Sustainable Rivers Program

Ohio River Systems Analysis

Prepared by:

U.S. Army Corps of Engineers, Pittsburgh District
1000 Liberty Avenue
Pittsburgh, Pennsylvania 15222

U.S. Army Corps of Engineers, Huntington District
502 8th Street
Huntington, West Virginia 25701

U.S. Army Corps of Engineers, Louisville District
600 Dr. Martin Luther King Jr. Place
Louisville, Kentucky 40202

Above: R. C. Byrd Locks and Dam in Huntington District (USACE photo)

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Executive Summary

The Ohio River is of national ecological and socioeconomic significance, containing a diverse aquatic community (approximately 160 fish and 120 mussel species) and providing vital services (e.g., navigation, recreation, drinking water) to over 22 million people. Altered hydrology has been identified as an urgent threat to the ecological sustainability of the Ohio River by affecting water quality, sediment transport and distribution, floodplain connectivity, and availability of/access to critical (e.g., spawning and rearing) habitats. To maximize the ecological sustainability of the Ohio River mainstem, the U.S. Army Corps of Engineers (USACE), Pittsburgh, Huntington, and Louisville Districts (subsequently referred to as 'Districts') completed a Sustainable Rivers Program study to develop the science and tools needed to identify potential ecological opportunities and strategic operations of its 19 navigation locks dams (L/Ds) while maintaining current mission goals (i.e., navigation, hydropower, etc.). Potential ecological opportunities and operational changes of reservoirs throughout the River basin were qualitatively considered to the extent that such changes could impact or improve water quality in the mainstem of the Ohio River.

Subject matter experts from each participating District reviewed publicly available data to inventory and baseline conditions within the Ohio River, including ecological, bathymetric, and infrastructure conditions. Data collection efforts focused on the mainstem of the Ohio River. Relevant ecological data included water quality characteristics and variability; presence and distribution of native, threatened, endangered, and non-native species; important habitat types; types and condition of navigation infrastructure; presence of hydropower operations; and municipal or privately-owned water intakes and other infrastructure (e.g., boat ramps, marinas, docks). Hydrologic data were collected to characterize aspects of basin-level hydrology critical to informing a systems approach to sustainable water management. Hydrologic data included travel times, pool elevations, and existing hydrologic and hydraulic (H&H) models.

Using the initial inventory of baseline conditions, the Districts then identified ecological opportunities for the Ohio River. Within the context of this study, opportunities were defined as the desirable environmental outcomes that are possible from future modifications to operations at USACE navigation projects and, to a limited extent, reservoirs. General opportunities identified under this study include improvements to hydrologic and hydraulic regimes (i.e., restoration of more natural flow patterns), water quality, quality and diversity of habitats, connectivity of habitats, and aquatic communities. To identify specific changes to operations or other actions (i.e., measures) capable of realizing ecological opportunities, the Districts identified target species and associated habitats using historic data for the Ohio River, characterized water quality attributes that could be improved through modifications to operations, and researched previous efforts and successes for each type of opportunity. Potential measures included changing the timing of water release, changing the method of water release (i.e., opening different gates), and implementation of conservation lockages for tributaries that experience less navigation. Other measures require programmatic changes or agreements, implementation of ecosystem restoration projects, or structural changes. Such measures were still considered under the context of this study to provide a comprehensive portfolio of actions that can be implemented to improve the ecological sustainability of the Ohio River.

Using the inventory of existing conditions, the Districts identified pool-specific and physical and operational constraints and considerations for each opportunity. Constraints are defined within the study context as factors that limit the ability to realize opportunities. Identified constraints include the dam type or construction, depths required to maintain commercial navigation, presence of other infrastructure (i.e., hydropower, water intakes, etc.), travel times from upstream reservoirs, legal obligations (i.e., hydropower licenses, etc.), and potential impacts to threatened and endangered species. Considerations are defined within the study context as factors to consider when attempting to realize opportunities, though these factors are considered to exert less control on opportunities than constraints. Considerations identified for this study include authorized purposes, major tributaries, presence of wildlife refuges, potential impacts to invasive or non-target species, potential impacts to erosion or sedimentation, current water control manuals or guide curves, and timeframe for analysis.

The Districts then utilized all available information to identify target pools and measures for modeling. The Districts developed site-specific, when possible, and general preliminary recommendations for further study of 10 environmental measures across the Ohio River Basin. These measures include: temporarily raising pool elevation, temporarily lowering pool elevation, flow manipulation for habitat improvement, selective withdrawal retrofits for flood risk management structures, structural changes, island restoration, invasive species control, modification of hydropower Operating Agreements, Rapid Watershed Assessments for tributaries, and conservation lockages.

H&H modeling was undertaken in three pools to determine what flow levels were necessary to ensure operational changes (specifically lowering the normal pool elevation) would not impact the navigability of the river. Pools were selected for H&H modeling through estimation of the area, as acres, that would potentially be exposed or submerged through changes in the pool elevation. One pool was selected in each District to allow comparison across the major sections of the river. Bathymetric and habitat analyses were also conducted to demonstrate the acreage and types of land that may be exposed or submerged through changes in the pool elevation. The benefits, costs, and additional considerations for each measure were documented. Preliminary recommendations developed as a result of these analyses will be shared externally to engage regional stakeholders in initial discussions regarding the management of ecological resources in the Ohio River basin.

Table of Contents

Abbreviations and Acronyms

CFS	cubic feet per second
CPUE	Catch per unit effort
CSO	Combined sewer overflow
CWA	Clean Water Act
DELT	Deformities, erosions, lesions, and tumors
DSAC	Dam Safety Action Classification
EPA	US Environmental Protection Agency
ERDC	U.S. Army Engineer Research and Development Center
ESA	Endangered Species Act
FERC	Federal Energy Regulatory Commission
HEC	Hydrologic Engineering Center
IENC	Inland electronic navigation charts
IPaC	Information for Planning and Consultation
KYDOW	Kentucky Division of Water
L/D	Locks and Dam
LRD	Great Lakes and Ohio River Division
LRH	Huntington District
LRL	Louisville District
LRP	Pittsburgh District
*m*ORFIN	Modified Ohio River Fish Index
MRLC	Multi-Resolution Land Characteristics
MVD	Mississippi Valley Division
NAB	Baltimore District
NAD	North Atlantic Division
NEPA	National Environmental Policy Act
NLCD	National land cover database
NRCS	Natural Resource Conservation Service
ORINWR	Ohio River Islands National Wildlife Refuge
ORSANCO	Ohio River Valley Water Sanitation Commission
PADEP	Pennsylvania Department of Environmental Protection
PAFBC	Pennsylvania Fish and Boat Commission
PCBs	Polychlorinated biphenyls
RWA	Rapid watershed assessment
SRP	Sustainable Rivers Program
TNC	The Nature Conservancy
TVA	Tennessee Valley Authority
USACE	U.S. Army Corps of Engineers
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
WRDA	Water Resources Development Act
WSEL	Water surface elevation

List of Tables

List of Figures

List of Appendices

1 Introduction

The Ohio River extends from its origin in Pittsburgh, Pennsylvania to its confluence with the Mississippi River near Cairo, Illinois. The Ohio River provides 981 miles of commercially navigable channel maintained through a system of 19 locks and dams (L/D) (Fig. 1). Spanning 14 states, the drainage area of the Ohio River is approximately 204,000 square miles. The mainstem of the river traverses six states, including Pennsylvania, Ohio, West Virginia, Kentucky, Indiana, and Illinois (USACE LRD 2000). The Ohio River is of national ecological and socioeconomic significance, containing a diverse aquatic community and providing vital services (e.g., navigation, recreation, drinking water) to over 22 million people (ORSANCO 2010). Human activities have significantly altered the ecological resources of the Ohio River, its floodplains, and its tributaries for centuries. Major activities occurring throughout the basin include forest harvest, agriculture, industrialization, urbanization, mineral extraction, and river impoundment (USACE LRD 2009).

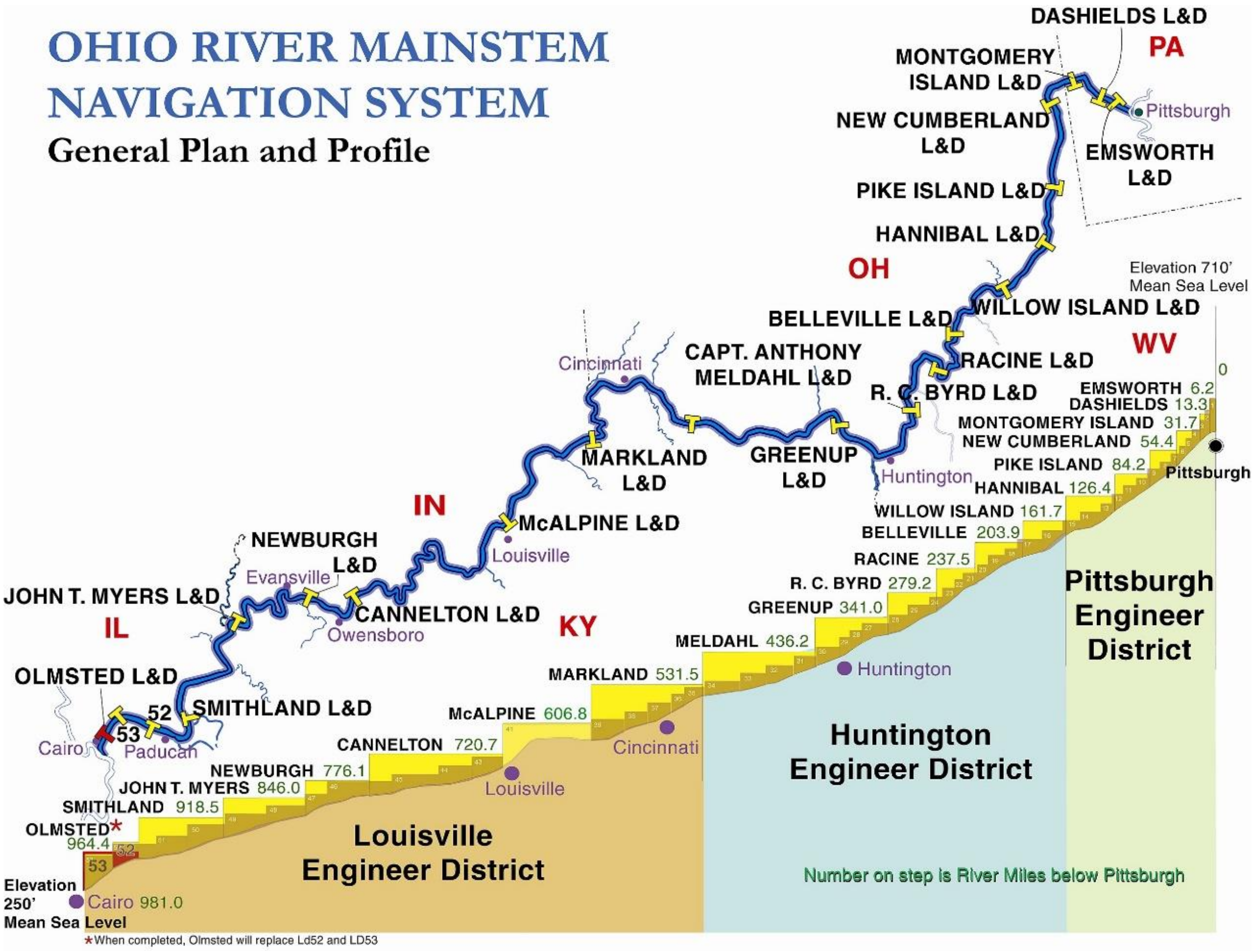

Fig. 1. The Ohio River Navigation System provides 981 miles of commercially navigable channel between Pittsburgh, Pennsylvania and Cairo, Illinois, where the river joins the Mississippi River.

Through the Sustainable Rivers Program (SRP), USACE Huntington (LRH), Louisville (LRL), and Pittsburgh (LRP) Districts collaboratively assessed the potential for changes in water infrastructure operations across all three districts to improve the ecological quality and sustainability of the Ohio River.

1.1 Study Authority

This study was conducted as part of SRP, a partnership between USACE and The Nature Conservancy (TNC). SRP aims to improve the ecological quality of rivers through change in water infrastructure operations that may restore or protect ecosystems, while maintaining or enhancing other project benefits and continuing to meet Congressionally authorized purposes. Traditionally, SRP focused on environmental flows, defined as the "quantity, timing, and quality of water flows required to sustain ecosystems." Recently, SRP has expanded its approach to explore additional actions at water infrastructure projects with potential to provide ecological benefit (USACE HEC, n.d.).

1.2 Problem Statement

Over the past 200 years, the Ohio River basin has experienced significant urbanization, mineral extraction, and water resource development. An estimated 65% of the forested floodplain within the basin was converted to other land use types between 1800 and 1970. Since 1900, island acreage within the basin has decreased by 43%. Impoundment of the river altered sediment transport and water levels throughout the river, altering the availability of riffles and sandbars. Such changes reduce the area and diversity of habitats available to fish and wildlife species and result in long-term changes to water quality dynamics throughout the river (USACE LRD 2009).

Significant improvements in the environmental quality of the Ohio River have been accomplished through implementation of environmental legislation and national, regional, and local restoration efforts. However, the pressures from urbanization, mineral extraction, and impoundment continue to impact the quality of the Ohio River. Altered hydrology remains an urgent threat to the ecological sustainability of the Ohio River by affecting water quality, sediment transport and distribution, floodplain connectivity, and availability of/access to critical (e.g., spawning and rearing) habitats.

1.3 Study Objectives

The overall goal of the three participating USACE districts was to develop the science and tools needed to maximize ecological sustainability of the Ohio River mainstem through strategic operations of its 19 navigation dams while maintaining current mission goals and authorized purposes (e.g., navigation, hydropower, etc.). Potential ecological opportunities and operational changes of reservoirs throughout the River basin were qualitatively considered to the extent that such changes could impact or improve water quality in the mainstem of the Ohio River. However, the ability of such changes to result in quantitative impacts to water quality and ecological sustainability of the Ohio River should be further analyzed prior to implementation of measures at reservoirs.

The specific objectives of this study were to:

1. Inventory and baseline conditions within the Ohio River.

2. Characterize critical aspects of basin-level hydrology and identify additional hydrologic modeling and tools that may be needed to inform a systems approach to sustainable water management.

3. Identify potential opportunities and measures to maximize ecological sustainability through reservoir and navigation system operations.

4. Engage regional stakeholders to develop a coordinated approach to further study and potential implementation of the ecological measures identified under the current study.

Successful completion of this study provides the foundation needed to inform future changes to the operation of USACE infrastructure, with the goal of improving ecological conditions and sustainability within the Ohio River. The system-scale (i.e., entire Ohio River Basin) represents the most appropriate scale at which to develop approaches to ecologically sustainable operations given the interdependence among all reservoirs and navigation dams in controlling flows within the Ohio River.

1.4 Study Approach

The Districts identified eight steps necessary to achieve the study objectives (Fig. 2). To facilitate collaboration and efficiency, the Districts developed three working teams for this effort: the Environmental Team, Hydrologic and Hydraulics (H&H) Team, and Geospatial Team. Each team consisted of subject matter experts from each District.

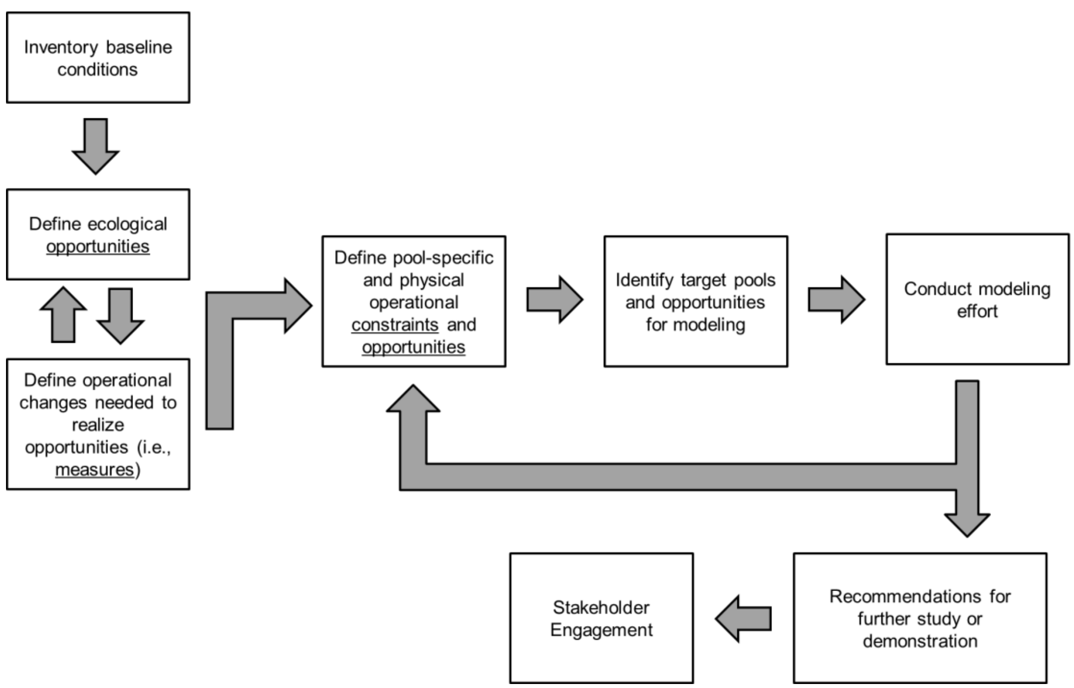

Fig. 2. This study utilized an iterative framework consisting of eight steps to identify opportunities and measures to maximize ecological sustainability through strategic operation of the Ohio River Navigation System.

Baseline conditions were defined as the current characteristics of the biological community, environmental conditions, land use, and infrastructure within the mainstem of the Ohio River. Information regarding baseline conditions was retrieved from existing literature, databases, and navigation charts by the Environmental, H&H, and Geospatial Teams.

Using the initial inventory of baseline conditions, the Environmental Team then identified ecological opportunities for the Ohio River. Within the context of this study, opportunities were defined as the desirable environmental outcomes that are possible from future modifications to operations at USACE reservoirs or L/Ds. General opportunities identified under this study include improvements to hydrologic and hydraulic regimes (i.e., restoration of more natural flow patterns), water quality, quality and diversity of habitats, connectivity of habitats, and aquatic communities. To identify specific measures to realize ecological opportunities, the Environmental team identified target species (i.e., threatened or endangered species, valuable game fish, mussel host species, extirpated species, and important waterfowl) and associated habitats using historic data for the Ohio River, characterized water quality attributes that could be improved through modifications to operations, and researched previous efforts and successes for each type of opportunity.

The Environmental Team then collaborated with the H&H Team to identify the specific changes to operations at navigation projects (i.e., measures) that would be required to realize specific ecological opportunities. Such measures included altering the pool elevation, changing the method of water release (i.e., opening different gates), and implementation of conservation lockages for tributaries that experience less navigation. Other measures require programmatic changes or agreements, implementation of ecosystem restoration projects, or structural changes. Such measures were still considered under the context of this study to provide a comprehensive portfolio of actions that can be implemented to improve the ecological sustainability of the Ohio River.

Using the inventory of existing conditions, the Environmental and H&H Teams identified pool-specific and physical and operational constraints and considerations for each opportunity. Constraints are defined within the study context as factors that limit the ability to realize opportunities. Such constraints include the dam type or construction, depths required to maintain commercial navigation, presence of other infrastructure (i.e., hydropower, water intakes, etc.), travel times from upstream reservoirs, legal obligations (i.e., Federal Energy Regulatory Commission (FERC) licenses, etc.), and potential impacts to threatened and endangered species. Considerations are defined within the study context as factors to consider when attempting to realize opportunities, though these factors are considered to exert less control on opportunities than constraints. Considerations identified for this study include authorized purposes, major tributaries, presence of wildlife refuges, potential impacts to invasive or non-target species, potential impacts to erosion or sedimentation, current water control manuals or guide curves, and timeframe for analysis. To refine the list of constraints and considerations, the Districts solicited input from the Operations Division, specifically the Chiefs of Locks and Dams for each District.

