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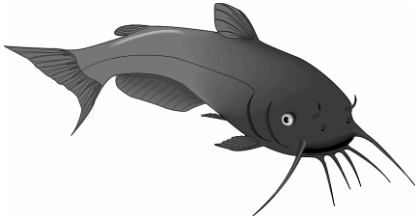


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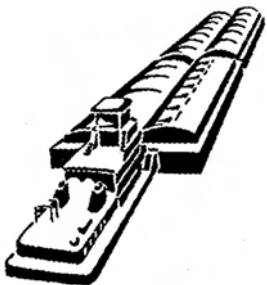


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Interim Report For The Upper Mississippi River – Illinois Waterway System Navigation Study



Improving Fish Passage Through Navigation Dams on the Upper Mississippi River System



US Army Corps
of Engineers

October 2004

Rock Island District
St. Louis District
St. Paul District

Improving Fish Passage Through Navigation Dams on the Upper Mississippi River System

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Interim report

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ABSTRACT: Improving fish passage through dams is recognized as an important way to restore river ecosystems. The Upper Mississippi River System (UMRS) has a series of 29 navigation dams on the Mississippi River and 7 navigation dams on the Illinois River. An interagency Fish Passage Team was formed to plan for improving fish passage at the UMRS navigation dams. This report was prepared to provide information for use in the Upper Mississippi River – Illinois Waterway Navigation Study. Of the 143 native fish species in the UMRS, at least 34 species are migratory. The design characteristics and operation of most UMRS navigation dams allow both upriver and downriver fish passage. Downriver fish passage can occur through the locks and the gated sections of the dams. Some of the dams in the system impose complete barriers to upriver fish passage except through the navigation locks. Opportunity for upriver fish passage through the navigation dams depends on hydraulic conditions at the dams, fish behavior and fish swimming abilities. Operational changes and structural modifications at UMRS navigation dams are possible and may improve opportunity for fish passage throughout the UMRS. Nature-like fishways designed to mimic a natural river channel show the most promise as fish passage improvements on the UMRS. Improved access to habitats should benefit fish and mussel populations in the river system.

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Contents

Preface	viii
1—Introduction	1
Purpose of the Fish Passage Study.....	3
Fish Passage Team.....	3
History of Concern About Fish Passage Through UMRS Dams.....	4
Objectives for Fish Passage Through UMRS Navigation Dams	5
2—Importance of Habitat Connectivity	8
Habitat Connectivity in Floodplain Rivers	8
Importance of Habitat Connectivity to Fish.....	8
Consequences of Restricted Fish Migrations.....	9
Effects on fish.....	9
Differences in historical vs. present fish distribution in the UMRS.....	11
Existing distribution patterns of UMRS migratory fish species.....	11
Observations on differences in fish abundance	12
Effects on Sport and Commercial Fisheries.....	13
Effects on Mussels	14
Effects on Wildlife.....	14
Effects on Ecosystem Structure and Resilience	14
3—Migratory Fishes of the UMRS	16
Fish Migrations	22
Behavior of UMRS Migratory Fishes.....	22
Swimming Performance of UMRS Fishes.....	26
4—Unionid Mussels in the UMRS	31
Present Distribution of Mussel Species	31
Historical Distribution of Mussel Species	31
5—Navigation Dams on the UMRS	33
Locations and Designs	33
Illinois River Dams.....	37
Dam Operation and Hydraulic Conditions	37
Hydraulic Conditions at Illinois River Dams.....	39
Hydraulic Conditions Over Spillways	39
Hydraulic Conditions in Lock Chambers	40
6—Fish Passage Through UMRS Dams	41
Downstream Fish Passage	41

Fish Passage Through Lock Chambers	41
Fish Passage Through Dam Gates	43
Fish Passage Over Spillways	44
Existing Opportunity for Upriver Fish Passage Through Navigation Dams	44
7—Fish Passage to and from the Floodplain.....	46
8—Fish Access to Tributaries	48
9—Nonindigenous Fishes in the UMRS	54
History and Presence of Nonindigenous Fish Species in the UMRS.....	54
Potential for Invasion by Nonindigenous Species	55
Nonindigenous Species Movement.....	56
Potential Effects of Improving Nonindigenous Fish Passage Through UMRS Dams.....	57
10—Alternatives for Improving Fish Passage Through UMRS Dams	58
Assisted Lockage	58
Modified Dam Gate Operation	59
Modified Dam Gate Bay Configuration	60
Technical Fishways.....	60
Nature-Like Fishways at Main Channel Navigation Dams	60
Small-Scale Fishways at Overflow Spillway Sections	61
Large-Scale Fish Passageways	62
Evaluation of Alternative Fishway Types.....	62
11—Alternatives for Limiting Dispersal of Nonindigenous Species	63
Dams Without Fish Passage.....	64
Dams With Fish Passage – Capture and Sorting	66
12—Benefits of Improving Fish Passage Through UMRS Dams.....	67
Increased Access to Habitats	67
Access to main stem river habitats	67
Fish access to tributaries.....	68
Effects of Improved Passage Through Dams on Fish Populations	71
Benefits of Improved Fish Passage to Sport and Commercial Fisheries	73
Other Benefits of Improved Fish Passage.....	73
Benefits of Improved Fish Passage to Mussels.....	73
Lock and Dam 3	73
Lock and Dam 6	74
Lock and Dam 8	74
Lock and Dam 19	74
Lock and Dam 21	74
Illinois River (Marseilles Lock and Dam).....	75
UMR Locks and Dams 2, 5, 9, 14, 22, 24	75
Potential for Whitewater Recreation.....	75
13—Priority of Fish Passage Improvements	76
Existing Opportunity for Fish Passage	76
Access to Habitat	76

Serial continuity of habitat between navigation pools	76
Access to main stem river habitat.....	77
Access to tributaries – Longitudinal Connectivity Index (LCI).....	77
Access to tributaries with hard substrate, high velocities, and cool water	78
Identification of Potential Fish Passage Improvements at Each Lock and Dam.....	79
Cost of Fish Passage Improvements	79
Identification of the Most Practicable Fish Passage Improvements	80
Identification of Priority Sites for Fish Passage Improvements	80
14—Monitoring and Evaluating the Effectiveness of Fish Passage Improvements	86
Setting Objectives for Restoration	86
Monitoring Fish Passage Through Dam Gates	87
Fish Passage Through Locks	87
Fish Passage Through Fishways	87
Effects on Fish Populations	88
Effects on Threatened and Endangered Species	88
Movements of Nonindigenous Species.....	89
Effects on Sport and Commercial Fisheries.....	89
Effects on Mussels	89
Operation, Maintenance, and Modifications to Fishways.....	89
15—Conclusions and Recommendations.....	91
Conclusions.....	91
Recommendations.....	91
References	93
Appendix A: Assessment of Existing Fish Passage Opportunity by Species.....	A1
Appendix B: Unionid Mussels	B1
Appendix C: Cost Estimates for Fish Passage Improvements on the Upper Mississippi River and Illinois Waterway	C1
Appendix D: Alternative Fish Passage Improvements at Upper Mississippi River System Locks and Dams	D1

