



DEPARTMENT OF NATURAL RESOURCES

FEASIBILITY STUDY

MISSISSIPPI RIVER LOCK AND DAM 5 SELECTIVE NATIVE FISH PASSAGE

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Prepared for:
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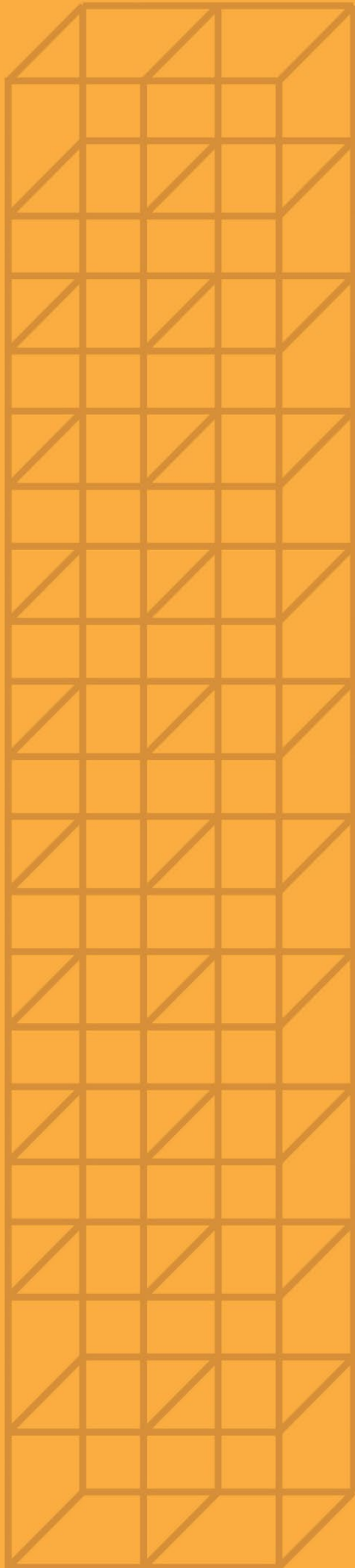


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EXECUTIVE SUMMARY

This report focuses on identifying and evaluating selective native fish passage options for potential implementation at Lock and Dam 5 (LD5) on the Mississippi River near Minnesota City, Minnesota.

In coordination with Minnesota Department of Natural Resources (DNR) staff, WSB developed a list of eight (8) existing fish passage options. We then applied three (3) levels of evaluation to this list. The first level was a pass/fail evaluation in which we determined if the option was or could be adapted to be selective; allowing native fish to pass and disallowing invasive fish to pass.

Four (4) options passed, and a second level evaluation was applied in which we used 10 metrics to score each option with a most preferred, moderately preferred, and least preferred qualitative score. A scoring matrix which provides a qualitative score for each metric along with comments was then created and is included in Appendix A.

In the final evaluation process the project team reviewed each of the four (4) options and included selectivity and deterrent augmentation components, added details to the design option based on site characteristics and data gathered on fish metrics, river flow, and LD5 operations. Cost estimates and operation and maintenance considerations were also developed in this phase.

The evaluation process detailed in this report is not intended to provide a singular recommended selective fish passage option. Rather, the purpose is to aggregate and synthesize input and discussion from the LD5 technical working group along with existing data on selected fish passage options, existing technology, and project team expertise to provide a robust evaluation that the DNR and its partners can use as a launching pad for further quantitative evaluation, prioritization, and potential selection of a selective native fish passage option that can be implemented at LD5 and from which findings can be scaled and applied to other locales where selective fish passage is needed.

1.0 INTRODUCTION

This section provides foundational information on the Mississippi River near LD5, the LD5 structural components, operations, and purpose, invasive and native fish species found near LD5, and a brief discussion on potential invasive fish deterrents that have been proposed for this location. This is the result of an initial literature review completed by the project team.

This same data can be found in multiple published reports covering a variety of topics such as invasive carp sampling surveys, invasive carp planning documents, LD5 deterrent feasibility studies and multiple others (see reference page).

We are presenting the foundational data in this document so that readers unfamiliar with LD5, the river, and/or the fish species present become informed and those that are familiar have that information in one document.

1.1 Project Purpose

The purpose of this project was to evaluate selective native fish passage options for LD5. Options selected for final evaluation need to disallow invasive fish passage while providing upstream passage for native fish.

1.2 Description of MS River upstream and downstream of LD5

The Mississippi River widens to approximately 3,500 feet two miles upstream, and the river narrows to an estimated 1,000 feet a mile downstream of LD5 with an average depth between 9 and 12 feet deep.

14.7 miles upstream of LD5 is Lock and Dam 4 (LD4) that controls a watershed of 57,100 square miles. This active lock and dam, which is located in Alma, WI and borders Minnesota, has a similar design to LD5 with two locks, six roller and 22 tainter gates spanning across the river, that provide flood control and watercraft navigation. This structure is the beginning of water control regulation for LD5 therefore inflow is determined based on operations of LD4 inflow and is computed as part of the “river program” based on gate settings or tailwater rating curve. The target pool elevation at Alma is 660' +/- 0.20' which if not met affects LD5 operations. If it is lower, it may be due to sedimentation buildup and dredging may be required at LD5.

9.6 miles downstream of LD5 is LD5A which controls a watershed of 59,105 square miles. This active lock and dam located near Fountain City, WI also contains two locks, but with five roller and tainter gates only spanning a portion of the Mississippi River. The remaining section of the river is controlled by a 1,000 ft. long concrete overflow spillway. LD5A is used for watercraft traffic, flood control, and recreational activities such as fishing.

1.3 Description of LD5

The descriptions below are based on descriptions in the *Water Control Manual, Mississippi River Nine Foot Channel Navigation Project, Lock and Dam 5, Minneiska, Minnesota, Appendix 5 of the Master Water Control Manual* updated September, 2002.

Elevations are referenced to the Mean Sea Level datum (1912 adjustment).

The descriptors left and right are referenced looking downstream.

1.3.1 Purpose of Facility

The main purpose of the facility, as part of the Inland Waterway Navigation System of the Upper Mississippi River Basin, is to maintain a minimum nine-foot-deep navigational channel for barge traffic on the Mississippi River. Facilities are also provided for recreation, but water is not controlled for that purpose.

1.3.2 Location

LD5 is located on the Mississippi River 738.1 river miles above the mouth of the Ohio River, 14.74 river miles below LD4, and 9.6 river miles above LD5A. The lock is on the right bank of the river 4.3 river miles below Minneiska, Minnesota and 12.4 river miles above Winona, Minnesota.

1.3.3 Ownership

LD5 is owned and operated by the United States Government, and is regulated, operated, and maintained by the United States Army Corps of Engineers (USACE), St. Paul District.

1.3.4 Description of Facility

LD5 consists of a main lock and an uncompleted auxiliary lock, a moveable dam section, and an earthen dike. The locks and the moveable dam are supported on timber piling driven into sand and gravel with sheet pile cutoff walls upstream and downstream.



FIGURE 1.3.4-1. Overhead View of LD5

Lock

The main lock is 110 feet wide with a clear length of 600 feet. The upper miter gates have a height of 20.0 feet and a sill elevation 642.0 feet. The lower miter gates have a height of 23.0 feet and a sill elevation of 639.0 feet. The top of the miter gates elevation is 662.0 feet, and the top of lock wall elevation is 665.0 feet. The filling and emptying of the lock chamber is controlled by two tainter valves; each at the upper and lower ends of the lock.



FIGURE 1.3.4-2. Photo of main lock taken from miter gate looking upstream to north end of main lock

Guidewalls are located upstream and downstream of the lock. The upper guide wall extends 521 feet upstream of the lock, and the lower guide wall extends 504 feet downstream of the lock.

The auxiliary lock consists only of an upper gate bay and has only a single set of miter gates with a height of 23.0 feet and a sill elevation of 639.0 feet. If needed, the miter gates in the auxiliary lock can be pulled and used to replace miter gates in the main lock as needed. There is currently a rock-filled, sheet pile bulkhead in place upstream of the auxiliary lock miter gates. USACE staff have indicated that there are currently no plans to complete the auxiliary lock and place it in service.



FIGURE 1.3.4-3. Upstream End of Auxiliary Lock (Primary Lock is to the left and above of the auxiliary lock in the image)

Moveable Dam

The movable dam is a 1,619-foot-long gated spillway consisting of 6 cylindrical roller gates, and 28 Tainter gates.

The roller gates are 60-feet wide by 20-feet high with a sill elevation of 640.0 feet and can be submerged up to three feet below normal pool. Each roller gate is operated by an individual, electrically operated hoist, and has a travel rate of approximately 0.75 feet per minute.



FIGURE 1.3.4-4. Roller Gates looking North

The tainter gates are 35-feet wide by 15-feet high with a sill elevation of 644.5 feet. Four of the tainter gates can be submerged up to two feet below normal pool. Each tainter gate is individually operated by an electrically operated central driving unit connected to two chain hoisting units. The tainter gates have a travel rate approximately equal to the roller gate travel rate of 0.75 feet per minute.



FIGURE 1.3.4-5. Span of Service Bridge Looking West with Tainter Gates and Service Crane (left side of image is downstream).

A service bridge, at elevation 688.0 feet, spans the entire length of the movable dam and storage yard and provides for operation of the 60-foot boom crane with a carrying capacity of 25 tons. The boom crane is used to move and place bulkheads for gate maintenance.

Earthen Dike

The earthen dike is 18,219 feet long and extends northwest from the end of the moveable dam section to the high ground on the Wisconsin side of the river. The earthen dike has a crest elevation that varies from 670.0 feet at the dam to 672.0 feet at the end of the dike. The dike has four aeration culverts: One 36-inch corrugated metal culvert which can be controlled by stoplogs which are stored on site, and three 48-inch corrugated metal culverts which are controlled by sluice gates.

1.3.5 Operation

The gates at the facility are operated to maintain a minimum upper pool elevation of 660.0 feet at the primary control point, which is located at river mile 749.3, approximately 2.7 miles downstream of Alma, Wisconsin, while maintaining a maximum drawdown at the dam of 0.5 feet to elevation 659.5 feet. Elevation is maintained at the primary control point until discharge at the dam is sufficient to allow for a drawdown at the dam. As discharge increases, the gates are raised to maintain the target elevation at the control point while also maintaining the maximum drawdown at the dam. Eventually, as discharge continues to increase, the gates are raised above the water surface and open river conditions exist. At this point, the dam is said to be “uncontrolled conditions.”

During non-winter operations, the gate adjustments required each day are determined by the Water Control River Manager, who sends orders via email to LD5 every day at least once per day in the morning. Required gate operations are determined based on flows from LD4 and from the Zumbro River using the Gate Regulation Schedule found in the *Water Control Manual*.

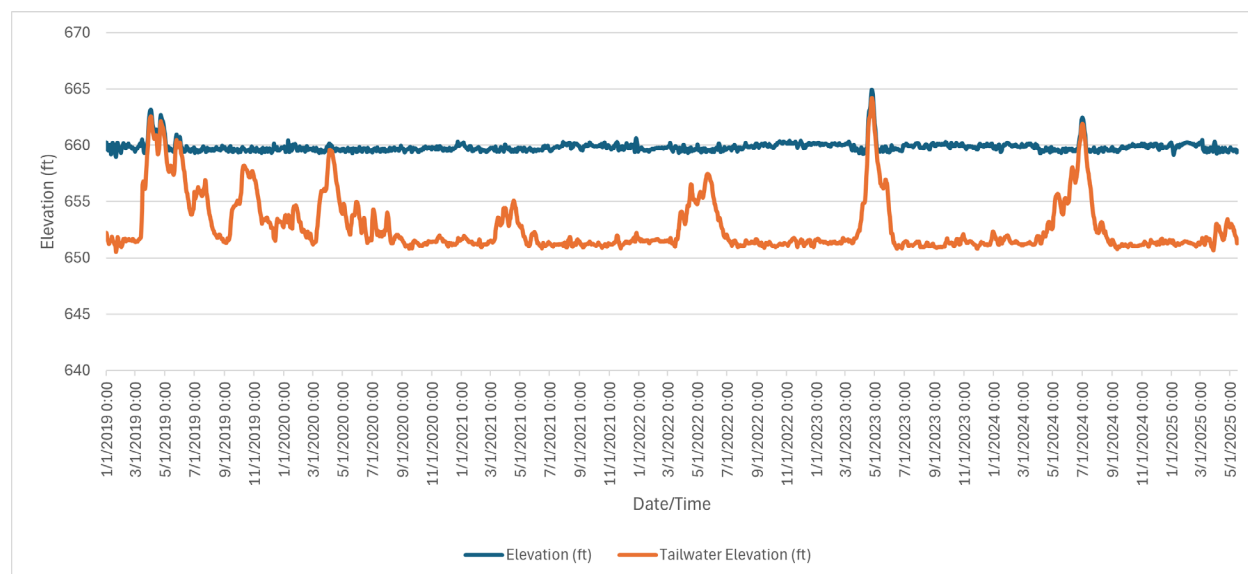


FIGURE 1.3.5-1. Timeseries plot of Pool Elevation (Blue Line) and Tailwater Elevation (Orange Line) starting January 1, 2019 and ending May 1, 2025.

As seen above, the upstream pool elevation is relatively static at 660' elevation except for five (5) periods; 1 in March/April 2019, 1 in April/May 2019, 1 in May/June 2019, 1 in April/May 2023 and the other in June/July of 2024. The downstream tailwater elevation shows more variability but rarely is in equilibrium with the upstream pool elevation. Based on the time series data above, this occurred five (5) times over a 6-year period. When this happens, fish may be able to pass over the structure as there would be no impediment to movement, except for flow velocity.

During winter operations, the tainter gates are set at predetermined heights and allowed to freeze in place based on an estimate of the anticipated minimum base flow for the winter months. The roller gates are submerged at a minimum of 1 foot in the winter and can be adjusted in the submerged position to provide some regulation of flow.

The main lock is operated as required to pass both commercial and recreational traffic up and downstream. During winter operation, the tainter valves in the lock walls are kept open so that the lock chamber will remain ice free. The auxiliary lock was never completed, is not used, and currently has a permanent bulkhead in place at the upstream end.

1.4 Fisheries

The fishery assemblage of the Mississippi River within and bordering Minnesota is diverse, which presents a challenge for designing a selective fish passage but underscores the need for one. We created a list of both native and invasive fish species that are present in the Mississippi River in this area using data from DNR surveys, the Upper Mississippi River Restoration Program-Long Term Resource Monitoring, and National Park Service's "Fish of the Mississippi River" webpage (accessed on 4/23/25) which resulted in 122 different species (native and invasive fish). This list was reduced to 102 species after discussion with DNR project staff to be reflective of those species which have been found within the stretch of river near LD5.

The FishPass sortable attribute database provides data on 4 primary attribute types that can influence movement which are phenological, morphological, physiological, and behavioral attribute data (Benoit, 2023). Using this data, we filtered the list to identify migratory species. However, FishPass includes an attribute titled “migratory and non-migratory” so those species were included in the list. The final list of migratory and migratory and non-migratory fish species is included in Appendix B. Species that were nonmigratory and not within range of LD5 were removed from the list. The remaining 83 species are migratory, nonmigratory and migratory, and within range of LD5. These species exhibit similar characteristics, including diet, preferred spawning temperature, and reproduction timing. A summary of additional life history characteristics compiled from the FishPass database can be found in Appendix C.

One option we explored was to develop a prioritized list of native fish species to reduce the volume of attribute data needed for consideration in development of the selective fish passage option such as swim speeds, size, etc., but after discussions with DNR staff, no native fish species priority list was created.

1.4.1 Invasive Carp

Three (3) invasive fish species were identified by the DNR as those that should be considered when designing a selective fish passage option, as the option would need to prevent movement of these species from downstream to the upstream pool. These include:

- Silver Carp (*Hypophthalmichthys molitrix*)
- Bighead Carp (*Hypophthalmichthys nobilis*)
- Grass Carp (*Ctenopharyngodon idella*)

Black Carp (*Mylopharyngodon piceus*) were not included in the lists described above as they are not found near LD5. The authors recognize there are other invasive fish species within the Mississippi River, but addressing passage of those species is not within the scope of this project.

These species were originally imported into the United States to support fish aquaculture operations and improve water quality in retention ponds. It is believed that large flood events enabled these fish to escape into the Mississippi River, where they established wild populations.

Invasive carp pose significant ecological, recreational, and economic threats. These species compete with native fish species for food, decrease water quality, and can damage watercraft and injure their operators (DNR, 2025). Silver and Bighead carp feed on plankton, which reduces the amount available for native fish (such as young lake sturgeon, paddlefish, and several other juvenile native fish) and has negative impacts at various trophic levels and to other non-fish species. Additionally, Silver Carp also jump when startled, which can cause serious injury to boaters, boat equipment, and other fish. Grass carp feed on submerged aquatic vegetation which reduces ecological integrity as native aquatic vegetation acts to reduce the erosive effect of wind, waves, boat wakes, sequesters phosphorous, and provides habitat for small fish and invertebrates.

Invasive carp reproduction has not been confirmed in Minnesota to date. However, invasive carp migrations are associated with spawning activity, rising water temperatures, and increased water levels. Their spread throughout Minnesota may be occurring during flood events and through lock and dam structures when the locks are opened for watercraft traffic or when gates are open. While there is no evidence of invasive carp reproduction in Minnesota, groups of adults have been caught in the Mississippi River. Invasive carp are known to spawn when water temperatures range from 17 °C to 32°C. Based on USACE water temperature data at LD5, these conditions typically occur between May and August, suggesting that reproductive activity could be possible during this period.

The burst and sustained swim speeds for carp species are summarized in Figures 1.4.1-1 and 1.4.1-2. It should be noted that swim speed data for grass carp reflects that of juvenile individuals. Juvenile grass

carp are provided due to a lack of literature regarding adult grass carp sustained and burst swim speeds. Body length of grass carp ranged from 2 to 9 centimeters. It is important to note that adult grass carp are expected to achieve faster swim speeds than is reflected in Figures 1.4.1-1 and 1.4.1-2. The body length of bighead carp in these studies ranged from 52.5 to 90.8 centimeters while the body length of silver carp ranged from 75 to 80.1 centimeters.

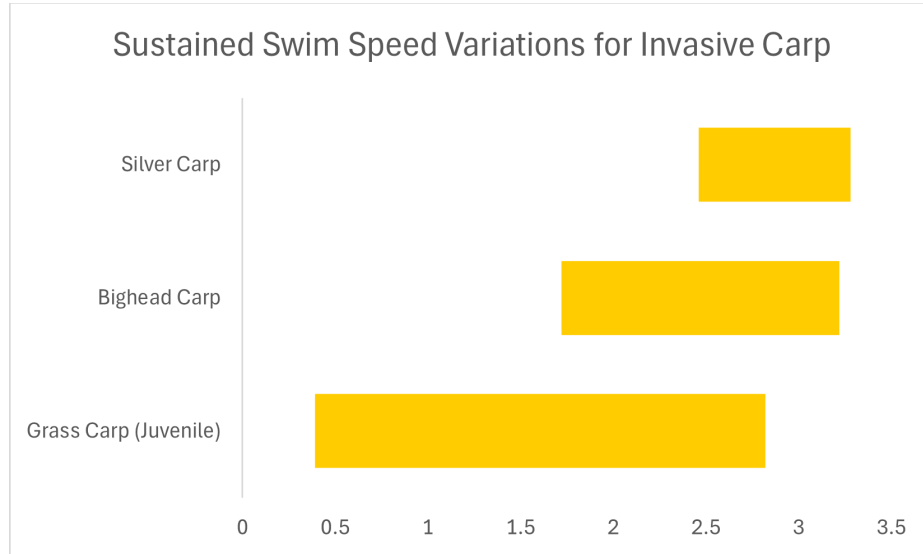


FIGURE 1.4.1-1. Invasive Carp Sustained Swim Speeds (>200-minutes).

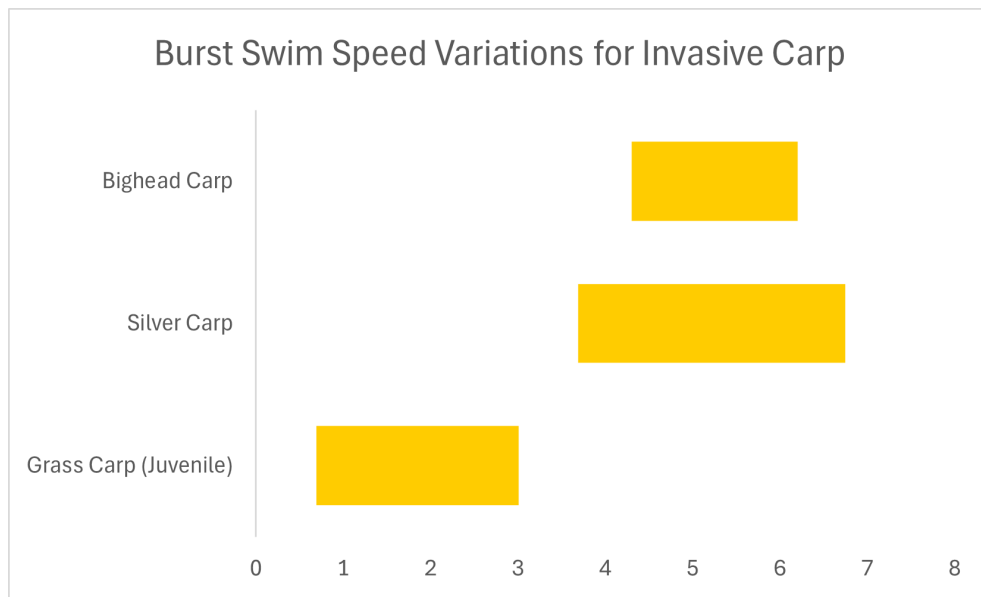


FIGURE 1.4.1-2. Invasive Carp Burst Swim Speeds (<30 seconds).

