UPPER OHIO NAVIGATION STUDY, PENNSYLVANIA
ENVIRONMENTAL APPENDIX

Fish Passage Study

Draft Upper Ohio Navigation Study
Fish Passage Feasibility Study Report
May 2010

Note to Reader:

The Pittsburgh District involved the U. S. Fish and Wildlife Service in a concept-level study of alternative fish passage strategies on the Upper Ohio River. A fish passage study was undertaken to fulfill an environmental commitment of the Ohio River Mainstem System Study. The results of this initial study report were subjected to further evaluation by the District. The Service's report results and preliminary recommendations do not represent the District's final conclusion regarding fish passage strategies as part of the Navigation Study.

The Reader is referred to the Main Report, Section 4.6.9.7 for the full discussion and conclusion of the fish passage strategies study. Also, please see Section 5.1.4. Environmental Features and Commitments, Environmentally Sustainable Design, for the Navigation Study recommendation to include replacement lock and dam design modifications for improving fish passage efficiencies at these existing navigation facilities.

Upper Ohio Navigation Study
Fish Passage Feasibility Study Report

Prepared for:
U.S. Army Corps of Engineers
Pittsburgh District

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Introduction

The damming of rivers has been identified as one of the most dramatic and widespread human impacts on the natural environment (Dynesius and Nilsson 1994). All of the large river systems in the northern third of the world are regulated, and most are totally controlled except under extreme flood conditions (Dynesius and Nilsson 1994; Stanford et al. 1996). Richter et al. (1997) stated that impoundment operations that resulted in habitat destruction and fragmentation are one of the three most significant threats to freshwater aquatic ecosystems. Obstruction of fish movements by dams has led to the extinction of some species over large areas, while other populations have become fragmented, risking future extinction (Dynesius and Nilsson 1994).

This phenomenon has been evident across North America. For example, all but one known extirpation of diadromous fishes in Virginia are primarily attributed to blockage of migration and dispersal routes by dams (Angermeier 1995). Winston et al. (1991) reported that four small-bodied cyprinid species were believed to be extirpated from the upper portions of the Red River in Oklahoma after the Altus Dam was constructed. Physical habitat alteration, including fragmentation by dams has been implicated as a causative factor in the extinction of 40 fish species or subspecies in North America since 1889 (Miller et al. 1989).

Low-head navigation dams can also affect the ability of fish to migrate upstream to suitable habitats for various life history requirements. Despite the fact that some navigation dams may allow passage under certain conditions, their negative effects on fish should not be underestimated (Larinier 2001). Winter and Van Densen (2001) found that fish species that needed to migrate upstream for at least one part of their life cycle were negatively affected by the construction of weirs in the River Vecht. They found that only 10 of 32 species could have passed all six of the weirs they studied in only 5-30% of years. Not one of the 32 species they listed could migrate upstream over any one weir every year. Helfrich et al. (1999) found that fish passage through low head diversion dams on the Yellowstone River was feasible under high flows for certain species such as sauger (*Sander canadensis*) and shorthead redhorse (*Moxostoma macrolepidotum*). However, they also found that the series of six dams represented a cumulative fish passage challenge that could ultimately restrict fish distributions and abundance.

Zigler et al. (2004) believed that navigation dams on the Upper Mississippi River (UMR) would affect fish movements in a similar fashion. They found that the paddlefish (*Polyodon spathula*) population of the UMR was fragmented, in an upstream direction, by navigation dams. Wilcox et al. (2004) suggested that the presence of navigation dams and the resulting limitations on access to suitable habitats was likely a factor in the decline of a number of species, such as lake sturgeon (*Acipenser fulvescens*) and skipjack herring (*Alosa chrysochloris*) in the UMR.

Navigation dams have had similar effects on the fish and mussel fauna of the Ohio River. These dams interfered with the spring migrations of Alabama shad (*Alosa alabamae*) and sturgeons, and impaired the migrations of other fishes (Pearson and Krumholz 1984; Pearson and Pearson 1989). Cooper (1983) reported that at least 16 species including shovelnose sturgeon (*Scaphirhynchus platorynchus*), paddlefish, and skipjack herring, were extirpated from Pennsylvania waters of the Ohio River and its tributaries. Heavy pollution was believed to be the primary factor in the decline of these species in this portion of the river. However, the dams likely played a role in their decline as well as the continued absence of many of these species.

Navigation dams on the Ohio River are and will continue to be a major factor affecting fish assemblages river wide (Thomas et al. 2005).

Many non-migratory fishes, especially small bodied species, may also be affected by their inability to pass upstream at navigation dams. Although many may be able to complete their entire life cycle within a given pool, upstream populations may become fragmented and isolated in the absence of immigration from downstream populations (Winter and Van Densen 2001). This is especially true for unionid mussels that may have specific host-fish species requirements. Watters (1996) demonstrated that dams as small as one meter high are obstacles to the distribution of some fishes, and therefore to the distribution of unionids. If fishes are prevented from moving upstream during the glochidial stage of mussel development, the mussels' dispersal mechanism is disrupted and can lead to complete recruitment failure for affected species (Knights et al. 2003; EnviroScience, Inc. 2009). Unionid mussels are the most highly threatened and rapidly declining group of freshwater organisms, and a major factor in their decline is the large scale impoundment of rivers (Vaughn and Taylor 1999). Eleven of 127 species of freshwater mussels native to the Ohio River have gone extinct since the turn of the 19th century; 46 of the remaining species are considered endangered or species of concern (Neves 2008; Knights et al. 2003).

Fish

Pearson and Pearson (1989) listed records of 122 fish species in the upper 327 miles of the Ohio River (Table 1). Although some of these such as lake sturgeon have been extirpated since the first records were made, the list is fairly comprehensive up to 1989. Since that time at least three additional species have been introduced to the Upper Ohio River, including grass carp (*Ctenopharyngodon idella*), white perch (*Morone americana*) and hybrid striped bass (*M. saxatilis x chrysops*).

Mussels

Forty species of native mussels are known to occur in the Upper Ohio River on the Ohio River Islands National Wildlife Refuge (Table 2; USFWS 2009). In addition, two species of invasive mussels, the zebra mussel (*Dreissena polymorpha*) and the Asiatic clam (*Corbicula fluminea*), have been introduced and are established in the river.

Emsworth Pool

The Emsworth Pool extends from the first dams on the Monongahela and Allegheny Rivers above Pittsburgh to Emsworth Locks and Dams (Figures 1-2). The actual Ohio River portion is only 6.2 miles long. The Ohio River Valley Water Sanitation Commission surveyed Emsworth Pool in 2007 (ORSANCO 2007). During this survey, 42 fish species were captured including eight species listed as threatened, endangered, or of special concern by the State of Pennsylvania. Habitat surveys at 15 sites revealed that the Emsworth Pool's substrate is mostly gravel and sand with some cobble and fine sediments. Riparian land use in the pool is primarily forest and industrial (ORSANCO 2007).

The fish community of the Emsworth Pool in 2007 was described as "exceptional" compared to other pools of the Ohio River (ORSANCO 2007). All of the metrics used in the Ohio River Fish Index (ORFIn) scored well in the Emsworth Pool except for the number of "great river species."

Great river species include those that are expected to predominate in great rivers, such as shovelnose sturgeon, paddlefish, mooneye (*Hiodon tergisus*), and skipjack herring (Emery et al. 2003). Many of these species are also of interest for potential fish passage projects.

Dashields Pool

The Dashields Pool is 7.1 miles long extending from Emsworth Dams to Dashields Locks and Dam (Figures 1-2). The pool was last surveyed in 2008 (ORSANCO 2008). The survey produced 31 fish species including five species listed as threatened, endangered, or of special concern by the State of Pennsylvania. Habitat surveys showed that the Dashields Pool's substrate was an even mixture of fine sediment, sand, gravel and cobble. Riparian land use in the pool is primarily forest, industrial, and residential (ORSANCO 2008).

The fish community of the Dashields Pool in 2008 was in relatively poor condition with the number of native species being one of the low-scoring ORFIn metrics (ORSANCO 2008). The pool received a low overall quality score, indicating that the pool is in poor biological condition. Currently, the Dashields Pool does not meet its aquatic life-use designation (ORSANCO 2008).

Montgomery Pool

The Montgomery Pool is 18.5 miles long, and extends from Dashields Locks and Dam to Montgomery Locks and Dam (Figures 1-2). The pool begins 13 miles below the city of Pittsburgh, and is heavily influenced by industrial activities. The Montgomery Pool was surveyed by ORSANCO in 2006 (ORSANCO 2006). Forty-one species were collected during this survey, with nine species listed as threatened, endangered, or of special concern by the State of Pennsylvania. Like the other pools in this reach, the habitat surveys revealed that the Montgomery Pool's substrate is primarily gravel and sand with some cobble and fine sediments. Riparian land use in the Montgomery Pool is primarily forest and industrial (ORSANCO 2006).

The fish community of the Montgomery Pool in 2006 was in fair to good condition (ORSANCO 2006). Based on ORFIn scores, five of the 15 sites sampled in Montgomery Pool received a good rating, while eight sites were fair, and two were poor. The two lowest performing metrics for the ORFIn were catch-per-unit effort (CPUE), due to high flows, and the number of great river species. However, low scores for great river species were expected because the metric is designed to demonstrate a response if and when many of the great river species return to the Ohio River (ORSANCO 2006).

New Cumberland Pool

The New Cumberland Pool extends from the Montgomery Locks and Dam to New Cumberland Locks and Dam, and is longer than the three pools above it at 22.7 miles. The last survey on New Cumberland Pool was done in 2005 (ORSANCO 2005). This survey was a repeat of the 2004 survey, in which the pool did not meet its aquatic life-use designation. The results of the 2004 survey were questioned, however, due to high flow conditions during the survey. During the 2005 survey, 50 fish species were captured, including seven species listed as threatened, endangered, or of special concern by the State of Pennsylvania. Habitat surveys showed that the New Cumberland Pool's substrate is an even mixture of sand, gravel, cobble, and fine sediments. Riparian land use in the pool is primarily industrial (ORSANCO 2005).

The results of the 2005 survey showed that all sites exceeded their expected ORFIn scores, and were fully supporting their aquatic life-use designation (ORSANCO 2008). The New Cumberland Pool (and the rest of the lower river) would theoretically be the avenue through which absent species might recolonize the upper river after fish passage projects are completed.

Need for Fish Passage at Upper Ohio River Dams

All of the mainstem Ohio River dams create at least partial obstacles to fish movements. Even under flood conditions when the fixed weir portions of the dams are topped and the gated portions are fully open it is likely that upstream movements of many fish would still be restricted (Pearson and Krumholz 1984). However, similar to the conclusion reached by Wilcox et al. (2004) for UMR dams, Knights et al. (2003) found that opportunities for upriver fish passage through navigation dams on the Ohio River varied considerably between dams and species.

Knights et al. (2003) conducted a thorough assessment of the upstream fish passage opportunities at mainstem navigation dams on the Ohio River. They related historic hydraulic conditions at the dams to migration timing and swimming ability of selected species. Although they found that some dams provided passage opportunities more often than others (i.e., greater frequency and duration of open river), those opportunities generally decreased in an upstream direction. The first eight Ohio River navigation dams downriver from Pittsburgh rarely attain open river and upstream fish passage through gates or over fixed weirs is probably rare. They found that generally any fish passage that occurs is through the lock chamber, which is probably not a viable means of population-level fish passage. Likewise, Zigler et al. (2004) found that movement though navigation locks was probably the only available pathway for paddlefish passage on the UMR during most of the year.

The Knights et al. (2003) comparison of fish swimming speeds and velocities through dam gates showed that velocities are always in excess of the prolonged swimming speeds of target fishes, even during open river conditions. They concluded that based on the pattern of open river conditions at Ohio River dams, the current potential for fish passage at Pittsburgh District dams is low. Some measure of reliable fish passage is needed at all of these dams, but perhaps the greatest need is at Emsworth, Dashields, and Montgomery (EDM) Locks and Dams.

Knights et al. (2003) found that, based on average water velocities at dam gates, it is unlikely that fish could pass through Ohio River dams with any lift greater than the minimum lift (open river). Even with the gates completely out of the water, Emsworth and Montgomery Locks and Dams maintain lifts of approximately 2 m and 1 m, respectively. Thus, the water velocities through the gated portions of these dams likely never decrease to the levels needed for fish passage. Knights et al. (2003) also found that the restricted flow dimensions over the fixed weir at Dashields Locks and Dam may result in high velocities that are never conducive to fish passage. Based on their findings, regarding the swimming speeds of most fishes, the facts that the EDM dams rarely attain open river, and that at open river conditions the EDM dams still maintain at least 1-2 m of lift, there is little or no opportunity for fish passage at these dams.

Fish passage projects are needed at the EDM dams. Stanford et al. (1996) identified maximization of fish passage efficiency as a primary strategy for the restoration of regulated rivers. Likewise, restoration of connectivity for Ohio River fish, mussels, and their habitats is a priority of the U.S. Fish and Wildlife Service (USFWS). In the Final USFWS Fish and Wildlife Coordination Act Report on the Ohio River Mainstem Systems Study Programmatic Environmental Impact Statement, Koch (2009) made the following recommendations to the U.S. Army Corps of Engineers:

[Re:] The Quality and Quantity of Riverine habitat and the Connectivity of Riverine Habitat in the Mainstem and Tributaries

Restore connectivity between the riverine portions of the mainstem river, and between riverine mainstem sections and the larger tributaries, and, enhance stream habitat quality in the lower reaches of tributaries. It may not be possible to achieve complete 'natural connectivity' for all aquatic resources. For certain resources and/or species it may require a long-term commitment from the Corps to seek and obtain funding of `active human intervention' to create connections and sustain certain resources at desirable levels. For example, this could involve the Corps working closely with state agencies, the Service, and others to fund propagation of mussels and/or riverine and interjurisdictional fishes to create, enhance, and/or maintain populations in appropriate riverine habitat.

[Re:] Freshwater (Unionid) Mussel and Snail Fauna

Restore native mussel populations in the Ohio River and reintroduce extirpated species where habitat is suitable and fish hosts are now present or can be reintroduced themselves.

The Corps should restore connectivity of mainstem mussel populations to each other and to tributary populations. This will most likely involve working with identified host fish and insuring they are able to access separate mussel assemblages both within and between pools. This may also involve active human intervention in the form of infecting and transporting fish hosts from one location to other locations.

Restore mobility of fish hosts through the dams at the appropriate times of year needed for mussel reproduction. This is discussed in more detail in the following fish passage section.

[Re:] Fish Fauna and Fish Passage

Restore connectivity between various habitats utilized by riverine fishes.

Create opportunities for adequate fish passage at all locks and dams on the mainstem Ohio River in order to improve connectivity between fish populations and mussel assemblages throughout the river. This will likely require construction of appropriate fish ladders and/or artificial streams circumventing the dams at most if not all such facilities. To place such fish passage structures at every lock and dam facility, the Corps will likely need to obtain special funding; however, the Corps could incorporate fish passage into expected large-scale improvements such as the replacement of locks (e.g., Emsworth, Dashields, and Montgomery Locks and Dams). The Corps should work closely with state agencies and the Service (e.g., Interagency Working Group) to determine how this effort should be prioritized. Based on the Corps fish studies it appears to be more acute in the upper portion of the river and the Service believes the locks and dams in the upper portion of the river; and, higher dams throughout the system should receive priority for this action.

The Corps should evaluate the feasibility of improving fish passage through locks by incorporating techniques to encourage fish to enter locks and `lock through' during normal lockages.

The Corps should evaluate the feasibility of utilizing lockages specifically designed to provide increased opportunities for fish to pass through the locks, and/or other adaptive management and active intervention to facilitate fish passage.

Modify lock chamber management to facilitate fish passage at key times, such as during paddlefish spawning migrations.

When replacing or adding additional filling capacity to a lock consider replacing the existing open/close valve with one that would allow partial flow to enter the chamber. This would allow flow to enter during "dummy lockages" - i.e., leaving the lower lock gates open for a fixed period of time with valves cracked open to provide an attracting flow within the open chamber. The lower gates would then be closed and the trapped fish locked upstream to the next pool.

Fish passage projects at the EDM dams will be a step toward meeting all of these recommendations. In anticipation of lock renovations at the EDM dams, the Upper Ohio Interagency Working Group (UOIWG) is currently assessing the feasibility of creating upstream fish passage opportunities as part of those renovation projects. This study will examine a number of alternatives for fish passage at the EDM dams that include nature-like and technical fishways, as well as non-structural measures, such as assisted fish lockage and dam-gate manipulations.

Project Goal and Objectives

Project goal:

Improve historic connectivity for populations of riverine fishes and mussels in the Upper Ohio River Basin.

Project Objectives:

1. Restore fish passage for the full spectrum of native species during all seasons.
2. Achieve greater spatial distribution and abundance of native fish and mussels in the Upper Ohio River pools.
3. Conduct pre-project and post-project monitoring specific to each site to evaluate current conditions and project success.
4. Document movement periods of target species based on water temperatures.
5. Document lessons learned and apply adaptive management techniques and principles to subsequent projects.
6. Provide rapids and riffles for spawning and macroinvertebrate habitat.
7. Provide for low-maintenance fish passage.

Potential Fish Passage Alternatives

A number of structural and non-structural alternatives were considered for fish passage at EDM dams (Tables 3-5). Alternatives considered were discussed, and screened as appropriate at this stage to eliminate non-viable options. Alternatives considered are listed below, followed by written descriptions of each.

Non-Structural Alternatives

- No Action
- Fish Lockage
- Dam gate manipulations

Structural Alternatives

- Nature-like Fishways
    - Rock ramp
    - Nature-like fishway

- Technical Fishways
    - Pool pass
    - Slot pass
    - Denil pass
    - Fish lock/elevator
- Dam Removal

NOTE: The fish passage alternative descriptions below are adapted for EDM dams from the Draft Lock and Dam 22 Fish Passage Improvement Project Implementation Report (USACE 2009).

Non-Structural Alternatives

No action

This alternative includes no change to the existing structures or the operation and maintenance (O&M) at a lock and dam. If no action is taken at EDM dams, the opportunity for migratory and other fish species to move between pools of the Upper Ohio River will remain unchanged. EDM dams do not currently provide adequate fish passage opportunities. Taking no action would not meet the goals and objectives of the project. However, the measure will be retained for alternative plan formulation in order to provide a point of comparison for other feasible measures.

Assisted fish lockage

This measure involves modification to the locking procedures to pass more fish around the dam. This operational measure could be applied at EDM dams through the existing main locks (future auxiliary locks) if new locks are constructed. Fish lockage has been used in at least four locations in the United States: on the Cape Fear River in North Carolina; the Allegheny River in Pennsylvania; and on the Tennessee River (Scott and Hevel 1991) and the Alabama River. Studies on the Mississippi River at Lock and Dam 25 indicate that some fish pass upriver through the lock chamber during normal operation (Johnson et al. 2005). Two case studies are presented to document procedures and findings of previous projects.

> **Cape Fear River, North Carolina.** Fish lockage has been used on the Cape Fear River in North Carolina to move anadromous fish species including Atlantic sturgeon, striped bass, American shad, and river herring. Populations of all these species are seriously depleted in the Cape Fear River system since the construction of three locks and dams from 1915 to 1934. These structures have prevented spawning fish from entering the upstream portions of the river, except during locking and periods of high flow.
>
> Experiments with fish lockages on the Cape Fear River began in 1962 and continue through today. The original method for locking fish was described by Nichols and Louder (1970) as opening the lower lock gates, then opening the upper gate valves sufficiently to create an attraction flow of 2 to 3 ft/sec through the lock chamber. This configuration was left for approximately one hour to allow fish to enter, then the lower lock gates were closed and the normal locking process was completed. These methods were modified in 1996 by keeping the outer lower miter gate in the closed position as the fish are attracted into the lock. This effectively boxed-in fish that were lured in by the attractant flows and discouraged them from exiting downstream before fish lockage begins. The fish lockage season was expanded to run from 1 March to 30 June, whereas previously it had covered only April and May. The hours of fish passage lockages were also expanded from 06:30 through 16:30 hrs to 06:00 through 20:00 hrs. In both methods boat lockages took priority over

fish lockages, and fish lockages were restricted to weekdays to minimize interference with recreational boat traffic.

Even with decades of fish lockage on the Cape Fear River at Locks 1, 2, and 3, researchers continued to document declines in anadromous fish populations (Rulifson et al. 1982). At the time the fish lockage procedures were changed, the Corps of Engineers, Wilmington District added a Denil type technical fishway to Lock and Dam 1 to supplement fish lockage as a Section 1135 project in 1996. Moser et al. (2000) studied the effect of these fish passage changes, finding that the new fish locking procedures increased movement of fish through the lock of telemetered adult American shad from 31 percent in 1996 to 61 percent in 1998. Even with these improvements, a 2003 study found that there continues to be significantly smaller runs of alewife and blueback herring in the Cape Fear River than in the two previous decades (Williams 2003) causing speculation that the cause of the continued drop in the Cape Fear herring populations may be due to reduced water quality from runoff from agriculture and expanding housing developments.

Allegheny River, Pennsylvania. Fish lockage has been used to facilitate walleye and sauger passage through the Corps of Engineers, Pittsburg District's Lock and Dams 5, 6, 7, 8 and 9, Allegheny River, Pennsylvania. These dams were constructed in the 1920s and 1930s and are run-of-the-river dams with small locks that are operated only during daylight hours. Hydropower generating stations are located at Dams 5, 6, 8, and 9 on the abutment side of the dam (away from the lock). There is very little to no navigation on these river reaches and these locks are generally not staffed unless fish are being locked through.

Fish lockage was first tried in the Allegheny River in the 1980s for 2 years until money and stakeholder interest ran out. In the 1990s the Corps and the Pennsylvania Fish & Boat Commission restarted the locking program at Lock 5 as part of a five year program initiated by the Pennsylvania Fish and Boat Commission to reintroduce sauger to the upper river (Mike Fowles, Pittsburg [*sic*] District, USACE, personal communication 2006). Fish lockage was attempted sequentially at each of the upstream dams through Lock 9. This program has continued beyond the initial five years and has been operating until present.

Anecdotal evidence indicates the Commission was successful at reintroducing sauger throughout the river system using this method. There may also be increases in the populations of freshwater drum but no studies of population-level response have been done to support these observations (Al Woolmer, Pennsylvania Fish and Boat Commission, personal communication 2006).

Upstream passage of target species through a navigation lock chamber can be enhanced by dedicated operation of one of the navigation locks at each of the EDM dams, under a protocol similar to the following:

1. With the upper miter gates closed and lock chamber lowered to tailwater level, open (or partially open) the lower miter gates. Partially open the lock fill gates to create an attraction flow and downstream current in the lock chamber and downstream reach for a designated period (e.g., 30 minutes) to induce fish to enter the lock. Fish could also be attracted into a lock chamber by adding ports to convey flow through the upper miter gates.

2. After the allocated time (e.g., 30 minutes) for allowing fish to enter the lock, the lower miter gates would be closed and the lock filled.

3. When the lock is filled to headpond level, the upper miter gates would be opened (or partially opened) and fish would be induced to leave the lock by creating a current by partial opening of the lock drain valves while the lower miter gates are in closed position.

4. After designated period (e.g., 30 minutes), close the upper miter gates and drain the lock to tailwater level via lock drain gates. This would provide attraction flow for fish below locks.

5. Repeat the cycle starting with step #1.

The O&M costs for fish lockage at Upper Mississippi River Lock and Dam 22 were estimated at $566 per lockage event (Wilcox et al. 2004). Actual costs for EDM dams will likely be different, but this figure provides good reference. Lock maintenance and rehabilitation costs are based upon a 25-year lock rehabilitation cycle. These costs are in addition to the existing operational costs at the lock.

Assisted lockages may not be sufficient to routinely pass large numbers or whole populations of fish in the Upper Ohio River. The limitations of using navigational locks as fishways include the considerably greater attracting flows for fish at the gated parts of the dams than at the locks, mixed rheotactic cues for fish within the lock chambers, the potential for disorientation and propeller entrainment as commercial vessels enter and leave the locks (Keevin et al. 2005), and wear of lock machinery and potential additional labor cost from additional lockage cycles. Construction of a second lock would make the original main lock chamber available more often for passing fish.

If new locks are built at EDM dams, the new locks will be built riverward of the existing main locks. These new locks and guard walls will extend a significant distance downstream in the tailwater areas of the dams, effectively separating the old main locks from the tailwater environment. If the only feasible option (due to traffic volume) will be to use the old lock for fish passage, migrating fish that are milling in the tailwaters would be unable to find the old lock (new auxiliary locks) because the entrance will be separated (essentially hidden) from the main flow by the new locks. While assisted lockage has a low likelihood of meeting the project goal and objectives, it will be retained for alternative plan formulation.

Dam gate manipulations

Emsworth and Montgomery Dams have moveable gates that extend to a sill on the river bottom and are operated to maintain a 9-foot deep navigation channel in the Upper Ohio River. At higher levels of river discharge, all the gates are raised out of the water and open river conditions occur. Larger and stronger swimming fish could potentially pass upriver through some Ohio River navigation dams during open river conditions. However, based on the results of the USGS study on the existing opportunities for upstream passage at Ohio River dams (Knights et al. 2003), EDM dams likely provide little opportunity for passage even at open river. Combined with the fact that EDM dams rarely attain open river, upstream passage opportunities at EDM dams are likely rare or non-existent.

It is also important to mention that just keeping one or two gates out of operation while the rest stay in operation is not an option. The other gates would maintain their respective pools, creating a waterfall through the open gate bays, with velocities too high for fish passage. If more gates were opened, the ability to maintain pool would quickly be diminished, and the effect would be the same as if all gates were open. This alternative does not meet project goals and objectives and cannot be used in conjunction with other measures; therefore, it was not retained for further consideration.

Structural Alternatives

Structural measures included nature-like fishways, technical fishways, dam removal, and notches through fixed-crest weirs. All constructed structural measures would likely require an ice and debris boom structure upstream of the constructed fishway. The boom would reduce the amount of debris which would have to be removed in order to maintain fishway functionality. The boom would also reduce damage to the fishway from ice and debris, which would reduce the number and frequency of repairs to the fishway.

Nature-like fishway

A nature-like fishway is a broad term for several styles of structures constructed with natural materials, with rock being the most common. Nature-like fishways have proven effective for a wide range of fish species with varying swimming abilities (DVWK 1996; 2002; Gaboury et al. 1995). The purpose of nature-like fishways is to simulate natural river channels. In addition to improving fish passage past dams, nature-like fishways provide benefit for many aquatic organisms. Figures 3-5 exhibit conceptual layouts of various nature-like fishways.

Rock ramps are nature-like fishways that simulate conditions of natural rapids. While rapids are not naturally abundant on the Ohio River, prior to navigation, rapids were present at the Falls of the Ohio, and likely at a number of locations on Ohio River tributaries. Rock ramps can be constructed to create continuous rapids where most of the ramp is fairly turbulent and has higher velocities, or they can be constructed to create pool/riffle conditions where the head loss occurs at steps with resting pools in between steps. Rock ramps have been used effectively to restore lake sturgeon spawning habitat (Aadland et al. 2005) and enhance macroinvertebrate communities (Litvan et al. 2006).

In addition to improving fish passage past dams, nature-like fishways provide year round habitat for fish and macroinvertebrates adapted to higher gradient river conditions. Rock riffles may provide important spawning habitat for a number of native species, including lake sturgeon (Wilcox et al.2004).

Nature-like fishways, or bypass channels, are gradually sloping open channels with a rough bottom or a series of riffles and pools (Wildman et al. 2003, Acharya et al. 2004). The closer a nature-like fishway matches the morphological characteristics of natural river habitat for the species present, the less likely hydraulic conditions will reach thresholds that limit fish passage (Parasiewicz et al. 1998). Nature-like fishways have proven effective for a wide range of fish species with varying swimming abilities (Katopodis and Aadland 2006).

A flow control structure is typically required at the upstream end of a nature-like bypass channel to restrict discharge and channel erosion from flood events and to facilitate maintenance dewatering. Access bridges are also required where the bypass channel passes under any existing roads. Due to limited federal property and extensive transportation infrastructure at the shore side of EDM dams, this alternative would require the purchase of private property and extensive infrastructure modifications which renders this alternative as an unlikely choice.

Ideally, the slope of any nature-like fishway would be gradual, with few very low vertical drops and bed materials to replicate the riverbed found below the dam (Wilcox et al. 2004). The nature-like fishways should be situated in an area where fish congregate and in a location which minimizes impact to navigation and the O&M of the dam. Other factors involved with the layout of the structures include minimizing ice and debris damage, reducing costs by minimizing fill material required, or reducing the amount of sheet pile used in the structure. Also, dam safety is a significant concern when making modifications to dam gates or fixed crest weirs. To ensure that fish can find the fishway, it is imperative to place the structure in a location where fish are present or in an area that attracts fish.

The closer a fishway recreates the natural habitat of a species, the greater the likelihood that species will be able to use the fishway. Velocities will be similar to that of natural river conditions so that fish will be able to use the fishway as if it were part of the original stream. Larger fishways would be a benefit, as they could pass more fish, could have greater attracting flows, and may be less likely to behaviorally deter fishway usage due to crowding. A smaller fishway could form a bottleneck for fish and could make the fish vulnerable to predation by birds.

A review of successful fishways (including small alpine rivers and larger lowland rivers) has found that around 10% of the minimum flow of the river passes through the fishways. These fishway projects passed a variety of fish species with different migration behaviors and swimming performance (USACE 2009).

Some fishways throughout the world are designed with 5% of the competing flow or the mean annual flow passing through the fishway. Parasiewicz et al. (1996; 1998) recommends a minimum functional discharge of 5% of the natural river discharge to provide the attractive flow to get fish to the fishway. However, a fishway of this size at Lock and Dam 22, for example, would have a bottom width of 540 feet to get to 5% of the mean annual flow, which is about 81,000 cubic feet per second, which would be cost prohibitive.

One of the important project constraints for fish passage is to ensure that any fish passage structure or measure not impact commercial navigation. Hydraulic analysis for the Lock and Dam 22 project determined that it is not necessarily the width of the structure which would impact navigation, as much as the location of the structure within the river. For EDM dams, however, there may not be many options for the size and location of a fishway due to space constraints.

Technical fishways

Most technical fishways are specially designed concrete, steel, or wooden channels that dissipate the energy of flowing water, creating hydraulic conditions that enable fish to swim past barriers. Other technical fishways, like locks or traps, move fish past barriers. Technical fishways are designed to be effective for target fish species, given their migration behavior and swimming performance. They range in size, but most are small, easy to site, and often have viewing windows that are useful in educating the public about fish movements.

Technical fishways such as Denil troughs, eel paths, baffled troughs, and pool and orifice troughs, are designed to be effective at passing the average bodied, strong swimming portions of the fish population. Technical fishway often use baffles, weirs or other engineered elements to increase roughness and slow down water movements to produce average flows, which fall within the swimming speeds for the target fish species. These engineered elements also create turbulence which increases the energy expenditure that a fish must use to maintain position in the water (Pavlov et al. 1994) and disorients small fish due to swirling flows (Pavlov and Tyuryukov 1993; Odeh et al. 2002) which may cause avoidance by certain species and sizes of fish. Fish locking and fish elevators are semi-successful at passing a wide variety of large and small fish (Carter 1954; Scott and Hevel 1991). They require frequent O&M and require fish to respond to prescribed attractant flows, usually during normal working (daylight) hours.

The likelihood of populations of warmwater fish successfully migrating past a series of dams using only technical fishways is small, yet at some dams a technical fishway may be the only option or may be useful as part of a suite of fish passage measures (Katopodis 1995a; 1995b). The "Salmon 2000" ecosystem restoration program used a combination of fishway types to pass salmon through the Rhine River system, including the world's largest modified vertical slot fishway, found at the Iffezheim Dam which was constructed in 2000 (Heimerl et al. 2001). These types of fishways can be roughened to provide suitable microhabitats and to slow down velocities for a greater variety of fish species.

There are several types of technical fishways used throughout the world for fish passage of various species. Those considered for EDM dams included pool pass, vertical slot pass, Denil pass, and fish lock/elevator. Operation and maintenance for technical fishways varies somewhat depending on the type of fishway selected. A review of literature and interviews with operators of technical fishways found that the type which has the least O&M requirements is the slot pass fishway (USACE 2009). Debris removal is anticipated to require more time than that required for the rock ramps, based in part, on the size of the structure openings. Smaller debris may have a greater negative impact on a technical fish passageway.

Pool pass fishways
Pool pass fishways consist of a series of vertical walls that creates pools with overflow cascades between them (Figure 6). The pool and weir fishway is the oldest of these designs and is generally used where the head pool levels can be closely regulated. This type of fishway has a limited operating capability under fluctuating operational pool levels, unless a special regulating section is provided at the upper end of the fishway system. Sturgeons have not been passed successfully in pool type fishways (Bell 1990). A variation of the pool pass fishway is to add a hole (orifice) to the vertical wall, though shad generally reject bottom types of orifice openings and may become trapped in square corners of the fishway (Bell 1990). There is also increased maintenance issues with an orifice pool pass design, where orifices become obstructed with debris and the fishway has to be drained to remove the clog.

This type of technical fishway would only pass certain fish species (not a broad range), would have a high level of operation and maintenance, and would be very susceptible to debris jams. This alternative was not retained for further consideration.

Vertical slot pass fishways
Vertical slot pass fishways (Figure 7) consist of a series of boxes with baffled vertical slots between them. This fishway would be constructed with concrete and steel, consisting of a series of 15 boxes (pools) with two baffled slots between the pools. There would be relatively low velocity water within each pool for fish to rest. The slots for the structure can be prefabricated off-site to facilitate the construction of the fishway. These pre-fabricated slots can also be easily removed for maintenance purposes, including removal of debris jams.

While a vertical slot technical fishway would have a small construction footprint when compared to the larger nature-like fishways, there are several disadvantages to technical fishways. Technical fishways typically only pass certain fish species (not a broad range), require a high level of operation and maintenance, are very susceptible to debris jams, and have less resting room between riffles. However, a vertical slot fishway will likely have the best chance of success when compared to other technical fishways (e.g. Denil, pool pass) for EDM dams. Vertical slot fishways are somewhat better at passing diverse species because the slots span the entire water column of the fishway, attracting both bottom and surface swimmers. As examples, the vertical slot fishways at the York Haven East Channel Dam on the Susquehanna River in York Haven, PA, and the Columbia Dam on the Broad River in Columbia, SC, have been shown to pass 29 and 34 species, respectively (Table 6). The vertical slot fishway has the best chance of success of the technical fishways because slot fishways are more successful at passing fish with a variety of swim speeds, are somewhat less prone to debris jams than other technical fishways, and have been used successfully throughout the United States. According to DVWK (2002), slot technical fishways should be given preference over other technical fishways. This alternative was retained for further consideration.

Denil fishways
Denil fishways use closely-spaced baffles to create rapid energy dissipation to control flow through a sloping trough which allows high velocities to dissipate quickly (Figure 8). Denil fishways are generally used for passing salmon, however, variations of these fishways have been tested on warmwater fishes with some success (McLeod and Nemenyi 1941; Katopodis et al. 1997) The largest disadvantage to this fishway is that higher velocities are encountered due to the steeper slope and fish must traverse the entire fishway in one pass without a resting area. Denil fishways are small fishways with a maximum width of four feet and are appropriate for smaller river systems, rather than large rivers like the Ohio (mean annual flow = 35.3k cfs). Denil fishways also have limited hydraulic capacity to handle water level fluctuations, and have high flow velocities at operating depths above four feet. Denil fishways are not considered viable fishways for use at EDM dams. The vertical slot fishway was chosen over the Denil fishway because it is more capable at handling changes in flows, head differences, and other factors associated with conditions at EDM dams. Denil fishways are very susceptible to these types of changes and only pass a limited number of fish species because of the strong turbulence. The Denil fishway would also only pass certain fish species

(not a broad range), would have a high level of operation and maintenance, and would be susceptible to debris jams. This alternative was not retained for further evaluation.

Fish lock or elevator

Fish locks and elevators physically lift fish over dams using a lock or elevator structure (Figure 9). For EDM dams, a low-level lock would likely have greater success and lower O&M costs than a larger, more complicated lock or elevator. Lock fishways operate by attracting fish through an entrance similar to that of a pool-type fishway, but instead of swimming up a channel the fish accumulate in a holding area at the base of the lock. This holding area is then sealed and filled with water to reach a level equal to the water upstream of the barrier, where fish are then able to swim out of the lock. To encourage fish to move through the various attraction and exit phases of the lock cycle, a combination of attraction flows and crowding screens can be used (Thorncraft and Harris 2000). An elevator would work in a similar fashion, but fish would actually be lifted and released above the dam. An example of the potential effectiveness of this alternative is the fish elevator at the Conowingo Dam on the Susquehanna River in Conowingo, PA, which has passed at least 44 fish species (Table 7). This alternative was retained for further consideration.

Notches through fixed crest weirs

This alternative would include one or more large notches into the existing fixed crest weir (only at Dashields Dam) spillway in an effort to provide enough flow to attract fish while maintaining the pool above the dam for navigation. Flow would be provided through the new notch(es) without any active manipulation. Flow through new notches in the fixed crest weir at Dashields Dam would be directly governed by the elevation and width of the notch, and upstream water elevations resulting from the operation of the upstream pool. The velocity of water flowing though a notch would be too high for most fish to pass unless the tailwater was less than one foot below the poolwater level. Since the tailwater is more than 1 foot below the poolwater a large percentage of time, it would be impractical to use notches for fish passage. This alternative was not retained for further evaluation.

Dam removal

Dam removal would effectively eliminate the fish barriers imposed by EDM dams, allowing free movement of fish and other aquatic life in both upriver and downriver directions. Dam removal is not an option because EDM dams are essential components of the navigation system on the Ohio River. This alternative would not avoid significant adverse effects on navigation of the Upper Ohio River, a project constraint. This alternative was not retained for further evaluation.

Viable Alternatives

Alternatives considered for fish passage at EDM dams up to this point are summarized in Tables 3-5, which denote the alternatives retained for consideration after the initial screening. All land-based technical and nature-like fishways will require extensive modification or relocation of existing shore-based infrastructure, as well as the acquisition (taking) of private property. As such, land based fishways are not considered viable alternatives, and are not recommended at this time. If additional information regarding real estate or existing transportation infrastructure becomes available, these options will be reconsidered. The most promising upstream fish passage alternatives from the above descriptions appear to be assisted fish lockages and several structural measures: in-stream rock ramps, vertical slot fishways, fish elevators, and fish locks. Conceptual plans and conceptual level construction cost estimates are provided for these more promising alternatives.

Alternative Plans

Conceptual plans and preliminary cost estimates developed by the FWS are provided for the most promising structural fish passage alternatives. For reference purposes, mean monthly flows for the Ohio River at Sewickley, PA, are given in Table 8.

Project constraints/considerations

Project constraints and considerations were discussed at the first scoping meeting for fish passage at EDM dams. The Upper Ohio Interagency Working Group (UOIWG) identified a number of general project constraints and considerations.

Continuity of operations for the 9-ft navigation channel

- The must be no interference with dam operations or water control.
- Equipment access at each dam must be maintained.
- Additional O&M costs must be minimized.
- Hydropower projects are probable for all three dams. This will affect the options for fish passage.
- Facility security must be maintained.
- Debris and ice passage or blockage must be factored into fish passage designs, as well as ease of clearing debris.

Engineering

- Structural and geotechnical integrity (e.g., preventing undercutting) must be maintained.
- Fish passage will have to be designed with lock rehabilitation as a priority.
- Hydraulic current changes associated with various design options, including hydropower options, that would affect barge approach or bank erosion must be taken into consideration.
- May require future hydropower designs to incorporate remote intake locations (i.e., away from upstream openings of fish passage facilities).

Physical

- Land use/acquisition, if any, must be from willing owners.
- Project must avoid increases in flood elevations.

Biological

- Target species' swimming abilities must be considered.
- Target species' ability to find the structure must be considered.
- Target species ability or inclination to use the structure must be considered.
- Predation due to artificial concentrations of fish must be considered.
- Fish must not be entrained by hydropower operations after they complete upstream passage.

Other

- Fish passage projects are dependent on adequate funding.
- Projects must account for the safety of the public and dam operations personnel.

- Angler access and public relations must be considered (this may be a good opportunity).