The Team utilized all available information to identify target pools and measures for modeling. A total of 10 measures were identified, including: temporarily raising pool elevation, temporarily lowering pool elevation, flow manipulation for habitat improvement, selective withdrawal retrofits for flood risk management structures, structural changes, island restoration, invasive species control, modification of hydropower Operating Agreements, Rapid Watershed Assessment for tributaries, and conservation lockages. The Environmental Team researched the benefits, costs, and additional considerations for each measure. H&H modeling was undertaken in three pools to ensure that operational changes (specifically lowering the normal pool elevation) would not impact the navigability of the river. Pools were selected for H&H modeling through estimation of the area, as acres, that would potentially be exposed or submerged through changes in the pool elevation. One pool was selected in each District to allow comparison across the major sections of the river. The Geospatial Team also conducted bathymetric and habitat analyses to demonstrate the acreage and types of land that may be exposed or submerged through changes in the pool elevation.

The Environmental, H&H, and Geospatial Teams then collaborated to develop recommendations for further study. These findings are presented in Sections 4 and 5 of this report. The findings of this study will be shared with external stakeholders for feedback and refinement.

2 Inventory of Existing Conditions

The Ohio River basin is a nationally significant economic and ecological resource. The Ohio River itself is home to a diverse, complex biological community. The navigation system provides a cost-effective alternative to transportation of goods via highways or railroads, while also providing additional societal benefits like drinking water and recreational opportunities. As part of the current effort, the Team inventoried existing conditions related to the ecology, infrastructure, and land use within the Ohio River basin. A brief summary of the existing conditions documented within the basin is provided in the following sections. More detailed information is provided for the physical characteristics of the L/Ds in Appendix 1(Physical Characteristics of Locks and Dams) and the ecological conditions in Appendix 2 (Ecological Characteristics of Navigation Pools).

2.1 Climate

Overall, climate within the Ohio River basin is considered temperate. Climate within the Ohio River basin is influenced by “latitude, elevation differences, large bodies of water (i.e., the Great Lakes, Gulf of Mexico, Atlantic Ocean), prevailing winds, jet stream, topography, and land cover” (USACE LRD 2009). These factors have created four climatic sub-zones within the Ohio River basin based on the Köppen classification system (Fig. 3). The two most prevalent climatic zones are the humid continental region (Köppen *Dfa* or *Dfb*) in the north and the humid subtropical region (Köppen *Cfa* or *Cfb*) in the south (USACE LRD 2009).

Humid continental climate is generally found in the mid-latitudes over large landmasses where polar and tropical land masses intersect. Humid continental climate is characterized by variable weather patterns and significant seasonal temperature variation. Typical seasonal temperature variation is within 15 – 22˚C (59 – 72˚F) but may be as high as 33˚C (91˚F) in the more inland areas within the climate zone (USACE LRD 2009).

Humid subtropical climate is a broad sub-zone generally characterized by hot and humid summers and mild winters. Significant precipitation is common in all seasons, with winter rainfall or snowfall associated with large storms directed by the westerlies winds. Precipitation experienced in summer is generally associated with thunderstorms or extreme weather events, like hurricanes or tropical storms (USACE LRD 2009).

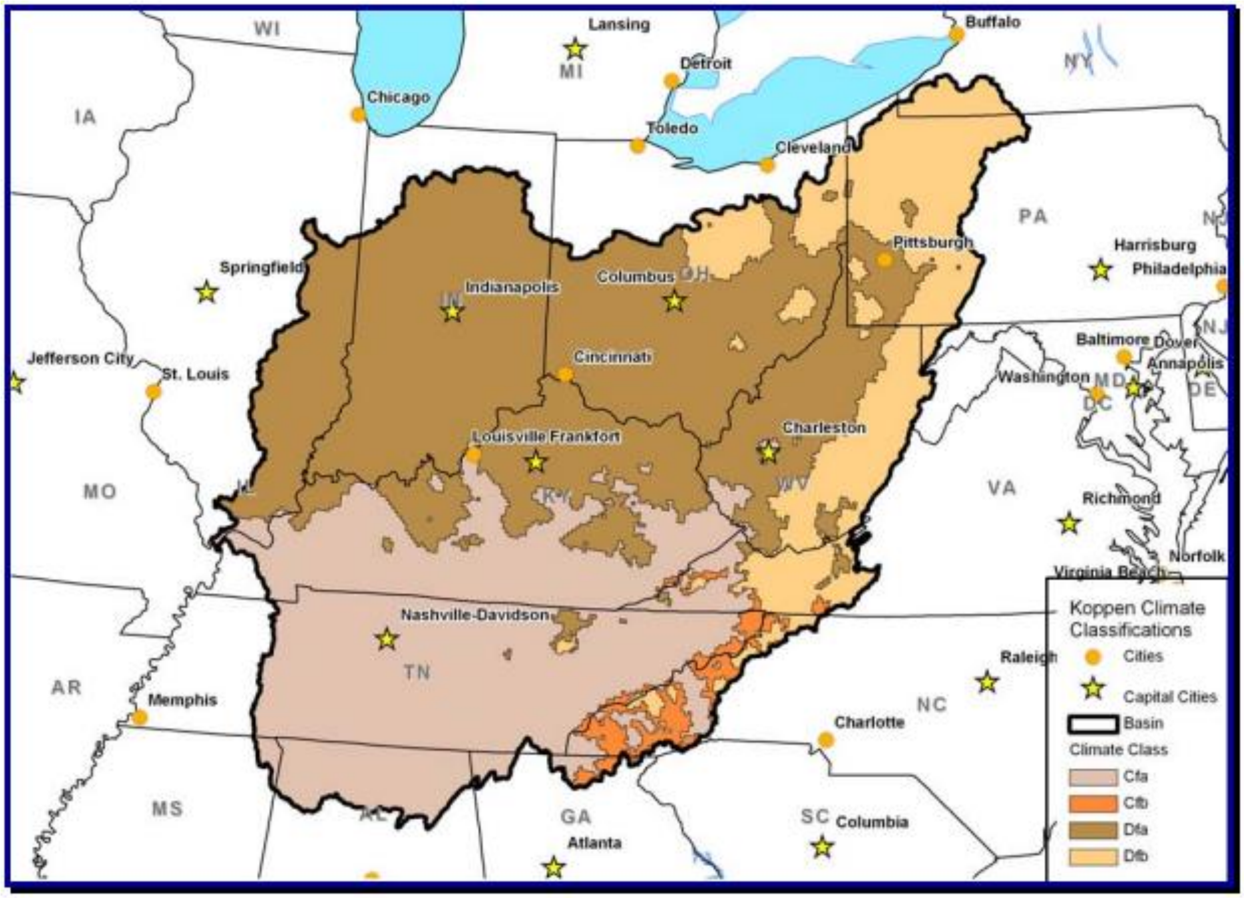

Fig. 3. According to the Köppen climate classification system, two major climatic sub-zones are present within the Ohio River basin: the humid continental (*Dfa* or *Dfb*) and humid subtropical (*Cfa* and *Cfb*) climate zones (USACE LRD 2009).

2.2 Land Use

Characterized by diverse terrain, the Ohio River basin features a variety of land use types. Historically, flatter areas within the basin are dominated by agriculture, sprawling urban and suburban development, and industrial development. The more severe terrain areas in the eastern and southern regions of the basin consist of more scattered urban and suburban development. Often, this development is limited to the floodplains of river valleys, which can significantly impact flood patterns in the region (USACE LRD 2009).

Land use patterns within the Ohio River basin were analyzed as part of the Ohio River Basin Comprehensive Reconnaissance Report using the USGS published Anderson Level 1 land cover classes for 2001 (Fig. 4). Based on the 2001 data, forest was identified as the dominant land cover type at 50.6% of total land cover (103,500 sq mi). Agriculture or cultivated lands was the second most common land use type at 34.7% of total land cover (71,100 sq mi), followed by shrub/grass at 9.0% (18,400 sq mi). Urban area comprised 3.1% of total land cover (6,200 sq mi). The remainder of the Ohio River basin is characterized by open water (1.4%), wetlands (0.8%), or barren (0.2%) land use types (USACE LRD 2009).

According to a Land Transformation Model study conducted by U.S. Environmental Protection Agency (EPA), approximately 90% of the area in the Ohio River basin has not changed land use/land cover classes since 1930. The greatest extent of land use change has affected agriculture. In 1930, agricultural was the dominant land use type in the basin. Since approximately 1950, the Ohio River basin has seen an increase in the area converted from agricultural to forestry. Today, forestry is the most common land use type in the Ohio River basin. However, agricultural land use within subwatersheds of the Ohio River basin still exceeds the 38% threshold beyond which impacts to water quality and stream macroinvertebrate community structure are typically observed (Pijanowski *et al*. 2014).

Based on data retrieved in the 2000 Census, the population of the Ohio River basin is approximately 27.0 million. Population density throughout the Ohio River basin varies significantly. Major population centers in the basin include Pittsburgh, Pennsylvania; Columbus, Ohio; Cincinnati, Ohio; Dayton, Ohio; Nashville, Tennessee; Indianapolis, Indiana; and Louisville, Kentucky. Most recent urbanization in the watershed has occurred near these metropolitan areas (USACE LRD 2009). As a result, some subwatersheds of the Ohio River basin exceed the 10% urban land use threshold beyond which impacts to water quality and stream macroinvertebrate community structure are typically observed (Pijanowski *et al.* 2014).

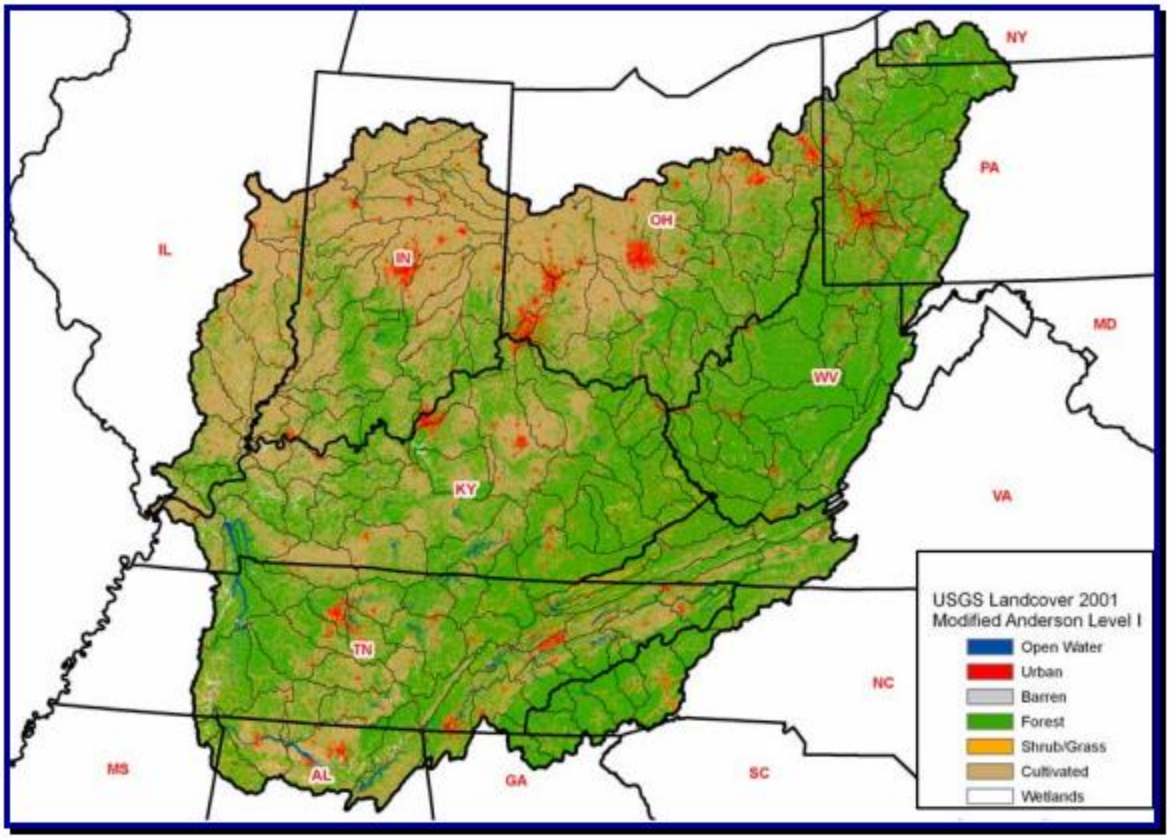

Fig. 4. Based on the 2001 USGS published Anderson Level 1 land cover classes, the majority of land use within the Ohio River basin is forest (50.7%), agriculture or cultivated land (34.8%), or shrub/grass (9.01%). Other land use types include urban (3.1%), open water (1.5%), wetlands (0.8%), or barren (0.2%) (USACE LRD 2009).

2.3 Navigation Infrastructure and Channel

Maintenance of the Ohio River Navigation System is critical to efficient transportation of large quantities of raw materials, energy resources, and goods throughout the Ohio River basin (USACE LRD 2009). Currently, the Ohio River Navigation System consists of 19 L/Ds that regulate approximately 964 of the 981 river miles of the channel. Operation and maintenance of these structures and the navigation channel is divided spatially amongst LRP, LRH, and LRL. Characteristics of the L/Ds are summarized in Appendix 1. The L/Ds are operated to maintain a minimum depth of nine (9) feet to support commercial navigation along the Ohio River mainstem (USACE LRD, n.d.). All locks consist of a main chamber and an auxiliary chamber. One L/D, Dashields, is a fixed crest dam with no gates. The number of gates at each other facility ranges from five at Olmsted L/D to 12 at Meldahl, Markland and Cannelton L/Ds. Most gates are Tainter gates; however, Emsworth and Montgomery L/Ds have vertical lift gates, and R.C. Byrd L/D has roller gates. Non-federal hydropower is currently present at 10 L/Ds.

Pool length varies throughout the Ohio River Navigation System. Pools are shortest near the headwaters of the Ohio River, with Emsworth L/D creating 6.5 miles of pool on the Ohio River and Dashields L/D creating 7.1 miles of pool (USACE LRP 2003). Between Pike Island L/D and R.C. Byrd L/D, pool lengths range between 30 – 45 miles (USACE LRP 2003, USACE LRH 2004). Between Greenup L/D and Olmsted L/D, pools are generally much longer, ranging between 60 – 114 miles, except for Newburgh pool (55 miles) and Olmsted pool (45.9 miles) (USACE LRH 2004, USACE LRL 2010).

2.4 Other Infrastructure

Several types of water resource infrastructure are prevalent within the Ohio River basin, including: Federal navigation L/Ds, discussed in the preceding section; Federal flood risk management facilities; state-financed public works; and county and municipal water treatment and distribution systems, stormwater collection systems, and sewage collection and treatment systems. Additional water resource infrastructure within the basin is privately owned and operated, including facilities owned and operated by riverside corporations (USACE LRD 2009).

Federal flood risk management projects range in size and complexity along the Ohio River mainstem and its tributaries. These projects may include upstream reservoirs, local flood warning systems, flood insurance, and floodproofing of existing structures to provide sufficient flood reduction benefits. Since the 1930s, USACE has constructed 83 reservoirs and 97 local protection projects within the Ohio River basin. Funding constraints coupled with aging equipment and infrastructure threaten the longevity of these structures. To assess the safety and condition of these structures, specifically dams, USACE's Dam Safety Program periodically inspects and ranks these structures using the Dam Safety Action Category (DSAC) method. These rankings are used to prioritize facilities for rehabilitation (USACE LRD 2009).

Some municipalities within the Ohio River basin utilize combined sanitary and storm sewer conveyance systems that predate the Clean Water Act (CWA) and other related environmental laws and regulations. These combined systems experience combined sewer overflows (CSOs) during heavy rain events, resulting in the discharge of raw, untreated sewage into receiving waterbodies. According to data provided by Ohio River Valley Water Sanitation Commission (ORSANCO), 49 municipalities have a total of 1,045 combined sewer outfalls that discharge into the Ohio River. High total suspended solids and bacteria concentrations typically associated with CSOs pose a significant threat to downstream municipal water intakes. Several state and Federal programs are available to assist communities in updating infrastructure, including combined sanitary and storm sewer systems. Such updates are being implemented throughout the Ohio River basin under programs like the USACE Environmental Infrastructure Assistance Program (USACE LRD 2009).

The Ohio River also plays an important role in water supply. Approximately 29 public water distributors withdraw water from the Ohio River mainstem. An additional 388 raw water intakes are located within the Ohio River and its tributaries to provide industrial and municipal water supplies. Currently, 16 USACE reservoirs are also used as sources of water through 31 water supply contracts in accordance with the Water Supply Act of 1958. The reliance on the Ohio River basin for water supply highlights the importance of maintaining sufficient water quality across the region (USACE LRD 2009).

2.5 Biological Community

The Ohio River sustains an ecologically diverse and nationally significant biological community. However, anthropogenic changes to the landscape have significantly altered the composition of this community. For example, 127 of the 297 freshwater mussel species native to North America resided in the Ohio River basin in the 20th century. Today, 11 of these mussel species are considered extinct, and many others are listed as endangered, threatened, or a species of concern under the Endangered Species Act (ESA) (Neves 2019). Invasive species, like the zebra mussel, have also been introduced throughout the basin, impacting ecology through displacement, competition, or predation of native species (USFWS 2012).

Key characteristics and trends of the biological community of the mainstem of the Ohio River are summarized in the following subsections. A complete inventory of characteristics and trends of the biological community is available in Appendix 2. In the following sections, the biological characteristics of the Ohio River may be summarized by region, if appropriate. For purposes of this study, regions of the Ohio River are broken out as follows: Upper Ohio region includes Emsworth through Hannibal pools (i.e., LRP), Middle Ohio region includes Willow Island through Meldahl pools (i.e., LRH), and Lower Ohio region includes Markland through Olmsted pools (i.e., LRL).

2.5.1 Fish Community

To date, the Ohio River is home to approximately 160 species of fish (ORSANCO n.d.). Generally, fish species richness does not display a significant trend along the spatial extent of the river. According to ORSANCO's most recent fish survey in each pool, fish species richness in the Ohio River ranges from 40 to 53 species. Major groups of species represented in the Ohio River include gar, shad, carp, minnow, sucker, catfish, sunfish, temperate bass, black bass, darter, perch, and lamprey, among others (ORSANCO 2018).

Based on the number of individuals caught during ORSANCO surveys conducted between 2010 and 2021, the dominant species in the Ohio River are gizzard shad (*Dorosoma cepedianum*), emerald shiner (*Notropis atherinoides*), channel shiner (*Notropis wickliffi*), freshwater drum (*Aplodinotus grunniens*), and threadfin shad (*Dorosoma petenese*). The top 10 most common species collected during ORSANCO surveys are provided in Table 1 below (ORSANCO 2021).

Table 1. The top 10 most common fish species are identified for the Ohio River based on the number of individuals collected during ORSANCO surveys conducted between 2010 and 2021.

Common Name:	**Scientific Name:**	**Number of Individuals Collected:**
Gizzard Shad	*Dorosoma cepedianum*	287,057
Emerald Shiner	*Notropis atherinoides*	103,367
Channel Shiner	*Notropis wickliffi*	79,815
Freshwater Drum	*Aplodinotus grunniens*	72,412
Threadfin Shad	*Dorosoma petenense*	41,721
Sauger	*Sander canadensis*	21,884
Bluegill	*Lepomis macrochirus*	21,520
Channel Catfish	*Ictalurus punctatus*	21,383
Smallmouth Buffalo	*Ictiobus bubalus*	12,286
Morone species	*Morone* species	11,993

To assess the quality of the river and fish community, ORSANCO developed the modified Ohio River Fish Index (*m*ORFIN) in 2008. The *m*ORFIN index consists of 13 metrics, including number of native species; number of intolerant species; number of sucker species; number of centrarchid species; number of Great River species; percentage of piscivores; percentage of invertivores; percentage of detritivores; percentage of tolerant species; percentage of lithophils; percentage of non-native species; number of deformities, erosions, lesions, and tumors (DELT) anomalies; and catch per unit effort (CPUE). The *m*ORFIN score is developed through a multi-step process based on biological and environmental data collected at 15 randomly selected sample sites within each pool. *m*ORFIN scores range from 0 to 60 and are divided into six categories to describe the biological condition of the river segment (Fig. 5) (ORSANCO 2010).

