Summary of Concepts at Selected Sites

Lower Maumee River Habitat Restoration Projects

P2# 499552

Great Lakes Restoration Initiative (GLRI)
Economy Act (31 U.S.C. 1535) for USEPA
Prepared by U.S. Army Corps of Engineers

January 2022

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LOWER MAUMEE RIVER HABITAT RESTORATION PROJECTS
Summary of Concepts at Selected Sites

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EXECUTIVE SUMMARY

This report has been prepared by the U.S. Army Corps of Engineers (USACE) on behalf of the U.S. Environmental Protection Agency (USEPA), in partnership with the Maumee Area of Concern Advisory Committee (MAAC) to provide preliminary planning and design for aquatic habitat restoration at three sites in the lower Maumee River. The report builds upon existing information, preliminary restoration designs, and input provided by project partners such as the University of Toledo, U.S. Geological Survey (USGS), Ohio Environmental Protection Agency (Ohio EPA), and other partners of the MAAC. Included in this report is a description of existing conditions, hydraulic analysis, and environmental analysis of the following proposed restoration projects located in the lower Maumee River:

1.0 Audubon Islands
2.0 Marengo Island
3.0 Delaware / Horseshoe Islands

Preliminary restoration designs and designs at each of these sites have been developed and include a combination of restoration measures such as invasive species removal, vegetative plantings, installation of rood wads and submerged trees, cove contouring, and chevron dike installation. The purpose of these restoration measures is to address existing impairments that have been identified in the lower Maumee River. These existing impairments include degradation of fish and wildlife populations, degradation of benthos, loss of fish and wildlife habitat, and erosion of high-quality habitats surrounding islands in the lower Maumee River. A qualitative forecast of ecological improvement at each restoration site has been formulated for comparison purposes and to optimize ecological benefits and predefined performance criteria.

An investigation into the challenges of project implementation, as well as potential environmental effects from proposed restoration activities, is provided for each restoration project. An inventory of challenges unique to each site, as well as environmental permitting and environmental compliance requirements have been identified, which will need to be further addressed during final design and construction.

It is recommended that the proposed Preliminary designs contained within this report for each of the three restoration sites should be considered further for ecosystem restoration and habitat restoration purposes. Furthermore, these designs were subject to preliminary hydraulic analysis, which should be taken into account when further design work begins. This report is designed to be used in conjunction with other studies to holistically evaluate the benefit of restoration sites described within this report.

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1.0 Introduction

1.1 Study Authority

This project is funded through the United States Environmental Protection Agency's (USEPA) Great Lakes Restoration Initiative (GLRI) Program under the authority of the Economy Act (31 U.S.C. 1535) for USEPA by the United States Army Corps of Engineers (USACE). This authorizes the USACE to provide goods and services to the USEPA to meet requirements under the GLRI program.

1.2 Background

As described in The Great Lakes Action Plan III, "The Great Lakes Restoration Initiative (GLRI or the Initiative) was launched in 2010 as a non-regulatory program to accelerate efforts to protect and restore the largest system of fresh surface water in the world, and to provide additional resources to make progress toward the most critical long-term goals for this important ecosystem (USEPA, 2019)." As further explained:

> *The GLRI has been a catalyst for unprecedented federal agency coordination, which has in turn produced unprecedented results. Under GLRI Action Plan III, the GLRI federal agencies that make up the GLRI Interagency Task Force and Regional Working Group will continue to use GLRI resources to strategically target the biggest threats to the Great Lakes ecosystem and associated human health issues. By adding GLRI resources to federal agency base budgets and using the combined resources to work with nonfederal partners to implement protection and restoration projects, GLRI federal agencies will continue to accelerate progress toward achieving long-term goals. To guide this work during the next five years, GLRI federal agencies have developed GLRI Action Plan III. All proposed federal actions are subject to final Congressional appropriations (USEPA, 2019).*

The projects that are implemented with GLRI funding are aligned with the following five Focus Areas:

1. Toxic Substances and Great Lakes Areas of Concern (AOCs)
2. Invasive Species
3. Nonpoint Source Pollution Impacts on Nearshore Health
4. Habitat & Species
5. Foundations for Future Restoration Actions

The funding for this project is related to Focus Area 1 for projects, studies, and activities that contribute to the eventual delisting of the Great Lakes AOCs, specifically, the Maumee AOC.

In 1987, the Great Lakes Water Quality Agreement (GLWQA) designated 43 areas of concern across the Great Lakes basin, including the Maumee AOC that drains to Lake Erie in Ohio. The Maumee AOC is comprised of 787 square miles, including several watersheds, which makes it one of the largest AOCs in the United States.

The Maumee AOC was originally identified as the area extending from Waterville located at river mile 22.8 downstream to Maumee Bay. In 2010, the AOC boundary was modified to include the headwaters of Swan Creek and Tenmile Creek. The Maumee AOC comprises about 800 square miles at the western end of Lake Erie (Figure *1*). Drainage of the pre-settlement Great Black Swamp, urbanization, shoreline armoring and alteration, and dredging have degraded the physical, biological, and chemical composition and ecology of the Maumee River and nearby tributaries to Lake Erie. Increased sedimentation within the Maumee River has also led to the loss of macrophyte beds that serve as important nursery habitat for macroinvertebrates and fish populations.

Ten Beneficial Use Impairments (BUIs) were initially identified in the Maumee AOC, one BUI was removed in 2015, and two more are expected to be removed in the near future. In the United States, the USEPA implements the Great Lakes Water Quality Agreement (GLWQA) through its Great Lakes National Program Office. Restoration and delisting is achieved through the identification and implementation of management actions to address each BUI.

In May 2018 and March 2019, the Maumee AOC Advisory Committee (MAAC), Subcommittee on Aquatic Habitat and Species, hosted workshops that included 50+ research scientists, engineers, and environmental managers to identify solutions to address the Maumee AOC and work toward the removal of BUIs and ultimately remove the Maumee AOC from the list of Great Lakes AOCs. The May 2018 workshop included a session that focused on the lower Maumee River and Maumee Bay. One of the outcomes of this workshop was the consensus among participants that, to provide realistic and feasible restoration recommendations for removing impairments to aquatic habitat and fish and macroinvertebrate communities, it would be essential to identify main-channel fluvial habitats that support or could be enhanced to support river biota.

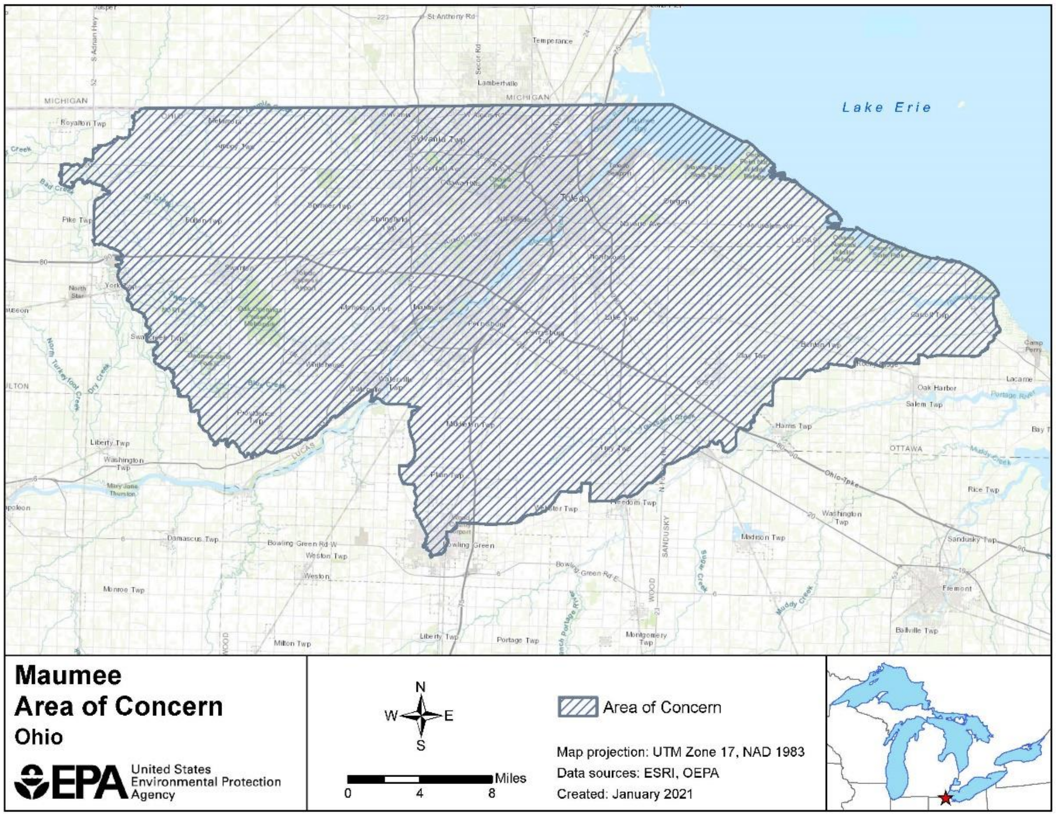


Figure 1: Maumee AOC Boundary Map, source USEPA.

1.3 Study Purpose and Need

This report evaluates the feasibility of an array of measures and project sites to implement aquatic ecosystem restoration in the lower Maumee River. This area of the river is an important aquatic resource which once consisted of wetlands and open water habitat that supports fish, migratory birds, and other wildlife. The habitat provided by formerly extensive wetlands has been degraded over the last two centuries through urbanization, industrialization, erosion, loss of wetland areas, and has become dominated by numerous invasive and exotic species. There is a need to improve the aquatic environment within the Maumee AOC which has been severely degraded and needs restoration.

Preliminary designs for proposed aquatic ecosystem restoration projects in the lower Maumee river have been developed to assist with increasing aquatic habitat heterogeneity, providing habitat for native species, stabilizing eroding riverbanks, and protect islands from further erosion.

The purpose of this study is to identify potential in-channel restoration measures and alternatives that address three BUIs in the Maumee River. The BUIs to be targeted are:

BUI 3 - Degradation of fish and wildlife populations
BUI 6 - Degradation of benthos
BUI 14 - Loss of fish and wildlife habitat

The fish and wildlife portions of BUI 3 and 14 have separate BUI restoration targets. The Maumee River projects contained in this report are being developed to specifically address the fisheries and aquatic components of these BUIs. Other projects that focus on restoration targets other than the aquatic components of these BUIs can be found listed in the Maumee AOC Data Management and Delisting System (DMDS) (https://partnersforcleanstreams.org/projects/data-management-and-delisting-system).

The Ohio Environmental Protection Agency (OHIO EPA) has established restoration targets for each BUI. The Fish Index of Biotic Integrity (FIBI), Modified Index of Well Being (MIwb), the Invertebrate Community Index (ICI), and Qualitative Habitat Evaluation Index (QHEI) for the aquatic components of for these three BUIs.

The restoration activities proposed in this report are designed to support the goal of improving the quality of the aquatic environment in the Maumee AOC. The purpose of the environmental restoration projects proposed in this report are to address the BUIs listed above and support the delisting of the AOC.

The proposed project objectives and restoration activities were developed cooperatively by the Maumee AOC Advisory Committee, the USGS, the University of Toledo, the USACE Buffalo District, and other involved agencies and organizations.

1.4 Feasibility Study Goal

The goal of this feasibility study is to present an array of preliminary concept designs and measures aimed at restoring degraded fish populations (BUI 3), degradation of benthos (BUI 6) and loss of fish habitat (BUI 14) in the Maumee River AOC.

1.5 Pertinent Reports and Studies

Several studies have been conducted that are useful in establishing baseline conditions. Brief descriptions of relevant documents are presented below.

- *Lower Maumee River Restoration Design Concepts,* March 2021. This report was prepared by University of Toledo, Bowling Green State University, and Hull & Associates, LLC, for the MAAC and Ohio EPA – This report presents preliminary ideas and concepts for restoration activities at select locations within the Maumee AOC to help address the BUIs. Restoration locations identified within the Maumee AOC include Audubon Islands, Main Channel, Grassy Island, and Delaware/Horseshoe Islands Complex. Restoration activities proposed include plantings, invasive species removal, root wads and submerged trees, dredging coves, wing dikes, and chevron dikes. Challenges and preliminary costs for these projects are also provided.

- *Identification of Optimal Sites for Maumee AOC Restoration Actions in the Lower Maumee River,* 2019, Bowling Green State University and University of Toledo – This report provides a baseline survey of the substrate, vegetation, fish that currently exist in the Maumee River AOC. It also provides locations and recommendations to augment and protect habitat in the Maumee River. Recommendations include preservation and creation of islands in the main channel of the river through the installation of structures such as rip rap dikes, SAV growth in island coves, native vegetation plantings, and installation of woody debris for structure/cover for fish.

In addition to the studies mentioned above a bank swallow survey, walleye spawning survey, and hydrology and hydraulic investigations have been performed to determine what types of impacts, both positive and negative, would occur if the proposed projects were to be constructed.

1.6 Lower Maumee River Study Area

The Maumee River watershed is in northwestern Ohio and drains 5,024 square miles in Ohio and flows through all or part of 18 counties (Ohio EPA, 2020). The Lower Maumee River runs through the center of the Maumee AOC. The geographic scope of the study area encompasses the main-channel and riparian habitats of the Lower Maumee River between Perrysburg at river mile 15 downstream to river mile 7 (near I-75 bridge crossing) (Figure 2).

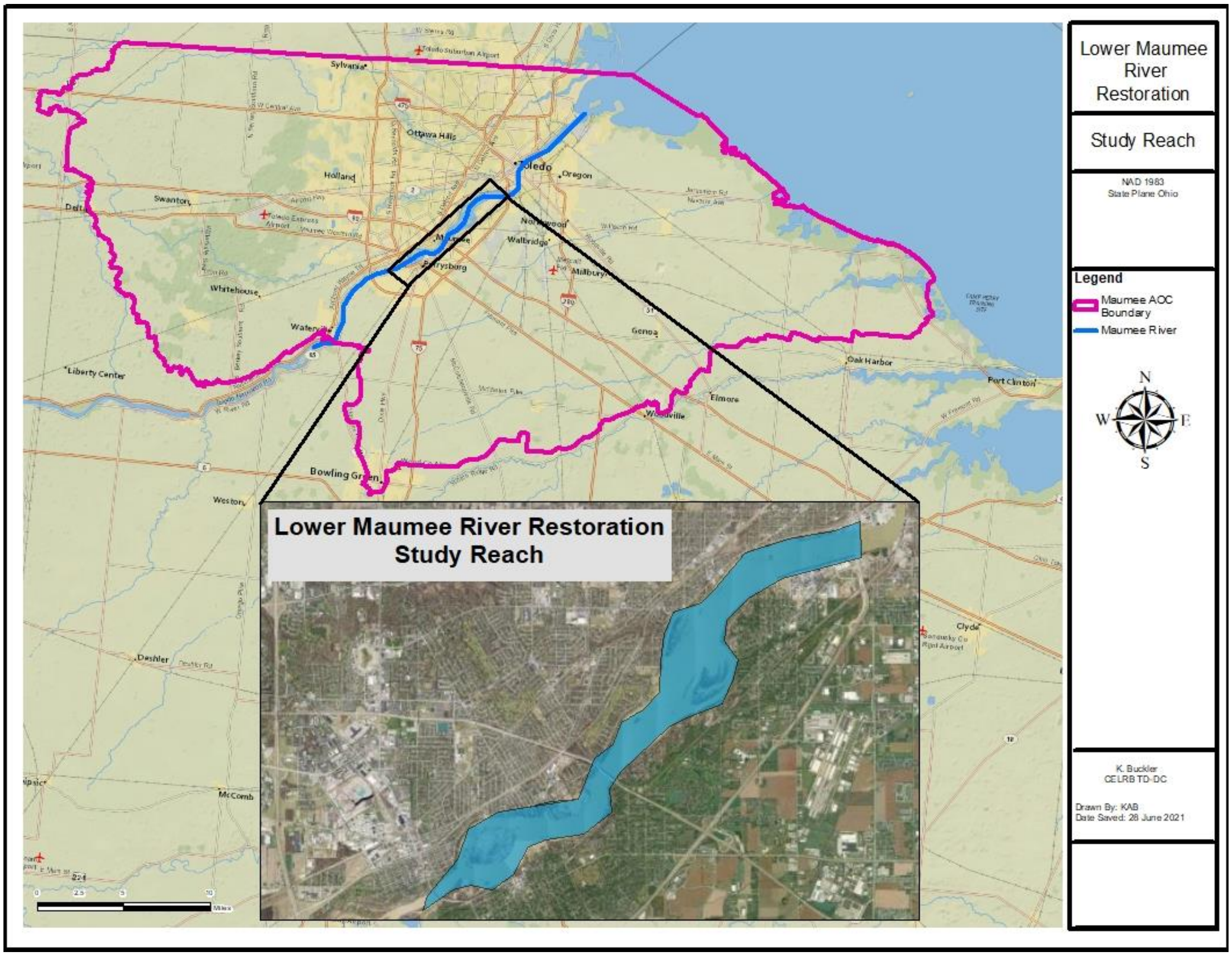


Figure 2: Lower Maumee River Study Reach.

Historically, much of northwest Ohio consisted of a large wetland complex of glacial origin known as the Great Black Swamp (Figure 3). This area was not continuous swamp but was characterized by a variety of vegetation types. Habitats known to exist included: deciduous swamp forests; beach ridges; oak openings (globally rare); wet prairies; and marshes, which happened to be particularly extensive along the Lake Erie shoreline between Toledo and Sandusky. In the 1850's, an organized effort to settle the area was spurred on by the development of railroads and use of drainage tile to effectively drain the Great Black Swamp, making the land available for agricultural use. In addition, due to rapid urbanization of the entire Maumee Bay region, large portions of native habitats have been lost.

Figure 3: Historical extent of the Great Black Swamp, source OHSHPO.

The U.S. Geological Survey delineated the Lower Maumee Watershed as an eight-digit hydrologic unit code (HUC) with an identified code of 04100009. The Maumee River is the largest tributary in the United States and Canada that discharges into Lake Erie, discharging just under 24 percent of the surface water that flows into Lake Erie. More sediment enters the Great Lakes System through the Maumee River than through any other Great Lakes tributary.

2.0 Existing Conditions and Significance of Maumee River

The Maumee River and its watershed are used for a variety of agricultural, industrial, and recreational purposes in Northwest Ohio. Four Ohio municipalities draw drinking water from the Maumee River (Ohio EPA, 2014). The 22.8 mile stretch of the Lower Maumee River encompassed by the Maumee AOC is home to nearly a dozen Metroparks and recreational areas, three boat launches, and 14 official access points for fishing, kayaking, and canoeing. The annual walleye (*Sander vitreus*) run that occurs from March – April is the largest walleye run east of the Mississippi River.

Despite historical degradation, the Maumee River maintains biological value for a variety of organisms. Among the three riverine stocks of larval walleye that migrate into Lake Erie (Maumee, Detroit, and Sandusky Rivers), the Maumee River contributes the greatest number of larval walleye (DuFour et. al, 2015). Best Management Practices that have been instituted in the watershed have improved water quality and have improved larval fish diversity in recent decades (Mapes et. al, 2015).

2.1 Physical/Natural Environment

2.1.1 Air Quality

The U.S. Environmental Protection Agency (USEPA) has developed maximum allowable concentrations of pollutant discharges into the air – referred to as National Ambient Air Quality Standards. Monitoring parameters include ozone, PM 2.5 particulates, PM 10 particulates, SO2, carbon monoxide, lead, and nitrogen dioxide. Each state has developed ambient air quality control standards that either be the same, or more restrictive, than the USEPA standards. Air quality conditions in the vicinity of the Lower Maumee project area do not currently contravene established air quality standards (OHIO EPA 2021).

2.1.2 Water Quality

Generally, as the Maumee River flows toward Lake Erie through low, flat agricultural land, its waters degrade in quality as a considerable sediment load is collected before passing through Toledo, where urban runoff/discharges further reduce river water quality. A low level of dissolved oxygen, as well as elevated levels of coliform bacteria, nutrients, turbidity, suspended solids, and discharges of heavy metals and pesticides, also degrade water quality. The Maumee River's water quality is poorest in the lower river, followed by the Maumee Bay waters, which then improve lakeward. The waters of Maumee Bay are more turbid than the lake, but less turbid than at the mouth of the Maumee River. Water quality violations of dissolved oxygen and fecal coliform are frequently recorded in the Maumee River and Bay. The main reasons for violations are combined and sanitary sewer overflows, urban runoff, failed septic systems, and upstream non-point source inputs (OHIO EPA, 2017).

The lower Maumee River has been identified as part of a Great Lakes AOC by the International Joint Commission. Identified BUIs include restriction on fish consumption, degradation of fish populations, fish tumors and other deformities, degradation of benthos, restriction on dredging activities, eutrophication or undesirable algae, beach closings, degradation of aesthetics, and loss of fish habitat (OHIO EPA, 2017). Most are caused by historic, residual and some remaining watershed activities, habitat modifications, and contaminants. The Maumee AOC Advisory Committee, facilitated by Partners for Clean Streams have developed and are pursuing remedial action plans to address these impairments.

2.1.3 Geology and Physiography

The Lower Maumee project area is located in the glaciated portion of Ohio. In this region of Ohio, the bedrock surface is buried under mainly glacial sediments that can be several-hundred-feet thick (ODNR, 2003). The land surface was smoothed by glaciation and masks a complexly dissected, underlying bedrock surface (Figure 4).

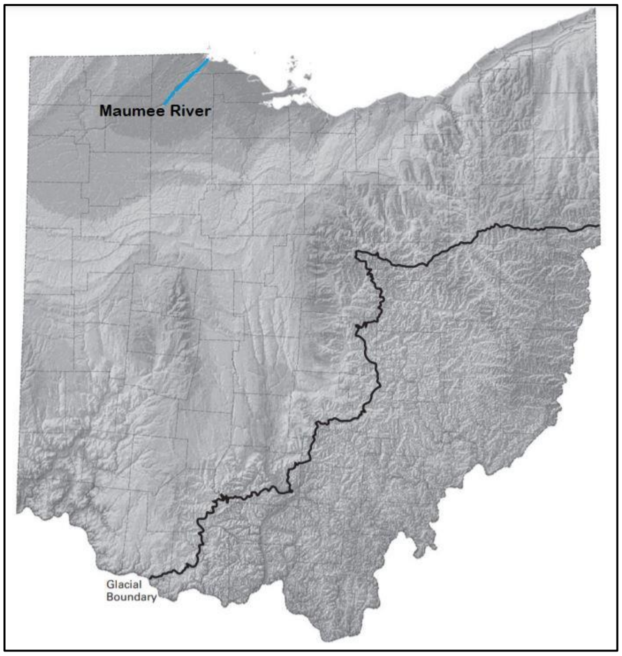


Figure 4: Shaded bedrock topography map of Ohio (Darker shading near the Maumee River indicates bedrock at lower elevations). Source, ODNR.

2.1.4 Fish and Wildlife Populations

2.1.4.1 Bank Swallow Habitat Study

In 2021, the University of Toledo completed an assessment of bank swallow population size and nesting habitat along Ewing Island (part of the Audubon Island complex). Bank swallow nesting habitat is typically characterized as vertical banks, cliffs, or bluffs composed of crumbling, erodible soils (Garrison and Turner, 2020).

When selecting a breeding site, bank swallows first select a colony and then a burrow location (Garrison and Turner, 2020). Breeding site fidelity can be relatively low because of the ephemeral nature of the breeding substrate (bluffs, banks, cliffs, etc.) due to erosion.

The University of Toledo conducted two boat surveys on 1 July and 20 July 2021. Each survey lasted two hours and consisted of close observation of the shoreline of Audubon Island State Nature Preserve and all islands and river shorelines upriver about two miles and downriver about 0.75 miles (Figure 5).

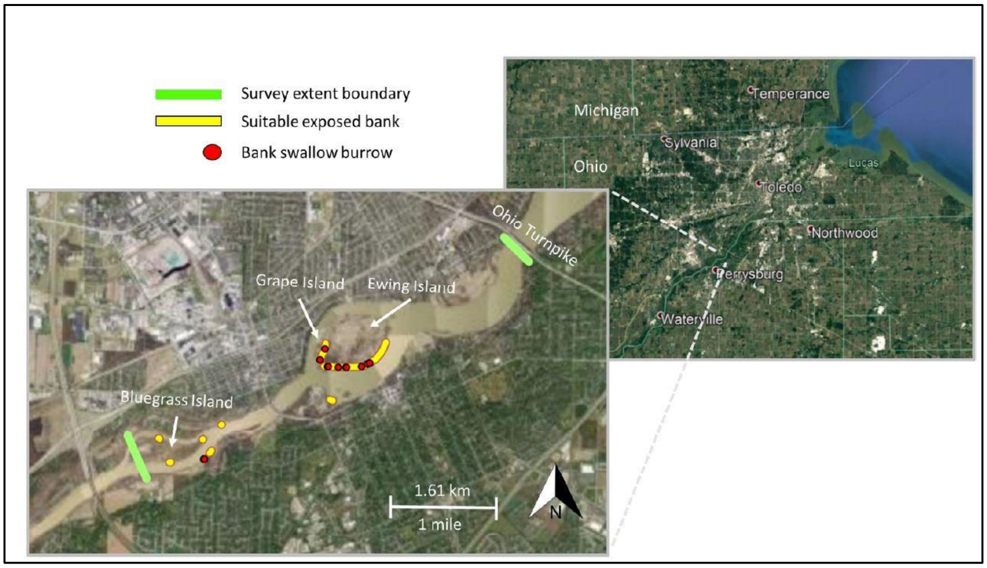


Figure 5: Bank swallow survey area and burrow locations. University of Toledo, 2021.

2.1.4.1.1 Survey Results

The surveyors observed a total of 15 burrows that were likely excavated and used for nesting attempts by bank swallows in the 2021 nesting season. Of those burrows, 13 were located on Ewing island, and two were located on the south shoreline of the Maumee River on a relatively small stretch of exposed bank.

The surveyors observed no evidence of current nesting by bank swallows and observed no adult or juvenile bank swallows in the survey area during both surveys. This lack of observation could mean that (1) nesting in 2021 was unsuccessful and adults move on shortly after failure, (2) there was successful nesting in 2021 that occurred earlier than normal, or (3) there was successful nesting, but post-fledging family groups were occupying areas not observable from the water.

2.1.4.1.2 Management recommendations

Any management action that alters or removes the exposed banks of Ewing Island would not have a measurably negative impact on the regional bank swallow population. Further, given the low productivity and frequently flooded nesting area on Ewing Island, it is possible that removing the eroding bank habitat would remove an ecological trap and would have a slight positive impact on the regional population (Streby, 2021). Any management actions that alter or remove this exposed bank at Ewing Island should be initiated prior to 15 May or after 1 July to avoid disrupting active nesting attempts (Streby, 2021).

2.1.4.2 Walleye Spawning Habitat Report

The Maumee River is one of three Lake Erie tributaries that contribute to Lake Erie larval walleye (*Sander vitreus*) production (DuFour et al., 2015). The Maumee River also supports one of the largest populations of migrating walleye east of the Mississippi River during the spring spawning run.

In the Maumee River, known spawning grounds start at about 5-20 miles upstream of the mouth of the river and continue 15.5 miles upstream to the Grand Rapids Dam (Figure 6).

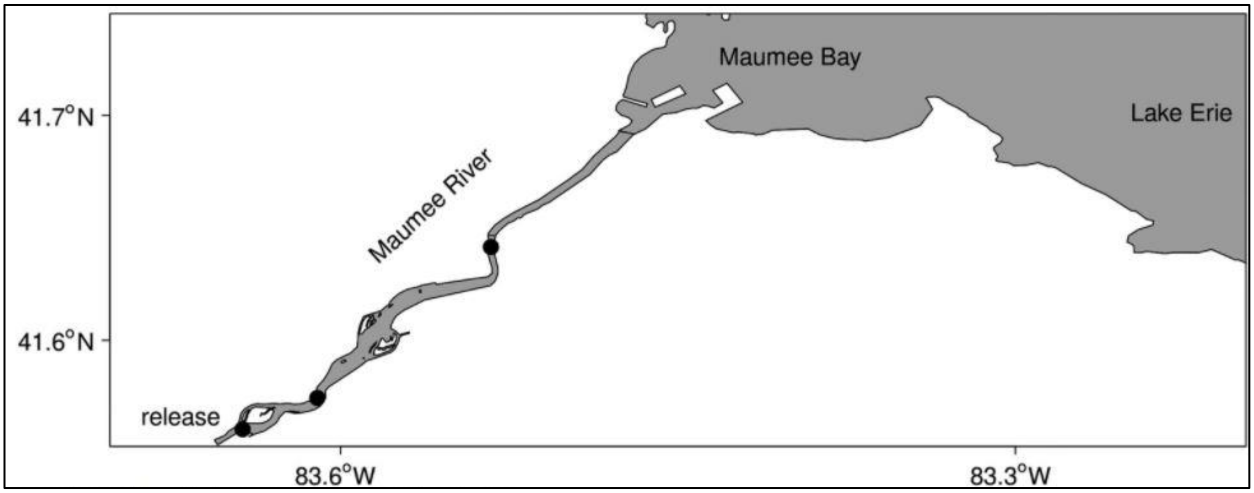


Figure 6: Walleye spawning grounds. Black dots known spawning grounds. Source, Schmidt et al. 2020.

Within this stretch of the Maumee River, ideal substrate, depth, and velocity conditions for walleye spawning are present (Schmidt et al., 2020). Schmidt et al. (2020) classified nearly all the substrate surrounding Audubon Islands as gravel substrates (Figure 7). Schmidt et al. integrated this substrate data along with depth and velocity measurements into two habitat suitability (HSI) models to classify Maumee River walleye spawning habitat conditions. The two HSI models indicated that under spring flow conditions, there was habitat around the Audubon Islands complex that was considered "moderate" suitability for walleye spawning (Figure 8 and Figure 9).

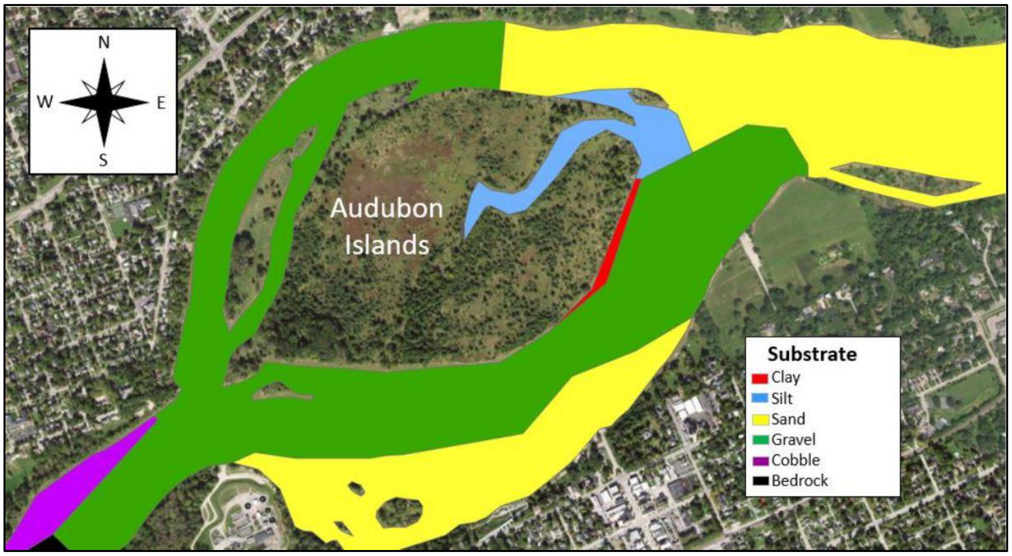


Figure 7: Substrate type delineations around the Audubon Islands used in Schmidt et al., 2020.

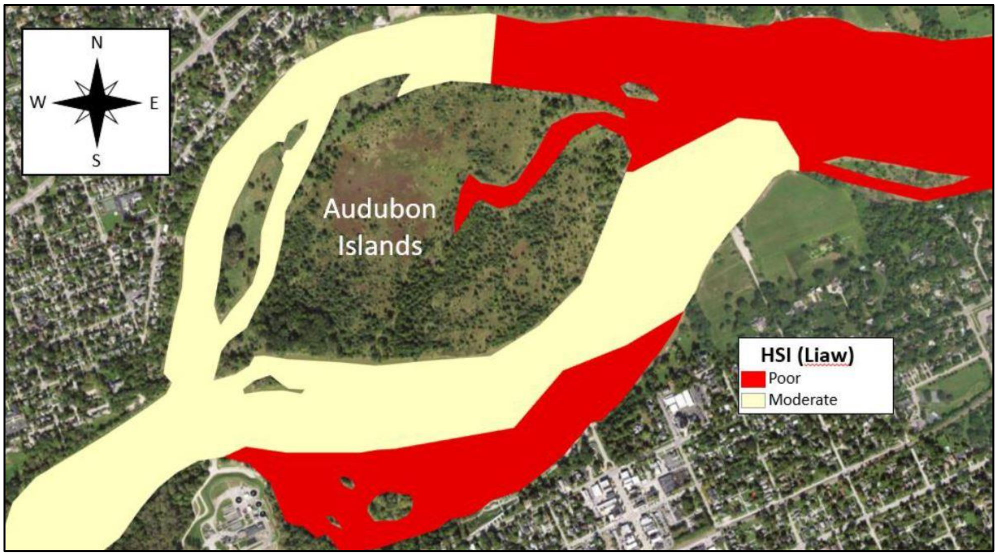


Figure 8: Output of Liaw HSI model for walleye spawning around Audubon Islands at median spring discharge.