1.4.2 Native Fish Species

Of the 83 species identified for consideration as discussed in section 1.4, 80 fish species are native to Minnesota. This list does not include any federally listed threatened or endangered species, however there are state-listed fish species within the project area. These are identified in Table 1 below.

TABLE 1.4.2-1. Fish Species Listed as Endangered, Threatened, or Special Concern by the State of Minnesota. This data was compiled using the DNR Rare Species Guide (DNR, 2025).

| Designation (State of MN) | Common Name | Scientific Name |
|---------------------------|------------------------------|--------------------------------|
| Endangered | Skipjack Herring | <i>Alosa chrysochloris</i> |
| | Crystal Darter | <i>Crystallaria asperella</i> |
| | Pallid Shiner | <i>Hybopsis amnis</i> |
| Threatened | Black Buffalo | <i>Ictiobus niger</i> |
| | Paddlefish | <i>Polyodon spathula</i> |
| Special Concern | Lake Sturgeon | <i>Acipenser fulvescens</i> |
| | American Eel | <i>Anguilla rostrata</i> |
| | Pirate Perch | <i>Aphredoderus gibbosus</i> |
| | Redside Dace | <i>Clinostomus elongatus</i> |
| | Blue Sucker | <i>Cycleptus elongatus</i> |
| | Bluntnose Darter | <i>Etheostoma chlorosoma</i> |
| | Mississippi Silvery Minnow | <i>Hybognathus nuchalis</i> |
| | Warmouth | <i>Lepomis gulosus</i> |
| | Yellow Bass | <i>Morone mississippiensis</i> |
| | Black Redhorse | <i>Moxostoma duquesnei</i> |
| Suckermouth Minnow | <i>Phenacobius mirabilis</i> | |

To create the list, a filtered search was performed. The data was filtered to show all federal and state listed fish species in Winona County. The search results are demonstrated in Table 1.4.2-1. The Pirate Perch, Redside Dace, and Warmouth are nonmigratory and are therefore not analyzed further within this report. Additionally, the Bluntnose Darter, Mississippi Silvery Minnow, and Pallid Shiner have an unknown migratory status; therefore, these species were not considered further or listed.

To determine which life history traits should be considered, a literature review was conducted, with a focus on studies from Minnesota. The review revealed that five fish guilds are most closely linked to the selective passage and movement of freshwater fish. These guilds were defined by several key attributes: maximum total length, trophic level, relative eye size, spawning temperature, spawning season, the presence or absence of ampullary electroreceptors, and hearing specializations (Benoit et al., 2024). In addition to these attributes, this report also includes the approximate body depth and climbing ability of each species. Utilizing data from the online FishPass database, these characteristics are compiled in Appendix C (Benoit et al., 2025). As discussed later in the report, (Final Evaluation- Deterrent Augmentation) attributes such as swim speeds, total length, body depth, and climbing ability were prioritized for selectivity based on size, shape, and swimming abilities.

Most species begin migrating when water temperatures reach between 9°C and 24°C. According to temperature data from the U.S. Army Corps of Engineers (USACE) at LD5, these conditions typically

occur between April and June. However, exact migration dates can vary each year depending on terrestrial temperatures and weather patterns. Fertilization of some species occurs in the water, where the eggs are also incubated and carried by the river's current. Once hatched, the larvae depend on river flow to find food and areas of dense vegetation for shelter. As they grow and age, fish continue to rely on the river for habitat, protection from predators, feeding, migration, and reproduction.

The swimming performance of fish can be categorized by one of three categories: sustained, prolonged, and burst swimming speeds (Beamish, 1978). Sustained swimming speed is maintained for long periods of time (generally more than 200 minutes). Burst swimming is fast, brief (less than 30 seconds) movement. Prolonged swimming is maintained for moderate periods of time (one to 200 seconds) and is transitional swimming between sustained and prolonged. (Hoover, et al. 2016). Unfortunately, there is a lack of literature concerning the swim speeds of the majority of the species found near LD5, likely due to the complexity of such a study. Despite these literature gaps, a review was conducted to find the burst and sustained swim speeds of many species found near LD5, which is located in Figure 1.4.2-1. In addition, various literature sources disagree or state different swim speeds (burst or sustained) for the same species. Because of this, we provide ranges of swim speeds found in the literature, but overlapping swim speeds can hinder the ability to select by swim speed as many of them speeds overlap. Additionally, invasive carp exhibit the fastest or one of the fastest swim speeds for both sustained and burst further complicating the ability to select using this metric.

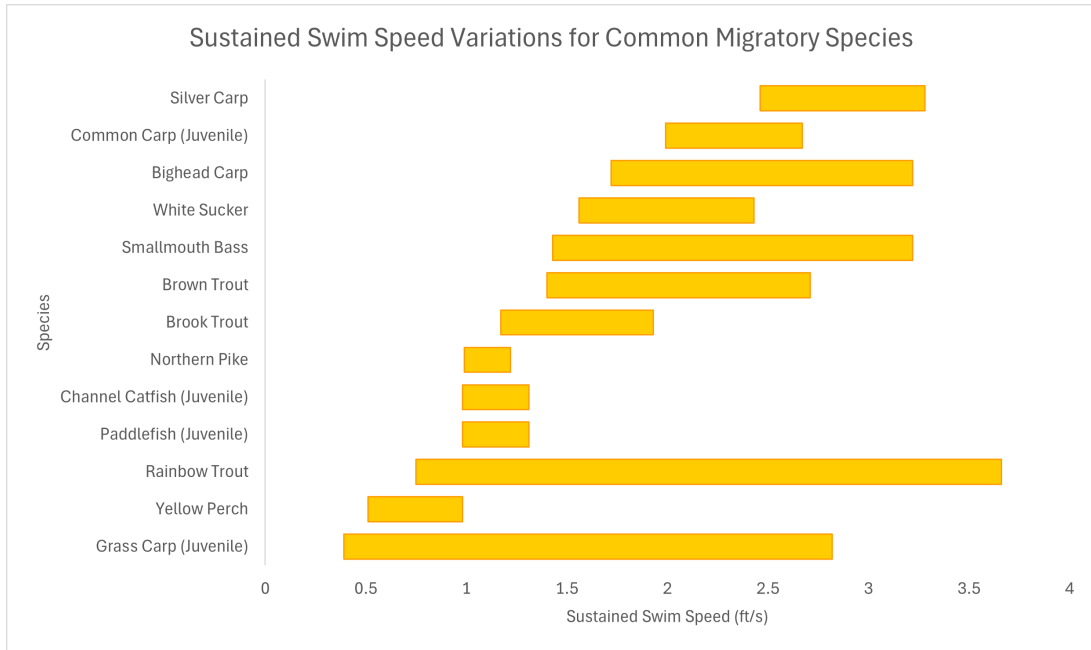


FIGURE 1.4.2-1. Sustained Swim Speeds for Selected Species

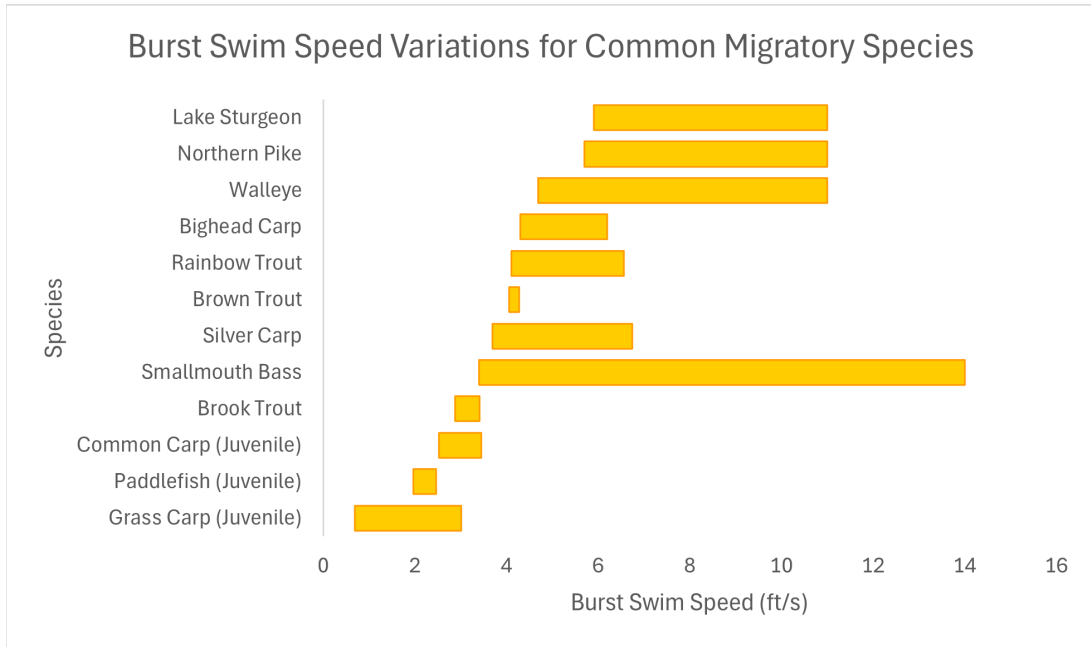


FIGURE 1.4.2-2. Burst Swim Speeds for Selected Species

At LD5, fish migrate upstream primarily through open gates (limited based on water flow velocity) and to a lesser extent the active lock during watercraft traffic operations. Studies are currently being finalized and started to examine invasive and native fish passage at LD5, but it is well established that dams restrict upstream movement, contributing to the decline of many fish populations (NOAA, 2025). Implementing fish passage solutions will support the unrestricted movement of native species and should help to increase their populations.

Based on current studies, upstream movement is halted when lock and dam structures are experiencing high hydraulic head conditions. Upstream passage occurs mainly when hydraulic head is low and open-river conditions are present (Fritts et al., 2024). In another study LD5 was proven to be a significant barrier to upstream fish passage compared to other lock and dam structures that also rarely experience open-river conditions (Zigler et al., 2004). Zigler et al. found that zero paddlefish tagged in Pool 5A passed upstream through LD5, while almost half of tagged paddlefish in Pool 8 passed upstream through LD7. While passage through the navigation lock may be infrequent, it is likely the only route of upstream movement for most of the year (Zigler et al., 2004).

1.5 Deterrent Options

As stated, the purpose of this project is to evaluate selective native fish passage options, not evaluate invasive fish deterrents as a standalone project. However, an understanding of what proposed deterrent options are being considered is important to avoid the location for this separate, standalone project and potentially incorporate elements of fish deterrents into the fish passage options that can augment any given option to make it selective. Deterrent augmentation options are discussed in a separate section of this report, but the narrative below discusses two (2) deterrent options for LD5 that are being considered.

1.5.1 UADS at LD19

In 2023 the U.S. Geological Survey published an update on their Underwater Acoustic Deterrent System (UADS) which had been installed at LD19 on the Mississippi River in 2021. The UADS was designed specifically for LD19 by USACE and USGS engineers and scientists and consists of 16 underwater transducers which produce sounds meant to deter invasive fish passage. The UADS is a purely acoustic system and does not use lights, bubbles, or other means of deterrence.

The USGS used two types of telemetry to evaluate how the UADS affects movement and behavior of both invasive and native fishes. The first is a 69-kHz system to evaluate long-distance fish movements (such as whether the carp have crossed the UADS during an operating cycle). The second is a 307-kHz system which provides detailed information on fish movements and positioning, helping determine more precisely how fish are responding to the sound stimuli provided by the UADS.

The USGS initially operated the UADS at LD19 in cycles of 80 hours on, 80 hours off. This established a periodic cycling schedule so that fish response could be evaluated across a broad range of conditions, including lock operations/vessel passage, weather and flow patterns, and annual fish migration patterns. Operation is now continuous.

Preliminary results suggest that operation of the UADS system reduces the passage of silver carp through the lock by 50%. Native fish such as the bigmouth buffalo were only 1.2 times more likely to pass the lock when the UADS was off versus when it was on.

1.5.2 BAFF at LD5

In 2022 Barr Engineering produced a feasibility study for the installation of a Bio-Acoustic Fish Fence (BAFF) at LD5. A BAFF uses a combination of sound, bubbles, and light to deter fish passage, and the

Barr study determined that a BAFF was preferable to an electrical deterrent barrier at LD5 because it was more selective to carp, had fewer impacts to lock operations (for both commercial and non-commercial traffic), and had fewer safety risks to both lock users and lock operations and maintenance staff. Similar testing of the BAFF to the UADS (as described above) shows that it is ~50% effective in limiting invasive carp passage with limited effect on native fish passage.

Barr also completed a 10% concept design and corresponding cost estimate for the BAFF at LD5.

2.0 OPTIONS EVALUATED

A list of fish passage options was developed based on project staff experience and existing project examples from similar projects in North America. Some of these options were previously identified by participants in the LD5 Workgroup including members from the DNR, USACE, USGS, WI DNR, and tribal natural resource agencies. These options included:

- Fish ladder
- Trap and truck
- Fish elevator
- Siphon fishway/fish cannon
- Gate control velocity
- Nature-like fishway/rock ramp
- Pipe through dam or abutment
- Spillway weir

The LD5 structure is owned and operated by the US Army Corps of Engineers as discussed in Section 1. Implementation and testing of the selective fish passage options identified and evaluated for this project should be done in collaboration with the US Army Corps of Engineers. Furthermore, any option chosen will require local, state, and federal permits which are not identified in this report.

Brief descriptions of each option are provided below.

2.1 Fish Ladder

A fish ladder is a permanent structure that creates a successive series of weirs and pools allowing fish to navigate the elevation change from the lower to upper pool. For LD5, the fish ladder would likely be built in the auxiliary lock, with an exit channel through the current upstream bulkhead. Selective passage measures could be installed at the downstream entrance, the upstream exit, and/or at an intermediate location.



FIGURE 2.1-1 Fish Ladder

2.2 Trap and Truck

Trap and truck refers to attracting the fish to a collection point within the LD5 system, capturing them using electrofishing or netting, and then sorting captured fish into native and invasive fish groups. Native fish would be transported to the upper pool for release, while invasive fish would be removed and disposed of.

2.3 Fish Elevator

A fish elevator consists of a mechanical system installed in the auxiliary lock which would attract fish into a box/cage, lift them out of the river and over the permanent bulkhead, and discharge the fish on the upstream side of the dam. Selective passage measures could be installed at the entrance to the fish

elevator, or at a station located on the upstream side of the lift box prior to the fish being discharged into the upper pool.



FIGURE 2.3-1 Fish Elevator

2.4 Fish Conveyor/Siphon Fishway

A fish conveyor/siphon fishway is a mechanical system that hydraulically moves fish through pipes over a dam or other barrier structure using the siphon effect. This system can facilitate transport in both directions over the dam but is generally intended to move fish from downstream to upstream. The system can be barge mounted and is compatible with a number of proprietary fish recognition systems. The barge would most likely be positioned in the auxiliary lock, with the siphon pipes discharging the fish over the current upstream bulkhead and into the upper pool.



FIGURE 2.4-1 Siphon Fishway

2.5 Gate Control Velocity

This passage option involves manipulating the existing dam gates to create velocities that are compatible with native fish swimming ability (burst and sustained swim speeds) and incompatible with invasive carp swimming abilities. Consideration of growth stage and vertical station within the water column (demersal, pelagic, benthopelagic) should also be made.

2.6 Nature-Like Fishway/Rock Ramp

A nature-like fishway or rock ramp aims to recreate a natural channel system as a way for fish to cross the elevation difference introduced by a dam structure. When constructed they are a passive structure which fish must swim through in order to travel from the lower pool to the upper pool; there is no mechanical means of propulsion or transport.



FIGURE 2.6-1 Rock Ramp Fishway

2.7 Pipe Through Dam or Abutment

A pipe through the dam or the abutment would work similarly to a siphon fishway, but instead of transporting fish over the dam it would transport them through the structural elements of the dam via a pipe. This pipe would be a permanent modification to the structural component of the dam, though engineering controls could be installed to stop or control flow through the pipe depending on the headwater and tailwater elevations at LD5.

2.8 Spillway Weir

Spillway weirs are structures which are attached to the existing spillway beneath the roller or Tainter gates that make the spillway more passable to fish moving from upstream to downstream. Spillway weirs do not facilitate the movement of fish from downstream to upstream.

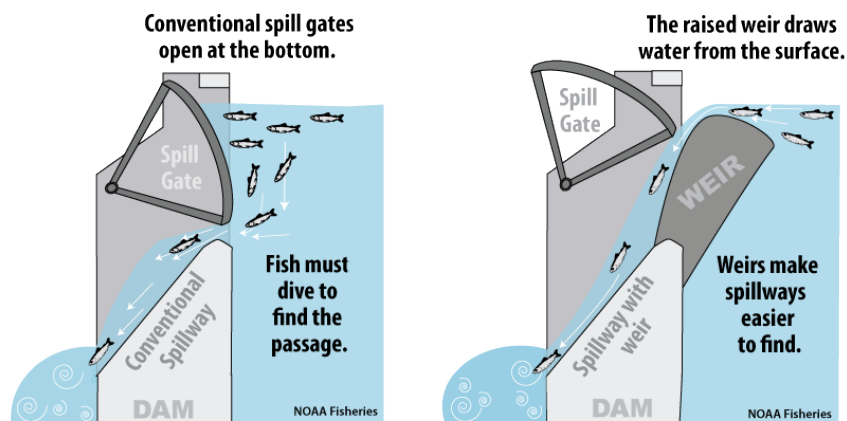


Figure 2.8-1 Spillway Weir

At this phase of the project, options were simply listed, and no evaluation was applied. We approached the evaluation process in this way as we wanted to include as many options as possible but save evaluation for a focused first level pass/fail designation given the time limitations of the project.

Early on in the project, we discussed the applicability of designing a selective fish passage option that could provide passage within the gates and be moved across the LD5 structure as needed. However, as data was collected on the velocity of discharge within and just downstream of the gates and dam operations, the team (after discussing with DNR project staff) pivoted from pursuing this as an option, focusing instead on the auxiliary lock. The project team did not rule out the possibility of fish passage through the gate structures but that analysis would need to be completed under a future project with a longer project schedule and additional data on fish swim speeds, more robust understanding of fish behavior as they approach the gates, and how adding passage may effect dam operations and structural integrity.

3.0 EVALUATION METHODOLOGY

Once the list of options was finalized, the project team applied multiple levels of evaluation methodology to refine and develop the options discussed at the end of this report.

3.1 First Level Evaluation (Pass-Fail)

All eight fish passage options were first evaluated on selectivity. This was the DNR's primary objective and thus it was evaluated on a pass/fail basis; a specific fish passage option either was highly selective for invasive species or could be adapted to be highly selective, in which case the option was evaluated as "pass." If a fish passage option was not selective or selectivity would be difficult to achieve via application of systems, it was evaluated as a "fail." Table 4.1-1 shows the results of the selectivity assessment.

A fish passage system at LD5 will need to function in concert with the planned deterrent system (discussed in Section 1.5) so as not to pass invasive fish from downstream to upstream as preventing this movement of invasive fish is the primary goal of the deterrent system.

3.2 Second Level Evaluation

To facilitate the second-level evaluation, WSB created a scoring matrix that included a number of metrics that each of the options that passed the first-level evaluation could be scored against. Some of these metrics included those that were provided to WSB by the DNR and included in a spreadsheet developed by the LD5 workgroup to evaluate a trap and sort option that could selectively trap and remove invasive carp and possibly pass native fish to the upstream side of LD5. These metrics were not prioritized or weighted as part of this second level evaluation but could be as part of a more detailed evaluation and feasibility project. Also, because of the conceptual nature of fish passage options, WSB decided to use a qualitative scoring system, with each criteria scored as "Most Preferred", "Moderately Preferred", or "Least Preferred". Note that a most preferred rating is considered to be the least cumbersome rating, followed by moderately preferred, then least preferred as the most cumbersome across all metrics. The cost rating of most preferred, means the option is lower or lowest among the options presented while the least preferred rating for portability means that the option is not portable.

3.2.1 Metric Definitions

The narrative below identifies the scoring metric along with a definition for that metric. Selectivity was initially included in the set of metrics and is the primary consideration for the various options. While we used it for the first level as a pass/fail rating, we originally wanted to include an additional rating that qualitatively rated the ability of the system to be able to distinguish between native and invasive fish species (artificial intelligence). After gathering data during the final evaluation, we determined that we could not accurately characterize the ability of an individual option to identify native and invasive fish as that is an evaluation of the hardware and software that could be added to the fish ladder and fish elevator options, is not applicable to the trap and truck option, and is already included with the Whooshh System. Based on these considerations we dropped this metric. If the fish ladder and fish elevator were selected for further evaluation, this could be included as a standalone process based on a variety of factors including how or where hardware would be mounted in or on a particular passage option.

