower Hudson PRISM

The Lower Hudson PRISM contracts with Hudson River Sloop Clearwater, Inc. to run an AIS Program that includes a watercraft inspection steward program, an education and outreach program, and a volunteer training/surveying program. This multifaceted program works to educate a wide variety of people throughout the Hudson Valley including, but not limited to, boaters, anglers, lake association members, and the general public about AIS identification and spread prevention, and to promote citizen science by getting locals involved in AIS early detection surveying.(see: https://www.lhprism.org)

St. Lawrence Eastern Lake Ontario (SLELO) PRISM

The SLELO PRISM is very active in terms or AIS monitoring and surveillance. SLELO and its partners Implement voluntary watercraft inspections and educational outreach along Eastern Lake Ontario, provide early detection surveillance of priority freshwater resources every two years, utilize innovative technology to detect AIS, and conduct volunteer citizen science initiatives. In 2017, the Eastern Lake Ontario Region the SLELO PRISM partnered with The Nature Conservancy, Cornell University and NYS Department of Environmental Conservation to implement a project to assess the feasibility of using environmental DNA, or eDNA, as an early detection tool for AIS. The SLELO eDNA monitoring program includes sampling in the Oswego River, a potential pathway between Lake Ontario and the Erie Canal (Williams et al. 2017). (see: https://www.sleloinvasives.org)

Western NY PRISM

The Western New York PRISM program has a watercraft inspection program where boat stewards perform voluntary watercraft inspections to remove visible aquatic plants and animals at boat launches in Western New York. This PRISM has also focused its efforts on early detection and reporting of AIS by professionals and citizen scientists through iMapInvasives. (see: https://www.wnyprism.org)

Adirondack Watershed Institute (AWI) and Adirondack Lake Assessment Program (ALAP)

The AWI is a component of Paul Smith's College that conducts regional-scale water quality monitoring and invasive species research and management. Current invasive species research projects include: investigating the effects of water temperature on growth rates of native and invasive milfoil; determining the probability of lakes harboring invasive aquatic plants based on landscape attributes and boater surveys to develop a risk model; and developing environmental DNA methods for surveillance of Asian clam and Zebra mussel. ALAP is a cooperative effort between Protect the Adirondacks and the Paul Smith’s College Adirondack Watershed Institute (AWI) that involves research and monitoring collaboration between scientists and volunteers

(Laxson et al. 2019). ALAP includes water quality monitoring for 73 lakes from the Adirondack Region. For many of these lakes, the ALAP dataset represents the only available source for information on water quality. While ALAP does not include specific monitoring for invasive species, its water quality database is an indicator of potential suitability and its monitoring of tropic status may help indicate changes to lake ecosystems as a result of AIS colonization. (see: https://www.adkwatershed.org/https%3A/www.adkwatershed.org/research/invasive-species and https://www.adkwatershed.org/adirondack-lake-assessment-program-alap)

New England Interstate Water Pollution Control Commission (NEIWPCC)

NEIWPCC staff assist the Lake Champlain Zebra Mussel Monitoring Program by sampling the lake and its tributaries for juvenile mussels (see Lake Champlain Basin Program). (see: https://neiwpcc.org)

Lake Champlain Basin Program (LCBP)

Ongoing Zebra mussel monitoring in Lake Champlain falls within the Lake Champlain Long-Term Water Quality and Biological Monitoring Project. The LCBP coordinates efforts with the Vermont Department of Environmental Conservation's Lake Champlain Zebra Mussel Monitoring Program to monitor for veliger (larvae), settled veliger (juvenile), and adult zebra mussel life stages at open-water and nearshore stations in Lake Champlain and its tributaries as well as twenty-six inland lakes deemed high risk for infestation. The program has stations located in southern Lake Champlain at Crown Point, Chipman Landing, and Benson Landing and the Mettawee and Poultney Rivers but does not currently monitor in the Champlain Canal. (see: https://www.lcbp.org and https://dec.vermont.gov/watershed/lakes-ponds/aquatic-invasives/monitoring/zebra-mussels)

Aquatic Invasive Rapid Response Plan

New York DEC has developed a rapid response policy that includes aquatic species; DFL-16-1/Rapid Response for Invasive Species: Framework for Response. In the event of a new invasive species infestation, the policy aims to give managers a framework to address the necessary components of an effective response including: coordination, communication, public outreach, planning, scientific analysis, information management, and compliance with legal and regulatory requirements, resources and logistics. (see: https://www.dec.ny.gov/docs/lands_forests_pdf/isrrprogrampolicy.pdf)

Other Cooperating Partners

Numerous other conservancy groups, lake associations, and soil and water conservation districts also participate in regional AIS monitoring.

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APPENDIX A

Summaries of Existing Information

APPENDIX A1

Ecological Summaries of AIS Guilds

This appendix includes descriptions of the following aquatic invasives species (AIS) guilds:

1. Fish – Unassisted Dispersal
2. Fish – Assisted Dispersal
3. Invertebrates – Crayfish
4. Invertebrates – Molluscs
5. Invertebrates – Pelagic
6. Aquatic Plants – Fragmenting
7. Aquatic Plants – Floating

1. FISH – UNASSISTED DISPERSAL

1.1. Species List

Four invasive fish with dispersal identified as the primary dispersal pathway have been identified as priority species of concern; many other invasive fish species, including several species of Asian carp have the potential to colonize the canal system and would benefit from control measures designed to manage these species. Since the four species in the Asian Carp group have similar ecology and life history, we have focused the Asian Carp summary on Bighead Carp but discuss distinguishing facts related to the other carp species as relevant.

Species	Common Name	Size
Morone americana	White Perch	Up to 58 cm
Alosa pseudoharengus	Alewife	25 cm, up to 38 cm
Tinca tinca	Tench	Up t0 84 cm
Hypophthalmichthys nobilis	Bighead Carp (representative of 4 Asian carp species)	Up to 140 cm

1.2. Ecology

All four of the fishes discussed in this group are generalists and have the capacity to establish populations in a variety of habitats across a broad geographic range and variable environmental conditions. White perch, for example are native to brackish waters along the Atlantic coast, ranging from the coastal areas of New Jersey as far south as South Carolina, but have successfully invaded freshwater lakes, reservoirs, and canals (Fuller et al. 2019a). White perch are primarily piscivorous, feeding on other fish; but, also are opportunistic predators that may eat fish eggs and larvae, annelids, insects, some crustaceans, and detritus (Fuller et al. 2019a). White Perch may prey on eggs of desirable sportfish including Walleye *Stizostedion (Vitreum vitreum*) and White Bass (*Morone chrysops*).

Alewife are anadromous fish native to offshore waters of North America, from Nova Scotia to South Carolina. In their native range, they ascend rivers in the spring to spawn (Scott and Crossman, 1973). However, where they have invaded lakes and reservoirs, Alewife complete their life cycle in freshwater and spawn successfully in a wide variety of habitats (ASMFC 2009; Fuller et al. 2019b). They are fecund can become overabundant in the new habitats without natural predators, altering the zooplankton community and native fish abundance by size-selective predation. Alewife are relatively long lived with a maximum age of 11 (Madenjian et al. 2008).

The Tench is a freshwater cyprinid that prefers shallow slow moving or still water such as ponds or lakes (Avlijaš et al. 2018). Tench have high tolerance to a broad range of environmental conditions and are able to survive in low oxygenated waters, helping them outcompete native species that are more sensitive to oxygen depletion and are unable to survive in highly productive waters (Boucher and Rutherford 2019). Tench will bury in the mud in attempt to wait out temporary anoxia, partial drying and/or cold or freezing temperatures (Baughman 1947). Rosa (1958) reported that live Tench have been successfully shipped live in without water in boxes of weeds without water. Tench also have a long-life span and can survive up to 20 years. Tench are generalist predators, exploiting a wide range of macroinvertebrates including zooplankton, insects, amphipods, crayfishes, gastropods and small bivalves (Avlijaš et al. 2018).

The food habits of the four Asian carp species vary. Bighead Carp is a powerful filter-feeder with a wide food spectrum that grows fast and reproduces quickly (Xie and Chen 2001), which makes this species a strong competitor. Their diets overlaps with that of planktivorous species (fish and invertebrates) and to some extent with that of the young of virtually all native fishes (Nico et al. 2019). Bighead Carp are thought to deplete plankton stocks for native larval fishes and mussels (Laird and Page 1996). Silver Carp is also planktivorous. In contrast, Grass Carp consume vegetation, and black carp are molluscivorous. Freedman et al. (2012) showed that resource use and trophic levels of the fish community change when Asian carp are present. Bighead carp prefer large rivers but can also inhabit smaller rivers and streams, as well as lakes and ponds (USFWS 2018). Asian carps are long-lived fish. Grass Carp live up to 11 years; Silver Carp can live up to 20 years.

1.2.1. Reproduction

White Perch spawn multiple times over the course of 10 to 21 days in the spring when water temperatures are between 10 and 16°C. Males and females congregate in large groups, and eggs and sperm are spread randomly throughout the water column. Males may spawn for the first time at 2 years, and females usually by 3 years. The fecundity of females ranges between 20,000 and 150,000 eggs (Jenkins and Burkhead 1994). Eggs hatch in 3-5 days, and larvae remain near the spawning area until they grow large enough to move downstream White perch are known to hybridize with native white (*Morone chrysops)* and yellow *(M. mississippiensis)* bass, a concern for fisheries managers (USFWS 2018)

Alewife spawn in spring when water temperatures are between 13-16°C. They spawn at night, near the surface, throughout nearshore areas including bays, harbors, and in tributaries (Scott and Crossman 1973). In landlocked populations, the spawning period is protracted, lasting more than a month. Mean fecundity is 11,150 for fish averaging 160 mm total length and

22,400 for fish averaging 192 mm (Hlavek and Norden 1978). The non-adhesive eggs are demersal and are broadcast at random over any type of bottom. Optimum temperature for egg incubation is 17.8ºC and incubation time varies from 15 days at 7.2ºC to 3.7 days at 21.1ºC (Edsall 1970). Alewife larvae average 3.8 mm at hatching (Heinrich 1981).

Tench are highly fecund and can spawn multiple times during a season. Spawning occurs at ~18°C in shallow, densely vegetated waters during the summer (May to August in Europe), potentially multiple times in a season, and involves the release of hundreds of thousands of eggs per kg of fish (Boucher and Rutherford 2019).

Female Bighead Carp reach sexual maturity at three years of age, while males can reach sexual maturity in two years; however, this varies significantly with changing environmental conditions (Huet 1970; Kolar et al. 2007). Bigheaded and Silver carp are spawn in large rivers and it is believed that a rising hydrograph (flood event) is a primary spawning cue (Kolar et al. 2007). Fecundity, in Asian carp, increases with age and body weight and is directly related to growth rate (Verigin et al. 1990). In its native range, Bighead Carp has a fecundity ranging from 280,000-1.1 million eggs and in North America the range is 4,792-1.6 million eggs. Bighead and Silver carp produce eggs that are semi-buoyant and require current to keep them from sinking to the bottom (Soin and Sukhanova 1972). The eggs float for 40-60 hours before hatching.

1.2.2. Habitat

White Perch are native to brackish environments and can tolerate a wide range of salinity from 0 to 18 ppt. Mortality for White Perch begins around 31°C (Dorfman and Westman 1970) and increases at temperatures of 32-35°C (Fischer et al. 1989). White Perch are able to survive low DO conditions (<1 mg/L) for durations less than 24-hours but prefer DO levels >3 mg-/L (Fischer et al. 1989).

In general, lake populations of Alewife overwinter offshore in deep water and move shoreward into shallower water in spring to spawn, after which they move back to open waters where they remain throughout the summer, occupying mid to upper levels in the water column. Alewife can tolerate water temperatures of 1 to 31-34 °C (Otto et al. 1976). Alewife are severely stressed by temperatures lower than 3ºC. In severe winters, as water temperature reach or fall below 1ºC, mass mortalities can occur.

Tench can withstand dissolved oxygen levels as low as 0.4 mg·L-1(Alabaster and Lloyd 1982) and can survive anoxic conditions as well as partial drying or freezing of lakes and ponds by burying in the mud (Baughman 1947). The thermal tolerance of Tench ranges from 0 to 38°C (Peňáz et al 1989).

Bighead Carp can tolerate salinities in the range of 6-12 parts per thousand. The preferred temperature for reproduction is about 25ºC; the maximum temperature in which Bighead Carp can survive is 38 ºC (USGS 2005). Bighead Carp can survive temperatures down to nearly freezing, on the order of 1ºC (Nico et al. 2019). Asian carp can tolerate very low oxygen levels. Bighead, Grass, and Silver carp juveniles are tolerant of oxygen levels lower than 0.5 mg/L. Black Carp is tolerant of oxygen levels as low as 2 mg/L. Among crucian carp, goldfish (*Carassius auratus*) have a wide temperature tolerance with a critical thermal minimum and maximum of 0.3 and 43.6 °C (Ford and Beitinger 2005). Goldfish also display the most extreme anoxia tolerance among teleosts, capable of surviving without oxygen for up to 4–5 months, limited only by the exhaustion of large liver glycogen stores (Fagernes et al. 2017).

1.2.3. Dispersal

Accelerated water velocity and height barriers may limit the dispersal ability of members of this guild (Table 1). However, these barrier types limit the upstream dispersal but not downstream movement.

Table 1. Swimming and leaping ability of fishes in the dispersal guild.

Common name	Maximum jumping height (m)	Maximum darting speed (m/s)	Average Total Length (m)	Migratory season
Alewife[a]	0.39[a]	2.77[a]	0.31	Spring
Bighead carp		1.89[d]	0.76-1.04	Fall
Silver Carp	0.21[e] 1.81-2.24[b]	2.06[d] 5.30-8.39[b]	0.53-0.92 (0.80)	Fall
Tench	unknown	Unknown, observed 0.27[c]		Non-migratory, spawn in summer
White Perch[a]	0.09[a]	1.36[a]	0.15	Spring

a From Meixler et al. 2009; Maximum jumping height and darting speed were calculated from total length.
b From Parsons et al. 2016 for silver carp.
c Rowe et al. 2008.
d Hoover et al. swim speed for 0.5 minute
e Shi et al. 2018; Height for age-0 Silver Carp

The most direct pathway for natural spread of Tench is by direct dispersal through a water way. There is a population of Tench in the St Lawrence River, that has been expanding westward and there have been multiple observations of Tench in Lake Champlain. Tagging studies estimate Tench can travel up to 30 km (Brylinski et al. 1984). Tench prefer very low flow conditions, below 0.25 m/s, but can tolerate up to 0.5m/s for short durations (van Emmerik and de Nie 2006 as cited by Avlijaš et al. 2018).

1.3. Potential Pathway(s) of Introduction

1.3.1. Dispersal

Invasive fishes are initially introduced by unauthorized intentional release (stocking for sportfish), escape from aquaculture facilities or from the aquarium trade or as bait by anglers. Once introduced, these species are able to spread and disperse widely amongst connected waterways through, downstream larval dispersal, exploratory movements of juveniles and adults and spawning migrations.

1.4. Status and Threat from USGS nonindigenous aquatic species database (USGS 2019)

Common Name	Status in Great Lakes Region	Prob-ability of Introduc-tion	Prob-ability of Establish-ment	Likely Environ-mental Impacts	Likely Socio-Economic Impacts
White Perch	Established in all five Great Lakes and their surrounding states: Lake Champlain; Lake Erie; Lake Ontario; Oak Orchard- Twelvemile; Oneida; Salmon-Sandy; Seneca	na	Established	High	Moderate
Alewife	Great Lakes including Lake Erie and Lake Ontario. Lake Champlain, and the following basins in New York: Black; Chaumont-Perch; Irondequoit-Ninemile; Oak Orchard-Twelvemile; Raisin River-St. Lawrence River; Salmon-Sandy; Saranac River; Seneca; St. Regis	na	Established	High	High
Tench	St. Lawrence and Humber Rivers, Lake Champlain and Lake St. Francis	High	High	Moderate	Low
Asian Carp (e.g., bighead carp, silver carp, grass carp, black carp)	Lake Erie[1]	High	High	Insufficient information	High

Probabilities from USGS. 2019. Nonindigenous Aquatic Species Database, Gainesville, FL. https://nas.er.usgs.gov

1 Three bighead carp adults were collected in Lake Erie between 1995 and 2000, but they are not thought to represent an established population (Cudmore et al. 2012). As of 2012, there were no bigheaded carps in or near the St. Lawrence River and opportunities for the introduction of bigheaded carps to the St. Lawrence River are not well understood. However, should they gain access to the St. Lawrence River, lake ballast water or natural dispersal would provide a direct route to Lake Ontario (Cudmore et al. 2012). Grass carp are present in Lake Erie and Lake Ontario as well as the lower Genesee River and middle and lower Hudson River.

1.5. Control

The management and control of invasive fishes can be classified into three categories: physical, chemical, and biological (USACE 2012). Each of these management types has some advantages and disadvantages and their efficacy is dependent on site-specific conditions. The USGS and others continue to test novel deterrent and removal techniques including complex sound and CO2 as deterrents at lock chambers and microparticle piscicides and CO2 as lethal control agents. Algal attractants are being tested to aid in removal efforts and enhance the effectiveness of microparticle piscicide application (ACRCC 2019).

1.5.1. Physical and Behavioral

Alewife and White Perch are desirable sportfish and once established an effective management option for controlling abundance has been unlimited harvest (Smith 2002). Electrofishing, gill, and seine netting may be used to reduce fish populations, but these methods are time-consuming and may injure non- target species (Britton et al. 2011).

Installing physical barriers in waterways may be effective in preventing the fishes within this guild from invading new habitats. Several different physical and behavioral barriers are being examined for potential to stop the dispersal of fishes including Asian carp. Physical barriers include dams, screens, earth berms, fences, electric barriers, bubble curtains, CO_2 barriers, acoustic barriers, strobe lights, high pressure sodium lights, screens, and dams.

Effective physical barriers to fish passage and dispersal include dams, gates, and screens (WDFW 2009). Screening technologies (including vertical plate, rotary drum, and others) are commonly used to prevent fish from entering municipal and irrigation system intakes, cooling water intake systems, and for guiding fish towards desired passage routes. Vertical barriers including spillways and culverts also restrict the upstream movement of fish. A vertical drop of > 3.7 vertical meters in height excludes all fishes including salmon (WDFW 2009). Various types of gates are often installed on culverts or surface water intakes and when partially or completely closed they are barriers to fish migration.

Velocity barriers are another type of physical barrier but are only effective at preventing upstream passage. To be effective the barrier length and flow velocity must be greater than the fish's leaping ability and swimming endurance (Table 1). A minimum flow of 7 feet per second over a distance of 180 feet was considered a complete barrier to upstream fish movement in a recent study of Chicago area waterways (USACE 2012). Similar to a velocity barrier, a gradient barrier can block fish movement if a gradient >20% is sustained for a distance of 160 meters (WDFW 2009). Accelerated water velocity channels will also prevent upstream movement of non-target aquatic organisms.

Significant work has been done to identify potential behavioral barriers that may serve to deter the movement of Bighead and Silver carp while allowing for navigation and shipping. Fish barriers that use electricity are one such type. Electrical fish barriers can function either as an impassable barricade or as a fish guidance system. A series of three electrical barriers on the Chicago Sanitary and Shipping Canal have been somewhat successful for preventing the spread of aquatic invasive species between the Great Lakes and Mississippi River basins (Noatch and Suski 2012).

Another barrier type that has received a great deal of attention has been the use of underwater sound (Noatch and Suski 2012). Acoustic barriers are being developed to specifically target AIS fish and while generally non-selective among fish species, may be more effect for fish with swim bladders. There are two general types of acoustic fish deterrents: continuous wave and pulsed wave. These deterrents use sound/pressure waves (noise) to affect fish behavior or cause injury. Field testing and research efforts in the lab continue to refine and optimize sound frequencies, sound pressure levels (SPLs), and speaker design to repel Asian carp while preventing injury to native species (ACRCC 2019). Acoustic barriers have shown promise for carp and may be effective for alewife.

The bubble curtain is the most elementary form of behavioral fish barrier, which in its simplest form consists of a perforated tube laid across a river bed through which compressed air is forced. The rising curtain forms a wall of bubbles that can deflect fish. Efficacy of the bubble curtain may be enhanced when combined with light or sound. While still in the experimental stage, a CO_2 bubble curtain (discussed more below) may have potential as a barrier as fish have shown avoidance behavior during recent studies (Noatch and Suski 2012).

High pressure sodium lights (1,000 watts) have been used to attract and hold fish to slow water areas located near a powerhouse spillway. Mercury lights have also been used as attractants for species-specific applications. Attractants may be used in combination to congregate fish that are avoiding other behavioral barriers or deterrents. The strobe light has been extensively evaluated as a fish deterrent in both laboratory and field situations and has been used in conjunction with other behavioral devices to increase the level of fish diversion. Combinations with bubble curtains may enhance the effectiveness of both, as the light can be projected onto the bubble sheet. Strobe lights can repel fish by producing an avoidance response (Noatch and Suski 2012).

1.5.2. Chemical

A variety of chemical compounds including carbon dioxide (CO2), ozone, nitrogen, and sodium thiosulfate can be used to alter water quality to discourage movement of invasive fish species through an aquatic pathway. Carbon dioxide (CO2) injected into water is being evaluated as a non-physical deterrent method for invasive Asian carp. Results from laboratory and mesocosm studies conducted by the USGS and others have shown that Asian carp avoid areas of elevated CO^2 (ACRCC 2019). The effectiveness of these controls depends on the biology of target species, concentration, and exposure time. Species that are exposed to sub-lethal concentrations or for too short of time, may be injured but may survive. Application of high concentrations of gases in an open, flowing system may be difficult to control. Biocides are chemicals designed to kill all sizes and life stages of organisms. The use of biocides may be especially effective in the treatment of ballast water or lock water. There are a variety of oxidizing, non-oxidizing, and other biocides that may be considered for treating fishes. The USGS continues to research novel chemical control and in 2018 conducted field trails to control silver carp and bighead carp with antimycin-incorporated microparticle and Ziram, a toxic chemical found to be selective to Grass Carp. The USGS is also working to synthesize designer chemicals that are selective to Asian carp (ACRCC 2019).

Piscicides such as Rotenone may be effective in managing small isolated populations of white perch, alewife, tench, and Asian carp; however would also result in significant mortality of non-target species present. Of the four chemical piscicides registered for use in the United States, antimycin A and rotenone are considered “general” piscicides for use on Alewife (USACE 2012) and potentially to control Asian carp. Rotenone has been reported to be effective eradication method for white perch (IJC 2011).

1.5.3. Biological

Biological control has been used to suppress growth and reproduction of the target species but, rarely, has resulted in eradication of a population. Biological control for fishes includes the introduction or management to encourage piscivorous fish species (e.g., Northern Pike (*Esox lucius*), Walleye (*Sander vitreus*), Largemouth Bass (*Micropterus salmoides*)), species in the Salmonidae family (hereafter referred to as salmonids), and the development of targeted disease agents as biological control agents against invasive fish. While Alewife populations have been reduced through increasing number of piscivorous fishes in certain habitats (O’Gorman et al. 2013), safe and effective biological control of Bighead Carp has not yet been demonstrated. Several potential technologies are being explored including: release of sterile male fish, triploid carp, transgenic alternatives (daughterless carp and Trojan genes), pheromones (sex lures or juvenile aggregation for traps), disease agents, parasites, and predators. Introduced predatory fish species and targeted disease agents have been considered for controlling silver carp and bighead carp. Effects on non-target fishes would also need to be considered. Biological attractants combined with physical removal may also be effective to control invasive fish populations, for example algal attractants and pheromones have the potential to stimulate and concentrate fishes to facilitate removal.

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2. FISH – ASSISTED DISPERSAL

2.1. Species List

Five invasive fishes have been identified as priority species of concern for dispersing as eggs and juveniles with human assistance; additional invasive fish species are present in the canal system and would benefit from control measures designed to manage these five species.

Species	Common Name	Size
Gymnocephalus cernua	Eurasian Ruffe	15-25 cm
Neogobius fluviatilis	Monkey Goby	up to 195-160 mm (males) and 128-115 mm (females)
Neogobius melanostomus	Round Goby	30.5 cm
Proterorhinus semilunaris	Freshwater Tubenose Goby	12.5 cm
Pseudorasbora parva	Stone Moroko (topmouth gudgeon)	2-7.5 cm, up to 11 cm

2.2. Ecology

The ecology of ruffe makes them well suited as an invader species (Fuller et al. 2019a). Ruffe mature as early as one year, have a high reproductive capacity, spawn multiple times over an protracted period, feed on an assortment of prey, and are tolerate a wide range of salinities, water temperatures, dissolved oxygen concentrations, substrates, depths, lentic and lotic environments, eutrophic to oligotrophic conditions (Adams and Maitland 1998; Hölker and Thiel 1998; Kovac 1998; Lehtonen et al. 1998; Ogle 1998). The diet of ruffe changes throughout the course of development, becoming more benthic in nature with increasing size (Ogle et al. 2004). Ruffe are often associated with bottom waters with soft sediments and can live at depths to 85 m (Fuller et al. 2019a). To avoid predators, ruffe are most active at night.

Monkey goby are small benthic fish that do not currently occur in North America. They are native to littoral zones of lakes and rivers in freshwater and brackish habitats in Eastern Europe (Baker et al. 2019). They are tolerant of a wide range of water temperatures and salinity. Monkey goby diet consists of macroinvertebrates, crustaceans, annelids, gastropods, and fishes, and is dominated by chironomid larvae (Grabowska et al. 2009). The invasion history of monkey goby is characterized by range expansions occurring from Eastern towards Western Europe. Round goby also have life history traits that promote invasive success including highly specialized large eggs with dense yolks, large sizes at first feeding, high parental investment, and long juvenile periods. The broad and plastic dietary niche of round goby also contributes to round goby being more widely established than the other invasive gobiids, such as the tubenose goby.

The tubenose goby has been far less studied than the other invasive Ponto-Caspian gobiid species. The tubenose goby is a benthic omnivore, consuming a wide variety of benthic invertebrates and occasionally larval fishes. They generally inhabit shallow (less than 5 m depth), slow-moving, nearshore environments. Tubenose goby prefer areas with abundant aquatic macrophytes, but can also be found in sandy areas (Jude and Deboe 1996). Unlike round goby, tubenose goby do not feed on zebra mussels (Vanderploeg et al. 2002). Tubenose goby may live as long as five years (Jude 1992).

The stone moroko (or topmouth gudgeon) is a small cyprinid fish native to East Asia, including Japan and parts of Korea and China (Witkowski 2009). Where introduced, stone moroko compete with native cyprinids for resources, become a significant component in the diet of piscivorous fishes, and may host and spread pathogens (Nowak and Szczerbik2009). Stone moroko are highly adaptable and have many of the life history traits of a successful invader including early maturity, batch spawning, nest guarding, and broad environmental tolerance limits (Fusaro et al 2019).

Stone moroko are omnivores whose diet generally includes zooplankton, micro-crustaceans, molluscs, fish eggs and larvae, algae, and plant detritus (Xie et al. 2000). Small age-0 individuals feed predominantly on zooplankton and phytoplankton and will shift their diet to chironomids and other benthic organisms as they grow (Gozlan et al. 2010). Where introduced and established, stone moroko are one of the most dominant species in fish assemblage (Kapusta et al. 2008; Tang et al. 2003). If introduced into the Great lakes region, stone moroko could cause decline in native fish populations and adversely affect predator-prey relationships (Fusaro et al 2019).

2.2.1. Reproduction

While ruffe can mature at age one, maturity is more common at age two or three and lengths of 11 to 12 cm. They spawn intermittently and can produce two or more batches of eggs. Following their first spawning, which usually occurs in April or May at water temperatures of 6-20°C (Kovac 1998; Ogle 1998), they can spawn again as a second batch of eggs matures typically within 30 days of first spawning. During spawning, ruffe deposit adhesive eggs on plants, logs, branches, sand, clay, gravel, or rocks at depths of 3 m or less (Ogle 1998). During first spawning, the females can release 4,000 to 200,000 eggs and during a second spawn they can release 350 to 6,000 eggs (Ogle 1998). The eggs are 0.34- 1.3 mm and hatch in 5 -12 days at 10 to 15°C. The larvae are 3.3- 4.4 mm at hatching (Kovac 1998; Ogle 1998).

The monkey goby has a maximum life span of 5-6 years, but in most studied populations in its natural range they do not live longer than 3-4 years (Pinchuk et al. 2003). The age of maturation observed in its natural range is from 2 years at a total length from 40 to 120 mm (Smirnov 1986; see Pinchuk et al. 2003 for review). It is a multiple spawner, with at least two broods per year. The spawning starts in April when water temperature exceeds 11-14˚C, reaches its peak in May at 18-19˚C and lasts until June or July. Eggs are deposited in a nest on the underside of different structures such as rocks, stones, logs, roots, algal clumps, and empty shells of molluscs, as well as on human artifacts such as litter and ropes. The males guard their eggs until they hatch, fan the clutch with their pectoral fins, and defend the nest aggressively. The number of eggs found in one nest ranges from 150 to 6,000, and more than one female may deposit eggs in the same nest (Bilko 1968).

Round goby are also multiple spawners, typically spawning every 3–4 weeks from April through to September in their native range (Charlebois et al. 1997). Spawning is cued by water temperature (9–26°C) and both gravid females and breeding-colored males have been captured as late as November in the Detroit River (MacInnis and Corkum 2000) due to prolonged warm water temperatures. In its native range, males mature at age 3 or 4 years and females at age 2 or 3 years (Miller 1986), but both sexes may mature up to a year earlier in the Great Lakes based on findings from the upper Detroit River (MacInnis and Corkum 2000). Males guard nests and may not feed during spawning, suggesting most males die after one spawning season (Charlebois et al. 1997), although this has yet to be confirmed. Up to 10,000 eggs from four to six females may be present in a nest, and fertilization and hatching rates are as high as 95 percent (Charlebois et al. 1997). Size at hatching is 5.5-5.7 mm. Larvae resemble adults at hatching and appear to be benthic, since they have no swim bladder (Pinchuk et al. 2003).

Similar to round goby, tubenose goby males will guard their nesting sites to defend their eggs and young. Variability in life-span has been observed among populations with tubenose goby living 1-4 years (Valová 2015). Tubenose gobies will nest under logs and rocks in the shallow fresh waters of the Great Lakes and their connecting rivers. The gobies will spawn multiple times during the warmer months of the year, between April and July, with some populations extending into August. Fecundity ranges from 379-1,024 eggs per female; tubenose goby fecundity is higher than that registered for other gobiid species of a similar size, although lower than that of other invasive gobiids.

The early life stages of both round goby and tubenose goby displayed significantly higher parasitic load for both native and exotic unionoid glochidia prevalence and intensity of infection than native fish (17 versus 2 percent and 3.3 versus 1.4 respectively). Compared to native fish, presence of invasive gobiids increased the total number of glochidia transported downstream on drifting fish by approximately 900 percent (Šlapanský et al. 2016).

Stone moroko typically reach sexual maturity in the first year of life spawn in batches during the spring and summer months, March to September (Zahorska and Kovac 2009; Gozlan et al. 2010). Asynchronous batch spawning improves larvae survival rates by reducing their susceptibility to changing environmental conditions (Katano and Maekawa 1997). During spawning, male stone moroko establish and guard their nests in a variety of substrates (including macrophytes) usually in structures with a cavity (Pinder and Gozlan 2003). After courtship, the female attaches highly adhesive eggs to the substrate prior to male fertilization (Gozlan et al. 2010). A single female can lay 121 to 7,124 eggs throughout the spawning season (Pinder and Gozlan 2003; Britton et al. 2008; Zahorska and Kovac 2009; Zahorska and Kovac 2013). The incubation period of the eggs is approximately seven days at 20 C (Pinder and Gozlan 2003).

2.2.2. Habitat

Ruffe thrive in eutrophic lakes but can tolerate a wide variety of salinities (up to 12 ppt), water temperatures (up to34°C), dissolved oxygen concentrations (as low as 2 mg/L, substrates, depths (to 85 m), lentic and lotic environments, eutrophic to oligotrophic conditions (Adams and Maitland 1998; Hölker and Thiel 1998; Kovac 1998; Lehtonen et al. 1998; Ogle 1998). The lower thermal tolerance of ruffe is not well documented; however, their native and invasive range includes northern latitudes where ruffe overwinter in ice-covered lakes. The temperature requirements (TL 50) of ruffe larvae have been determined to be 10°C to 21.5°C (Ogle 1998).

The monkey goby is a benthic euryhaline species, inhabiting from the entirely freshwaters of rivers and man-made lakes to brackish and polyhaline salinities of the Black, Azov and Caspian seas. In the Caspian region, 0-17 ppt salinity is tolerated (CABI 2019). Monkey goby tolerate temperatures from 4-20˚C.

Round goby also tolerate a wide range of habitat conditions. They exhibit a wide salinity tolerance, inhabiting fresh, brackish and marine waters (Cross and Rawding 2009) with a reported salinity tolerance of up to 40·5ppt (Moskal'kova 1996). However, there are no known marine populations (Charlebois et al. 1997) and a recent laboratory experiment found that all round goby died within 48 hours under 30 ppt salinity (Ellis and MacIsaac, 2009). Round goby are tolerant of very low dissolved oxygen levels, but may attempt to escape hypoxic conditions. Critical lethal threshold values range from 0·4 to 1·3 mg l^{-1} (Charlebois et al. 1997). Monkey goby prefer habitats with oxygen saturation of at least 50-60percent (CABI 2019). Round goby also have a wide thermal tolerance, ranging from 1 to 30◦ C (Moskal'kova 1996), but prefer warmer water; their optimal temperature is estimated to be 26◦ C (Lee and Johnson 2005).

The tubenose goby displays quite a large habitat tolerance. It is found in lakes, estuaries, rivers, lentic streams, canals and in side arms (Erös et al. 2005; Kottelat and Freyhof 2007), though strictly confined to shallow littoral areas. Despite numerous studies referring to habitat preference (e.g., French and Jude 2001; Leslie et al. 2002; Naseka et al. 2005), data on tubenose goby habitat use is scarce. On a mesohabitat scale Jude and DeBoe (1996) and Kocovsky et al. (2011) document an affinity to riprap and macrophyte cover, respectively.

Stone moroko demonstrate great adaptability and tolerance of poor habitat quality (Beyer et al. 2007), including a relatively high tolerance to rotenone exposure for a cyprinid (Allen et al. 2006). The exact thermal and dissolved oxygen tolerances of are not well documented but a range of 2 to 28°C and tolerance of very low DO conditions have been reported (Fusaro et al. 2019). Stone moroko live in freshwater and brackish environments and can tolerate salinity up to 13.7 ppt (Scott et al. 2007).

2.2.3. Dispersal

Following its initial introduction, round goby has spread both through natural dispersal and through commercial shipping within invaded ecosystems (Kornis et al. 2012). They are typically sedentary (Bjorklund and Almqvist 2010) with limited home ranges [conservatively estimated at 5 m^2 by Ray and Corkum (2001)], but individuals occasionally move long distances. River colonization appears to be driven by 'stratified dispersal', a combination of diffusion over short distances by most individuals and long-distance colonization by migrant individuals (Bronnenhuber et al. 2011). Tierney et al. (2011) were able to demonstrate that round gobies were surprisingly good swimmers, despite their benthic adaptations, utilizing a form of 'burst-and-hold' swimming (startle bursts of up to 163 cm s−1 recorded).

Despite some documentation of rapid spreading of tubenose gobies via navigable rivers (Naseka et al. 2005, Manné and Poulet 2008), there have been no studies of "natural" spreading patterns unaffiliated with anthropogenic factors. Recent studies suggest that downstream juvenile drift is an important dispersal tool for the tubenose goby (Zitek et al. 2004). Size of drifting fish was restricted to a narrow range of 6–8 mm and 5–8 mm for round and tubenose goby, respectively. Drift in both species occurred almost completely during the night (Janac et al. 2013).

Dispersal of stone moroko is primarily as a contaminant of fish consignments, with secondary natural dispersal. The use of a wide range of spawning substrates by stone moroko allows eggs to be transported on macrophytes.

2.3. Potential Pathway(s) of Introduction

2.3.1. Unintentional Transport

Round goby were introduced to the Great Lakes via freighter ballast. Passive dispersal of gobiids by ships, especially cargo vessels, seems to occur regularly (Ahnelt et al. 1998). It is connected with the gobiids concealment behavior, in which they may occupy holes and depressions on ships hulls. Males can use ships hulls as places for nests, and be transported together with fertile eggs for long distances. This behavior, along with their dockside presence, predisposes gobies to be taken into ballast tanks. Round goby eggs may also be spread by ship hull fouling (Corkum et al. 2004), but this has not been directly observed (Adrian-Kalchhauser et al. 2017).

The introduction of tubenose goby into the Great Lakes appears to be the result of ballast water discharges from transoceanic ships. This species was then spread by freighters operating within the Great Lakes. The tubenose goby lays its eggs on vegetation and may also be transported between waterways when boats, motors, and trailers are not cleaned of plants.

2.4. Status and Threat from USGS database

Common Name	Status in Great Lakes Region	Probability of Introduction	Probability of Establishment	Likely Environmental Impacts	Likely Socio-Economic Impacts
Eurasian Ruffe	in Great Lakes, not yet in Canal System	NA	NA	moderate	unknown
Monkey Goby	watchlist	moderate	high	moderate	low
Round Goby	in Canal System	NA	NA	high	high
Tubenose Goby	in Great Lakes, not yet in Canal System	NA	unknown	unknown	unknown
Stone Moroko	watchlist	low	moderate	high	high

2.5. Control

2.5.1. Physical

Various types of physical controls that have been used to control other non-indigenous fish might also be effective in managing ruffe, gobies, and stone moroko. Physical treatments may include electrical barriers, bubble curtains, strobe lights, acoustics, reservoir drawdowns/dewatering, traps, nets, electrofishing, and combinations of these treatments. The small size of these species many make traditional physical removal methods, such as netting and electrofishing, difficult (Britton and Brazier 2006). Containment procedures must address all life stages in order to effectively isolate and eradicate populations of stone moroko; screening efforts for this species were ineffective in prohibiting the movement of fish less than 20 mm (Britton and Brazier 2006).

Electrical barriers may be successful at limiting the movement of Round Gobies. In tank studies, Round Gobies did not move through such a barrier (Savino et al. 2001). In the Chicago Sanitary and Ship canal, an electric barrier was constructed in part to prevent the spread of round goby into the Mississippi River catchment (Steingraeber and Thiel 2000). While round goby crossed the barrier site prior to its activation, electric barriers effectively prevent passage by round goby and other fishes (Steingraeber and Thiel 2000).

Rollo et al. (2007) and Isabella-Valenzi and Higgs (2016) reported Round Gobies will approach a speaker emitting conspecific male calls in the field. Therefore Round Goby phonotaxis could be used to lure gravid females to traps. As Round Gobies will spawn multiple times throughout late spring and summer, they should remain receptive to male calls and bioacoustic capture for the entire breeding season.

2.5.2. Chemical

Piscicides such as the lampricide 3-trifluoromethyl-4nitrophenol (TFM) are used to control ruffe populations.

The IJC (2011) recommends rotenone for control of Round Goby in rapid response scenarios. Of the four chemical piscicides registered for use in the United States, antimycin A and rotenone are considered “general” piscicides, but no studies have been found of their effects on round goby (GLMRIS 2012).

In 2004, round goby was discovered in Pefferlaw Brook, a tributary to Lake Simcoe, Ontario. It was deemed a serious threat to Simcoe’s angling industry (Kurji et al., 2006) and in 2005, rotenone was applied to a 5 km stretch of Pefferlaw Brook with the sole goal of eradicating round goby (Borwick and Brownson 2006; Corkum et al. 2008). Unfortunately, in this instance several individuals were captured a few months after treatment and despite an intense seining effort to remove the remaining round goby, individuals have since been captured in Lake Simcoe.

Round goby are susceptible to bottom-release formulations of two piscicides (Bayluscide and antimycin); such treatments selectively target benthic fishes such as gobiids, an improvement over chemicals that kill indiscriminately (Schreier et al. 2008).

In England, stone moroko were successfully eradication from a lake by screening of outfalls to prevent fish movements off site and chemical treatment (Britton and Brazer 2006). Eradication involved the fishery being treated twice with a rotenone-based piscicide with applications a month apart. Following the rotenone application, no stone moroko were recorded in the lake (Britton and Brazer 2006).

2.5.3. Biological

The primary predators of ruffe in North America include northern pike, burbot, lake trout, smallmouth bass, black crappie, bullheads, walleye, and yellow perch (Ogle 1998). In 1989-1990, fisheries managers in Lake Superior tried to control ruffe by limiting sport fish catch of their predators and stocking walleye and northern pike. These efforts were unsuccessful in limiting ruffe numbers. Sea Grant-funded research at the University of Minnesota has identified the pheromone, 20β-S as a reproductive hormone that serves as an attractant and may be useful for managing invasive ruffe populations (Sorenson et al. 2004). Other pheromones have been found to repel ruffe and may have management applications.

Although many other species consume Round Goby, no effective and species-specific biocontrol has been identified. Among other species, native Burbot are being investigated for their potential to control goby populations (Madenjian et al. 2011). Janssen and Jude (2014) suggest one strategy to control round goby populations might be to stock native fish predators that consume high numbers of round goby including smallmouth bass or stock other native round goby predators such as Lake Erie water snakes.

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3. INVERTEBRATES – CRAYFISH

3.1. Species List

Three invasive crayfish have been identified as priority species of concern; additional invasive crayfish species are present in the canal system and would benefit from control measures designed to manage these three species.

Species	Common Name	Size
Procambarus clarkii	red swamp crayfish	5.5-12 cm
Cherax destructor	common yabby (crayfish)	10-20 cm, up to 30 cm
Procambarus virginalis	marmorkreb (marbled crayfish)	10-13 cm

3.2. Ecology

Invasive crayfish are successful colonizers due to specific features that increase their invasive ability in different climatic and geographic areas including ecological plasticity, adaptation of its biology and life cycle to changing environmental conditions, high tolerance to salinity, oxygen and temperature variations, high somatic growth and reproductive output, short development time and flexible feeding strategy (Alcorlo et al. 2004; Gherardi 2006; Jones et al. 2009). Therefore, after establishment, these species may quickly become keystone species and cause serious changes in native plant and animal communities, altering water quality and sediment characteristics (Gherardi 2007). These species are also known to carry and spread parasites lethal to native crayfish species.

3.2.1. Reproduction

The life cycle of the red swamp crayfish is relatively short, with an onset of sexual maturity occurring in as few as two months and a total generation time of four and a half months (Huner and Barr 1991). Breeding typically takes place in the fall, though in warmer, wetter regions, there may be a second reproductive period in the spring. Yue et al. (2008) suggest that red swamp crayfish are parthenogenic.

Common yabby typically have two spawning events per season, approximately 1,000 eggs per spawn. Spring and summer are typical reproductive seasons (Withnall 2000).

Marbled crayfish are a recently speciated crayfish that reproduces through parthenogenesis; all specimens are female and lay unfertilized eggs that develop into genetically identical offspring (Scholtz et al. 2003; Martin et al. 2007; Vogt et al. 2008). They have high fecundity, breed year round, and single individuals are capable of starting new populations. This species has spread widely across Europe, into Africa and Japan. Reproduction ceases for marbled crayfish above 30˚C.

3.2.2. Habitat

These invasive crustaceans have wide thermal tolerances, with generally warmer thermal optima. All three species tolerate temperatures 1-35˚C with optima of 18-30˚C. Crayfish species are able to resist freezing and some desiccation by burrowing and traveling overland in the absence of water. Both red swamp crayfish and marbled crayfish have successfully invaded temperate climates with temperatures well below their thermal optima. Similarly, all three species are highly tolerant of salinity and oxygen variations. Common yabby can survive up to 48 hours in seawater, although stress associated with salinity tolerance impairs growth (Withnall 2000)

3.2.3. Dispersal

The red swamp crayfish exhibits two types of behavior. One is a wandering phase that involves short peaks of high speed of movement; the other an immobile stage during which it hides in its burrow by day and only comes out at dusk to forage. Breeding male crayfish in the wandering phase may travel as far as 17 km from their site of origin within four days' time (GISD 2019). Marbled crayfish disperse from high density populations moving overland several hundred meters to access new habitat.

3.3. Potential Pathway(s) of Introduction

3.3.1. Unauthorized Intentional Release

Crayfish have been spread by unauthorized intentional release. Individuals can be released from aquaculture or from the aquarium trade or as bait by anglers. Intended disposal via the sanitary system (being flushed down toilets) is likely to be ineffective, as many red swamp crayfish has been seen in urban zones around waste water treatment areas, having apparently survived treatment (Nagy 2019).

3.4. Status and Threat from GLANSIS Database

Common Name	Status in Great Lakes Region	Probability of Introduc-tion	Probability of Establishment	Likely Environ-mental Impacts	Likely Socio-Economic Impacts
Red Swamp Crayfish	in Lake Eerie, but not Canal System[1]	NA			
Common Yabby	On watchlist	low	moderate	moderate	Low
Marmorkreb (Marbled Crayfish)	On watchlist	high	moderate	High	moderate

[2] A population of crayfish originally identified as Procambarus clarkii from the Seneca system, New York was later verified as Procambarus acutus (11/28/2017).

3.5. Control

3.5.1. Physical

Georgia crawfish, a relative to red swamp and marbled crayfish is known to be susceptible to drought (Dorn and Trexler 2007). Provided that Georgia crawfish and marbled crayfish share this characteristic, draining habitats for longer periods might reduce confined populations. However, many crayfish, including red swamp, common yabby, and marbled crayfish, are capable of walking overland to disperse into new environments.

The use of physical barriers and diversions has been reviewed as a method to control non-indigenous crayfish species populations in Europe and America (Kerby et al. 2005; Dana et al. 2011; Gherardi et al. 2011; Frings et al. 2013). Kerby et al. (2005) observed that red swamp crayfish movement was significantly reduced by natural barriers, although an individual was observed climbing upstream over a sloping moss-covered dam in the dry. Crayfish have been observed moving upstream through fish ladders designed for American eels in the Shenandoah River (Welsh and Loughman 2015). The eel ladders were covered stainless steel sluices with an internal peg board substrate at a slope of 30˚ -50˚. In lab experiments to test barrier design for signal crayfish, Frings et al. (2013) emphasized the importance of smooth barrier materials and concluded that promising barrier locations are pre-existing structures such as fish ladders alongside weirs, where flow velocities are controlled, sedimentation risks are low, maintenance is done regularly and the bed profile is suitable to connect barriers to banks to discourage overland travel. Other physical control methods include the use of electric fences and vibrations (Gherardi et al. 2011), although electric fences were only moderately successful at restricting crayfish movement (Peters et al. 2008).

3.5.2. Chemical

The application of biocides such as pyrethroid insecticides at the very early stages of invasions or in confined habitats may result in complete eradication of Marbled Crayfish (Sandodden and Johnsen 2010). At a larger scale, however, the use of biocides is both expensive and ineffective because of adverse impacts on non-target organisms (Anastácio et al. 1995) and the tendency of crayfish to escape lethal doses by retreating into burrows or by climbing out of the water.

There has been little success in controlling red swamp crayfish once the crayfish is established. Pesticides have been applied to control the species in agricultural fields, but this produced severe impacts on bird populations and consequently this approach is discouraged (MacKenzie 1986). Salt can be used as a chemical control in confined settings; yabby crawfish will die at a salinity of 25 ppt or above (NSW Department of Primary Industries 2017).

3.5.3. Biological

No specific data exists on marbled crayfish control, but native predatory fish have been shown to have potential effects controlling other crayfish populations. Eels in particular are good candidates to control unwanted crayfish populations and have been shown to be effective for red swamp crayfish in combination with other control methods like intensive trapping (Aquiloni et al. 2010; Musseau et al. 2014). One study observed in a mesocosm experiment that Northern pike (Esox Lucius) were an efficient predator of crayfish independent of prey size (Neveu 2001 in Gherardi et al. 2011).

A lake population of the invasive rusty crayfish has recently been nearly eradicated through a combination of trapping and fish predator management (Hein et al. 2007). Due to marbled crayfish vulnerability to fish predation (Huner and Barr 1991), a similar approach may work for this species, although such an effort by Frutiger and Muller (2002) was unsuccessful.

The use of microbial agents to control crayfish populations has been reviewed in previous studies (Gherardi et al. 2011; Scalici et al. 2009). Common yabby is known to be susceptible to the crayfish plague, Aphanomyces astaci (Scalici et al. 2009), of which North American species are much more resistant (Persson et al. 1987; Unestam 1975). Four populations of common yabby in Spain were eradicated by introducing signal crayfish (Pacifastacus leniusculus) infected with the plague into the populations (J. Dieguez-Uribeondo, pers. comm. in Souty-Grosset et al., 2006 via Scalici et al. 2009). Common yabby is also susceptible to the microsporidian disease, Thelohania parastaci (Moodie 2003) and the Cherax destructor systemic parvo-like virus (CdSPV) (Edgerton et al. 1997 in Diggles 2011). Gherardi et al. (2011) mentions that the use of genetically modified strains of A. astaci has been hypothesized as a potential way to control invasive crayfish in Europe, but there is a significant risk that using a genetically modified strain in conjunction with the existing wild-type could affect more than just the target species. The use of microbial agents as a method of control for common yabby would also warrant the consideration of indirect effects on native crayfish populations.

Aside from predatory fish and disease, other potential methods of control would be the use of sex pheromones or the release of sterile males. Aquiloni and Gherardi (2010) observed the capability of sex pheromones as a method of control in another species of crayfish, which could have implications for the control of common yabby if it becomes established in the Great Lakes. Additionally, the release of sterile male common yabby into a population could be an effective method of control if the species were to become established. The sterile male release technique is species-specific and sterilization techniques have been successfully demonstrated for red swamp crayfish in laboratory settings (Aquiloni et al. 2009) and in combination with intensive trapping, has proved to be particularly effective in a small lake (Casette Lake, Italy) with about 87 percent reduction of a red swamp crayfish population after two years of activity (Aquiloni and Zanetti 2014).

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4. INVERTEBRATES – MOLLUSCS

4.1. Species List

Six invasive molluscs have been identified as priority species of concern; additional invasive mollusc species are present in the canal system and would benefit from control measures designed to manage these species.

Species	Common Name	Size
Dreissena polymorpha	zebra mussel	up to 50 mm
Dreissena rostriformis bugensis	quagga mussel	Up to 40 mm
Limnoperna fortunei	golden mussel	20-30 mm, up to 45 mm
Corbicula fluminea	Asian clam	up to 50 mm
Potamopyrgus antipodarum	New Zealand mudsnail	4-6 mm, up to 12 mm
Bithynia tentaculata	Faucet snail	12-15 mm

4.2. Ecology

Invasive molluscs, including mussels and aquatic snails, are efficient colonizers that can disperse using multiple pathways during various life phases. Invasive mollusc species are highly tolerant of a variety of environmental conditions and often thrive in degraded habitats. Molluscs have high reproductive potential enabling them to reach extremely high densities and can cause significant ecological and economic damage by altering benthic and pelagic communities and food webs. They also may cause biofouling of suitable substrates and facilities. Once established, most molluscs are able to disperse efficiently and often go undetected during the larval life-stage.

Zebra mussels and quagga mussels (hereafter, referred to collectively as dreissenid mussels) and golden mussels are filter feeders that have many functional similarities including size, filter-feeding rate, rapid growth, short life span, early sexual maturity, high fecundity with planktonic larvae, and attachment in high densities to hard substrates by means of strong byssal threads (Karatayev et al. 2007). All three species attached to any stable substrate in the water column or benthos forming thick colonies (Benson 2019a; Benson 2019b; Fusaro 2019). At high densities, dreissenids and golden mussels remove substantial amounts of phytoplankton and suspended particulates from the water column. Golden mussels consume a wider variety of phytoplankton and zooplankton than dreissenids making them able to adjust their diet based on prey availability and thrive despite low food availability (Frau et al. 2013; Rojas Molina et al. 2012; Oliveira et al. 2010). The life span is two to nine years.

The Asian clam is a filter feeder that removes particles from the water column (Foster 2019). Asian clams have one of the highest filtration rates per biomass, compared to native freshwater bivalves (McMahon 1991). As ecosystem engineers Asian clams impact habitat structure, biomineralization, oxygenation and benthic planktonic community structure and can alter the nutrient cycle and the food web structure (Karatayev et al. 2007; Sousa et al. 2009). One of the major impacts of Asian Clam is a reduction of planktonic communities and associated changes that may include enhancing light penetration and increased the macrophyte coverage. In contrast to dreissenids, Asian clams can be found at the sediment surface or slightly buried. Its ability to reproduce rapidly, coupled with low tolerance of cold temperatures can produce large annual fluctuations in population in northern water bodies. The life span is one to seven years (Foster 2019).

The New Zealand (NZ) mudsnail is a nocturnal grazer, feeding on plant and animal detritus, epiphytic and periphytic algae, sediments and diatoms (Benson 2019c). At high densities, the NZ mudsnail can dominate secondary production (Hall et al. 2006). The NZ mudsnail tolerates siltation, thrives in disturbed watersheds, and benefits from high nutrient flows allowing for filamentous green algae growth. In the Great Lakes they are found at depths of 4-45 m on silt and sand substrate (Levri et al. 2007; Zaranko et al. 1997). The Faucet snail is commonly found in freshwater ponds, shallow lakes, and canals; The Faucet snail is adaptable to multiple food sources and can function as both a scraper and a collector-filterer, grazing on algae on the substrate, as well as using its gills to filter suspended algae from the water column (Kipp 2019). The life span of faucet snails is up to three years. The Faucet snail is frequently associated with introduced milfoil Myriophyllum spicatum (Vincent et al. 1981) and amongst introduced mussels (Ricciardi et al. 1997).

4.2.1. Reproduction

Dreissenids and golden mussels are dioecious with males and females releasing gametes and, external fertilization occurring in the water column in the spring (McMahon 1996). Mating is limited to males and females in proximity to each other and usually occurs in the spring or summer, depending on water temperature (Ianniello 2013). Spawning may start when the water temperature reaches 12°C and release rate is maximized above 17-18°C (McMahon 1996). Over 40,000 eggs can be laid in a reproductive cycle and up to one million in a spawning season. Spawning may be protracted in waters that are warm throughout the year. After the eggs are fertilized, the larvae (veligers) are free-swimming for up to a month and are dispersed with water currents. During the settling stage, larvae search for a suitable substrate. Habitats and facility components in low or intermittent flow areas are the most susceptible to colonization and fouling. Mussels have difficulty attaching to hard surfaces at velocities greater than 1-2 ft/s-1 (Clarke and McMahon 2011). The main difference in reproduction between golden mussels and Dreissena are that golden mussels spawn continually when water temperatures are favorable while Dreissena are batch spawners.

The Asian clam is hermaphroditic with reproduction and larval release occurring biannually in the spring and in the late summer. The Asian clam is believed to practice self-fertilization (simultaneous hermaphrodites), enabling rapid colony regeneration when colony populations are low (Qiu et al. 2001).

The New Zealand mud snail is ovoviviparous and parthenogenic. Native populations in New Zealand consist of diploid sexual and triploid parthenogenically cloned females, as well as sexually functional males (less than 5% of the total population). All introduced populations in North America are clonal, consisting of genetically identical females. The snail produces approximately 230 young per year. Reproduction occurs in spring and summer, and the life cycle is annual (Gerard et al. 2003; Lively and Jokela 2002; Schreiber et al. 1998; Zaranko et al. 1997).

The faucet Snail is dioecious and lays its eggs on rocks, wood, and shells. Egg-laying occurs from May to July when water temperature is 20ºC or higher, and sometimes a second time in October and November by females born early in the year. Fecundity may reach up to 347 eggs. Eggs hatch in three weeks to three months, depending on water temperature (Jokinen 1992; Korotneva and Dregol'skaya 1992).

4.2.2. Habitat

As with most molluscs, calcium and pH levels influence shell building and hence survival and growth. With zebra mussels, some discrepancy exists when comparing temperature tolerance limits of North American and European populations. Although shell growth has been reported to occur at temperatures as low as 3°C, Lake St. Clair populations and some European populations display shell growth at 6–8°C. Zebra mussels do not tolerate temperatures <0°C and 24-hour exposure to freezing temperatures is lethal as is -3°C for 10 hours and -10°C for 2 hours (Claudi 2018). The optimal temperature range for adults extends to 20–25°C, but zebra mussels can persist in temperatures up to 30°C. Similar to zebra mussels, water temperatures of 28°C begin to cause significant mortality to quagga mussels, and 32-35°C is considered lethal for both species (Antonov and Shkorbatov 1990, as cited in Mills 1996). Quagga mussels are able to settle on both hard and soft substrates while zebra mussels require a hard substrate.

The native and introduced ranges of golden mussel include extremes of pollution, water temperature, pH, and nutrient levels, demonstrating its adaptability to waters that are not suitable to Quagga and Zebra mussels., such as lakes with low calcium concentrations, high temperatures, low oxygen levels, and those ecosystems considered to be highly polluted (Boltovskoy et al. 2006; Karatayev et al. 2007). The golden mussel can also survive in a wider range of salinities than either the quagga or zebra mussel and may inhabit fresh and brackish waters in lakes, rivers, wetlands, and bays with temperatures ranging from 4-35°C. While the tolerance for low temperature is not well documented it is able to survive short periods with water temperature as low as 0°C (Oliveira et al. 2010); in Japan the golden mussel survives winter water temperatures of 5°C to 6°C (Magara et al. 2001), and in Korea populations have been reported, with winter surface water temperatures as low as 0C (Choi and Kim 1985). The Golden mussel appears to be more tolerant to high temperatures than Zebra Mussels and the temperatures required to kill 50% (LT50) and 100% (SM100) varied in experiments between 42.2 and 51.8°C (Perepelizin and Boltovskoy 2011). Golden mussels attach well to hard substrate (including of biological origin), minimally to soft substrate, as well as macrophytes and reeds (Karatayev et al. 2007). Zebra and quagga mussels require dissolved oxygen concentrations ≥1.8 mg/L while golden mussels require ≥1.0 mg/L. Golden mussels is also more tolerant of lower pH, lower oxygen and calcium concentrations than D. polymorpha, which allows it to flourish in slightly acidic and soft waters, where the zebra mussel cannot survive (Karatayev et al. 2007).

The Asian clam is able to tolerate temperatures between 2-30°C and can colonize a variety of substrates; death by exposure to winter temperatures may help reduced population size (USACE 2012).

The New Zealand mud snail is able to tolerate temperatures of 0-34°C (Cox and Rutherford 2000; Zaranko et al. 1997). Freezing has been studied for controlling the New Zealand mudsnail (Richards et al. 2004).

Faucet snail inhabits waters with pH of 6.6–8.4, conductivity of 87–2320 µmhos/cm, Ca++ of 5–89 ppm, and Na+ of 4–291 ppm (Jokinen 1992). Faucet snails have been recorded to withstand desiccation for over 8 d in dry containers and a temperature of 21°C. The thermal tolerance of faucet snails are not well documented, egg-laying occurs when water temperature is 20ºC or higher and oocytes develop poorly at temperatures of 30–34ºC. Faucet snail had 100 percent mortality when exposed to 50°C water for 1 minute (Mitchell and Cole 2008).