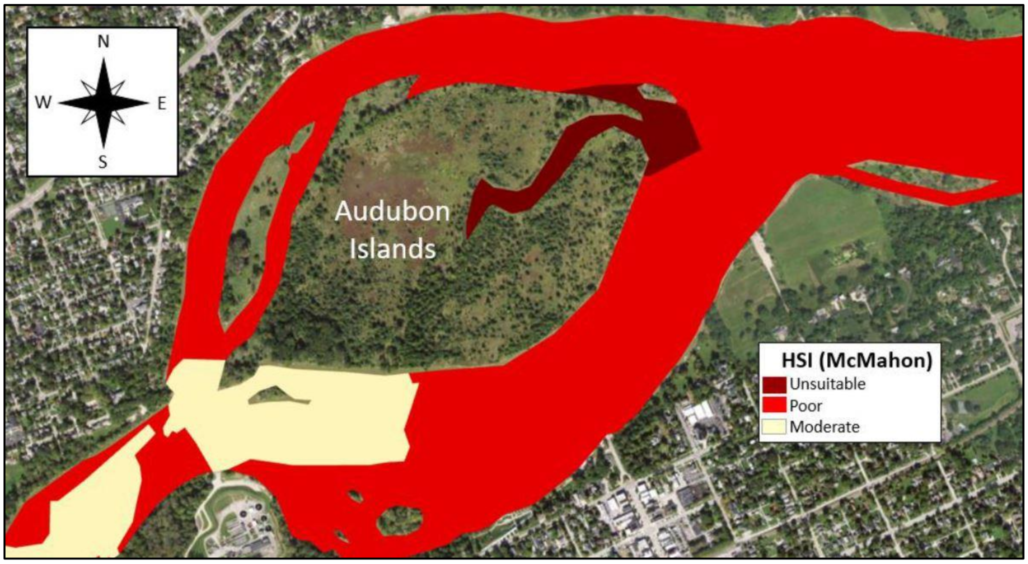


Figure 9: Output of McMahon HSI model for walleye spawning around Audubon Islands at median spring discharge.

Management Recommendations

Based on the HSI model outputs, it is assumed that walleye spawning habitat is present throughout the Audubon Island complex. All the proposed in-water preliminary restoration designs around the Audubon Islands complex, except for the preliminary cove designs, could potentially modify existing walleye spawning habitat. Therefore, the University of Toledo (UT) recommends avoiding any restoration activity that could substantially modify this spawning habitat.

Restoration projects that include the installation of woody debris, engineered log jams, rock barrier reefs, and planting of live or rooted stakes and wetland plugs along the shorelines of the Audubon Islands fall within or near areas defined as “moderately” suitable spawning habitat for walleye. The potential impact these projects can have on walleye spawning activities could vary depending on the type of installation, the method of installation, the in-water footprint of the installation, and the timing of construction. Depending on the size of the in-water habitat features, these habitat features could have a either a very low or a moderate effect on river hydrology. For example, constructing short rock barrier reefs would have a larger impact on the river’s hydrology than the installation of riparian vegetation. The placement of dredged sediments could also have a significant impact on walleye spawning; therefore, it is recommended that no dredged sediments be place near the spawning grounds.

The precise impacts of the existing preliminary restoration designs on walleye habitat will not be fully known without a detailed study of the hydrologic effects of proposed preliminary restoration designs. Therefore, it is important that any of the proposed preliminary restoration designs do not involve construction activities or the installation of structures that could cause major disturbances to river hydrology, geomorphology, or water quality. UT researchers also suggest avoiding construction of rocky dike structures in the Audubon Islands reach given their potential to redirect flows and modify sedimentation processes. If rocky dike structures are carried forward to the design phase, UT recommends a detailed assessment to ensure that they will not affect the high-quality cobble and gravel substrates located around the Audubon Islands complex.

Disturbing the river during critical spawning periods should be avoided. Any restoration project that involves in-water work should not take place immediately before or during the walleye spawning run. The existing in-water work restriction from 15 March – 30 June should be strictly adhered to. It is also recommended that biologists familiar with walleye ecology be consulted throughout the restoration project design and implementation.

2.1.4.3 Fisheries

The Western Basin of Lake Erie, including Maumee Bay and River, supports an important commercial and sport fishery. Important sport fish, in terms of the number of fish harvested in District 1 (Western Basin) include yellow perch, walleye, white bass, white perch, channel catfish, freshwater drum, smallmouth bass, steelhead trout, and to a lesser extent largemouth bass, rock bass, bluegill, chinook salmon, white crappie and round goby (Ohio Division of Wildlife [ODNR], 2021). In terms of hours spent by sport fisherman pursuing these species, walleye, yellow perch, smallmouth bass, largemouth bass, and white bass comprise the most popular species sought, with the others listed above representing primarily incidental catches (ODNR, 2021). Fish species comprising the commercial catch in District 1 by pounds harvested include white perch, white bass, yellow perch, channel catfish, freshwater drum, quillback, buffalo, lake whitefish, carp, suckers, bullhead, gizzard shad, goldfish, and burbot. Other species present in the Western Basin that comprise the forage fish base include troutperch, emerald shiner, gizzard shad, spottail shiner, rainbow smelt, alewife, and silver chub. Diet composition studies showed the primary diet of walleye and white bass in the Western Basin to be comprised of gizzard shard and emerald shiner (ODNR, 2021). Sport fish sought in the Maumee River generally included walleye and white bass (ODNR, 2021).

Both Maumee Bay and the Maumee River provide spawning and/or nursery habitat for a number ofthe above-mentioned fish species.

2.1.4.4 Threatened, Endangered, and Candidate Species

A review of the U.S. Fish and Wildlife Service Information for Planning and Consultation website (accessed in December 2021) indicates that the project lies within the range of 11 federally listed threatened, endangered, and candidate species. Table *1* provides the species and general information concerning their habitat preferences.

Table 1: Federally listed threatened and endangered species within the project reach

Species	**Federal Status**	**Habitat**
Mammals		
Indiana bat (*Myotis sodalis*)	Endangered	Hibernates in caves and mines. Summer roost in live or dead trees with peeling (exfoliating) bark, cracks, or crevices. Stream corridors, riparian areas, and upland woodlots provide forage sites.
Northern long-eared bat (*Myotis septentrionalis*)	Threatened	Hibernates in caves and mines. Autumn swarms in surrounding wooded areas. Late spring and summer forages and roosts in upland forests.
Birds		
Kirtland's warbler (*Setophaga kirtlandii*)	Endangered	Migrate along Lake Erie shoreline through Ohio in late April-May and late August-early October.
Red knot (*Calidris canutus rufa*)	Threatened	Migrating and wintering knots use marine habitats – beaches, lagoons, mudflats, estuaries – that contain an abundance of prey.
Flowering plants		
Eastern prairie fringed orchid (*Platanthera leucophaea*)	Threatened	Occurs in a wide variety of habitats, from mesic prairie to wetlands such as sedge meadows, marsh edges, even bogs. It requires full sun for optimum growth and flowering and a grassy habitat with little or no woody encroachment.
Reptiles		
Eastern massassauga (*Sistrurus catenatus*)	Threatened	Massasaugas live in wet areas including wet prairies, marshes, fens, sedge meadows, peatlands, and low areas along rivers and lakes. Massasaugas also use adjacent uplands (shrubland, open woodlands, prairie) during part of the year.
Clams		
Northern riffleshell (*Epioblasma torulosa rangiana*)	Endangered	Found in a wide variety of streams. It buries itself in bottoms of firmly packed sand or gravel with its feeding siphons exposed.
Rayed bean (*Villosa fabalis*)	Endangered	Lives in smaller, headwater creeks, but it is sometimes found in large rivers and wave-washed areas of glacial lakes. Prefers gravel or sand substrates, and is often found in and around roots of aquatic vegetation.
Insects		
Karner blue butterfly (*Lycaeides melissa samuelis*)	Endangered	Karner blue butterflies are found in the northern part of the wild lupine's range.
Monarch butterfly (*Danaus plexippus*)	Candidate	During the breeding season, monarchs lay their eggs on their obligate milkweed host plant (primarily *Asclepias* spp).

Rusty patched bumble bee (*Bombus affinis*)	Endangered	Lives in a variety of habitats, including prairies, woodlands, marshes, farms, parks and gardens.

While the bald eagle (*Haliaeetus leucocephalus*) is no longer a federally listed species, it is afforded protection under both the Bald and Golden Eagle Protection Act and the Migratory Bird Treaty Act. There is a known bald eagle nest site on Ewing Island; therefore, measures must be taken to reduce impacts to the nesting pair.

2.1.5 Climate Change

A literature review has been included to summarize peer reviewed science regarding natural and human driven climate trends in the study region. A synthesis of peer reviewed climate literature is available from the Corps of Engineers for the Great Lakes Region and is referenced as the primary source of information in this literature review (USACE, 2015). In general, temperatures, precipitation, and streamflow have all been noted to increase throughout the Great Lakes Region, although there is less consensus amongst studies of precipitation and streamflow. The trends and literary consensus found within observed and projected hydrometerological datasets, as presented in the synthesis of peer reviewed climate literature available from the Corps of Engineers for the Great Lakes Region (USACE, 2015).

Historic, observed temperatures are noted to increase throughout the region, although some studies of seasonality show a decrease in fall or winter temperatures. Although observed precipitation increases overall, several studies showed variability within the region, with lower increases or decreases towards the northwest and greater increases in Michigan and western New York. Finally, several studies noted increases in observed streamflow in some areas of the region, while other areas showed no significant trends.

There is strong consensus in the literature that air temperatures will increase in the study region over the next century. The projected increase in mean annual air temperature ranges from 2.7 to 7.2°F by the latter half of the 21st century (ELPC, 2019). Reasonable consensus is also seen in the literature with respect to projected increases in extreme temperature events, including more frequent, longer, and more intense summer heat waves.

Projections of precipitation in the study area are less certain than those associated with air temperature. Most of the studies project increases, but there are some studies which project decreases. Some studies project variability in trends within the region or by season. Similarly, while the projections tend toward more intense and frequent storm events than the recent past, some projections show a reduction in the frequency and intensity of storms in parts of the Great Lakes Region.

Significant uncertainty exists in hydrologic projections for this region. In some cases, projections generated by coupling General Circulation Models (GCMs) with macro–scale hydrologic models indicate a reduction in future streamflow, but in other cases results indicate a potential increase in streamflow in the study region.

2.2 Riverine and Riparian Conditions

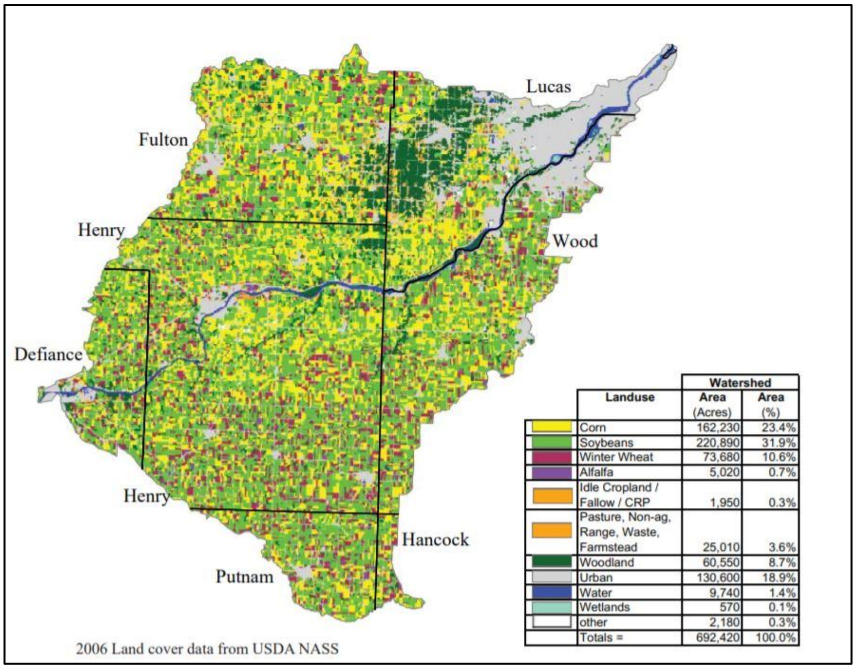
2.2.1 Maumee River Watershed Characteristics

The Lower Maumee River Watershed extends across the Major Land Resource Area (MLRA) 99. This MLRA is a nearly level glacial plain with a few scattered ridges of sandy soils that represent past shorelines and moraines (NRCS, 2009).

Land Use

According to the USDA-NRCS National Resources Inventory (NRI), from 1982 to 1997, there was an increase of about 25,400 acres of urban/built land, representing about 3.7 percent of the Lower Maumee Watershed (NRCS, 2009). According to the NRI, in 1997, the watershed consisted of about 67 percent cropland, 1 percent pastureland, 6 percent forestland, 1.5 percent minor cover/uses, 12 percent rural transportation, 1 percent water, less than 1 percent Conservation Reserve Program, and about 6 percent urban/built-up land.

In 2006, the watershed consisted of about 67 percent cropland, 3.6 percent pastureland, and urban/build land accounted for about 18.9% of the watershed area (Figure 10).



		Watershed	
	Landuse	Area (Acres)	Area (%)
🟨	Corn	162,230	23.4%
🟩	Soybeans	220,890	31.9%
🟥	Winter Wheat	73,680	10.6%
🟪	Alfalfa	5,020	0.7%
🟧	Idle Cropland / Fallow / CRP	1,950	0.3%
🟧	Pasture, Non-ag, Range, Waste, Farmstead	25,010	3.6%
🟩	Woodland	60,550	8.7%
⬜	Urban	130,600	18.9%
🟦	Water	9,740	1.4%
🟦	Wetlands	570	0.1%
☐	other	2,180	0.3%
	Totals =	692,420	100.0%

2006 Land cover data from USDA NASS

Figure 10: Land use map. NRCS, 2009.

2.2.2 Maumee Area of Concern Status

The Maumee AOC is comprised of 787 square miles, including several watersheds draining to Lake Erie, making it one of the largest AOCs in the United States.

Originally, the Maumee AOC had 10 BUIs. One BUI, Added Costs to Industry or Agriculture, was removed in 2015. The nine remaining BUIs, listed below, are impairing waterways that ultimately flow into Lake Erie.

Sample data collected by Ohio EPA in 2012 indicate the lacustuary portion of the Maumee River is impaired for fish populations, benthic populations, and fish habitat. The lacustuary is defined as the lower 15 miles of the river. On average, the lacustuary reaches 90% of the target for the IBI and 98% of the target for the MIwb. There are very few intolerant fish species and proportionally too many sunfish species. Consistently high omnivore metric scores suggest impact of physical and chemical stressors and the high percentages of pioneering species suggest an unstable environment affected by anthropogenic stress. Impaired fish metrics reflect the urban landscape, dredging of the federal shipping channel, and the impounded nature of the lacustuary. Benthic populations are severely impaired, reaching only 34% of the target ICI score. The ICI at impaired sites scored particularly poor for the metrics assessing sensitive taxa, percent gatherers, mayfly taxa, Diptera, and percent taxa other than Diptera. Fish habitat is also degraded, reaching 83% of the target QHEI score, but a detailed assessment of the reasons for impairment is not available.

Remaining BUIs

- Restrictions on Fish and Wildlife Consumption
- Degradation of Fish and Wildlife Populations
- Fish Tumors or other Deformities
- Degradation of Benthos
- Restrictions on Dredging Activities
- Eutrophication or Undesirable Algae
- Beach Closings
- Degradation of Aesthetics
- Added Costs to Agriculture or Industry (*Removed 2015)*
- Loss of Fish and Wildlife Habitat

The three Maumee AOC BUIs that focus on impairments to the biological communities and associated habitats are: BUI 3 (Degradation of fish and wildlife populations), BUI 6 (Degradation of benthos), and BUI 14 (Loss of fish and wildlife habitat).

The status of the fish portion of BUI 3 is based on the scores of the Index of Biotic Integrity (IBI) and the Modified Index of Well-being (MIwb) as established by the OHIO EPA. The beneficial use is considered restored when average IBI and average MIwb values within an assessment unit do not significantly diverge from state biological criteria. The status of BUI 6 is based on the scores of the Invertebrate Community Index (ICI). Lastly, the status of the fish portion of BUI 14 is based on the Qualitative Habitat Evaluation Index (QHEI) which is an assessment of the physical characteristics of a sampled stream. Beneficial use is considered restored when the average QHEI within an assessment unit does diverge from state biological guidelines.

2.3 Socio-Economic Resources

2.3.1 Cultural Resources

In broad terms, "cultural resources" can be represented by historic buildings and structures, historic districts, archaeological sites, Native American traditional places, and traditional ways of life. Cultural resources also include “historic properties,” which, as defined by the National Historic Preservation Act, include any prehistoric or historic district, site, building, structure, or object included in, or eligible for inclusion in the National Register of Historic Places (NRHP)(36 CFR 800.16).

For this study, the effort to identify historic properties within the study area was initiated by the establishment of the area of potential effect (APE) for the proposed project. The APE is defined as the geographic area within which an undertaking may directly or indirectly cause changes in the character or use of historic properties, if any such properties exist. The APE is influenced by the scale and nature of an undertaking and may be different for different kinds of effects caused by the undertaking (36 CFR 800.16). The APE for direct impacts is limited to the footprint of the proposed project areas and may change during the design phase. The APE for indirect visual impacts would extend beyond the footprint of these structures to encompass buildings and structures within view of the proposed projects.

Information regarding the existing condition of cultural resources can be accessed using the Ohio SHPO Online Mapping System available at https://www.ohiohistory.org/preserve/state-historic-preservation-office/mapping). Consultation with the Ohio State Historic Preservation Office (OH SHPO) and any interested parties per Section 106 of the National Historic Preservation Act is ongoing and should continue.

2.4 Restoration Site Locations

Preliminary designs for proposed restoration projects in the Lower Maumee River have been developed with significant input from member agencies and organizations supporting the MAAC. These Preliminary designs include activities that seek to increase aquatic habitat heterogeneity, protect eroding riverbanks, and protect in-channel islands from further erosion. Within this stretch of the Lower Maumee River, 12 project sites were identified and have been generally grouped into three focus areas targeted for restoration. The three focus areas include:

1. Audubon Islands
2. Marengo Island
3. Delaware/Horseshoe Islands

2.4.1 Audubon Islands

The Audubon Islands are a nature preserve in Maumee, Ohio and are located approximately 13 miles upstream of the mouth of the Maumee River (Figure 11). The preserve is a set of two islands (Grape and Ewing Islands) separated by a narrow channel and totaling 192 acres in size. The islands are owned and managed locally by the Toledo Metropolitan Park District, except for one parcel (No. 3649312) on the north side of Ewing Island, which is privately owned.

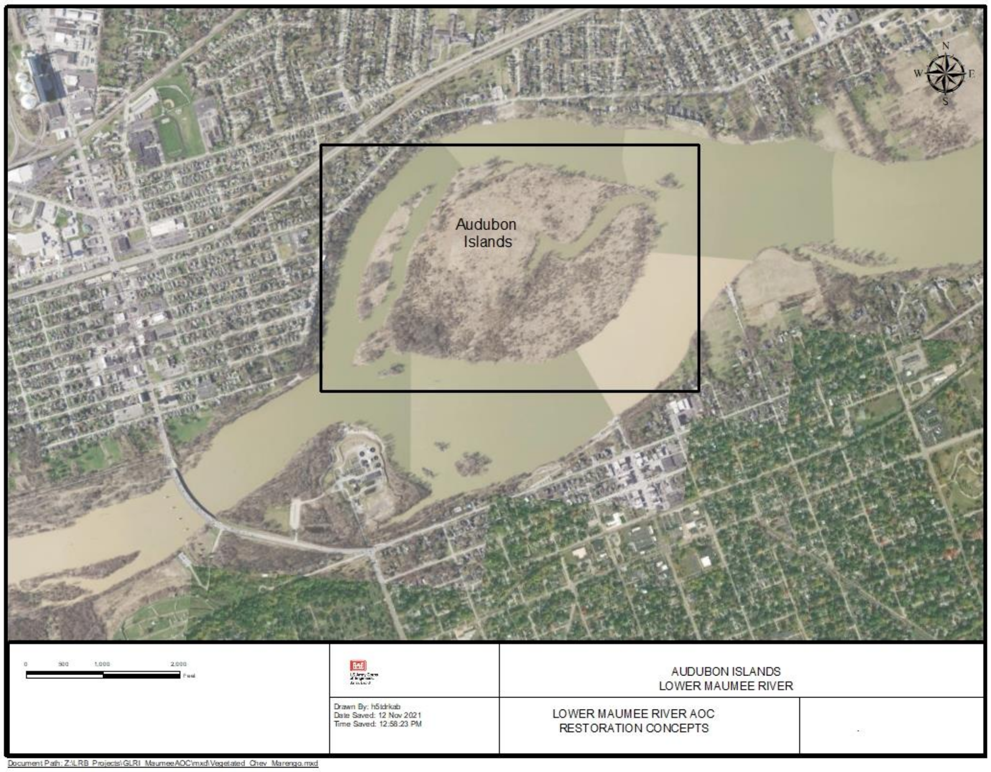


Figure 11: Audubon Islands, Lower Maumee River, Ohio.

Ewing Island, the larger of the two islands, is full of history and has been known by several names: McKee's, Pilliod, Ewing, and Audubon. Now a part of Side Cut Metropark, it was home to Ottawa Indians. Between 1783 and 1794, it was known as Col. McKee's Island and was farmed as part of Alexander McKee's Department of Indian Affairs post. In about 1874, Xavier Pilliod acquired the land. Pilliod was a gathering spot for picnickers and fishermen. There used to be a farmhouse and large barn on the island and farmers tilled the fertile land and brought the crops to land via a "DUKW[1]". The name Ewing Island, according to Wood County Historical Society, comes from William W. Ewing, who was a Lucas County Common Pleas Court judge in the 1880's. In the 1980's, descendants of the Pilliod's sold the property, that had been in their family since the 19th Century, to the Audubon Society as a preserve (Oregon Jerusalem Historical Society).

This extensive history has left its mark on the island. Drain tiles are evident on aerial imagery, the topography is unnaturally flat, and non-native plant species dominate the upland portions of the island. Bank erosion is evident along much of the shoreline of Ewing Island (Figure 12). There is a large central cove on Ewing Island. This cove is relatively protected from wave action and ice scour. The bottom substrate consists of fine sediments, and the bottom elevation is uniform throughout. During low water and seiche events, the cove sediments become exposed to form an extensive mudflat.

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[1] DUKW, also call duck, was a 2.5-ton six-wheel amphibious truck used in World War II by the U.S. Army and Marine Corps. (Britannica.com/technology/DUKW)

Figure 12: Bank erosion along Ewing Island.

The Audubon Islands have been decreasing in area since at least the 1970's (Figure *19*). The cause of this erosion is unknown, but it is likely a combination of increased river flows, ice scour, and increasing lake levels. Ewing Island has lost a total of 14 acres or 5.5 percent of its area since the 1970's. Most of the area loss has occurred at the upstream and downstream ends of Ewing Island.

Fish species richness and fish abundance scores for July electrofishing and August trawls were low along Audubon Islands relative to other summer 2019 sampling sites in the study reach. The index of biologic integrity (IBI) for July electrofishing received the lowest possible score. As a result, the Audubon Islands were identified for restoration activities by Hintz et al. (2019).

2.4.2 Marengo Island

Marengo Island is an approximately 3.5-acre island located 10.5 miles upstream of the mouth of the Maumee River (Figure 13). Based on historical aerial imagery (Figure 14 and Figure 21), Marengo Island has lost 50 percent of its landmass to erosion. The island loss calculation method is described further down in section 3.3.

Fish species richness and fish abundance scores for July electrofishing, August electrofishing, and August trawls were low at this site relative to other summer 2019 sampling sites in the study reach. The IBI for July electrofishing received the lowest possible score. Macroinvertebrate total abundance was also low at this site relative to other sampling sites. As a result, this project was identified for restoration activities by Hintz et al. (2019).

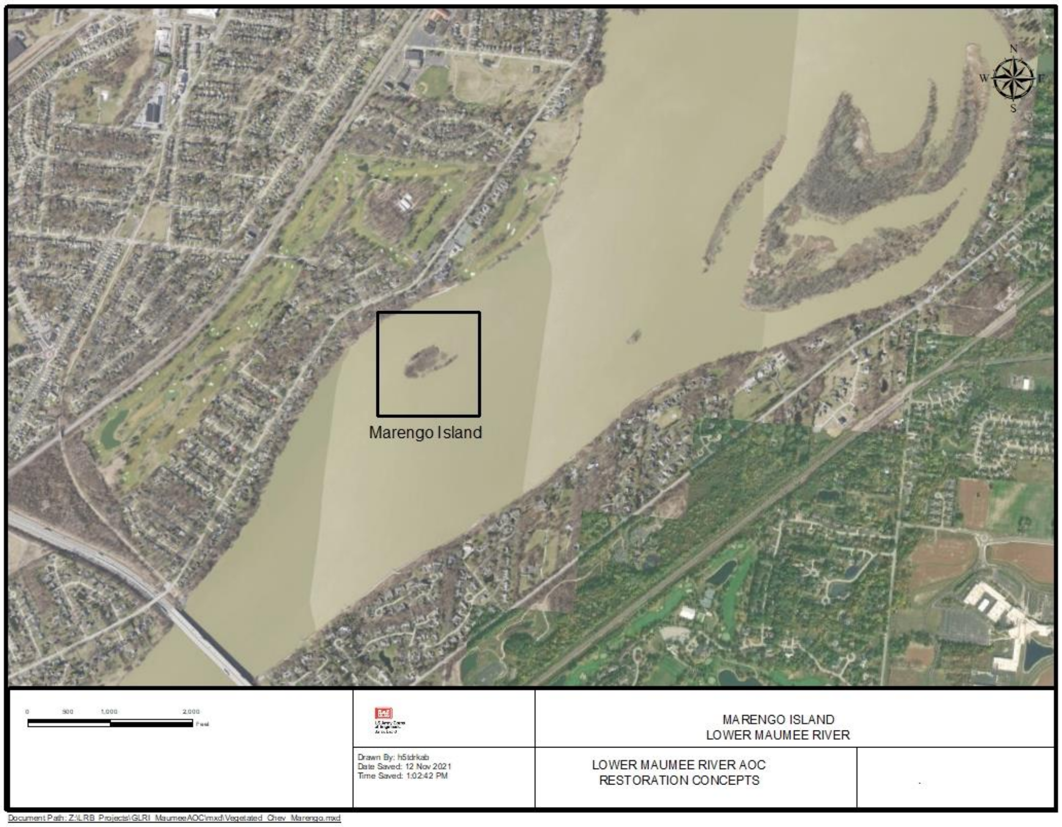


Figure 13: Marengo Island, Lower Maumee River.

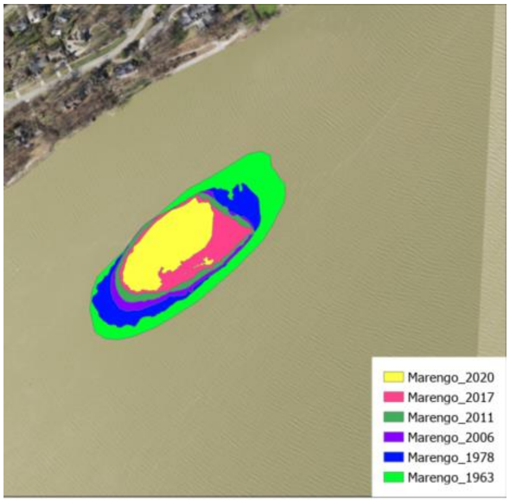


Figure 14: Marengo Island land area loss since 1963.

2.4.3 Delaware / Horseshoe Islands

The Delaware/Horseshoe Complex is a set of islands approximately 9 miles upstream of the mouth of the Maumee River (Figure 15). The islands are located within the City of Toledo. The complex consists of four upland land masses that remain from the original two islands, the two largest areas being the approximately 37-acre Delaware and 13-acre Horseshoe Islands. These two islands appear as a single island in most aerial imagery as they are separated by a very narrow channel. Just east of Horseshoe Island is an approximately 5-acre area that was once part of Horseshoe Island but is now separated by a narrow channel. About 500 feet downstream of these three areas is another small island remnant that is approximately 1.7 acres. The Delaware/Horseshoe complex also has lost 39 percent of landmass due to erosion (Figure 20).

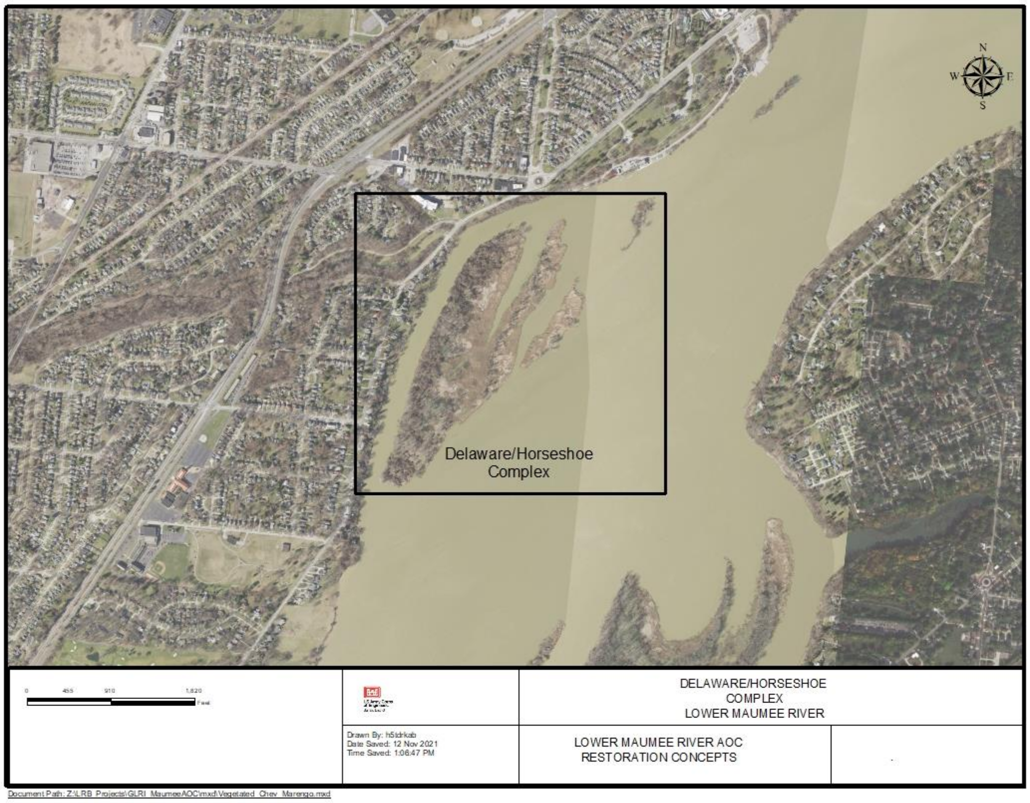


Figure 15: Delaware/Horseshoe complex.

3.0 Hydrology, Hydraulics, Sediment, and Ice

We evaluate various aspects of hydrology (river flow duration, frequency, and trends; Lake Erie water level seasonal, annual fluctuations and long term trends; and a statistical analysis of actual island erosion versus apparent erosion from rising Lake Erie water levels); hydraulics (an existing hydraulic model and use of that model to assess: ranges of water levels at project locations, island inundation frequency, potential floodplain impacts of proposed projects, average channel velocities and shear, bathymetric profiles of the island edges, and an assessment of cove bottom elevations); substrate and turbidity (bottom substrates, bedrock depths, a conceptual model of cove depths over time, and suspended sediment concentrations and turbidity measurements), and ice considerations. Where applicable, we address design implications of various findings in sub-sections titled: *Implications for Design*.