SF 298

List of Figures

Figure 1.	Upper Mississippi River – Illinois Waterway locks and dams	2
Figure 2.	Pattern of seasonal movements of many Upper Mississippi River System fishes (after McKeown 1984).....	9

Figure 3.	Cross section of a typical Tainter gate on an Upper Mississippi River navigation dam. Dimensions are in feet.....	34
Figure 4.	Cross section of a typical roller gate on an Upper Mississippi River navigation dam. Dimensions are in feet.....	35
Figure 5.	Current velocity near a pier in the end gate bay at Lock and Dam 25 during uncontrolled conditions with dam gates raised out of the water	37
Figure 6.	Percent of time that gates are raised out of the water at Upper Mississippi River navigation dams.....	39
Figure 7.	Contiguous and isolated floodplain areas of the Upper Mississippi and Illinois Rivers	47
Figure 8.	Dams on tributaries to the Missouri, Upper Mississippi, and Illinois Rivers with capacity greater than 5000 acre-feet.....	48
Figure 9.	Total length (km) of fish-accessible tributaries by navigation pool and stream order for the Upper Mississippi River	52
Figure 10.	Total length (km) of fish-accessible tributaries by navigation pool and stream order for the Illinois Waterway.....	53
Figure 11.	Water area (ha) of Upper Mississippi River navigation pools	68
Figure 12.	Length (km) of major tributaries to the first dam or natural barrier, by Upper Mississippi River navigation pool.....	72

List of Tables

Table 1.	Fish Passage Team Members	3
Table 2.	Upper Mississippi River Fishes.....	17
Table 3.	Behavioral and Reproductive Characteristics Fishes in the UMRS That are Known to be or are Probably Migratory.....	23
Table 4.	Estimates of Prolonged Swimming Performance of Upper Mississippi River System Migratory Fishes.....	28

Table 5.	Design Data for Upper Mississippi River Navigation Dams	36
Table 6.	Tributaries to the Upper Mississippi and Illinois Rivers.....	49
Table 7.	Initial Cost Estimate for Locking Fish Through UMRS Dams	59
Table 8.	Aquatic Nuisance Species of Concern in the UMRS	63
Table 9.	Potential Measures to Control the Movement of Invasive Aquatic Species	65
Table 10.	Aquatic Habitat Types and Areas (ha) Associated with Upper Mississippi River Navigation Dams.....	69
Table 11.	Aquatic Habitat Types and Areas (ha) Associated with the Illinois River Navigation Dams.....	71
Table 12.	Longitudinal Connectivity Index for Each Navigation Pool of the UMRS (Pools shaded green have a high LCI, yellow moderate, and red have a low LCI)	79
Table 13.	Estimated Cost of Fishways at UMRS Dams.....	80
Table 14.	Comparison of Upper Mississippi River Dams for Priority for Fish Passage Improvement	83
Table 15.	Comparison of Illinois River Dams for Priority for Fish Passage Improvements, Excluding Peoria and La Grange, Brandon Road, Lockport, and T.J. O'Brien Lock and Dams.....	85

Preface

This work reported herein was conducted as part of the Upper Mississippi River – Illinois Waterway (UMR – IWW) System Navigation Study. The information in this interim report will be considered in the plan formulation process for the System Navigation Study.

The UMR – IWW System Navigation Study is being conducted by the U.S. Army Engineer Districts, Rock Island, St. Louis, and St. Paul, under the authority of Section 216 of the Flood Control Act of 1970. The Navigation Study scope is to examine the feasibility of navigation improvements on the UMR – IWW system to reduce future delays to commercial navigation traffic, and to examine alternatives to attain a more sustainable river ecosystem. The study will determine the location and appropriate timing for navigation improvements and other river management actions in the system from the present to the year 2050. The Navigation Study Feasibility Report and Environmental Impact Statement will serve as the decision documents for recommendations by the U.S. Army Corps of Engineers to Congress.

An interdisciplinary and interagency team prepared this report. The Navigation Study Fish Passage Team consists of scientists and engineers from the U.S. Army Corps of Engineers, the U.S. Geological Survey, the U.S. Fish and Wildlife Service, the Wisconsin Department of Natural Resources, the Minnesota Department of Natural Resources, the Illinois Department of Natural Resources, the Iowa Department of Natural Resources, and the Missouri Department of Conservation.

This report was written by Messrs. Daniel Wilcox, Elliott Stefanik, and Dan Kelner of the U.S. Army Engineer District, St. Paul; Mark Cornish, Daniel Johnson, and Isaac Hodgins of the U.S. Army Engineer District, Rock Island; Steve Zigler of the U.S. Geological Survey Upper Midwest Environmental Science Center; and Brian Johnson of the U.S. Army Engineer District, St. Louis. The authors wish to acknowledge and thank the many others who contributed encouragement, ideas, data, and literature, and would like to thank Dr. Leslie Holland-Bartels, Dr. Joseph Wlosinski, Mr. Michael Dewey, Mr. Brian Ickes, and Mr. Brent Knights of the U.S. Geological Survey Upper Midwest Environmental Science Center for their many contributions to this subject of fish passage through dams on the Upper Mississippi River. The authors also thank Drs. Glenn Parsons, Jan Hoover, and Jack Kilgore, U.S. Army Engineer Research and Development Center (ERDC), for providing fish swimming performance data. Mr. Ken Barr, Environmental Team Leader, and Messrs. Dennis Lundberg and

Scott Whitney, Project Managers, U.S. Army Engineer District, Rock Island; Mr. Jeffrey DeZellar, Project Manager, and Mr. Terry Birkenstock, Environmental and Economics Analysis Branch Chief, U.S. Army Engineer District, St. Paul, provided administrative direction and funding for this effort.

Navigation Study Fish Passage Team members reviewed the draft of this report. Dr. Piotr Parasiewicz of Cornell University, Ithaca, NY, and Dr. Alexander Haro of the S.O. Conte Anadromous Fish Laboratory, Turners Falls, MN, provided independent technical review of the draft report. This study was funded by the U.S. Army Engineer District, Rock Island, through the Upper Mississippi River – Illinois Waterway System Navigation Study.