- **Cost:** the total monetary expense associated with installing and operating the fish passage option. Costs are subdivided as follows.
 - Design and construction costs: one-time and up-front expenses which are incurred before the fish passage system begins operations.
 - Operations and maintenance costs: ongoing costs which are budgeted as recurring on a monthly or yearly basis for the life of the system.
- **Safety:** this has several subcriteria, as the LD5 system serves many user groups. The list of subcriteria is:

- Dam safety: the ability of LD5 to manage flows on the Mississippi River safely.
- Commercial barge traffic: the ability of commercial barges to safely navigate the lock.
- Recreational traffic: the ability of recreational river users to safely navigate the lock and the headwater and tailwater areas as permitted by the Corps.
- Dam Operations Staff: LD5 employs a lockmaster and several technicians who operate and maintain the lock. All fish passage options must evaluate any potential change in operations for their impact on dam operations staff and their ability to do their work safely.
- **Labor:** this also has several subcriteria, as labor is used differently across different fish passage options.
 - On site operation: does the option require on-site human labor?
 - Image/video review during initial operation: for video-based AI systems, does the fish passage option require human staffing during the start-up or AI learning phase?
 - Image/video viewing during regular operation: for video-based AI systems, does the fish passage option require human staffing as part of standard operating procedure?
 - Handling/sorting of fish: does the fish passage option require staff handling or sorting of invasive fish to remove them from the native fish population?
- **Navigation:** the primary purpose of LD5 is to maintain a 9' channel for commercial barge traffic, but it is also used by recreational watercraft on a regular basis. Each fish passage option was evaluated on potential impacts to both commercial and recreational traffic.
- **Engineering:** each fish passage option was evaluated on the difficulty of meeting the engineering requirements for its safe and effective use.
- **River Hydraulics:** each fish passage option was evaluated for potential impacts to flow rate, velocity, and shear stress through the dam during normal operations.
- **Automation Difficulty:** During project scoping the DNR indicated interest in systems that could be automated to minimize labor costs. This criterion indicates the level of challenge present in integrating automated or artificial intelligence systems into each fish passage option.
- **Maintenance:** this is a qualitative evaluation of the expected maintenance activities associated with each fish passage option.
- **Portability:** is this fish passage option moveable among different sections of LD5 to accommodate various flow regimes or seasonal variations in fish migration

3.2.2 Scoring Criteria

Table 3.2.2-1 below shows each of the scoring criteria with a qualitative definition of the scoring rating (most preferred, moderately preferred, or least preferred). Actual scores for each selective fish passage option are discussed in Section 4.2, and the final scoring matrix is provided in Appendix A.

Table 3.2.2-1. Scoring Matrix Criteria and Rating Descriptions

| | Most Preferred | Moderately Preferred | Least Preferred |
|--|---|--|--|
| Cost | | | |
| Design, Engineering, Permitting, and Construction | Low-cost relative to options presented. | Moderate cost relative to options presented. | High-cost relative to options presented. |
| Annual Operation and Maintenance (including staffing and energy costs) | Low relative to options presented. | Moderate relative to options presented. | High relative to options presented. |

| Safety | | | |
|--|---|---|---|
| Dam Safety | Option does not impact current operations of LD5, nor the ability of the project to pass flood flows. | Option has potential impacts on LD5, or the ability of the project to pass flood flows to the degree facility operations may need to be modified. | Option has significant impacts on LD5, or the ability of the project to pass flood flows to the degree of modification of other project facilities is needed. |
| Commercial (Barge) traffic | Option does not pose a navigational risk to commercial traffic. | Option does pose a slight navigational risk to commercial traffic, requiring extra attentiveness from commercial vessel operators. | Option does pose a significant navigational risk to commercial traffic, requiring additional changes to the overall facility. |
| Recreational Traffic | Option does not pose a risk to recreational traffic. | Option does pose a slight navigational risk to recreational traffic, requiring extra attentiveness from recreational vessel operators. | Option does pose a significant navigational risk to recreational traffic, requiring additional changes to the overall facility. |
| Dam Operations Staff | Option does not pose a safety risk to dam operations staff. | Option increases safety risk to dam operations staff requiring additional protective barriers or PPE. | Option poses a moderate or high risk to the safety of dam operations staff. |
| Labor | | | |
| On-site operation | Option does not require onsite operation | NA | Option requires staff onsite to operate. |
| Image/video review- initial operation | Option does not require images to be uploaded, and AI trained. | NA | Option requires images to be uploaded, and AI trained. |
| Image/Video viewing during operation | Option does not require staff to view any images or video. | Option requires some staff review. | Option requires staff to view video/images to release fish. |
| Handling/ Sorting of fish | Option requires no handling/sorting. | Option requires staff to handle/sort fish to be disposed of at final "gate". | Option requires handling/sorting as a primary means of selectivity, release, and disposal. |
| Maintenance | The option requires maintenance on an as-needed basis. | Option requires annual maintenance | Option requires monthly maintenance |

| | | | |
|------------------------------|--|---|--|
| Navigation | Device is not located on most active lock, and minor river flow to passage areas that commercial and rec traffic can still navigate. | Device is located on/near most active lock, and river flow to passage areas are adjusted so that commercial and recreational traffic will need warning signage. | Device is located on/near most active lock, and river flow to passage areas are adjusted so that commercial will need to be warned ahead of time. Recreational traffic will either not or at times not be allowed through due to high flows or obstructions. |
| Engineering | Uses existing or previously designed systems | Uses new systems at LD5 with standard design practices | Uses new systems at LD5 with developing or cutting-edge designs OR uses new systems at LD5 with multiple engineered components |
| River Hydraulics | Limited to no change to hydraulics (flow through locks or over the dam, velocity, and shear stresses) during normal operation | Moderate changes to hydraulics (flow through locks or over the dam, velocity, and shear stresses) during normal operation; could impact recreational traffic | Significant changes to hydraulics (flow through locks or over the dam, velocity, and shear stresses) during normal operation; could impact recreational traffic or increase risks to commercial traffic |
| Automation Difficulty | AI options are available and are part of an existing/previously designed system | AI options are available, but they need to be attached and integrated | AI options are unavailable for this option |
| Maintenance | Minimal staff intervention | Staff intervention weekly | Daily staff intervention |
| Portability | Portable | Somewhat portable | Not Portable |

3.3 Final Evaluation

Final evaluation focused on the 4 options from the second level evaluation, but involved the project team discussing each option qualitatively, adding deterrent and selectivity augmentation options, specifying passage operations, and including cost estimates.

4.0 FISH PASSAGE OPTIONS EVALUATION

WSB identified the auxiliary lock area as a site for the selective fish passage installation as the auxiliary lock is not being utilized for operations, and where the installation of a new facility would cause minimal disruption to lock and dam operation. The disadvantage of this area is that a lack of flow means fish are not naturally attracted to this area of the LD5 structure. While the generation of attraction flow would be part of any fish passage installation in the auxiliary lock, it would be difficult to generate a flow that would compete with the flow through the adjacent dam gates. It has been assumed, however, that the addition of attraction flow to this area would work in concert with fish deterrence measures currently being studied for installation downstream of the dam gates. Attraction flow and other attractant and deterrent augmentation of the options identified in the final evaluation are discussed in detail in Section 4.3.

The remainder of Section 4 is used to discuss the first and second level and final evaluation results.

4.1 First Level Evaluation (Pass/Fail)

Based on this first level of evaluation, four of the eight fish passage options passed the selectivity assessment and were elevated to the second level evaluation using a scoring matrix.

| <i>Fish Passage Option</i> | <i>Score (Pass/Fail)</i> | <i>Note</i> |
|---------------------------------|--------------------------|--|
| Fish Ladder | Pass | Selectivity measures required on intake |
| Trap and Truck | Pass | Selectivity achieved post-collection and before releasing collected fish |
| Fish Elevator | Pass | Selectivity measures required on intake |
| Siphon Fishway/Fish Cannon | Pass | Selectivity measures required on intake |
| Gate Control Velocity | Fail | Installation of selectivity measures on roller or Tainter gates not compatible with gate operation |
| Nature-like fishway / rock ramp | Fail | Too difficult to install selectivity measures on a large intake |
| Pipe through dam/abutment | Fail | Difficult to access for selectivity |
| Spillway weir | Fail | Not suitable for selectivity measures installation; |

4.1.1 Fish Ladder

While a fish ladder is not inherently selective, selective passage measures could be installed at the downstream entrance, the upstream exit, and/or at an intermediate location. In this way, a fish ladder could be designed to achieve the selectivity goals of the DNR and should be considered for further evaluation.

4.1.2 Trap and Truck

After capturing fish via electrofishing or netting operations and sorting them into batches of native and invasive fish, the batch of native fish would be transported to the upper pool for release, while invasive fish would be removed from the system and disposed of. Performing the trap and truck operation in this fashion would achieve the selectivity goals of the DNR. This option should be considered for further evaluation.

4.1.3 Fish Elevator

While an elevator is not inherently selective, selective passage measures could be installed at either the entrance to the fish elevator, or at a station located on the upstream side of the lift box prior to the fish being discharged into the upper pool or be staffed so fish can be manually sorted. In this way, a fish ladder could be designed to achieve the selectivity goals of the DNR and should be considered for further evaluation.

4.1.4 Siphon Fishway / Cannon

Selectivity measures could be installed at the entrance to the siphon spillway or fish cannon. In this way, a siphon fishway or fish cannon can be designed to achieve the selectivity goals of the DNR and therefore should be considered for further evaluation.

4.1.5 Gate Control Velocity

This system is not inherently selective and would need to be paired with a deterrent to achieve selectivity.

It would be difficult to design a gate control velocity system which would meet the DNR's selectivity criteria and therefore did not receive further evaluation under this project but would need to be considered to address fish passage that is currently occurring at the gates (in review).

4.1.6 Nature-Like Fishway / Rock Ramp

This system is not inherently selective; they are designed to provide passage for a wide range of aquatic species, and they do not generally have design features which differentiate between native and invasive species.

Because these systems have large inlet structures that look like natural waterways, it would be difficult to install selectivity measures (such as cameras) on the intake. These systems would also have to contend with turbidity in the natural system which may interfere with their ability to appropriately identify fish. Therefore, this system is highly unlikely to meet the DNR's selectivity criteria and should not receive further evaluation.

4.1.7 Pipe Through Dam / Abutment

This system would be difficult to customize for selectivity; the flow through the pipe would largely depend on the difference in head between the upstream and downstream sides of the dam. In order to be passable during the largest range of conditions the pipe would need to be placed low in the water column, making access difficult. It would also be difficult to remove non-native fish from this system because it does not have a point of access above the water surface. Because of the difficulty in designing this system to meet the DNR's selectivity criteria, this system should not receive further evaluation.

4.1.8 Spillway Weir

Because spillway weirs are designed to facilitate passage in one direction only and because it would be difficult to meet the DNR's selectivity criteria while maintaining the function of the roller or Tainter gates, this system should not receive further evaluation.

4.2 Second-Level Evaluation Results

Using the methodology described in Section 3.2, the 4 options that "passed" the first level evaluation were scored against the matrix. The results of that scoring, design changes, and additional details are described for each of the 4 selective fish passage options below. The ratings are categorical, most preferred, moderately preferred, and least preferred, and a description of each of these ratings is described in Table 3.2.2-1.

4.2.1 Fish Ladder

The fish ladder would be a permanent concrete structure located within the auxiliary lock. Fish would enter the fish ladder near the downstream end of the river wall and exit via channels built through the upstream auxiliary lock bulkhead. An access bridge would be installed over the exit channels to maintain

lock and dam staff access to the movable dam, and to facilitate fish sorting. Manual fish sorting would be performed in the uppermost fish ladder pool to remove invasive species prior to releasing a batch of native fish into the upper river pool. A moveable upstream screen would be required to prevent fish passage until invasive species, if present, could be sorted and removed. Identification of invasive species could be aided by cameras, allowing remote monitoring and potentially remote release of “clean” batches of native fish. This is explored and discussed in the final evaluation.

4.2.1.1 Cost – Least Preferred

Design, Engineering, Permitting and Construction – Least Preferred

Construction of a permanent fishway structure in the auxiliary lock structure would have high design and construction costs. Design costs would be least preferred as not only would the structural and mechanical components need to be designed, but extensive hydraulic modelling would need to be completed to determine the arrangement of baffles and weirs to achieve the desired flow patterns for various species of fish. Construction costs would be driven by access limitations, water control, and the need to coordinate with lock operations.

Annual Operation and Maintenance – Moderately Preferred

Operational costs would be moderate as the fishway operates passively, with gravity creating the flow through the ladder. Maintenance would primarily consist of clearing debris from the fish ladder to keep it flowing properly. Additional costs would come from the need for staff to perform the manual sorting of fish at the selection point of the ladder, which would be the uppermost pool of the ladder.

4.2.1.2 Safety – Moderately Preferred

Dam Safety – Moderately Preferred

Exit channels for the fishway would be installed through the upstream bulkhead. The design of the fishway would need to avoid impacting the stability of the bulkhead. Additionally, the fishway structure itself could potentially lower the flows that would be able to pass over the bulkhead during floods, raising flood elevations at the dam.

Commercial (Barge) Traffic – Most Preferred

The fish ladder location in the auxiliary lock would result in no interference with commercial traffic through the facility. While some inflow will be generated into the fish ladder, it would not be enough to affect large vessels.

Recreational Traffic – Moderately Preferred

The fish ladder location in the auxiliary lock would result in no direct interference with commercial traffic through the facility. Some inflow, however, will be generated into the fish ladder, and could potentially affect a recreational vessel. Recreational vessels should be kept away from the upstream and downstream ends of the fish ladder.

Dam Operations Staff – Most Preferred

The bulkhead in the auxiliary lock currently serves as a path for lock and dam staff to access the gates on the moveable dam. Where the fish ladder exit channels would go through the bulkhead, an access bridge with handrails would be installed, maintaining safe access through the area.

4.2.1.3 Labor – Least Preferred

On-Site Operation – Least Preferred

Staff will need to perform fish sorting operations at the upstream end of the ladder to remove invasive species prior to releasing native fish into the upper river pool and will need to operate the moveable screens in the upstream sorting area.

Image/video review – Initial Operation – Least Preferred

The fish ladder is currently proposed to utilize manual sorting. However, AI could potentially be paired with cameras in the sorting area at the upstream end of the fish ladder to assist in identifying the presence of invasive fish. This would need to be developed under an initial training scenario.

Image/Video Viewing During Operation – Moderately Preferred

The fish ladder is currently proposed to use manual sorting. If AI hardware and software were integrated, staff would be required to view the images as part of a QA/QC standard operating procedure to ensure that an acceptable level of error (which may be 0%) is being achieved. Alternatively, images and/or video could be live streamed, and staff could remotely view fish accumulated in the sorting area at the upstream end of the fish ladder to determine whether invasive species are present prior to releasing the fish into the river upper pool.

Handling/Sorting of Fish – Least Preferred

Manual handling and sorting of fish are the primary means of selectivity for the fish ladder.

Maintenance – Moderately Preferred

Debris that accumulates in the fish ladder will need to be cleared when it accumulates to the point of obstructing flows through the ladder. This is expected to be needed one to two times a year. A debris boom upstream of the ladder would help prevent debris from entering the fish ladder, but would, itself, need to be cleared of debris on approximately the same schedule.

4.2.1.4 Navigation – Moderately Preferred

The fish ladder is in the unused, auxiliary spillway, and generates minor flow that should not be an impediment to commercial traffic but may be a hazard to recreational traffic. See discussion in Section 4.2.1.2. Signage may be required to keep recreational traffic clear of the area.

4.2.1.5 Engineering – Least Preferred

The fish ladder would be a highly engineered structure involving the hydraulic design of the fish ladder, the structural design of fish ladder walls and baffles, exclusion screen, and hoist supports, and mechanical and electrical design of screen hoisting equipment.

4.2.1.6 River Hydraulics – Moderately Preferred

The fish ladder will require flow through the ladder to operate. This flow, while small compared to the capacity of the moveable dam gates, may necessitate a change in gate operations. Additionally, the flows in this area may be large enough to impact recreational vessels which come too close to the upstream end of the fish ladder.

4.2.1.7 - Automation Difficulty – Moderately Preferred

Options for using AI for automating species selection are somewhat limited based on current technology and application. However, there are options for imaging and AI applications. These would require that the option is designed to allow the imaging technology (true color) to be able to view and capture quality images that the algorithm could recognize consistently for selectivity of invasive fish species.

Additionally, the AI would require a training period and evaluation of its ability to accurately identify invasive fish species prior to full deployment and reliance on AI automation.

4.2.1.8 - Maintenance – Moderately Preferred

Debris that accumulates in the fish ladder will need to be cleared when it accumulates to the point of obstructing flows through the ladder. This is expected to be needed one to two times a year. A debris boom upstream of the ladder would help prevent debris from entering the fish ladder, but would, itself, need to be cleared of debris on approximately the same schedule.

4.2.1.9 - Portability – Least Preferred

The fish ladder is a permanent structure and not portable.

4.2.1.10 - Selectivity

As discussed in Section 3.2.1, we did not provide a rating for selectivity. However, we recognized that selectivity should be discussed briefly. Selectivity would be provided through manual sorting of fish in the upstream pool of the fish ladder and is expected to be a highly effective, if laborious, method of invasive species removal. All hardware and software components could be added to this option as discussed in the final evaluation section.

4.2.2 Trap and Truck

Trap and truck refers to trapping fish (native and invasive) downstream and/or within LD5, removing them from the Mississippi River, and disposing of invasive species. Traps located downstream or upstream of the roller and tainter gates were discussed and evaluated, but the lack of engineering plans and 3D flow environment data (received later in the project), disagreement on burst and sustained fish swim speeds, and uncertainty of the ability to make this design selective, removed this approach from further consideration. WSB evaluated several options for the trapping system but upon discussion with the DNR, and consideration of other options, the use of a boat electrofisher was the preferred method for trapping fish. DNR staff on the boat would collect and sort stunned fish downstream of the LD5 structure. Captured invasive carp would be brought to shore for disposal while native fish species would be ferried through the navigational lock and released on the upstream side of the dam.

Invasive carp are difficult to capture via electrofishing due to their sensitivity to noise and vibration, the close proximity needed to stun and net them from an electrofishing boat, and their intense behavioral response to watercraft (electrical pulse). Since removing invasive carp is one priority of the DNR, other passage options that trap and sort may be more desirable for implementation. Additionally, electrofishing is depth limited so native pelagic or benthopelagic fish may not be effectively sampled or captured through this option.

4.2.2.1 Cost – Most Preferred

Design, Engineering, Permitting, and Construction – Most Preferred

Trap and truck is a low-cost fish passage option because it does not include design and construction of new structures. A permit may be required for invasive carp transport, but no other permits would be required.

Annual Operation and Maintenance – Most Preferred

The costs associated with trap and truck are for DNR staff time and operation of an electrofishing boat which is already owned by the DNR, as well as for disposal of any invasive species captured during the process.

4.2.2.2 Safety – Most Preferred

Trap and truck has low impacts to the safe operations of LD5. Trap and truck can have safety risks to staff who have to remove the fish from the river and identify them correctly before sorting them, primarily associated with the process of electrofishing. However, DNR staff have appropriate training in completing these activities.

Dam Safety – Most Preferred

Trap and truck does not impact current operations of LD5, nor does it impact the ability of the structure to pass flood flows. Trap and truck operations would likely cease during high water levels, the specific limits to be determined by the DNR in consultation with USACE.

Commercial (Barge) Traffic – Most Preferred

Trap and truck does not pose a navigational risk to commercial traffic. The electrofishing boat is expected to give way to commercial traffic and would not interfere with their use of the lock.

Recreational Traffic – Most Preferred

Trap and truck does not pose a risk to recreational traffic. The electrofishing boat would pass through the main lock a minimum of twice on a round trip, but this activity would likely take place on a weekday when recreational traffic is minimal.

Dam Operations Staff – Most Preferred

There are no known risks to dam operations staff for trap and truck.

4.2.2.3 Labor – Least Preferred

On-Site Operation - Least Preferred

Trap and truck requires staff on the electrofishing boat for boat operation and navigation as well as fish identification, these staff would be from the DNR. It does not require staff time at LD5.

Image/Video Review During Initial Operation – Most Preferred

Trap and truck would not utilize image analysis for fish identification.

Image/Video Viewing During Operation – Most Preferred

Trap and truck would identify captured fish in the field and would not require remote image/video viewing.

Handling/Sorting of fish – Least Preferred

Trap and truck relies on DNR staff directly handling and sorting fish as a primary means of selectivity, release, and disposal.

Maintenance – Most Preferred

The primary maintenance associated with trap and truck is maintenance of the electrofishing boat and associated electrofishing equipment. The DNR has a maintenance schedule for the boat, and the additional use of the boat may increase the maintenance, likely on an as needed basis. This does not include fueling the boat, which is expected to be required on each trip, depending on the selected launch point.

4.2.2.4 Navigation – Most Preferred

Trap and truck would make no changes to the active lock and would increase traffic through the lock minimally due to the need to bring native fish upstream. If we assume that there would be 3 trips through the lock for each day that staff were electrofishing and electrofishing would occur 3 times/week for a 7-month time period, that will add 9 boat trips through the lock weekly, 36 trips monthly, 252 trips annually. This would be a 7.7% increase in annual lockages using the 2024 LD5 statistics showing a total of 3,259 lockages (1,349 commercial lockages and 1,901 recreational).

4.2.2.5 Engineering – Most Preferred

Trap and truck uses existing or previously designed systems. Furthermore, electrofishing on the Mississippi River is an activity that the DNR already completes, so additional design or engineering is not necessary.

4.2.2.6 River Hydraulics – Most Preferred

Trap and truck activities are not expected to change the hydraulics of LD5 during normal operation.

4.2.2.7 Automation Difficulty – Least Preferred

Artificial intelligence options are not currently available on the DNR's electrofishing boat and are not expected to be suitable for installation there in the time frame for this study.

4.2.2.8 Maintenance – Most Preferred

LD5 staff are not expected to complete any maintenance activities associated with trap and truck; all maintenance activities would be carried out by DNR staff.

4.2.2.9 Portability – Most Preferred

For the purposes of this report, trap and truck is assumed to be a method for moving native fishes from upstream to downstream of the LD5 structure. DNR staff can complete the electrofishing at any point along the downstream side of the dam and release collected native fish at any point along the upstream side of the dam. It is also possible that the trap and truck system could be utilized on the upstream side of the dam and facilitate fish passage to the downstream side, though that is deemed less critical at the current moment.

4.2.2.10 Selectivity

This system is highly selective as fish can be identified on site by trained staff and non-invasive species can be returned to the Mississippi River.