The following is a summary of design implications from the analyses presented in this section:

- Annual peak flows are increasing on the Maumee River which will tend to enhance island erosion, which justifies protecting these diverse ecosystems.
- The islands are disappearing due both to actual erosion as well as rising water levels, so features to prevent future erosion and enhance island building were designed.
- Lake Erie water levels appear to have trended upward potentially indicating higher future lake levels. Further evaluation should be performed to determine if a latter, statistically stationary, portion of the period of record exists and could be used to determine the range of Lake Erie water surface elevations over which project features be designed.
- Water levels range dramatically at project locations as a function of both widely varying lake levels and fluctuations in Maumee River flows. Section "Implications for Design (Range of Typical Water Levels at Project Locations)" includes a proposed top elevation for the proposed chevron dike among other considerations.
- The islands all overtop periodically, during which the coves are likely scoured, so any feature that might impact this periodic scouring process could be problematic for cove longevity. And their morphology should be considered as a potential factor in supporting high quality wetlands (with Grassy Island as a reference site).
- Cove recontouring should create equal wetland areas over a range of water depths and should use steep slopes to support perennial adaptation to year-to-year water level fluctuations.
- To create the steeper slopes needed for the cove recontouring, coarse substrate additions will be required to supplement the silty sediment there.
- Site specific depth-to-bedrock data will be required to assess the feasibility of constructing features with driven vertical wooden posts and to accurately estimate quantities of stone required to build various features.
- Suspended sediment concentration data are likely a limiting factor on the success of macro-invertebrates, fish, and aquatic vegetation, so the design should include turbidity refugia and sediment resistant vegetation. Sediment concentration data should be collected in the coves to further inform design.

3.1 Maumee River Flow Frequencies

3.1.1 Flow Duration Analysis (Exceedance Flows) for Maumee River at Waterville Gage

The USGS stream gage at Waterville, OH (USGS ID No. 04193500) is located approximately 10 miles upstream from Audubon Islands. We performed a flow duration analysis on daily mean flow values for the full period of record for the Waterville gage (35,962 daily flow values with most data from the period 1921-2021). Results of the flow duration analysis are shown in

Table 2. The highest daily mean flow value on record was 113,000 cubic feet per second (cfs) and the lowest value on record was 5 cfs. The 50% exceedance (median) flow is 1,770 cfs (50 cms), while 90% of all flows are in the range of 162 cfs (4.59 cms; 95% exceedance) to 23,500 cfs (665 cm; 5% exceedance).

3.1.2 FEMA Flood Insurance Study (FIS) Flow Frequencies

The project area is fully contained within two counties. In the project area, the Maumee River marks the boundary between Lucas County on the west and Wood County on the east.

Flood Insurance Study (FIS) reports were completed for Wood County in 2011 (FEMA, 2011) and Lucas County in 2016 (FEMA, 2016). The Lucas County FIS uses the hydrology and hydraulics from the Wood County FIS. And the Wood County FIS uses flow frequencies from the “original” Wood County FIS which were based on a log-Pearson Type III (Bulletin 17B) analysis on the Waterville gage. The FIS flow frequencies are listed in Table 3 for the 10%, 2%, 1%, and 0.2% annual chance (i.e., 10-year, 50-year, 100-year, and 500-year recurrence interval) events.

Table 2: Flow Duration Analysis Results

Percent of Time Exceeded	Flow (cfs)	Flow (cms)
99	63	1.8
95	162	4.59
90	250	7.08
80	448	12.7
50	1,770	50.1
25	5,730	152
15	10,600	300
10	15,000	425
5	23,500	665
2	34,700	983
1	43,600	1,230
0.1	77,000	2,180

Table 3: FEMA Flood Insurance Study (FIS) Peak Discharges

		--------------------- FIS Flows in CFS -------------			
RAS RS*	**Location**	**10% ACE**	**2% ACE**	**1% ACE**	**0.2% ACE**
48965.49	US End of Model	81,600	110,000	123,000	154,000
32,403.830	At State Route 64, Waterville Gage	81,600	110,000	123,000	154,000
15,134.260	Just US of Grassy Creek	82,000	110,600	123,800	155,100
7,637.285	Just US of Swan Creek	82,300	111,100	124,300	155,800
		---------------------- FIS Flows in CMS -----------			
RAS RS*	**Location**	**10% ACE**	**2% ACE**	**1% ACE**	**0.2% ACE**

48965.49	US End of Model	2,311	3,115	3,483	4,361
32,403.830	At State Route 64, Waterville Gage	2,311	3,115	3,483	4,361
15,134.260	Just US of Grassy Creek	2,322	3,132	3,506	4,392
7,637.285	Just US of Swan Creek	2,330	3,146	3,520	4,412

* - River stationing in meters from downstream end of model, closest model cross-section, HEC-RAS model used in this study.

3.1.3 Non-Stationarity and Trend Analysis on Waterville Gage

We assessed whether annual peak flows in the Maumee River, at the Waterville gage, were stationary (i.e., had a constant mean, standard deviation, and variance). We used the online USACE Non-Stationarity Detection (NSD) Tool (https://climate.sec.usace.army.mil/nsd/) which was developed in conjunction with USACE (2017). The NSD tool uses ten statistical tests for significant non-stationarity in mean, standard deviation, and/or variance.

We detected non-stationarities in mean flow at 1965 (Lombard-Wilcoxon test) and in distribution at 1974 (Energy Divisive Method). The results, shown in Figure 16, indicate the mean of annual peak flows in the period prior to 1965 was 52,000 cfs, and shifted to 63,000 cfs post-1965, an increase of 21%.

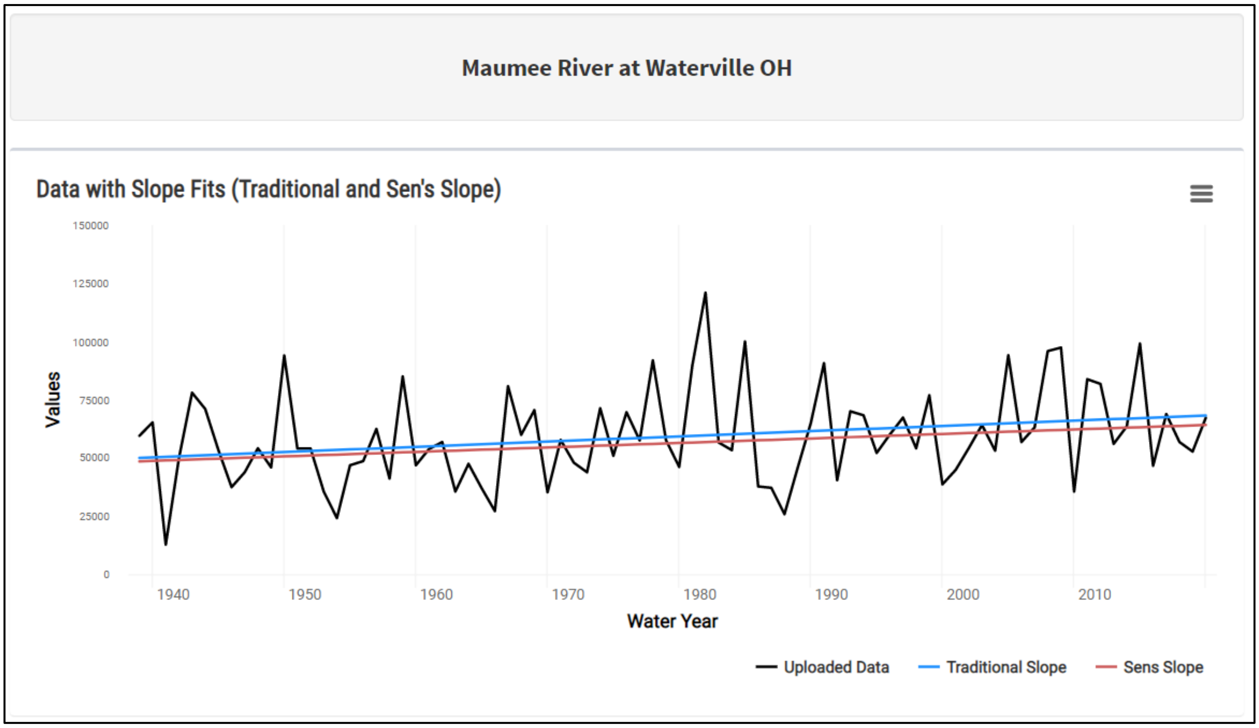
We also used the NSD tool to perform a trend analysis on annual peak flows at the Waterville gage, using the t-Test, Mann-Kendall, and Spearman Rank Order tests. All three tests identified a statistically significant upward trend in annual peak flows at the 0.05 level of significance (p values for all tests were 0.02; see Figure 17).

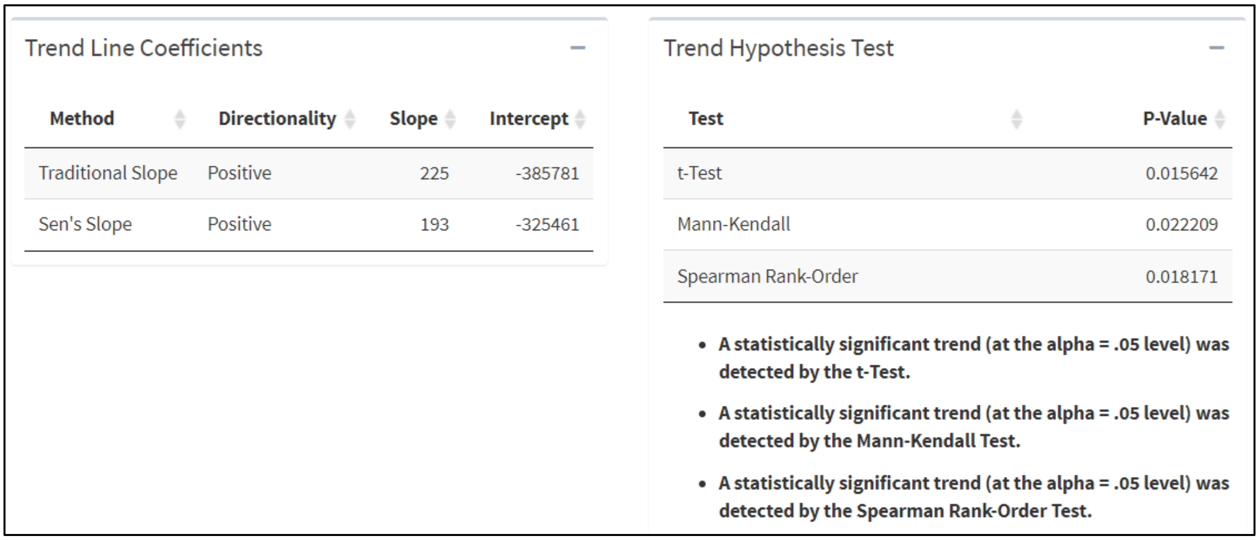
Implications for Design (3.1.3 Non-Stationarity and Trend Analysis on Waterville Gage)

The theory of hydraulic geometry, rooted in empirical studies and first described by Leopold and Maddock (1953), states that the dimensions and slope of a river are a function of the flows it carries. So as flows increase, so do the width, depth, and inverse slope (or length) of a river. Given the observed upward trend in annual peak flows, we expect the width of the river to have increased over time. This likely explains why the islands have eroded significantly over many decades (see Statistical Analysis of Island Erosion and Lake Erie Water Level Impact on Size.) Depth may also have increased over time, though data to evaluate this is likely unavailable, and adjustments to river depth may be constrained by bedrock in some locations.

Given that the increasing trend in river flows continues, property owners can expect to see continued or increased erosion in locations where the river needs to widen to accommodate the flow. However, given the ecosystem value of the islands in terms of enhanced fish and macro-invertebrate habitat, restoring and/or providing protection to these features is important for preserving these valued, diverse island ecosystems.

Figure 16. Non-Stationarity Detection Tool Results.





Method	Directionality	Slope	Intercept
Traditional Slope	Positive	225	-385781
Sen's Slope	Positive	193	-325461

Test	P-Value
t-Test	0.015642
Mann-Kendall	0.022209
Spearman Rank-Order	0.018171

- **A statistically significant trend (at the alpha = .05 level) was detected by the t-Test.**
- **A statistically significant trend (at the alpha = .05 level) was detected by the Mann-Kendall Test.**
- **A statistically significant trend (at the alpha = .05 level) was detected by the Spearman Rank-Order Test.**

Figure 17. Results of Trend Analysis on Annual Peak Flows, Waterville Gage.

3.1.4 Flow Frequency Analysis (Bulletin 17C) for Waterville Gage (1965-Present)

We also performed a flow frequency analysis on annual peak flow data as per the latest federal guidance (i.e., Bulletin 17C analysis) (England, et al. 2018). We selected the more recent stationary period of record (1965-present) to reflect current flow frequencies more accurately. Results of the analysis are shown in Table 4.

Despite the increasing trend in annual peak flows, the results of this Bulletin 17C analysis compare closely with the FEMA FIS flows for the 1% ACE and 2% ACE flows. The difference for the 0.2% ACE flow is well within the large 90% confidence limit range, but the low end of the 90% confidence limit for the 10% ACE in this analysis exceeds the FEMA FIS value, consistent with a rising trend in flows. So, the increase in annual peak flows may be more focused on higher frequency occurrences.

Table 4: Results of Bulletin 17C Flow Frequency Analysis on Annual Peak Flows, Waterville Gage (in cfs and cms)

Computed Curve Flow (cfs)	**Annual Chance Exceedance**	**Range in 95% Confidence Interval Flow (cfs)**
141,805	0.2	117,588 - 193,789
130,718	0.5	111,889 - 169,762
122,030	1	106,838 - 152,695
113,007	2	100,960 - 136,388
100,375	5	91,522 - 115,643
90,038	10	82,812 - 100,423
78,597	20	72,587 - 85,721
59,800	50	55,140 - 64,826
44,692	80	40,341 - 48,737
38,104	90	33,235 - 42,043
33,276	95	27,618 - 37,313
25,565	99	18,244 - 30,100
Computed Curve Flow (cms)	**Annual Chance Exceedance**	**Range in 95% Confidence Interval Flow (cms)**
4,015	0.2	3,330 - 5,487
3,702	0.5	3,168 - 4,807
3,456	1	3,025 - 4,324
3,200	2	2,859 - 3,862
2,842	5	2,592 - 3,275
2,550	10	2,345 - 2,844
2,226	20	2,055 - 2,427
1,693	50	1,561 - 1,836
1,266	80	1,142 - 1,380
1,079	90	941 - 1,191

942	95	782 - 1,057
724	99	517 - 852

3.2 Lake Erie Water Elevation Range and Frequencies

In addition to flows, Lake Erie water levels have a significant impact on water levels at these lacustuary project locations. Table 5 presents various NOAA Lake Erie water level statistics (high, low, long-term average; highest monthly mean, lowest monthly mean). Table 5 also presents annual chance exceedance Lake Erie Water level statistics included in the Lucas County FIS (FEMA, 2016) and which are based on a study by USACE (1988).

Table 5: Lake Erie Water Level Statistics

Statistic	**Lake Erie Water Levels**			
	ft, IGLD85	**m, IGLD85**	**ft, NAVD88**	**m, NAVD88**
0.2% ACE (500-year)***	578.9	176.45	579.1	176.51
1% ACE (100-year)***	578.0	176.18	578.2	176.24
2% ACE (50-year)***	577.5	176.02	577.7	176.08
10% ACE (10-year)***	576.4	175.69	576.6	175.75
High*	574.30	175.05	574.50	175.11
Highest Monthly Mean (JUN 2019)**	574.70	175.17	574.90	175.23
Long-Term Average*	571.30	174.13	571.50	174.19
Lowest Monthly Mean (DEC 1934)**	567.83	173.08	568.03	173.14
Low*	568.20	173.19	568.40	173.25

* - Source: https://coast.noaa.gov/llv/#/lake/erie
** - Source:
https://tidesandcurrents.noaa.gov/waterlevels.html?id=9063085&units=metric&bdate=19410928&edate=20000928&timezone=LST/LDT&datum=IGLD&interval=m&action=
*** - Source: FEMA, 2016. FIS for Lucas County; for portions of Lake Erie West of Cedar Point, and entire shoreline of Maumee Bay.

3.2.1 Seasonal Fluctuations in Lake Erie water levels

According to FEMA (2006), "Lake Erie water levels vary seasonally, with high water levels typically occurring during the summer months and low water levels occurring during the winter months." Long-term mean Lake Erie water levels show an average seasonal fluctuation of 1.0 ft (0.30 m) (USACE, 2021).

3.2.2 Annual Fluctuations in Lake Erie Water Levels

We assessed the annual fluctuation in Lake Erie water levels by examining the full period of record for the NOAA gage in Toledo (NOAA Station ID: 9063085, adjacent to the U.S. Coast Guard Station in Toledo). We found average monthly water levels fluctuate over the course of a water year by a minimum of 0.15 m (0.49 ft), a maximum of 0.98 m (3.22 ft), and an average of 0.55 m (1.80 ft).

3.2.3 Long Term Trend in Lake Erie Water Levels

The IJC (2012) Upper Great Lakes Study assessed trends in net basin supply (NBS) for Lake Erie. Net basin supply (NBS) is the net amount of water entering each Great Lake resulting from precipitation falling directly on the lake surface, runoff to the lake from the surrounding drainage basin, and evaporation from the lake. It does not include the inflow from the upstream Great Lake or any diversions (IJC, 2012). Unfortunately, the study did not assess for trends in Lake Erie water levels.

Using monthly average Lake Erie water levels, for the full period of record of 110 years, we plotted the data and a regression line, as shown in Figure 18. The plot shows an apparent upward trend with an R^2 of 0.22, and a slope of 0.0000154 m/day (or 0.0056 m/yr., or 0.56 cm/yr., or 62 cm over the full 110-year period of record) or 0.0000505 ft/day (or 0.0184 ft/yr, or 0.22 in/yr, or 24 in/yr).

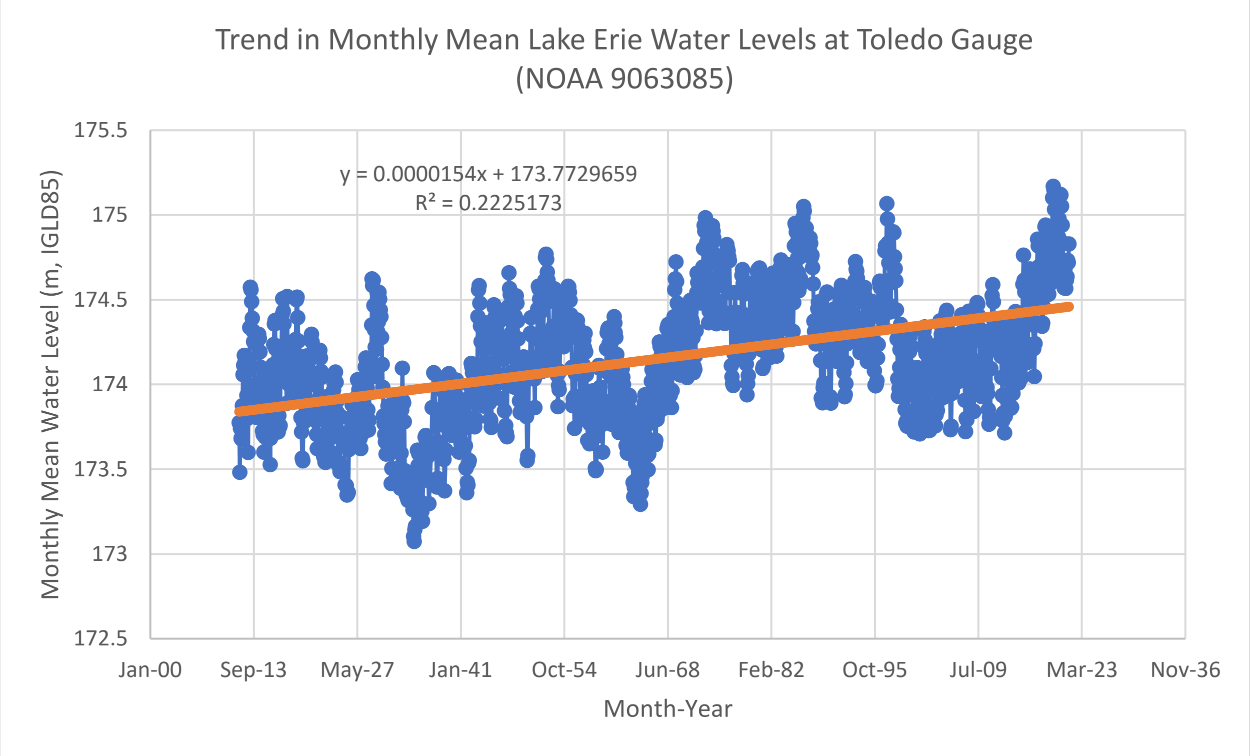


Figure 18. Trend in Monthly Mean Lake Erie Water Levels at Toledo Gauge from October 1911 to July 2021 from START DATE to END DATE.

Implications for Design (Long Term Trend in Lake Erie Water Levels)

For the design phase, we recommend assessing whether the trend shown in Figure 18 is statistically significant. If shown to be statistically significant, we recommend identifying a latter portion of the period of record which can be shown to be statistically stationary. This could be used to establish the range of water levels over which the project would be designed to perform. Performing this analysis would potentially result in a smaller range than the full historic range, allowing to better optimize the design for maximum benefit.

Additionally, when designing planting zones for submerged aquatic vegetation (SAV) and emergent vegetation, we recommend considering water levels expected, or ideally observed, at the start of the planting period and the potential range over which they might fluctuate from month to month. Vegetation would then be planted in the elevation ranges most likely to result in depth ranges most appropriate for each vegetation type.

3.3 Statistical Analysis of Island Erosion and Lake Erie Water Level Impact on Size

Marengo Island, Audubon Islands, and Delaware/Horseshoe (Delaware) Island have all been observed to be shrinking over time. However, it has been unclear whether this was due to rising Lake Erie water levels or due to erosion. To get a clearer understanding of the root causes of the shrinkage, the area and water levels of these islands were assessed and compared over different years.

For each island, the area was determined using imagery imported to ArcGIS Pro and manually delineated to determine the area. This approach introduces potential error as shallow water areas could be mistaken for land and vice versa especially for older, less clear imagery. Another potential error in the area measurements is that the imagery used has trees and other foliage present which makes edge identification uncertain.

Four sets of imagery that were collected through the Ohio Statewide Imagery Program (OSIP) were downloaded from the Ohio Geographically Referenced Information Program (OGRIP).

- OSIP1, created in 2006
- OSIP2, created in 2011
- OSIP3_2017, created in 2017
- OSIP3_2020, created in 2020.

The metadata was referenced for all datasets to determine when the imagery was collected. The associated metadata did not provide specific collection dates for any of the OSIP data sets. The meta data for OSIP1 stated that the imagery was collected during March and April 2006. And for the three other OSIP datasets, the metadata stated images were collected in the Spring during leaf-off conditions. As such, we assumed that these three OSIP datasets were also all collected in the months of March and April of their respective year. The OSIP datasets were downloaded as .tiff files and added to an ArcGIS Pro project.

In addition to the OSIP datasets, we used historic imagery from 1978, obtained from the USACE Buffalo District (USACE-LRB) library. These photos were scanned and then georeferenced in ArcGIS Pro using control points. These 1978 photos were lacking surrounding areas so in some cases it was difficult to determine control points. While the georeferencing was sufficient for Marengo Island, it was determined to be inaccurate for Audubon Islands and Delaware Island, based on comparison with other datasets which showed the scale and orientation of the islands were slightly off. Additional imagery was downloaded from Earth Explorer (EE) for all three islands. We downloaded an aerial photo from 1963 covering Marengo and Delaware Island and georeferenced it in ArcGIS Pro. We also downloaded two aerial photos covering Audubon

Islands, one from 1987 and one from 1970, and both were georeferenced in ArcGIS. The photos from EE showed more surrounding areas so there were more locations to establish control points. All aerial photos from EE list the day that the photo was collected. Table 6 summarizes the aerial imagery used in this analysis.

Table 6: Overview of Aerial Imagery Datasets

Dataset	**Collection Date(s)**	**Applicable Islands**
EE 1963	May 2nd, 1963	Marengo and Delaware
EE 1970	May 21st, 1970	Audubon
USACE-LRB 1978	June 23rd, 1978	Marengo
EE 1987	March 1st, 1987	Audubon
OSIP1	March-April, 2006	All
OSIP2	March-April, 2011	All
OSIP3_2017	March-April, 2017	All
OSIP3_2017	March-April, 2020	All

After all datasets were added in ArcGIS Pro and all aerial photos georeferenced, we manually drew polygons to delineate the island boundaries and determine their areas for each imagery year. Note that the analysis for Audubon Islands considered three separate islands: Ewing Island, Grape Island, and a small island near the north of Ewing Island, referred to herein as North Island. We were unable to include the other small island southwest of Ewing Island in this analysis due to difficulties in defining the island’s boundaries in some aerial imagery. Creating polygons also allowed for a visual image of how the islands have changed over time as shown in Figure 19, Figure 20, and Figure 21. These comparisons are considered apparent changes in size since they do not consider variability in water level.

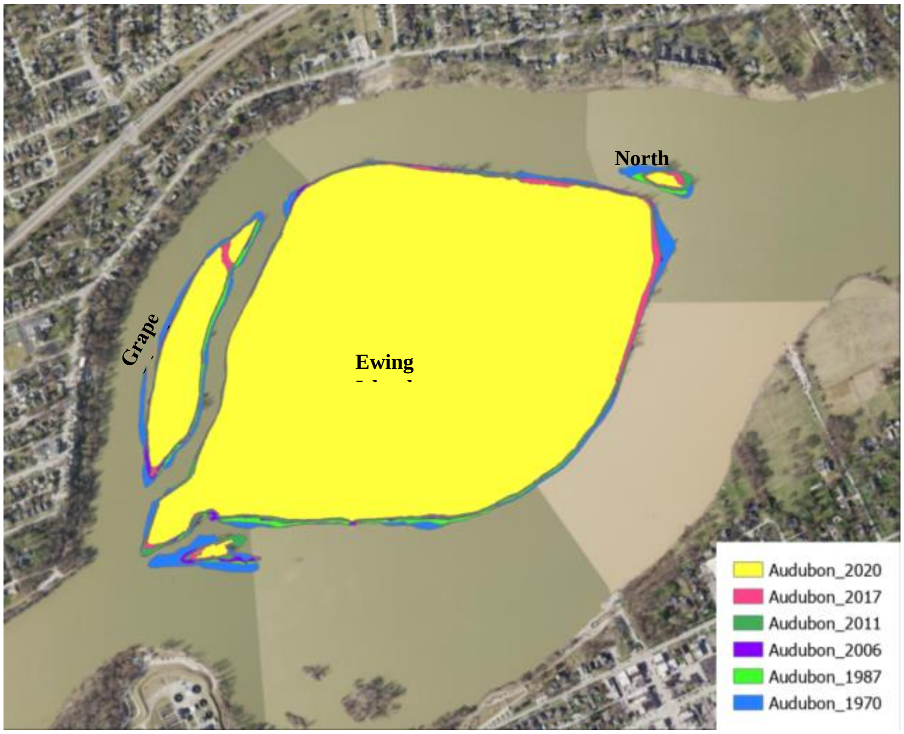


Figure 19: Change in Apparent Size of Audubon Islands over Time based on Aerial Imagery.

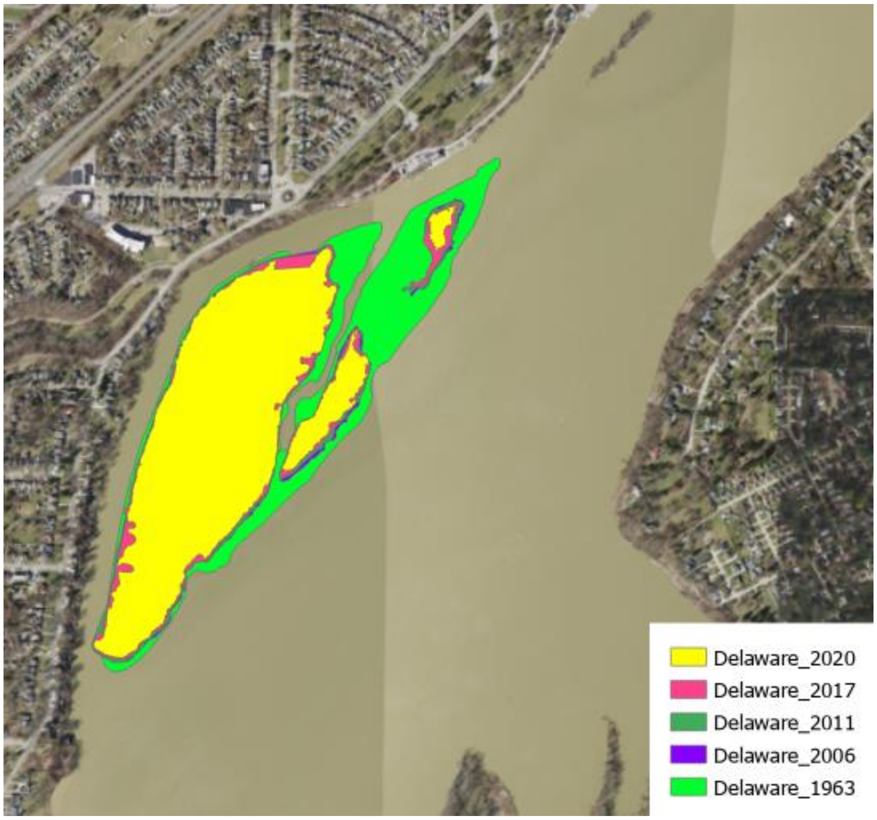


Figure 20: Change in Apparent Size of Delaware Island over Time based on Aerial Imagery.

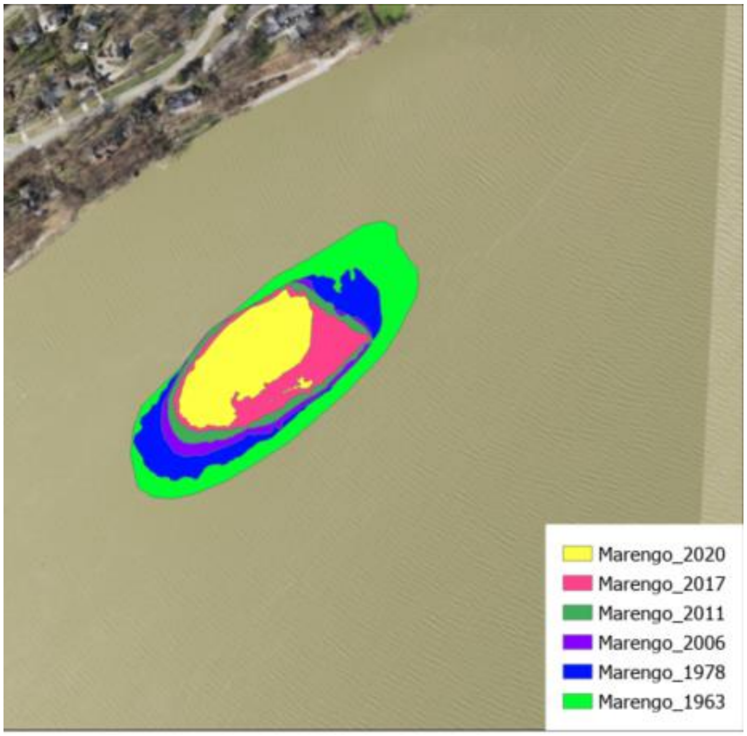


Figure 21: Change in Apparent Size of Marengo Island over Time Based on Aerial Imagery.

The figures above clearly show that the area of the islands have changed over time. However, the water levels have also changed over time. To relate the island areas to water levels (apparent change due to submergence) and time (actual change due to erosion), we first determined the water level for each imagery dataset. We used the National Oceanic and Atmospheric Administration (NOAA) Tides and Currents database for station 9063085 in Toledo, Ohio, i.e., where Lake Erie and the Maumee River meet. For the 1963 dataset, only monthly high, low and, mean levels were available, so the mean level was used. For the datasets from 1970, 1978, and 1987, each image was collected on a single day. And since there were hourly data available for each of these years, we determined the associated water level by calculating the mean for the hourly data between 0700 and 1800, assuming the image was collected sometime during the day. For the OSIP data, we calculated the mean water level for the months over which the imagery was collected. An overview of the water level for each dataset is shown in Table 7.