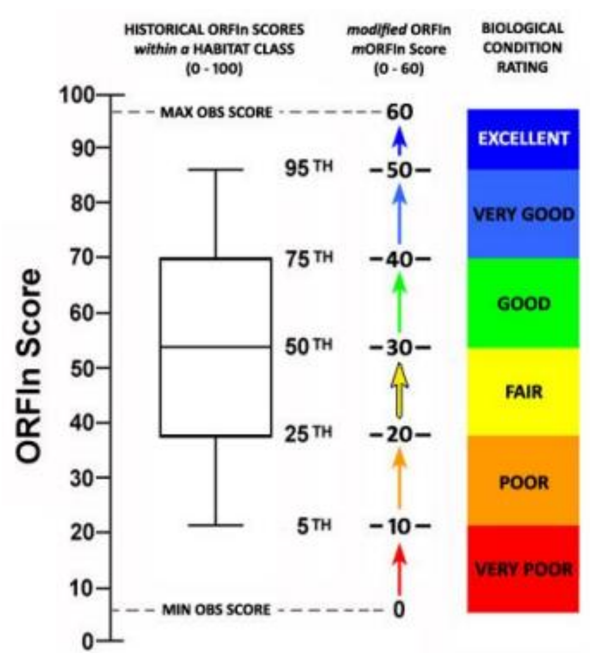

Fig. 5: *m*ORFIN scores range from 0 to 60, and scores are divided into six categories to describe the biological condition of the river segment (ORSANCO 2010).

The Ohio River can be separated into three segments to summarize recent *m*ORFIN scores (Table 2). The Upper Ohio region consists of the first six pools from Emsworth to Hannibal L/Ds. *m*ORFIN scores for this region are divided evenly between the “fair” or “good” categories (scores between 24.2 – 34.4) (ORSANCO 2018, ORSANCO 2017, ORSANCO 2015, ORSANCO 2013). The Middle Ohio region consists of six pools from Willow Island to Mehldahl L/D. Most pools within the Middle Ohio region are considered “good” quality based on *m*ORFIN scores between 30.8 and 36.2 (ORSANCO 2016, ORSANCO 2015, ORSANCO 2013), although Belleville pool is considered “fair” quality (score of 24.5) (ORSANCO 2014) and Greenup pool is considered very good quality (score of 44.5) (ORSANCO 2016). The Lower Ohio region consists of the final seven pools between Markland and Olmsted L/D. All pools within the Lower Ohio region are considered “good” or “very good” quality based on *m*ORFIN scores between 31.2 and 43.9 (ORSANCO 2017, ORSANCO 2016, ORSANCO 2015, ORSANCO 2014, ORSANCO 2013).

Table 2. ORSANCO mORFIN scores indicate that all pools within the Ohio River are considered “fair” quality or better. The most recent mORFIN score for each pool is provided in the table below (ORSANCO 2013-2018).

Region:	**Pool:**	***m*ORFIN score:**	**Narrative Description:**
Upper Ohio	Emsworth	27.83	Fair
	Dashields	30.8	Good
	Montgomery	32	Good
	New Cumberland	27.8	Fair
	Pike Island	24.2	Fair
	Hannibal	34.4	Good
Middle Ohio	Willow Island	35.8	Good
	Belleville	24.5	Fair
	Racine	31	Good
	R.C. Byrd	30.8	Good
	Greenup	44.5	Very Good
	Meldahl	36.15	Good
Lower Ohio	Markland	37.7	Good
	McAlpine	43.9	Very Good
	Cannelton	41.8	Very Good
	Newburgh	33.6	Good
	John T. Myers	38	Good
	Smithland	31.2	Good
	Olmsted	37.1	Good

2.5.2 Mussel Community

The Ohio River basin has historically been a hotspot for mussel diversity, containing 127 of the 297 freshwater mussel species native to North America. Over time, mussel diversity and abundance has decreased overall in the basin, with 11 species extirpated from the basin and many more species protected under the ESA (Neves 2019). Data regarding mussel diversity and abundance is not available for all pools in the Ohio River.

Overall, the greatest diversity of mussels is observed in the Lower Ohio (see Table 2 for pools within the Lower Ohio segment). Species richness ranges from 39 in Smithland pool to 57 in

Markland pool (Haag and Cicerello 2016). According to USFWS Information for Planning and Consultation (IPaC) data, several mussel species present in the Lower Ohio are considered threatened or endangered under the ESA (IPaC 2021). Significant threats to mussel species include sedimentation, barriers to host movement, altered hydrology, channelization, dredging, and non-native invasive mussels (Stark 2013).

2.5.3 Threatened and Endangered Species

Federally listed threatened and endangered species are known to inhabit the Ohio River and its riparian area from its headwaters in Pittsburgh to its confluence with the mainstem of the Mississippi River at Cairo (Table 3). Critical habitat is also designated within the immediate vicinity of the Ohio River for the Indiana bat in the Greenup, Meldahl, and Cannelton pools (IPaC 2021). Recovery of threatened and endangered species populations is important to sustaining the diversity of the Ohio River.

Table 3. The mainstem of the Ohio River is within the range of multiple federally listed threatened and endangered species (IPaC 2021).

Common Name:	Scientific Name:	Protection Status:
Clubshell	*Pleurobema clava*	Endangered
Fanshell	*Cyprogenia stegaria*	Endangered
Fat pocketbook	*Potamilus capax*	Endangered
Gray bat	*Myotis grisescens*	Endangered
Indiana bat	*Myotis sodalis*	Endangered
Monarch butterfly	*Danaus plexippus*	Candidate
Northern long-eared bat	*Myotis septentrionalis*	Threatened
Northern riffleshell	*Epioblasma torulosa rangiana*	Endangered
Orangefoot pimpleback	*Plethobasus cooperianus*	Endangered
Pink mucket	*Lampsilis abrupta*	Endangered
Price’s Potato-bean	*Apios priceana*	Threatened
Purple cat’s paw	*Epioblasma obliquata obliquata*	Endangered
Rabbitsfoot	*Quadrula cylindrica cylindrica*	Threatened
Rayed bean	*Villosa fabalis*	Endangered
Ring pink	*Obovaria retusa*	Endangered
Rough pigtoe	*Pleurobema plenum*	Endangered
Sheepnose	*Plethobasus cyphyus*	Endangered
Short’s bladderpod	*Physaria globosa*	Endangered
Short’s goldenrod	*Solidago shortii*	Endangered
Small whorled pogonia	*Isotria medeoloides*	Threatened
Snuffbox	*Epioblasma triquetra*	Endangered
Spectaclecase	*Cumberlandia monodonta*	Endangered
Virginia spiraea	*Spiraea virginiana*	Threatened

2.5.4 Invasive Species

Invasive species are defined as those non-native species that cause or have the potential to cause economic, environmental, or human health harm or may threaten natural resources or use of natural resources. Invasive species can cause significant damage to native ecosystems through alteration of predator-prey relationships, nutrient cycling, and competition dynamics. In some situations, natural predators of invasive species are not present in the ecosystem of interest, allowing invasive species to outcompete native species (Homans and Newman 2011). Known aquatic and terrestrial invasive species are briefly discussed in the two sections that follow. Additional information regarding the range of these species in the Ohio River is provided in Appendix 2.

2.5.4.1 Aquatic Invasive Species

Several aquatic invasive species are present within the mainstem of the Ohio River (Table 4). Some of these species were purposefully introduced into the United States to perform a certain function and have since become invasive. For example, several carp species (silver, grass, black, and bighead carp) were introduced in the southern United States to reduce phytoplankton abundance downstream of wastewater treatment plant discharges and have since utilized flood events and other means to expand their range north of the Mississippi River. Goldfish were originally introduced in the 1600s to increase fish diversity. Other species are thought to have been unintentionally introduced. One such species is the zebra mussel, which has expanded its range by attaching to barges and recreational vessels (Ackerson *et al.* 2019).

Table 4. Aquatic invasive species known within the mainstem of the Ohio River can significantly impact the ecology of the river (USGS 2021).

Common Name:	**Scientific Name:**	**Ecological Impacts:**
Goldfish	*Carassius auratus*	Sediment disruption; food web disruption; disease, parasite, or bacteria spread; hybridization (Ackerson *et al.* 2018)
Grass carp	*Ctenopharyngodon idella*	Excess predation on plants and phytoplankton; food web disruption; nutrient cycling disruption (Ackerson *et al.* 2018)
Common carp	*Cyprinus carpio*	Vegetation destruction; sediment disruption; habitat degradation; egg consumption (Nico *et al.* 2019)
Bighead carp	*Hypophthalmichthys nobilis*	Excess predation on plants and phytoplankton; food web disruption; nutrient cycling disruption (Ackerson *et al.* 2018)
Silver carp	*Hypophthalmichthys molitrix*	Excess predation on plants and phytoplankton; food web disruption; nutrient cycling disruption (Ackerson *et al.* 2018)
Black carp	*Mylopharyngodon piceus*	Excess predation on plants and phytoplankton; food web disruption; nutrient cycling disruption (Ackerson *et al.* 2018)
Asian clam	*Corbicula fluminea*	Substrate alteration; excess competition (Foster *et al.* 2019)
Zebra mussel	*Dressina polymorpha*	Food web disruption; oligotrophication; nutrient and oxygen depletion; overpopulation (Ackerson *et al.* 2018)
Quagga mussel	*Dreissena rostriformis bugensis*	Food web disruption; water clarity increase; oxygen depletion; potential polychlorinated biphenyl (PCB) contamination (Benson *et al.* 2019a)
Freshwater jellyfish	*Craspedacusta sowerbyi*	Increased predation pressure on zooplankton*; trophic cascades* (McKercher *et al.* 2021)

Scud	*Echinogammarus ischnus*	Displacement; excess predation* (Benson *et al.* 2021)
Freshwater bryozoan	*Lophopodella carteri*	Colonization of mussel shells*; fish and salamander kills via coelomic fluid ingestion* (Fuller *et al.* 2019)
Waterflea	*Daphnia lumholtzi*	Excess competition*; decline in zooplankton productivity* (Benson *et al.* 2019b)
Hydrilla	*Hydrilla verticillata [monoecious]*	Excess spatial competition; displacement; shading; reduced foraging efficiency; stratification; oxygen reduction; fish kills; zooplankton and phytoplankton decline (Jacono *et al.* 2015)
Curly-leaf pondweed	*Potamogeton crispus*	Displacement; decreased water clarity; algal blooms (MNDNR 2015)
Common water-hyacinth	*Eichhornia crassipes*	Dissolved oxygen reduction; shading; creation of mosquito breeding habitat; creation of impenetrable barrier on water surface (Pfingsten *et al.* 2021)
Brazilian waterweed	*Egeria densa*	Water flow restriction; sedimentation; water quality fluctuations (Pfingsten *et al.* 2016)
Water mint	*Mentha aquatica*	Unknown (Cao and Berent 2021)
Brittle waternymph	*Najas minor*	Displacement of native macrophytes (Pfingsten *et al.* 2021)
Eurasian watermilfoil	*Myriophyllum spicatum*	Displacement; reduction in biodiversity of aquatic plants; shading; reduced abundance and diversity of macroinvertebrates; reduction in foraging space; water quality degradation; oxygen depletion (Pfingsten *et al.* 2018)

* Ecological impacts are still under investigation for this species and, therefore, this impact is considered potential. Further research is needed to confirm the extent of this impact.

2.5.4.2 Terrestrial Invasive Species

This inventory of terrestrial invasive species focuses on plant species, which likely have the greatest impact on adjacent waterways through changes to bank stability, nutrient cycling, organic inputs, and others. Known terrestrial invasive plant species are presented in Table 5. Some terrestrial invasive plant species were intentionally introduced in the United States for ornamental purposes, like purple loosestrife (Ackerson *et al.* 2019) or tree-of-heaven (Rhoads and Block 2011). Other species are suspected to have been unintentionally introduced through transportation along canals or highways, like narrow-leaved cattail (Cao *et al.* 2021).

Table 5. Terrestrial invasive species known along the mainstem of the Ohio River can significantly impact the ecology of the river (USGS 2021).

Common Name:	Scientific Name:	Ecological Impacts:
Japanese knotweed	*Fallopia japonica* var. *japonica*	Shading; decrease in stream flow; indirect reduction in arthropod abundance; suppression of moss growth (Brown 2021)
Tree-of-heaven	*Ailanthus altissima*	Excess competition; displacement; agricultural impacts; toxin production preventing establishment of other species (Rhoads and Block 2011)
Purple loosestrife	*Lythrum salicaria*	Excess competition; displacement; wetland loss; biogeochemical and hydrological alterations in wetlands; loss of basking, breeding, nesting, and foraging sites (Cao *et al.* 2021)
Narrow-leaved cattail	*Typha angustifolia*	Excess competition; displacement (Cao *et al.* 2018)
Keek	*Rorippa sylvestris*	Displacement (Cao and Sturtevant 2019)
Reed canary grass	*Phalaris arundinacea*	Excess competition; displacement; sediment deposition; alterations to substrate microbial and fungi communities; decreased insect biodiversity (Sturtevant *et al.* 2021)
Common reed	*Phragmites australis australis*	Habitat alteration; competition; displacement; water quality improvement in agricultural settings; food web alterations (Sturtevant *et al.* 2021)

* Ecological impacts are still under investigation for this species and, therefore, this impact is considered potential. Further research is needed to confirm the extent of this impact.

2.6 Water Quality

Water quality is an important component of all USACE Civil Works missions. As such, Water Quality Teams within each District monitor and evaluate water quality trends and issues across all projects, including reservoirs (USACE LRP, n.d.). Generally, water becomes slightly warmer and dissolved matter concentrations, alkalinity, and planktonic algae density and diversity increase as it moves downstream along the Ohio River, with numerous local anomalies throughout the system (USACE LRD 2000).

Generally, weak trends in dissolved oxygen and temperature ($\leq 5^{\circ}$ F) stratification are observed throughout the Ohio River mainstem. Trends of metal concentrations vary throughout the mainstem. In the Upper Ohio region, moderate to strong decreasing trends in metal concentrations are observed. In the Lower Ohio region, however, magnesium concentrations display a strong, significant increasing trend, while other metals (aluminum, iron, manganese, and zinc) indicate a decreasing trend or no trend. No significant trends in dissolved oxygen, temperature, or metal concentrations are observed in the Middle Ohio region (USACE HEC 2018).

Publicly available Ohio River bimonthly water sampling data collected by ORSANCO from 2000 to 2021 shows that average nitrogen (NO_2 and NO_3) and phosphorus concentrations generally increase as water moves downstream. Numerous factors may contribute to this increase, including land use, volume of flow, and tributary inputs, but further investigation is required to identify and characterize the cause of this trend (ORSANCO 2022). Limited analysis of the data provided by ORSANCO was completed, and further investigation of the dataset is recommended prior to conducting any nutrient management activities in the Ohio River. Furthermore, significant gaps are present within the dataset that limit the ability to analyze nutrient trends along all navigation pools over the same time period.

The Clean Water Act delegates the responsibility of developing water quality standards to the State (40 CFR §131). One required component of water quality standards is to assign designated uses to each waterbody to articulate the goals and expectations for the waterbody, including protection and propagation of fish, shellfish, and wildlife; recreation; public drinking water supply; and agricultural, industrial, navigational, and other purposes (EPA, 2021). Designated uses of the Ohio River include aquatic life, potable water supply, fish consumption, and recreational uses. Segments of the Ohio River are currently listed as impaired for fish consumption and recreational uses. Known causes of these impairments include CSOs, dioxin, PCBs (PADEP 2020), *E. coli*, and iron (KDOW 2021).

2.7 Aquatic Habitat

Major tributaries to the Ohio River include the Allegheny, Monongahela, Muskingum, Kanawha, Big Sandy, Guyandotte, Scioto, Great Miami, Licking, Kentucky, Green, Wabash, Tennessee, and Cumberland rivers. The Tennessee and Cumberland rivers are also considered two of the richest ecological regions in the United States, particularly in terms of species diversity (USACE LRD 2009). The Allegheny River also provides one of the most populous freshwater mussel habitats in the world (USFWS n.d.). The Green River supports one of the most diverse mussel faunas (over 70 species) in North America (Isom 1974, TNC 1998); a high concentration of species considered rare, threatened, or endangered at the state or federal level (Cicerello and Hannon 1990); and over 150 species of fish (TNC 1998). These tributaries serve as sources of biodiversity, alternative habitat, nutrients, and other water quality parameters for the mainstem of the Ohio River.

Due to the presence of the navigation system and the resulting alteration of river flow, embayments have formed at the confluence of many tributaries with the Ohio River. Embayments are areas where the stream channel has widened over time and are characterized by slow flow resulting in sediment deposition, leading to increased sedimentation. Ongoing sediment deposition has covered important substrate structure and reduced depth variation within embayments. As a result, habitat diversity within the embayments has decreased since the construction of the navigation system (USACE LRD 2000).

Backwater and side channel habitats serve as important production and nursery areas for fish species within the Ohio River mainstem. Such habitats include sloughs, oxbows, embayments, and bayous. Ongoing sedimentation may result in reductions in the availability and/or quality of backwater and sidechannel habitats and, therefore, reductions in the spawning, nursery, and foraging habitats for some fish species (USACE LRD 2000).

Islands are another important habitat type in the Ohio River system. Sand and gravel deposits off the shore of islands provide habitat for mussels. The prevalence of submerged aquatic vegetation on these deposits also creates fish habitat (USFWS 2017). Fish are also attracted to the riffle habitat created at the heads of the islands as water moves over the sand and gravel deposits. However, significant urban or industrial development has occurred on some islands, such as Neville Island in the Upper Ohio. Increased development may result in excess sedimentation, increased runoff, and/or increased local water pollution. Additionally, since the construction of the navigation system, significant erosion has occurred along islands within the Ohio River. There were 124 islands documented in the Ohio River at the start of the 19th century, and as of 2000, at least 31 of these islands have completely eroded away (USACE LRD 2000).

2.8 Riparian and Floodplain

Floodplains generally consist of several types of habitat, including tributary channels, backwater habitats, riparian forests, and wetlands. The heterogeneity of floodplains provides a multitude of biological benefits and ecosystem services. In seasonally flooded ecosystems, floodplains provide important inputs of food and nutrients that benefit fisheries production. Many fish species utilize floodplains for spawning, nursing, and foraging. Floodplains also contribute to nutrient cycling, specifically through denitrification. To realize these benefits, however, the floodplain must be connected to the river channel (Schramm *et al.* 2015).

Historically, the floodplain of the Ohio River consisted predominately of bottomland forest. Over time, the floodplain was cleared and drained for agricultural and urban land use. Since 1800, USFWS estimates that 71% of the forested riparian habitat has been lost in Pittsburgh District, 66% in Huntington District, and 37.6% in Louisville District. It has been estimated that approximately 1000 miles of forested riparian habitat has been lost along the Ohio River over the past 200 years (USACE LRD 2000).