4.2.3. Dispersal

Dreissenid mussels were likely first introduced to the Great Lakes as result of ballast water discharge from transoceanic ships that were carrying veligers, juveniles, or adult mussels (McMahon 1996). Their rapid dispersal throughout the Great Lakes and major river systems was due to the passive drifting of the larval stage (the free-floating or "pelagic" veliger), and its ability to attach to boats (and barges) navigating these lakes and rivers and being transported between them. Overland dispersal between unconnected waterways occurs via boats and boat trailers from infested waters. Under cool, humid conditions, dreissenid mussels can stay alive for several days or weeks out of water. It is also possible that predators may spread zebra mussels, for examples blue catfish (*Ictalurus furcatus*) have shown to pass live adult zebra mussels and Asian clams through their guts (Gatlin et al. 2013). The golden mussel has not yet been detected in North American but a similar history of invasion and dispersal is documented in South America.

The dispersal of Asian clams is primarily associated with human activities (Counts 1986; Isom 1986). Current methods of introduction include bait bucket introductions (Counts 1986), accidental introductions associated with imported aquaculture species (Counts 1986), and intentional introductions by people who acquire Asian clams in food markets (Devick 1991). The only other significant dispersal agent is thought to be passive movement via water currents (Isom 1986); while the clams can survive through the gut of some predators (Gatlin et al. 2013), fish, and birds are not considered to be significant distribution vectors (Counts 1986; Isom 1986).

The New Zealand mudsnail was most likely introduced to the Great Lakes in ships from Europe, where there are nonindigenous populations (Leppäkoski and Olenin 2000; Levri et al. 2007; Zaranko et al. 1997) or in the water of live gamefish shipped from infested waters to western rivers in the United States. New Zealand mudsnails easily hitchhike with fish and aquatic plants. Overland dispersal between unconnected waterways is also possible for this snail by angler's or paddler's equipment. The mudsnail can survive passage through the guts of fish and may be transported by animals (Bruce 2006).

Faucet snails are native to Europe, and arrived in the Great Lakes through ballast water transport in the 1870s. They can be transported overland by boats, trailers, anchors, duck decoys, and other equipment that is moved between water bodies. Faucet snails can live for up to a month in dry mud.

4.3. Potential Pathway(s) of Introduction

4.3.1. Unintentional Transport

Molluscs have been spread by unauthorized intentional release.

4.4. Status and Threat from USGS nonindigenous aquatic species database (USGS 2019)

Common Name	Status in Great Lakes Region	Probability of Introduction	Probability of Establish-ment	Likely Environ-mental Impacts	Likely Socio-Economic Impacts
Zebra Mussel	Established all Great Lakes by 1990, in New York is established in the Hudson, St. Lawrence, Susquehanna and Seneca rivers and lakes including Lake Champlain and Owasco (Finger Lakes).	na	na	High	high
Quagga Mussel	Well established in the Great Lakes, Lake St. Clair, Saginaw Bay, and throughout the St. Lawrence River north to Quebec City. In New York Lake Ontario, Lake Erie, Erie Canal, Seneca and Cayuga Lakes (Finger Lakes), Skaneateles Lake, Keuka Lake, Niagara River, Black Rock Canal.	na	na	High	High
Golden Mussel	Watchlist: predicted to be future threat. Native to Southeast Asia, established in South America.	Low: Transoceanic Shipping	High	High	high
Asian Clam	Widespread in New York including Irondequoit-Ninemile; Lake Champlain; Lake Erie; Niagara; Hudson, Oak Orchard-Twelvemile; Seneca	na	na	Moderate	moderate
New Zealand Mud Snail)	Established in Lake Ontario, Lake Erie, Lake Michigan and most likely in Lake Superior and is expanding its range within the Great Lakes basin. In New York established in Lake Erie; Lake Ontario; Oak Orchard-Twelvemile; Seneca	high	moderate	high	moderate
Faucet Snail	Established in Lakes Ontario, Michigan and Erie. Widespread in New York including Hudson, Lake Champlain, Finger Lakes, Irondequoit-Ninemile Mohawk Niagara, Oak Orchard-Twelvemile Seneca, Oneida, Oswego	na	na	High	moderate

Probabilities from USGS. 2019. Nonindigenous Aquatic Species Database, Gainesville, FL. https://nas.er.usgs.gov

4.5. Control

The management and control of invasive molluscs can be classified into three categories: physical, chemical, and biological (USACE 2012). Each category has some advantages and disadvantages and efficacy is dependent on site-specific conditions. Preventive control methods for sessile molluscs include toxic materials, antifouling paints or coatings, chemical treatments, and mechanical filtration and some non-chemical processes such as acoustical vibration and electric fields. Reactive control methods consist of mechanical cleaning, high-pressure water jetting, carbon dioxide pellet blasting, freezing, and desiccation treatment (USACE 2012). Thermal treatment and chlorination can be used initially as a reactive treatment and then preventively as regular maintenance to prevent further fouling. The use of extremely low frequency electromagnetism may prove to be a viable means of nonchemical control.

4.5.1. Physical

Effective physical controls of dreissena include using infiltration intakes or sandfilter intakes (filter out veligers), thermal treatments, carbon dioxide pellet blasting, high-pressure water jet cleaning, mechanical cleaning, freezing, scraping, scrubbing, pigging, and desiccation. Potential controls include the use of benthic mats, electrical fields, pulse acoustics, low-frequency electromagnetism (Ryan 1998), ultraviolet light (UV light), and reduced pressure (USACE 2012).

Thermal treatments are lethal to molluscs. Zebra and Quagga mussels do not tolerate temperatures <0°C and 24-hour exposure to freezing temperatures is lethal as is -3°C for 10 hours and -10°C for 2 hours (Claudi 2018). Hot thermal treatment for zebra mussels requires exposure to 40°C (104°F) water for a minimum of one hour or 36°C (97°F) for a minimum of 24 hours. Flushing engines, cooling systems, live wells and bilge with water over 110°F will kill veligers and 140°F will kill adults. Thermal treatment has proven successful in many situations; however, in long pipe systems water temperature may be hard to maintain and infestations with dense clusters may allow the bottom layer of mussels to be buffered enough from thermal treatment to allow survival.

Desiccation can be used to effectively kill adult and larval dreissenids. Effective desiccation treatment requires complete dewatering of the affected area for a minimum of two to three weeks in non-freezing temperatures. Dewatering time may be reduced to one week when air temperature exceeds 25 °C. Air drying equipment for 5 days will kill most larvae and smaller mussels, but large mussels may survive two weeks out of water. While less research has been done on of dreissenid and golden mussels desiccation at low air temperatures, dewatering and exposure to freezing air temperatures (consistent) requires a minimum of 2 days at 0°C and 5 to 7 hours at -3°C (Payne 1992; Grazio and Montz 2002).

Filtration systems can be used to exclude mussel veligers from low volume project facilities. Both uV and 40 to 80 micron filter treatments can be used to kill or excluded larval mussels. An advantage of a filtration system is that exclusion avoids the need to treating infested systems. However, filtration can also capture and kill desirable larval and planktonic organisms and may not be a viable option in location with a heavy sediment load.

Mechanical cleaning and/or high-pressure water cleaning are effective methods for removal of dreissenids from transport vehicles or facilities. Various methods include mechanical raking and scraping, hydrojetting/power spraying, and pipe pigging. For power spraying, water pressure of 2,000 to 3,000 pounds per square inch (psi) is needed to remove attached zebra mussels. In addition, depending on colonization rates, mechanical or physical removal may be needed. Physical removal of visible vegetation (which may harbor small mussels) from boats, trailers and other equipment being moved from one water body to another is an important method in controlling the spread of dreissenids. Electric current may also inhibit zebra mussel settlement and survival and researchers have evaluated the use of sinusoidal Alternating Current (AC) and 20% duty cycle square-wave Pulsed Direct Current (PDC) for controlling adult zebra mussels (Luoma et al. 2017).

Asian Clams are not tolerant of fluctuating environmental conditions (particularly temperature and oxygen) and is prone to large die-offs, this suggests that short-term chemical manipulation may be useful in controlling populations. Asian clams may be controlled at intake pipes by heating influent water to 37°C (GISD 2019). Screens and traps are also commonly employed to prevent Corbicula colonization of water intakes (GISD 2019). Benthic barriers have been demonstrated to be effective for short-term control of Corbicula fluminea, but non-target mortality to other benthic invertebrates may be high (Wittmann et al. 2012).

For the New Zealand mudsnail, effective physical treatments include the use of temperature, humidity, or desiccation. Mudsnails cannot withstand freezing or desiccation at high temperatures and low humidity (Dwyer et al. 2003; Richards et al. 2004). Putting fishing gear in a freezer for 6-8 hours, or water maintained at 120°F for a few minutes, will kill attached NZ mudsnails (Medhurst 2003; Richards 2004). Drying fishing gear at 84-86°F for at least 24 hours or at 104°F for at least two hours has also been shown to be effective (Richards et al. 2004).

4.5.2. Chemical

A variety of chemical treatments can be used to kill molluscs. Some materials used successfully to kill dreissenids include: bromine, chlorine, chlorine dioxide, hydrogen peroxide, ozone, potassium salts, potassium permanganate, sodium hypochlorite, sodium salts, and designer molluscides. Sodium hypochlorite or bleach is perhaps the most commonly used oxidizing chemical treatment to kill or prevent settlement of zebra mussels. Many water treatment and hydroelectric facilities use a chlorination injection system for two to three weeks in the spring and fall or on a daily or periodic basis to discourage zebra mussel attachment. Chlorination of water at 1 to 5 ppm is sufficient to kill zebra mussels. Many factors can influence the effectiveness of chlorine, such as temperature, pH, chlorine concentration, exposure time, type and quantity of chlorine compounds formed, and the size and physiological state of the zebra mussels treated. For best results 2.5 ppm total residual chlorine (TRC) will kill adults in 10 to 15 days. Other studies have shown that adult golden mussels are highly resistant to low doses of chlorine (Cataldo et al. 2003).

Chemicals that cause oxygen deprivation such as hydrogen sulfide gas or sodium metasulfite can cause mussel mortality. To be most effective, the system to be treated must be well-sealed; mussels will survive for long periods in fairly low-oxygen environments. depending on water volume and mussel density, it could take one week for a system to go sufficiently anoxic to assure a kill. The amount of time needed for a kill can be reduced if the water is warmer (up to about 25°C). Potassium chloride (kCl) or potash can be injected as a liquid to 100 ppm concentration and allowed to soak for 48 hours to achieve 100 percent mortality. Potash is more benign in regard to environmental effects than most other chemical treatments.

4.5.3. Biological

Currently, Zequanox is the only EPA registered molluscicide that has demonstrated toxicity to dreissenids and minimal impacts to native Unionid mussels (Luoma et al. 2015). Zequanox is a specific strain (CL145A) of the soil bacterium *Pseudomonas flourescens* can cause mortality in dreissenid mussels (Meehan et al. 2014; Luoma et al. 2015). When used on open water treatments, Zequanox has been demonstrated to reduce populations but does not cause 100 percent mortality to the exposed population (Meehan et al. 2014). Predation by migrating diving ducks, fish species, and crayfish may reduce mussel abundance, though the effects are short-lived (Bially and MacIsaac 2000). Invasive round goby, when abundant, are effective at suppressing dreissenid mussels (Lederer et al. 2008). Other biological controls being researched are selectively toxic microbes and parasites that may play a role in management of Dreissena populations (Molloy 1998). Laboratory testing shows larvae (Abdel-Fattah 2011; Molloy 2002). Parasites of NZ mudsnails from New Zealand may become useful to control population size by inhibiting reproduction. Studies of the efficacy and specificity of a trematode parasite from the native range of NZ mudsnails as a biological control agent have shown positive results (Dybdahl et al. 2005).

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5. INVERTEBRATES – PELAGIC

5.1. Species List

Two invasive pelagic invertebrates have been identified as priority species of concern; additional invasive invertebrate species are present in the canal system and would benefit from control measures designed to manage these two species.

Species	Common Name	Size
Cercopagis pengoi	fishhook waterflea	1–3 mm in length without tail, 6–13 mm with tail
Dikerogammarus villosus	killer shrimp	up to 30mm

5.2. Ecology

The fishhook waterflea is a species of planktonic cladoceran crustaceans that live in brackish and freshwater lakes. It is a pelagic species, found in higher abundance further from the shore (Benson 2019). The life span of a water flea can be several days up to a week. In recent decades it was introduced in ballast water to the Great Lakes and a number of adjacent lakes, and has become a pest classified among the 100 worst invasive species of the world. Fishhook waterflea is a predatory cladoceran and thus a competitor to other planktivorous invertebrates and smaller fishes like alewife and rainbow smelt.

Killer shrimp are a species of amphipod crustacean which has become invasive across the Western Europe. In the areas it has invaded, it lives in a wide range of habitats and will kill many other animals, often not eating them (Dettloff et al. 2019). It is fast-growing, reaching sexual maturity in 4–8 weeks.

5.3. Reproduction

In the spring, the fish hook water flea population emerges from resting eggs that have laid dormant over the winter. At this time continuing through their peak production period, from spring through fall, the population is comprised of mostly females. With the absence of males, the females reproduce through parthenogenesis; the offspring are clones of the mother. When the water temperature begins to cool and food becomes scarce in the fall, both males and females are produced via parthenogenesis and these fleas in turn reproduce sexually. The eggs produced by sexual reproduction have a thick coating that allows them to withstand the winter on the lake bottom. These eggs are called resting eggs and can lie dormant for long periods of time. Resting eggs are also resistant to desiccation, freeze-drying and ingestion by predators.

Resting eggs have been observed to pass undamaged through the gut of herring (Antsulevich and Välipakka 2000). They can be easily transported to other drainage basins by various vectors, particularly if they are still held by the female's body; her barbed caudal spine allows attachment to ropes, fishing lines, waterfowl feathers, aquatic gear, vegetation and mud whether she is alive or dead. The number of resting eggs found in benthic sediment can be very high, up to 5,000-9,000 eggs per square meter and they remain viable for several years (Sopanen 2008).

Killer shrimp grow faster than many freshwater amphipods (Piscart et al. 2003) and reach sexual maturity earlier, with females as small as 6 mm in length having broods (Piscart et al. 2003; Devin et al. 2004; Pöckl 2007; Pöckl 2009) at 33-60 days old, depending on water temperatures (Piscart et al. 2003; Pöckl 2009). Mean fecundity is around 30 eggs per female; however, females can lay up to 194 eggs per clutch, giving this species the highest fecundity of the European gammarids (Devin et al. 2004; Kley and Maier 2003; Pöckl 2007). Once sexual maturity has been reached, the breeding period of killer shrimp is also relatively long and under European climatic conditions, ranges from 9 to 12 months (Devin et al. 2004; Pöckl 2007; Pöckl 2009).

5.4. Habitat

The fishhook waterflea is found both in brackish waters and freshwaters (Birnbaum 2011). It exhibits a great deal of environmental tolerance to salinity and temperature, as the species can persist in waters as cold as 3 degrees Celsius and as high as 38 degrees Celsius and salinities ranging from 0.1 to 17 ppt (Gorokhova et al. 2000; Kane et al. 2003). Although present throughout the water column, the greatest abundance of the fishhook waterflea is found in the upper 20 meters of the water column (Benoît et al. 2002; Krylov et al. 1999). Studies have found that they appear in the summer plankton at water temperatures between 15 and 17°C, with peak abundance between mid-July and mid-August, at temperatures of 16-26^{o}C and at salinities of up to 10 ppt (Krylov et al. 1999).

Killer shrimp inhabit fresh and brackish water, lakes, rivers, and canals in areas with low current velocity (Devin and Beisel 2007). They can adapt to a wide variety of substrates as well as a wide range of temperature, salinity, and oxygen levels. This species is able to tolerate temperatures from 0-35°C, with an optimal temperature range of 5-15°C (bij de Vaate 2001; van der Velde et al. 2009). It naturally occurs at 17 ppt but can tolerate salinities ranging from 0 to 20 ppt (bij de Vaate 2001; Grigorovich et al. 2003). While able to survive short exposure (3 hours) to full strength seawater, D. villosus experiences 100% mortality when exposed to 34 ppt for 24 hours (Santagata et al. 2009). The lethal minimum oxygen concentration for this species is 0.380 mg O_2/L.

Killer shrimp have been documented to have a high tolerance for air exposure; they have been observed to survive out of water for 6 days within damp zebra mussel shell clusters covering the sides of boats, even when boats are removed from the water (Rewicz et al. 2014). In addition, Bącela-Spychalska et al. (2013) has reported survival for 3–5 days within the folds of a moist neoprene diving suit. Killer shrimp have also been observed to survive up to 6 days in a pile of macrophytes and roots left out of water (Rewicz et al. 2014).

5.5. Dispersal

The prolonged diapause of fishhook waterflea promotes short and long-distance dispersal. Despite the potential of waterfowl and fish predators to transfer resting eggs, boaters and ballast water of ships are considered as primary vectors in the Great Lakes area (Makarewicz et al. 2001).

Killer shrimp undertake behavioral drift downstream in the water column; Riel et al. (2011) showed this species is a dominant component of the drifting aquatic macroinvertebrates in the River Rhine. The dispersal rate of this species across Europe is similar to that of many other Ponto-Caspian invasive amphipods, spreading across the entire European continent in roughly 50 years (bij de Vaate et al. 2001).

5.6. Potential Pathway(s) of Introduction

5.6.1. Unintentional Transport

Fishhook waterfleas and killer shrimp can be introduced on aquatic equipment, including fishing equipment, recreational boats, and trailers. For Fishhook Waterflea, fishing lines are a documented pathway for introduction to additional water bodies. They can be easily transported to other drainage basins by various vectors including attachment to ropes, fishing lines, waterfowl feathers, aquatic gear, vegetation, and mud.

While there has been mention of hull fouling of ocean-going vessels as an alternate pathway of introduction for killer shrimp, supporting evidence is unavailable at this time. Their high tolerance to air exposure increases the potential for overland transport.

5.6.2. Animal Vectors

Fishhook Waterflea resting eggs are not easily digested and can survive consumption by predators, such as alewife, rainbow smelt, herring and yellow perch and other bait fish. Resting eggs can pass through the gut of live fish or survive decomposition of deceased consumers. It is through this manner that they are transported across waterbodies via fishes. They are also found on feathers and in the digestive tract of waterfowl and can be transported via waterfowl movements.

5.7. Status and Threat from USGS database

Common Name	Status in Great Lakes Region	Probability of Introduction	Probability of Establishment	Likely Environmental Impacts	Likely Socio-Economic Impacts
fishhook waterflea	Lake Eerie, Lake Ontario, Finger Lakes, Lake Champlain	NA	established	high	low
killer shrimp	watch list		high	high	low

5.8. Control

5.8.1. Physical

Cleaning all aquatic/fishing equipment including downrigger lines and monofilament on reels with high pressure (>250 psi) or hot (>50C) water after each use can be used to physically remove fishhook waterflea (Ontario's Invading Species Awareness Program). MacNeill et al. (2004) reviewed the effect of heating the fishhook water flea resting egg. Exposure to boiling water (212^{o}F) was 95 percent effective after 10 seconds. At 40° C (<110^{o}F), effectiveness decreased to 50 percent after 10 seconds.

Fishing lines designed to prevent the spread of fishhook waterfleas – such as the Flea Flicker brand have been proven effective in reducing fouling (Jacobs and MacIsaac 2007).

Electron beam irradiation has been used to control microorganisms in aquatic pathways, including fishhook waterflea (GLMRIS 2012). Electron beam irradiation is a non-selective control method which exposes water to low doses of radiation using gamma-sterilizers or electron accelerators, breaking down DNA in living organisms while leaving behind no by-products (GLMRIS 2012). Ultraviolet (UV) light can also effectively control microorganisms, including fishhook waterflea, in water treatment facilities and narrow channels, where UV filters can be used to emit UV light into passing water, penetrating cell walls and rearranging DNA of microorganisms (GLMRIS 2012).

Killer shrimp are sensitive to salinity; a common ballast treatment is 24 hour exposure to seawater. In a review of biosecurity treatments for killer shrimp, the most effective eradication method was found to be heated water (50°C), which resulted in an instant 100 percent mortality level (Sebire et al. 2018). In contrast, carbonated water only induced narcosis.

5.8.2. Desiccation

Fishhook waterflea resting eggs are tolerant of desiccation, including freeze drying. Despite some mortality, killer shrimp were able to survive for at least 16 days in damp conditions (Anderson et al. 2015) and Fielding (2011) reported survival after 15 days out of water.

5.8.3. Chemical

Sodium chloride was the most effective and applicable chemical treatment tested at length in the cladoceran and, combined with physical treatment via mechanical filtration of water or hot water immersion of equipment (to also manage the risk of diapausing eggs), represents an effective option for the control of non-indigenous zooplankton, with limited impact on stenohaline fish (Tremblay et al. 2019). Abdel-Fattah (2011) suggested that oxidizing biocides are likely effective for killer shrimp.

5.8.4. Biological

Pothoven et al. (2007) found that adult large alewives consume fishhook waterflea in Lake Michigan, but not significantly enough to control the species. In contrast, a study of fishhook waterflea as a prey item in Lake Ontario found that at least 70 percent of alewives larger than 70 mm contained fishhook waterflea spines (Bushnoe et al. 2003). The same study also found spines in rainbow smelt stomachs (Bushnoe et al. 2003). Gorokhova et al. (2004) found that in the northern Baltic proper, herring and sprat are the dominant predators of fishhook waterfleas, and a possible source of biological control through fisheries management, though it is possible that fully mature resting eggs may survive passage through fish digestive systems.

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6. AQUATIC PLANTS – FRAGMENTING

6.1. Species List

Six invasive fragmenting aquatic plants/algae species have been identified as species of concern; additional invasive aquatic plant species are present in the canal system and would benefit from control measures designed to manage these seven species.

Species	Common Name	Size
Egeria densa	Brazilian elodea	3-5 m long
Hydrilla verticillata	Hydrilla	6 m long
Lagarosiphon major	Curly waterweed	6 m long
Myriophyllum aquaticum	Parrot-Feather	2-5 m long
Myriophyllum spicatum	Eurasian watermilfoil	10 m long
Nitellopsis obtusa	Starry stonewort	80 cm long
Potamogeton crispus L	Curly-leaf pondweed	5 m long

6.2. Ecology

Invasive aquatic plants have become successful invaders in waterbodies across the United States, with the ability to grow rapidly (Example Hydrilla's 6– 10 m stems can add up to 3 cm per day) and occupy a wide range of aquatic habitats with varied environmental conditions. Once established, they not only out complete native plant species for light and nutrient resources by creating dense canopies and floating vegetative mats, these species alter the physical and chemical characteristics of the habitat interfering with water flow, boat traffic and habitat quality for other aquatic life forms.

This guild is made up of perennial submerging invasive aquatic plant and algae species. What differentiates species in this guild is that they reproduce, largely through fragmentation. Fragmentation is a type of vegetative clonal propagation which provides intermediate to long distance dispersal. Fragments are formed by the mechanical breakage of the plant stem by disturbances in the water, such as those generated by boats, swimmers, animals, and wave action. After separation from the parent plant, fragments usually descend to the sediment where they produce roots, anchor and establish new plants. All aquatic plants listed this guild have been documented to utilize fragmentation as a means of propagation (Patten 1956; Langeland and Sutton 1980; Hoshovsky and Anderson 2001; Parsons and Cuthberson 2001; Balgie et al. 2010; Pullman and Crawford 2010; DiTomaso et al. 2013).

6.3. Reproduction

Asexual vegetative reproduction is fairly ubiquitous among aquatic plant species and is the primary form of reproduction for plants in this guild. Aquatic plants utilize one or more different type of strategies for vegetative reproductive including: rhizomes, stolons, tubers, turions, and fragmentation.

Fragmentation is the primary method of reproduction and colonization for Brazilian elodea, Hydrilla, curly waterweed, Eurasian watermilfoil and freshwater alga, starry stonewort. Eurasian watermilfoil for example, will autofragment after it flowers, which it does twice a year, typically mid-June and late-July. Eurasian watermilfoil then dies back in the fall, but the root system can survive the winter (Patten 1956; Perkins and Sytsma 1987; Nichols 1975).Because many aquatic species (e.g. Ranunculus spp., Myriophyllum spp., Potamogeton spp., and Elodea canadensis) have meristems closely distributed along their stems, fragments can as small as 1 to 6 cm can successfully develop into new plants (Riis et al. 2009; Heidbüchel and Hussner 2019). For Brazilian elodea, only fragments containing double nodes develop into new plants (DiTomaso et al. 2013). In addition, large vegetation mats of Brazilian elodea and Hydrilla had fragmented and survived as free floating vegetation mats dispersing out from the parent colony.

Localized expansion is provided by rhizomes, stolons, and tuber growth. Stolons and creeping rhizomes are horizontal plant stem that extend outward from the parent plant and produce new plants in the immediate node area. Parrot-feather, Eurasian watermilfoil, curly-leaf pondweed, and Brazilian elodea all utilizes stolons or creeping rhizomes as reproductive methods. Because new stems sprout of rhizomes buried in the sediment, as long as sediment does not freeze, the substrate will insulates these species from cold winter temperatures. Hydrilla do not produce stolons, but can reproduce with tubers, which can remain viable out of water for several days (Basiouny et al. 1978) and in undisturbed sediment for over 4 years (Van and Steward 1990). A single tuber can grow to produce more than 6,000 new tubers per m^2 (Sutten et al. 1992).

Other types of reproduction include dispersal of seeds or turions. Turions are specialized buds which are dispersed and remain dormant through the winter. Both curly-leaf pondweed and Hydrilla can also produce turions before dormancy. Curly-leaf pondweed has a life cycle that is fairly unique for submersed aquatic plants. Rather than dropping the turions at the end of the growing season to lie dormant over winter, curly-leaf pondweed produces and releases turions by early summer, before dying. The turions then lay dormant over summer and sprout in the fall when water temperature drops below 19 °C. The sprouts overwinter in a slow growth dormant state until spring (Woolf 2014). Starry stonewort produces small star shaped bulbils along its nodes, with higher concentrations growing on rhizomal nodes. These bulbils are present throughout the year and can sprout in three to five days under the right conditions (Bharathan 1987; Midwood et al. 2016; Larkin et al. 2018). Long term viability of bulbils is unknown.

Both Eurasian watermilfoil and curly-leaf pondweed can produce seeds through sexual reproduction. However, because these seeds seldom, if ever, develop into seedlings in North America populations, it is not considered an important means of reproduction for species propagation or expansion. Eurasian watermilfoil produce fruits which break apart into nutlets. Fruits detach from the plant and can float downstream for a period of time before sinking. Nutlets can survival for 7 years under dry conditions (Patten 1956; DiTomaso et al. 2013). Curly-leaf pondweed seeds can last approximately 5 years in moist conditions and 1.5 years under dry conditions, though this is poorly documented (DiTomaso et al. 2013).

6.4. Habitat

The submerged aquatic plants in this guild can be found in a wide variety of freshwater and brackish aquatic habitats and conditions. In general, these species prefer slow moving freshwater habitats such as reservoirs, lakes, ponds, canals, rivers, and drainage ditches. However, parrot -feather and Eurasian watermilfoil have been found to grow in swifter moving stream and river habitats. Although curly waterweed has not been introduced into the United States, it has established itself in lakes, streams, and ponds in temperate climate counties of Western Europe.

All the aquatic plants in this guild, with the exception of parrot-feather, can survive in low light environments allowing them to thrive in deep ponds and lakes or other turbid environments. Brazilian elodea has a low light requirement and cannot tolerate high light intensities or high levels of ultraviolet and blue light, as it experiences chlorophyll damage at light levels of 1250 lux (Parsons and Cuthbertson 2001; Casati et al. 2002). Both Hydrilla and curly-leaf pondweed can survive in environments with less than 1% of the surface irradiance (Stuckey et al. 1978; Tobiessen and Snow 1983). Parrot feather is found in both the emergent and the submersed plant communities of freshwater and requires habitats where light can penetrate to the bottom. While it grows best when rooted in shallow water, it has been known to occur as a floating plant in the deep water of nutrient-enriched lakes. It is well adapted to life at the water's edge and can survive when stranded on dewatered river banks and lake shores. Many plants in this guild have high cold tolerances. The plant can overwinter as propagules, dormant shoots, or semi-dormant shoots until spring when temperatures rise (Parsons and Cuthbertson 2001). For example, curly-leaf pondweed unique live history is selective of cool climate conditions (Valley 2012). Although, Brazilian elodea has a wide temperature threshold (3-35°C), its growth becomes limited when species are exposed beyond this range (Yarrow et al. 2009). Starry stonewort has been recorded in water temperatures ranging from 0–24°C (Pullman and Crawford 2010). Curly waterweed, can survive in cold regions and tolerate temperatures as low as -1 °C, before tissue damage occurs. Even though curly waterweed has established in cold regions, exposure to ice will result in large amount of plant tissue damage, but does not kill the plant (Bannister 1990; Centre for Ecology and Hydrology 2004; Matthews et al. 2014). Only parrot-feather is extremely cold temperature sensitive. At temperatures below 10°C, parrot-feather growth is limited and hard or extended period of frost may kill emergent parrot-feather shoots in northern latitudes (WIDNR 2011; Pennington 2014).

6.5. Dispersal

As discussed above in the Section 6.3, wide range dispersal of these aquatic plants occurs as a result of fragmentation. Pieces of stem or root fragments that break off a result of the mechanical shearing of water flows, wave action, waterfowl activity, and boating. For localize dispersal, these aquatic plants utilize a variety of other vegetative reproduction methods

6.6. Potential Pathway(s) of Introduction

6.6.1. Unintentional Transport

The invasive aquatic plants in this guild have been introduced into new waters primarily via castaway and hitchhiking of fragments on recreational equipment including: boats, their motors and trailers, live wells, docking lines, float planes, and fishing equipment. Stem pieces attach themselves to these vehicle vectors and are carried to a new location where they can take root in the substrate and establish into new plant colonies.

6.6.2. Unauthorized Intentional Release

Many of these aquatic plants were first introduced into North America through the dumping of unwanted pond or aquarium contents. Eurasian watermilfoil, parrot-feather, Brazilian elodea, and Hydrilla were, and in some areas still are, popular plants for aquariums (DiTomasa et al. 2013). Curly-leaf pondweed, which is widely distributed across the United States, is believed to have been released as a contaminant in water used to transport fishes and fish eggs to hatcheries (Stuckey 1979). Starry stonewort was originally introduced into the Great Lakes by water discharge from transoceanic ships (IISG 2019).

Floating plant fragments and turoins can drift in currents and stream flow to move this species into new waterbodies (DiTomasa et al. 2013).

6.6.3. Animal Vectors

Fragments of plant material can cling to the feet and feathers migrating waterfowl. Some researchers speculate that Eurasian watermilfoil may be spread by wildlife or waterfowl after ingesting the fruits of the plant. However, no direct evidence exists to support this theory (Madison 2014).

6.7. Status and Threat from GLANSIS database

Common Name	Status in Great Lakes Region	Probability of Intro-duction	Probability of Establishment	Likely Environ-mental Impacts	Likely Socio-Economic Impacts
Parrot-feather	Not currently G.L.	High	Moderate	High	Moderate
Hydrilla	On watchlist	Moderate	High	High	Moderate
Brazilian elodea	In N.A., not G.L.	High	High	High	High
Curly-leaf pondweed	Occurs	Established	Established	Moderate	Moderate
Eurasian watermilfoil	Occurs	Established	Established	High	High
Oxygen Weed	Not yet in U.S.	NA	NA	NA	NA
Starry stonewort	In Lake Erie and Ontario	Established	Established	Moderate	High

6.8. Control

6.8.1. Physical

Effective physical controls of aquatic plants include pulling stems, mechanically mowing/cutting, and dewatering. Since the mowing and removal process can easily create suspended plant fragments, if not done properly, it can encourage the dispersal of plant fragments. Systematically hand pulling stems and roots can provide a temporary control method; however, this approach is very labor intensive as dense mats are heavy and is generally used for small localized outbreaks.

Summer and winter dewatering is a very effective form of treatment with each offering different strategies. Dewatering during mid-summer can be effective in controlling Hydrilla, curly-leaf pondweed, and Eurasian watermilfoil by desiccating plant material (Pickman and Barnes 2017). Because mainly of these plants reproduce through stolons and rhizomes, dewatering becomes more effective when combined with sediment-applied herbicide or with the removal of the top 15 to 46 cm (6-18 inches) of substrate.

Winter dewatering can be effective against parrot-feather, Hydrilla, and Brazilian elodea because stems usually die during periods of prolonged near-freezing temperatures (Anderson 2013). Drawdowns are a potential strategy for controlling starry stonewort. However, the viability the their bulbils following desiccation and freezing is a knowledge gap still being investigated (Larkin et al. 2018). Dewatering can be effective methods against small populations of Brazilian elodea, but large mats of biomass can protect the interior stems from freezing during winter dewatering. A study during a 22 day winter time drawdown of Lake Mulwala in Australia, showed even without even without a significant frosts (coldest temperature observed -1.6°C), it was effective in killing exposed stems of Brazilian elodea. However, it was much less effective in killing the bottom stems and crowns, because they were insulated under near dense vegetation mats (Dugdale et al. 2012).The best time to dewater for parrot-feather control is during the winter time because it is very cold intolerant.

Because these plants need to be rooted to establish, installing of benthic barriers near boat launches and docks where infestations typically first are introduce, can be an effective control method. Barriers have been shown to work to prevent and control Hydrilla, Eurasian watermilfoil, and curly-leaf pondweed (Haller 2014; Madsen 2014; Woolf 2014).

6.8.2. Chemical

Because invasive aquatic plants utilize a variety of growth forms and reproduction methods, there is no uniform treatment of invasive plant species. A variety of chemical herbicides can be used to treat and control aquatic plant species. A significant problem associated with chemical control of any submersed aquatic species is the dilution of the herbicide. In addition, water flow or movement greatly reduces the amount of time the plant is exposed to the herbicide. Application rates and amounts depend on site-specific factors such as infestation size, water depth and chemistry, and water flow rates. For all herbicides the best time to apply is in the early spring to early summer, before plants can grow and disperse fragments, axillary nodes, or turions.

Fast active herbicides such as Diquat, work well as a control method for most all plant species in this guild (Netherland 2009). While Parrot feather's waxy cuticle on stems and leaves can only be penetrated with a wetting agent, use of 2,4-D and triclopyr as a foliar applications have resulted in consistent control of parrot feather (Hofstra 2006; Moreira et al. 1999). Cooper-based algaecides have been shown to reduce abundance and inhibit the growth of planktonic and filamentous alga species, but their effectiveness with starry stonewort is still being researched (Hackett et al. 2017; Larkin et al. 2018). Although, slow-acting systemic herbicides such as including fluridone, are usually recommended as a whole-lake treatment, it often works great when applied to plants and sediment following dewatering.

6.8.3. Biological

Although biological control methods for aquatic invasive plants are limited or not well researched, the most widely used biological control is sterile triploid grass carp (white amur). This fish is relatively nonselective herbivorous fish the will consume most native and nonnative plant species. These non-native grass carp consume 20 to 100 percent of their body weight in aquatic vegetation each day and can live for twenty years (Hoshovsky and Anderson 2001). It may be the most cost-effective method that currently exists for Brazilian elodea eradication, as well as other aquatic plants. Grass carp are not recommended for parrot feather control as fish generally avoid eating this plant due to its high tannin content and do not feed on Eurasian watermilfoil (Catarino et al. 1997; Madsen 2014). In addition, as there are known biological controls for starry stonewort, grass carp would not be an effective control.

Other biological control methods have included the use of insects, but these types of treatments do not have the same broad effectiveness as grass crap. The Australian stem-boring weevil (*Bagous hydrillae* and *Bagous hydrillae*) were released in Florida to control Hydrilla, but hand no success. The leaf-mining fly (*Hydrellia pakistanae*) has been documented to reduce infestations of Hydrilla U.S. and to control Brazilian elodea in Argentina (Walsh et al. 2013; ACF, 2016). Leaf feeding beetle (Lysathia spp.) have been evaluated for control of parrot feather infestations The leaf-feeding beetle showed some promise in South Africa by significantly reducing emergent shoot biomass (Cilliers 1999; Mabulu pers. comm. 2004 in Mabulu 2005); however, this agent is not approved for use in the United States. In addition, a North American weevil, Euhrychiopsis lecotie, may be associated with natural declines of Eurasian watermilfoil at northern lakes (Creed Jr. and Sheldon 1995; Sheldon 1994).

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7. AQUATIC PLANTS – FLOATING

7.1. Species List

Three invasive aquatic plants have been identified as priority species of concern; additional invasive aquatic plant species are present in the canal system and would benefit from control measures designed to manage these three species.

Species	Common Name	Size
Hydrocharis morsus-ranae L	European frogbit	
Stratiotes aloides	Water soldier	10-18 mm long
Trapa natans L.	Water chestnut	Up to 5 m long

7.2. Ecology

These invasive macrophytes express relatively plastic life histories and can grow rapidly and occupy a wide range of aquatic habitats with varied environmental conditions. Once established in a waterbody, they can create a host of social, economic, and ecological issues. What makes this invasive macrophyte guild distinctive is that each species in it has a leaf structure which floats on the surface of the water. The entire plant or the floating structure can easily become dislodged by wind, current action, boats, or swimming fauna. This mechanism allows the plant to drift throughout a waterbody into new, previous unreachable locations.

European frogbit, for example, is an aquatic plant with large, leathery, heart-shaped leaves that can grow to form dense floating mats of interlocking plants. The root system is well developed, but does not normally anchor the plant to the substrate, allowing it to exist in a free floating state (Environment Canada 2003; Nault and Mikulyuk 2009).

Water soldier has a unique life history selective for growth in areas that experience cold weather. These plants are perennial, monocotyledonous freshwater herbs which grow submerged in autumn and winter and become buoyant in the spring and summer, forming dense floating rosettes up to 50 cm tall (Nielsen and Borum 2008). As temperatures drop in the fall, plants return to the bottom of the water column; their decaying roots and leaves increase their specific gravity and pull the plant rosettes down to the sediment where they remain over winter (Cook and Urmi-König 1983). Because their roots are used primarily as a support structure (as opposed to nutrient uptake), and only loosely hold the rosette in the sediment, they can be easily dislodged allowing the entire rosette to relocate to a new location with the current (Nielsen and Borum 2008).

Water chestnut is the only annual invasive aquatic plant of concern. It has a submerged stem anchored to the mud and extending upwards to the surface of the water. At the surface, leaves form a floating rosette that can grow as large as 30 cm in diameter. Rosettes are buoyant due to inflated petioles or bladder-like leafstalks just below the rosette of leaves. The rosettes detach from their stems and float to another location. Even after the rosette separates from its stem, it is still able to produce and drop nutlets; the stems also can grow another rosette (Methe et al. 1993).

7.3. Reproduction

Asexual vegetative reproduction is fairly ubiquitous among perennial macrophytes and includes many different strategies including: stolons or underwater runners, tubers, turions, and fragments. Macrophytes reproduce sexually as well. In the case of water chestnut, which is an annual, this plant exclusively reproduces from seeds.

The invasive populations of European frogbit in North America rely on the expansion of stolons and the dispersal of turions to reproduce. Stolons grow from a parent plant forming offsets or juvenile plants. Over time, these stolons can break down forming a new parent plant (O'Neill, Jr. 2007). In the autumn, the ends of the stolons produce turions (vegetative buds), which break off of the main plant, sink to the bottom of the waterbody, and lay dormant over the winter (O'Neill, Jr. 2007). In the spring, the turions float to the surface and grow into a new plant (IL DNR 2009). A single plant can create up to 150 turions in a single growing season (Sarneel 2013; O'Neill, Jr. 2007; IL DNR 2009). The average size of a mature turion is 2.25 cm in length (Canning 2017). Once turions float back to the surface they can remain floating for up to 6 months; indicating that dispersal via waterways is probably essential to the expansion of this species (Sarneel 2012).

The invasive population of water soldier in North America also reproduces vegetatively. In fact, the population in Ontario has only been observed to produce flowers once, occurring in 2014 (Canning 2017). Similarly to European frogbit, water soldier relies on the expansion of stolons to form colonial offsets and the dispersal of turions to reproduce. Water soldiers produce turions starting in late summer and continue into midwinter. After the parent plant has already sunken back underwater, they drop their turions. The turions germinate and appear as miniature rosettes in the spring (Renman 1989; Canning 2017). Buds have high capacity to disperse over long distances via water (84% of propagules resprouted, and 92% were still floating after 187 days) (Sarneel 2013).

Water chestnut is the only aquatic plant in this guild to reproduce sexually. After pollination, each water chestnut's rosette produces and disperses up to 15 nutlets. The nutlets are approximately 2.54 cm wide, with sharp barbed spikes, and can remain viable for up to 12 years (Swearingen et al. 2002). In late summer, the nutlets mature and drop, then quickly sink to the sediment, as they are approximately 20% more dense than water, and are anchored to the sediment by the spikes. To germinate, the nutlets must experience a period of dormancy at cold temperatures (< 8°C) (Kurihara and Ikusima 1991; Des Jardin 2015). The following spring, the nutlets begin to germinate within a month after water temperatures warm above 10 °C. A single nutlet can produce 15-20 rosettes because the rhizome can branch laterally to produce multiple upright stems (Maryland Sea Grant 2012).

7.4. Habitat

Because the species in this guild are free floating or loosely rooted, they all utilize aquatic habitats with slow moving water, including: ponds, canals, open ditches, marshes, and along the edges of lakes and streams. The species in this guild are fairly elastic and can tolerate a wide range of climatic and water quality conditions.

European frogbit grows well in calcium-rich waters and prefers a habitat with water pH between 6.5-7.8 (Catling and Dore 1982; O'Neill, Jr. 2007). Acidic, nutrient poor waters may restrict its spread (Catling and Porebski 1995). Turions can tolerate only a brief period of freezing conditions, ranging from less than 10 days up to several weeks (Catling et al. 2003). Organic substrate is necessary for European frogbit development and it does not tolerate waters with a mineral substrate.

Water soldier prefers shallow habitats, with slow moving water and nutrient rich grows organic soils. However, it has been documented to grow in waters with moderate flows and depths up 7 m (Tarkowska-Kukuryk 2006). Water soldier is tolerant of a wide pH range (pH 4.5-8.5) (Cook and Urmi-König 1983; Canning 2017). Water soldier’s native range includes Scandinavian counties, and as a cold tolerant species it has been observed to actively photosynthesize and produce offsets under ice thicknesses of 70 cm (Renman 1989).

Water chestnut thrives in slow moving, nutrient-rich fresh water with muddy bottoms, rarely growing in waters with swift currents or low organic material (Takamura et al. 2003; DiTomaso et al. 2013). Most often found growing in waters 2 m deep, water chestnut can also grow in waters as deep as 5 m (Muenscher 1944).The plant prefers pH of 6.7–8.2 and alkalinity of 12–128 mg/L calcium carbonate (Crow and Hellquist 1983). Water chestnut can tolerate salinity up to 0.1% and can survival in tidal freshwater marshes, such as the Hudson River (Coote et al. 2001; Hummel and Findlay 2006; DiTomaso et al. 2013).

7.5. Dispersal

Local dispersal of these plants can occur either by the colonization of offset through stolons or the dispersal of nutlets or turions. Refer to Section 7.4 for more detail.

For all species in this guild, hydrochoric dispersal is the primary means by which these plants move over long distances. Because mature plants in this guild are loosely rooted and occur in a floating life form at some part of their life history, they can easily become dislodged by wind, current action, boats, or swimming fauna. As a result, the entire plant can then drift throughout a waterbody into new, previous unreachable locations. In addition, both European frogbit and water soldier produce buoyant turions which can also be diapered by moving water. Both water soldier and European frogbit turions have been documented to remain buoyant for over 6 months following release (Sarneel 2012; Sarneel 2013).

7.6. Potential Pathway(s) of Introduction

7.6.1. Unintentional Transport

Aquatic invasive plants in this guild can spread from existing waterways as hitchhikers on recreational equipment including: boats, their motors and trailers, canoes, live wells, docking lines, float planes, and fishing equipment. Because these species are either free floating or loosely rooted, these recreational vectors can move and relocate an entire plant (IL DNR 2009; DiTomaso et al. 2013; Cahill et al. 2018).

7.6.2. Unauthorized Intentional Release

All invasive plant species in this guild were first introduced into North America by escaping from ornamental water gardens.

7.6.3. Hydrochoric

As discussed in Section 7.5, hydrochoric dispersal is the primary vector for all species in this guild to increase their disturbance.

7.6.4. Animal Vectors

Wildlife has been documented as transmission vectors for species in this guild. Water chestnut nutlets have four sharp barbed spikes; they can attach themselves on to the feathers, talons, and webbed feet of numerous waterfowl and furred mammals. European frogbit have been observed being transferred as great as distances of 2 km attached on the feet of great blue herons (Ardea herodias) (Catling et al. 2003; Nault and Mikulyuk 2009).

7.7. Status and Threat from GLANSIS database

Common Name	Status in Great Lakes Region	Probability of Introduc-tion	Probability of Establishment	Likely Environ-mental Impacts	Likely Socio-Economic Impacts
European frogbit	Introduced	Introduced	Established	Moderate	Moderate
Water soldiers	Established in Ontario, Canada	High	Moderate	Moderate	Moderate
Water chestnut	Introduced	Introduced	Established	Moderate	High

7.8. Control

7.8.1. Physical

Depending on the size of the infected areas, either hand or mechanical harvesting can effectively control infestations of water chestnut as the species is not spread by fragmentation and roots are easily uplifted from the sediment (Naylor 2003). Mechanical harvesting of plants should occur in late July (after seeds have formed but before they mature), in order to effectively break the reproductive cycle of the plant (Maryland Sea Grant 2012). However, the longevity and quantity of seeds in the sediment's seed bank may make it necessary to repeat the operation for at least 5 to 10 years to eradicate the species. Mechanical removal methods have been used annually in Sodus Bay, New York since the 1960s, but the water chestnut population persists (USEPA 2000). However, mechanical removal followed by an application of 2,4-D was able to eradicate a population of water chestnut in Maryland (Naylor 2003).

The effectiveness of mechanical harvesting of water soldier has not been conclusively evaluated (Snyder et al. 2016). However, in the Trent River, Ontario, hand harvesting was initially found to be as effective at treating water soldier as chemical treatment. Difficulty in correctly identifying water soldier in dense macrophyte communities and turbid water reduced the efficacy of hand removal (Anonymous 2014 in Snyder et al. 2016; Canning 2017). Mechanical harvest is not an effective control method for European frogbit. However, spring time manual harvest of European frogbit, after the turions have begun growing but before dense mats form, could provide temporary control (Catling et al. 2003; IL DNR 2009; WI DNR 2012).

In addition to harvesting, laboratory and greenhouse studies by Wu and Wu (2006) demonstrated that ultrasonic waves of 20 kHz, aimed directly at water chestnut stems and petioles, for 10 seconds resulted in 100% plant death. However, *in-situ* testing has yet to be studied. Shade-cloth enclosures designed to prevent sunlight were utilized on three populations of water soldier in Ontario. After two months, all water soldier plants covered by the enclosures were deceased (OISAP 2016).

Winter drawdowns are not generally used for control of water chestnut because the seeds are likely to survive in the sediments (Wagner 2004). However, winter dewatering is a possible control method for European frogbit in small water bodies and should occur after turions have germinated, but before extensive growth occurs (Catling et al. 2003). Summer drawdowns have been used occasionally to control water chestnut. To be effective, a summer drawdown should be conducted after late May/early June when water chestnut has sprouted, and water levels are drawn down far enough to dry the sediment and kill the vegetation.

7.8.2. Chemical

As explained in Section 6.8.2 in the Fragmenting Aquatic Plants section, there are a variety of chemical herbicides that can be used to treat and control aquatic plant species. Usually chemical treatment is more effective with infestations located in non-flowing waters. The herbicide used most often for control of water chestnut is 2,4–D, which is usually applied in early summer when plants are just reaching the water surface. Diquat is often effective with both water solider and European frogbit (Snyder et al. 2016).

7.8.3. Biological

There are not many biological controls methods available for control of water chestnuts or European frogbit. The leaf beetle *Galerucella birmanica* has significant negative impacts on water chestnuts populations in its native ecosystems in China (Ding et al. 2006). However, this species has many other host species in the U.S., making it unsuitable for use as a biocontrol agent (Maryland Sea Grant 2012). Grass carp, *Ctenopharyngodon idella*, have been documented to feed on European frogbit and water chestnut; however, the introduction of this species may also have a negative effect on native vegetation.

Herbivorous fish and birds, such as swans, were shown to be able to limit the establishment and growth of water soldier by 60% and resulted in decreased survival over 16 weeks. *S. aloides* is also vulnerable to fungi such as *Fusarium roseum* (Cook and Urmi-Konig 1983), but use of any pathogenic control should be cautiously employed in order to minimize non-target effects.

7.9. Citations

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APPENDIX A2

Deterrent Technology Summary Table

Control	Control Type	Control Method	Fish-Assisted Dispersal	Fish- Dispersal	Crayfish	Pelagic Invertebrates	Molluscs	Plant-Fragmenting	Plant-Floating	Advantages	Disadvantages
Physical	Barriers	Air Bubble Curtains		✓						lower cost barrier 50 -95% effective, effective in dark effective in shallow water	requires clear water for high end effectiveness, cost of sir production and water depth limit application, rarely used
		Water Jets In Lock	✓	✓						may knock molluscs off boats, not yet tested	previously determined not effective for excluding fish at cooling water intakes
		Electric		✓	✓		✓			commonly used	field disruptions allow passage, costly, time to implement, not effective on small fish, upstream only high cost, safety risk arcing
		Bio-acoustic Fence (BAFF)		✓						highly effective in lab (98% carp)	Upstream movement
		Sound Wave Barriers (Acoustic, Ultra Sonic, etc.)	✓	✓						< 80% effective, human health safety can be tailored for target species, somewhat	few field tests, can be taxon specific
		Strobe lights		✓						low cost	low effectiveness, very species/site specific
		High Pressure Sodium Lights		✓						will attract blue back herring	low effectiveness, rarely more effective than strobes
		Screens - Vertical Plate, Rotary Drum		✓					✓	up to 100% effective for fish tested and approved designs could be stand alone or an enhancement	Cleaning and O&M
		Filter Water treatment Plant	✓	✓	✓	✓	✓	✓	✓	up to 100% effective	limitations on flow, high cost
		CO_2 Barrier		✓						not species specific would be effective in contained water body	expensive
		Velocity Barriers		✓	✓					proven technique for fish	barrier to upstream movement only
		Vertical Barriers	✓	✓	✓	✓	✓			low maintenance high efficacy	generally used for upstream passage only may prevent movement of non-target migrants
		Benthic Barrier/Mats					✓	✓		short term, local effectiveness	ongoing maintenance can provide substrate for molluscs may limit desired taxa
	Dewatering / Drawdowns	Hydrologic Separation	✓	✓	✓	✓	✓	✓	✓	low maintenance can be independent of hydrology immediate action supports watershed restoration	human use, prevents movement of native organisms, unintended fishery consequences
		Summer Drawdown					✓	✓	✓	immediate action, short term impact on recreation	best paired with herbicide or sediment removal for plants
		Winter Drawdown (freezing)				✓	✓	✓	✓		best at lower densities thick vegetation mats may not freeze adequately for control

Control	Control Type	Control Method	Fish-Assisted Dispersal	Fish- Dispersal	Crayfish	Pelagic Invertebrates	Molluscs	Plant-Fragmenting	Plant-Floating	Advantages	Disadvantages
Physical	Cleaning Methods / Water Treatment	High Temperature/Steam Washing	✓	✓	✓	✓	✓	✓	✓	kills everything non-toxic	labor intensive not stand-alone needs boat lift debris disposal/mgmt
		Pressure Washing	✓			✓	✓	✓	✓	kills everything non-toxic	labor intensive not stand-alone needs boat lift debris disposal/mgmt
		Carbon dioxide pellet blasting					✓			proven on aircraft, pellets dissolve upon impact leaving no residue	CO2 generating input
		Salt water wash									
		Chlorine , bromine, etc.									
	Manual / Mechanical Harvest	Fish Capture (nets, E-Fishing, seine, sport fishing, etc...)	✓	✓	✓					reduces population targets species of concern easily implemented proven techniques	not 100 % effective intensive ongoing labor required not stand-alone control hydrology dependent harder to monitor effectiveness
		Harvesting					✓	✓	✓	reduces population targets species of concern useful for small batched populations	not 100 % effective intensive ongoing effort required not stand-alone control hydrology dependent
	Others	Electron beam irradiation				✓				highly effective for targeted organisms	requires closed system not appropriate for open water application not 100 % effective
		Ultraviolet (UV)				✓				kills small, hard to contain organisms	requires closed system not appropriate for open water application
		Salt water (Dead Sea bath)	✓	✓	✓	✓	✓	✓	✓	recyclable human health safety minimize ecological risk independent of hydrology	not stand-alone, with boat lift highly corrosive to metal experimental treatment
		Thermal Treatments (Hot bath)	✓	✓	✓	✓	✓	✓	✓	recyclable water source human health and safety minimal ecological risk independent of hydrology takes advantage of proven technique general effectiveness at high temps (140°F)	not stand-alone, with boat lift works with a boat lift water temp above 120°F damages fiberglass experimental as bath concept requires heat source
Outreach		Educational Program on AIS and NY Canals	✓	✓	✓	✓	✓	✓	✓	overall increased public awareness will help minimize future risks	
		Canal Boat Wash Steward Program	✓		✓	✓	✓	✓	✓	overall increased public awareness/ engagement will help minimize future risks, job creating	labor intensive not stand-alone, cleaning method

Control	Control Type	Control Method	Fish-Assisted Dispersal	Fish- Dispersal	Crayfish	Pelagic Invertebrates	Molluscs	Plant-Fragmenting	Plant-Floating	Advantages	Disadvantages
Chemical	Biocides (e.g., piscicides, herbicides, etc.)		✓	✓	✓	✓	✓	✓	✓	highly effective for targeted organisms	kills non-target organisms not stand-alone control human health disposal requirements effectiveness may be temperature dependent high risk unintended ecological consequences risk requires more than one biocide and multiple applications over time
	Changing Water Quality	Nitrogen	✓	✓	✓		✓			guild specific proven effective readily available	Adult fish more tolerant than young fish may increase ammonia may affect non-targeted organisms unintended ecological risk downstream
		Carbon dioxide (CO2)	✓	✓	✓		✓				may repel fish at sub-lethal levels may affect non-targeted organisms unintended ecological risks
		Sodium thiosulfate		✓							deoxygenated compound may not be effective for goldfish disposal requirements high maintenance continual application high risk unintended ecological consequences
		Ozone	✓	✓	✓						rendered ineffective in presence of organic matter lethal to fishes
	Water Treatment	Chlorine , bromine, etc.	✓	✓	✓	✓	✓			highly effective for many organisms Cl^- can be neutralized prior to discharge	kills non-target organisms not stand-alone control human health risks, byproducts chamber or bath required Organic mater reduces effectiveness, increase dose high maintenance continual application high risk unintended ecological consequences
Biological	All Biological Control	Predatory fishes insects disease agents	✓	✓	✓	✓	✓	✓	✓		unintended ecological consequences efficacy variable in different environments
		Deleterious gene spread	✓	✓						could be targeted treatment	species specific effort possible for carp, sea lamprey, and crayfish long term unintended ecological consequences
		Trojan Y chromosome/ Daughterless genetic control	✓	✓	✓					potential theoretical path to elimination of invasive population for specific fishes	experimental, unintended ecological consequences

APPENDIX B

Deterrent Technology Evaluation Process

APPENDIX B1

Criteria Document

EVALUATION PROCESS AND INITIAL CRITERIA REVISED FOR CRITERIA WEIGHTING PHASE 2

Introduction

This document provides a description of the process used to evaluate and combine aquatic invasive species (AIS) deterrent concepts into AIS deterrent network system alternatives (system alternatives), facilitated with an initial brainstorm workshop. Ultimately, the goal was to combine the most promising deterrent concepts into two to four networked AIS system alternatives and utilize this evaluation process and final criteria to help select the most promising networked system of AIS deterrents. The process first developed and compared deterrent concepts, and then networked system alternatives, for potential feasibility and effectiveness. This document describes the grid analysis technique (Pugh Matrix), used to break the deterrent concepts and then system alternatives down into discrete elements for comparison, evaluation, and optimization.

1. EVALUATION PROCESS

A grid analysis was used to help develop consensus of design solutions to identify networked deterrent systems for further discussion and development. It was valuable as a tool for developing a mutual understanding of each concept/alternative, understanding values and points of view of others on the team doing the evaluation, and for optimizing both the deterrent concept and networked system alternatives. This process was not just about selecting a winner. This basic process is commonly used to assist engineering decisions; we emphasize specific parts of the process and use some statistics to help highlight important aspects.

Some benefits of using this method were that it:

- Helped remove personal judgments from decisions.
- Developed a clear common understanding of options being considered.
- Helped diverse stakeholders understand each other's values and issues.
- Provided a quantitative technique to rank multi-dimensional options.
- Could test sensitivity of objectives and project features.
- Was rational and consistent; scientists, engineers, and managers love numbers and rational decisions.

- Provided a framework for discussion, understanding, consensus-building.

The process of the analysis was as follows. Each of these components of the grid analysis is further explained below.

- Defined evaluation criteria.
- Weighted criteria.
- Developed and described alternatives.
- Scored alternatives for each criterion.
- Multiplied each score by the criteria weight.
- Sum and present the score-weight products for each alternative.

1.1. Define Evaluation Criteria

Evaluation criteria were developed that were used to evaluate each deterrent concept. The deterrent concepts were first evaluated with a pros and cons and fatal flaw analysis, and then our Team decided which technologies merited inclusion in the more formal Pugh Matrix method to further rank the deterrent concepts. Each criterion was a positive attribute and could be considered an objective of the concept/alternative. Note that the criteria are not all thresholds that had to be entirely satisfied. Most criteria were satisfied to different degrees by various concepts, though failure of concepts/alternatives to satisfy certain specific, essential criteria did result in fatal flaws.

Evaluation criteria were grouped into four categories: effectiveness, risk, operations and maintenance, and cost. This facilitated consideration of the many aspects of effectiveness to be balanced with the less multifaceted cost criteria. Both the criteria categories and individual criteria within them had different levels of importance and were weighed appropriately as part of the technology comparison. An important step early in the process was to define the evaluation criteria together as a team during the Brainstorm Workshop. The criteria were refined as the concepts were further developed. This was a transparent process where this document was updated and revised, with a clear trail of modifications in archived versions.

Table 1 is a schematic example of the grid analysis. This is greatly simplified for the sake of explanation. Ultimately, the NYS Canal AIS Study matrix was used to evaluate 35 technologies.

Table 1. Schematic example of Pugh Matrix grid analysis.