The UOIWG also identified a number of site-specific design constraints and considerations.

Emsworth L&D (Main and Back Channel Dams)

- Hazardous waste on Neville Island (current and legacy contaminants).
- Lost spillway capacity must be replaced.
- Lock expansion under study at Main Dam.
- Limited federal land available.
- Hydropower proposal under study at Neville Island end of both dams.
- Water level control critical in Emsworth pool.

Dashields L&D

- Lost spillway capacity must be replaced.
- Lock expansion under study.
- Limited federal land available.
- Conrail at East end of spillway.
- No access road or electric power at east side of spillway.
- Deep scour hole below spillway.
- Hydropower proposal under study at east bank.

Montgomery L&D

- Lost spillway capacity must be replaced.
- Lock expansion under study.
- Limited federal land available.
- Conrail at North end of spillway.
- Hydropower proposal under study at north bank.
- Fixed crest spillway segment at north bank.

Rock ramp fishways

The rock ramp fishways proposed at the three projects are constructed rock-lined channels with parabolic shaped boulder weirs to form a series of low gradient pools. (See Conceptual Plans E-3, D-3, and M-3 in Appendix A). The rock ramp fishway will be similar in design to the rock ramp fishway proposed by the USACE at Lock and Dam 22 on the upper Mississippi River in Missouri. The rock ramp fishways proposed at the EDM projects will be in-stream channels passing through the fixed crest spillway segment (at Dashields and Montgomery) or spillway gates (at Emsworth Main and Back Channel) at the opposite shore from the navigation locks. Proposed channel slope is 3% maximum with a minimum pool depth of 4 feet. The rock ramp channel base width can range from 50 to 100 ft. The rock ramp fishway will provides critical riffle type habitat as well as effective upstream and downstream fish passage. The entrance to the rock ramp fishway should be close to the source of continuous flow at the barrier (spillway or future powerhouse tailrace). A submerged rock ramp is proposed at the fishway entrance as well as a flow control structure to minimize the width of spillway disturbance and to control entrance flow field. A control structure is also proposed at the upstream end of the rock ramp fishway to restrict flood flows and to facilitate maintenance dewatering. A sheet pile cofferdam will be required to facilitate project construction. CFD computer modeling of the flow field is recommended at each project to optimize entrance configuration and attraction flows.

Vertical slot fishways
A vertical slot fishway with twin full-depth slots is proposed as a viable structural alternative at the three projects (See Conceptual Plans E-2, D-2, and M-2 in Appendix A). The fishway can be constructed of reinforced concrete with prefabricated fishway baffles. A vertical slot fishway is a passive self-regulating pool-type fishway which allows volitional upstream fish passage at all pool depths upstream. Cofferdams will be required to facilitate fishway construction. We anticipate the fishway will be on steel or concrete pile foundation at the Emsworth and Montgomery projects and similarly or directly on bedrock at Dashields. CFD flow modeling of the fishway and anticipated spillway flow field at each project is recommended.

The vertical slot fishway will have the following design features:

Fishway Pool size	12 feet (ft) wide x 16 ft long
Floor slope	1 on 32 (3.1%)
Drop per pool	6 inches (in)
Normal pool depth	6 ft
Slot width (twin slots)	18 in
Normal flow in fishway	70 cfs
Fishway entrance width	10 ft
Exit channel width	12 ft
Attraction flow at entrance	up to 250 cfs
Auxiliary attraction flow from headpond	180 cfs

Number of fishway pools
- Emsworth = 36 pools
- Dashields = 20 pools
- Montgomery = 36 pools

Fishway Amenities:
- Dewatering bulkheads at fishway entrance and exit
- Trash rack at fishway exit
- Fish viewing window at exit channel (optional)
- Floor grating over entire fishway
- Attraction water flow diffusion chamber at entrance
- Rock substrate in fishway pools and transport channels
- Hinged gate at spillway adjacent to fishway for flow control
- Submerged rock ramp at fishway entrance
- Angled floating debris boom in headpond at fishway exit

Fish elevator (Fish lift)
A fish elevator (Fish lift) is a viable structural fishway alternative at the three EDM projects. (See Conceptual Plans E-4, D-4, and M-4 in Appendix A). A fish elevator is a mechanical device which allows fish to swim freely into an entrance channel and fish crowding pool at tailpool level. After a designated period of time, fish are crowded via a trolley-mounted fish crowder (bar rack) onto the hopper bay where they are lifted via a submerged steel hopper to the headpond

level exit channel via cable and electric hoist. Fish are sluiced from the raised hopper to the exit channel and allowed to swim into the headpond. The hopper is lowered to tailpool level for the next lift cycle. Cycle time can vary from 3 lifts per hour to two lifts per day. Fish elevators have moving mechanical parts as compared to a passive pool type fishways and typically require operating personnel to function. Fish lift operations are controlled and monitored by PLC control system from a central on-site control station. CFD modeling is recommended during the design stage to verify siting and operating flow field for the fish elevator (or fish lock).

Design Features:

Level entrance channel	10 ft wide
Hopper bay	10 ft x 10 ft
Exit channel	10 ft wide
Operating flow	up to 250 cfs
Normal lift	
Emsworth & Montgomery	18 ft
Dashields	10 ft

Fishway Amenities: (Same as Vertical slot fishway)

Fish lock

A fish lock has essentially the same design configuration and operating features as a fish elevator – except the fish are crowded into and then raised to headpond level in a water-filled vertical lock chamber rather than a water filled steel hopper. (See Conceptual Plans E-4, D-4, and M-4 in Appendix A). The lock chamber has two operating gates – one at the entry portal at tailpool level and a discharge gate at headpond level. A hoistable sloping floor brail (screen) is used to crowd fish from the lock chamber into the exit channel. The lock chamber is drained via gated conduits to tailpool level after the lifting cycle and the crowding/locking cycle repeats as necessary. Fish locks are typically used at projects with very large fish biomass or where large fish (>5 ft long) are targeted for upstream passage.

Design Features: Same as fish elevator except vertical lock chamber is substituted for hopper bay.

Conceptual-Level Cost Estimates for Fishways

Table 9 provides a summary of conceptual-level construction cost estimates for the designated type of fishway at each of the EDM projects. These estimated costs include engineering design and construction management, and a 20% contingency, considered normal for this conceptual level estimate. Estimated costs for providing lost spillway capacity caused by permanent fishway construction are not included in the estimated fishway costs.

Evaluation and Comparison of Alternative Plans

Several planning tools will ultimately have to be used to determine which alternative is the best option for fish passage at EDM dams. These will account for engineering constraints and considerations at each dam, costs to build and maintain a given structure, hydraulic models, navigation concerns, lock modernization options, biological effectiveness, and the ability of a given alternative to meet the overall project goal and objectives.

This report primarily focuses on the biological aspect of fish passage planning, so the only planning tool discussed here will be the Fish Passage Connectivity Index (FPCI). The FPCI was developed to evaluate ecosystem outputs of alternative measures for fish passage improvements on the Upper Mississippi River and Illinois Waterway System (UMRS) for cost effectiveness and incremental analysis (USACE 2009). The FPCI is detailed in Appendix B, which was adapted from the Draft Fish Passage Connectivity Index Model Certification Report, developed for the U.S. Army Corps of Engineers planning model certification process. The model has potential for application to fish passage projects on other river systems (i.e., Upper Ohio River) but is not currently certified for use as a generic planning model. However, we have begun the process of adapting it for Upper Ohio River fish passage projects.

Potential Environmental Effects
Fish passage at EDM dams may:

Pros - Advantages

- **Restore mainstem connectivity for native fishes and mussels in the Upper Ohio River;**
- **Provide access to, and potentially create, additional spawning, feeding, and nursery habitat for native fishes in pools below and above the dams;**
- **Provide enhanced benefits for species restorations/reintroductions in the Upper Ohio River;**
  (Natural resource management agencies that wish to restore native species (e.g., paddlefish, sturgeons, native mussels) to the Ohio River will likely have greater incentive to make the investment if their target species will have unimpeded access to a larger portion of the watershed.)
- **Provide opportunities for scientific study of the effects of enhanced fish passage in large river systems; and/or…**
- **Provide adaptive management opportunities for future fish passage projects.**
  (Few fish passage projects have been completed at navigation dams on mainstem navigation rivers in the U.S. These projects will provide abundant opportunities to learn and apply that knowledge to future projects.)

Cons - Disadvantages

- **Have high cost;**
  (If planned fish passage projects on the Upper Mississippi River are any guide, the potential cost of fish passage projects at EDM dams will be high. However, the cost of these projects must be weighed against the potential benefits, as well as opportunity. If the only opportunity to enhance fish passage will be during lock modernization, then that must be taken into consideration.)
- **Alter the ability to regulate the Ohio River; and/or…**
  (Any structural fish passage alternative will require space, and there is not a great deal of available space to work with at EDM dams. Any space taken up by fish passage in the gated sections of the dams may reduce the amount of water that can be discharged under flood conditions. In addition, the flood levels in the Upper Ohio River, especially Emsworth Pool, cannot be raised. Structural alternatives will present a difficult, although not insurmountable, challenge for USACE engineers as they move forward in the planning process.)

- **Potentially create enhanced pathways for, or acceleration of, invasive species dispersal into the Upper Ohio River.**
  (One of the primary concerns about development of fish passage is the potential to facilitate invasion of new waters by invasive species. Barriers have actually been built, and many others maintained in Great Lakes tributaries to restrict the spawning migrations of sea lampreys (Pratt et al. 2009). Restoring the connectivity of some Great Lakes tributaries without regard to the continued exclusion of sea lampreys could be devastating to the continued control of this non-native pest (AFS 2004). Although a number of aquatic invasive species have recently been found in the Mississippi River basin, bighead carp (*Hypophthalmichthys nobilis*) and silver carp (*H. molitrix*) are currently the most prolific, and most visible, threat in the upper portions of the watershed. Concerns about facilitating their spread through fish passage are legitimate, and reconciliation of those concerns is not a trivial matter.

  Bighead and silver carp likely will eventually invade the Upper Ohio River and its tributaries. Their progress throughout the Upper Mississippi River system in recent years has proven time and again that they are capable of navigating their way through mainstem navigation dams, sometimes even when locks are the only option. For example, bighead and silver carp are already becoming abundant above Mississippi River Lock and Dam 19. Lock and Dam 19 is a hydroelectric facility, and there is no possibility of fish movement through gates. Bighead carp have been found as far north as Lake Pepin (Pool 4) of the Mississippi River, and as far as Markland Locks and Dam on the Ohio River (USGS 2009), and there have been recent sightings of silver carp in the Brandon Road Pool of the Upper Illinois Waterway, only a few miles from Lake Michigan.

  The goal of the U.S. Fish and Wildlife Service's National Fish Passage Program is, "…to restore native fish and other aquatic species to self-sustaining levels by reconnecting habitat that barriers have fragmented, *where such reconnection would not result in a net negative ecological effect such as providing increased habitat to aquatic nuisance species* (USFWS 2006)." Although dam removal is not an option at EDM dams, the American Fisheries Society's (AFS) policy on dam removal states that the AFS supports dam removal when it is determined that "the benefits of dam removal outweigh the costs associated with societal, cultural, environmental, economic, engineering, and technical issues…" (AFS 2004).

  Essentially, any fish passage project must weigh the environmental costs against the potential benefits. In this case, we are weighing the facilitated movement of Asian carps and other invasive species against the benefits of restored or enhanced connectivity of the riverine ecosystem for native species. In the Upper Mississippi River, Asian carps are already established above and below the two dams slated for fish passage projects. At EDM dams, however, fish passage will likely facilitate the expansion of these species into the Upper Ohio, Monongahela, and Allegheny watersheds. The UOIWG will have to weigh this against the possibility that it may be better to provide the benefit of fish passage for native species, than to ultimately end up with Asian carp anyway.)

Analyses or Information Needed

Some of the information needs for further development of fish passage projects are below.

1. Detailed information on fish lockage opportunities at EDM dams.
2. Determination of whether assisted lockage is feasible with the level of commercial and recreational traffic present at the locks.
3. Classify and quantify fish habitat available in the pools and tributaries to head of slack water for use in FPCI.
4. CFD modeling of proposed fishway and tailwater flow fields.
5. Analyses of potential acceleration of Asian carp and other invasive species.

Preliminary Recommendations

Based on the information currently available, we make the following recommendations for fish passage at EDM dams. **These recommendations are preliminary.** As alternatives are further developed and additional information becomes available, these recommendations may change.

Emsworth Locks and Dams

The greatest issue facing most of the viable fish passage alternatives at Emsworth Locks and Dams is the availability of adequate space. With the anticipated loss of the only fixed-crest weir and the critical nature of pool regulation in the Emsworth Pool, we feel that the best option would be a vertical slot fishway adjacent to Neville Island, on either the main channel or the back channel. In addition, assisted fish lockage could be used as a supplemental fish passage option.

Dashields Locks and Dam

The recommended plan for Dashields Locks and Dam is a rock ramp structure at the north end of the fixed crest weir. Rock ramps will likely provide the greatest opportunity for fish passage, and score the highest on the FPCI (thus far). In addition, because of the extensive length of fixed crest weir, space availability for rock ramp construction is not an issue at Dashields Locks and Dam.

Montgomery Locks and Dam

The recommended plan for Montgomery Locks and Dam is a rock ramp structure at the north fixed crest weir. Again, rock ramps will likely provide the greatest opportunity for fish passage. Although Montgomery does not enjoy the available space found at Dashields, we still feel that a rock ramp will be the best option. If hydropower becomes an issue, this will have to be reassessed.

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Table 1. Fish species (n = 122) reported in the upper 327 miles of the Ohio River (Pearson and Pearson 1989). An asterisk (*) indicates introduced species, two asterisks (**) indicate species introduced since 1989.

Latin name	Common name	Latin name	Common name
Ichthyomyzon bdellium	Ohio lamprey	Hypentelium nigricans	Northern hogsucker
Ichtkyomyzon castaneus	Chestnut lamprey	Ictiobus bubalus	Smallmouth buffalo
Ichthyomyzon unicuspis	Silver lamprey	Ictiobus cyprinellus	Bigmouth buffalo
Lampetra aepyptera	Least brook lamprey	Ictiobus niger	Black buffalo
Lampetra appendix	American brook lamprey	Minytrema melanops	Spotted sucker
Acipenser fulvescens	Lake sturgeon	Moxostoma anisurum	Silver redhorse
Scaphirhynchus platorynchus	Shovelnose sturgeon	Moxostoma carinatum	River redhorse
Polyodon spathula	Paddlefish	Moxostoma duquesnei	Black redhorse
Lepisosteus osseus	Longnose gar	Moxostoma erythrurum	Golden redhorse
Lepisosteus platostomus	Shortnose gar	Moxostoma macrolepidotum	Shorthead redhorse
Amia calva	Bowfin	Ictalurus catus *	White catfish
Anguilla rostrata	American eel	Ictalurus furcatus	Blue catfish
Alosa chrysochloris	Skipjack herring	Ictalurus melas	Black bullhead
Alosa pseudoharengus *	Alewife	Ictalurus natalis	Yellow bullhead
Dorosoma cepedianum	Gizzard shad	Ictalurus nebulosus	Brown bullhead
Hiodon alosoides	Goldeye	Ictalurus punctatus	Channel catfish
Hiodon tergisus	Mooneye	Noturus eleutherus	Mountain madtom
Oncorhynchus mykiss*	Rainbow trout	Noturus flavus	Stonecat
Salmo trutta *	Brown trout	Noturus gyrinus	Tadpole madtom
Esox americanus vermiculatus	Grass pickerel	Noturus miurus	Brindled madtom
Esox lucius*	Northern pike	Pylodictis olivaris	Flathead catfish
Esox masquinongy	Muskellunge	Percopsis omiscomaycus	Trout perch
Campostoma anomalum	Central stoneroller	Fundulus diaphanus *	Banded killifish
Carassius auratus *	Goldfish	Fundulus heteroclitus *	Mummichog
Ctenopharyngodon idella**	Grass carp	Fundulus notatus	Blackstripe topminnow
Cyprinus carpio *	Common carp	Labidesthes sicculus	Brook silverside
Ericymba buccata	Silverjaw minnow	Morone americana**	White perch
Hybognathus nuchalis	Mississippi silvery minnow	Morone chrysops	White bass
Macrhybopsis aestivalis	Speckled chub	Morone saxatilis *	Striped bass
Hybopsis amblops	Bigeye chub	Morone saxatilis x chrysops**	Hybrid striped bass
Erimystax dissimilis	Streamline chub	Ambloplites rupestris	Rock bass
Macrhybopsis storeriana	Silver chub	Lepomis cyanellus	Green sunfish
Erimystax x-punctata	Gravel chub	Lepomis gibbosus	Pumpkinseed
Nocomis micropogon	River Chub	Lepomis gulosus	Warmouth
Notemigonus crysoleucas	Golden shiner	Lepomis humilis	Orangespotted sunfish
Notropis atherinoides	Emerald shiner	Lepomis macrochirus	Bluegill
Notropis blennius	River shiner	Lepomis megalotis	Longear sunfish
Notropis boops	Bigeye shiner	Lepomis microlophus	Redear sunfish
Notropis buchanani	Ghost shiner	Micropterus dolomieui	Smallmouth bass
Luxilus chrysocephalus	Striped shiner	Micropterus punctulatus	Spotted bass
Luxilus cornutus	Common shiner	Micropterus salmoides	Largemouth bass
Notropis heterolepis	Blacknose shiner	Pomoxis annularis	White crappie
Notropis hudsonius	Spottail shiner	Pomoxis nigromaculatus	Black crappie
Notropis photogenis	Silver shiner	Crystallaria asprella	Crystal darter
Notropis rubellus	Rosyface Shiner	Ammocrypta pellucida	Eastern sand darter
Cyprinella spiloptera	Spotfin shiner	Etheostoma blennioides	Greenside darter
Notropis stramineus	Sand shiner	Etheostoma caeruleum	Rainbow darter
Notropis volucellus	Mimic shiner	Etheostoma flabellare	Fantail darter
Notropis whipplei	Steelcolor shiner	Etheostoma nigrum	Johnny darter
Phenacobius mirabilis	Suckermouth minnow	Etheostoma spectabile	Orangethroat darter
Phoxinus erythrogaster	Southern redbelly dace	Etheostoma variatum	Variegate darter
Pimephales notatus	Bluntnose minnow	Etheostoma zonale	Banded darter
Pimepbales promelas	Fathead minnow	Perca flavescens	Yellow perch
Pimephales vigilax	Bullhead minnow	Percina caprodes	Logperch
Rhinichthys atratulus	Blacknose dace	Percina copelandi	Channel darter
Semutilus atromaculatus	Creek chub	Percina evides	Gilt darter
Carpiodes carpio	River carpsucker	Percina macrocephala	Longhead darter
Carpiodes cyprinus	Quillback	Percina maculata	Blackside darter
Carpiodes velifer	Highfin carpsucker	Percina sciera	Dusky darter
Catostomus commersoni	White sucker	Percina shumardi	River darter
Cycleptus elongatus	Blue sucker	Sander canadensis	Sauger
Erimyzon sucetta	Lake chubsucker	Sander vitreus	Walleye
		Aplodinotus grunniens	Freshwater drum

Table 2. Mussel species (n = 40) of the Ohio River Islands National Wildlife Refuge and the Upper Ohio River. An asterisk (*) denotes introduced species.

Latin Name	Common Name
Corbicula fluminea*	Asiatic clam
Dreissena polymorpha*	Zebra mussel
Actinonaias ligamentina	Mucket
Amblema plicata	Three-ridge
Anodonta suborbiculata	Flat Floater
Cyclonaias tuberculata	Purple wartyback
Cyprogenia stegaria	Eastern Fanshell
Ellipsaria lineolata	Butterfly
Elliptio crassidens	Elephant ear
Elliptio dilatata	Spike
Fusconaia ebena	Ebony shell
Fusconaia flava	Wabash pigtoe
Fusconaia subrotunda	Long solid
Lampsilis abrupta	Pink mucket
Lampsilis cardium	Plain pocketbook
Lampsilis ovata	Sharp-ridged pocketbook
Lampsilis siliquoidea	Fatmucket
Lampsilis teres	Yellow sandshell
Lasmigona complanata	White heelsplitter
Lasmigona costata	Fluted shell
Leptodea fragilis	Fragile papershell
Ligumia recta	Black sandshell
Megalonaias nervosa	Washboard
Obliquaria reflexa	Threehorn wartyback
Obovaria olivaria	Hickorynut
Obovaria subrotunda	Round hickorynut
Plethobasus cyphyus	Sheepnose
Pleurobema cordatum	Ohio pigtoe
Pleurobema sintoxia	Round pigtoe
Potamilus alatus	Pink heelsplitter
Potamilus ohiensis	Pink papershell
Ptychobranchus fasciolaris	Kidneyshell
Pyganodon grandis	Giant floater
Quadrula metanevra	Monkeyface
Quadrula nodulata	Wartyback
Quadrula pustulosa	Pimpleback
Quadrula quadrula	Mapleleaf
Strophitus undulatus	Creeper (Squawfoot)
Toxolasma parvus	Lilliput
Tritogonia verrucosa	Pistolgrip
Truncilla donaciformis	Fawnsfoot
Truncilla truncata	Deertoe
Uniomerus tetralasmus	Pondhorn
Utterbackia imbecillis	Paper pondshell

Table 3. All alternatives considered for fish passage at Emsworth Locks and Dam on the Upper Ohio River. Shaded alternatives were not retained for consideration after initial screening.

Non-Structural Measures	Liklihood of Meeting Project Objectives*				Retain?	Reasoning
	1	2	6	7		
	Restore passage for all species	Greater fish and mussel distribution	Rapids and riffle habitat	Low O&M		
No Action	-	-	-	-	No	Would not meet project objectives
Assisted Fish Lockage (auxiliary lock only)	M	M	-	L	Yes	Would have ongoing O&M costs during seasonal movement periods, but initial construction costs would be relatively low (if anything).
Dam Gate Manipulations	L	L	-	L	No	Passable open river conditions are already rare or non-existent at these dams. It is doubtful that gate manipulation would provide reasonable fish passage opportunities for the range of native species in the upper Ohio River.

Structural Measures	Liklihood of Meeting Project Objectives*				Retain?	Reasoning
Nature-like fishway through island	H	H	H	M	No	Due to the existing transportation infrastructure and extensive private land issues that would be present on the island, this alternative was removed from consideration
Nature-like fishway around dam on island	H	H	H	M	Yes	Nature-like fishways/rock ramps have been shown to pass a wide range of species. Given an appropriate design, nature-like fishways and rock ramps probably have the greatest chance of meeting all of the project objectives.
Rock ramp around dam on island	H	H	H	M	Yes	Nature-like fishways/rock ramps have been shown to pass a wide range of species. Given an appropriate design, nature-like fishways and rock ramps probably have the greatest chance of meeting all of the project objectives.
Rock ramp in gate bay on main dam	H	H	H	M	Yes	This option will have many of the same advantages of the other nature-like fishway/rock ramp options, but would likely have greater maintenance costs given its location. It may also have a greater effect on navigation.
Rock ramp in gate bay on back channel	H	H	H	M	Yes	This option will have many of the same advantages of the other nature-like fishway/rock ramp options, but would likely have greater maintenance costs given its location. It may also have a greater effect on navigation.
Vertical slot fishway on main dam	M	M	-	M	Yes	Of the technical fishway options, the vertical slot has the greatest chance of passing a wide variety of fish. Because the slots cover the entire water column, the fishway may attract both benthic and pelagic swimmers.
Pool pass fishway on main dam	L	M	-	L	No	These fishways typically pass a relatively narrow range of species.
Denil fishway on main dam	L	M	-	L	No	These fishways typically pass a relatively narrow range of species.
Vertical slot fishway on back channel	M	M	-	M	Yes	Of the technical fishway options, the vertical slot has the greatest chance of passing a wide variety of fish. Because the slots cover the entire water column, the fishway may attract both benthic and pelagic swimmers.
Pool pass fishway on back channel	L	M	-	L	No	These fishways typically pass a relatively narrow range of species.
Denil fishway on back channel	L	M	-	L	No	These fishways typically pass a relatively narrow range of species.
Fish lock/elevator on main dam	M	M	-	L	Yes	Fish elevators can work to move fish past a barrier, but they are relatively inefficient in addition to having high construction and O&M costs.
Fish lock/elevator on back channel	M	M	-	L	Yes	"
Dam Removal	H	H	-	H	No	Would not fit within project constraints

* H - High; M - Medium; L -Low

Constraints/Considerations:

Hazardous waste on Neville Island
Gates may have to be reconfigured to accommodate loss of discharge capacity
Lock expansion may eliminate fixed crest and part or all of 1st gate
This is the most important pool due to the high volume of commercial and recreational traffic as well as being centered in the City of Pittsburgh
Have to consider the operations plan for water control in the pool
There is limited federal land available
There may be a public education opportunity
Emsworth is a major recreational lock as well as commercial

Table 4. All alternatives considered for fish passage at Dashields Locks and Dam on the Upper Ohio River. Shaded alternatives were not retained for consideration after initial screening.

Non-Structural Measures	Liklihood of Meeting Project Objectives*				Retain?	Reasoning
	1	2	6	7		
	Restore passage for all species	Greater fish and mussel distribution	Rapids and riffle habitat	Low O&M		
No Action	-	-	-	-	No	Would not meet project objectives
Assisted Fish Lockage	M	M	-	L	Yes	Would have ongoing O&M costs, but initial construction costs would be relatively low (if anything).

Structural Measures	Liklihood of Meeting Project Objectives*				Retain?	Reasoning
Nature-like fishway around dam	H	H	H	M	No	This alternative has been removed from consideration because of the lack of available space around the end of the dam.
Rock ramp on end of fixed crest	H	H	H	M	Yes	Nature-like fishways/rock ramps have been shown to pass a wide range of species. Given an appropriate design, nature-like fishways and rock ramps probably have the greatest chance of meeting all of the project objectives.
Rock ramp across entire of fixed crest	H	H	H	L	No	Given the depth of the plunge pool below the fixed crest, construction of this alternative would require a vast volume of material. This alternative was removed from consideration.
Rock ramp above dam	H	H	H	M	Yes	This option will have many of the same advantages of the other nature-like fishway/rock ramp options, but would likely have higher construction/maintenance costs.
Rock ramp above/below (straddling) dam	H	H	H	M	Yes	This option will have many of the same advantages of the other nature-like fishway/rock ramp options, but would likely have higher construction/maintenance costs.
Vertical slot fishway on fixed crest	M	M	-	M	Yes	Of the technical fishway options, the vertical slot has the greatest chance of passing a wide variety of fish. Because the slots cover the entire water column, the fishway may attract both benthic and pelagic swimmers.
Pool pass fishway on fixed crest	L	M	-	L	No	These fishways typically pass a relatively narrow range of species.
Denil fishway on fixed crest	L	M	-	L	No	These fishways typically pass a relatively narrow range of species.
Notch in fixed crest	L	L	-	M	No	This option would probably not allow fish passage during most flows due to the high velocity and elevation differences that would likely exist in the notch. This would also be likely to lower the upstream pool elevation.
Fish lock/elevator on fixed crest	M	M	-	L	Yes	Fish elevators can work to move fish past a barrier, but they are relatively inefficient in addition to having high construction and O&M costs.
Dam Removal	H	H	-	H	No	Would not fit within project constraints

* H - High; M - Medium; L -Low

Constraints/Considerations:
Only about 10 ft of lift
Deep scour hole is present below the dam face
There are land ownership issues to address for any alternative outside of the current ownership
Hydropower is a possibility
This dam will allow us to place the structure where the fish are actually congregating better than at the other dams
May have a space between the locks to work with
A ramp could be upstream or downstream

Table 5. All alternatives considered for fish passage at Montgomery Locks and Dam on the Upper Ohio River. Shaded alternatives were not retained for consideration after initial screening.

Non-Structural Measures	Liklihood of Meeting Project Objectives*				Retain?	Reasoning
	1	2	6	7		
	Restore passage for all species	Greater fish and mussel distribution	Rapids and riffle habitat	Low O&M		
No Action	-	-	-	-	No	Would not meet project objectives
Assisted Fish Lockage	M	M	-	L	Yes	Would have ongoing O&M costs, but initial construction costs would be relatively low (if anything).
Dam Gate Manpulations	L	L	-	L	No	Passable open river conditions are already rare or non-existent at these dams. It is doubtful that gate manipulation would provide reasonable fish passage opportunities for the range of native species in the upper Ohio River.

Structural Measures	Liklihood of Meeting Project Objectives*				Retain?	Reasoning
Nature-like fishway on north end of dam	H	H	H	M	No	This alternative has been removed from consideration because of the lack of available space around the end of the dam.
Nature-like fishway on south end of dam	H	H	H	M	No	This alternative was screened because the entrance of the fishway would not be near the main flow of the river, it would also be hidden behind the new lock, and the logistics and cost of building it were believed to be too high.
Rock ramp below dam on north fixed weir	H	H	H	M	Yes	Nature-like fishways/rock ramps have been shown to pass a wide range of species. Given an appropriate design, nature-like fishways and rock ramps probably have the greatest chance of meeting all of the project objectives. This alternative was screened because the entrance of the fishway would not be near the main flow of the river, it would also be hidden behind the new lock, and the logistics and cost of building it was believed to be too high.
Rock ramp above dam on north fixed weir	H	H	H	M	Yes	This option will have many of the same advantages of the other nature-like fishway/rock ramp options, but would likely have higher construction/maintenance costs.
Rock ramp straddling dam on north fixed weir	H	H	H	M	Yes	This option will have many of the same advantages of the other nature-like fishway/rock ramp options, but would likely have higher construction/maintenance costs.
Vertical slot fishway	M	M	-	M	Yes	Of the technical fishway options, the vertical slot has the greatest chance of passing a wide variety of fish. Because the slots cover the entire water column, the fishway may attract both benthic and pelagic swimmers.
Denil fishway	L	M	-	L	No	These fishways typically pass a relatively narrow range of species.
Pool pass fishway	L	M	-	L	No	These fishways typically pass a relatively narrow range of species.
Fish lock/elevator	M	M	-	L	Yes	Fish elevators can work to move fish past a barrier, but they are relatively inefficient in addition to having high construction and O&M costs.
Dam Removal	H	H	-	H	No	Would not fit within project constraints

* H - High; M - Medium; L -Low

Constraints/Considerations:

Fixed weir on the RDB may be conducive to a rock ramp
No negative effects on the embayment above the dam
There will be land ownership concerns
Removal of dam gate by lock expansion
Potential hydropower development

Table 6. Fish species that have been passed through vertical slot fishways at the York Haven East Channel Dam on the Susquehanna River in York Haven, PA (St. Pierre 2001) and the Columbia Dam on the Broad River in Columbia, SC (Hand 2007; 2009).

York Haven East Channel Dam (n = 29)	Columbia Dam (n = 34)
American shad	American shad
Blueback herring	Blue catfish
Gizzard shad	Blueback herring
Striped bass	Bluegill
Rainbow trout	Brassy jumprock
Brown trout	Channel catfish
Muskellunge	Common carp
Common carp	Flathead catfish
Quillback	Gizzard shad
White sucker	Highfin carpsucker
Shorthead redhorse	Largemouth bass
White catfish	Longnose gar
Yellow bullhead	Northern hogsucker
Brown bullhead	Notchlip redhorse
Channel catfish	Quillback
Rock bass	Redbreast sunfish
Redbreast sunfish	Robust redhorse
Green sunfish	Shorthead redhorse
Pumkinseed	Smallmouth bass
Bluegill	Smallmouth buffalo
Smallmouth bass	Spotted sucker
Largemouth bass	Striped bass
White crappie	Striped jumprock
Black crappie	Threadfin shad
Yellow perch	Common shiner
Walleye	Redear sunfish
Northern hog sucker	White perch
Fallfish	Black bullhead
Tiger muskellunge	Bluehead chub
	Longear sunfish
	Lake chubsucker
	Creek chubsucker
	Spotted sunfish
	Tessellated darter

Table 7. Fish species (n = 44) passed by the fish elevator at the Conowingo Dam on the Susquehanna River in Conowingo, PA (St. Pierre 2001).

Species passed	
American shad	Rock Bass
Alewife	Redbreast sunfish
Blueback herring	Green sunfish
Gizzard shad	Pumkinseed
Hickory shad	Bluegill
Striped bass	Smallmouth bass
White perch	Largemouth bass
American eel	White crappie
Brook trout	Black crappie
Brown trout	Tessellated darter
Rainbow trout	Banded darter
Common carp	Shield darter
Comely shiner	Atlantic needlefish
Spottail shiner	Tiger muskellunge
Spotfin shiner	Muskellunge
Quillback	Yellow perch
White sucker	Walleye
Shorthead redhorse	Sea lamprey
White catfish	Log perch
Yellow bullhead	Splake
Brown bullhead	Creek chubsucker
Channel catfish	Bluntnose minnow

Table 8. Mean monthly flow at USGS Gaging Station on Ohio River at Sewickley, PA (1980-2008; gaging station located on left bank, 50 ft upstream from Dashields Dam).

Month	Mean Flow (cfs)
January	45,600
February	50,600
March	60,300
April	54,700
May	39,600
June	27,000
July	19,200
August	15,000
September	16,100
October	17,800
November	33,400
December	44,400
Mean annual flow	35,300
Mean annual flood	175,000

Table 9. Conceptual-level cost estimates for viable fish passage alternatives at Emsworth, Dashields, and Montgomery Locks and Dams. An asterisk (*) indicates a cost estimate that has not been derived.

Project	Fishway Option	Estimated Cost (2009 Price Levels): Engineering & Construction ($ Millions)	Estimated Cost (2009 Price Levels): Operation & Maintenance ($ Thousands)
Emsworth Locks & Dams			
Main Dam	Assisted Fish Lockage	*	*
	Rock Ramp Fishway	16.8	24/month
	Vertical Slot Fishway	28.3	35/month
	Fish Lift	15.4	54/month
	Fish Lock	16.1	54/month
Back Channel Dam	Assisted Fish Lockage	-	-
	Rock Ramp Fishway	16.8	24/month
	Vertical Slot Fishway	28.3	35/month
	Fish Lift	15.4	54/month
	Fish Lock	16.1	54/month
Dashields Locks & Dam			
	Assisted Fish Lockage	*	*
	Rock Ramp Fishway	11.7	19/month
	Vertical Slot Fishway	13.0	27/month
	Fish Lift	12.3	50/month
	Fish Lock	12.9	50/month
Montgomery Locks & Dam			
	Assisted Fish Lockage	*	*
	Rock Ramp Fishway	16.1	24/month
	Vertical Slot Fishway	28.3	35/month
	Fish Lift	15.4	50/month
	Fish Lock	16.1	50/month

Figure 1. Emsworth (top), Dashields (center), and Montgomery (bottom) locks and dams on the Upper Ohio River (U.S. Army Corps of Engineers).

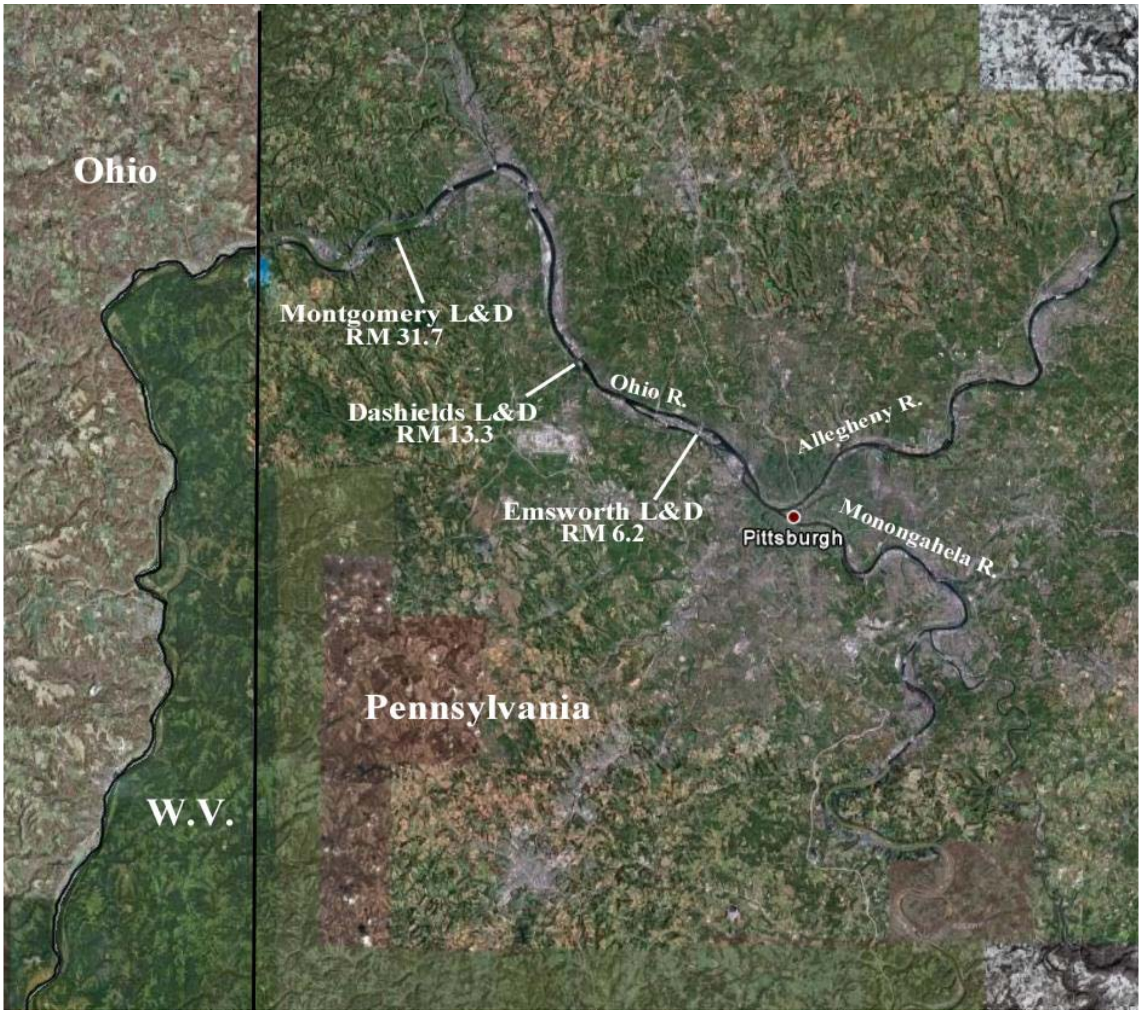


Figure 2. Map of the Upper Ohio River showing the locations of Emsworth, Dashields, and Montgomery locks and dams.

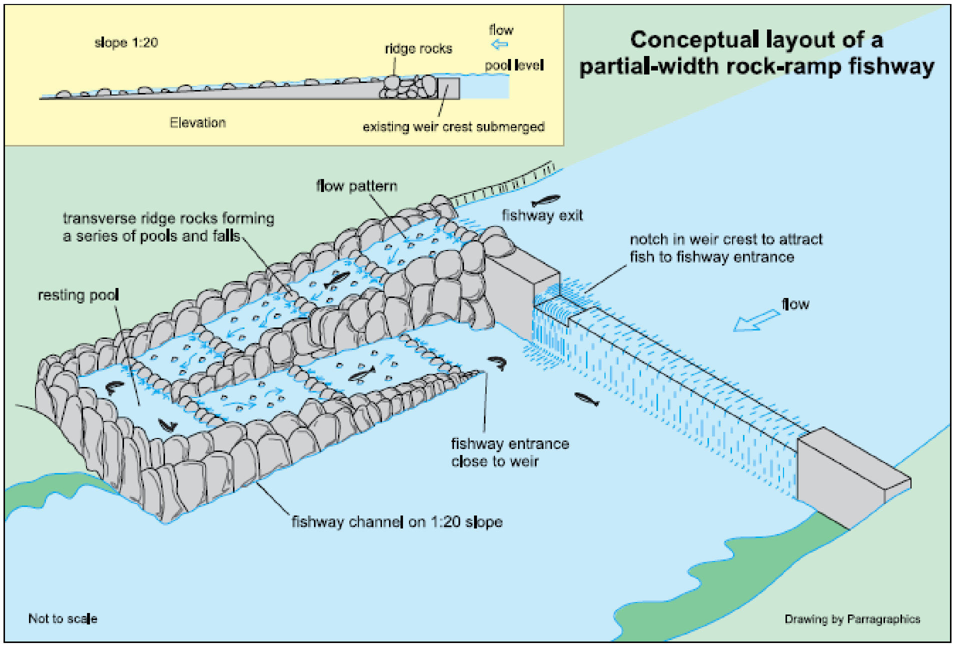


Figure 3. Conceptual layout of a partial-width rock ramp fishway (Thorncraft and Harris 2000).