Today, the Ohio River floodplain remains highly modified. Armored banks and nearshore roads or railroads are common throughout the Ohio River (ORSANCO 2014). The floodplain along Emsworth and Dashields pools is heavily developed with industrial and residential land uses (ORSANCO 2013, ORSANCO 2018). Development generally decreases along the Upper Ohio reach of the river (ORSANCO 2013, ORSANCO 2015, ORSANCO 2017, ORSANCO 2018) to Hannibal pool, where the floodplain supports a large amount of vegetation (ORSANCO 2013). In the Middle Ohio region, agriculture is more prevalent in the floodplain, particularly in R.C. Byrd (ORSANCO 2013) and Meldahl pools (ORSANCO 2017). The floodplain of Willow Island pool is largely within the federally protected Wayne National Forest (ORSANCO 2016). However, industrial activity still exerts a significant influence on the pools in the Middle Ohio (ORSANCO 2013, ORSANCO 2014, ORSANCO 2016). In the Lower Ohio region, agriculture and urban development limit the extent of the riparian corridor along much of the river. In areas where agriculture or urban development are present, the riparian corridor is very narrow, if present at all (ORSANCO 2013, ORSANCO 2014, ORSANCO 2015, ORSANCO 2016, ORSANCO 2017).

Geospatial personnel within each of the Districts analyzed land use within the riparian area to characterize current conditions. For this analysis, the riparian area was defined as a 150-ft buffer along each bank of the Ohio River. The inland electronic navigation charts (IENC) were used to define the Ohio River channel. Land use was analyzed using the 2019 National Land Cover Database (NLCD) Multi-Resolution Land Characteristics (MRLC) dataset published by the U.S. Geological Survey (USGS) (USGS 2021). A summary of land use types within the riparian area by District is provided in Fig. 6, while detailed information for each pool is provided in Appendix 3 (Riparian Land Use Analysis).

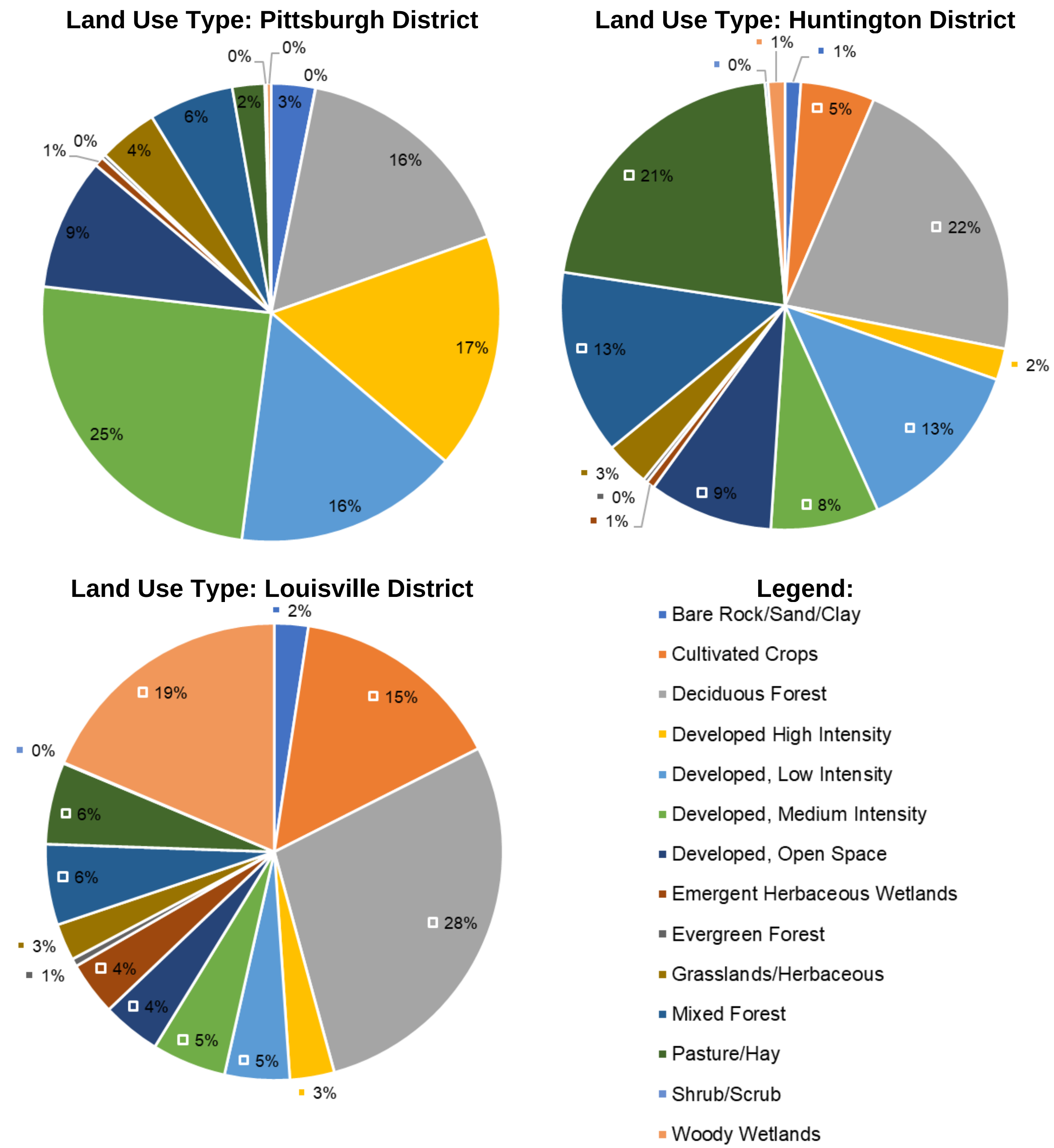

Fig. 6. The percentage of each land use type within the 150-ft riparian area was summarized by District (USGS 2021).

2.9 Wildlife Refuges and Other Protected Ecosystems

Important ecosystems within the Ohio River are protected at local, state, and federal levels. This report focuses on the federally protected ecosystems along the mainstem of the Ohio River. Additional ecosystems protected at the State level are provided in Appendix 2.

2.9.1 Ohio River Islands National Wildlife Refuge

The Ohio River Islands National Wildlife Refuge (ORINWR) was established by USFWS in 1990 to protect, restore, and conserve island habitat within a 362-mile reach of the Ohio River between Shippingsport, Pennsylvania, and Manchester, Ohio (USACE LRD 2000). Currently, twenty-two islands and four mainland areas are part of the ORINWR. In total, ORINWR covers 3,440 acres of land and underwater habitat. All but four ORINWR islands are located in West Virginia, with two islands in Pennsylvania and two in Kentucky. USFWS ORINWR is actively working to stabilize riverbanks and restore the historic island boundaries throughout its jurisdiction (USFWS 2013). Pools containing or intersecting ORINWR lands include: New Cumberland, Hannibal, Willow Island, Belleville, Racine, and Meldahl (USFWS 2013, USACE LRP 2003, USACE LRH 2004, USACE LRL 2010).

2.9.2 Other Federally Protected Land

Multiple federally protected ecosystems are present along the Ohio River mainstem. A subset of these ecosystems is presented in Table 6. These ecosystems represent important sources of biodiversity, vital habitat, and unique cultural resources.

Table 6. In addition to the ORINWR islands, multiple federally protected ecosystems are present along the Ohio River mainstem.

Ecosystem name:	Managing agency:	Description:
Wayne National Forest	U.S. Forest Service	Approximately 250,000 acres of protected forest scattered throughout the Appalachian foothills in southeastern Ohio (USDA 2015A)

Falls of Ohio National Wildlife Conservation Area	USACE LRL and Indiana Department of Natural Resources	Approximately 1,400 acres of land and water within Indiana including approximately 220 acres of fossilized coral reef; one the largest naturally exposed fossil beds in the world (USACE LRL n.d.)
Hoosier National Forest	U.S. Forest Service	204,000-acre forest in Indiana consisting of old growth forest, historic landmarks, and rock shelters, bluffs, and coves with rare plants (USDA 2015B)
Green River National Wildlife Refuge and Conservation Partnership	USFWS	Small, recently established refuge in Henderson, Kentucky near the confluence of the Green River with the Ohio River; important wetland forest habitat with intent to develop a 53,000-acre Conservation Partnership Area (USFWS 2020)
Shawnee National Forest	U.S. Forest Service	289,000-acre forest in Southern Illinois between the Ohio and Mississippi Rivers with unique geological and cultural features; consists of six ecoregions and high biodiversity (USDA n.d.)

3 Potential Future Conditions

Future economic and environmental conditions within the Ohio River basin will have important implications with respect to how this ecosystem will be managed moving forward. Future conditions anticipated to have a direct impact on the opportunities and recommendations analyzed in this study include changes in navigation trends, major USACE construction projects, and climate change.

3.1 Navigation Trends

Substantial increases in traffic within the Ohio River Navigation System began around 1980 when electric generating plants began to rely more heavily on coal than oil and gas. However, between 2005 and 2012, traffic within the Ohio River Navigation System declined. This decline is mainly attributed to reduced reliance on coal by electric generating plants, indicating a shift to oil and gas for energy generation from the 1980 – 2005 period (USACE LRP 2016).

Recent traffic demand forecasts suggest traffic levels along the Ohio River will remain static or trend slightly downward. This is attributed to a significant decline in the demand for utility and coking coal (USACE PCXIN 2020).

3.2 Major USACE Projects

At the time of this report (February 2021), three USACE projects are currently ongoing or planned along the Ohio River (Table 7). Two of the projects, the Upper Ohio Navigation Project and Greenup L/D, KY General Reevaluation Report, involve rehabilitation or replacement of L/D features. The Ohio River Locks and Dams Regional Master Plan proposes updates and changes to the management and operation of six L/Ds in LRH. Currently, no ecosystem restoration projects are under investigation or construction in the Ohio River mainstem.

Table 7. Three USACE projects are currently under construction or planned along the Ohio River.

Project name:	District:	Status:	Description:
Upper Ohio Navigation Project	LRP	Design and construction	Replacement/Expansion of auxiliary lock chamber at Emsworth, Dashields, and Montgomery L/Ds; authorized in 2016 Water Infrastructure Improvements for the Nation Act (USACE n.d.)
North Shore Section 206 Aquatic Ecosystem Restoration Study	LRP	Design and construction	Restoration of 7/3 acres of aquatic and floodplain habitat through floodplain wetland restoration, placement of aquatic substrate and habitat features, invasive species removal, and other project features (USACE LRP 2017)
Ohio River Locks and Dams Regional Master Plan	LRH	Ongoing	Updates to the Regional Master Plan for Meldahl, Greenup, R. C. Byrd, Racine, Belleville, and Willow Island L/Ds
Greenup L/D, KY General Reevaluation Report	LRH	Preconstruction engineering and design	Rehabilitation of Greenup L/D, including extension of auxiliary lock, extension of downstream guide wall, filling and emptying system improvements, installation of miter gate quick changeout system, construction of off-site dry dock, and environmental mitigation (USACE LRH n.d.)

3.3 Climate Change

The Ohio River basin is considered a water rich region due to the significant amount of rainfall experienced annually. Historically, droughts and major flood events have been considered isolated or occur infrequently and the impacts could be minimized through strategic operation of water infrastructure by the primary water resource operating agencies (USACE, Tennessee Valley Authority [TVA] and Natural Resource Conservation Service [NRCS]). However, current climate change models indicate that extreme hydrologic events will potentially be more prevalent, more severe, and longer in duration. Climate change models also suggest that weather (i.e., temperature, precipitation, winds, humidity, evaporation) may stray from established patterns and thereby become more difficult to predict. These changes may manifest as increased frequency and severity of spring and late autumn flood events, increased streamflow variability in autumn, overall increases in maximum stream flows, overall decreases in minimum stream flows, and increased drought conditions. Models suggest that these effects will accelerate after 2040. Overall, climate change will likely challenge the capacity of existing infrastructure and affect the ability of resource agencies to mitigate and minimize impacts of extreme weather events. Some infrastructure is designed to a factor of safety, enabling continued facility operation during extreme conditions (USACE IWR and ORBA 2017).

Impacts associated with climate change may threaten the quality of aquatic ecosystems in the Ohio River. Increased precipitation and runoff may contribute to increased erosion, sedimentation, and pollutant transport across the landscape. As the air temperature increases, water temperature may also increase in streams, which can threaten aquatic species if temperatures exceed species' tolerances. Temperature threshold exceedances may result in migration or extirpation, if barriers to species passage (e.g., dams, infrastructure) prevent migration. Other potential impacts to aquatic ecosystems associated with climate change include increased prevalence and diversity of invasive species, increased disease transmission, and increased pest infestations (USACE IWR and ORBA 2017).

4 Opportunity Identification and Prioritization

Opportunities, constraints, and considerations were identified to develop and prioritize potential future modifications of USACE operations with the goal of maximizing ecological benefits and improving sustainability. These opportunities, constraints, and considerations were broadly defined for the entire Ohio River mainstem. When applicable, pools were selected for further evaluation based on specific measures, discussed in Sections 4 and 5 of this report.

4.1 Ecological Opportunities

Within the context of this study, opportunities are defined as desirable environmental outcomes that are possible from future modifications to operations at USACE's reservoirs or L/Ds.

A list of target species was developed to guide identification of ecological opportunities (Appendix 4, Target Species List). Target species were considered to be those species with high conservation value (i.e., threatened or endangered species), unique niches (i.e., mussel host species), significant recreational value (i.e., game fish, waterfowl), or reduced ranges (i.e, extirpated) in the Ohio River basin. Non-target species were also identified to refine ecological opportunities and identify potential considerations. Non-target species are those species whose proliferation may negatively impact target species or ecology (i.e., nutrient cycling, spatial distributions, etc.). In this study, non-target species were limited to those invasive species shown to negatively impact ecosystems in which they are introduced. The list of target and non-target species developed as part of the current effort is not exhaustive, and this list should be refined on a site-specific basis when considering implementation or further study of any ecological measure identified in this study.

Based on the inventory of existing conditions, five potential ecological opportunities were identified:

1. <u>Restoration of more natural hydrologic and hydraulic regimes</u> – Development of the navigation system transformed the Ohio River mainstem from a free-flowing system to a series of pools (USACE LRD 2009). Restoration of natural hydrologic and hydraulic regimes may benefit native species through changes in seasonal flow patterns, habitat variability, and water quality.

2. <u>Improvement in water quality</u> – Reductions in stratification or concentrations of pollutants in the river system may increase the quality of the biological community in the Ohio River and the sustainability of the ecosystem.

3. <u>Improvement in quality and diversity of habitats</u> – Development of the navigation system reduced the diversity of habitats in the Ohio River by transforming the mainstem into a series of pools. This transformation reduced the number of riffle habitats and variation in depth and

altered sediment transport such that habitats may experience more sedimentation or erosion than preconstruction conditions (USACE LRD 2009). Restoration of these habitats will increase variability within the system and provide additional resources for foraging, spawning, and other activities.

4. Connectivity of habitats – Presence of the L/Ds reduced habitat connectivity throughout the Ohio River system. Improvement in the connectivity of habitats across the mainstem may increase species movement and result in an overall increase in resource availability.

5. Improvement in quality of aquatic communities – Multiple species once native to the region have been extirpated (Neves 2019) and invasive species have been introduced into the system (USGS 2021). Reductions in native species adapted to the conditions of the Ohio River may reduce the sustainability of the ecosystem, particularly with respect to its ability to respond to extreme weather events or changed conditions. Improvement in the diversity and quality of the aquatic community is anticipated to increase the sustainability of the Ohio River basin.

4.2 Constraints and Considerations

Identification of constraints and considerations is a critical step toward identifying and prioritizing realistic actions designed to improve ecological conditions. Within the context of this study, constraints are defined as those factors that limit the ability to realize ecological opportunities. Constraints would require significant resources to overcome. Considerations, on the other hand, are defined within the context of this study as factors that may affect the feasibility or likelihood of realizing ecological opportunities. As such, considerations should be taken into account when attempting to realize ecological opportunities; however, they generally exert less control over realizing ecological opportunities than constraints.

4.2.1 Constraints

In the context of this study, six potential constraints were identified:

1. L/D type and construction – Implementation of a construction project to change the type of L/Ds present at any facility will require significant resource dedication and Congressional approval. As such, ecological opportunities are limited by the type of L/Ds currently present (as of December 2021) at each facility.

2. Depths required to maintain navigation – The Ohio River Navigation System is designed to maintain the navigation channel at a minimum depth of nine feet. All ecological opportunities are considered within the context of the requirement to maintain this navigable depth. This constraint is specifically important in understanding the feasibility of any proposed changes to the normal pool elevation.

3. Presence of other infrastructure along the river – Infrastructure along the Ohio River mainstem includes privately and publicly owned facilities. These facilities were designed based upon the assumed maintenance of a specific pool elevation, and changes to the pool elevation may alter the functionality of these facilities. For the purposes of this study, all infrastructure is assumed to be located below the depth required to maintain the 9-foot

navigation depth. This assumption must be verified prior to implementation of any environmental opportunities at a specific pool.

4. Travel times – Within the context of this study, travel times are defined as the amount of time elapsed between the point at which a water molecule enters the pool and the point at which the molecule exits the pool. Travel times were calculated for each navigation pool (Appendix 1) but were not incorporated into the analysis. Potential impacts of management actions to travel times and potential impacts to water quality associated with altered travel times should be further investigated during a feasibility study prior to implementation.

5. Legal obligations – Several legal agreements may be implemented at USACE L/Ds. Federal Energy Regulatory Commission (FERC) licenses for hydropower facilities are common along the Ohio River Navigation System. The terms and conditions of these legal agreements are considered constraints, and for the purposes of this event, it was assumed environmental opportunities cannot modify USACE's ability to satisfy its legal obligations under any agreement.

6. Potential impacts to threatened or endangered species – The ESA prohibits import, export, or take of species listed as threatened or endangered. Under the ESA, USACE is required to consult with USFWS for any actions that may impact federally listed threatened or endangered species and to take actions to avoid or minimize such impacts. Actions that may negatively impact threatened or endangered species may conflict with the goal of the current effort, which is to increase the ecological sustainability of the Ohio River system. As such, measures considered under this study should not result in adverse impacts to threatened or endangered species.

4.2.2 Considerations

Within the context of this study, eight potential considerations were identified:

1. Authorized purposes –Navigation is the primary authorized purpose for all L/Ds in the Ohio River Navigation System. L/Ds within LRP and LRH also have secondary authorized purposes including recreation and fish/wildlife (i.e., sport fishing and wildlife, fisheries habitat, wildlife preservation, endangered and threatened species conservation, etc.) (USACE HEC 1994). Application of the constraints identified in the preceding section will ensure no opportunities preclude the ability to meet the authorized purposes of the L/Ds; however, the authorized purposes should still be considered for all ecological opportunities.

2. Major tributaries – Tributaries to the Ohio River are important sources of biodiversity and impact the quality and quantity of water in the mainstem. While detailed investigation of these tributaries is beyond the scope of the current effort, the potential for management measures to affect tributaries and for tributaries to modulate ecological response to management measures are important considerations for all opportunities. For example, tributaries contribute biodiversity and nutrients to the mainstem of the Ohio River, while also altering the habitat of the mainstem near the confluence with the Ohio River. Prior to implementation of any opportunity, the potential impacts to tributaries must be further investigated.

3. Presence of wildlife refuges – Wildlife refuges are valuable and protected ecosystems within the Ohio River. The potential for any opportunity to affect wildlife refuges should be considered and documented for further investigation prior to implementation.

4. Potential impacts to invasive species – Some environmental opportunities may result in unintended positive or negative impacts to invasive species. Such impacts may include potential range expansion or disturbance. The potential for any opportunity to impact invasive species should be considered and documented for further investigation prior to implementation.

5. Potential impacts to non-target species – Environmental opportunities were identified, in part, using a list of target species and associated habitat requirements. However, changes to the Ohio River system may result in unintended impacts to non-target species. Such impacts may include potential reduction in suitable habitat or food web alteration. Prior to implementation, it is recommended that the ecology of the specific pool be further researched to allow for consideration of potential impacts to any non-target species.

6. Potential impacts to erosion or sedimentation – Erosion and sedimentation are prevalent throughout the Ohio River basin and mainstem. Potential increases in erosion or sedimentation may affect nearshore development, habitat availability and quality, dredging operations, and other ecological and operational concerns. The potential for proposed measures to impact erosion and sedimentation were broadly analyzed; however, it is recommended that site-specific investigations of potential impacts to erosion or sedimentation be conducted prior to implementation of any measure.