We recommend this system proceeds to concept design because it is highly selective and has minimal impacts to the Lock and Dam system.

4.2.3 Fish Elevator

A fish elevator concept involves passing native species while inhibiting invasive species passage within the auxiliary lock of LD5. The structural components of the system are installed within the auxiliary lock as well on top of the bulkhead. This approach allows for no interference with watercraft navigation in the active lock. The system involves fish traveling to an elevator holding tank which lifts the fish above the bulkhead. Once lifted to the bulkhead, they are deposited into various sorting tanks for staff to manually sort native from invasive species. Native species are passed upstream through spillways in the tanks while invasive species are brought to a secondary tank. This secondary tank is then reassessed for accuracy, and any outlier native species are passed upstream. This tank is drained, and invasive carp are removed for disposal.

This design is highly selective due to the manual sorting required. In future stages of this project an automated system for identifying invasive carp can be installed. This AI camera can adhere to the lift spillway prior to fish entering the tanks. The recognition software would focus on detecting invasive carp species only, and once detected, sort them via an added spillway directly to the secondary tank. This would involve no staff manually sorting fish. Manual components included in the future design would involve trucking invasive carp offsite and general maintenance.

4.2.3.1 Cost – Least Preferred

Design, Engineering, Permitting and Construction – Least Preferred

Construction of a permanent elevator including the holding tanks above the bulkhead would be high due to the inability of the concept to be moved. The elevator and holding tank due to the site conditions would be required at this location. Due to this, the elevator design will need significant structural design and hydraulic computations.

Annual Operation and Maintenance – Moderately Preferred

The annual operations cost will be moderate, assuming the concept design is staged to an automatic system in the future. Initial operation costs will be high due to the requirement that staff must be on site sorting fish. If AI components are installed the cost of manual labor can be greatly reduced.

4.2.3.2 Safety – Moderately Preferred

Dam Safety – Moderately Preferred

Safety concerns regarding the fish elevator will be moderate.

Commercial (Barge) Traffic – Most Preferred

Risk to barge traffic is low due to the concept design being located within the auxiliary lock. This lock does not pass watercraft traffic and therefore does not interfere with current traffic.

Recreational Traffic– Moderately Preferred

The elevator will be in the auxiliary lock where recreational watercraft may occasionally come near. Signage will require no recreational traffic near the auxiliary lock to adequately mitigate risk.

Dam Operations Staff – Moderately Preferred

Due to the lift station being a moving piece that will require maintenance at or below the normal water surface elevation of the dam, there is a potential risk to staff. Staff located onsite during typical working hours on the bulkhead to sort fish will have minimal risk if any. Overall risk to staff is generally low for automatic systems.

4.2.3.3 Labor – Least Preferred

On-Site Operation – Least Preferred

Staff would be needed on site to manually sort and release native fish in the tanks along the bulkhead and remove invasive carp for disposal. Due to the unknown volume of fish in the vicinity of LD5 and of that volume of fish how many would be transported by the elevator to the tanks, we are assuming it would require 2 FTE for sorting and removal. Staff hand sorting would eventually be replaced by AI as discussed in the final evaluation.

Image/video review – Initial Operation – Least Preferred

The current design relies on manual sorting. Automated systems could be installed and would involve image recognition for detection of carp species. Once detected, the secondary spillway would transport these fish into a secondary tank. This system would take time to develop recognition of carp species and therefore reviewing images/videos of the tanks and spillways to train AI would be relatively laborious.

Image/Video Viewing During Operation – Moderately Preferred

The current design relies on manual sorting. Automated systems could be installed and would involve image recognition for detection of carp species. Once the automated system is fully operational (after the training period, invasive fish would automatically be steered into the secondary holding tank on the bulkhead. Staff would still need to review images and holding tanks as a QA/QC standard operating procedure with the frequency determined by the percentage error from initial training and continuous review. Depending on the volume of fish passing through the system, it may be a high labor-intensive task.

Handling/Sorting of Fish – Least Preferred

The fish elevator concept will require a high labor value to sort fish. If the automated system is implemented staff will be required to empty the secondary tank. Depending on the volume of fish, this may be high.

Maintenance – Least Preferred

The elevator concept will require routine maintenance of all equipment to ensure functionality. It is expected to require high amounts of labor to maintain the fish elevator structure as well as the sorting pools.

4.2.3.4 Navigation – Moderately Preferred

The fish elevator entrance will have an attractive flow design meaning river hydraulics would be manipulated to create a navigable pathway for fish. Due to this design, moderate flow change in the auxiliary lock can affect recreational traffic. It is recommended that signage be installed to avoid recreational traffic in this area.

4.2.3.5 Engineering – Least Preferred

The fish elevator design will require a number of engineering disciplines to secure the design. Structural components being a large portion due to the construction underwater and portions located on the bulkhead. The elevator would also require detailed hydraulic computations to avoid interference with dam operations and avoid effects to the floodplain. The system also integrates many moving parts requiring in-depth mechanical engineering for the lift and conveyer system.

4.2.3.6 River Hydraulics – Moderately Preferred

The fish elevator design would involve a long-sealed flume underwater to the actual lift of the system. This sealed flume will have enhanced flow patterns within to attract both native and invasive fish. These flows are expected to be moderate, therefore the impact on river hydraulics would not be significant to that of the active gates.

4.2.3.7 - Automation Difficulty – Moderately Preferred

The fish elevator system involves an automation system in the future to avoid manual labor. Multiple hardware and software applications are available for inclusion but would need to be attached and integrated.

4.2.3.8 - Maintenance – Moderately Preferred

General maintenance of the system is expected to be moderate. With the lift station needing regular maintenance and the holding tank area low maintenance. Areas with moving parts will require most of the routine inspections in order for the system to function adequately.

4.2.3.9 - Portability – Least Preferred

The fish elevator design is structurally bound in the area where it is installed. It does not have the option for portability.

4.2.3.10 - Selectivity

The system, whether automatic or manual, would be highly selective. In the manual sorting with properly trained staff it is expected invasive carp are unlikely to pass upstream when received in the first holding tank. The automatic sorting once established will provide an additional selective measure into the secondary tank. This secondary tank can also be sorted manually after the AI detection to ensure carp species were adequately detected.

4.2.4 Whooshh Pneumatic Fish Passage

The Whooshh pneumatic fish passage system is a multi-component system that would be installed within the auxiliary lock. This system is composed of three Whooshh Innovations products- the FlowGuidance, PassagePortal Model F, and TUber. The culmination of these products results in a final design of fish attractant, sorting, passage, and transportation of invasive species. The FlowGuidance component would create an attractant flow to encourage fish to swim inside the PassagePortal. Fish are then dewatered for identification. If a fish is identified as native, it will pass through a MigratorTube over the bulkhead and be released upstream. If the fish is identified as invasive, it will pass through a MigratorTube into a holding tank on the bulkhead. The invasive fish will then be manually inserted into the TUber system, which includes a SalmonCannon, blower and liquid separator, a generator, tower and reel and MigratorTube. The carp will be transported through the MigratorTube across the miter gate to land for disposal. The TUber is a mobile transport system on a trailer that can be parked near the invasive fish tank on the bulkhead from which the mylar tubes could be deployed across the miter gate when invasive fish need to be moved from the tank to land for disposal. The MigratorTube can then be rolled back onto the TUber system when not in use so as not to impede navigation in the lock. An alternative to transporting the invasive carp across the miter gate via the TUber is to offload the carp using the TUber into a parked boat, constructing a scaffolding high enough not to disturb commercial and recreational vessels over the active lock, utilizing the tunnels within the walls of LD5, or to install the TUber along the upstream sill along the bottom of the active lock.

4.2.4.1 Cost – Moderately Preferred

Design, Engineering, Permitting and Construction – Moderately Preferred

Construction of a permanent Whooshh passage system in the auxiliary lock structure would have moderate design and construction costs. Design costs would be moderate as the structural and mechanical components need to be designed and specified for LD5. MigratorTubes may need to be custom to accommodate for the larger fish species.

Annual Operation and Maintenance – Moderately Preferred

Operational costs would be moderate as the Whooshh system operates passively. Maintenance would primarily consist of pump repairs, unclogging tubes, and software updates to the FishLRecognition system. Additional costs are needed for staff to perform the manual transport of invasive carp to land through the TUber.

4.2.4.2. Safety – Most Preferred

Dam Safety – Most Preferred

The PassagePortal structure will be anchored with four spud poles which can be customized to accommodate for flood events. The TUber transport system located on the bulkhead is fully mobile and can be transported in anticipation of flood events. While the holding tank located on the bulkhead is immobile, it should not significantly impact flows in the event of a flood.

Commercial (Barge) Traffic – Most Preferred

PassagePortal and FlowGuidance in the auxiliary lock would result in no interference with commercial traffic through the facility. While some outflow will be generated to attract fish, it would not be enough to affect large vessels.

Recreational Traffic – Moderately Preferred

The outflow generated by the FlowGuidance may impact recreational traffic. Recreational vessels should be kept away from the upstream and downstream ends of the PassagePortal and FlowGuidance.

Dam Operations Staff – Most Preferred

The bulkhead above the auxiliary lock currently serves as a path for lock and dam staff to access the gates on the moveable dam. An access bridge with handrails would be installed where the MigratorTubes cross the bulkhead. This would maintain safe access through the area.

4.2.4.3 Labor – Most Preferred

On-Site Operation – Most Preferred

Staff will need to transport native and invasive fish during the AI training phase. After the AI model is sufficiently trained, staff will only be needed to transport invasive carp.

Image/video review – Initial Operation – Moderately Preferred

PassagePortal requires images to be uploaded and the AI model to be trained. Approximately 1,000 images of each invasive species will need to be captured to sufficiently train the model. Whooshh may already have enough images of some carp species and may only need a subsample of other carp species to finalize training and meet image recognition error requirements.

Image/Video Viewing During Operation – Most Preferred

Staff would not be required to view fish accumulated in the holding tank or other intermediate structure before release.

Handling/Sorting of Fish – Moderately Preferred

Manual handling of fish is required to transport invasive carp for disposal if an automated process is not developed. However, sorting of fish is fully automated.

Maintenance – Most Preferred

The Whooshh passage system would likely require maintenance on an as needed basis. The system is designed to be almost fully automated with minimal maintenance requirements.

4.2.4.4 Navigation – Most Preferred

The Whooshh passage system is in the auxiliary lock and generates flow that should not impact commercial traffic but may have a small impact on recreational traffic. Signage may be required to keep recreational traffic clear of the area. During invasive transport, the MigratorTube would be deployed across the miter gate when no commercial or recreational traffic is present. Invasive fish transport from the bulkhead to land would need to be halted and the MigratorTube pulled back from the miter gate if

recreational or commercial traffic arrives, but the transport of invasive fish from the bulkhead to land should take a relatively short period of time so as not to impact commercial or recreational traffic in the active lock. Alternatively, invasive fish could be loaded from the bulkhead to a transport boat via the MigratorTube then brought to land.

4.2.4.5 Engineering – Most Preferred

The Whooshh passage system is a compilation of already engineered structures and components including the FlowGuidance flow velocity enhancement system, FishLRecognition, BurstBuster, MigratorTubes, and TUber. These systems have already been designed, so minimal engineering at LD5 to accommodate these systems is expected.

4.2.4.6 River Hydraulics – Moderately Preferred

The FlowGuidance would produce excess flow to attract fish into the PassagePortal. This additional flow may be large enough to impact recreational traffic that comes close enough to the PassagePortal.

4.2.4.7 - Automation Difficulty – Most Preferred

AI fish species recognition is included within the PassagePortal in the FishLRecognition component.

4.2.4.8 - Maintenance – Most Preferred

It is anticipated that maintenance would occur as needed for pump repairs, unclogging MigratorTubes, software updates, and ridding the components of debris.

4.2.4.9 - Portability – Moderately Preferred

The PassagePortal is designed as a floating barge within the auxiliary lock. We assigned a moderate rating to portability as the barge would need to be anchored to the bottom, so moving it would require abandoning and installing the anchor system. Additionally, under the current design the MigratorTubes are attached to the top of the bulkhead and feed two (2) tanks. These tubes would need to be affixed somewhere along the catwalk above the gates and tanks would need to be included. While this could be achieved, it does limit the portability as it is not as simple as just moving the barge portion.

4.2.4.10 - Selectivity

The FishLRecognition system is highly accurate. Any native species that may be misidentified and transported to the invasive holding tank can be manually removed.

4.3 Final Evaluation

The final phase of this project is presented below. Each selective fish passage option is provided with its own subsection under which we provide a final description of the option after project team discussion and addition of deterrent and selectivity augmentation options, along with a cost estimate.

4.3.1 Fish Ladder



FIGURE 4.3.1-1 Fish Ladder Concept

4.3.1.1 - Description

A permanent dual fish ladder structure would be installed in the auxiliary lock, with exit channels constructed through the upstream bulkhead into the upper pool. The fish ladder operates passively using the gravity flow of water over and/or through successive weirs both to provide a series of pools fish can use to navigate upstream and to provide attraction flow at the fish ladder entrance (downstream end). As flow would continually pass through the ladder, this flow would need to be accounted for in the operation of the gates. A grated deck access bridge would be constructed over the exit channels to both allow USACE staff access to the rest of the facility, and to allow for invasive carp removal operations and fish ladder maintenance.

One ladder, termed the “Small Species Ladder,” would have an exclusion rack at the entrance (downstream end) which would permit only species smaller than the invasive carp to pass into this ladder. Small species entering this portion of the ladder would then navigate the ladder to the upstream end, and swim freely into the upper pool of the river. This ladder would be designed with flows that permit smaller species with lower swim speeds to navigate upstream. In the event that reproduction of invasive carp is documented in Minnesota in the future, this part of the ladder would need to be redesigned or augmented to prevent smaller sized invasive carp from being passed.



FIGURE 4.3.1.1-1 – Large Species (left) and Small Species (right) Fish Ladder Entrances

The other ladder, termed the “Large Species Ladder,” would have an open entrance and would selectively pass native species the same size or larger than the invasive carp species. Higher flows in this ladder would assist in excluding smaller species from this ladder, decreasing the number of species that need to be evaluated for passage. The removal of invasive species would occur in the uppermost fish ladder pool immediately prior to release into the upriver pool. This uppermost fish ladder pool would have both upstream and downstream screens which can be raised and lowered by electric hoists. Fish would congregate in the upper fish ladder pool while the upstream screen is down. Periodically, the downstream screen would be lowered, and the fish in the upper pool would be inspected for the presence of invasive carp. Invasive carp, if present, would be removed, then the upstream screen would be raised, allowing the native species to swim into the upper pool of the river. The upstream screen would then be lowered, the downstream screen would be raised, and the process would be repeated. Release of the downstream gates could be done remotely using cameras mounted for viewing and triggers that use gravity to drop the gates. This could be done when a large enough number of fish that could make identification and sorting difficult have been aggregated in the upper pool of the ladder or done on a timed, regular basis.

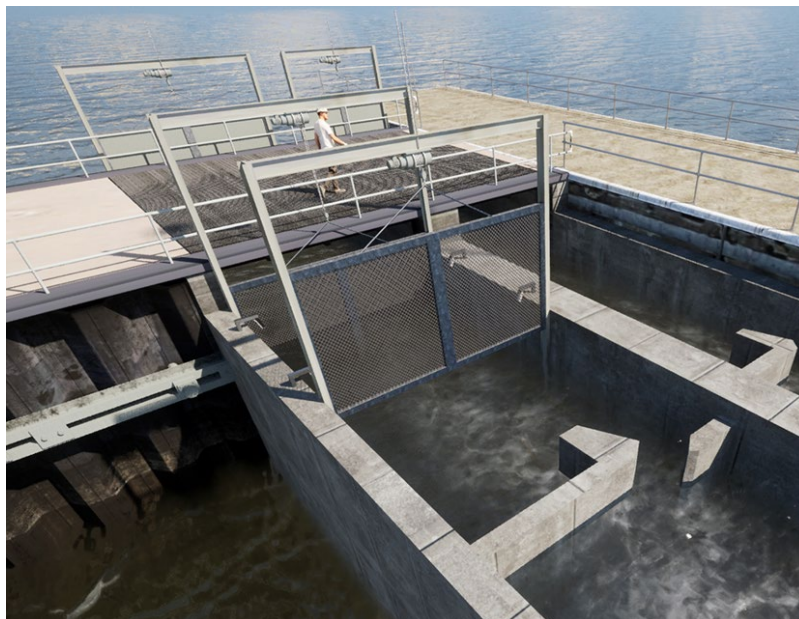


FIGURE 4.3.1.1-2 – Fish Ladder Large Species Upper Pool

Inspections in the upper fish ladder pool can be completed by trained staff to have a very low passage rate of invasive carp. Cameras in this area could allow for real-time remote monitoring for invasive species, potentially supplemented through AI fish recognition, and could allow for remote release of native species into the upper river pool if no invasive carp are detected. Removal of invasive species would need to be performed manually. A permanent electrofishing apparatus could be installed to stun the fish and allow the invasive carp to be netted and removed.

4.3.1.2 Cost Estimate

Estimated construction and operating costs for the fish ladder option was based on estimated construction costs per meter of dam height provided in the article *Cost and Relative Effectiveness of Lake Sturgeon passage systems in the US and Canada* (Bruch and Haxton, 2023) and are shown in Table 4.3.1.2-1 below. The elevations used to determine the wall height are shown in Table 4.3.1.2-2 below. As the costs provided in this article are in 2020 US dollars and an escalation rate of 3% per year over 5 years was applied to update the costs to 2025 US dollars. Additionally, site specific estimated construction and operating costs, such as the bulkhead modifications and staff costs for fish sorting operations were added separately.

TABLE 4.3.1.2-1 Estimated Unit Construction Costs and Annual Operating Costs from Bruch and Haxton (Escalated to 2025 USD)

| | Unit Construction Cost | Annual Operating Cost |
|-------------|---------------------------------|-----------------------|
| Fish Ladder | \$1.28 Million/meter dam height | \$9,100 |

TABLE 4.3.1.2-2 Elevations Used in Determination of Dam Height

| | | |
|------------------------------|----------------|--------------------------------|
| Upper Pool Target Elevation | EL. 660.0 ft | Operations Manual |
| Floor of Auxiliary Lock Area | EL. 637.0 ft | Original Construction Drawings |
| Height | 23 ft (7.01 m) | |

Design and permitting costs were assumed to be 10% and 3% of construction costs, respectively.

The total construction, design, and permitting cost was then assigned a range of -30% to +50% of the estimated costs as recommended by the American Association of Cost Estimators (AACE) for a Class 4 cost estimate, which is the designation for a conceptual or screening level estimate. The detailed cost breakdowns are shown below.

Estimated Construction Cost: \$8M to \$17.2M (2025 USD)

Estimated Annual Operating Cost: \$261,343 (2025 USD)

TABLE 4.3.1.2-3 Fish Ladder Estimated Construction Cost Breakdown

| | | |
|-----------------------------------|---------------------|-----------|
| Estimated Unit Cost: | \$1,280,000 | per meter |
| Dam Height: | 7.01 | meter |
| Estimated Cost: | \$8,973,000 | |
| <u>Additional Estimated Costs</u> | | |
| Bulkhead Modifications | \$1,000,000 | |
| Sorting Hardware | \$100,000 | |
| Screens and Operators | <u>\$50,000</u> | |
| Subtotal: | \$10,123,000 | |
| Design Cost (10%): | \$1,012,000 | |
| Permitting Cost (3%): | <u>\$304,000</u> | |
| Total Estimated Cost: | \$11,439,000 | |
| Minimum Estimated Cost (-30%): | \$8,007,000 | |
| Maximum Estimated Cost (+50%): | \$17,159,000 | |

TABLE 4.3.1.2-4 Fish Ladder Estimated Annual Operating Costs with Labor

| | | |
|--------------------------------------|------------------|----------------------------|
| Fish Ladder Estimated Annual O&M: | \$9,100 | |
| Fish Sorting and release Operations: | <u>\$200,000</u> | 2 FTE (\$100,000/year x 2) |
| Subtotal: | \$209,075 | |
| Contingency (25%): | <u>\$52,269</u> | |
| Total: | \$261,343 | |

The table above provides the estimated annual O&M costs calculated from Bruch and Haxton, 2023 (\$9,100), along with labor estimates and contingency. Labor is calculated using a cost factor of \$100,000/FTE from DNR staff. We assume that we would need 2 staff/shift and 1 shift/day for operation over a 12-month period.

Staff would need to observe the uppermost ladder pool for the presence of invasive carp. If no invasive carp were present, then staff could simply raise the upstream gate and release all fish in the pool to the upstream side of LD5. If invasive carp were present, staff would need to sort, capture, and manually remove them from the uppermost pool ladder and transport them to an offsite location for disposal.

We assume that these FTE positions do not currently exist and would need to be created.

4.3.2 Fish Elevator

4.3.2.1 Description

The fish elevator concept would exploit fish migratory patterns as they travel upstream at LD5. The concept would be installed in the auxiliary lock with a sealed chamber spanning the lock walls. Based on data collected that suggests fish are attracted to the flow in the miter and tainter gates, the entrance of the chamber would widen near the roller gates. This entrance near the gates utilizes the flow generated by the dam and additional siphons located within the chamber to generate an attractant flow which should attract fish. Fish would swim from the chamber entrance near the gates to the downstream end of the bulkhead to the vertical lift section. Here a gated opening in the elevator structure holds fish. Closing

gates would be activated then fish would be lifted via a mesh grate that lifts them out of the auxiliary lock to the top of the bulkhead.