1 Introduction

The U.S. Army Corps of Engineers is examining the feasibility of improving navigation infrastructure on the Upper Mississippi River System (UMRS) in the Upper Mississippi River – Illinois Waterway System Navigation Study. The UMRs includes the Upper Mississippi River (UMR) extending 1,356 km from the mouth of the Ohio River at Cairo, Illinois, to the head of navigation at Minneapolis, Minnesota (Figure 1). The Illinois River and the Illinois Waterway are part of the UMRs, extending from the confluence with the Mississippi River at Grafton Illinois to Lake Michigan at Chicago. The UMRs also includes navigable portions of the Minnesota River, the St. Croix River (Minnesota-Wisconsin) and the Kaskaskia River (Illinois).

A series of 29 navigation locks and dams is used to manage water levels on 1033 km of the northern reach of the UMR. The head at the dams during low flow ranges from about 2.0 to 11.6 m, but approaches zero at most dams during high flows. The UMR navigation dams have been named by number in sequence downstream from Lock and Dam 1 in St. Paul, Minnesota, to Lock and Dam 27 near St. Louis, Missouri. Exceptions include Upper and Lower St. Anthony Falls Locks and Dams at the head of navigation in Minneapolis, Minnesota, Lock and Dam 5A near Fountain City, Wisconsin, and there is no Lock and Dam 23. Melvin Price Locks and Dam replaced the former Lock and Dam 26. The navigation pool (reservoir) upstream of each dam is referred to by the same number as the dam (e.g., Lock and Dam 9 impounds Pool 9). The Illinois Waterway has eight navigation locks and dams, ranging in head from 1.5 to 12.2 m. The Kaskaskia River has one navigation dam, with a nominal head of 3.6 m.

The Navigation Study is focusing on ways to reduce delays to commercial navigation traffic at the locks in the system. Increased lock capacity and efficiency is expected to result in increased navigation traffic, increased hydraulic disturbance of the river environment, and impacts to habitats and river life. The Navigation Study is also examining ways to manage and restore toward a more sustainable river ecosystem.

The UMRs supports 143 species of indigenous fish (Pitlo et al. 1995) and both recreational and commercial fisheries. Dams restrict fish movements in regulated rivers throughout the world (Petts 1989). On the UMRs, dams impose at least partial barriers to fish passage (Fremling et al. 1989). Improving upriver fish passage through the navigation dams is recognized as a way to manage the UMRs toward a more sustainable river ecosystem (UMRCC 2001).

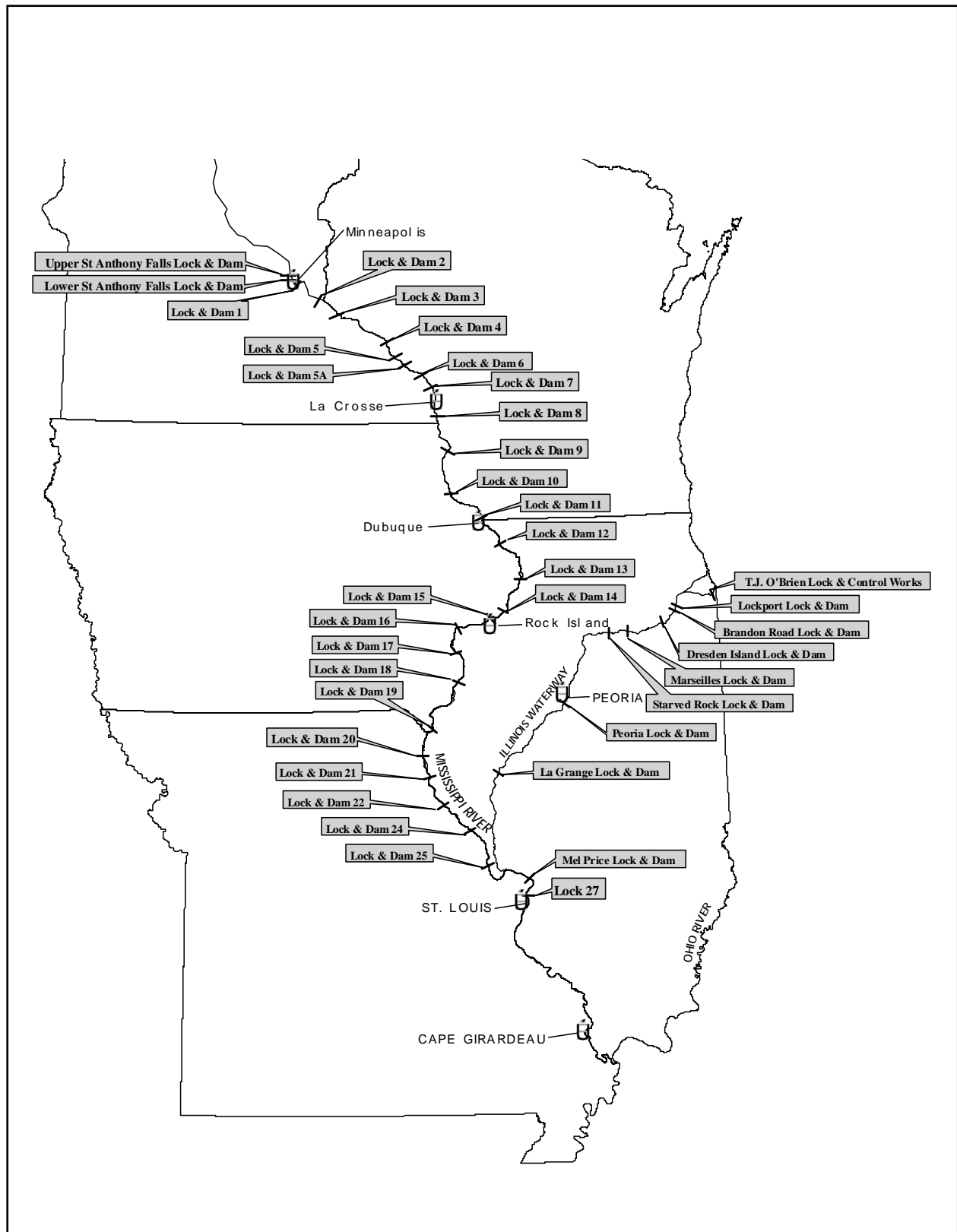


Figure 1. Upper Mississippi River – Illinois Waterway locks and dams

Purpose of the Fish Passage Study

This study was conducted to provide information needed for the Navigation Study planning process. A variety of actions are being considered for navigation improvements, navigation system operation and maintenance, management of habitats and biota, and ecosystem restoration alternatives that would affect or contribute to sustainability of the river ecosystem. Actions to improve fish passage at UMRS navigation dams may be recommended to Congress based on this report. Parts of this report may be included in the Draft Navigation Study Feasibility Report and Draft Environmental Impact Statement. This Fish Passage Study was conducted at a reconnaissance level of detail. Implementation of fish passage improvements at the UMRS navigation dams will require further detailed planning and design.