Evaluation Criteria (Objectives)	Criteria Weights	Alternative 1 Score	Alternative 1 Weighted Score	Alternative 2 Score	Alternative 2 Weighted Score
Criteria 1	6	5	30	5	30
Criteria 2	10	2	20	8	80
Criteria 3	1	9	9	4	4
Criteria 4	3	3	9	8	24
Weighted Totals			**68**		**138**

1.2. Weight Criteria

Both the criteria categories and individual criteria within them had different levels of importance and were weighted appropriately. The criteria categories were weighted using a proportion so as to sum to 1. The individual criterion weighting used a scale of zero to ten. If a criterion scored “zero” it had no influence on the design. It could be left on the list for discussion or because it was important to other parties. Alternatively, if the Team agreed that it was not a differentiator, it could be removed to simplify the process. To challenge us to differentiate among the criteria by not allowing all criteria to be weighed ten, we stipulated that the average weight for each component had to be five. In the schematic example above, the weights vary from 1 to 10 and average 5.

It is possible for different stakeholders to do their own weighting; weightings reflect perceptions of the relative value of aspects of the project. The differences in weights among various stakeholders highlight differences in values and subsequent differences in final scores highlight where discussion is needed to achieve consensus.

1.3. Score Alternatives

The next steps were to score how well each concept satisfied each criterion and put the score into the appropriate cell in the matrix. We used a ten-point (zero to ten) semantic scoring system. A three-point or seven-point scoring system is often used for this, but we used the wider range to create room for a deterrent to be incrementally improved by modifying it.

The Team did not get to the full scoring and use of the Pugh Matrix at the Brainstorm workshop, since the goal of the workshop was to initially develop and select the best concepts, and then combine them into a networked deterrent system. The full Team initially scored the alternatives independently. Large differences among individual scores highlighted differences among the Team that merited further discussion. Differences were due to differences in familiarity with information available, or the experience of individual Team members, or differences in understanding of the concept or alternative. Individuals then modified their scoring, and/or the description of each technology or criteria was modified as necessary until we achieved a common understanding of each concept and criterion. The goal was to achieve a true common understanding of each score, not just to agree on a number.

1.4. Simple Math

Each final score was multiplied by the weight for that criterion to calculate the weighted score. In the schematic example above, Alternative 2 scored much higher than Alternative 1 for Criteria 2. The importance of the criteria, weighted 10, overwhelmed the fact that Alternative 1 scored much higher than Alternative 2 for Criteria 3, because it was only weighted a value of three. Then the weighted scores were summed for each of the four criteria categories. Finally, the category weights were applied, the criteria scores combined and the totals were compared. We emphasize that the entire process was used as a means for communication, mutual understanding, and optimization of concepts, rather than to simply calculate a final score. To optimize alternatives, the lower-ranking alternatives could be “challenged” by addressing the specific criteria that caused them to score low. We could focus on the criteria for which the weighted scores differed the most; these are the criteria that most affected the total scores. This used the highest scoring concepts to optimize the low-scoring ones and was an important part of this process.

Note that if additional stakeholders are eventually brought into the process, the Pugh Matrix spreadsheets can be provided to other parties to do their own weighting independently. Differences in final results among parties are valid when they are differences in values reflected in the criteria weights. Parties are also welcome to challenge scores applied to technologies, and the discussion is important. Again, the process can emphasize a mutual understanding of the concepts and any information available that affects scores and can compare the sums of the client and stakeholders. For example, where are the differences? If there is a significant difference among highest ranking alternatives, we can ask “why.” We can also look at the differences in weighted scores between matrices scored by different parties. The greatest differences will highlight the criteria that are the key sources of differences. We can then ask what can be done to a concept with a lower score to raise it closer to the higher score.

2. CONCEPT CRITERIA

This section provides a description of desirable criteria to describe, compare, optimize, and guide the selection of deterrent concepts. To develop the concept criteria, the R2 Team utilized the initial guild summaries, information from the phone interviews with identified stakeholders and regional experts, and discussion amongst the Team to identify criteria that could show differences among any concepts that might be considered. A key step of the Brainstorm Workshop was to work together to critique, add to, and then group and consolidate this list.

Each criterion is defined such that it is positive; that is to say, that higher compliance is reflected by a higher score. There are often few, if any, hard data to use in the weighting and scoring criteria. Weights and scores are generally based on professional opinion and experience with similar facilities or effectiveness with similar species.

The following descriptions provide and initial description of the preliminary criteria. This section has been updated based on discussions during the brainstorm workshop and describes the fully developed criteria descriptions that subsequently were used in the Pugh Matrix analyses for deterrent technologies.

2.1. Deterrent Effectiveness at Normal Flows

This category evaluates a deterrent's effectiveness during flows typically encountered during the operation season. Effectiveness varies by dispersal method, so we divided this criterion to allow scoring for the various AIS dispersal methods.

Water Dispersal

A high score under this category means the deterrent is very effective in preventing AIS that disperse via flows between locks, gates, various water bodies.

Terrestrial Dispersal

A high score under this category means the deterrent is very effective in preventing the spread of AIS that also can disperse over ground, for example, snakehead, crayfish, etc. In addition, physical features that include designs with smooth aprons would reduce the ability of aquatic organisms to crawl out of the canal and were scored higher.

Hitchhikers

This category covers AIS that are transported by boats, waterfowl, and other dispersal methods of organisms that effectively "hitchhike" on equipment or other species. A component that facilitates examination of bait buckets and live wells would score high for this criterion.

Certainty of Effectiveness

This criterion reflects the level of certainty in the deterrent's success in blocking the spread of AIS relative to other concepts/alternatives. A high score will indicate that the alternative is more certain to be effective than others. Certainty is often reflected by experience and knowledge of other similar operating or prototype facilities where biological data exists. Certainty might also be enhanced by researching other similar concepts, or the potential to do prototype research at specific sites. It is included as a criterion because of the importance of a deterrent's effectiveness, and because the certainty of the estimate may vary greatly. Though the scores of two alternatives might be the same, the higher certainty of one concept/alternative (based on knowledge of existing data, or operating systems) could make it preferable over another.

Ability to Monitor Effectiveness

The ease of the ability to monitor effectiveness scored higher.

2.2. Deterrent Effectiveness at Flood Flows

This category evaluates a deterrent's effectiveness during flood flows, which may represent more of a "pass/fail" analysis. For example, this category would score high if a component maintained its effectiveness during flood flows but would score very low if it failed. Effectiveness may vary by dispersal method, so we have initially divided this criterion to allow for scoring of the various AIS dispersal methods. The same sub-categories as described above are provided for this criterion.

- Water Dispersal
- Terrestrial Dispersal
- Hitchhikers
- Certainty of Effectiveness
- Ability to Monitor Effectiveness (easy scores higher)

2.3. Ecological Issues (fish, plants/algae, invertebrates)

Ecological issues associated with a concept included fish, plants/algae, and invertebrates, (e.g.; crustaceans and molluscs.) A deterrent may perform differently for these different species, so we have separated them into the following categories for scoring.

Fisheries – Compatibility with Fish Passage

A deterrent concept scored high if it blocked the target AIS but could still be compatible with and provide fish passage for desired fish species. Specific components that can be conducive to selective fish passage will also score higher.

Restoration Benefits

Broader ecosystem restoration opportunities that are associated with or made feasible by the deterrent concept scored higher. Components that support restoration actions such as reducing sediment runoff, reconnecting flood plains, encouraging native flora and fauna etc. also scored higher. For example, hydrologic separation can facilitate watershed restoration. Wash stations could receive a moderate score for minimizing spread of invasive hitchhiker species and indirectly helping native species.

Unintended Ecological Impacts

This criterion was scored high for the concepts that have the least potential for unintended ecological consequences. Examples would be unintentional mortality on native species, damage to their habitat, or disruption to migratory patterns for established native/desired species.

2.4. Human Health

This criterion helped to quantify the potential for other human health issues created, exacerbated, or avoided with the various AIS barrier concepts. The least potential for any human health issues associated with the following sub-categories had the highest scores.

Biocide/Pollution Release into Waterways

A concept that relies on chemical treatment or biocides that may have potential harmful human health effects scored lower than an alternative that either avoided or minimized the need for chemicals/biocides.

Electric Shock Concerns

Use of electric barriers could create a public health hazard or a hazard for wild and domestic animals to get shocked. Concepts with the least potential for electric shock scored the highest.

2.5. Implementation Timeframe

The various deterrent concepts may have very different implementation timelines. We scored alternatives with their ability to meet both near-term and future AIS deterrent goals as follows:

Near-term

The ability to create an effective deterrent in the very near term, such as closing a flood gate, scored high for this criterion.

Future

The ability to create an effective deterrent over a longer time frame to accommodate permitting, social acceptance, etc. scored higher in this criterion.

2.6. Other Technical Issues

This category addressed other technical issues developed during the brainstorm session, such as:

Adaptive Management

Deterrent concepts/alternatives that are easy to modify scored higher than alternatives that would require abandonment or a major retrofit.

Prototypes in Existence

Deterrent components that have proven performance in similar applications scored highest, while components that have successfully been tested or deployed for other purposes received moderate scores.

2.7. Socio-Political issues

This category captured specific socio-political issues that were important to the different stakeholders. It was beneficial to provide score for subcategories, such as the following:

Consistency with Ongoing AIS Programs

Concepts that are consistent or compatible with ongoing AIS programs scored higher for this criterion. For example, a boat wash that included examination of live wells and bait containers would enhance containment of invasive plants ongoing in the western canal and Finger Lakes.

Navigation

The ability to meet the goals of enhanced local recreational boating and reduction of through-canal traffic is the basis of this criterion. Scoring was conducted as follows:

- A high score of 10 represented a barrier component that facilitates local navigation and discourages "through-canal" navigation.
- A neutral score of 5 represented a barrier component that is neutral for local navigation, and through-canal navigation.
- A low score of 0 represents a barrier component that facilitated through-canal and discouraged local navigation.

Recreation

Ability to accommodate or enhance recreational opportunities other than fishing (handled separately) scored higher.

Fishing

Ability to enhance or provide fishing opportunities or support existing fisheries scored higher. A component that prevents future negative impacts from AIS on an area of the canal with highly valued fishing, for example the Brown Trout fishery in Ontario Lake tributaries that receive flow from the canal, scored higher.

Local Employment Opportunities

Ability to enhance or provide local employment opportunities scored higher.

2.8. Ability to Permit

This category may need to be subdivided into individual permit needs that may be important for consideration in the local region.

Ability to Obtain USACE Permits

Ability to more easily obtain a USACE permit scored higher. Scores for this category were based on precedents (high score) and perceived permit complexity (lower score).

2.9. Operation and Maintenance

These criteria were intended to capture all issues related to operation and maintenance of a technology. This is an important category and is subdivided into the following subcategories.

Operations Personnel and Public Safety

This criterion focused on the New York Power Authority canal and hydropower operations staff safety. Concepts that were the simplest or safest to operate scored the highest. This criterion also allowed us to capture a technology's potential to affect public safety. Concepts that were the least likely to cause or create public safety concerns scored higher.

Reliability/Durability

The most reliable and durable concepts scored higher.

Compatibility with Current Function

The concepts that were most compatible with the current function scored higher.

Ability to Handle Debris

Concepts that could most easily and reliably handle debris scored higher.

Sediment Handling

Concepts that could most easily and reliably handle sediment, or require the least dredging, scored higher.

Ice Operations

Concepts that could most easily and reliably handle ice operations, or ease start-up/shut-down scored higher.

Security

Concepts with the least concern for necessary security scored higher.

Chemical Storage

Concepts with the least need for chemical storage (such as chlorine or biocides) scored higher.

Terrorism Concerns

Concepts with the least concern for protection from potential terrorist acts scored higher (e.g., chemical storage).

2.10. Cost

Cost was an important criterion, and was subdivided into the categories below.

Capital Cost

This is the relative capital cost for design and construction. Concepts with the lowest estimated costs relative to other concepts scored higher.

Operation and Maintenance

This is the relative operation and maintenance (O&M) cost. Concepts with the lowest estimated O&M costs relative to other concepts scored higher.

Certainty of Cost Estimate at Feasibility Level

This is the relative certainty of estimated costs at this feasibility level of analysis. Concepts with the most certainty scored higher.

APPENDIX B2

Technology Summary Table

Control	Control Type	Control Method	Description	Fish-Assisted Dispersal	Fish- Dispersal	Crayfish	Pelagic invertebrates	Molluscs	Plant-Fragmenting	Plant-Floating	Advantages	Disadvantages
Physical	Barriers	Water Jets	Multiple longitudinal rows of jets forward facing placed at a slight 22.5 angle off of the vertical to remove small and/or stunned fish entrained between the barges. Requires water intakes for the jets and pumps.	✓	✓						may knock molluscs off boats, not yet tested	previously determined not effective for excluding fish at cooling water intakes
		Screens - Vertical Plate, Rotary Drum	a variety of screen materials (e.g. woven cloth, perforated plate, or profile wire) mounted over an opening; may or may not have an automatic cleaning mechanism to remove debris.		✓					✓	up to 100% effective for fish tested and approved designs	Upstream movement barrier only
		Filter Water treatment Plant	Four types of filters are generally used in water treatment: slow sand filters, rapid sand filters, pressure filters, and diatomaceous earth filters. Slow sand filters are used for small groundwater systems; rapid sand filters are used for surface water treatment; pressure filters are used for iron and manganese removal in small groundwater systems; and diatomaceous earth filters are used in the food and beverage industry and for treatment of swimming pools.	✓	✓	✓	✓	✓	✓	✓	up to 100% effective	limitations on flow, high cost
		CO_2/pH Treatment	Injects carbon dioxide gas using a bubbler delivery system, through anchored tubing near the bottom of a flowing waterway. Implementation would include the construction of a CO2 generation plant.		✓							expensive, low effectiveness, not taxon specific. If applied in an open system, prolonged exposure to acidified water may injure submersed structures and channel walls and may alter sediment chemistry. Introducing the required quantity of CO2 into the waterway may reduce the water's temperature. Due to its gaseous properties, CO2 may prove to be ineffective in open flowing systems.
		Velocity Barriers			✓	✓					proven technique for fish, low cost	barrier to upstream movement only
		Vertical Barriers	A vertical concrete wall that rises to a height that exceeds the leaping abilities of fish when combined with shallow, fast-flowing water over an apron designed to produce uniform water velocities that exceed fish swimming abilities Prevents upstream passage	✓	✓	✓	✓	✓			low maintenance high efficacy	generally used for upstream passage only may prevent movement of non-target migrants
		Benthic Barrier/Mats	System designed to prevent the establishment of plants, control existing plants, and to interfere with respiration in fish and macroinvertebrates. Consist of an anchored textile or plastic material, which is placed over existing vegetation, or in a location to prevent the establishment of aquatic vegetation.					✓	✓		short term, local effectiveness	ongoing maintenance can provide substrate for molluscs may limit desired taxa

Control	Control Type	Control Method	Description	Fish-Assisted Dispersal	Fish- Dispersal	Crayfish	Pelagic invertebrates	Molluscs	Plant-Fragmenting	Plant-Floating	Advantages	Disadvantages
Physical	Dewatering / Drawdowns	Hydrologic Separation	Measure such as permanent gate closure or dewatering that permanently halts water flow without a bypass available for aquatic organisms	✓	✓	✓	✓	✓	✓	✓	low maintenance can be independent of hydrology immediate action supports watershed restoration	human use, prevents movement of native organisms, unintended fishery consequences
		Summer Drawdown	Water level drawdowns to expose ANS to the air. Exposure to the air quickly leads to death for most active water-breathing organisms like fish, but mollusks and plants are more tolerant to desiccation and have life stages that can be highly resistant to desiccation					✓	✓	✓	immediate action, short term impact on recreation	best paired with herbicide or sediment removal for plants
		Winter Drawdown (freezing)					✓	✓	✓	✓		best at lower densities thick vegetation mats may not freeze adequately for control
	Cleaning Methods / Water Treatment	High Temperature/Steam Washing	Spraying pressurized hot water or steam to kill and remove ANS from boats, pipes and structures	✓	✓	✓	✓	✓	✓	✓	kills everything non-toxic	labor intensive not stand-alone needs boat lift debris disposal/mgmt
		Pressure Washing	Cleaning method for boats/watercraft. Requires vessel removal from water and management of waste water. More effective with hot water (140ºF)	✓			✓	✓	✓	✓	kills everything non-toxic	labor intensive not stand-alone needs boat lift debris disposal/mgmt
		Carbon dioxide pellet blasting	Similar to sand blasting with frozen CO2 pellets instead of sand. CO2 pellet blasting leaves no blasting medium residue because the CO2 pellets turn into a gas at room temperature. CO2 pellet blasting flash freezes the target organism, both killing it and making it brittle and easier to remove					✓			proven on aircraft, pellets dissolve upon impact leaving no residue	CO2 generating input

Control	Control Type	Control Method	Description	Fish-Assisted Dispersal	Fish- Dispersal	Crayfish	Pelagic invertebrates	Molluscs	Plant-Fragmenting	Plant-Floating	Advantages	Disadvantages
Physical	Others	Electron beam irradiation	Water treatment in contained areas by exposing contaminated water to low doses of radiation from gamma-sterilizers or electron accelerators. Electron beam irradiation can break down DNA in living organisms, resulting in microbial sterilization				✓				highly effective for targeted organisms	requires closed system not appropriate for open water application not 100 % effective
		Ultraviolet (UV)	An enclosed chamber containing a series of UV-emitting light bulbs. As water flows through the chamber, UV light deactivates the DNA of bacteria, viruses and other pathogens, which destroys their ability to multiply and cause disease and affects spore germination and chloroplast function in several algae species				✓				kills small, hard to contain organisms	requires closed system not appropriate for open water application
		Salt water (Dead Sea bath)	Lethal zone created with high salinity water, creating a kill zone for AIS. Requires contained bath for "dipping" watercraft into. Does not involve releasing salt water into waterway.	✓	✓	✓	✓	✓	✓	✓	recyclable human health safety minimize ecological risk independent of hydrology	not stand-alone, with boat lift highly corrosive to metal experimental treatment
		Thermal Treatments (Hot bath)	Lethal zone created with heated water, creating a kill zone for AIS. Requires contained bath for "dipping" watercraft into. Does not involve releasing heated water into waterway.	✓	✓	✓	✓	✓	✓	✓	recyclable water source human health and safety minimal ecological risk independent of hydrology takes advantage of proven technique general effectiveness at high temps (140°F)	not stand-alone, with boat lift works with a boat lift water temp above 120°F damages fiberglass experimental as bath concept requires heat source

Control	Control Type	Control Method	Description	Fish-Assisted Dispersal	Fish- Dispersal	Crayfish	Pelagic invertebrates	Molluscs	Plant-Fragmenting	Plant-Floating	Advantages	Disadvantages
Sensory	Behavioral	Air Bubble Curtains	Wall of bubbles rising from a bottom-resting bubbler manifold (perforated pipe) supplied with compressed air Can be enhanced with addition of sound signal		✓						lower cost barrier 50 -95% effective, effective in dark	requires clear water for high end effectiveness, cost of sir production and water depth limit application, rarely used
		Sound Wave Barriers (Acoustic, Ultra Sonic, etc.)	underwater sound (projectors powered by audio amplifiers and electronic signal generators) to create a repellent acoustic field, comprised of near- and far-field sound component	✓	✓						< 80% effective, human health safety	few field tests, can be taxon specific
		Strobe lights	Produce flashes of light at rapid rates to alter fish movements		✓						low cost	low effectiveness, very species/site specific
		High Pressure Sodium Lights	Lights to guide fish away from intakes		✓						will attract blue back herring	low effectiveness, rarely more effective than strobes
		Electric Fences	Electrodes emit pulsed DC charges into the water Can be used to deter, stun, or kill the organism A stunning strength field is only effective as deterrent to upstream movement		✓	✓		✓			commonly used	field disruptions allow passage, costly, time to implement, not effective on small fish, high cost, safety risk
		Bio-acoustic Fence (BAFF)	Bio Acoustic Fish Fence (BAFF) uses a combination of sensory stimuli that produce a linear barrier, guiding fish away from the point of water collection. Customized sound signals, directional strobe lighting and an air bubble curtain provide directional control. The BAFF uses an air blower or compressor to supply pressurized air to create a continuous bubble curtain, and to supply the control pressure line in the BAFF Control Unit. A temperature/pressure resistant pipe delivers air from the air blower or compressor to the BAFF Control Unit and BAFF Units.		✓						highly effective in lab (98% carp)	
		CO2 Barrier	CO2 injection into water as a sensory deterrent for fish		✓						lab studies suggest all species tested respond	Highly experimental, in lab avoidance rates as low as 50%
Outreach		Educational Program on AIS and NY Canals		✓	✓	✓	✓	✓	✓	✓	overall increased public awareness will help minimize future risks	
		Canal Boat Wash Steward Program	Boat washing facilities at boat ramps/access points. Each wash station is run by individuals trained to identify invasive species and properly decontaminate any evident or suspected threat.	✓		✓	✓	✓	✓	✓	overall increased public awareness/ engagement will help minimize future risks, job creating	labor intensive not stand-alone, cleaning method

Control	Control Type	Control Method	Description	Fish-Assisted Dispersal	Fish- Dispersal	Crayfish	Pelagic invertebrates	Molluscs	Plant-Fragmenting	Plant-Floating	Advantages	Disadvantages
Chemical	Biocides (e.g., piscicides, herbicides, etc.)		Chemicals designed to kill all live stages of organisms Effectiveness varies with concentration and exposure time	✓	✓	✓	✓	✓	✓	✓	highly effective for targeted organisms	kills non-target organisms not stand-alone control human health disposal requirements effectiveness may be temperature dependent high risk unintended ecological consequences risk requires more than one biocide and multiple applications over time
	Changing Water Quality	Nitrogen	Supersaturation of water with nitrogen gas bubbles applied using a porous diffuser	✓	✓	✓		✓			guild specific proven effective readily available	Adult fish more tolerant than young fish may increase ammonia may affect non-targeted organisms unintended ecological risk downstream
		Carbon dioxide (CO2)	Supersaturation of water with CO2 gas bubbles applied using a porous diffuser Reduces the pH of water Onsite production required	✓	✓	✓		✓				adjusts pH to lethal levels may affect non-targeted organisms unintended ecological risks
		Sodium thiosulfate	Typically used to neutralize chlorine and iodine Supplied chemical suppliers as a colorless, granulated, crystalline substance with a pH of 8.0 Is applied by dissolving in water at desired concentration		✓							deoxygenated compound may not be effective for goldfish disposal requirements high maintenance continual application high risk unintended ecological consequences
		Ozone	Ozone oxidation of water must be created onsite by using high voltage sparks or intense ultraviolet light to produce ozone and applied using porous diffusers, radial diffusers, or venturi injectors	✓	✓	✓						rendered ineffective in presence of organic matter lethal to fishes
	Water Treatment	Chlorine , bromine, etc.	Oxidizing chemical disinfectants Treatment systems inject dilute solutions into ballast or treatment water to a desired solution strength	✓	✓	✓	✓	✓			highly effective for many organisms Cl^- can be neutralized prior to discharge	kills non-target organisms not stand-alone control human health risks, byproducts chamber or bath required Organic mater reduces effectiveness, increase dose high maintenance continual application high risk unintended ecological consequences

Control	Control Type	Control Method	Description	Fish-Assisted Dispersal	Fish- Dispersal	Crayfish	Pelagic invertebrates	Molluscs	Plant-Fragmenting	Plant-Floating	Advantages	Disadvantages
Biological	Manual / Mechanical Harvest	Fish Capture (nets, E-Fishing, seine, sport fishing, etc...)	A variety of nets and traps may be used to catch targeted species for physical removal and disposal	✓	✓	✓					reduces population targets species of concern easily implemented proven techniques	not 100 % effective intensive ongoing labor required not stand-alone control hydrology dependent harder to monitor effectiveness
		Harvesting	Controlled harvest is the removal of an organisms for consumption or use					✓	✓	✓	reduces population targets species of concern useful for small batched populations	not 100 % effective intensive ongoing effort required not stand-alone control hydrology dependent
	All Biological Control	Predatory fishes insects disease agents	The use of predatory species or targeted disease agent to reduce pest populations of another organism Often, biocontrol agents are imported from the native range of the target species	✓	✓	✓	✓	✓	✓	✓		unintended ecological consequences efficacy variable in different environments
		Deleterious gene spread	Involves the production and release of genetically altered fish that bear a deleterious genetic construct (transgene) designed to disrupt a specific aspect of the organism's life cycle or biology	✓	✓						could be targeted treatment	species specific effort possible for carp, sea lamprey, and crayfish long term unintended ecological consequences
		Trojan Y chromosome/ Daughterless genetic control	Autocidal genetic biocontrol methods proposed as a means to eliminate invasive fish by changing the sex ratio of the population	✓	✓	✓					potential theoretical path to elimination of invasive population for specific fishes	experimental, unintended ecological consequences

APPENDIX B3

Results

	Wt. 0-10			Wt. 0-10					
	Score 0-10	Std Dev		DEP	DP2	GG	KS	MK	PS
Effectiveness	0.35								
Deterrent Effectiveness at Normal Flows									
Water dispersal	9.7	0.7		10	10	10	10	10	8
Terrestrial dispersal	1.8	0.4		2	2	2	2	1	2
Hitchhikers (via boats, waterfowl)	6.8	0.9		7	6	6	6	8	8
Certainty of effectiveness	4.3	1.4		4	7	3	3	5	4
Ability to monitor effectiveness	3.7	1.2		3	6	4	4	3	2
Deterrent Effectiveness at Flood Flows									
Water dispersal	8.2	0.4		9	8	8	8	8	8
Terrestrial dispersal	3.0	1.2		5	3	3	3	1	3
Hitchhikers (via boats, waterfowl)	5.8	0.9		4	6	6	6	6	7
Certainty of effectiveness	3.0	0.6		3	4	3	3	3	2
Ability to monitor effectiveness	1.7	0.9		3	3	1	1	1	1
Ecological Issues									
Fisheries - compatibility with fish passage	4.8	1.9		7	7	3	3	6	3
Restoration benefits	6.5	1.3		9	6	6	6	7	5
Unintended consequences	6.3	1.4		4	7	7	7	8	5
Risk	0.15								
Human Health									
Biocide release into waterways	9.5	0.8		10	8	10	10	9	10
Electric shock concerns (i.e., electric barriers)	5.2	1.7		7	7	5	5	5	2
Implementation Timeframe									
Near-term	8.7	0.7		9	8	8	8	10	9
Future	6.7	0.5		6	7	7	7	7	6
Other Technical Issues									
Adaptive management (easy to modify)	7.7	0.7		6	8	8	8	8	8
Existing prototypes in existence	5.2	0.7		6	5	5	5	4	6
Socio-Political Issues									
Consistency with ongoing AIS programs	6.2	0.4		7	6	6	6	6	6
Navigation	4.4	1.7			3	3	3	6	7
Recreation	6.0	0.6		5	6	6	6	6	7
Fishing	5.0	0.0			5	5	5	5	5
Local employment opportunities	2.3	0.7		3	3	2	2	1	3
Ability to Permit									
USACE permits	4.0	2.1		5	2	2	2	6	7
Operation and Maintenance	0.15								
Operations personnel and public safety	7.7	0.7		9	8	7	7	7	8
Reliability and durability	7.8	0.4		7	8	8	8	8	8
Ability to handle debris	4.2	1.7		7	3	3	3	3	6
Sediment handling (dredging)	3.3	1.9		6	2	2	2	2	6
Ice operations	4.3	0.5		5	4	4	4	4	5
Security	5.3	1.2		4	5	5	5	5	8
Chemical storage	3.0	1.4		3	3	2	2	2	6
Terrorist concerns	4.2	0.9		3	3	5	5	5	4
Cost	0.35								
Capital	5.8	1.2		7	5	5	5	8	5
Operation and maintenance	7.3	2.0		3	8	8	8	9	8
Certainty of cost at feasibility level	3.3	1.4		5	3	3	3	1	5

Subtotal averages	
Effectiveness	5.1
Risk	5.9
O&M	5.0
Cost	5.5
Sum of Weights	1.00

Downstream Dispersal Prevention Strategy
5/22/2019

#	Criterion	Wt 0 - 10 (0-1.0)	1 Air Bubble Curtain Score 0-10	Product	2 Water Jets Score 0-10	Product	3 Electric Fences Score 0-10	Product	4 Bio-acoustic Fences (BAFF) Score 0-10	Product	5 Sound Wave Deterrents (Acoustic, ultra-sonic, etc.) Score 0-10	Product	6 Strobe Lights Score 0-10	Product	7 High Pressure Sodium Lights Score 0-10	Product	8 Screens Score 0-10	Product	9 Filter, Water Treatment Plant Score 0-10	Product	10 CO_2 Deterrent Score 0-10	Product
	Effectiveness	0.35																				
	Deterrent Effectiveness at Normal Flows																					
1	Water dispersal	10	4	37	2	23	7	63	7	69	5	47	3	27	3	27	8	81	9	90	5	47
2	Terrestrial dispersal	2	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	2	3	6	2	4
3	Hitchhikers (via boats, waterfowl)	7	1	8	2	11	1	8	1	9	2	16	1	9	1	8	1	8	2	11	1	8
4	Certainty of effectiveness	4	4	15	3	13	7	30	6	27	4	19	4	18	4	19	9	39	9	40	7	28
5	Ability to monitor effectiveness	4	7	26	6	23	8	29	8	28	7	26	6	22	6	23	9	31	9	32	8	28
	Deterrent Effectiveness at Flood Flows																					
6	Water dispersal	8	2	18	2	16	4	33	4	35	3	25	2	19	2	19	6	46	9	75	4	29
7	Terrestrial dispersal	3	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	3	2	5	1	3
8	Hitchhikers (via boats, waterfowl)	6	1	7	1	8	1	7	1	5	1	8	1	7	1	6	1	5	2	9	1	4
9	Certainty of effectiveness	3	3	8	2	7	6	18	5	14	4	11	4	12	4	13	8	23	8	25	5	14
10	Ability to monitor effectiveness	2	5	8	4	7	5	8	5	8	4	6	4	7	5	8	6	10	7	12	5	8
	Ecological Issues																					
11	Fisheries - compatibility with fish passage	5	5	26	7	31	4	17	5	26	6	27	6	27	6	27	5	23	3	15	5	23
12	Restoration benefits	7	1	9	1	9	1	8	2	13	2	10	1	9	1	9	3	17	7	43	2	13
13	Unintended consequences	6	8	52	8	52	5	31	7	43	7	43	7	46	7	46	8	51	8	50	4	26
	Risk	0.15																				
	Human Health																					
15	Biocide/Pollution release into waterways	10	9	87	9	86	9	82	9	86	9	87	9	84	9	84	9	89	8	73	9	81
16	Electric shock concerns (i.e., electric barriers)	5	8	42	9	45	1	3	9	47	9	48	8	40	8	39	10	50	10	50	9	48
	Implementation Timeframe	0																				
17	Near-term	9	9	74	7	62	6	55	8	66	8	68	9	77	9	77	8	68	5	40	5	45
18	Future	7	9	62	9	60	8	54	9	57	8	54	9	59	9	59	9	62	8	56	8	56
	Other Technical Issues																					
19	Adaptive management (easy to modify)	8	8	58	7	50	5	36	8	61	8	59	8	63	8	63	5	35	4	31	7	50
20	Existing prototypes in existence	5	7	37	6	33	8	43	8	39	7	36	8	40	8	40	10	49	10	49	3	13
	Socio-Political Issues																					
23	Consistency with ongoing AIS programs	6	8	51	8	50	8	50	8	49	8	47	8	48	8	48	9	52	8	51	7	45
24	Navigation	4	5	21	5	20	6	25	5	23	5	22	5	22	5	22	8	34	5	20	5	20
25	Recreation	6	8	45	5	31	2	9	6	35	4	24	6	38	6	38	4	25	4	26	5	27
26	Fishing	5	7	33	7	33	4	22	6	32	5	27	5	24	6	30	7	33	7	33	5	27
27	Local employment opportunities	2	4	9	5	11	5	12	5	12	4	9	3	7	3	8	6	14	9	20	5	11
	Ability to Permit																					
28	USACE permits	4	8	31	8	30	7	29	7	28	7	29	8	31	8	31	6	25	6	25	6	25
	Operation and Maintenance	0.15																				
29	Operations personnel and public safety	8	8	61	7	56	5	40	7	54	7	56	8	61	8	61	8	60	8	58	7	55
30	Reliability and durability	8	6	43	6	43	4	27	6	47	6	47	6	48	6	48	7	57	7	52	5	39
31	Ability to handle debris	4	8	33	7	28	7	30	7	28	7	28	7	28	7	28	6	24	6	26	8	33
32	Sediment handling (dredging)	3	7	22	7	23	6	19	6	21	7	24	6	20	6	20	7	22	6	21	8	25
33	Ice operations	4	7	29	6	27	5	21	7	31	7	30	7	30	7	30	6	24	6	26	5	20
34	Security	5	8	44	9	45	3	18	8	41	8	44	9	47	9	47	8	43	6	29	6	31
35	Chemical storage	3	10	29	10	29	9	28	10	29	9	28	10	29	10	29	9	28	8	23	5	15
36	Terrorist concerns	4	9	35	9	36	7	27	10	40	9	35	9	38	9	38	8	32	6	26	6	25
	Cost	0.35																				
37	Capital	6	6	37	6	34	4	23	6	33	7	40	7	42	8	44	5	27	2	9	5	27
38	Operation and maintenance	7	7	54	8	55	6	46	7	49	8	55	8	56	7	54	5	35	2	15	6	44
39	Certainty of cost at feasibility level	3	8	26	7	23	6	20	7	24	7	24	8	28	8	28	9	28	7	22	5	16

#	Criterion	Wt 0 - 10 (0-1.0)	11 Velocity Barrier Score 0-10	Product	12 Vertical Barrier Score 0-10	Product	13 Benthic Barrier /Mats Score 0-10	Product	14 Hydrologic Separation Score 0-10	Product	15 Summer Drawdown Score 0-10	Product	16 Winter Draw-down (freezing) Score 0-10	Product	17 High Temperature /Steam Washing Score 0-10	Product	18 Pressure Washing Score 0-10	Product	19 Carbon Dioxide Pellet blasting Score 0-10	Product	20 Fish Capture Score 0-10	Product
	Effectiveness	0.35																				
	Deterrent Effectiveness at Normal Flows																					
1	Water dispersal	10	7	64	8	76	3	24	10	95	6	55	6	60	3	31	3	27	3	29	4	40
2	Terrestrial dispersal	2	1	2	4	7	1	1	6	10	2	3	4	7	3	6	3	5	3	6	4	6
3	Hitchhikers (via boats, waterfowl)	7	1	6	1	9	1	7	7	50	4	25	4	25	8	52	6	42	8	52	2	14
4	Certainty of effectiveness	4	8	33	8	35	6	24	10	41	6	25	7	28	8	33	7	31	7	31	5	22
5	Ability to monitor effectiveness	4	8	30	8	29	6	20	9	32	6	20	6	20	7	27	7	26	7	24	4	16
	Deterrent Effectiveness at Flood Flows																					
6	Water dispersal	8	5	41	5	41	2	19	9	71	4	35	5	38	3	26	3	23	3	23	2	18
7	Terrestrial dispersal	3	1	3	2	5	1	2	6	18	2	6	3	9	3	9	3	8	3	9	3	8
8	Hitchhikers (via boats, waterfowl)	6	1	4	3	18	1	4	7	39	2	14	2	13	6	33	6	36	8	47	2	12
9	Certainty of effectiveness	3	7	21	7	21	4	12	9	27	4	12	5	14	8	23	7	22	7	22	4	11
10	Ability to monitor effectiveness	2	8	13	8	14	5	8	8	13	5	8	5	8	7	12	8	13	7	12	4	6
	Ecological Issues																					
11	Fisheries - compatibility with fish passage	5	2	10	2	11	9	45	0	2	5	22	5	24	9	43	9	44	9	43	8	39
12	Restoration benefits	7	3	16	2	13	2	13	9	60	4	28	6	37	1	9	1	9	1	9	3	21
13	Unintended consequences	6	6	35	6	39	5	33	9	54	5	34	7	43	8	53	9	55	8	51	6	39
	Risk	0.15																				
	Human Health																					
15	Biocide/Pollution release into waterways	10	10	93	9	89	9	87	10	95	9	81	9	89	9	84	10	90	9	86	9	87
16	Electric shock concerns (i.e., electric barriers)	5	10	52	10	52	10	52	10	52	10	51	10	51	10	49	10	49	9	48	10	49
	Implementation Timeframe	0																				
17	Near-term	9	6	51	7	58	9	79	9	78	8	72	9	75	9	78	9	79	7	61	9	77
18	Future	7	9	61	10	64	10	64	9	62	9	57	9	59	9	60	9	61	8	56	9	61
	Other Technical Issues																					
19	Adaptive management (easy to modify)	8	5	36	5	41	9	66	3	20	9	70	9	72	8	64	9	65	8	64	9	72
20	Existing prototypes in existence	5	9	47	9	46	9	48	10	49	9	46	8	42	9	46	10	49	6	29	9	47
	Socio-Political Issues																					
23	Consistency with ongoing AIS programs	6	8	50	9	52	9	54	9	58	9	53	9	53	9	52	9	53	7	44	9	57
24	Navigation	4	7	32	8	33	5	22	9	41	6	24	6	26	4	19	4	19	4	19	5	22
25	Recreation	6	5	30	4	25	7	40	3	19	1	7	7	42	4	23	4	23	4	24	6	38
26	Fishing	5	6	31	6	29	6	28	7	37	2	8	5	23	6	28	6	29	6	32	7	33
27	Local employment opportunities	2	3	6	3	6	4	10	6	13	2	4	3	7	7	16	7	16	6	15	7	16
	Ability to Permit																					
28	USACE permits	4	6	23	6	22	8	31	7	28	7	29	8	33	9	35	9	36	8	31	8	32
	Operation and Maintenance	0.15																				
29	Operations personnel and public safety	8	7	56	8	58	8	61	9	69	8	58	7	55	7	52	7	55	6	47	8	59
30	Reliability and durability	8	8	63	9	68	5	38	9	72	7	57	8	59	6	50	6	50	6	46	7	54
31	Ability to handle debris	4	8	33	8	33	8	32	9	37	8	33	8	33	9	37	9	37	8	34	7	29
32	Sediment handling (dredging)	3	7	23	7	24	2	7	9	29	8	26	8	26	9	31	9	31	8	27	8	26
33	Ice operations	4	5	23	8	35	4	19	10	41	9	39	9	37	8	35	8	34	8	34	4	17
34	Security	5	6	34	7	39	9	48	9	50	8	44	8	44	8	44	9	45	7	36	9	45
35	Chemical storage	3	10	29	10	29	10	29	10	29	10	29	10	29	8	24	9	26	5	15	9	27
36	Terrorist concerns	4	8	34	8	33	9	39	9	35	9	38	9	37	8	34	9	37	7	30	10	40
	Cost	0.35																				
37	Capital	6	5	26	5	29	6	33	10	55	8	46	7	42	7	43	7	43	7	39	5	29
38	Operation and maintenance	7	8	59	9	64	6	45	9	65	8	56	7	49	7	50	7	50	7	49	7	48
39	Certainty of cost at feasibility level	3	8	26	8	27	7	22	8	27	8	27	8	27	8	28	9	28	5	18	8	25

#	Criterion	Wt 0 - 10 (0-1.0)	21 Harvesting Score 0-10	Product	24 Salt Water (Dead Sea Bath) Score 0-10	Product	25 Thermal Treatment (Hot Bath) Score 0-10	Product	26 Canal Boat Wash Steward Program Score 0-10	Product	27 Biocides (e.g., piscicides, herbicides, etc.) Score 0-10	Product	29 Water Treatment: Gasses Score 0-10	Product	32 Water Treatment: Chemical Score 0-10	Product	33 Predator Intro-duction Score 0-10	Product	34 Deleterious Gene Spread Score 0-10	Product	35 Trojan Y chromo-some Score 0-10	Product
	Effectiveness	0.35																				
	Deterrent Effectiveness at Normal Flows																					
1	Water dispersal	10	4	39	7	68	8	73	4	34	7	68	6	53	6	60	4	35	7	71	7	69
2	Terrestrial dispersal	2	4	6	4	6	3	6	6	11	5	9	3	5	3	5	2	4	7	13	7	13
3	Hitchhikers (via boats, waterfowl)	7	2	14	6	40	5	34	7	50	8	51	6	40	5	34	2	15	6	43	7	44
4	Certainty of effectiveness	4	5	20	5	20	6	27	7	30	8	33	6	27	8	33	3	14	5	23	4	18
5	Ability to monitor effectiveness	4	4	14	7	26	7	25	6	22	7	26	6	23	7	24	4	15	6	21	5	19
	Deterrent Effectiveness at Flood Flows																					
6	Water dispersal	8	2	19	6	48	5	42	3	27	5	41	4	31	4	35	3	27	7	60	7	60
7	Terrestrial dispersal	3	3	9	3	9	3	8	4	11	3	10	3	8	2	7	2	6	7	21	7	21
8	Hitchhikers (via boats, waterfowl)	6	2	12	5	30	4	21	6	36	6	33	4	25	4	22	2	12	7	40	7	38
9	Certainty of effectiveness	3	3	10	3	10	5	14	6	18	6	18	5	14	6	17	3	9	6	17	5	14
10	Ability to monitor effectiveness	2	3	6	6	10	5	9	5	8	5	8	5	8	6	9	4	6	5	8	5	8
	Ecological Issues																					
11	Fisheries - compatibility with fish passage	5	8	39	1	6	1	6	9	45	1	6	2	7	2	7	9	42	10	47	10	47
12	Restoration benefits	7	3	22	1	7	1	9	4	27	2	15	1	7	1	7	2	14	4	23	3	22
13	Unintended consequences	6	5	33	7	44	7	45	9	56	4	27	4	22	3	20	2	13	3	17	3	16
	Risk	0.15																				
	Human Health																					
15	Biocide/Pollution release into waterways	10	9	87	8	79	9	86	8	76	1	13	8	76	2	14	9	87	9	81	9	84
16	Electric shock concerns (i.e., electric barriers)	5	10	52	10	51	9	47	10	49	10	51	9	47	9	47	10	52	10	52	10	52
	Implementation Timeframe	0																				
17	Near-term	9	9	77	7	59	7	62	9	78	6	55	6	53	7	61	6	51	2	16	2	20
18	Future	7	9	61	8	50	8	52	10	63	8	54	8	56	8	56	8	56	8	53	8	53
	Other Technical Issues																					
19	Adaptive management (easy to modify)	8	9	70	6	46	7	54	9	69	8	60	8	58	8	58	2	15	2	18	2	18
20	Existing prototypes in existence	5	9	46	0	0	0	0	9	48	8	40	5	24	7	35	8	40	1	5	2	8
	Socio-Political Issues																					
23	Consistency with ongoing AIS programs	6	9	57	7	44	7	44	10	59	8	49	6	36	6	36	6	37	4	23	4	23
24	Navigation	4	5	23	3	14	4	17	6	24	5	21	4	19	4	19	5	22	5	22	5	22
25	Recreation	6	6	35	4	26	4	25	4	26	4	22	5	31	4	24	6	37	4	21	4	21
26	Fishing	5	7	33	3	15	4	18	6	28	2	9	3	15	3	15	6	29	8	38	8	38
27	Local employment opportunities	2	7	17	7	16	7	17	8	19	6	14	6	14	6	13	4	9	2	5	2	5
	Ability to Permit																					
28	USACE permits	4	8	32	7	29	7	29	9	37	5	21	6	24	6	23	6	25	5	21	5	21
	Operation and Maintenance	0.15																				
29	Operations personnel and public safety	8	8	63	7	55	7	56	8	64	5	36	5	37	5	36	7	52	7	50	7	50
30	Reliability and durability	8	7	54	7	51	7	51	8	59	6	47	6	46	6	47	6	44	5	35	5	35
31	Ability to handle debris	4	7	30	8	33	8	33	9	36	8	33	7	30	8	34	9	38	9	39	9	39
32	Sediment handling (dredging)	3	8	27	8	27	9	29	9	29	8	26	8	26	8	26	9	28	9	30	9	30
33	Ice operations	4	5	23	7	30	6	27	8	35	6	27	6	25	6	26	9	38	9	39	9	39
34	Security	5	9	46	7	36	7	38	8	44	5	25	5	24	4	23	8	43	8	42	8	42
35	Chemical storage	3	9	27	8	23	9	26	8	25	2	7	3	10	3	8	9	28	9	26	9	26
36	Terrorist concerns	4	10	40	8	33	8	33	9	39	5	22	5	19	4	16	9	36	5	22	5	20
	Cost	0.35																				
37	Capital	6	5	29	6	35	6	37	8	46	6	36	6	37	6	33	7	43	6	33	6	34
38	Operation and maintenance	7	7	51	5	39	6	44	7	50	5	39	6	40	5	38	8	56	6	43	6	43
39	Certainty of cost at feasibility level	3	8	26	6	19	6	20	8	28	7	24	6	18	6	21	6	19	4	12	3	10

Subtotals

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	24	25	26	27	29	32	33	34	35
Effectiveness																														
Gross score	215	202	253	279	240	207	207	338	412	234	278	318	211	510	286	325	355	340	357	251	241	322	318	374	346	271	280	212	403	388
Normalized	42	40	50	55	47	41	41	66	81	46	55	62	41	100	56	64	70	67	70	49	47	63	62	73	68	53	55	41	79	76
Risk																														
Gross score	550	509	421	535	510	533	539	536	474	447	511	517	583	552	503	572	553	570	508	590	589	430	449	576	410	452	399	459	354	365
Normalized	93	86	71	91	87	90	91	91	80	76	87	88	99	94	85	97	94	97	86	100	100	73	76	98	69	77	68	78	60	62
O&M																														
Gross score	297	288	210	290	292	302	302	290	261	244	294	319	273	362	322	318	307	314	269	297	309	287	294	331	222	217	215	306	282	280
Normalized	82	80	58	80	81	83	83	80	72	67	81	88	75	100	89	88	85	87	74	82	85	79	81	91	61	60	60	85	78	77
Cost																														
Gross score	117	112	90	106	119	126	125	91	45	87	111	119	101	147	129	118	121	121	106	102	106	93	101	124	99	96	92	118	88	87
Normalized	80	76	61	72	81	86	85	62	31	59	76	81	68	100	88	80	82	83	72	69	72	63	69	84	67	65	63	81	60	59
Total																														
Gross score, weighted by category	**243**	**229**	**215**	**258**	**246**	**242**	**242**	**274**	**270**	**216**	**257**	**278**	**237**	**367**	**269**	**289**	**295**	**294**	**278**	**256**	**256**	**253**	**258**	**310**	**250**	**229**	**222**	**230**	**267**	**263**
Normalized, weighted by category	**66**	**62**	**58**	**70**	**67**	**66**	**66**	**75**	**74**	**59**	**70**	**76**	**65**	**100**	**73**	**79**	**81**	**80**	**76**	**70**	**70**	**69**	**70**	**85**	**68**	**62**	**61**	**63**	**73**	**72**

Downstream Dispersal Prevention Strategy

5/22/2019

		Wt 0 - 10 (0-1.0)	1 Air Bubble Curtain							2 Water Jets							3 Electric Fences						
			DP	DP	GG	KS	MK	PS	SD	DP	DP	GG	KS	MK	PS	SD	DP	DP	GG	KS	MK	PS	SD
	Effectiveness	0.35																					
	Deterrent Effectiveness at Normal Flows																						
1	Water dispersal	10	2	6	3	4	2	6	1.7	1	6	2	1	1	3	1.8	6	8	7	7	6	5	1.0
2	Terrestrial dispersal	2	0	2	0	0	0	2	0.9	0	2	0	0	0	2	0.9	0	2	0	0	0	2	0.9
3	Hitchhikers (via boats, waterfowl)	7	0	3	0	0	0	4	1.7	0	3	1	1	0	5	1.8	0	5	0	0	0	2	1.9
4	Certainty of effectiveness	4	2	4	5	3	3	4	1.0	2	4	4	2	3	3	0.8	4	8	8	6	9	7	1.6
5	Ability to monitor effectiveness	4	7	6	8	10	6	6	1.5	7	6	8	5	6	5	1.1	7	7	8	10	8	8	1.0
	Deterrent Effectiveness at Flood Flows																						
6	Water dispersal	8	1	5	2	2	1	2	1.3	1	5	1	2	1	2	1.4	2	7	4	5	2	4	1.7
7	Terrestrial dispersal	3	0	2	0	0	0	1	0.8	0	2	0	0	0	1	0.8	0	2	0	0	0	1	0.8
8	Hitchhikers (via boats, waterfowl)	6	0	3	0	0	0	4	1.7	0	3	1	1	0	3	1.2	0	5	0	0	0	2	1.9
9	Certainty of effectiveness	3	3	2	3	2	3	2	0.5	3	2	1	2	3	2	0.7	4	7	6	4	9	5	1.8
10	Ability to monitor effectiveness	2	6	5	2	7	6	3	1.8	6	5	2	3	6	3	1.6	5	6	2	7	6	3	1.8
	Ecological Issues																						
11	Fisheries - compatibility with fish passage	5	6	8	7	4	3	4	1.8	6	9	9	5	4	6	1.9	4	3	7	2	3	2	1.7
12	Restoration benefits	7	1	2	1	1	1	2	0.5	1	2	1	1	1	2	0.5	1	2	1	1	1	1	0.4
13	Unintended consequences	6	9	8	7	10	8	7	1.1	9	9	7	10	8	6	1.3	5	3	4	8	6	3	1.8
	Risk	0.15																					
	Human Health																						
15	Biocide/Pollution release into waterways	10	9	10	10	10	7	9	1.1	9	10	10	10	7	8	1.2	8	10	10	10	6	8	1.5
16	Electric shock concerns (i.e., electric barriers)	5	8	10	8	9	7	7	1.1	8	10	10	10	7	7	1.4	1	1	1	0	0	0	0.5
	Implementation Timeframe	0																					
17	Near-term	9	7	10	7	10	9	8	1.3	7	10	7	5	7	7	1.5	5	7	7	7	5	7	0.9
18	Future	7	9	10	9	10	9	9	0.5	9	10	9	10	7	9	1.0	6	7	9	10	10	7	1.6
	Other Technical Issues																						
19	Adaptive management (easy to modify)	8	9	9	6	9	7	5	1.6	9	9	5	5	7	4	2.0	5	7	2	7	4	3	1.9
20	Existing prototypes in existence	5	6	8	7	10	5	7	1.6	5	10	6	5	5	7	1.8	9	10	8	5	9	9	1.6
	Socio-Political Issues																						
23	Consistency with ongoing AIS programs	6	10	9	7	10	9	5	1.8	10	9	6	10	9	5	2.0	7	10	7	10	9	6	1.6
24	Navigation	4	5		5	4	5		0.4	6		4	3	5		1.1	6		5	5	7		0.8
25	Recreation	6	8	8	8	10	6	5	1.6	2	8	7	5	4	5	2.0	3	1	1	0	3	1	1.1
26	Fishing	5	5	6	9	5	8	6	1.5	6	6	8	5	8	6	1.1	4	1	4	5	7	5	1.8
27	Local employment opportunities	2	5	3	5	1	5	4	1.5	5	4	6	1	7	5	1.9	5	5	5	5	7	5	0.7
	Ability to Permit																						
28	USACE permits	4	8	7	8	9	9	6	1.1	8	7	8	9	7	6	1.0	5	9	7	8	9	5	1.7
	Operation and Maintenance	0.15																					
29	Operations personnel and public safety	8	9	8	8	9	7	7	0.8	8	8	7	8	6	7	0.7	2	9	5	5	5	5	2.0
30	Reliability and durability	8	8	6	2	5	6	6	1.8	8	6	2	5	6	6	1.8	4	2	2	3	5	5	1.3
31	Ability to handle debris	4	9	6	8	10	6	8	1.5	8	5	6	7	6	8	1.1	5	8	8	9	5	8	1.6
32	Sediment handling (dredging)	3	5	9	8	6	8	4	1.8	5	9	5	7	9	7	1.6	4	5	8	5	8	5	1.6
33	Ice operations	4	5	9	5	9	6	6	1.7	5	9	5	7	6	6	1.4	2	3	7	6	5	6	1.8
34	Security	5	9	5	9	9	9	9	1.5	9	5	9	10	9	9	1.6	3	1	3	3	7	3	1.8
35	Chemical storage	3	10	10	9	10	9	9	0.5	10	10	9	10	9	9	0.5	10	10	8	10	8	9	0.9
36	Terrorist concerns	4	10	5	9	9	9	9	1.6	10	5	9	10	9	9	1.7	5	5	8	8	8	5	1.5
	Cost	0.35																					
37	Capital	6	9	6	3	6	8	6	1.9	9	6	3	5	7	5	1.9	6	3	2	3	6	4	1.5
38	Operation and maintenance	7	9	8	7	7	7	6	0.9	9	8	7	7	7	7	0.8	8	3	7	7	7	6	1.6
39	Certainty of cost at feasibility level	3	9	8	8	10	6	6	1.5	9	8	8	5	5	6	1.6	4	5	8	6	7	6	1.3

		Wt 0 - 10 (0-1.0)	4 Bio-acoustic Fences (BAFF)							5 Sound Wave Deterrents (Acoustic, ultra-sonic, etc.)							6 Strobe Lights						
			DP	DP	GG	KS	MK	PS	SD	DP	DP	GG	KS	MK	PS	SD	DP	DP	GG	KS	MK	PS	SD
	Effectiveness	0.35																					
	Deterrent Effectiveness at Normal Flows																						
1	Water dispersal	10	7	7	6	6	9	8	1.1	5	7	3	4	5	5	1.2	3	5	3	1	2	3	1.2
2	Terrestrial dispersal	2	0	2	0	0	0	2	0.9	1	2	0	0	0	2	0.9	0	2	0	0	0	2	0.9
3	Hitchhikers (via boats, waterfowl)	7	1	2	1	1	1	2	0.5	1	5	1	1	1	5	1.9	0	4	0	0	0	4	1.9
4	Certainty of effectiveness	4	5	7	7	5	7	7	0.9	2	7	5	5	3	4	1.6	2	5	6	5	3	4	1.3
5	Ability to monitor effectiveness	4	7	6	8	10	8	6	1.4	7	6	7	10	7	6	1.3	7	5	7	5	6	6	0.8
	Deterrent Effectiveness at Flood Flows																						
6	Water dispersal	8	3	6	3	6	4	4	1.2	2	6	2	4	2	2	1.5	2	5	1	1	2	3	1.4
7	Terrestrial dispersal	3	0	2	0	0	0	1	0.8	0	2	0	0	0	1	0.8	0	2	0	0	0	1	0.8
8	Hitchhikers (via boats, waterfowl)	6	1	1	1	0	0	2	0.7	0	5	0	0	0	3	2.0	0	4	0	0	0	3	1.7
9	Certainty of effectiveness	3	4	6	5	5	5	2	1.3	3	6	2	5	3	2	1.5	3	4	3	8	3	3	1.8
10	Ability to monitor effectiveness	2	5	5	2	7	5	3	1.6	4	4	2	5	5	3	1.1	6	5	1	5	6	3	1.8
	Ecological Issues																						
11	Fisheries - compatibility with fish passage	5	4	8	7	4	4	5	1.6	6	8	7	4	3	5	1.7	6	7	6	5	5	5	0.7
12	Restoration benefits	7	2	2	2	2	2	2	0.0	1	2	1	1	1	3	0.8	1	2	1	1	1	2	0.5
13	Unintended consequences	6	8	8	6	8	6	5	1.2	8	8	5	8	8	4	1.7	8	8	6	10	8	4	1.9
	Risk	0.15																					
	Human Health																						
15	Biocide/Pollution release into waterways	10	8	10	10	10	8	8	1.0	9	10	10	10	7	9	1.1	9	10	10	10	8	6	1.5
16	Electric shock concerns (i.e., electric barriers)	5	8	10	7	10	9	10	1.2	8	10	8	10	10	10	0.9	8	5	8	10	8	8	1.5
	Implementation Timeframe	0																					
17	Near-term	9	7	5	8	10	8	8	1.5	7	5	9	9	8	9	1.5	8	8	9	10	9	9	0.7
18	Future	7	8	8	9	10	8	8	0.8	8	5	9	10	8	9	1.6	8	8	9	10	9	9	0.7
	Other Technical Issues																						
19	Adaptive management (easy to modify)	8	9	9	6	10	7	7	1.4	9	9	5	10	8	5	2.0	9	9	6	10	9	6	1.6
20	Existing prototypes in existence	5	7	7	7	10	7	7	1.1	6	9	5	10	5	7	1.9	7	8	5	10	7	9	1.6
	Socio-Political Issues																						
23	Consistency with ongoing AIS programs	6	8	8	7	10	9	6	1.3	8	8	6	10	9	5	1.7	8	8	5	10	9	7	1.6
24	Navigation	4	6		5	5	5		0.4	5		5	5	5		0.0	5		5	5	5		0.0
25	Recreation	6	5	8	5	7	5	5	1.2	2	5	1	5	5	6	1.8	5	8	5	10	5	5	2.0
26	Fishing	5	4	7	7	6	9	5	1.6	4	7	3	5	8	5	1.7	2	7	5	5	5	5	1.5
27	Local employment opportunities	2	6	4	5	5	7	5	0.9	5	2	6	1	5	3	1.8	5	2	5	1	4	2	1.6
	Ability to Permit																						
28	USACE permits	4	6	5	8	9	9	5	1.7	8	5	8	9	9	5	1.7	8	4	8	9	10	7	1.9
	Operation and Maintenance	0.15																					
29	Operations personnel and public safety	8	8	7	7	8	6	6	0.8	8	7	7	8	7	7	0.5	9	7	8	9	7	8	0.8
30	Reliability and durability	8	6	7	5	5	7	6	0.8	8	7	3	5	6	7	1.6	9	5	4	6	6	7	1.6
31	Ability to handle debris	4	6	5	9	8	6	6	1.4	8	5	8	8	6	6	1.2	8	5	8	9	5	6	1.6
32	Sediment handling (dredging)	3	5	6	9	5	8	4	1.8	7	6	9	9	8	5	1.5	8	6	2	7	7	6	1.9
33	Ice operations	4	5	8	9	9	6	6	1.6	5	8	8	9	6	5	1.6	6	8	8	9	4	7	1.6
34	Security	5	7	5	9	9	9	7	1.5	9	5	8	9	9	9	1.5	8	8	8	10	10	9	0.9
35	Chemical storage	3	10	10	9	10	10	9	0.5	10	10	7	10	9	9	1.1	10	10	8	10	10	9	0.8
36	Terrorist concerns	4	10	9	9	10	10	9	0.5	9	9	6	9	9	9	1.1	9	9	7	10	10	9	1.0
	Cost	0.35																					
37	Capital	6	7	8	5	3	7	4	1.8	8	8	4	8	7	6	1.5	9	6	4	8	9	7	1.8
38	Operation and maintenance	7	8	5	7	7	7	6	0.9	9	8	7	7	7	7	0.8	9	8	8	8	6	7	0.9
39	Certainty of cost at feasibility level	3	5	8	8	9	8	5	1.6	6	8	8	10	6	6	1.5	9	8	8	10	8	7	0.9