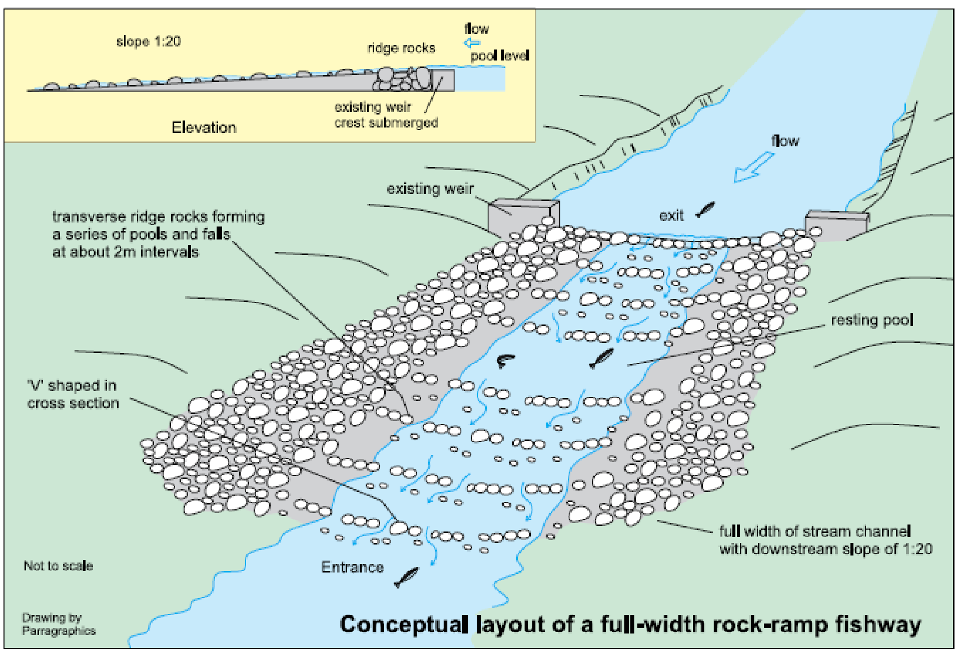


Figure 4. Conceptual layout of full width rock ramp fishway (Thorncraft and Harris 2000).

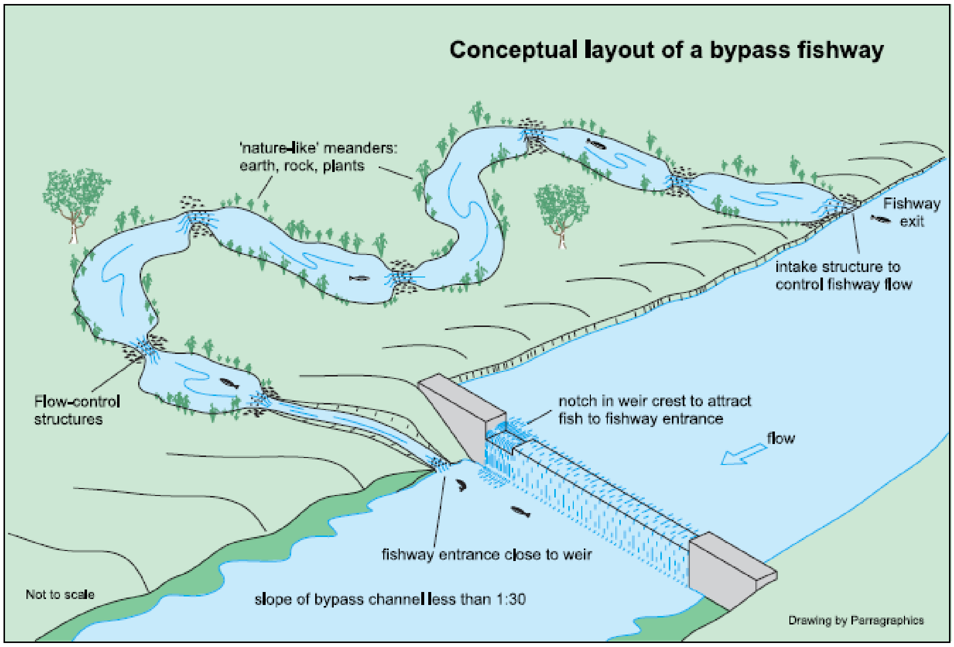


Figure 5. Conceptual layout of bypass fishway (Thorncraft and Harris 2000).

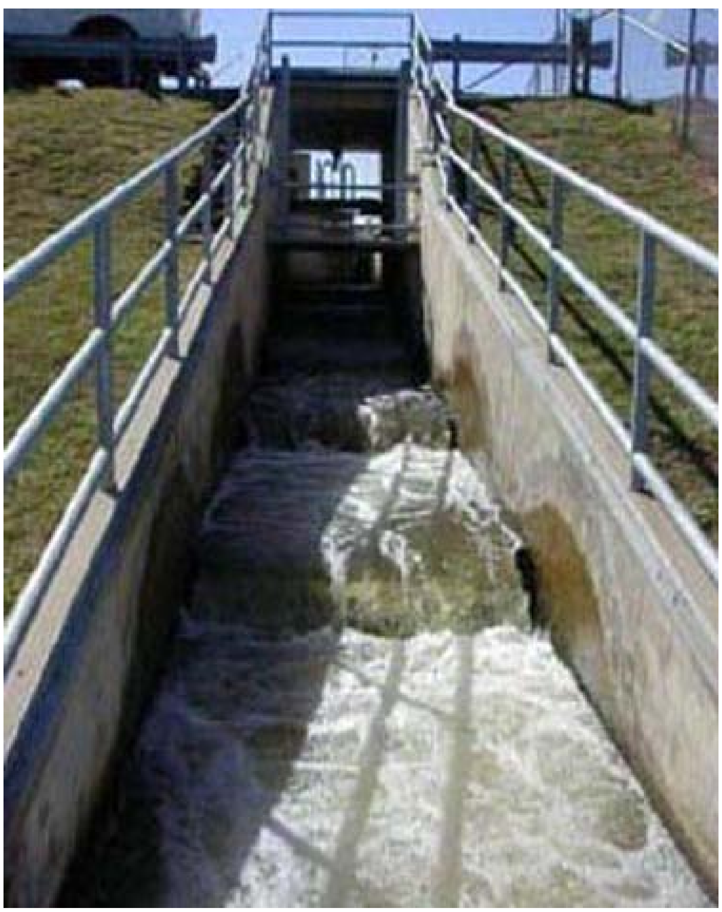


Figure 6. Pool pass fishway (www.michigan.gov)

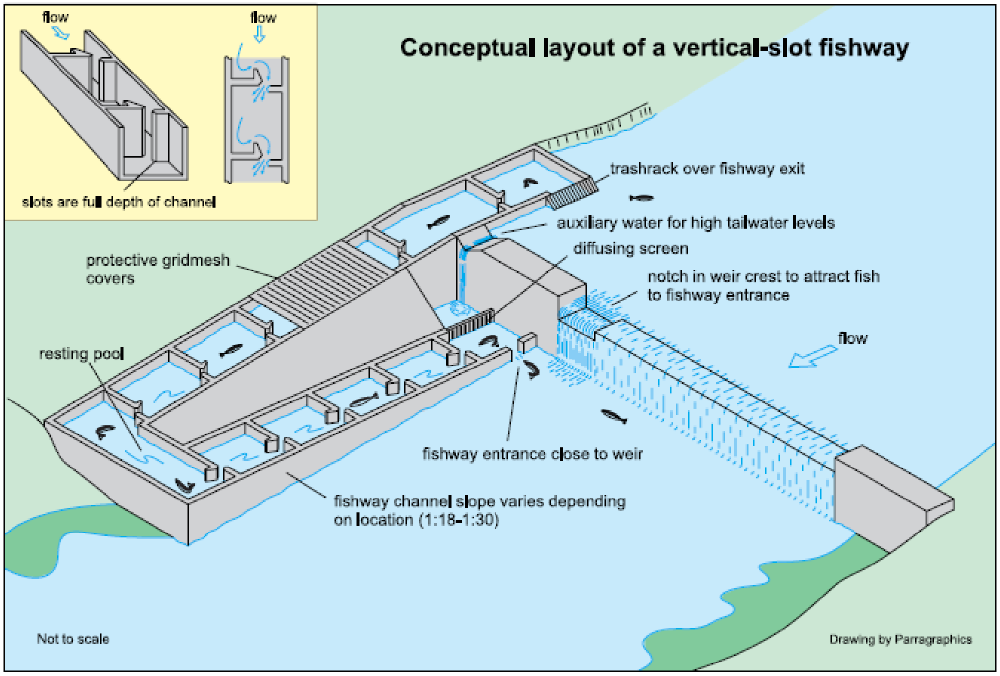


Figure 7. Conceptual layout of a vertical slot fishway (Thorncraft and Harris 2000).

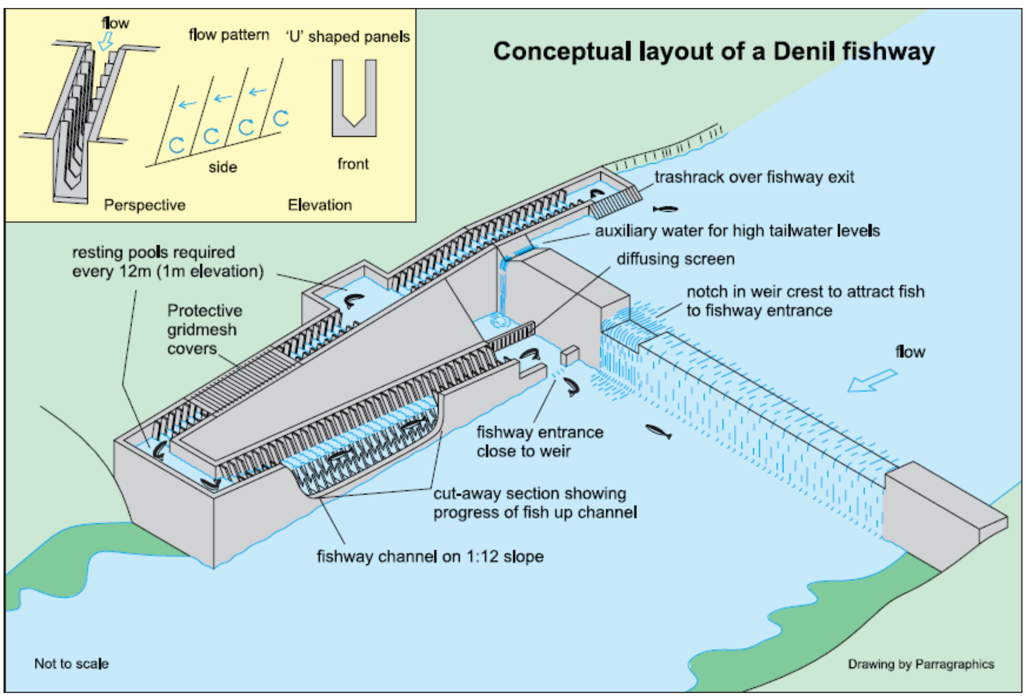


Figure 8. Conceptual layout of a Denil fishway (Thorncraft and Harris 2000).

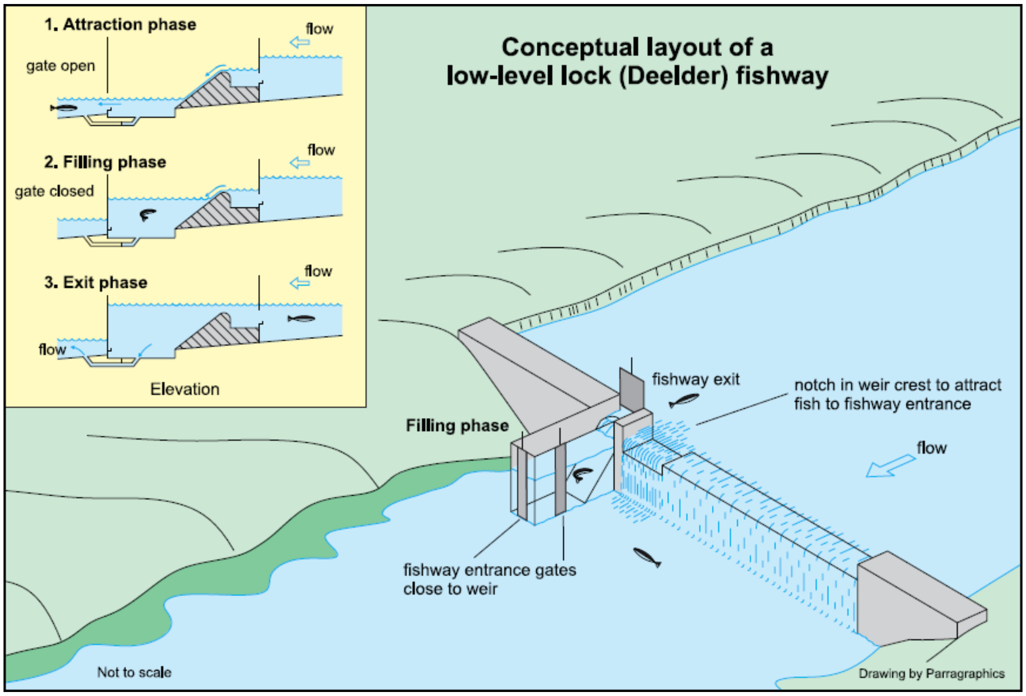
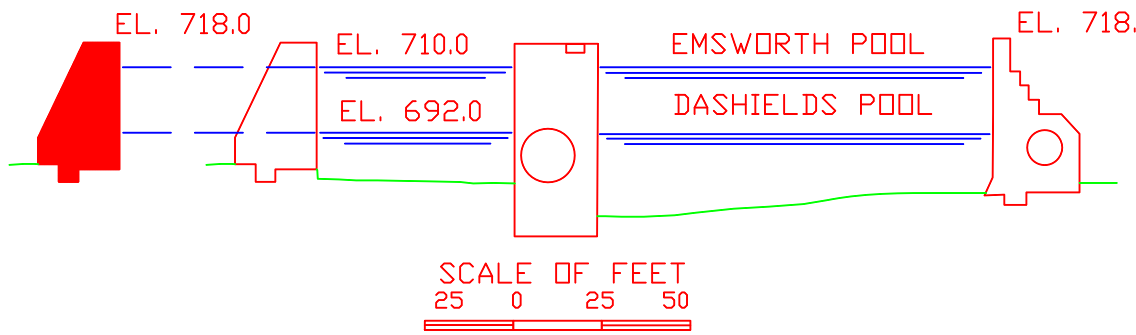


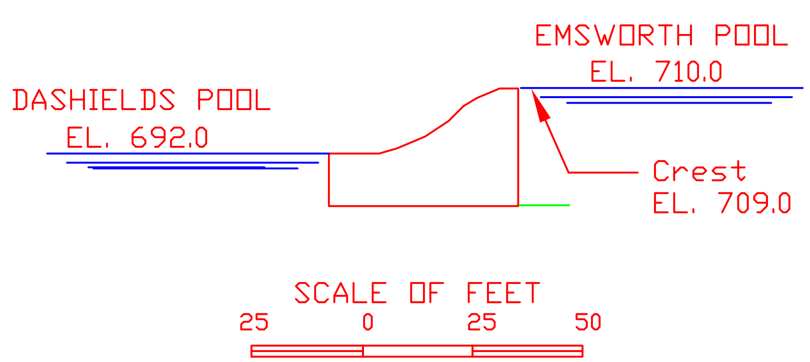
Figure 9. Conceptual layout of a low-level fish lock (Thorncraft and Harris 2000).

Appendix A

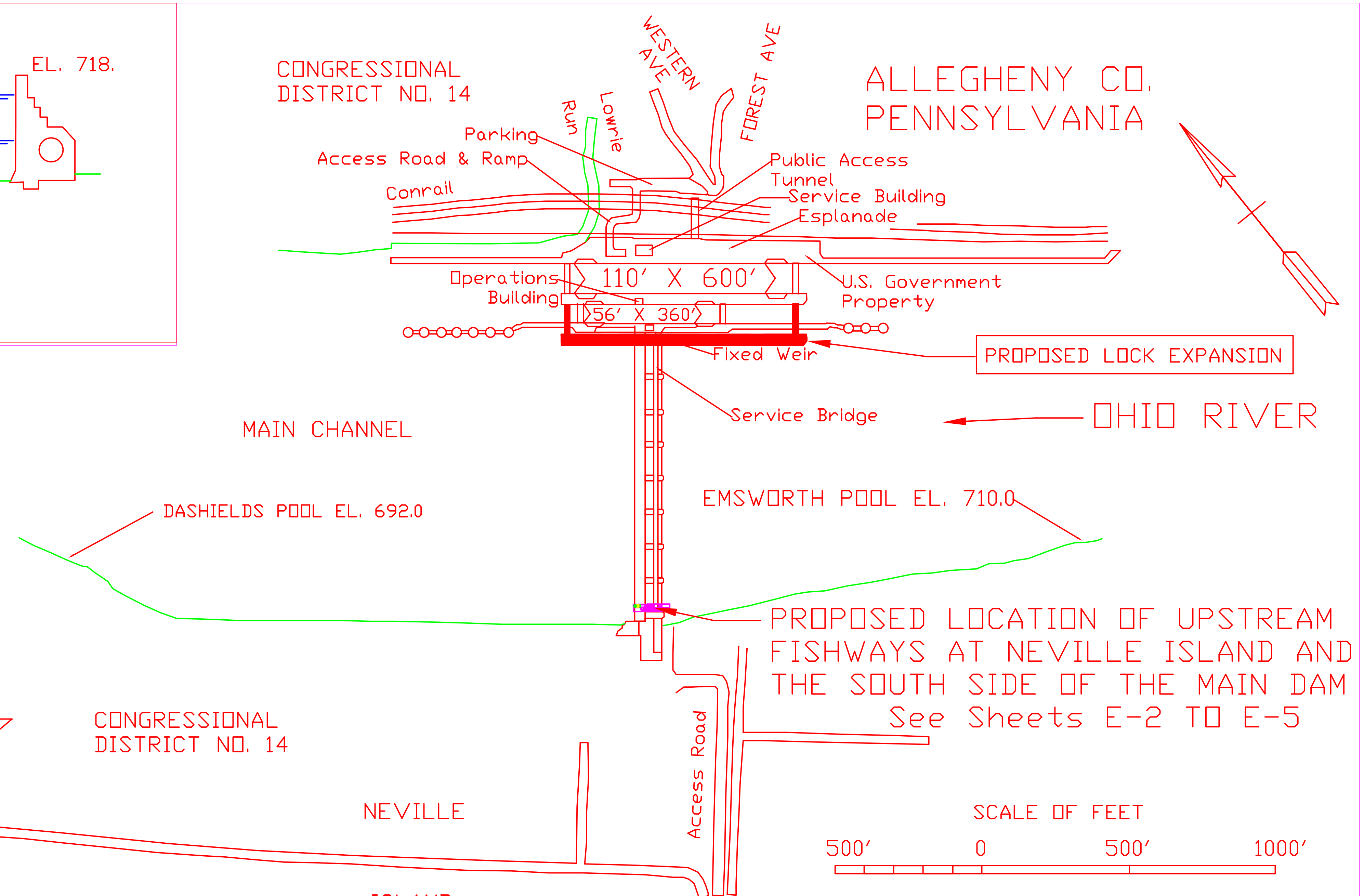
Fishway Plans



SECTION THROUGH LOCKS



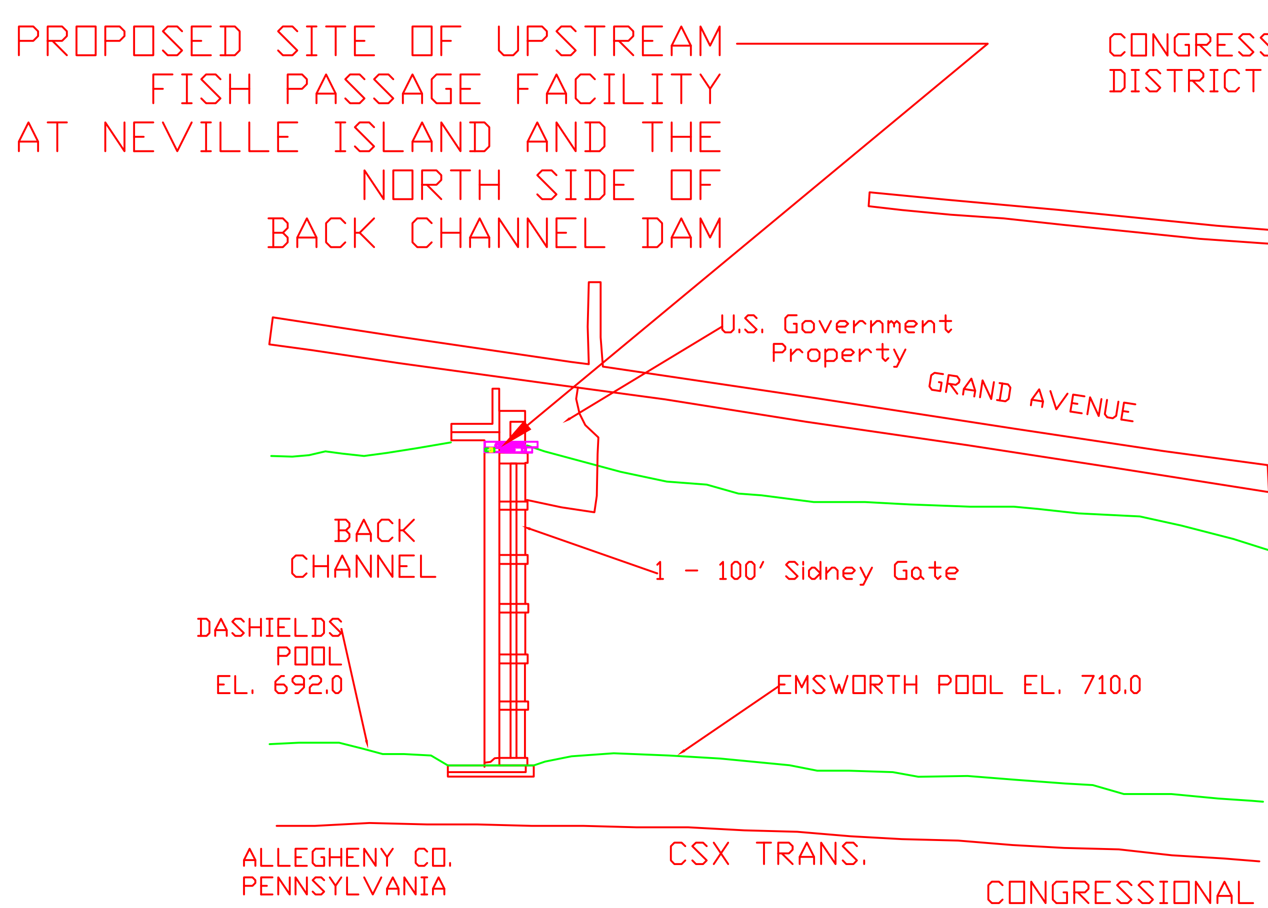
SECTION THROUGH FIXED WEIR



PLAN MAIN CHANNEL LOCK & DAM

CONSTRAINTS

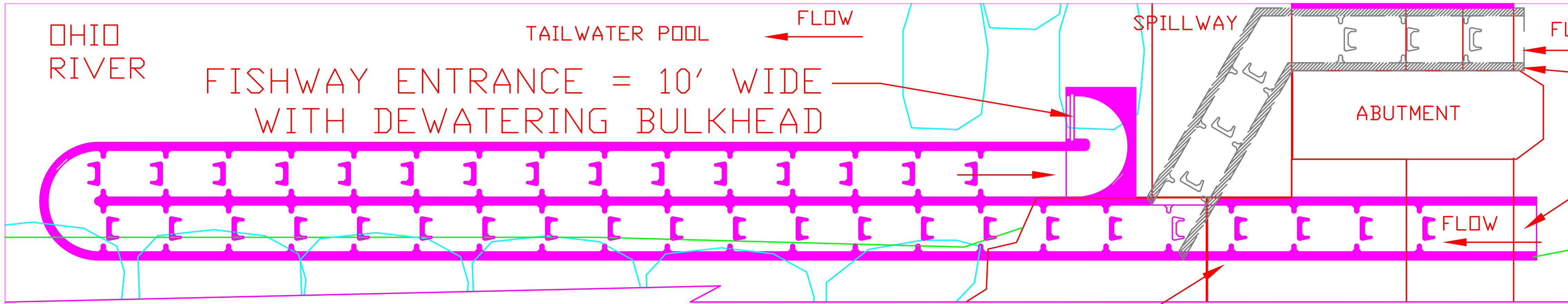
- o HYDROPOWER PROPOSAL UNDER STUDY
- o VERY LIMITED FEDERAL LAND AVAILABLE
- o HAZARDOUS WASTES ON NEVILLE ISLAND
- o LOST SPILLWAY CAPACITY NEEDS REPLACEMENT
- o LOCK EXPANSION MAY ELIMINATE FIXED CREST SPILLWAY AND PORTION OF SPILLWAY GATE
- o WATER LEVEL CONTROL IS CRITICAL IN EMSWORTH POOL
- o EMSWORTH IS MAJOR RECREATION AND COMMERCIAL LOCK



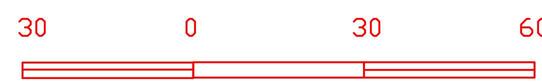
PLAN BACK CHANNEL DAM

CONCEPTUAL LOCATION OF FISH PASSAGE ALTERNATIVES
AT EMSWORTH LOCKS AND DAMS ON THE OHIO RIVER
EMSWORTH, PA
BY RIZZO, ORVIS, FWS, OCTOBER 2009

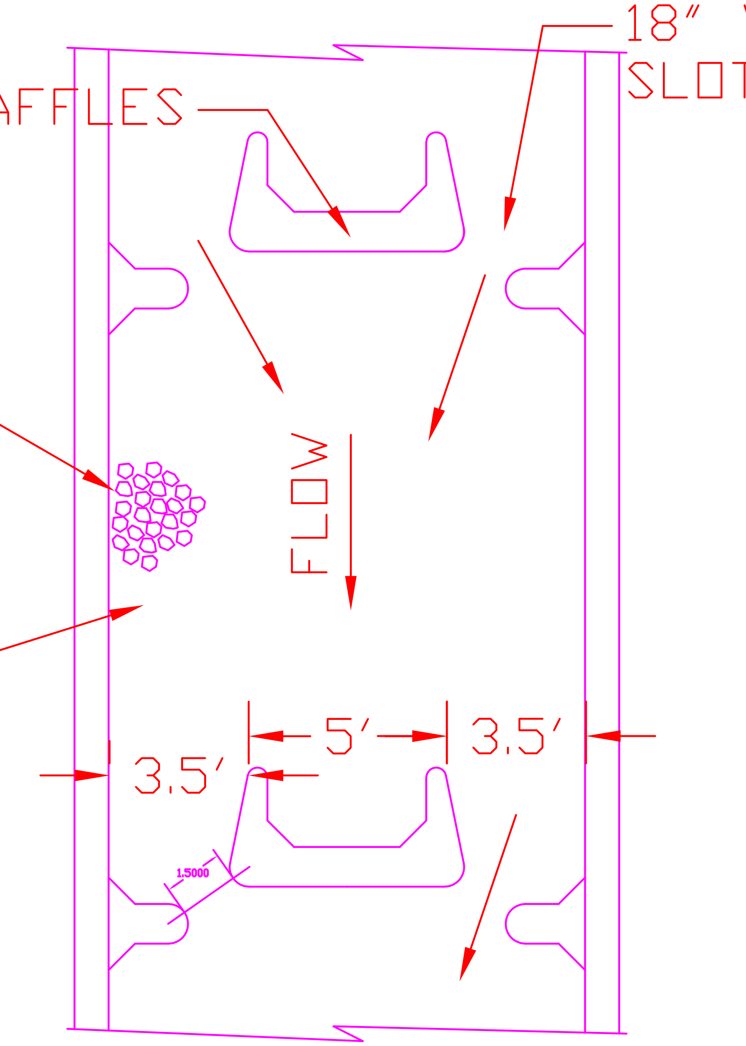
SHEET E-1



PROPOSED DUAL VERTICAL SLOT FISHWAY
SITING AT EMSWORTH MAIN DAM

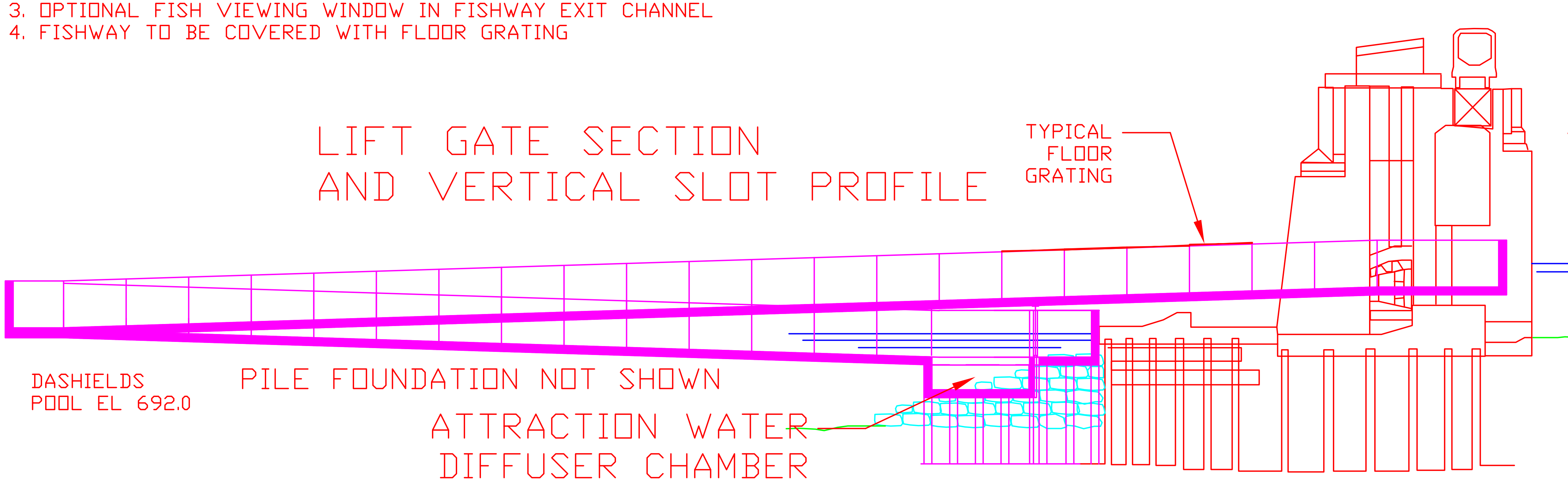


VERTICAL SLOT AND ABUTMENT
PLAN VIEW



VERTICAL SLOT FISHWAY
POOL DETAILS

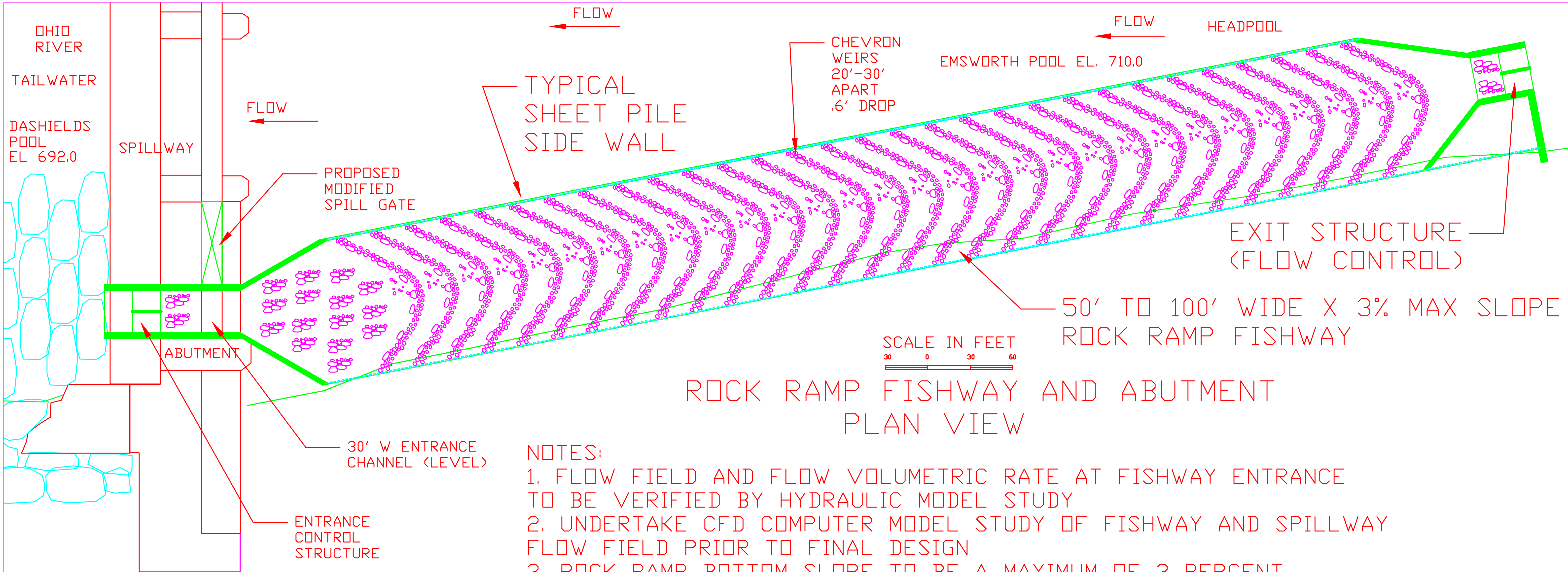
NOTES:
1. UP TO 250 CFS ATTRACTION FLOW AT FISHWAY ENTRANCE
TO BE VERIFIED BY HYDRAULIC MODEL STUDY
2. UNDERTAKE CFD COMPUTER MODEL STUDY OF FISHWAY AND SPILLWAY
FLOW FIELD PRIOR TO FINAL DESIGN
3. OPTIONAL FISH VIEWING WINDOW IN FISHWAY EXIT CHANNEL
4. FISHWAY TO BE COVERED WITH FLOOR GRATING



LIFT GATE SECTION
AND VERTICAL SLOT PROFILE

CONCEPTUAL PLAN AND PROFILE
OF VERTICAL SLOT FISHWAY
PROPOSED AT EMSWORTH MAIN DAM
OHIO RIVER, EMSWORTH, PA
BY RIZZO, ORVIS, FWS, OCT 2009

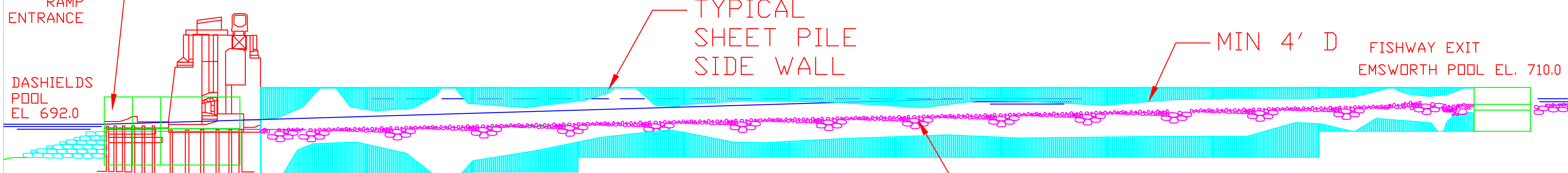
SHEET E-2



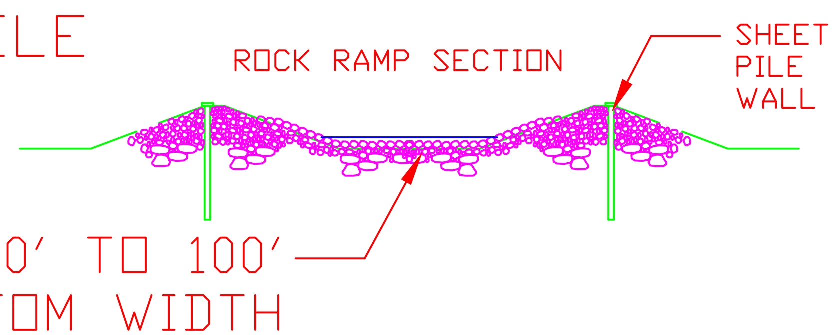
ROCK RAMP FISHWAY AND ABUTMENT PLAN VIEW

NOTES:

1. FLOW FIELD AND FLOW VOLUMETRIC RATE AT FISHWAY ENTRANCE TO BE VERIFIED BY HYDRAULIC MODEL STUDY
2. UNDERTAKE CFD COMPUTER MODEL STUDY OF FISHWAY AND SPILLWAY FLOW FIELD PRIOR TO FINAL DESIGN
3. ROCK RAMP BOTTOM SLOPE TO BE A MAXIMUM OF 3 PERCENT
4. FLOW DEPTH IN RAMP POOLS TO BE A MINIMUM OF 4 FEET