Fish Passage Team

An interdisciplinary and interagency Navigation Study Fish Passage Team was formed to prepare this report. Fish Passage Team members included engineers and scientists from three Federal agencies and five UMRS states (Table 1). Team members contributed ideas, data, and literature that were incorporated into this report, met to discuss its content, and they reviewed the draft report.

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History of Concern About Fish Passage Through UMR Dams

In the late 1800s, concern about fish passage through dams on U.S. rivers moved Congress to pass a law (Title 33, Navigation and Navigable Waters, Chapter 12, Sub-Chapter 4, section 608) that states:

Whenever river and harbor improvements shall be found to operate (whether by lock and dam or otherwise), as obstructions to the passage of fish, the Secretary of the Army may, in his discretion, direct and cause to be constructed practical, efficient fishways, to be paid for out of the general appropriations for the streams on which such fishways may be constructed.

Fish passage through UMR dams has been a subject of concern since before the construction of the hydropower dam at Keokuk, Iowa in 1913 (now called Lock and Dam 19) (Coker 1914; Scarpino 1985). The proposed construction of the UMR 9-Foot Channel Navigation Project raised public concern about inundation of the Upper Mississippi Wildlife and Fish Refuge (Anfinson 1994, 2003). The U.S. Bureau of Fisheries (Ellis 1932), after a 1930 survey of the UMR, concluded:

...the construction of permanent fixed water-level dams in connection with the 9-foot channel need not be incompatible with fisheries interests. On the contrary, the construction of these dams may be made to increase fish production and to better fish conditions in the upper Mississippi River if proper cooperation be given by those interested in fish conservation. This involves the setting aside of suitable fish refuges, elimination of unnecessary erosion silt from the Mississippi River, and the removal of various municipal wastes from the stream. These are problems facing the fisheries interests, regardless of the construction work of the War Department.

Ellis did not mention concern about fish movements through the proposed dams in the survey report. The report from the Chief of Engineers (War Department 1932), to which the Bureau of Fisheries survey was appended, served as the basis for authorization of the Upper Mississippi River 9-Foot Channel navigation project. The War Department report (page 22, paragraph 19.3) states:

The strong currents through the gates, locks, and other openings, will attract fish to these openings, through which, the board feels, they will be able to pass more readily than through any fishway. Fishways through the dams will, however, be installed if shown to be necessary.

After the construction of the navigation dams on the UMR, the increased extent of shallow aquatic and wetland habitat in the impounded areas of the river floodplain was accompanied by an increased abundance of lentic fishes (Fremling and Claflin 1984). Except for noting the decline in skipjack herring

(*Alosa chrysochloris*), blue suckers (*Cypleptus elongatus*), and Alabama (Ohio) shad (*Alosa alabamae*) (Coker 1930), opportunity for fish passage through UMR dams was not a major issue of concern. A series of fish mark-recapture and telemetry studies was conducted, starting in the 1950s, that demonstrated that a number of UMR fishes migrate through the navigation dams (e.g., Hubley and Jergens 1959; Kuehn 1959; Hubley 1963; Finke 1966; Bahr 1977; Holzer and Von Ruden 1983; Hurley 1983; reviewed by Holland et al. 1984a). Hubley (1963) concluded that, “During periods of high water in the spring the gates of the dams are raised to allow unimpeded flow, and it is thought that most fish pass through the dams during this season.”

Proposals to install hydropower facilities in UMR dams renewed concern about fish passage in the 1980s (Holland 1984; Wilcox 1990). More recently, advances in telemetry have allowed multiple-year tracking of individual fish, documenting their movements (or lack of movements) through UMR navigation dams (Knights et al. 2002; Zigler et al. 2003, in press).

The U.S. Geological Survey conducted a survey of 96 selected UMRS fisheries managers and scientists (Ickes 2000). The survey revealed that the fisheries scientists and managers consider improved fish passage on the UMRS an important aspect of ecosystem restoration. Survey respondents were most concerned about effects of restricted fish passage associated with access to habitat, mussels, community composition and diversity, endangered and threatened species, and fish population dynamics. Survey respondents had lower concern about effects of restricted fish passage through UMRS dams on exotic species and recreational or commercial fisheries.

Decline in aquatic habitats and abundance of UMR fishes in the seven decades since the construction of the navigation dams has generated interest in integrated management of the UMRS ecosystem and has renewed concern about fish passage through the dams. The Upper Mississippi River Conservation Committee, an interagency organization of river managers and scientists, identified improving fish passage through UMRS navigation dams as a primary management objective for restoring the river ecosystem (UMRCC 2001).

That fish passage improvements at UMRS dams have not been made over the last seven decades may be due to the interjurisdictional nature of the fisheries, the relatively low economic importance of the UMRS commercial and sport fisheries to the regional economy, and the lack of obligate diadromous coastal species like salmon or shad in the system. Serious attention to the fish passage needs of interior potadromous species has been increasing only recently.

Objectives for Fish Passage Through UMRS Navigation Dams

Goals and objectives for condition of the UMRS ecosystem have been identified as part of the Navigation Study. They derive from previous river management plans, interagency coordination efforts (Navigation Environmental Coordinating Committee), the UMRS Environmental Management Program

Habitat Needs Assessment, Pool Plans developed by interagency teams at the Corps District level, and from a series of stakeholder workshops conducted for the Navigation Study (DeHaan et al. 2003). Goals and objectives for the UMRS ecosystem that relate to fish passage through the navigation dams include:

a. *Goals* (DeHaan et al. 2003).

- (1) Ensure sustaining, whole, and beautiful river ecosystem.
- (2) Ensure long-term compatibility of the economic uses and ecological integrity of the UMRS.
- (3) Balance economic, environmental, and social conditions so as to meet the current and future needs of the Upper Mississippi River System without compromising the ability of future generations to meet their needs.
- (4) Maintain viable populations of native species in situ.
- (5) Represent all native ecosystem types across their natural range of variation.
- (6) Restore and maintain evolutionary and ecological processes (e.g., disturbance regimes, hydrologic regime, nutrient cycles, etc.).
- (7) Integrate human uses and occupancy within these constraints.

b. *Selected objectives for condition of the river ecosystem* (DeHaan et al. 2003).