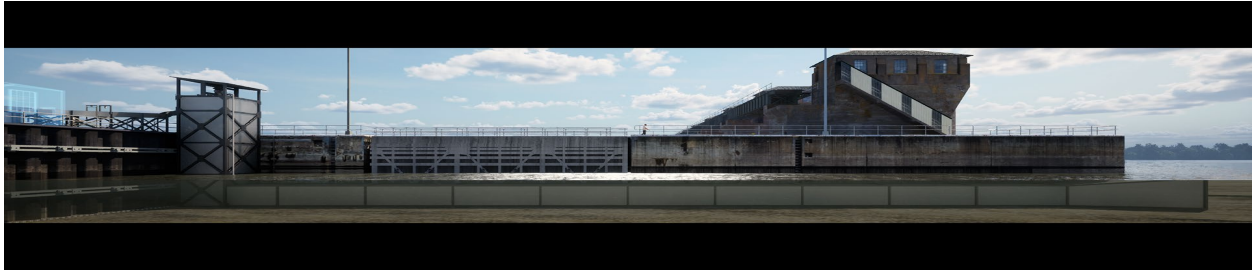


FIGURE 4.3.2.1-1 Fish Elevator Concept

At the top of the vertical lift spray nozzles fitted above the mesh grate at the top of the lift flush the fish onto a spillway that leads to tanks on the bulkhead where they can be sorted. Inspections can be completed by trained staff to eliminate the passage of invasive carp. This is a labor-intensive process which can be supplemented by automated systems in the future. See Figure 4.2-2 and 4.2-3 for the manual versus automated system.

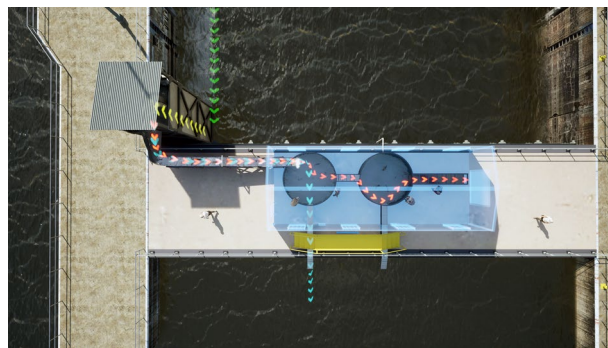


Figure 4.3.2.1-2 - Manual Sorting

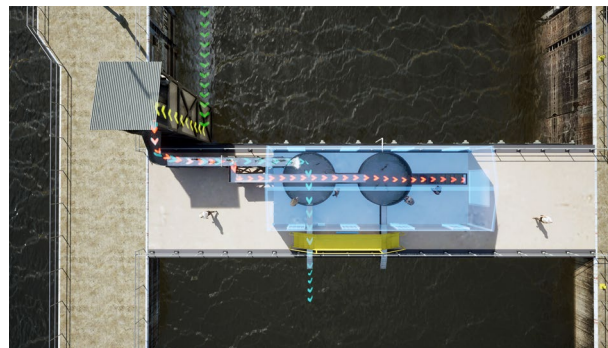


Figure 4.3.2.1-3 – Automated Sorting

**Blue arrows indicate native species, and red arrows represent invasive species of fish.*

In the above figures the manual sorting would require staffing the first tank to view and sort all fish species. Native fish species can be allowed to pass through a gate positioned over the upstream end of the bulkhead. Invasive carp would be directed to the secondary tank by staff. The secondary tank is fitted with a flume to pass native species that inadvertently escape to the second tank. The carp in the secondary tank are then removed from the tank and disposed of.

The fully automated system seen in Figure 4.2-3 involves adding to the existing structure. A secondary spillway is attached to the primary spillway with a gate at the confluence with the primary spillway. Multiple cameras would be installed within the vertical lift to identify dewatered fish from different angles as they are lifted to the top of the bulkhead. An AI algorithm would be employed to identify invasive carp and label the individual fish or batch of fish as invasive or native. Based on this identification of individual fish or batches, fish would be directed to the spillway that leads to the native fish tank or invasive fish tank. This automated system greatly reduces the number of staff hours required to operate this option.

This option is highly engineered and would not be portable around the LD5 structure.

4.3.2.2 Cost Estimate

Estimated construction and operating costs for the fish elevator option were based on estimated construction costs per meter of dam height provided in the article *Cost and relative effectiveness of Lake Sturgeon passage systems in the US and Canada* (Bruch and Haxton, 2023) and are shown in Table 4.3.2.2-1 below. The elevations used to determine the wall height are shown in Table 4.3.2.2-2 below. As the costs provided in this article are in 2020 US dollars and an escalation rate of 3% per year over 5 years was applied to update the costs to 2025 US dollars. Additionally, site specific estimated construction and operating costs such as the sorting facility and staff costs for fish sorting operations were added separately.

TABLE 4.3.2.2-1 Estimated Unit Construction Costs and Annual Operating Costs from Bruch and Haxton (Escalated to 2025 USD)

| | Unit Construction Cost | Annual Operating Cost |
|---------------|---------------------------------|-----------------------|
| Fish Elevator | \$1.85 Million/meter dam height | \$26,104 |

TABLE 4.3.2.2-2 Elevations Used in Determination of Dam Height

| | | |
|------------------------------|----------------|--------------------------------|
| Upper Pool Target Elevation | EL. 660.0 ft | Operations Manual |
| Floor of Auxiliary Lock Area | EL. 637.0 ft | Original Construction Drawings |
| Height | 23 ft (7.01 m) | |

Design and permitting costs were assumed to be 10% and 3% of construction costs, respectively.

The total construction, design, and permitting cost was then assigned a range of –30% to +50% of the estimated costs as recommended by the American Association of Cost Estimators for a Class 4 cost estimate, which is the designation for a conceptual or screening level estimate.

Detailed cost breakdowns for the fish elevator are shown below:

Estimated Construction Cost: \$10.4M to \$22.2M (2025 USD)

Estimated Annual Operating Costs: \$282,631 (2025 USD)

TABLE 4.3.2.2-3 Fish Elevator Estimated Construction Cost Breakdown

| | | |
|-----------------------------------|---------------------|--|
| Estimated Unit Cost: | \$1,850,000 | per meter |
| Dam Height: | 7.01 | meter |
| Estimated Cost: | \$12,969,000 | |
| <u>Additional Estimated Costs</u> | | |
| Sorting Hardware | \$100,000 | |
| Prefab Building | \$50,000 | |
| Subtotal: | \$13,119,000 | |
| Design Cost (10%): | \$1,312,000 | |
| Permitting Cost (3%): | \$394,000 | |
| Total Estimated Cost: | \$14,825,000 | |
| Minimum Estimated Cost (-30%) | \$10,378,000 | AACE Class 4 Screening Level Cost Estimate |
| Maximum Estimated Cost (+50%) | \$22,238,000 | |

TABLE 4.3.2.2-4 Fish Elevator Estimated Annual Operating Costs

| | | |
|-------------------------------------|------------------|----------------------------|
| Fish Elevator Estimated Annual O&M: | \$26,104 | |
| Fish Sorting Operations: | \$200,000 | 2 FTE (\$100,000/year x 2) |
| Subtotal: | \$226,104 | |
| Contingency (25%): | \$56,526 | |
| Total: | \$282,631 | |

Similar to the Fish Ladder O&M costs, we provided an annual O&M cost taken from Bruch and Haxton, 2023 and included labor and contingency.

Labor is calculated using the same cost basis as the Fish Ladder; \$100,000/FTE. The fish elevator would require 2 FTE to examine both tanks on top of the bulkhead to release native fish through the gates into the upstream pool and sort invasive carp into the second tank for removal and disposal.

We assume that these FTE positions do not currently exist and would need to be created.

4.3.3 Whooshh Pneumatic Fish Passage

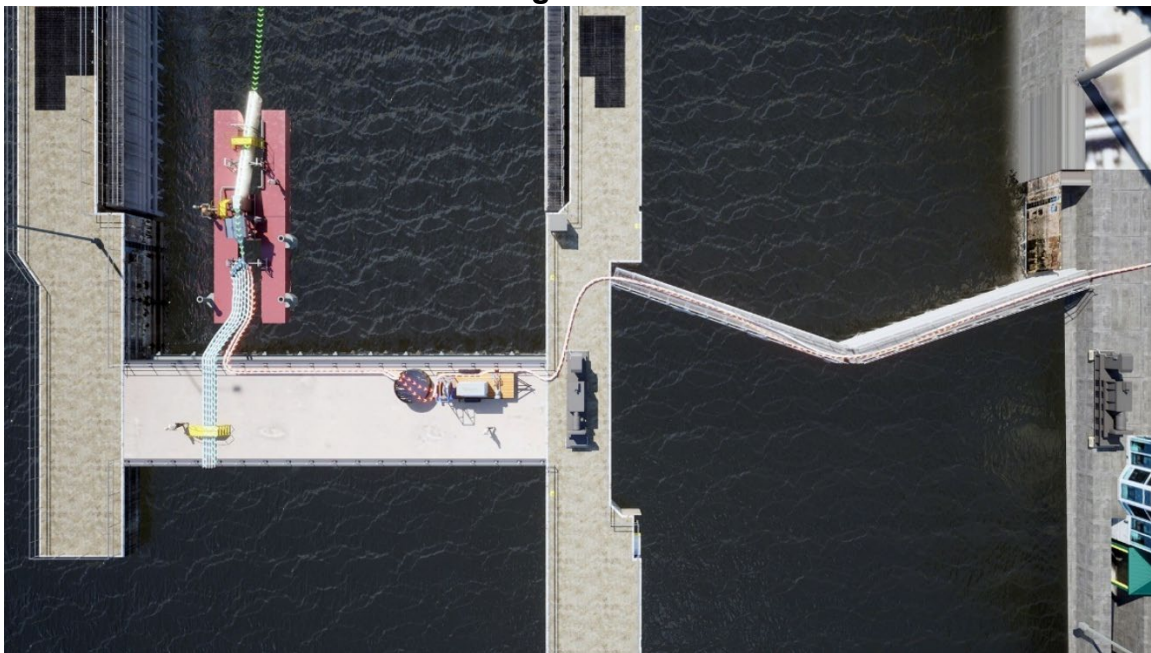


FIGURE 4.3.3-1 Whooshh Pneumatic Fish Passage Concept

4.3.3.1 Description

The Whooshh passage system is a collection of Whooshh Innovations components, including the FlowGuidance, PassagePortal Model F, and TUBer (Figure 4.3.3-1). The Whooshh passage system is proposed to be placed in the auxiliary lock and would require coordination and approval by the USACE. This system is the only one of the options that we evaluated as an “all-in-one package” where the fish movement and selection are automated and combined, as the fish ladder and fish elevator would need to have an AI selection device added to the fish movement structure to be able to identify invasive fish and select them for removal.

The FlowGuidance component is a flow velocity enhancement system. It would be placed adjacent to the PassagePortal, where it would augment existing limited flow velocities in the auxiliary lock to encourage fish to enter the PassagePortal. The fish would swim up the ramp of the PassagePortal, indicated by the green arrows in Figure 4.3.3-1. After reaching the top of the ramp, the fish would be dewatered and enter the FishLRecognition system. The FishLRecognition would capture nine real color and nine near-infrared images from three different angles. These images will be analyzed by an AI model to be categorized as native or invasive, which is capable of an identification rate of 40 fish per minute (2,400 fish/hour or 57,600 fish/day). Fish that are identified as native would pass upstream through one of six MigratorTubes that connect to the PassagePortal and stretch over and across the bulkhead (Figure 4.3.3.1-1). These tubes are indicated by the blue arrows in Figures 4.3.3.1-1 and 4.3.3.1-2.

There are multiple options and configurations for transporting invasive carp from the Whooshh system for removal and disposal. We developed a concept where invasive carp (as identified in the FishLRecognition System) would be transported through one of two MigratorTubes into a holding tank located on the bulkhead. In addition to the holding tank, the TUBer, a mobile fish transport system, would be placed on the bulkhead next to the holding tank. The TUBer includes a SalmonCannon, blower and liquid separator, a generator, tower and reel and MigratorTube. Staff would stretch the MigratorTube across the miter gate during removal operations only and invasive carp from the holding tank would be inserted manually into the tube. Invasive carp would travel through one MigratorTube across the miter

gate to land for disposal. The path taken by invasive species is indicated by red arrows in Figures 4.3.3.1-1 and 4.3.3.1-2. We developed this concept to avoid impacts to commercial and recreational traffic within the active lock.

There may be other options for moving invasive carp from the holding tank to land for disposal such as constructing a scaffolding over the active lock that is high enough to avoid any interference with commercial and recreational vessels, utilizing existing tunnels within the walls of LD5, or installing a TUber along the upstream sill along the bottom of the active lock. These were not evaluated, rather the final design utilized the approach described above to allow us to develop a cost estimate for the final report.

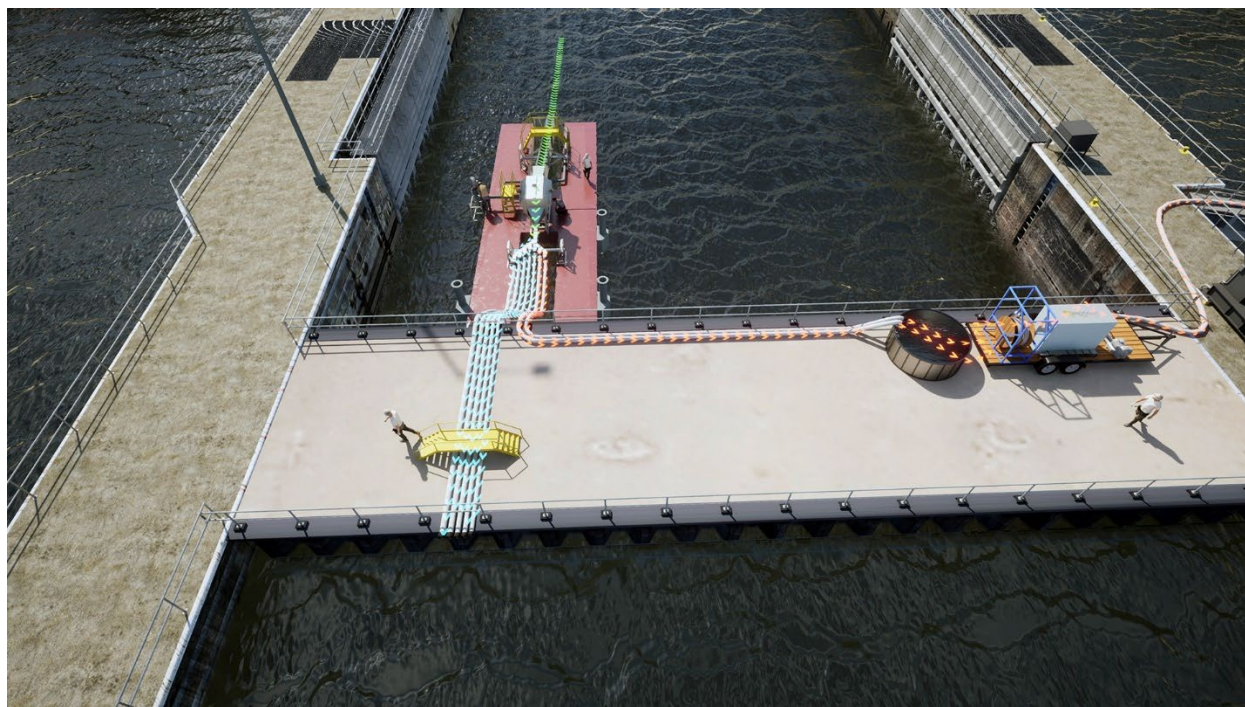


Figure 4.3.3.1-1 Overview of PassagePortal and TUber Post Training Period

While the FishLRecognition system is “in training” to identify invasive carp, a preliminary design is proposed to test and ensure model accuracy (Figure 4.3.3.1-2). This includes two holding tanks on the bulkhead, one of which would contain the fish the model recognizes as native, and the other containing identified invasive carp. Fish that are identified as native will pass through one of six MigratorTubes into a holding tank on the bulkhead, indicated by the blue arrows in Figure 4.3.3.1-2. Fish that are identified as invasive will pass through one of two MigratorTubes into a holding tank also located on the bulkhead. Invasive species would be transported through the TUber system, indicated by the red arrows in Figure 4.3.3.1-2. Additional labor will be required during this training phase to pass the native species upstream from their holding tank and evaluate the system as a whole.

The AI training could also be accomplished utilizing images of invasive carp from an existing image library developed as part of the FishPass Project or from other projects in the Midwest that may have images of invasive carp from which the AI algorithm has been refined. The AI could also be trained on-site by passing fish (invasive carp and native species) manually into the FishLRecognition System and collecting the fish once they leave the system to ensure they are identified correctly until an acceptable level of accuracy is achieved.

The option described and shown in Figure 4.3.3.1-2 below provides a safety factor so as not to allow for invasive carp to be passed until manually inspected by DNR staff and vet the automated process prior to full implementation and allowing fish identified as native to be passed directly to the upstream pool.



Figure 4.3.3.1-2 Preliminary Design During AI Training

4.3.3.2 Cost Estimate

WSB worked with Whooshh to obtain pricing for a PassagePortal Model F system with 30' spud poles. The quote received noted that shipping was excluded from the quote and it did not include installation of the system.

The purchase price from Whooshh was treated as an AACE Class 2 cost estimate, with a range of -5% to +20%. The estimated costs not provided by Whooshh (shipping, installation, etc.) were treated as a AACE Class 4 cost estimate with a range of -30% to plus 50%. The low and high costs were added together to obtain the total range of estimated costs. The detailed cost breakdown is provided below.

Assuming an onsite team of 2 DNR staff consisting of a Fisheries Specialist (\$32/hr.) and an Invasive Carp Field Lead (\$39/hr.) working 8 hours/day, 5 days/week, for a 1-month period, we estimate a total of \$11,360 for the training period.

Bruch and Haxton 2023, did not include data on annual O&M costs for the Whooshh System as was the case for the fish ladder and fish elevator options. However, we used the figure associated with the fish elevator for the annual O&M cost factor as the elevator and Whooshh are somewhat similar in the level of mechanization to move fish, and no other costing information was available at the time we developed the cost estimate. See below for discussion on the cost basis and calculations for annual O&M.

Estimated Procurement and Installation Cost: \$4 M to \$5.3M (2025 USD)

Estimated Annual Operating Costs After First Year: \$61,620 (2025 USD)

A detailed cost breakdown is provided below.

TABLE 4.3.3.2-1 Whooshh Pneumatic Fish Passage Estimated Purchase and Installation Cost

| | | |
|------------------------------|--------------------|---|
| Whooshh Quote: | | |
| Passage Portal Model F | \$3,604,000 | |
| TUber | \$252,000 | |
| FlowGuidance | \$150,000 | |
| Subtotal: | \$4,006,000 | |
| Low Estimate (-5%): | \$3,806,000 | AACE Class 2 Bid Level Estimate |
| High Estimate (+20%): | \$4,807,000 | |
| | | |
| <u>Estimated Costs</u> | | |
| Shipping Costs (5%): | \$200,000 | |
| Installation: | \$100,000 | |
| Total Estimated Costs: | \$300,000 | |
| Low Estimated Costs (-30%): | \$210,000 | ACE Class 4 Screening Level Cost Estimate |
| High Estimated Costs: (+50): | \$450,000 | |
| | | |
| Total Low Estimated Costs: | \$4,016,000 | |
| Total High Estimated Costs: | \$5,257,000 | |

TABLE 4.3.3.2-2 Whoosh Pneumatic Fish Passage Estimated Annual Operating Costs

| | |
|-------------------------------------|-----------------|
| Annual O&M (based on fish elevator) | \$26,000 |
| Annual labor | \$23,296 |
| Subtotal: | \$49,296 |
| Contingency (25%): | \$12,324 |
| Total: | \$61,620 |

As described above, the annual O&M factor was taken from Bruch and Haxton, 2023, for the fish elevator option as both the fish elevator and Whooshh are highly mechanized selective fish passage options, and no other annual O&M factor was available.

The annual labor line item was calculated using two (2) staff to inspect the system and load invasive carp from a holding tank on top of the bulkhead to land for disposal using the TUber system as described in the section above. The cost basis for this used 2 DNR staff, a Fisheries Intern (\$20/hr.) and a Fisheries Specialist (\$32/hr.) for 8 hours/day, 2 days/week, for a 7-month period. We limited the operational period of the Whooshh System to avoid issues from ice formation on the equipment and safety issues from slippery surfaces. Additionally, we were unsure of the presence of fish during the winter months and the need for fish passage during these periods. Since the labor requirements for this option are not full-time, limited to less than a full year, and could be further reduced if an option to automate removal and disposal completely rather than use the method discussed above (2 staff using the TUber system to transport invasive carp to land), this option would utilize existing DNR staff from the invasive carp team. An increased workload and reduced allotment of staff to other invasive carp issues by these staff should be

considered as the total number of hours / year for each individual staff would be 448 (64 hours/month for 7 months).

4.3.4 Trap and Truck

4.3.4.1 Description

Trap and truck refers to trapping fish (native and invasive) downstream and/or within LD5, removing them from the Mississippi River, and disposing of them. WSB evaluated several options for the trapping system but upon discussion with the DNR and consideration of other options, the use of a boat electrofisher was the preferred method for trapping fish. A team of 3 DNR staff using an electrofishing boat would collect and sort stunned fish downstream of the LD5 structure. Captured invasive carp would be brought to shore for disposal while native fish species would be ferried through the navigational lock and released on the upstream side of the dam.

Traps located downstream or upstream of the roller and tainter gates were discussed and evaluated, but the lack of engineering plans and 3D flow environment data (received later in the project), disagreement on burst and sustained fish swim speeds, and uncertainty of the ability to make this design selective, removed this design from further consideration.