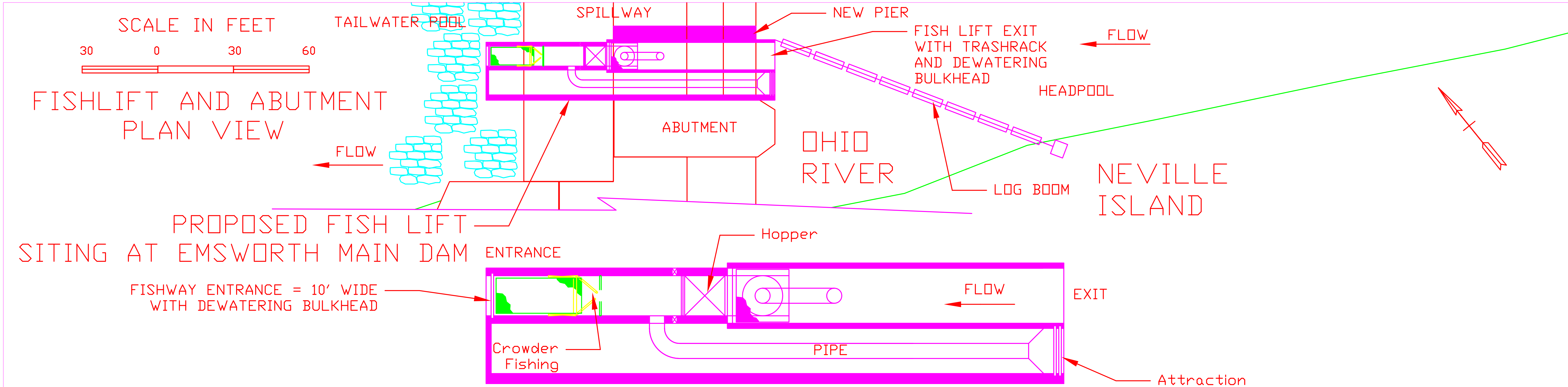


LIFT GATE SECTION AND ROCK RAMP PROFILE



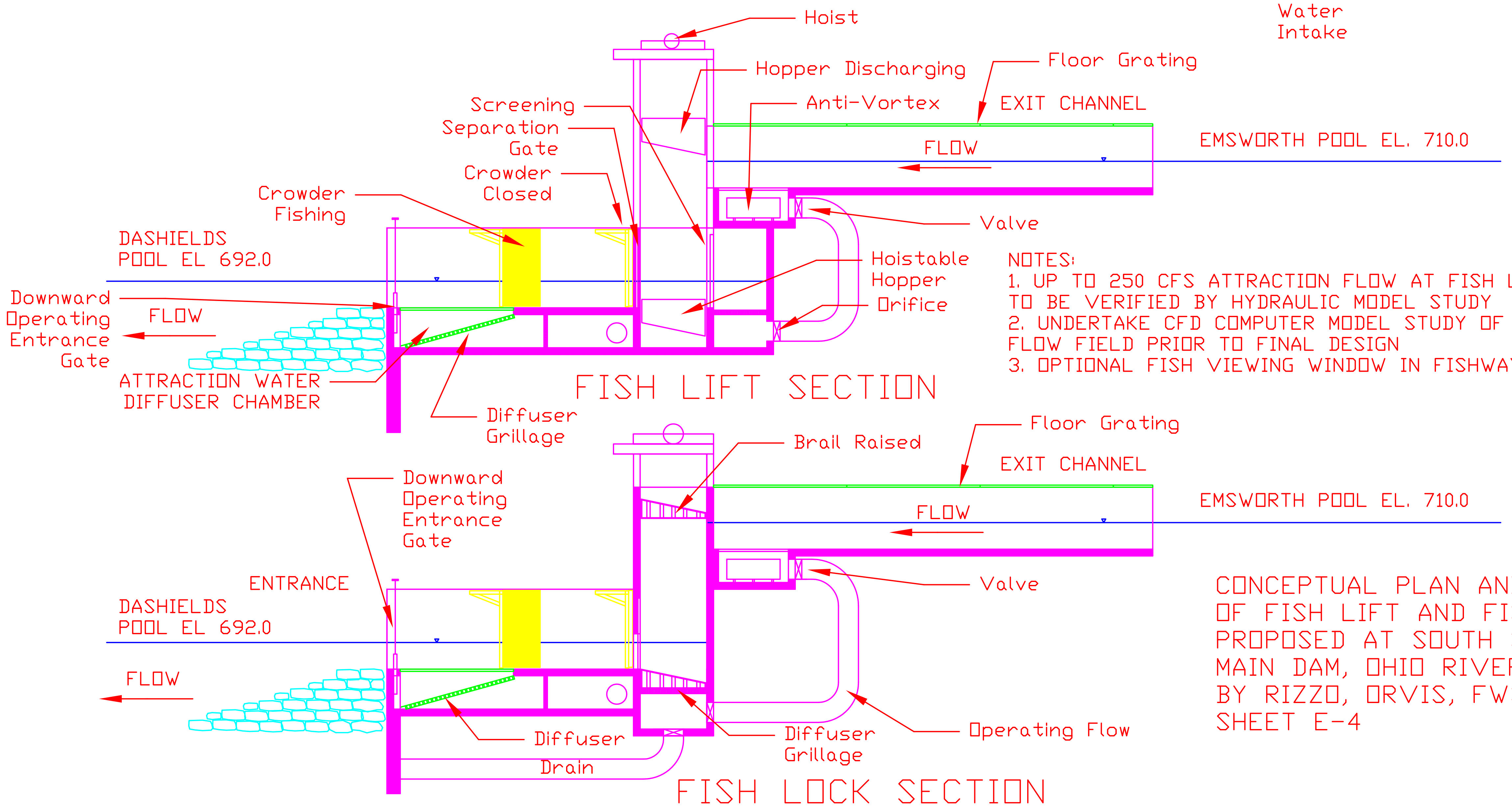
CONCEPTUAL PLAN AND PROFILE
OF ROCK RAMP FISHWAY
PROPOSED AT EMSWORTH MAIN DAM
OHIO RIVER, EMSWORTH, PA
BY RIZZO, ORVIS, FWS, OCTOBER 2009
SHEET E-3

SHEET E-3



FISHLIFT AND ABUTMENT PLAN VIEW

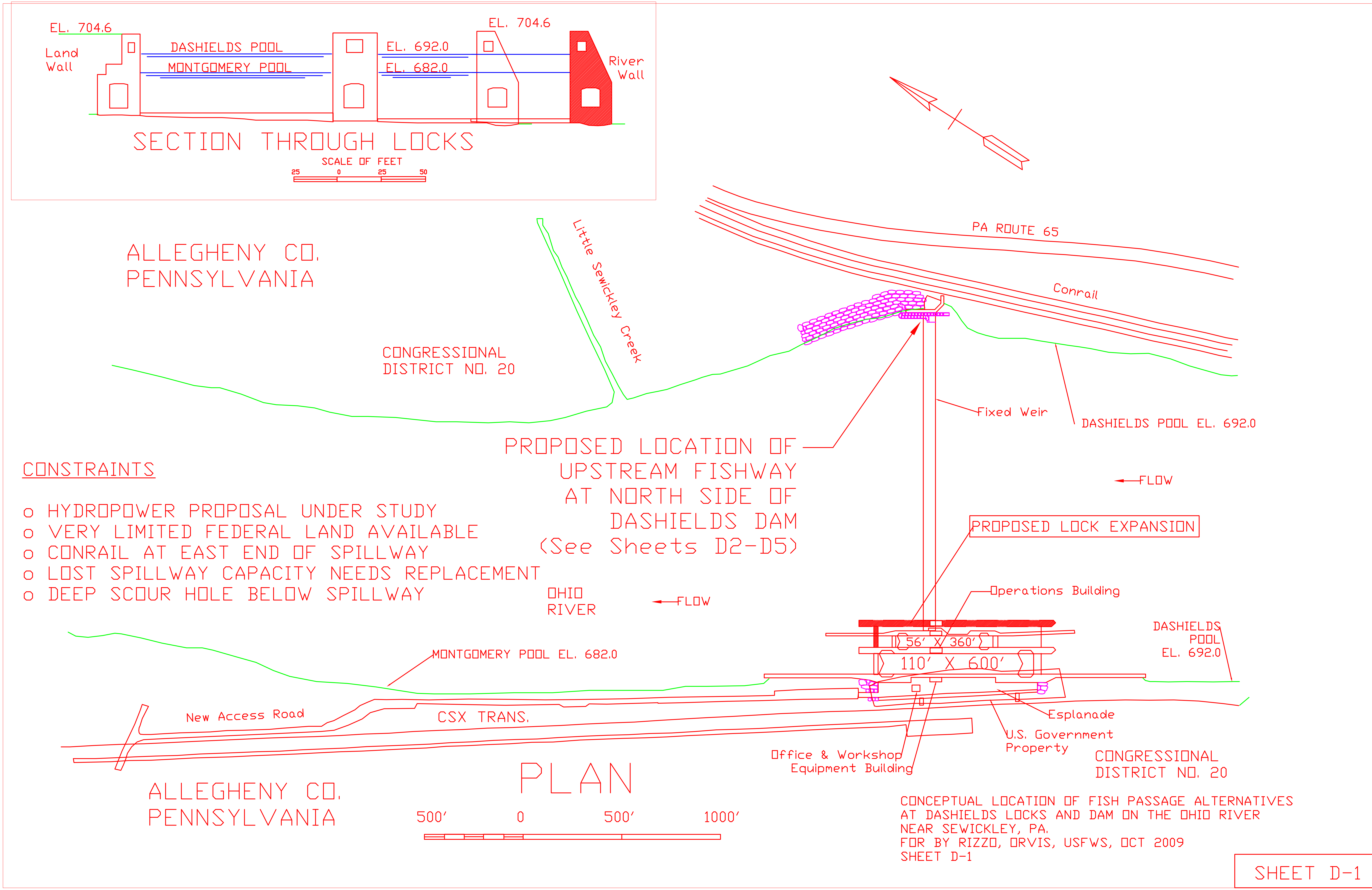
SITING AT EMSWORTH MAIN DAM

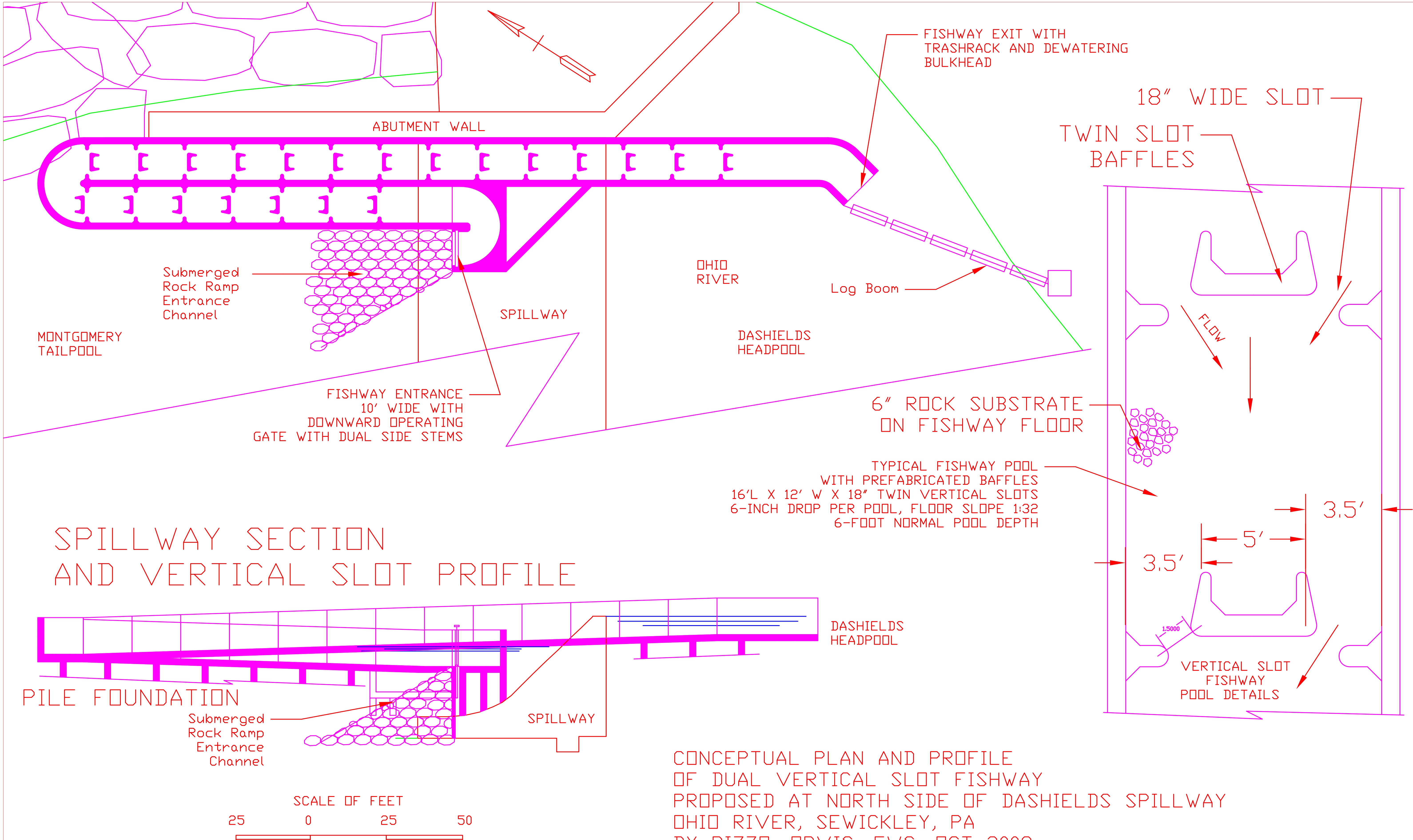


NOTES:
1. UP TO 250 CFS ATTRACTION FLOW AT FISH LIFT ENTRANCE TO BE VERIFIED BY HYDRAULIC MODEL STUDY
2. UNDERTAKE CFD COMPUTER MODEL STUDY OF FISH LIFT AND SPILLWAY FLOW FIELD PRIOR TO FINAL DESIGN
3. OPTIONAL FISH VIEWING WINDOW IN FISHWAY EXIT CHANNEL

CONCEPTUAL PLAN AND SECTIONS
OF FISH LIFT AND FISH LOCK
PROPOSED AT SOUTH SIDE OF EMSWORTH
MAIN DAM, OHIO RIVER, EMSWORTH, PA
BY RIZZO, ORVIS, FWS, OCT 2009
SHEET E-4

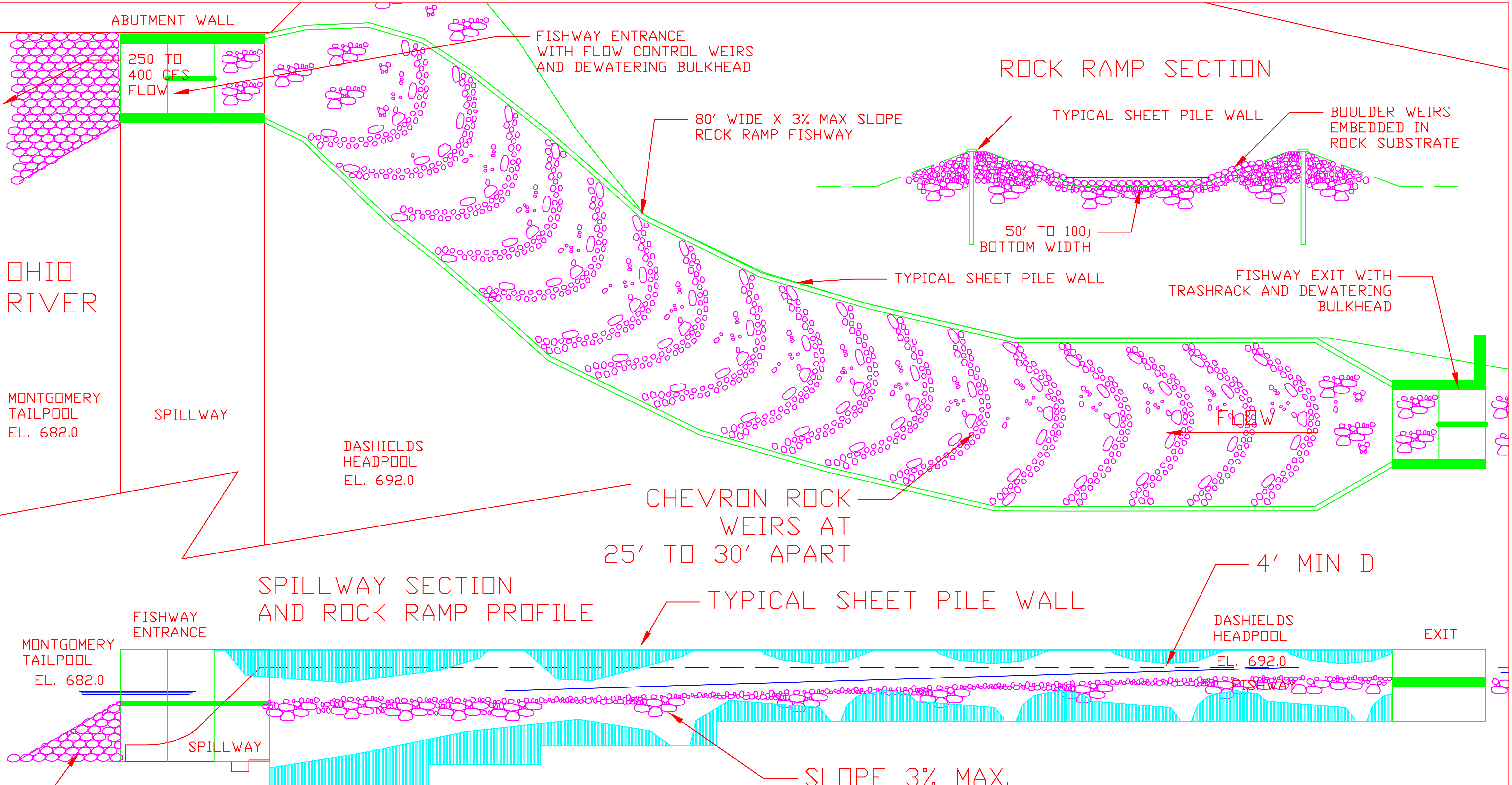
SHEET E-4


EL. 704.6
Land Wall
DASHIELDS POOL
MONTGOMERY POOL
EL. 692.0
EL. 682.0
EL. 704.6
River Wall
SECTION THROUGH LOCKS
SCALE OF FEET
25 0 25 50
ALLEGHENY CO.
PENNSYLVANIA
Little Sewickley Creek
CONGRESSIONAL DISTRICT NO. 20
PA ROUTE 65
Conrail
Fixed Weir
DASHIELDS POOL EL. 692.0
PROPOSED LOCATION OF UPSTREAM FISHWAY AT NORTH SIDE OF DASHIELDS DAM (See Sheets D2-D5)
FLOW
CONSTRAINTS
o HYDROPOWER PROPOSAL UNDER STUDY
o VERY LIMITED FEDERAL LAND AVAILABLE
o CONRAIL AT EAST END OF SPILLWAY
o LOST SPILLWAY CAPACITY NEEDS REPLACEMENT
o DEEP SCOUR HOLE BELOW SPILLWAY
OHIO RIVER
FLOW
PROPOSED LOCK EXPANSION
Operations Building
56' X 360'
110' X 600'
DASHIELDS POOL EL. 692.0
MONTGOMERY POOL EL. 682.0
New Access Road
CSX TRANS.
Office & Workshop Equipment Building
Esplanade
U.S. Government Property
CONGRESSIONAL DISTRICT NO. 20
ALLEGHENY CO.
PENNSYLVANIA
PLAN
500' 0 500' 1000'
CONCEPTUAL LOCATION OF FISH PASSAGE ALTERNATIVES
AT DASHIELDS LOCKS AND DAM ON THE OHIO RIVER
NEAR SEWICKLEY, PA.
FOR BY RIZZO, ORVIS, USFWS, OCT 2009
SHEET D-1
SHEET D-1



CONCEPTUAL PLAN AND PROFILE
OF DUAL VERTICAL SLOT FISHWAY
PROPOSED AT NORTH SIDE OF DASHIELDS SPILLWAY
OHIO RIVER, SEWICKLEY, PA
BY RIZZO, ORVIS, FWS, OCT 2009
SHEET D-2

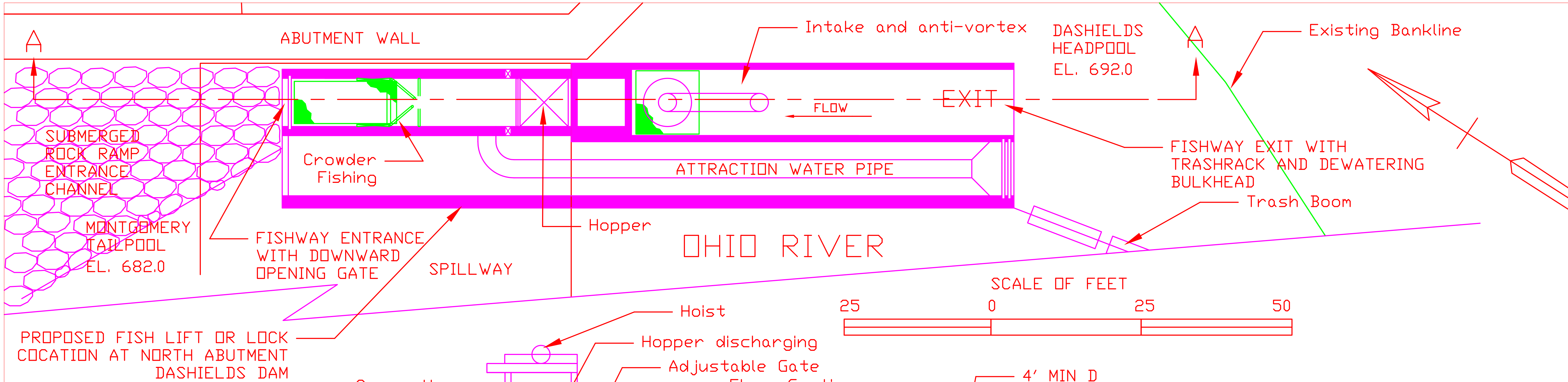
SHEET D-2

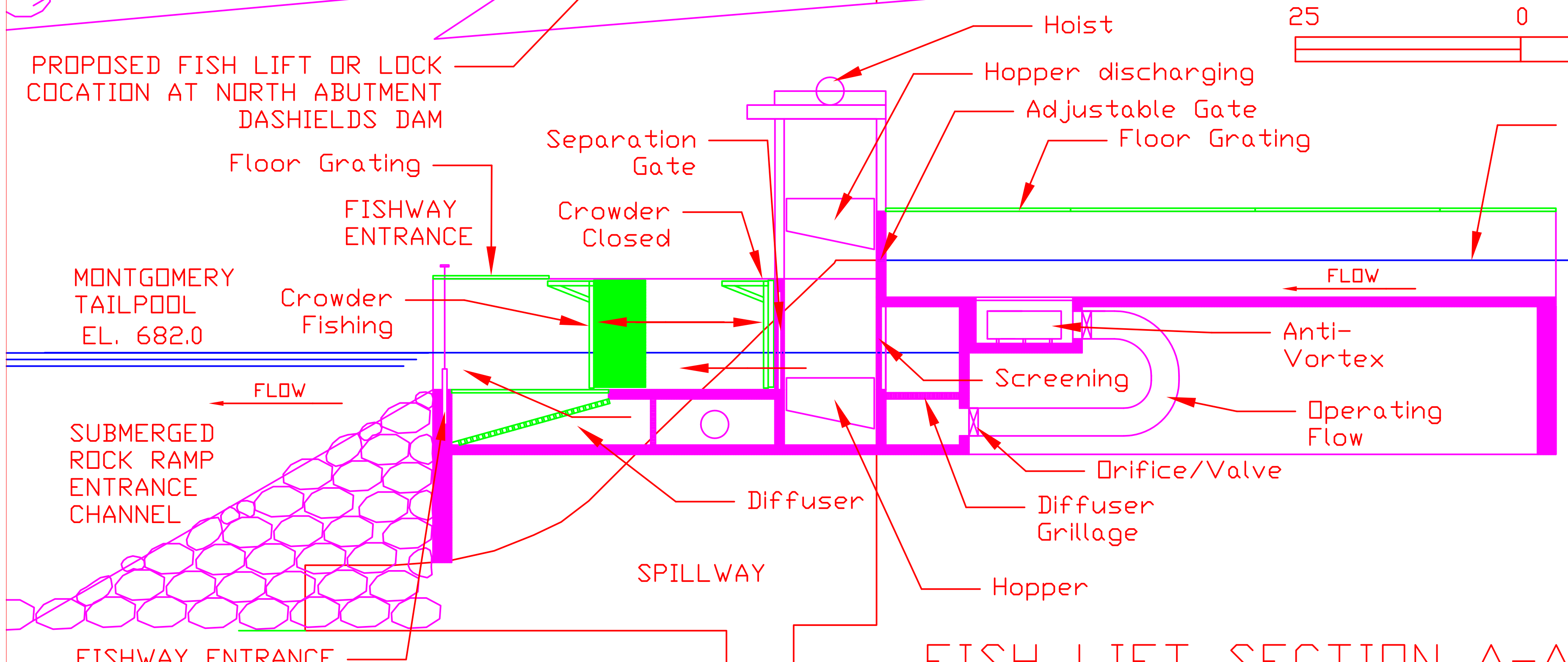


NOTES:
1. FLOW FIELD AND OPERATING FLOW AT FISHWAY ENTRANCE TO BE VERIFIED BY HYDRAULIC MODEL STUDY
2. UNDERTAKE CFD COMPUTER MODEL STUDY OF FISHWAY AND SPILLWAY PRIOR TO FINAL DESIGN
3. ROCK RAMP BOTTOM SLOPE TO BE A MAXIMUM OF 3%
4. FISHWAY FLOW DEPTH TO BE A MINIMUM OF 4 FEET

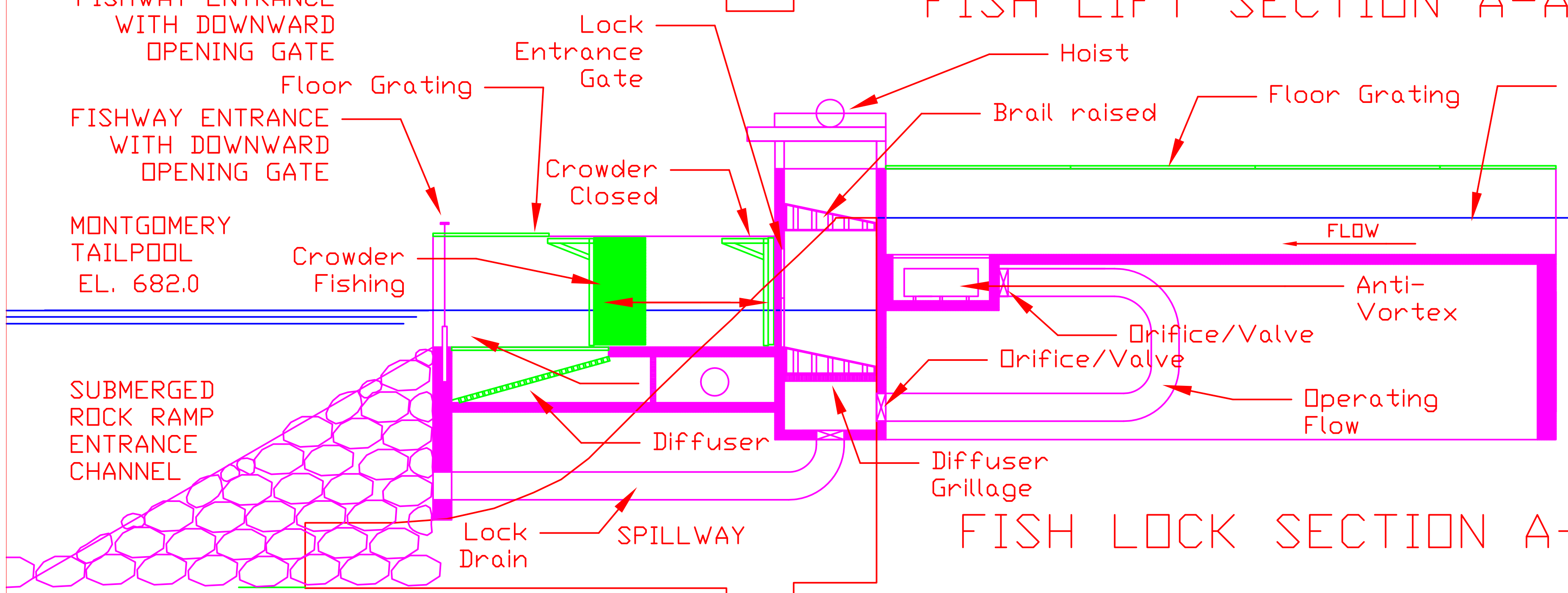
CONCEPTUAL PLAN AND PROFILE
OF UPSTREAM ROCK RAMP FISHWAY
PROPOSED AT DASHIELDS SPILLWAY
OHIO RIVER, SEWICKLEY, PA
BY RIZZO, ORVIS, FWS, OCT 2009
SHEET D-3

SHEET D-3





FISH LIFT SECTION A-A

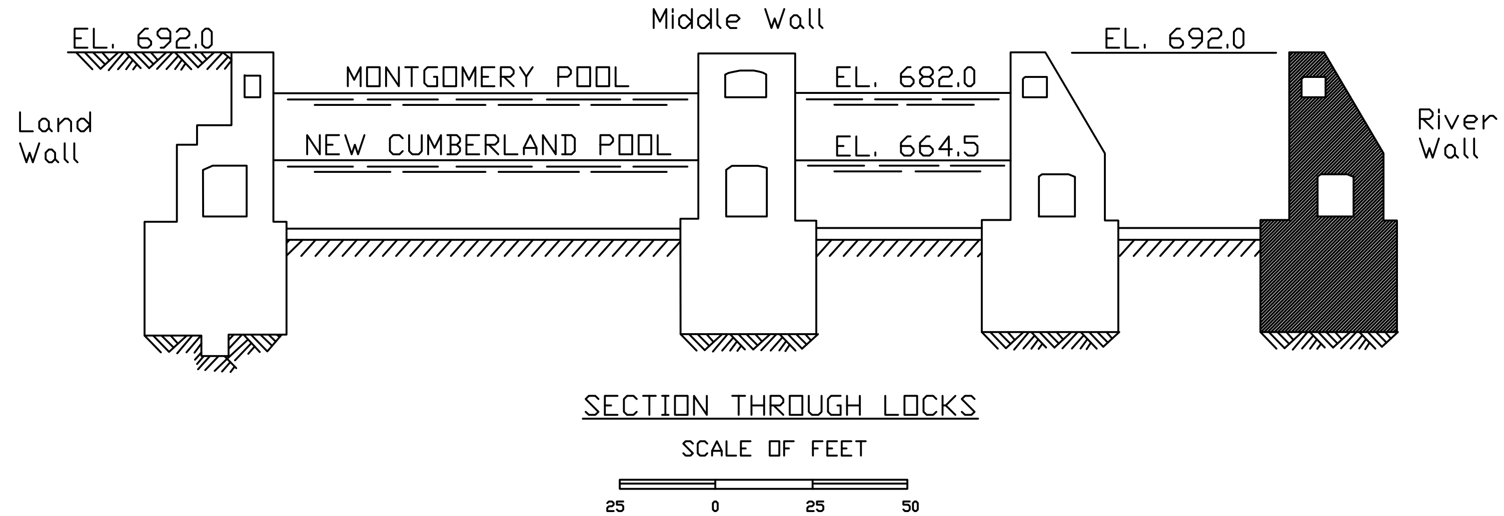


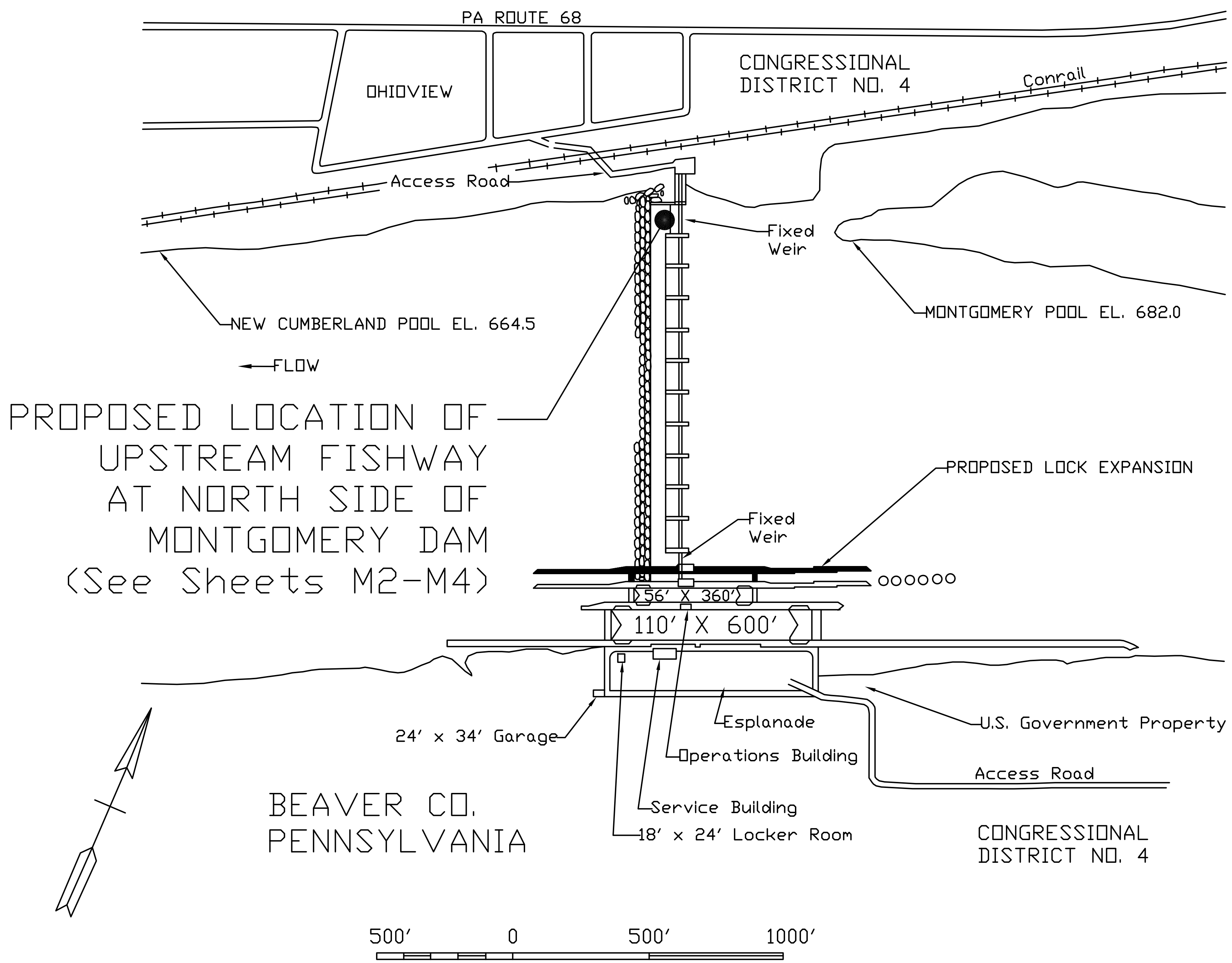
FISH LOCK SECTION A-A

NOTES:
1. UP TO 250 CFS ATTRACTION FLOW AT FISH LIFT
ENTRANCE TO BE VERIFIED BY HYDRAULIC MODEL STUDY
2. UNDERTAKE CFD COMPUTER MODEL STUDY OF FISH LIFT OR LOCK
AND SPILLWAY FLOW FIELD PRIOR TO FINAL DESIGN
3. OPTIONAL FISH VIEWING WINDOW IN EXIT CHANNEL (not shown)

CONCEPTUAL PLAN AND PROFILE
OF PROPOSED FISH LIFT
AT DASHIELDS SPILLWAY ABUTMENT
OHIO RIVER, SEWICKLEY, PA
BY RIZZO, ORVIS, FWS, OCT 2009
SHEET D-4

SHEET D-4



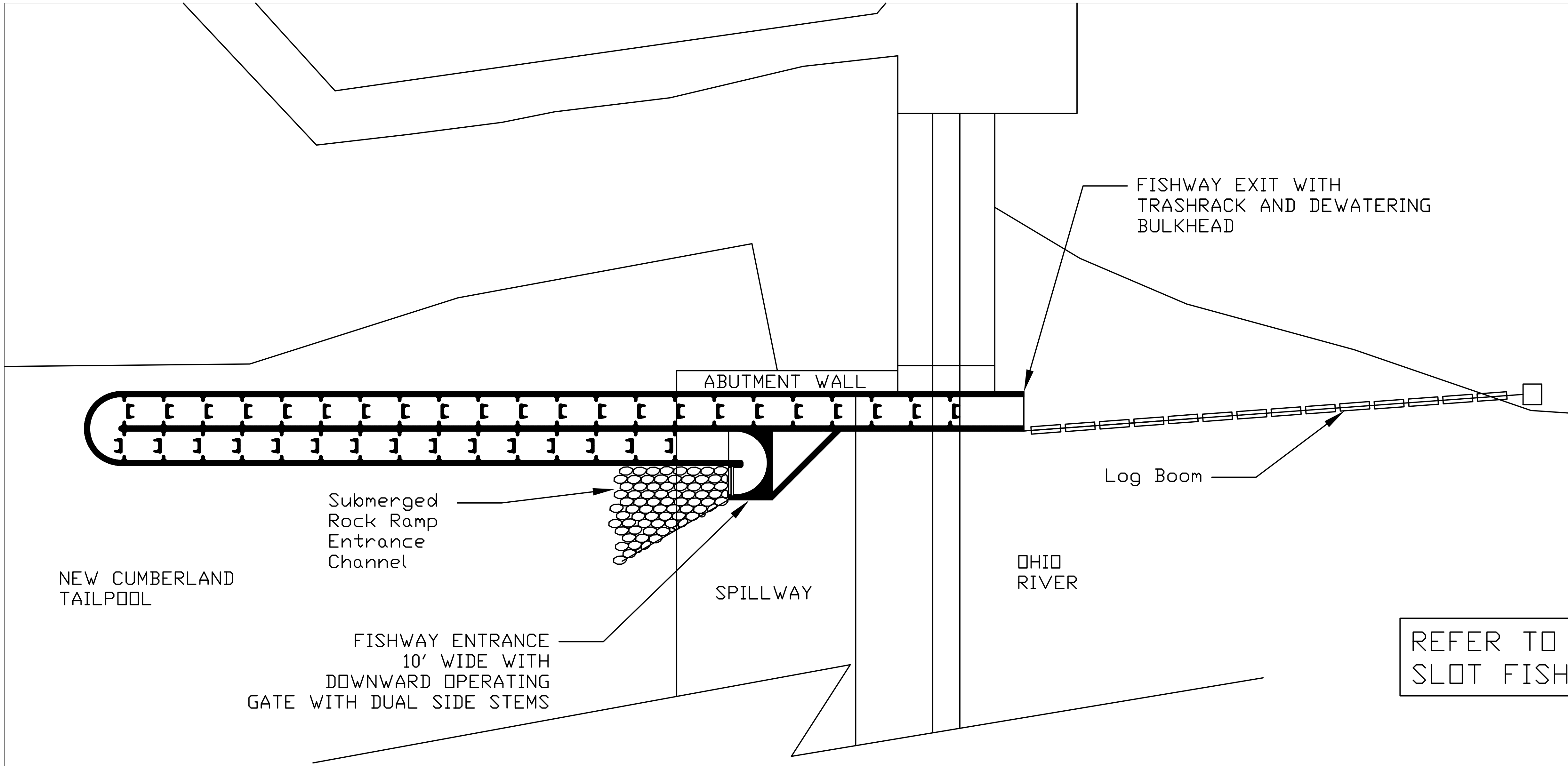


CONSTRAINTS

- HYDROPOWER PROPOSAL UNDER STUDY
- VERY LIMITED FEDERAL LAND AVAILABLE
- CONRAIL AT NORTH END OF SPILLWAY
- LOST SPILLWAY CAPACITY NEEDS REPLACEMENT

CONCEPTUAL LOCATION OF FISH PASSAGE ALTERNATIVES
AT MONTGOMERY LOCKS AND DAM ON THE OHIO RIVER
NEAR SHIPPINGPORT, PA.
FOR BY RIZZO, ORVIS, USFWS, OCT 2009
SHEET M-1