- (1) Maintain viable populations of native mussel species throughout their range in the UMRS at levels of abundance in keeping with their biotic potential.
- (2) Maintain the diversity and extent of native mussel communities throughout their range in the UMRS.
- (3) Maintain viable populations of native fish species throughout their range in the UMRS at levels of abundance in keeping with their biotic potential.
- (4) Maintain the diversity and extent of native fish communities throughout their range in the UMRS.
- (5) Prevent the introduction and dispersion of exotic invasive species.
- (6) Reduce the extent and abundance of exotic invasive species.
- (7) Reduce the adverse effects of invasive species on native biota.

Many nonindigenous fish species are threatening native fishes in the United States (Pimental et al. 2000). Limiting the invasion of nonindigenous fish species presents conflicts with efforts to improve fish passage upriver through the navigation dams. The ongoing invasion of Asian carp (FishPro 2004) has raised

concern about the ecological and economic impacts of nonindigenous fish in the UMRS.

No specific objectives for fish passage through the UMRS navigation dams have been set, because no attempts have yet been made to improve fish passage. Objectives for migratory fishes and Unionid mussels should be set to restore them to their pre-impoundment geographical ranges and their population sizes commensurate with their biotic potential. Objectives for fish passage improvements should include objectives for hydraulic conditions and operations and maintenance requirements.

2 Importance of Habitat Connectivity

Habitat Connectivity in Floodplain Rivers

Aquatic habitat connectivity (connection by surface water of sufficient depth to allow movement of materials and organisms) is important for the movement of water, dissolved oxygen, sediment, plant nutrients, organic matter, and river organisms (Knowlton and Jones 1997).

Impoundment of the UMRS navigation system increased lateral connectivity by continuously flooding low-lying portions of the floodplain, which were formerly only seasonally inundated. The navigation dams decreased longitudinal habitat connectivity for migratory fishes by impeding movements along the main channels within the river system (West, Inc. 2000).

Importance of Habitat Connectivity to Fish

An important attribute of aquatic habitat for river fishes is connectivity, the continuous nature of aquatic habitats in main channels, secondary channels, floodplain water bodies, and tributaries. Natural rivers contain a heterogeneous mosaic of aquatic habitats that are very dynamic in both a spatial and temporal sense. River habitats can substantially vary over scales from short- (e.g., flood events), medium- (e.g., seasonal), and long-term (annual, decadal, or longer). Fish in rivers have evolved migratory and life history strategies that take advantage of these complex, changing riverscapes.

Habitat connectivity is important in terms of fulfilling seasonal and life stage-specific habitat needs for river fishes. Fish undergo alimantal (food procurement), climatic (seasonal habitat movements), and gametic (reproduction) migrations in rivers (McKeown 1984) (Figure 2). In addition to the conceptual model by McKeown, others (e.g., Fauch et al. 2002; Schlosser 1991) have identified refinements regarding migrations that are common features of fish life histories including migrations that occur between different feeding habitats, and migrations associated with refugia during catastrophic events such as floods, droughts, and extreme water quality conditions (i.e., high temperature, low dissolved oxygen).

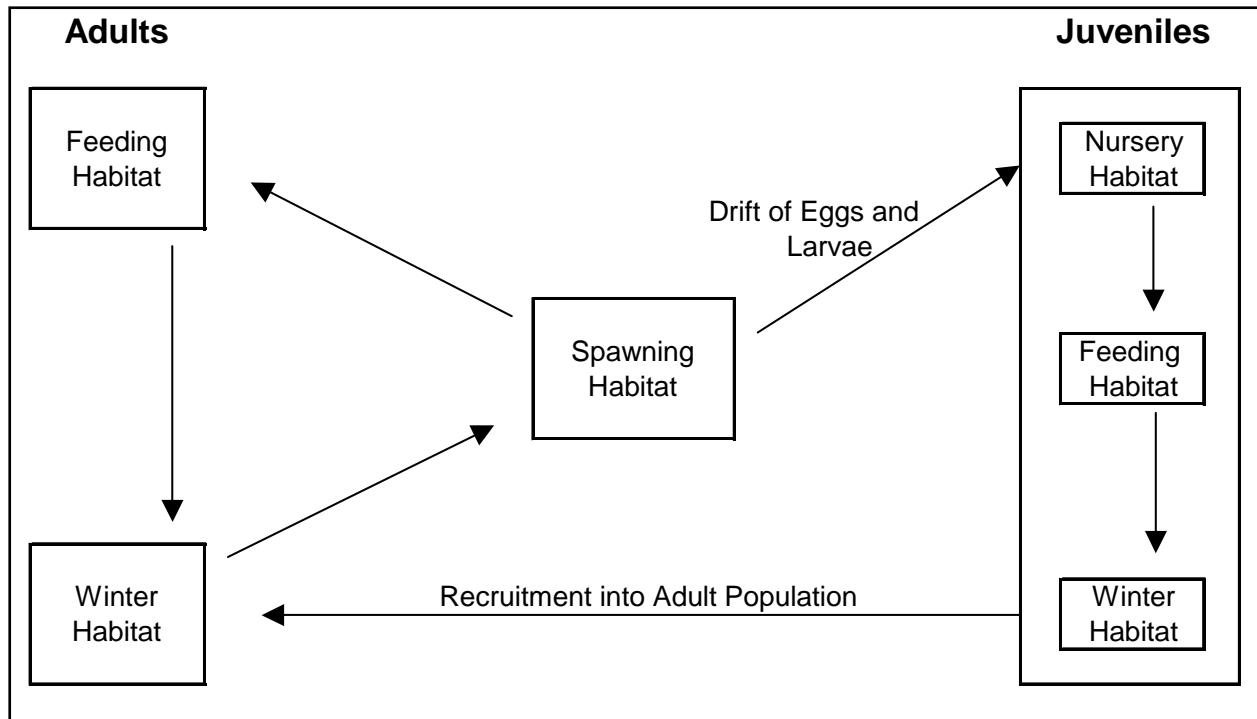


Figure 2. Pattern of seasonal movements of many Upper Mississippi River System fishes (after McKeown 1984)

Daget (1960) recognized both longitudinal (within the main channels and tributaries) and lateral (between the main channel and the floodplain) migration of fishes in floodplain rivers. Welcomme (1979) noted that these categories of fish migration are applicable to floodplain rivers worldwide.

Consequences of Restricted Fish Migrations

Effects on fish

Dams reduce the connectivity of aquatic habitat by restricting movements of river fishes, in addition to other effects of impoundment and river regulation. Impeded fish movements resulting from dams have been implicated in altered fish community structure and declines of many fish populations in rivers throughout the world (Northcote 1998; Pringle et al. 2000). Restrictions on movements of migratory fish in a river system limit the extent and quality of habitats that they can occupy. Effects of reduced access to habitats can be expressed at the individual, population, and community levels.