7. Current water control manuals/guide curves – Water control manuals specify how USACE operates reservoirs to meet congressionally-authorized purposes, including water supply and navigation. Water control manuals must be reviewed every 10 years, at a minimum. While water control manuals can be updated and changed, the provisions of the water control manuals are important to consider when evaluating the feasibility of any opportunity to improve mainstem conditions through operational changes at a specific reservoir.

8. Timeframe for analysis – No new data collection was conducted under the current effort. Therefore, the Team relied on the most recent publicly available datasets to inventory existing conditions and identify environmental opportunities. Prior to implementation of any opportunity, it is recommended that environmental data be reviewed to ensure incorporation of any new datasets into planning and operational decisions.

5. Assessment of Ecological Measures

Ten unique ecological measures were researched and analyzed under the current effort, including: temporarily raising pool elevation, temporarily lowering pool elevation, flow manipulation for habitat improvement, selective withdrawal retrofits for flood risk management structures, structural changes, island restoration, invasive species control, modification of hydropower Operating Agreements, Rapid Watershed Assessments for tributaries, and conservation lockages for tributaries.

The study team analyzed potential benefits and limitations associated with implementation of each measure in the Ohio River basin. This information was then synthesized to develop recommendations, when possible, for further study for each measure.

5.1 Temporarily Raising Pool Elevation

The presence of dams on the Ohio River significantly affects the hydrological regime, reducing hydrologic variability. These changes affect aquatic habitats and associated species, which have adapted to natural flow regimes and rely on stochastic changes in hydrologic conditions as part of their life history. Several species of fish, birds, aquatic macroinvertebrates, mussels, and other organisms have adapted to natural flow regimes and rely on stochastic changes in hydrologic conditions as part of their life history. Incorporating temporary raises in water surface elevation in Ohio River pools (within operational limits) may provide USACE an opportunity to mitigate the loss of periodic flood conditions that can benefit the ecosystem.

Temporary pool raises were implemented at two reservoirs on the Des Moines River in Iowa, Lake Red Rock and Saylorville Lake (U.S. Army Corps of Engineers - Rock Island District; TNC 2017; Theiling *et al.* 2021). In partnership with the Iowa Department of Natural Resources, the Rock Island District raises water levels in the fall to inundate reservoir delta wetlands, which support waterfowl migration. In the past, these reservoirs were lowered to the flood control pool level, but now higher pool levels are maintained through the winter for as long as possible until approximately April. Once flood risk decreases in early summer, pools are raised again to support late spawning fishes before the pools are gradually drawn down in mid-late summer.

The Rock Island District identified several benefits resulting from these reservoir pool changes. Maintaining higher pool elevations through the spring supports habitat for reptile overwintering and early spring spawning for fishes, such as crappie. The early summer drawdown exposes mudflats that allow the proliferation of wetland vegetation and expose invertebrates that provide food for birds and other organisms. However, these benefits were realized in flood risk management reservoirs, which differ significantly from run-of-the-river navigation projects like the Ohio River. As such, the operations utilized in the Lake Red Rock and Saylorville Lake reservoirs may not be applicable to the Ohio River, and the environmental benefits resulting from temporary pool raises may vary between these systems.

Studies conducted by USACE in the Mississippi Valley Division (MVD) have evaluated various alternatives to operations of Mississippi River L/Ds for potential environmental benefits, including pool raises. Beginning in 1995, the St. Paul District discontinued the practice of a 0.25 ft winter drawdown in all of their Mississippi River pools in an effort to provide better habitat in backwater areas for overwintering aquatic species. The St. Paul District determined that the increased water volume and connectivity to the mainstem provided more suitable habitat for various species over winter by increasing dissolved oxygen levels, water temperatures, and water depth. They also posed that it might provide more and/or better habitat for furbearers that utilize aquatic habitats over winter (e.g., beavers and muskrats) (Water Level Management Task Force 1996; Landwehr *et al.* 2004).

These studies in MVD also evaluated spring pool raises. Spring raises have the potential to provide flooded terrestrial habitats that can serve as spawning areas for northern pike and walleye, as well as suitable habitat for young-of-year fish, waterfowl broods, and wading birds. Spring pool raises may only be required during years with low springtime flows (Water Level Management Task Force 1996; Landwehr *et al.* 2004). Landwehr *et al.* (2004) suggested that spring pool raises could be abruptly stopped and lowered in late May to strand invasive carp (i.e., bighead, black, grass, and silver carp) eggs and limit invasive carp recruitment. Further evaluation should be conducted for determining what season would maximize potential benefits of a temporary pool raise for specific projects.

In summary, a variety of environmental benefits may occur with the use of temporary pool raises in large rivers. Temporary pool raises in navigation pools can mimic flooding conditions that support environmental responses, especially when operated in coordination with seasonal ecological processes. The following functions may be achieved by temporary raises in river pool levels (adapted from Richter *et al.* 2006):

- Provide migration and spawning cues for fish;
- Trigger new phase in life cycle (e.g., insects);
- Enable fish to spawn on floodplain;
- Provide nursery area for juvenile fish;
- Provide new feeding opportunities for fish and waterfowl;
- Recharge floodplain water table;
- Maintain diversity in floodplain forest types through prolonged inundation (i.e., different plant species have different tolerances);
- Control distribution and abundance of plants on floodplain;
- Deposit nutrients on floodplain;
- Maintain balance of species in aquatic and riparian communities;
- Create sites for recruitment of colonizing plants;
- Shape physical habitats of floodplain;
- Deposit gravel and cobbles in spawning areas;
- Flush organic materials (food) and woody debris (habitat structures) into channel;
- Purge invasive/introduced species from aquatic and riparian communities;
- Disburse seeds and fruits of riparian plants;
- Drive lateral movement of river channel, forming new habitats (e.g., secondary channels, oxbow lakes); and
- Provide plant seedlings with prolonged access to soil moisture.

Pool raises will likely not negatively impact navigation and, in fact, would likely benefit navigation by increasing channel depth. However, there are several potential negative effects of implementing temporary and/or extended pool raises, which include (adapted from Landwehr *et al.* 2004):

- Costs associated with developing/modifying infrastructure to accommodate higher pool levels;

- Increased labor costs due to potentially increased number of gate operations;
- Mortality to trees and other terrestrial vegetation;
- Flooding of furbearer dens;
- Greater mobilization of sediments;
- Potential reduction in suitable habitat for production of submersed aquatic vegetation, depending on channel morphology, overbank topography, and light penetration;
- If pool raises are greater than existing flowage easement boundaries, then acquisition of additional real estate rights of use may be required, which might require congressional authority; and
- Potential modifications to existing recreational infrastructure, such as boat ramps, marinas, and docks.

These potential negative impacts are dependent upon the extent and duration of the pool raise, season, and existing conditions for the pool. Proper cost-benefit analysis must be conducted on a case-by-case basis.

5.2 Temporarily Lowering Pool Elevation

Temporary drawdowns consist of lowering pool elevations to expose mud flats. The effects of this action are still being studied, but drawdowns in other river systems, particularly the Upper Mississippi, indicate that numerous environmental and ecological benefits can be expected.

Several drawdowns have been conducted in the USACE St. Paul District on Pools 5, 6, and 8 of the Upper Mississippi River. In 2001, Pool 8 was lowered by 1.5-ft for part of the vegetation growing season (June 30 to September 15) to expose an estimated 1,950 acres of mudflats. The 1.5-ft drawdown was then repeated in 2002 from July 2 to September 15. Pool 5 was also lowered by 1.5-ft in 2005 from June 13 to September 15 to expose approximately 998 acres of mudflats. After years of attempting to implement a 1-ft drawdown at Pool 6, river conditions permitted one to be initiated in 2010 from June 18 through August 26 to expose approximately 54 acres of mudflats. Pool elevation levels were lowered at a rate of about 2.5 inches per day. Once the drawdowns were complete, the pools were raised at a rate of 1 inch per day (Kenow *et al.* 2015). In all three of the pools, deep marsh perennials, shallow marsh perennials and annuals, and rooted floating aquatic communities were improved, positive effects on fish spawning and nursery areas were observed, and the availability of forage for migrating waterfowl and shorebirds increased. Fish populations and water quality in the area were not adversely impacted by the drawdown and contaminant bioavailability was not increased (Kenow *et al.* 2015).

Implementation of the drawdowns in the St. Paul District required planning and coordination. The public was informed of the drawdown and its potential impacts. The drawdowns were scheduled well in advance and the public was alerted when re-scheduling was necessary due to unfavorable river conditions. Potential problem areas for commercial and recreational navigation were identified and boat docks and channel markers were moved to prevent issues. Additional dredging beyond normal annual maintenance amount was also required to ensure navigation was not impacted. By taking these preventative measures, no decreases in boating activities resulted directly from the drawdowns in any of the pools (Kenow *et al.* 2015).

Although there were many positive effects of the drawdowns in Pools 5, 6, and 8, St. Paul District encountered several obstacles during implementation. The river system's flow was a notable challenge. Drawdowns were postponed or canceled mid-drawdown multiple times due to unfavorable flow conditions that would make the drawdown impracticable or damaging to the existing pool conditions. When implemented, the amount of dredging required to maintain navigability was costly but paid for by other funding sources (Kenow *et al.* 2015).

While the Upper Mississippi River pool modifications may have different hydrologic and hydraulic factors than the Ohio River, these case studies indicate some potential effects of drawdowns on aquatic ecosystems, wildlife, and navigation. In general, many positive impacts can be attributed to the lowering of pool elevations during the growing season, including:

- Increased vegetation growth on the mudflats exposed due to the drawdowns (Kenow *et al.* 2015, TNC 2020, Garvey *et al.* 2003);
- Greater fish (including young-of-year) attraction from increased vegetation growth and associated benefits of these habitats on spawning and/or nursing activities (Kenow *et al.* 2015, TNC 2020, Coulter *et al.* 2019);
- Greater waterfowl and shorebird attraction from increased vegetation growth and associated benefits as a habitat and food source (Kenow *et al.* 2015, TNC 2020, Garvey *et al.* 2003);
- Continued growth of emergent vegetation for years after the drawdown and maintenance of growth without additional drawdowns (River Resources Forum 2007);
- Annual variability in vegetative growth mimicking the river's original environmental variability, which can lead to increased biodiversity in fish and wildlife. (Coulter *et al.* 2019, Garvey *et al.* 2003);
- Maintenance of backwater pools that are important zones for denitrification, particularly during summer months (Houser and Richardson 2010); and
- Increased sediment consolidation (Theiling 1995).

Although performing a river pool drawdown can have many positive impacts, a few potential negative impacts can also occur. Below is a list of potential negative impacts.

- Commercial and recreational navigation may be hindered (River Resources Forum, n.d.).
- Drawdown reduces upstream river levels and associated head for hydropower operations (Kenow *et al*. 2015).
- Additional dredging beyond typical maintenance levels may be needed to maintain channel depths for commercial and recreational navigation (Kenow *et al.* 2015).
- Drawdowns can potentially increase velocity in the river's main channel leading to increased sedimentation transport (River Resources Forum, n.d.).
- Winter drawdowns can negatively impact the overwintering of wildlife and reduce vegetation in the river (Kenow *et al.* 2015, USDA NRCS 2003).

Many considerations must be evaluated when deciding whether to implement a river pool drawdown at a specific site. If this measure is chosen for further study, the following items will need to be further researched and studied.

- All river channels must remain at a depth suitable for commercial navigation. By performing a drawdown, the channel may be shallower than the minimum required depth. Additional dredging may be required to perform the drawdown and ensure a suitable navigation depth. A drawdown may also limit access for recreational navigation. Additional dredging, relocation of boat docks, or relocation of buoys to warn boaters of dangerous areas may also be required to ensure continued use of the pool (TNC 2020).
- Seasonal flow rates may be too high or too low to perform drawdowns leading to unpredictability and inconsistency in the ability to implement a drawdown (Kenow *et al.* 2015)
- Drawdowns can be performed at any point during the year for many different reasons. Different outcomes will be realized depending on the time of year, some of which may be damaging to the river pool environment (Kenow *et al.* 2015; USDA NRCS 2003).
- Changes in pool elevation may impact hydropower facilities, and these potential impacts will likely require additional coordination with hydropower entities.
- River pool elevation must remain at heights where water intakes are not impacted.

The extent of potential positive and negative impacts from temporarily lowering pool elevation will vary depending upon a number of site-specific factors, including existing pool conditions, season, and extent and duration of pool change. It is recommended that a feasibility study be conducted at any site recommended for this measure.

5.3 Flow Manipulation for Habitat Improvement

This measure optimizes the operation of navigation dams to benefit downstream organisms and habitats. Modification of operations could take place seasonally, year-round, or in response to maintenance actions. The operational change with the greatest potential to manipulate habitat is a modification of the gate operating schedule to allow for flow pattern changes downstream.

Currently, operations are modified at the R.C. Byrd and C.A. Meldahl L/Ds within the Huntington District as a mitigative measure for the dredging program. Changing the typical operations of the gates during disposal operations minimizes impacts to the downstream mussel communities. Specifically, the R.C. Byrd northern gates (6,7, and 8) are prioritized for operation to allow clear, oxygenated water to flow over the mussel beds while turbid waters are steered toward the thalweg of the river. A similar strategy could be used at other locks and dams on the Ohio River during certain times of the year to make downstream conditions more favorable to organisms or to minimize impacts from maintenance operations. The USACE Engineer Research and Development Center (ERDC) has the numerical modeling capabilities to forecast the potential habitat benefits that result from these operational changes.

5.4 Selective Withdrawal Retrofits for Flood Risk Management Structures

Flood control reservoirs can be sources or sinks of nutrients and other constituents that can be harmful at extreme concentrations. Better management of the water quality in the lake and the outflows can increase the overall quality of all downstream waters. This measure is targeted for the operation of flood risk management reservoirs in the Ohio River basin.

Many of the Corps' lakes become stratified in the summer affecting the water quality of the lake significantly. By retrofitting existing dams with selective withdrawal structures, it would allow the project to release water from the most appropriate elevations in the lake. Many lakes do not have selective withdrawal capabilities, but some outlet structures may provide the opportunity for retrofits that would allow for selective water quality operability. A study conducted by the Huntington District found that the operation of selective withdrawal systems at three reservoirs in the Scioto River basin (Alum Creek, Deer Creek, and Paint Creek) allowed for retention of poorer quality water typically found at lower depths and release of higher quality water at shallower depths (USACE LRH, n.d.).

The Huntington District has begun retrofitting five projects in the Muskingum watershed with simple outflow modifications. These trash rack weir modifications have allowed projects to reduce the amount of anoxic, hydrogen sulfide laden discharges. It has also resulted in warmer, oxygenated conditions downstream which is more favorable than the previous anoxic, cold-water conditions. In other watersheds, the release of phosphorus, nitrogen, and metals could be better managed for downstream benefits. These benefits would continue downstream to the Ohio River. These opportunities could range from simple and inexpensive weir additions, like those conducted by Huntington District using Operational funding, to complex construction of new intake towers, which would be significantly more expensive. Selective withdrawal retrofits in other Divisions have been pursued to benefit threatened and endangered species, and these retrofits have been funded through the reauthorization of WRDA.

While selective withdrawal retrofits are effective in alleviating stratification and water quality issues in reservoirs, the extent to which these changes may impact water quality on the mainstem of the Ohio River requires further investigation. Prior to implementation of selective withdrawal retrofits at any reservoir with the goal of improving mainstem water quality, the impact of such retrofits on the mainstem should be researched to ensure the retrofit is effective.

5.5 Structural Changes

Structural changes to existing lock and dam structures on the Ohio River can address various environmental problems that result from the dam's presence or operation, including inhibited movement of aquatic organisms, fragmentation of habitat, and degraded water quality. Potential structural changes that could be implemented at Ohio River dams include fishways, water quality gates, and aeration structures.

5.5.1 Fishways

Dams act as barriers for movement upstream to some fish species and other aquatic organisms whose communities rely on host-fish migration. Fishways are structural modifications that can benefit fish populations by providing an opportunity for fish to access waters upstream of dams that would otherwise be difficult or impossible to access because of the dams. Based on a report from the USFWS from a Fish Passage Feasibility Study in the Upper Ohio River, there are several different types of fishways that may be suitable for installation at Ohio River dams, including: nature-like fishways, technical fishways, pool pass fishways, vertical slot pass fishways, Denil fishways, and fish locks or elevators (see Caswell *et al.* 2010 for definitions and descriptions of each). Each type of fishway has benefits and drawbacks specific to its design, and some fishway designs may benefit certain fish but not others. Caswell *et al.* (2010) gave detailed descriptions and limitations of each design.

Generally, fishways have some benefits in common. These benefits are listed below, adapted from Caswell *et al.* (2010), and apply to not only the Ohio River, but to the entire Ohio River navigation system:

- Restore mainstem connectivity for native fishes and mussels;
- Provide access to, and potentially create through construction of artificial streams as nature-like fishways, additional spawning, feeding, and nursery habitat for native fishes in pools below and above dams;
- Benefits to migratory species, such as sturgeons, paddlefish, American eel, and others, that require river connectivity as part of their life history;
- Provide enhanced benefits for species restorations/reintroductions, like mussels and associated fish host species;
- Provide opportunities for scientific study of the effects of enhanced fish passage in large river systems; and
- Provide adaptive management opportunities for future fish passage studies.

Common drawbacks to fishways include the following (adapted from Caswell *et al.* 2010):

- Have high cost;
- Could alter the ability to regulate the Ohio River; and
- Potentially create enhanced pathways for or acceleration of invasive species dispersal into the Upper Ohio River.

Knights *et al.* (2003) assessed upstream fish passage along the Ohio River and found that conditions at most dams provide only limited fish movement through the lock chamber, and the current level of movement is likely not a viable means of population level fish passage. Therefore, fishways at any dams along the river could be beneficial for the river's aquatic community. Further consideration of target species and limitation of the specific dam sites should be considered when selecting a type of fishway for a specific dam. It is also important to note that the weirs of some L/Ds on the Ohio River, particularly from McAlpine L/D downstream, are overtopped at least annually during spring flood events. Such overtopping may provide for fish migration during flood events, but the frequency of such events should be analyzed to determine if fishways would enhance passage opportunities at the site.

5.5.2 Aeration Structures

Aeration structures serve to oxygenate water at dams where conditions and/or operations at the dam degrade dissolved oxygen levels downstream. Aeration structures are most commonly used at hydropower-generating dams, especially in the summer, when operations result in dissolved oxygen levels below state water quality criteria (which ranges from 4-6 mg/L in the Ohio River) because they draw water from deeper, oxygen-depleted waters and little to no oxygen is added to the water as it passes through the plant and is discharged back downstream. Different types of aeration structures that can be installed at hydropower plants include autoventing turbines, surface water pumps, and oxygen injection systems. Each structure is described below:

- Autoventing turbines increase the concentration of dissolved oxygen in hydropower releases by aspirating and mixing air with the water passing through the runner (Hopping *et al.* 1997). Autoventing turbines at the Norris hydropower plant in Tennessee have been shown to increase dissolved oxygen levels by up to 5.5 mg/L (March 1996). The main drawback to this aeration structure is the high initial and continued maintenance costs; although, this aeration technique is a relatively cost-effective method for increasing dissolved oxygen in hydropower releases. Another consideration is potential efficiency loss, which March (1996) estimated to range from 0 to 4 percent.
- Surface water pumps increase dissolved oxygen in the water being taken into the plant by moving surface water, which is more oxygenated than water at lower elevations near the intake, towards the plant's intake (Mobley *et al.* 1995). Increasing the dissolved oxygen of the plant's intake water has been shown to increase the dissolved oxygen levels of the outflow. The main drawback to this structure is the high installation, operation, and maintenance costs; although, surface water pumps were shown to be cheaper to operate than other aeration structures/strategies like the oxygen diffuser/injection system. Another drawback is that it can be difficult for the pumps to accommodate seasonal fluctuations of the pool and to withstand wind and wave energy. Additional structure may be needed to stabilize and support the pumps, which can add to the cost and space required to utilize them.
- Oxygen injection systems involve pumping air into the deoxygenated hypolimnetic water before it enters the hydropower plant. A perforated hose is installed just off the bottom of the pool or reservoir upstream from a dam/hydropower intake, and oxygen is injected into the hose, which creates bubbles that oxygenate the hypolimnetic, oxygen-depleted water. Dissolved oxygen increased 1-3 mg/L at certain TVA dams with oxygen injection systems in place (Higgins *et al.* 1999). The main disadvantage to this aeration structure is cost. Installation and maintenance costs for oxygen injection is typically higher than the other aeration options discussed in this section. This method is typically used at hydropower plants located at reservoir dams, so more research into the suitability of this technique at Ohio River dams is needed.