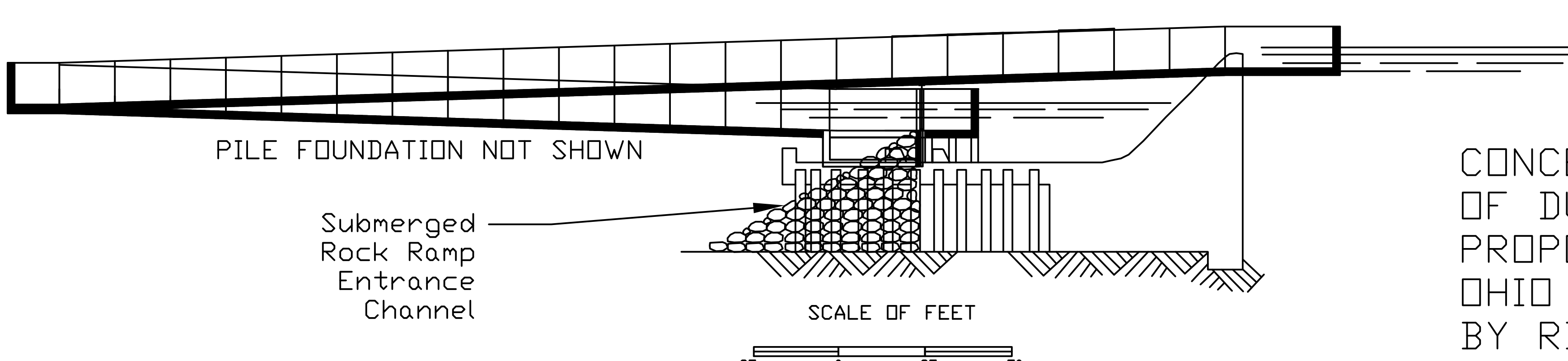
SHEET M-1



REFER TO SHEET D-2 FOR VERTICAL SLOT FISHWAY DETAILS

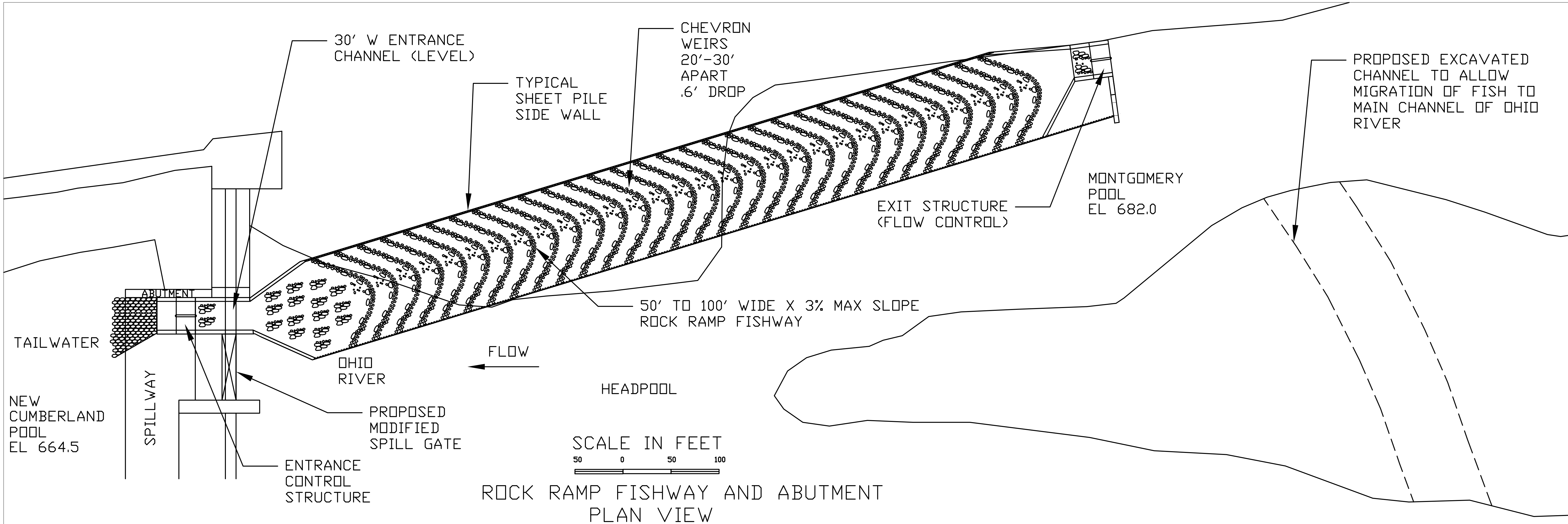
NOTES:
1. UP TO 250 CFS ATTRACTION FLOW AT FISHWAY ENTRANCE TO BE VERIFIED BY HYDRAULIC MODEL STUDY
2. UNDERTAKE CFD COMPUTER MODEL STUDY OF FISHWAY AND SPILLWAY FLOW FIELD PRIOR TO FINAL DESIGN
3. OPTIONAL FISH VIEWING WINDOW IN FISHWAY EXIT CHANNEL
4. FISHWAY TO BE COVERED WITH FLOOR GRATING

SPILLWAY SECTION
AND VERTICAL SLOT PROFILE



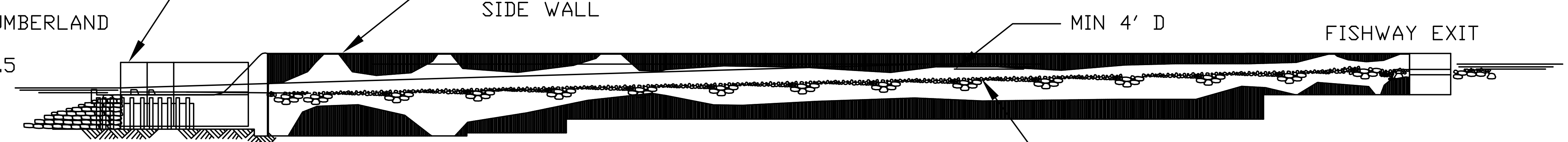
CONCEPTUAL PLAN AND PROFILE
OF DUAL VERTICAL SLOT FISHWAY
PROPOSED AT NORTH SIDE OF MONTGOMERY SPILLWAY
OHIO RIVER, NEAR SHIPPINGPORT, PA
BY RIZZO, ORVIS, FWS, OCT 2009
SHEET M-2

SHEET M-2

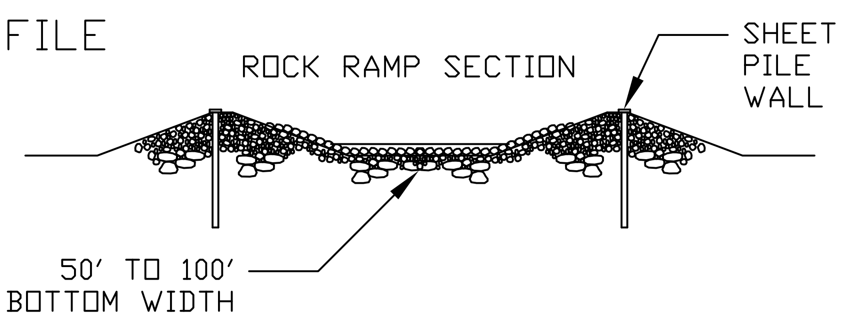


ROCK RAMP FISHWAY AND ABUTMENT
PLAN VIEW

NOTES:
1. FLOW FIELD AND OPERATING FLOW AT FISHWAY ENTRANCE TO BE VERIFIED BY HYDRAULIC MODEL STUDY
2. UNDERTAKE CFD COMPUTER MODEL STUDY OF FISHWAY AND SPILLWAY FLOW FIELD PRIOR TO FINAL DESIGN
3. ROCK RAMP BOTTOM SLOPE TO BE A MAXIMUM OF 3 PERCENT
4. FLOW DEPTH IN RAMP POOLS TO BE A MINIMUM OF 4 FEET



SPILLWAY SECTION
AND ROCK RAMP PROFILE



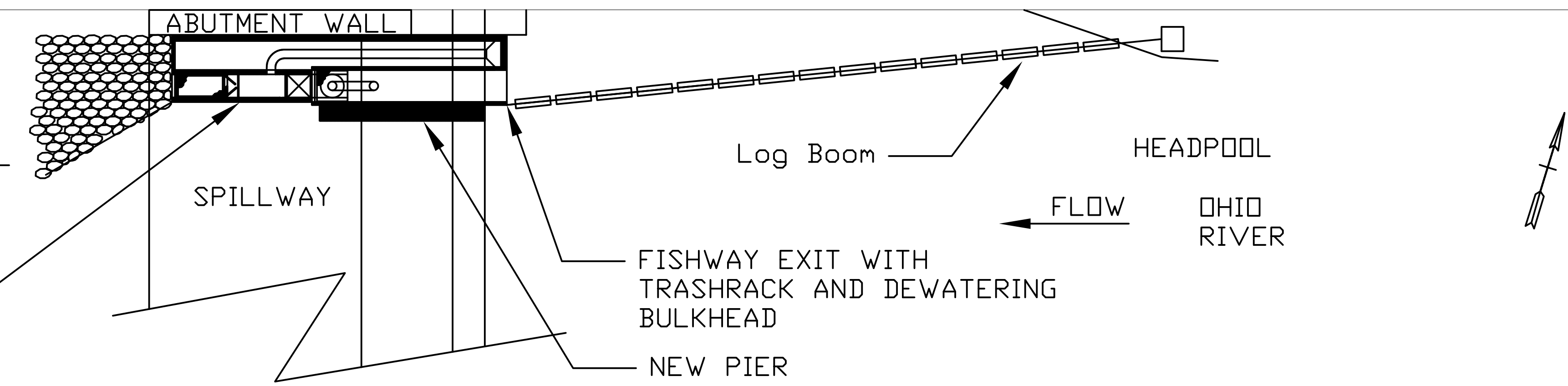
CONCEPTUAL PLAN AND PROFILE
OF ROCK RAMP FISHWAY
PROPOSED AT MONTGOMERY DAM
OHIO RIVER, NEAR SHIPPINGPORT, PA
BY RIZZO, ORVIS, FWS, OCTOBER 2009
SHEET M-3

SHEET M-3

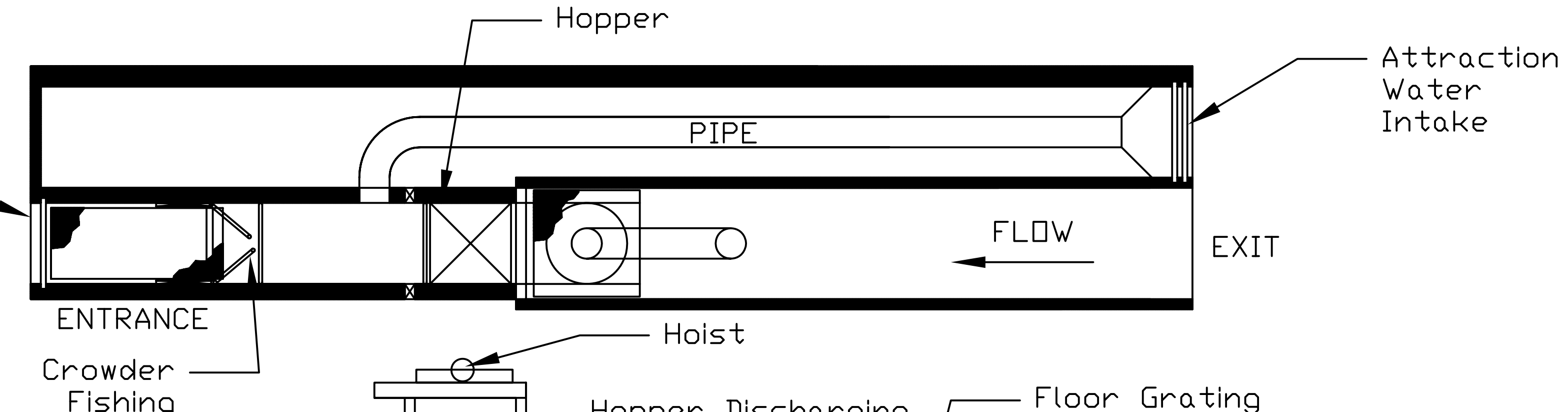
SCALE IN FEET

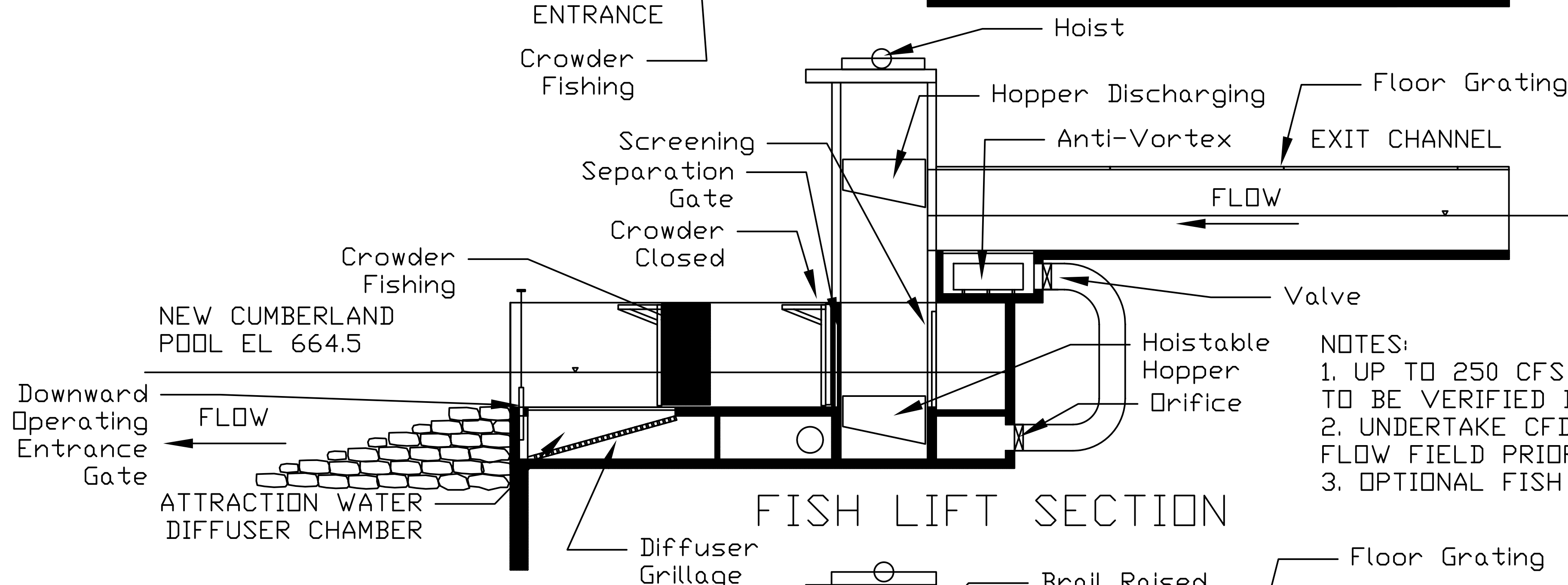
30 0 30 60

FISHLIFT AND ABUTMENT
PLAN VIEW



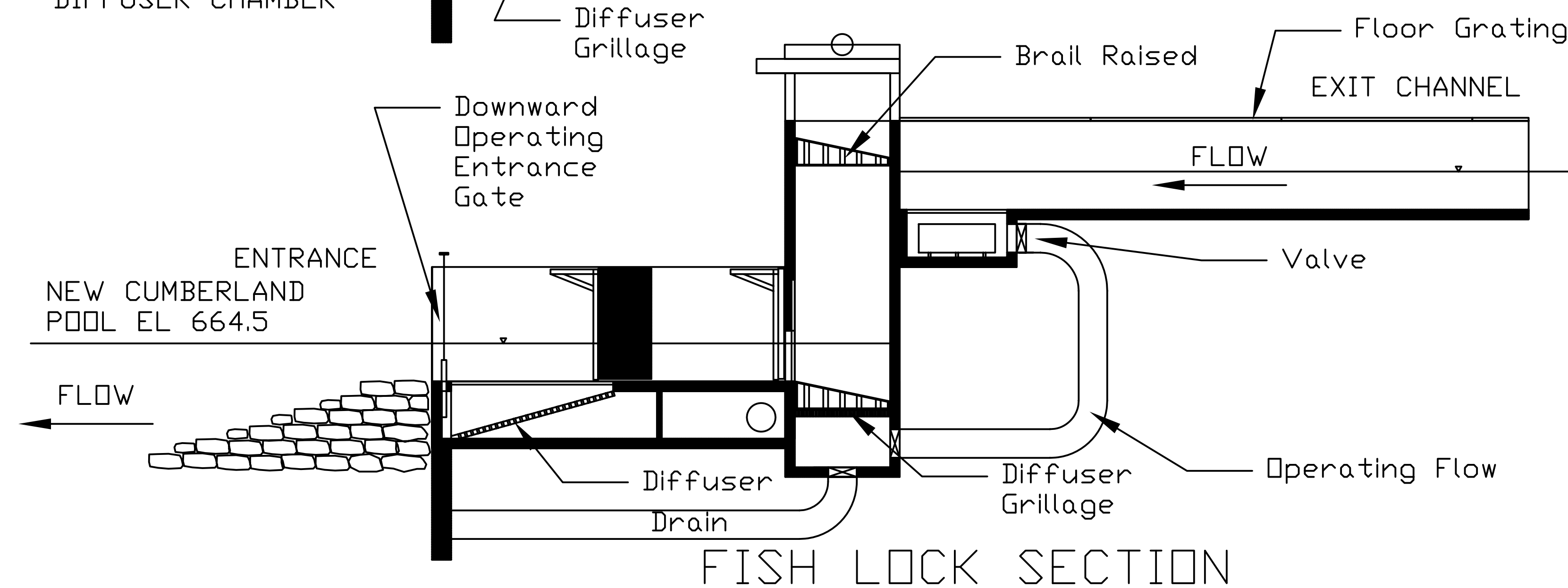
PROPOSED FISH LIFT
SITING AT MOTGOMERY DAM





FISH LIFT SECTION

NOTES:
1. UP TO 250 CFS ATTRACTION FLOW AT FISH LIFT ENTRANCE TO BE VERIFIED BY HYDRAULIC MODEL STUDY
2. UNDERTAKE CFD COMPUTER MODEL STUDY OF FISH LIFT AND SPILLWAY FLOW FIELD PRIOR TO FINAL DESIGN
3. OPTIONAL FISH VIEWING WINDOW IN FISHWAY EXIT CHANNEL



FISH LOCK SECTION

CONCEPTUAL PLAN AND SECTIONS
OF FISH LIFT AND FISH LOCK
PROPOSED AT NORTH SIDE OF MONTGOMERY
DAM, OHIO RIVER, NEAR SHIPPINGPORT, PA
BY RIZZO, ORVIS, FWS, OCT 2009
SHEET E-4

SHEET M-4

Appendix B

Fish Passage Connectivity Index (FPCI)

I. Background

The Fish Passage Connectivity Index (FPCI) was developed to evaluate ecosystem outputs of alternative measures for fish passage improvements on the Upper Mississippi River and Illinois Waterway System (UMRS) for cost effectiveness and incremental analysis**. This document was adapted from the Draft Fish Passage Connectivity Index Model Certification Report, which was developed for the U.S. Army Corps of Engineers planning model certification process. The model has potential for application to fish passage projects on other river systems, but is not currently certified for use in plan formulation.** Though the FPCI is adapted to the Lock & Dam 22 fish passage project and its diverse cool- and warm-water fish community, it may have application to other systems with appropriate modifications. We have begun the process of adapting it for the Upper Ohio River fish passage projects at Emsworth, Dashields, and Montgomery (EDM) Locks and Dams.

Capabilities and Limitations of the Model

The FPCI model is a simple logic construct used to evaluate the potential effectiveness of alternative fish passage improvement measures for use in cost effectiveness and incremental analysis. Because fish passage improvements have not yet been made to UMRS or Ohio River dams and because we have no project monitoring and evaluation results, the FPCI remains untested. However, it is based on available information and serves to distinguish between alternative measures in plan formulation.

1. **Capabilities**

Habitat Benefit Quantification. The estimation of FPCI units provides a surrogate that enables a habitat-based alternatives evaluation for focal species in the Upper Ohio River. Because we currently lack population-level response predictive capabilities, this habitat-based approach provides a planning tool to evaluate the alternative measures.

Upstream Migration. The FPCI is capable of estimating the incremental benefit of upstream fish passage for thirty focal species. Upriver movements of fish in the Ohio River are often blocked by the navigation dams, but because of the design of the dams, downriver fish movements through the dams appear to occur without delay or induced mortality. However, a recent unpublished study related to the Lock and Dam 22 project has suggested that downriver fish movements may also be affected (Brooks et al. 2009). For our purposes, however, this model focuses on upstream passage.

2. **Limitations**

System-Level Analyses. The FPCI was not developed for a system-wide analysis of alternative fish passage improvement measures or for project sequencing. The model was developed to assess how well the alternative measures would improve connectivity for upriver fish movements between the two navigation pools.

Downstream and Lateral Migration. The FPCI addresses upriver movements of adult fishes. It does not address downriver or lateral fish movements (between channels and floodplain). It does not address fish migrations to wintering areas, which are typically in a downstream direction in the fall.

Ichthyoplankton and Juvenile Fish. The FPCI does not address movements of non-adult life stages of fish like downriver drift of ichthyoplankton or lateral and longitudinal movements of juveniles.

Invasive Species. The FPCI does not address movements of invasive species like Asian carp and it does not address the risk of enabling the range expansion of invasive species. The risks associated with spread of invasive should be considered for all fish passage projects.

Predation. The FPCI does not include consideration of the potential for increased predation of fish by concentrating fish and predators near fishways.

Secondary Benefits. The FPCI does not consider the indirect or secondary benefits of fish passage. Secondary benefits should be identified early in the plan formulation process to ensure that all aspects of the project contribute to the project objectives.

Increased opportunity for upriver fish movements through Upper Ohio River Dams would provide fish with access to additional habitats in the upper pools and their tributaries. This would contribute to increased reproductive success, survival and growth of juveniles, genetic diversity and population-level responses of increased geographic range and abundance. Increased habitat utilization could lead to a more diverse, abundant, and genetically enriched fish community in the Upper Ohio River that is more resistant to environmental disturbances. Increased opportunity for upriver fish movements will also have benefits for native mussel populations.

II. Model Description

A. Fish Passage Connectivity Index

The FPCI is a simple arithmetic index that can be adjusted to fit the characteristics of fishes present at locks and dams on the Upper Ohio River and characteristics of fish passage alternative measures. The index is calculated as:

Equation

$$\epsilon = \frac{\Sigma_{i..n} [(E_i \times U_i \times D_i)/25]}{n}$$

Where,

- ϵ = Fish Passage Connectivity Index.
- i = a fish species that occurs in Pool or reach below the dam.
- n = number of fish species included in the index.
- E_i = Chance of encountering the fishway entrance is a calculated value ranging from 1 to 5. 5 indicates highly likely, 3 indicates moderate probability, 1 indicates unlikely.
- U_i = Potential for species i to use the fish passage pathway or fishway (5 = Good, 3 = Moderate, 1 = Poor, 0 = None). Considering adult fish swimming performance and hydraulic conditions within the fishway or fish travel pathway.

- D_i = Duration of availability; fraction of the upriver migration period for fish species i that the passage pathway is available. D_i incorporates a risk component (i.e., the potential failure of an alternative to perform or be available during a critical fish movement period.)

B. Description of the Input Data

1. Upper Ohio River Target Species

Fishery experts from federal, state, and interstate agencies, universities, and non-governmental organizations involved in the EDM Fish Passage Projects were consulted on a list of "target" species that would be used to evaluate the potential effectiveness of fish passage alternatives at EDM Dams. The Upper Ohio Interagency Working Group determined that the initial list of species should include Pennsylvania state listed species, known mussel host species, and additional species adequate to 'represent' functional groups across the full spectrum of Upper Ohio River Species. Meeting the first two criteria resulted in a list of 100 species. Coincidentally, nearly all genera were represented, which served to meet the third criteria.

Once the working list of 100 target species was developed, local fishery experts were asked to narrow the list based on their knowledge and experience with the species' geographic ranges or level of biological relevance to the fish passage projects. Through several iterations, the Working Group ultimately settled on a list of 30 Upper Ohio River species that would represent the spectrum of species in the river, and could be used to evaluate the potential effectiveness of various fish passage alternatives.

Relative abundance of each species was estimated using long-term catch data from the Upper Ohio River Emsworth, Dashields, Montgomery, and New Cumberland Pools (ORSANCO 2009). Fish species were assigned relative abundances in one of four categories based on percent composition in the overall catch for the four pools: rare (0-0.019%), occasional (0.020-0.299%), common (0.300-0.999%), and abundant (>1%). Gizzard shad, emerald shiner, and Cyprinidae spp. were removed from the catch total due to their extraordinarily large contributions to the overall catch.

2. Grouping Fish Species into Guilds

Fishes on the list of "target species" were grouped into guilds and classified by their behavior and swimming performance (Table 1). This set of fish guilds is modeled after the set developed by the Lock and Dam 22 Project Delivery Team. The guilds are based on fish behavior and swimming performance using a combination of information from the fisheries literature and the professional judgment of Ohio River fishery biologists. This information was used to estimate the chance of encountering the fishway entrance (E_i) and the potential to use the fishway (U_i) in the FPCI.

3. Estimating the Potential for Fish to Encounter the Fishway Entrance (E_i)

It is generally not difficult to pass a significant portion of the total river flow through a fishway on a small river due to scale. On a larger river like the Mississippi or Ohio, it becomes more difficult to pass a large percentage of river discharge through a fishway simply due to the expense of building a fishway large enough. On large rivers, Larinier (2001) recommended an attraction flow of around 10 percent of the minimum flow of the river (for the lower design flow), and between 1 and 1.5 percent of the higher design flow for a well located fishway.

E_i was designed to simulate the relationship between discharge and location mathematically within the FPCI. E_i was estimated considering the width of the fishway and the location of fishway entrance in relation to the expected behavior of the fish guild. E_i ranges from 1 to 5 and is unique to each alternative and fish guild. The two components that make up E_i are fishway size (F_s) and fishway location (F_l).

The relationship between E_i, F_s and F_l is expressed in the equation:

$$E_i = (F_s+F_l)/2$$

Where,

- E_i = the potential for fish to encounter the fishway entrance
- F_s = the size of the fishway relative to the discharge of the river under low flow conditions
- F_l = the location of the fishway entrance in relation to the expected behavior of the fish guild

F_s was used to classify measures based upon the percentage of discharge of the river under low flow conditions on a 1-5 scale. For the UMRS Lock and Dam 22 project, this value was assigned based on expected discharge within a fishway as a percentage of the river's flow. In anticipation of flow and discharge data for fish passage alternatives at EDM Dams, this value was initially based on the width of a fishway entrance (i.e., <25' = 1; 25-50'=2, 50-75'=3, 75-100'=4, >100'=5).

F_l was used to determine if the measures were well located for each fish guild based on swimming performance and behavior. Swimming performance is important because it indicates the flow conditions that a fish prefers and behavior is important because it indicates the vertical and horizontal position within the flow field that a fish would generally select. Initial values were assigned based on three categories: 5 indicated the entrance was directly adjacent to the primary discharge flow of the river and preferred habitat of a species; 3 indicated the entrance was near the primary discharge flow and preferred habitat; 1 indicated the entrance was in another location.

4. Estimating the Potential (U_i) for Fish to Use Alternative Fish Passage Measures

An estimate of the potential for fish to use alternative fish passage measures (U_i) based upon the adult fish swimming performance and hydraulic conditions within the fishway or fish travel pathway. The minimum current velocity at the hydraulic steps for each alternative measure, based on velocities determined for the UMRS Lock and Dam 22 project, was compared to the swimming ability for each Ohio River target species and appropriate values were estimated for assigned for U_i.

Some fish have unique characteristics that affect their U_i. For example, the paddlefish can detect electrical fields emanating from metal structures in the water and avoid them; therefore, the U_i

rating for paddlefish was low for measures that had substantial metal components such as a technical fishway.

Critical current velocities (Ucrit) for prolonged swimming by adult fish of size at first year of reproduction for Ohio River target species were estimated based on literature reports on fish swimming performance trials, and were modeled after Wilcox et al. (2004; Table 2). Although information about swimming performance of many fishes is incomplete, experimental swimming performance data for morphologically similar species were used for species without experimental results. This information was used to estimate the potential (U_i) for species i to be physically and behaviorally able to travel upstream through the alternative measures fishways and travel pathways for the FPCI. Table 3 gives a summary of target species abundance and swimming ability.

5. Estimating the Duration of Availability (Di) of the Alternative Measures

Table 4 presents information about the seasonal movements of Upper Ohio River target species based on fisheries literature and Ohio River water temperature records (adapted from Knights et al. 2003). The estimated spawning periods are based on water temperatures reported in the fisheries literature (see Table 4) and the long-term average water temperature record by week of year for EDM Dams (Knights et al. 2003). Estimated pre-spawning and spawning movement periods are shown in Table 5, and are based on reports from the literature. This information was used to estimate the duration of availability (D_i) in the FPCI.

Fishways were assumed to be continuously available for fish migration, therefore all were assigned a D_i of 1. Assisted fish lockage was assumed to be done five times per day during the fish migration period (March – June) and twice per day the rest of the year. We assumed a one-hour time for fish to accumulate in the lock chamber prior to lockage. A D_i of 0.12 (5/24 hrs March – June; 2/24 hrs rest of year) was estimated for the fish lockage alternative measure for all fish species.

6. Fish Passage Through the Lock Chamber

Fish can pass upriver through the lock chamber, although that pathway is only intermittently available and is unlikely to allow upriver movements of large numbers of fish, given the lack of attracting flows, orientation of currents in the lock chamber and the presence of commercial tows transiting the lock.

7. Velocities and Hydraulic Conditions in Alternative Fishways

Velocities of specific fishways proposed for EDM Dams have not been estimated. Velocities used are based on those estimated for the UMRS Lock and Dam 22 fish passage project. Hydraulic conditions in fishway measures for Lock and Dam 22 were estimated using information from the fisheries literature for the technical fishway (Bell 1991) and through an ADH model of rock ramp fishways. Velocities through the vertical slot of the technical fishway alternative would be approximately 6.5 ft/sec. Velocities for assisted lockage and constructed fish locks at EDM Dams were estimated to be 1.0 ft/sec or less. Velocities between the riffle boulders in the rock ramp fishways would range from approximately 6.5 ft/sec at the center of the fishway to <2.0 f/sec between the riffle boulders along the shallower edges of the fishways. This information was compared to fish swim speed to help estimate the potential for species i to use the fishway (U_i) in the FPCI equation.

C. Description of the Output Data

Output data is expressed in habitat units which are derived from the relationship of the effectiveness of the fishway (Fish Passage Connectivity Index) and the amount of habitat available in the Pool above the dam for each species. The resulting species habitat units are then averaged for each alternative. Table 6 provides an example of how these output data were calculated. The averages of these data are then summarized in a simple spreadsheet summary table of fish passage connectivity and corresponding habitat units. Habitat units for Upper Ohio River pools have not been calculated at the time this report was finalized; however, once they are, habitat units for the FPCI will be calculated by multiplying the FPCI by the total acres of available preferred habitat in Upper Ohio River Pools for each species. The total area of available habitat is the same for all alternatives, unique to each of the EDM Dams' pools.

III. Technical Quality

A. Theory

The theory behind this model is that each species has unique swimming performance and behavior. The potential effectiveness of fish passage alternative measures can be evaluated based on how well each of the fishes at EDM Dams may find the migration pathway through the dam and make their way into the next pool when moving upriver. The Habitat Unit portion of the model assumes that availability of habitat and habitat connectivity is limiting the abundance and spatial distribution of each species and that each species has certain preferences for use of certain habitat types. Restoring connectivity for the fish community will reestablish an important biological component to the habitat structure. Restoring fish to an aquatic community restores ecosystem functions. Fish affect biological and physical elements of the aquatic ecosystem they occupy. For instance, bringing predatory fish species into balance may affect the population size of herbivorous fish, in turn affecting plant communities. The greater the degree of connection between the upstream and downstream habitats, the closer the ecosystem can be restored to a healthy condition, providing benefits to the larger ecosystem and society.

B. Assumptions

Assumptions inherent in the model include:

- We currently do not have the capability to predict the population-level responses of fishes to fish passage improvements at EDM Dams.
- The potential effectiveness of alternative fish passage measures is based on the swimming performance and behavior characteristics of target species.
- The potential effectiveness of alternative fish passage measures is also based on their temporal availability, size, location, and hydraulic characteristics.
- There is additional carrying capacity for migratory fishes in upstream habitat.
- Habitat Unit approach provides a habitat-based surrogate to evaluating the benefits of potential alternative fish passage measures.
- The quality of habitats in the upstream pool would be beneficial to the migratory fish populations.

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Table 1. Guilds of Ohio River target species for evaluation of fish passage at Upper Ohio River locks and dams, based on behavior and swimming performance. Benthic – swims near the river bottom; Littoral – swims in shallow water; Pelagic – swims throughout the water column, often near the surface.

	Benthic	Littoral	Pelagic
Strong	Blue sucker	American eel Sauger Walleye	Paddlefish Skipjack herring White bass
Medium	Shovelnose sturgeon River carpsucker Highfin carpsucker Bigmouth buffalo Channel catfish Flathead catfish Freshwater drum	Smallmouth bass Spotted bass Largemouth bass	Mooneye
Weak	River Chub Striped shiner Rainbow darter Bluebreast darter Tippecanoe darter Logperch Slenderhead Darter	Muskellunge Spotfin shiner Brook silverside Bluegill	Longnose gar

Table 2. Estimates of Prolonged Swimming Performance of UMRS Migratory Fishes modeled after Wilcox et al. (2004).

Estimated of prolonged swimming speeds of Upper Ohio River focal species

Species	Scientific Name	Length mm TL	TL or FL/SL	U_{crit} Model (cm/s)	n test fish	Reference	Estimated adult fish U_{crit} (cm/s)	Estimated adult fish U_{crit} (ft/s)	Comments on U_{crit}
Shovelnose sturgeon	*Scaphirhyncus platorynchus*	551 [23] (FL)	1.08 [23]	1.6 SL	9	1, 2, 23	82	2.7	adult fish (46 cm to 50.9 cm SL)
				none - tests of individual fish	5	3, 23	65 to 116	2.1	adult fish (53 cm to 64 cm SL)
Paddlefish	*Polyodon spathula*	1020 [23] (FL)	1.182 [23]	1.0 SL	1	1, 2, 23	86	2.8	1immature fish (65.4 cm SL)
				1.5 SL	4	1, 2, 23	129	4.2	test fish (37.2 cm - 38.1 SL)
Longnose gar	*Lepisosteus osseus*	500 [23]	TL = FL [23]	4.9 FL^0.55 (surrogate: norther pike)	0	4, 23	21	0.7	surrogate, probably low
American eel	*Anguilla rostrata*	900 [23]	1 [23]	none found		23			Unknown
Skipjack herring	*Alosa chrysochloris*	254 [23]	1.25 [23] (estimate)	2.9 SL (surrogate: goldeye)	58	1, 2, 23	59	1.9	surrogate, probably low
Mooneye	*Hiodon alosoides*	255 [23]	1.25 [23] (estimate)	2.9 SL (surrogate: goldeye)	58	1, 2, 23	59	1.9	surrogate
Muskellunge	*Esox masquinongy*			None Found					
River chub	*Nocomis micropogon*			None Found					
Striped shiner	*Luxilus chrysocephalus*	76 [19]		4.4 TL @ 20 degrees C	15	7	33.44	1.1	Surrogate: Spotfin Shiner Test Fish (75 mm - 84 mm)
				None- tests of individual fish	?	5	50 to 60	1.6 to 2.0	Surrogate: Topeka Shiner Test Fish (3.0 cm to 4.2 cm SL)
				None- tests of individual fish	14	6	31.7	1	Surrogate: Cardinal Shiner Test Fish (46 mm to 72 mm TL) low complexity (smooth) substrate
				(surrogate: Cardinal Shiner)	8	6	26.48	0.9	Surrogate: Cardinal Shiner Test Fish (45 mm to 67 mm TL) high complexity (rocky) substrate
Spotfin shiner	Cyprinella spiloptera	64 [19]		4.4 TL @ 20 degrees C	15	7	28.16	0.9	Test Fish (75 mm - 84 mm)
				None- tests of individual fish	?	5	50 to 60	1.6 to 2.0	Surrogate: Topeka Shiner Test Fish (3.0 cm to 4.2 cm SL)
				None- tests of individual fish	14	6	31.7	1	Surrogate: Cardinal Shiner Test Fish (46 mm to 72 mm TL) low complexity (smooth) substrate
				(surrogate: Cardinal Shiner)	8	6	26.48	0.9	Surrogate: Cardinal Shiner Test Fish (45 mm to 67 mm TL) high complexity (rocky) substrate
River carpsucker	Carpiodes carpio	305 [19]		None Found					
Highfin carpsucker	*Carpiodes velifer*	249 [23]	1.22 [23] (estimate)	25.5 + 0.97 SL (Surrogate: smallmouth buffalo)	0	8, 23	45	1.5	surrogate
Blue sucker	*Cycleptus elongatus*	487 [23]	1.19 [23]	1.9 SL	11	1, 2, 23	78	2.6	test fish (33.9 cm to 48.5cm SL)
Bigmouth buffalo	*Ictiobus cyprinellus*	393 [23]	1.25 [23]	2.0 SL	9	1, 2, 23	63	2.1	test fish (16.9 cm to 43.5 cm SL)
				Mean of 3 min. Cv tests	2	9, 23	59	1.9	test fish (mean 40.8 cm SL)
Channel catfish	*Ictalurus punctatus*	330 [23]	1.2 [23]	3.05 SL	28	1, 2, 23	84	2.7	test fish (14.2 cm to 41.5 cm SL)
				3.0 TL at 20 degrees C	25	9, 23	99	3.2	temperature response test test fish (14.0 cm to 15.4 cm TL)
				Mean of 3 min. U_{crit} tests	4	9, 23	57	1.9	test fish (Mean 36.25 cm SL)
Flathead catfish	*Pylodictis olivaris*	457 [23]	1.15 [23] (estimate)	3.05 SL (surrogate: channel catfish)	0	1, 2, 23	121	4	surrogate
				Mean of 3 min. U_{crit} tests	5	9, 23	68	2.2	test fish (Mean 43.5 cm SL)
Brook silverside	Labidesthes sicculus	64 [19]		None- tests of individual fish (surrogate: Inland Silverside)	7	11	~32	1	surrogate: Inland Silverside test fish (4.1 cm - 5.0 cm SL) during day in light
					6	11	~34	1.1	surrogate: Inland Silverside test fish (4.1 cm - 5.0 cm SL) during night in dark
White bass	*Morone chrysops*	313 [23]	1.2 [23] (estimate)	4.6 SL	13	1, 2, 23	120	3.9	test fish (9.8 cm to 21.8 cm SL)
Bluegill	Lepomis macrochirus	178 [23]	1.26 [21]	~3 BL @ 25 degrees C	12	12	42.4	1.4	test fish (13.5 cm - 17.5 cm)
Smallmouth bass	*Micropterus dolomieu*	200 [23]	1.2 [23]	3.41 SL (surrogate: largemouth bass)	0	13, 23	63	2.1	surrogate
				None-tests of Individual Fish	10	24	111.3	3.7	test fish (Mean 31.0 cm TL)
Spotted bass	Micropterus punctulatus	254 [19]	1.2 (estimate)	3.41 SL (surrogate: largemouth bass)	50	13, 23	72	2.4	surrogate
Largemouth bass	*Micropterus salmoides*	254 [23]	1.215 [23]	5.0 TL @ 20 degrees C	15	7, 23	127	4.2	temperature response test test fish (5.2 cm to 6.4 cm)
				3.41 SL	50	13, 23	71	2.3	conditioning response test test fish (10.9 cm to 14.2 cm FL)
				4.5 TL	>100	14, 23	114	3.8	temperature, D.O. response test test fish (Mean 8.2 cm TL)
				3.84 SL	21	15, 23	80	2.6	performance repeatability test test fish small (Mean 9.4 cm FL)
Rainbow darter	Etheostoma caeruleum	33 [19]		None- tests of individual fish	12	6	22.49	0.7	test fish (39 mm to 48 mm TL) low complexity (smooth) substrate
				(surrogate: Orangethroat darter)	7	6	17.25	0.6	test fish (40 mm to 55 mm TL) high complexity (rocky) substrate
Bluebreast darter	Etheostoma camurum	?		None- tests of individual fish	12	6	22.49	0.7	test fish (39 mm to 48 mm TL) low complexity (smooth) substrate
				(surrogate: Orangethroat darter)	7	6	17.25	0.6	test fish (40 mm to 55 mm TL) high complexity (rocky) substrate
Tippecanoe darter	Etheostoma tippecanoe	?		None- tests of individual fish	12	6	22.49	0.7	test fish (39 mm to 48 mm TL) low complexity (smooth) substrate
				(surrogate: Orangethroat darter)	7	6	17.25	0.6	test fish (40 mm to 55 mm TL) high complexity (rocky) substrate
Logperch	Percina caprodes	102 [19]		None Found					
Slenderhead darter	Percina phoxocephala	51 [19]		None Found					
Sauger	*Sander vitreum*	249 [23]	1.2 [23] (estimate)	3.8 SL	15	1, 2, 23	79	2.6	test fish (5.1 cm to 41.5 cm SL)
Walleye	*Sander canadense*	454 [23]	1.2 [23] (estimate)	3.04 SL	6	1, 2, 23	115	3.8	test fish (15.4 cm to 40.8 cm SL)
				13.07 FL^0.51	54	4, 23	83	2.7	test fish (8 cm to 38 cm FL)
Freshwater drum	*Aplodinotus grunniens*	351 [23]	1.3 [23] (estimate)	3.0 SL	11	1, 2, 23	81	2.7	test fish (17.7 cm to 30.2 cm SL)

From Wilcox et al. table with his references

From other reference using surrogate- No Ucrit model

From other reference - No Ucrit model

From reference with Ucrit model

From other reference using surrogate with Ucrit model

Ucrit model from surrogate from Wilcox et al. table

None Found (No Fill)

1-Tunink 1976
2-Schmulbach et al. 1981
3-Adams et al. 1997
4-Jones et al. 1974
5-Adams et al. 2000
6-Scott and Magoulick 2008
7-Hocutt 1973
8-Adams and Parsons 1998
9-Parsons and Bartlett 1997
10-Webb 1986
11-Young et al. 2004
12-Kelsch 1996
13-Farlinger and Beamish 1977
14-Dalberg et al. 1968
15-Kolok 1992
16-Kieffer and Cooke 2009 From:Parsons and Smiley 2003
17-Parsons and Sylvester 1992
18-Nelson 1989
19-Pflieger 1997
20-Scott and Crossman 1973
21-Beckman 1948
22-Carlander and Smith 1945
23-Wilcox et al. 2004
24-Cooke and Bunt 2001

Table 3. Summary of Upper Ohio River fish passage target species relative abundance and swimming ability.