Table 7: Water Levels Associated with Aerial Imagery Datasets

Aerial Imagery Dataset	**Imagery Collection Date(s)**	**Water Level (IGLD85, ft)**
EE 1963	May 2nd, 1963	570.66
EE 1970	May 21st, 1970	572.15
USACE-LRB 1978	June 23rd, 1978	572.90
EE 1987	March 1st, 1987	573.27
OSIP1	March-April, 2006	571.39
OSIP2	March-April, 2011	571.42
OSIP3_2017	March-April, 2017	572.79
OSIP3_2017	March-April, 2020	574.22

We compiled the island areas and water levels for each collection date by island, for each island as shown in Table 8, Table 9, Table 10, Table 11, and Table 12. The analysis includes three of the Audubon Islands: The main island (Ewing Island), the small northern island, and the island to the west (Grape Island).

Table 8: Marengo Island Data Overview

Year	**Time (years)**	**Dataset**	**Collection Date**	**Area (Acres)**	**Water Level (IGLD85, ft)**
1963	0	EE 1963	May 2nd, 1963	8.69	570.66
1978	15	USACE-LRB 1978	June 23rd, 1978	5.86	572.90
2006	43	OSIP1	March-April, 2006	4.63	571.39
2011	48	OSIP2	March-April, 2011	4.15	571.42
2017	54	OSIP3_2017	March-April, 2017	3.50	572.79
2020	57	OSIP3_2020	March-April, 2020	2.22	574.22

Table 9: Delaware Island Data Overview

Year	**Time (years)**	**Dataset**	**Collection Date**	**Area (Acres)**	**Water Level (IGLD85, ft)**
1963	0	EE 1963	May 2nd, 1963	88.69	570.66
2006	43	OSIP1	March-April, 2006	59.93	571.39
2011	48	OSIP2	March-April, 2011	59.77	571.42
2017	54	OSIP3_2017	March-April, 2017	58.21	572.79
2020	57	OSIP3_2020	March-April, 2020	53.12	574.22

Table 10: Audubon Main Island (Ewing Island) Data Overview

Year	**Time (years)**	**Dataset**	**Collection Date**	**Area (Acres)**	**Water Level (IGLD85, ft)**
1970	0	EE 1970	May 21st, 1970	165.21	572.15
1987	17	EE 1987	March 1st, 1987	154.97	573.27
2006	36	OSIP1	March-April, 2006	157.90	571.39
2011	41	OSIP2	March-April, 2011	156.79	571.42
2017	47	OSIP3_2017	March-April, 2017	154.91	572.79
2020	50	OSIP3_2020	March-April, 2020	149.55	574.221

Table 11: Audubon North Island Data Overview

Year	**Time (years)**	**Dataset**	**Collection Date**	**Area (Acres)**	**Water Level (IGLD85, ft)**
1970	0	EE 1970	May 21st, 1970	1.59	572.15
1987	17	EE 1987	March 1st, 1987	0.84	573.27
2006	36	OSIP1	March-April, 2006	0.84	571.39
2011	41	OSIP2	March-April, 2011	0.93	571.42
2017	47	OSIP3_2017	March-April, 2017	0.62	572.79
2020	50	OSIP3_2020	March-April, 2020	0.40	574.221

Table 12: Audubon West Island (Grape Island) Data Overview

Year	**Time (years)**	**Dataset**	**Collection Date**	**Area (Acres)**	**Water Level (IGLD85, ft)**
1970	0	EE 1970	May 21st, 1970	14.73	572.15
1987	17	EE 1987	March 1st, 1987	11.08	573.27
2006	36	OSIP1	March-April, 2006	11.72	571.39
2011	41	OSIP2	March-April, 2011	11.30	571.42
2017	47	OSIP3_2017	March-April, 2017	10.92	572.79
2020	50	OSIP3_2020	March-April, 2020	10.26	574.221

We performed a multiple linear regression analysis for each island to assess the change in area overtime, while controlling for water level. We used the LINEST function in Excel where the known x's were assigned to be the area, the known y's were assigned to be time and water level. The LINEST function in Excel is parameterized as follows:

LINEST(known x's, known y's, [const, stats]

Known x's are filled using the independent variables (water level, time) and known y's with the dependent variable (island areas). *Const* is filled with true or false where false assumes the y intercept equals 0. *Stats* when true provides additional information such as the (coefficient of determination) R^2, the F statistic, etc. When doing the multiple linear regression, both *const* and *stats* were set to true.

Time was changed from the imagery collection year to the number of years that had passed since the first dataset. For Marengo and Delaware Island the first dataset, and thus year 0, was 1963 and for Audubon Island the first dataset and thus year 0 was 1970. The LINEST multiple linear regression output included the partial regression coefficient for water level (rate of change in area with respect to time while controlling for water level) and partial regression coefficient for water level (rate of change in water level while controlling for time), as well as the R^2. The term R^2 is a measure of the goodness of fit and is the proportion of the variation in the dependent variable that is explained by the independent variables. We checked and confirmed that the assumptions of ordinary least squares (OLS) linear regression were upheld (i.e., linear relationships, normally distributed residuals, no heteroscedasticity, no autocorrelation, reasonable level of multicollinearity). The results of the multiple linear regression are shown in Table 13.

Table 13: Multiple Linear Regression Results by Island

Island	**Water Level Coefficient (acre/ft)**	**Time Coefficient (acre/year)**	R^2
Marengo	-0.5322	-0.0768	0.9883
Delaware	0.2223	-0.6122	0.9838
Audubon (Ewing)	-2.3984	-0.1829	0.8914
Audubon (North)	-0.1362	-0.0165	0.9089
Audubon (Grape)	-0.4074	-0.0635	0.7860

The multiple linear regression equations can be used to determine how island areas have changed overtime, while controlling for varying water levels.

To further assess whether water level or time has had the greatest impact on island area, we performed a standardized multiple linear regression to generate a standardized slope output, which better reflects the relative weight of each independent variable. To do so, we first computed the Standard Score (Z-Score) for the values of area, water level, and time that were used in the initial computation. We calculated the Z-Score by subtracting the observed values by their mean and then dividing by their standard deviation. We then used the LINEST function with the known y (dependent variable) being the z-scores of areas, and the known x's (independent variables) being the z-scores of time and water level. We kept the *const* variable as "false" for this calculation since we would not expect the area to be zero at time and water level values of zero. As expected, the r^2 for the standardized regression are equal to those for the non-standardized regression. The results are shown in Table 14.

Table 14: Standardized Multiple Linear Regression for All Islands

Island	**Water Level Coefficient**	**Time Coefficient**	r^2	**Greatest Impact on Area**
Marengo	-0.3104	-0.796704	0.9883	Time
Delaware	0.0223	-1.0080	0.9838	Time
Audubon (Ewing)	-0.5183	-0.6950	0.8914	Time
Audubon (North)	-0.3773	-0.8054	0.9089	Time
Audubon (Grape)	-0.2864	-0.7853	0.7860	Time

Comparing coefficients, time has a greater impact on area than water level. Considering the results of both analyses, while water level has impacted the area of the islands, the amount of time that has passed has led to a greater overall impact on area (i.e., since the time coefficient is larger than water level coefficient). Note that the water level slope for Delaware is positive; this most likely occurred due to difficulties in delineating the island area in the cove where a large amount of reed growth has occurred thus making the island land mass appear larger that it is. The overall trend is that water level does not have as large an impact as time does. Note that error is potentially induced when determining areas, when georeferencing historic imagery, and when determining the water level associated with each image.

Using the results from the multiple linear regression, we calculated the area loss due to time (while controlling for water level) and the area loss from change in water level (while controlling for time) as shown in Table 15.

Table 15: Area Loss for All Islands

Island	Calculated Area Loss from Time (acres)	Calculated Area Loss from Water Level (acres)	Calculated Total Loss (acres)	Calculated Area Loss from Time / Initial Island Area	Apparent Loss based on Imagery* (acres)	Difference in Calculated and Apparent (acres)
Marengo	4.3784	1.8926	6.2710	50.36%	6.4724	0.2014
Delaware	34.8968	-0.7905	34.1062	39.35%	35.5666	-1.4603
Audubon (Ewing)	9.1427	4.9593	14.1020	5.53%	15.6656	-1.5635
Audubon (North)	0.8262	0.2816	1.1078	51.91%	1.1828	-0.0750
Audubon (Grape)	3.1761	0.8425	4.0185	21.55%	4.4688	0.4503

* - Loss based on comparing latest imagery to earliest imagery.

From the table above, the calculated area lost over time (i.e., actual loss due to erosion) is quite significant at 6%-52% loss over a period of 50-57 years. And percent loss appears to be inversely correlated with island size with the smallest islands (Marengo and Audubon North) seeing the largest percent losses (i.e., 50% and 52%, respectively). And while percent loss is relatively small for Ewing Island at 5.5%, it in fact represents the largest quantity of land loss at 14 acres.

Implications for Design (Statistical Analysis of Island Erosion and Lake Erie Water Level Impact on Size)

The above analysis conclusively demonstrates the islands in this study are diminishing in size due to actual erosion. Additionally, Shane, et al (2021) showed that the upstream and downstream ends of these islands are associated with higher levels of fish species richness and density. So, project features that serve to protect the islands from erosion, increase their size, or create additional island habitat should all enhance fish populations.

3.4 Hydraulic Modeling Analyses with HEC-RAS

3.4.1 Model Background

A 1D hydraulic model of the Lower Maumee was originally developed by Jessica Collier while a PhD student at the University of Toledo, as part of a PhD dissertation (Collier, 2018). The model was generated using the Hydrologic Engineering Center (HEC) River Analysis System (RAS) hydraulic model. Taaja Tucker at USGS later modified the HEC-RAS model to produce depth and velocity maps and combine them with substrate data to determine habitat suitability for Walleye. Inputs and products of the study are available via a USGS data release (Tucker et al. 2020).

We used the HEC-RAS model in this feasibility study to assess:

- Range of typical water levels at project locations
- Island inundation frequency
- Potential impact of project features on flood water surface profiles
- Maximum average channel velocities and shear
- Bathymetric profile of island edges at project locations
- Cove bottom elevations

3.4.2 Range of Typical Water Levels at Project Locations

To determine the typical range of water levels at project locations, we ran HEC-RAS simulations using various flow rates as well as various Lake Erie water levels as the model downstream boundary condition. We used a set of three flows, roughly at the 50%, 10%, and 5% chance exceedance flows (using 50 cms, 425 cms, and 675 cms, respectively), representing median flow and typical higher flows. And we used low, long-term average, and high Lake Erie water levels. In total, water level simulation results were generated and tabulated for nine flow / water level combinations at each potential project site as described in UT/Hull (2021) Table 16.

The results indicate that water levels at the project locations are significantly affected by Lake Erie water levels for all proposed sites. When flow is at the 50% chance exceedance level, or lower, water levels are essentially Lake Erie levels. However, the degree to which water levels during a 5% chance exceedance flow are higher than water levels during the 50% chance exceedance flow is a function of both Lake Erie levels and location. When Lake Erie levels are low (i.e., at elevation 173.19 m), water levels at the upstream end of Audubon Island are 0.8 m (2.6 ft) higher for a 5% chance exceedance flow than for a 50% chance exceedance flow. However, when Lake Erie levels are high (i.e., at elevation 175.05 m), water levels at the upstream end of Audubon Island are just 0.18 m (0.6 ft) higher for a 5% chance exceedance flow than a 50% chance exceedance flow. And for the downstream-most sites, i.e., for Marengo and Delaware/Horseshoe Islands, the change in water level from median to high flow is less than 0.3 m (1.0 ft), whether Lake Erie levels are high or low.

Table 16: Typical Range of Water Surface Elevations at Project Locations for Range of Flows and Lake Erie Water Levels

			Low Erie		**Median Erie**		**High Erie**
			173.19 m		**174.173 m**		**175.05 m**
Location Description	**Q Total***		**W.S. Elev**		**W.S. Elev**		**W.S. Elev**
	(m3/s)		**(m)**		**(m)**		**(m)**
US End Audubon Island	50		173.2		174.18		175.05
US End Audubon Island	425		173.63		174.33		175.13
US End Audubon Island	675		174		174.53		175.23
		High – Low:	**0.8**		**0.35**		**0.18**
Middle Audubon Island	50		173.2		174.18		175.05
Middle Audubon Island	425		173.56		174.31		175.12
Middle Audubon Island	675		173.91		174.49		175.22
		High - Low:	**0.71**		**0.31**		**0.17**
DS End Audubon Island	50		173.2		174.17		175.05
DS End Audubon Island	425		173.53		174.3		175.11
DS End Audubon Island	675		173.87		174.47		175.21
		High - Low:	**0.51**		**0.22**		**0.12**
Marengo Island	50		173.19		174.17		175.05
Marengo Island	425		173.32		174.23		175.08
Marengo Island	675		173.48		174.3		175.12
		High - Low:	**0.2**		**0.1**		**0.06**
DS End Horseshoe Island	50		173.19		174.17		175.05
DS End Horseshoe Island	425		173.27		174.21		175.07
DS End Horseshoe Island	675		173.38		174.27		175.11
		High - Low:	**0.19**		**0.1**		**0.06**

* - Flows represent approximate 50%, 10%, and 5% chance exceedance flows. “High – Low” is the difference between the 5% chance exceedance and 50% chance exceedance flow water surface elevations.

Implications for Design (Range of Typical Water Levels at Project Locations)

For design, the following approaches/issues should be considered.

Chevron Dikes

Design of the top-elevation of the chevron dikes should consider water levels at the dike for a range of Lake Erie water levels. Chevron dike top elevations are typically set at the water surface elevation for 2-year flow. However, in selecting a top elevation, consideration should be given for how the chevron would perform under a 2-year flow with minimum Lake Erie level versus a 2-year flow for maximum Lake Erie level. For feasibility level costing purposes, we suggest using the 2-year flow with an average Lake Erie level (from the HEC-RAS model, 2-year flow, average Lake Erie water level, water surface elevation at Marengo Island = 174.84 m, NAVD88; depth = 4.1 m).

Placement of Large Wood Features

If woody debris is placed near the top of the range of typical water levels at a project site, the feature will be high and dry during low water years. And given the island side slopes presented above, to ensure large wood features are always at least partially under water, submerged logs and root wads would need to be placed a distance away from the bank. Anchored logs would then not be directly connected to the above water bank but placed on the underwater side slope of the islands. Angular stone used as boulder anchors would help prevent the logs from moving under high flow conditions.

Planting Depths for Emergent Vegetation

Ideally, any emergent or submerged vegetation to be planted for this project would be able to handle the wide range of water levels presented above, including both typical long- and short-term water level fluctuations.

As a short-term fluctuation consideration, herbaceous plantings in the splash zone (i.e., the zone between normal high and normal low) should be made based on the Lake Erie water levels at the time of planting (as opposed to when design drawings are drafted). These plants would also need to consider forecast Lake Erie water levels as well as the uncertainty range of about 1.5 ft that is typical in these 6-month forecasts (see USACE, 2021). Long-term water level fluctuations can be used to determine the bank zone (i.e., zone above normal high water), in which herbaceous and woody vegetation can be planted. That is, the highest monthly Lake Erie elevation can be used to set the lowest elevation for vegetation that cannot remain submerged for long periods of time (e.g., a month or more).

3.4.3 Island Inundation Frequency

We also used the HEC-RAS model, with the original model geometry, to assess the frequency at which the islands are inundated by high flows. We used the flows from the Bulletin 17C flow frequency analysis, and the long-term average Lake Erie water level (174.19 m, NAVD88) (https://coast.noaa.gov/llv/#/lake/erie). We included Grassy Island in this analysis as we consider it as a reference site for design in that it has been noted to have good habitat for juvenile fish. The model results for the island inundation frequency assessment are shown in Table 17. Marengo Island is totally inundated for the 1-year (99% ACE) event. It should be noted, however, that the RAS model elevation data for Marengo Island appears significantly lower than that from lidar data. Grape, Grassy, and Delaware Islands are all partially inundated at the 2-year (50% ACE) event, and mostly or totally inundated at the 5-year (20% ACE) event. Ewing Island is partially inundated by the 5-year (20% ACE) event and mostly inundated by the 20-year (5% ACE) event. As discussed later in the Statistical Analysis of Island Erosion and Lake Erie Water Level Impact on Size section, the frequency at which the islands are inundated may have a role in the rate at which they are eroding. Also, it seems reasonable to assume that island overtopping events are critical in maintaining cove depths (see 3.5.3 Conceptual Model of Coves Depths over Time).

Table 17: Inundation Frequency for Project Area Islands

	Partial Inundation		**Most/Total Inundation**	
Island	**Recurrence Interval**	**Annual Chance Exceedance**	**Recurrence Interval**	**Annual Chance Exceedance**
Grape	2-yr	50%	5-yr	20%
Ewing	5-yr	20%	20-yr	5%
Marengo*	5-yr	20%	10-yr	10%
Grassy**	2-yr	50%	5-yr	20%
Delaware	2-yr	50%	5-yr	20%

* - RAS model elevation data for Marengo Island is low relative to available lidar elevation data, so the inundation frequencies presented here are likely over-estimates.

** - Grassy Island included here as a reference site.

We also assessed island inundation frequency for each of the islands using lidar data and historical Lake Erie water levels. In Figure 22, Figure 23, Figure 24, and Figure 25, land areas in white would be above water when Lake Erie is at its highest recorded monthly average level (175.17 m, IGLD85), while those areas in color would be submerged. While vegetation, trees particularly, would extend above the water line, the land in the colored areas itself would be submerged. This aspect of island morphology may be an important component in determining habitat, especially for juvenile fish.

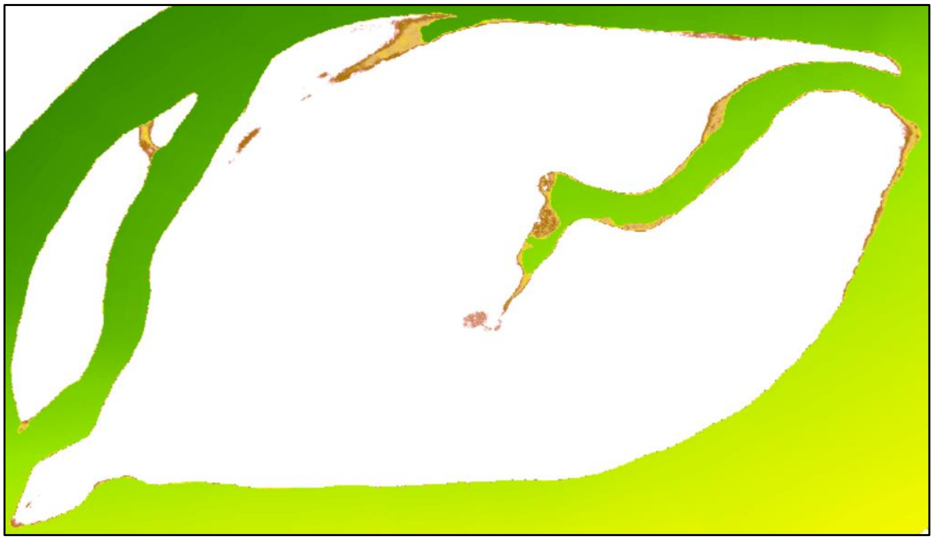


Figure 22. Audubon Island: Areas above Maximum Monthly Average Lake Erie Level (White) and Areas below (Colors).

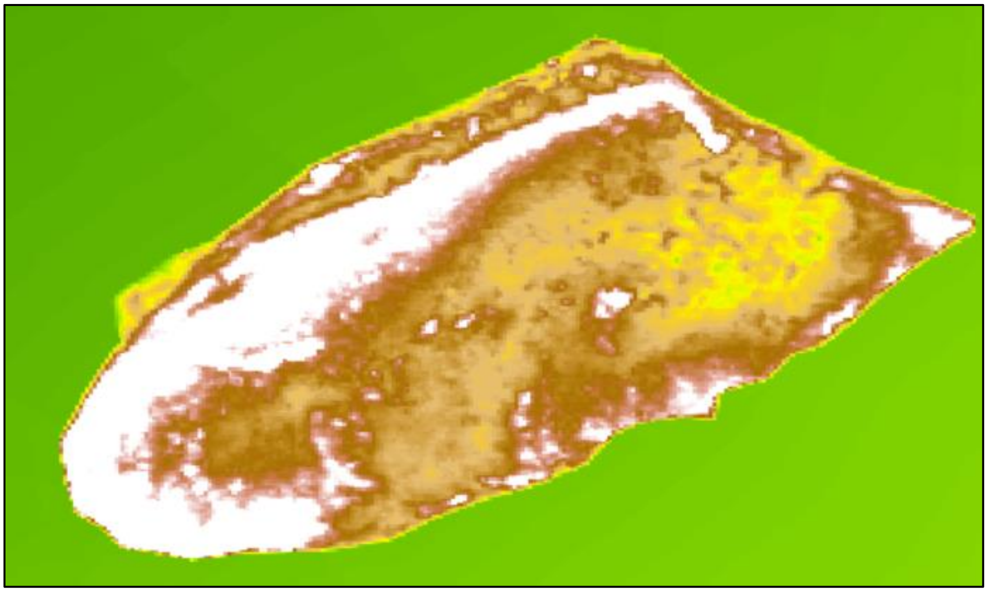


Figure 23. Marengo Island: Areas above Maximum Monthly Average Lake Erie Level (White) and Areas below (Colors).

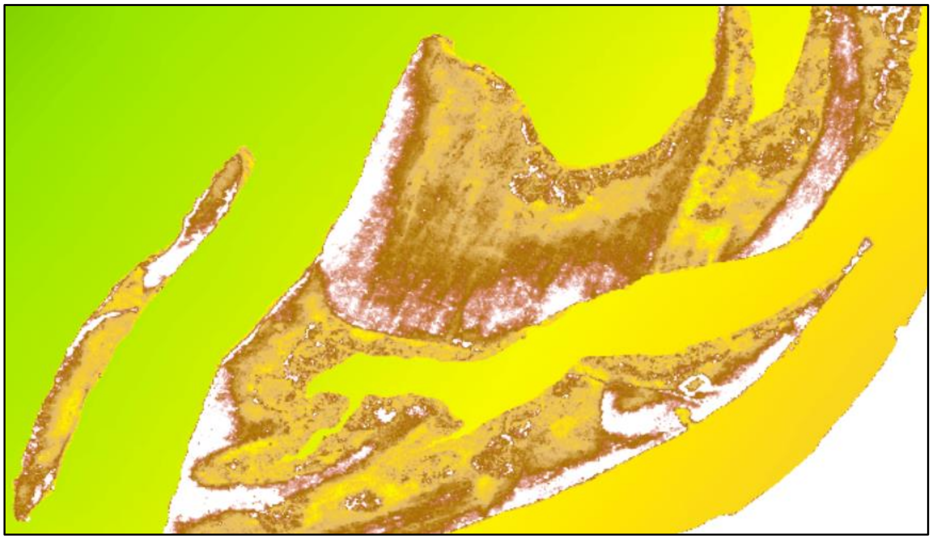


Figure 24. Grassy Island: Areas above Maximum Monthly Average Lake Erie Level (White) and Areas below (Colors).

Figure 25. Delaware/Horseshoe Island: Areas above Maximum Monthly Average Lake Erie Level (White) and Areas below (Colors).

Implications for Design (Island Inundation Frequency)

If coves are periodically scoured out during high island overtopping flows, then designs should ensure this process in not interrupted or the coves could eventually fill in with sediment.

Additionally, the morphology of the islands may be a key determinant of aquatic habitat, particularly regarding frequency of inundation. So, assuming this is a key factor driving why Grassy Island (included in this analysis as a reference site) has such good habitat for juvenile fish, it would be logical to replicate this topography in other island coves.

3.4.4 Potential Impact of Project Features on Flood Water Surface Profiles

We used the HEC-RAS model to assess the degree to which project features might impact water surface profiles under flood flow conditions. This assessment has implications for whether project features could be permitted in accordance with FEMA floodplain regulations.

We updated the original HEC-RAS model to create a baseline for an induced flooding analysis. To do so, we first assessed the degree to which the original model reflected the flood profiles shown in the Flood Insurance Study (FIS). We found the model was under-predicting the 1% ACE (100-year) water levels in the project areas by as much as 1.0 m relative to the FIS. While the UT/USGS model was calibrated to gage and velocity data and is thus expected to accurately reflect current conditions for the flows of interest in that study, it may not accurately reflect flows in an extreme flood scenario. It should be noted that this induced flooding analysis would typically be performed with a model that is considered the duplicative effective model. A more detailed modeling analysis, outside the scope of this study, would need to be performed were a Letter of Map Revision (LOMR) application need to be submitted in accordance with FEMA regulations.

To calibrate the model, Manning's n roughness values were increased until the model 1% ACE flood profiles matched the FIS 1% ACE flood profile to within 0.1 m. To do so, channel n values were increased from 0.033 to 0.048. Floodplain n values were not adjusted as they tended to reflect the high end of the range of n values in the literature for the floodplain types found along the Lower Maumee River.

We then created a With-Project Condition version of the model by updating the model geometry to reflect site features that might impact flood water surface elevations, as follows:

- To represent the root wad and submerged tree features at the outer edges of Audubon Islands, we used a rectangular, vertical blocked obstruction 5 m wide from elevation 174.0 m to the channel bottom. This was meant to represent the total cross-sectional area obstructed by a root wad / submerged tree feature, assuming the structure extends out 5 m (~15 ft) into the river, and stone fill would be needed as a foundation, set at the same slope as existing island, creating a sloped rectangle, at a roughness of roughly 5 m.
- For the dredging and SAV planting at the Ewing Island cove, we assumed the additional cross-sectional area of flow roughly offsets the SAV planting, so, no modifications were performed.
- To represent the chevron dike upstream of Marengo Island, we used a blocked obstruction in the model. We added a blocked obstruction that was 180 m wide (a rough estimate of the linear projected width of the feature) up to an elevation of 175.0 m (a rough estimate of the 2-year flood elevation at this location).
- Finally, to represent the submerged trees and SAV planting in the two coves of Delaware/Horseshoe Island, we increased the Manning's n value from 0.048 to 0.068 representing a sluggish reach with weeds and deep pools (Chow, 1959).

Results of induced flooding model simulations indicated the submerged trees and SAV plantings in the Delaware/Horseshoe Island cove increased water surface elevations for the 1% ACE (100-year) event by 0.01 m (1 cm) for three model XSs (~1,200 m) upstream of the site. Further, the chevron dike at Marengo Island was found to increase water surface elevations by 0.02 m for seven model XSs (~1,900 m) upstream of the site, and combined with the features on Audubon Islands, raised water surface elevations by 0.01-0.02m well upstream of Audubon Islands. So, to assess the impact of the root wads and submerged trees on Audubon Islands alone, we removed the chevron dike at Marengo Island, and re-ran the model. The results showed the root wads and submerged trees on the edges of Audubon Islands raised water surface elevations by 0.01 m for three XSs (~800 m) upstream of the island, but also not directly upstream. So, overall, the original project features as designed would be expected to raise water levels by no more than 2 cm, during a 1% ACE (100-year) event.

We assessed these results considering national floodplain management regulations by coordinating with local floodplain administrators from Lucas County and the City of Toledo. While national regulations require a condition of "no-rise" be demonstrated for development in a floodway, that condition is interpreted in terms of the precision at which FEMA publishes base (100-year) flood elevations. Since base flood levels are published to the tenth of a foot, flood profiles would need to increase by 0.1 ft or 0.03 m to trigger a publishable change. In addition, all the areas that would be impacted by these minor changes in flood levels are within a deep valley, where the vast majority of structures are well above the floodplain and valley floor, and only a very limited number of structures are located within the 1% ACE (100-year) floodplain. Additionally, the EFDC modeling effort includes a similar assessment. We expect that some of the rise identified by RAS will be lessened in a 2D/3D context since the water surface is not required to be flat across any given channel cross-section. That is, any rise may have only a local impact near where the features are being implemented on and near the islands, and that impact may not extend to the mainland where floodplain impacts would be of concern.

3.4.5 Bathymetric Profile of Island Edges at Project Locations

We examined the HEC-RAS model cross-sections to assess island side slopes, specifically at locations of project features such as root wads and submerged tree structures. The model geometry indicates the following slopes:

- Ewing Island, Right Side: 5.5:1, 6.3:1
- Ewing left side, DS end: 3.3:1
- Grape left side: 0.15 = 6.7:1

3.4.6 Cove Bottom Elevations

We assessed the bottom elevations of the coves at Ewing Island and Delaware/Horseshoe Island using depth measurements collected during a site visit, NOAA Lake Erie water level data during the same time and informed by HEC-RAS model results (see Section 3.4.2 Range of Typical Water Levels at Project Locations).

During a kayak excursion on Friday 20 AUG 2021 at 0900-1100, depths to bottom sediments were measured at 80-90 cm, using a measuring stick. Lake Erie water levels during the same time averaged 174.86m, IGLD85 (https://tidesandcurrents.noaa.gov/), only about 0.1 m below the highest monthly mean on record. And based on the Waterville gage, flows at that time were ~25 cms (quite low), meaning the water level at the coves would have been essentially equivalent to the Lake Erie level. As a result, if, for example, these informal measurements were found to be correct, we would estimate the cove bottom elevations at ~174.0 m.

Keith Shane from University of Toledo (UT), and numerous individuals from the public outreach effort, report that the coves are at times mudflats at lower flow. With cove bottom elevations of ~174.0 m, the coves would be very shallow when the lake is at its long-term average water level (174.13m). And with the lowest monthly mean Lake Erie level at 173.3m, the coves would be mostly dry during low Lake Erie levels, with pulses of flow only during high river flow.

Implications for Design (Cove Bottom Elevations)

Macroinvertebrates and fish prefer shallow water habitat, especially water less than 2 m deep (Shane et al. 2021). But water levels in the river are dictated by water levels in Lake Erie, which vary by as much as 2 m. During design, it will be essential to develop cove bottom elevation contours such that:

- There is always have a good amount of wetland and shallow water fish habitat, even during extreme water levels, to not result in temporary near- or total loss of habitat.
- Water levels are optimal during March-June, which are critical to the development of juvenile fish.

In addition, steep slopes in the coves would allow for perennials to adapt to significant changes in water levels from year to year. Variability in cove depths could be achieved by a combination of excavating deeper holes and creating elevated hummocks. We recommend the design consider adding structures that would help maintain holes through scouring during flushing events, e.g., with rock riffles or locked log weirs on the upstream end of the holes. We also recommend creating hummock structures out of logs and other woody debris and coarse sediments, with sufficient elevation to support woody plants on the top. And we recommend considering using the coves with good juvenile fish habitat in Grassy Island as analog in the design of cove restoration for Ewing and Delaware/Horseshoe Island. And we recommend a field study be performed early in the design phase to collect detailed data on existing cove bottom elevations.

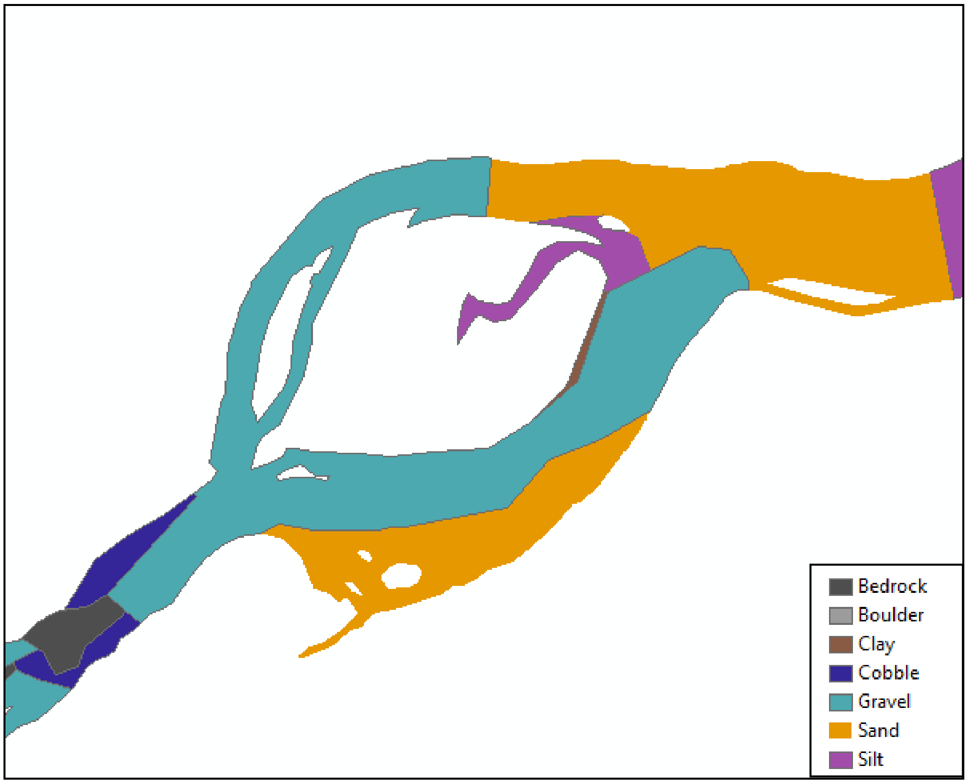


Figure 26. Bottom Substrate near Audubon Island (Source: Tucker, et al. 2020).