		Wt 0 - 10 (0-1.0)	7 High Pressure Sodium Lights							8 Screens							9 Filter, Water Treatment Plant						
			DP	DP	GG	KS	MK	PS	SD	DP	DP	GG	KS	MK	PS	SD	DP	DP	GG	KS	MK	PS	SD
	Effectiveness	0.35																					
	Deterrent Effectiveness at Normal Flows																						
1	Water dispersal	10	3	6	2	1	2	3	1.6	9	9	9	7	9	7	0.9	10	9	10	10	10	7	1.1
2	Terrestrial dispersal	2	0	2	0	0	0	2	0.9	0	2	2	0	0	4	1.5	2	5	5	1	2	4	1.6
3	Hitchhikers (via boats, waterfowl)	7	0	3	0	0	0	4	1.7	0	2	1	0	0	4	1.5	0	4	2	0	0	4	1.8
4	Certainty of effectiveness	4	3	6	6	5	3	3	1.4	10	8	9	10	9	8	0.8	10	8	10	10	9	8	0.9
5	Ability to monitor effectiveness	4	7	6	7	5	6	6	0.7	9	8	8	10	9	7	1.0	9	8	10	10	9	7	1.1
	Deterrent Effectiveness at Flood Flows																						
6	Water dispersal	8	2	5	1	1	2	3	1.4	6	6	6	7	6	3	1.2	10	9	9	10	10	7	1.1
7	Terrestrial dispersal	3	0	2	0	0	0	1	0.8	0	2	2	0	0	1	0.9	1	3	2	1	2	1	0.7
8	Hitchhikers (via boats, waterfowl)	6	0	3	0	0	0	3	1.4	0	2	1	0	0	2	0.9	0	4	2	0	0	3	1.6
9	Certainty of effectiveness	3	3	5	3	8	3	3	1.9	9	7	6	10	9	5	1.8	9	8	6	9	9	8	1.1
10	Ability to monitor effectiveness	2	6	6	1	5	6	3	1.9	6	8	4	7	7	4	1.5	7	8	9	9	7	3	2.0
	Ecological Issues																						
11	Fisheries - compatibility with fish passage	5	6	7	6	5	5	5	0.7	6	2	7	5	6	2	2.0	5	2	5	1	1	4	1.7
12	Restoration benefits	7	1	2	1	1	1	2	0.5	4	5	1	1	1	4	1.7	6	8	5	10	6	5	1.8
13	Unintended consequences	6	8	8	6	10	8	4	1.9	7	7	8	10	9	7	1.2	9	7	9	5	10	7	1.7
	Risk	0.15																					
	Human Health																						
15	Biocide/Pollution release into waterways	10	9	10	10	10	8	6	1.5	9	10	10	10	10	7	1.1	5	10	9	9	6	7	1.8
16	Electric shock concerns (i.e., electric barriers)	5	8	5	8	10	7	7	1.5	8	10	10	10	10	10	0.7	9	10	9	10	10	10	0.5
	Implementation Timeframe	0																					
17	Near-term	9	8	8	9	10	9	9	0.7	5	10	7	10	7	8	1.8	3	3	5	6	5	6	1.2
18	Future	7	8	8	9	10	9	9	0.7	9	10	9	10	10	8	0.7	9	6	9	10	10	6	1.7
	Other Technical Issues																						
19	Adaptive management (easy to modify)	8	9	9	6	10	9	6	1.6	6	6	3	6	4	2	1.6	3	6	5	5	3	2	1.4
20	Existing prototypes in existence	5	7	8	6	10	7	9	1.3	10	10	8	10	10	9	0.8	10	10	8	10	10	9	0.8
	Socio-Political Issues																						
23	Consistency with ongoing AIS programs	6	8	8	5	10	9	7	1.6	9	10	7	10	9	6	1.5	9	10	7	10	9	5	1.8
24	Navigation	4	5		5	5	5		0.0	10		7	6	8		1.5	5		5	3	5		0.9
25	Recreation	6	5	8	5	10	5	5	2.0	3	7	3	5	3	4	1.5	4	7	3	5	5	2	1.6
26	Fishing	5	5	7	9	5	5	5	1.5	7	8	7	5	9	4	1.7	7	9	7	5	8	4	1.7
27	Local employment opportunities	2	5	2	6	1	4	2	1.8	8	3	5	5	8	7	1.8	9	8	9	10	8	7	1.0
	Ability to Permit																						
28	USACE permits	4	8	5	8	9	10	7	1.6	7	6	8	5	7	5	1.1	6	7	7	5	9	4	1.6
	Operation and Maintenance	0.15																					
29	Operations personnel and public safety	8	9	7	8	9	7	8	0.8	7	8	8	9	9	6	1.1	6	7	8	9	9	6	1.3
30	Reliability and durability	8	9	5	4	6	6	7	1.6	8	8	6	8	9	5	1.4	8	8	4	8	8	4	1.9
31	Ability to handle debris	4	8	5	8	9	5	6	1.6	6	7	3	5	9	5	1.9	6	8	3	7	9	5	2.0
32	Sediment handling (dredging)	3	8	6	2	7	7	6	1.9	7	7	5	8	9	3	2.0	6	8	4	7	9	4	1.9
33	Ice operations	4	6	8	8	9	4	7	1.6	5	7	2	7	7	5	1.8	5	6	3	9	8	5	2.0
34	Security	5	8	8	8	10	10	9	0.9	7	9	8	10	9	5	1.6	7	5	4	6	6	5	1.0
35	Chemical storage	3	10	10	8	10	10	9	0.8	9	10	9	10	9	9	0.5	7	9	9	9	6	5	1.6
36	Terrorist concerns	4	9	9	7	10	10	9	1.0	9	6	8	9	9	5	1.6	8	6	6	7	6	5	0.9
	Cost	0.35																					
37	Capital	6	9	8	4	8	9	7	1.7	5	8	4	2	4	5	1.8	2	2	1	0	0	4	1.4
38	Operation and maintenance	7	9	8	7	7	6	7	0.9	5	6	6	2	7	3	1.8	4	4	1	0	0	3	1.7
39	Certainty of cost at feasibility level	3	9	8	8	10	8	7	0.9	8	10	8	10	9	6	1.4	6	4	7	8	9	5	1.7

Downstream Dispersal Prevention Strategy
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#	Criterion	Wt 0 - 10 (0-1.0)	10 CO2 Deterrent							11 Velocity Barrier							12 Vertical Barrier						
			DP	DP	GG	KS	MK	PS	SD	DP	DP	GG	KS	MK	PS	SD	DP	DP	GG	KS	MK	PS	SD
	Effectiveness	0.35																					
	Deterrent Effectiveness at Normal Flows																						
1	Water dispersal	10	5	7	3	3	6	5	1.5	7	9	8	7	6	3	1.9	9	9	10	8	7	4	2.0
2	Terrestrial dispersal	2	1	5	1	1	1	3	1.5	0	4	1	0	0	3	1.6	5	6	1	2	5	3	1.8
3	Hitchhikers (via boats, waterfowl)	7	0	2	0	0	0	5	1.9	0	1	1	0	0	3	1.1	0	5	0	0	0	3	2.0
4	Certainty of effectiveness	4	8	7	4	8	8	4	1.8	9	8	8	9	7	5	1.4	9	8	9	10	7	5	1.6
5	Ability to monitor effectiveness	4	7	7	6	10	8	7	1.3	8	8	8	9	9	7	0.7	9	8	8	10	9	4	1.9
	Deterrent Effectiveness at Flood Flows																						
6	Water dispersal	8	5	6	1	3	5	1	2.0	4	7	7	6	4	2	1.8	4	7	7	6	4	2	1.8
7	Terrestrial dispersal	3	0	5	0	0	0	1	1.8	0	4	0	0	0	1	1.5	1	5	1	2	0	1	1.6
8	Hitchhikers (via boats, waterfowl)	6	0	2	0	0	0	2	0.9	0	1	0	0	0	3	1.1	5	5	1	1	5	2	1.9
9	Certainty of effectiveness	3	6	6	2	5	6	3	1.6	7	9	6	9	7	4	1.7	7	7	7	10	7	4	1.7
10	Ability to monitor effectiveness	2	5	6	2	6	5	3	1.5	9	8	6	9	9	5	1.6	9	7	7	10	9	7	1.2
	Ecological Issues																						
11	Fisheries - compatibility with fish passage	5	3	8	6	5	5	2	2.0	3	1	5	0	1	3	1.7	3	1	5	0	2	3	1.6
12	Restoration benefits	7	1	5	1	1	1	3	1.5	3	6	1	1	1	3	1.8	3	3	1	1	1	3	1.0
13	Unintended consequences	6	5	6	3	6	3	2	1.6	6	5	6	6	6	4	0.8	6	5	6	6	6	8	0.9
	Risk	0.15																					
	Human Health																						
15	Biocide/Pollution release into waterways	10	7	10	10	10	7	7	1.5	10	10	10	10	10	9	0.4	10	10	10	10	10	6	1.5
16	Electric shock concerns (i.e., electric barriers)	5	9	10	9	10	9	9	0.5	10	10	10	10	10	10	0.0	10	10	10	10	10	10	0.0
	Implementation Timeframe	0																					
17	Near-term	9	5	5	7	7	4	3	1.5	4	6	7	7	5	6	1.1	4	6	7	7	7	9	1.5
18	Future	7	7	9	9	10	8	7	1.1	10	10	9	10	10	6	1.5	10	10	9	10	10	9	0.5
	Other Technical Issues																						
19	Adaptive management (easy to modify)	8	7	9	5	9	5	4	2.0	5	5	3	7	5	3	1.4	5	5	3	8	6	5	1.5
20	Existing prototypes in existence	5	2	3	2	2	2	4	0.8	10	10	8	10	10	7	1.2	9	10	10	10	7	7	1.3
	Socio-Political Issues																						
23	Consistency with ongoing AIS programs	6	7	6	6	10	9	6	1.6	10	10	8	10	5	6	2.0	10	10	9	10	5	7	1.9
24	Navigation	4	5		5	4	4		0.5	8		7	6	8		0.8	10		7	6	7		1.5
25	Recreation	6	5	5	3	7	5	2	1.6	5	2	7	5	5	6	1.5	3	2	7	2	5	6	2.0
26	Fishing	5	6	8	4	5	7	2	2.0	6	5	8	5	9	4	1.8	6	2	8	5	7	7	2.0
27	Local employment opportunities	2	5	4	5	2	8	3	1.9	4	2	1	0	6	2	2.0	3	2	1	0	6	4	2.0
	Ability to Permit																						
28	USACE permits	4	8	6	7	7	6	4	1.2	6	4	4	9	7	4	1.9	5	4	4	9	7	4	1.9
	Operation and Maintenance	0.15																					
29	Operations personnel and public safety	8	7	8	7	7	7	7	0.4	7	6	7	9	9	6	1.2	6	6	7	9	9	8	1.3
30	Reliability and durability	8	8	5	3	5	5	4	1.5	7	9	9	9	9	5	1.5	9	8	9	9	9	8	0.5
31	Ability to handle debris	4	8	9	8	7	9	7	0.8	9	9	7	9	8	5	1.5	9	10	7	9	8	5	1.6
32	Sediment handling (dredging)	3	8	8	8	8	9	4	1.6	7	4	8	8	8	7	1.4	8	8	8	8	6	5	1.2
33	Ice operations	4	3	7	5	5	5	3	1.4	5	4	4	8	8	3	2.0	8	9	5	10	10	7	1.8
34	Security	5	8	6	4	5	7	5	1.3	8	4	5	8	8	5	1.7	9	7	5	9	9	5	1.8
35	Chemical storage	3	8	3	3	4	7	5	1.9	10	10	9	10	9	9	0.5	10	10	9	10	9	9	0.5
36	Terrorist concerns	4	7	8	3	6	7	5	1.6	9	7	5	10	9	9	1.7	9	7	5	9	9	9	1.5
	Cost	0.35																					
37	Capital	6	6	7	3	5	4	3	1.5	4	7	3	6	3	4	1.5	3	8	3	7	4	5	1.9
38	Operation and maintenance	7	7	6	4	9	5	5	1.6	9	8	9	10	7	5	1.6	9	10	9	10	7	7	1.2
39	Certainty of cost at feasibility level	3	5	6	4	7	4	2	1.6	8	8	8	10	7	6	1.2	8	9	8	10	7	6	1.3

#	Criterion	Wt 0 - 10 (0-1.0)	13 Benthic Barrier /Mats							14 Hydrologic Separation							15 Summer Drawdown						
			DP	DP	GG	KS	MK	PS	SD	DP	DP	GG	KS	MK	PS	SD	DP	DP	GG	KS	MK	PS	SD
	Effectiveness	0.35																					
	Deterrent Effectiveness at Normal Flows																						
1	Water dispersal	10	4	3	3	0	3	2	1.3	10	9	10	10	10	10	0.4	6	8	7	3	4	6	1.7
2	Terrestrial dispersal	2	0	2	0	0	0	2	0.9	6	8	4	3	5	8	1.9	3	2	1	0	1	3	1.1
3	Hitchhikers (via boats, waterfowl)	7	0	2	0	0	0	4	1.5	7	6	10	5	7	9	1.7	4	4	2	2	3	7	1.7
4	Certainty of effectiveness	4	7	6	5	7	3	5	1.4	10	9	9	10	10	9	0.5	5	6	6	6	4	7	0.9
5	Ability to monitor effectiveness	4	4	4	5	7	6	7	1.3	9	8	8	10	8	9	0.7	6	5	3	5	6	8	1.5
	Deterrent Effectiveness at Flood Flows																						
6	Water dispersal	8	2	3	3	0	2	4	1.2	9	9	10	10	9	5	1.7	5	7	6	3	3	2	1.8
7	Terrestrial dispersal	3	0	2	0	0	0	1	0.8	6	9	3	4	6	7	2.0	3	2	1	0	4	2	1.3
8	Hitchhikers (via boats, waterfowl)	6	0	2	0	0	0	2	0.9	7	6	6	6	7	8	0.7	4	4	1	0	4	1	1.7
9	Certainty of effectiveness	3	3	5	4	7	3	2	1.6	10	9	9	10	10	5	1.8	4	5	3	6	4	2	1.3
10	Ability to monitor effectiveness	2	6	3	3	7	6	3	1.7	8	8	7	10	8	6	1.2	6	4	3	5	6	3	1.3
	Ecological Issues																						
11	Fisheries - compatibility with fish passage	5	9	9	10	10	9	9	0.5	0	1	0	0	0	1	0.5	2	7	5	6	4	3	1.7
12	Restoration benefits	7	1	5	1	1	1	3	1.5	9	9	10	10	9	8	0.7	6	7	3	3	4	3	1.6
13	Unintended consequences	6	8	5	3	5	7	3	1.9	10	8	7	10	9	7	1.3	6	7	4	5	6	4	1.1
	Risk	0.15																					
	Human Health																						
15	Biocide/Pollution release into waterways	10	8	10	10	10	10	7	1.2	10	10	10	10	10	10	0.0	9	9	9	9	9	6	1.1
16	Electric shock concerns (i.e., electric barriers)	5	10	10	10	10	10	10	0.0	10	10	10	10	10	10	0.0	9	10	10	10	10	10	0.4
	Implementation Timeframe	0																					
17	Near-term	9	8	10	8	10	10	9	0.9	10	8	10	10	10	6	1.5	9	7	8	10	9	7	1.1
18	Future	7	10	10	9	10	10	9	0.5	10	10	10	10	10	6	1.5	9	7	9	10	9	7	1.1
	Other Technical Issues																						
19	Adaptive management (easy to modify)	8	9	8	8	10	9	8	0.7	3	3	2	3	3	2	0.5	10	10	6	10	10	9	1.5
20	Existing prototypes in existence	5	10	10	7	10	10	9	1.1	10	9	9	10	10	9	0.5	8	10	8	10	8	9	0.9
	Socio-Political Issues																						
23	Consistency with ongoing AIS programs	6	9	10	8	10	10	6	1.5	10	10	9	10	9	8	0.7	7	10	9	10	9	7	1.2
24	Navigation	4	5		5	5	5		0.0	10		9	9	9		0.4	6		6	6	4		0.9
25	Recreation	6	5	8	7	10	5	5	1.9	5	1	5	0	5	3	2.0	1	2	1	0	0	3	1.1
26	Fishing	5	6	8	3	5	5	7	1.6	9	7	8	5	9	6	1.5	2	1	1	3	1	2	0.7
27	Local employment opportunities	2	3	4	4	1	7	6	2.0	7	9	5	5	5	3	1.9	3	1	2	0	1	4	1.3
	Ability to Permit																						
28	USACE permits	4	10	5	8	6	10	7	1.9	7	8	6	6	8	7	0.8	9	8	7	5	10	5	1.9
	Operation and Maintenance	0.15																					
29	Operations personnel and public safety	8	8	6	7	9	10	8	1.3	10	5	10	10	10	9	1.8	6	4	8	10	10	7	2.1
30	Reliability and durability	8	3	7	2	6	6	5	1.8	10	9	9	10	9	8	0.7	7	6	8	9	9	5	1.5
31	Ability to handle debris	4	5	10	5	9	9	8	2.0	10	10	8	10	10	5	1.9	6	10	6	10	10	6	2.0
32	Sediment handling (dredging)	3	2	4	2	1	1	3	1.1	10	6	8	10	10	8	1.5	5	7	8	10	10	6	1.9
33	Ice operations	4	2	6	3	7	5	3	1.8	10	10	8	10	10	9	0.8	10	10	10	10	5	9	1.8
34	Security	5	8	10	8	10	10	8	1.0	10	9	8	10	10	9	0.7	8	8	5	10	9	9	1.6
35	Chemical storage	3	9	10	9	10	10	9	0.5	10	10	9	10	10	9	0.5	10	10	9	10	9	9	0.5
36	Terrorist concerns	4	9	9	9	10	10	9	0.5	10	7	5	10	10	9	1.9	8	9	9	10	9	9	0.6
	Cost	0.35																					
37	Capital	6	6	6	4	6	9	3	1.9	9	10	9	10	10	9	0.5	7	6	8	10	10	6	1.7
38	Operation and maintenance	7	5	7	5	9	7	4	1.7	9	8	9	10	10	7	1.1	7	7	7	9	10	6	1.4
39	Certainty of cost at feasibility level	3	8	5	6	8	9	4	1.8	9	5	9	10	9	6	1.8	9	8	8	10	9	5	1.6

#	Criterion	Wt 0 - 10 (0-1.0)	16 Winter Draw-down (freezing)							17 High Temperature /Steam Washing							18 Pressure Washing						
			DP	DP	GG	KS	MK	PS	SD	DP	DP	GG	KS	MK	PS	SD	DP	DP	GG	KS	MK	PS	SD
	Effectiveness	0.35																					
	Deterrent Effectiveness at Normal Flows																						
1	Water dispersal	10	6	8	9	3	5	6	2.0	5	3	1	1	5	4	1.7	4	3	1	1	5	3	1.5
2	Terrestrial dispersal	2	5	4	2	2	5	6	1.5	6	3	1	1	5	3	1.9	5	2	1	1	4	3	1.5
3	Hitchhikers (via boats, waterfowl)	7	3	4	3	3	3	6	1.1	7	5	7	10	9	8	1.6	5	4	7	8	7	6	1.3
4	Certainty of effectiveness	4	8	6	7	6	5	7	1.0	8	6	6	10	9	7	1.5	8	5	6	10	8	6	1.7
5	Ability to monitor effectiveness	4	7	5	2	5	7	7	1.8	7	7	5	10	9	6	1.7	7	6	5	10	9	5	1.9
	Deterrent Effectiveness at Flood Flows																						
6	Water dispersal	8	5	7	7	3	4	2	1.9	5	3	1	1	5	4	1.7	5	3	1	1	5	2	1.7
7	Terrestrial dispersal	3	5	4	1	0	5	2	2.0	5	3	1	1	5	2	1.7	5	2	1	1	4	2	1.5
8	Hitchhikers (via boats, waterfowl)	6	4	4	1	0	3	1	1.6	5	5	7	8	7	2	2.0	4	4	7	8	6	8	1.7
9	Certainty of effectiveness	3	5	4	5	6	5	2	1.3	8	5	6	10	9	7	1.7	8	4	6	10	8	7	1.9
10	Ability to monitor effectiveness	2	7	4	2	5	7	3	1.9	7	7	5	10	9	6	1.7	9	6	5	10	9	6	1.9
	Ecological Issues																						
11	Fisheries - compatibility with fish passage	5	2	7	5	7	6	3	1.9	9	7	10	10	9	8	1.1	9	9	10	10	9	8	0.7
12	Restoration benefits	7	7	7	5	5	7	3	1.5	0	5	0	0	0	3	2.0	0	5	0	0	0	3	2.0
13	Unintended consequences	6	7	7	5	10	8	4	2.0	8	9	8	10	9	6	1.2	9	9	9	10	9	6	1.2
	Risk	0.15																					
	Human Health																						
15	Biocide/Pollution release into waterways	10	10	10	10	10	10	6	1.5	8	10	10	10	10	5	1.9	9	10	10	10	10	8	0.8
16	Electric shock concerns (i.e., electric barriers)	5	9	10	10	10	10	10	0.4	8	10	9	10	10	10	0.8	8	10	9	10	10	10	0.8
	Implementation Timeframe	0																					
17	Near-term	9	10	7	8	10	10	7	1.4	9	9	9	10	9	8	0.6	9	9	9	10	9	9	0.4
18	Future	7	10	7	9	10	10	7	1.3	9	9	9	10	9	8	0.6	9	9	9	10	9	9	0.4
	Other Technical Issues																						
19	Adaptive management (easy to modify)	8	10	10	7	10	10	9	1.1	9	10	6	10	9	6	1.7	9	10	6	10	9	7	1.5
20	Existing prototypes in existence	5	6	10	6	10	8	9	1.7	7	10	8	10	9	9	1.1	9	10	10	10	9	9	0.5
	Socio-Political Issues																						
23	Consistency with ongoing AIS programs	6	7	10	9	10	9	7	1.2	9	10	6	10	8	8	1.4	9	10	7	10	8	8	1.1
24	Navigation	4	9		5	5	5		1.7	5		2	4	6		1.5	5		2	4	6		1.5
25	Recreation	6	5	8	9	10	5	5	2.1	2	3	5	7	2	4	1.8	2	3	6	6	2	4	1.7
26	Fishing	5	6	3	3	5	7	4	1.5	5	4	7	5	9	3	2.0	5	4	8	5	9	4	2.0
27	Local employment opportunities	2	5	1	2	0	5	4	2.0	7	7	6	7	7	7	0.4	7	7	6	7	7	7	0.4
	Ability to Permit																						
28	USACE permits	4	10	8	7	10	10	5	1.9	10	6	9	8	10	9	1.4	10	6	10	9	10	9	1.4
	Operation and Maintenance	0.15																					
29	Operations personnel and public safety	8	5	4	8	10	9	7	2.1	8	4	7	8	8	6	1.5	8	3	7	9	9	7	2.0
30	Reliability and durability	8	7	7	8	9	9	5	1.4	8	5	4	7	9	5	1.8	8	5	4	6	9	6	1.7
31	Ability to handle debris	4	6	10	6	10	10	6	2.0	9	10	8	9	10	7	1.1	9	10	8	9	10	7	1.1
32	Sediment handling (dredging)	3	5	7	8	10	10	6	1.9	9	9	8	10	10	9	0.7	9	9	8	10	10	9	0.7
33	Ice operations	4	8	7	7	10	10	9	1.3	6	9	5	10	10	9	2.0	6	8	5	9	10	9	1.8
34	Security	5	8	8	5	10	9	9	1.6	8	10	8	9	8	7	0.9	8	10	8	9	9	7	1.0
35	Chemical storage	3	10	10	9	10	9	9	0.5	8	10	5	10	8	6	1.9	8	10	5	10	9	9	1.7
36	Terrorist concerns	4	8	9	8	10	9	9	0.7	8	8	7	9	8	9	0.7	9	10	7	9	9	9	0.9
	Cost	0.35																					
37	Capital	6	7	6	8	9	9	4	1.8	7	8	6	8	9	6	1.1	7	6	7	9	9	6	1.2
38	Operation and maintenance	7	6	5	7	9	9	4	1.9	8	6	5	7	9	6	1.3	8	5	5	8	9	6	1.6
39	Certainty of cost at feasibility level	3	9	8	8	10	9	5	1.6	8	7	8	10	9	8	0.9	8	7	9	10	9	8	1.0

Downstream Dispersal Prevention Strategy
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		Wt 0 - 10 (0-1.0)	19 Carbon Dioxide Pellet blasting							20 Fish Capture							21 Harvesting						
			DP	DP	GG	KS	MK	PS	SD	DP	DP	GG	KS	MK	PS	SD	DP	DP	GG	KS	MK	PS	SD
	Effectiveness	**0.35**																					
	Deterrent Effectiveness at Normal Flows																						
1	Water dispersal	10	5	3	1	1	5	3	1.6	5	6	3	1	5	5	1.7	3	7	3	1	5	5	1.9
2	Terrestrial dispersal	2	5	4	1	1	5	3	1.7	5	6	1	1	5	3	2.0	5	6	1	1	5	3	2.0
3	Hitchhikers (via boats, waterfowl)	7	7	7	8	10	9	5	1.6	0	6	1	1	1	3	2.0	0	6	1	1	1	3	2.0
4	Certainty of effectiveness	4	8	7	6	8	9	5	1.3	6	4	5	8	3	4	1.6	6	4	3	8	3	4	1.8
5	Ability to monitor effectiveness	4	7	6	5	9	9	4	1.9	3	6	5	5	3	4	1.1	3	6	2	5	3	4	1.3
	Deterrent Effectiveness at Flood Flows																						
6	Water dispersal	8	5	3	1	1	5	2	1.7	1	5	2	1	1	3	1.5	1	6	2	1	1	3	1.8
7	Terrestrial dispersal	3	5	4	1	1	5	2	1.7	4	5	1	1	4	1	1.7	4	6	1	1	4	1	2.0
8	Hitchhikers (via boats, waterfowl)	6	7	7	8	10	9	7	1.2	1	6	1	1	1	2	1.8	1	6	1	1	1	2	1.8
9	Certainty of effectiveness	3	9	6	6	8	9	5	1.6	3	3	2	8	3	3	2.0	3	3	2	7	3	2	1.7
10	Ability to monitor effectiveness	2	9	5	6	10	8	5	2.0	3	5	3	5	3	3	0.9	3	5	1	5	3	3	1.4
	Ecological Issues																						
11	Fisheries - compatibility with fish passage	5	9	9	10	10	9	6	1.3	7	7	10	10	7	7	1.4	7	7	10	10	7	7	1.4
12	Restoration benefits	7	0	5	0	0	0	3	2.0	2	6	2	1	2	6	2.0	2	6	2	2	3	5	1.6
13	Unintended consequences	6	6	9	8	10	8	7	1.3	7	5	8	5	6	6	1.1	7	4	5	5	6	4	1.1
	Risk	**0.15**																					
	Human Health																						
15	Biocide/Pollution release into waterways	10	8	10	9	10	9	8	0.8	9	10	9	10	10	7	1.1	9	10	9	10	10	7	1.1
16	Electric shock concerns (i.e., electric barriers)	5	8	10	8	10	10	10	0.9	10	10	7	10	10	10	1.1	10	10	10	10	10	10	0.0
	Implementation Timeframe	0																					
17	Near-term	9	8	7	8	5	8	6	1.2	9	8	9	10	9	8	0.7	9	8	8	10	9	9	0.7
18	Future	7	9	7	9	10	9	6	1.4	9	9	9	10	9	9	0.4	9	9	9	10	9	9	0.4
	Other Technical Issues																						
19	Adaptive management (easy to modify)	8	9	10	6	10	8	7	1.5	10	10	7	10	10	9	1.1	10	8	8	10	10	9	0.9
20	Existing prototypes in existence	5	6	8	4	5	7	4	1.5	9	10	7	10	9	9	1.0	9	10	6	10	9	9	1.3
	Socio-Political Issues																						
23	Consistency with ongoing AIS programs	6	7	8	4	10	8	6	1.9	9	10	10	10	8	8	0.9	9	10	10	10	8	8	0.9
24	Navigation	4	5		2	4	6		1.5	5		5	5	5		0.0	5		6	5	5		0.4
25	Recreation	6	2	3	5	6	2	6	1.7	5	4	8	9	5	7	1.8	5	4	8	8	5	5	1.6
26	Fishing	5	5	4	7	5	9	8	1.8	8	5	8	5	8	6	1.4	8	5	8	5	8	6	1.4
27	Local employment opportunities	2	7	5	5	7	7	7	0.9	8	4	9	5	8	7	1.8	8	9	7	5	8	7	1.2
	Ability to Permit																						
28	USACE permits	4	8	4	8	9	9	9	1.8	8	4	8	10	9	9	1.9	8	4	8	10	9	9	1.9
	Operation and Maintenance	**0.15**																					
29	Operations personnel and public safety	8	5	6	5	7	8	6	1.1	8	8	5	9	9	7	1.4	8	8	8	9	9	7	0.7
30	Reliability and durability	8	7	5	3	7	9	4	2.0	7	6	4	8	9	7	1.6	7	7	3	8	9	7	1.9
31	Ability to handle debris	4	8	10	8	9	10	4	2.0	7	5	8	9	7	6	1.3	7	5	8	9	7	7	1.2
32	Sediment handling (dredging)	3	8	9	8	10	10	4	2.0	8	8	5	10	10	6	1.9	8	9	5	10	10	6	1.9
33	Ice operations	4	7	8	4	9	10	9	2.0	3	6	4	5	0	5	2.0	3	6	4	5	5	9	1.9
34	Security	5	7	9	4	8	8	5	1.8	7	9	8	10	10	7	1.3	7	9	8	10	10	8	1.1
35	Chemical storage	3	6	3	3	5	8	5	1.7	10	10	5	10	10	9	1.8	10	10	5	10	10	9	1.8
36	Terrorist concerns	4	5	9	4	8	8	9	2.0	10	10	9	10	10	9	0.5	10	10	9	10	10	9	0.5
	Cost	**0.35**																					
37	Capital	6	7	8	4	8	9	4	2.0	6	4	6	6	3	5	1.2	4	3	8	7	3	5	1.9
38	Operation and maintenance	7	8	7	6	5	8	6	1.1	8	7	3	6	9	6	1.9	8	7	8	6	9	4	1.6
39	Certainty of cost at feasibility level	3	5	6	3	6	8	4	1.6	6	8	7	9	8	7	1.0	6	8	8	9	8	7	0.9

		Wt 0 - 10 (0-1.0)	24 Salt Water (Dead Sea Bath)							25 Thermal Treatment (Hot Bath)							26 Canal Boat Wash Steward Program							27 Biocides (e.g., piscicides, herbicides, etc.)						
			DP	DP	GG	KS	MK	PS	SD	DP	DP	GG	KS	MK	PS	SD	DP	DP	GG	KS	MK	PS	SD	DP	DP	GG	KS	MK	PS	SD
	Effectiveness	**0.35**																												
	Deterrent Effectiveness at Normal Flows																													
1	Water dispersal	10	8	8	4	8	9	5	1.8	8	8	5	8	9	7	1.3	5	5	1	1	5	4	1.8	8	9	7	7	8	3	1.9
2	Terrestrial dispersal	2	5	6	1	1	5	3	2.0	5	3	1	1	5	3	1.6	6	7	5	5	5	8	1.2	7	6	3	3	7	3	1.9
3	Hitchhikers (via boats, waterfowl)	7	4	7	4	8	8	4	1.9	5	3	3	8	7	4	1.9	6	7	8	7	8	8	0.7	8	6	7	10	9	5	1.7
4	Certainty of effectiveness	4	5	6	3	8	3	3	1.9	5	6	6	10	5	6	1.7	6	8	7	7	7	6	0.7	8	8	7	10	8	5	1.5
5	Ability to monitor effectiveness	4	7	6	5	10	8	6	1.6	7	5	7	10	8	4	2.0	5	8	7	5	4	7	1.4	7	8	5	10	7	6	1.6
	Deterrent Effectiveness at Flood Flows																													
6	Water dispersal	8	7	7	3	7	7	4	1.7	6	6	4	6	7	2	1.7	5	5	1	1	5	3	1.8	6	7	5	5	6	1	1.9
7	Terrestrial dispersal	3	4	5	1	1	4	2	1.6	4	3	1	1	6	1	1.9	5	6	1	1	5	3	2.0	5	5	1	1	5	2	1.9
8	Hitchhikers (via boats, waterfowl)	6	3	6	3	7	6	6	1.6	3	3	2	6	6	2	1.7	6	7	7	7	8	2	2.0	6	6	5	8	7	2	1.9
9	Certainty of effectiveness	3	1	5	2	6	2	4	1.8	3	5	5	8	4	2	1.9	6	7	6	7	7	2	1.8	6	7	6	8	6	2	1.9
10	Ability to monitor effectiveness	2	6	5	4	9	7	4	1.8	6	4	6	8	6	2	1.9	5	7	6	5	4	2	1.6	5	6	4	8	5	2	1.8
	Ecological Issues																													
11	Fisheries - compatibility with fish passage	5	1	2	1	1	1	1	0.4	1	2	1	1	1	1	0.4	9	9	10	10	9	9	0.5	0	3	1	0	0	4	1.6
12	Restoration benefits	7	0	3	0	0	0	3	1.4	0	5	0	0	0	3	2.0	2	7	3	4	3	6	1.8	1	6	1	1	1	4	2.0
13	Unintended consequences	6	7	7	5	10	7	6	1.5	7	7	7	9	7	6	0.9	9	9	9	10	9	7	0.9	5	5	2	2	5	7	1.8
	Risk	**0.15**																												
	Human Health																													
15	Biocide/Pollution release into waterways	10	7	10	9	10	7	7	1.4	7	10	10	10	10	7	1.4	8	10	5	10	9	6	1.9	1	3	0	0	1	3	1.2
16	Electric shock concerns (i.e., electric barriers)	5	10	10	9	10	10	10	0.4	10	10	4	10	10	10	2.2	10	10	7	10	10	10	1.1	9	10	10	10	10	10	0.4
	Implementation Timeframe	0																												
17	Near-term	9	5	7	8	8	5	8	1.3	5	7	8	9	5	9	1.7	10	8	7	10	10	9	1.2	4	8	7	8	5	6	1.5
18	Future	7	6	8	9	9	4	9	1.9	6	8	9	9	6	9	1.3	10	9	9	10	10	9	0.5	6	9	9	10	6	9	1.6
	Other Technical Issues																													
19	Adaptive management (easy to modify)	8	7	8	5	6	6	4	1.3	6	10	5	9	7	5	1.9	10	10	8	10	8	8	1.0	6	10	7	9	7	8	1.3
20	Existing prototypes in existence	5	0	0	0	0	0	0	0.0	0	0	0	0	0	0	0.0	10	10	8	10	10	8	0.9	8	10	8	8	4	9	1.9
	Socio-Political Issues																													
23	Consistency with ongoing AIS programs	6	7	8	7	10	5	6	1.6	8	8	6	10	5	6	1.7	10	10	9	10	9	9	0.5	7	10	7	10	5	9	1.8
24	Navigation	4	6		3	2	2		1.6	6		2	3	4		1.5	6		4	4	8		1.7	5		5	5	4		0.4
25	Recreation	6	3	3	6	7	2	5	1.8	2	3	6	7	2	5	2.0	3	4	6	6	3	4	1.2	2	5	4	5	2	4	1.2
26	Fishing	5	2	2	2	5	5	2	1.4	2	2	5	5	5	2	1.5	2	7	8	5	9	2	2.8	2	4	1	0	0	4	1.7
27	Local employment opportunities	2	7	8	5	8	7	7	1.0	7	8	7	8	7	7	0.5	8	10	9	8	7	8	0.9	6	5	8	3	7	6	1.6
	Ability to Permit																													
28	USACE permits	4	7	4	7	9	7	9	1.7	7	4	7	9	7	9	1.7	10	6	10	10	10	9	1.5	4	6	7	7	2	6	1.8
	Operation and Maintenance	**0.15**																												
29	Operations personnel and public safety	8	7	5	6	9	9	7	1.5	6	7	7	8	9	7	0.9	8	8	8	9	9	8	0.5	3	8	4	5	2	6	2.0
30	Reliability and durability	8	8	6	5	8	7	5	1.3	8	6	4	7	8	6	1.4	9	7	8	8	6	7	1.0	5	9	5	6	5	6	1.4
31	Ability to handle debris	4	7	8	8	9	9	7	0.8	7	8	8	9	9	7	0.8	8	8	9	10	10	7	1.1	6	7	9	9	9	8	1.2
32	Sediment handling (dredging)	3	7	9	7	10	10	5	1.8	7	9	8	10	10	8	1.1	10	7	8	10	10	7	1.4	5	9	9	10	8	6	1.8
33	Ice operations	4	4	8	5	8	9	7	1.8	4	8	3	8	7	7	2.0	8	6	7	9	10	8	1.3	5	5	8	8	4	7	1.6
34	Security	5	8	6	7	8	7	5	1.1	8	6	8	8	8	5	1.2	9	7	8	10	10	6	1.5	5	6	5	6	2	4	1.4
35	Chemical storage	3	8	8	6	8	7	8	0.8	9	8	9	10	8	8	0.7	10	8	5	10	10	7	1.9	1	2	1	2	1	6	1.8
36	Terrorist concerns	4	8	8	8	9	7	7	0.7	8	8	8	9	8	7	0.6	9	10	8	10	10	9	0.7	5	5	4	5	3	9	1.9
	Cost	**0.35**																												
37	Capital	6	4	7	7	7	4	7	1.4	6	8	7	6	4	7	1.2	7	7	7	9	10	7	1.2	8	5	8	5	4	7	1.6
38	Operation and maintenance	7	6	6	5	5	5	5	0.5	7	7	5	6	5	6	0.8	8	7	3	8	9	6	2.0	7	6	5	3	5	6	1.2
39	Certainty of cost at feasibility level	3	5	6	6	7	4	6	0.9	4	6	8	7	5	6	1.3	8	6	9	10	9	8	1.2	8	4	8	10	6	7	1.9

Downstream Dispersal Prevention Strategy
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		Wt 0 - 10 (0-1.0)	29 Water Treatment: Gasses							32 Water Treatment: Chemical							33 Predator Intro-duction							34 Deleterious Gene Spread							35 Trojan Y chromo-some						
			DP	DP	GG	KS	MK	PS	SD	DP	DP	GG	KS	MK	PS	SD	DP	DP	GG	KS	MK	PS	SD	DP	DP	GG	KS	MK	PS	SD	DP	DP	GG	KS	MK	PS	SD
	Effectiveness	**0.35**																																			
	Deterrent Effectiveness at Normal Flows																																				
1	Water dispersal	10	6	9	3	4	6	5	1.9	6	9	3	8	5	6	2.0	3	6	2	3	4	4	1.2	8	9	6	8	9	4	1.8	8	9	7	8	8	3	2.0
2	Terrestrial dispersal	2	4	4	1	1	4	3	1.3	5	2	1	1	5	3	1.7	3	4	1	0	3	3	1.4	7	9	6	8	8	6	1.1	7	9	7	8	8	3	1.9
3	Hitchhikers (via boats, waterfowl)	7	7	4	4	7	7	6	1.3	6	5	3	3	6	7	1.5	2	5	1	0	2	3	1.6	7	9	6	5	8	3	2.0	7	9	7	5	8	3	2.0
4	Certainty of effectiveness	4	5	9	7	8	5	4	1.8	7	9	7	10	7	5	1.6	5	3	2	3	3	4	0.9	5	8	4	8	4	3	2.0	4	5	4	5	4	3	0.7
5	Ability to monitor effectiveness	4	7	6	4	9	7	5	1.6	7	7	4	9	7	5	1.6	4	4	4	5	4	4	0.4	5	9	3	7	5	5	1.9	5	8	2	6	5	5	1.8
	Deterrent Effectiveness at Flood Flows																																				
6	Water dispersal	8	4	6	2	4	5	2	1.5	5	7	2	6	4	2	1.9	4	4	1	3	4	4	1.1	8	9	6	8	9	4	1.8	8	9	7	8	8	4	1.6
7	Terrestrial dispersal	3	3	4	1	1	4	2	1.3	5	2	1	1	4	1	1.6	3	4	0	0	3	1	1.6	7	9	6	8	8	3	2.0	7	9	7	8	8	3	1.9
8	Hitchhikers (via boats, waterfowl)	6	5	4	2	7	6	2	1.9	6	5	2	3	5	2	1.6	2	5	0	0	2	3	1.7	7	9	6	5	8	6	1.3	7	9	7	5	8	3	2.0
9	Certainty of effectiveness	3	4	3	4	8	5	3	1.7	7	6	5	8	6	2	1.9	3	3	1	3	3	4	0.9	5	8	4	8	4	4	1.8	4	8	4	5	4	3	1.6
10	Ability to monitor effectiveness	2	6	5	2	8	6	3	2.0	7	6	3	8	6	3	1.9	4	4	1	5	4	3	1.3	5	7	2	7	5	3	1.9	5	7	2	6	5	3	1.7
	Ecological Issues																																				
11	Fisheries - compatibility with fish passage	5	1	3	1	0	1	3	1.1	1	3	1	1	1	2	0.8	10	9	10	5	10	8	1.8	10	9	10	10	10	9	0.5	10	9	10	10	10	9	0.5
12	Restoration benefits	7	0	3	0	0	0	3	1.4	0	3	0	0	0	3	1.4	1	4	1	1	1	5	1.7	4	6	1	1	5	4	1.9	4	5	1	1	6	3	1.9
13	Unintended consequences	6	4	4	3	5	2	3	1.0	1	4	5	5	1	3	1.7	2	1	1	0	5	3	1.6	3	1	1	3	4	4	1.2	2	1	1	3	4	4	1.3
	Risk	**0.15**																																			
	Human Health																																				
15	Biocide/Pollution release into waterways	10	7	10	7	10	7	7	1.4	1	3	1	0	1	3	1.1	7	10	10	10	10	8	1.2	7	10	10	10	9	5	1.9	7	10	10	10	9	7	1.3
16	Electric shock concerns (i.e., electric barriers)	5	9	10	9	9	9	9	0.4	8	10	9	9	9	9	0.6	10	10	10	10	10	10	0.0	10	10	10	10	10	10	0.0	10	10	10	10	10	10	0.0
	Implementation Timeframe	0																																			
17	Near-term	9	4	6	7	10	5	5	2.0	4	8	8	10	6	6	1.9	5	6	7	5	5	7	0.9	3	1	3	0	3	1	1.2	3	1	3	3	3	1	0.9
18	Future	7	8	6	9	10	8	9	1.2	7	8	9	10	7	9	1.1	7	8	9	10	7	9	1.1	7	8	9	10	9	5	1.6	7	8	9	10	9	5	1.6
	Other Technical Issues																																				
19	Adaptive management (easy to modify)	8	6	10	6	8	6	9	1.6	7	10	6	8	6	8	1.4	3	2	2	0	2	3	1.0	1	1	2	0	1	9	3.0	1	1	2	0	1	9	3.0
20	Existing prototypes in existence	5	5	5	6	5	2	5	1.2	7	8	8	8	5	5	1.3	8	9	5	8	8	9	1.3	1	1	3	0	0	1	1.0	1	1	3	3	0	1	1.1
	Socio-Political Issues																																				
23	Consistency with ongoing AIS programs	6	5	8	3	10	5	4	2.4	5	8	5	8	6	3	1.8	5	8	4	4	7	8	1.7	5	1	4	6	5	1	2.0	5	1	4	6	5	1	2.0
24	Navigation	4	5		5	3	4		0.8	5		5	3	4		0.8	5		5	5	5		0.0	5		5	5	5		0.0	5		5	5	5		0.0
25	Recreation	6	3	7	6	8	4	3	2.0	3	5	3	7	3	3	1.5	5	6	5	10	5	6	1.8	2	2	5	5	5	2	1.5	2	2	5	5	5	2	1.5
26	Fishing	5	2	4	5	5	0	2	1.8	2	4	5	5	0	2	1.8	5	9	5	4	6	6	1.6	7	10	8	5	8	7	1.5	7	10	8	5	8	8	1.5
27	Local employment opportunities	2	4	6	7	8	7	3	1.8	4	4	6	9	7	4	1.9	5	2	5	0	5	5	2.0	5	1	1	0	5	2	2.0	5	1	1	0	5	2	2.0
	Ability to Permit																																				
28	USACE permits	4	5	5	7	9	5	5	1.5	4	7	7	7	2	7	2.0	5	3	8	8	5	8	2.0	5	3	8	7	5	3	1.9	5	3	8	7	5	3	1.9
	Operation and Maintenance	**0.15**																																			
29	Operations personnel and public safety	8	4	7	4	6	5	3	1.3	4	6	4	5	3	6	1.1	6	3	8	9	8	7	2.0	6	3	8	8	8	6	1.8	6	3	8	8	8	6	1.8
30	Reliability and durability	8	5	9	3	6	7	5	1.9	6	7	5	6	6	6	0.6	8	6	4	3	5	8	1.9	6	7	2	3	5	4	1.7	6	7	2	3	5	4	1.7
31	Ability to handle debris	4	6	5	8	9	10	5	2.0	7	8	8	9	10	7	1.1	8	8	9	10	10	9	0.8	8	10	9	10	10	9	0.7	8	10	9	10	10	9	0.7
32	Sediment handling (dredging)	3	5	9	9	10	8	5	2.0	5	9	9	10	8	5	2.0	8	9	8	9	9	8	0.5	8	10	9	9	9	9	0.6	8	10	9	9	9	9	0.6
33	Ice operations	4	5	7	7	8	5	3	1.7	5	7	7	8	4	5	1.4	7	10	8	9	10	8	1.1	7	10	9	9	10	9	1.0	7	10	9	9	10	9	1.0
34	Security	5	5	4	5	5	3	5	0.8	4	2	5	6	2	7	1.9	6	8	8	9	10	7	1.3	7	10	8	9	9	4	2.0	7	10	8	9	9	4	2.0
35	Chemical storage	3	3	2	3	4	2	6	1.4	2	3	2	2	1	6	1.6	7	10	9	10	10	9	1.1	7	10	9	10	10	5	1.9	7	10	9	10	10	5	1.9
36	Terrorist concerns	4	5	5	3	5	5	5	0.7	4	5	4	4	1	5	1.3	6	10	7	10	10	9	1.6	4	3	7	7	7	3	1.9	4	3	7	6	6	3	1.6
	Cost	**0.35**																																			
37	Capital	6	8	9	3	6	6	6	1.9	8	6	6	6	4	4	1.4	6	6	8	9	8	7	1.1	5	5	6	5	8	5	1.1	5	5	6	6	8	5	1.1
38	Operation and maintenance	7	7	8	3	3	7	5	2.0	7	7	4	3	5	5	1.5	7	4	9	10	9	7	2.0	5	3	8	8	7	4	2.0	5	3	8	8	7	4	2.0
39	Certainty of cost at feasibility level	3	6	7	5	5	5	5	0.8	6	5	8	9	4	6	1.7	5	3	8	7	5	7	1.7	7	3	4	2	3	2	1.7	4	3	4	2	3	2	0.8

APPENDIX C

Effectiveness Analysis

1. INTRODUCTION

This appendix documents the analytical tool used to estimate effectiveness of networked deterrent alternatives. Each networked deterrent alternative would be effective if it were to stop all types of AIS from using the Erie Canal to move among the four key waterbody groups (Great Lakes, Finger Lakes, Oneida Lake, and the Hudson River) under normal flow conditions. Thus, in order to be 100% effective, the networked deterrent must prevent movement of all AIC along each of the following pathways (Figure 1):

1. From Lake Erie/Ontario into Oneida Lake;
2. From Lake Erie/Ontario into the Finger Lakes;
3. From the Finger Lakes into Oneida Lake;
4. From Oneida Lake into the Finger Lakes;
5. From the Hudson River into Oneida Lake; and
6. From Oneida Lake into the Hudson River.

Note that the networked alternatives were not designed explicitly to protect the Great Lakes, although it does address movement from the Hudson to the Great Lakes. Also, the potential route from Lake Champlain (assumed connected to the Great Lakes through the St. Lawrence River) into the Hudson River is not included in this effectiveness analysis.

For each networked deterrent alternative, effectiveness has been summarized by the expected relative increase in probabilities of AIS being prevented from traversing the six pathways above when the network is in place. It is important to distinguish between the effectiveness of the networked deterrent and the probability of invasion, which is not being estimated or reported here. Invasion probabilities would vary substantially by species and require more detailed specific research.

2. METHODS

For estimating networked deterrent alternative effectiveness, AIS have been broken into the following biological groups, which may differ with respect to movement probabilities and deterrent response:

1. Active dispersers (includes juvenile and adult lifestages of many fishes and adult lamprey);
2. Passive dispersers (defined by downstream-only movement, includes early lifestages of fishes, invertebrates and mollusks, as well as whole or parts of plants); and

3. Hitchhikers (assisted dispersal, which can include juvenile and adult lifestages of fish and lamprey, pelagic invertebrates, mollusks, as well as seeds or parts of fragmenting plants).

In addition, Asian carp have been separately assessed due to specific interest in preventing movement of this high concern set of actively invading species.

The probability of each AIS type (Active, Passive, Hitchhikers, and Asian Carp) successfully traversing the NYSCS through each of the six pathways in a one-year time period was estimated for the no-action baseline scenario and for each networked deterrent alternative. For each scenario and each pathway,

Probability of exclusion = (1 – probability of successful traverse).

The relative increase in probability of exclusion of the networked alternative over baseline is the effectiveness estimate for each pathway:

$$\text{Relative increase} = \frac{(Network\ Probability\ of\ Exclusion - Baseline\ Probability\ of\ Exclusion)}{Baseline\ Probability\ of\ Exclusion}.$$

The relative increase was also estimated for a 25-year time period, and this summary result was used for comparing effectiveness among the networked alternatives.

The effectiveness analysis is thus a relative comparison of the probabilities that each type of AIS can move through the highlighted segments of the Canal System under each networked deterrent alternative, compared to the current baseline probability. These probabilities were estimated based on available data and professional judgement where no data were found; as such they contain varying amounts of uncertainty. To account for the uncertainty, a bounding analysis was conducted. Reasonable upper and lower limits for each individual model parameter were included to create a range of potential parameter values. Monte Carlo simulations were then used to estimate a range of effectiveness results that could be expected.

2.1. Model Assumptions and Limitations

Effectiveness was defined in terms of stopping movement among watersheds and did not explicitly account for species that may already be present and/or established within the Canal. Rather, an inherent assumption to the model was that a deterrent strategy for preventing entry for AIS currently outside the Canal System would accomplish a proportionate increase in effectiveness for preventing movement of species already occurring along a Canal pathway. This assumption was necessary to evaluate effectiveness for species guilds as described in Section 3.2 of the report.

The model assumed that each type of AIS was present and entering the Canal System at the start of the first segment in each pathway. Thus, the effectiveness analysis did not account for differing probabilities of entrance among species, among pathways, or through time, but rather estimated the probability of successfully completing each pathway if AIS have entered the pathway at the start of the first segment.

The model assumed that AIS entering the first segment of a canal pathway did not change from one dispersal group to another within the canal. For example, water fleas may enter the canal passively, then become attached to a boat somewhere within the canal. Conversely, water fleas may enter the canal as hitchhikers, then detach from the boat and become passive dispersers. These behaviors and the probabilities that accompany them are species-specific. Although it may be possible to expand the model to include some general assumptions regarding the probability of AIS changing dispersal modes mid-canal, this was not incorporated into the current model.

Effectiveness was estimated for a one-year and a 25-year time period. The 25-year time period assumed independence among years and no change in underlying assumptions over time. For example, boat traffic was assumed to follow similar patterns for 25 years.

Due to differing assumptions regarding migration and turbine survival, active AIS were separated into four subcategories or guilds for the effectiveness estimation along some pathway segments: Asian carp, other fish, lamprey, and crawlers. The effectiveness numbers were then combined into an overall effectiveness result based on assumptions of species prevalence (described below in Section 2.4 Effectiveness Estimates).

2.2. Effectiveness Framework

The effectiveness framework (Figure 1) presents a schematic of the six previously defined pathways (green arrows) identified by two-letter acronyms. Note that Lake Erie and Lake Ontario were assumed to be completely connected to each other and to Lake Champlain (through the St. Lawrence River). Although AIS can move from the Great Lakes into the Hudson River through Lake Champlain, that route was not considered under this model framework. Each of the six labeled pathways was divided into segments defined by different flow directions, water sources, and/or movement probabilities for AIS categories (Table 1, Figure 2 through Figure 7). Probabilities of AIS movement were estimated for each segment, then combined to form total probabilities along each pathway. The process for estimating movement probabilities differed among dispersal mechanisms, as detailed below. Baseline probabilities were not estimated for passive dispersers because each pathway contained an upstream segment combined with increasing elevation so there was no mechanism for AIS to fully traverse these pathways using passive dispersal.

Most probabilities used in the effectiveness analysis were estimated based on literature and/or professional judgement, and therefore contained uncertainty. This parameter uncertainty, as well as variability among individuals in the population was considered using a bounding range of values for each component probability. The range of values included a most likely probability (the mode), along with reasonable minimum and maximum boundaries on what the probability might be. The estimation for each type of probability is described in more detail in the sections below, with the range identified with mode (lower bound – upper bound).

2.2.1. Baseline Probabilities for Active Dispersers

For active dispersers, the first step in the model was to estimate the baseline probability of movement through each segment of each pathway, as described below.

2.2.1.1. Component Probabilities

For each pathway segment (e.g., GO0, GO2, etc.), the probability of passage through a segment ($\mathbf{P_{seg}}$) was broken into three components: the probability of entering the segment ($\mathbf{P_{arrival}}$), the probability that the segment could be successfully entered based on season ($\mathbf{P_{path}}$), and the probability that the segment could be successfully traversed given that the first two conditions were met ($\mathbf{P_{pass|(arrival\ and\ path)}}$). Each segment in a pathway was dependent on the previous segments. The components were then multiplied to estimate the probability for each segment:

$$\mathbf{P_{seg} = P_{arrival} \times P_{path} \times P_{pass|\ (arrival\ and\ path)}}.$$

$\mathbf{P_{arrival}}$ is the probability the AIS arrived within the segment, meaning it moves from the (end of the) previous segment into the (start of the) current segment, given that it has moved through the previous segment. For the initial segment in each pathway, $\mathbf{P_{arrival}}$ was set to 1 according to the definition of effectiveness. For other segments, $\mathbf{P_{arrival}}$ was based on a comparison of the relative flow volumes among the available route choices (Table 2).

$\mathbf{P_{path}}$ is the probability that an open pathway exists through the segment at any given time during a one-year interval. Some segments are shut down for part of the year, so the probability of movement through the canal in one year is reduced compared to segments that are open all year. This reduction in probability due to the navigation season was applied only once per pathway, based on the shortest navigation window. For example, if the first segment is open 6/12 months, then $\mathbf{P_{path}}$ for the first segment was 0.5 (50%), and any following segments were 1 (100%), unless they are open for less time than the first segment (Table 2). There was no uncertainty applied for this parameter.

$\mathbf{P}_{\mathbf{pass|\ (arrival,\ path)}}$ is the probability of AIS passing through the segment, given arrival at the entrance and an open pathway. The $\mathbf{P}_{\mathbf{pass|\ (arrival,\ path)}}$ estimates were generally dependent on dispersal rates, the length of the segment, flow direction, and successful navigation through locks, hydropower facilities, and invasive species deterrents as discussed below. Thus, in most cases, this was a compound probability based on multiplying the probabilities of independent events. For example, for a downstream segment with a hydropower plant, this component for fish would be the product of two estimated probabilities: the probability that fish entering the segment during navigation season would move through the entire canal (i.e., as opposed to staying in place or returning in the opposite direction after traveling part way through the canal); and the probability that (or estimated proportion of) fish would be expected to successfully pass the hydropower plant (turbines or spillway) or navigate through the locks. Methods for estimating the individual probabilities comprising $\mathbf{P}_{\mathbf{pass|\ (arrival\ and\ path)}}$ are described in the sections below.

Probability of Movement through Open Segments (in one year)

We assumed a high proportion of invasive swimming species (fish and lamprey), 90% (75-100%), entering a segment of the canal would move through the entire segment, regardless of distance. Movement probabilities for segments less than 20 miles long were increased to 95% (90-100%), and for segments less than 10 miles long were increased to 100% (with no uncertainty).

For invasive crawlers, we assumed 35% (20-50%) would migrate beyond a local area, and that the probability of crawlers traversing entire segments of the canal was based on the (approximate) length of the segment as well as the distance already traveled by the individual (Anastácio et al. 2015). We assumed that crawlers that choose to migrate have an annual travel distance ranging from 24 to 268 miles per year with a strong right skew (i.e., most crawlers travel in the lower part of this range; Gherardi and Barbaresi 2000). This distance distribution was estimated with a truncated lognormal distribution with mean ranging from 30 to 50 miles/year and coefficient of variation = 1.3 (Figure 8).

Probability of Successfully Passing through Locks with Vessel Traffic

We assumed that 10% (5-25%) of fish and lamprey could successfully navigate through locks in an upstream or downstream direction. Fish movement through locks has been studied in many river systems managed for navigation. Many studies confirmed lock use by documenting fish presence when locks were drained. Other studies have evaluated the possibility of designing locks specifically for fish passage or managing lockages to maximize fish passage (e.g., Moser et al. 2000; Bailey et al. 2004). Fewer studies evaluated the percentage of fish using navigation locks for movement.

The passage of migratory fish through navigation locks was generally low, given the low attraction of these facilities located in relatively calm zones to enable boats to maneuver (Larinier and Marmulla 2004). Less than 1.5 percent of migrating fish have used the lock at the Bonneville dam on the Columbia River (Monan et al. 1970). Simcox et al. (2015), found that eight percent of paddlefish used locks to move. Nichols and Louder (1970) found a similar lock usage rate of 4.5-11.4 percent for shad and alewife. A study of 10 species in the Welland Canal, which has eight locks over approximately 27 miles, found that 3.9 percent of tagged fish moved from the canal to a lake (Kim and Mandrak 2016). Approximately 16 percent of tagged fish passed through at least one lock and three percent passed through two locks in series.

We assumed crawlers would have the same passage probability as fish for going through locks with boat traffic, but we assumed a higher overall 12% (5-30%) probability for crawlers, with 2% additional passage probability added based on rough estimation of their ability to crawl past at least one lock if the facility closes while they are within.

Probability of Successfully Passing Hydropower Facilities

We assumed 0% (no uncertainty) upstream passage of active species through hydropower facilities other than through locks as discussed above. This includes the Varick Dam upstream of Lock 08, the Baldwinsville Dam adjacent to Lock E24 and Cohoes Falls upstream of Lock E2.