Common Name	Scientific Name	Relative Abundance	Swimming Behavior	Swimming Performance	Swimming Speed (Ucrit)
Shovelnose sturgeon	*Scaphirhyncus platorynchus*	Extirpated	Benthic	Medium	82
Paddlefish	*Polyodon spathula*	Reintroduced	Pelagic	Strong	86
Longnose gar	*Lepisosteus osseus*	Common	Pelagic	Weak	~~129~~
American eel	*Anguilla rostrata*	Rare	Littoral	Weak	
Skipjack herring	*Alosa chrysochloris*	Rare	Pelagic	Strong	59
Mooneye	*Hiodon alosoides*	Rare	Pelagic	Medium	59
Muskellunge	*Esox masquinongy*	Rare	Littoral	Weak	
River Chub	*Nocomis micropogon*	Rare	Benthic	Weak	
Striped shiner	*Luxilus chrysocephalus*	Rare	Benthic	Weak	33
Spotfin shiner	*Cyprinella spiloptera*	Occasional	Littoral	Weak	28
River carpsucker	*Carpiodes carpio*	Common	Benthic	Medium	
Highfin carpsucker	*Carpiodes velifer*	Occasional	Benthic	Medium	45
blue sucker	*Cycleptus elongatus*	Rare	Benthic	Strong	78
Bigmouth buffalo	*Ictiobus cyprinellus*	Rare	Benthic	Medium	63
Channel catfish	*Ictalurus punctatus*	Abundant	Benthic	Medium	84
Flathead catfish	*Pylodictis olivaria*	Common	Benthic	Medium	121
Brook silverside	*Labidesthes sicculus*	Rare	Littoral	Weak	32
White bass	*Morone chrysops*	Abundant	Pelagic	Strong	120
Bluegill	*Lepomis macrochirus*	Abundant	Littoral	Weak	42
Smallmouth bass	*Micropterus salmoides*	Abundant	Littoral	Medium	63
Spotted bass	*Micropterus punctulatus*	Common	Littoral	Medium	72
Largemouth bass	*Micropterus dolomieu*	Common	Littoral	Medium	127
Rainbow darter	*Etheostoma caeruleum*	Occasional	Benthic	Weak	22
Bluebreast darter	*Etheostoma camurum*	Rare	Benthic	Weak	22
Tippecanoe darter	*Etheostoma tippecanoe*	Rare	Benthic	Weak	22
Logperch	*Percina caprodes*	Abundant	Benthic	Weak	
Slenderhead Darter	*Percina shumardi*	Rare	Benthic	Weak	
Sauger	*Sander vitreum*	Abundant	Littoral	Strong	79
Walleye	*Sander canadense*	Common	Littoral	Strong	115
Freshwater drum	*Aplodinotus grunniens*	Abundant	Benthic	Medium	81

Table 4. Timing and temperature information used to estimate timing of upriver pre-spawning and spawning fish movements in the Upper Ohio River.

Common Name	Scientific Name	Spawning Time	Water Temperature During Spawning
Shovelnose sturgeon	*Scaphirhyncus platorynchus*	May, early June[2]	15.5 - 21.5 °C [2, 4, 5, 15]
Paddlefish	*Polyodon spathula*	April, May [2, 6]	10.0 - 17.0 °C [2]
Longnose gar	*Lepisosteus osseus*	May, June[2, 3]	19.5 - 21.0 °C [2]
American eel	*Anguilla rostrata*	Migrate to sea in fall and winter[7] (Catadromous)	
Skipjack herring	*Alosa chrysochloris*	April - July [2, 8]	9 - 16 °C [15]
Mooneye	*Hiodon alosoides*	April, May[2, 3]	8 - 15 °C [15]
Muskellunge	*Esox masquinongy*	Mid-April - Mid-June [1]	9.5 - 15.5 °C [1]
River chub	*Nocomis micropogon*	May - June[1]	15 -26.7 °C [1]
Striped shiner	*Luxilus chrysocephalus*	Late April - Mid-June [14]	>15.6 °C [7]
Spotfin shiner	*Cyprinella spiloptera*	Throughout summer [1, 7]	
River carpsucker	*Carpiodes carpio*	Late Spring - Early Summer [7]	19 - 24 °C [7]
Highfin carpsucker	*Carpiodes velifer*	Mid-May - July [2]	19.0 - 28.0 °C [15]
Blue sucker	*Cycleptus elongatus*	May - June [2, 11]	10 - 15.6 °C [2, 8]
Bigmouth buffalo	*Ictiobus cyprinellus*	April - May [2]	15.6 - 18.3 °C [2, 3]
Channel catfish	*Ictalurus punctatus*	April - October [2]	21 - 30 °C [1]
Flathead catfish	*Pylodictis olivaria*	Peaks June - July [1]	20 - 30 °C [15]
Brook silverside	*Labidesthes sicculus*	May - August 1	17 - 23 °C [1]
White bass	*Morone chrysops*	April - June [2]	12.5 - 26.1 °C [2, 12]
Bluegill	*Lepomis macrochirus*	May - August [1]	≤24.5 [10]
Smallmouth bass	*Micropterus salmoides*	May, June [2, 3]	12.8 - 23.9 °C [2]
Spotted bass	*Micropterus punctulatus*	April - May [1]	15 - 19 °C [1]
Largemouth bass	*Micropterus dolomieu*	April - July [2, 3]	16.7 - 18.3 °C [2]
Rainbow darter	*Etheostoma caeruleum*	Late February - Mid-June[1]	≥15 °C [7]
Bluebreast darter	*Etheostoma camurum*	Mid-May - Early August[1]	21 - 24 °C [1]
Tippecanoe darter	*Etheostoma tippecanoe*	July - Mid-August [1]	23 - 27 °C [15]
Logperch	*Percina caprodes*	Mid-March - Mid-July [1]	10 - low 20 °s C [1]
Slenderhead darter	*Percina phoxocephala*	April - June [15]	18 - 22 °C [15]
Sauger	*Sander vitreum*	April - May [2, 13]	6.1 - 11.7 °C [2]
Walleye	*Sander canadense*	March - April [2, 3]	3.3 - 6.7 °C (prespawn) 5 - 10 °C (Spawn)[2]
Freshwater drum	*Aplodinotus grunniens*	May, June [2, 3]	18.9 - 22.2 °C [2]

References:

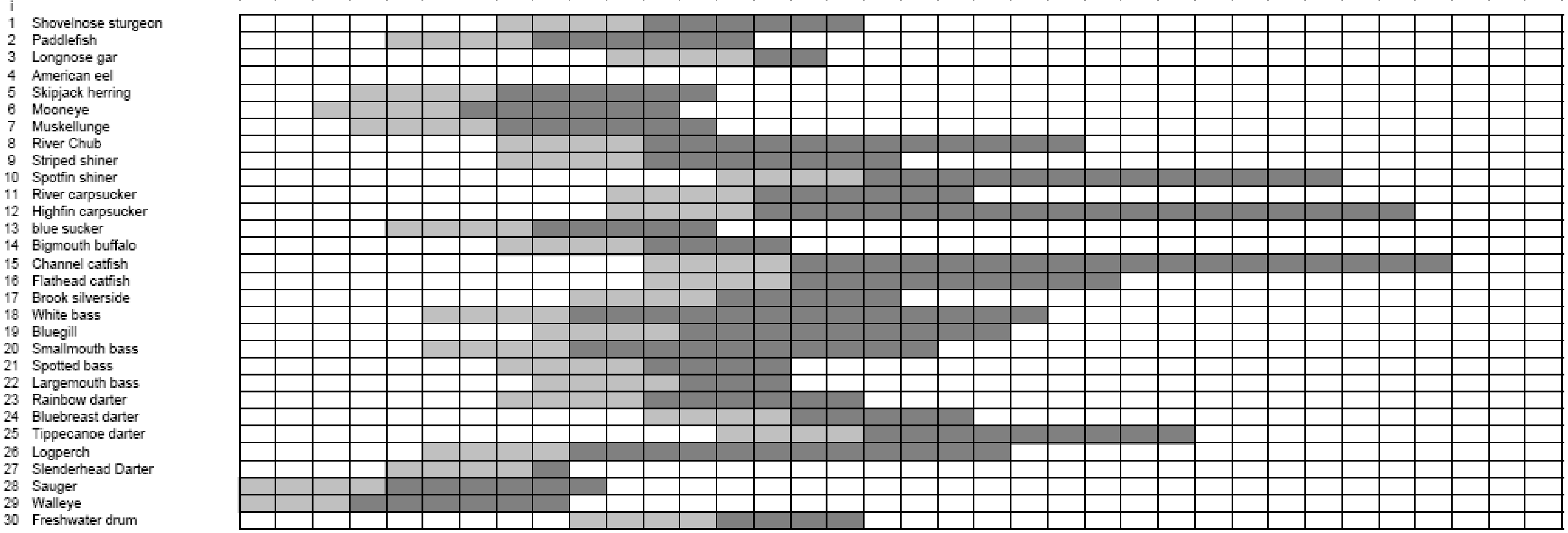
1-Jenkins and Burkhead 1994	5-Hurley et al. 1983	9-Franklin and Smith 1963	13-Priegel 1969
2-Wilcox et al. 2004	6-Purkett 1961	10-Scott and Crossman 1973	14-Pflieger1997
3-Becker 1983	7-Etnier and Starnes 1993	11-Coker 1930	15-Wallus et al. 1990
4-Christenson 1975	8-Harlan and Speaker 1956	12-Horall 1962	

Table 5. Seasonal timing of upriver pre-spawning and spawning fish movements in the Upper Ohio River (adapted from Knights et al. 2003; Wilcox et al. 2004).

Pre-spawning movement period
Spawning period

Month of year:			March				April					May				June				July					August				September				October			
Week of year:	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42
Average water temperature (deg C)[1]																																				
Emsworth	3	4	4	5	6	7	8	9	10	12	14	15	16	18	19	20	22	23	24	24	25	26	26	27	27	27	26	26	26	25	24	23	21	19	18	16
Dashields	3	4	4	5	6	7	8	9	10	12	14	15	16	18	19	20	22	23	24	24	25	26	26	27	27	27	26	26	26	25	24	23	21	19	18	16
Montgomery	3	4	5	5	6	7	8	9	10	12	14	15	16	17	19	20	22	23	24	24	25	26	27	27	27	27	26	26	26	25	24	23	22	20	18	17

i



[1]Knights et.al 2003

Table 6. Example of the Habitat Units Calculation for a Hypothetical UMRS Fish Passage Measure (Measure N) Using Fish Passage Connectivity Index (€).

Common Name	**Habitat Preference**	**Available Habitat in Upstream Pool**					**Total Available Preferred Habitat in Upstream**	**Measure N € = Fish Passage Connectivity**	**Measure N Habitat Units (€ X acres)**
		A	**B**	**C**	**D**	**E**			
		Contiguous Floodplain Lake - Abandoned Channel	Main Channel-Channel	Main Channel – Nav.	Secondary Channel	Tertiary Channel			
		(acres)	(acres)	(acres)	(acres)	(acres)	(acres)		
Fish Species 1	B	x	10344	x	x	x	10344	0.18	1862
Fish Species 2	A, B, D, E	415	10344	x	3121	10	13890	0.70	9723
Fish Species 3	A, B, C, D, E	415	10344	4856	3121	10	18746	0.56	10498
								Avg.	7361

Migratory fish species and preferred habitats of migratory fish species are identified through a literature review and interagency consultation.

Aquatic habitats are based upon previously published reports and/or GIS land cover classification.

Habitat Units for each species are averaged for each measure and reported in acres.

Appendix C

Interagency Working Group Meeting Notes

Meeting Notes
Upper Ohio Interagency Working Group
Fish Passage Meeting
July 22-23, 2008

Day 1

1. Welcome and Introductions
   Conrad Weiser welcomed the group, and introductions were made. Meeting attendees were:

Kevin Logan	Tim Higgs	Nate Caswell	Eric J. Chapman
Conrad Weiser	Tom Swor	Rob Simmonds	Sara Walfoort
Tom Maier	Dan Wilcox	Ben Rizzo	Mike Koryak
Bob Burstynowicz	Frank Borsuk	Sue Thompson	Jim McCarville
Jeff Benedict	Patricia Morrison	Jeff Thomas	
Dave Rieger	Melissia Carter	Charles Bier	

2. Overview of Emsworth, Dashields, and Montgomery Dams - **Burstynowicz**
   Burstynowicz gave a brief summary of the characteristics of each dam including the history structural issues associated with each (PowerPoint presentation is included). FERC permit applications exist for each dam including back channel dam at Emsworth.
   a. Permit is a 3 year process and was just started a few months ago; construction is an additional 2 years or so.
   b. Designs are still in the conceptual phase, only very generic information is available at this point
   c. FERC has an extensive review process which will help determine how their project would relate to a fish passage project
   d. Brookfield Power is the applicant at all three projects (two permits at Emsworth for the main and back channel dams
   e. Montgomery Dam is highest priority of the three
   f. FERC will have some mitigation responsibility and should be coordinated with closely so that we can do our projects in a way that they are as complementary as possible
   g. Permittee is required to do pre-project studies that also may be complementary to our efforts.
   h. www.ferc.gov – great site to get all FERC-related info;

3. Defining the problem – Migratory Fishes in the Ohio River, Existing opportunities for upstream passage at EDM Dams - **Caswell**
   Caswell summarized
   Knights, B. C., J. H. Wlosinski, J. A. Kalas, and S. W. Bailey. 2003. Upstream fish passage opportunities at Ohio River mainstem dams. U.S. Geological Survey, Upper Midwest Environmental Sciences Center, La Crosse, Wisconsin, November 2003. 95 pp. Appendixes A-B. (PowerPoint presentation is included)
   Report focused on existing opportunities for fish passage based on frequency of open river conditions at Ohio River dams. Open river occurs infrequently at Pittsburgh District dams, providing little opportunity for open river passage.
   Q – Could open river frequency be increased by leaving one or two gates open more often?

A - Historical scour issues typically prevent USACE from fully opening a single gate or two to increase ‘open river’ opportunities. Partially open gates cause a different hydrological condition (i.e., type of flow) that is less conducive to fish passage in addition to an increased velocity by constricting flow and raising head.
Q – Is downstream passage an issue as well?
A – Downstream movement is not as much of an issue; might be some behavioral avoidance due to lights, structure, etc, but the flows are navigable based on telemetry and mark-recapture studies.

4. Overview of fish passage improvement alternatives - **Caswell**
Caswell gave a brief overview of possible structural and non-structural fish passage alternatives as well as conceptual designs put forth for the Lock and Dam 22 Fish Passage Project.
Comment - Assisted lockage might work well based on ORSANCO observations based on historic lock sampling. When the attracting flows were longer and higher than during a standard sample they captured much greater than average numbers of fish with at least some species that are not typically collected. There is currently very frequent lock operation and so there might be frequent passage opportunities.
Comment - Keep in mind that if hydropower goes through, some attraction flow would be on opposite side of river from locks.
Q - How can you provide more flow through the locks? A – Valve operations or floodway bulkheads (if available) in a lock chamber could provide flow.

5. Large river fish passage – An Upper Mississippi River perspective - **Wilcox**
Improving Fish Passage Through Navigation Dams on the Upper Mississippi River System
Wilcox gave a summary of information pertaining to fish passage improvements on the Upper Mississippi River (UMR) (PowerPoint presentation included).
Q - What about dams that are outside the mainstem and floodplain? A – They are not part of the authority for this study, but there are varying levels of interest in the UMR states.
Q - Did you consider fish lockage at the UMR dams? A - Could get some fish through the locks, but there are many fish to get through. We estimated the cost to operate the lock specifically for fish passage, but there was not likely to be good enough attracting flow due to most flow passing through the dam gates. We decided to keep the lockage alternative as a supplemental technique rather than a primary.
Q - What about endangered species…how did they factor in? A - We looked first at passing all species and then primarily at passing migratory species. We didn’t distinguish listed species specifically.

6. Planning for fish passage improvements at Lock and Dam 22 and Melvin Price Locks and Dam Mississippi River - **Wilcox**
Wilcox gave a summary of planning efforts specific to the UMR Fish Passage Projects (PowerPoint presentation included).
Q - What about debris in the proposed fishway? A – We have a tentative plan for a fixed debris boom.

7. Fish Passage Effectiveness Index - **Wilcox**
Wilcox gave a summary of the format and status of the Fish Passage Effectiveness Index (PowerPoint presentation included).

Q - Are the models certified? A - Not yet, but very close.
Q - Are they applicable to the Upper Ohio? A - Yes, they were specifically made generic enough to use in places other than the UMR.
Q - Does last formula put a dollar value on ecosystem benefits to each project? A - The formula presented will show the relative increase in value but not dollars. Hopefully that will come as the environmental economics field continues to develop.
Q – Invasive species? A - Bighead carp have reproducing populations above LD19; both silver and bighead individuals exist above LD19. There is a concerted effort to try and keep Asian carps from moving upstream. Currently there is authorization for a USACE feasibility study to look at potential carp barriers on the upper part of the UMR. Current project locations (Mel Price and LD22) have Asian carps both above and below. The hope is that the fish passage provided will improve native fish populations and allow them to better compete with invasive species.
Q – Is there potential for removing Asian carp at fish passageway? A - Yes, devices are in use in Australia to remove common carp. Is it effective for common carp, but is labor intensive to deal with all the carp that are captured.

8. Discussion - **Caswell facilitate**
   <u>Setting goals and objectives</u>
   a. Q - What about other fish passage issues downstream? A – The hope is that the ORMSS is funded and projects are completed downstream. EDM are apparently among the biggest fish passage problems, and the Feasibility study is now underway, so we appear to be starting in one of the most critical areas. These projects will be used as example/test projects for additional potential projects downstream.
      Comment – We will need a draft EDM feasibility report by Sept 2009, so we don't have much time to do additional studies. We will need to use what information we have available and will have to make some assumptions.
      Comment - We will need more info on potential for fish lockage as key to our discussions and alternative evaluations.
      Q/Comment - Should we be including other dams on the non-navigable tributaries at this stage in the study where there is no chance for fish passage (e.g. Beaver River)?
      Comment - Propeller induced mortality in locks needs to be considered. We will need to do something beyond routine lockage to pass fish. Plus, will they find the lock with all the flow through dam gates?
      Q/Comment - Need to know where the fish are congregating now – can we do hydroacoustics over the next year? A – Possibly.
      Decision: What is our study area? Can we consider dams other than EDM? A - Once ROD is signed for ORMSS, we will have many options for fish passage. If we get outside of EDM, then we would need to find a different authority. For now, let's stick with EDM because those are the projects that are included in this lock expansion study.
      Q - Are we doing migratory species only or is this 'all species' or is this 'big river' species including mussels?
   b. **Project goal: Improve historic connectivity for populations of riverine fishes and mussels in the Upper Ohio River Basin.** [Restoring function, structure, and/or process = 'connectivity' in our case for native species.]

        i. Example - Maybe provide for 70% overlap among pools, bring back 20 species of the missing mussels, etc.
            1. How would you monitor that? What does it look like now?
        ii. Q - Invasive species issues? A - ORMSS identified that existing dams are not effective barriers to exotic species (particularly Asian carps) and thus are not something that will stop us from pursuing fish passage.

c. **Project objectives**
    i. Restore fish passage for the full spectrum of native species during all seasons
        -majority of the time (%?)
    ii. Achieve greater spatial distribution and abundance of native fish and mussels in the Upper Ohio River pools
    iii. Conduct pre-project and post-project monitoring specific to each site to evaluate current conditions and project success
    iv. Document movement periods of target species based on water temperatures
    v. Document lessons learned and apply adaptive management techniques and principles to subsequent projects
    vi. Provide rapids and riffles for spawning and macroinvertebrate habitat
    vii. Provide for low-maintenance fish passage

<u>Analyses or other information needed</u>

a. Detailed information on fish lockage – pre-project survey to see what (species, numbers) can be attracted into the lock efficiently compared mix of species in the tailwater.
b. Determine if assisted lockage is feasible with the level of commercial and recreational traffic present at the locks.
c. Hydroacoustic assessment of fish aggregations in each tailwater; may need some species identification as well.
d. Classify and quantify fish habitat available in the pools and tributaries to the first barrier for use in Effectiveness Index.
e. Identify records of fish and mussel occurrence in each pool to identify what should be there and look at opportunities for reintroduction via fish passage.

<u>Identifying target species</u>

a. The group started with the list of 44 species taken from the Knights et al (2003) report, and attempted to develop the list of target species for this project. Discussion points and questions covered:
    i. All species?
    ii. Migratory species only?
    iii. Known mussel host species? - Ohio State University database
    iv. Pennsylvania TEC Listed species? - PFBC
    v. Objectives state "full spectrum of species"
    vi. Full spectrum is fine, but will we be able to apply the Effectiveness Index to all 120 or so species given that we will likely only have limited information available for a number of them?
b. Group then discussed the option of using a subset of species that would serve to represent the full spectrum while accounting for species of special interest
c. **Decision:** The list of target species would include:
    i. **Pennsylvania TEC species**

ii. **Known mussel host species**
iii. **Additional species adequate to 'represent' functional groups across the full spectrum of Upper Ohio River Species**

d. **Task:** Nate Caswell will attempt to develop a list of target species. Others that volunteered, were volunteered, or will be asked to assist with this task include Bob Ventorini (3 Rivers-PFBC), Rick Spear, Eric Chapman, and Jeff Thomas

Identifying initial constraints at EDM Dams

a. Group discussed project constraints by starting with a list of constraints identified for the UMR Fish Passage Projects
b. Operations & Maintenance
   i. Continuing to operate the 9-ft navigation channel.
   ii. Not interfering with dam operations/water control
   iii. Maintaining access to the dam for equipment
   iv. Additional O&M costs
   v. Hydropower projects are probable
   vi. Maintain facility security
   vii. Debris and ice passage/blockage
c. Engineering
   i. Maintaining structural and geotechnical integrity (undercutting)
   ii. Fish passage will have to be designed with lock rehabilitation as a priority
   iii. Hydraulic current changes associated with various design options, including hydropower, that would affect barge approach or bank erosion
   iv. May require future hydropower designs to incorporate remote intake locations (i.e., away from upstream openings of fish passage facilities).
d. Physical
   i. Land use/acquisition will be from willing owners – very limited options
   ii. Avoid increases in flood elevations
e. Biological
   i. Target species swimming abilities
   ii. Target species ability to find the structure (i.e. where are the fish concentrating naturally?)
   iii. Target species ability or inclination to use the structure
   iv. Predation due to concentration of fish
   v. No target fish entrainment by hydropower after they complete upstream passage
f. Other
   i. Project is dependent on adequate funding
   ii. Safety
   iii. Angler access/PR

Day 2

9. Discussion continued (Caswell facilitate)
Would FERC potentially be a cooperating agency on the feasibility study EIS? Unlikely due to limited staff resources and large project workload (Wilcox). We may be able to take advantage of environmental studies required of FERC licensees to supplement our feasibility study information needs, particularly related to our fish passage work. The UMR has a lot of fish passage information already developed that could be made available if asked.

Greg Conover recently completed a 4-year Asian carp management plan. Our design plans should acknowledge, and not contradict, those goals. Include in our study foresight towards using designs that incorporate ongoing fish control research and technology.

Classification and quantification of aquatic habitat in the Ohio, and the Allegheny and Monongahela rivers branches of the Emsworth Pool, would be useful in evaluating benefits of fish passage

Need to examine fish and mussel species records in the Allegheny and Monongahela rivers as a basis for evaluating opportunities for improvement in species diversity and distribution.

<u>Identify possible fish passage alternatives for consideration at EDM Dams</u>
Group discussed possible fish passage alternatives and site-specific constraints for each dam

<u>Emsworth</u>

1. Assisted lockage – is possible but we would need to determine how many fish we could pass and whether or not we could get enough attraction flow in the lock given the other flows through the dam (little empirical info on effectiveness – currently fixed hydroacoustics project on Mel Price LD to determine how many fish are actually passing through lock)
2. Bypass channel – could go through the island, could go around the end of the dam on the island; could be long and gradual as in typical bypass channel, could be more of a rock ramp that just goes around the dam
    a. Bypass channel would increase discharge capacity as opposed to other options that may restrict
    b. Will have land ownership and contaminant concerns
    c. Would need to provide bridges to access dam, etc.
3. Technical fishway – uses less space and less water
    a. Could work for weaker species if the head between pools in fishway is low enough (~3 inches); would be roughly 1000 feet long
    b. Would need to wrap around to keep attraction flow near competing flows at the dam
    c. Back channel gates – option for location of multiple fishways. (Migratory fish prefer main channel (Wilcox)).
    d. Possible space between lock chambers that might be built into new design – multiple options (hydraulic modeling required; like Mel Price Locks).
    e. May need deflection wall to direct discharge in a direction that will minimize effect on navigation
4. Rock ramp in gate bay – preferable location would be in the main river as opposed to back channel
    a. Would lose discharge capacity because bottom of fishway through gate would be higher than current sill
5. Dam Gate manipulations – possible, but unlikely to provide adequate fish passage
6. Lock/elevators – probably a stretch due to high maintenance
    a. Would be a good way to collect data on what is passing as all fish are contained in a hopper
7. General constraints and design considerations

a. Hazardous waste on Neville Island
b. Gates may have to be reconfigured to accommodate loss of discharge capacity
c. Lock expansion may eliminate fixed crest and part or all of 1st gate
d. This is the most important pool
e. Have to consider the operations plan for water control in the pool
f. There is limited federal land available
g. There may be a public education opportunity
h. Emsworth is a major recreational lock as well as commercial

Dashields

1. Assisted lockage – is possible but we would need to determine how many fish we could pass and whether or not we could get enough attraction flow in the lock given the other flows through the dam (little empirical info on effectiveness – currently fixed hydroacoustics project on Mel Price LD to determine how many fish are actually passing through lock)
    a. This may be a better option for Dashields than the UMR because the thalwag more or less leads through the locks while the fixed crest weir was built on an island. Regardless, more info to evaluate effectiveness is needed
    b. Aux lock would likely be used for fish passage – will need to look at traffic, possibility of leaving the valves open longer, possibly running in the evenings when traffic lighter and many fish more likely to move (Note: Data presented in the ORMSS Capacity Attachment to the Environmental Appendix shows that Ohio River commercial traffic arrivals have very little variation by month, day of week or hour of day but recreational traffic is highly dependent upon month, day of week or hour of day. These relationships hold for all Ohio River locks.)
    c. Will need to look at O&M costs in addition to any modifications that would be needed
2. Bypass channel – could be wrapped around in property east of Little Sewickley Creek but would need to cut through dam at some point due to very limited property to run bypass channel around the dam
    a. Bypass channel would increase discharge capacity as opposed to other options that may restrict; will need to address land ownership
3. Technical fishway – uses less space and less water
    a. Could work for weaker species if the head between pools in fishway is low enough (~ 3 inches); would be roughly 600 feet long
    b. Would need to wrap around to keep attraction flow near competing flows at the dam
    c. Need to consider the configuration of the scour hole below the dam and natural aggregations of fish
    d. Would have to be built on one end of the fixed crest or the other to provide better access for construction and maintenance
4. Notch – likely not feasible due to higher velocities through notch and possible concern over lowering pool
5. Rock ramp – Need to consider the scour hole and aggregations of fish
    a. Would be built on one end of the fixed crest or the other to provide better access for construction and maintenance
    b. Could possibly do the entire face of dam to reduce drowning hazard, but primary passage area would have gradual slope and notch through spillway

    c. Could consider an upstream ramp due to the shallow area above the dam requiring less fill. This would also put the opening at the face of the dam where fish are already going to concentrate
6. Lock/elevators – probably a stretch due to high maintenance
    a. Would be a good way to collect data on what is passing as all fish are contained in a hopper
7. Gate bay with adjustable sill that would allow us to create a 'notch'
    a. Could be accessible when the tailwater elevation is high, but not high enough to reach level of the rest of the dam
    b. Will need to have hydrologist look at this option to see if velocities would work and to see what sort of 'waterfall' you may have
8. General constraints and design considerations
    a. Only about 10 ft of lift
    b. Deep scour hole is present below the dam face
    c. There are land ownership issues to address for any alternative outside of the current ownership
    d. Hydropower is a possibility
    e. This dam will allow us to place the structure where the fish are actually congregating better than at the other dams
    f. May have a space between the locks to work with
    g. A ramp could be upstream or downstream

<u>Montgomery</u>

1. Assisted lockage – need to determine how many fish we could pass and whether or not we could get enough attraction flow
    a. May be a better option for Montgomery than the UMR because there are steep banks on the lock side of the river that fish might already be moving along naturally
    b. Will still have lots of flow through the gates, will just depend on where fish are naturally approaching – need hydroacoustics and assisted lockage assessments.
2. Bypass channel – possible to wrap around on lowland property on south side; potential bypass channel on north side in conjunction with the backwater
    a. Steep banks on south side might have fish traveling along, but would be difficult to locate entrance/attraction flow close to the dam
    b. Possible navigation issues being right by locks
    c. Bypass channel would increase discharge capacity as opposed to other options that may restrict
    d. Would need to acquire land
    e. Would need to provide bridges to access dam, etc.

3. Technical fishway – uses less space and less water
    a. Could work for weaker species if the head between pools in fishway is low enough (~3 inches)
    b. Would be roughly 1000 feet long
    c. Would need to wrap around to keep attraction flow near competing flows at the dam
    d. Possible space between lock chambers might be built into new design – multiple options

    e. May need deflection wall to direct discharge in a direction that will minimize effect on navigation
4. Rock ramp – fixed weir on RDB may be option
    a. This is the same option that hydropower will be looking at
    b. Will need to consider how best to fit ramp to the site (possibly above, below, or combination of the two)
    c. Would lose discharge capacity because bottom of fishway through gate would be higher than current sill
5. Gate manipulations – unlikely to provide fish passage
6. Lock/elevators – probably a stretch due to high maintenance
    a. Would be a good way to collect data on what is passing as all fish are contained in a hopper
7. General constraints and design considerations
    a. Fixed weir on the RDB may be conducive to a rock ramp
    b. No negative effects on the backwater above the dam
    c. There will be land ownership concerns

Meeting Notes
Upper Ohio Interagency Working Group
Fish Passage Connectivity Index Meeting
September 16, 2009
9am – 4pm
Gander Mountain
Washington, Pennsylvania

I. Welcome and Introductions - **Caswell**

Participants: Nate Caswell, Rob Simmonds, Tom Maier, Conrad Weiser, Patty Morrison, Eric Chapman, Bruce Kish, Bill Kimmel, Dave Argent

II. Meeting goals/desired outcomes - **Caswell**

- Primary goal is to get the input of local fishery experts and engineers to populate the FPCI spreadsheets. As many of you have heard already, much of the input data are somewhat subjective, so this is the best way for us to minimize that subjectivity
- What we don't want to do is get too caught up in lengthy discussions of every detail. We will be trying to cover a lot and there's a good chance that we won't get through it all.
- We just need to reach a consensus on most things, and hopefully if we don't get done, I will have enough to finish it myself
- That said, the input data I am going to show you is my stab at it – **everything** I put down is up for discussion or changes as you deem necessary

II. Hydroacoustic survey results – **Weiser/Maier**

Tom Maier and Conrad Weiser gave an overview of the results of the mobile hydroacoustic fish surveys that were conducted in October 2008, May 2009, and June 2009. The draft report for these surveys was just recently received and will be made available after it goes through the review process.

Questions/comments

Q - Would something like a camera or DIDSON work better to allow us to target ideal migration conditions and abundances?

A - Potentially. We may need to do additional surveys with this or other gears to get the information we need

Q - Can we do surveys in the evening when we might have more fish congregating at the dam trying to pass?

A - Potentially. If more surveys are needed and done, could probably do night surveys

C - Existing gill net data backs up fish locations in Emsworth Back Channel. Also, most telemetered, stocked juvenile paddlefish were found to congregate in the back channel in the same area where hydroacoustics indicated fish.

C - Would have been great to have real time photos of what the river was doing when the data was being taken. Each collection of data is just a snapshot that is based on the flow and what gates were open on that particular day.

C - Really need to get all lines of evidence and data together and in a spatial context so that we can consider all lines of evidence.

Q - What other examples of how to do fish passage on large rivers out there. Should we also be doing a single project on the OHR to see what works before we build another? That is, should we build "adaptive management" into these projects?

A - Yes. If fish passage is pursued at all three dams, that will likely be the way these take place anyway. Depending on schedules for construction, we may be able to build one and learn from it before building another.

III. Project status – working alternatives – **Caswell/Rizzo**

A. Emsworth
B. Dashields
C. Montgomery

- Caswell briefly revisited the alternatives being considered for each dam.

Questions/comments

Q - Do we know if fish want to go into habitats above the dams? What would make a darter want to move from one place to another?

A - The idea is that we give the fish the opportunity to find where they want to be….provide the opportunity to move when and if they want to

Q - Is this designed for resident fish or for migratory fish? Seems like it is more for migratory fish than to move darters.

A - We could weight our index to 'migratory' fish if so desired.

C - There is evidence that 'resident' fish such as catfish actually move quite a bit. There is data for the OHR that several of these species are moving a lot.

Q - What is the possibility of using recycled materials from other locations where structures are being torn out and barge the materials to these sites?

A - USACE is looking at beneficial use of all de-constructed materials.

Q - Don't we have data that shows that assisted lockage is a good option?

A - Yes, we need to also recognize though that we have human factor coming into play in terms of someone actually operating the lock for assisted lockage as well as whether or not you would have time for locks to be operated in a way to attract fish (i.e., are there even opportunities for the attractant flow to run long enough?).

Q - What is method for making final determination?

A - It will be based on biological feasibility, cost, and structural feasibility.

Q - Can we evaluate how effective our fishway is at passing fish?

A - Yes, there are feasible ways to count fish but the cost and feasibility depends on the type of fishway.

IV. FPCI Purpose and overview – **Caswell**

- Caswell gave an overview of the input data so everyone understands it and the mathematics.
- Index isn't really up for debate at this point. Once it is certified for the UMR, if there are changes that are necessary for the UOHR, we can address those then.

V. Target species – **Group discussion**

A. List review – We intended to simply go over the list, but the group in attendance was interested in discussing whether or not to further reduce the list. A somewhat lengthy discussion followed, which ultimately culminated in whittling the list down to 30 species. Below are some of the comments, questions, and concerns raised during this discussion.

Questions/comments

Q - If all fish occur in all pools, then why do we need fish passage?

C - If genetics is a concern, then we should be doing genetic testing, but there are probably enough fish getting through to provide sufficient mixing.

C - Silver chub is no longer a listed species.

Q - Shouldn't we really be selling this from a migratory fish perspective?
A - But also need to account for mussel hosts that would need to move.
C - From a biological standpoint, the more fish we pass the better, but then we have a huge list and people will ask why pass all these fish that are already there.
C - From a mussel perspective, they are NOT present in these pools even though their hosts are present. There are only about 10 species rather than the 30 that are expected.

Q - Do we need to need to critically review this list and reduce it to key in on the most important species?
A - Yes we need to do this.

We did a quick rundown of species to highlight those that we felt were most critical to further evaluate given our limited time and given that we don't want to overwhelm people when trying to present justification for fish passage. Group thought that too many species diluted our focus and justification for fish passage, rather than the other way around. Hard to justify passing fish that are common in all pools. Really needed to focus on those fish that are extirpated, restricted in abundance due to dams, or are key mussel hosts that are needed for mussel recolonization.

B. Abundance
Caswell gave the group an overview on how he estimated the abundance of species on the list (Used ORSANCO 2009 Fish DB). The group thought that the methods were acceptable given the proposed use of the data.
- The group ran through each species briefly

Questions/Comments
C - ORSANCO sampling effort is different among pools.
Q - Where do bighead and silver carp fit into this?
A - We won't include them in our table because we are looking at the 'benefit' to species and there is no benefit from passing Asian carp. We do need to be sure that passage of invasive species is fully evaluated in these projects as a whole to determine what is the overall best course of action. Passage, or no passage? More benefit to natives than the detriment from passage of invasives?
Action – Group decided to pool abundances across pools rather than break them out.
-

C. Swimming performance
- Explained that swimming performance classification is simply my shot based on species' swimming ability, body type, and classification from UMR

D. Swimming behavior
- Again, my stab at it

E. Preferred habitat
- Can probably eliminate some habitat types – only saw one or two islands and one backwater
Group eliminated several habitat types

VI. FPCI Input data – **Group discussion that led to population of enough of the alternative spreadsheets that Caswell was able to fill in the rest.**

Action – Eliminated nature like fishway from Montgomery Dam

Fish Passage Connectivity Index (FPCI)

Ranking of Alternatives

Emsworth L/Ds

OHIO RIVER FOCAL SPECIES

									Available Habitat in Emsworth Pool [1]				
									A	B	C	D	
i	Common Name	Scientific Name	Dashields Pool Relative Abundance	Emsworth Pool Relative Abundance	Swimming Behavior	Swimming Performance	Swimming Speed (Ucrit)	Habitat Preference	Main Channel (acres)	Secondary Channel (acres)	Contiguous Embayment (acres)	Tributary Mouth (up to head of slack water) (acres)	Total Available Preferred Habitat in Emsworth Pool (acres)
1	Shovelnose sturgeon	*Scaphirhyncus platorynchus*	Extirpated	Extirpated	Benthic	Medium	82	A,B,D	2659	344	0	21	3024
2	Paddlefish	*Polyodon spathula*	Listed	Listed	Pelagic	Strong	86	A,B,D	2659	344	0	21	3024
3	Longnose gar	*Lepisosteus osseus*	Occasional	Common	Pelagic	Weak	21	A,B,C,D	2659	344	0	21	3024
4	American eel	*Anguilla rostrata*	Occasional	Rare	Littoral	Weak		A,B,D	2659	344	0	21	3024
5	Skipjack herring	*Alosa chrysochloris*	Listed	Listed	Pelagic	Strong	59	A,B	2659	344	0	0	3003
6	Mooneye	*Hiodon alosoides*	Listed	Listed	Pelagic	Medium	59	A,B,C,D	2659	344	0	21	3024
7	Muskellunge	*Esox masquinongy*	Rare	Rare	Littoral	Weak		A,B,C,D	2659	344	0	21	3024
8	River Chub	*Nocomis micropogon*	Rare	Rare	Benthic	Weak		A,B,D	2659	344	0	21	3024
9	Striped shiner	*Luxilus chrysocephalus*	Rare	Rare	Benthic	Weak	33	A,B,D	2659	344	0	21	3024
10	Spotfin shiner	*Cyprinella spiloptera*	Common	Occasional	Littoral	Weak	28	A,B,C,D	2659	344	0	21	3024
11	River carpsucker	*Carpiodes carpio*	Occasional	Common	Benthic	Weak		A,B,C,D	2659	344	0	21	3024
12	Highfin carpsucker	*Carpiodes velifer*	Rare	Rare	Benthic	Weak	45	A,B,D	2659	344	0	21	3024
13	blue sucker	*Cycleptus elongatus*	Rare	Rare	Benthic	Strong	78	A,B	2659	344	0	0	3003
14	Bigmouth buffalo	*Ictiobus cyprinellus*	Listed	Listed	Benthic	Medium	63	A,B,D	2659	344	0	21	3024
15	Channel catfish	*Ictalurus punctatus*	Abundant	Abundant	Benthic	Medium	84	A,B,C,D	2659	344	0	21	3024
16	Flathead catfish	*Pylodictis olivaria*	Common	Common	Benthic	Medium	121	A,B,C,D	2659	344	0	21	3024
17	Brook silverside	*Labidesthes sicculus*	Listed	Listed	Littoral	Weak	32	A,B,C,D	2659	344	0	21	3024
18	White bass	*Morone chrysops*	Abundant	Abundant	Pelagic	Strong	120	A,B,C,D	2659	344	0	21	3024
19	Bluegill	*Lepomis macrochirus*	Abundant	Abundant	Littoral	Weak	42	A,B,C,D	2659	344	0	21	3024
20	Smallmouth bass	*Micropterus salmoides*	Abundant	Abundant	Littoral	Medium	63	A,B,C,D	2659	344	0	21	3024
21	Spotted bass	*Micropterus punctulatus*	Common	Abundant	Littoral	Medium	72	A,B,C,D	2659	344	0	21	3024
22	Largemouth bass	*Micropterus dolomieu*	Occasional	Occasional	Littoral	Medium	127	A,B,C,D	2659	344	0	21	3024
23	Rainbow darter	*Etheostoma caeruleum*	Occasional	Rare	Benthic	Weak	22	A,B,D	2659	344	0	21	3024
24	Bluebreast darter	*Etheostoma camurum*	Listed	Listed	Benthic	Weak	22	A,B,D	2659	344	0	21	3024
25	Tippecanoe darter	*Etheostoma tippecanoe*	Listed	Listed	Benthic	Weak	22	A,B,D	2659	344	0	21	3024
26	Logperch	*Percina caprodes*	Abundant	Abundant	Benthic	Weak		A,B,D	2659	344	0	21	3024
27	Slenderhead Darter	*Percina shumardi*	Rare	Rare	Benthic	Weak		A,B,D	2659	344	0	21	3024
28	Sauger	*Sander vitreum*	Abundant	Abundant	Littoral	Strong	79	A,B,D	2659	344	0	21	3024
29	Walleye	*Sander canadense*	Common	Abundant	Littoral	Strong	115	A,B,D	2659	344	0	21	3024
30	Freshwater drum	*Aplodinotus grunniens*	Abundant	Abundant	Benthic	Medium	81	A,B,C,D	2659	344	0	21	3024

[1] Aquatic habitat acreages derived from "normal"/bankful GIS data (higher level "floodstage" data questionable).