3.5 Maumee River Bottom Substrate and Sediment Concentrations and Transport

3.5.1 Bottom Substrate

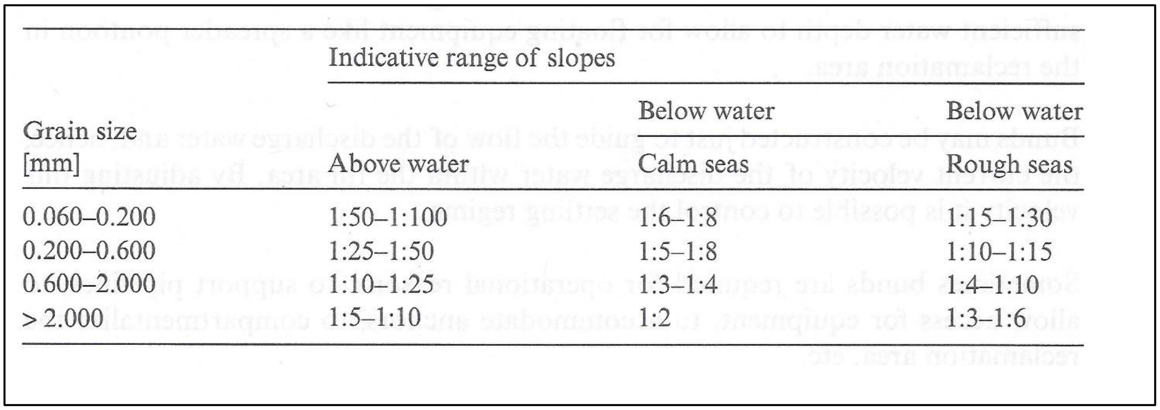
Substrate data was collected in the project areas through a combination of side scan sonar and ground-truthed substrate collections as described in Schmidt et al. 2020. Data from this study is available online (Tucker et al. 2020). Mapped substrates from this data are shown in Figure 26 and Figure 27, below.

Figure 27. Bottom Substrate near Marengo, Grassy, and Delaware/Horseshoe Islands (Source: Tucker, et al. 2020).

Implications for Design (Bottom Substrate)

As discussed in Implications for Design (Cove Bottom Elevations), higher cove slopes have the advantage of allowing perennials to adapt to significant annual fluctuations in Lake Erie water levels. However, substrate gradation and placement method both limit achievable bottom slopes. When placed above water, resulting slopes are significantly lower than when placed below water (see Table 18). And gravel (i.e., grain size > 2.0 mm) or coarse sand (grain size 0.6 - 2.0 mm), would be required to achieve appreciable below water slopes. Above-water placement of fines is expected to result in essentially flat bathymetry (see Table 19). While mechanical below-water placement might produce steeper slopes, below-water placement is likely infeasible in a shallow water context. We recommend field observations of slope and grain size be taken and used to help inform slope designs that are achievable. However, it seems clear that hummock creation or other contouring will require use of coarse sediments.

Table 18: Resulting Sediment Slopes when Placed Above or Below Water (by Hydraulic Discharge), by Grain Size (Van der Kolff & van't Holff, 2012)



Grain size [mm]	Indicative range of slopes		
	Above water	Below water Calm seas	Below water Rough seas
0.060–0.200	1:50–1:100	1:6–1:8	1:15–1:30
0.200–0.600	1:25–1:50	1:5–1:8	1:10–1:15
0.600–2.000	1:10–1:25	1:3–1:4	1:4–1:10
> 2.000	1:5–1:10	1:2	1:3–1:6

Table 19: Generalized Resulting Slopes for Above-Water Placement of Sediments (Hayes, 2021)

Description	Deposition Slope (V/H)	Deposition Slope (H:V)
Clumps	0.200	5:1
Gravel	0.100	10:1
Sand	0.020	50:1
Fine Sand	0.010	100:1
Silt	0.004	250:1
Clay	0.001	1000:1

3.5.2 Bedrock Depths

During a kayak excursion in August 2021, a simple paddle probe test indicated bedrock was near the bottom in the Delaware/Horseshoe Island cove inlet. While detailed surficial substrate data was collected in this area by UT, locations with a thin layer of sediment on top of bedrock would indicate the sediment class rather than bedrock. Additional studies of depth to bedrock will be required to inform design. The following sources were compiled by Beth Sparks-Jackson:

- Bedrock Geology and Bedrock Topography GIS of Ohio: New Data and Applications for Public Access: https://pubs.usgs.gov/of/2003/of03-471/mcdonald/index.html
- Shaded Bedrock-Topography Map of Ohio: https://ohiodnr.gov/static/documents/geology/MiscMap_OhioShadedBedrockTopography_2003.pdf (includes bedrock elevations for glaciated portions of the state, and topography for the remaining portions).
- Ohio Geography Interactive Map at https://gis.ohiodnr.gov/website/dgs/geologyviewer/# (includes bedrock data shapefiles including point measures of bedrock elevations and contours based on the point measures and bedrock maps).

Implications for Design (Bedrock Depths)

Where shallow, bedrock depths could limit dredge depths, the ability to build a stone shelf at right depth, and/or the ability to pile drive the vertical wooden posts associated with engineered log jams and woody debris habitat features. Shallow bedrock would be advantageous however in constructing the chevron dike and rock barrier reefs as it would ensure the features were well founded. We recommend site specific bedrock depth data be collected at locations proposed for all engineered log jams, woody debris habitat features, chevron dikes, and coves. This data can be collected manually using a dynamic cone penetrometer (DCP) probe, under low water conditions or from a streambank.

3.5.3 Conceptual Model of Coves Depths over Time

It is reasonable to wonder if the island coves have filled in overtime and, thus how long would they take to fill in again if excavated. If the coves experienced net deposition, one would expect they would already be filled to near high-water elevations. So, for them to have persisted over decades over which aerial imagery is available, or more likely for eons, some periodic counteracting scour would need to have occurred. We posit two distinct hydraulic conditions whereby water would flow out of coves at a high enough velocity, and with enough shear force, to scour bottom sediments:

- High flow, island overtopping events: Seen in lidar data, it seems clear that periodic high flow events have carved channels or flow paths through the islands (see Figure 28, Figure 29, Figure 30, and Figure 31).
- If the islands themselves have been shaped by high flow, it follows that the coves likely would be as well.
- Seiche event under extreme Lake Erie water levels: A rising seiche event under low Lake Erie levels would cause the water in the coves to rapidly rise and then quickly fall, potentially leading to high enough velocities as the impounded water exits the cove. And in reverse, a falling seiche event under high Lake Erie levels could cause a rapid outflowing of water that might also scour sediments.

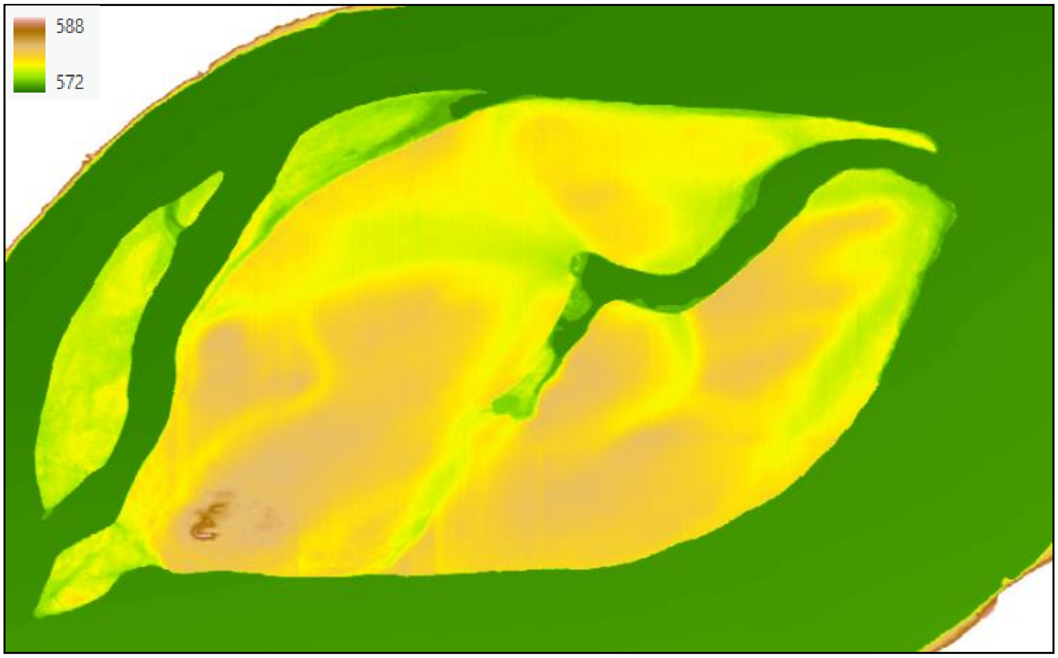


Figure 28. Lidar-Derived Elevation (ft) for Audubon Islands.

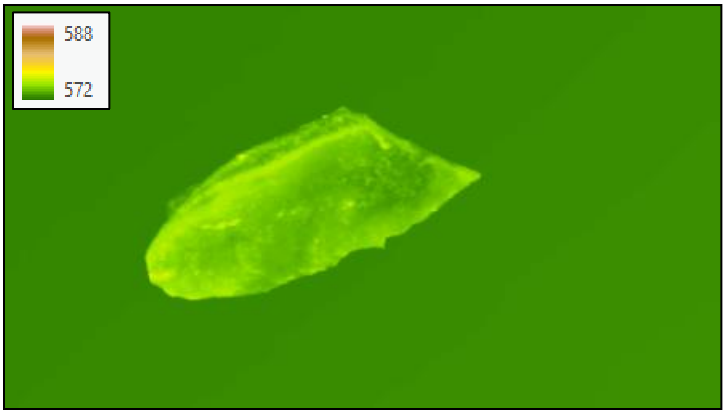


Figure 29. Lidar-Derived Elevation (ft) for Marengo Island.

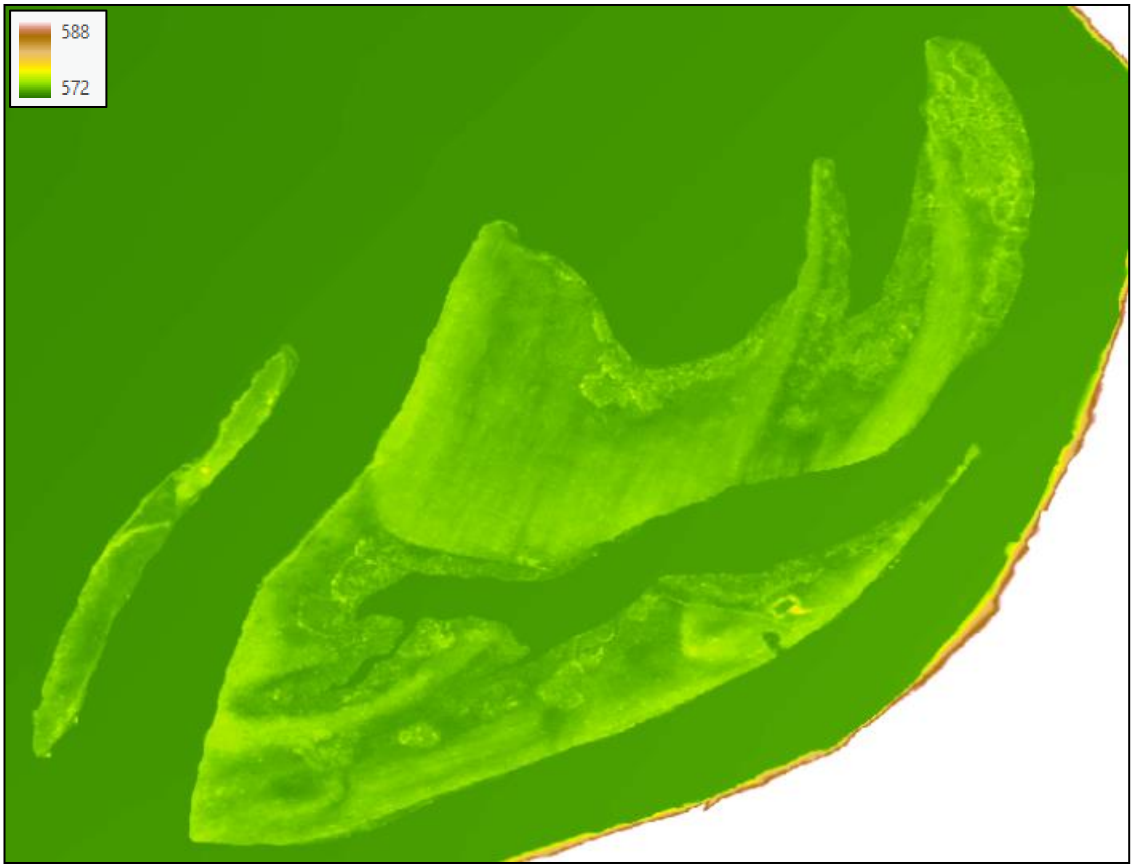


Figure 30. Lidar-Derived Elevation (ft) for Grassy Island.

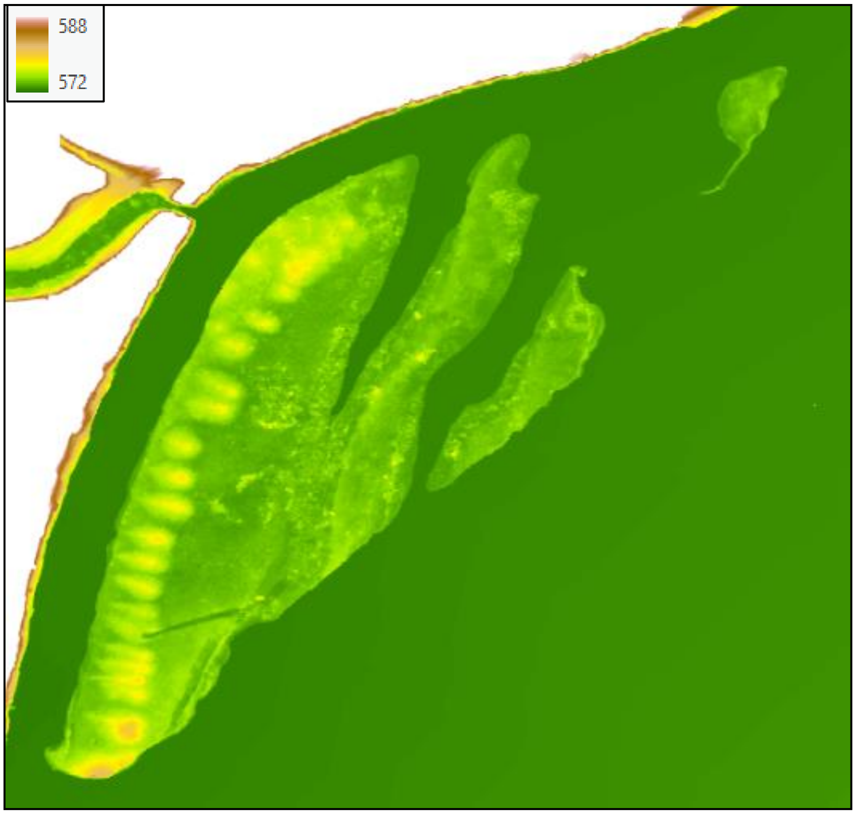


Figure 31. Lidar-Derived Elevation (ft) for Delaware/Horseshoe Island.

In either case, it is likely that occasional hydraulic events in the coves provide for a periodic flushing of sediments. This would counteract a more continuous process whereby sediments carried into the cove as river levels rise during high flows settle out over time in the generally quiescent coves. This conceptual model of the coves will be further evaluated as part of the EFDC modeling.

Implications for Design (Conceptual Model of Cove Depths over Time)

If periodic scour of the coves is essential to maintaining their current depths, it will be essential to evaluate cove recontouring plans to determine if periodic fine sediment removal is still able to occur as designed. For example, pools dredged in the coves might need to be designed with upstream rock riffles or log weirs to ensure they are periodically scoured.

3.5.4 Suspended Sediment Concentrations and Turbidity Measurements

We obtained mean annual suspended sediment concentration data from the USGS gage at Waterville OH (USGS ID 04193500). For the full period of record (1951-2003), the average mean annual concentration of suspended sediments was 85 mg/L, and the range was 33 – 133 mg/L. There appears to be a slight decrease in sediment concentrations over time, but the R^2 is very low at 0.013. According to Griffiths and Walton (1978), the upper tolerance level for suspended sediment is between 80-100 mg/l for fish, and as low as 10-15 mg/l for bottom invertebrates" (USEPA, 2003). SAV can tolerate one to two summers with concentrations > 32 mg/L (UMRCC, 2002). While aerial imagery appears to indicate that the coves provide at least a temporary refuge from high turbidity (see Figure 32), we are not aware of any turbidity or suspended sediment concentrations data having been collected in the island coves. And though eel grass (i.e., Vallisneria) has found to be successful in Otter Creek, we are not aware of any examples of SAV being successful in the area. As such, it seems suspended sediment concentrations are likely a limiting factor for SAV and macroinvertebrate populations in the Lower Maumee.

Figure 32. Potential Indication of Sediment Refugia Provided by Island Coves (Source: Google Earth, image date 3/20/2021).

Implications for Design (Suspended Sediment Concentrations)

We recommend proceeding with SAV plantings with the understanding that there is a risk of failure due to high turbidity, but that it be considered as part of a layering of features that still provide ecological uplift in case the SAV fails. We also recommend collecting turbidity data in coves during the design phase. And if concentrations are found to decrease with distance from the cove mouth, it implies SAV would do better at the upstream end and those locations should be planted preferentially. Additionally, targeting sediment resistant vegetation, even if not SAV, would be preferred. Finally, we recommend creating and/or enhancing sediment refugia as part of this project. On Delaware Island this can be accomplished by reconnecting the southern portion of the island that is currently separate from the rest. In addition, a long rock barrier reef could be implemented to connect the entire southern pieces of the islands, thus creating a sediment refuge roughly three times the size of the current refuge.

3.6 Ice Considerations

Ice impacts have been observed in the Lower Maumee River. In particular, the islands experienced an ice dam and ice scour event in 2015. During a recent kayak excursion, ice scar was evident on a tree on Audubon Island (see Figure 33).

Figure 33. Ice Scar Evidence on a Tree on Audubon Island.

The USACE Cold Regions Research and Engineering Laboratory (CRREL) and the Buffalo District evaluated the potential impacts of ice on river restoration features, and the potential for river restoration features to enhance ice jams, specifically regarding river restoration projects on the Buffalo River (USACE, 2015b). Findings from this analysis include the following:

- Ice jams are associated with a variety of factors including: Confluences of two rivers, channel constrictions, sharp bends, islands, bridge piers, shallow river reaches, low velocity pools, edges of solid ice cover, and sudden changes in the slope of the water surface.
- Locations of previous and historical ice jams would be among the more likely locations for future ice jams.
- Evidence of ice scarring implies a site is at risk for impacts from future ice jam events and any restoration planned for this site should address this risk.
- Border ice (i.e., along a riverbank) forms first, and will thus tend to encapsulate any restoration features built along the banks.
- The formation and release of breakup ice jams is the most important ice process related to river habitat structure, due to the potential for ice gouging and the possibility of ice-induced hydraulic scour.
- Occasional ice damage to habitat restoration features in the restoration project areas is to be expected, as this is a process that occurs naturally and affects riverbanks and vegetation.
- Nearshore shelves along the river's edge helps protect against ice damage as they can ground ice rubble and this stationary ice can then serve to protect structures from ice movement in the channel.
- Ice breakup is most closely associated with high flow and thicker ice, with some association with rapidity of runoff (i.e., short time to peak discharge). The momentum of broken ice contributes to further breakup (USACE, 2009) (Environment Canada NB, 1989).

In addition, a post-project assessment of ice impacts on Buffalo River restoration features at the Ellicott St. site found that anchored submerged logs remained in place where they were below the ice layer while submerged logs that were closer to the surface had been pushed up onto the riverbank.

Implications for Design (Ice Considerations)

Ice scour is anticipated especially in exposed areas and project designs need to endure ice forces. We recommend a site-specific evaluation of where ice jams have formed in the past, using the CRREL Ice-Jam Database (IJDB) or other historical records potentially supplemented by observations of ice scarring on trees. Additionally, we recommend considering whether the features as proposed might influence where ice jams are likely to occur in the future. And given the above, we recommend determining whether the proposed restoration features are out of harm's way or are of sufficient strength to withstand ice jam forces.

All features would need to be designed considering the forces of expanding and cracking ice sheets, with ice load expected to be the controlling case for design. Engineered log jams (ELJ) structures that can recruit woody debris floating from upstream, could be designed to resist ice forces. Design for these structures would be based on standard design approaches to considering ice loads on circular piers (i.e., wooden post moorings).

Submerged logs and root wads along the sides of an island would be vulnerable to ice forces. Given the wide range of water level fluctuations, and the objective of generating shallow water habitat, it would not be possible to have submerged logs that were always deep enough to avoid ice impacts and yet were shallow enough to provide habitat benefits. However, considering this risk, chains/cables could be sized to withstand the tension load if the submerged log / root wad were to be moved by ice. While the feature would not stay in place, it might still provide habitat, despite being moved down river.

Submerged logs and root wads in coves would be exposed to less frequent and less dramatic ice floes (large packs of floating ice). Ice floes in coves would occur only when ice is breaking up in the coves and an early Spring high flow is overtopping the island, or a seiche event leads to rising and then quickly falling levels. These coincident events may happen quite infrequently, but the frequency could be assessed in design and the risk assessed, and/or design adjusted to accommodate the scenario.

Chevron dikes, detached breakwaters, and the stone shelf could be designed to withstand ice forces using standardized design methodologies for stone features.

Riparian plantings could not be protected feasibly from direct ice forces. However live stakes would be considerably more vulnerable to ice particularly in the first winter before roots have a chance to form and in subsequent early years due to slow establishment. As such, we recommend preferring rooted vegetation over live stakes for riparian plantings.

4.0 Plan Formulation

4.1 Problems and Opportunities

As watersheds become more developed and impervious surfaces, such as parking lots, roofs, sidewalks, and driveways cover more area within a watershed, there is a reduction in precipitation infiltration into the groundwater. This reduction in water retention and increase in overland flow routes water quickly downstream increasing base flows and peak discharges, resulting in channel incision, floodplain isolation and accelerated erosion of stream banks. Over time, these hydrologic and geomorphic changes degrade in-channel habitat for aquatic species and isolate the floodplain from overbank flows, degrading habitat for riparian species. This high level of disturbance often makes areas more susceptible to the establishment of invasive species. This is a common phenomenon experienced in the Lower Maumee River watershed where existing conditions exhibited in the study area are a result of extensive human alteration.

This degradation of the aquatic environment has led the U.S. Environmental Protection Agency (USEPA) to identify the Maumee River as an “Area of Concern (AOC)” where significant beneficial use impairments (BUIs) have occurred because of human activities at the local level. The USEPA has identified the following BUIs in the Maumee AOC:

- *Degraded Fish and Wildlife Populations (BUI #3)* – Environmental conditions to support healthy, self-sustaining communities of desired fish and wildlife are at lower levels and abundance than what would be expected from the amount and quality of suitable physical, chemical, and biological habitat present in the Maumee AOC.

- *Degradation of Benthos (BUI #6)* – Benthos are organisms that live in the sediment or near the bottom of a river or lake. Sediment contamination and other factors can diminish their populations. Benthos make up the base of aquatic systems and are therefore important to ecosystem health. The Maumee AOC's benthic community structure is substantially lower quality when compared to non-AOC reference sites.

- *Loss of Fish and Wildlife Habitat (BUI #14)* – Local fish and wildlife habitat in the Maumee AOC are impaired or lacking altogether. Restoration actions are needed to create and reestablish habitat with the physical, chemical, and biological characteristics necessary to support native fish and wildlife populations.

After a community assessment of fish and wildlife, including macroinvertebrates in the Lower Maumee River, areas were identified that could be protected, enhanced, and rehabilitated to increase biodiversity. In particular, the large island complexes present in the lower Maumee River had the greatest diversity and abundance of fish and macroinvertebrates and were ideal sites for preservation and habitat rehabilitation (Hintz et al., 2019).

Islands in the Maumee River are ideal for habitat rehabilitation projects seeking to improve fish and invertebrate diversity and abundance. However, these islands are also experiencing erosion. Erosion control and protection measures could be designed and incorporated into preliminary restoration designs to keep these important habitat areas within the Maumee AOC.

Given the important role that alluvial island complexes have in supporting fish and invertebrate communities (Thorp 1992; Gurnell and Petts 2002), this remaining cluster of islands is thought to contain high quality habitat and provide the greatest opportunity for restoration of habitat in this stretch of the Maumee River. Rehabilitation projects could include the installation of woody debris such as downed trees and root wads, planting of live or rooted stakes and wetland plugs along shorelines, dredging activities in coves to improve habitat heterogeneity, and planting of native submerged aquatic vegetation within coves.

4.2 Objectives

Objectives for the Lower Maumee River Restoration project were developed cooperatively among the USACE, the USGS, Ohio EPA and the University of Toledo (UT). The primary objective of this feasibility study is to develop up to four preliminary project restoration designs that best meet the goals of the project, which is to address the three BUIs mentioned in Section 4.1.

Each of the design concepts presented in the sections below have been developed to enhance fish and macroinvertebrate habitat in the mainstem of the Maumee River, with particular emphasis on addressing BUIs 3) Degradation of fish and wildlife populations 6) Degradation of benthos, and 14) Loss of fish and wildlife habitat. These concepts have also been designed to include the following preliminary restoration designs:

- Increasing topographic heterogeneity and increase in-stream habitat complexity and diversity
- Providing greater habitat diversity and complexity in the nearshore and riparian zones
- Improving species richness and density in the fish, macroinvertebrate, and native plant communities
- Controlling invasive plant species
- Expanding and enhancing high-quality shallow water and wetland habitat along island edges
- Developing low-maintenance, self-sustaining preliminary restoration designs

4.3 Constraints

Constraints are restrictions that limit the planning process and are unique to each planning study. They are statements of things unique to a specific project that must be avoided or taken into consideration during the planning phase of a project. Listed below are constraints that have been identified for this project.

- Projects will require permission and access from public and private landowners, and in some cases, coordination with adjacent riparian property owners.
- Ice floes in the Maumee River exert strong shear forces on any restoration features proposed and present a risk for damage after construction.
- Seiche events in this stretch of the Maumee River result in significant daily variations in water levels and some of which cause the river to flow upstream, which may affect the performance of some restoration features (e.g., chevron dikes, dredged coves, etc.).
- There is a potential for the presence of archaeological artifacts around some proposed project sites. Restoration efforts recommended for some project sites may need to be altered to incorporate feedback from the State Historic Preservation Office (SHPO) and federally recognized tribes which may affect project sites selected for implementation.
- Walleye spawning habitat exists in the stretch of river in the vicinity of the Audubon Islands complex. To protect walleye habitat, activities that could potentially modify existing walleye spawning habitat should be avoided. This includes but is not limited to dredging activities and construction of rocky dike structures in this reach given their potential to redirect flows and modify sedimentation processes.
- It is important that in-water construction does not take place immediately before or during the walleye spawning run. There is an in-water work restriction from 15 March – 30 June that should protect spawning walleye and other potentially sensitive species such as white bass and steelhead.

- There is a Bald Eagle's nest at the southern shore of Ewing Island near the upstream end of the reef installation on the design feature map. Additionally, the exposed banks of Ewing Island appear to be used seasonally by bank swallows. Any action proposed to alter or remove the exposed banks of Ewing Island should be initiated prior to 15 May or after 1 July to avoid disrupting active nesting activities.

4.4 Future Without Project Condition

The forecast of the future without project condition reflects the anticipated conditions during the period of analysis if no action is implemented and provides the basis from which alternative plans are formulated and impacts assessed. Without a project, it is expected that the current geomorphic, hydrologic, and biologic processes would be allowed to continue on their present course.

In absence of any habitat restoration project, it is anticipated that the quality of in-channel, riparian, and floodplain habitats will remain degraded and the extent of invasive species along the river corridor and associated floodplain will continue to dominate certain areas and possibly increase. Bank erosion and continued spread of invasive species will continue to prevent native riparian vegetation from reaching mature stages, limiting the amount of large woody material being able to enter the river system which is beneficial to in-stream fauna. Overhanging vegetation is also a source of such woody material, and both are critical for a functioning river ecosystem. As a result, the Qualitative Habitat Evaluation Index (QHEI), Fish Index of Biotic Integrity (FIBI), Modified Index of Well-Being (MIwb)and Invertebrate Community Index (ICI) scores for the Lower Maumee River assessment units will continue to be depressed in some river reaches.

4.5 Restoration Measures

A variety of restoration measures have been developed based on discussions among the USGS, the USACE, and the University of Toledo. The restoration measures described below could be implemented alone, or in combination with other measures to achieve the restoration goals. It is recommended that vegetation planting and invasive species management be included in any restoration design concept(s) carried forward to the design phase.

4.5.1 Vegetation Planting

Riparian areas are an important component of healthy watersheds and ecological function. Vegetated riparian areas provide critical habitat for wildlife, act as buffers between upland areas and the river helping to filter pollutants such as nutrients and sediment, help to reduce stream bank erosion and maintain stable channel geomorphology, provide shade, helping to keep water temperatures lower supporting higher dissolved oxygen levels which are important to aquatic and fish habitat. Finally, native riparian trees, shrubs, and grasses not only provide shade but organic matter, and eventually woody debris to river. As a result of all the above, mature riparian vegetation is associated with higher IBI and QHEI index scores.

Flood-resistant herbaceous emergent aquatic plants (e.g. swamp milkweed, arrowhead, water willow, etc.) are recommended to be planted in the “splash zone,” which is the portion of the riverbank that is between the normal high- and low-water stages. Herbaceous and woody plants (e.g. willow species, river birch, dogwood species, etc.) that can tolerate occasional submergence should be planted in the “bank zone,” which is above the normal high-water level, but may still be exposed to waves, erosive flows, and ice and debris movement.

Revegetation efforts can be maximized by considering the current and future climate trajectory of the region. Sufficient evidence now exists that vegetation communities have been shifting slowly northward and will continue to do so at rates commensurate with various climate change scenarios. The primary species planted for revegetation must be an ideal fit for the current climate to ensure establishment as well as the ability to outcompete invasive species. Additional species can be used, however, that match the anticipated climate trajectory to ensure a stable, and adaptable vegetation community.

Table 20 lists tree species expected to gain in importance value under the average of three low-emission global climate change models. While some are species currently having importance values greater than zero (e.g., white oak, flowering dogwood), others currently have importance values of zero (e.g,. blackjack oak, black hickory).

Native trees to be considered may include cottonwood, box elder, red maple, sugar maple, sycamore, swamp white oak, white oak, red oak, pin oak, black walnut, silver maple, alder, black cherry, shagbark hickory, bitternut hickory, and Ohio buckeye. Ultimately, the selection of tree species will be determined during the engineering and design phase and should be based on local expertise and knowledge of potential pathogens that could limit viability. Native species of cultural significance to regionally associated American Indian Tribes will be included in the plant list.

Table 20: Trees gaining in importance value under average of three low emission scenario global climate change models.

Common Name	**Scientific Name**	**ClimIndx**	**ModRely**	**ModCur**	**Gcm3AvgLoDif**
post oak	Quercus stellata	4	1	0	10.12
osage-orange	Maclura pomifera	3.5	2	0	9.33
eastern redcedar	Juniperus virginiana	4	2	0	3.83
black oak	Quercus velutina	1.5	1	2.14	3.71
flowering dogwood	Cornus florida	0	1	2.83	3.33
white oak	Quercus alba	3.5	1	3.86	2.64
shagbark hickory	Carya ovata	4	2	1	2.52
blackjack oak	Quercus marilandica	3	2	0	2.46
hackberry	Celtis occidentalis	3	2	0	2
black hickory	Carya texana	3.5	1	0	1.98
shingle oak	Quercus imbricaria	3.5	2	0	1.81
common persimmon	Diospyros virginiana	3.5	2	0	1.17
chinkapin oak	Quercus muehlenbergii	4	2	0	1.14
bitternut hickory	Carya cordiformis	3.5	3	0	1
eastern redbud	Cercis canadensis	2.5	2	0	1
red mulberry	Morus rubra	3.5	3	0	1
winged elm	Ulmus alata	4.5	1	0	1
scarlet oak	Quercus coccinea	3.5	1	0	0.98
honeylocust	Gleditsia triacanthos	4	3	0	0.86
slippery elm	Ulmus rubra	0	2	1.98	0.71
black walnut	Juglans nigra	3.5	2	1.98	0.17
pignut hickory	Carya glabra	3.5	1	1.86	0.14
green ash	Fraxinus pennsylvanica	3.5	2	0.86	0.14
silver maple	Acer saccharinum	2.5	2	0.98	0.04
black willow	Salix nigra	3	3	0.02	0.02

ClimIndx = index of how strongly the species is driven by climate (higher value = more strongly driven).
ModRely = model reliability with 1 being most reliable; 2 moderate and 3 low.
ModCur = Modeled current importance value.
Gcm3AvgLoDif = Change in importance value under average of 3 low emission scenario GCMs.