Information on the effects of dams and reduced connectivity of most potadromous fish populations, including the UMRS, is scarce. However, impeding migrations that freshwater fish use to optimize growth, fecundity, and survival can ultimately affect fish production (Northcote 1978). Reduced access to prime foraging habitat can result in greater expenditure of energy for foraging and reduce growth of individual fish. Reduced access to suitable winter habitat can

limit over-winter survival. Restrictions on movements of migratory fish can have significant adverse effects on pre-spawning movements, limit access to suitable spawning habitats, and limit the size of spawning aggregations.

Fish concentrate in tailwaters below the navigation dams due to the barriers to upriver movement and the deep and higher velocity habitat. Small fish passing downstream through the dam gates may be stressed or disoriented, and vulnerable to predation by piscivorous fish and birds. The navigation dams on the UMRS concentrate migratory fish in tailwater areas; while this provides popular sport fisheries, it exposes fish to greater exploitation.

Some fish species appear to exhibit learned migration behavior, homing to specific locations year after year (Pitlo 1992, Osborn and Schupp 1985). Dams that are occasionally passable, like many on the UMRS, limit reliable access to habitats and the potential for inter-annual reinforcement of learned migration behavior.

Reduced spawning success, individual growth and survival due to restricted access to suitable habitats can be expressed at the population level by reduced recruitment and population size. Many of the migratory fishes in the UMRS have declined in abundance in the seven decades that most of the navigation dams have been in place. The declines in abundance of skipjack herring and Alabama shad following construction of the Keokuk dam in 1913 (Coker 1929) were clear examples of population-level response to restricted range of migration.

Although they are still present above Lock and Dam 19, impoundment of the UMR may have contributed to the greatly reduced abundance of other long-distance migratory species such as lake sturgeon, paddlefish, blue sucker, and blue catfish. The large schools of long-distance migrating fish that were observed prior to dam construction (Coker 1914; Forbes and Richardson 1920; Jordan and Evermann 1923; Coker 1930) may have contributed to their reproductive success. Large numbers of fish in proximity may have stimulated spawning behavior and contributed to higher egg fertilization rates than occur today in smaller spawning aggregations.

Restricted opportunity for access and availability of winter habitat may reduce over-winter survival for a number of migratory species, such as largemouth and smallmouth bass, in some parts of the UMR.

Sufficient interpool movement of most UMR fishes probably occurs to prevent genetic isolation, although opportunity for upriver gene flow is very limited.

Evidence for these effects on UMRS fish populations is limited. Examination of the relative abundance and inter-pool distribution of UMR fishes (Pitlo et al. 1995) provides little indication of the consequences of restricted upriver fish passage on the UMR. UMRS fish population data are generally not available to compare the size and structure of populations of the same species in adjoining navigation pools with a greater and lesser amount of accessible habitat, as mediated by opportunity for fish passage through dams.

Differences in historical vs. present fish distribution in the UMRS

Review and comparison of historical versus present distribution status of UMRS fishes has proven difficult because of limited historical information. Coker (1929) discussed some of the historical distribution of UMR fishes, including a comparison of both spatial and temporal distribution adjacent to the hydroelectric dam at Keokuk, Iowa (now Lock and Dam 19). This facility was constructed in 1913. Except for the navigation lock, the dam is completely impassable to fish, forming the first major migration barrier on the UMR. Coker (1929) reported the dramatic reduction in skipjack herring (*Alosa chrysochloris*) upriver from the Keokuk Dam in the years following construction of this hydroelectric facility. Since Coker's work, the decline of skipjack herring has been well documented.

Skipjack herring were reported to be abundant during the 1860s in Lake Pepin, in what is now Pool 4 (Carlander 1954, cited in USGS 1999). Eddy and Underhill (1974, cited in Becker 1983) stated that between 1911 and 1913 several apparent skipjack had been collected from Lake Pepin, including both adults and young, "...which indicated that they must have spawned somewhere in that vicinity." References discussed by Becker (1983) suggested that the skipjack were found, and may have been common, within the Mississippi River as far upstream as Minneapolis, Minnesota; in the St. Croix River below Taylors Falls; and in the Minnesota River to its headwaters in Big Stone Lake. The St. Croix River joins the UMR above Lock and Dam 3, and the Minnesota River joins the UMR above Lock and Dam 2.

Since construction of the hydroelectric dam at Keokuk, few skipjack herring have been collected farther upstream. Becker (1983) stated that no recent records are available from Wisconsin. Wisconsin DNR lists the skipjack as nearly extirpated in Wisconsin. A small number of individual skipjack herring found their way northward to Pool 9 during the 1993 flood (R. Benjamin, Wisconsin Department of Natural Resources, personal communication, 2003), apparently getting past Lock and Dam 19 through the lock chamber, then through the upriver navigation dams that had their gates out of the water.

In addition to skipjack, Coker (1929) also noted that abundance of blue catfish upstream of the Keokuk dam declined shortly after dam construction, although Coker points out that blue catfish (*Ictalurus furcatus*) may have never been found in large numbers upstream prior to dam construction.

Other UMRS migratory fish species also have had declines in abundance relative to historical levels. Lake sturgeon (*Acipenser fulvescens*), and blue sucker (*Cycleptus elongatus*) are additional migratory species that are apparently less common in the UMR than prior to construction of the navigation system (USGS 1999).

Existing distribution patterns of UMRS migratory fish species

In addition to differences in historical abundance, observable differences in existing abundance of migratory fishes between UMRS pools could indicate

possible areas where reduced fish passage is affecting certain populations. Large datasets for fish abundance on the UMRS do exist in several forms. These include data collected by the Long Term Resource Monitoring Program (LTRMP) through its intensive sampling of the UMRS. To identify possible differences in fish populations among UMRS pools, we reviewed the Upper Mississippi River Conservation Committee (UMRCC) document “*Distribution and Relative Abundance of Upper Mississippi River fishes*” (Pitlo et al. 1995). This review constitutes the best compilation of fish species and relative abundance by UMRS navigation pool.

Pitlo et al. (1995) used a qualitative description of species abundance within each UMRS pool, as well as adjacent sections of the UMR open river reach. These qualitative descriptions of abundance were reviewed for obvious differences in abundance among pools. These observations were made visually without any statistical analyses. To assist with observations, the categories were grouped to see if any discernable differences emerged. For example, data for all species from a pool labeled as Abundant, Common, and Occasional were grouped into a “common” category and compared to those labeled as Uncommon, Rare, Historical, or as a Stray, which were considered “uncommon.”