4.3.4.2 Cost Estimate

The estimated costs of trap and truck operations as outlined in this report are based on assumed hours of operations and on labor and equipment rates provided to WSB by the DNR. WSB assumed that trap and truck operations would occur 3 days/week for 7 months/year. Each workday is assumed to be an 8-hour day with three staff, totaling 672 hours a year per staff. As the trap and truck operations can be carried out by the DNR using current staff and equipment, no purchase or construction costs are included with this option.

Before beginning a trap and truck operation, WSB recommends that the DNR and USACE have a coordination meeting to discuss the standard operating procedure. The DNR may also wish to draft a training document specifying the staffing and workflows for trap and truck activities. The staff time for completing these activities is not included in the costs shown below. Finally, the costs do not include disposal of any invasive species captured during trap and truck operations. This is primarily because the number of invasive species congregating below LD5 is currently not well known and disposal procedures have not been determined. Disposal costs can be estimated for preliminary volumes in the SOP and adjusted after the first few months of trap and truck operations.

A cost breakdown is provided below:

Annual Operation Costs: \$86,814

TABLE 4.3.4.2-1 Trap and Truck Estimated Annual Operating Cost

| | | |
|--|-----------------|--|
| Hours Per Year | 672 | Based on 8 hours/working day, 3 days/week for a 7-month (April-October) period |
| Labor | | |
| Fisheries Intern | \$13,440 | Assumes \$20/hour |
| Fisheries Specialist | \$21,504 | Assumes \$32/hour |
| Invasive carp field lead | \$26,208 | Assumes \$39/hour |
| Total Labor per Year: | \$61,152 | |
| Equipment Fees | | |
| Fuel per day (boat) | \$25 | Assumes 5 gallons/day @ \$5/gallon for premium/non-ethanol |
| Fuel per day (Truck) | \$64 | Assumes 10 miles/gallon mileage (towing) @ 186 miles round trip from Central Region Office and \$3.43/gallon mid-grade (AAA August 2025) |
| Fuel per day (generator) | \$10 | Assumes 2 gallons/day of premium non-ethanol @ \$5/gallon |
| Total Equipment Fees: | \$8,299 | Using 84 Working Days/Year |
| Subtotal: | \$69,451 | |
| 25% Contingency: | \$17,363 | |
| Total Estimated Annual Operating Cost: | \$86,814 | |

4.3.5 Selectivity Augmentation Options

Section 4.3.5 provides general information on various selectivity augmentation options that are needed to improve or convert an option from simply providing fish passage to providing selective fish passage and the ability to trap and remove invasive carp. The following options have not necessarily been identified as part of the final design for each of the options, rather we are presenting this as section for consideration and further adaptation if deemed applicable to one or more of the selective fish passage options.

4.3.5.1 Exclusion Rack

This deterrent can be included to select for size between species (interspecies) and within the same species (intraspecies) based on life stage (fingerling, juvenile, subadult, adult). An exclusion rack is applicable to the fish elevator, fish ladder, and Whooshh. The openings between the vertical slats may be sized to exclude subadult and larger silver carp from entering the ladder, elevator, or Whooshh as juvenile and young of year (YoY) invasive carp have not been captured near LD5. This can reduce the volume of fish that need to be identified by either staff or AI, further reducing the probability that invasive carp will be passed. An exclusion rack can also be used to sort fish to allow for a “small fish” passage system that will allow for specific passage of native fish species that do not grow to large size or YoY/juvenile life stages of native fish that do grow to large size. The width of the openings between vertical slats should be sized based on measured values of native fish species (or life stages) that managers want to ensure pass and not overlap with measured widths of invasive carp. This data was not available at the time of this report but should be gathered if this deterrent augmentation option is pursued.

4.3.5.2 Fish Recognition Systems

This option presents the greatest opportunity for automating the selective fish passage process. We met with three (3) vendors (InnovaSea - HydroAI, Biotactic - BRAIN, and Whooshh- FishLRecognition) to gather information on imaging hardware and AI software capabilities of fish recognition for application to this project. We also identified and met with one other vendor (Ocean Marine) to discuss the use of sonar for identification of invasive carp species (SoundsMetrics- ARIS Explorer 3000). Our approach is to provide an understanding of the imaging options (cameras) along with existing and future opportunities to pair with AI for full automation of selective fish passage. For the AI component we propose the system (algorithm) be able to identify the invasive carp species identified in Section 1.4.1 and determine if the fish being imaged is invasive (one of three species listed) or native; a binary choice. This would shorten the period of time needed for training and development of the AI. Additional species identification capabilities could be added post implementation which could provide a wealth of information on native species movement and abundance. Systems to enumerate specific fish species are already operational in in Canada and the US, such as the Alaska Department of Fish and Game's use of sonar (DIDSON and ARIS), the Bruce Power Nuclear Generating Station's use of Biotactic AI and underwater camera's for measuring changes in fish biomass in the Saugeen River Watershed, Ontario, and InnovaSea's use of HydroAI to monitor Alewife for Nova Scotia Power.

InnovaSea, a Canadian company, combines real-color imaging with AI software to provide species identification and enumeration. InnovaSea uses the Barlusa camera to collect real-color images. This small, compact camera would be installed on the fishway, preferably in a location where the fish has been dewatered or where the water is clear and slow-moving to increase accuracy. The fish would be imaged, and the data collected would be sent remotely to the cloud via StarLink for real-time data access. The fish would then be identified using InnovaSea's AI software HydroAI as 'invasive' or 'native'. A summary of the process InnovaSea would use to implement their product at LD5 as well as an estimate of the time expected for each phase is included in Figure 4.3.5.2-1.

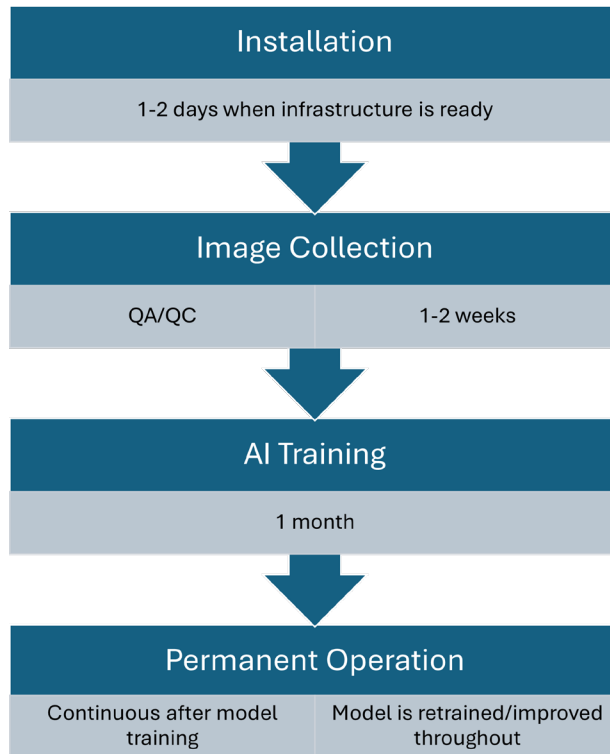


FIGURE 4.3.5.2-1 InnovaSea Process Figure

Biotactic, a Canadian company, uses the Bravo G3 real-color camera combined with the BRAIN AI software to provide species identification and enumeration. Like InnovaSea, Biotactic would install a series of small, compact cameras along the fishway. These would be installed in a location where the fish has been dewatered or where the water is clear and slow-moving so that accuracy is enhanced and there is minimal overlap of fish. The imaging data would be sent remotely to be identified as 'invasive' or 'native' by the AI software. A summary of the process Biotactic would use to implement their product at LD5 as well as an estimate of the time expected for each phase is included in Figure 4.3.5.2-2.

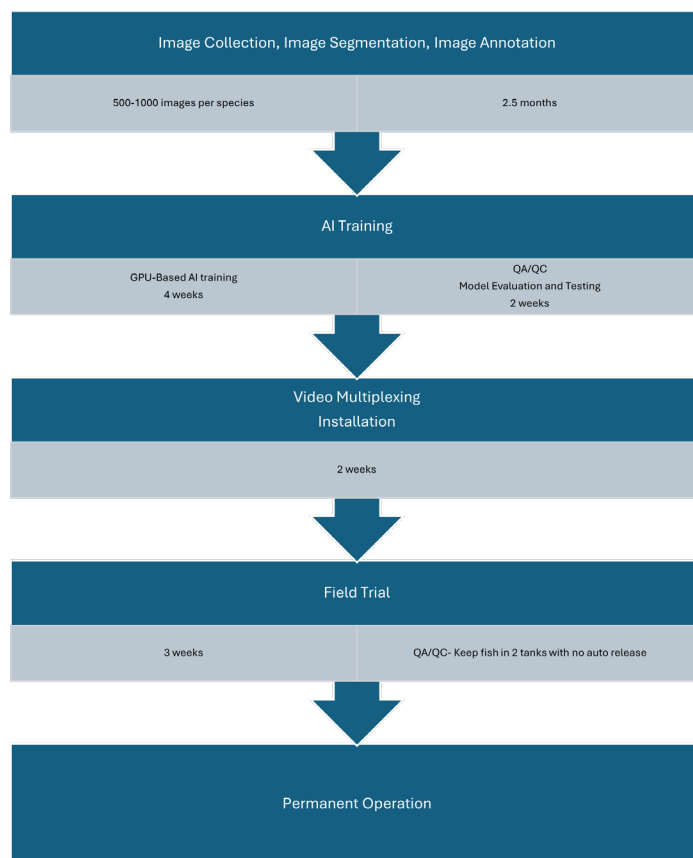


FIGURE 4.3.5.2-2 Biotactic Process Figure

Whooshh Innovations, an American company, combines fish passage with imaging hardware and AI software. The imaging hardware and AI software are combined into one product, the FishLRecognition component, to identify fish in addition to collecting body measurement data such as length and girth. The FishLRecognition system uses a combination of 3 real-color and 3 near-infrared cameras to collect 18 images of the dewatered fish. The fish will be identified as 'invasive' or 'native', similar to all other AI options proposed. A process figure from Whooshh Innovations was not produced.

Preliminary work has already begun on this as part of the FishPass project referenced in Section 1.4. This work includes the development of a high precision fish classifier as described in Eickholt, et al. 2020 and an image library developed as part of the same project. It should be noted that staff from Whooshh Innovations were involved with this project (the paper references and includes an image of the FishLRecognition scanner) and appear to have further developed this as part of their existing offering. The image library includes images of 23 bighead carp, 42 common carp, 2 goldfish, 4 grass carp, and 903 silver carp as part of the 4,971 individual fish images of 13 species. Accuracy of the test dataset was 95% for single fish image and 97% for ensemble (batches of fish) images.

Imaging hardware for the Biotactic and HydroAI systems use true color images from commercially available cameras. Biotactic uses the BravoG3 camera and HydroAI uses the Barlus camera. The Whooshh FishLRecognition system utilizes a combination of true color and near-infrared imaging to improve accuracy and brings fish into the FishLRecognition System (somewhat dewatered) to identify them rather than identifying within the water column. These true color systems are limited by water clarity (increased turbidity results in decreased range and accuracy) and have a relatively short range (< 1.5') in very turbid water. Publicly available data from the Upper Mississippi River Restoration Program-Long Term Resources Monitoring (LTRM) shows that secchi depth between March and the end of September typically averages ~2.5' (Field Station 1- Lake City, MN) between 2019 and 2024. However, secchi depth can be <1' during some periods which can compromise the system's ability to identify fish when underwater. To address this, the fish elevator option dewater the fish and utilizes multiple cameras while the fish ladder directs fish to a shallow pool at the top of the ladder and keeps them confined until the batch is identified as infested (one or more invasive fish) or uninfested (no invasive fish). To further enhance imaging clear water could be added to a holding pen, lighting could be added, and/or painting the sides/bottom of the holding area with light colored paint.

Sonar provides an interesting opportunity for imaging and AI integration as the range is much larger (up to 100') and is not as affected by turbidity. However, detail is lost, and high turbulence can wash the image out preventing the ability to get an image. There are examples of marine applications of using sonar for speciation and the Alaska Department of Fish and Game regularly uses sonar for counting fish in rivers. Development of a deep learning application (AI) specific to sonar images of select species described in Section 1.4 would need to be completed to allow for implementation of this technology. A summary of vendors, products, and cost estimates is found in Figure 4.3.5.2-3.

| Vendor | Product | Cost | Notes |
|---------------------|--|---|--|
| Sound Metrics | Aris Explorer 3000 | \$89,950.00 | Need to pair with AI software 1 camera |
| Biotactic | Bravo G3 and BRAIN | \$318,085.50 | Camera quality depends on turbidity 5 cameras Hardware and software processing for 1 year |
| Whooshh Innovations | PassagePortal Model F FlowGuidance Tuber | \$4,000,000.00 | Hardware and software |
| InnovaSea | Barlus Camera and HydroAI | \$140,000.00 for first year \$115,000.00 for subsequent years | 2 cameras Hardware and software Identification software is fairly new Camera quality depends on turbidity |

FIGURE 4.3.5.2-3 Summary of AI Vendors, Products, and Cost Estimate

4.3.5.3 Flow Velocity

Based on current research, velocity, as it relates to fish behavior in passage systems, refers to the localized speed of water that fish directly experience. This is critical when evaluating how fish respond to hydraulic conditions. Invasive fish species often possess similar or greater burst swim speeds to native species. However, velocity can be used to sort fish based on their morphological and behavioral adaptations. Fish that reside primarily in lakes, such as centrarchids (e.g., bass and sunfish), typically have tall, narrow bodies suited for short bursts of speed but are less stable in flowing water. In contrast, riverine species like cyprinids possess rounder body shapes that enhance their ability to navigate sustained flow conditions. This difference in body profile and swimming capability can be leveraged to design passage systems that favor native species while discouraging invasives. Additionally, turbulence - a pattern within flow - may offer another layer of selectivity. Hans Tritico's doctoral research at the

University of Michigan explores how fish interact with turbulence in habitat selection and swimming behavior. While promising, turbulence is significantly more challenging to measure and quantify compared to velocity, limiting its practical application in fish passage design. While velocity may not serve as a strong deterrent for invasive species, it holds potential as a sorting mechanism when integrated thoughtfully into fish passage systems. Swim speed ability could be exploited to trap invasive carp by increasing flow and including a trapping mechanism within the increased flow field to a threshold that can only be exceeded by invasive carp and non-native fish. This would theoretically result in only invasive carp being trapped and available for removal. Further exploration of species-specific velocity preferences and turbulence navigation could enhance selectivity.

4.3.5.4 Sound, Air Curtains, Electrical Guidance Systems

Section 1.5 describes two (2) deterrent options currently being considered for use at LD5 that use sound exclusively and sound and air bubbles. While this is expected to deter invasive carp from entering the lock, conversely it could guide fish towards the auxiliary lock as it would be expected to be devoid of these stimuli. Similarly, if feasible to line the gates with these deterrents, the only “stimuli gap” could be the auxiliary lock. This could increase the number of fish (invasive and native) that may attempt to use the auxiliary lock and be selectively passed.

Electrical guidance systems have been used in a variety of projects to pass native fish or remove/block invasive fish in a variety of applications and environments. These systems could be applied in a similar way as the sound and bubble deterrents to guide or herd fish from the active lock and gates to the auxiliary lock passage option to increase the number of fish passed (native) or removed (invasive), but may be more targeted as the electrical field wouldn't be as diffuse as a sound field and potentially less penetrable as an air curtain. This would require a full evaluation to determine if an electrical guidance system is practical and possible from an engineering perspective.

4.3.6 Attractants

4.3.6.1 Pheromones

F prostaglandins, a pheromone released by female silver carp, have been shown to attract male silver carp, even though this pheromone seems to be species-specific (Sorensen, P., et al., 2019). It should be noted that F prostaglandins will only attract male carp, while androstenedione could be used to attract females (Sorensen, P. & Stacey, N., 2004). While both pheromones have been demonstrated to attract carp, both male and female attractants should not be used in tandem to discourage spawning events.

The use of native fish pheromones to target key species could also be implemented to encourage passage and aggregation. For example, McDougall, C., et al., found the release of lake sturgeon pheromones attracted and increased reproductive activity at release sites (2025). While using native species' pheromones may be useful for target species, it will not be a suitable attractant for all native species.

4.3.6.2 Heat

Water temperature greatly influences carp development and behavior (Li, Y., et al., 2024). Additionally, the DNR reported bighead carp capture at the Xcel Energy King Power Plant in 2015 (MAISRC, 2015). It can be inferred that warm water discharge from the power plant influenced carp congregation. Considering this information, a small water heater could be deployed near the entry point of the fish passage option to encourage invasive carp to enter. A hydro powered turbine could be designed to naturally heat water using river flow. The river flow would generate electricity, which could then be used to power a water heater. This attractant would inherently be most useful during winter months when water temperatures are below 50 degrees Fahrenheit.

The use of heat as an attractant may also encourage native fish species to use the fish passage option. Research shows that increased water temperatures raise metabolism in fish, increasing their activity and feeding frequency. The deployment of a water heater would not negatively impact native species, and it may encourage entry into the fish passage option.

4.3.6.3 Flow

It has long been known that flow velocities influence swimming and migratory behavior in fish. Different species of fish have a variety of morphological adaptations and therefore have different swimming abilities and swim path selection processes. An important aspect of fishway design is to produce high velocities to encourage fish to enter the fish passage system. This means that the fish passage option must outcompete LD5's natural current velocities within the downstream area of the gates. To understand what the current velocity is at LD5, we consulted with Dr. David Smith, with the U.S. Army Corps of Engineers Engineering Research and Development Center, who created a computational fluid dynamics model at LD5. Using this model, we found a median current velocity of 17 ft/s from a vertical splice of the entire dam situated underneath the center gate wall. Although this data is useful, it may not be indicative of the specific velocity of water at the auxiliary lock, where the fish passage option would be placed. Further studies or modelling must be undertaken to understand the velocity at the gate near the auxiliary lock. This is critical in understanding what current velocity will be needed to encourage fish to enter the fish passage system.

Whooshh Innovations' FlowGuidance, is capable of producing artificial flow regimes to attract fish. The FlowGuidance consists of an eductor, pump, frame with anchor points, and fish screen. The pump injects water into the eductor at high pressure. The water ejected from the eductor is expelled in a cone-like shape from the FlowGuidance at a higher pressure and volume producing flow. The eductor comes in a variety of sizes which produce varying output velocities (Table 4.3.6.3-1). This flow velocity enhancement system could be placed at the entrance of the fish passage option chosen to encourage fish entry.

TABLE 4.3.6.3-1 FlowGuidance Eductor Size and Output Velocities

| FlowGuidance Size (Eductor Diameter, inches) | Output Velocity (ft/s) |
|--|------------------------|
| 4 | 12.13 |
| 6 | 10.21 |
| 8 | 10.15 |
| 12 | 11.23 |
| 16 | 12.64 |

4.3.6.4 Lights

Fish and other organisms are attracted to light through phototaxis. The best example of this is seen in phytoplankton. Phytoplankton are attracted to light and therefore experience positive phototaxis. Species can also experience negative phototaxis. This is best seen in zooplankton during diel-vertical migration; zooplankton sink low in the water column during the day and rise to the surface of the water column at night. Historically, light-emitting diodes (LEDs) have been used to improve fishing catch rates and reduce bycatch, using the mechanism of phototaxis to capture fish (Yochum, N., et al., 2024). Studies have also shown that the certain wavelengths of light that fish are attracted to can be species specific (Yu, M., et al., 2022). This is likely because various wavelengths of light are absorbed differently throughout the water column. For example, Yu, M., et al. found species that experienced diel-vertical migrations are adaptive to a wider range of wavelengths because the species is naturally exposed to varying wavelengths throughout the day (2018). They found a similar pattern with benthic species; since red light is absorbed within the first 10-30 meters of the water column, benthic species experienced negative phototaxis when exposed to red light. Species have also evolved to adapt to their environment, which includes depth and water transparency (Yu, M., et al., 2022). Humborstad, O., et al. found that catch rates of cod significantly increased while using LED bait pots that attracted krill, even though cod did not respond to light separately (2018). This could mean that fish that are not independently attracted to light may become so indirectly so as to follow prey that experience positive phototaxis.

It has been shown that Bighead carp experience negative phototaxis (Dennis, C., and Sorensen, P., 2020). Dennis and Sorensen found that 80% of bighead carp passage was blocked by exposure to high intensity white light in a dimly lit flume. This study also found that constant light was more effective than

strobing light in dimly lit conditions, and that the light became more effective with repeated exposure (2020). However, strobing light was more effective at deterring passage in dark conditions compared to a dimly lit flume. Dennis and Sorensen found the lower frequency (2 Hz) strobing light was equally effective as the 5 Hz and 12 Hz strobing light and therefore recommended using a lower-frequency strobing light to reduce the risk of epileptic shock. This study also included the effects of light on a native fish species, the largemouth bass. Dennis and Sorensen found the variation in background lighting strongly influenced the rate of passage for this species. Specifically, largemouth bass passage was blocked by 85% while using a strobing light in a dark flume, and 60% while using constant light in a dark flume. However, largemouth bass passage increased while using strobing and constant light while in a dimly lit flume. These results confirm that reactions to light are species specific and could be applied to increase selectivity for native fish. This may depend on a variety of other factors, such as background lighting.

4.3.6.5 Food

Finally, food can be used as an attractant for invasive carp species. Ghosal, R., et al., found adult silver carp were attracted to the baited side of a pond compared to the side of the pond that was not baited (2022). It should be noted that this attractant may be less effective during periods of colder water or when natural food is present (Ghosal, R., et al. 2018). The deployment of food can be used as a cost-effective method of attracting invasive carp species for trapping and removal.

Bait for native fish could also be deployed in tandem with invasive carp food to attract native fish species to different sites or to increase the overall volume of fish that would pass into the selective fish passage option. For example, according to the DNR article *How to Catch Lake Sturgeon*, insect larvae, snails, leeches, small mussels, and small fish could be used as an attractant for lake sturgeon (2025). Native fish food attractant could be used to target specific species but likely will not be effective in attracting all native species expected to be found near LD5.