EMSWORTH LOCKS AND DAMS

i	OHR Focal Species		A: Fish Lockage (aux. lock)							
i	Common Name		Є = Fish Passage Connectivity Є = Σ (Ei x Ui x Di /25)/n	Fs Size of Fishway	Fl Fishway Location	Ei Chance of Encounter	Minimum Current Velocity at Hydraulic Steps (ft/sec)	Ui Potential for Species to Use Fishway Type	Di Duration of year passable	Ei x Ui x Di
			0.02							
1	Shovelnose sturgeon			5	2	3.5	1	2	0.12	0.8
2	Paddlefish			5	1	3	1	3	0.12	1.1
3	Longnose gar			5	1	3	1	3	0.12	1.1
4	American eel			5	2	3.5	1	3	0.12	1.3
5	Skipjack herring			5	1	3	1	3	0.12	1.1
6	Mooneye			5	1	3	1	3	0.12	1.1
7	Muskellunge			5	2	3.5	1	3	0.12	1.3
8	River Chub			5	2	3.5	1	2	0.12	0.8
9	Striped shiner			5	2	3.5	1	2	0.12	0.8
10	Spotfin shiner			5	2	3.5	1	3	0.12	1.3
11	River carpsucker			5	2	3.5	1	2	0.12	0.8
12	Highfin carpsucker			5	2	3.5	1	2	0.12	0.8
13	blue sucker			5	2	3.5	1	2	0.12	0.8
14	Bigmouth buffalo			5	2	3.5	1	2	0.12	0.8
15	Channel catfish			5	2	3.5	1	2	0.12	0.8
16	Flathead catfish			5	2	3.5	1	2	0.12	0.8
17	Brook silverside			5	2	3.5	1	3	0.12	1.3
18	White bass			5	1	3	1	3	0.12	1.1
19	Bluegill			5	2	3.5	1	3	0.12	1.3
20	Smallmouth bass			5	2	3.5	1	3	0.12	1.3
21	Spotted bass			5	2	3.5	1	3	0.12	1.3
22	Largemouth bass			5	2	3.5	1	3	0.12	1.3
23	Rainbow darter			5	2	3.5	1	2	0.12	0.8
24	Bluebreast darter			5	2	3.5	1	2	0.12	0.8
25	Tippecanoe darter			5	2	3.5	1	2	0.12	0.8
26	Logperch			5	2	3.5	1	2	0.12	0.8
27	Slenderhead Darter			5	2	3.5	1	2	0.12	0.8
28	Sauger			5	2	3.5	1	3	0.12	1.3
29	Walleye			5	2	3.5	1	3	0.12	1.3
30	Freshwater drum			5	2	3.5	1	2	0.12	0.8
									Sum Ei x Ui x Di:	30.6

EMSWORTH LOCKS AND DAMS

i	OHR Focal Species Common Name	B: Vertical slot fishway adjacent to island on main dam Є = Fish Passage Connectivity Є = Σ (Ei x Ui x Di /25)/n	Fs Size of Fishway	Fl Fishway Location	Ei Chance of Encounter	Minimum Current Velocity at Hydraulic Steps (ft/sec)	Ui Potential for Species to Use Fishway Type	Di Duration of year passable	Ei x Ui x Di
		0.13							
1	Shovelnose sturgeon		1	3	2	6.5	3	1.0	6.0
2	Paddlefish		1	2	1.5	6.5	1	1.0	1.5
3	Longnose gar		1	2	1.5	6.5	1	1.0	1.5
4	American eel		1	5	3	6.5	2	1.0	6.0
5	Skipjack herring		1	2	1.5	6.5	5	1.0	7.5
6	Mooneye		1	2	1.5	6.5	3	1.0	4.5
7	Muskellunge		1	5	3	6.5	2	1.0	6.0
8	River Chub		1	3	2	6.5	1	1.0	2.0
9	Striped shiner		1	3	2	6.5	1	1.0	2.0
10	Spotfin shiner		1	5	3	6.5	1	1.0	3.0
11	River carpsucker		1	3	2	6.5	3	1.0	6.0
12	Highfin carpsucker		1	3	2	6.5	3	1.0	6.0
13	blue sucker		1	3	2	6.5	5	1.0	10.0
14	Bigmouth buffalo		1	3	2	6.5	3	1.0	6.0
15	Channel catfish		1	3	2	6.5	3	1.0	6.0
16	Flathead catfish		1	3	2	6.5	3	1.0	6.0
17	Brook silverside		1	5	3	6.5	1	1.0	3.0
18	White bass		1	2	1.5	6.5	5	1.0	7.5
19	Bluegill		1	5	3	6.5	1	1.0	3.0
20	Smallmouth bass		1	5	3	6.5	3	1.0	9.0
21	Spotted bass		1	5	3	6.5	3	1.0	9.0
22	Largemouth bass		1	5	3	6.5	3	1.0	9.0
23	Rainbow darter		1	3	2	6.5	3	1.0	6.0
24	Bluebreast darter		1	3	2	6.5	3	1.0	6.0
25	Tippecanoe darter		1	3	2	6.5	3	1.0	6.0
26	Logperch		1	3	2	6.5	3	1.0	6.0
27	Slenderhead Darter		1	3	2	6.5	3	1.0	6.0
28	Sauger		1	5	3	6.5	5	1.0	15.0
29	Walleye		1	5	3	6.5	5	1.0	15.0
30	Freshwater drum		1	3	2	6.5	3	1.0	6.0
								Sum Ei x Ui x Di:	186.5

EMSWORTH LOCKS AND DAMS

	OHR Focal Species	C: Vertical slot fishway adjacent to island on back channel dam							
i	Common Name	Є = Fish Passage Connectivity Є = Σ (Ei x Ui x Di /25)/n	Fs Size of Fishway	Fl Fishway Location	Ei Chance of Encounter	Minimum Current Velocity at Hydraulic Steps (ft/sec)	Ui Potential for Species to Use Fishway Type	Di Duration of year passable	Ei x Ui x Di
		0.10							
1	Shovelnose sturgeon		1	2	1.5	6.5	3	1.0	4.5
2	Paddlefish		1	1	1	6.5	1	1.0	1.0
3	Longnose gar		1	1	1	6.5	1	1.0	1.0
4	American eel		1	4	2.5	6.5	2	1.0	5.0
5	Skipjack herring		1	1	1	6.5	5	1.0	5.0
6	Mooneye		1	1	1	6.5	3	1.0	3.0
7	Muskellunge		1	4	2.5	6.5	2	1.0	5.0
8	River Chub		1	2	1.5	6.5	1	1.0	1.5
9	Striped shiner		1	2	1.5	6.5	1	1.0	1.5
10	Spotfin shiner		1	4	2.5	6.5	1	1.0	2.5
11	River carpsucker		1	2	1.5	6.5	3	1.0	4.5
12	Highfin carpsucker		1	2	1.5	6.5	3	1.0	4.5
13	blue sucker		1	2	1.5	6.5	5	1.0	7.5
14	Bigmouth buffalo		1	2	1.5	6.5	3	1.0	4.5
15	Channel catfish		1	2	1.5	6.5	3	1.0	4.5
16	Flathead catfish		1	2	1.5	6.5	3	1.0	4.5
17	Brook silverside		1	4	2.5	6.5	1	1.0	2.5
18	White bass		1	1	1	6.5	5	1.0	5.0
19	Bluegill		1	4	2.5	6.5	1	1.0	2.5
20	Smallmouth bass		1	4	2.5	6.5	3	1.0	7.5
21	Spotted bass		1	4	2.5	6.5	3	1.0	7.5
22	Largemouth bass		1	4	2.5	6.5	3	1.0	7.5
23	Rainbow darter		1	2	1.5	6.5	3	1.0	4.5
24	Bluebreast darter		1	2	1.5	6.5	3	1.0	4.5
25	Tippecanoe darter		1	2	1.5	6.5	3	1.0	4.5
26	Logperch		1	2	1.5	6.5	3	1.0	4.5
27	Slenderhead Darter		1	2	1.5	6.5	3	1.0	4.5
28	Sauger		1	4	2.5	6.5	5	1.0	12.5
29	Walleye		1	4	2.5	6.5	5	1.0	12.5
30	Freshwater drum		1	2	1.5	6.5	3	1.0	4.5
								Sum Ei x Ui x Di:	144.5

EMSWORTH LOCKS AND DAMS

	OHR Focal Species	D: Fish lock adjacent to island on main dam								
i	Common Name	Є = Fish Passage Connectivity Є = Σ (Ei x Ui x Di /25)/n	Fs Size of Fishway	Fl Fishway Location	Ei Chance of Encounter	Minimum Current Velocity at Hydraulic Steps (ft/sec)	Ui Potential for Species to Use Fishway Type	Di Duration of year passable	Ei x Ui x Di
		0.15							
1	Shovelnose sturgeon		1	3	2	1	4	1.0	8.0
2	Paddlefish		1	2	1.5	1	1	1.0	1.5
3	Longnose gar		1	2	1.5	1	2	1.0	3.0
4	American eel		1	5	3	1	3	1.0	9.0
5	Skipjack herring		1	2	1.5	1	4	1.0	6.0
6	Mooneye		1	2	1.5	1	4	1.0	6.0
7	Muskellunge		1	5	3	1	3	1.0	9.0
8	River Chub		1	3	2	1	2	1.0	4.0
9	Striped shiner		1	3	2	1	2	1.0	4.0
10	Spotfin shiner		1	5	3	1	2	1.0	6.0
11	River carpsucker		1	3	2	1	3	1.0	6.0
12	Highfin carpsucker		1	3	2	1	3	1.0	6.0
13	blue sucker		1	3	2	1	3	1.0	6.0
14	Bigmouth buffalo		1	3	2	1	3	1.0	6.0
15	Channel catfish		1	3	2	1	4	1.0	8.0
16	Flathead catfish		1	3	2	1	4	1.0	8.0
17	Brook silverside		1	5	3	1	2	1.0	6.0
18	White bass		1	2	1.5	1	4	1.0	6.0
19	Bluegill		1	5	3	1	4	1.0	12.0
20	Smallmouth bass		1	5	3	1	4	1.0	12.0
21	Spotted bass		1	5	3	1	4	1.0	12.0
22	Largemouth bass		1	5	3	1	4	1.0	12.0
23	Rainbow darter		1	3	2	1	3	1.0	6.0
24	Bluebreast darter		1	3	2	1	3	1.0	6.0
25	Tippecanoe darter		1	3	2	1	3	1.0	6.0
26	Logperch		1	3	2	1	3	1.0	6.0
27	Slenderhead Darter		1	3	2	1	3	1.0	6.0
28	Sauger		1	5	3	1	3	1.0	9.0
29	Walleye		1	5	3	1	3	1.0	9.0
30	Freshwater drum		1	3	2	1	3	1.0	6.0
								Sum Ei x Ui x Di:	210.5

EMSWORTH LOCKS AND DAMS

	OHR Focal Species	E: Fish lock adjacent to island on back channel dam							
i	Common Name	Є = Fish Passage Connectivity Є = Σ (Ei x Ui x Di /25)/n	Fs Size of Fishway	Fl Fishway Location	Ei Chance of Encounter	Minimum Current Velocity at Hydraulic Steps (ft/sec)	Ui Potential for Species to Use Fishway Type	Di Duration of year passable	Ei x Ui x Di
		0.11							
1	Shovelnose sturgeon		1	2	1.5	1	4	1.0	6.0
2	Paddlefish		1	1	1	1	1	1.0	1.0
3	Longnose gar		1	1	1	1	2	1.0	2.0
4	American eel		1	4	2.5	1	3	1.0	7.5
5	Skipjack herring		1	1	1	1	4	1.0	4.0
6	Mooneye		1	1	1	1	4	1.0	4.0
7	Muskellunge		1	4	2.5	1	3	1.0	7.5
8	River Chub		1	2	1.5	1	2	1.0	3.0
9	Striped shiner		1	2	1.5	1	2	1.0	3.0
10	Spotfin shiner		1	4	2.5	1	2	1.0	5.0
11	River carpsucker		1	2	1.5	1	3	1.0	4.5
12	Highfin carpsucker		1	2	1.5	1	3	1.0	4.5
13	blue sucker		1	2	1.5	1	3	1.0	4.5
14	Bigmouth buffalo		1	2	1.5	1	3	1.0	4.5
15	Channel catfish		1	2	1.5	1	4	1.0	6.0
16	Flathead catfish		1	2	1.5	1	4	1.0	6.0
17	Brook silverside		1	4	2.5	1	2	1.0	5.0
18	White bass		1	1	1	1	4	1.0	4.0
19	Bluegill		1	4	2.5	1	4	1.0	10.0
20	Smallmouth bass		1	4	2.5	1	4	1.0	10.0
21	Spotted bass		1	4	2.5	1	4	1.0	10.0
22	Largemouth bass		1	4	2.5	1	4	1.0	10.0
23	Rainbow darter		1	2	1.5	1	3	1.0	4.5
24	Bluebreast darter		1	2	1.5	1	3	1.0	4.5
25	Tippecanoe darter		1	2	1.5	1	3	1.0	4.5
26	Logperch		1	2	1.5	1	3	1.0	4.5
27	Slenderhead Darter		1	2	1.5	1	3	1.0	4.5
28	Sauger		1	4	2.5	1	3	1.0	7.5
29	Walleye		1	4	2.5	1	3	1.0	7.5
30	Freshwater drum		1	2	1.5	1	3	1.0	4.5
								Sum Ei x Ui x Di:	164.0

EMSWORTH LOCKS AND DAMS

	OHR Focal Species	F: Nature-like fishway around end of dam on island (min. 50' width)							
i	Common Name	Є = Fish Passage Connectivity Є = Σ (Ei x Ui x Di /25)/n	Fs Size of Fishway	Fl Fishway Location	Ei Chance of Encounter	Minimum Current Velocity at Hydraulic Steps (ft/sec)	Ui Potential for Species to Use Fishway Type	Di Duration of year passable	Ei x Ui x Di
		0.24							
1	Shovelnose sturgeon		3	3	3	2	3	1.0	9.0
2	Paddlefish		3	2	2.5	2	3	1.0	7.5
3	Longnose gar		3	2	2.5	2	2	1.0	5.0
4	American eel		3	5	4	2	4	1.0	16.0
5	Skipjack herring		3	2	2.5	2	3	1.0	7.5
6	Mooneye		3	2	2.5	2	4	1.0	10.0
7	Muskellunge		3	5	4	2	4	1.0	16.0
8	River Chub		3	3	3	2	4	1.0	12.0
9	Striped shiner		3	3	3	2	4	1.0	12.0
10	Spotfin shiner		3	5	4	2	4	1.0	16.0
11	River carpsucker		3	3	3	2	3	1.0	9.0
12	Highfin carpsucker		3	3	3	2	3	1.0	9.0
13	blue sucker		3	3	3	2	3	1.0	9.0
14	Bigmouth buffalo		3	3	3	2	3	1.0	9.0
15	Channel catfish		3	3	3	2	4	1.0	12.0
16	Flathead catfish		3	3	3	2	4	1.0	12.0
17	Brook silverside		3	5	4	2	4	1.0	16.0
18	White bass		3	2	2.5	2	4	1.0	10.0
19	Bluegill		3	5	4	2	3	1.0	12.0
20	Smallmouth bass		3	5	4	2	4	1.0	16.0
21	Spotted bass		3	5	4	2	3	1.0	12.0
22	Largemouth bass		3	5	4	2	3	1.0	12.0
23	Rainbow darter		3	3	3	2	4	1.0	12.0
24	Bluebreast darter		3	3	3	2	4	1.0	12.0
25	Tippecanoe darter		3	3	3	2	4	1.0	12.0
26	Logperch		3	3	3	2	4	1.0	12.0
27	Slenderhead Darter		3	3	3	2	4	1.0	12.0
28	Sauger		3	5	4	2	4	1.0	16.0
29	Walleye		3	5	4	2	4	1.0	16.0
30	Freshwater drum		3	3	3	2	4	1.0	12.0
								Sum Ei x Ui x Di:	353.0

EMSWORTH LOCKS AND DAMS

	OHR Focal Species	G: Rock ramp around end of dam on island (min. 50' bottom width)							
i	Common Name	Є = Fish Passage Connectivity Є = Σ (Ei x Ui x Di /25)/n	Fs Size of Fishway	Fl Fishway Location	Ei Chance of Encounter	Minimum Current Velocity at Hydraulic Steps (ft/sec)	Ui Potential for Species to Use Fishway Type	Di Duration of year passable	Ei x Ui x Di
		0.26							
1	Shovelnose sturgeon		3	3	3	2	4	1.0	12.0
2	Paddlefish		3	2	2.5	2	4	1.0	10.0
3	Longnose gar		3	2	2.5	2	3	1.0	7.5
4	American eel		3	5	4	2	4	1.0	16.0
5	Skipjack herring		3	2	2.5	2	4	1.0	10.0
6	Mooneye		3	2	2.5	2	3	1.0	7.5
7	Muskellunge		3	5	4	2	4	1.0	16.0
8	River Chub		3	3	3	2	4	1.0	12.0
9	Striped shiner		3	3	3	2	4	1.0	12.0
10	Spotfin shiner		3	5	4	2	4	1.0	16.0
11	River carpsucker		3	3	3	2	4	1.0	12.0
12	Highfin carpsucker		3	3	3	2	4	1.0	12.0
13	blue sucker		3	3	3	2	5	1.0	15.0
14	Bigmouth buffalo		3	3	3	2	4	1.0	12.0
15	Channel catfish		3	3	3	2	4	1.0	12.0
16	Flathead catfish		3	3	3	2	4	1.0	12.0
17	Brook silverside		3	5	4	2	3	1.0	12.0
18	White bass		3	2	2.5	2	4	1.0	10.0
19	Bluegill		3	5	4	2	3	1.0	12.0
20	Smallmouth bass		3	5	4	2	4	1.0	16.0
21	Spotted bass		3	5	4	2	3	1.0	12.0
22	Largemouth bass		3	5	4	2	3	1.0	12.0
23	Rainbow darter		3	3	3	2	4	1.0	12.0
24	Bluebreast darter		3	3	3	2	4	1.0	12.0
25	Tippecanoe darter		3	3	3	2	4	1.0	12.0
26	Logperch		3	3	3	2	4	1.0	12.0
27	Slenderhead Darter		3	3	3	2	4	1.0	12.0
28	Sauger		3	5	4	2	4	1.0	16.0
29	Walleye		3	5	4	2	4	1.0	16.0
30	Freshwater drum		3	3	3	2	4	1.0	12.0
								Sum Ei x Ui x Di:	372.0

EMSWORTH LOCKS AND DAMS

	OHR Focal Species	H: Rock ramp in gate bay adjacent to island on main dam (min. 50' bottom width)							
i	Common Name	Є = Fish Passage Connectivity Є = Σ (Ei x Ui x Di /25)/n	Fs Size of Fishway	Fl Fishway Location	Ei Chance of Encounter	Minimum Current Velocity at Hydraulic Steps (ft/sec)	Ui Potential for Species to Use Fishway Type	Di Duration of year passable	Ei x Ui x Di
		0.30							
1	Shovelnose sturgeon		4	3	3.5	2	4	1.0	14.0
2	Paddlefish		4	2	3	2	4	1.0	12.0
3	Longnose gar		4	2	3	2	3	1.0	9.0
4	American eel		4	5	4.5	2	4	1.0	18.0
5	Skipjack herring		4	2	3	2	4	1.0	12.0
6	Mooneye		4	2	3	2	3	1.0	9.0
7	Muskellunge		4	5	4.5	2	4	1.0	18.0
8	River Chub		4	3	3.5	2	4	1.0	14.0
9	Striped shiner		4	3	3.5	2	4	1.0	14.0
10	Spotfin shiner		4	5	4.5	2	4	1.0	18.0
11	River carpsucker		4	3	3.5	2	4	1.0	14.0
12	Highfin carpsucker		4	3	3.5	2	4	1.0	14.0
13	blue sucker		4	3	3.5	2	5	1.0	17.5
14	Bigmouth buffalo		4	3	3.5	2	4	1.0	14.0
15	Channel catfish		4	3	3.5	2	4	1.0	14.0
16	Flathead catfish		4	3	3.5	2	4	1.0	14.0
17	Brook silverside		4	5	4.5	2	3	1.0	13.5
18	White bass		4	2	3	2	4	1.0	12.0
19	Bluegill		4	5	4.5	2	3	1.0	13.5
20	Smallmouth bass		4	5	4.5	2	4	1.0	18.0
21	Spotted bass		4	5	4.5	2	3	1.0	13.5
22	Largemouth bass		4	5	4.5	2	3	1.0	13.5
23	Rainbow darter		4	3	3.5	2	4	1.0	14.0
24	Bluebreast darter		4	3	3.5	2	4	1.0	14.0
25	Tippecanoe darter		4	3	3.5	2	4	1.0	14.0
26	Logperch		4	3	3.5	2	4	1.0	14.0
27	Slenderhead Darter		4	3	3.5	2	4	1.0	14.0
28	Sauger		4	5	4.5	2	4	1.0	18.0
29	Walleye		4	5	4.5	2	4	1.0	18.0
30	Freshwater drum		4	3	3.5	2	4	1.0	14.0
								Sum Ei x Ui x Di:	429.5

EMSWORTH LOCKS AND DAMS

i	OHR Focal Species Common Name	Є = Fish Passage Connectivity Є = Σ (Ei x Ui x Di /25)/n	Fs Size of Fishway	Fl Fishway Location	Ei Chance of Encounter	Minimum Current Velocity at Hydraulic Steps (ft/sec)	Ui Potential for Species to Use Fishway Type	Di Duration of year passable	Ei x Ui x Di
		I: Rock ramp in gate bay adjacent to island on back channel dam (min. 50' bottom width)							
		0.26							
1	Shovelnose sturgeon		4	2	3	2	4	1.0	12.0
2	Paddlefish		4	1	2.5	2	4	1.0	10.0
3	Longnose gar		4	1	2.5	2	3	1.0	7.5
4	American eel		4	4	4	2	4	1.0	16.0
5	Skipjack herring		4	1	2.5	2	4	1.0	10.0
6	Mooneye		4	1	2.5	2	3	1.0	7.5
7	Muskellunge		4	4	4	2	4	1.0	16.0
8	River Chub		4	2	3	2	4	1.0	12.0
9	Striped shiner		4	2	3	2	4	1.0	12.0
10	Spotfin shiner		4	4	4	2	4	1.0	16.0
11	River carpsucker		4	2	3	2	4	1.0	12.0
12	Highfin carpsucker		4	2	3	2	4	1.0	12.0
13	blue sucker		4	2	3	2	5	1.0	15.0
14	Bigmouth buffalo		4	2	3	2	4	1.0	12.0
15	Channel catfish		4	2	3	2	4	1.0	12.0
16	Flathead catfish		4	2	3	2	4	1.0	12.0
17	Brook silverside		4	4	4	2	3	1.0	12.0
18	White bass		4	1	2.5	2	4	1.0	10.0
19	Bluegill		4	4	4	2	3	1.0	12.0
20	Smallmouth bass		4	4	4	2	4	1.0	16.0
21	Spotted bass		4	4	4	2	3	1.0	12.0
22	Largemouth bass		4	4	4	2	3	1.0	12.0
23	Rainbow darter		4	2	3	2	4	1.0	12.0
24	Bluebreast darter		4	2	3	2	4	1.0	12.0
25	Tippecanoe darter		4	2	3	2	4	1.0	12.0
26	Logperch		4	2	3	2	4	1.0	12.0
27	Slenderhead Darter		4	2	3	2	4	1.0	12.0
28	Sauger		4	4	4	2	4	1.0	16.0
29	Walleye		4	4	4	2	4	1.0	16.0
30	Freshwater drum		4	2	3	2	4	1.0	12.0
								Sum Ei x Ui x Di:	372.0

EMSWORTH LOCKS AND DAMS HABITAT UNITS

	OHR Focal Species	A: Fish Lockage (aux. lock)			B: Vertical slot fishway adjacent to island on main dam			C: Vertical slot fishway adjacent to island on back channel dam		
i	Common Name	Є = Fish Passage Effectiveness	Habitat Units by Species (acres)	Habitat Units Sum (Є X acres)	Є = Fish Passage Effectiveness	Habitat Units by Species (acres)	Habitat Units Sum (Є X acres)	Є = Fish Passage Effectiveness	Habitat Units by Species (acres)	Habitat Units Sum (Є X acres)
1	Shovelnose sturgeon	0.02	3024	63.82	0.13	3024	388.95	0.10	3024	301.36
2	Paddlefish	0.02	3024	63.82	0.13	3024	388.95	0.10	3024	301.36
3	Longnose gar	0.02	3024	63.82	0.13	3024	388.95	0.10	3024	301.36
4	American eel	0.02	3024	63.82	0.13	3024	388.95	0.10	3024	301.36
5	Skipjack herring	0.02	3003	63.37	0.13	3003	386.25	0.10	3003	299.26
6	Mooneye	0.02	3024	63.82	0.13	3024	388.95	0.10	3024	301.36
7	Muskellunge	0.02	3024	63.82	0.13	3024	388.95	0.10	3024	301.36
8	River Chub	0.02	3024	63.82	0.13	3024	388.95	0.10	3024	301.36
9	Striped shiner	0.02	3024	63.82	0.13	3024	388.95	0.10	3024	301.36
10	Spotfin shiner	0.02	3024	63.82	0.13	3024	388.95	0.10	3024	301.36
11	River carpsucker	0.02	3024	63.82	0.13	3024	388.95	0.10	3024	301.36
12	Highfin carpsucker	0.02	3024	63.82	0.13	3024	388.95	0.10	3024	301.36
13	blue sucker	0.02	3003	63.37	0.13	3003	386.25	0.10	3003	299.26
14	Bigmouth buffalo	0.02	3024	63.82	0.13	3024	388.95	0.10	3024	301.36
15	Channel catfish	0.02	3024	63.82	0.13	3024	388.95	0.10	3024	301.36
16	Flathead catfish	0.02	3024	63.82	0.13	3024	388.95	0.10	3024	301.36
17	Brook silverside	0.02	3024	63.82	0.13	3024	388.95	0.10	3024	301.36
18	White bass	0.02	3024	63.82	0.13	3024	388.95	0.10	3024	301.36
19	Bluegill	0.02	3024	63.82	0.13	3024	388.95	0.10	3024	301.36
20	Smallmouth bass	0.02	3024	63.82	0.13	3024	388.95	0.10	3024	301.36
21	Spotted bass	0.02	3024	63.82	0.13	3024	388.95	0.10	3024	301.36
22	Largemouth bass	0.02	3024	63.82	0.13	3024	388.95	0.10	3024	301.36
23	Rainbow darter	0.02	3024	63.82	0.13	3024	388.95	0.10	3024	301.36
24	Bluebreast darter	0.02	3024	63.82	0.13	3024	388.95	0.10	3024	301.36
25	Tippecanoe darter	0.02	3024	63.82	0.13	3024	388.95	0.10	3024	301.36
26	Logperch	0.02	3024	63.82	0.13	3024	388.95	0.10	3024	301.36
27	Slenderhead Darter	0.02	3024	63.82	0.13	3024	388.95	0.10	3024	301.36
28	Sauger	0.02	3024	63.82	0.13	3024	388.95	0.10	3024	301.36
29	Walleye	0.02	3024	63.82	0.13	3024	388.95	0.10	3024	301.36
30	Freshwater drum	0.02	3024	63.82	0.13	3024	388.95	0.10	3024	301.36
			average HU =	63.79		average HU =	388.77		average HU =	301.22

EMSWORTH LOCKS AND DAMS HABITAT UNITS

i	OHR Focal Species	D: Fish lock adjacent to island on main dam			E: Fish lock adjacent to island on back channel dam			F: Nature-like fishway around end of dam on island (min. 50' width)		
i	Common Name	Є = Fish Passage Effectiveness	Habitat Units by Species (acres)	Habitat Units Sum (Є X acres)	Є = Fish Passage Effectiveness	Habitat Units by Species (acres)	Habitat Units Sum (Є X acres)	Є = Fish Passage Effectiveness	Habitat Units by Species (acres)	Habitat Units Sum (Є X acres)
1	Shovelnose sturgeon	0.15	3024	439.00	0.11	3024	342.02	0.24	3024	736.19
2	Paddlefish	0.15	3024	439.00	0.11	3024	342.02	0.24	3024	736.19
3	Longnose gar	0.15	3024	439.00	0.11	3024	342.02	0.24	3024	736.19
4	American eel	0.15	3024	439.00	0.11	3024	342.02	0.24	3024	736.19
5	Skipjack herring	0.15	3003	435.95	0.11	3003	339.65	0.24	3003	731.08
6	Mooneye	0.15	3024	439.00	0.11	3024	342.02	0.24	3024	736.19
7	Muskellunge	0.15	3024	439.00	0.11	3024	342.02	0.24	3024	736.19
8	River Chub	0.15	3024	439.00	0.11	3024	342.02	0.24	3024	736.19
9	Striped shiner	0.15	3024	439.00	0.11	3024	342.02	0.24	3024	736.19
10	Spotfin shiner	0.15	3024	439.00	0.11	3024	342.02	0.24	3024	736.19
11	River carpsucker	0.15	3024	439.00	0.11	3024	342.02	0.24	3024	736.19
12	Highfin carpsucker	0.15	3024	439.00	0.11	3024	342.02	0.24	3024	736.19
13	blue sucker	0.15	3003	435.95	0.11	3003	339.65	0.24	3003	731.08
14	Bigmouth buffalo	0.15	3024	439.00	0.11	3024	342.02	0.24	3024	736.19
15	Channel catfish	0.15	3024	439.00	0.11	3024	342.02	0.24	3024	736.19
16	Flathead catfish	0.15	3024	439.00	0.11	3024	342.02	0.24	3024	736.19
17	Brook silverside	0.15	3024	439.00	0.11	3024	342.02	0.24	3024	736.19
18	White bass	0.15	3024	439.00	0.11	3024	342.02	0.24	3024	736.19
19	Bluegill	0.15	3024	439.00	0.11	3024	342.02	0.24	3024	736.19
20	Smallmouth bass	0.15	3024	439.00	0.11	3024	342.02	0.24	3024	736.19
21	Spotted bass	0.15	3024	439.00	0.11	3024	342.02	0.24	3024	736.19
22	Largemouth bass	0.15	3024	439.00	0.11	3024	342.02	0.24	3024	736.19
23	Rainbow darter	0.15	3024	439.00	0.11	3024	342.02	0.24	3024	736.19
24	Bluebreast darter	0.15	3024	439.00	0.11	3024	342.02	0.24	3024	736.19
25	Tippecanoe darter	0.15	3024	439.00	0.11	3024	342.02	0.24	3024	736.19
26	Logperch	0.15	3024	439.00	0.11	3024	342.02	0.24	3024	736.19
27	Slenderhead Darter	0.15	3024	439.00	0.11	3024	342.02	0.24	3024	736.19
28	Sauger	0.15	3024	439.00	0.11	3024	342.02	0.24	3024	736.19
29	Walleye	0.15	3024	439.00	0.11	3024	342.02	0.24	3024	736.19
30	Freshwater drum	0.15	3024	439.00	0.11	3024	342.02	0.24	3024	736.19
			average HU =	438.80		average HU =	341.87		average HU =	735.85

EMSWORTH LOCKS AND DAMS HABITAT UNITS

	OHR Focal Species	G: Rock ramp around end of dam on island (min. 50' bottom width)			H: Rock ramp in gate bay adjacent to island on main dam (min. 50' bottom width)			I: Rock ramp in gate bay adjacent to island on back channel dam (min. 50' bottom width)		
i	Common Name	Є = Fish Passage Effectiveness	Habitat Units by Species (acres)	Habitat Units Sum (Є X acres)	Є = Fish Passage Effectiveness	Habitat Units by Species (acres)	Habitat Units Sum (Є X acres)	Є = Fish Passage Effectiveness	Habitat Units by Species (acres)	Habitat Units Sum (Є X acres)
1	Shovelnose sturgeon	0.26	3024	775.81	0.30	3024	895.73	0.26	3024	775.81
2	Paddlefish	0.26	3024	775.81	0.30	3024	895.73	0.26	3024	775.81
3	Longnose gar	0.26	3024	775.81	0.30	3024	895.73	0.26	3024	775.81
4	American eel	0.26	3024	775.81	0.30	3024	895.73	0.26	3024	775.81
5	Skipjack herring	0.26	3003	770.42	0.30	3003	889.51	0.26	3003	770.42
6	Mooneye	0.26	3024	775.81	0.30	3024	895.73	0.26	3024	775.81
7	Muskellunge	0.26	3024	775.81	0.30	3024	895.73	0.26	3024	775.81
8	River Chub	0.26	3024	775.81	0.30	3024	895.73	0.26	3024	775.81
9	Striped shiner	0.26	3024	775.81	0.30	3024	895.73	0.26	3024	775.81
10	Spotfin shiner	0.26	3024	775.81	0.30	3024	895.73	0.26	3024	775.81
11	River carpsucker	0.26	3024	775.81	0.30	3024	895.73	0.26	3024	775.81
12	Highfin carpsucker	0.26	3024	775.81	0.30	3024	895.73	0.26	3024	775.81
13	blue sucker	0.26	3003	770.42	0.30	3003	889.51	0.26	3003	770.42
14	Bigmouth buffalo	0.26	3024	775.81	0.30	3024	895.73	0.26	3024	775.81
15	Channel catfish	0.26	3024	775.81	0.30	3024	895.73	0.26	3024	775.81
16	Flathead catfish	0.26	3024	775.81	0.30	3024	895.73	0.26	3024	775.81
17	Brook silverside	0.26	3024	775.81	0.30	3024	895.73	0.26	3024	775.81
18	White bass	0.26	3024	775.81	0.30	3024	895.73	0.26	3024	775.81
19	Bluegill	0.26	3024	775.81	0.30	3024	895.73	0.26	3024	775.81
20	Smallmouth bass	0.26	3024	775.81	0.30	3024	895.73	0.26	3024	775.81
21	Spotted bass	0.26	3024	775.81	0.30	3024	895.73	0.26	3024	775.81
22	Largemouth bass	0.26	3024	775.81	0.30	3024	895.73	0.26	3024	775.81
23	Rainbow darter	0.26	3024	775.81	0.30	3024	895.73	0.26	3024	775.81
24	Bluebreast darter	0.26	3024	775.81	0.30	3024	895.73	0.26	3024	775.81
25	Tippecanoe darter	0.26	3024	775.81	0.30	3024	895.73	0.26	3024	775.81
26	Logperch	0.26	3024	775.81	0.30	3024	895.73	0.26	3024	775.81
27	Slenderhead Darter	0.26	3024	775.81	0.30	3024	895.73	0.26	3024	775.81
28	Sauger	0.26	3024	775.81	0.30	3024	895.73	0.26	3024	775.81
29	Walleye	0.26	3024	775.81	0.30	3024	895.73	0.26	3024	775.81
30	Freshwater drum	0.26	3024	775.81	0.30	3024	895.73	0.26	3024	775.81
			average HU =	775.45		average HU =	895.31		average HU =	775.45

Emsworth Summary - Connectivity Rank of Fish Passage Alternatives

Measures	Є = Fish Passage Connectivity Є = Σ (Ei x Ui x Di /25)/n	Rank	Habitat Units
A: Fish Lockage (aux. lock)	**0.02**	**9**	**64**
B: Vertical slot fishway adjacent to island on main dam	**0.13**	**6**	**389**
C: Vertical slot fishway adjacent to island on back channel dam	**0.10**	**8**	**301**
D: Fish lock adjacent to island on main dam	**0.15**	**5**	**439**
E: Fish lock adjacent to island on back channel dam	**0.11**	**7**	**342**
F: Nature-like fishway around end of dam on island (min. 50' width)	**0.24**	**4**	**736**
G: Rock ramp around end of dam on island (min. 50' bottom width)	**0.26**	**2**	**775**
H: Rock ramp in gate bay adjacent to island on main dam (min. 50' bottom width)	**0.30**	**1**	**895**
I: Rock ramp in gate bay adjacent to island on back channel dam (min. 50' bottom width)	**0.26**	**2**	**775**

Fish Passage Connectivity Index (FPCI)

Ranking of Alternatives

Dashield L/D

									Available Habitat in Dashields Pool [1]				
									A	B	C	D	
i	Common Name	Scientific Name	Dashields Pool Relative Abundance	Emsworth Pool Relative Abundance	Swimming Behavior	Swimming Performance	Swimming Speed (Ucrit)	Habitat Preference	Main Channel (acres)	Secondary Channel (acres)	Contiguous Embayment (acres)	Tributary Mouth (up to head of slack water) (acres)	Total Available Preferred Habitat in Dashields Pool (acres)
1	Shovelnose sturgeon	*Scaphirhyncus platorynchus*	Extirpated	Extirpated	Benthic	Medium	82	A,B,D	986	243	0	0	1229
2	Paddlefish	*Polyodon spathula*	Listed	Listed	Pelagic	Strong	86	A,B,D	986	243	0	0	1229
3	Longnose gar	*Lepisosteus osseus*	Occasional	Common	Pelagic	Weak	21	A,B,C,D	986	243	0	0	1229
4	American eel	*Anguilla rostrata*	Occasional	Rare	Littoral	Weak		A,B,D	986	243	0	0	1229
5	Skipjack herring	*Alosa chrysochloris*	Listed	Listed	Pelagic	Strong	59	A,B	986	243	0	0	1229
6	Mooneye	*Hiodon alosoides*	Listed	Listed	Pelagic	Medium	59	A,B,C,D	986	243	0	0	1229
7	Muskellunge	*Esox masquinongy*	Rare	Rare	Littoral	Weak		A,B,C,D	986	243	0	0	1229
8	River Chub	*Nocomis micropogon*	Rare	Rare	Benthic	Weak		A,B,D	986	243	0	0	1229
9	Striped shiner	*Luxilus chrysocephalus*	Rare	Rare	Benthic	Weak	33	A,B,D	986	243	0	0	1229
10	Spotfin shiner	*Cyprinella spiloptera*	Common	Occasional	Littoral	Weak	28	A,B,C,D	986	243	0	0	1229
11	River carpsucker	*Carpiodes carpio*	Occasional	Common	Benthic	Weak		A,B,C,D	986	243	0	0	1229
12	Highfin carpsucker	*Carpiodes velifer*	Rare	Rare	Benthic	Weak	45	A,B,D	986	243	0	0	1229
13	blue sucker	*Cycleptus elongatus*	Rare	Rare	Benthic	Strong	78	A,B	986	243	0	0	1229
14	Bigmouth buffalo	*Ictiobus cyprinellus*	Listed	Listed	Benthic	Medium	63	A,B,D	986	243	0	0	1229
15	Channel catfish	*Ictalurus punctatus*	Abundant	Abundant	Benthic	Medium	84	A,B,C,D	986	243	0	0	1229
16	Flathead catfish	*Pylodictis olivaria*	Common	Common	Benthic	Medium	121	A,B,C,D	986	243	0	0	1229
17	Brook silverside	*Labidesthes sicculus*	Listed	Listed	Littoral	Weak	32	A,B,C,D	986	243	0	0	1229
18	White bass	*Morone chrysops*	Abundant	Abundant	Pelagic	Strong	120	A,B,C,D	986	243	0	0	1229
19	Bluegill	*Lepomis macrochirus*	Abundant	Abundant	Littoral	Weak	42	A,B,C,D	986	243	0	0	1229
20	Smallmouth bass	*Micropterus salmoides*	Abundant	Abundant	Littoral	Medium	63	A,B,C,D	986	243	0	0	1229
21	Spotted bass	*Micropterus punctulatus*	Common	Abundant	Littoral	Medium	72	A,B,C,D	986	243	0	0	1229
22	Largemouth bass	*Micropterus dolomieu*	Occasional	Occasional	Littoral	Medium	127	A,B,C,D	986	243	0	0	1229
23	Rainbow darter	*Etheostoma caeruleum*	Occasional	Rare	Benthic	Weak	22	A,B,D	986	243	0	0	1229
24	Bluebreast darter	*Etheostoma camurum*	Listed	Listed	Benthic	Weak	22	A,B,D	986	243	0	0	1229
25	Tippecanoe darter	*Etheostoma tippecanoe*	Listed	Listed	Benthic	Weak	22	A,B,D	986	243	0	0	1229
26	Logperch	*Percina caprodes*	Abundant	Abundant	Benthic	Weak		A,B,D	986	243	0	0	1229
27	Slenderhead Darter	*Percina shumardi*	Rare	Rare	Benthic	Weak		A,B,D	986	243	0	0	1229
28	Sauger	*Sander vitreum*	Abundant	Abundant	Littoral	Strong	79	A,B,D	986	243	0	0	1229
29	Walleye	*Sander canadense*	Common	Abundant	Littoral	Strong	115	A,B,D	986	243	0	0	1229
30	Freshwater drum	*Aplodinotus grunniens*	Abundant	Abundant	Benthic	Medium	81	A,B,C,D	986	243	0	0	1229

[1] Aquatic habitat acreages derived from "normal"/bankful GIS data (higher level "floodstage" data questionable).