Observations on differences in fish abundance

The list in Pitlo et al. (1995) does not indicate marked population differences among pools for migratory fish species. However, some general trends are apparent. When Abundant and Common fish are grouped, and compared to those from remaining categories (Occasional, Uncommon, Rare, etc.) a few trends may exist among migratory species. Smallmouth buffalo (*Ictiobus bubalus*) are listed as abundant or common in all pools from Pool 8 downstream, but as occasional or uncommon in all pools upstream. Conversely, spotted sucker (*Minytrema melanops*) are listed as abundant or common in most pools above and including Pool 18, but occasional or uncommon in all pools downstream. These differences in spatial occurrence may be related to habitat preferences as much as habitat connectivity.

When Abundant, Common, and Occasional (A, C, O) fish are grouped, and compared to those from remaining categories (Uncommon, Rare, etc.) additional trends also may exist. Paddlefish (*Polyodon spathula*) were listed as A, C, or O from Pool 9 downstream through all pools. It was uncommon in all pools upstream. Goldeye (*Hiodon alosoides*) were listed as A, C, or O from Pool 19 downstream through all pools, and uncommon in all pools upstream. Similarly, skipjack herring (*Alosa chrysochloris*) and blue catfish (*Ictalurus furcatus*) were listed as A, C, or O from Pool 20 downstream through all pools, and uncommon in all pools upstream.

Conversely, white sucker (*Catostomus commersoni*) and silver redhorse (*Moxostoma anisurum*) were listed as A, C, or O within upper pools (e.g., above Pool 9), and uncommon in all pools downstream. Golden redhorse (*Moxostoma erythrum*) was listed as A, C, or O in all but one pool above Pool 15, and uncommon in all pools downstream.

In addition to these trends, some species appeared to have a patchy distribution within the UMR. For example, American eel (*Anguilla rostrata*) was listed as occasional in all pools above and including Pool 7, and below and including Pool 20, with all pools between listed as uncommon. Other species seemed to have various levels of abundance throughout the river. However, this seemed to vary by species, without any differences seemingly tied to specific locations (i.e., adjacent to specific UMR dams).

Drawing any strong conclusions from Pitlo et al.'s (1995) data set is difficult. Observations of fish species abundance are characterized qualitatively, thus it's difficult to make distinctions between categories such as "common" and "uncommon." Pitlo et al. (1995) also discuss weaknesses of the data set, including gear selectivity, and differences in sampling effort, which were targeted towards various species.

Differences in relative abundance observed among pools or river reaches could be attributable to many factors, including water quality, habitat conditions, harvest levels, restricted ability for upstream movements, as well as others. Effects of impoundment of the river system modified habitat conditions, favoring lentic species and reduced habitat available for lotic species. For example, many species show spatial differences in distribution between the upper, more riverine and the lower impounded reaches within navigation pools (Fremling et al. 1989). These differences in fish abundance are probably due to spatial differences in habitat conditions, and not necessarily to restricted movement through the navigation dams.

Review of the dataset suggests some trends in fish population abundance among pools. As might be expected, Lock and Dam 19 indicates a breakpoint in abundance for fish such as blue catfish, gold eye and skipjack herring. However, even at Lock and Dam 19, which has long been an almost complete migration barrier, differences in fish populations upstream and downstream did not appear as dramatic as might be anticipated.

Effects on Sport and Commercial Fisheries

Large populations of lake sturgeon, paddlefish, channel catfish, blue catfish, and buffalo fish in the UMRS once sustained a regionally significant commercial fishery (Townsend 1902). Impoundment of the river system changed habitat conditions, fish community composition, and the fishing experience for both sport and commercial fishers. Fishing in the riverine reservoirs presents a very different set of conditions than in an unimpounded system. Reduced abundance of commercially harvested fish in the UMRS in the last century has resulted in considerably fewer fishers working the fishery, markedly reduced catches, and marginalized economic importance of the fishery. Restricted movements of fish through the UMRS navigation dams was not the only cause for decline of the commercial fishery, but was a contributing factor.

Sport fishing on the UMRS is popular and an important part of the regional economy (Carlson et al. 1995). For example, angler expenditures associated with Pool 4 sport fishing (Wisconsin and Minnesota) were estimated to be \$3,849,356

in 2000 (J. Hoxmeier, Minnesota Department of Natural Resources, Lake City, MN, personal communication, 2003). Although tailwater sport fisheries are popular, they may result in increased exploitation of game fish where they concentrate below dams. Commercial fishing floats provide anglers without boats opportunity to fish in the tailwater areas below a number of the dams. Restricted movement of fish through the navigation dams is a contributing factor limiting the abundance of game fish, thereby limiting sport fishing opportunity.

Indirect effects of restricted fish movements on sport and commercial fisheries in the UMRS, such as reduced prey abundance, could be significant. For example, large schools of skipjack herring migrated up the river system to spawn. Young of year skipjack herring may have once been an important component of the forage fish base.

Effects on Mussels

Genetic isolation, near-complete interruption of recruitment, and near extirpation of the Unionid mussel, ebonyshell (*Fusconaia ebena*), in the northern reaches of the UMR has been attributed to the markedly reduced upriver migrations of the ebonyshell's glochidial host fish, skipjack herring (Eddy and Surber 1943, Fuller 1980). Restricted movements of fish between navigation pools may restrict gene flow within mussel species dependent on a single fish species as their glochidial host (Romano et al. 1991). Large spawning aggregations of migratory fish may once have played a key role in the life history and reproductive success of Unionid mussels in the UMRS. Appendix B provides accounts by mussel species, their host fish species, and their historic and present distributions.

Effects on Wildlife

Restricted movements of fish in the river system affect fish eating birds, such as herons, eagles, and ospreys, and fish-eating mammals such as river otters, raccoons, and bears. The navigation dams on the UMRS have altered prey abundance and spatial availability for these wildlife species. Eagles concentrate in tailwater areas where open water in winter and fish stressed by passing downstream through the dam gates provide easy foraging. Large spawning aggregations of migratory fish in tributaries may have once provided important seasonal forage.

Effects on Ecosystem Structure and Resilience

Impoundment and regulation of the UMRS had profound effects on ecosystem structure and resilience, by modifying the hydrologic, sediment, water quality, and thermal regimes of the system, as well as causing extensive habitat changes.

Habitat connectivity is important in maintaining biodiversity. Caley and Schluter (1997) and Noss (1990) described factors that structure diversity

patterns of local species assemblages. Connectivity affects beta diversity, the turnover, or movement of species between habitat patches and ultimately gamma diversity, the number of species in a region. Local biotic communities in rivers are in dynamic equilibrium and are often altered by disturbance events such as floods and droughts. Lack of connection between habitats has significant implications for redistribution, recolonization, and local extinctions of fish and other biota within rivers. The fish communities of tributaries are influenced by seasonal influx of spawning fish from higher order rivers in the system. Migratory fish provide concentrations of biomass for piscivorous birds and mammals. Reproductive products, larvae, and juveniles of migratory fishes greatly affect the trophic structure of lower order stream communities.