In the downstream direction, relative probabilities of passing through the turbines, spillway, or locks were based on average annual flow proportions. For fish and lamprey, the probability of successful downstream passage through a spillway was assumed to be 100% (no uncertainty). Crawlers were assumed to be benthic and travel downstream through the turbines or the locks only, based on average flow proportions.

Active dispersers that are entrained through a hydropower plant may suffer injury or mortality. At low-head facilities like those in the Erie Canal System, most fish injuries/mortalities occurring at hydropower projects are from direct contact with turbine blades (Franke et al. 1997). We assumed probability of successful passage through the turbines differs for the active AIS subgroups, as follows:

- *Asian Carp*: 85% (76-88%). This expected range of turbine survival was based on the size of adult Silver and Bighead carp (60-120 cm) and blade strike probability from Franke et al. 1997 and was cross-checked with field studies in the EPRI (1997) turbine mortality database. We assumed use of horizontal, pit-type Kaplan turbine units at low-head projects with 15-25 ft of head.
- *Fish other than carp*: 94% (84-98%). This expected range of turbine survival was based on the size of adult non-carp fishes in dispersal and assisted dispersal guilds (12-80 cm; average 33 cm) and blade strike probability from Franke et al. (1997) and was cross-

checked with field studies in the EPRI (1997) turbine mortality database. We assumed use of horizontal, pit-type Kaplan turbine units at low-head projects with 15-25 ft of head.

- *Lamprey*: 74% (62-85%). Due to their unique body shape and swimming behavior, field studies of eels were used to estimate turbine mortality for lamprey. Data were obtained on the expected range of turbine survival for American and European Eels entrained through horizontal, pit-type Kaplan turbine units at low-head projects (Hadderingh and Bakker 1998; Heisey et al. 2017; ICES 2007; Larinier and Travade 2002; Winter et al. 2006).
- *Crawlers*: 94% (84-98%). No published estimates of crawfish survival through turbines were available, so general estimates for fish were applied to crawlers.

2.2.1.2. Pathway Probabilities

The probabilities that AIS would traverse individual segments were the products of the component probabilities relevant to that segment. The probabilities for the six canal pathways among waterbodies were then calculated as composite probabilities of the segment probabilities as detailed below. To account for uncertainty, the pathway probabilities were calculated with 1000 Monte Carlo simulations. Probability values included in each simulation were randomly selected from the component probability distributions explained above. Therefore, effectiveness estimates for each pathway are presented as a distribution of results rather than a single estimate. In each case, the distribution can be summarized by a median or mean result, but also can be viewed as an entire distribution to evaluate a reasonable range of potential outcomes.

Great Lakes to Oneida Lake Pathway (GO)

We assumed AIS could travel from the Great Lakes to Oneida Lake through two connections displayed in the effectiveness framework and labeled with segments GO0-GO2-GO3-GO5 or GO4-GO5 (Figure 2). The segment labeled GO1 in the framework (The Genesee River) was assumed impassable in an upstream direction due to natural barriers (waterfalls; $\mathbf{P_{GO1}} = 0$). The probability of AIS traveling into Oneida Lake via one of the two routes (or both routes) was found by summing the probabilities for each route, then subtracting the joint probability, which would otherwise be double counted by simple summation.

$$\mathbf{P_{GO}} = (\mathbf{P_{GO0}} \times \mathbf{P_{GO2|GO0}} \times \mathbf{P_{GO3|GO2,\,GO0}} \times \mathbf{P_{GO5|GO3,\,GO2,\,GO0}})$$

$$+ (\mathbf{P_{GO4}} \times \mathbf{P_{GO5|GO4}})$$

$$- (\mathbf{P_{GO0}} \times \mathbf{P_{GO2|GO0}} \times \mathbf{P_{GO3|GO2,\,GO0}} \times \mathbf{P_{GO5|GO3,\,GO2,\,GO0}}) \times (\mathbf{P_{GO4}} \times \mathbf{P_{GO5|GO4}})$$

Great Lakes to Finger Lakes Pathway (GF)

We assumed AIS can travel from the Great Lakes to the Finger Lakes via two connections displayed in the effectiveness framework and labeled as GF0-GF2-GF5 or GF3-GF4-GF5 (Figure 3). The segment labeled GF1 (The Genesee River) was assumed to be impassable in the upstream direction due to natural barriers (waterfalls; $\mathbf{P_{GF1}} = 0$). The probability of AIS traveling into the Finger Lakes via one of the two routes (or both routes) was found by summing the probabilities for each route, then subtracting the joint probability, which would otherwise be double counted by simple summation.

$$\mathbf{P_{GF}} = (\mathbf{P_{GF0}} \times \mathbf{P_{GF2|GF0}} \times \mathbf{P_{GF5|GF2,\,GF0}})$$

$$\mathbf{+\ (P_{GF3}} \times \mathbf{P_{GF4|GF3}} \times \mathbf{P_{GF5|GF3,\,GF4}})$$

$$-\ (\mathbf{P_{GF0}} \times \mathbf{P_{GF2|GF0}} \times \mathbf{P_{GF5|GF2,\,GF0}}) \times \mathbf{(P_{GF3}} \times \mathbf{P_{GF4|GF3}} \times \mathbf{P_{GF5|GF3,\,GF4}})$$

Oneida Lake to Finger Lakes Pathway (OF)

There was only one route from Oneida Lake to the Finger Lakes (Figure 4):

$$\mathbf{P_{OF}} = (\mathbf{P_{OF0}} \times \mathbf{P_{OF1|OF0}} \times \mathbf{P_{OF2|OF1,\,OF0}}).$$

Finger Lakes to Oneida Lake Pathway (FO)

There was only one route from the Finger Lakes to Oneida Lake (Figure 5):

$$\mathbf{P_{FO}} = (\mathbf{P_{FO0}} \times \mathbf{P_{FO1|FO0}} \times \mathbf{P_{FO2|FO1,\,FO0}}).$$

Oneida Lake to the Hudson River Pathway (OH)

There was only one route from Oneida Lake to the Hudson River (Figure 6):

$$\mathbf{P_{OH}} = (\mathbf{P_{OH0}} \times \mathbf{P_{OH1|OH0}} \times \mathbf{P_{OH2|OH1,\,OH0}}).$$

Hudson River to Oneida Lake Pathway (HO)

There was only one route from the Hudson River to Oneida Lake (Figure 7):

$$\mathbf{P_{OF}} = (\mathbf{P_{HO0}} \times \mathbf{P_{HO1|HO0}} \times \mathbf{P_{HO2|HO1,\,HO0}}).$$

2.2.2. Baseline Probabilities for Hitchhikers

The process for estimating baseline probabilities for hitchhikers was based on available data for boat traffic through the Canal System. The probability that a hitchhiking AIS attached to a boat entering the first segment of any pathway would traverse the entire pathway depended on the probability that the boat completed the pathway. Lockage data have been collected on the boats that pass each lock and guard gate; thus, we were able to estimate the proportion of boats entering the canal at a specific location (e.g., Lock E34 heading east for the GO pathway) that were also recorded exiting the canal at another location (e.g., Lock E23 heading east for the GO pathway). Two estimates were available for each route over six years, due to variation in lockage recording at different locks. The variability in lockage recording and among years provided estimates of uncertainty for these parameters. The “true” probabilities in any given year were assumed to come from a normal distribution (truncated at 0 and 1) with mean and variance estimated from the available data (Table 3).

Under the assumption that hitchhikers were attached to boats moving into the canal during navigation season, the pathway probabilities were estimated as follows.

Great Lakes to Oneida Lake Pathway (GO)

We assumed AIS could travel from the Great Lakes to Oneida Lake through two connections displayed in the effectiveness framework and labeled with segments GO0-GO2-GO3-GO5 or GO4-GO5 (Figure 2). The segment labeled GO1 in the framework (The Genesee River) was assumed impassable in an upstream direction due to natural barriers (waterfalls; $\mathbf{P}_{\mathbf{GO1}} = 0$). The probability of AIS traveling into Oneida Lake via one of the two routes (or both routes) was found by summing the probabilities for each route, then subtracting the joint probability, which would otherwise be double counted by simple summation.

$$\mathbf{P}_{\mathbf{GO}} = (\mathbf{P}_{\mathbf{GO0\text{-}GO5}}) + (\mathbf{P}_{\mathbf{GO4\text{-}GO5}}) - (\mathbf{P}_{\mathbf{GO0\text{-}GO5}} \times \mathbf{P}_{\mathbf{GO4\text{-}GO5}}),$$

where

$\mathbf{P}_{\mathbf{GO0\text{-}GO5}}$ is the probability a boat entering the Erie Canal from Tonawanda Creek will exit the canal in Oneida Lake; and

$\mathbf{P}_{\mathbf{GO4\text{-}GO5}}$ is the probability a boat entering the Oswego Canal from Lake Ontario will exit the canal in Oneida Lake (Table 3).

Great Lakes to Finger Lakes Pathway (GF)

We assumed AIS can travel from the Great Lakes to the Finger Lakes via two connections displayed in the effectiveness framework and labeled as GF0-GF2-GF5 or GF3-GF4-GF5 (Figure 3). The segment labeled GF1 (The Genesee River) was assumed to be impassable in the upstream direction due to natural barriers (waterfalls; $\mathbf{P}_{\mathbf{GF1}} = 0$). The probability of AIS traveling into the Finger Lakes via one of the two routes (or both routes) was found by summing the probabilities for each route, then subtracting the joint probability, which would otherwise be double counted by simple summation.

$$\mathbf{P_{GF}} = (\mathbf{P_{GF0\text{-}GF5}}) + (\mathbf{P_{GF3\text{-}GF5}}) - (\mathbf{P_{GF0\text{-}GF5}} \times \mathbf{P_{GF3\text{-}GF5}}),$$

where

$\mathbf{P_{GF0\text{-}GF5}}$ is the probability a boat entering the Erie Canal from Tonawanda Creek will exit the canal in the Finger Lakes.

$\mathbf{P_{GF3\text{-}GF5}}$ is the probability a boat entering the Oswego Canal from Lake Ontario will exit the canal in the Finger Lakes (Table 3).

Oneida Lake to Finger Lakes Pathway (OF)

There was only one route from Oneida Lake to the Finger Lakes (Figure 4):

$\mathbf{P_{OF}}$ is the probability a boat entering the Erie Canal from Oneida Lake traveling west will exit the canal in the Finger Lakes (Table 3).

Finger Lakes to Oneida Lake Pathway (FO)

There was only one route from the Finger Lakes to Oneida Lake (Figure 5):

$\mathbf{P_{FO}}$ is the probability a boat entering the Erie Canal from the Finger Lakes will exit the canal in Oneida Lake (Table 3).

Oneida Lake to the Hudson River Pathway (OH)

There was only one route from Oneida Lake to the Hudson River (Figure 6):

$\mathbf{P_{OH}}$ is the probability a boat entering the Erie Canal from Oneida Lake traveling east will exit the canal in the Hudson River (Table 3).

Hudson River to Oneida Lake Pathway (HO)

There was only one route from the Hudson River to Oneida Lake (Figure 7):

$\mathbf{P_{HO}}$ is the probability a boat entering the Erie Canal (Mohawk River) from the Hudson River will exit the canal in Oneida Lake (Table 3).

2.3. Deterrent Effectiveness

Deterrents installed to reduce or prevent movement through a segment of the canal reduced the probability of AIS passing through the segment, $\mathbf{P_{pass|\,(arrival,\,path)}}$, based on estimates of the deterrent effectiveness for preventing movement of each type of AIS. Effectiveness for each deterrent advanced for consideration was estimated based on searches of peer-reviewed and grey literature as well as personal communication with experts in some technologies. This effectiveness review first focused on AIS in general and then considered deterrent effectiveness for hitchhiking AIS and active AIS dispersers (adult life phases of Asian carp, other fishes, lamprey, and crawlers; Table 4 and Table 5). For the effectiveness analysis, passive dispersers were excluded from using the six pathways for movement under baseline conditions due to upstream conditions in at least one segment. However, the effectiveness of individual deterrents for passive dispersal, including egg or larvae life-phases and fragmenting plants and seeds has been included in the sections below.

2.3.1. Hydrologic Separation

Hydrologic separation within the Erie Canal can be achieved through permanent closure of canal features, such as locks or guard gates. Hydrologic separation would stop flow in the canal in both directions. This would prevent direct water transport of AIS at the location of separation.

- *Asian Carp, Other fishes, lamprey, hitchhikers*: 100% (no uncertainty).

In a study that used structured expert judgement to quantify the efficacy of control strategies for Asian carp the performance-weighted expert estimate of hydrologic separation effectiveness was 99% (95,100; median, 5th and 95th percentiles; Wittmann et al. 2014).

- *Crawlers*: 98% (95-100%)

Hydrologic separation removes all surface water connection, but crawlers are unique among AIS, in that many crayfish, including red swamp, common yabby and marbled crayfish, are capable of walking overland to disperse into new environments (Cruz and Rebelo 2007). A study of red crayfish estimated a maximum distance for active dispersal on dry land as approximately 1.6 km if walking continuously and always heading in one direction (Banha and Anastácio 2014).

2.3.2. Hydrologic Separation with a Dry Reach

Hydrologic separation within the Erie Canal can be achieved through permanent closure of canal features, such as locks or guard gates. Hydrologic separation would stop flow in the canal in both directions. This would prevent direct water transport of AIS at the location of separation. Hydrologic separation with a dry reach occurs when two or more locks or gates in a series are closed and the area in between is desiccated except for groundwater/seepage and stormwater.

- *Asian Carp, Other fishes, lamprey, crawlers, and hitchhikers*: 100% (no uncertainty).

A sufficiently long dry reach should effectively deter AIS movement, even crawlers. A minimum dry reach length of approximately 1 mile is required to deter crawfish overland dispersal (Banha and Anastácio 2014).

2.3.3. Lock Closure, Boat Lift and Wash

Locks would be permanently closed and the gates sealed to stop all flow and leakage and associated navigation through the lock. Boat inspection and wash stations would include boat lifts or rails capable of moving boats around the locks for inspection of AIS, cleaning/decontaminating and transport. Boat washing is intended to remove hitchhiking plants, mollusks that can attach to vessel surfaces, and pelagic invertebrates and even small bodied benthic fishes that hide in mussel beds when boats become heavily encrusted or in any location that contains a pool of water.

- *Asian carp, other fishes, lamprey, passive dispersers*: Upstream 100%, Downstream 0% (no uncertainty)

Lock closure would remove an upstream passage route for all active and passive dispersers including Asian carp, other fishes and lamprey. Some dams on the Oswego Canal have eel ramps, but based on NYDEC operation of traps associated with the ramps it was assumed that AIS would not be passed upstream. Lock closure was not anticipated to have any effect on the downstream passage rate of fishes, because alternate routes downstream over spillways and through bypass channels are available.

- *Crawlers*: Upstream 98% (95-100%), Downstream 0%

Like hydrologic separation, we assumed a 2 percent overland travel rate for crawlers around closed lock structures and associated facilities.

- *Hitchhikers:* Plants 83% (65-94%); Animals 96% (85-98%) (Note 50% of hitchhikers assumed to be plants and 50% assumed to be animals for estimating passage with this deterrent).

Many laboratory studies have evaluated the upper lethal limit of the thermal tolerance of AIS. These studies generally estimated mortality rates under thermal exposures of varying temperatures, durations, and acclimation conditions. Although these studies form a helpful basis for developing boat wash protocols, they are not sufficient to evaluate likely boat wash efficacy. Laboratory studies have also been done to evaluate pressure washing in controlled settings. In addition, the efficacy of high pressure washes on various boats under field conditions was summarized by Rothlisberger et al. (2010), who observed that visual inspection and hand removal reduced adhering macrophytes on trailered boats by 88% ± 5% (mean ± SE), while decontamination using high-pressure (1800 psi) and low-pressure washing (40 psi) resulted in macrophyte removal rates of 83% ± 4% and 62% ± 3%, respectively. Rothlisberger et al. (2010) similarly documented a 91% effectiveness for removing small bodied organisms from boats using high-pressure washing. Given the universal lethality of 140 degrees for 10 seconds for all tested AIS animals, we assumed that hot high-pressure washing would be even more effective.

2.3.4. BAFF

A Bio-Acoustic Fish Fence (BAFF) with a synchronized high intensity light system (SILAS™) manufactured and patented by Fish Guidance Systems (FGS) Ltd. (United Kingdom) (Welton et al. 1997, 2002) is proposed for the Western Erie Canal near Tonawanda Creek.

- *Asian carp*: 95% (84-98%)

The FGS BAFF/SILAS system used at Tonawanda would be designed to target the audible range of Asian carp (100 to 3500 Hz; Vetter et al. 2018). Laboratory and raceway studies of BAFF-type systems without lights have consistently shown deflection efficiency of 84-100% for Bighead Carp. Using a 20-2000Hz cyclic sound designed for Asian carps in a hatchery raceway, a BAFF deterred 95% of bighead carp over three days (Pegg and Chick 2004; Taylor et al. 2005). Most recently, Dennis et al. (2019) tested a BAFF type system built to simulate the FGS BAFF/SILAS system. Tests were conducted in a laboratory raceway with repeated, short-duration (6 minute) trials and showed a blockage efficiency of 97 ± 13% for Bighead Carp (Dennis et al. 2019). Short duration field studies (3-d) with a FGS BAFF system equipped with SILAS have suggested effectiveness up to 99-100% for both Silver and Bighead carp; however, for these studies Asian carp were collected and released downstream of the BAFF array and may have not been motivated to move upstream (Ruebush et al. 2012).

The effectiveness of the FGS patented BAFF system is associated with proprietary acoustics and their frequency range. A BAFF-like system operating between 100-1000Hz consistently deterred about 80% of Silver Carp and 83% of all Bighead Carp (Zielinski and Sorensen 2016) during short (7-h to 3-d) duration experiments. Similarly, an FGS BAFF operating with a frequency range of 20-500 HZ was only 57% effective for Bighead Carp: however, effectiveness increased to 95% when sound frequencies of 20 -2000 HZ were used (Pegg and Chick 2004).

Testing of acoustic stimuli alone have demonstrated mixed results (Vetter et al. 2015, Dennis et al. 2019; Wamboldt et al. 2019). Vetter and others (2015) found that the complex broadband sound of underwater field recordings of outboard motors (0–10 kHz) was effective in altering the behavior of Silver Carp in a controlled pond setting. In a field study using an acoustic deterrent using a broadband boat motor sound (60–24,000 Hz) in the hearing range of Bighead and Silver carp, Wamboldt et al. (2019) documented a strong initial response to the onset of the acoustic stimulus but found no evidence of long-term effectiveness to prevent fish from moving through a culvert. In a raceway flume experiment the outboard motor sound alone had blockage efficiencies of 76 ± 29%; the particular sound developed by FGS for Asian carp was more effective (Dennis et al. 2019).

Whereas an air curtain alone could block bighead carp (59% +/- 36%), it was much more effective when coupled with the cyclic sound developed by FGS (Dennis et al. 2019). More recent studies show that adding a 2hz strobing light further increases the efficiency of an air curtain coupled with the FGS cyclic sound (i.e., the BAFF) (Dennis and Sorensen, unpublished results)

In a study that used structured expert judgement to quantify the efficacy of control strategies for Asian carp the performance weighted expert estimates of BAFF effectiveness was 92% (85,95; median, 5th and 95th percentiles; Wittmann et al. 2014).

- *Other fish*: 60% (25-98%)

The BAFF system could be specifically designed to target the primary audible range of Asian carp (20 to 2000 Hz) and, if so, it may have different effect on non-Cyprinidae fish families and fishes without hearing specializations (Zielinski and Sorensen 2016). Alternatively, the manufacturer has confirmed that the acoustic feature could be designed to target audible ranges for more than one target species to improve overall deterrence. Data on the efficacy of these acoustic on non-hearing specialist fish taxa is limited.

When an FGS BAFF was used as a fish guidance measure in the Sacramento River entrainment of juvenile Chinook Salmon (*Oncorhynchus tshawytscha*) into a canal was reduced from 22.3 to 7.7% (Perry et al 2014). Testing of an FGS BAFF system in a raceway environment with repeated, short-duration (6 minute) trials showed a blockage efficiency of 87 ± 24% for Largemouth Bass, a non-hearing specialist fish (Dennis et al. 2019). Similar results are apparent for other North American perciforms (Feely and Sorensen, unpublished results).

- *Lamprey*: unknown

No literature or studies on the FGS BAFF system effectiveness for lamprey were found.

- *Crawlers*: unknown

No literature or studies on the FGS BAFF system effectiveness for crayfish were found.

- *Hitchhikers:* 0%

The BAFF is not expected to affect hitchhiker movement rates on aquatic vessels.

2.3.5. AIS Barrier Screen

A barrier screen can be an effective deterrent for numerous types and sizes of AIS. The effectiveness of a screen is a function of opening size, approach velocity, direction of flow with respect to target organisms (e.g., a screen designed to block upstream movements might only consider the sizes of mobile organisms), and ability to perform under a range of flows and debris loads. The barrier screen would need to be self-cleaning to prevent build-up of debris or fouling and keep the screen functioning at capacity within acceptable approach velocity parameters. While a specific screen slot size has not been determined at this point in conceptual design (Section 3.5), for the purposes of effectiveness modeling, a wedge wire barrier screen with 1.75mm slot size was evaluated. This measure would be paired with a lock closure and is therefore assumed to be applied to 100 percent of downstream flow under typical operating conditions.

- *Asian Carp*: 98% (95-100%)

The AIS barrier screen would physically exclude non-larval juvenile, sub-adult and adult Asian carp. However, a small number of fish may be able to pass downstream during high-flow events or other potential events where the screen would be rendered inoperable, such as excessive debris loads or fouling. Passive floating larval-sized Asian carp may be able to pass through the AIS barrier screen in a downstream direction. Based on the sizes of ichthyoplankton in general, a 1.75 mm screen would exclude around 35% of larval life-stage Asian carp and most fish over 16-20mm in length would not be able to physically pass through the barrier screen (Table 6). The lock closure associated with the barrier screen location would prevent all upstream and downstream movements through the lock chambers during lockages.

- *Other fishes*: 98% (95-100%)

The AIS barrier screen would physically exclude non-larval juvenile, sub-adult and adult dispersing fishes. However, a small number of fish may be able to pass downstream during high-flow events or other potential events where the screen would be rendered inoperable, such as excessive debris loads or fouling. Passively dispersing larval-sized fishes may be able to pass through the AIS barrier screen in a downstream direction. Based on the sizes of ichthyoplankton in general, a 1.75 mm screen would exclude around 35% of larval life-stage dispersing fishes and most fish over 16-20mm in length would not be able to physically pass through the barrier screen (Table 6).

- Sea Lamprey: 98% (95-100%)

The AIS barrier screen would physically exclude non-larval juvenile, sub-adult and adult Sea Lamprey. However, there are other potential events where the screen would be rendered inoperable, such as excessive debris loads or fouling. We do not anticipate that larval lamprey would encounter the AIS barrier screen. Lamprey incubate and develop as larvae (ammocoetes) in the interstices of gravel and silt and do not undergo downstream movements until transformation to the parasitic life-phase at the size of 5-7 inches (Wigley 1959). The main design requirements for a vertical mesh screen barrier for lamprey are slots with less than or equal to 13 mm (0.5 in) spacing (Applegate and Smith 1951).

- *Crawlers*: 98% (95-100%)

The AIS barrier screen would physically block crawlers. However, a small number of crawlers may be able to pass downstream during high-flow events or other potential events where the screen would be rendered inoperable, such as excessive debris loads or fouling. A small number of crawlers may also be able to bypass the barrier screen by movement overland.

- *Passive dispersers* (downstream): 0-98%

Passive larval dispersing life-stages of hitchhiking animals and some plant fragments and seeds may be able to physically fit though the AIS barrier screen. The screen would not be effective for mussel veligers which are very small and require 40-50-micron size mesh. Depending on the final screen size selected and performance of the cleaning system, the exclusion of fragmenting plans and floating seeds could be high.

2.4. Effectiveness Estimates

Because there are multiple routes through the Canal System, and multiple dispersal modes, the networked deterrent alternatives have been compared based on their respective relative reductions to AIS travel under baseline conditions. To facilitate these estimates, pathway exclusion probabilities were first estimated for each alternative by AIS dispersal group. This required multiplying existing baseline segment probabilities by simulated deterrent probabilities from the deterrent effectiveness estimates (Table 4 and Table 5). This resulted in pathway exclusion probabilities for each alternative over one year. The 25-year exclusion rates were found by assuming independence among years and calculating the one-year exclusion rate raised to the 25th power.

The relative increase in probability of exclusion of the networked alternative over baseline is the effectiveness estimate for each pathway:

$$\text{Relative increase} = \frac{(Network\ Probability\ of\ Exclusion - Baseline\ Probability\ of\ Exclusion)}{Baseline\ Probability\ of\ Exclusion}.$$

This summary result was calculated for each Monte Carlo simulation (n=1000), and the distribution of these results was used for comparing effectiveness among the networked alternatives.

Effectiveness results for the AIS groups (Asian carp, other fish, lamprey, crawlers, and hitchhikers) were combined into an overall effectiveness estimate based on the proportion of these groups on the “least wanted” AIS list identified by The Great Lakes and St. Lawrence Governors and Premiers (GLSGP 2019; Table 7).

3. EFFECTIVENESS RESULTS

The bounding analysis model using Monte Carlo simulations was run for the three networked deterrent alternatives. The estimated relative reduction in the potential for AIS to travel along six Canal pathways in a 25-year time period is displayed by AIS group (Asian carp, other fish, lamprey, crawlers, hitchhikers) in Figure 9 through Figure 14.

The effectiveness results for all AIS groups combined are displayed in Figure 15 for each of the six Canal pathways.

Alternative 1 was estimated to be 100% effective for protecting the Hudson River from AIS entering via Oneida Lake, and 100% effective for protecting Oneida Lake and the western Erie Canal System from AIS entering via the Hudson River. The hydrologic separation and dry canal deterrent near Rome is predicted to stop movement of all AIS through this section in both directions. Alternative 1 offers no deterrents to prevent movement of AIS between the Great Lakes, the Finger Lakes, and Oneida Lake (0% effective).

Alternative 2 was estimated to be 100% effective for protecting the Hudson River from AIS entering via Oneida Lake, and 100% effective for protecting Oneida Lake and the western Erie Canal System from AIS entering via the Hudson River, due to the hydrologic separation and dry canal deterrent near Rome. Alternative 2 was estimated to prevent 100% of fish (including Asian carp) and lamprey from using the Canal System to travel from the Great Lakes to the Finger Lakes or Oneida Lake because of the hydrologic separation in Rochester (WGL) and the closed lock in the Oswego Canal (O7/8). Crawlers were not predicted to be 100% reduced due to their ability to move on land and dry structures to circumnavigate the deterrents. However, these species are considered unlikely to be able to traverse these pathways unassisted due to the long distance and number of locks in place. Hitchhiking AIS entering from Lake Ontario and traveling up the Oswego Canal have relatively high baseline probabilities of being carried into Oneida Lake or into the Finger Lakes (Table 3). The boat wash at Lock O7/8 may have high effectiveness for removing hitchhikers, but some hitchhiking AIS would eventually be carried into these lakes (i.e., over 25 years). Overall, Alternative 2 was estimated to reduce overall AIS movement from Lake Erie and Lake Ontario into the Finger Lakes by 55-58% and to reduce overall AIS movement from Lake Erie and Lake Ontario into Oneida Lake by 55-71%. Alternative 2 offered no deterrents to prevent movement of AIS between the Finger Lakes and Oneida Lake (0% effective).

Alternative 3 was estimated to be 100% effective for protecting the Hudson River from AIS entering via Oneida Lake, and 100% effective for protecting Oneida Lake and the western Erie Canal System from AIS entering via the Hudson River; again, due to the hydrologic separation and dry canal deterrent near Rome. With the BAFF, closed lock, and fish screen deterrents in the western end of the Erie Canal and the closed lock near Lake Ontario on the Oswego Canal, Alternative 3 was also estimated to prevent 99% of fish (including Asian carp) and lamprey movement from the Great Lakes to the Finger Lakes and Oneida Lake. Thus, Alternative 3 is less effective than Alternative 2 for these routes for these species because Alternative 2 has the 100% effective hydrologic separation at Rochester (WGL). Alternative 3 is more effective for crawlers and hitchhikers along these routes because it contains additional closed locks and boat washes that further deter these species. Overall, Alternative 3 was expected to prevent 80-91% of AIS movement from Lake Erie and Lake Ontario into the Finger Lakes and to prevent 91-95% of AIS movement from Lake Erie and Lake Ontario into Oneida Lake. Alternative 3 offers additional deterrents to prevent movement between the Finger Lakes and Oneida Lake. It is estimated to reduce AIS movement from Oneida Lake to the Finger Lakes by 95-98%, including 100% of fish and lamprey movement along this route because of the closed lock and boat wash at Baldwinsville. Alternative 3 is estimated to prevent 40-45% of potential AIS movement from the Finger Lakes to Oneida Lake, but it is 0% effective for fish and lamprey movement, and only 5-15% effective for crawlers in this direction.

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Table 1. Definition of Canal segments along six AIS pathways.

Pathway Segment	Name	Direction	Start	End	Approximate Length (miles)	Approximate Range of Monthly Average Flow (cfs) May-October	Approximate Range of Channel Width (ft)
GO0, GF0	Western Erie Canal	Downstream	Tonawanda Creek	Genesee River	67	800	84-93
GO1, GF1	Genesee River	Upstream	Lake Ontario	Erie Canal at Genesee River	12	1,080- 6,110	150-435
GO2, GF2	Western Erie Canal	Downstream	Genesee River	Seneca Canal/River	59	100-200	90-230
GO4, GF3	Oswego Canal	Upstream	Lake Ontario	Seneca/Oneida/Oswego Confluence	23	2,200-12,000	290-700
GO3, FO1	Central Erie Canal	Downstream	Cayuga &Seneca Canal	Oswego Canal/River	41	1,550-4,060	220-460
GF4, OF1	Central Erie Canal	Upstream	Oswego Canal/River	Cayuga &Seneca Canal	41	1,550-4,060	220-460
GO5, FO2	Central Erie Canal	Upstream	Seneca/Oneida/Oswego Confluence	Oneida Lake	14	1,030-2,980	180-360
OF0	Central Erie Canal	Downstream	Oneida Lake	Seneca/Oneida/Oswego Confluence	14	1,030-2,980	180-360
GF5, OF2	Cayuga-Seneca Canal	Upstream	Erie Canal	Cayuga Lake	4	255-960	220-300
FO0	Cayuga-Seneca Canal	Downstream	Cayuga Lake	Erie Canal	4	255-960	220-300
OH0	Eastern Erie Canal	Upstream	Oneida Lake	Mohawk River (Rome)	14	100-350	111-246
HO1	Eastern Erie Canal	Downstream	Mohawk River (Rome)	Oneida Lake	14	100-350	111-246
OH1	Eastern Erie Canal	Downstream	Mohawk River (Rome)	Hudson River	115	100-6,520	45-900
HO0	Eastern Erie Canal	Upstream	Hudson River	Mohawk River (Rome)	115	100-6,520	45-900

Table 2. Probability that active dispersers arrive or enter each segment ($P_{arrival}$) and probability the segment has an open pathway (P_{path}; based on navigation season), contingent on previous segments completed.

Segment[1,2]	$P_{arrival}$ Mode	$P_{arrival}$ Range	P_{path} Mode
GO0	100%		50%
GO2|GO0	10%	(2-35%)	100%
GO3| (GO0, GO2)	50%	(25-75%)	100%
GO5| (GO0, GO2, GO3)	33%		100%
GO4	100%	(15-60%)	50%
GO5|GO4	40%	(15-65%)	100%
GF0	100%		50%
GF2|GF0	10%	(2-35%)	100%
GF3	100%	(15-60%)	50%
GF4|GF3	60%	(35-85%)	100%
GF5| (GF2, GF0)	50%	(25-75%)	100%
GF5| (GF4, GF3)	90%	(75-99%)	100%
FO0	100%		50%
FO1|FO0	90%	(75-99%)	100%
FO2| (FO1, FO0)	30%	(15-40%)	100%
OF0	100%		100%
OF1|OF0	40%	(25-50%)	50%
OF2| (OF1, OF0)	90%	(75-99%)	100%

[1] The symbol "|" means "given" (i.e., OF1|OF0 refers to segment probabilities for segment OF1 contingent on the knowledge that segment OF0 already being completed.

[2] The baseline probability for active dispersers for pathways HO and OH have not been estimated because all current proposed networked deterrent alternatives will be 100% effective for stopping all active dispersers.

Table 3. Probability hitchhiking AIS traverse pathways of the Erie Canal System estimated by proportions of boats recorded to have entered and exited at listed locks from 2011- 2016.

	Locks		Estimated Probability Random Boat Travels Entire Pathway	
Pathway	**Entry**	**Exit**	**Mean**	**Standard Deviation**
GO	E34	E23	10%	1.7%
	O8	E23	67%	4.4%
GF	E34	C&S1	7.8%	1.7%
	O8	C&S1	21%	4.7%
FO	C&S1	E23	24%	3.0%
OF	E23	C&S1	11%	1.8%
HO	E2	E22	64%	10%
OH	E22	E2	53%	10%

Table 4. Downstream dispersal effectiveness estimates. For simulations, statistical distributions were triangular densities with the given mode and upper and lower boundaries, except where otherwise noted.

Deterrent Technology	Dispersing Fish	Asian Carp	Sea Lamprey	Crawlers	Hitchhikers	Passive Dispersers
Hydrologic Separation	100%	100%	100%	98%	100%	100%
Hydrologic Separation with Dry Reach	100%	100%	100%	100%	100%	100%
Lock Closure Lift and Wash	0%	0%	0%	0%	Plants 83% (65-94%)[1] Animals 96% (85-98%)[1]	0%
BAFF	60% (25-98%)	95% (84-98%)	0% (0-20%)	0% (0-20%)	0%	0%
AIS Barrier Screen	98% (95-100%)	98% (95-100%)	98% (95-100%)	98% (95-100%)	NA	Plants 0-98%[2] Animals 0-98%[2]

[1]This is the mean, 25th, and 75th percentiles of the truncated normal distribution used for this parameter.

[2]AIS barrier screen effectiveness for passive dispersing larval life-phases and plants will depend on screen slot-size selected.

Table 5. Upstream dispersal effectiveness estimates. For simulations, statistical distributions were triangular densities with the given mode and upper and lower boundaries, except where otherwise noted.

Deterrent Technology	Dispersing Fish	Asian Carp	Sea Lamprey	Crawlers	Hitchhikers
BAFF	60% (25-98%)	95% (84-98%)	0% (0-20%)	0% (0-20%)	0%
AIS Barrier Screen	98% (95-100%)	98% (95-100%)	98% (95-100%)	98% (95-100%)	NA
Hydrologic Separation	100%	100%	100%	98% (95-100%)	100%
Hydrologic Separation with Dry Reach	100%	100%	100%	100%	100%
Lock Closure Lift & Wash	100%	100%	100%	98%	Plants 83% (65-94%)[1] Animals 96% (85-98%)[1]

[1]This is the mean, 25th, and 75th percentiles of the truncated normal distribution used for this parameter.

Table 6. Larval fish exclusion size and entrainment reduction with various wedge wire screen slot sizes.

Screen Slot Size (mm)	Fish Exclusion size (length, mm)	Ichthyoplankton Entrainment Reduction (%)[c]
0.5	4.6-6.6[a]	80
0.75	7[b]	77.1
1	9[b]	67.6
1.75	16[b]	34.6[d]
3	24[b]	15.8
4		7.8
6		1.8

a fish exclusion length is the range of average length for Centrarchids, Clupeids, and Cyprinids based on field evaluation (McDonald and Karchesky 2010)

b fish exclusion length based on estimated proportion of 0.5 for goby larvae (Tenera 2013)

c based on the probably of entrainment for larvae of 15 taxonomic categories of fish, extrapolated to the size at which the larvae are no longer susceptible to entrainment, 20–25 mm (from Tenera 2013)

d entrainment reduction based on 2mm slot spacing

Table 7. AIS "least wanted" species groups used in weighting.

	Carp	Other Fishes	Lamprey	Crawlers	Hitchhikers	Total
	Bighead Carp	Northern Snakehead	Sea Lamprey	Yabby	Killer Shrimp	
	Silver Carp	Stone Moroko		Marmorkreb	Golden Mussel	
	Grass Carp	Zander			New Zealand Mud Snail	
	Black Carp	Wels Catfish			Hydrilla	
		Tench			Brazilian Elodea	
					Water Soldier	
					European Water Chestnut	
					Parrot Feather	
					Yellow Floating Heart	
					European Frogbit	
Subtotal	4	5	1	2	10	22
Proportion	0.18	0.23	0.05	0.09	0.45	1.00

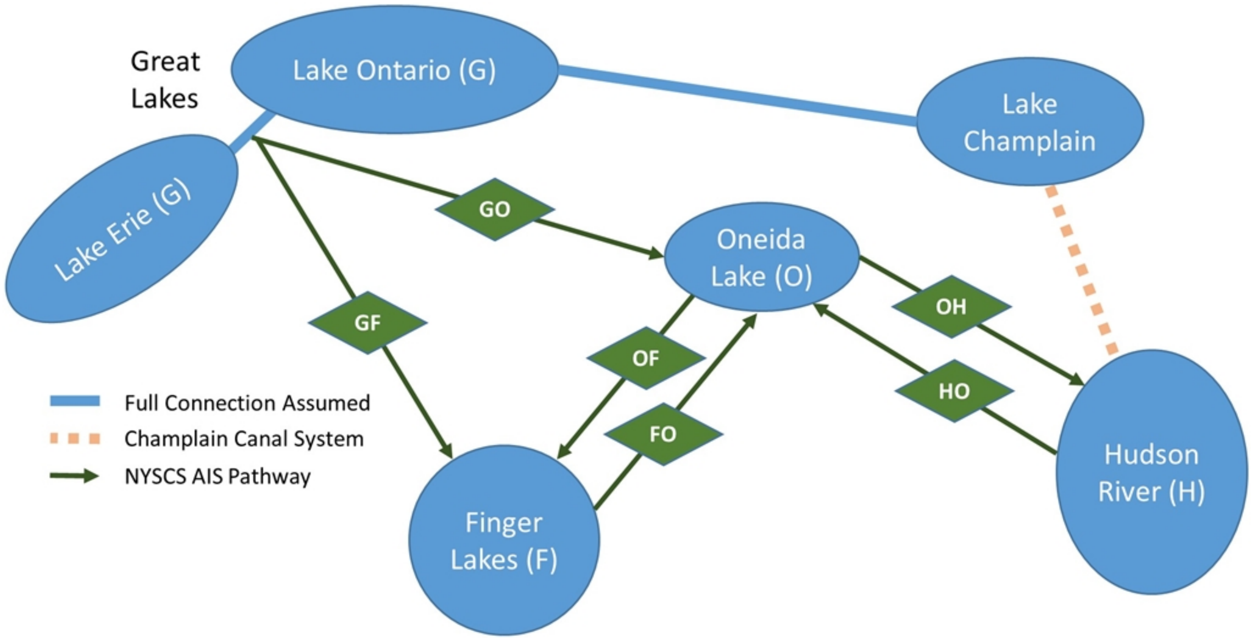

Figure 1. **Schematic of directional AIS connections that the networked deterrent is intended to stop, labeled with the initials of "from" and "to" waterbody (e.g., Great Lakes to Finger Lakes is GF).**

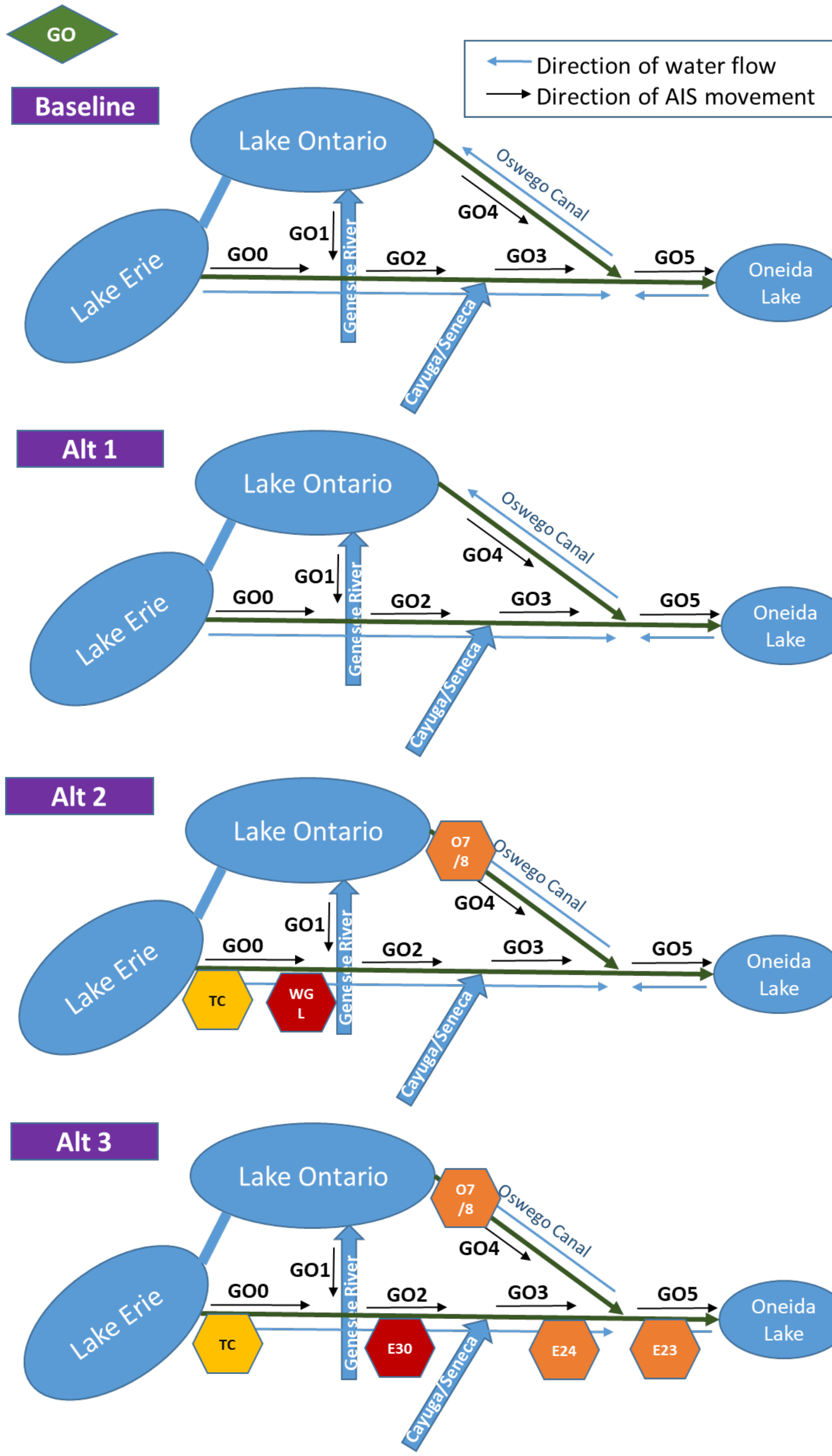

Figure 2. **Segmented pathway for AIS from Great Lakes to Oneida Lake (GO) under baseline and three networked deterrent alternatives. Deterrents are hexagons labeled with planned lock location (TC = Tonawanda Creek at Erie Canal entrance).**

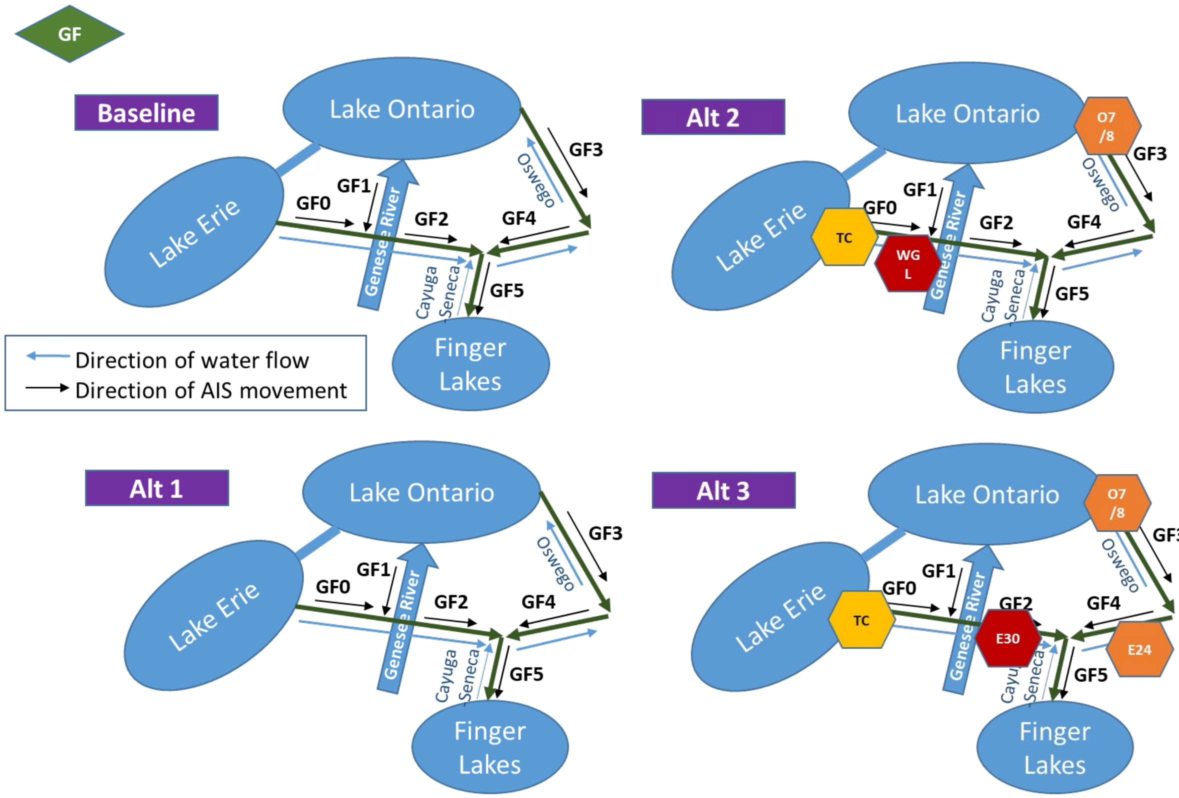

Figure 3. **Segmented pathway for AIS from Great Lakes to the Finger Lakes (GF) under baseline and three networked deterrent alternatives. Deterrents are hexagons labeled with planned lock location (TC = Tonawanda Creek at Erie Canal entrance).**

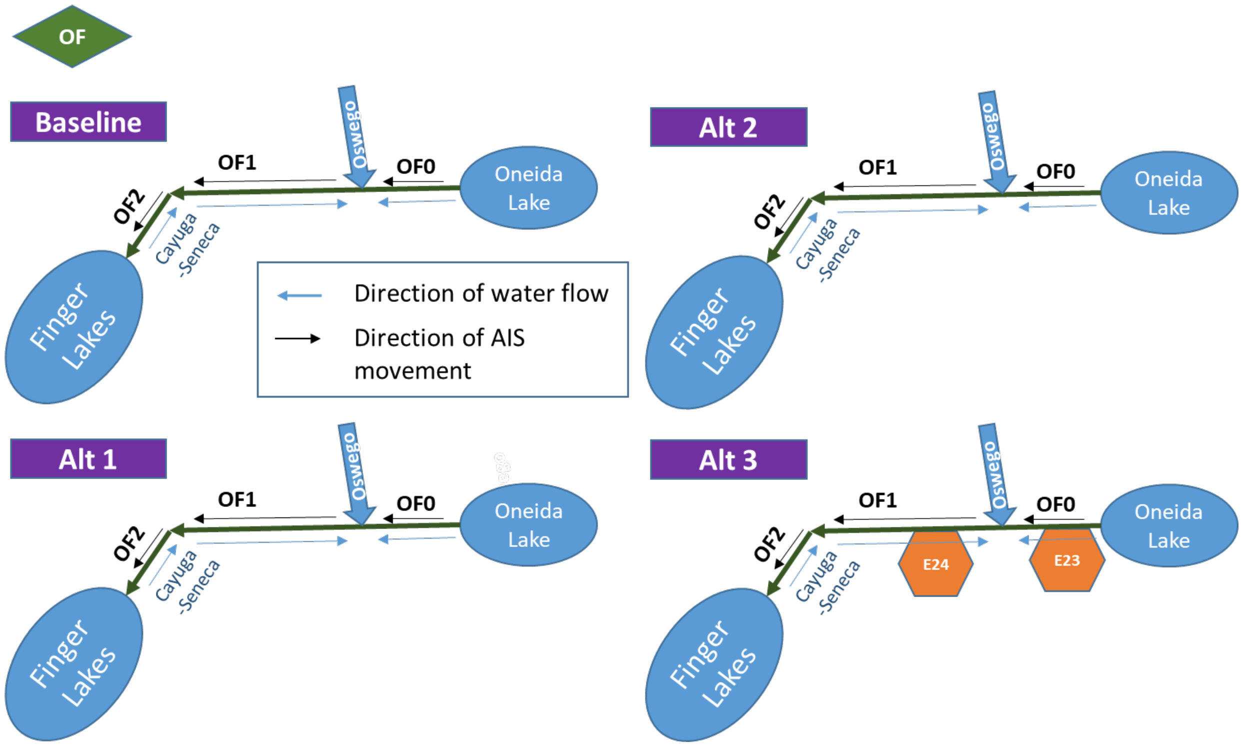

Figure 4. **Segmented pathway for AIS from Oneida Lake to the Finger Lakes (OF) under baseline and three networked deterrent alternatives. Deterrents are hexagons labeled with planned lock location.**

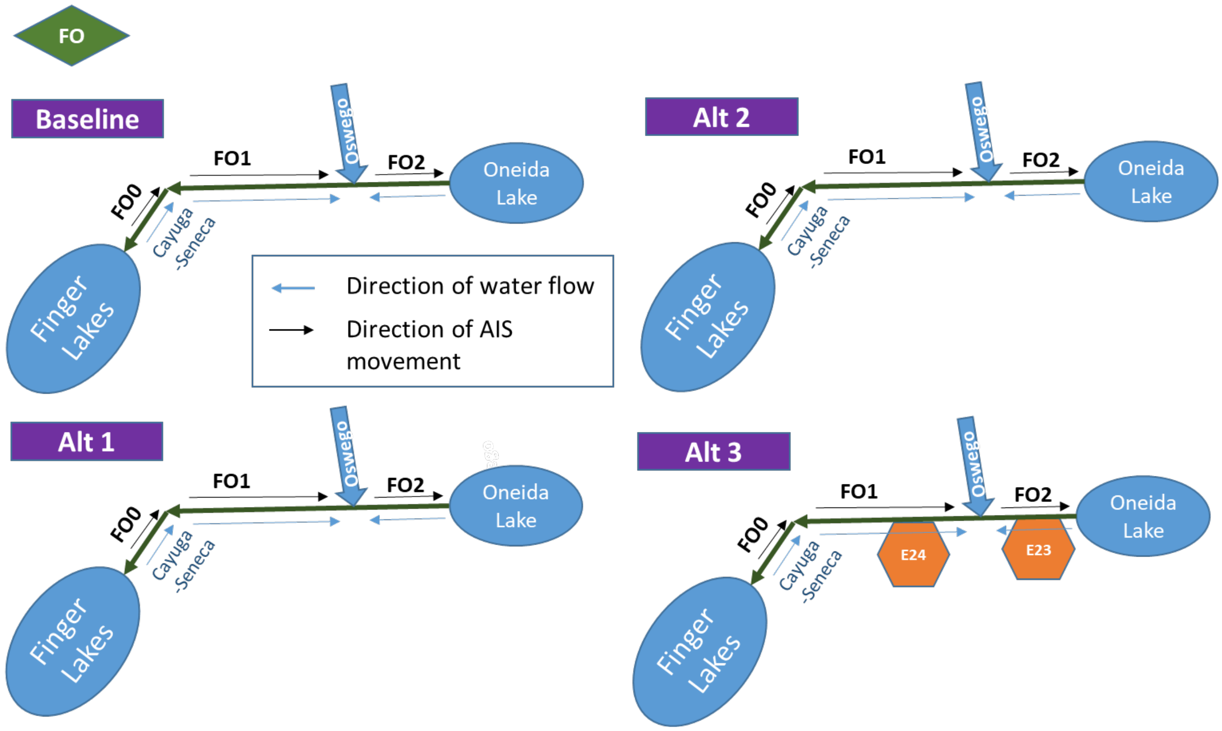

Figure 5. **Segmented pathway for AIS from the Finger Lakes to Oneida Lake (FO) under baseline and three networked deterrent alternatives. Deterrents are hexagons labeled with planned lock location.**

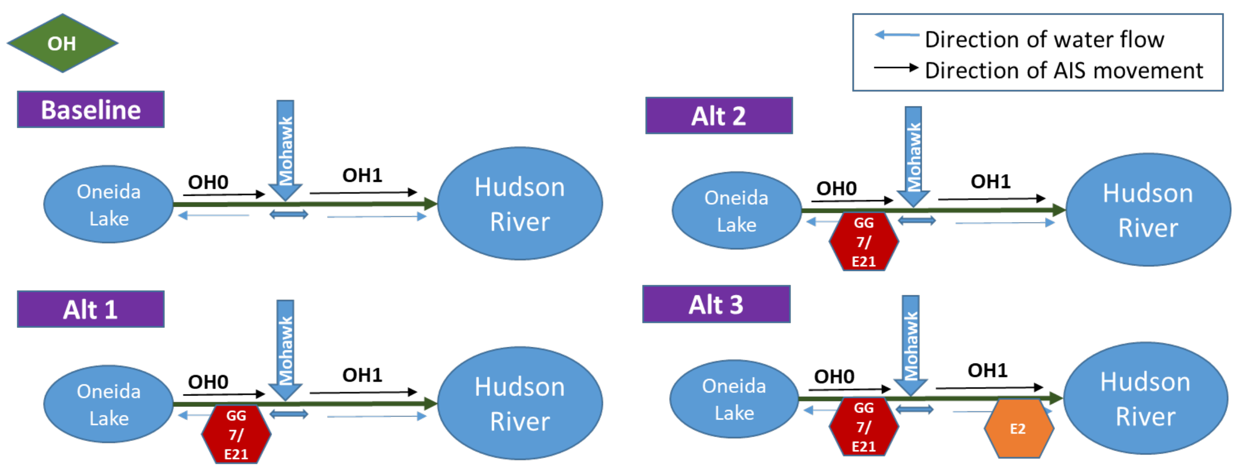

Figure 6. **Segmented pathway for AIS from Oneida Lake to the Hudson River (OH) under baseline and three networked deterrent alternatives. Deterrents are hexagons labeled with planned lock location.**

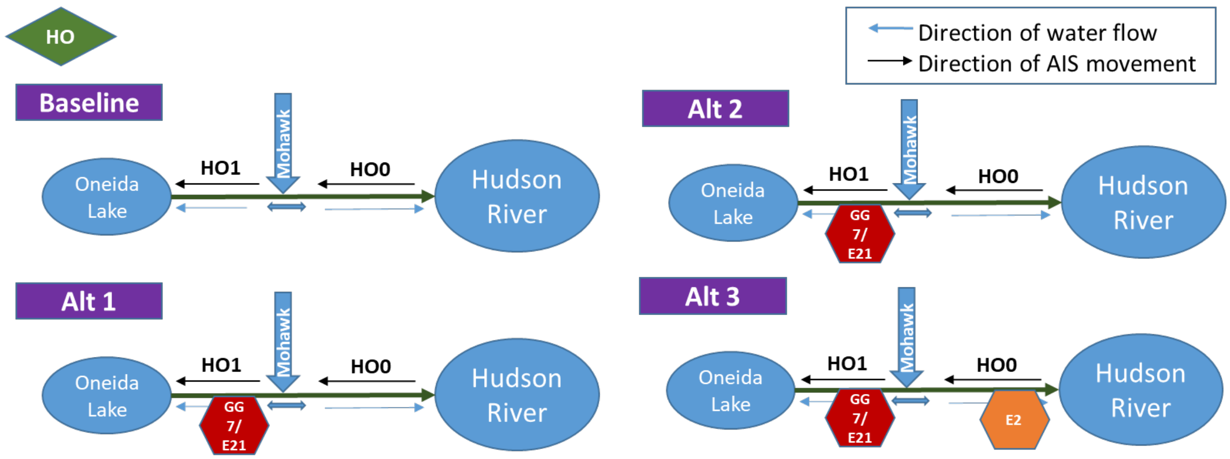

Figure 7. **Segmented pathway for AIS from the Hudson River to Oneida Lake (HO) under baseline and three networked deterrent alternatives. Deterrents are hexagons labeled with planned lock location.**

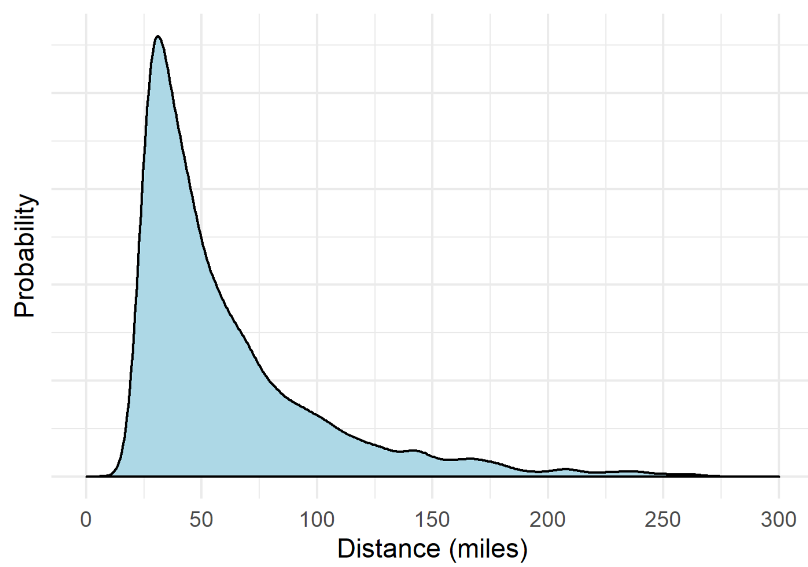

Figure 8. **Assumed distribution of travel distance for the 20-50% of crawling aquatic invasive species that move beyond a local area.**