DASHIELDS LOCKS AND DAM

	OHR Focal Species	A: Fish Lockage (aux. lock)							
i	Common Name	Є = Fish Passage Connectivity Є = Σ (Ei x Ui x Di /25)/n	Fs Size of Fishway	Fl Fishway Location	Ei Chance of Encounter	Minimum Current Velocity at Hydraulic Steps (ft/sec)	Ui Potential for Species to Use Fishway Type	Di Duration of year passable	Ei x Ui x Di
		0.02							
1	Shovelnose sturgeon		5	2	3.5	1	2	0.12	0.8
2	Paddlefish		5	1	3	1	3	0.12	1.1
3	Longnose gar		5	1	3	1	3	0.12	1.1
4	American eel		5	2	3.5	1	3	0.12	1.3
5	Skipjack herring		5	1	3	1	3	0.12	1.1
6	Mooneye		5	1	3	1	3	0.12	1.1
7	Muskellunge		5	2	3.5	1	3	0.12	1.3
8	River Chub		5	2	3.5	1	2	0.12	0.8
9	Striped shiner		5	2	3.5	1	2	0.12	0.8
10	Spotfin shiner		5	2	3.5	1	3	0.12	1.3
11	River carpsucker		5	2	3.5	1	2	0.12	0.8
12	Highfin carpsucker		5	2	3.5	1	2	0.12	0.8
13	blue sucker		5	2	3.5	1	2	0.12	0.8
14	Bigmouth buffalo		5	2	3.5	1	2	0.12	0.8
15	Channel catfish		5	2	3.5	1	2	0.12	0.8
16	Flathead catfish		5	2	3.5	1	2	0.12	0.8
17	Brook silverside		5	2	3.5	1	3	0.12	1.3
18	White bass		5	1	3	1	3	0.12	1.1
19	Bluegill		5	2	3.5	1	3	0.12	1.3
20	Smallmouth bass		5	2	3.5	1	3	0.12	1.3
21	Spotted bass		5	2	3.5	1	3	0.12	1.3
22	Largemouth bass		5	2	3.5	1	3	0.12	1.3
23	Rainbow darter		5	2	3.5	1	2	0.12	0.8
24	Bluebreast darter		5	2	3.5	1	2	0.12	0.8
25	Tippecanoe darter		5	2	3.5	1	2	0.12	0.8
26	Logperch		5	2	3.5	1	2	0.12	0.8
27	Slenderhead Darter		5	2	3.5	1	2	0.12	0.8
28	Sauger		5	2	3.5	1	3	0.12	1.3
29	Walleye		5	2	3.5	1	3	0.12	1.3
30	Freshwater drum		5	2	3.5	1	2	0.12	0.8
								Sum Ei x Ui x Di:	30.6

DASHIELDS LOCKS AND DAM

i	OHR Focal Species Common Name	Є = Fish Passage Connectivity Є = Σ (Ei x Ui x Di /25)/n	Fs Size of Fishway	Fl Fishway Location	Ei Chance of Encounter	Minimum Current Velocity at Hydraulic Steps (ft/sec)	Ui Potential for Species to Use Fishway Type	Di Duration of year passable	Ei x Ui x Di
		B: Vertical slot fishway below fixed crest on north end							
		0.13							
1	Shovelnose sturgeon		1	3	2	6.5	3	1.0	6.0
2	Paddlefish		1	2	1.5	6.5	1	1.0	1.5
3	Longnose gar		1	2	1.5	6.5	1	1.0	1.5
4	American eel		1	5	3	6.5	2	1.0	6.0
5	Skipjack herring		1	2	1.5	6.5	5	1.0	7.5
6	Mooneye		1	2	1.5	6.5	3	1.0	4.5
7	Muskellunge		1	5	3	6.5	2	1.0	6.0
8	River Chub		1	3	2	6.5	1	1.0	2.0
9	Striped shiner		1	3	2	6.5	1	1.0	2.0
10	Spotfin shiner		1	5	3	6.5	1	1.0	3.0
11	River carpsucker		1	3	2	6.5	3	1.0	6.0
12	Highfin carpsucker		1	3	2	6.5	3	1.0	6.0
13	blue sucker		1	3	2	6.5	5	1.0	10.0
14	Bigmouth buffalo		1	3	2	6.5	3	1.0	6.0
15	Channel catfish		1	3	2	6.5	3	1.0	6.0
16	Flathead catfish		1	3	2	6.5	3	1.0	6.0
17	Brook silverside		1	5	3	6.5	1	1.0	3.0
18	White bass		1	2	1.5	6.5	5	1.0	7.5
19	Bluegill		1	5	3	6.5	1	1.0	3.0
20	Smallmouth bass		1	5	3	6.5	3	1.0	9.0
21	Spotted bass		1	5	3	6.5	3	1.0	9.0
22	Largemouth bass		1	5	3	6.5	3	1.0	9.0
23	Rainbow darter		1	3	2	6.5	3	1.0	6.0
24	Bluebreast darter		1	3	2	6.5	3	1.0	6.0
25	Tippecanoe darter		1	3	2	6.5	3	1.0	6.0
26	Logperch		1	3	2	6.5	3	1.0	6.0
27	Slenderhead Darter		1	3	2	6.5	3	1.0	6.0
28	Sauger		1	5	3	6.5	5	1.0	15.0
29	Walleye		1	5	3	6.5	5	1.0	15.0
30	Freshwater drum		1	3	2	6.5	3	1.0	6.0
								Sum Ei x Ui x Di:	186.5

DASHIELDS LOCKS AND DAM

	OHR Focal Species	C: Fish Lock below fixed crest on north end							
i	Common Name	Є = Fish Passage Connectivity Є = Σ (Ei x Ui x Di /25)/n	Fs Size of Fishway	Fl Fishway Location	Ei Chance of Encounter	Minimum Current Velocity at Hydraulic Steps (ft/sec)	Ui Potential for Species to Use Fishway Type	Di Duration of year passable	Ei x Ui x Di
		0.15							
1	Shovelnose sturgeon		1	3	2	1	4	1.0	8.0
2	Paddlefish		1	2	1.5	1	1	1.0	1.5
3	Longnose gar		1	2	1.5	1	2	1.0	3.0
4	American eel		1	5	3	1	3	1.0	9.0
5	Skipjack herring		1	2	1.5	1	4	1.0	6.0
6	Mooneye		1	2	1.5	1	4	1.0	6.0
7	Muskellunge		1	5	3	1	3	1.0	9.0
8	River Chub		1	3	2	1	2	1.0	4.0
9	Striped shiner		1	3	2	1	2	1.0	4.0
10	Spotfin shiner		1	5	3	1	2	1.0	6.0
11	River carpsucker		1	3	2	1	3	1.0	6.0
12	Highfin carpsucker		1	3	2	1	3	1.0	6.0
13	blue sucker		1	3	2	1	3	1.0	6.0
14	Bigmouth buffalo		1	3	2	1	3	1.0	6.0
15	Channel catfish		1	3	2	1	4	1.0	8.0
16	Flathead catfish		1	3	2	1	4	1.0	8.0
17	Brook silverside		1	5	3	1	2	1.0	6.0
18	White bass		1	2	1.5	1	4	1.0	6.0
19	Bluegill		1	5	3	1	4	1.0	12.0
20	Smallmouth bass		1	5	3	1	4	1.0	12.0
21	Spotted bass		1	5	3	1	4	1.0	12.0
22	Largemouth bass		1	5	3	1	4	1.0	12.0
23	Rainbow darter		1	3	2	1	3	1.0	6.0
24	Bluebreast darter		1	3	2	1	3	1.0	6.0
25	Tippecanoe darter		1	3	2	1	3	1.0	6.0
26	Logperch		1	3	2	1	3	1.0	6.0
27	Slenderhead Darter		1	3	2	1	3	1.0	6.0
28	Sauger		1	5	3	1	3	1.0	9.0
29	Walleye		1	5	3	1	3	1.0	9.0
30	Freshwater drum		1	3	2	1	3	1.0	6.0
								Sum Ei x Ui x Di:	210.5

DASHIELDS LOCKS AND DAM

i	OHR Focal Species	E: Rock ramp below fixed crest on north end (min. 50' bottom width)							
i	Common Name	Є = Fish Passage Connectivity Є = Σ (Ei x Ui x Di /25)/n	Fs Size of Fishway	Fl Fishway Location	Ei Chance of Encounter	Minimum Current Velocity at Hydraulic Steps (ft/sec)	Ui Potential for Species to Use Fishway Type	Di Duration of year passable	Ei x Ui x Di
		0.26							
1	Shovelnose sturgeon		3	3	3	2	4	1.0	12.0
2	Paddlefish		3	2	2.5	2	4	1.0	10.0
3	Longnose gar		3	2	2.5	2	3	1.0	7.5
4	American eel		3	5	4	2	4	1.0	16.0
5	Skipjack herring		3	2	2.5	2	4	1.0	10.0
6	Mooneye		3	2	2.5	2	3	1.0	7.5
7	Muskellunge		3	5	4	2	4	1.0	16.0
8	River Chub		3	3	3	2	4	1.0	12.0
9	Striped shiner		3	3	3	2	4	1.0	12.0
10	Spotfin shiner		3	5	4	2	4	1.0	16.0
11	River carpsucker		3	3	3	2	4	1.0	12.0
12	Highfin carpsucker		3	3	3	2	4	1.0	12.0
13	blue sucker		3	3	3	2	5	1.0	15.0
14	Bigmouth buffalo		3	3	3	2	4	1.0	12.0
15	Channel catfish		3	3	3	2	4	1.0	12.0
16	Flathead catfish		3	3	3	2	4	1.0	12.0
17	Brook silverside		3	5	4	2	3	1.0	12.0
18	White bass		3	2	2.5	2	4	1.0	10.0
19	Bluegill		3	5	4	2	3	1.0	12.0
20	Smallmouth bass		3	5	4	2	4	1.0	16.0
21	Spotted bass		3	5	4	2	3	1.0	12.0
22	Largemouth bass		3	5	4	2	3	1.0	12.0
23	Rainbow darter		3	3	3	2	4	1.0	12.0
24	Bluebreast darter		3	3	3	2	4	1.0	12.0
25	Tippecanoe darter		3	3	3	2	4	1.0	12.0
26	Logperch		3	3	3	2	4	1.0	12.0
27	Slenderhead Darter		3	3	3	2	4	1.0	12.0
28	Sauger		3	5	4	2	4	1.0	16.0
29	Walleye		3	5	4	2	4	1.0	16.0
30	Freshwater drum		3	3	3	2	4	1.0	12.0
								Sum Ei x Ui x Di:	372.0

pg. 1/2	OHR Focal Species		A: Fish Lockage (aux. lock)				B: Vertical slot fishway below north fixed crest		
i	Common Name		Є = Fish Passage Effectiveness	Habitat Units by Species (acres)	Habitat Units Sum (Є X acres)		Є = Fish Passage Effectiveness	Habitat Units by Species (acres)	Habitat Units Sum (Є X acres)
1	Shovelnose sturgeon		0.02	1229	25.94		0.13	1229	158.07
2	Paddlefish		0.02	1229	25.94		0.13	1229	158.07
3	Longnose gar		0.02	1229	25.94		0.13	1229	158.07
4	American eel		0.02	1229	25.94		0.13	1229	158.07
5	Skipjack herring		0.02	1229	25.94		0.13	1229	158.07
6	Mooneye		0.02	1229	25.94		0.13	1229	158.07
7	Muskellunge		0.02	1229	25.94		0.13	1229	158.07
8	River Chub		0.02	1229	25.94		0.13	1229	158.07
9	Striped shiner		0.02	1229	25.94		0.13	1229	158.07
10	Spotfin shiner		0.02	1229	25.94		0.13	1229	158.07
11	River carpsucker		0.02	1229	25.94		0.13	1229	158.07
12	Highfin carpsucker		0.02	1229	25.94		0.13	1229	158.07
13	blue sucker		0.02	1229	25.94		0.13	1229	158.07
14	Bigmouth buffalo		0.02	1229	25.94		0.13	1229	158.07
15	Channel catfish		0.02	1229	25.94		0.13	1229	158.07
16	Flathead catfish		0.02	1229	25.94		0.13	1229	158.07
17	Brook silverside		0.02	1229	25.94		0.13	1229	158.07
18	White bass		0.02	1229	25.94		0.13	1229	158.07
19	Bluegill		0.02	1229	25.94		0.13	1229	158.07
20	Smallmouth bass		0.02	1229	25.94		0.13	1229	158.07
21	Spotted bass		0.02	1229	25.94		0.13	1229	158.07
22	Largemouth bass		0.02	1229	25.94		0.13	1229	158.07
23	Rainbow darter		0.02	1229	25.94		0.13	1229	158.07
24	Bluebreast darter		0.02	1229	25.94		0.13	1229	158.07
25	Tippecanoe darter		0.02	1229	25.94		0.13	1229	158.07
26	Logperch		0.02	1229	25.94		0.13	1229	158.07
27	Slenderhead Darter		0.02	1229	25.94		0.13	1229	158.07
28	Sauger		0.02	1229	25.94		0.13	1229	158.07
29	Walleye		0.02	1229	25.94		0.13	1229	158.07
30	Freshwater drum		0.02	1229	25.94		0.13	1229	158.07
				average HU =	25.94			average HU =	158.07

pg.2/2	OHR Focal Species	C: Fish Lock below north fixed crest			E: Rock ramp below north fixed crest (min. 50' bottom width)		
i	Common Name	Є = Fish Passage Effectiveness	Habitat Units by Species (acres)	Habitat Units Sum (Є X acres)	Є = Fish Passage Effectiveness	Habitat Units by Species (acres)	Habitat Units Sum (Є X acres)
1	Shovelnose sturgeon	0.15	1229	178.42	0.26	1229	315.30
2	Paddlefish	0.15	1229	178.42	0.26	1229	315.30
3	Longnose gar	0.15	1229	178.42	0.26	1229	315.30
4	American eel	0.15	1229	178.42	0.26	1229	315.30
5	Skipjack herring	0.15	1229	178.42	0.26	1229	315.30
6	Mooneye	0.15	1229	178.42	0.26	1229	315.30
7	Muskellunge	0.15	1229	178.42	0.26	1229	315.30
8	River Chub	0.15	1229	178.42	0.26	1229	315.30
9	Striped shiner	0.15	1229	178.42	0.26	1229	315.30
10	Spotfin shiner	0.15	1229	178.42	0.26	1229	315.30
11	River carpsucker	0.15	1229	178.42	0.26	1229	315.30
12	Highfin carpsucker	0.15	1229	178.42	0.26	1229	315.30
13	blue sucker	0.15	1229	178.42	0.26	1229	315.30
14	Bigmouth buffalo	0.15	1229	178.42	0.26	1229	315.30
15	Channel catfish	0.15	1229	178.42	0.26	1229	315.30
16	Flathead catfish	0.15	1229	178.42	0.26	1229	315.30
17	Brook silverside	0.15	1229	178.42	0.26	1229	315.30
18	White bass	0.15	1229	178.42	0.26	1229	315.30
19	Bluegill	0.15	1229	178.42	0.26	1229	315.30
20	Smallmouth bass	0.15	1229	178.42	0.26	1229	315.30
21	Spotted bass	0.15	1229	178.42	0.26	1229	315.30
22	Largemouth bass	0.15	1229	178.42	0.26	1229	315.30
23	Rainbow darter	0.15	1229	178.42	0.26	1229	315.30
24	Bluebreast darter	0.15	1229	178.42	0.26	1229	315.30
25	Tippecanoe darter	0.15	1229	178.42	0.26	1229	315.30
26	Logperch	0.15	1229	178.42	0.26	1229	315.30
27	Slenderhead Darter	0.15	1229	178.42	0.26	1229	315.30
28	Sauger	0.15	1229	178.42	0.26	1229	315.30
29	Walleye	0.15	1229	178.42	0.26	1229	315.30
30	Freshwater drum	0.15	1229	178.42	0.26	1229	315.30
			average HU =	178.42		average HU =	315.30

Dashields Summary - Connectivity Rank of Fish Passage Alternatives

Measures	**Є = Fish Passage Connectivity Є = Σ (Ei x Ui x Di /25)/n**	**Rank**	**Habitat Units**
A: Fish Lockage (aux. lock)	**0.02**	**4**	**26**
B: Vertical slot fishway below north fixed crest	**0.13**	**3**	**158**
C: Fish Lock below north fixed crest	**0.15**	**2**	**178**
E: Rock ramp below north fixed crest (min. 50' bottom width)	**0.26**	**1**	**315**

Fish Passage Connectivity Index (FPCI)

Ranking of Alternatives

Montgomery L/D

OHIO RIVER FOCAL SPECIES

i	Common Name	Scientific Name	Dashields Pool Relative Abundance	Emsworth Pool Relative Abundance	Swimming Behavior	Swimming Performance	Swimming Speed (Ucrit)	Habitat Preference	Available Habitat in Montgomery Pool[1] A Main Channel (acres)	B Secondary Channel (acres)	C Contiguous Embayment (acres)	D Tributary Mouth (up to head of slack water) (acres)	Total Available Preferred Habitat in Montgomery Pool (acres)
1	Shovelnose sturgeon	*Scaphirhyncus platorynchus*	Extirpated	Extirpated	Benthic	Medium	82	A,B,D	2858	0	0	190	3048
2	Paddlefish	*Polyodon spathula*	Listed	Listed	Pelagic	Strong	86	A,B,D	2858	0	0	190	3048
3	Longnose gar	*Lepisosteus osseus*	Occasional	Common	Pelagic	Weak	21	A,B,C,D	2858	0	22	190	3070
4	American eel	*Anguilla rostrata*	Occasional	Rare	Littoral	Weak		A,B,D	2858	0	0	190	3048
5	Skipjack herring	*Alosa chrysochloris*	Listed	Listed	Pelagic	Strong	59	A,B	2858	0	0	0	2858
6	Mooneye	*Hiodon alosoides*	Listed	Listed	Pelagic	Medium	59	A,B,C,D	2858	0	22	190	3070
7	Muskellunge	*Esox masquinongy*	Rare	Rare	Littoral	Weak		A,B,C,D	2858	0	22	190	3070
8	River Chub	*Nocomis micropogon*	Rare	Rare	Benthic	Weak		A,B,D	2858	0	0	190	3048
9	Striped shiner	*Luxilus chrysocephalus*	Rare	Rare	Benthic	Weak	33	A,B,D	2858	0	0	190	3048
10	Spotfin shiner	*Cyprinella spiloptera*	Common	Occasional	Littoral	Weak	28	A,B,C,D	2858	0	22	190	3070
11	River carpsucker	*Carpiodes carpio*	Occasional	Common	Benthic	Weak		A,B,C,D	2858	0	22	190	3070
12	Highfin carpsucker	*Carpiodes velifer*	Rare	Rare	Benthic	Weak	45	A,B,D	2858	0	0	190	3048
13	blue sucker	*Cycleptus elongatus*	Rare	Rare	Benthic	Strong	78	A,B	2858	0	0	0	2858
14	Bigmouth buffalo	*Ictiobus cyprinellus*	Listed	Listed	Benthic	Medium	63	A,B,D	2858	0	0	190	3048
15	Channel catfish	*Ictalurus punctatus*	Abundant	Abundant	Benthic	Medium	84	A,B,C,D	2858	0	22	190	3070
16	Flathead catfish	*Pylodictis olivaria*	Common	Common	Benthic	Medium	121	A,B,C,D	2858	0	22	190	3070
17	Brook silverside	*Labidesthes sicculus*	Listed	Listed	Littoral	Weak	32	A,B,C,D	2858	0	22	190	3070
18	White bass	*Morone chrysops*	Abundant	Abundant	Pelagic	Strong	120	A,B,C,D	2858	0	22	190	3070
19	Bluegill	*Lepomis macrochirus*	Abundant	Abundant	Littoral	Weak	42	A,B,C,D	2858	0	22	190	3070
20	Smallmouth bass	*Micropterus salmoides*	Abundant	Abundant	Littoral	Medium	63	A,B,C,D	2858	0	22	190	3070
21	Spotted bass	*Micropterus punctulatus*	Common	Abundant	Littoral	Medium	72	A,B,C,D	2858	0	22	190	3070
22	Largemouth bass	*Micropterus dolomieu*	Occasional	Occasional	Littoral	Medium	127	A,B,C,D	2858	0	22	190	3070
23	Rainbow darter	*Etheostoma caeruleum*	Occasional	Rare	Benthic	Weak	22	A,B,D	2858	0	0	190	3048
24	Bluebreast darter	*Etheostoma camurum*	Listed	Listed	Benthic	Weak	22	A,B,D	2858	0	0	190	3048
25	Tippecanoe darter	*Etheostoma tippecanoe*	Listed	Listed	Benthic	Weak	22	A,B,D	2858	0	0	190	3048
26	Logperch	*Percina caprodes*	Abundant	Abundant	Benthic	Weak		A,B,D	2858	0	0	190	3048
27	Slenderhead Darter	*Percina shumardi*	Rare	Rare	Benthic	Weak		A,B,D	2858	0	0	190	3048
28	Sauger	*Sander vitreum*	Abundant	Abundant	Littoral	Strong	79	A,B,D	2858	0	0	190	3048
29	Walleye	*Sander canadense*	Common	Abundant	Littoral	Strong	115	A,B,D	2858	0	0	190	3048
30	Freshwater drum	*Aplodinotus grunniens*	Abundant	Abundant	Benthic	Medium	81	A,B,C,D	2858	0	22	190	3070

[1] Aquatic habitat acreages derived from "normal"/bankful GIS data (higher level "floodstage" data questionable).

MONTGOMERY LOCKS AND DAM

	OHR Focal Species	A: Fish Lockage (aux. lock)							
i	Common Name	Є = Fish Passage Connectivity Є = Σ (Ei x Ui x Di /25)/n	Fs Size of Fishway	Fl Fishway Location	Ei Chance of Encounter	Minimum Current Velocity at Hydraulic Steps (ft/sec)	Ui Potential for Species to Use Fishway Type	Di Duration of year passable	Ei x Ui x Di
		0.02							
1	Shovelnose sturgeon		5	2	3.5	1	2	0.12	0.8
2	Paddlefish		5	1	3	1	3	0.12	1.1
3	Longnose gar		5	1	3	1	3	0.12	1.1
4	American eel		5	2	3.5	1	3	0.12	1.3
5	Skipjack herring		5	1	3	1	3	0.12	1.1
6	Mooneye		5	1	3	1	3	0.12	1.1
7	Muskellunge		5	2	3.5	1	3	0.12	1.3
8	River Chub		5	2	3.5	1	2	0.12	0.8
9	Striped shiner		5	2	3.5	1	2	0.12	0.8
10	Spotfin shiner		5	2	3.5	1	3	0.12	1.3
11	River carpsucker		5	2	3.5	1	2	0.12	0.8
12	Highfin carpsucker		5	2	3.5	1	2	0.12	0.8
13	blue sucker		5	2	3.5	1	2	0.12	0.8
14	Bigmouth buffalo		5	2	3.5	1	2	0.12	0.8
15	Channel catfish		5	2	3.5	1	2	0.12	0.8
16	Flathead catfish		5	2	3.5	1	2	0.12	0.8
17	Brook silverside		5	2	3.5	1	3	0.12	1.3
18	White bass		5	1	3	1	3	0.12	1.1
19	Bluegill		5	2	3.5	1	3	0.12	1.3
20	Smallmouth bass		5	2	3.5	1	3	0.12	1.3
21	Spotted bass		5	2	3.5	1	3	0.12	1.3
22	Largemouth bass		5	2	3.5	1	3	0.12	1.3
23	Rainbow darter		5	2	3.5	1	2	0.12	0.8
24	Bluebreast darter		5	2	3.5	1	2	0.12	0.8
25	Tippecanoe darter		5	2	3.5	1	2	0.12	0.8
26	Logperch		5	2	3.5	1	2	0.12	0.8
27	Slenderhead Darter		5	2	3.5	1	2	0.12	0.8
28	Sauger		5	2	3.5	1	3	0.12	1.3
29	Walleye		5	2	3.5	1	3	0.12	1.3
30	Freshwater drum		5	2	3.5	1	2	0.12	0.8
								Sum Ei x Ui x Di:	30.6

MONTGOMERY LOCKS AND DAM

	OHR Focal Species	B: Vertical slot fishway below north fixed crest							
i	Common Name	Є = Fish Passage Connectivity Є = Σ (Ei x Ui x Di /25)/n	Fs Size of Fishway	Fl Fishway Location	Ei Chance of Encounter	Minimum Current Velocity at Hydraulic Steps (ft/sec)	Ui Potential for Species to Use Fishway Type	Di Duration of year passable	Ei x Ui x Di
		0.13							
1	Shovelnose sturgeon		1	3	2	6.5	3	1.0	6.0
2	Paddlefish		1	2	1.5	6.5	1	1.0	1.5
3	Longnose gar		1	2	1.5	6.5	1	1.0	1.5
4	American eel		1	5	3	6.5	2	1.0	6.0
5	Skipjack herring		1	2	1.5	6.5	5	1.0	7.5
6	Mooneye		1	2	1.5	6.5	3	1.0	4.5
7	Muskellunge		1	5	3	6.5	2	1.0	6.0
8	River Chub		1	3	2	6.5	1	1.0	2.0
9	Striped shiner		1	3	2	6.5	1	1.0	2.0
10	Spotfin shiner		1	5	3	6.5	1	1.0	3.0
11	River carpsucker		1	3	2	6.5	3	1.0	6.0
12	Highfin carpsucker		1	3	2	6.5	3	1.0	6.0
13	blue sucker		1	3	2	6.5	5	1.0	10.0
14	Bigmouth buffalo		1	3	2	6.5	3	1.0	6.0
15	Channel catfish		1	3	2	6.5	3	1.0	6.0
16	Flathead catfish		1	3	2	6.5	3	1.0	6.0
17	Brook silverside		1	5	3	6.5	1	1.0	3.0
18	White bass		1	2	1.5	6.5	5	1.0	7.5
19	Bluegill		1	5	3	6.5	1	1.0	3.0
20	Smallmouth bass		1	5	3	6.5	3	1.0	9.0
21	Spotted bass		1	5	3	6.5	3	1.0	9.0
22	Largemouth bass		1	5	3	6.5	3	1.0	9.0
23	Rainbow darter		1	3	2	6.5	3	1.0	6.0
24	Bluebreast darter		1	3	2	6.5	3	1.0	6.0
25	Tippecanoe darter		1	3	2	6.5	3	1.0	6.0
26	Logperch		1	3	2	6.5	3	1.0	6.0
27	Slenderhead Darter		1	3	2	6.5	3	1.0	6.0
28	Sauger		1	5	3	6.5	5	1.0	15.0
29	Walleye		1	5	3	6.5	5	1.0	15.0
30	Freshwater drum		1	3	2	6.5	3	1.0	6.0
								Sum Ei x Ui x Di:	186.5

MONTGOMERY LOCKS AND DAM

	OHR Focal Species	C: Fish Lock below north fixed crest							
i	Common Name	Є = Fish Passage Connectivity Є = Σ (Ei x Ui x Di /25)/n	Fs Size of Fishway	Fl Fishway Location	Ei Chance of Encounter	Minimum Current Velocity at Hydraulic Steps (ft/sec)	Ui Potential for Species to Use Fishway Type	Di Duration of year passable	Ei x Ui x Di
		0.15							
1	Shovelnose sturgeon		1	3	2	1	4	1.0	8.0
2	Paddlefish		1	2	1.5	1	1	1.0	1.5
3	Longnose gar		1	2	1.5	1	2	1.0	3.0
4	American eel		1	5	3	1	3	1.0	9.0
5	Skipjack herring		1	2	1.5	1	4	1.0	6.0
6	Mooneye		1	2	1.5	1	4	1.0	6.0
7	Muskellunge		1	5	3	1	3	1.0	9.0
8	River Chub		1	3	2	1	2	1.0	4.0
9	Striped shiner		1	3	2	1	2	1.0	4.0
10	Spotfin shiner		1	5	3	1	2	1.0	6.0
11	River carpsucker		1	3	2	1	3	1.0	6.0
12	Highfin carpsucker		1	3	2	1	3	1.0	6.0
13	blue sucker		1	3	2	1	3	1.0	6.0
14	Bigmouth buffalo		1	3	2	1	3	1.0	6.0
15	Channel catfish		1	3	2	1	4	1.0	8.0
16	Flathead catfish		1	3	2	1	4	1.0	8.0
17	Brook silverside		1	5	3	1	2	1.0	6.0
18	White bass		1	2	1.5	1	4	1.0	6.0
19	Bluegill		1	5	3	1	4	1.0	12.0
20	Smallmouth bass		1	5	3	1	4	1.0	12.0
21	Spotted bass		1	5	3	1	4	1.0	12.0
22	Largemouth bass		1	5	3	1	4	1.0	12.0
23	Rainbow darter		1	3	2	1	3	1.0	6.0
24	Bluebreast darter		1	3	2	1	3	1.0	6.0
25	Tippecanoe darter		1	3	2	1	3	1.0	6.0
26	Logperch		1	3	2	1	3	1.0	6.0
27	Slenderhead Darter		1	3	2	1	3	1.0	6.0
28	Sauger		1	5	3	1	3	1.0	9.0
29	Walleye		1	5	3	1	3	1.0	9.0
30	Freshwater drum		1	3	2	1	3	1.0	6.0
								Sum Ei x Ui x Di:	210.5

MONTGOMERY LOCKS AND DAM

i	OHR Focal Species Common Name	E: Rock ramp below north fixed crest (min. 50' bottom width) Є = Fish Passage Connectivity Є = Σ (Ei x Ui x Di /25)/n	Fs Size of Fishway	Fl Fishway Location	Ei Chance of Encounter	Minimum Current Velocity at Hydraulic Steps (ft/sec)	Ui Potential for Species to Use Fishway Type	Di Duration of year passable	Ei x Ui x Di
		0.26							
1	Shovelnose sturgeon		3	3	3	2	4	1.0	12.0
2	Paddlefish		3	2	2.5	2	4	1.0	10.0
3	Longnose gar		3	2	2.5	2	3	1.0	7.5
4	American eel		3	5	4	2	4	1.0	16.0
5	Skipjack herring		3	2	2.5	2	4	1.0	10.0
6	Mooneye		3	2	2.5	2	3	1.0	7.5
7	Muskellunge		3	5	4	2	4	1.0	16.0
8	River Chub		3	3	3	2	4	1.0	12.0
9	Striped shiner		3	3	3	2	4	1.0	12.0
10	Spotfin shiner		3	5	4	2	4	1.0	16.0
11	River carpsucker		3	3	3	2	4	1.0	12.0
12	Highfin carpsucker		3	3	3	2	4	1.0	12.0
13	blue sucker		3	3	3	2	5	1.0	15.0
14	Bigmouth buffalo		3	3	3	2	4	1.0	12.0
15	Channel catfish		3	3	3	2	4	1.0	12.0
16	Flathead catfish		3	3	3	2	4	1.0	12.0
17	Brook silverside		3	5	4	2	3	1.0	12.0
18	White bass		3	2	2.5	2	4	1.0	10.0
19	Bluegill		3	5	4	2	3	1.0	12.0
20	Smallmouth bass		3	5	4	2	4	1.0	16.0
21	Spotted bass		3	5	4	2	3	1.0	12.0
22	Largemouth bass		3	5	4	2	3	1.0	12.0
23	Rainbow darter		3	3	3	2	4	1.0	12.0
24	Bluebreast darter		3	3	3	2	4	1.0	12.0
25	Tippecanoe darter		3	3	3	2	4	1.0	12.0
26	Logperch		3	3	3	2	4	1.0	12.0
27	Slenderhead Darter		3	3	3	2	4	1.0	12.0
28	Sauger		3	5	4	2	4	1.0	16.0
29	Walleye		3	5	4	2	4	1.0	16.0
30	Freshwater drum		3	3	3	2	4	1.0	12.0
								Sum Ei x Ui x Di:	372.0

pg.1/2	OHR Focal Species	A: Fish Lockage (aux. lock)			B: Vertical slot fishway below north fixed crest		
i	Common Name	Є = Fish Passage Effectiveness	Habitat Units by Species (acres)	Habitat Units Sum (Є X acres)	Є = Fish Passage Effectiveness	Habitat Units by Species (acres)	Habitat Units Sum (Є X acres)
1	Shovelnose sturgeon	0.02	3048	64.32	0.13	3048	392.04
2	Paddlefish	0.02	3048	64.32	0.13	3048	392.04
3	Longnose gar	0.02	3070	64.79	0.13	3070	394.87
4	American eel	0.02	3048	64.32	0.13	3048	392.04
5	Skipjack herring	0.02	2858	60.31	0.13	2858	367.60
6	Mooneye	0.02	3070	64.79	0.13	3070	394.87
7	Muskellunge	0.02	3070	64.79	0.13	3070	394.87
8	River Chub	0.02	3048	64.32	0.13	3048	392.04
9	Striped shiner	0.02	3048	64.32	0.13	3048	392.04
10	Spotfin shiner	0.02	3070	64.79	0.13	3070	394.87
11	River carpsucker	0.02	3070	64.79	0.13	3070	394.87
12	Highfin carpsucker	0.02	3048	64.32	0.13	3048	392.04
13	blue sucker	0.02	2858	60.31	0.13	2858	367.60
14	Bigmouth buffalo	0.02	3048	64.32	0.13	3048	392.04
15	Channel catfish	0.02	3070	64.79	0.13	3070	394.87
16	Flathead catfish	0.02	3070	64.79	0.13	3070	394.87
17	Brook silverside	0.02	3070	64.79	0.13	3070	394.87
18	White bass	0.02	3070	64.79	0.13	3070	394.87
19	Bluegill	0.02	3070	64.79	0.13	3070	394.87
20	Smallmouth bass	0.02	3070	64.79	0.13	3070	394.87
21	Spotted bass	0.02	3070	64.79	0.13	3070	394.87
22	Largemouth bass	0.02	3070	64.79	0.13	3070	394.87
23	Rainbow darter	0.02	3048	64.32	0.13	3048	392.04
24	Bluebreast darter	0.02	3048	64.32	0.13	3048	392.04
25	Tippecanoe darter	0.02	3048	64.32	0.13	3048	392.04
26	Logperch	0.02	3048	64.32	0.13	3048	392.04
27	Slenderhead Darter	0.02	3048	64.32	0.13	3048	392.04
28	Sauger	0.02	3048	64.32	0.13	3048	392.04
29	Walleye	0.02	3048	64.32	0.13	3048	392.04
30	Freshwater drum	0.02	3070	64.79	0.13	3070	394.87
			average HU =	64.27		average HU =	391.73

pg.2/2	OHR Focal Species	C: Fish Lock below north fixed crest			E: Rock ramp below north fixed crest (min. 50' bottom width)		
i	Common Name	Є = Fish Passage Effectiveness	Habitat Units by Species (acres)	Habitat Units Sum (Є X acres)	Є = Fish Passage Effectiveness	Habitat Units by Species (acres)	Habitat Units Sum (Є X acres)
1	Shovelnose sturgeon	0.15	3048	442.49	0.26	3048	781.97
2	Paddlefish	0.15	3048	442.49	0.26	3048	781.97
3	Longnose gar	0.15	3070	445.68	0.26	3070	787.61
4	American eel	0.15	3048	442.49	0.26	3048	781.97
5	Skipjack herring	0.15	2858	414.90	0.26	2858	733.22
6	Mooneye	0.15	3070	445.68	0.26	3070	787.61
7	Muskellunge	0.15	3070	445.68	0.26	3070	787.61
8	River Chub	0.15	3048	442.49	0.26	3048	781.97
9	Striped shiner	0.15	3048	442.49	0.26	3048	781.97
10	Spotfin shiner	0.15	3070	445.68	0.26	3070	787.61
11	River carpsucker	0.15	3070	445.68	0.26	3070	787.61
12	Highfin carpsucker	0.15	3048	442.49	0.26	3048	781.97
13	blue sucker	0.15	2858	414.90	0.26	2858	733.22
14	Bigmouth buffalo	0.15	3048	442.49	0.26	3048	781.97
15	Channel catfish	0.15	3070	445.68	0.26	3070	787.61
16	Flathead catfish	0.15	3070	445.68	0.26	3070	787.61
17	Brook silverside	0.15	3070	445.68	0.26	3070	787.61
18	White bass	0.15	3070	445.68	0.26	3070	787.61
19	Bluegill	0.15	3070	445.68	0.26	3070	787.61
20	Smallmouth bass	0.15	3070	445.68	0.26	3070	787.61
21	Spotted bass	0.15	3070	445.68	0.26	3070	787.61
22	Largemouth bass	0.15	3070	445.68	0.26	3070	787.61
23	Rainbow darter	0.15	3048	442.49	0.26	3048	781.97
24	Bluebreast darter	0.15	3048	442.49	0.26	3048	781.97
25	Tippecanoe darter	0.15	3048	442.49	0.26	3048	781.97
26	Logperch	0.15	3048	442.49	0.26	3048	781.97
27	Slenderhead Darter	0.15	3048	442.49	0.26	3048	781.97
28	Sauger	0.15	3048	442.49	0.26	3048	781.97
29	Walleye	0.15	3048	442.49	0.26	3048	781.97
30	Freshwater drum	0.15	3070	445.68	0.26	3070	787.61
			average HU	442.14		average HU	781.35

Montgomery Summary - Connectivity Rank of Fish Passage Alternatives

Measures	Є = Fish Passage Connectivity Є = Σ (Ei x Ui x Di /25)/n	Rank	Habitat Units
A: Fish Lockage (aux. lock)	0.02	4	64
B: Vertical slot fishway below north fixed crest	0.13	3	392
C: Fish Lock below north fixed crest	0.15	2	442
E: Rock ramp below north fixed crest (min. 50' bottom width)	0.26	1	781