5.0 TEST PROCEDURES FOR SELECTED FISH PASSAGE OPTION(S)

In future phases of the project, the DNR will need to complete detailed analyses of proposed fish passage options. There are several methods of analysis which can be used to evaluate concept designs based in their engineering and hydraulic characteristics, but they fall broadly into two camps: physical modeling and computational modeling.

5.1 Computational Modeling

Computational modeling involves creating a digital model of an existing or proposed structure. Computational models are used in many disciplines but for studying fish passage through LD5 the DNR would likely use a computational fluid dynamics (CFD) model. Computational fluid dynamics allows the user to model the movement of a fluid, whether flowing freely or under pressure, in all three dimensions across time.

The DNR already has access to an existing CFD model of LD5. Dr. David Smith with the U.S. Army Corps of Engineers Engineering Research and Development Center (ERDC) has already created a CFD model of LD5 in order to model hydraulics and fish passage. This model shows hydraulic characteristics including but not limited to three-dimensional velocity, three-dimensional acceleration, and water depth.

ERDC also has a model of fish swimming behavior that can predict the ability of fish to pass through the LD5 structure based on the flow patterns around it and swimming abilities of individual species. The fish model uses the output of the CFD model as its inputs, meaning that the ability of fish to pass through the LD5 structure depends on the hydraulic characteristics the fish senses in its vicinity such as turbulence, velocity, and water depth.

WSB met with Dr. Smith in May 2025 to discuss the models and their current results. Dr. Smith provided a summary of current model findings, including the following:

- There is very little fish passage through the dam until the flow through the dam is between 105,000 and 109,000 cfs.
- Around 115,000 cfs, dam operators start to have less control over the volume of water passed by the gate position, the river hydraulics are starting to be less impacted by the structure.
- The dam is considered to be at “open river” conditions when all gates are fully open at approximately 120,000 cfs.
- Most fish passage below these flow events are through the lock chamber. Studies suggest that a typical percentage of tagged fish which pass through the lock chamber is 5% or less. This is likely due to a lack of attraction flow that guides them in and out of the structure.

5.1.1 Using Computational Modeling for Fish Passage Evaluation

The DNR is well positioned to use the existing CFD model for evaluation of fish passage options through LD5. Of the four fish passage options recommended for further study in Section 4, only two are suitable for modeling using the existing CFD model; a fish ladder and a fish elevator. Trap and truck does not have a new physical structure which requires hydraulic assessment, and a siphon fishway or fish cannon is a (mostly) moveable structure which does not depend on dam hydraulics for movement of water through it.

The DNR could work with ERDC to create CFD models of either the fish ladder or the fish elevator if they are selected as suitable fish passage options at LD5. The structure would likely need to have preliminary design completed before the modeling could begin, as specific information about each design such as location within the LD5 complex, sizes, and inlet and outlet elevations would need to be decided before CFD analysis could begin. However, the existing model of LD5 and the existing working relationship between the DNR and ERDC is undoubtedly an asset to further investigation of fish passage options at LD5.

5.2 Physical Modeling

Physical modeling involves creating a scaled physical model of an existing or proposed structure. Physical modeling is often used for planning, public engagement, structural design, and the validation and calibration of computational models. The St. Anthony Falls Laboratory (SAFL) is a hydraulics and fluid dynamics lab located at the University of Minnesota with extensive experience in designing, building, and operating physical models of hydraulic structures. While they are not the only option for the creation of a physical model for evaluating fish passage at LD5, they were able to provide WSB with an understanding of the physical modeling process which would be useful for DNR staff evaluating options for the next phase of this project.

WSB staff met with Matt Lueker and Jeff Maar of SAFL in May 2025 to discuss the potential scope, schedule, and budget for creating a physical model for use in evaluating fish passage at LD5. They explained the process as follows

- The first step is scoping, which can take several months. SAFL usually prefers to limit the number of flow scenarios assessed per contract to approximately five; additional flow scenarios can be added later.
- Following the completion of scope definition, SAFL staff will build a scaled-down model of the physical geometry using plastic (for dam structures) and concrete (for the surrounding bathymetry and topography). Construction of a physical model usually requires at least six months.
- Flow rates and hydrology are determined via Froude scaling and based on the flow scenarios determined in the project scope.
- Testing and results collection generally take six months to complete.
- A ballpark cost estimate for a physical model of this size and complexity is \$400,000 to \$500,000. Specific costs would be determined during the scoping process.

Similar to computational modeling, physical modeling would only be suitable for evaluating the fish ladder and fish elevator options. Due to the long timescale of physical modeling and the inability to change physical attributes of the model post-construction, physical modeling is likely most suitable for evaluating advanced designs that have already been examined using CFD methods. The model results could then be used as verification or calibration for the CFD model before final design is complete.

5.3 Visualization 3-D Model

The 3D model used for the visualization effort was created based on reference photos of the project site. Because there were no CAD files or drawings to work from, the modeling effort for the lock and dam and the various structures was limited to what could be ascertained mostly from photos from the April 2025 field visit and a few drawings discovered in historical archives on the internet.

3DS Max was used to model the various components of the dam such as the tainter gates and roller gates. Unreal Engine was used to assemble the various components of the models and ultimately for the visualization to render out the various images used in the report and to present the passage options during the project presentation.

The 3D max file could be used to build upon for future visualization, but for it to be used for engineering purposes or any sort of schematic design it would need to be checked and verified with actual as-built drawings of the structures. The 3D models can be exported from 3DS Max to AutoCAD .dwg format for use in AutoCAD or Microstation to take the model and designs further.

The 3DS Max file (and texture maps) and the Unreal Engine project have both been provided to the DNR.

6.0 Discussion

This report provides a launching pad for agency staff and partners to further evaluate the selective fish passage options presented in this report, through additional data collection, design, and discussion as funding becomes available.

The scope and level of detail able to be provided in this report is limited due to constraints such as the project duration, agency requirements for data requests and the availability of some data. WSB had 19 weeks to complete the literature review, list and evaluate the various passage options, meet with agency staff to review, complete a site visit, meet with vendors that provide selective fish passage hardware and services and integrate that data, create visualization models, and draft this report. Requests made to the Army Corp of Engineers for LD5 construction plans and operations manual were delayed due to federal processing to private businesses. The legality concerns on the already constrained timeline meant concepts were designed from public data at the forefront.

Concurrent projects related to LD5 also limited the ability for WSB to utilize data for certain conceptual design computations as these are in progress. A LD5 deterrent analysis, which models computation fluid dynamics (CFD) of the area and includes a sensory fish movement model, is in progress by the Army Corps of Engineers. The final study and report are not currently published, and finalized data would aid in determining concept location and design using migratory patterns and swim speeds.

6.1 Cost Estimate Summary

WSB performed conceptual/screening level cost estimates for the four options which proceeded to second level and final evaluation. Table 6.1-1 below shows the estimated construction and annual operating costs for each option. Further detail on the development of these estimates is provided in section 4.3.

TABLE 6.1-1 Cost Estimates (2025 USD)

| Option | Low Estimate ¹ | High Estimate ¹ | Estimated Annual Operating Costs with Labor |
|--------------------------|---------------------------|----------------------------|---|
| Fish Ladder | \$8M | \$17.2M | \$261,343 |
| Fish Elevator | \$10.4M | \$22.2M | \$282,631 |
| Whooshh Pneumatic System | \$4.3M | \$5.8M | \$61,620 |
| Trap and Truck | N/A | N/A | \$86,114 |

¹Includes design, permitting, and construction

6.2 Data Gaps

Multiple data gaps were identified during this project as is normal during a conceptual exercise. We felt it important to identify these gaps below to provide additional specificity and accuracy to the designs and cost estimates which may allow the selection of a specific selective fish passage option at some point in the future.

The volume of fish expected to be at LD5 at any given point in time is unknown. This greatly affects the size and scale of the passage option and will need to be determined to complete a structural design for the fish ladder and fish elevator. However, all passage options were selected with this unknown in consideration as they can be scaled to reflect the volume of fish estimated to frequent LD5.

A relatively small, but important data gap that can help with the design of an exclusion rack would be measuring and documenting maximum width of invasive carp.

We did not include a discussion on flow velocities in the auxiliary lock in comparison to those near the roller and tainter gates and fish swim speeds (burst and sustained) as we were unable to run the CFD model. However, we were provided with outputs from the model for specific gate scenarios that described

flow velocity and volume across the downstream side of the LD5 structure, but due to limited project time and the fish movement model discussed above being incomplete, we did not include this in the analysis. This data is important so as to identify the necessary flow velocity to attract fish to the entrance of the selected fish passage option and for design of the fish ladder.

Structural drawings of the auxiliary lock area were not received from the USACE until near the project end and thus did not weigh heavily in fish passage option evaluation. Further evaluation and engineering and construction plans will require this information.

The existing bathymetric data did not include the entirety of the floor of the auxiliary lock. This data should be collected as it will be necessary to design and implement three of the four options (not necessary for trap and truck).

Disposal options for invasive carp have not been determined at this time, but will be critical to the final design, process, and cost estimate of any selective fish passage option. Our options assume that invasive carp will be identified, sorted from native fish, and removed from the system, but we do not specify what is done with invasive carp or where they will be taken (except to land adjacent to LD5 on the Minnesota side of the structure).

Ultimately this report provides resource managers, researchers, and policy makers with concept level design information and visuals to facilitate discussion and further evaluation of the four options discussed in the final evaluation. We intended to develop a framework in which additional information could be included as it becomes available to move towards a more quantitative evaluation, from the qualitative one provided in the second level. This will also allow for the development of more specific designs and accurate cost estimates as funding becomes available in the future.

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Appendix A

Scoring Matrix

Main Passage Structure- Downstream to Upstream Passage Ratings

| STRUCTURE TYPE | SELECTIVITY | | SELECTION CRITERIA | | | | | | | | | |
|--|--|--|--|---|---|--|---|--|---|--|---|--|
| | PASS/FAIL RATING | SELECTIVITY COMMENT | DESIGN, ENGINEERING, PERMITTING, AND CONSTRUCTION COST | ANNUAL OPERATION AND MAINTENANCE COST | SAFETY RISK | LABOR NEEDS | NAVIGATION | ENGINEERING | RIVER HYDRAULICS | AUTOMATION DIFFICULTY | MAINTENANCE | PORTABILITY |
| Fish Ladder | PASS: We can control velocity and lock sizing, but it should be used alongside something else since carp can jump. When augmented with selectivity mechanisms. | The option is highly selective with trained staff manually sorting fish. | ★ Typical design is 1:10 (V/H). The dam is 26' high, so we need 260 LF of room + grading to build. | ★★ Operational costs are moderate due to the passive fishway design. Maintenance mainly involves clearing debris from the ladder, with additional costs for staff to manually sort fish at the selection point. | ★★ Impact to bulkhead can cause flooding. Recreational traffic can be affected by inflow of ladder. Low to no impact to commercial traffic. | ★ Staff required to sort fish and maintenance to avoid clogging. | ★★ If constructed in the auxiliary lock this poses less concern regarding navigability. If the ladder extends out of the aux lock due to construction length, this will obstruct recreational/ barge traffic. | ★ This will involve multiple sectors of engineering to design. If the USACE is looking for new structures or use of the auxiliary lock | ★★ We will need to see how the structure affects the water level and if we can control the velocities in the ladder to suit the river and native species. | ★★ AI will need to be attached and integrated. | ★★ Debris removal and potentially adding a trap/ sorting system for carp that get caught. | ★ Immobile. |
| Trap and Truck | PASS: At LD5 selectivity would likely be achieved by sorting by species after electrofishing downstream of the dam. Native species would move through the locks on the boat and be released in the upstream pool. | Highly selective, uses MNDNR fisheries staff to identify fish before moving native fish upstream and removing invasives. | ★★★ No new structures or construction required. MNDNR may wish to write an SOP for the work and will need to determine what will happen to captured invasive fish. | ★★★ Assumes three days of electrofishing per week from April to October - \$86,000 per year. | ★★★ Largest risk is to staff on the electrofishing boat but these staff have been trained for this activity. Risks to public, dam staff, and commercial traffic are very low. | ★ Staff needed to trap, sort any native species that are caught, and truck offsite. | ★★★ Electrofishing boat would need to traverse the lock either two or four times per day. This is not likely to impede commercial navigation and timing of lock travel can be flexible. | ★★★ No structures or construction required. | ★★★ No changes to the hydraulic operations of the existing dam. | ★ Automation likely not compatible with installation on a DNR electrofishing boat. | ★★★ Requires maintenance of boat and trailer (accounted for in costs) and training for staff. These costs would be for DNR unless a cost share agreement with USACE is reached. | ★★★ Highly mobile, allows for fishing around entire downstream dam structure (within boating safety limits). |
| Fish Elevator | PASS: Manual sorting of fish would occur in the holding tanks by trained staff. Future scaling would include AI to select invasive carp species into a secondary holding tank. | Highly selective, uses MNDNR fisheries staff to identify fish before moving native fish upstream and removing invasives. Include AI recognition eventually that will automate the sorting process. | ★ New construction design for tank holding building, lift station, and channel chamber. Will involve structural work and work underwater. | ★★ Cost of including labor will be high for manually sorting fish until the AI recognizes carp species. Components of the computer system to store and manage data on site will increase costs. | ★★ Impacts to bulkhead, maintenance cleaning of lift station and underwater flume. Low impacts to commercial traffic and moderate to recreation traffic. | ★ Not fully automated until AI recognizes carp species. This can take a full year of computer learning, therefore high labor initially. Low labor in the future. | ★★ If built on the auxiliary lock, navigability is less of a concern since barge and recreational traffic avoid this lock. However, flow adjustments to attract fish may impact recreational traffic. | ★ Highly engineered in both structural, mechanical, and hydraulics. | ★★ Since the lift isn't on the active lock or gates, flow impacts are minimal. Some attractant flow will be added, slightly changing upstream head, so understanding river hydraulics is essential. | ★★ Automation needed after AI learns the species. Once implemented, the AI component will be doing most, if not all, of the sorting. | ★★ Regular hydraulic lift maintenance for high water volumes, manual fish sorting unless AI recognition is implemented, and routine debris cleaning of the elevator. | ★ Not possible since structure is installed on the bulkhead. A secondary lift can be added on the east auxiliary wall if needed. |
| Siphon Fishway/ Whooshh Fish Cannon | PASS: Includes AI and sorting capabilities as part of the design. | The Fish Recognition system is highly accurate. Any native species that may be misidentified and transported to the invasive holding tank can be manually removed. | ★★ Design costs would be moderate as the structural and mechanical components aren't as major, since this has portable tubes. | ★★ Operates passively with only maintenance of pump repairs, unclogging tubes, and updating software. Added cost for staff to perform manual transport. | ★★★ Low risk to staff and commercial traffic. Some attractive flow will pose some risk to recreation traffic. | ★★★ If automated, no staff is needed; if not, training from the installation company will be required. | ★★★ Siphon will be too small to affect small watercrafts such as kayaks or canoes. Placed in auxiliary lock, so will not impede boat traffic. | ★★★ Would require some structural/ hydraulic engineering, but mainly software engineering. | ★★ Minimal if any affects, unless passing large amounts of flow. | ★★★ Pre-trained AI can identify invasive fish species and is included within PassagePortal. | ★★★ Could be high if the cannon is constantly running or if it is prone to clogging, otherwise low maintenance. | ★★ Tubes are mobile and most components are except for anchoring system. |

RATINGS: ★ LEAST PREFERRED ★★ MODERATELY PREFERRED ★★★ MOST PREFERRED

Appendix B

Species List

Migratory Species

| Common Name | Scientific Name |
|-----------------------------|------------------------------------|
| Lake Sturgeon | <i>Acipenser fulvescens</i> |
| Skipjack Herring | <i>Alosa chrysochloris</i> |
| Black Bullhead | <i>Ameiurus melas</i> |
| American Eel | <i>Anguilla rostrata</i> |
| Goldfish | <i>Carassius auratus</i> |
| River Carpsucker | <i>Carpionodes carpio</i> |
| Quillback | <i>Carpionodes cyprinus</i> |
| Highfin Carpsucker | <i>Carpionodes velifer</i> |
| White Sucker | <i>Catostomus commersonii</i> |
| Grass Carp | <i>Ctenopharyngodon idella</i> |
| Blue Sucker | <i>Cycleptus elongatus</i> |
| Common Carp | <i>Cyprinus carpio</i> |
| Gizzard Shad | <i>Dorosoma cepedianum</i> |
| Northern Pike | <i>Esox lucius</i> |
| Muskellunge (Musky, Muskie) | <i>Esox masquinongy</i> |
| Mud Darter | <i>Etheostoma asprigene</i> |
| Rainbow Darter | <i>Etheostoma caeruleum</i> |
| Fantail Darter | <i>Etheostoma flabellare</i> |
| Least Darter | <i>Etheostoma microperca</i> |
| Johnny Darter | <i>Etheostoma nigrum</i> |
| Goldeye | <i>Hiodon alosoides</i> |
| Mooneye | <i>Hiodon tergisus</i> |
| Northern Hog Sucker | <i>Hypentelium nigricans</i> |
| Silver Carp | <i>Hypophthalmichthys molitrix</i> |
| Bighead Carp | <i>Hypophthalmichthys nobilis</i> |
| Chestnut Lamprey | <i>Ichthyomyzon castaneus</i> |
| Silver Lamprey | <i>Ichthyomyzon unicuspis</i> |
| Blue Catfish | <i>Ictalurus furcatus</i> |
| Channel Catfish | <i>Ictalurus punctatus</i> |
| Smallmouth Buffalo | <i>Ictiobus bubalus</i> |
| Bigmouth Buffalo | <i>Ictiobus cyprinellus</i> |
| Black Buffalo | <i>Ictiobus niger</i> |
| American Brook Lamprey | <i>Lampetra appendix</i> |
| Long-nosed Gar | <i>Lepisosteus osseus</i> |
| Common Shiner | <i>Luxilus cornutus</i> |
| Shoal Chub | <i>Macrhybopsis hyostoma</i> |
| Silver Chub | <i>Macrhybopsis storeriana</i> |
| Smallmouth Bass | <i>Micropterus dolomieu</i> |
| White Bass | <i>Morone chrysops</i> |
| Yellow Bass | <i>Morone mississippiensis</i> |
| Silver Redhorse | <i>Moxostoma anisurum</i> |

| | |
|---------------------|-------------------------------------|
| River Redhorse | <i>Moxostoma carinatum</i> |
| Black Redhorse | <i>Moxostoma duquesnei</i> |
| Shorthead Redhorse | <i>Moxostoma macrolepidotum</i> |
| Greater Redhorse | <i>Moxostoma valenciennesi</i> |
| Bigmouth Shiner | <i>Notropis dorsalis</i> |
| Stonecat | <i>Noturus flavus</i> |
| Logperch | <i>Percina caprodes</i> |
| Blackside Darter | <i>Percina maculata</i> |
| Slenderhead Darter | <i>Percina phoxocephala</i> |
| Paddlefish | <i>Polyodon spathula</i> |
| White Crappie | <i>Pomoxis annularis</i> |
| Black Crappie | <i>Pomoxis nigromaculatus</i> |
| Flathead Catfish | <i>Pylodictis olivaris</i> |
| Blacknose Dace | <i>Rhinichthys atratulus</i> |
| Sauger | <i>Sander canadensis</i> |
| Shovelnose Sturgeon | <i>Scaphirhynchus platyrhynchus</i> |
| Creek Chub | <i>Semotilus atromaculatus</i> |

Both Migratory and Nonmigratory Species

| Common Name | Scientific Name |
|------------------------------|--------------------------------|
| Brown Bullhead | <i>Ameiurus nebulosus</i> |
| Bowfin | <i>Amia calva</i> |
| Freshwater Drum (Sheepshead) | <i>Aplodinotus grunniens</i> |
| Central Stoneroller | <i>Campostoma anomalum</i> |
| Southern Redbelly Dace | <i>Chrosomus erythrogaster</i> |
| Crystal Darter | <i>Crystallaria asprella</i> |
| Brook Stickleback | <i>Culaea inconstans</i> |
| Iowa Darter | <i>Etheostoma exile</i> |
| Pumpkinseed | <i>Lepomis gibbosus</i> |
| Burbot | <i>Lota lota</i> |
| Largemouth Bass | <i>Micropterus salmoides</i> |
| Spotted Sucker | <i>Minytrema melanops</i> |
| Golden Redhorse | <i>Moxostoma erythrurum</i> |
| Emerald Shiner | <i>Notropis atherinoides</i> |
| Spottail Shiner | <i>Notropis hudsonius</i> |
| Rainbow Trout | <i>Oncorhynchus mykiss</i> |
| Yellow Perch | <i>Perca flavescens</i> |
| Trout-perch | <i>Percopsis omiscomaycus</i> |
| Longnose Dace | <i>Rhinichthys cataractae</i> |
| Brown Trout | <i>Salmo trutta</i> |
| Brook Trout | <i>Salvelinus fontinalis</i> |
| Walleye | <i>Sander vitreus</i> |
| Central Mudminnow | <i>Umbra limi</i> |
| Northern Redbelly Dace | <i>Chrosomus eos</i> |
| Suckermouth Minnow | <i>Phenacobius mirabilis</i> |