The main benefit of all aeration structures is to improve dissolved oxygen concentration in water downstream from the dam, which is essential to all aquatic life in the Ohio River. The main disadvantage is the cost associated with the installation, operation, and maintenance of the structures. Also, installation of these structures would be difficult as it would have to be implemented by the hydropower operators. The Corps would not be able to install such structures. Any of these structures would be best suited for a dam with hydropower operations that is not able to meet their dissolved oxygen targets or standards downstream from the plant.

5.5.3 Water Quality Gates

Water quality gates can be implemented at navigation dams to improve water quality, namely dissolved oxygen concentrations, downstream from the dam. A water quality gate was installed at Braddock Lock and Dam on the Monongahela River in 2004 with the goal of improving dissolved oxygen downstream of the dam, particularly during low to moderate flow periods. The gate was developed to permit a steep plunge angle which creates turbulence and maximizes entrained bubble contact time in the tailwater (Corps 1991). Testing completed downstream of the dam showed significantly higher dissolved oxygen levels in the tailwater when the water quality gate was in use, than when it was not in use (C. Nim, USACE Pittsburgh Water Quality Team, personal communication, December 16, 2021). Additional study is required to assess the downstream limits of dissolved oxygen improvement. Pools with low dissolved oxygen could benefit from the addition of this structure. However, the main drawback of this structure is the high installation and maintenance costs.

Another form of water quality gate is a selective withdrawal gate. Selective withdrawal is commonly used at reservoirs to influence the temperature and dissolved oxygen of the reservoir's tailwater (*see* Section 4.4 of this report).

5.6 Island Restoration

At least 214 islands were historically documented in the Ohio River. Many of the islands contain native communities of plants and animals that are endemic to the Ohio River. Islands contain a diverse variety of habitat types interspersed on and around the surface, including bottomland or riparian forest, shallow nearshore habitat, and deep-water habitat. The diversity in habitat type makes islands very attractive to a wide variety of species, including birds, mammals, fish, and mussels. Islands serve as important spawning, nesting, feeding, foraging, and resting habitats (USFWS 2017b).

Since the construction of the Ohio River Navigation System, the once shallow Ohio River has changed dramatically. To maintain a minimum channel depth of nine feet, the navigation system keeps the Ohio River at a constant flood stage compared to historic depths. Constant submergence and saturation at the island foundation increase the sediment's susceptibility to erosion. This increased sensitivity to erosion combined with increased exposure to wakes from boat traffic has caused many islands to erode over time (USFWS 2020). At least 31 islands in the Ohio River have completely eroded away since the 1900s (USACE LRD 2000).

As vulnerable, high-value ecosystems in the Ohio River, islands are attractive candidates for restoration action. Through collaboration with USFWS and appropriate state agencies, USACE has implemented projects to beneficially reuse uncontaminated material dredged from navigation projects (i.e., maintenance dredging, rehabilitation projects, etc.) to restore ORINWR islands. Such projects benefit USACE by reducing the volume of dredged material that needs to be landfilled, thereby reducing project costs. These projects also benefit USFWS by restoring the islands to their historic area and providing erosion protection through construction of ring dikes around the new island surface. Georgetown Island was the first ORINWR island restored through this partnership between USACE and USFWS (USFWS 2020). To date, USACE has also implemented these activities at Phillis Island.

Development of such restoration projects requires significant planning, design, and collaboration with USFWS and state agencies. Dredged material must be tested to ensure compliance with state and federal requirements for the placement of dredged material in the river. A CWA Section 404 permit and CWA Section 401 water quality certification may also be required. Mussel surveys and relocations may be necessary to comply with state and federal regulations and ensure threatened, endangered, or otherwise protected mussels are not adversely impacted during construction. Island restoration may also require the agencies to complete documentation and public notice and/or consultation processes required under the National Environmental Policy Act (NEPA). Other environmental laws or regulations may apply to prospective restoration projects. In assessing the feasibility of island restoration projects, USACE should consider not only the environmental benefits that may arise from the project, but also the overall cost of ensuring proper design and environmental compliance. Within LRD, these projects have historically been funded as part of the disposal options for maintenance dredging or navigation projects and have not been separately pursued under any of USACE's ecosystem restoration authorities.

Other USACE Divisions have received specific authorizations from Congress to implement island restoration projects. One such project is the Paul S. Sarbanes Ecosystem Restoration Project at Poplar Island (Poplar Island Project) in Maryland, managed by USACE North Atlantic Division, Baltimore District (NAB). The Poplar Island Project was originally authorized under Section 537 of the Water Resources Development Act (WRDA) of 1998 as an ecosystem restoration and beneficial use of dredged material project. At completion, approximately 68 million cubic yards of dredged material will be placed at the project site to restore 1,715 acres of island habitat, including 829 acres of upland, 776 acres of wetland, and 110 acres of open water embayment habitats (USACE NAB 2020). While the Poplar Island Project is significantly larger than the scope of island restoration considered for the Ohio River, the Project demonstrates USACE's ability to utilize other project authorization authorities for the restoration of island habitats using dredged material.

5.7 Invasive Species Control

The introduction of non-indigenous invasive species to riverine systems has altered ecosystems worldwide. Invasive species can induce cascade effects throughout riverine food webs, altering competitive interactions and trophic structure and resource availability (Pyron *et al.* 2017). Whether introduced accidentally or intentionally, invasive species often grow faster, mature earlier, disperse more readily, and have few natural predators. When established, they can threaten ecological stability, outcompete native species, reduce biodiversity, degrade water quality, or otherwise negatively affect commercial, agricultural, or recreational activities. Invasive species also have the potential to severely impact the economy, environment, and human health. The negative effects of invasive species on our environment and economy have the potential to inflict billions of dollars of damages annually in the United States. Aquatic invasive species such as invasive carp (i.e., bighead, black, grass, and silver carp), round goby, curly leaf pondweed, hydrilla, and zebra mussels, have been documented in the Ohio River Basin and have the potential to cause lasting environmental and economic damage (Tables 4 and 5).

Ideally, environmental opportunities discussed below would be implemented with a focus on one or more invasive species and associated habitat requirements with the goal of reducing, eliminating, or controlling their spread. However, many of the design or operational changes to the Ohio River system proposed would be difficult to implement in a way that effectively isolates or targets invasives in a manner that does not incur unintended impacts to non-target species.

One of the most significant impacts of dams on the Ohio River to the ecosystem is the restriction of variability in flow regimes within the system. As discussed in Section 5.1 of this report, the manipulation of hydrologic and hydraulic regimes (i.e., regulating the quantity, timing, and quality of water flows) has the potential to benefit aquatic and riparian ecosystems in the Ohio River mainstem and is a viable alternative to improve seasonal flow patterns, habitat variability, and water quality to benefit native species. Temporary pool raises may also be used to manage invasive populations. Landwehr *et al.* (2004) suggested that spring pool raises could be abruptly stopped and lowered in late May to strand invasive carp eggs and limit invasive carp recruitment. The effectiveness of this strategy would be highly dependent on timing, weather, and many other factors.

While the creation of backwater and side channel habitats within the Ohio River mainstem via temporary or seasonal pool raises have the potential to benefit native fishes, studies also indicate that invasive species also use the sloughs, oxbows, embayments, and slackwater areas created by the inundation of floodplains for spawning, foraging, and the development of young (USACE LRD 2000, Love *et al.* 2018).

In the short- and long-term, navigation dams on the mainstem of the Ohio River may have the effect of slowing or preventing the spread of aquatic invasive species. As discussed previously, fishways are structural modifications that can benefit fish populations by providing an opportunity for fish to access waters upstream of dams that would otherwise be difficult or impossible to access because of the dams. While the benefits to native species are well known, the use of these structures has the potential to facilitate the movement and accelerate the dispersal of invasive species like the invasive carp in the Ohio River. Collectively known as invasive carp, bighead carp (*Hypophthalmichthys nobilis*) and silver carp (*H. molitrix*), are planktivorous fishes that have invaded aquatic ecosystems throughout the Mississippi River Basin of North America. The plankton diet of invasive carp overlaps with many native species and the combination of high biomass and plankton consumption of these fish suggests that their presence has a negative impact on trophic pathways of native taxa. Irons *et al.* (2007) found decreased body condition in two likely competitor fishes (gizzard shad, *Dorosoma cepedianum*, and bigmouth buffalo, *Ictiobus cyprinellus*) in the Illinois River following invasive carp invasion.

These species pose a serious threat to the Ohio River basin. Large numbers of invasive carp are now found in the lower Ohio River and tributaries below the Markland Locks and Dam and their abundance and distribution have been steadily increasing upstream in the Ohio River. Invasive carp densities are influenced by a number environmental and anthropogenic factors including water chemistry, climate, harvest, primary and secondary production, and climatic and hydrologic connectivity (Gibson-Reinemer *et al.* 2017). While general life history requirements for these species include suitably warm temperatures, a fluctuation in water level, and moderate to swift current to maintain the suspension of eggs until hatching for successful reproduction, the relationship of hydrology on the reproductive success of invasive carp is complicated and the scope of manipulation of hydrologic regimes proposed in this study is not likely to impact the fecundity or recruitment of the species on a large scale.

Additional strategies that may be used in the control or monitoring of invasive carp include coordination with state and Federal agencies in their implementation of invasive carp control programs. Invasive carp management plans (including contractual harvest) have been implemented to prevent range expansion into vulnerable systems such as the Great Lakes and can be used in the Ohio River basin. Prevention and control are vitally important for limiting establishment of invasive carps in the Ohio River and physical removal may be the most effective strategy to slow their upstream expansion (Jackson and Stump 2016). There are ongoing removal efforts by Federal and state agencies that utilize electroshocking and gill netting in the removal of invasive carp and researchers have experimented with novel gear types, attractants, and the use of sound to congregate invasive carp for capture.

As part of the federal government's unprecedented commitment to prevent invasive carp introduction into the Great Lakes watershed, the Corps, in cooperation with the U.S. Geological Survey, has recently installed an acoustic deterrent system that uses underwater speakers to play sounds that deter invasive carp at Mississippi River Lock and Dam 19 between Keokuk, Iowa, and Hamilton, Illinois. The Corps has also recently contributed $226 million for the Brandon Road Lock and Dam Project on the Des Plaines River near Joliet, Illinois which will involve the construction of an array of technological barriers, including an air-bubble curtain, an electric barrier, a flushing lock, and an underwater acoustic fish deterrent, designed to block the movement of invasive carp into the Great Lakes and St. Lawrence River where they pose a serious threat to the regions $7 billion commercial and sport fishing industry and $15 billion recreational boating industry. A similar commitment is urgently needed in the Ohio River basin given the regional implications of this problem.

5.8 Modification of Hydropower Operating Agreements

ORSANCO has stated that "During low flow periods, aeration at dams is the major source of oxygen to the Ohio River." It is imperative that the USACE protect the aeration capacity of the Ohio River navigation structures. Revision of the Memorandum of Operating Agreements (MOA) between the USACE and non-federal hydropower developers provides an opportunity to do so. These MOAs should provide that during critical flow periods, the hydropower developers will work with the USACE lockmasters to maintain compliance with state and Federal Energy Regulatory Commission water quality targets. This could involve the transfer of full or partial flows from the hydropower project to the navigation dam, the addition of aeration structures or air injection, or the cessation of power generation during periods of low dissolved oxygen. These MOAs are considered "living documents" that can be modified at any time.

5.9 Rapid Watershed Assessment for Tributaries

Rapid Watershed Assessments (RWAs) are tools that can be developed to help natural resource managers determine areas of concern or target conservation areas. Modeled after the Natural Resources Conservation Service's (NRCS) RWA, the intent is "to increase the speed and efficiency generating information to guide conservation implementation, as well as the speed and efficiency of putting it into the hands of local decision makers" (USDA 2021). RWAs have been used by ERDC and USACE Districts throughout the United States. ERDC, in collaboration with LRP Reservoir and District staff, has utilized this methodology and adapted it to both Mosquito Creek Lake and Shenango River Lake watersheds. The primary components of the rapid watershed assessments include a geodatabase of watershed features (e.g., water features, digital elevation models, land use-land cover etc.) and a report that consists of a compilation of geospatial, social, biological, chemical, and physical data and findings for a target watershed.

Publicly available data are identified, collected, compiled, and analyzed to provide natural resource managers with an accessible product that can be used for conservation and planning purposes.

The benefits of RWAs listed by the NRCS (USDA 2007) are as follows:

- Provide a quick and inexpensive source of information on which to base decisions about conservation priorities, allocation of resources, funding for implementation, and how to report outcomes/results;
- Provide enough detail to identify conservation activities that can be taken without waiting on further watershed-level studies or analyses;
- Provide a preliminary source of information for standard environmental evaluations;
- Determine if there is a need for further detailed analysis or watershed studies;
- Identify if there are infrastructure needs;
- Address multiple concerns and objectives of landowners and communities;
- Enhance established local and state partnerships;
- Enable landowners and communities to decide on the best mix of NRCS programs and other funding sources to meet their resource concerns; and
- Evaluate availability of conservation program tools (cost share, easements, technical assistance).

The limitations of RWAs largely center on the availability of high-quality, publicly available data. While some datasets can be uniform in scope and application, such as those from Federal agencies that tend to have a broader purview, differences can exist. In the application of a RWA for Ohio River tributaries, one potential discrepancy may arise from the availability, or types, of geospatial data available from state agencies. Due to water quality standard and classification differences, degrees and extents of water quality impairment can differ substantially from state to state, which is often apparent in their spatial data. This issue was encountered during the RWA of Shenango River Lake when comparing waterbody impairment between the state of Ohio and Pennsylvania (Fig. 7).

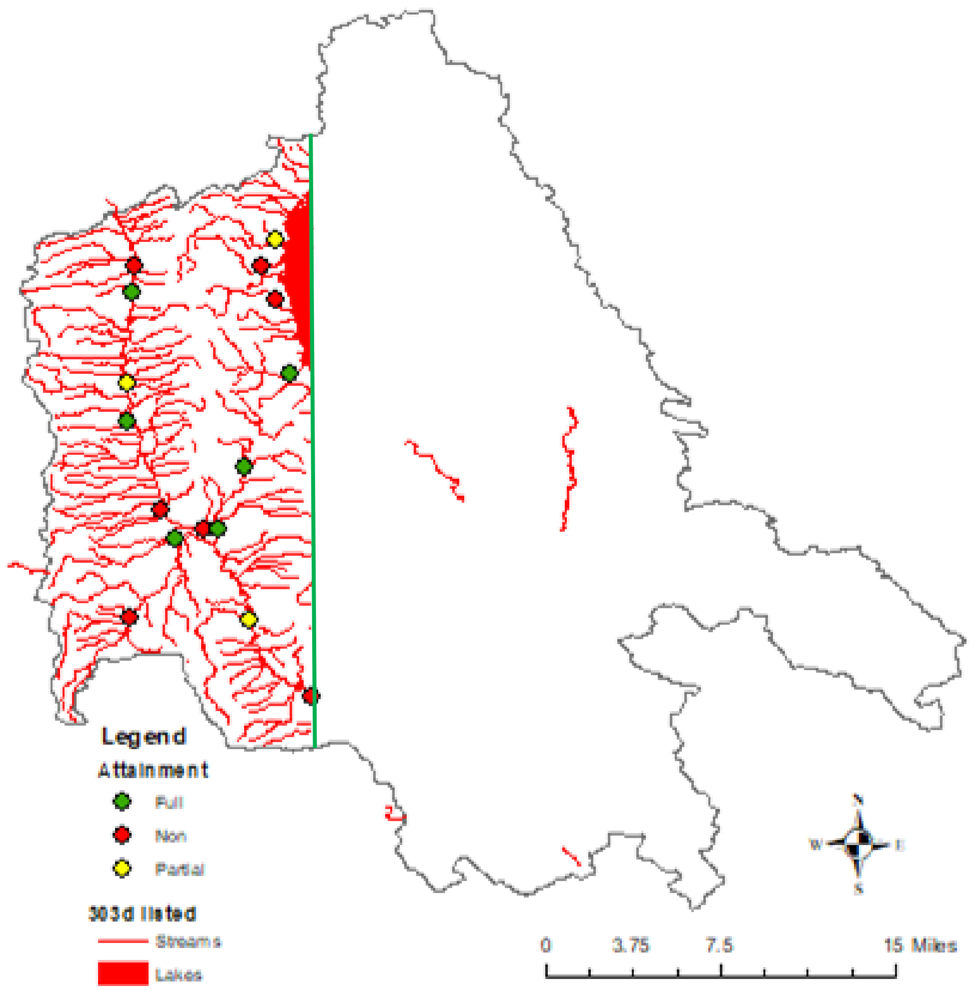

Fig. 7. The RWA of Shenango River Lake demonstrates the potential discrepancies in data availability across states. In this example, the waterbody impairment status could not be compared accurately between streams in Ohio (left of green line) and Pennsylvania (right of green line) due to the differences in state classification of waterbodies. The Ohio classification system shows a significantly greater number of streams that are listed as impaired on the 303(d) list because impairment is designated at a watershed basis, while the Pennsylvania classification system shows only four stream reaches listed as impaired because impaired is designated for each individual stream reach.

In Ohio, impairment applies to the entire watershed, whereas in Pennsylvania, impairment is limited to the stream reach in which the impairment was documented. In addition, one state's regulatory program may focus on a particular issue that isn't as much of a concern for another state. Nonetheless, non-uniformity or a lack of datasets is a minor limitation when compared with the multiple benefits that RWAs provide.

5.10 Conservation Lockages

Conservation lockage, the act of operating lock systems specifically to enhance fish passage, has the potential to impact species dispersal between tributaries and the mainstem of the Ohio River as well as across navigation pools. Conservation lockages have been conducted and/or studied at a handful of locations along the East Coast, as well as the Upper Mississippi, Ohio, and Allegheny Rivers. The few studies that have been conducted suggest minor success without certain operational or structural modifications (Wilcox *et al.*2004, Knights *et al.* 2003). The Pennsylvania Fish and Boat Commission (PAFBC) has documented large numbers of fish within the lock chambers of the Ohio River (Ventorini 2011). However, it has been noted that fish may accumulate in lock chambers because it is difficult for them to find their way out of the upstream gates given the length of the lock chamber, currents that are not oriented in the direction of river flow, and being entrained in the lock emptying conduits during down lock cycles (Wilcox *et al.* 2004). Argent *et al.* (2016) have noted that areas of free-flowing water and the tailwaters below locks and dams appear to hold more fish than impounded reaches. If given the right hydrologic and environmental conditions, there is no reason to suspect that fish would not pass through a lock and dam.