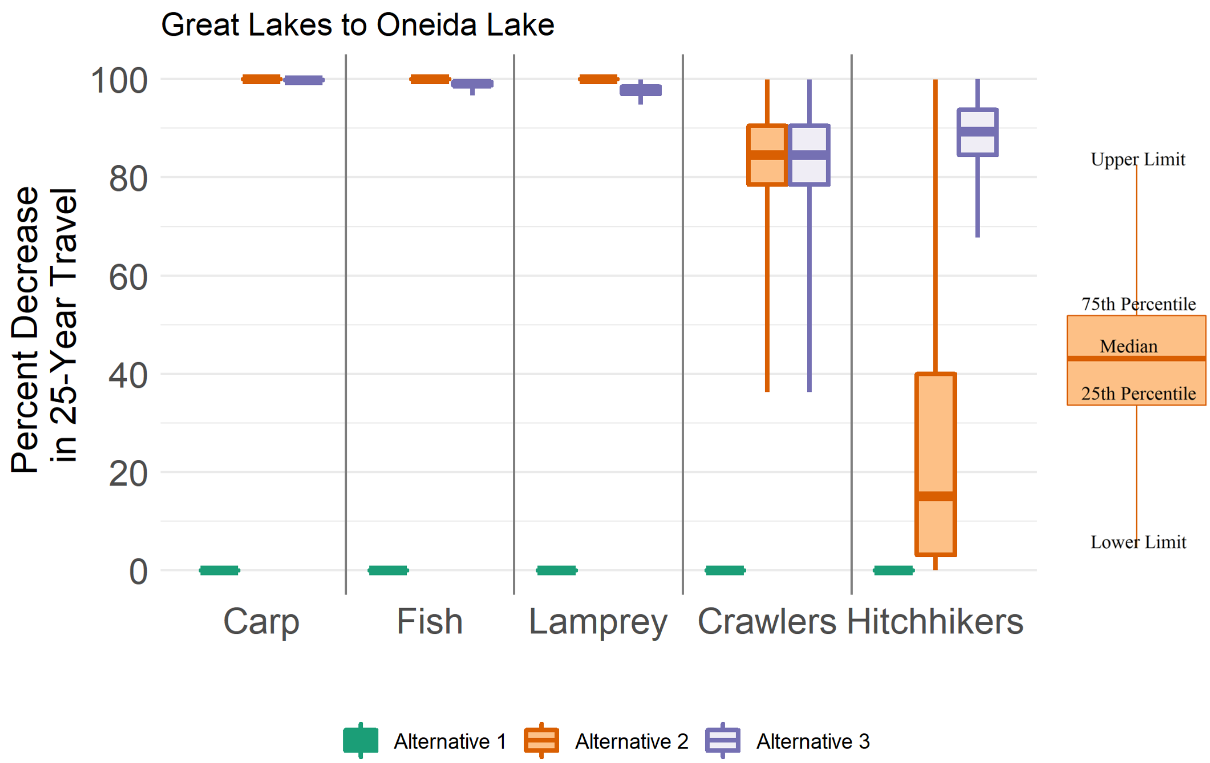

Figure 9. **Boxplot comparing effectiveness results for three networked deterrent alternatives for the Great Lakes to Oneida Lake pathway, for each modeled AIS group. The boxplots display the median result (50% greater and 50% less), the range with most probability (25th – 75th percentile box), and the full range of possible results based on the Monte Carlo bounding analysis.**

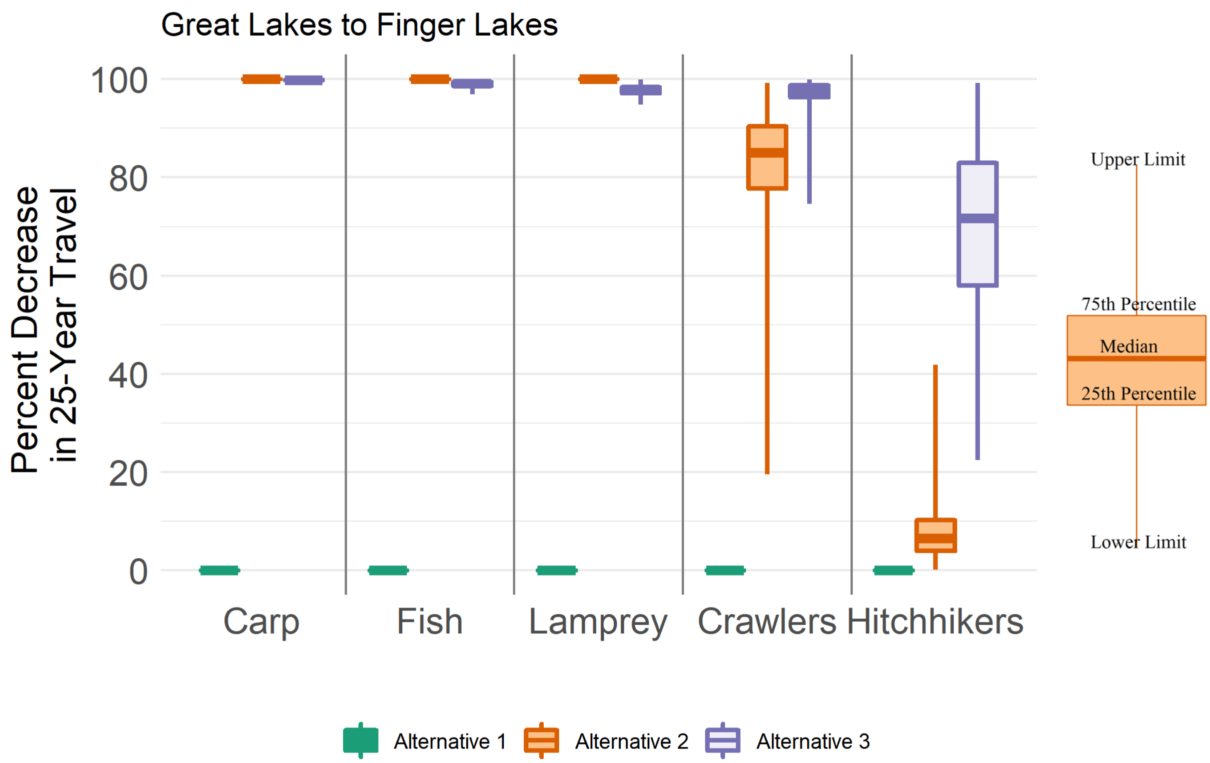

Figure 10. **Boxplot comparing effectiveness results for three networked deterrent alternatives for the Great Lakes to Finger Lakes pathway, for each modeled AIS group. The boxplots display the median result (50% greater and 50% less), the range with most probability (25th – 75th percentile box), and the full range of possible results based on the Monte Carlo bounding analysis.**

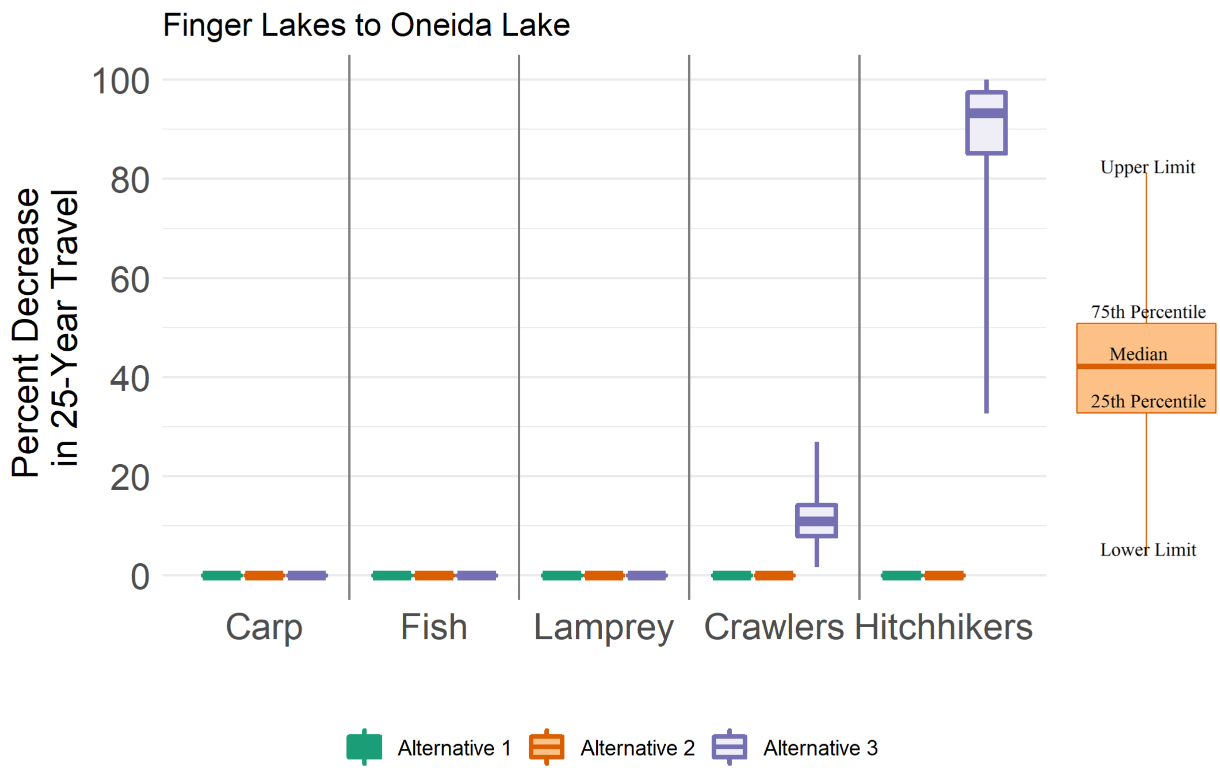

Figure 11. **Boxplot comparing effectiveness results for three networked deterrent alternatives for the Finger Lakes to Oneida Lake pathway, for each modeled AIS group. The boxplots display the median result (50% greater and 50% less), the range with most probability (25th – 75th percentile box), and the full range of possible results based on the Monte Carlo bounding analysis. NOTE: 0% Effectiveness for Asian carp along this route is not expected to be impactful because Asian carp are not currently resident in the Finger Lakes and would have 0% chance of reaching the Finger Lakes under Alternative 2).**

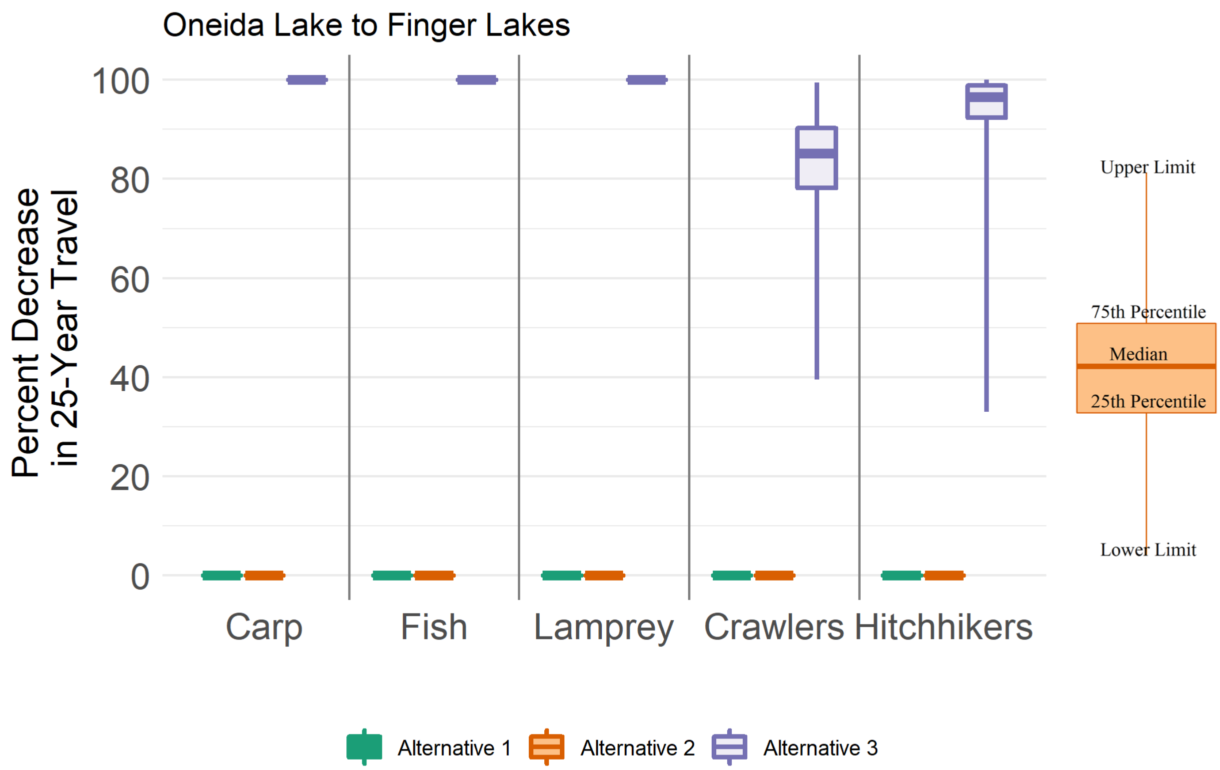

Figure 12. **Boxplot comparing effectiveness results for three networked deterrent alternatives for the Oneida Lake to Finger Lakes pathway, for each modeled AIS group. The boxplots display the median result (50% greater and 50% less), the range with most probability (25th – 75th percentile box), and the full range of possible results based on the Monte Carlo bounding analysis. NOTE: 0% Effectiveness for Asian carp along this route is not expected to be impactful because Asian carp are not currently resident in Oneida Lake and would have 0% chance of reaching Oneida Lake under Alternative 2).**

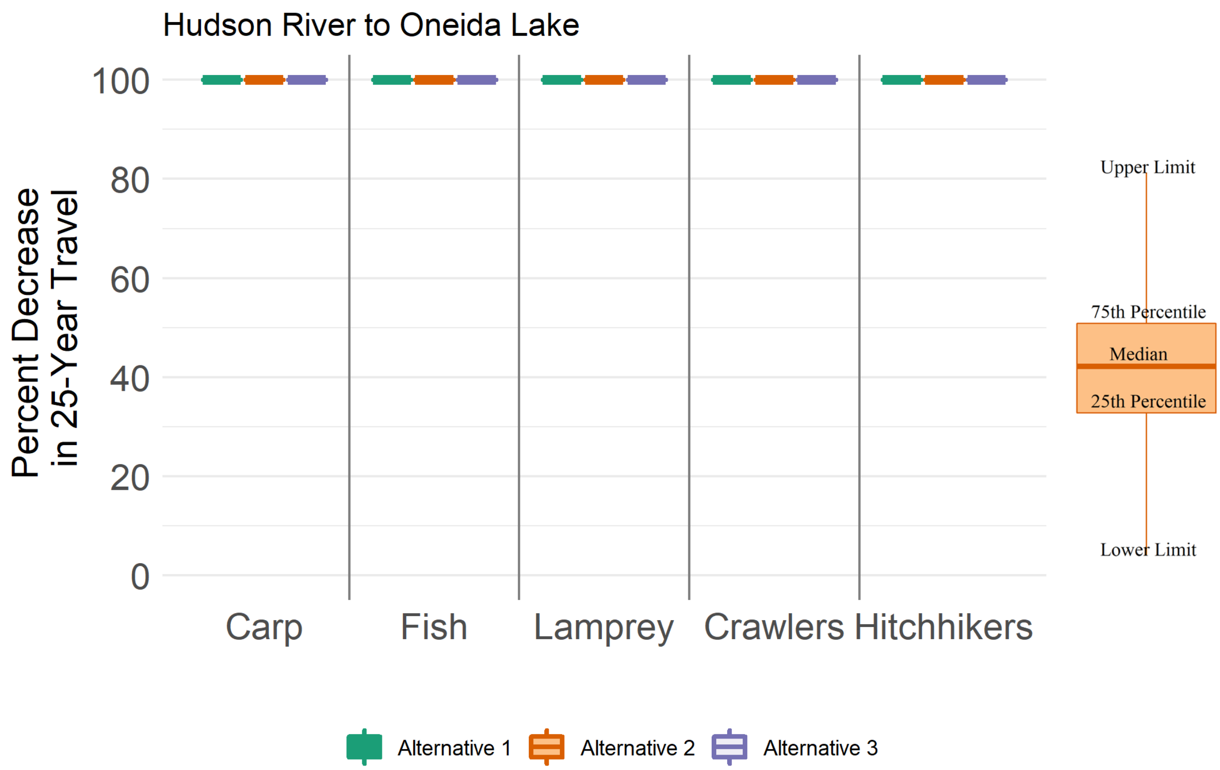

Figure 13. **Boxplot comparing effectiveness results for three networked deterrent alternatives for the Hudson River to Oneida Lake pathway, for each modeled AIS group. The boxplots display the median result (50% greater and 50% less), the range with most probability (25th – 75th percentile box), and the full range of possible results based on the Monte Carlo bounding analysis.**

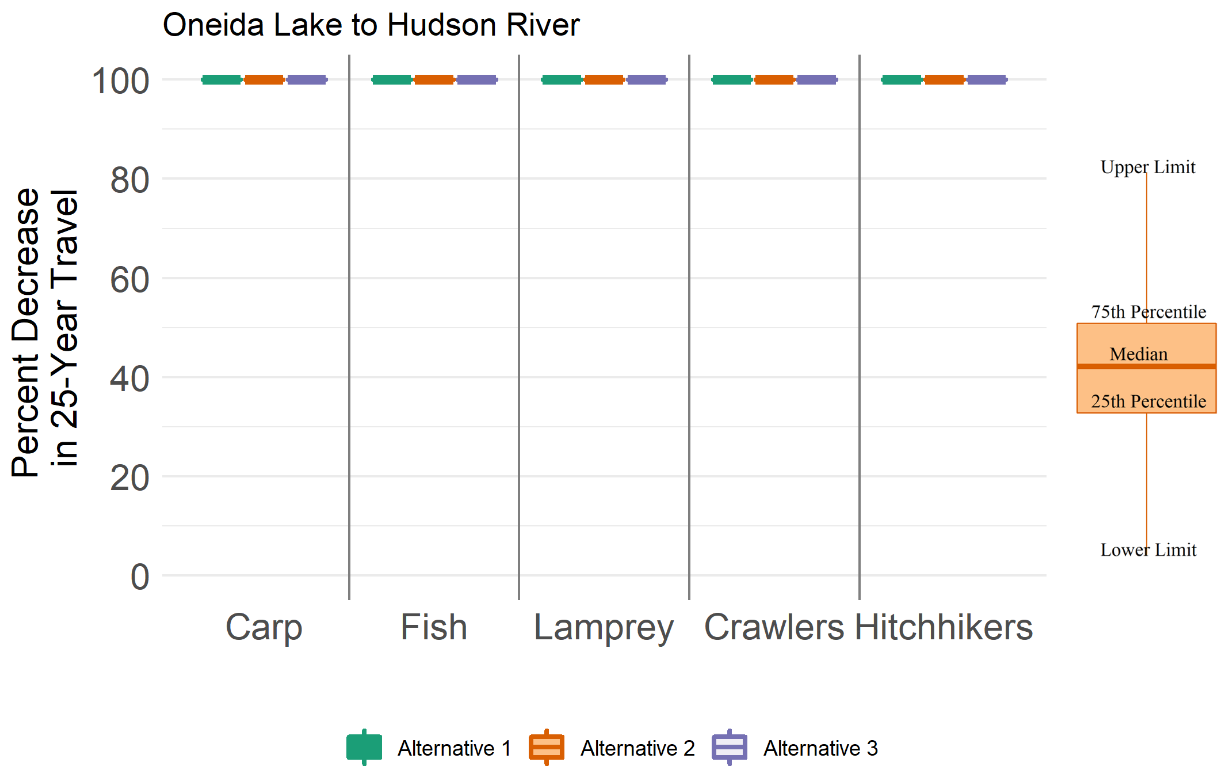

Figure 14. **Boxplot comparing effectiveness results for three networked deterrent alternatives for the Oneida Lake to Hudson River pathway, for each modeled AIS group. The boxplots display the median result (50% greater and 50% less), the range with most probability (25th – 75th percentile box), and the full range of possible results based on the Monte Carlo bounding analysis.**

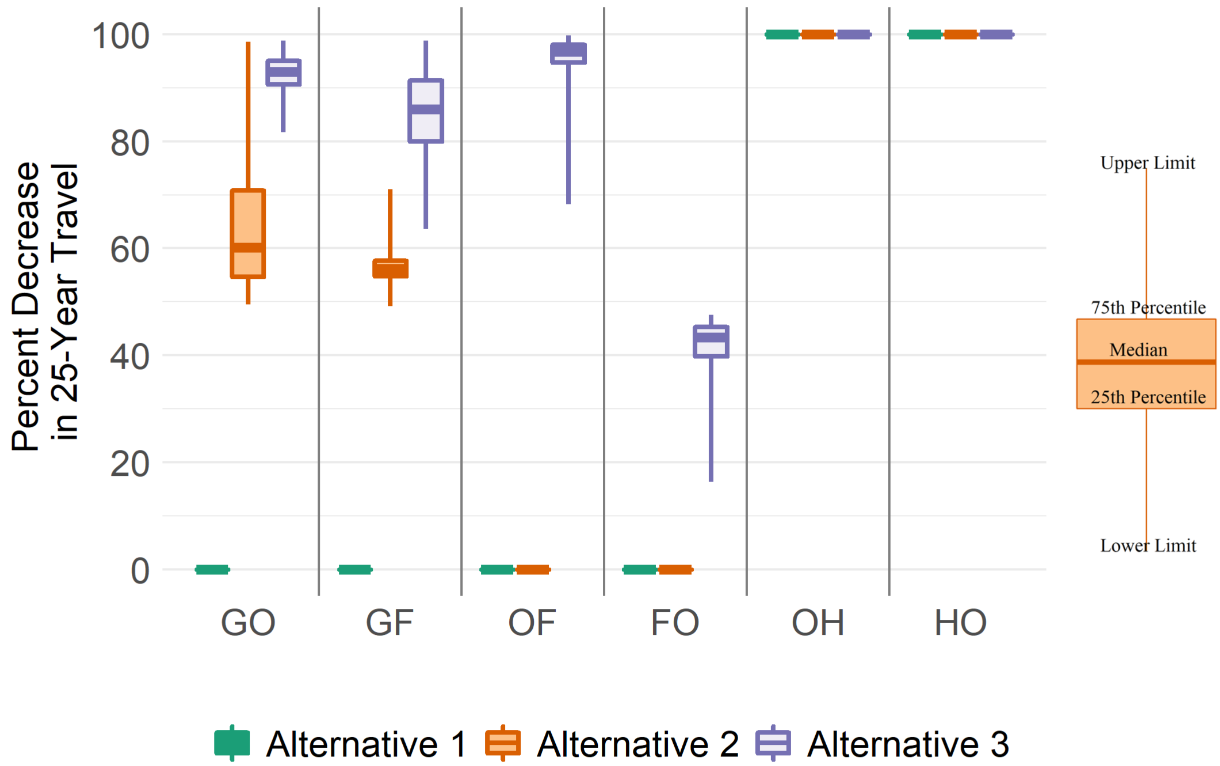

Figure 15. **Boxplot comparing effectiveness results for three networked deterrent alternatives for each pathway, combined across the modeled AIS groups using relative weightings. The boxplots display the median result (50% greater and 50% less), the range with most probability (25th – 75th percentile box), and the full range of possible results based on the Monte Carlo bounding analysis.**

APPENDIX D

Preliminary Cost Estimation

1. COST ESTIMATING INTRODUCTION AND METHODS

This appendix describes the methods and results of the planning-level cost evaluation for installation and operation of three networked alternatives for deterring AIS movement through the Erie Canal. Opinions of Probable Construction Costs (OPCC) were estimated for each of the three networked alternatives described in Section 4 of the report, which are:

- Alternative 1 – Protect the Hudson
- Alternative 2 – Watershed Divide
- Alternative 3 – Key Watershed Protection

Each alternative is described below by summarizing the necessary AIS deterrent measures and actions associated with each alternative and their associated costs. The total estimated cost for each alternative is summarized in Section 5 at the end of this appendix and those values are provided in the body of the report.

These cost estimates are intended for comparing the alternatives, and to identify a reasonable planning level capital cost of implementing these alternatives, including design, permitting, and construction costs. Additionally, annual operations and maintenance (O&M) costs are identified for each solution. This information provides a good basis for comparison and cost planning for the future. All costs are quoted in 2019 dollars calibrated for up-state New York.

1.1. Capital Cost

The OPCC estimates included the construction cost, plus a contingency, design and permitting cost. The cost estimates were largely based on applicable major features of similar constructed projects, or high-level quantity take-offs and estimation using senior level engineering judgement, with limited calls to vendors where applicable. This parametric approach was based on a review of available literature and similar or reference projects that were scaled and calibrated to these recommendations. Other feature costs were estimated based on quantity take-offs and unit pricing (such as soil or concrete fill). Provisions for redundant equipment were included for each alternative to assure no significant downtime would occur for canal usage. For example, where two pressure washers were required for a boat wash, the cost of a spare pressure washer is identified and included. Similarly, for larger equipment such as a boat lift, the cost of that item was inflated to include a critical spare parts package with its initial purchase.

The OPCC was developed to the American Association of Cost Engineers International (AACEI) CLASS 5 Cost Estimate, which is generally prepared for screening design concepts. The level of engineering to inform the CLASS 5 estimate is 0% to 2% complete with an accuracy of -50 to

+100 percent. The total project cost included a contingency cost of 20% of the total construction cost, and design/permitting costs of 30% of the total construction cost. The cost estimate included a range defined by three capital costs including the estimated cost, plus a low and high range cost. The low range was assumed to be 70% of the total estimated cost while the high is 150%. No costs were estimated for State Historic Preservation Office (SHPO) consultation or measures with any of the facilities. Those costs could be highly variable and would be addressed outside the scope of this study.

1.2. General O&M Cost

Operations and maintenance (O&M) costs were estimated for each alternative and AIS deterrent measure as a percentage of the capital cost. The percentages applied to each of the components are presented in Table 1. These costs included the general operating and maintenance of the facility and should be used for comparison purposes only.

Table 1. General annual maintenance cost basis.

Category	Percentage
Structural	5.0%
Mechanical/Electrical	15.0%

Note the 15% used for mechanical/electrical components related to about a 6-year replacement cycle of equipment (such as compressors, pressure washers, etc.). Labor costs associated with O&M of the facility were estimated assuming a full time equivalent (FTE) labor cost of $60/hr. This rate included all overhead and benefits, and was intended to represent a blend of supervisor and general laborer skill levels that would be required to operate boat lifts, boat cleaning equipment, and associated operational requirements.

1.3. Power and Fuel Costs

The power costs included the power to operate electrical or diesel fuel equipment over the operational period noted for each alternative. Power costs were estimated at $0.13/kWh, and diesel costs for self-powered equipment and trucking were estimated at $3.50 per gallon.

Sections 2 through 4 provide a description of the cost estimated developed for each alternative, with a brief introduction of the measures, actions, and assumptions, plus a more detailed spreadsheet that presents assumptions by line items. Section 5 provides an overall summary of costs for comparison.

2. COST ESTIMATE FOR NETWORKED ALTERNATIVE 1: PROTECT THE HUDSON

Networked Alternative 1 would hydrologically separate the Great Lakes and Hudson River basins with Hydrologic Separation at the summit of the Erie Canal and the divide between Mohawk and Oneida watersheds, as described in Section 4.1 and illustrated on Figure 1 (Figure 4-1 in the report and repeated below) with Measure A.

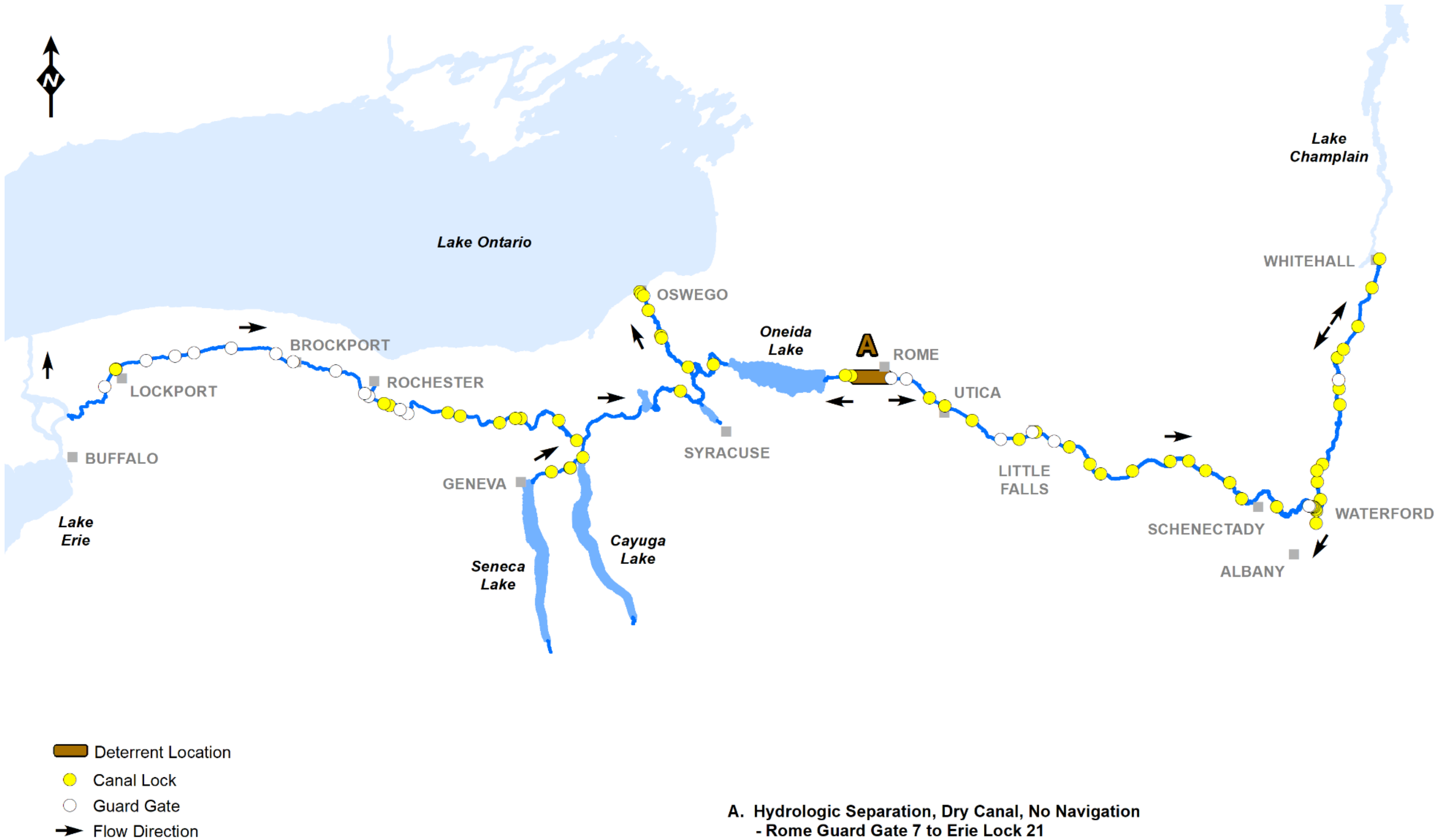

Figure 1. A schematic depicting deterrents and changing flow patterns associated with Alternative 1, Protect the Hudson (from body of report).

Figure 2 provides an enlarged view of Measure A – Hydrologic Separation at Rome, with the actions necessary to implement this measure.

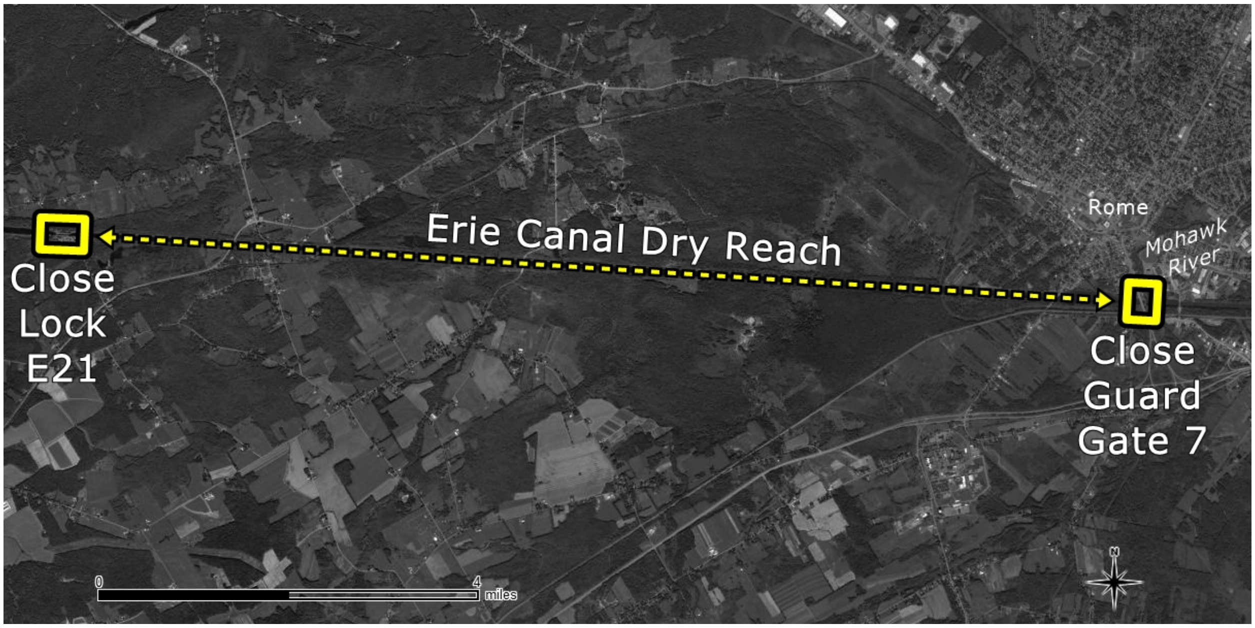

Figure 2. Measure A Definition, Hydrologic Separation at Rome with associated actions.

Required actions for estimating the cost of Measure A are:

1. Permanently Close Guard Gate G7.
2. Permanently Close Lock E21.
3. Block the Erie Canal and drain the Canal to provide impassable area for AIS between E21 and G7 (Pools Brook).

Additional detail to facilitate cost estimating for these actions is provided below and summarized in Table 2.

1. Permanently Close Guard Gate G7 (see Figures 3 and 4). This would block flow from the Mohawk River from flowing to the west via the Erie Canal. All flow from the upper Mohawk River that enters the Canal just east of Gate G7 would be diverted into the Erie Canal and associated drainage toward the Mohawk River to the south, and directed east toward the Hudson River.
   a. Close the gate.
   b. Close off area to flowing water to allow concrete work.

c. Install concrete seal blocks on the dewatered side of the gate to permanently prevent any seepage.

d. Decommission gate operating equipment.

   i. Since it would no longer be operated, decommissioning would avoid future operation and maintenance activities and costs for the gate.

Figure 3. Guard Gate G7 – West Rome Gate, view looking to the west.

2. Permanently Close Lock E21. Lock E21 would be permanently closed to stop all flow and leakage and associated navigation through the lock (Figures 4-7).

   a. Seal both the upstream and downstream miter gate joints with concrete.

      i. Center gap between the two gates.

      ii. Side seals along walls.

   b. Seal the fill and drain conduits with concrete.

   c. Decommission lock operating equipment.

d. Since it would no longer be operated, decommissioning would avoid future operation and maintenance activities and costs for the lock.

e. An alternate approach would be to close and seal the maintenance bulkheads upstream and downstream of the lock, in which case the lock gates could be abandoned, removed, or otherwise addressed.

Figure 4. Looking to the east from Lock E21 (towards GG7).

Figure 5. **Lock E21, looking towards the east (toward GG7).**

Figure 6. **View of lock operating equipment at Lock E21.**

Figure 7. View of Lock E21 miter gates.

3. Permanently Drain the Erie Canal between E21 and G7 (Pools Brook). Goal is to create a completely dry reach to discourage invertebrates from crawling between watersheds.
    a. Length is about 8.25 miles. Ideal goal would be to drain and dry, or fill, a one-mile length of Canal to eliminate the AIS vector. However, there are creeks flowing from the north towards the south that intersect the Canal. To estimate this option reasonably we would need more information about drainage into the pool, seepage, etc., and that level of effort is beyond the current scope.
    b. To estimate costs for this AIS Measure, we assumed filling 1,000 feet of Canal adjacent to the west side of G7 towards E21. This is a narrow section of Canal before it widens out to the west into Pools Brook (see Figure 8), so we feel this was a reasonable assumption. We also assumed the remainder of the Canal would self-drain.
        i. Fill with graded soil to create solid driving foundation that is impermeable along 1,000 feet of length.
        ii. Provide impermeable geomembrane barrier at both ends to seal flow through the fill. This is conservative with the gate seal.

1. Average Width (from Google Map measurement) is approximately 150 feet.
2. Average Depth, by definition 14' minimum. Assume 16' for cost estimate, and verify later if carried forward.
3. Volume of fill is roughly calculated in Table 2 assuming a trapezoidal cross section and adding 20%.

iii. Assume Canal can drain on its own. Alternate would be to consider excavating a drain or pumping the Canal. This could be refined further in consultation with NYPA if this measure were to be carried forward.

iv. In Summary, the fill length, drains, and optimization of this alternative will require further discussions and preliminary design efforts, but this approach provides a reasonable first estimate of the measure and associated issues.

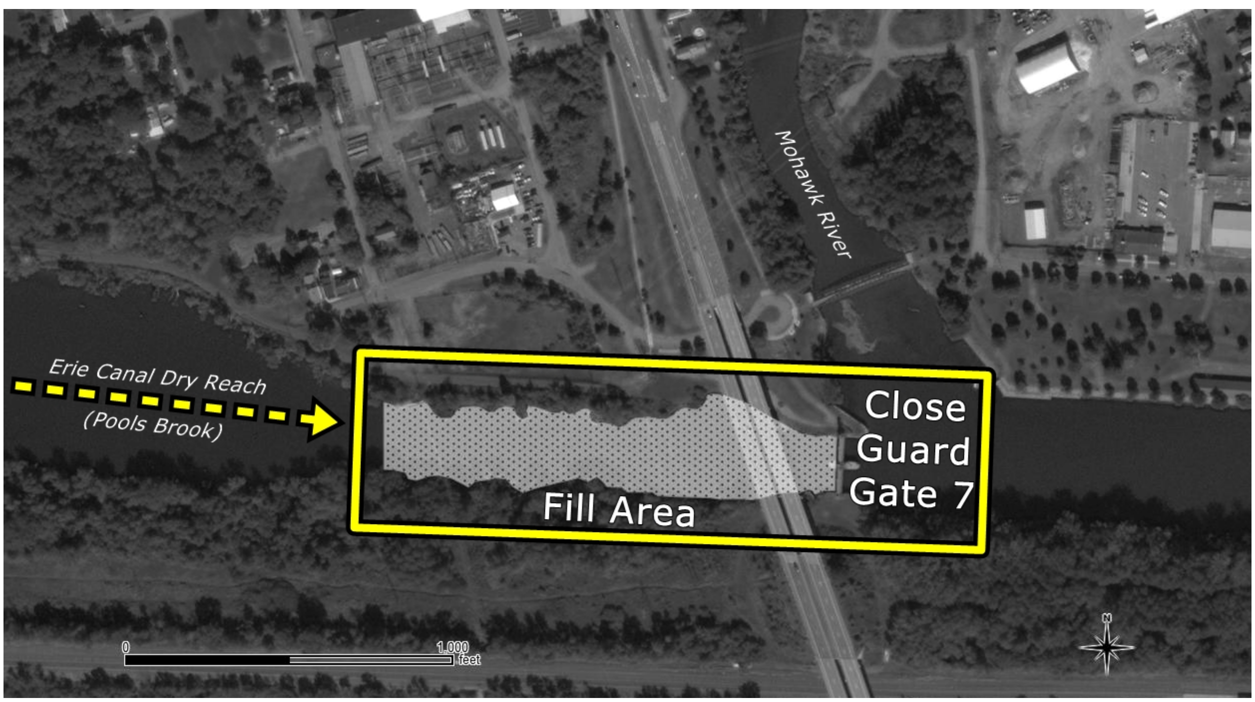

Figure 8. View of Gate G7 to the west towards Pools Brook, showing length of fill area of ~1,000 feet x ~150 feet (as per Google Maps).

2.1. Alternative 1 Cost Summary for Measure A

Table 2 provides a summary of the assumptions used for Measure A, which is also the single measure that also defines Alternative 1.

Table 2. Measure A (Alternative 1) Opinion of Probable Construction Cost.

A. Isolate Canal between Gate G7 and Lock E21							
ITEM	**DESCRIPTION**	**QUANTITY**	**UNIT**	**UNIT PRICE**		**TOTAL**	
1	*Mob and Demob*	*1*	*LS*	*$*	*152,000*	*$*	*152,000*
2	*Water Handling and Temporary Seals @ Gate G7*	*1*	*LS*	*$*	*60,000*	*$*	*60,000*
3	*Permanent Concrete Seals, (2 x 16'h + 40'w) x 2 sets x 3' x 3'*	*48*	*CY*	*$*	*2,000*	*$*	*96,000*
4	*Decommission Equipment @ Gate G7*	*1*	*LS*	*$*	*30,000*	*$*	*30,000*
5	*Water Handling and Temporary Seals @ Lock E21*	*1*	*LS*	*$*	*80,000*	*$*	*80,000*
6	*Permanent Concrete Seals, (2 x 25'h +30'w) x 2 sets x 3' x 3'*	*53*	*CY*	*$*	*2,000*	*$*	*106,667*
7	*Permanent Concrete Seals for Fill/Drains, (4 ea x 20 lf x 16 sf)*	*47*	*CY*	*$*	*1,000*	*$*	*47,407*
8	*Decommission Equipment @ Lock E21*	*1*	*LS*	*$*	*40,000*	*$*	*40,000*
9	*Fill 1000' of Canal (100' w x 20' d)*	*74,000*	*CY*	*$*	*12*	*$*	*888,000*
10	*Geomembrane at each end of Fill*	*667*	*SY*	*$*	*25*	*$*	*16,667*
	CONSTRUCTION COST (rounded to $100,000)					**$**	**1,500,000**
	Contingency (rounded to nearest $100,000)				**20%**	**$**	**300,000**
	Design and Permitting (rounded to nearest $100,000)				**30%**	**$**	**500,000**
	TOTAL COST - 2019 USD (rounded to nearest $100,000)					**$**	**2,300,000**
	Low Range, minus 30% (rounded to nearest $100,000)					**$**	**1,600,000**
	High Range, plus 50% (rounded to nearest $100,000)					**$**	**3,500,000**

Table 3 provides a summary of the estimated Operations and Maintenance (O&M) costs for Measure A (Alternative 1). This measure requires no labor or equipment operations, but a 5% allowance of the capital cost was assumed to monitor and inspect the gate, locks, and fill. As noted above, this cost should be further vetted and developed with NYPA.

Table 3. Measure A (Alternative 1) estimated O&M costs.

Maintenance Cost as a Percentage of Capital Cost			**%**	**O&M Cost**	
Structural (rounded to nearest $1,000)	$	266,741	5.0%	$	13,000
Mech/Elec (rounded to nearest $1,000)	$	-	15.0%	$	-
Total (rounded to nearest $1,000)				**$**	**13,000**

2.2. Alternative 1 Total Cost Summary

Table 4 provides a summary of all Alternative 1 measures, which is simply Measure A.

Table 4. Alternative 1 cost summary.

Measure	Capital Cost	Capital Cost Low Range	Capital Cost High Range	Operating Cost	Maintenance Cost	Total O&M Cost
A	$ 2,300,000	$ 1,600,000	$ 3,500,000	$ -	$ 13,000	$ 13,000
Total	**$ 2,300,000**	**$ 1,600,000**	**$ 3,500,000**	**$ -**	**$ 13,000**	**$ 13,000**

2.3. Avoided Cost Discussion for Measure A

This alternative would change the operational and maintenance requirements for the closed locks, which would have an associated avoided cost to the Canal Corporation. These costs would at a minimum likely include:

- Not having to rebuild Lock E21 at some point.
- Not having to staff Lock E21 and Gate G7.
- Avoiding pumping out Lock E21 every 10 years.
- Not having to rebuild Guard Gate G7 at some point.
- Reduced cost to maintain adjacent DOT bridge.

It was not within the scope of this study to estimate these costs, but simply to identify avoided costs as they could be significant.

3. Cost Estimate for Networked Alternative 2: Watershed Divide

The objective of Networked Alternative 2 was to diminish the probability of AIS using Erie Canal for eastward passage from Lake Erie and Lake Ontario, westward passage from the Hudson River, as well as containing any AIS within the three central watersheds: Finger Lakes, Oneida, and Oswego as illustrated with Figure 9 (Figure 4-3 in the report and repeated below). This alternative is composed of the following measures:

1. Measure A – Hydrologic Separation at Rome,
2. Measure B – Lock Closure with Boat Lift/Wash at Oswego, Locks O7-O8,
3. Measure C – Bio Acoustic Fish Fence/Synchronized High Intensity Light System (BAFF/SILAS) at Tonawanda Creek,
4. Measure D – Hydrologic Separation, No Navigation at West Guard Lock in Rochester.

The development of cost estimates for each measure is described further in Sections 3.1 – 3.4, and a total cost summary of Alternative 2 is provided in Section 3.5.

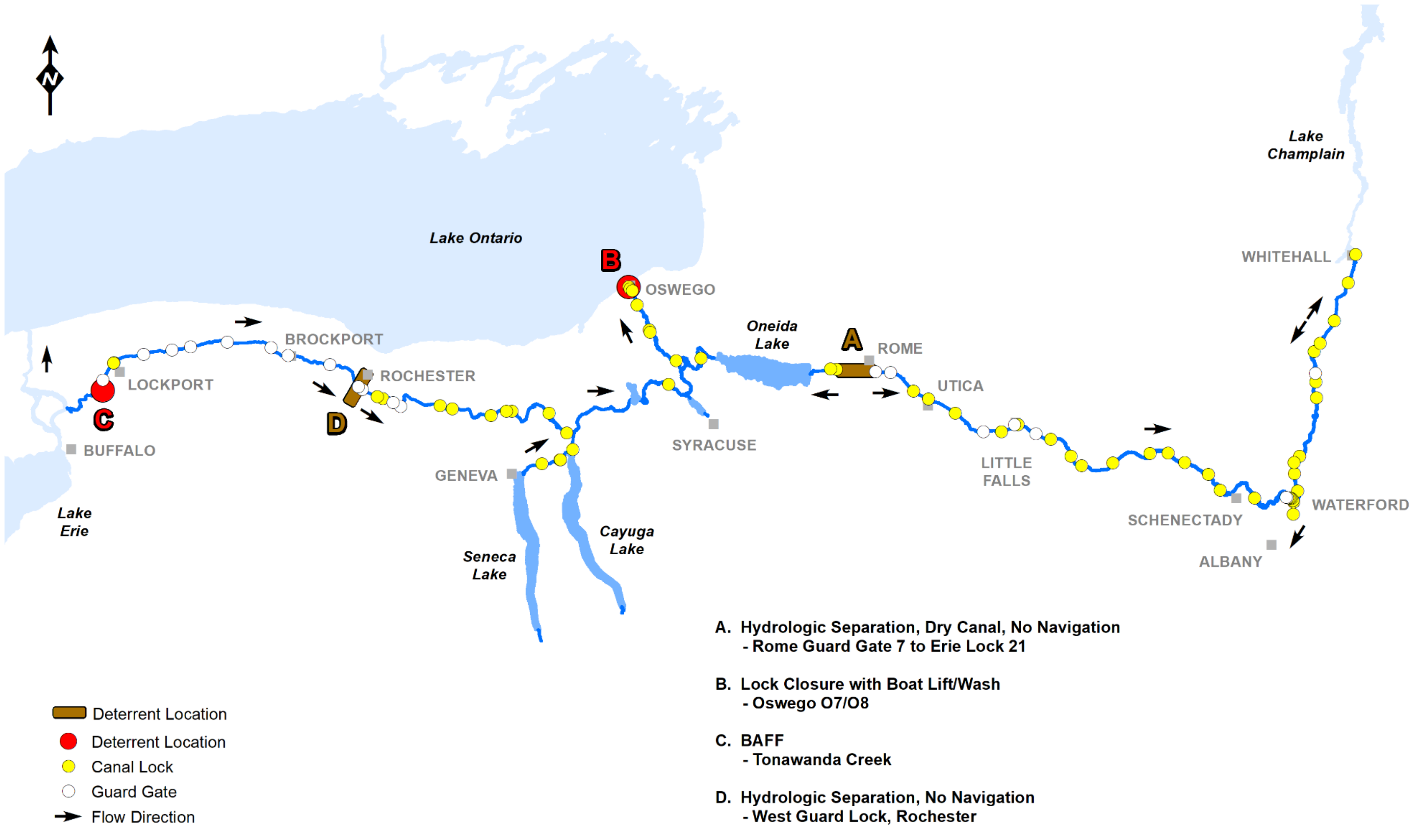

Figure 9. A schematic depicting deterrents and changing flow patterns associated with Alternative 2, The Watershed Divide (from body of report).

3.1. Cost Summary for Measure A – Hydrologic Separation at Rome

Required actions for estimating the cost of Measure A are described above in Section 2.

3.2. Cost Summary for Measure B – Lock Closure with Boat Lift/Wash at Oswego, Locks O7-O8

Figure 10 provides an enlarged view of Measure B – Lock Closure with Boat Lift/Wash at Oswego, Locks O7-O8. Locks O7 and O8 are linked together by a Canal along the Oswego River, so closing the lock effectively means closing both locks, and transporting boats around the two locks. The transport distance could be over the locks or adjacent to the locks, and distance is approximately 3,000 feet. The transport of boats was assumed to be achieved with a tractor/low boy assembly over local roads and 1,200 feet of new roadway adjacent to the canal. Figures 11-12 provide aerial views of the area for further clarification on the existing configuration.

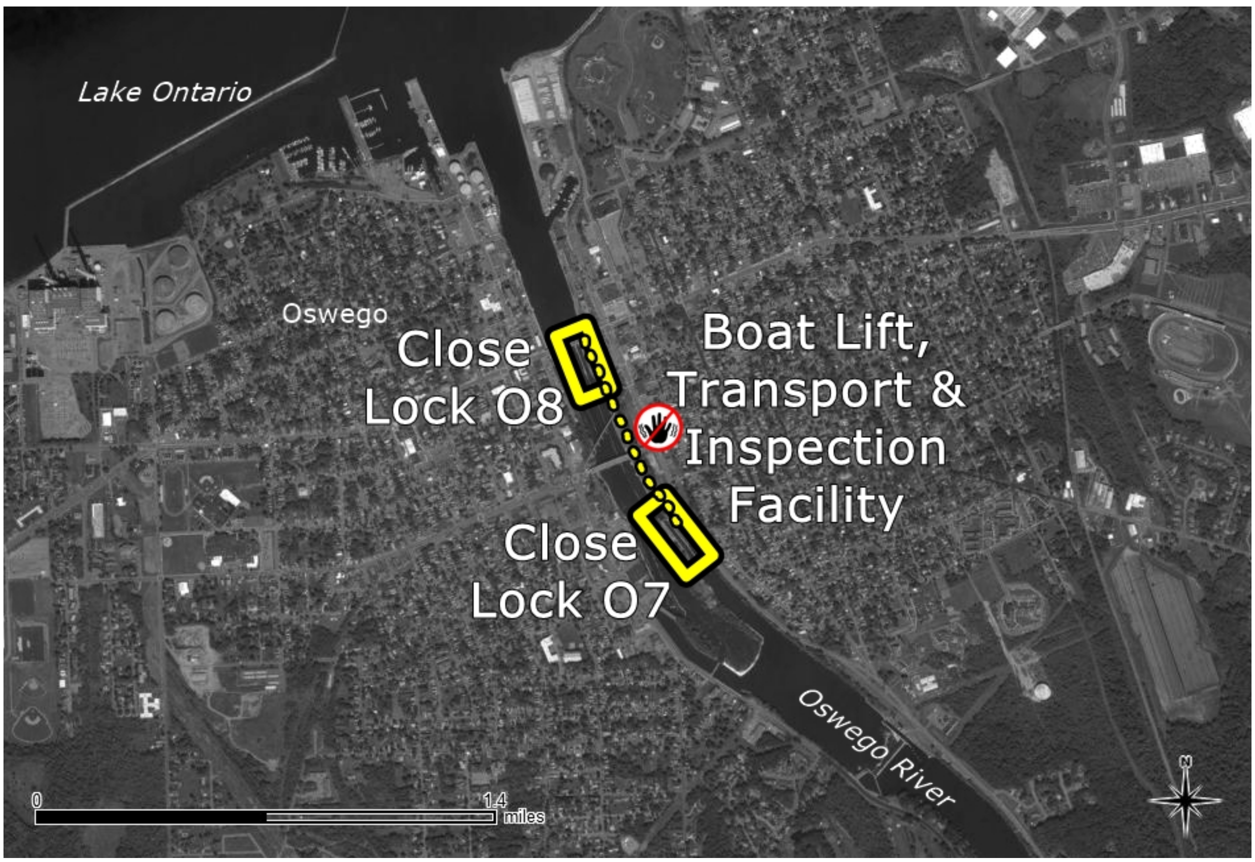

Figure 10. Measure B Definition, Hydrologic Separation at Rome with associated actions.

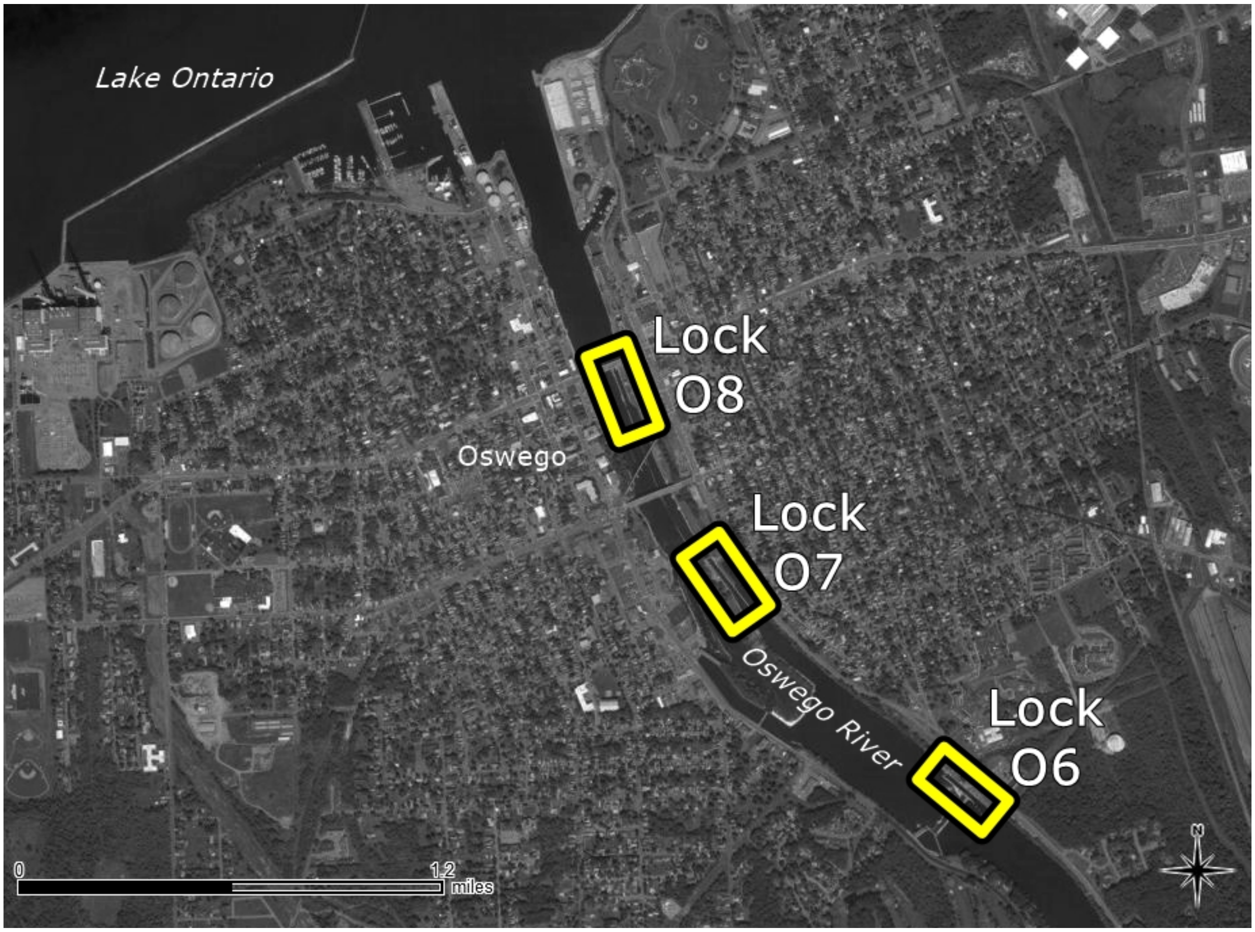

Figure 11. Aerial view of Locks O8, O7, and O6 to illustrate how locks operate in series.

Required actions for estimating the cost of Measure B are:

1. Permanently Close Locks O8 and O7. These measures have similar assumption as described for the Lock E21 closure in Alternative 1 (see Section 2.1).
    a. Essentially both locks must be closed as they operate in series.
    b. Seal all four lock miter gates with concrete.
    c. Seal all lock drain/fill conduits.
    d. Decommission the lock mechanical equipment.
    e. An alternate approach would be to close and seal the maintenance bulkheads upstream and downstream of the lock, in which case the lock gates could be abandoned, removed, or otherwise addressed.
    f. Additional detail on the cost estimate is provided in Table 6.

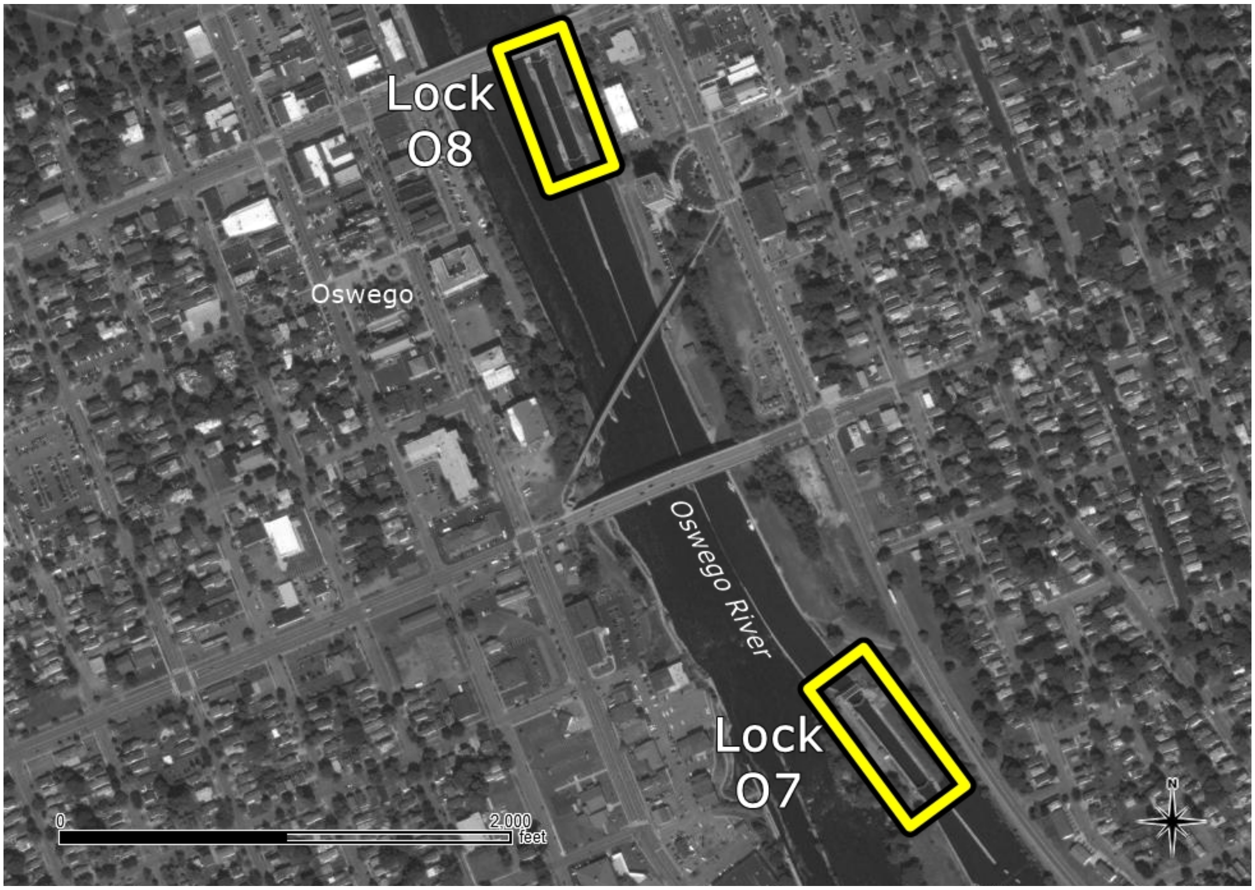

Figure 12. Enlarged aerial view of Locks O8 and O7.