4.5.2 Invasive Plant Removal

Vegetation planting would perform best when done in conjunction with an invasive species management protocol. Effective invasive species treatment would allow for the establishment of a wide range of native riparian vegetation. Once established, the new riparian vegetation would outcompete the invasive species and maintain a natural and structurally complex riparian zone.

There are numerous invasive plant species within the Lower Maumee Restoration study reach, most notably common reed (*Phragmites australis*). This aggressive invasive species can rapidly form dense stands that crowd out or shade native vegetation and can turn rich habitats into monocultures devoid of the diversity needed to support a thriving ecosystem. This species would be targeted for removal where native plantings are to be installed. A combination of physical, mechanical, and chemical methods would be used to remove common reed from the restoration area. This initial treatment would need to be monitored and followed up by yearly targeted or spot treatments to prevent the re-establishment of the common reed colony.

Invasive species propagules are constantly being supplied from upstream sources; therefore, it is unrealistic to assume complete eradication of any particular invasive species. It is important to manage invasive species populations for a duration of time sufficient to allow the native plantings to effectively compete with the invasive species. A four-year invasive species management protocol is recommended for the most pervasive invasive species found in the project area. The control schedule for common reed is described below.

- **1st year early summer:** Late June, cut/mow *Phragmites* stand.
- **1st year fall:** Late August – early September, spray re-sprouting stands with maximum dose of over-water approved glyphosate (RoundUp™ or Rodeo™). Chemical treatment must start in the fall when *Phragmites* is still physiologically active. Spray a complete application to fully leaved plants after tasseling. Follow-up mowing no sooner than 30 days following spray treatment. Remove mowed material from area by raking, then burn the material.
- **2nd year spring:** Hand pull resprouted or newly germinated individuals. Till area to break up rhizome and prepare seed bed. Plant or seed temporary cover crop.
- **2nd year fall:** Spot spray remaining individuals. Plant or seed 50-75% of permanent vegetation no sooner than 30 days following spray application.
- **3rd year spring:** Monitor native vegetation/plantings. Spot spray remaining *Phragmites* individuals. Plant or seed remaining permanent vegetation.
- **3rd year fall:** Monitor native vegetation/plantings. Spot spray or hand pull remaining *Phragmites* individuals.
- **4th year spring:** Monitor native vegetation/plantings. Spot spray or hand pull remaining individuals.
- **4th year fall:** Monitor native vegetation/plantings. Spot spray or hand pull remaining individuals.

4.5.3 Installation of Rood Wads and Submerged Trees

Trees that grow in the riparian zone can be transported into the river channel due to floods, erosion, wind damage, disease, beaver activity, or natural mortality. These trees are often referred to as large woody debris (LWD), which can consist of a wide range of types and sizes including logs, coarse roots, smaller branches, or an entire tree with an intact rootwad. The loss of a natural LWD supply regime (Wohl 2011) is well recognized as a major factor contributing to degraded river structure and function (Beechie et al. 2010). Root wads and submerged trees may be lost from river channels due to reduced quantity or size of riparian and floodplain vegetation, channel hardening that limits the natural erosion and LWD recruitment regime (Beechie et al. 2010), or active removal for navigation or flood control (Wohl 2014). LWD is an important and naturally occurring component of aquatic habitat and stream ecosystem integrity (Karr and Chu 2000).

Introducing LWD into riverine systems has been a common restoration technique for decades (Cashman et al. 2018). One of the most common methods of adding woody debris has been the process of felling (cutting down), yarding (dragging to the stream), and bucking (hoisting into position), and then properly securing the LWD in the active channel that is being restored (Zapalka 1997). The LWD can be added to the river unanchored or by anchoring (i.e. buried or cabled). LWD as part of Lower Maumee River restoration would be placed strategically to enhance habitat and provide streambank protection, while considering recreational boating and kayak passage and safety.

Placement of LWD can create structural habitat features or localized streambank stability, but the primary objective of restoring a natural LWD regime to river corridors should be the associated hydro-morphological and ecological function endpoints. Structurally focused restorations often do not speed the rate of recovery in dynamic streams (Miller and Kochel 2010), yet structurally-simple LWD features (e.g. deflector logs) have dominated restoration practice (Cashman et al. 2018). More complex LWD features that are part of natural systems have the potential to provide functional uplift to stream corridors (Wohl 2014). Natural LWD recruitment is typically the result of lateral channel migration that exists as part of a negative feedback system wherein the ultimate extent of lateral migration is limited by the streambank protection afforded by LWD (Beechie et al. 2010). This dynamically stable system produces floodplain patches that are stable enough to grow mature trees that serve as sources of future LWD. This autogenic nature of LWD recruitment is reliant on natural streambank erosion and is more likely to increase habitat heterogeneity and ecological functions than stable, structurally based LWD features (Florsheim et al. 2008).

LWD placement in river corridors in isolation is not expected to result in functional uplift due to the risk of streamflow flanking the structure, and the tendency of simple, structurally based restoration features to transfer erosive forces downstream. As such, the addition of complex LWD features (e.g., locked-log crib structures, structurally complex log grade control, or floodplain roughness features) should be implemented strategically in conjunction with other restoration measures. LWD is typically an integral component of streambank bioengineering and can be used for stabilization and/or pool scour development. Log grade control features—designed for increasing tributary floodplain access may themselves be considered LWD and can be enhanced by more structural complexity (e.g., rootwads) and complementary LWD features. Integrating LWD features as part of other restoration measures has the potential to initiate a more natural LWD recruitment regime for the overall Lower Maumee River system.

The benefits associated with adding LWD and promoting the autogenic recruitment of LWD include improved fish habitat by increased types and sizes of pools, sediment storage, and scour within the river channel; dissipation of energy; and enhanced biological diversity. LWD also provides colonization areas for different types of macroinvertebrates, resulting in high densities of macroinvertebrate prey for fish.

4.5.4 Cove Contouring

Mechanical or hydraulic dredging can be used to create or enhance shallow water habitat in existing coves of islands. Island coves would be dredged to water depths sufficient to promote submerged aquatic vegetation (SAV) growth. The growth of SAV provides nursery habitat for juvenile fish and provides a food source for macroinvertebrates (Hintz et al., 2019). However, SAV would need to be protected from high flows and waves.

4.5.5 Chevron Dike Installation

Chevron dikes are V – or U – shaped structures constructed parallel to the flow of the river, typically to the two-year flood elevation. The rock dike material may provide habitat for macroinvertebrates, thereby providing a food source for fish. Chevron dikes also increase habitat diversity by redistributing flow and sediment in the river. According to the UMRR EMP Environmental Design Handbook, periods of high water may cause scour to occur downstream of the dike's apex and the sediment suspended by this is expected to be deposited immediately downstream where it may eventually form a new island or aid in building or maintaining existing islands. The scour hole formed during high flow events also provides an area of slack water during low flows, which provides additional fish habitat during low flow events (USACE, 2012).

5.0 Project Site Plans

Within this stretch of the Maumee River, 12 project sites were originally identified and have been further refined and grouped into three general focus areas:

1. Audubon Islands
2. Marengo Island
3. Delaware / Horseshoe Islands

5.1 Audubon Islands

5.1.1 Audubon Islands Concept 1: Rock Barrier Reefs

Concept Narrative

Rock barrier reefs are a series of small, detached stone breakwaters, with crests slightly above the average water level. These structures could be used to provide protection from wave action, ice scour, and other physical disturbances upstream, downstream, and along the sides of the in-stream islands.

The rock barrier reefs would provide habitat for fish species by providing protection from predators, feeding opportunities, and shelter from currents. The location of the rock barrier reefs close to the shoreline of the riverine islands encourages biological exchanges between the aquatic and terrestrial habitats. Rock reefs also provide hard surfaces in largely soft natural habitats, thereby providing diversity within the aquatic habitat.

The reefs would provide areas of calm water, and potentially lower turbidity levels, which would facilitate the growth and expansion of emergent and submergent vegetation. The development of this vegetation would provide additional habitat benefits for fish and macroinvertebrate populations.

Similar structures have been used with success along Beaver Island, on Grand Island in the Upper Niagara River, NY (Figure 34 through Figure 36). These structures have been used to address shoreline erosion, lack of wetlands along the river's edge, loss of aquatic habitat, and limited places for birds and wildlife to breed and forage. The placement of these structures close to the shoreline creates areas of flow refugia that encourages the growth and expansion of submerged and emergent vegetation, and the expansion of river wetland habitat.

The rock structures could be placed in proximity to the shoreline (e.g., as close as 30 feet from the shoreline) to reduce impacts to navigation. However, increasing the distance from the shoreline would increase the size of the shoreline habitat to be restored/created. The rock barrier reefs may also provide additional access for shoreline fishing.

The design life for a stone reef is typically 50-years.

Figure 34: Detached rock reefs along the shoreline of Beaver Island, Grand Island, NY. Source, Google Earth 2021.

Figure 35: Rock barrier reefs along the eastern shore of Beaver Island, Grand Island, NY. Source, Google Earth 2021.

Figure 36: Rock reef and cabled logs/submerged trees. Source: Buffalo Niagara Riverkeeper.

Concept Location

Rock barrier reefs can be used to enhance the habitat along the sides of Maumee River islands which typically have lower IBI and macroinvertebrate diversity. The reefs would be placed along the south shore of Ewing Island and the south shore of Grape Island. The rock reefs could be used in conjunction with submerged trees or cabled logs to enhance and create fish and macroinvertebrate habitat in the area (Figure 37).

Riparian plantings would also benefit from the protection of the rock barrier reefs. The rock barrier reefs would provide protection from erosion and ice scour along the shoreline. Therefore, it is recommended that riparian plantings be considered in conjunction with the construction of the rock barrier reefs to increase biological exchange between terrestrial and aquatic habitats.

Concept Design

Rock barrier reefs would be installed along the shoreline of Grape and Ewing Islands (Figure 37). The footprint of the proposed reefs would be determined during the design phase.

The reefs would be constructed with a stone base consisting of 18-inch diameter rock; however, exact rock sizing would be determined during the design phase. The surface of the reef would consist of stone ranging in size from 9 to 12-inch cobble. The reef would be designed to have an irregular surface, consisting of a range of rock sizes, as well as low and high spots to allow high flow events and waves to overtop them, thereby dissipating the erosive energy to the shoreline.

The low profile, irregular crest, and relatively short length of the reefs is designed to allow some flushing and flow-through under a wide range of water levels conditions, while still preventing erosive forces from affecting the nearshore habitat.

Sedimentation is expected to occur behind the reef structures. This is a benefit, as it would facilitate wetland expansion between the shoreline and the constructed reef.

Live stakes or rooted stakes would be driven into the existing banks on Grape and Ewing Island. Emergent plugs would be installed behind the reefs if water depths are sufficient for the growth and expansion of emergent vegetation.

Rock barrier reefs placed around the Audubon Islands complex could affect existing walleye spawning habitat. Additional modeling would be needed to determine the impacts this concept would have on the walleye spawning habitat. Depending on the results of the modeling study, this concept would need to be eliminated or modified to reduce or eliminate impacts to walleye spawning habitat.

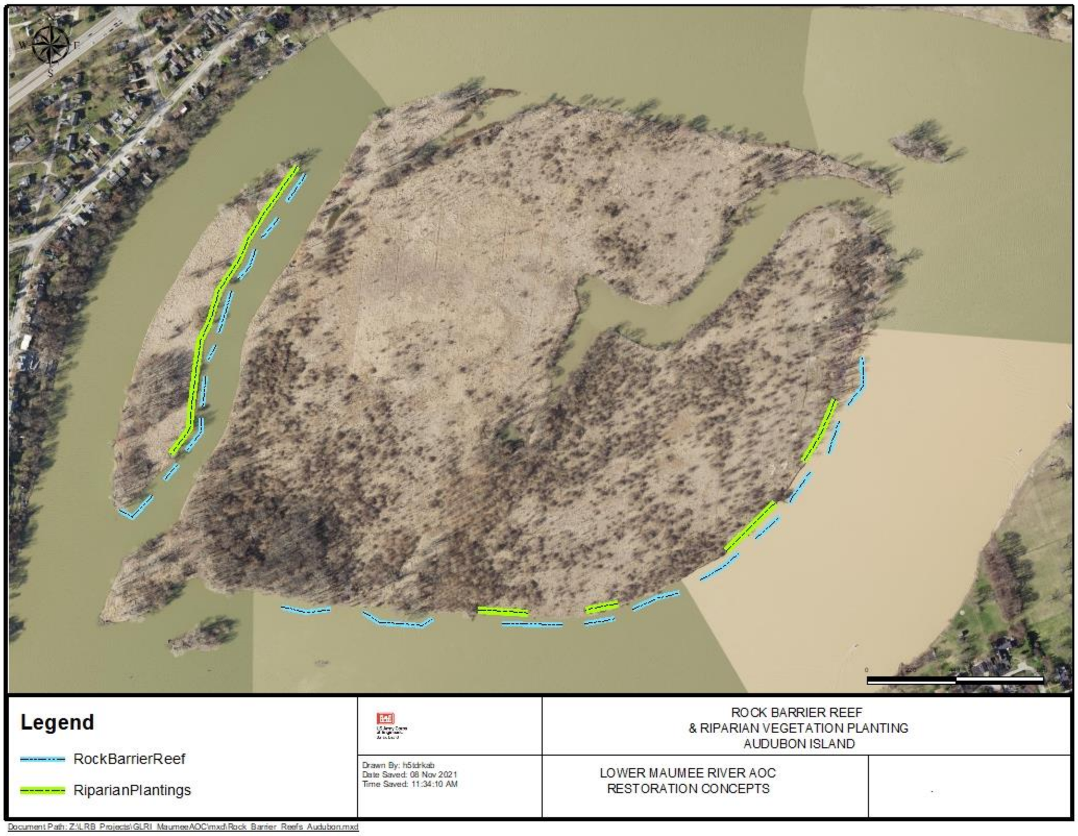


Figure 37: Rock barrier reef and riparian vegetation planting on Ewing and Grape Islands.

Live or rooted stakes should be placed along the lowest portion of the bank and should be driven into the bank such that the live stakes are angled at both 90-degrees and 45-degrees from the bank (Figure 38). Live stakes should be driven into the bank by at least 75 percent of their length, and no more than the top eight inches of the stake should be visible aboveground. Live stakes should be staggered in a random pattern along the bank and planted densely at 1-2 feet apart.

Emergent plugs would be installed behind the reefs if water depths and substrate characteristics are sufficient for the growth and expansion of emergent vegetation.

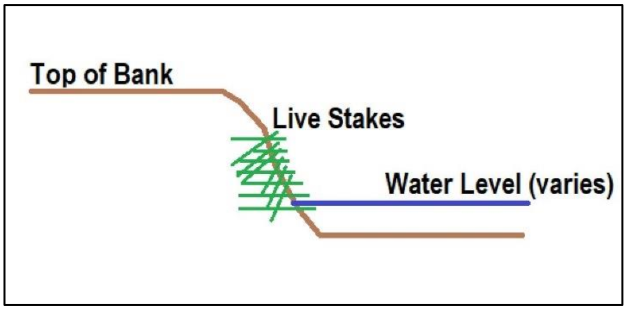


Figure 38: Live stake location and orientation along the lower bank.

Qualitative Ecological Benefits

In the absence of detailed baseline biological and physical habitat metrics, best professional judgement has been used in this study to assess the degree of ecological uplift afforded by each restoration concept. Therefore, the below sections represent a qualitative assessment of the benefits of each restoration concept.

This concept would restore and protect shallow shoreline wetland habitat, which is the type of habitat recognized as one of the most significant losses to the Lower Maumee River ecosystem due to AOC-related causes. Shallow water habitats exhibit the highest biodiversity in the Lower Maumee River ecosystem. This concept would also encourage the growth of macrophytes, which would afford greater habitat heterogeneity for benthic species.

The addition of shallow water habitat along the edges of the river islands would create linkages between the aquatic and terrestrial habitats. Riparian vegetation, now protected by the rock barrier reefs, would begin to overhang the shallow water habitat, thereby shading and cooling the surface waters. This riparian vegetation would provide an alternative source of organic matter to the riverine habitat. Terrestrial animals falling into the water from riparian plants would constitute a major source of high-quality food for the benthic organisms.

Rock reefs placed in the Upper Niagara River have been shown to create shallow nearshore emergent and SAV habitat. In addition to the restoration of lost habitat, the rock reefs would provide shelter, foraging, and spawning habitat for Maumee River fish species.

The addition of cabled logs or submerged trees in the lee of the reefs would provide habitat for macroinvertebrates. Over time, submerged aquatic and emergent vegetation would colonize the area between the shore and the rock reef, thereby expanding coastal wetland habitat.

This concept would address the Degradation of Benthos and Loss of Fish and Wildlife Habitat BUIs.

The amount of habitat restored would depend on the length of shoreline to receive the benefit of the rock reefs and cabled logs.

Qualitative lift in IBI scores: The Index of Biotic Integrity (IBI) is a score based on the performance of the biological community. This index is designed to measure the aquatic vertebrate community and the surrounding conditions by using fish species as indicators. The sampled site is compared against a relatively undisturbed reference site with similar geographical and climatic conditions.

The IBI scores range from 12 – 60. The existing IBI scores downstream of Ewing Island were collected in 2012. The scores at the two sites downstream of Ewing Island (at river mile 13.3) were calculated to be 36 (marginally good) and 29 (fair).

The restoration concept described above would be expected to improve the following IBI variables:

- Variable 1: Total number of species
- Variable 6: Percent of tolerant species

- Variable 7: Percent of omnivorous species
- Variable 8: Percent of insectivorous species
- Variable 10: Number of individuals

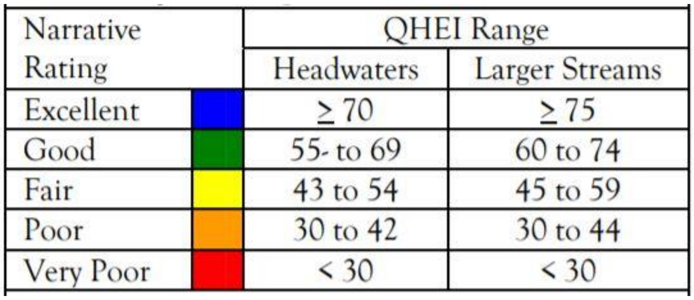
Qualitative lift in ICI scores: The invertebrate community index (ICI) is similar to the IBI and measures the health of the macroinvertebrate community. This index is comprised of 10 metrics where sampled sites are also compared to a reference site.

The ICI scores range from 0 – 60. The existing ICI score downstream of Ewing Island (at river mile 13.3) was calculated to be 12, which is reflective of poor resource conditions.

The restoration concept described above would be expected to improve the following ICI variables, when compared to an undisturbed reference site:

- Variable 1: Total number of taxa
- Variable 4: Total number of dipteran taxa
- Variable 8: Percent of other dipterans and non-insects
- Variable 9: Percent of tolerant organisms
- Variable 10: Total number of EPT taxa

Qualitative lift in QHEI scores: The qualitative habitat evaluation index **(**QHEI) is used to measure the physical habitat quality within the river. The QHEI is composed of six principal metrics: (1) substrate; (2) in-stream cover; (3) channel morphology; (4) riparian zone and bank erosion; (5) pool/glide and riffle-run quality; and (6) map gradient. Each of the metrics are scored individually, and then summed to provide the total QHEI score, with a maximum possible score of 100. Figure 39 shows how the QHEI scores relate to a narrative rating.



Narrative Rating		QHEI Range	
		Headwaters	Larger Streams
Excellent	🟦	≥ 70	≥ 75
Good	🟩	55- to 69	60 to 74
Fair	🟨	43 to 54	45 to 59
Poor	🟧	30 to 42	30 to 44
Very Poor	🟥	< 30	< 30

Figure 39: QHEI narrative rating guide.

The existing QHEI score downstream of Ewing Island (at river mile 13.3) was calculated to be 45, which is reflective of fair physical habitat conditions.

The restoration concept described above would be expected to improve the following QHEI metrics:

- Substrate
- In-stream cover
- Riparian zone and bank erosion

Concept Summary

Table 21: Rock Barrier Reef Concept Summary

Concept Summary			
Existing Shoreline Conditions			
	Acres	**Linear foot**	
Shallow water zone	Negligible		
Eroding banks		3,493	
Post-Construction Shoreline Conditions			
Shallow water zone			
Ewing Island	4.90		
Grape Island	2.35		
Maximum Length of Improvements			
Ewing Island		3,493	
Grape Island		1,921	
Expected Benefits			
	Yes	**No**	**Maybe**
Fish habitat	X		
Macroinvertebrate habitat	X		
SAV habitat / Turbidity refuge			X
Shoreline protection	X		
Riparian plantings	X		
Increased habitat complexity	X		
Walleye spawning grounds impacts	X		
Estimated Costs			
	High	**Low**	**Scalable**
			X

Project site #1 encompasses about 2,000 linear feet of shoreline along the southeastern side of Ewing Island. This section of the shoreline consists of an eroded bank, which extends approximately 3-4 feet above the water surface depending on water levels, and sparse vegetation on the upper bank.

5.1.2 Audubon Island Complex (Ewing/Grape) Concept 2: Stone Shelf with Engineered Log Jam (ELJ)

Concept Narrative

This concept uses large stone, small cobble/gravel, and large woody debris to enhance and extend the shallow-water habitat along the shorelines of the Maumee River islands (Figure 40).

This concept uses large stone capped with gravel/cobble to serve as bank protection, walleye spawning habitat, and protects and extends high-quality shallow habitat under all water-level scenarios and flow conditions. Vertical logs, angled upstream and out from the bank, would act as wood traps thereby creating an engineered log jam along the shoreline. This woody habitat would be ideal for juvenile fish and macroinvertebrates.

The vertical logs would need to be embedded by a certain percentage of their length to withstand ice damage. During the design phase, practitioners should use standardized techniques to assess ice damage on wood piers.

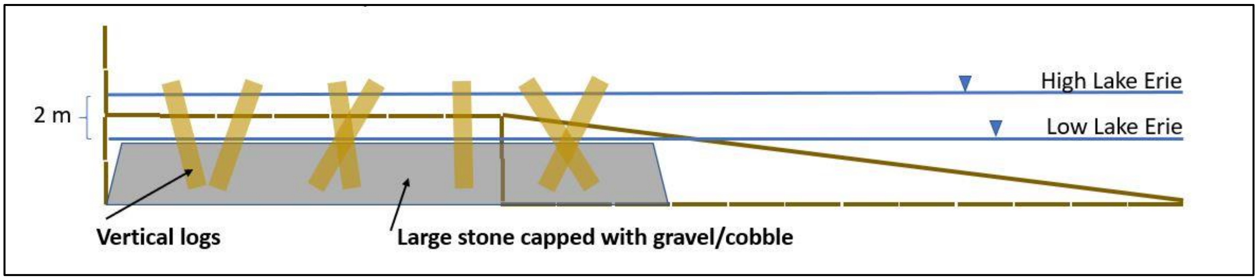


Figure 40: Stone shelf with engineered log jam.

Concept Location

This concept would be applied along the right side of Ewing Island or along the left side of Grape Island (Figure 41).

Concept Design

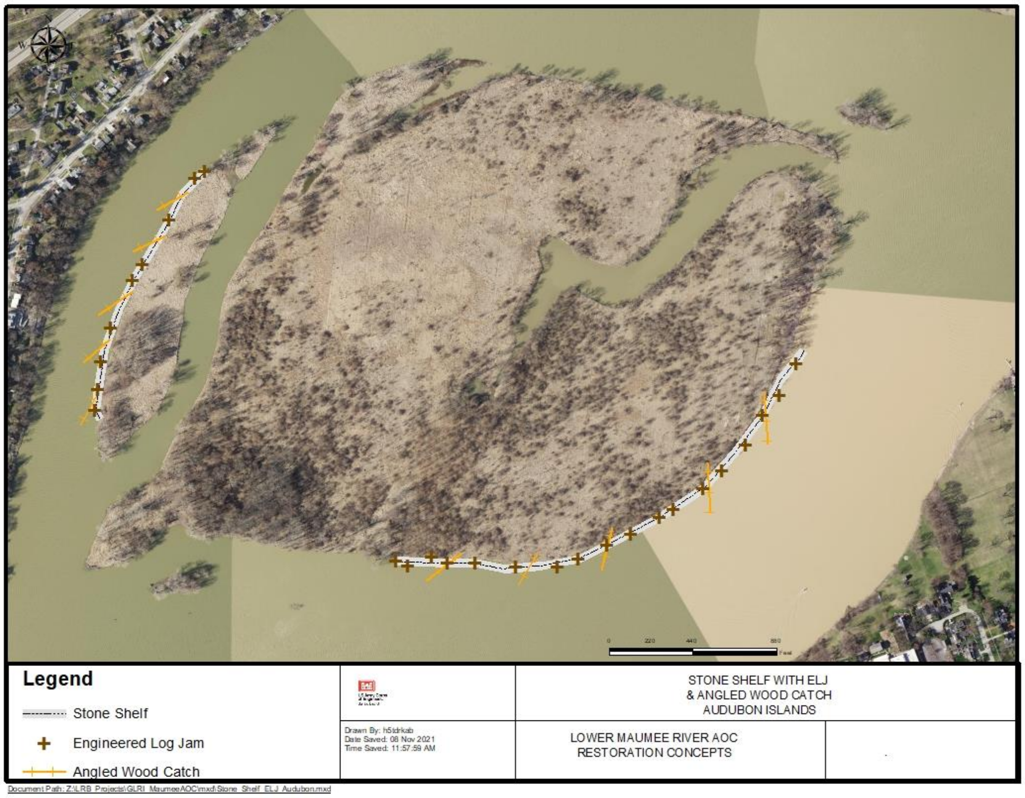


Figure 41: Stone shelf with ELJ and angled wood traps.

A continuous stone shelf would be constructed along the right side of Ewing Island and the left side of Grape Island. Wooden piers would be driven into the substrate to simulate natural log jams along the banks of each of the islands.

A stone shelf placed around the Audubon Islands complex could affect existing walleye spawning habitat. Additional modeling would be needed to determine the impacts this concept would have on the walleye spawning habitat. Depending on the results of the modeling study, this concept would need to be eliminated or modified to reduce or eliminate impacts to walleye spawning habitat.

Qualitative Ecological Evaluation

Although IBI scores measured throughout the entire Lower Maumee River system are not expected to improve following implementation of the above-mentioned restoration concept, measurements within and in the immediate vicinity of the restoration footprint would be expected to show some measurable increase in habitat value.

This concept would extend the shallow/nearshore aquatic habitat. The addition of cobble/gravel substrates in the nearshore zone would create spawning habitat in areas that are currently devoid of spawning habitat. The addition of logs would provide immediate habitat for macroinvertebrates. The vertical logs would be self-sustaining, in that, they would trap woody debris. This trapped woody debris would provide additional habitat for both fish and macroinvertebrates. The sediments trapped by the woody habitat could lead to shoreline aggradation and increased heterogeneity which would create ecological connections between aquatic and upland habitat types.

The addition of riparian tree plantings would improve the ecological connectivity between aquatic and riparian habitats.

Qualitative lift in IBI scores:

The IBI scores range from 12 – 60. The existing IBI scores downstream of Ewing Island were collected in 2012. The scores at the two sites downstream of Ewing Island (at river mile 13.3) were calculated to be 36 (marginally good) and 29 (fair).

The restoration concept described above would be expected to improve the following IBI variables:

- Variable 1: Total number of species
- Variable 6: Percent of tolerant species
- Variable 7: Percent of omnivorous species
- Variable 8: Percent of insectivorous species
- Variable 10: Number of individuals

Qualitative lift in ICI scores:

The ICI scores range from 0 – 60. The existing ICI score downstream of Ewing Island (at river mile 13.3) was calculated to be 12, which is reflective of poor resource conditions.

The restoration concept described above would be expected to improve the following ICI variables, when compared to an undisturbed reference site:

- Variable 1: Total number of taxa

- Variable 4: Total number of dipteran taxa
- Variable 8: Percent of other dipterans and non-insects
- Variable 9: Percent of tolerant organisms
- Variable 10: Total number of EPT taxa

Qualitative lift in QHEI scores:

The existing QHEI score downstream of Ewing Island (at river mile 13.3) was calculated to be 45, which is reflective of fair physical habitat conditions.

The restoration concept described above would be expected to improve the following QHEI metrics:

- Substrate
- In-stream cover
- Riparian zone and bank erosion

Concept Summary

Table 22: Engineered rock shelf concept summary

Concept Summary			
Existing Shoreline Conditions			
	Acres	**Linear foot**	
Shallow water zone	Negligible		
Eroding banks		3,493	
Post-Construction Shoreline Conditions			
Shallow water zone			
Ewing Island	4.90		
Grape Island	2.35		
Maximum Length of Improvements			
Ewing Island		3,493	
Grape Island		1,921	
Expected Benefits			
	Yes	**No**	**Maybe**
Fish habitat	X		
Macroinvertebrate habitat	X		
SAV habitat / Turbidity refuge			X
Shoreline protection	X		
Riparian plantings	X		
Increased habitat complexity	X		
Walleye spawning grounds	X		
Estimated Costs			
	High	**Low**	**Scalable**
			X

5.1.3 Audubon Islands Concept 3: Cove Contouring and Submerged Trees

Concept Narrative

Cove contouring would add topographic or bathymetric heterogeneity to the coves found on Ewing and Delaware Island. Currently, the habitat within the coves consists of uniform substrate types, depth, and flow conditions.

The addition of this variability would translate to variable flow and substrate characteristics within the cove. In addition to adding topographic heterogeneity, submerged trees or root wads would be added to provide additional habitat within the cove.

Although not currently being considered for restoration activities, nearby Grassy Island, could provide a model of how restoration in the coves of Audubon and Delaware/Horseshoe complexes could be designed. Grassy Island has more topographic heterogeneity, habitat complexity, and water-depth variability within its coves. Near surface water temperatures also appear to be cooler within the Grassy Island coves, as compared to surface waters in the main and side channels.

The vegetation on Grassy Island is more diverse and includes areas of upland and wetland habitat with an undulating topography. Using Grassy Island as an analog, the coves along Ewing Island would be contoured to have a hummocky topography and bathymetry (Figure 42). Areas of the coves would be dredged to create areas of deeper water, with the dredged sediment being used to create areas of higher relief within the coves.

Creating topographic heterogeneity within the coves provides opportunities for vegetation to become established and form zonation patterns characterized by one or more plant species, with each plant species being adapted to a particular water depth.

Design features such as planted hummocks have been used in wastewater treatment wetlands to maintain vegetation balance by providing variable water depths for managing plant growth (Thullen et al., 2005). Vegetation management using hummocks can also promote higher dissolved oxygen in the water column, thereby improving water quality within the cove.

Deeper water surrounding the hummocks provides habitat for fish species, especially during low water-level conditions.

Cove contouring would be designed to provide habitat variability under both low and high water-level conditions.

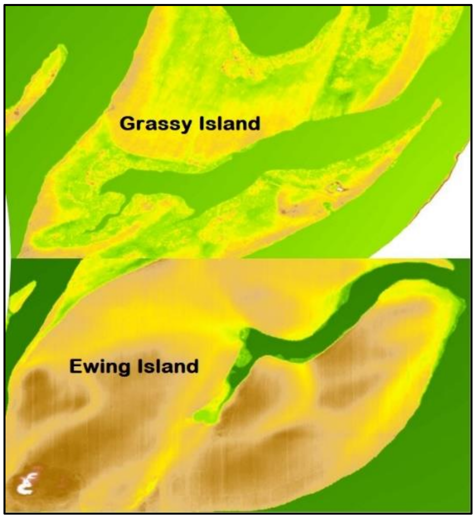


Figure 42: Cove contouring using Grassy Island as a reference condition.

Concept Location

The topography and elevations found on Grassy Island would be used as reference targets to be replicated at Ewing Island (Figure 43).

Concept Design

Figure 43: Cove contouring with planted hummocks and submerged trees/root wads.