Sauger (*Sander canadensis*) have been documented to use lock culverts on the Tennessee River to gain access to the lock chamber and then pass upstream with commercial traffic (Scott and Hevel 1991). These movements are highly seasonal and correspond to the spawning migration. The researchers also noted the success of passage to be correlated to the design and location of the downstream culvert discharge ports, with the strongest correlations occurring at L/Ds with numerous smaller ports distributed over a long distance rather than a single large discharge port. Sauger, like channel catfish (*Ictalurus punctatus*) and sturgeon (*Acipenseridae* sp.), are benthic fish, so similar strategies for passing these types of fish could likely be applied. Studies have also documented large numbers of American shad passing upstream through the Cape Fear L/D No. 1 on Cape Fear River and the New Savannah Bluff L/D on the Savannah River (Moser *et al.* 2000). However, it was noted that both locks have light lockage traffic and therefore the lock operators have the flexibility to implement special fish passage operations that most likely would conflict with normal commercial and/or recreational vessel passage in heavy use systems like the Ohio River (Smith *et al.* 2013). Research on three L/Ds on the Alabama River starting at the Claiborne L/D, showed little success for both paddlefish (*Polyodon spathula*) and smallmouth buffalo (*Ictiobus bubalus*) in using lock chambers to migrate upstream (McKee 2019). Fish lockage was also tried on the Allegheny River in the 1980s and 1990s on L/D 5-9. Anecdotal evidence from the PAFBC suggests that this method was successful in reintroducing sauger (*Sander canadensis*) throughout the river system. However, there have been no population level studies to support this conclusion (Caswell *et al.* 2010).

If this opportunity is implemented, there are considerations identified from the literature that would need to be studied and evaluated before implementation. They are (Smith *et al.* 2013):

- Physical structure of the L/D and hydraulic effects of the downstream approach to the lock chamber;
- Competing priorities with navigational lockage for commercial and recreational traffic;
- Excessively loaded barges that restrict water volume for fish;
- Entrainment of fish through propellers;
- Physical and hydraulic effects of the upstream approach to the lock chamber;

- Opportunities for invasive species such as the invasive carp (*Cyprinus carpio*); and
- While some L/Ds may provide passage opportunities, these opportunities generally decreased in an upstream direction along the Ohio River due to increases in water velocity and physical structure of the L/Ds (Knights *et al*. 2003).

While fish passage is needed along the Ohio River, based on the literature available, conservation lockage may not be a viable option for any of the L/Ds within the Districts given water velocities, currents, and the physical structure of the Districts' L/Ds (Knights *et al.* 2003). However, opportunities may increase further downstream. It is also important to consider the ability of Lock Operators to prioritize conservation lockages given the frequency of commercial traffic on the Ohio River mainstem (Caswell 2010).

6. Preliminary Recommendations for Further Study

Preliminary recommendations for further study were developed by the Districts based on pool characteristics, potential benefits and limitations of each measure, and targeted resources (i.e., restoration of limited habitat, threatened and endangered species presence, water quality targets, etc.). These recommendations are briefly summarized by measure below.

Recommendations presented in this report should be considered preliminary, and additional investigation and comparison of the potential costs and benefits of each measure should be conducted prior to implementation of any measures at any location recommended in this report. Because this study considered the full Ohio River basin, the recommendations are based on assumptions and the availability of data across the system. Additional information can be verified, measured, or considered on a smaller scale (e.g., District or HUC-12 scale) when evaluating any measure for implementation.

6.1 Temporarily Raising Pool Elevation

Pools were prioritized for further study of temporary pool raises using a three-tiered process. First, operational constraints were identified for all navigation pools (Table 8). Operational constraints include the type of L/D (i.e., fixed crest or gated), presence of non-federal hydropower, ongoing construction projects, and significant riverside development. Pools with significant constraints that dictate the operation of the L/D were considered not to be suitable for temporary pool changes and ranked a 3. Implementation of pool level changes were considered not to be feasible for these pools, and therefore, the pools were not considered further. The remaining pools were assigned a 1 if no operational constraints were identified and a 2 if few operational constraints were identified. A geospatial analysis of land use within the 100-foot riparian area was utilized to assign second tier categories. Pools with 50% or more natural riparian vegetation (i.e., the sum of all wetland, forest, grassland/herbaceous, and scrub/shrub land use types) were assigned a 1, those with 25% - 50% natural riparian vegetation were assigned a 2, and pools with less than 25% riparian vegetation were assigned a 3. A second geospatial analysis was conducted to rank pools based on the area that would be submerged under a 1-ft pool raise. Pools that would have greater than 200 acres submerged were assigned a 1, those that would have 100 – 200 acres submerged were assigned a 2, and those with less than 100 acres submerged were assigned a 3. The sum of these rankings was then calculated to prioritize pools for implementation.

Table 8. Summary of prioritization criteria for temporary pool raises.

Criteria	Category 1	Category 2	Category 3
Operational constraints	No operational constraints	Few operational constraints	Significant operational constraints
Natural vegetation within riparian area (100-ft)	50 – 100%	25 – 50%	0 – 25%
Acreage submerged by 1-ft pool raise	200 + acres	100 – 200 acres	0 – 100 acres

An initial, high-level assessment of existing structural and operational constraints indicates that five pools would not be suitable for implementation of temporary pool raises. An ongoing construction project, the Upper Ohio Navigation Project, will result in potential operational changes to Emsworth, Dashields, and Montgomery that would alter the feasibility of implementing pool changes at these facilities. Therefore, the facilities were considered to have significant operational constraints. R.C. Byrd must be strategically operated to prevent flooding at the confluence of the Kanawha River with the Ohio River, and implementation of temporary pool raises may exacerbate flooding concerns. Therefore, R.C. Byrd was considered to have significant operational constraints. McAlpine pool has a large riverside development for which the water level is managed, and therefore, implementation of the temporary pool raise at McAlpine was considered not feasible. Implementation of a significant (1-ft or more) pool raise at Olmsted would likely be very challenging because Olmsted is the only wicket dam on the Ohio River with a hinged-pool operation. Moreover, modifying the pool elevation at Olmsted would require coordinating operations with conditions in various large rivers to prevent downstream flooding. As such, Olmsted was considered to have significant operational constraints. Emsworth, Dashields, Montgomery, R.C. Byrd, McAlpine, and Olmsted were all listed in the 3rd category for operational constraints and not considered further.

Hannibal, Willow Island, Belleville, Racine, Greenup, C. A. Meldahl, Markland, Cannelton, and Smithland have potential for higher pools but are limited by the maximum designed head differential for non-Federal hydropower plants present at each facility. Feasibility of raising the pool at these facilities would depend on the downstream pool elevation and whether the difference between the upper and lower pools would be greater than the head differential designed for the hydropower plant. All of the hydropower plants currently present have been designed with maximum head differentials near the current operating settings. In addition to this concern, raises in pools downstream of hydropower projects might lower the head differential, which reduces the ability of the plant to generate as efficiently as it would at the maximum head differential. These considerations would need to be further analyzed and evaluated on a case-by-case basis. A historical duration analysis is recommended to estimate the likelihood of favorable conditions for such operations (e.g., the percentage of time that Markland pool maintains at least 60,000 cfs for the month of July based on data for the past 20 years). Hannibal, Willow Island, Belleville, Racine, Greenup, Meldahl, Markland, Cannelton, and Smithland were all listed in the 2nd category for operational constraints.

No significant operational constraints were identified for New Cumberland, Pike Island, Newburgh, or J. T. Myers pools. Therefore, these pools were all ranked in the 1st category for operational constraints.

Riparian land use is an important factor when prioritizing pools for temporary pool raises because it provides an approximation of what type of habitat will be submerged during the raise. In general, pools with relatively high levels of natural vegetation in the riparian area are likely to provide the greatest ecological benefit. Synthesizing the results of the land cover analysis (Appendix 3), Ohio River pools have the following percentages of natural vegetation (i.e., the sum of landcover types woody wetlands, emergent herbaceous wetlands, deciduous forest, evergreen forest, mixed forest, grasslands/herbaceous, and shrub/scrub) within the riparian area: Smithland (72%), Cannelton (59%), J. T. Myers (58%), Meldahl (55%), Willow Island (48%), Markland (47%), Newburgh (46%), New Cumberland (41%), Belleville (40%), Racine (37%), Hannibal (36%), Greenup (28%), and Pike Island (28%). As such, category 1 pools include Smithland, Cannelton, J. T. Myers, and Meldahl. Category 2 pools include Willow Island, Markland, Newburgh, New Cumberland, Belleville, Racine, Hannibal, Greenup, and Pike Island. No pools were listed in category 3 for this analysis.

Based on the geospatial analysis results (Appendix 5, Area of Change Analysis), the pools that would provide the largest area of newly submerged habitat with a 1-ft pool raise are Smithland (373.86 acres), Newburgh (269.18 acres), J. T. Myers (233.85 acres), and Willow Island (231.96 acres). Smithland, Newburgh, J. T. Myers, and Willow Island were all ranked as 1 for acreage submerged. Greenup, Markland, and Cannelton would provide 100-200 acres of submerged habitat, and therefore, these pools were ranked in category 2. The remaining pools would provide less than 100 acres of submerged habitat and were therefore assigned category 3. To provide the largest ecological benefit, Smithland is considered a top priority for implementing a seasonal 1-ft raise, simply because it would provide the largest area of available habitat. Newburgh, J. T. Myers, and Willow Island are considered secondary priorities. Greenup, Markland, and Cannelton would also be good candidates based on these findings.

Seasonal or temporary pool raises can have significant positive impacts on the environment when operated properly and can be best utilized for Ohio River pools that have the functional capacity to do so, target natural riparian landcover types, and have large amounts of habitat potentially affected by pool raises. Based on these factors, the highest priority pools for implementation of temporary pool raises are J. T. Myers, Newburgh, and Smithland. These three pools are discussed in detail here, but Table 9 provides for a priority ranking for all pools. J. T. Myers is among the highest priorities for pool raises because it has high functional capacity, >200 acres of submerged area with 1-ft raise, and >50% of natural vegetation within riparian zone. Newburgh holds similar potential (high functional capacity, >200 acres of submerged area with 1-ft raise, 46% of natural vegetation within riparian zone). Smithland should be considered a high priority because it would have the most area submerged with a 1-ft raise (373.86 acres) and the second highest proportion of natural vegetation in the riparian zone (72%); however, it may be limited due to constraints imposed by the non-Federal hydropower facility. Table 9 summarizes the prioritization as discussed in this paragraph.

Table 9. Ohio River pool prioritization for temporary pool raise operations.

Pool	**Priority (overall)**	**Prioritization Categories**		
		Operational constraints	**Natural riparian vegetation**	**Acreage submerged**
Emsworth	Screen	3	N/A	N/A
Dashields	Screen	3	N/A	N/A
Montgomery	Screen	3	N/A	N/A
New Cumberland	6	1	2	3
Pike Island	6	1	2	3
Hannibal	7	2	2	3
Willow Island	5	2	2	1
Belleville	7	2	2	3
Racine	7	2	2	3
R.C. Byrd	Screen	3	N/A	N/A
Greenup	6	2	2	2
Meldahl	6	2	1	3
Markland	6	2	2	2
McAlpine	Screen	3	N/A	N/A
Cannelton	5	2	1	2
Newburgh	4	1	2	1
J. T. Myers	3	1	1	1
Smithland	4	2	1	1
Olmsted	Screen	3	N/A	N/A

6.2 Temporarily Lowering Pool Elevation

6.2.1 Initial Feasibility Modeling

Any operational changes to the pool elevation must not impact the authorized purpose of the L/Ds, namely navigation. Therefore, any pools in which temporary pool drawdowns are implemented must be able to maintain the minimum navigation depth of 9-feet. To assess feasibility of implementing temporary pool drawdowns at any navigation pool in the Ohio River, three pools were selected for initial representative H&H modeling using a two-tier prioritization process. First, initial analysis of the operational constraints present at each L/D was conducted to identify those facilities with the fewest number of constraints (*see* Section 6.1). This analysis eliminated the following pools from further consideration: Emsworth, Dashields, and Montgomery due to the ongoing USACE navigation project (e.g., the Upper Ohio Navigation Project), R.C. Byrd due to potential for impacts along the Kanawha River, McAlpine due to the presence of riverside development, and Olmsted due to operational complexities (i.e., hinged pool, wicket dam, and impact of/to Mississippi River). The remaining pools were prioritized for initial H&H modeling based on a high-level analysis of the acreage to be exposed under a 1-foot pool drop, calculated using publicly available bathymetric data. This analysis indicated that Pike Island, Greenup, and Smithland pools would likely provide the largest acreage of exposed habitat in each District, and analysis of the feasibility of maintaining the navigation channel in these three pools would provide representative models for the Upper, Middle, and Lower Ohio regions. However, as discussed in Section 6.2.2, more comprehensive geospatial analysis of the potential acreage exposed by the 1-foot pool change indicated that other pools may provide greater acreages.

As further discussed in the Hydraulic Modeling analysis in Appendix 6, maintenance of the navigation channel under a 1-foot pool elevation drop was found to be feasible at all pools. To prevent impacts to navigation in the Pike Island and Smithland pools, minimum inflows must be available to achieve adequate slope in the river and thus depths at upstream shallow points when reducing the pool elevation at the dam. For a 1-foot decrease in pool at Pike Island L/D, a minimum of 10,000 cfs would be required; flows must be approximately 60,000 cfs in the Smithland pool to maintain navigation at Raliegh Bar. Enacting such pool drawdowns would require knowledge of the current and forecasted flows in order to ensure that depths were adequate for navigation across shallow points. As also discussed in Appendix 6, there are a number of limitations to the data currently available and modeling accuracy that would need to be improved upon to support better forecast information for implementation of this potential measure.

For purposes of this study, the results of H&H modeling were assumed to be representative of all pool conditions, and therefore, it was assumed that the minimum navigable depth can be maintained across all pools prioritized for further study. However, pool-specific channel and flow conditions may limit the ability to maintain the navigation channel under shallower conditions. As such, H&H modeling should be conducted at any pool considered for implementation of temporary pool elevation decreases to assess the potential to impact the navigation channel.

Furthermore, all water inlets were assumed to be below the minimum navigable channel depth for purposes of this effort. The potential to disconnect water inlets as a result of temporary pool elevation decreases is not documented for the Ohio River. This factor should be further investigated as part of a feasibility study for any pool in which this measure is considered for implementation.

6.2.2 Prioritization Framework

Pools were prioritized for further study of temporary pool drawdowns using a two-tiered process. First, operational constraints were identified for all navigation pools (Table 10). Operational constraints include the type of L/D (i.e., fixed crest or gated), presence of non-federal hydropower, ongoing construction projects, and significant riverside development. Pools with significant constraints that dictate the operation of the L/D were considered not to be suitable for temporary pool changes and ranked a 3. Implementation of pool level changes were considered not to be feasible for these pools, and therefore, the pools were not considered further. The remaining pools were assigned a 1 if no operational constraints were identified and a 2 if few operational constraints were identified. For the second tier, a geospatial analysis was conducted to rank pools based on the area that would be exposed by a 1-ft pool drawdown. Pools that would have greater than 200 acres exposed were assigned a 1, those that would have 100 – 200 acres exposed were assigned a 2, and those with less than 100 acres exposed were assigned a 3. The sum of these rankings was then calculated to prioritize pools for implementation.

Table 10. Summary of prioritization criteria for temporary pool drawdowns.

Criteria	Category 1	Category 2	Category 3
Operational constraints	No operational constraints	Few operational constraints	Significant operational constraints
Acreage exposed by 1-ft pool drawdown	200 + acres	100 – 200 acres	0 – 100 acres

Pools were categorized by the extent of operational constraints present at each L/D using the same process as described in Section 6.1 and briefly summarized here. An initial, high-level assessment of existing structural and operational constraints indicates that five pools would not be suitable for implementation of temporary pool drawdowns. Emsworth, Dashields, Montgomery, R.C. Byrd, McAlpine, and Olmsted were all listed in the 3rd category for operational constraints and not considered further. Hydropower was considered an important constraint that may impact feasibility of implementing temporary drawdowns because hydropower generation capacity is directed related to river levels. Thus, all pools with hydropower operations currently present were ranked as category 2. These included Hannibal, Willow Island, Belleville, Racine, Greenup, Meldahl, Markland, Cannelton, and Smithland. No significant operational constraints were identified for New Cumberland, Pike Island, Newburgh, or J. T. Myers pools. Therefore, these pools were all ranked in the 1st category for operational constraints.

Based on the geospatial analysis results (Appendix 5, Area of Change Analysis), the pools that would provide the largest area of newly exposed habitat with a 1-ft pool drawdown are Smithland (394.7 acres), J. T. Myers (316.1 acres), Markland (273.7 acres), Willow Island (235.6 acres), and Cannelton (209.7 acres). Smithland, J. T. Myers, Markland, Willow Island, and Cannelton were all ranked as 1 for acreage exposed. Newburgh, Greenup, and New Cumberland would provide 100-200 acres of exposed habitat, and therefore, these pools were ranked in category 2. The remaining pools would provide less than 100 acres of exposed habitat and were therefore assigned category 3.

Based on the prioritization framework presented here, the highest priority pool for implementation of temporary pool drawdowns is J. T. Myers. Secondary priority pools include New Cumberland, Willow Island, Markland, Cannelton, Newburgh, and Smithland. J. T. Myers is considered the highest priority for temporary drawdowns because it has limited operational constraints (i.e., gated infrastructure, no hydropower operations) and would create high acreage of exposed habitat (316.1 acres). New Cumberland and Newburgh pools are considered secondary priorities due to the lack of known operational constraints present at the L/D and potential to generate between 100 – 200 acres of exposed habitat. Willow Island, Markland, Cannelton, and Smithland pools are also considered secondary priorities because these pools have known operational constraints (i.e., presence of hydropower operations) but would generate over 200 acres of exposed habitat. The potential impacts of temporary drawdowns on current hydropower operations should be investigated further to determine the feasibility of these operational changes at Willow Island, Markland, Cannelton, and Smithland. Table 11 summarizes the prioritization as discussed in this paragraph.

Based on the prioritization frameworks presented in this study, priority locations for pool lowering generally align well with pool raising locations. Synergistic operational plans could be developed to seasonally maximize ecological benefits associated with water level fluctuations (e.g., higher pools in the winter and spring with subsequent drawdowns during growing seasons).

Table 11. Ohio River pool prioritization for temporary pool drawdowns.

Pool	**Priority (overall)**	**Prioritization Categories**	
		Operational constraints	**Acreage exposed**
Emsworth	Screen	3	N/A
Dashields	Screen	3	N/A
Montgomery	Screen	3	N/A
New Cumberland	3	1	2
Pike Island	4	1	3
Hannibal	5	2	3
Willow Island	3	2	1
Belleville	5	2	3
Racine	5	2	3
R.C. Byrd	Screen	3	N/A
Greenup	4	2	2
Meldahl	5	2	3
Markland	3	2	1
McAlpine	Screen	3	N/A
Cannelton	3	2	1
Newburgh	3	1	2
J. T. Myers	2	1	1
Smithland	3	2	1

6.3 Flow Manipulation for Habitat Improvement

Pools were prioritized for further study of flow manipulation for habitat improvement using a two-tiered screening process followed by a categorical rank. The first step in the screening process considered operational constraints. Flow manipulation through changes in gate operating schedules is not feasible at any L/D without gates. All L/Ds on the mainstem of the Ohio River have multiple gates except for Dashields. Dashields is a fixed-crest dam, and therefore, it is not feasible to implement flow manipulation through changes in gate operating schedules at Dashields. Dashields was screened from further consideration.

The remaining pools were then screened based on the known presence of federally protected mussel species in the pool. Implementation of flow manipulation measures at these pools may maximize the potential ecological uplift by improving habitat and aiding in the conservation of federally protected species. Presence of federally listed mussel species was identified using the USFWS IPaC tool (Appendix 2). Those pools with known presence of federally protected mussel species were then placed into three categories: 1-5 species in category 3, 5-10 species in category 2, and more than 10 species in category 1.

Federally protected mussel species are present in the Ohio River from Hannibal pool through Olmsted pool. Because federally protected mussel species are not known to inhabit the pool, Emsworth, Montgomery, New Cumberland, and Pike Island pools were screened from further consideration for purposes of this study. It is important to note, however, that implementation of flow manipulation at these pools may serve other conservation or mitigation goals, and therefore, the pools should be considered as appropriate to satisfy District and regional goals.