2. Add two boat lifts, inspection, portable wash station, and tractor/low boy assembly to transport boats from the downstream side of Lock 08 to the upstream side of O7. The goal would be to remove boats from the Canal, inspect them for aquatic invasive species presence, pressure wash the boats over a contained basin with hot water, flush and drain engine cooling systems, ballast tanks, bait boxes, decks, and equipment, and return the boats back to the Canal on the other side of the locks via overland cart or rail. Items include the following, and more detail on the estimate is provided in Table 6.
    a. Provide equipment for mooring on either side of the closed lock, to facilitate vessel occupants' egress prior to the inspection and reboarding after inspection/treatment.
    b. Boat lift equipment, assuming 40-ton capacity wheeled motorized boat sling lift at each end (e.g., downstream of Lock O8 and upstream of Lock O7).
    c. Boat lift frame assembly for the vessels:
        i. Would need to accommodate the full range of vessel sizes and motorized drive systems up to 60 feet long and 40 tons.

ii. Assume assembly rails to be placed adjacent to the locks or over the locks.

iii. Allowance for sitework to provide boat lift for boat lift frame.

d. Variables for the boat wash design would include:

i. Acceptable delay for boaters going through the process. This would be an important issue that would require further analysis outside of this study to determine when peak loadings will occur, what is viewed as an "acceptable delay" given the proposed boat cleaning measures, etc.

ii. Number of personnel available and number of simultaneous hot water pressure wash systems.

iii. Boat lift / inspection / wash processing time.

iv. Clean water supply for the boat wash.

v. Water heating equipment capacity.

vi. Wastewater retention and treatment prior to release, or assume wash water gets directed to the same side of the wash area as removed.

vii. And other ancillary facilities.

e. Labor for operating the boat inspection/wash station. Initial estimates for labor were based on limited and preliminary boat data provided by the Canal Corporation. The first three columns in Table 5 summarize preliminary data of actual lockages per year by vessel size based on 2016 data. The last two columns are an estimate of what could be expected annually, and a daily peak value. Daily peak values were based on taking the total annual number over an average peak 3-month period to be conservative (max annual / 3 months / 30d / mon = peak day). This limited analysis provides some backup to the assumptions for staffing. Even if the peak daily number were triple what this estimate shows, the maximum number of boats/day would be relatively low and manageable.

Table 5. Boat lockage data at O7 and O8.

Boat Length (feet)	# Boats Passing O7 per year	# Boats Passing O8 per year	Assumed Max Yearly Value	Assumed Max Peak # Boats per Day
>16	12	13	20	1
16-26	166	175	200	3
26-40	447	453	500	6
40-65	416	417	450	5
Unknown	190	188	200	3

f. Operating hours. As per NYPA's Canal web site, operating hours for Locks O7/O8 are as follows:

   i. Navigation Season is May 17-Oct 16, 7:00 am – 5:00 pm (10 hrs/day).

   ii. Extended hours are provided from May 16 – September 11 from 7:00 am – 10:00 pm (15 hrs/day).

g. Personnel: the following assumptions were utilized for personnel, with the intent to be somewhat conservative from a personnel safety perspective. Based on the low number of boats, staffing levels may be able to be reduced.

   i. 2 crews of 2 washers.

   ii. 2 inspectors/lift operators.

   iii. FTE cost of labor assumed at $60/hr.

   iv. Additional detail is provided in the summary worksheet below.

h. Land costs. Assume this is Canal Corporation land, and no costs are needed for land ownership or access easements.

3. Close Locks O7-O8 to commercial navigation.

   a. This measure was noted based on boat lift and rail capacity limitations.

   b. No costs are assumed for this measure.

3.2.1. Cost Summary for Measure B

Table 6 provides a summary of the assumptions used for Measure B, with additional detail from the higher-level assumptions noted above. Note the boat wash program is costed to represent a portable system as a pilot program. Additionally, a more robust conceptual design considering all variable and boat processing time, labor levels, etc. is recommended to better refine the cost estimates. Attachment 1 at the end of this appendix provides a preliminary cost analysis using a more permanent boat lift/inspection/wash approach.

Table 6. Measure B Opinion of Probable Construction Cost.

B Lock Closure and Boat Lift / Wash (Oswego O7 / O8)					
ITEM	**DESCRIPTION**	**QUANTITY**	**UNIT**	**UNIT PRICE**	**TOTAL**
1	*Mob and Demob*	*1*	*LS*	*$ 210,000*	*$ 210,000*
2	*Water Handling and Temporary Seals @ Lock 07*	*1*	*LS*	*$ 60,000*	*$ 60,000*
3	*Permanent Concrete Seals, (2 x 15'h + 50'w) x 2 sets x 3' x 3'*	*53*	*CY*	*$ 2,000*	*$ 106,667*
4	*Decommission Equipment @ Lock O7*	*1*	*LS*	*$ 30,000*	*$ 30,000*
5	*Water Handling and Temporary Seals @ Lock O8*	*1*	*LS*	*$ 60,000*	*$ 60,000*
6	*Permanent Concrete Seals, (2 x 11'h + 50'w) x 2 sets x 3' x 3'*	*49*	*CY*	*$ 2,000*	*$ 98,667*
7	*Decommission Equipment @ Lock O8*	*1*	*LS*	*$ 30,000*	*$ 30,000*
8	*Permanent Concrete Seals, (2 x 25'h +30'w) x 2 sets x 3' x 3'*	*47*	*CY*	*$ 1,000*	*$ 47,407*
9	*Dewater Canal (7 days at 4 cfs)*	*1*	*LS*	*$ 10,000*	*$ 10,000*
10	*Grading and Earthwork*	*300*	*CY*	*$ 20*	*$ 6,000*
11	*General Site Improvments (Access Road & Walkways*	*1*	*LS*	*$ 200,000*	*$ 200,000*
12	*Portable Boat Cleaning Basin*	*1*	*LS*	*$ 20,000*	*$ 20,000*
13	*Portable Boat Cleaning Equipment (2 x 4gpm pressure washers with water heater)*	*1*	*LS*	*$ 150,000*	*$ 150,000*
14	*Spare Cleaning Equipment (pumps, wands, heater, generator parts)*	*1*	*LS*	*$ 15,000*	*$ 15,000*
15	*Boat Hoist Support Frame*	*2*	*EA*	*$ 60,000*	*$ 120,000*
16	*Boat Hoist Mechanical (40 tn Sling Lift)*	*2*	*EA*	*$ 300,000*	*$ 600,000*
17	*Semi-Tractor and 40 tn Lowboy*	*1*	*EA*	*$ 130,000*	*$ 130,000*
18	*Lowboy Sling Cradle*	*1*	*EA*	*600*	*$ 600*
19	*Spare Transport Parts (motors, filters, slings, bearings, wheels, cable)*	*1*	*LS*	*$ 30,000*	*$ 30,000*
20	*Temp Floating Dock (2 x 100'l x 8'w)*	*1,600*	*SF*	*35*	*$ 56,000*
21	*Road Improvements for Truck Access*	*1,200*	*FT*	*$ 100*	*$ 120,000*
	CONSTRUCTION COST (rounded to nearest $100,000)				**$ 2,100,000**
	Contingency (rounded to nearest $100,000)			**20%**	**$ 400,000**
	Design and Permitting (rounded to nearest $100,000)			**30%**	**$ 600,000**
	TOTAL COST - 2019 USD (rounded to nearest $100,000)				**$ 3,100,000**
	Low Range, minus 30% (rounded to nearest $100,000)				**$ 2,200,000**
	High Range, plus 50% (rounded to nearest $100,000)				**$ 4,700,000**

Table 7 provides a summary of the estimated O&M costs for Measure B with noted assumptions.

Table 7. Measure B estimated O&M costs.

Measure B Power and Operating Cost		
Length of Season, Months		5
Length of Season, Days		152
Boat Cleaning, kW - 82 kW Heater (8 gpm with 70 deg F rise) + 6 kw Pumping 2 x 4 gpm		86
Percent of time operating - 6 hours per day 4 days per week during season		14%
Power Demand, kW		12
Boat Lift, kW		40
Percent of time operating - 1 hour per day 4 days per week during season		2%
Power Demand, kW		0.95
Trucking Gallons of Diesel per day		1.0
Trucking Gallons of Diesel per Season		152
Hours per Season		*3650*
Energy per Season, kWh		*48319*
Gallons of Diesel		*3728*
Cost of Diesel	*$*	*3.50*
Energy Cost per Season (rounded to nearest $100)	***$***	***13,000***
Number of Personnel		*6*
FTE Cost		*60*
Hours per day (7am to 5 pm) for 35 of 152 days		*10*
Extended Hours per day (7am to 10 pm) for 117 of 152 days		*15*
Hours per Season		*2105*
Personnel Cost per Season (rounded to nearest $1000)	***$***	***758,000***
Allowance for off-season / peak use (10% Extra - rounded to nearest $1000)	***$***	***77,000***
Operating Cost per Season (rounded to nearest $1000)	**$**	**848,000**

Maintenance Cost as a Percentage of Capital Cost		**%**		**O&M Cost**
Structural (rounded to nearest $1,000)	$ 1,168,741	5.0%	$	58,000
Mech/Elec (rounded to nearest $1,000)	$ 480,600	15.0%	$	72,000
Total (rounded to nearest $1,000)			**$**	**130,000**

3.2.2. Avoided Cost Discussion for Measure B

This alternative would change the operational and maintenance requirements for the closed locks, which would have an associated avoided cost to the Canal Corporation. These costs would at a minimum likely include:

- Not having to rebuild Locks O7 and O8 in the future.
- Not having to staff Locks O7 and O8.
- Avoiding pumping out Locks O7 and O8 every 10 years.
- Reducing the maintenance associated with Locks O7 and O8.

It was not within the scope of this study to estimate these costs, but simply to identify avoided costs as they could be significant.

3.3. Cost Summary for Measure C – BAFF/SILAS at Tonawanda Creek

Measure C includes installation of the BAFF/SILAS at the intersection between the Erie Canal and Tonawanda Creek. See Figure 13 for a general vicinity view, and Figure 14 for an enlarged view of the recommended location.

Figure 13. **BAFF/SILAS system location aerial (to the east of Tonawanda, see red circle near Tonawanda Creek).**

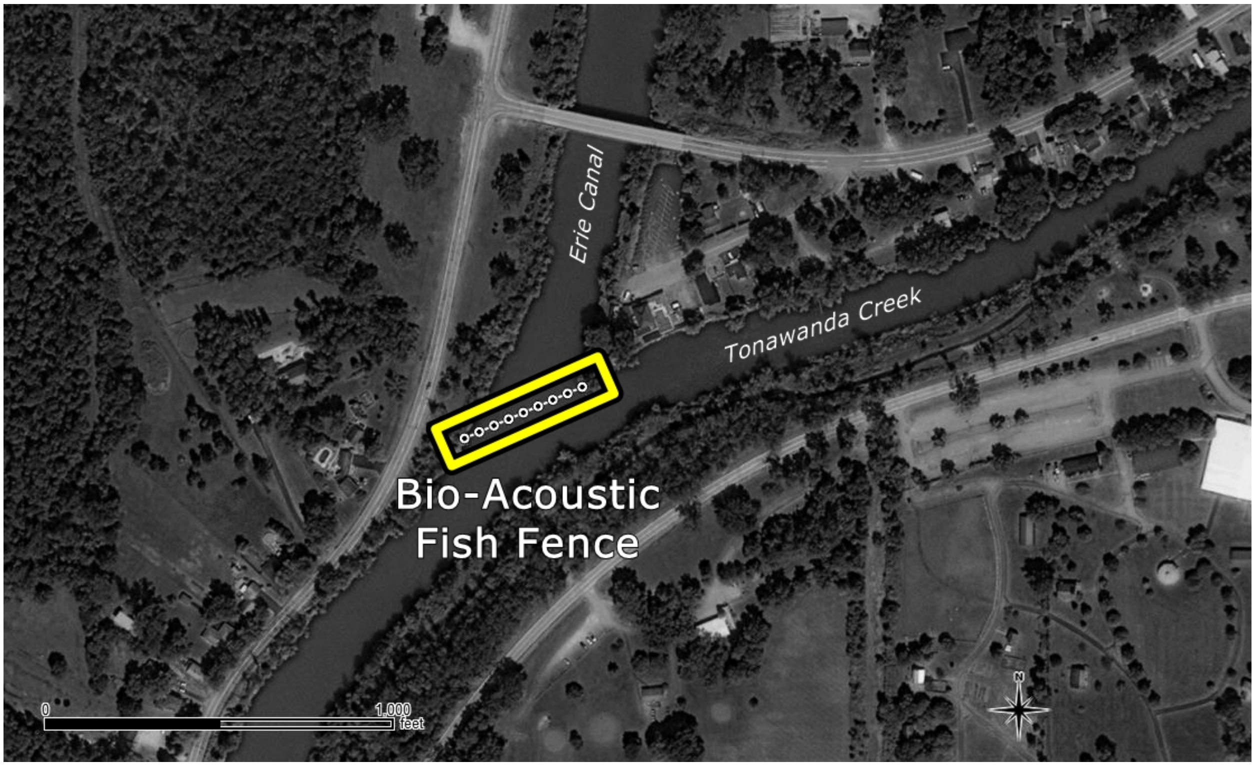

Figure 14. BAFF/SILAS deterrent location near Tonawanda Creek.

The BAFF/SILAS would be strategically located to provide deterred fish a choice to continue into Tonawanda Creek, or to turn around and go back through the Erie Canal. Components of the BAFF/SILAS are listed in the cost summary table in Section 3.3.1., and described further in Section 3.5.3 of the report body. Cost estimated are based on foundation and equipment costs relative to information provided by the proprietary BAFF/SILAS vendor (Fish Guidance Systems, www.fgs.world) and quantity take-offs based on high level review and professional experience as follows.

1. The general dimensions of the BAFF/SILAS are summarized below:
    a. Length ~ 250’ (based on Google Maps).
    b. Depth ~ 15’ (assumed for Canal section).
2. The BAFF/SILAS will be constructed with the following features.
    a. Concrete foundation and abutments.
    b. Air piping.
    c. Sitework.
    d. Mechanical equipment.

i. Compressor.

ii. Sound generator.

iii. Lighting.

iv. Controls equipment.

v. Site lighting and convenience electrical.

3. Electrical loads are based on:
   a. Air compressor (largest load).
   b. Sound generator.
   c. Lighting.
   d. Control equipment.
4. Assumed BAFF/SILAS will be located on Canal Corporation property near this site, or property/access easements will not be a significant cost.
5. See summary cost estimating tables below for additional detail.

3.3.1. Cost Summary for Measure C

Table 8 provides a summary of the assumptions used for Measure C.

Table 8. Measure C Opinion of Probable Construction Cost.

2C. BAFF at Tonawanda Creek					
ITEM	**DESCRIPTION**	**QUANTITY**	**UNIT**	**UNIT PRICE**	**TOTAL**
1	*Mob and Demob*	*1*	*LS*	*$ 413,000*	*$ 413,000*
2	*Water Handling and Temporary Cofferdam*	*1*	*LS*	*$ 400,000*	*$ 400,000*
3	*Grading Channel Bottom (6'h x 15'w x 250'l)*	*833*	*CY*	*$ 40*	*$ 33,333*
4	*Concrete Sill (3'h x 10'w x 250'l)*	*278*	*CY*	*$ 1,500*	*$ 416,667*
5	*General Site Improvments (Access Road, Walkways, Landscaping)*	*1*	*LS*	*$ 200,000*	*$ 200,000*
6	*Electrical and Equipment Building*	*1*	*LS*	*$ 250,000*	*$ 250,000*
7	*Air Compressors (75 hp - 322 scfm x 2 for redundancy)*	*1*	*LS*	*$ 200,000*	*$ 200,000*
8	*Air Piping*	*1*	*LS*	*$ 120,000*	*$ 120,000*
9	*BAFF Assembly*	*1*	*LS*	*$ 1,000,000*	*$ 1,000,000*
10	*Spare Parts (Filters, Fluids, Belts, Bearing, BAFF Module, BAFF lights and electrical)*	*1*	*LS*	*$ 100,000*	*$ 100,000*
11	*Electrical and Controls*	*1*	*LS*	*$ 700,000*	*$ 700,000*
12	*Testing and Startup*	*1*	*LS*	*$ 300,000*	*$ 300,000*
	CONSTRUCTION COST (rounded to nearest $100,000)				**$ 4,100,000**
	Contingency (rounded to nearest $100,000)			**20%**	**$ 800,000**
	Design and Permitting (rounded to nearest $100,000)			**30%**	**$ 1,200,000**
	TOTAL COST - 2019 USD (rounded to nearest $100,000)				**$ 6,100,000**
	Low Range, minus 30% (rounded to nearest $100,000)				**$ 4,300,000**
	High Range, plus 50% (rounded to nearest $100,000)				**$ 9,200,000**

Table 9 provides a summary of the estimated O&M costs for Measure C.

Table 9. Measure C estimated O&M costs.

Measure C Power and Operating Cost	
Length of Season, Months	5
Length of Season, Days	152
75 hp Compressor Horsepower, kW	58
Percent of time operating - 24 hours per day 7 days per week during season	100%
Power Demand, kW	58
BAFF Lighting and Sound, kW	14
Percent of time operating - 24 hours per day 7 days per week during season	100%
Power Demand, kW	14
Misc Power Load, kW - continuous	1
Total Continuous Power Load, kW	73
Hours per Season	3650
Energy per Season, kWh	267,987
Cost per kWh	$ 0.13
Energy Cost per Season (rounded to nearest $100)	***$ 34,800***
Number of Personnel	*1*
FTE Cost	*60*
Hours per day (Noon to 4 pm)	*4*
Hours per Season (weekdays)	*435*
Personnel Cost per Season (rounded to nearest $1000)	***$ 26,000***
Operating Cost per Season (rounded to nearest $1000)	**$ 61,000**

Maintenance Cost as a Percentage of Capital Cost		**%**	**O&M Cost**
Structural (rounded to nearest $1,000)	$ 666,667	5.0%	$ 33,000
Mech/Elec (rounded to nearest $1,000)	$ 2,220,000	15.0%	$ 333,000
Total (rounded to nearest $1,000)			**$ 366,000**

3.3.2. Avoided Cost Discussion for Measure C

This alternative would not change the operational and maintenance requirements for any locks or gate and would not avoid any costs to the Canal Corporation.

3.4. Cost Summary for Measure D – Hydrologic Separation at Rochester Guard Gate

Measure D would close and seal the West Rochester Guard Gate/Lock (Figures 15-16).

This measure was estimated similarly to the Rome Guard Gate described in Section 2.1. Additional detail is provided in the estimate worksheet below.

Figure 15. Location of Rochester West Guard Gate. Genesee River crosses the Erie Canal.

Figure 16. Rochester West Guard Gate.

3.4.1. Cost Summary for Measure D

Table 10 provides a summary of the assumptions used for Measure D.

Table 10. Measure D Opinion of Probable Construction Cost.

2D. Hydrologic Separation (West Guard Lock, Rochester)						
ITEM	**DESCRIPTION**	**QUANTITY**	**UNIT**	**UNIT PRICE**		**TOTAL**
1	*Mob and Demob*	*1*	*LS*	*$ 35,000*		*$ 35,000*
2	*Water Handling and Temporary Seals @ West Guard Gate*	*1*	*LS*	*$ 150,000*		*$ 150,000*
3	*Permanent Concrete Seals, (2 x 25'h + 50'w) x 2 sets x 3' x 3'*	*67*	*CY*	*$ 2,000*		*$ 133,333*
4	*Decommission Equipment @ West Guard Gate*	*1*	*LS*	*$ 30,000*		*$ 30,000*
	CONSTRUCTION COST (rounded to $100,000)					**$ 300,000**
	Contingency (rounded to nearest $100,000)				**20%**	**$ 100,000**
	Design and Permitting (rounded to nearest $100,000)				**30%**	**$ 100,000**
	TOTAL COST - 2019 USD (rounded to nearest $100,000)					**$ 500,000**
	Low Range, minus 30% (rounded to nearest $100,000)					**$ 400,000**
	High Range, plus 50% (rounded to nearest $100,000)					**$ 800,000**

Table 11 provides a summary of the estimated O&M costs for Measure D.

Table 11. Measure D estimated O&M costs.

Maintenance Cost as a Percentage of Capital Cost		**%**	**O&M Cost**
Structural (rounded to nearest $1,000)	$ 133,333	5.0%	$ 7,000
Mech/Elec (rounded to nearest $1,000)	$ -	15.0%	$ -
Total (rounded to nearest $1,000)			**$ 7,000**

3.4.2. Avoided Cost Discussion for Measure D

This alternative would change the operational and maintenance requirements for the closed locks, which would have an associated avoided cost to the Canal Corporation. These costs would at a minimum likely include:

- Not having to rebuild the Rochester West Guard gate in the future.
- Not having to operate the Rochester West Guard gate.
- A reduction in the maintenance associated with the Rochester West Guard gate.

It was not within the scope of this study to estimate these costs, but simply to identify avoided costs as they could be significant.

3.5. Alternative 2 Total Cost Summary

Table 12 provides a summary of all four measures that define Alternative 2.

Table 12. Alternative 2 cost summary.

Measure	Capital Cost	Capital Cost Low Range	Capital Cost High Range	Operating Cost	Maintenance Cost	Total O&M Cost
A	$ 2,300,000	$ 1,600,000	$ 3,500,000	$ -	$ 13,000	$ 13,000
B	$ 3,100,000	$ 2,200,000	$ 4,700,000	$ 848,000	$ 130,000	$ 978,000
C	$ 6,100,000	$ 4,300,000	$ 9,200,000	$ 61,000	$ 366,000	$ 427,000
D2	$ 500,000	$ 400,000	$ 800,000	$ -	$ 7,000	$ 7,000
Total	**$ 12,000,000**	**$ 8,500,000**	**$ 18,200,000**	**$ 909,000**	**$ 516,000**	**$ 1,425,000**

4. Cost Estimate for Networked Alternative 3: Key Watershed Protection

The objective of Networked Alternative 3 is to reduce the probability of AIS passage from Lakes Erie and Ontario via the Erie Canal to the Finger Lakes, Oneida Lake, as well as from the Hudson River to the Upper Mohawk River as illustrated in Figure 17 (Figure 4-7 in the report and repeated below). This alternative is composed of the following measures:

1. Measure A – Hydrologic Separation at Rome
2. Measure B – Lock Closure with Boat Lift/Wash at Oswego, Locks O7-O8
3. Measure C – BAFF/SILAS at Tonawanda Creek
4. Measure D – Lock Closure with Boat Lift/Wash and Fish Screen on Bypass Canal at Macedon, Lock E30
5. Measure E – Lock Closure with Boat Lift/Wash at Baldwinsville, Lock E24
6. Measure F – Lock Closure with Boat Lift/Wash at Brewerton, Lock E23
7. Measure G – Lock Closure with Boat Lift/Wash at Waterford, Lock E2

The development of cost estimates for each measure are described further in Sections 4.1 – 4.7, and a total cost summary of Alternative 3 is provided in Section 4.8.

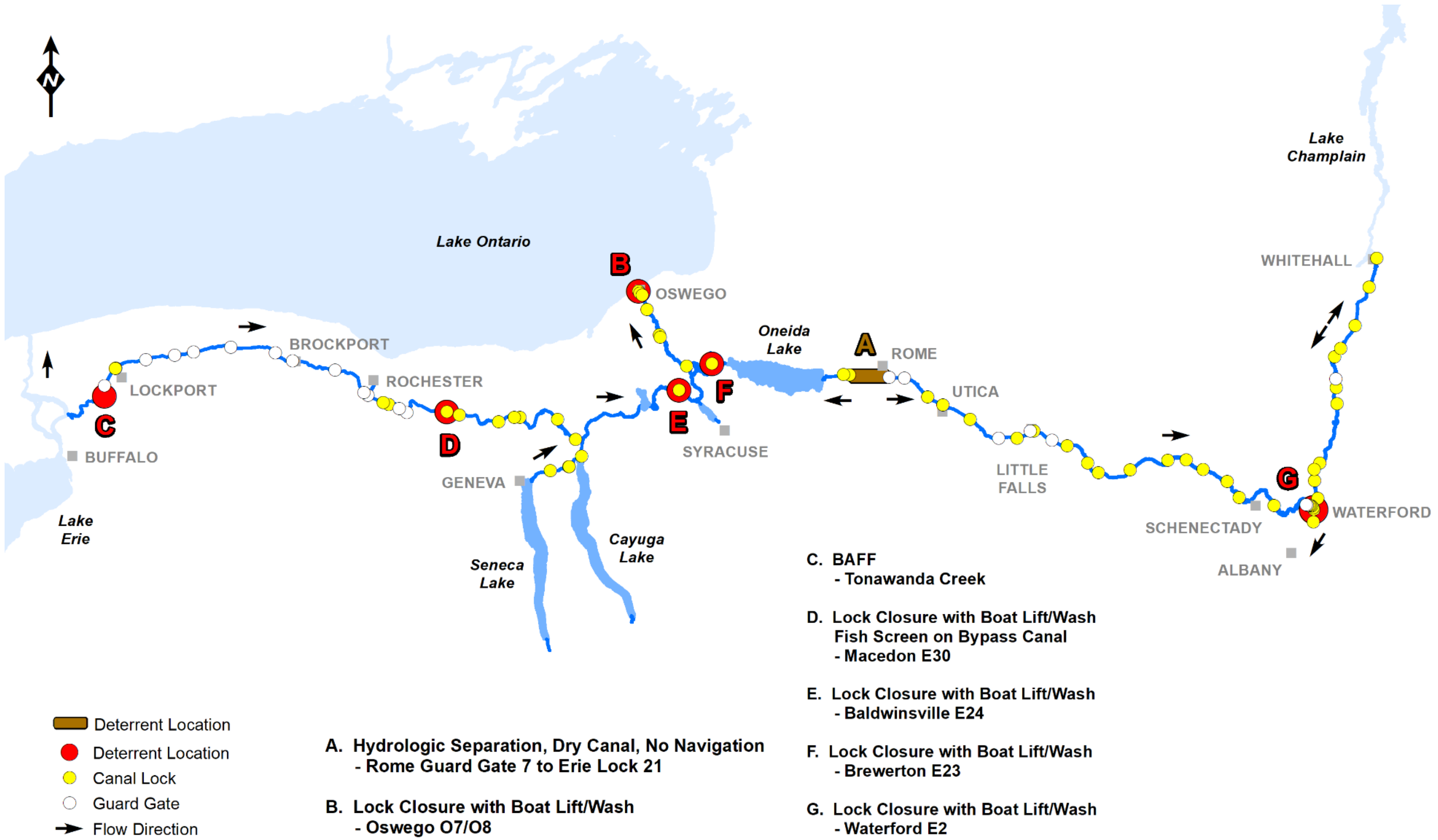

Figure 17. A schematic depicting deterrents and changing flow patterns associated with Alternative 3, Key Watershed Protection (from body of report).

4.1. Cost Summary for Measure A – Hydrologic Separation at Rome

Required actions for estimating the cost of Measure A are described above in Section 2.

4.2. Cost Summary for Measure B – Lock Closure with Boat Lift/Wash at Oswego, Locks O7-O8

Required actions for estimating the cost of Measure A are described above in Section 3.2.

4.3. Cost Summary for Measure C –BAFF/SILAS at Tonawanda Creek

Required actions for estimating the cost of Measure A are described above in Section 3.3.

4.4. Cost Summary for Measure D – Lock Closure with Boat Lift/Wash and Fish Screen on Bypass Canal at Macedon, Lock E30

This measure is composed of ceasing lock operations at Lock E30, located near Macedon, and installing a fish barrier screen at the Macedon Bypass Channel. See Figure 18 for the general location of Lock E30, and Figure 19 for an enlarged view of the screen area.

Figure 18. Aerial view of Measure D vicinity near Macedon.

Figure 19. Aerial view showing Lock E30 and the Macedon Bypass Channel.

1. Measures for closing and sealing the Lock E30 are similar to those described in Section 2.1 for closing Lock E21. See Table 13 for specific assumptions for this site.
2. Provide boat lift/inspection/wash station at Lock E21. Measures for the boat lift/inspection/wash station are similar but smaller than those described in Section 3.2 for Locks O7/O8. See Table 13 for specific assumptions for this site.
    a. Besides being a shorter transport distance, the operating hours for Lock E21 were estimated as follows and were used for the O&M estimate in Table 14.
        i. May 17 – October 16, 7:00 AM – 5:00 PM (10 hours/day)
        ii. Extended hours from May 17 - September 11 of 7:00 AM – 7:00 PM (12 hours/day)
        iii. A crew of 4 people is assumed rather than 6.
3. Install Fish Barrier Screen at Macedon Bypass Channel (see Figure 20). Assume depth of 14 feet, and available length is about 135 feet (per google maps measurement)
    a. Provide barrier screen on bypass channel
        i. For this estimate, set screen size for 200 cfs design flow.
            a. Note this could be reduced, total flow is for lockage flow and potential lazy river concept. Consider irrigation and other recreational flows

b. Use 1.75mm screen mesh, Hydrolox® traveling belt screens

    i. Proven for trout and salmonids

    ii. See Table 3-2 in the report. This mesh size will likely be in the 30% effectiveness range to filter larval stages of fish and molluscs and plankton species, but should be quite effective in filtering juveniles and adults of target fish species.

    iii. As the mesh sizes gets smaller, it could be more effective for very small organisms, but the ability to stay ahead of clogging is a key concern, and the screen would become more expensive.

c. Set design approach velocity at 0.2 fps, which is conservative for an actively cleaned fish screen to help facilitate heavy debris loading and keep up with the automate screen cleaning system.

d. See Table 13 for more detailed cost estimating assumptions.

Figure 20. Enlarged view of Fish Screen location at entrance of Macedon Bypass Channel.

4.4.1. Cost Summary for Measure D

Table 13 provides a summary of the assumptions used for Measure D. Table 14 provides a summary of the estimated O&M costs for Measure D.

Table 13. Measure D Opinion of Probable Construction Cost.

3D. Lock Closure, Boat Lift / Wash, Fish					
ITEM	**DESCRIPTION**	**QUANTITY**	**UNIT**	**UNIT PRICE**	**TOTAL**
1	*Mob and Demob*	*1*	*LS*	*$ 600,000*	*$ 600,000*
2	*Water Handling and Temporary Seals @ Lock E30*	*1*	*LS*	*$ 60,000*	*$ 60,000*
3	*Permanent Concrete Seals, (2 x 16'h + 45'w) x 2 sets x 3' x 3'*	*51*	*CY*	*$ 2,000*	*$ 102,667*
4	*Decommission Equipment @ Lock E30*	*1*	*LS*	*$ 30,000*	*$ 30,000*
5	*Water Handling and Temporary Seals @ Lock E30*	*1*	*LS*	*$ 60,000*	*$ 60,000*
6	*Permanent Concrete Seals for Fill/Drains, (4 ea x 20 lf x 16 sf)*	*47*	*CY*	*$ 1,000*	*$ 47,407*
7	*Dewater Canal*	*1*	*LS*	*$ 3,000*	*$ 3,000*
8	*Grading and Earthwork*	*100*	*CY*	*$ 20*	*$ 2,000*
9	*General Site Improvments (Access Road & Walkways*	*1*	*LS*	*$ 100,000*	*$ 100,000*
10	*Portable Boat Cleaning Basin and Pump*	*1*	*LS*	*$ 30,000*	*$ 30,000*
11	*Portable Boat Cleaning Equipment (2 x 4gpm pressure washers with water heater)*	*1*	*LS*	*$ 150,000*	*$ 150,000*
12	*Spare Cleaning Equipment (pumps, wands, heater, generator parts)*	*1*	*LS*	*$ 15,000*	*$ 15,000*
13	*Boat Hoist Support Frame*	*2*	*EA*	*$ 100,000*	*$ 200,000*
14	*Boat Hoist Mechanical (40 tn Sling Lift)*	*1*	*EA*	*$ 300,000*	*$ 300,000*
15	*Spare Transport Parts (motors, filters, slings, bearings, wheels, cable)*	*1*	*LS*	*$ 30,000*	*$ 30,000*
16	*Temp Floating Dock (2 x 100'l x 8'w)*	*1,600*	*SF*	*35*	*$ 56,000*
17	*Water Handling and Cofferdam at Fish Screen*	*1*	*LS*	*$ 300,000*	*$ 300,000*
18	*Grading and Earthwork*	*400*	*CY*	*$ 20*	*$ 8,000*
19	*General Site Improvments (Access Road, Walkways, Landscaping)*	*1*	*LS*	*$ 200,000*	*$ 200,000*
20	*Screen Foundation and side walls*	*200*	*CY*	*$ 2,000*	*$ 400,000*
21	*Screen Support Structure*	*1*	*LS*	*$ 500,000*	*$ 500,000*
22	*Fish Screens (12.5'w x 11' submerged)*	*8*	*EA*	*$ 180,000*	*$ 1,440,000*
23	*Debris Conveyance Disposal System*	*1*	*LS*	*$ 600,000*	*$ 600,000*
24	*Spare Screen Assembly*	*1*	*LS*	*$ 180,000*	*$ 180,000*
25	*Equipment and Electrical Building*	*1*	*LS*	*$ 200,000*	*$ 200,000*
26	*Electrical*	*1*	*LS*	*$ 300,000*	*$ 300,000*
27	*Testing and Startup*	*1*	*LS*	*$ 50,000*	*$ 50,000*
	CONSTRUCTION COST (rounded to nearest $100,000)				**$ 6,000,000**
	Contingency (rounded to nearest $100,000)			**20%**	**$ 1,200,000**
	Design and Permitting (rounded to nearest $100,000)			**30%**	**$ 1,800,000**
	TOTAL COST - 2019 USD (rounded to nearest $100,000)				**$ 9,000,000**
	Low Range, minus 30% (rounded to nearest $100,000)				**$ 6,300,000**
	High Range, plus 50% (rounded to nearest $100,000)				**$ 13,500,000**

Table 14. Measure D estimated O&M costs.

Measure D Power and Operating Cost		
Length of Season, Months		5
Length of Season, Days		152
Boat Cleaning, kW - 82 kW Heater (8 gpm with 70 deg F rise) + 6 kw Pumping 2 x 4 gpm		86
Percent of time operating - 6 hours per day 4 days per week during season		14%
Power Demand, kW		12
Boat Lift, kW		40
Percent of time operating - 1 hour per day 4 days per week during season		2%
Power Demand, kW		0.95
Hours per Season		*3650*
Energy per Season, kWh		*48319*
Gallons of Diesel		*3576*
Cost of Diesel	*$*	*3.50*
Energy Cost per Season (rounded to nearest $100)	***$***	***12,500***
Fish Screen, kW - 8 x 5hp motors + 25 hp backwash pumps + 10 hp debris		55.5
Percent of time operating - 4 hours per day 7 days per week during season		17%
Power Demand, kW		9.25
Misc Power Load, kW - continuous		1
Total Continuous Power Load, kW		10
Hours per Season		*3650*
Energy per Season, kWh		*37413*
Cost per kWh	*$*	*0.13*
Energy Cost per Season (rounded to nearest $100)	***$***	***4,900***
Number of Personnel		*4*
FTE Cost		*60*
Hours per day (7am to 5 pm) for 35 of 152 days		*10*
Extended Hours per day (7am to 10 pm) for 117 of 152 days		*12*
Hours per Season		*1754*
Personnel Cost per Season (rounded to nearest $1000)	***$***	***421,000***
Allowance for off-season / peak use (10% Extra - rounded to nearest $1000)	***$***	***44,000***
Operating Cost per Season (rounded to nearest $1000)	**$**	**482,000**

Maintenance Cost as a Percentage of Capital Cost		**%**	**O&M Cost**	
Structural (rounded to nearest $1,000)	$ 1,488,667	5.0%	$	74,000
Mech/Elec (rounded to nearest $1,000)	$ 3,090,000	15.0%	$	464,000
Total (rounded to nearest $1,000)			**$**	**538,000**

4.4.2. Avoided Cost Discussion for Measure D

This alternative would change the operational and maintenance requirements for the closed locks, which would have an associated avoided cost to the Canal Corporation. These costs would at a minimum likely include:

- Not having to rebuild Lock E30 in the future.
- Not having to staff Lock E30.
- Avoiding pumping out Lock E30 every 10 years.
- A reduction in the maintenance associated with Lock E30.

It was not within the scope of this study to estimate these costs, but simply to identify avoided costs as they could be significant.

4.5. Cost Summary for Measure E – Lock Closure with Boat Lift/Wash at Baldwinsville, Lock E24

This measure would close Lock E24 at Baldwinsville and would provide a boat lift/inspection/wash to allow continued navigation. Figure 21 provides a vicinity location for the lock, Figure 22 provides an aerial view of Lock E24, and Figure 23 provides an enlarged view of Lock E24.

1. Measures for closing and sealing Lock E24 are similar to those described in Section 2.1 for closing Lock E21. See Table 15 for specific assumptions for this site.
2. Provide boat lift/inspection/wash station at Lock E24. Measures for the boat lift/inspection/wash station are similar but smaller than those described in Section 3.2 for Locks O7/O8. See Table 15 for specific assumptions for this site.
    a. While Lock E24 would have a shorter transport distance than Lock O7/O8, the operating hours for Lock E24 were assumed to be the same as O7/O8 and the boat lift would be used for transport rather than the tractor/low boy assembly.
    b. Assumes 4 personnel.

Figure 21. **Vicinity map for Locks E24 and E23.**

Figure 22. **Aerial view of Lock E24 at Baldwinsville.**

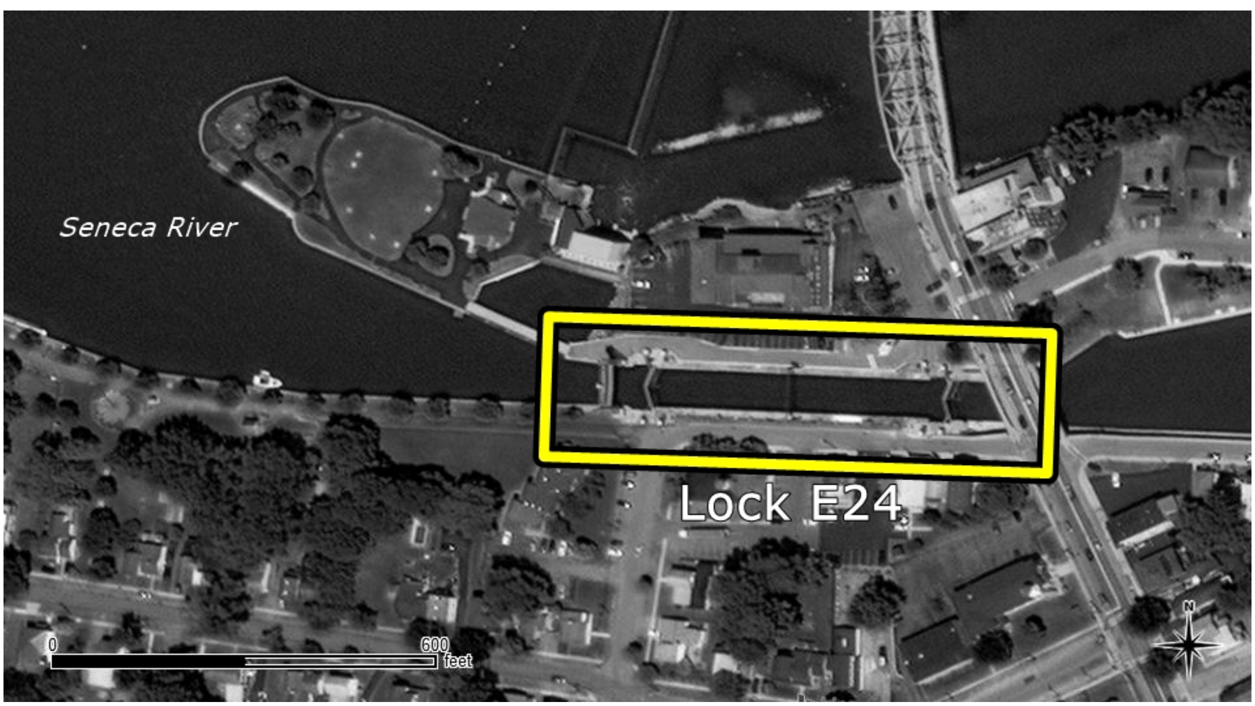

Figure 23. Enlarged aerial view of Lock E24 at Baldwinsville.

4.5.1. Cost Summary for Measure E

Table 15 provides a summary of the assumptions used for Measure E. Table 16 provides a summary of the estimated O&M costs for Measure E.

Table 15. Measure E Opinion of Probable Construction Cost.

E Lock Closure and Boat Lift (Baldwinsville E24)					
ITEM	**DESCRIPTION**	**QUANTITY**	**UNIT**	**UNIT PRICE**	**TOTAL**
1	*Mob and Demob*	*1*	*LS*	*$ 130,000*	*$ 130,000*
2	*Water Handling and Temporary Seals @ Lock E24*	*1*	*LS*	*$ 60,000*	*$ 60,000*
3	*Permanent Concrete Seals, (2 x 12'h + 45'w) x 2 sets x 3' x 3'*	*46*	*CY*	*$ 2,000*	*$ 92,000*
4	*Decommission Equipment @ Lock E24*	*1*	*LS*	*$ 30,000*	*$ 30,000*
5	*Water Handling and Temporary Seals @ Lock E24*	*1*	*LS*	*$ 60,000*	*$ 60,000*
6	*Permanent Concrete Seals for Fill/Drains, (4 ea x 20 lf x 16 sf)*	*47*	*CY*	*$ 1,000*	*$ 47,407*
7	*Dewater Canal*	*1*	*LS*	*$ 3,000*	*$ 3,000*
8	*General Site Improvments (Access Road & Walkways*	*1*	*LS*	*$ 100,000*	*$ 100,000*
9	*Portable Boat Cleaning Basin and Pump*	*1*	*LS*	*$ 30,000*	*$ 30,000*
10	*Portable Boat Cleaning Equipment (2 x 4gpm pressure washers with water heater)*	*1*	*LS*	*$ 150,000*	*$ 150,000*
11	*Spare Cleaning Equipment (pumps, wands, heater, generator parts)*	*1*	*LS*	*$ 15,000*	*$ 15,000*
12	*Boat Hoist Support Frame*	*2*	*EA*	*$ 100,000*	*$ 200,000*
13	*Boat Hoist Mechanical (40 tn Sling Lift)*	*1*	*EA*	*$ 300,000*	*$ 300,000*
14	*Spare Transport Parts (motors, filters, slings, bearings, wheels, cable)*	*1*	*LS*	*$ 30,000*	*$ 30,000*
15	*Temp Floating Dock (2 x 100'l x 8'w)*	*1,600*	*SF*	*35*	*$ 56,000*
	CONSTRUCTION COST (rounded to nearest $100,000)				**$ 1,300,000**
	Contingency (rounded to nearest $100,000)			**20%**	**$ 300,000**
	Design and Permitting (rounded to nearest $100,000)			**30%**	**$ 400,000**
	TOTAL COST - 2019 USD (rounded to nearest $100,000)				**$ 2,000,000**
	Low Range, minus 30% (rounded to nearest $100,000)				**$ 1,400,000**
	High Range, plus 50% (rounded to nearest $100,000)				**$ 3,000,000**

Table 16. Measure E estimated O&M costs.

Measure E Power and Operating Cost		
Length of Season, Months		5
Length of Season, Days		152
Boat Cleaning, kW - 82 kW Heater (8 gpm with 70 deg F rise) + 6 kw Pumping 2 x 4 gpm		86
Percent of time operating - 6 hours per day 4 days per week during season		14%
Power Demand, kW		12
Boat Lift, kW		40
Percent of time operating - 1 hour per day 4 days per week during season		2%
Power Demand, kW		0.95
Hours per Season		*3650*
Energy per Season, kWh		*48319*
Gallons of Diesel		*3576*
Cost of Diesel	*$*	*3.50*
Energy Cost per Season (rounded to nearest $100)	***$***	***12,500***
Number of Personnel		*4*
FTE Cost		*60*
Hours per day (7am to 5 pm) for 35 of 152 days		*10*
Extended Hours per day (7am to 10 pm) for 117 of 152 days		*15*
Hours per Season		*2105*
Personnel Cost per Season (rounded to nearest $1000)	***$***	***505,000***
Allowance for off-season / peak use (10% Extra - rounded to nearest $1000)	***$***	***52,000***
Operating Cost per Season (rounded to nearest $1000)	**$**	**570,000**

Maintenance Cost as a Percentage of Capital Cost			**%**		**O&M Cost**
Structural (rounded to nearest $1,000)	$	439,407	5.0%	$	22,000
Mech/Elec (rounded to nearest $1,000)	$	536,000	15.0%	$	80,000
Total (rounded to nearest $1,000)				**$**	**102,000**

4.5.2. Avoided Cost Discussion for Measure E

This alternative would change the operational and maintenance requirements for the closed locks, which would have an associated avoided cost to the Canal Corporation. These costs would at a minimum likely include:

- Not having to rebuild Lock E24 in the future.
- Not having to staff Lock E24.
- Avoiding pumping out Lock E24 every 10 years.

- Not having to staff Lock E24.
- A reduction in the maintenance associated with Lock E24.

It was not within the scope of this study to estimate these costs, but simply to identify avoided costs as they could be significant.

4.6. Cost Summary for Measure F – Lock Closure with Boat Lift/Wash at Brewerton, Lock E23

This measure would close Lock E23 at Brewerton and would provide a boat lift/inspection/wash to allow continued navigation. Figure 24 provides a vicinity location for the lock, and Figure 25 provides an enlarged aerial view of Lock E23.

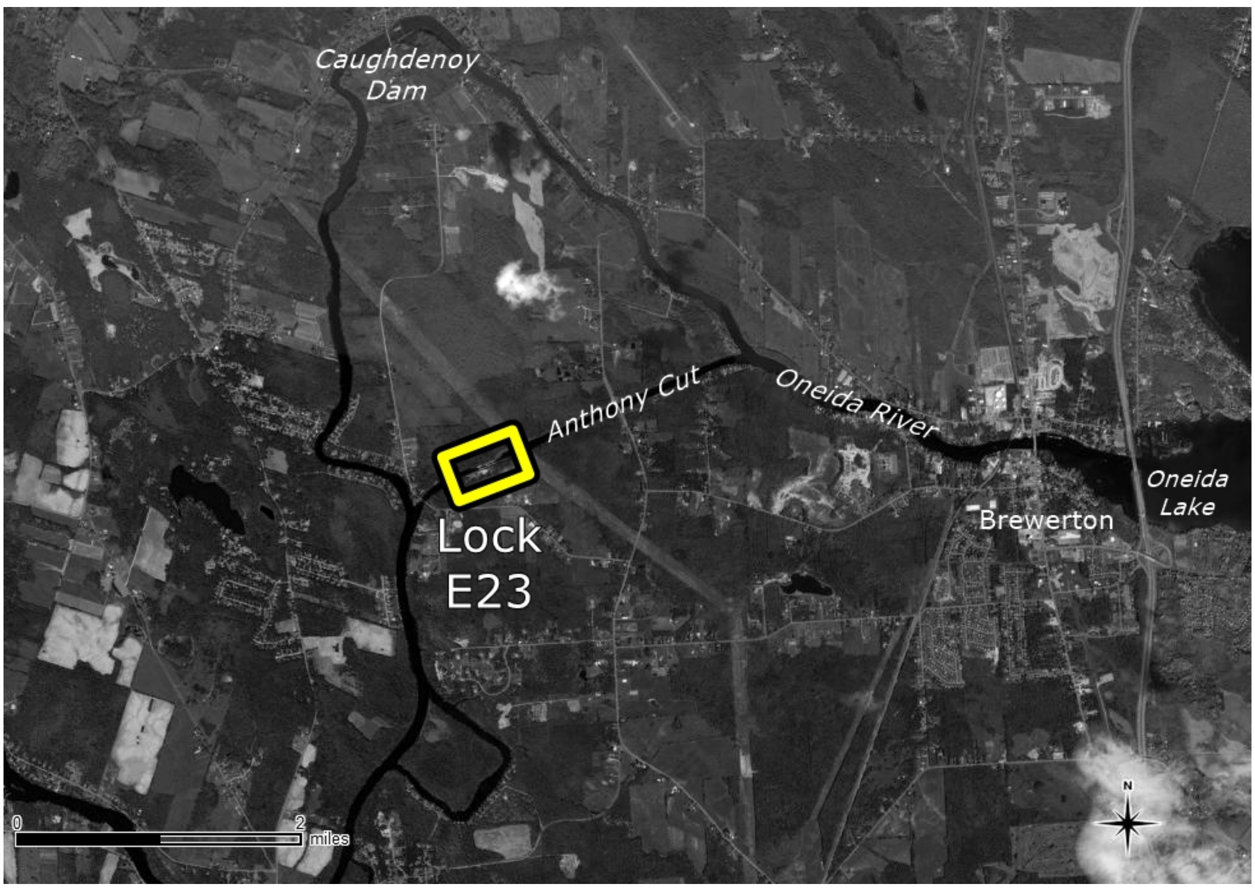

Figure 24. Aerial view of Lock E23, Oneida Lake to the right.

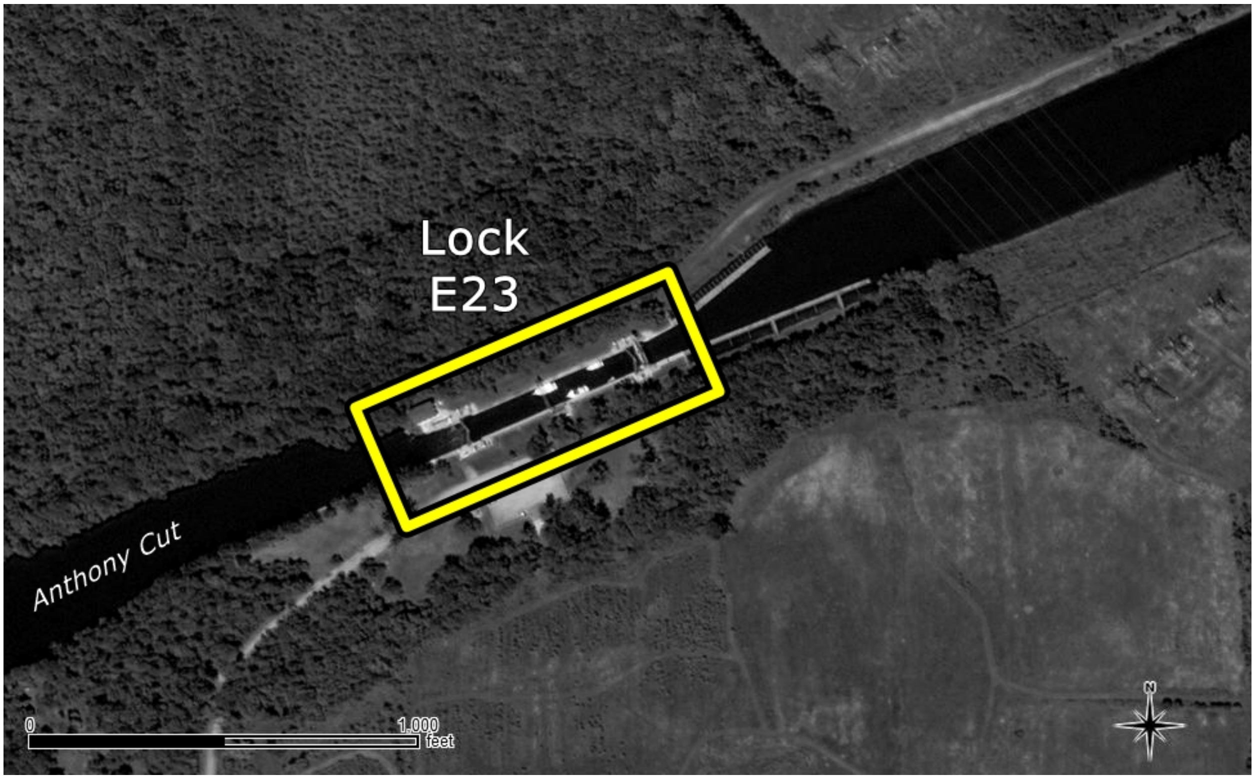

Figure 25. Enlarged aerial view of Lock E23.

1. Measures for closing and sealing the Lock E23 were similar to those described in Section 2.1 for closing Lock E21. See Table 17 for specific assumptions for this site.
2. Provide boat lift/inspection/wash station at Lock E24. Measures for the boat lift/inspection/wash station were assumed to be similar but smaller than those described in Section 3.2 for Locks O7/O8 with 4 personnel. See Table 17 for specific assumptions for this site.

4.6.1. Cost Summary for Measure F

Table 17 provides a summary of the assumptions used for Measure F. Table 18 provides a summary of the estimated O&M costs for Measure F.

Table 17. Measure F Opinion of Probable Construction Cost.

F Lock Closure and Boat Lift (Baldwinsville E23)					
ITEM	**DESCRIPTION**	**QUANTITY**	**UNIT**	**UNIT PRICE**	**TOTAL**
1	*Mob and Demob*	*1*	*LS*	*$ 129,000*	*$ 129,000*
2	*Water Handling and Temporary Seals @ Lock E23*	*1*	*LS*	*$ 60,000*	*$ 60,000*
3	*Permanent Concrete Seals, (2 x 8'h + 45'w) x 2 sets x 3' x 3'*	*41*	*CY*	*$ 2,000*	*$ 81,333*
4	*Decommission Equipment @ Lock E23*	*1*	*LS*	*$ 30,000*	*$ 30,000*
5	*Water Handling and Temporary Seals @ Lock E23*	*1*	*LS*	*$ 60,000*	*$ 60,000*
6	*Permanent Concrete Seals for Fill/Drains, (4 ea x 20 lf x 16 sf)*	*47*	*CY*	*$ 1,000*	*$ 47,407*
7	*Dewater Canal*	*1*	*LS*	*$ 3,000*	*$ 3,000*
8	*General Site Improvments (Access Road & Walkways*	*1*	*LS*	*$ 100,000*	*$ 100,000*
9	*Portable Boat Cleaning Basin and Pump*	*1*	*LS*	*$ 30,000*	*$ 30,000*
10	*Portable Boat Cleaning Equipment (2 x 4gpm pressure washers with water heater)*	*1*	*LS*	*$ 150,000*	*$ 150,000*
11	*Spare Cleaning Equipment (pumps, wands, heater, generator parts)*	*1*	*LS*	*$ 15,000*	*$ 15,000*
12	*Boat Hoist Support Frame*	*2*	*EA*	*$ 100,000*	*$ 200,000*
13	*Boat Hoist Mechanical (40 tn Sling Lift)*	*1*	*EA*	*$ 300,000*	*$ 300,000*
14	*Spare Transport Parts (motors, filters, slings, bearings, wheels, cable)*	*1*	*LS*	*$ 30,000*	*$ 30,000*
15	*Temp Floating Dock (2 x 100'l x 8'w)*	*1,600*	*SF*	*35*	*$ 56,000*
	CONSTRUCTION COST (rounded to nearest $100,000)				**$ 1,300,000**
	Contingency (rounded to nearest $100,000)			**20%**	**$ 300,000**
	Design and Permitting (rounded to nearest $100,000)			**30%**	**$ 400,000**
	TOTAL COST - 2019 USD (rounded to nearest $100,000)				**$ 2,000,000**
	Low Range, minus 30% (rounded to nearest $100,000)				**$ 1,400,000**
	High Range, plus 50% (rounded to nearest $100,000)				**$ 3,000,000**

Table 18. Measure F estimated O&M costs.

Measure F Power and Operating Cost		
Length of Season, Months		5
Length of Season, Days		152
Boat Cleaning, kW - 82 kW Heater (8 gpm with 70 deg F rise) + 6 kw Pumping 2 x 4 gpm		86
Percent of time operating - 6 hours per day 4 days per week during season		14%
Power Demand, kW		12
Boat Lift, kW		40
Percent of time operating - 1 hour per day 4 days per week during season		2%
Power Demand, kW		0.95
Hours per Season		*3650*
Energy per Season, kWh		*48319*
Gallons of Diesel		*3576*
Cost of Diesel	*$*	*3.50*
Energy Cost per Season (rounded to nearest $100)	***$***	***12,500***
Number of Personnel		*4*
FTE Cost		*60*
Hours per day (7am to 5 pm) for 152 days		*10*
Hours per Season		*1521*
Personnel Cost per Season (rounded to nearest $1000)	***$***	***365,000***
Allowance for off-season / peak use (10% Extra - rounded to nearest $1000)	***$***	***38,000***
Operating Cost per Season (rounded to nearest $1000)	**$**	**416,000**

Maintenance Cost as a Percentage of Capital Cost			**%**		**O&M Cost**
Structural (rounded to nearest $1,000)	$	428,741	5.0%	$	21,000
Mech/Elec (rounded to nearest $1,000)	$	536,000	15.0%	$	80,000
Total (rounded to nearest $1,000)				**$**	**101,000**

4.6.2. Avoided Cost Discussion for Measure F

This alternative would change the operational and maintenance requirements for the closed locks, which would have an associated avoided cost to the Canal Corporation. These costs would at a minimum likely include:

- Not having to rebuild Lock E23 in the future.
- Not having to staff Lock E23.

- Avoiding pumping out Lock E23 every 10 years.
- A reduction in the maintenance associated with Lock E23.