The entire cove, from the mouth to the most upstream point, would be contoured to create areas of deeper water and areas of shallower water, with some areas rising above average high-water levels and planted with herbaceous vegetation.

The hummocks would be designed as shallow planting beds situated throughout the cove. The dredged sediments likely consist of fine silty clay material, which would require a containment structure to maintain the shape of the hummocks. Tree logs could be stacked or arranged to create a container for the dredged sediment (Figure 44). Additionally, the sediment could be amended with coarser-grained substrate to provide additional structure and heterogeneity. Once constructed, the hummock would be planted with flood-tolerant woody vegetation such as willows and dogwoods.

The size, height, and shape of the hummocks would be determined during the design phase. It is recommended that a variety of sizes, shapes, and elevations be designed to maximize habitat variability. Over time, the logs would decompose; however, the structure of the hummock would be maintained by the woody vegetation that has become established within the hummock sediments.

Submerged logs and root wads would be added throughout the coves to provide additional fish and macroinvertebrate habitat. The submerged trees would require anchoring or cabling to prevent movement during high water-level conditions.

Tribal representatives requested engagement throughout the process as it continues to assist with the determination of appropriate placement/use of any dredged material.

Figure 44: Logs used to contain dredged sediment. Logs would form the base of the planted hummock.

Qualitative Ecological Evaluation

Cove contouring would improve habitat heterogeneity within the Ewing Island cove. The addition of deeper water habitat surrounding the planted hummocks would serve as refugia during low water and seiche events. The shallow water and emergent habitats created by the planted hummocks would provide nursery habitat for juvenile fish and would create protected foraging habitat for avifauna. The roots of the planted vegetation would help to remove pollutants from the water column and would provide habitat for macroinvertebrates.

The addition of submerged trees and root wads to the shoreline and in-stream habitat within the cove would provide fish habitat and refugia, as well as macroinvertebrate habitat.

Qualitative lift in IBI scores:

The overall habitat within the Ewing Island cove is expected to show a measurable increase in value following implementation of this concept. The restoration concept described above would be expected to improve the following IBI variables:

- Variable 1: Total number of species
- Variable 6: Percent of tolerant species
- Variable 7: Percent of omnivorous species
- Variable 8: Percent of insectivorous species
- Variable 10: Number of individuals

Qualitative lift in ICI scores:

The restoration concept described above would be expected to improve the following ICI variables, when compared to an undisturbed reference site:

- Variable 1: Total number of taxa
- Variable 4: Total number of dipteran taxa
- Variable 8: Percent of other dipterans and non-insects
- Variable 9: Percent of tolerant organisms
- Variable 10: Total number of EPT taxa

Qualitative lift in QHEI scores:

The restoration concept described above would be expected to improve the following QHEI metrics within the Ewing Island cove:

- Substrate
- In-stream cover
- Riparian zone and bank erosion

Concept Summary

Table 23: Cove contouring concept summary

Concept Summary			
Existing Shoreline Conditions			
	Acres	**Sq. Ft.**	
Shallow water zone	5.74		
SAV habitat	Negligible		
Post-Construction Shoreline Conditions			
Shallow water zone	2.1		
Deep water zone	3.64		
Maximum Area of Improvements			
Ewing Island	5.74		
Expected Benefits			
	Yes	**No**	**Maybe**
Fish habitat	X		
Macroinvertebrate habitat	X		
SAV habitat / Turbidity refuge			X
Shoreline protection		X	
Riparian plantings	X		
Increased habitat complexity	X		
Walley spawning grounds		X	
Estimated Costs			
	High	**Low**	**Scalable**
			X

5.2 Marengo Island

5.2.1 Marengo Island Concept 1: Vegetated Chevron

Concept Narrative

Chevrons are dike structures designed as blunt nosed and arch shaped. The purpose of constructing a chevron dike is to use the energy of the river to redistribute flow and sediment. They are used to allow flow separation and create both channel deepening, side channel development, and middle bar formation (Figure 45). The placement of a chevron dike upstream of Marengo Island would act as a barrier to erosion from upstream flows, and sediment trapped downstream of the chevron would be redeposited along Marengo Island, thereby expanding the upstream end of Marengo Island.

Figure 45: Chevron dike upstream of LaGrange Island in 2011. Source, Environmental Design Handbook, 2012.

The aquatic community found near a river training structure, such as a chevron dike, is relatively diverse, owing to the range of available habitat types within a relatively small area. The St. Louis USACE District contracted a study that analyzed invertebrate populations on the dikes and surrounding riverbed to determine if chevron dikes were providing macroinvertebrate habitat. The macroinvertebrate assemblages were compared between the interior dike rock, exterior dike rock, interior soft substrate, and the surrounding soft substrate. The study concluded that diversity and taxonomic richness was higher on dikes than in the surrounding soft substrates (Ecological Specialists, Inc. 1997).

Sandheinrich and Atchison (1986) found dike fields provide a varied range of depths, substrates, and currents that increase habitat complexity and affect fish distributions and community diversity.

Chevron dikes can be used to enhance the river's habitat diversity when properly designed. This design concept would "soften" the chevron dike design by segmenting or notching the chevron and widening the segments to allow vegetation to become established on the segments. Dredged sediment could be used as a planting medium on the chevron segments. The chevron shape would remain, thereby retaining the flow and sediment redistributing properties of the structure.

Concept Location

A vegetated, segmented, or notched chevron would be constructed just upstream of Marengo Island (Figure 46).

Concept Design

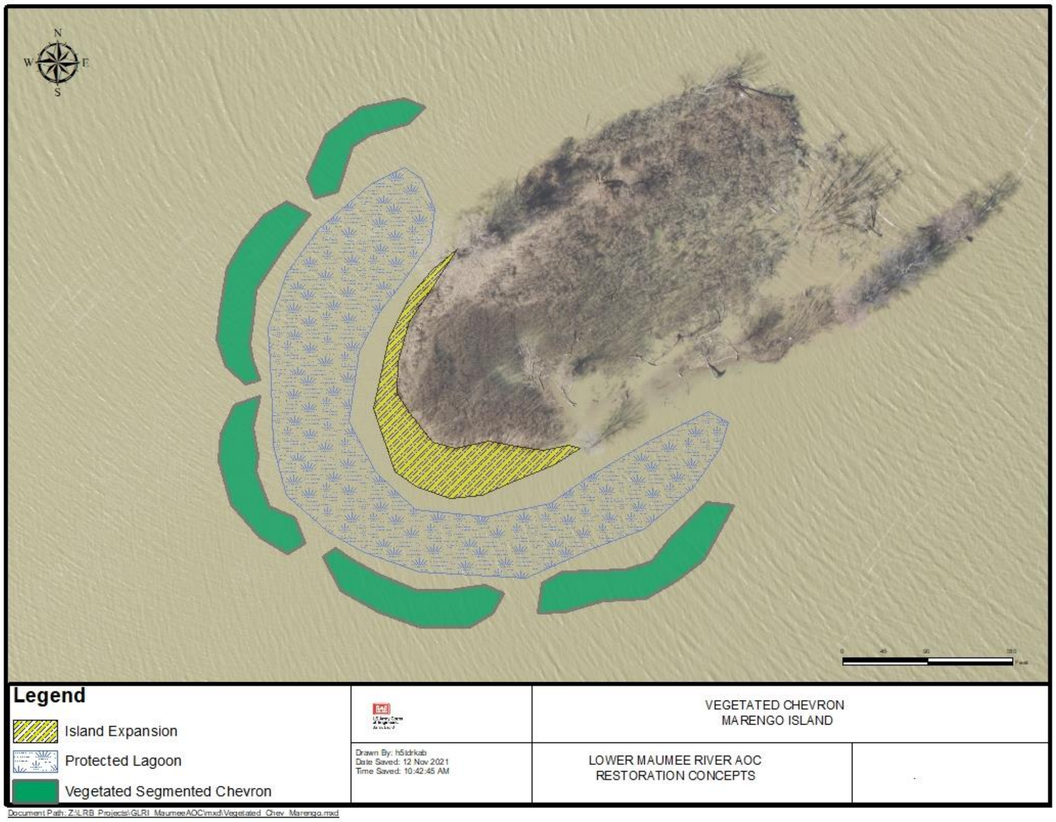


Figure 46: Vegetated chevron concept at Marengo Island.

A series of short chevron segments would be constructed in an arch upstream of Marengo Island. The segments would be filled with soil and planted with native riparian and emergent vegetation well adapted to withstanding fluctuating water levels and ice scour.

Chevron dikes would be constructed with a core of large boulders and topped with smaller-sized stones. Stone sizing is determined by velocities and shear stresses within the section of the river. Stone sizing would be determined during the design phase.

The chevron segments would be built to a 2-year flood elevation. River flows overtopping the structures during high water periods create scour holes inside the arc of the chevron just downstream of the structure's apex. Downstream of this scour hole, the sediments would be redeposited to create a shallow bar.

This scour and redeposition of sediments would be lessened by segmenting the chevron; however, the habitat heterogeneity (e.g., variable depths, substrates, and flow velocities) created by the segmented chevron would still be expected to be significantly higher than that afforded by the surrounding river habitat. Determining whether the chevron would be segmented or notched would be assessed during the design phase.

After the flows drop below the crest of the structure, the scour hole formed at high flow becomes an area of deep slack water. This environment would benefit the needs of overwintering fish and provides habitat for juvenile and larval fish. The plant life established on the segments would provide organic matter to the river. The vegetated segments would also provide cover, nesting, and foraging habitat for a variety of avifauna.

Qualitative Ecological Benefits

Chevron dikes have short-term and long-term effects on major riverine ecosystems. Short-term effects include increases in aquatic habitat diversity which, in turn, results in high densities and diversities of fish and macroinvertebrates within the main stem of the river. Chevron dikes often support the most diverse fish and macroinvertebrate community of any habitat within the river, apart from naturally occurring river-island complexes and shoals. Moderate and slow-water areas within the influence of the chevron dike provide important spawning and nursery areas for many lotic species of fish within the river. The variable stone sizes of the chevron dike provide hard substrates for colonization by populations of invertebrates. Interstitial spaces between rocks may provide areas of moderate flow for juvenile and forage fish.

By constructing a vegetated, segmented chevron dike, the ecological benefits are increased by increasing the proportion of wetted area, and native vegetation provides additional organic material to the river system. Additionally, a vegetated more natural structure was met with initial positive feedback by riparian land owners and river users.

Qualitative lift in IBI scores: The existing IBI scores downstream of Ewing Island were collected in 2012. The scores at the two sites downstream of Ewing Island (at river mile 13.3) were calculated to be 36 (marginally good) and 29 (fair).

The restoration concept described above would be expected to see an improvement to the following IBI variables:

- Variable 1: Total number of species
- Variable 6: Percent of tolerant species
- Variable 7: Percent of omnivorous species
- Variable 8: Percent of insectivorous species
- Variable 10: Number of individuals

Qualitative lift in ICI scores: The existing ICI score downstream of Ewing Island (at river mile 13.3) was calculated to be 12, which is reflective of poor resource conditions.

The restoration concept described above would be expected to see an improvement to the following ICI variables, when compared to an undisturbed reference site:

- Variable 1: Total number of taxa
- Variable 4: Total number of dipteran taxa
- Variable 8: Percent of other dipterans and non-insects
- Variable 9: Percent of tolerant organisms
- Variable 10: Total number of EPT taxa

Qualitative lift in QHEI scores: The existing QHEI score downstream of Ewing Island (at river mile 13.3) was calculated to be 45, which is reflective of fair physical habitat conditions.

The restoration concept described above would be expected to see an improvement the following QHEI metrics:

- Substrate
- In-stream cover
- Riparian zone and bank erosion

Concept Summary

Table 24: Vegetated chevron concept summary

Concept Summary			
Existing Shoreline Conditions			
	Acres	**Sq. Ft.**	
Shallow water zone	Negligible		
Eroding banks		804	
Post-Construction Shoreline Conditions			
Shallow water zone	0.45		
Protected lagoon	2.0		
Maximum Area of Improvements			
Marengo Island	4.3		
Expected Benefits			
	Yes	**No**	**Maybe**
Fish habitat	X		
Macroinvertebrate habitat	X		
SAV habitat / Turbidity refuge		X	
Shoreline protection	X		
Riparian plantings	X		
Increased habitat complexity	X		
Walleye spawning grounds		X	
Island expansion			X
Estimated Costs			
	High	**Low**	**Scalable**
	X		

5.2.2 Marengo Island Concept 2: Downstream Archipelago or Woody Habitat Structures

Concept Narrative

This concept would create barrier islands or woody habitat structures downstream of Marengo Island for the purpose of protecting the island from erosive forces originating from downstream. The concept is similar to the vegetated chevron concept in that it would protect and enhance the shallow water habitat downstream of Marengo Island. Marengo Island has lost a total area of 6.3 acres to shoreline erosion, which is approximately half the original area. This concept would help to re-establish portions of the historical footprint of Marengo Island.

The concept consists of a series of small, low elevation offshore islands surrounding the area off the downstream end of Marengo Island. The islands would be constructed by stacking large armor stone to an elevation that approximates the 2-year flood elevation. The stone would be used to contain soil or dredged sediment, which would then be planted with native vegetation adapted to water level fluctuation and ice scour. A shallow emergent wetland shelf would be constructed around the perimeter of each constructed island to further maximize habitat variability and habitat connectivity.

Woody habitat structures could be constructed as a standalone project, or in conjunction with the construction of the barrier islands. Woody habitat structures have been used in large river systems to control the flow of the river and to improve in-stream habitat complexity (Figure 47).

Figure 47: Woody habitat structure used in a large river system.

Based on visual and historic aerial image evidence, we assume that sufficient woody debris loads from upstream would be sufficient to populate the woody habitat structures with large woody debris (Figure 48).

Figure 48: Google Earth image of Marengo Island from August 2020 showing substantial woody debris accumulation.

Concept Location

Barrier islands and/or woody habitat structures would be constructed downstream of Marengo Island (Figure 49).

Concept Design

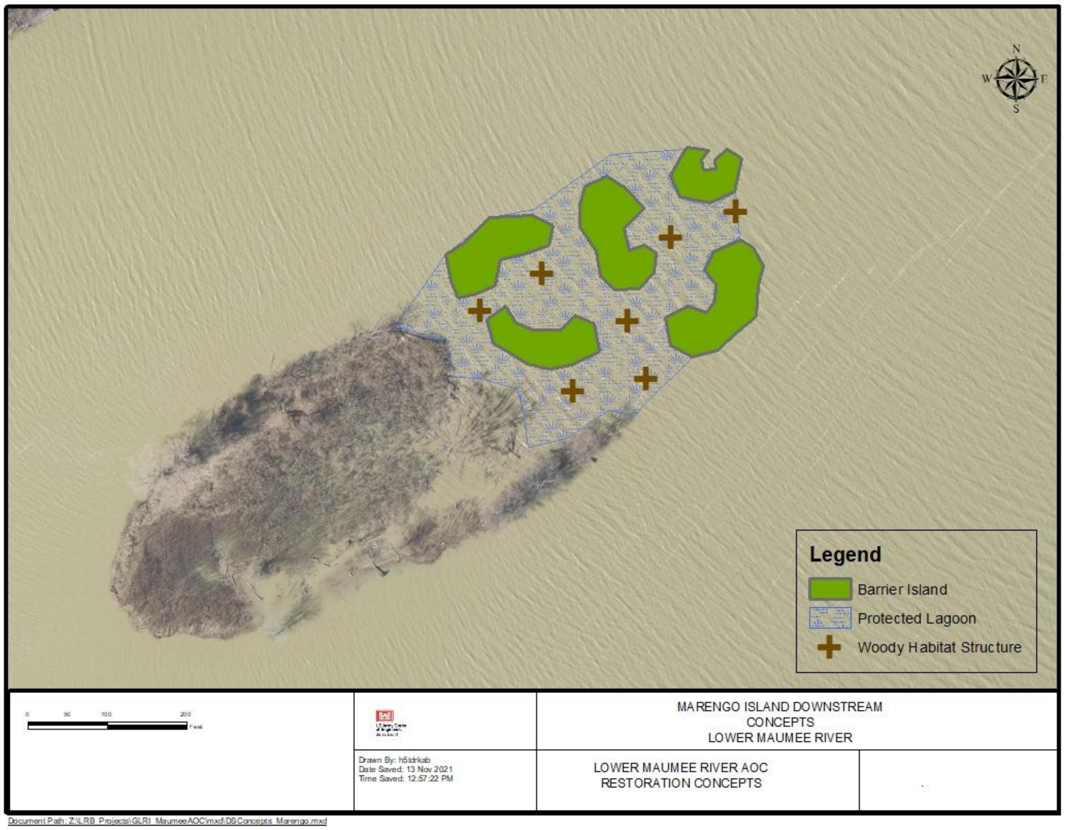


Figure 49: Downstream barrier islands and/or woody habitat structures at Marengo Island.

This concept design would consist of a series of small, irregular offshore islands surrounding the downstream end of Marengo Island. The islands would be constructed with a large stone revetment filled with soil or dredged sediment. The crest of the stone revetment would be constructed to the 2-year flood elevation. The surface of the islands would be planted with native vegetation suited to fluctuating water levels and ice scour. The islands would be constructed with an emergent wetland shelf to further connect the terrestrial and aquatic habitats. The emergent wetland shelf would be constructed to have about two feet of water depth during high water levels and would be exposed during low water periods.

Woody habitat structures would be constructed either alone, or in conjunction with the barrier islands, to further enhance the habitat for fish and macroinvertebrates.

Qualitative Ecological Benefits

Based on the biotic and abiotic data presented in the 2019 Maumee AOC Restoration Actions Report, the area around Marengo Island has relatively low habitat quality and provides low to marginal fish and macroinvertebrate habitat. These conditions would be improved considerably by implementing the vegetated chevron restoration concept.

The construction of barrier islands downstream of Marengo Island would increase the proportion of high-quality of river-island complexes in the Lower Maumee River. The shallow area downstream of Marengo Island is currently marginal fish habitat. This area would be improved considerably by creating a protected lagoon that offers spawning and nursery habitat for many species of game fish. The barrier islands would be vegetated with native herbaceous and woody vegetation. Over time, this vegetation would overhang, shade, and cool the surface waters downstream of Marengo Island. The organic matter generated by the vegetation would provide important detritus into the river system; thereby creating and maintaining macroinvertebrate habitat.

The installation of woody habitat structures in the waters downstream of Marengo Island would provide benefits similar to those of the downstream barrier islands. Woody habitat structures would protect the nearshore habitat from wave energy from the north. In addition, the woody habitat structures would trap and accumulate sediments over time, thereby increasing habitat heterogeneity in the waters downstream of Marengo Island. In addition to trapping sediments, the structures would also trap woody debris moving through the system. Over time, the accumulation of sediments and woody debris could create conditions suitable for the establishment of emergent vegetation.

Qualitative lift in IBI scores: The existing IBI score at Marengo Island was collected in August 2019. The score of 12-15 is of relatively poor quality.

The restoration concept described above would be expected to see an improvement to the following IBI variables:

- Variable 1: Total number of species
- Variable 6: Percent of tolerant species
- Variable 7: Percent of omnivorous species
- Variable 8: Percent of insectivorous species
- Variable 10: Number of individuals

Qualitative lift in ICI scores: Total invertebrate abundance on Hester-Dendy sampling units was calculated at 95-252, which is considered relatively low among sampled sites. Percent chironomid abundance on Hester-Dendy sampling units was calculated at 54.3 – 68.6, which is moderate among sampled sites.

The restoration concept described above would be expected to see an improvement to the following ICI variables, when compared to an undisturbed reference site:

- Variable 1: Total number of taxa
- Variable 4: Total number of dipteran taxa
- Variable 8: Percent of other dipterans and non-insects
- Variable 9: Percent of tolerant organisms

- Variable 10: Total number of EPT taxa

Qualitative lift in QHEI scores: The existing QHEI score downstream of Marengo Island (at river mile 13.3) was calculated to be 45, which is reflective of fair physical habitat conditions.

The restoration concept described above would be expected to see an improvement to the following QHEI metrics:

- Substrate
- In-stream cover
- Riparian zone and bank erosion

Concept Summary

Table 25: Downstream barrier islands and woody habitat structures concept summary

Concept Summary			
Existing Shoreline Conditions			
	Acres	**Sq. Ft.**	
Shallow water zone	1.92		
Eroded shoreline		804	
Post-Construction Shoreline Conditions			
Protected lagoon	1.92		
Shallow water zone	.72		
Maximum Area of Improvements			
Marengo Island	2.39		
Expected Benefits			
	Yes	**No**	**Maybe**
Fish habitat	X		
Macroinvertebrate habitat	X		
SAV habitat / Turbidity refuge		X	
Shoreline protection	X		
Riparian plantings	X		
Increased habitat complexity	X		
Walleye spawning grounds		X	
Estimated Costs			
	High	**Low**	**Scalable**
	X (islands)	**X (woody Habitat)**	

5.3 Delaware / Horseshoe Complex

Many of the preliminary restoration designs described above could also be applied at the Delaware/Horseshoe complex. The concepts that can be also applied to the Delaware/Horseshoe complex include the following:

- Rock barrier reefs
- Cove contouring

- Submerged trees/root wads
- Barrier islands

The above concepts are shown in Figure 50 and are described below. Table 25 provides a screening summary of each of the above concepts that could be applied to the Delaware/Horseshoe Island complex.

Land loss and erosion within the Delaware/Horseshoe complex has been the most pronounced of the three islands under consideration in this study. Mitigating or reversing island erosion at the Delaware/Horseshoe complex has been voiced as an important topic during recent public outreach events. While reversing erosion does not necessarily address the three BUIs targeted for this restoration effort, it is possible to develop preliminary restoration designs that address both erosion and the three BUIs in this section of the river. The preliminary restoration designs that address both erosion and habitat quality are 1) continuous rock barrier reef, 2) barrier islands, 3) woody habitat structures, and 4) island connection using vegetated rock sill. These concepts could be implemented singly or in combination with other concepts to achieve the desired island protection and in-stream habitat improvements.

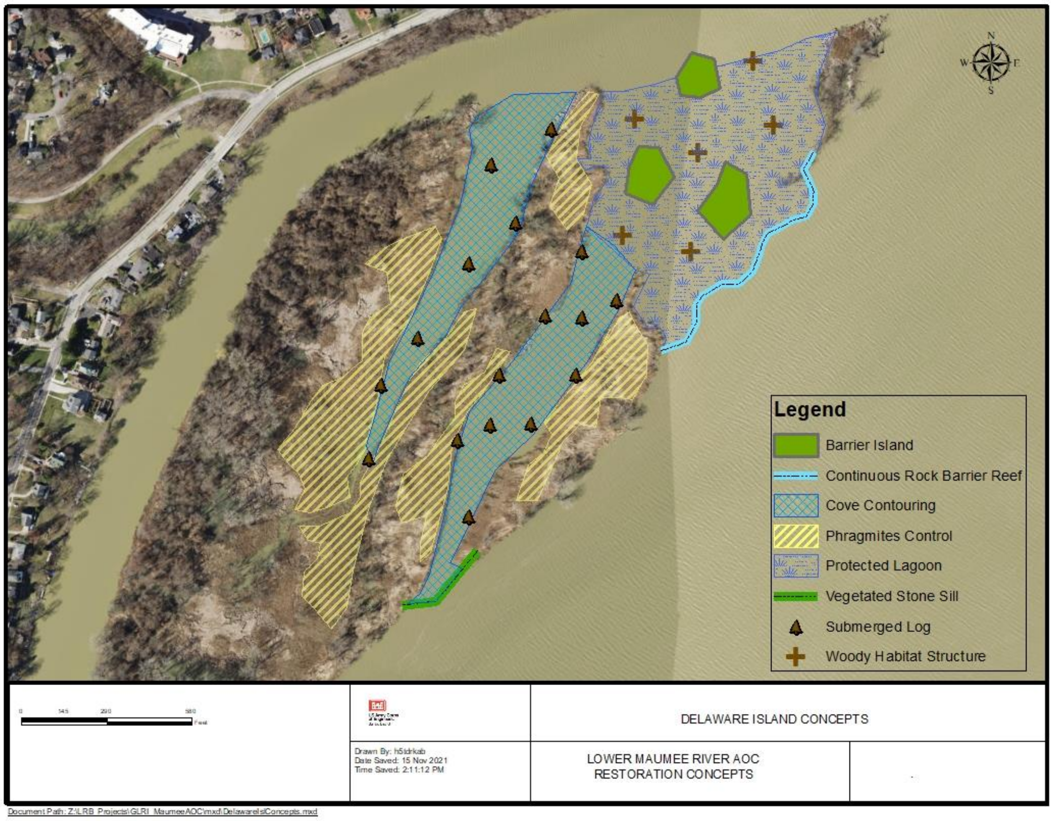


Figure 50: Delaware/Horseshoe Complex preliminary restoration designs.

Rock Barrier Reef: This concept is similar to that described for the Audubon Islands. However, for the Delaware/Horseshoe complex, the rock barrier reef would be continuous instead of segmented. The stone reef would extend continuously from the downstream end of the main island to the upstream end of the detached island as shown in blue on Figure 50.

The continuous stone reef would provide maximum protection to the lagoon behind the reef. In addition, the continuous stone reef would have significantly more potential for creating a sediment refuge for the growth and expansion of SAV.

The barrier reef may be segmented to reduce cost; however, the lagoon protection afforded by segmenting the reef would be lowered.

The rock barrier reef could be combined with woody habitat structures to enhance fish and macroinvertebrate habitat in the protected lagoon. Table 26 provides a summary of the rock barrier reef concept at the Delaware/Horseshoe Island Complex.

Table 26: Rock barrier reef concept at Delaware Complex

Concept Summary			
Existing Shoreline Conditions			
	Acres	**Linear foot**	
Shallow water zone	Negligible		
Eroding banks		2,500	
Post-Construction Conditions			
Protected lagoon	9.4		
Vegetated rock barrier		840	
Maximum Length of Improvements			
Delaware/Horseshoe Complex		840	
Expected Benefits			
	Yes	**No**	**Maybe**
Fish habitat	X		
Macroinvertebrate habitat			X
SAV habitat / Turbidity refuge	X		
Shoreline protection	X		
Riparian plantings		X	
Increased habitat complexity	X		
Walleye spawning grounds impacts		X	
Estimated Costs			
	High	**Low**	**Scalable**
			X

Cove Contouring: Contouring the coves of Delaware/Horseshoe island would be similar to that described for the Ewing Island cove. Adding submerged trees or root wads to the coves would further enhance the habitat for fish and macroinvertebrates. Table 27 provides a summary of the cove contouring concept at the Delaware/Horseshoe Island Complex.

Table 27: Cove contouring concept for the Delaware Complex

Concept Summary			
Existing Shoreline Conditions			
	Acres	**Linear foot**	
Shallow water zone	11.2		
SAV habitat	Negligible		
Post-Construction Shoreline Conditions			
Shallow water zone	9.0		
Deep pools	2.2		
Maximum Area of Improvements			
Delaware Island	11.2		
Expected Benefits			
	Yes	**No**	**Maybe**
Fish habitat	X		
Macroinvertebrate habitat	X		
SAV habitat / Turbidity refuge			X
Shoreline protection		X	
Riparian plantings	X		
Increased habitat complexity	X		
Walley spawning grounds		X	
Estimated Costs			
	High	**Low**	**Scalable**
		X	

Downstream Archipelago: A series of low elevation, vegetated islands would be constructed downstream of the Delaware/Horseshoe island complex. This concept would re-establish some of the former footprint of the island, as well as provide important habitat complexity in this area that is currently marginal for fish habitat. Table 28 provides a summary of the archipelago concept downstream of the Delaware/Horseshoe Island Complex.

Table 28: Downstream archipelago concept summary

Concept Summary		
Existing Shoreline Conditions		
	Acres	**Linear foot**
Shallow water zone	11.2	
Post-Construction Shoreline Conditions		
Island habitat	1.54	
Shallow water zone	9.66	
Maximum Area of Improvements		
Delaware/Horseshoe	1.54	

Expected Benefits			
	Yes	**No**	**Maybe**
Fish habitat	X		
Macroinvertebrate habitat	X		
SAV habitat / Turbidity refuge		X	
Shoreline protection		X	
Riparian plantings	X		
Increased habitat complexity	X		
Walleye spawning grounds		X	
Estimated Costs			
	High	**Low**	**Scalable**
	X		

Woody Habitat Structures: These structures would be installed downstream of Delaware/Horseshoe islands, and could either serve as standalone habitat features, or could be used in conjunction with either the continuous barrier reef or the barrier islands to create a protected lagoon and further enhance the habitat for fish and macroinvertebrates. Table 29 summarizes the downstream woody habitat structures concept for the Delaware/Horseshoe Island Complex. Without additional protection from barrier reefs or islands, standalone woody structures may be subject to strong impacts from ice and wave action. Exploring combinations of restoration elements is recommended during full engineering and design.

Table 29: Woody habitat structures concept summary

Concept Summary			
Existing Shoreline Conditions			
	Acres	**Linear foot**	
Shallow water zone	11.2		
Post-Construction Shoreline Conditions			
Woody habitat	0.10		
Shallow water zone	11.2		
Maximum Area of Improvements			
Delaware/Horseshoe	11.3		
Expected Benefits			
	Yes	**No**	**Maybe**
Fish habitat	X		
Macroinvertebrate habitat	X		
SAV habitat / Turbidity refuge		X	
Shoreline protection	X		
Riparian plantings		X	
Increased habitat complexity	X		
Walleye spawning grounds		X	
Estimated Costs			
	High	**Low**	**Scalable**
		X	

In addition to the above-described concepts, two additional preliminary restoration designs could be applied at Delaware island, these include using goats as *Phragmites* control, and constructing a vegetated stone sill to reconnect the easternmost segment of Delaware Island to the main island. These two concepts could be applied alone, or in conjunction with any of the above-described concepts. These two new concepts are described in the sections below.

5.3.1 Goats as Invasive Species Management

Concept Summary

Phragmites australis is a widespread invasive plant that reaches average heights of over 3 meters, forms dense monocultures, and generates thick layers of leaf litter, thereby outcompeting native plants for light, space, and nutrients. Since its introduction during the 18th century, no cost-effective, long-term control measures have been found. All forms of chemical, mechanical, and biological (insect) control have been found to be largely ineffective.

Observational and experimental evidence have revealed that top-down forces, such as livestock grazing, limits *Phragmites* in its native range in Europe (Silliman et al. 2014).

Experimental field tests in North America demonstrate that rotational goat grazing can reduce *Phragmites* cover from 100 percent to 20 percent, and that cows and horses readily consume this plant (Silliman et al., 2014). Comparative studies in European marshes suggests that livestock strongly restricts *Phragmites* distribution and facilitate the growth of shorter grasses and forbs in its native habitat. Silliman et al. suggests that livestock has the potential to offer an effective, pesticide-free solution to managers trying to eradicate *Phragmites,* as well as other invasive plants that form vast monocultures in the United States.

Livestock grazing has been found to reduce the competitive advantage of *Phragmites* through a combination of eating down or trampling live stems, breaking up the litter mat, and severing rhizomes with their hooves (Turner, 1987). Combined, these activities can increase the light availability to native plants, reduce belowground competition for nutrients, and provide opportunities for colonization of native plants, estuarine nekton, and even endangered turtles (Silliman et al. 2014).

Focused goat grazing could be used as part of a long-term invasive species management strategy against the *Phragmites* stands on any of the Lower Maumee River islands. Goat grazing would not eradicate *Phragmites*; however, it would allow native plants to gain a foothold and eventually compete with *Phragmites.* Grazing would be combined with a comprehensive revegetation effort on the Delaware/Horseshoe complex. Table 30 provides a summary of the goats grazing concept summary.

Table 30: Goats as invasive species management concept summary

Concept Summary			
Existing Shoreline Conditions			
	Acres	**Linear foot**	
Phragmites colony	11.5		
Shallow water zone	11.2		
Post-Construction Shoreline Conditions			
Restored wetland vegetation	11.5		
Shallow water zone	11.2		
Maximum Area of Improvements			
Delaware/Horseshoe	11.5		
Expected Benefits			
	Yes	**No**	**Maybe**
Fish habitat		X	
Macroinvertebrate habitat		X	
SAV habitat / Turbidity refuge		X	
Shoreline protection		X	
Riparian plantings	X		
Increased habitat complexity	X		
Walleye spawning grounds		X	
Estimated Costs			
	High	**Low**	**Scalable**
		X	

5.3.2 Island Connection via Vegetated Stone Sill

Concept Summary

A vegetated stone sill would be constructed to connect the main island of Delaware Island with the large, detached island to the right of Delaware Island (Figure 50, green line). Reattaching the islands would create a second protected cove on the Delaware/Horseshoe complex. By creating a vegetated barrier between the cove and the main river channel, the waters within the cove could become less turbid over time and could more closely resemble the less turbid waters in the western Delaware Island cove. Increased water clarity could lead to the growth and expansion of SAV within the newly protected cove. The cove contouring concept and submerged trees/root wads could be used in conjunction with the vegetated stone sill. This concept should be considered in combination with submerged tree plantings and contouring to achieve fish and macroinvertebrate habitat improvements. Table 31 provides a summary of the vegetated stone sill island connection concept for the Delaware/Horseshoe Island Complex.