Appendix C

Life History Characteristics

| Common Name | Scientific Name | Vertical Station | Maximum Total Length (in) | Body Depth (%TL) | Eye Size (%HL) | Migratory Status | Spring Spawn | Summer Spawn | Fall Spawn | Winter Spawn | 33.8-46.4 F | 48.2-60.8 F | 62.6-75.2 F | 77-89.6 F | Hearing Specialization | Trophic Level | Presence of Ampullary Electroreceptors | Climbing Ability |
|------------------------------------|------------------------------------|------------------|---------------------------|------------------|----------------|------------------|--------------|--------------|------------|--------------|-------------|-------------|-------------|-------------|------------------------|---------------|--|------------------|
| Lake Sturgeon ^{1,3} | <i>Acipenser fulvescens</i> | demersal | 107.874015 | 12.56 | 7.58 | migratory | 1 | 0 | 0 | 0 | 0 | 75 | 25 | 0 | 0 | 3.3 | 1 | 0 |
| Skipjack herring | <i>Alosa chrysochloris</i> | pelagic | 23.5629921 | 22.6 | 19.2 | migratory | 1 | 1 | 0 | 0 | NA | NA | NA | NA | 1 | 3.9 | 0 | 0 |
| Black Bullhead | <i>Ameiurus melas</i> | demersal | 25.9842519 | 28.5 | 14 | migratory | 1 | 0 | 0 | 0 | 0 | 35.71428571 | 57.14285714 | 7.14285714 | 1 | 3.8 | 1 | 0 |
| Brown Bullhead | <i>Ameiurus nebulosus</i> | demersal | 21.6535433 | 19.6 | 11.9 | both | 1 | 0 | 0 | 0 | 0 | 18.75 | 50 | 31.25 | 1 | 3.7 | 1 | 0 |
| Bowfin | <i>Amia calva</i> | demersal | 42.9133858 | 19.45 | 15.7 | both | 1 | 0 | 0 | 0 | 0 | 25 | 75 | 0 | 0 | 3.8 | 0 | 0 |
| Western Sand Darter ^{2,4} | <i>Ammocrypta clara</i> | demersal | 2.79527559 | 9.8 | 28.6 | migratory | 1 | 1 | 0 | 0 | NA | NA | NA | NA | 0 | 3.3 | 0 | 0 |
| American Eel | <i>Anguilla rostrata</i> | demersal | 59.8425196 | 6.8 | 7.2 | migratory | 1 | 0 | 0 | 1 | 0 | 0 | 100 | 0 | 0 | 3.8 | 0 | 1 |
| Freshwater Drum | <i>Aplodinotus grunniens</i> | demersal | 37.4015748 | 26.9 | 29.7 | both | 1 | 1 | 0 | 0 | 0 | 0 | 77.77777778 | 22.22222222 | NA | 3.4 | 0 | 0 |
| Central Stoneroller | <i>Campostoma anomalum</i> | benthopelagic | 8.66141732 | 22.2 | 12.4 | both | 1 | 0 | 0 | 0 | 0 | 27.27272727 | 72.72727273 | 0 | 1 | 2 | 0 | 0 |
| Goldfish | <i>Carassius auratus</i> | benthopelagic | 18.8976378 | 26.27 | 24.87 | migratory | 1 | 1 | 0 | 0 | 0 | 10 | 80 | 10 | 1 | 2 | 0 | 0 |
| Quillback ^{1,5} | <i>Carpoides cyprinus</i> | demersal | 25.9842519 | 27.5 | 21.6 | migratory | 1 | 0 | 0 | 0 | 16.66666667 | 66.66666667 | 16.66666667 | 0 | 1 | 2.6 | 0 | 0 |
| White Sucker ^{1,6} | <i>Catostomus commersonii</i> | demersal | 25.5905511 | 18 | 21.4 | migratory | 1 | 0 | 0 | 0 | 0 | 63.63636364 | 36.36363636 | 0 | 1 | 2.8 | 0 | 0 |
| Northern Redbelly Dace | <i>Chrosomus eos</i> | demersal | 3.14960629 | 16.7 | 27.2 | both | 1 | 1 | 0 | 0 | 0 | 44.44444444 | 55.55555556 | 0 | 1 | 2.5 | 0 | 0 |
| Southern Redbelly Dace | <i>Chrosomus erythrogaster</i> | demersal | 3.58267716 | 21.7 | 25.8 | both | 1 | 0 | 0 | 0 | 0 | 0 | 62.5 | 37.5 | 1 | 2.5 | 0 | 0 |
| Grass Carp | <i>Ctenopharyngodon idella</i> | benthopelagic | 59.0551181 | 22.43 | 15.63 | migratory | 1 | 0 | 0 | 0 | 0 | 0 | 100 | 0 | 1 | 2 | 0 | 0 |
| Brook Stickleback | <i>Culaea inconstans</i> | demersal | 3.42519685 | 18.5 | 27.8 | both | 1 | 1 | 0 | 0 | 8.333333333 | 66.66666667 | 25 | 0 | 0 | 3.2 | 0 | 0 |
| Common Carp | <i>Cyprinus carpio</i> | benthopelagic | 47.2440944 | 33.55 | 17.6 | migratory | 1 | 1 | 0 | 0 | 0 | 0 | 80 | 20 | 1 | 3.1 | 0 | 0 |
| Gizzard Shad | <i>Dorosoma cepedianum</i> | pelagic | 24.3700787 | 32.3 | 20 | migratory | 0 | 1 | 0 | 0 | 0 | 0 | 100 | 0 | 1 | 2.4 | 0 | 0 |
| Northern Pike | <i>Esox lucius</i> | pelagic | 59.0551181 | 14.2 | 10.2 | migratory | 1 | 0 | 0 | 0 | 62.5 | 37.5 | 0 | 0 | 0 | 4.1 | 0 | 0 |
| Muskellunge | <i>Esox masquinongy</i> | demersal | 72.0472440 | 18.2 | 18.3 | migratory | 1 | 0 | 0 | 0 | 0 | 100 | 0 | 0 | 0 | 4.5 | 0 | 0 |
| Rainbow Darter | <i>Etheostoma caeruleum</i> | benthopelagic | 3.03149606 | 20.8 | 25.6 | migratory | 1 | 0 | 0 | 0 | 0 | 50 | 50 | 0 | 0 | 3.3 | 0 | 0 |
| Iowa Darter | <i>Etheostoma exile</i> | benthopelagic | 2.83464566 | 15.8 | 25 | both | 1 | 0 | 0 | 0 | 0 | 100 | 0 | 0 | 0 | 3.5 | 0 | 0 |
| Fantail Darter | <i>Etheostoma flabellare</i> | benthopelagic | 3.30708661 | 16.7 | 24.2 | migratory | 1 | 0 | 0 | 0 | 0 | 80 | 20 | 0 | 0 | 3.2 | 0 | 0 |
| Least Darter | <i>Etheostoma microperca</i> | benthopelagic | 1.73228346 | 17.5 | 28.2 | migratory | 1 | 0 | 0 | 0 | 0 | 66.66666667 | 33.33333333 | 0 | 0 | 3.5 | 0 | 0 |
| Johnny Darter | <i>Etheostoma nigrum</i> | benthopelagic | 2.83464566 | 13.6 | 27.1 | migratory | 1 | 0 | 0 | 0 | 0 | 50 | 50 | 0 | 0 | 3.2 | 0 | 0 |
| Tessellated Darter ^{2,7} | <i>Etheostoma olmstedi</i> | benthopelagic | 4.33070866 | 13.9 | 19.1 | undetermined | 1 | 0 | 0 | 0 | 0 | 57.14285714 | 42.85714286 | 0 | 0 | 2.9 | 0 | 0 |
| Mooneye ^{1,8} | <i>Hiodon tergisus</i> | pelagic | 18.5039370 | 27.4 | 30.6 | migratory | 1 | 0 | 0 | 0 | 0 | 100 | 0 | 0 | 0 | 3.7 | 0 | 0 |
| Northern Hogsucker | <i>Hypentelium nigricans</i> | demersal | 24.0157480 | 16.4 | 13.8 | migratory | 1 | 0 | 0 | 0 | 0 | 50 | 50 | 0 | 1 | 3.3 | 0 | 0 |
| Silver Carp | <i>Hypophthalmichthys molitrix</i> | benthopelagic | 47.2440944 | 26.65 | 14.8 | migratory | 1 | 1 | 0 | 0 | 0 | 0 | 100 | 0 | 1 | 2 | 0 | 0 |
| Bighead Carp | <i>Hypophthalmichthys nobilis</i> | benthopelagic | 70.3543307 | 24.5 | 11.6 | migratory | 1 | 1 | 0 | 0 | 0 | 0 | 80 | 20 | 1 | 2.8 | 0 | 0 |
| Chestnut Lamprey | <i>Ichthyomyzon castaneus</i> | demersal | 14.9606299 | 9.3 | 4.48 | migratory | 1 | 0 | 0 | 0 | 0 | 25 | 75 | 0 | 0 | 4.5 | 1 | 1 |
| Silver Lamprey | <i>Ichthyomyzon unicuspis</i> | demersal | 15.4330708 | 9.03 | 4.33 | migratory | 1 | 0 | 0 | 0 | 0 | 36.36363636 | 63.63636364 | 0 | 0 | 4.5 | 1 | 1 |
| Blue Catfish | <i>Ictalurus furcatus</i> | demersal | 64.9606299 | 21.2 | 24 | migratory | 1 | 1 | 0 | 0 | 0 | 0 | 100 | 0 | 1 | 3.4 | 1 | 0 |
| Channel Catfish | <i>Ictalurus punctatus</i> | demersal | 51.9685039 | 19.7 | 12.7 | migratory | 1 | 1 | 0 | 0 | 0 | 0 | 44.44444444 | 55.55555556 | 1 | 4.2 | 1 | 0 |
| Smallmouth Buffalo | <i>Ictiobus bubalus</i> | demersal | 44.0944881 | 28.6 | 27.7 | migratory | 1 | 0 | 0 | 0 | 0 | 71.42857143 | 28.57142857 | 0 | 1 | 3 | 0 | 0 |
| Bigmouth Buffalo | <i>Ictiobus cyprinellus</i> | benthopelagic | 48.4251968 | 27.2 | 11.5 | migratory | 1 | 0 | 0 | 0 | 0 | 20 | 80 | 0 | 1 | 3.1 | 0 | 0 |
| Black Buffalo | <i>Ictiobus niger</i> | demersal | 48.4251968 | 29 | 17.3 | migratory | 1 | 0 | 0 | 0 | 0 | 100 | 0 | 0 | 1 | 3.4 | 0 | 0 |
| American Brook Lamprey | <i>Lampetra appendix</i> | demersal | 13.7795275 | 7.39 | 10.26 | migratory | 1 | 0 | 0 | 0 | 13.33333333 | 53.33333333 | 33.33333333 | 0 | 0 | 3.2 | 1 | 1 |
| Longnose Gar | <i>Lepisosteus osseus</i> | demersal | 78.7401574 | 7.55 | 7.5 | migratory | 1 | 0 | 0 | 0 | 0 | 0 | 100 | 0 | 0 | 4.2 | 0 | 0 |
| Pumpkinseed | <i>Lepomis gibbosus</i> | benthopelagic | 15.7480315 | 44.1 | 19.2 | both | 1 | 1 | 0 | 0 | 0 | 0 | 80 | 20 | 0 | 3.3 | 0 | 0 |

| Common Name | Scientific Name | Vertical Station | Maximum Total Length (in) | Body Depth (% TL) | Eye Size (% HL) | Migratory Status | Spring Spawn | Summer Spawn | Fall Spawn | Winter Spawn | 33.8-46.4 F | 48.2-60.8 F | 62.6-75.2 F | 77-89.6 F | Hearing Specialization | Trophic Level | Presence of Ampullary Electroreceptors | Climbing Ability |
|----------------------------|---------------------------------|------------------|---------------------------|-------------------|-----------------|------------------|--------------|--------------|------------|--------------|-------------|-------------|-------------|------------|------------------------|---------------|--|------------------|
| Burbot | <i>Lota lota</i> | demersal | 59.8425196 | 12.6 | 12.4 | both | 0 | 0 | 0 | 1 | 100 | 0 | 0 | 0 | 1 | 3.8 | 0 | 0 |
| Common Shiner | <i>Luxilus cornutus</i> | demersal | 7.08661417 | 22.95 | 27.6 | migratory | 1 | 0 | 0 | 0 | 0 | 9.090909091 | 72.72727273 | 18.1818182 | 1 | 2.8 | 0 | 0 |
| Silver Chub ^{1,9} | <i>Macrhybopsis storeriana</i> | demersal | 9.05511811 | 18.3 | 29.4 | migratory | 0 | 1 | 0 | 0 | 0 | 0 | 100 | 0 | 1 | 3.6 | 0 | 0 |
| Smallmouth Bass | <i>Micropterus dolomieu</i> | benthopelagic | 27.1653543 | 26.7 | 15.1 | migratory | 1 | 0 | 0 | 0 | 0 | 50 | 50 | 0 | 0 | 3.6 | 0 | 0 |
| Largemouth Bass | <i>Micropterus salmoides</i> | benthopelagic | 38.1889763 | 28.55 | 15.1 | both | 1 | 0 | 0 | 0 | 0 | 28.57142857 | 71.42857143 | 0 | 0 | 3.8 | 0 | 0 |
| Spotted Sucker | <i>Mnytrema melanops</i> | demersal | 19.6850393 | 21.6 | 21.2 | both | 1 | 0 | 0 | 0 | 0 | 55.55555556 | 44.44444444 | 0 | 1 | 3.4 | 0 | 0 |
| White Bass | <i>Morone chrysops</i> | benthopelagic | 17.7165354 | 30.5 | 26.4 | migratory | 1 | 0 | 0 | 0 | 0 | 30 | 70 | 0 | 0 | 4 | 0 | 0 |
| Yellow Bass | <i>Morone mississippiensis</i> | demersal | 18.1102362 | 32.4 | 15.2 | migratory | 1 | 0 | 0 | 0 | 0 | 16.66666667 | 66.66666667 | 16.6666667 | 0 | 4.1 | 0 | 0 |
| Silver Redhorse | <i>Moxostoma anisurum</i> | demersal | 29.1338582 | 22 | 24.5 | migratory | 1 | 0 | 0 | 0 | 0 | 100 | 0 | 0 | 1 | 3 | 0 | 0 |
| River Redhorse | <i>Moxostoma carinatum</i> | demersal | 30.3149606 | 21.8 | 25.2 | migratory | 1 | 0 | 0 | 0 | 0 | 10 | 80 | 10 | 1 | 3.6 | 0 | 0 |
| Black Redhorse | <i>Moxostoma duquesni</i> | demersal | 20.0787401 | 21.6 | 18.9 | migratory | 1 | 0 | 0 | 0 | 0 | 37.5 | 62.5 | 0 | 1 | 3 | 0 | 0 |
| Golden Redhorse | <i>Moxostoma erythrurum</i> | demersal | 30.7086614 | 21.2 | 28.3 | both | 1 | 0 | 0 | 0 | 0 | 50 | 50 | 0 | 1 | 3 | 0 | 0 |
| Shorthead Redhorse | <i>Moxostoma macrolepidotum</i> | demersal | 29.5275590 | 21.7 | 19.1 | migratory | 1 | 0 | 0 | 0 | 0 | 77.77777778 | 22.22222222 | 0 | 1 | 3.1 | 0 | 0 |
| Greater Redhorse | <i>Moxostoma valenciennesi</i> | demersal | 31.4960629 | 23.2 | 17.5 | migratory | 1 | 0 | 0 | 0 | 0 | 57.14285714 | 42.85714286 | 0 | 1 | 3.3 | 0 | 0 |
| Emerald Shiner | <i>Notropis atherinoides</i> | benthopelagic | 5.11811023 | 15.6 | 25.2 | both | 0 | 1 | 0 | 0 | 0 | 0 | 100 | 0 | 1 | 2.8 | 0 | 0 |
| Bigmouth Shiner | <i>Notropis dorsalis</i> | benthopelagic | 3.14960629 | 18.1 | 26.4 | migratory | 1 | 1 | 0 | 0 | NA | NA | NA | NA | 1 | 2.9 | 0 | 0 |
| Spottail Shiner | <i>Notropis hudsonius</i> | benthopelagic | 5.90551181 | 14.6 | 29 | both | 1 | 0 | 0 | 0 | 0 | 25 | 75 | 0 | 1 | 2.1 | 0 | 0 |
| Stonecat | <i>Noturus flavus</i> | demersal | 12.2047244 | 12.07 | 19.2 | migratory | 1 | 1 | 0 | 0 | 0 | 0 | 28.57142857 | 71.4285714 | 1 | 3.2 | 1 | 0 |
| Rainbow Trout | <i>Oncorhynchus mykiss</i> | benthopelagic | 48.0314960 | 22.4 | 18 | both | 1 | 0 | 0 | 0 | 0 | 100 | 0 | 0 | 0 | 4.1 | 0 | 0 |
| Yellow Perch | <i>Perca flavescens</i> | benthopelagic | 19.6850393 | 23.4 | 19.5 | both | 1 | 0 | 0 | 0 | 42.85714286 | 57.14285714 | 0 | 0 | 0 | 3.7 | 0 | 0 |
| Logperch | <i>Percina caprodes</i> | benthopelagic | 7.08661417 | 14.1 | 23.9 | migratory | 1 | 0 | 0 | 0 | 0 | 77.77777778 | 22.22222222 | 0 | 0 | 3.4 | 0 | 0 |
| Blackside Darter | <i>Percina maculata</i> | benthopelagic | 4.33070866 | 17.2 | 23.7 | migratory | 1 | 0 | 0 | 0 | 0 | 50 | 50 | 0 | 0 | 4 | 0 | 0 |
| Slenderhead Darter | <i>Percina phoxocephala</i> | benthopelagic | 3.77952755 | 17.4 | 35.1 | migratory | 1 | 0 | 0 | 0 | 0 | 50 | 50 | 0 | 0 | 3.4 | 0 | 0 |
| Trout-perch | <i>Percopsis omiscomaycus</i> | demersal | 7.87401574 | 17.4 | 29.6 | both | 1 | 1 | 0 | 0 | 0 | 87.5 | 12.5 | 0 | 0 | 3.4 | 0 | 0 |
| Suckermouth Minnow | <i>Phenacobius mirabilis</i> | demersal | 4.72440944 | 17.2 | 19.8 | both | 1 | 1 | 0 | 0 | 0 | 25 | 66.66666667 | 8.33333333 | 1 | 2.9 | 0 | 0 |
| Paddlefish | <i>Polyodon spathula</i> | demersal | 87.0078740 | 18.7 | 1.7 | migratory | 1 | 0 | 0 | 0 | 0 | 71.42857143 | 28.57142857 | 0 | 0 | 3.4 | 1 | 0 |
| White Crappie | <i>Pomoxis annularis</i> | demersal | 20.8661417 | 36.4 | 19 | migratory | 1 | 0 | 0 | 0 | 0 | 20 | 80 | 0 | 0 | 4.4 | 0 | 0 |
| Black Crappie | <i>Pomoxis nigromaculatus</i> | benthopelagic | 19.2913385 | 36.3 | 18.5 | migratory | 1 | 0 | 0 | 0 | 0 | 33.33333333 | 66.66666667 | 0 | 0 | 3.8 | 0 | 0 |
| Flathead Catfish | <i>Pylodictis olivaris</i> | demersal | 61.0236220 | 19.4 | 10.4 | migratory | 0 | 1 | 0 | 0 | 0 | 0 | 60 | 40 | 1 | 3.8 | 1 | 0 |
| Blacknose Dace | <i>Rhinichthys atratulus</i> | demersal | 4.88188976 | 17.6 | 23.8 | migratory | 1 | 0 | 0 | 0 | 0 | 14.28571429 | 85.71428571 | 0 | 1 | 3.1 | 0 | 0 |
| Longnose Dace | <i>Rhinichthys cataractae</i> | demersal | 8.85826771 | 17 | 20.7 | both | 1 | 1 | 0 | 0 | 0 | 46.15384615 | 53.84615385 | 0 | 1 | 3.2 | 0 | 0 |
| Brown Trout | <i>Salmo trutta</i> | pelagic | 55.1181102 | 19.95 | 23.7 | both | 0 | 0 | 1 | 0 | 75 | 25 | 0 | 0 | 0 | 3.4 | 0 | 0 |
| Brook Trout | <i>Salvelinus fontinalis</i> | benthopelagic | 33.8582677 | 26.4 | 21.2 | both | 0 | 0 | 1 | 0 | 100 | 0 | 0 | 0 | 0 | 3.3 | 0 | 0 |
| Sauger | <i>Sander canadensis</i> | demersal | 29.9212598 | 21.7 | 14.8 | migratory | 1 | 0 | 0 | 0 | 42.85714286 | 57.14285714 | 0 | 0 | 0 | 4.1 | 0 | 0 |
| Walleye | <i>Sander vitreus</i> | benthopelagic | 48.5866141 | 15.5 | 19.7 | both | 1 | 0 | 0 | 0 | 62.5 | 37.5 | 0 | 0 | 0 | 4.5 | 0 | 0 |
| Creek Chub | <i>Semotilus atromaculatus</i> | demersal | 11.9291338 | 18.2 | 20.6 | migratory | 1 | 0 | 0 | 0 | 0 | 83.33333333 | 16.66666667 | 0 | 1 | 4 | 0 | 0 |
| Central Mudminnow | <i>Umbra limi</i> | demersal | 5.51181102 | 17.4 | 21.9 | both | 1 | 0 | 0 | 0 | 0 | 100 | 0 | 0 | 0 | 3.7 | 0 | 0 |

¹Green rows represent species that are included on the species list and are also used as substitutes for listed species.

²Blue rows represent species that are not on the species list but are used as substitutes for listed species.

³Substituted for Shovelnose Sturgeon

⁴Substituted for Crystal Darter

⁵Substituted for Highfin Carpsucker and River Carpsucker

⁶Substituted for Blue Sucker

⁷Substituted for Mud Darter

⁸Substituted for Goldeye

⁹Substituted for Shoal Chub