It was not within the scope of this study to estimate these costs, but simply to identify avoided costs as they could be significant.

4.7. Cost Summary for Measure G – Lock Closure with Boat Lift/Wash at Waterford, Lock E2

This measure would close Lock E2 at Waterford, and would provide a boat lift/inspection/wash. Figure 26 provides a vicinity location for the lock, Figure 27 provides an aerial view of Lock E2 and the Mohawk and Hudson Rivers, and Figure 28 provides an enlarged aerial view of Lock E2.

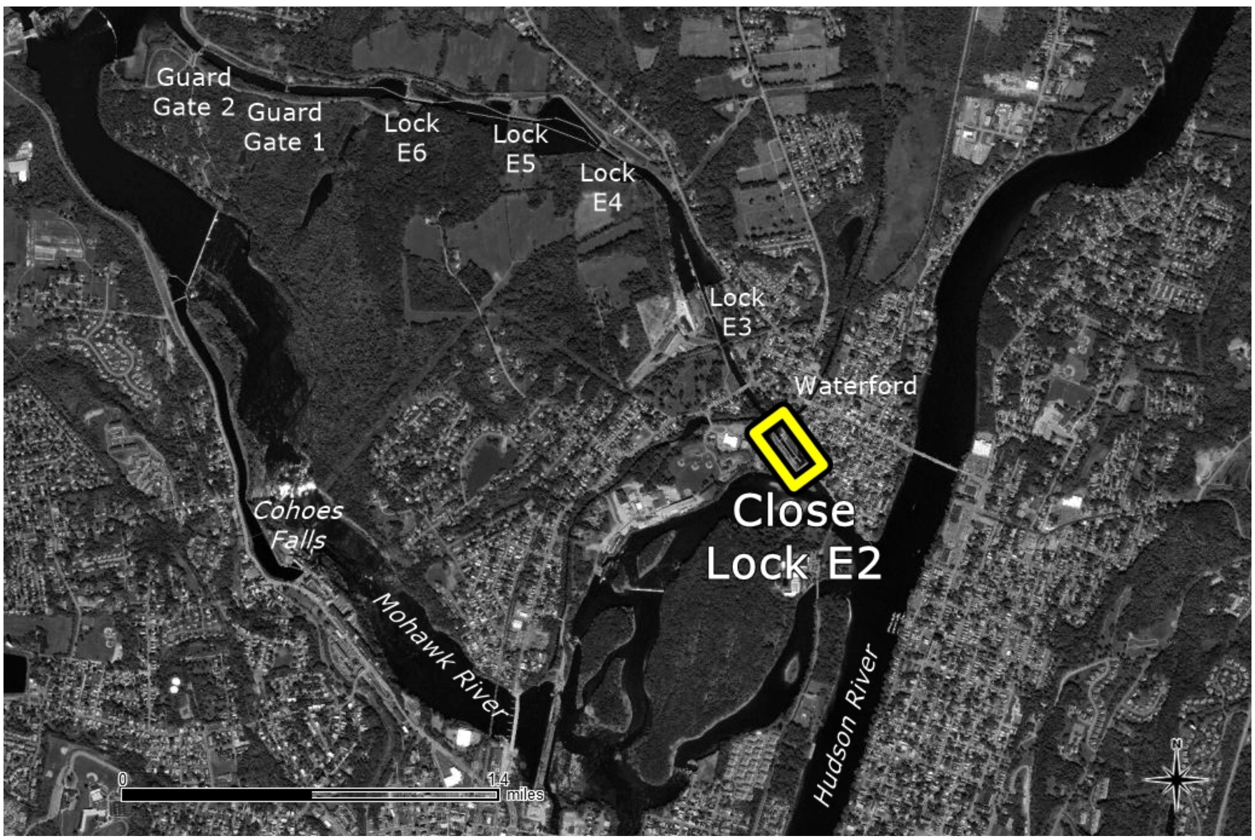

Figure 26. Vicinity of Lock E2 at the Waterford Flight at the confluence of the Mohawk and Hudson rivers.

Figure 27. **Aerial view of Lock E2 and the Mohawk and Hudson rivers.**

Figure 28. **Enlarged aerial view of Lock E2.**

1. Measures for closing and sealing the Lock E2 were similar to those described in Section 2.1 for closing Lock E21. See Table 19 for specific assumptions for this site.
2. Provide boat lift/inspection/wash station at Lock E24. Measures for the boat lift/inspection/wash station were assumed to be similar but smaller than those described in Section 3.2 for Locks O7/O8 with 4 personnel. See Table 19 for specific assumptions for this site.
    a. Besides being a shorter transport distance, the operating hours for Lock E2 were assumed to be as follows, and were used for the O&M estimate in Table 20.
        i. May 17 – October 16, 7:00 AM – 5:00 PM (10 hours/day)
        ii. Extended hours from May 17 - September 11, Thursday – Monday of 7:00 AM – 10:00 PM (12 hours/day)

4.7.1. Cost Summary for Measure G

Table 19 provides a summary of the assumptions used for Measure G. Table 20 provides a summary of the estimated O&M costs for Measure G.

Table 19. Measure G Opinion of Probable Construction Cost.

G Lock Closure and Boat Lift (Baldwinsville E2)							
ITEM	**DESCRIPTION**	**QUANTITY**	**UNIT**	**UNIT PRICE**		**TOTAL**	
1	*Mob and Demob*	*1*	*LS*	*$*	*132,000*	*$*	*132,000*
2	*Water Handling and Temporary Seals @ Lock E2*	*1*	*LS*	*$*	*60,000*	*$*	*60,000*
3	*Permanent Concrete Seals, (2 x 14'h + 50'w) x 2 sets x 3' x 3'*	*52*	*CY*	*$*	*2,000*	*$*	*104,000*
4	*Decommission Equipment @ Lock E2*	*1*	*LS*	*$*	*30,000*	*$*	*30,000*
5	*Water Handling and Temporary Seals @ Lock E2*	*1*	*LS*	*$*	*60,000*	*$*	*60,000*
6	*Permanent Concrete Seals for Fill/Drains, (4 ea x 20 lf x 16 sf)*	*47*	*CY*	*$*	*1,000*	*$*	*47,407*
7	*Dewater Canal*	*1*	*LS*	*$*	*3,000*	*$*	*3,000*
8	*General Site Improvments (Access Road & Walkways*	*1*	*LS*	*$*	*100,000*	*$*	*100,000*
9	*Portable Boat Cleaning Basin and Pump*	*1*	*LS*	*$*	*30,000*	*$*	*30,000*
10	*Portable Boat Cleaning Equipment (2 x 4gpm pressure washers with water heater)*	*1*	*LS*	*$*	*150,000*	*$*	*150,000*
11	*Spare Cleaning Equipment (pumps, wands, heater, generator parts)*	*1*	*LS*	*$*	*15,000*	*$*	*15,000*
12	*Boat Hoist Support Frame*	*2*	*EA*	*$*	*100,000*	*$*	*200,000*
13	*Boat Hoist Mechanical (40 tn Sling Lift)*	*1*	*EA*	*$*	*300,000*	*$*	*300,000*
14	*Spare Transport Parts (motors, filters, slings, bearings, wheels, cable)*	*1*	*LS*	*$*	*30,000*	*$*	*30,000*
15	*Temp Floating Dock (2 x 100'l x 8'w)*	*1,600*	*SF*		*35*	*$*	*56,000*
	CONSTRUCTION COST (rounded to nearest $100,000)					**$**	**1,300,000**
	Contingency (rounded to nearest $100,000)				**20%**	**$**	**300,000**
	Design and Permitting (rounded to nearest $100,000)				**30%**	**$**	**400,000**
	TOTAL COST - 2019 USD (rounded to nearest $100,000)					**$**	**2,000,000**
	Low Range, minus 30% (rounded to nearest $100,000)					**$**	**1,400,000**
	High Range, plus 50% (rounded to nearest $100,000)					**$**	**3,000,000**

Table 20. Measure G estimated O&M costs.

Measure G Power and Operating Cost		
Length of Season, Months		5
Length of Season, Days		152
Boat Cleaning, kW - 82 kW Heater (8 gpm with 70 deg F rise) + 6 kw Pumping 2 x 4 gpm		86
Percent of time operating - 6 hours per day 4 days per week during season		14%
Power Demand, kW		12
Boat Lift, kW		40
Percent of time operating - 1 hour per day 4 days per week during season		2%
Power Demand, kW		0.95
Hours per Season		*3650*
Energy per Season, kWh		*48319*
Gallons of Diesel		*3576*
Cost of Diesel	*$*	*3.50*
Energy Cost per Season (rounded to nearest $100)	***$***	***12,500***
Number of Personnel		*4*
FTE Cost		*60*
Hours per day (7am to 5 pm) for 68 of 152 days		*10*
Extended Hours per day (7am to 10 pm) for 84 of 152 days		*15*
Hours per Season		*1940*
Personnel Cost per Season (rounded to nearest $1000)	***$***	***466,000***
Allowance for off-season / peak use (10% Extra - rounded to nearest $1000)	***$***	***48,000***
Operating Cost per Season (rounded to nearest $1000)	**$**	**527,000**

Maintenance Cost as a Percentage of Capital Cost			**%**	**O&M Cost**	
Structural (rounded to nearest $1,000)	$	451,407	5.0%	$	23,000
Mech/Elec (rounded to nearest $1,000)	$	536,000	15.0%	$	80,000
Total (rounded to nearest $1,000)				**$**	**103,000**

4.7.2. Avoided Cost Discussion for Measure G

This alternative would change the operational and maintenance requirements for the closed lock, which would have an associated avoided cost to the Canal Corporation. These costs would at a minimum likely include:

- Not having to rebuild Lock E2 in the future.
- Not having to staff Lock E2.
- Avoiding pumping out Lock E2 every 10 years.

- A reduction in the maintenance associated with Lock E2.

It was not within the scope of this study to estimate these costs, but simply to identify avoided costs as they could be significant.

4.8. Alternative 3 Total Cost Summary

Table 21 provides a summary of all 7 measures that define Alternative 3.

Table 21. Alternative 3 cost summary.

Measure	Capital Cost	Capital Cost Low Range	Capital Cost High Range	Operating Cost	Maintenance Cost	Total O&M Cost
A	$ 2,300,000	$ 1,600,000	$ 3,500,000	$ -	$ 13,000	$ 13,000
B	$ 3,100,000	$ 2,200,000	$ 4,700,000	$ 848,000	$ 130,000	$ 978,000
C	$ 6,100,000	$ 4,300,000	$ 9,200,000	$ 61,000	$ 366,000	$ 427,000
D3	$ 9,000,000	$ 6,300,000	$ 13,500,000	$ 482,000	$ 538,000	$ 1,020,000
E	$ 2,000,000	$ 1,400,000	$ 3,000,000	$ 570,000	$ 102,000	$ 672,000
F	$ 2,000,000	$ 1,400,000	$ 3,000,000	$ 416,000	$ 101,000	$ 517,000
G	$ 2,000,000	$ 1,400,000	$ 3,000,000	$ 527,000	$ 103,000	$ 630,000
Total	**$ 26,500,000**	**$ 18,600,000**	**$ 39,900,000**	**$ 2,904,000**	**$ 1,353,000**	**$ 4,257,000**

5. Cost Estimate Summary by Alternative

Table 22 provides a summary of the total cost estimates of each alternative for comparison.

Table 22. Summary of OPCCs and O&M costs for the Networked Alternatives.

Alternative	Capital Cost[1]	Annual O&M Cost[2]
1 – Protect the Hudson	$2.3 m ($1.6 m to $3.5 m)	$13,000
2 – Watershed Divide	$12.0 m ($8.5 m to $18.2 m)	$1,425,000
3 – Key Watershed Protection	$26.5 m ($18.6 m to $39.9 m)	$4,257,000

1 Capital costs rounded to nearest $100,000

2 Annual O&M costs rounded to the nearest $1,000.

ATTACHMENT 1

Opinions of Probable Construction Cost and Estimated O&M Costs for Those Measures That Include Boat Lift and Boat Wash Systems as Permanent Facilities (B, 3D, E, F, and G)

This attachment presents optional costs associated with measures that include boat lift and cleaning facilities. The estimates presented in the appendix above were based on "pilot programs" constructed with temporary facilities. This attachment provides preliminary cost estimates based on constructing more permanent facilities for the boat lift and transport facilities as well as the boat cleaning facilities. The planned permanent facilities could house most of the equipment (water heaters, pumps, electrical, etc.) in a building with an electrical power service rather than a portable generator.

Measure B Opinion of Probable Construction Cost with permanent facilities.

ITEM	DESCRIPTION	QUANTITY	UNIT	UNIT PRICE	TOTAL
	B Lock Closure and Boat Lift / Wash (Oswego O7 / O8)				
1	*Mob and Demob*	1	LS	$ 646,000	$ 646,000
2	*Water Handling and Temporary Seals @ Lock 07*	1	LS	$ 60,000	$ 60,000
3	*Permanent Concrete Seals, (2 x 15'h + 50'w) x 2 sets x 3' x 3'*	53	CY	$ 2,000	$ 106,667
4	*Decommission Equipment @ Lock O7*	1	LS	$ 30,000	$ 30,000
5	*Water Handling and Temporary Seals @ Lock O8*	1	LS	$ 60,000	$ 60,000
6	*Permanent Concrete Seals, (2 x 11'h + 50'w) x 2 sets x 3' x 3'*	49	CY	$ 2,000	$ 98,667
7	*Decommission Equipment @ Lock O8*	1	LS	$ 30,000	$ 30,000
8	*Permanent Concrete Seals, (2 x 25'h +30'w) x 2 sets x 3' x 3'*	47	CY	$ 1,000	$ 47,407
9	*Dewater Canal (7 days at 4 cfs)*	1	LS	$ 10,000	$ 10,000
10	*Grading and Earthwork*	300	CY	$ 20	$ 6,000
11	*General Site Improvements (Parking, Walkways, Landscaping)*	1	LS	$ 400,000	$ 400,000
12	*Boat Cleaning Basin (70''l x 20' w x 1.5' t)*	78	CY	$ 2,000	$ 155,556
13	*Boat Cleaning Equipment (3 x 4gpm pressure washers with water heater)*	1	LS	$ 150,000	$ 150,000
14	*Spare Cleaning Equipment (pumps, wands, heater, generator parts)*	1	LS	$ 15,000	$ 15,000
15	*Equipment and Electrical Building*	1	LS	$ 200,000	$ 200,000
16	*Boat Hoist Structural*	2	EA	$ 100,000	$ 200,000
17	*Boat Hoist Mechanical (40 tn Sling Lift)*	2	EA	$ 300,000	$ 600,000
18	*Boat Transfer Cart*	1	EA	$ 100,000	$ 100,000
19	*Boat Transfer Rails between O7 and O8*	3,000	LF	600	$ 1,800,000
20	*Spare Transport Parts (motors, filters, slings, bearings, wheels, cable)*	1	LS	$ 30,000	$ 30,000
21	*Floating Dock (2 x 100'l x 8'w)*	1,600	SF	50	$ 80,000
22	*Land Side Access (Wall, walkway, stairs: 2 x 300' l x 1't x (4'+10'+6')w)*	444	CY	$ 2,000	$ 888,889
23	*Electrical*	1	LS	$ 600,000	$ 600,000
24	*Testing and Startup*	1	LS	$ 150,000	$ 150,000
	CONSTRUCTION COST (rounded to nearest $100,000)				**$ 6,500,000**
	Contingency (rounded to nearest $100,000)			**20%**	**$ 1,300,000**
	Design and Permitting (rounded to nearest $100,000)			**30%**	**$ 2,000,000**
	TOTAL COST - 2019 USD (rounded to nearest $100,000)				**$ 9,800,000**
	Low Range, minus 30% (rounded to nearest $100,000)				**$ 6,900,000**
	High Range, plus 50% (rounded to nearest $100,000)				**$ 14,700,000**

Measure B estimated O&M costs with permanent facilities.

Measure B Power and Operating Cost		
Length of Season, Months		5
Length of Season, Days		152
Boat Cleaning, kW - 123 kW Heater (12 gpm with 70 deg F rise) + 6 kw Pumping 3 x 4 gpm		129
Percent of time operating - 6 hours per day 4 days per week during season		14%
Power Demand, kW		18
Boat Lift, kW		40
Percent of time operating - 1 hour per day 4 days per week during season		2%
Power Demand, kW		0.95
Misc Power Load, kW - continuous		1
Total Continuous Power Load, kW		20
Hours per Season		*3650*
Energy per Season, kWh		*74390*
Cost per kWh		*0.13*
Energy Cost per Season (rounded to nearest $100)	***$***	***9,700***
Number of Personnel		*6*
FTE Cost		*60*
Hours per day (7am to 5 pm) for 35 of 152 days		*10*
Extended Hours per day (7am to 10 pm) for 117 of 152 days		*15*
Hours per Season		*2105*
Personnel Cost per Season (rounded to nearest $1000)	***$***	***758,000***
Allowance for off-season / peak use (10% Extra - rounded to nearest $1000)	***$***	***77,000***
Operating Cost per Season (rounded to nearest $1000)	**$**	**845,000**

O&M Cost as a Percentage of Capital Cost		**%**		**O&M Cost**
Structural (rounded to nearest $1,000)	$ 3,577,185	5.0%	$	179,000
Mech/Elec (rounded to nearest $1,000)	$ 1,850,000	15.0%	$	278,000
Total (rounded to nearest $1,000)			**$**	**457,000**

Measure D Opinion of Probable Construction Cost with permanent facilities.

3D. Lock Closure, Boat Lift / Wash, Fish					
ITEM	**DESCRIPTION**	**QUANTITY**	**UNIT**	**UNIT PRICE**	**TOTAL**
1	*Mob and Demob*	*1*	*LS*	*$ 830,000*	*$ 830,000*
2	*Water Handling and Temporary Seals @ Lock E30*	*1*	*LS*	*$ 60,000*	*$ 60,000*
3	*Permanent Concrete Seals, (2 x 16'h + 45'w) x 2 sets x 3' x 3'*	*51*	*CY*	*$ 2,000*	*$ 102,667*
4	*Decommission Equipment @ Lock E30*	*1*	*LS*	*$ 30,000*	*$ 30,000*
5	*Water Handling and Temporary Seals @ Lock E30*	*1*	*LS*	*$ 60,000*	*$ 60,000*
6	*Permanent Concrete Seals for Fill/Drains, (4 ea x 20 lf x 16 sf)*	*47*	*CY*	*$ 1,000*	*$ 47,407*
7	*Dewater Canal*	*1*	*LS*	*$ 3,000*	*$ 3,000*
8	*Grading and Earthwork*	*100*	*CY*	*$ 20*	*$ 2,000*
9	*General Site Improvments (Access Road, Walkways, Landscaping)*	*1*	*LS*	*$ 200,000*	*$ 200,000*
10	*Boat Cleaning Basin (70"l x 20' w x 1.5' t)*	*78*	*CY*	*$ 2,000*	*$ 155,556*
11	*Boat Cleaning Equipment (3 x 4gpm pressure washers with water heater)*	*1*	*LS*	*$ 150,000*	*$ 150,000*
12	*Spare Cleaning Equipment (pumps, wands, heater, generator parts)*	*1*	*LS*	*$ 15,000*	*$ 15,000*
13	*Equipment and Electrical Building*	*1*	*LS*	*$ 200,000*	*$ 200,000*
14	*Boat Hoist Structural*	*2*	*EA*	*$ 100,000*	*$ 200,000*
15	*Boat Hoist Mechanical (40 tn Sling Lift)*	*2*	*EA*	*$ 300,000*	*$ 600,000*
16	*Boat Transfer Cart*	*1*	*EA*	*$ 100,000*	*$ 100,000*
17	*Boat Transfer Rails between O7 and O8*	*230*	*LF*	*600*	*$ 138,000*
18	*Floating Dock (2 x 100'l x 8'w)*	*1,600*	*SF*	*50*	*$ 80,000*
19	*Land Side Access (Wall, walkway, stairs: 2 x 200' l x 1't x (4' + 10' + 6'w)*	*296*	*CY*	*$ 2,000*	*$ 592,593*
20	*Electrical*	*1*	*LS*	*$ 400,000*	*$ 400,000*
21	*Testing and Startup*	*1*	*LS*	*$ 150,000*	*$ 150,000*
22	*Water Handling and Cofferdam at Fish Screen*	*1*	*LS*	*$ 300,000*	*$ 300,000*
23	*Grading and Earthwork*	*400*	*CY*	*$ 20*	*$ 8,000*
24	*General Site Improvments (Access Road, Walkways, Landscaping)*	*1*	*LS*	*$ 200,000*	*$ 200,000*
25	*Screen Foundation and side walls*	*200*	*CY*	*$ 2,000*	*$ 400,000*
26	*Screen Support Structure*	*1*	*LS*	*$ 500,000*	*$ 500,000*
27	*Fish Screens (12.5'w x 11' submerged)*	*8*	*EA*	*$ 180,000*	*$ 1,440,000*
28	*Debris Conveyance Disposal System*	*1*	*LS*	*$ 600,000*	*$ 600,000*
29	*Spare Screen Assembly*	*1*	*LS*	*$ 180,000*	*$ 180,000*
30	*Equipment and Electrical Building*	*1*	*LS*	*$ 200,000*	*$ 200,000*
31	*Electrical*	*1*	*LS*	*$ 300,000*	*$ 300,000*
32	*Testing and Startup*	*1*	*LS*	*$ 50,000*	*$ 50,000*
	CONSTRUCTION COST (rounded to nearest $100,000)				**$ 8,300,000**
	Contingency (rounded to nearest $100,000)			**20%**	**$ 1,700,000**
	Design and Permitting (rounded to nearest $100,000)			**30%**	**$ 2,500,000**
	TOTAL COST - 2019 USD (rounded to nearest $100,000)				**$ 12,500,000**
	Low Range, minus 30% (rounded to nearest $100,000)				**$ 8,800,000**
	High Range, plus 50% (rounded to nearest $100,000)				**$ 18,800,000**

Measure D estimated O&M costs with permanent facilities.

Measure D Power and Operating Cost		
Length of Season, Months		5
Length of Season, Days		152
Boat Cleaning, kW - 123 kW Heater (12 gpm with 70 deg F rise) + 6 kw Pumping 3 x 4 gpm		129
Percent of time operating - 6 hours per day 4 days per week during season		14%
Power Demand, kW		18
Boat Lift, kW		40
Percent of time operating - 1 hour per day 4 days per week during season		2%
Power Demand, kW		0.95
Fish Screen, kW - 8 x 5hp motors + 25 hp backwash pumps + 10 hp debris		55.5
Percent of time operating - 4 hours per day 7 days per week during season		17%
Power Demand, kW		9.25
Misc Power Load, kW - continuous		1
Total Continuous Power Load, kW		30
Hours per Season		*3650*
Energy per Season, kWh		*108153*
Cost per kWh		*0.13*
Energy Cost per Season (rounded to nearest $100)	***$***	***14,100***
Number of Personnel		*4*
FTE Cost		*60*
Hours per day (7am to 5 pm) for 35 of 152 days		*10*
Extended Hours per day (7am to 10 pm) for 117 of 152 days		*12*
Hours per Season		*1754*
Personnel Cost per Season (rounded to nearest $1000)	***$***	***421,000***
Allowance for off-season / peak use (10% Extra - rounded to nearest $1000)	***$***	***44,000***
Operating Cost per Season (rounded to nearest $1000)	**$**	**479,000**

O&M Cost as a Percentage of Capital Cost		**%**		**O&M Cost**
Structural (rounded to nearest $1,000)	$ 2,568,815	5.0%	$	128,000
Mech/Elec (rounded to nearest $1,000)	$ 3,990,000	15.0%	$	599,000
Total (rounded to nearest $1,000)			**$**	**727,000**

Measure E Opinion of Probable Construction Cost with permanent facilities.

E	Lock Closure and Boat Lift (Baldwinsville E24)				
ITEM	**DESCRIPTION**	**QUANTITY**	**UNIT**	**UNIT PRICE**	**TOTAL**
1	*Mob and Demob*	*1*	*LS*	*$ 348,000*	*$ 348,000*
2	*Water Handling and Temporary Seals @ Lock E24*	*1*	*LS*	*$ 60,000*	*$ 60,000*
3	*Permanent Concrete Seals, (2 x 12'h + 45'w) x 2 sets x 3' x 3'*	*46*	*CY*	*$ 2,000*	*$ 92,000*
4	*Decommission Equipment @ Lock E24*	*1*	*LS*	*$ 30,000*	*$ 30,000*
5	*Water Handling and Temporary Seals @ Lock E24*	*1*	*LS*	*$ 60,000*	*$ 60,000*
6	*Permanent Concrete Seals for Fill/Drains, (4 ea x 20 lf x 16 sf)*	*47*	*CY*	*$ 1,000*	*$ 47,407*
7	*Dewater Canal*	*1*	*LS*	*$ 3,000*	*$ 3,000*
8	*General Site Improvments (Access Road, Walkways, Landscaping)*	*1*	*LS*	*$ 200,000*	*$ 200,000*
9	*Boat Cleaning Basin (70"l x 20' w x 1.5' t)*	*78*	*CY*	*$ 2,000*	*$ 155,556*
10	*Boat Cleaning Equipment (3 x 4gpm pressure washers with water heater)*	*1*	*LS*	*$ 150,000*	*$ 150,000*
11	*Spare Cleaning Equipment (pumps, wands, heater, generator parts)*	*1*	*LS*	*$ 15,000*	*$ 15,000*
12	*Equipment and Electrical Building*	*1*	*LS*	*$ 200,000*	*$ 200,000*
13	*Boat Hoist Structural*	*2*	*EA*	*$ 100,000*	*$ 200,000*
14	*Boat Hoist Mechanical (40 tn Sling Lift)*	*2*	*EA*	*$ 300,000*	*$ 600,000*
15	*Boat Transfer Cart*	*1*	*EA*	*$ 100,000*	*$ 100,000*
16	*Boat Transfer Rails*	*350*	*LF*	*600*	*$ 210,000*
17	*Spare Transport Parts (motors, filters, slings, bearings, wheels, cable)*	*1*	*LS*	*$ 30,000*	*$ 30,000*
18	*Floating Dock (2 x 100'l x 8'w)*	*1,600*	*SF*	*50*	*$ 80,000*
19	*Land Side Access (Wall, walkway, stairs: 2 x 100' l x 1't x 8'w)*	*59*	*CY*	*$ 2,500*	*$ 148,148*
20	*Electrical*	*1*	*LS*	*$ 600,000*	*$ 600,000*
21	*Testing and Startup*	*1*	*LS*	*$ 150,000*	*$ 150,000*
	CONSTRUCTION COST (rounded to nearest $100,000)				**$ 3,500,000**
	Contingency (rounded to nearest $100,000)			**20%**	**$ 700,000**
	Design and Permitting (rounded to nearest $100,000)			**30%**	**$ 1,100,000**
	TOTAL COST - 2019 USD (rounded to nearest $100,000)				**$ 5,300,000**
	Low Range, minus 30% (rounded to nearest $100,000)				**$ 3,700,000**
	High Range, plus 50% (rounded to nearest $100,000)				**$ 8,000,000**

Measure E estimated O&M costs with permanent facilities.

Measure E Power and Operating Cost		
Length of Season, Months		5
Length of Season, Days		152
Boat Cleaning, kW - 123 kW Heater (12 gpm with 70 deg F rise) + 6 kw Pumping 3 x 4 gpm		129
Percent of time operating - 6 hours per day 4 days per week during season		14%
Power Demand, kW		18
Boat Lift, kW		40
Percent of time operating - 1 hour per day 4 days per week during season		2%
Power Demand, kW		0.95
Misc Power Load, kW - continuous		1
Total Continuous Power Load, kW		20
Hours per Season		*3650*
Energy per Season, kWh		*74390*
Cost per kWh		*0.13*
Energy Cost per Season (rounded to nearest $100)	***$***	***9,700***
Number of Personnel		*4*
FTE Cost		*60*
Hours per day (7am to 5 pm) for 35 of 152 days		*10*
Extended Hours per day (7am to 10 pm) for 117 of 152 days		*15*
Hours per Season		*2105*
Personnel Cost per Season (rounded to nearest $1000)	***$***	***505,000***
Allowance for off-season / peak use (10% Extra - rounded to nearest $1000)	***$***	***51,000***
Operating Cost per Season (rounded to nearest $1000)	**$**	**566,000**

O&M Cost as a Percentage of Capital Cost		**%**		**O&M Cost**
Structural (rounded to nearest $1,000)	$ 1,133,111	5.0%	$	57,000
Mech/Elec (rounded to nearest $1,000)	$ 1,650,000	15.0%	$	248,000
Total (rounded to nearest $1,000)			**$**	**305,000**

Measure F Opinion of Probable Construction Cost with permanent facilities.

F Lock Closure and Boat Lift (Baldwinsville E23)					
ITEM	**DESCRIPTION**	**QUANTITY**	**UNIT**	**UNIT PRICE**	**TOTAL**
1	*Mob and Demob*	*1*	*LS*	*$ 347,000*	*$ 347,000*
2	*Water Handling and Temporary Seals @ Lock E24*	*1*	*LS*	*$ 60,000*	*$ 60,000*
3	*Permanent Concrete Seals, (2 x 8'h + 45'w) x 2 sets x 3' x 3'*	*41*	*CY*	*$ 2,000*	*$ 81,333*
4	*Decommission Equipment @ Lock E23*	*1*	*LS*	*$ 30,000*	*$ 30,000*
5	*Water Handling and Temporary Seals @ Lock E24*	*1*	*LS*	*$ 60,000*	*$ 60,000*
6	*Permanent Concrete Seals for Fill/Drains, (4 ea x 20 lf x 16 sf)*	*47*	*CY*	*$ 1,000*	*$ 47,407*
7	*Dewater Canal*	*1*	*LS*	*$ 3,000*	*$ 3,000*
8	*General Site Improvments (Access Road, Walkways, Landscaping)*	*1*	*LS*	*$ 200,000*	*$ 200,000*
9	*Boat Cleaning Basin (70"l x 20' w x 1.5' t)*	*78*	*CY*	*$ 2,000*	*$ 155,556*
10	*Boat Cleaning Equipment (3 x 4gpm pressure washers with water heater)*	*1*	*LS*	*$ 150,000*	*$ 150,000*
11	*Spare Cleaning Equipment (pumps, wands, heater, generator parts)*	*1*	*LS*	*$ 15,000*	*$ 15,000*
12	*Equipment and Electrical Building*	*1*	*LS*	*$ 200,000*	*$ 200,000*
13	*Boat Hoist Structural*	*2*	*EA*	*$ 100,000*	*$ 200,000*
14	*Boat Hoist Mechanical (40 tn Sling Lift)*	*2*	*EA*	*$ 300,000*	*$ 600,000*
15	*Boat Transfer Cart*	*1*	*EA*	*$ 100,000*	*$ 100,000*
16	*Boat Transfer Rails*	*350*	*LF*	*600*	*$ 210,000*
17	*Spare Transport Parts (motors, filters, slings, bearings, wheels, cable)*	*1*	*LS*	*$ 30,000*	*$ 30,000*
18	*Floating Dock (2 x 100'l x 8'w)*	*1,600*	*SF*	*50*	*$ 80,000*
19	*Land Side Access (Wall, walkway, stairs: 2 x 100' l x 1't x 8'w)*	*59*	*CY*	*$ 2,500*	*$ 148,148*
20	*Electrical*	*1*	*LS*	*$ 600,000*	*$ 600,000*
21	*Testing and Startup*	*1*	*LS*	*$ 150,000*	*$ 150,000*
	CONSTRUCTION COST (rounded to nearest $100,000)				**$ 3,500,000**
	Contingency (rounded to nearest $100,000)			**20%**	**$ 700,000**
	Design and Permitting (rounded to nearest $100,000)			**30%**	**$ 1,100,000**
	TOTAL COST - 2019 USD (rounded to nearest $100,000)				**$ 5,300,000**
	Low Range, minus 30% (rounded to nearest $100,000)				**$ 3,700,000**
	High Range, plus 50% (rounded to nearest $100,000)				**$ 8,000,000**

Measure F estimated O&M costs with permanent facilities.

Measure F Power and Operating Cost		
Length of Season, Months		5
Length of Season, Days		152
Boat Cleaning, kW - 123 kW Heater (12 gpm with 70 deg F rise) + 6 kw Pumping 3 x 4 gpm		129
Percent of time operating - 6 hours per day 4 days per week during season		14%
Power Demand, kW		18
Boat Lift, kW		40
Percent of time operating - 1 hour per day 4 days per week during season		2%
Power Demand, kW		0.95
Misc Power Load, kW - continuous		1
Total Continuous Power Load, kW		20
Hours per Season		*3650*
Energy per Season, kWh		*74390*
Cost per kWh		*0.13*
Energy Cost per Season (rounded to nearest $100)	***$***	***9,700***
Number of Personnel		*4*
FTE Cost		*60*
Hours per day (7am to 5 pm) for 152 days		*10*
Hours per Season		*1521*
Personnel Cost per Season (rounded to nearest $1000)	***$***	***365,000***
Allowance for off-season / peak use (10% Extra - rounded to nearest $1000)	***$***	***37,000***
Operating Cost per Season (rounded to nearest $1000)	**$**	**412,000**

O&M Cost as a Percentage of Capital Cost		**%**		**O&M Cost**
Structural (rounded to nearest $1,000)	$ 1,122,444	5.0%	$	56,000
Mech/Elec (rounded to nearest $1,000)	$ 1,650,000	15.0%	$	248,000
Total (rounded to nearest $1,000)			**$**	**304,000**

Measure G Opinion of Probable Construction Cost with permanent facilities.

G Lock Closure and Boat Lift (Baldwinsville E2)					
ITEM	**DESCRIPTION**	**QUANTITY**	**UNIT**	**UNIT PRICE**	**TOTAL**
1	*Mob and Demob*	*1*	*LS*	*$ 349,000*	*$ 349,000*
2	*Water Handling and Temporary Seals @ Lock E24*	*1*	*LS*	*$ 60,000*	*$ 60,000*
3	*Permanent Concrete Seals, (2 x 14'h + 50'w) x 2 sets x 3' x 3'*	*52*	*CY*	*$ 2,000*	*$ 104,000*
4	*Decommission Equipment @ Lock E2*	*1*	*LS*	*$ 30,000*	*$ 30,000*
5	*Water Handling and Temporary Seals @ Lock E24*	*1*	*LS*	*$ 60,000*	*$ 60,000*
6	*Permanent Concrete Seals for Fill/Drains, (4 ea x 20 lf x 16 sf)*	*47*	*CY*	*$ 1,000*	*$ 47,407*
7	*Dewater Canal*	*1*	*LS*	*$ 3,000*	*$ 3,000*
8	*General Site Improvments (Access Road, Walkways, Landscaping)*	*1*	*LS*	*$ 200,000*	*$ 200,000*
9	*Boat Cleaning Basin (70"l x 20' w x 1.5' t)*	*78*	*CY*	*$ 2,000*	*$ 155,556*
10	*Boat Cleaning Equipment (3 x 4gpm pressure washers with water heater)*	*1*	*LS*	*$ 150,000*	*$ 150,000*
	Spare Cleaning Equipment (pumps, wands, heater, generator parts)	*1*	*LS*	*$ 15,000*	*$ 15,000*
11	*Equipment and Electrical Building*	*1*	*LS*	*$ 200,000*	*$ 200,000*
12	*Boat Hoist Structural*	*2*	*EA*	*$ 100,000*	*$ 200,000*
13	*Boat Hoist Mechanical (40 tn Sling Lift)*	*2*	*EA*	*$ 300,000*	*$ 600,000*
14	*Boat Transfer Cart*	*1*	*EA*	*$ 100,000*	*$ 100,000*
15	*Boat Transfer Rails*	*350*	*LF*	*600*	*$ 210,000*
	Spare Transport Parts (motors, filters, slings, bearings, wheels, cable)	*1*	*LS*	*$ 30,000*	*$ 30,000*
16	*Floating Dock (2 x 100'l x 8'w)*	*1,600*	*SF*	*50*	*$ 80,000*
17	*Land Side Access (Wall, walkway, stairs: 2 x 100' l x 1't x 8'w)*	*59*	*CY*	*$ 2,500*	*$ 148,148*
18	*Electrical*	*1*	*LS*	*$ 600,000*	*$ 600,000*
19	*Testing and Startup*	*1*	*LS*	*$ 150,000*	*$ 150,000*
	CONSTRUCTION COST (rounded to nearest $100,000)				**$ 3,500,000**
	Contingency (rounded to nearest $100,000)			**20%**	**$ 700,000**
	Design and Permitting (rounded to nearest $100,000)			**30%**	**$ 1,100,000**
	TOTAL COST - 2019 USD (rounded to nearest $100,000)				**$ 5,300,000**
	Low Range, minus 30% (rounded to nearest $100,000)				**$ 3,700,000**
	High Range, plus 50% (rounded to nearest $100,000)				**$ 8,000,000**

Measure G estimated O&M costs with permanent facilities.

Measure G Power and Operating Cost		
Length of Season, Months		5
Length of Season, Days		152
Boat Cleaning, kW - 123 kW Heater (12 gpm with 70 deg F rise) + 6 kw Pumping 3 x 4 gpm		129
Percent of time operating - 6 hours per day 4 days per week during season		14%
Power Demand, kW		18
Boat Lift, kW		40
Percent of time operating - 1 hour per day 4 days per week during season		2%
Power Demand, kW		0.95
Misc Power Load, kW - continuous		1
Total Continuous Power Load, kW		20
Hours per Season		*3650*
Energy per Season, kWh		*74390*
Cost per kWh		*0.13*
Energy Cost per Season (rounded to nearest $100)	***$***	***9,700***
Number of Personnel		*4*
FTE Cost		*60*
Hours per day (7am to 5 pm) for 68 of 152 days		*10*
Extended Hours per day (7am to 10 pm) for 84 of 152 days		*15*
Hours per Season		*1940*
Personnel Cost per Season (rounded to nearest $1000)	***$***	***466,000***
Allowance for off-season / peak use (10% Extra - rounded to nearest $1000)	***$***	***48,000***
Operating Cost per Season (rounded to nearest $1000)	**$**	**524,000**

O&M Cost as a Percentage of Capital Cost		**%**		**O&M Cost**
Structural (rounded to nearest $1,000)	$ 1,145,111	5.0%	$	57,000
Mech/Elec (rounded to nearest $1,000)	$ 1,650,000	15.0%	$	248,000
Total (rounded to nearest $1,000)			**$**	**305,000**

APPENDIX E

Permitting

Alternative 1

Level of Government	Agency	Permit/ Consultation Name	Reason for Permit	Duration of Agency Review	Permit Fees	Information Required for Application	Statute	Notes
Federal	U.S. Army Corps of Engineers (USACE)	Individual Permit- Section 10	Closing of gates would alter navigation. As would construction of boat lift structures.	Individual permit decisions are within two to three months from receipt of a complete application. In emergencies, decisions can be made in a matter of hours or days. 60 days should be allotted to allow for permit applications to be reviewed for completeness. 4 to 6 months should be expected for total review process.	$10 for a non-commercial activity, $100 for a commercial or industrial activity; Do not send a fee when submitting application, Corps will ask to submit required fee upon issuance	• Joint Application Form and requires Application Needs numbers 1-19 (please see Application Needs tab) • Environmental Questionnaire and requires Application Needs numbers 3, 4, 16, 18, and 19	Section 10 of the Rivers and Harbors Act of 1899 (33 U.S.C. 403) prohibits the obstruction or alteration of navigable waters of the United States without a permit from the Corps of Engineers.	
Federal	U.S. Army Corps of Engineers (USACE)	Individual Permit-Section 404	Installation of boat lift and potential support structures (piles, bulkheads, etc.) would be classified as fill	Individual permit decisions are within two to three months from receipt of a complete application. In emergencies, decisions can be made in a matter of hours or days. 60 days should be allotted to allow for permit applications to be reviewed for completeness. 4 to 6 months should be expected for total review process.	$10 for a non-commercial activity, $100 for a commercial or industrial activity; Do not send a fee when submitting application, Corps will ask to submit required fee upon issuance	• Joint Application Form and requires Application Need numbers 1-18 (please see Application Needs tab)	United States Army Corps of Engineers (USACE) - Section 404 of the Clean Water Act – Required for discharge or dredge or fill material into jurisdictional waters and wetlands of the United States.	
Federal/State	U.S. Army Corps of Engineers (USACE)/ New York State Department of Conservation (NYSDEC)	Individual Permit- Water Quality Certification: Section 401	A State Water Quality Certification is a pre-requisite for the issuance of a Section 404 permit.	Individual permit decisions are within two to three months from receipt of a complete application. In emergencies, decisions can be made in a matter of hours or days. 60 days should be allotted to allow for permit applications to be reviewed for completeness. 4 to 6 months should be expected for total review process.	$10 for a non-commercial activity, $100 for a commercial or industrial activity; Do not send a fee when submitting application, Corps will ask to submit required fee upon issuance	• Joint Application Form and requires Application Need numbers 1-18 (please see Application Needs tab)	United States Army Corps of Engineers (USACE) - Section 401 of the Clean Water Act – Requires State Water Quality Certification (WQC), as a prerequisite of issuance of Section 404 permit of the Clean Water Act and the WQC is issued by state regulatory agencies.	
Federal/State	New York State Department of State - Coastal Management Program	State/Federal Consistency Assessment	A NYSDOS CMP Federal Consistency Assessment is required for any proposed activity that will occur within and/or direction affect the State's Coastal Area. Coastal Zone assessment is also required in order to complete SEQRA review.	Up to 6 months. Typically completed in 1 to 2 months.	None	• NYSDOS CMP Federal Consistency Assessment requires Application Needs numbers 1, 2, 9, and 25	Consistency under New York State's Coastal Management Program as required by U.S. Department of Commerce regulations (15 CFR 930.57).	Assessment to include conformance with Local Waterfront Revitalization Programs (LWRP). LWRPs identified for City of Oswego, City of Rochester, and City of Albany. Application forms can be found at the links below. https://www.dos.ny.gov/opd/programs/pdfs/Consistency/FCAF_fillable.pdf https://www.dos.ny.gov/opd/programs/pdfs/caf2.pdf
Federal	U.S. Fish and Wildlife Service (USFWS)	Endangered Species Act - Section 7	No activity is authorized under any individual permit which "may affect" a listed species or critical habitat, unless ESA Section 7 consultation addressing the effects of the proposed activity has been completed. USFWS assists with determination of whether a federally-listed, proposed, or candidate species, and/or designated "critical habitat" may occur within a proposed project area.	Typically one month. May require bat surveys for suitable habitat.	None	• Use of USFWS IPaC identified northern long-eared bat and Indiana bat within the vicinity of the alternatives. No critical habitat identified. • Lake sturgeon identified on NYSDEC's environmental resource mapper.	Section 7 of Endangered Species Act.	This consultation is required prior to the issuance of USACE permits.

Level of Government	Agency	Permit/ Consultation Name	Reason for Permit	Duration of Agency Review	Permit Fees	Information Required for Application	Statute	Notes
Federal/State	New York State Historic Preservation Office (NYSHPO)	Section 106 Consultation Section 14.09 of the New York State Historic Preservation Act (NYSHPA)	Historic nature of the Erie Canal and potential historic properties in the surrounding area	Typically one month	None	• Information gathered during desktop review, such as use of the Cultural Resource Information System (CRIS) • CRIS can also be used to submit consultations and requires Application Needs numbers 1, 3, 9, 16 and optional 10, 11, 19, 26, • Visual impact assessment may be required for historic resources along dry canal section or in area of boat lifts.	National Historic Preservation Act of 1966 (as amended) (16 U.S.C. 70) – Section 106 Consultation (Advisory Council on Historic Preservation) – Consultation with the State Historic Preservation Offices (SHPO) of New York, relative to potential effects on historic properties is required.	This consultation must be completed prior to completion of SEQRA review or issuance of USACE permits.
State	Any State or local agency issuing a permit or undertaking the action would be subject to SEQR compliance.	State Environmental Quality Review Act (SEQRA)Environmental Impact assessment would be required under SEQRA.	Assessment under SEQRA may be required if the project involves the physical alteration of 10 acres. Could also be considered an Unlisted Action if under 10 acres of disturbance from creation of a dry canal. All discretionary decisions of an agency to approve, fund, or directly undertake an action which may affect the environment are subject to review under SEQR. Also any unlisted action that may affect 2.5 acres and affect a historic structure or historic place would require SEQRA review.	Will vary based on whether or not an Environmental Impact Statement (EIS) is required. If no EIS, can be completed in 2-3 months. If EIS is required additional reviews and public review periods will be required. Can take more than 6 months. 6NYCRR Part 617 details SEQRA review process.	None	The information contained in the Short or Long Environmental Assessment forms. The EAF Mapper supplies much of the necessary information. https://www.dec.ny.gov/permits/6191.html	6NYCRR part 617 State Environmental Quality Review Environmental Conservation Law Sections 3-0301(1)(b), 3-0301(2)(m) and 8-0113	SEQRA review can be submitted concurrently with permit applications, but must be completed prior to issuance of State level permits.
State	New York State Department of Environmental Conservation	Supplement D1 to Joint Permit Application: Permit for the Construction, Reconstruction, or Repair of a Dam or other Water Impounding Structure	Modification or sealing of locks would constitute work on a water impounding structure.	Would be submitted and reviewed as a supplement to the Joint Permit Application which typically has 4-6 month review duration. 6NYCRR Part 621 details review process.	None	NYSDEC Supplement D-1 for the Construction, Reconstruction or Repair of Dam or other Impoundment Structure. Application Need numbers 6, 16, and 19-23	Article 15 of the New York State Environmental Conservation Law	Application form can be found at this link: https://www.dec.ny.gov/docs/permits_ej_operations_pdf/spplmntd1.pdf
State	New York State Department of Environmental Conservation	New York State Pollution Discharge Elimination Permit	Potential discharge of bleach and warm wash water associated with the operation of the boat wash may require a permit.	Typically 4-6 months and will vary depending on whether or not a public hearing is required. Review procedures are detailed in 6NYCRR Part 621.	Will vary with volume of discharge. For industrial sources with an average discharge of less than 10,000 gallons per day the annual permit fee is $675.	Information required for application is contained in form NY2C and can be found at this link: https://www.dec.ny.gov/docs/permits_ej_operations_pdf/form2c.pdf	Article 17 of the New York State Environmental Conservation Law	-
State	New York State Department of Environmental Conservation	SPDES Stormwater Discharges from Construction Activities	Before commencing construction activity, the owner or operator of a construction project that will involve soil disturbance of one or more acres must obtain covered under the State Pollutant Discharge Elimination System (SPDES) General Permit for Stormwater Discharges from Construction Activity.	5 to 60 calendar days depending on if conforming or non-conforming SWPPP.	$110 for construction Construction (one time initial authorization fee) $110 per disturbed acre and $675 per future impervious acres	Information on the size, duration, and nature of project related disturbance as well as construction and stormwater control methods.	Section 402 of the Clean Water Act Article 17, Titles 7, 8 and Article 70 of the Environmental Conservation Law	http://www.dec.ny.gov/chemical/43133.html

Level of Government	Agency	Permit/ Consultation Name	Reason for Permit	Duration of Agency Review	Permit Fees	Information Required for Application	Statute	Notes
State	Office of General Services - Underwater Lands	Permit to Occupy State-Owned Underwater Lands	Project activities will take place in State-owned underwater lands	Typically one month	None	See application needs number 28-34. Information required is contained in the application form at this link: https://ogs.ny.gov/system/files/documents/2019/03/75-7b-easement2-08-2019.pdf	Article 6 Section 75 Subdivision 7(b) of the Public Lands Law	SEQRA review documents can be submitted concurrently with permit applications, but SEQR review must be complete before permit issuance.
State	New York State Department of Conservation (NYSDEC)	Freshwater Wetlands	Project activities will take place in wetlands or within 100ft buffer zone.	Typically 4-6 months and will vary depending on whether or not a public hearing is required. Review procedures are detailed in 6NYCRR Part 621.	$200	Delineation of wetlands at project site, site plans, photos, description of activity. Utilizes the same NYSDEC USACE Joint Permit Application Form.	NY ECL Article 24	http://www.dec.ny.gov/permits/6058.html
State	New York State Canal Corporation	Canal Permit: Occupancy or Work	Occupancy permits are issued to allow the occupation and use of Canal real property irrespective of whether any work-related activity may be occurring on such property. Occupancy permits are issued for an array of temporary approved uses including access, beautification, water diversion, docking and many other uses as long as they do not interfere with operation or maintenance of the Canal System and are consistent with the Canal Recreation way Plan and the Corporation's goals. Work permits are issued to allow an improvement or a physical alteration to be made to Canal real property. Work permits may also be issued for short term use that may not warrant an occupancy permit, such as an event on Canal property or for contractor pre-bid visits.	Not stated within application materials	$25.00	Description and location of activity. Application form can be found at this link http://www.canals.ny.gov/business/realproperty/permits.html	N/A	-
Municipal*	City of Rome	Site Plan Review	Site plan review is required for large projects.	Public hearing within 62 days of receipt of complete application. Planning board must issue decision within 30 days of hearing.	Major Site Plan Application (more than 1 acre or more than 5,000 square feet) = $250.00 Minor Site Plan Application (less than 1 acres and less than 5,000 square feet) = $50.00	The information required is contained within the application form at this link: https://romenewyork.com/wp-content/uploads/2016/04/Planning-Board-Application-2016.pdf	Chapter 80 - Zoning Code Article XIX. - Zoning Applications Sec. 80-19.4-Site Plan Review	Completed SEQRA EAF documents are required with submission of application.
Municipal*	Village of Fort Edward	Site Plan Review	The overall purpose of the site plan review is to plan for the design of commercial, residential and industrial development when it occurs on a single parcel of land and to assess the suitability of the proposed development to the natural conditions of the site and compatibility with surrounding uses.	Determination of completeness within 45 days of the filing of a site plan application. Public hearing within 62 days of receipt of complete application. Decision within 62 days of completion of public hearing.	$50.00 processing fee - additional fees may be required before Planning Board review	The information required for is contained within the application form at this link: https://villageoffortedward.com/assets/pdf_files/UPDATED-%20Site%20Plan%20Review%20Requirements.pdf	Part II: General Legislation/ Zoning Article IX Site Plan Review §350-9-1 through 9-5.	Completed SEQRA EAF documents are required with submission of application.

Level of Government	Agency	Permit/ Consultation Name	Reason for Permit	Duration of Agency Review	Permit Fees	Information Required for Application	Statute	Notes
Municipal*	City of Rochester	Site Preparation Permit	A site preparation permit is required when activities are within wetlands, within the floodplain of any watercourse, excavation which affects more than 50 cubic yards of material, filling which exceeds a total of 50 cubic yards of material within any parcel or contiguous area.	Within 60 days after the date of filing a complete application	$750 if a SWPPP is required, $250 if no SWPPP required	The information required is contained within the application form at this link: https://www.cityofrochester.gov/zoningforms/	Part II, General Ordinances / Building Code / Site Preparation and Stormwater Pollution Prevention Part I Site Preparation § 39-400 through 414	Completed SEQRA EAF documents are required with submission of application.
Municipal*	City of Oswego	Site Plan Review	All building permits must undergo a site plan review and approval by the planning board before a building permit is issued	Not stated within the regulations. Applications are reviewed monthly by the planning and zoning commission. Likely similar to the other municipalities listed.	$150 for Site Plan Review and/or Special Permit	The information required is contained within the application form at this link: https://www.oswegony.org/government/planning-board-application	Part II: general Legislation / Zoning Article XXII Site Plan Approval §280-48 through 51	Completed SEQRA EAF documents are required with submission of application.

*Municipal permits are only anticipated if construction footprint exceeds NYPA property boundaries.

Alternative 2

Level of Government	Agency	Permit/ Consultation Name	Reason for Permit	Duration of Agency Review	Permit Fees	Information Required for Application	Statute	Notes
ALL PERMITS FROM ALTERNATIVE ONE PLUS THE POTENTIAL PERMITS BELOW.								
Federal	Environmental Protection Agency	Federal Insecticide Fungicide Rodenticide Act (FIFRA)	Use of carbon dioxide as a pesticide/piscicide is subject to EPA review and may require FIFRA registration, if the proposed use differs from the existing EPA-accepted label	The Agency will complete its review of applications as expeditiously as possible	New Use Pattern up to $33,800 Old Chemical up to $4,000 Amendment up to $700	Information for application can be found at 40 CFR CFR § 152.50 - Contents of application (https://www.law.cornell.edu/cfr/text/40/152.50)	40 CFR Part 152 - Pesticide Registration and Classification Procedures	Potentially applies if the use of CO_2 as a deterrent is considered a piscicide as indicated in page 218 of the Great Lakes and Mississippi River Interbasin Study-Brandon Road EIS. https://usace.contentdm.oclc.org/utils/getfile/collection/p16021coll7/id/11394
State	New York State Department of Conservation (NYSDEC)	SPDES Aquatic Pesticides General Permit	Discharge of CO_2 into waters of NY may constitute the discharge of a pollutant or be considered a pesticide.	One month.	Annual fee of $110. No fee for permit application review.	Necessary information is contained in the Noticed of Intent Forms (NOI) and includes the targeted pests, EPA registration numbers, application information, and project locations.	Article 17 of the Environmental Conservation Law	The use CO_2 has the potential to lower pH in the area of discharge. pH impacts would be a part of the water quality certificate review. NY water quality standard for pH is a delta of 0.1 pH units

Alternative 3

Level of Government	Agency	Permit/ Consultation Name	Reason for Permit	Duration of Agency Review	Permit Fees	Information Required for Application	Statute	Notes
ALL PERMITS FROM ALTERNATIVES ONE AND TWO PLUS THE POTENTIAL PERMITS BELOW.								
Municipal*	Town of Cicero	Site Plan Review	Site plan review is required for all new construction of structures. Would likely be required for boat lift and wash.	Review shall commence with the first meeting after receipt of a complete application, and a decision to approve, approve with modifications, or disapprove such proposal shall be made no later than 62 days from the first Planning Board meeting at which a complete application is received	$1,000 if SWPPP required Medium Site Plan filing fee $400 Legal fee $1,000, Engineering Deposit $3,000 Major Site Plan Engineering Deposit $7,500-$11,000	https://ciceronewyork.net/wp-content/uploads/2019/03/Site-Plan-Application-3-28-19.pdf	Part II: General Legislation / Zoning Article VII Site Plan Approval §210-27 through 210-29	Brewerton a part of the Town of Cicero https://ecode360.com/12300188?highlight=plan,planning,plans,site,site%20plan,site%20plans&searchId=2502284645434449#12300188
Municipal*	Village of Baldwinsville	Site Plan Review	Site plan review is required for all new construction of structures. Would likely be required for boat lift and wash.	Not stated within the regulations	Site Plan $250	http://www.baldwinsville.org/boards/planning	Part II: General Legislation / Zoning Article XIII Site Plan Approval §345-33 through 345-35	https://ecode360.com/15972197?highlight=plan,planning,plans,review,site,site%20plan,site%20plan%20review,site%20plans&searchId=2527552351089096#15972197
Municipal*	Town of Waterford	Site Plan Review	Site plan review is required for all new construction of structures. Would likely be required for boat lift and wash.	Within 45 days of receipt of the application for site plan approval or, if a public hearing is held, within 45 days of the public hearing, the Planning Board shall render a decision.	$50	http://www.town.waterford.ny.us/government/town-services/town-zoning-board.html	Part II: General Legislation / Zoning Chapter 131 Site Plan Review §131-10 through 131-18	https://www.ecode360.com/13678802

*Municipal permits are only anticipated if construction footprint exceeds NYPA property boundaries.

Requirements for permit applications.

Item Number	Item Description	Application Need
1	General Description of Planned Project	JPA
2	Purpose	JPA
3	Description of type of structures, and area affected, quantity of fill	JPA
4	Volume of Dredged material and location of material placement	JPA
5	Description of Construction, Work Methods and Equipment	JPA
6	Sequence of Activities	JPA
7	Schedule	JPA
8	Alternatives Considered	JPA
9	Permits Required and Status	JPA
10	Description of Existing Site Conditions	JPA
11	Proposed Site Changes	JPA
12	Pollution Control methods and proposed mitigation for environmental impacts	JPA
13	Erosion & Silt Control methods	JPA
14	Location Map	JPA
15	Project Plans	JPA
16	At least 3 color photographs taken from multiple directions	JPA
17	SEQR Environmental Assessment Forms	JPA
18	Names and addresses of adjacent property owners	Environmental Questionnaire
19	Environmental Impact Statement/Assessment	Environmental Questionnaire
20	A plan showing the proposed dam and dam appurtenances, horizontal and vertical controls, the normal water level in the lake or pond, the limits of the owner’s property, the location of drill holes, test pits or other foundation exploration, the location of borrow areas, and topographic contours at the dam and around the anticipated reservoir area, including 2-foot contours to 6 feet above high water level.	Supplement D-1
21	A profile along the dam axis from abutment to abutment and a cross section diagram of the dam at its maximum height, showing original, existing, and proposed conditions.	Supplement D-1
22	A profile along the center line and a cross section diagram, or diagrams, of the spillways, including stilling basins, outlet work, and other details of the design of the structures.	Supplement D-1
23	A description of construction inspection activities, to be performed by the applicant’s engineer, to ensure that work is performed in conformance with the approved design.	Supplement D-1

Item Number	Item Description	Application Need
24	A record of subsurface investigation and soils information used by the design engineer or conservationist for foundation and borrow assessment.	Supplement D-1
25	Coastal Assessment under policies described in the Coastal Management Program Document	NYSDOS Federal Consistency Assessment Form
26	GIS shapefiles	
27	A map made by a licensed land surveyor pursuant to Section 7208 of the New York State Education Law showing the location of proposed structure(s), the upland property of the applicant and those of adjoining properties along the waterfront;	NYSOGS Application for easement, lease, or permitted use of land underwater.
28	A metes and bounds description of the lands applies for including the desired width of the proposed easement. The description shall refer to permanent tie points or monuments on the shore;	NYSOGS Application for easement, lease, or permitted use of land underwater.
29	A certified copy of the deed(s) of the applicant's adjacent upland;	NYSOGS Application for easement, lease, or permitted use of land underwater.
30	A copy of adjoining shorefront deed(s) and a copy of the applicable tax map section;	NYSOGS Application for easement, lease, or permitted use of land underwater.
31	A duplicate copy of any permit or letter issued by a local or governmental regulatory agency including but not limited to the U.S. Department of the Army Corps of Engineers, the New York State Department of State, The New York State Department of Environmental conservation.	NYSOGS Application for easement, lease, or permitted use of land underwater.
32	A completed environmental assessment form, if applicable	NYSOGS Application for easement, lease, or permitted use of land underwater.
33	Other satisfactory evidence of compliance with the State Environmental Quality Review Act;	NYSOGS Application for easement, lease, or permitted use of land underwater.
34	The Commissioner may require additional submissions such as permits and/or letters from the NYS Office of Parks, Recreation and Historic Preservation, the Power Authority of the State of New York and county or local agencies.	NYSOGS Application for easement, lease, or permitted use of land underwater.