The remaining pools were then assigned a categorical ranking based on the number of federally protected mussel species known within the pool. Less than five federally protected mussel species are known to inhabit Hannibal and Willow Island pools, and therefore, these pools were assigned to category 3. Between 5 and 10 federally protected mussel species are known to be present within Belleville, Racine, R.C. Byrd, and Cannelton pools, so these pools were assigned to category 2. Greater than 10 federally protected mussel species are known to be present within Greenup, Meldahl, Markland, McAlpine, Newburgh, J. T. Myers, Smithland, and Olmsted pools, and so these pools were assigned to category 1.

Based on this analysis of the full extent of the Ohio River mainstem, the highest priority pools for implementation of flow manipulation measures are Greenup, Meldahl, Markland, McAlpine, Newburgh, J. T. Myers, Smithland, and Olmsted (Table 12). These pools were prioritized based on system-wide conservation and management goals, but priorities may differ on smaller scales. Therefore, the prioritization presented in this study is meant to serve as a guiding framework, and additional pools should be considered to satisfy local conservation and management goals as appropriate.

Table 12. Ohio River pool prioritization for flow manipulation for habitat improvement.

Pool	Priority	Presence of Gates	Presence of ESA Mussels	Categorical Rank
Emsworth	Screen	Present	Absent	Screen
Dashields	Screen	Absent	Screen	Screen
Montgomery	Screen	Present	Absent	Screen
New Cumberland	Screen	Present	Absent	Screen
Pike Island	Screen	Present	Absent	Screen
Hannibal	3	Present	Present	3
Willow Island	3	Present	Present	3
Belleville	2	Present	Present	2
Racine	2	Present	Present	2
R.C. Byrd	2	Present	Present	2
Greenup	1	Present	Present	1
Meldahl	1	Present	Present	1
Markland	1	Present	Present	1
McAlpine	1	Present	Present	1
Cannelton	2	Present	Present	2
Newburgh	1	Present	Present	1
J. T. Myers	1	Present	Present	1
Smithland	1	Present	Present	1
Olmsted	1	Present	Present	1

6.4 Selective Withdrawal Retrofits for Flood Risk Management Structures

Selective withdrawal retrofits are better suited for installation at reservoirs, where facilities are not operated to allow for navigation passage, compared to the pools within the navigation system. For purposes of this study, selective withdrawal retrofits are considered to provide the greatest benefit to reservoirs that stratify because the retrofits will allow the release of water from different layers to manage downstream water quality. As such, reservoirs that are known to stratify are considered priorities for implementation of selective withdrawal retrofits.

Reservoirs that stratify were identified using publicly available water quality data collected by each District. Within LRH, two reservoirs within the Muskingum watershed, Leesville and Atwood, are known to stratify. Significant operational constraints complicate implementation of these retrofits compared to the other Muskingum watershed reservoirs. Leesville and Atwood have a concrete curtain that hangs from the outlet structure platform over the gates and above the trash rack that impacts the flow through the gates. Additional design efforts are required to address this issue, and LRH is currently considering smaller trash rack weirs to reduce the amount of hydrogen sulfide gas production at the outflows. Despite these complications, Leesville and Atwood are still high priority reservoirs for implementation of retrofits within LRH. The Buckhorn, Cecil M. Harden, Cagles Mill, Rough River, and West Fork reservoirs are considered priorities for selective withdrawal retrofits in LRL, and the Kinzua, Youghiogheny, Tygart, and Berlin reservoirs are considered highest priority for LRP.

Due to the scope and scale of the current effort, significant analysis of reservoir conditions and potential ecological benefits of changed operations of reservoirs could not be conducted. Additional analysis of the potential for selective withdrawal retrofits to meet authorized purposes (i.e, downstream water quality management) or management goals should be conducted when considering implementation at any reservoir.

6.5 Structural Changes

Structural changes investigated as part of the current effort include fishways, water quality gates, and aeration structures. Because these structures address different ecological concerns, fishways are prioritized differently than water quality gates and aeration structures. Water quality gates and aeration structures both address dissolved oxygen concentrations, and therefore, the same prioritization framework was used for these structures.

6.5.1 Fishways

Fishways provide ecological benefit by allowing species movement between navigation pools that otherwise would be inaccessible due to the presence of the dam. As such, fishways may be prioritized in pools with federally protected fish species, important mussel host species, or valuable recreational or game species. As of the date of this report, no federally protected fish species are known within any of the Ohio River navigation pools. Additional analysis is required to identify important mussel host species and valuable recreational or game species within the Ohio River that may benefit from these structures.

Fishways also have the potential to enhance invasive species dispersal by providing passage to pools that would otherwise be inaccessible. To prevent range expansion, pools with known populations of invasive fish species may not be suitable candidates for fishway implementation. Invasive carp have colonized the navigation pools and tributaries along the lower Ohio River. The current upstream limit of invasive carp populations is the Markland pool. To limit invasive species dispersal upstream, fishways should not be implemented at or below Markland L/D. The potential to provide additional upstream dispersal pathways of invasive carp should be considered when analyzing the feasibility of fishways at Meldahl L/D due to its proximity to Markland L/D.

6.5.2 Aeration Structures and Water Quality Gates

Aeration structures and water quality gates may improve water quality through increased aeration and dissolved oxygen downstream of the L/D. These structures are most effective during low to moderate flow periods. Therefore, pools known to experience low dissolved oxygen concentrations during low flow periods should be prioritized for implementation of these structures.

All Ohio River navigation pools regularly meet dissolved oxygen targets, which vary slightly across the regions. While additional oxygenation of these pools may improve water quality conditions, it is uncertain if such an increase would result in significant ecological benefit. A cost-benefit analysis should be conducted prior to implementation of aeration structures or water quality gates at any pool.

6.6 Island Restoration

Islands are present within all pools except Montgomery and Greenup. Islands within the Ohio River were prioritized for restoration based on land use (i.e., predominately industrial, vegetated, or submerged) and potential for long-term protection (Table 13). Each of these factors are described in further detail below.

Several islands along the Ohio River are highly developed and industrialized. Restoration of these islands may not provide significant ecological uplift due to spatial limitations for habitat creation and potential water quality issues. Google Earth was utilized to qualitatively assess the degree of development at each of the islands in the Ohio River. Based on this analysis, some islands listed in navigation charts were found to be submerged.

Islands that were found to be predominately vegetated were then assessed for the potential for long-term protection. Islands that are part of a state or federal nature preservation, wildlife management area (WMA), wildlife refuge, or other protected ecosystem are considered to have long-term protection, whereas the long-term protection of islands that are privately owned is considered unknown.

Islands that are part of the ORINWR refuge are considered highest priority for restoration because USFWS has already reached out to USACE regarding restoration of these islands. Additionally, USACE has already begun restoration efforts at two ORINWR islands, Georgetown and Phillis, and these islands can serve as a roadmap to implementation at other sites.

Comparison of the ecological quality of individual ORINWR islands and development of specific recommendations for restoration across the Ohio River is beyond the scope of the current effort. Based on the information reviewed for this study, it is recommended that any pool in which ORINWR islands are present be prioritized for further research to determine the feasibility of this measure. As such, New Cumberland, Hannibal, Willow Island, Belleville, Racine, and Meldahl pools (USFWS 2013, USACE LRP 2003, USACE LRH 2004, USACE LRL 2010) are considered priority pools for island restoration.

Table 13. Prioritization framework for island restoration in Ohio River basin.

Pool	Island	Priority	Land Use	Long-Term Protection
Emsworth	Brunot	Screen	Industrial	Unknown
	Davis	3	Vegetated	Unknown
	Neville	Screen	Industrial	Unknown
Dashields	Neville	Screen	Industrial	Unknown
Montgomery	Not present	N/A	N/A	N/A
New Cumberland	Phillis	1	Vegetated	ORINWR
	Georgetown	1	Vegetated	ORINWR
	Babbs	3	Vegetated / Residential	Unknown
	Cluster Islands	Screen	Industrial / Residential	Unknown
Pike Island	Griffen	3	Vegetated	Unknown
	Browns	Screen	Industrial	Unknown
Hannibal	Upper Sister	Screen	Submerged	N/A
	Lower Sister	3	Vegetated	Unknown
	Wheeling	Screen	Industrial	Unknown / ORINWR

Pool	Island	Priority	Land Use	Long-Term Protection
Hannibal (cont.)	Captina Creek	1	Vegetated	ORINWR
	Fish Creek	1	Vegetated	ORINWR
	Boggs	Screen	Vegetated / Industrial	Unknown
Willow Island	Paden	1	Vegetated	ORINWR
	Williamson	1	Vegetated	ORINWR
	Witten Towhead	1	Vegetated	ORINWR
	Wells	1	Vegetated	ORINWR
	2 Unnamed Island	3	Vegetated	Unknown
	Grape	1	Vegetated	ORINWR
	Middle	1	Vegetated / Residential	ORINWR
	Broadback / Middle Brothers	1	Vegetated	ORINWR
	Eureka / Lower Brothers	3	Vegetated	Unknown
Belleville	Buckley / Marietta	1	Vegetated	ORINWR
	Muskingum	1	Vegetated	ORINWR
	Vienna / Halfway	3	Vegetated	Unknown
	Neal	1	Vegetated	Unknown / ORINWR
	Blennerhassett	2	Vegetated / Agricultural	Historical state park
	Mustapha	3	Vegetated	Unknown
	Newbery	Screen	Eroded	Unknown
Racine	Buffington	1	Vegetated	ORINWR
	Letart	1	Vegetated	ORINWR
R.C. Byrd	Eightmile	3	Vegetated	Unknown
	Gallipolis	3	Vegetated	Unknown
Greenup	Not present	N/A	N/A	N/A
Meldahl	Brush Creek	3	Vegetated	Unknown
	Manchester (2)	1	Vegetated	ORINWR
Markland	Laughery	3	Vegetated / Eroded	Unknown
McAlpine	Shippingport	Screen	Vegetated / Industrial	Unknown
	Towhead	3	Vegetated	Unknown
	Six Mile	2	Vegetated	KY nature preserve
	Twelve Mile	3	Vegetated	Unknown
	Eighteen Mile	3	Vegetated	Unknown
Cannelton	Flint	Screen	Agricultural	Unknown
	Sand	3	Vegetated	Unknown
Newburgh	Scuffletown	3	Vegetated	Unknown
	French (#1)	3	Vegetated	Unknown
	French (#2)	Screen	Agricultural	Unknown
	Ellis	3	Vegetated	Unknown
	Little Hurricane	3	Vegetated	Unknown
	Yellowbank	3	Vegetated	Unknown
	Anderson	3	Vegetated	Unknown
J. T. Myers	Slim	3	Vegetated	Unknown
	Towhead	3	Vegetated	Unknown
	Mt. Vernon	Screen	Industrial	Unknown
	Diamond	3	Vegetated	Unknown
	Deadman’s	3	Vegetated	Unknown
	Henderson	3	Vegetated	Unknown
	Dutch	3	Vegetated	Unknown
Smithland	Stewarts	2	Vegetated	KY WMA

Pool	Island	Priority	Land Use	Long-Term Protection
Smithland	Ron Deau	2	Vegetated	KY WMA
	Pryor	2	Vegetated	KY WMA
	Sisters	2	Vegetated	KY WMA
	Hurricane	3	Vegetated	Unknown
	Cave in Rock	3	Vegetated	Unknown
	Sturgeon	3	Vegetated	Unknown
	Wabash	3	Vegetated	Unknown
Olmsted	Hamletsburg	3	Vegetated	Unknown
	Cumberland	3	Vegetated	Unknown
	Towhead	3	Vegetated	Unknown
	Owens	3	Vegetated	Unknown

6.7 Invasive Species Control

Invasive species control may benefit any pool in the Ohio River, as well as its tributaries, because many of these species are ubiquitous or are rapidly expanding their ranges within the project area. Prioritization of specific pools for invasive species control is limited by available data. Many species are known to be present within the Ohio River, but pool-specific presence/absence data is not available for all species. It is recommended that pool-level invasive species population data be collected prior to implementation of this measure to develop targeted control methods.

Invasive carp (i.e., bighead, black, grass, and silver carp) are currently known in, around, and below Markland L/D in LRL, so efforts to target invasive carp specifically should be focused within of its range. As such, invasive carp control measures should be prioritized for Markland, McAlpine, Cannelton, Newburgh, J. T. Myers, Smithland, and Olmsted.

Meldahl pool is also a high priority area for implementation of invasive carp measures. While invasive carp are only known to be present as far upstream as Markland pool, the fish may move upstream through locks or other modes of transportation. Implementation of controls at Meldahl L/D would serve as a second tier defense to prevent invasive carp movement upstream should they enter the pool.

Federal and state wildlife agencies conduct annual removal efforts of invasive carp in the Ohio River mainstem that involve the use of conventional methods including electrofishing and netting. Because lock and dams form barriers to the movement and dispersal to these species, USACE should work closely with these agencies in these efforts. USACE currently has ongoing projects designed to control the movement of invasive carps into the Great Lakes and has also initiated funding to study novel technologies to be used as barriers or deterrents in the movement of these species in the Mississippi River basin. These technologies include air-bubble curtains, an electric barrier, a flushing lock, and underwater electric barriers and acoustic fish deterrent systems all of which have the potential to be employed at Ohio River locks and dams to limit the movement and dispersal of invasive carps in the basin. More study is needed in this vein.

6.8 Modification of Hydropower Operating Agreements

Modification of hydropower Operating Agreements may result in downstream dissolved oxygen benefits at any pool with hydropower. At the time of this report, Willow Island, Belleville, Racine, R.C. Byrd, Greenup, Meldahl, Markland, McAlpine, Cannelton, and Smithland have hydropower operations. Each of these pools are currently meeting dissolved oxygen targets. However, modification of the Operating Agreements may result increased aeration that can ensure adequate concentrations of dissolved oxygen are available in periods of low flow. Additional investigation in annual dissolved oxygen variability at each pool with hydropower operations should be conducted to better target this measure.

6.9 Rapid Watershed Assessment for Tributaries

RWAs are tools to assist in identification of areas that may need water quality or other ecological improvement. RWAs may be most effective for management of smaller watersheds, like reservoirs and tributaries to the Ohio River. As such, RWAs may be beneficial in any reservoir under consideration for additional management actions.

RWAs have not been developed for the mainstem Ohio River basin. No pool-specific recommendations for RWAs were identified as part of the current effort. RWAs developed for reservoirs and tributaries should be reviewed to assess the impact of the RWA and associated management actions on the mainstem of the Ohio River.

6.10 Conservation Lockages

Additional research is required to ascertain the benefits associated with conservation lockages. Preliminary findings and anecdotal evidence suggest that implementation of conservation lockages on the mainstem of the Ohio River would not be appropriate due to the hydraulic head present at the L/D that would prevent fish movement upstream. Conservation lockages may be appropriate for implementation at tributaries if the hydraulic head would not preclude fish passage. Tributaries with low traffic through L/Ds would be considered priority for conservation lockages. Such tributaries include the upper Allegheny and upper Monongahela Rivers in LRP.

7. Summary of Conclusions and Next Steps

Within the scope of this project, ten viable measures to increase the sustainability of the Ohio River basin were identified. Major benefits and drawbacks of each opportunity documented in this report should be referenced when making decisions regarding further study or implementation of any ecological measure. Preliminary recommendations for further study are summarized by pool in Table 14. A feasibility study is recommended prior to implementation of any measure at a specific site to conduct a comprehensive analysis of the potential benefits, limitations, and drawbacks of implementation at a finer scale than was possible under this study.

This study assumes that modifications to reservoir operations will result in water quality improvement on the Ohio River mainstem. However, the extent to which these operational changes will impact mainstem water quality is not well understood. Additional research and investigation along this vein is required to confirm the potential and extent to which reservoir operations impact the mainstem.

Additionally, recommendations and findings presented in this report are based on existing data. Therefore, further investigation of specific sites within the Ohio River basin may identify resources or opportunities for ecological improvement not represented in the current datasets. It is recommended that feasibility studies or other related efforts characterize the need to obtain updated ecological data and utilize the best available data in decision making.

This report details project activities up to stakeholder engagement. The Team intends to begin stakeholder engagement in March 2022 through identification of and coordination with key stakeholders. The Team intends to broaden and build upon initial stakeholder engagement efforts utilizing future SRP or other project funding. This report will serve as the foundation to build partnerships and identify and implement specific projects in the Ohio River Basin to improve ecological sustainability.

Table 14. Pools were prioritized for further study of each measure using frameworks discussed in Section 6 of this report. The compilation of recommendations below were developed on a basin-wide scale and, therefore, are not prioritized by district. Specific district management and conservation goals should be considered when selecting measures and sites for further study.

	Pool																			
Measure	Emsworth	Dashields	Montgomery	New Cumberland	Pike Island	Hannibal	Willow Island	Belleville	Racine	R.C. Byrd	Greenup	Meldahl	Markland	McAlpine	Cannelton	Newburgh	J. T. Myers	Smithland	Olmsted	Tributaries / Reservoirs
Temporarily raising pool elevation																X	X	X		
Temporarily lowering pool elevation				X			X						X		X	X	X	X		
Flow manipulation for habitat improvement											X	X	X	X		X	X	X	X	
Selective withdrawal retrofits for flood risk																				X
Structural changes (i.e., fishways)	X	X	X	X	X	X	X	X	X	X	X									
Island restoration				X		X	X	X	X			X								
Invasive species control												X	X	X	X	X	X	X	X	
Modification of hydropower Operating Agreements							X	X	X	X	X	X	X	X	X			X		
Rapid Watershed Assessment for tributaries																				X
Conservation lockages																				X

Glossary of Terms

Abundance – number of individuals of a particular species within a particular location

Biodiversity (biological diversity) – variety of life within a particular location; considers both species richness and evenness (i.e., proportion of species at a site)

Conservation lockage – the act of operating lock systems specifically to enhance fish passage

Critical habitat – defined under the Endangered Species Act (ESA) as the specific geographic areas that are essential to the recovery of an endangered or threatened species (USFWS 2021)

Dam Safety Action Category (DSAC) – U.S. Army Corps of Engineers method of assessing the safety and condition of dams to prioritize facilities for rehabilitation

Environmental flows – "the quantity, timing, and quality of water flows required to sustain ecosystems" (USACE HEC, n.d.)

Fishways – structural modifications to dams that provide an opportunity for fish to access waters upstream of dams that would otherwise be difficult or impossible to access

Humid continental climate – climate zone characterized by variable weather patterns and significant seasonal temperature variation; generally found in mid-latitude regions over large land masses; includes Köppen climate zones *Dfa* and *Dfb* (USACE LRD 2009)

Humid subtropical climate – climate zone characterized by hot and humid summers and mild winters with significant precipitation in all seasons; includes Köppen climate zones *Cfa* and *Cfb* (USACE LRD 2009)

Invasive species – non-native species that "cause or have the potential to cause economic, environmental, or human health harm or may threaten natural resources or use of natural resources" (Homans and Newman 2011)

Köppen climate classification system – system that identifies five climate zones based on temperature, precipitation, and other factors (USACE LRD 2009)

Modified Ohio River Fish Index (*m*ORFIN) – index developed by Ohio River Valley Water Sanitation Commission (ORSANCO) to measure the quality of the river and fish community; consists of 13 metrics, including number of native species; number of intolerant species; number of sucker species; number of centrarchid species; number of Great River species; percentage of piscivores; percentage of invertivores; percentage of detritivores; percentage of tolerant species; percentage of lithophils; percentage of non-native species; number of deformities, erosions, lesions, and tumors (DELT) anomalies; and catch per unit effort (CPUE)

Rapid Watershed Assessments (RWAs) – tools to help natural resource managers determine areas of concern or target conservation areas; modeled after the Natural Resource Conservation Service's (NRCS) Rapid Watershed Assessment

Species richness – metric comprising of the number of species in a defined area

Sustainable Rivers Program – a partnership between the U.S. Army Corps of Engineers and The Nature Conservancy (TNC) to improve the ecological equality of rivers through change in water infrastructure operations that may restore or protect ecosystems, while maintaining or enhancing other project benefits and continuing to meet Congressionally authorized purposes (USACE HEC, n.d.)

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