Table 31: Vegetated stone sill island connection concept summary

Concept Summary			
Existing Shoreline Conditions			
	Acres	**Linear foot**	
Shallow water zone	11.2		
Post-Construction Shoreline Conditions			
Protected cove	4.7		
Shallow water zone	11.2		
Maximum Area of Improvements			
Delaware/Horseshoe	4.7		
Expected Benefits			
	Yes	**No**	**Maybe**
Fish habitat		X	
Macroinvertebrate habitat		X	
SAV habitat / Turbidity refuge	X		
Shoreline protection			X
Riparian plantings	X		
Increased habitat complexity	X		
Walleye spawning grounds		X	
Estimated Costs			
	High	**Low**	**Scalable**
		X	

5.4 Maumee River Concepts Summary

Table 32 below qualitatively compares each of the above-described restoration measures in terms of high, medium, or low regarding associated habitat improvements and costs. These assessments are qualitative in nature and should be used to rank each restoration concept according to overall project goals and objectives.

Table 32: Summary of Maumee River Concepts

Restoration Site	Concept	Max Restoration Area	Habitat Benefits						Cost
			Fish Habitat	Macro. Habitat	Island Protection	Habitat Complexity	Walleye Spawning grounds	Sediment Refuge	
Audubon Islands	**Rock Barrier Reef**	7.2 acres	Moderate	Moderate	High	Moderate	Yes	No	High
	Stone Shelf with ELJ	7.2 acres	High	High	High	High	Yes	No	High
	Cove Contouring	5.7 acres	High	High	Low	High	No	Low	Medium
Marengo Island	**Vegetated Chevron**	4.3 acres	High	Low	High	Moderate	No	No	High
	Downstream Archipelago	2.4 acres	Low	Low	High	Moderate	No	No	High
	Downstream Woody Habitat	0.5 acres	High	High	Low	Moderate	No	No	Low
Delaware/Horseshoe Complex	**Rock Barrier Reef & Protected Lagoon**	1,089 lf (reef) 11.8 acres (lagoon)	High	Low	High	Moderate	No	Yes	High
	Cove Contouring	9.95 acres	High	Moderate	Low	High	No	No	Medium
	Submerged Trees (coves)	9.95 acres	Moderate	High	Low	Moderate	No	No	Low
	Barrier Islands	1.54 acres	Moderate	Moderate	High	High	No	No	High
	Vegetated stone sill (Island Connection)	4.7 acres	Low	Low	Moderate	Low	No	Yes	Medium
	Woody Habitat Structures	0.35 acres	Moderate	High	Moderate	Moderate	No	No	Low

5.5 Cost Estimates

Rough Order of Magnitude (ROM) Cost Estimates will be prepared by a Cost Engineer, commensurate with the level of detail of the preliminary design and project descriptions. Cost estimates for both construction and total project cost will be calculated. Costs will be broken out in multi-site project (like Audubon Island Complex). The following cost estimates will be compiled in a separate report and provided to project stakeholders:

- Construction Costs
- Construction Costs other than materials (transport, staging, etc.)
- Mobilization
- Permits, environmental allowances, and SHPO/106 surveys
- QAPP preparation
- Long-term Operations and Maintenance plan preparation
- Engineering and design construction management
- Post construction monitoring
- Construction contingency

5.6 Risk and Uncertainty

It is essential to document the assumptions made and uncertainties encountered during the course of planning analyses. A risk and uncertainty analysis has been completed to identify the degree of risk and uncertainty associated with this project. Estimates for project management, planning, environmental, real estate, hydrologic, hydraulic, cost engineering, and economic parameters were used in the analysis to determine their related uncertainty. The risk and uncertainty analysis completed was based on the professional judgement and prior experience of team members based on the information currently available. The results of the analysis concluded all risk and uncertainty for this project moving forward was low and at acceptable levels.

5.6.1 Environmental

Due to this project being an aquatic ecosystem restoration project, risks associated with restoration plans were thoroughly evaluated. Overall, there is low risk associated with the planting plans not performing as predicted. Sufficient investigations to the level of project complexity were performed to ensure that the restored plant communities would not revert to invasive, weedy species again by (a) lessons learned from similar aquatic ecosystem restoration projects completed by USACE, (b) designing plant communities to the hydrology and geomorphology instead of planting communities not indicative of a system, and (c) a dedicated sponsor that will maintain the project as constructed with intended ecological benefits.

Complete eradication of invasive species always presents a certain level of risk and uncertainty as the chances of reinvasion are likely to occur without proper management, increasingly so when native species have not yet established. Invasive plant species are adapted for colonizing areas that are disturbed so an invasive species treatment plan is proposed which includes spraying and mowing with tillage to reduce the risk of reinvasion and reestablishment. A long-term invasive species monitoring, and adaptive management plan has been prepared to reduce the risk of invasive species from reoccurring. Measures incorporated into these plans have been found to work on similar habitat restoration projects.

Native plantings have an associated risk of not establishing due to a variety of unforeseen events such as predation from herbivorous animals and insects. Periods of drought, flood, or early frost can alter the survival percentage of plantings. Although historical records can help to predict the best possible location and timing of new plantings, single unforeseen events may lead to failure. To mitigate these risks, planting over several years, overplanting and/or adaptive management and monitoring can be incorporated into the overall planting plan.

Invasive and Exotic Species

Zebra Mussels & Quagga Mussels (Dreissena polymorpha & D. bugensis)

The arrival of two non-native mussels, zebra and quagga mussels, poses a threat to native fish egg incubation on reefs throughout the Great Lakes and their tributaries. Once zebra mussels have become established in a body of water, they rapidly colonize any available hard substrate. Zebra mussels are present on most of the shallow reefs in the lower Great Lakes, in densities varying from a few individuals per square meter to mats over 5 cm thick (Marsden, 2001). If walleye or lake trout eggs cannot settle into interstices, they are vulnerable to predation and damage from wave action. Any eggs that do settle into substrate fouled by zebra mussels may be suffocated by the deposition of feces, or by local deoxygenation caused by reduced circulation and organic breakdown of these materials (Marsden, 2001). It has been suggested that lake trout evaluate the cleanliness of a substrate prior to spawning; therefore, they may avoid spawning on substrates heavily fouled by zebra mussels (Marsden and Krueger, 1991). Some natural reefs are free of zebra mussel fouling, this may be due to ice scour in the winter and exposure to wind action. It is therefore crucial to evaluate natural reefs as reference areas to help inform the design of built reefs to help reduce the potential for zebra mussel fouling.

Round Goby (Neogobius melanostomus)

The round goby was first introduced into the St. Clair River in 1990. The species has since spread to all five Great Lakes, with large populations in Lake Erie and Ontario. The round goby perches on rocks and other substrates in shallow areas. It has also been reported to flourish in a variety of habitat types including open sandy areas and in abundant aquatic macrophytes (Jude and DeBoe 1996; Clapp et al. 2001). The round goby also has a well-developed sensory system that enhances its ability to detect water movement. This allows it to feed in complete darkness, giving it an advantage over other fish in the same habitat (Lederer et. al, 2008). The zebra mussel may have facilitated the invasion of the Round Goby and other Eurasian species by providing an abundant food source (Ricciardi and MacIsaac, 2000).

The round goby has a high environmental impact on the Lake Erie fishery. The numbers of native fish species have declined in areas where the round goby has become abundant (Crossman et al. 1992). In laboratory experiments, this species has been found to prey on darters and other small fishes, as well as lake trout and walleye eggs and fry. It may feed on eggs and fry of sculpin (*Cottus* spp.), darters, and logperch (*Percina caprodes*) (Marsden and Jude 1995) and has also been found to have a significant overlap in diet preference with many native fish species.

The invasion of Round Goby into Lake Erie has had very real environmental and economic impacts. The State of Ohio has shut down the smallmouth bass fishery in Lake Erie during the months of May and June because high predation rates on nests are affecting smallmouth recruitment. Under normal circumstances, male smallmouth bass guard nests and are effective in keeping round goby away. When males are removed, the round goby immediately invades and has been shown to eat up to 4,000 eggs within 15 minutes (National Invasive Species Council 2004).

Grass Carp (Ctenopharyngodon Idella)

Grass Carp, commonly used in aquaculture to control plant growth, escaped captivity in the Mississippi River and have been in the Great Lakes since 1975 (USGS, 2020). Spawning surveys have documented spawning since 2015 in the Sandusky River.

The USFWS use "invasive carp" to refer to Bighead Carp (*Hypophthalmichthys nobilis*), Silver Carp (*Hypophthalmichthys molitrix*), Black Carp (*Mylopharyngodon piceus*) and Grass Carp. Each species was intentionally introduced into the United States as a biological control. All have the potential to threaten Ohio's fisheries and aquatic ecosystems. Bighead Carp and Silver Carp are increasingly present in the Ohio River, with the greatest populations in the westernmost reaches. Grass Carp have been found throughout Ohio; however, findings of diploid Grass Carp capable of reproducing have been rare and limited to western Lake Erie, the Maumee and Sandusky rivers.

Carp displace emergent and submergent vegetation through feeding and, to some extent, spawning activities. Their diet consists of molluscs, insects, worms, crustaceans, algae, and aquatic plants (dead or living) and seeds. Carp uproot vegetation when searching for food and during feeding. Therefore, any aquatic plantings associated with a restoration concept would need to be protected against herbivory from grass carp or other invasive carp species that may be present within the river system.

The most effective method for protecting aquatic vegetation is to install a fish and wildlife exclosure or pen-like structure around the planting area, thereby excluding grass carp from entering the planting area. These exclosures are typically constructed of wire mounted on metal frames driven into the bottom sediments. These exclosures would need to be monitored periodically to ensure there is sufficient contact between the wire fencing and the bottom sediments, and to ensure non-target species are not trapped in the fencing.

5.6.2 Hydrologic and Hydraulic

There are design and performance risks in all projects. Analysis of features and its interaction with natural processes and external factors are done to lower the risk of failure to the greatest extent practicable. Placement and design of proposed features for this project have low risk of not meeting performance criteria. Nevertheless, any project and its design elements has a degree of risk and uncertainty. The following is a summary of design and performance risks associated with the various proposed features, as relating to hydrology, hydraulics, sediment, substrate, and ice.

- Engineered Log Jams (ELJs) and Large Woody Habitat Features: These features come with a design risk in that if bedrock is discovered too close to the channel bottom, there would be no clear way to proceed with a design given that plans to construct these features assume the vertical wooden posts are driven into the sediment and supported by surrounding stone. They also come with a performance risk that they may fail to retain woody debris for significant durations of time if upstream flows during seiche events dislodge woody debris, enabling it to move downstream. A durability/longevity risk for these features is that if not properly designed, ice forces might destroy part or all these features thereby eliminating their ability to trap wood from upstream or act as habitat for fish.

- Chevron Dikes: These features have a design risk in that in attempting to modify the traditional dimensions of these structures to achieve a more natural look, it may not be possible to design for or guarantee the ecological performance for which these features are known to provide (e.g., scour hole and fish overwintering habitat, island formation, etc.). Another design risk is that available design guidance and evaluation studies, based on experience with these structures in the Mississippi River and elsewhere, may not fully address how to design these features in a Lacustuary with significant inter-annual fluctuations in Lake Erie water levels. And a performance risk is that these features change flow patterns in a way that negatively affects riverbanks elsewhere.

- Rock Barrier Reefs: These features have the same performance risk as the chevron dikes in terms of changing flow patterns, but also come with the opportunity to reinstate protection from adverse flows provided by the historic footprint of Delaware/Horseshoe Island. An additional performance risk is that areas between the rock barrier reefs and islands might experience enhanced fine sediment deposition creating a murky substrate. And if portions of the reefs become submerged, particularly during periods of high Lake Erie water levels, and the reefs are not marked to Coast Guard standards, boat hazards might result.

- Cove Submerged Logs: Design of these features will need to address high flow scenarios, whether from seiche or island overtopping events where excess shear forces dislodge them from their intended locations.

- Cove SAV: These features come with the risk that the turbidity refuge provided by the cove is not sufficient to support SAV growth. They also are at risk from being quickly consumed, or dramatically grazed back, by Grass Carp. SAV may also be at risk from wave action, ice scour, and fluctuations in water level, especially during establishment. Possible risks should be evaluated during hydraulic modeling efforts.

- Cove Hummocks: These features include a design risk on Audubon Island that, given a requirement to keep all dredged sediments with the island and without depositing on upland areas, it may not be possible to create the desired steeper slopes. This is because the fine sediments that currently exist in the coves will not support steeper slopes themselves, and there may not be sufficient room then to add all the coarse sediment needed to create steeper slopes.

- All Features: Based on discussion with the current floodplain administrators, and considering preliminary modeling, we believe the risk of the design being disapproved by floodplain administrators is low. This assumes that the two-dimensional hydraulic modeling identifies a somewhat smaller rise in flood waters along the riverbanks than the one dimensional model.

5.6.3 Real Estate

Real estate investigation and analysis for the proposed restoration projects were conducted by the University of Toledo, Hull and Associates, LLC (Hull), and the City of Toledo, and is outside the scope of this report. A summary of real estate related investigations and analyses will be provided by Hull and The University of Toledo in a separate report.

5.6.4 Cultural Resources

Another area of risk and uncertainty identified involves cultural interests among the Audubon Island complex. Preliminary designs and potential areas of disturbance have been discussed with interested tribal representatives. The project, as currently proposed, can be designed to minimize or avoid impacts to the islands. For example, any soil disturbance and staging areas will be minimized to the greatest extent possible. Dredge material from cove contouring should not be placed in uplands. Disturbance of upland or riparian soils will be limited to plantings, installing erosion protection or habitat enhancements along the shoreline.

Feedback from tribal representatives of the proposed project has been positive and supportive. Interested tribes and SHPO will be given the opportunity to comment and review final designs prior to any construction activities commencing. While not anticipated, substantial changes to current restoration proposals during final design have the potential to result in habitat and benefit loss. Furthermore, any archeological artifacts found at the project site could have the potential to delay the project during construction. Coordination with tribal representatives and the SHPO should continue which will reduce or eliminate risk and uncertainty involving potential impacts to cultural resources.

Some risk and uncertainty are intrinsic in the planning and design of aquatic ecosystem restoration projects. All measured or estimated values in project planning and design are best estimates of key variables, factors, parameters, and data components. Overall, risk and uncertainty for the project is at acceptable levels and can be mitigated for and reduced to the greatest extent possible.

6.0 Plan Implementation

6.1 Design and Implementation Phase

The Maumee AOC Advisory Committee and Ohio EPA, will evaluate the contents of this report in order to guide anticipated funding requests for future phases of project implementation. The USGS' role is to coordinate activities and provide technical support. A tentative schedule for implementation of habitat management actions will augment the overall schedule for completion of all AOC management actions. During the next phase (detailed design), the final engineering design of the selected plan will be completed along with a corresponding Operations and Maintenance (O&M) Manual. A detailed set of plans and specifications will then be prepared in order to solicit and award a construction contract. Once the design phase has been completed and funding is available, the construction contract may be advertised and awarded.

6.2 Monitoring and Adaptive Management Plan

A comprehensive monitoring and adaptive management plan should be developed for the chosen preliminary restoration designs.

The purpose of a monitoring and adaptive management plan is to provide data that can suggest mid-course corrections that should be implemented to better realize the project's objectives. Developing river restoration monitoring objectives would serve as a framework for assessing the physical habitat within the river channel, vegetation performance, and water quality improvements. The restoration site should be monitored bi-annually for a period of at least five years after restoration activities are complete. At the end of each year, data collected as described below shall be used to identify any issues regarding the physical habitat, vegetation establishment, and recommend interventions. It is estimated that proposed monitoring could be accomplished for about $10,000 – $15,000 per year.

The methods used for monitoring include the establishment of fixed photo points, physical habitat assessments, biological assessments, and vegetation assessments (if necessary). The following standardized protocols should be used to assess performance:

- Physical habitat assessments:
    1. Qualitative Habitat Assessment Index (QHEI)
    2. Water Quality Measurements: temperature, DO, pH, specific conductivity, turbidity
- Biological assessments (aquatic life usage):
    1. Fish Index of Biotic Integrity (FIBI)
    2. Modified Index of Well Being (MIwb)
    3. Invertebrate Community Index (ICI)
- Customized assessments based on restoration concept:
    1. Coverage of riparian vegetation within restoration area
    2. Presence and coverage of plant species installed during restoration
    3. Presence and coverage of invasive plant species
    4. Visual assessments of habitat quality

6.2.1 Performance Standards and Adaptive Management

The overall goal of the project is to contribute to BUI removal within the Lower Maumee River. Ecological performance standards are used to ensure that the restoration activities are achieving project goals. Development of performance standards should take place during the engineering and design phase of this project. The following performance standards are example performance standards that could be used to assess the success of the chosen restoration concept:

Performance Standard #1: QHEI metric scores must show an increase by the end of the second year following construction activities.

Performance Standard #2: Measurable increases in the Fish IBI, MIwb, and ICI, scores throughout the project reach two years after construction activities have been completed.

Performance Standard #3: Riparian vegetation communities must exhibit at least 80 percent native species composition by the end of the second growing season following construction activities.

Performance Standard #4: No more than 10 percent cumulative areal cover of the riparian zone may be vegetated with the following species: common reed, European buckthorn, or Japanese knotweed.

The following adaptive management measures will be considered if the aforementioned performance standards are not achieved:

Adaptive Management Measure #1: If the fish and macro-invertebrate abundance and diversity do not increase as indicated by Fish IBI and ICI scores, measures should be implemented to further enhance habitat quality with the project reach.

Adaptive Management Measure #2: If the above invasive species vegetation thresholds are exceeded (i.e., not met) at the end of any monitoring year, corrective measures should be implemented to preclude the growth of the above listed species within the restoration area. Corrective measures include additional herbicide applications to invasive species, increased mechanical treatment (e.g., cutting or hand-pulling) and/or additional plantings to compete with invasive species.

6.3 Real Estate

Real estate investigation and analysis for this project is being conducted by the University of Toledo and is outside the scope of work of this report. A final real estate investigation will be provided by the University of Toledo to stakeholders in a separate report. after this report has been finalized.

6.4 Operations and Maintenance

During detailed design an Operations and Maintenance (O&M) Manual for the project should be completed and followed upon physical completion of the project. This O&M Manual should outline repairs, replacements, and rehabilitation necessary to provide longevity and maximize long term benefits of the project.

6.5 Regulatory Requirements

The following regulatory requirements, permits and approvals are required for this project. This list includes but is not limited to:

- Clean Water Act Section 401/404 Individual Permit
- Section 9 and 10 of the Rivers and Harbors Act Nationwide Permit
- FEMA Floodplain Development Permit

- Section 106 of the National Historic Preservation Act
- Section 7 of the Endangered Species Act and the Fish and Wildlife Coordination Act
- Mussel survey to determine if threatened or endangered mussels are located in the project area.
- ODNR Office of Coastal Management (submerged lands leases, structure permits, etc.)

7.0 Public Involvement, Review, and Coordination

The University of Toledo is responsible for conducting all outreach activities for both the general public and stakeholder groups. Public involvement is currently ongoing and outside the scope of work of this report. Analysis and review of public involvement activities are therefore outside the scope of work of this report. Additionally, this is not intended to serve as a NEPA review. A final public involvement report will be provided by the University of Toledo to project stakeholders in a separate report once this report has been finalized.

8.0 References

Beechie T.J., Sear D.A., Olden J.D., Pess G.R., Buffington J.M., Moir H., Roni P., Pollock M.M. 2010. Process based principles for restoring river ecosystems. BioScience 60, 209–222.

Cashman MJ, Wharton G, Harvey GL, Naura M, Bryden A. 2018. Trends in the use of large wood in UK river restoration projects: insights from the National River Restoration Inventory. Water and Environment 0, 1-11. DOI: 10.1111/wej.12407

Chow, 1959. Open-Channel Hydraulics. McGraw Hill. ISBN-13: 978-1-932846-18-8.

Clapp, D.F., P.J. Schneeberger, D.J. Jude, G. Madison, and C. Pistis. 2001. Monitoring round goby (*Neogobius melanostomus*) population expansion in eastern and northern Lake Michigan. Journal of Great Lakes Research 27(3):335-341.

Collier, Jessica J., 2018. Creating a Spatially Explicit Habitat Suitability Index Model for Lake Sturgeon (*Acipenser fulvescens*) in the Maumee River, Ohio. Submitted to the Graduate Faculty as partial fulfillment of the requirements for the Doctor of Philosophy Degree in Biology (Ecology Track). University of Toledo, May 2018. (Downloaded from: https://etd.ohiolink.edu/apexprod/rws_olink/r/1501/10?clear=10&p10_accession_num=toledo1525350340081516).

Crossman, E.J., E. Holm, R. Cholmondeley, and K. Tuininga. 1992. First record for Canada of the rudd, *Scardinius erythrophthalmus*, and notes on the introduced round goby, *Neogobius melanostomus*. Canadian Field-Naturalist 106(2):206-209.

DuFour, M. R., May, C. J., Roseman, E. F., Ludsin, S. A., Vandergoot, C. S., Pritt, J. J., Fraker, M. E., Davis, J. J., Tyson, J. T., Miner, J. G., Marschall, E. A., Mayer, C. M. 2015. Portfolio theory as a management tool to guide conservation and restoration of multi-stock fish populations. Ecosphere 6, 1-21.

England, J.F., Jr., Cohn, T.A., Faber, B.A., Stedinger, J.R., Thomas, W.O., Jr., Veilleux, A.G., Kiang, J.E., and Mason, R.R., Jr., 2018, Guidelines for determining flood flow frequency—Bulletin17C:U.S. Geological Survey Techniques and Methods, book4, chap. B5, 148p., https://doi.org/10.3133/tm4.

Environment Canada NB, 1989. New Brunswick River Ice Manual. Prepared by the New Brunswick Subcommittee on River Ice. Inland Waters Directorate, Department of Environment.

Environmental Law and Policy Center. 2019. An assessment of the impacts of climate change on the Great Lakes.

FEMA, 2011. Flood Insurance Study: Wood County, Ohio, and Incorporated Areas.

FEMA, 2016. Flood Insurance Study: Lucas County, Ohio, and Incorporated Areas.

Florsheim JL, Mount JF, Chin A. 2008. Bank erosion as a desirable attribute of rivers. BioScience 58(6), 519-529. DOI: 10.1641/B580608

Garrison, B. A., and Turner. 2020. Bank Swallow (*Riparia riparia*), version 1.0. In Birds of the World (S. M. Billerman, Editor). Cornell Lab or Ornithology, Ithaca, NY, USA.

Griffiths, W., and B. Walton. 1978, The effects of sedimentation on the aquatic biota. Alberta Oil Sands Environmental Research Program, Report # 35.

Hayes, Donald, 2021. Personal communication. September 22, 2021 via email. Research Environmental Engineer, Retired. USACE Engineer Research and Development Center. Vicksburg, MS.

Hintz, W. and Shane, K. 2021. Walleye Spawning Habitat Delineation near the Audubon Islands State Nature Preserve. University of Toledo.

Hintz, W., Shane, K., Crail, T., Mayer, C., Oubre, M., and Miner, J. 2019. Final Report Identification of Optimal Sites for Maumee AOC Restoration Actions in the Lower Maumee River.

Jude, D.J., and S.F. DeBoe. 1996. Possible impact of gobies and other introduced species on habitat restoration efforts. Canadian Journal of Fisheries and Aquatic Sciences 53(S1):136-141.

Karr J. R., Chu E. W. 2000. Sustaining Living Rivers. Hydrobiologia 422(423),1-14, DOI: 10.1023/A:1017097611303

Lederer, A.M., Janssen, J., Reed, T., and Wolf, A. 2008. Impacts of the introduced round goby (*Apollonia melanostoma*) on Dreissenids (*Dreissena polymorpha* and *Dreissena bugensis*) and on macroinvertebrate community between 2003 and 2006 in the littoral zone of Green Bay, Michigan. Journal of Great Lakes Research, 34(4):690-797.

Leopold, L. B., & Maddock, T. US Geological Survey. (1953). The Hydraulic Geometry of Stream Channels and Some Physiographic Implications. Professional Paper 252. Washington, DC.

Mapes, R.L., M. R. DuFour, J. J. Pritt, and C. M. Mayer. 2015. Larval fish assemblage recovery: a reflection of environmental change in a large degraded river. Restoration Ecology 23:85-93.

Marsden, J.E. and M.A. Chotkowski. 2001. Lake trout spawning on artificial reefs and the effect of zebra mussels: Fatal attraction? Journal of Great Lakes Research. 27(1): 33-43.

Marsden, J.E. and C.C. Krueger. 1991. Spawning by hatchery-origin lake trout in Lake Ontario: data from egg collections, substrate analysis, and diver observations. Canadian Journal of Fisheries and Aquatic Science. 48:2377-2384.

Marsden, J.E., and D.J. Jude. 1995. Round gobies invade North America. Fact sheet produced by Sea Grant at Ohio State University, Columbus, OH.

Maumee AOC Advisory Committee (MAAC) and Ohio Environmental Protection Agency (OHIO EPA). 2021. Lower Maumee River Restoration Design Concepts.

Miller J.R., Kochel C. 2010. Assessment of channel dynamics, in-stream structures and post-project channel adjustments in North Carolina and its implications to effective stream restoration. Environmental Earth Sciences 59(8), 1681-1692, DOI: 10.1007/s12665-009-0150-1

Mion, J. B., R. A. Rein, and E. A. Marschall. 1998. *River discharge drives survival of larval walleye*. Ecological Applications 8(1):88-103.

National Invasive Species Council. 2004. Weekly Notice May 27, 2004-June 3, 2004.

Natural Resources Conservation Service. 2009. Lower Maumee Watershed (OH) HUC: 04100009 Rapid Watershed Assessment – Data Profile Lower Maumee Watershed.

Ohio Department of Natural Resources (ODNR). 2021. Ohio’s Lake Erie Fisheries. 2020 Annual Data Report. ODNR Division of Wildlife, Lake Erie Fisheries Units, Fairport and Sandusky.

Ohio Environmental Protection Agency (Ohio EPA). 2020. Integrated Water Quality Monitoring and Assessment Report. Division of Surface Water. Final Report. Available at https://epa.ohio.gov/static/Portals/35/tmdl/2020intreport/2020_Final_IR_CompleteReport_May2020.pdf?ver=2020-05-11-150221-420

Ohio Environmental Protection Agency (OHIO EPA). 2017. Delisting Targets for Ohio Areas of Concern. Ohio EPA Division of Surface Water Lake Erie Program. Accessed November 2021. Available at https://www.epa.gov/sites/default/files/2020-09/documents/new_delisting_guidance_restoration_targets_for_ohios_aocs_v3_dec.2017.pdf

Ricciardi, I.I., MacIsaac, H.J. 2000. Recent mass invasion of the North American Great Lakes by Ponto-Caspian species. Trends in Ecological Evolution. 15(2): 62-65.

Roseman, E. F., W. W. Taylor, D. B. Hayes, J. Fofrich Sr., and R. L. Knight. 2002. *Evidence of walleye spawning in Maumee Bay, Lake Erie*. Ohio Journal of Science 102(3):51-55.

Schmidt, B. A., Tucker, T. R., Collier, J. J., Mayer, C. M., Roseman, E. F., Stott, W., Pritt, J. J. 2020. Determining habitat limitations of Maumee River Walleye production to western Lake Erie fish stocks: documenting a spawning ground barrier. Journal of Great Lakes Research 46, 1661–1673.

Shane, K.D., M.J. Oubre, T.D. Crail, J.G. Miner, C.M. Mayer, T.E. Sasak, R.L. DeBruyne, J.J. Miller, E.F. Roseman, and W.D. Hintz. Towards improving an Area of Concern: Main-channel habitat rehabilitation priorities for the Maumee River. Journal of Great Lakes Research 47 (2021) 1429-1436.

Silliman, B. R., T. J. Mozdzer, C. Angelini, J. E. Brundage, P. Esselink, J. P. Bakker, K. B. Gedan, J. van de Koppel, and A. H. Baldwin. 2014. Livestock as a potential biological control agent for an invasive wetland plant. PeerJ. DOI 10.7717/peerj.567.

Streby, H., and Kramer, R. 2021. Assessment of Bank Swallow Population Size and Nesting Habitat at Proposed Erosion Control Project Site on Audubon Islands State Nature Preserve. University of Toledo.

Trautman, M. B. 1981. *The Fishes of Ohio*. Columbus: Ohio State University Press.

Tucker, T.R., Schmidt, B.A., Collier, J.J., Mayer, C.M., Roseman, E.F., Stott, W., and Pritt, J.J., 2020, Walleye (Sander vitreus) egg deposition and spawning habitat suitability in the Maumee River, OH (2014-2015): U.S. Geological Survey data release, https://doi.org/10.5066/P9214IQU.

Turner, M. G. 1987. Effects of grazing by feral horses, clipping, trampling, and burning on a Georgia salt-marsh. Estuaries 10:54-60.

UMRCC, 2002. Upper Mississippi River Conservation Committed (UMRCC) Water Quality Technical Section. 2002. Upper Mississippi River Water Quality Assessment. 184 pp. http://www.epa.gov/r5water/umr_wq_assess.htm

USACE, 1988. Revised Report on Great Lakes Open-Coast Flood Levels; Detroit District. April 1988.

USACE, 2009. Buffalo River Area of Concern Ice Investigation. Draft Report to USEPA – Great Lakes National Program Office. By Ice Engineering Research Group, Cold Regions Research and Engineering Laboratory (CRREL).

United States Army Corps of Engineers. 2015. Recent US Climate Change and Hydrology Literature Applicable to US Army Corps of Engineers Missions – Great Lakes Region. Civil Works Technical Report, CWTS-2015-07. U.S. Army Corps of Engineers, Washington, D.C

USACE, 2015b. MEMORANDUM for USEPA Great Lakes National Program Office (GLNPO). SUBJECT: Potential Impacts of Ice on Habitat Restoration Features and of Restoration Features on Ice Jam Formation in the Buffalo River Area of Concern (AOC). LRB-TD-HD. 4 August 2015.

USACE, 2017. ETL 1100-2-3. Guidance for Detection of Nonstationarities in Annual Maximum Discharges. CECW-CE. 28 April 2017.

USACE, 2021. Monthly Bulletin of Lake Levels for the Great Lakes, Detroit District. https://www.lre.usace.army.mil/missions/great-lakes-information/great-lakes-water-levels/water-level-forecast/monthly-bulletin-of-great-lakes-water-levels/. Accessed August 2021.

USEPA, 2003. Developing Water Quality Criteria for Suspended and Bedded Sediments (SABS): Potential Approaches. A USEPA Science Advisory Board Consultation. DRAFT. USEPA Office of Water, Office of Science and Technology. August 2003.

USEPA, 2019. Great Lakes Restoration Initiative Action Plan III Fiscal Year 2020 – Fiscal Year 2024. https://www.epa.gov/sites/default/files/2019-10/documents/glri-action-plan-3-201910-30pp.pdf. Accessed November 2021.

United States Environmental Protection Agency (USEPA). 2020. Great Lakes AOCs – BUI Descriptions. https://www.epa.gov/great-lakes-aocs/bui-descriptions.

UT/Hull, 2021. Lower Maumee River Restoration Design Concepts. Prepared for Maumee AOC Advisory Committee (MAAC) and Ohio EPA; Prepared by University of Toledo, BGSU, Hull. March 2021.

Van der Kolff & van ‘t Hoff, 2012. Hydraulic Fill Manual (1st edition), CRC Press/Balkema Taylor & Francis Group, November 2012.

Wohl E. E., Cenderelli D. A., Dwire K. A, Ryan-Burkett S. E., Young M. K., Fausch K. D. 2009. Large In-Stream Wood Studies: A Call for Common Metrics. Earth Surface Processes and Landforms 35, 618-625.

Wohl E. E. 2011. Seeing the forest and the trees: Wood in stream restoration in the Colorado Front Range, United States. Pages 399–418 in Simon A, Bennett SJ, Castro JM, eds. Stream Restoration in Dynamic Fluvial Systems: Scientific Approaches, Analyses, and Tools. American Geophysical Union.

Zapzalka T. 1997. Restoring Large Woody Debris to Streams. Restoration and Reclamation Review. Student On-Line Journal 2(1). Spring 1997. Department of Horticultural Science, University of Minnesota, St. Paul, MN.