3 Migratory Fishes of the UMRS

The UMRS supports an ancient and diverse community of fishes. The UMRS fish community is unique among large rivers of the temperate zones in that it supports an unusually large number of fish species (USGS 1999). The UMRS served as a dispersal pathway and refuge for fish during a number of glacial and inter-glacial periods when connections to the Gulf of Mexico, St. Lawrence, Hudson's Bay, and Pacific drainages occurred (Burr and Page 1986). As of 1995, 156 species representing 29 families of fish have been collected from the UMRS since record keeping began in the 19th century (Pitlo et al. 1995). Of these, 143 species are indigenous.

At least 34 fish species are known to be migratory based on mark-recapture and telemetry data (from various reports listed in Ickes et al. 2001) or are probably migratory in the UMR as indicated in fisheries literature (Table 2). This number of migratory species (34) is probably an underestimate of the true number due to the lack of life history information about many fish species in the UMRS. Most of these migratory species are potadromous as defined by Meyers (1949) and Harden-Jones (1968) with annual population movements within the river system. The American eel, a catadromous species, spawns in the mid-Atlantic and migrates into freshwater to mature. Eels must pass upriver through or over UMR dams, as indicated by reports of their presence in the upriver navigation pools (Pitlo et al. 1995, Becker 1983). The Alabama shad is an anadromous species that migrates from the Gulf of Mexico into the Mississippi River system to reproduce (Coker 1930, Robison and Buchanan 1988).

The pallid sturgeon (*Scaphyrhynchus alba*) is a Federally listed endangered species that occurs in the UMR below the confluence with the Missouri River. The species formerly occurred in the Mississippi River at least as far upstream as Grafton, Illinois (Forbes and Richardson 1905), but there are no recent reports from the Mississippi upstream from the mouth of the Missouri (Pflieger 1997). Pallid sturgeon are migratory (USFWS 1993b, Berg 1981), but may never have been abundant in the UMR.

Table 2
Upper Mississippi River Fishes

Families, Species		Indigenous	Introduced	Probable Stray	Known to Move Through UMR Dams	Known to be Migratory in UMR	Probably Migratory in UMR
PETROMYZONTIDAE							
Chestnut lamprey	<i>Ichthyomyzon castaneus</i>	X					
Silver Lamprey	<i>Ichthyomyzon unicuspis</i>	X					X
CARCHARHINIDAE							
Bull shark	<i>Carcharhinus leucas</i>			X			
ACIPENSERIDAE							
Lake sturgeon	<i>Acipenser fulvescens</i>	X			X	X	
Pallid sturgeon	<i>Scaphirhynchus albus</i>	X					X
Shovelnose sturgeon	<i>Scaphirhynchus platyrhynchus</i>	X			X	X	
POLYDONTIDAE							
Paddlefish	<i>Polyodon spathula</i>	X			X	X	
LEPISOSTEIDAE							
Alligator gar	<i>Lepisosteus spatula</i>	X					
Longnose gar	<i>Lepisosteus osseus</i>	X					X
Shortnose gar	<i>Lepisosteus platostomus</i>	X					
Spotted gar	<i>Lepisosteus oculatus</i>	X					
AMMIIDAE							
Bowfin	<i>Amia calva</i>	X					
HIODONTIDAE							
Goldeye	<i>Hiodon alosoides</i>	X					X
Mooneye	<i>Hiodon tergisus</i>	X					X
ANGUILLIDAE							
American eel	<i>Anguilla rostrata</i>	X			X	X	
CLUPEIDAE							
Alabama shad	<i>Alosa alabamae</i>	X				X	
Gizzard shad	<i>Dorosoma cepedianum</i>	X					
Skipjack herring	<i>Alosa chrysochloris</i>	X			X	X	
Threadfin shad	<i>Dorosoma petenense</i>	X					
CYPRINIDAE							
Bigeye shiner	<i>Notropis boops</i>	X					
Bighead carp	<i>Hypophthalmichthys nobilis</i>		X				
Bigmouth shiner	<i>Notropis dorsalis</i>	X					
Blacknose dace	<i>Rhinichthys strartulus</i>	X					

(Sheet 1 of 5)

Table 2 (Continued)

Families, Species		Indigenous	Introduced	Probable Stray	Known to Move Through UMR Dams	Known to be Migratory in UMR	Probably Migratory in UMR
CYPRINIDAE (Cont)							
Blacktail shiner	<i>Cyprinella venusta</i>	X					
Bluntnose minnow	<i>Pimephales notatus</i>	X					
Brassy minnow	<i>Hybognathus hankinsoni</i>	X					
Bullhead minnow	<i>Pimephales vigilax</i>	X					
Central stoneroller	<i>Campostoma anomalm</i>	X					
Channel shiner	<i>Notropis wickliffi</i>	X					
Common carp	<i>Cyprinus carpio</i>		X				
Common shiner	<i>Luxilus comutus</i>	X					
Creek chub	<i>Semotilus atromaculatus</i>	X					
Emerald shiner	<i>Notropis atherinoides</i>	X					
Fathead minnow	<i>Pimephales promelas</i>	X					
Flathead chub	<i>Platgobio gracillis</i>	X					
Ghost shiner	<i>Notropis buchmanii</i>	X					
Golden shiner	<i>Notemigonus crysoleucas</i>	X					
Goldfish	<i>Carrasius auratus</i>		X				
Grass carp	<i>Ctenopharyngodon idella</i>		X				
Gravel chub	<i>Erimystax x-punctatus</i>	X					
Hornyhead chub	<i>Nocomis biguttatus</i>	X					
Mimic shiner	<i>Notropis volucellus</i>	X					
Mississippi silvery minnow	<i>Hybognathus nuchalia</i>	X					
Northern redbelly dace	<i>Phoxinus eos</i>	X					
Ozark minnow	<i>Notropis nubilus</i>	X					
Pallid shiner	<i>Notropis amnis</i>	X					
Pearl dace	<i>Margariscus margarita</i>	X					
Plains minnow	<i>Hybognathus nuchalia</i>	X					
Pugnose minnow	<i>Opsopoedus emiliae</i>	X					
Pugnose shiner	<i>Notropis anogenus</i>	X					
Red shiner	<i>Cyprinella lutrensis</i>	X					
Redfin shiner	<i>Lythrurus umbratilla</i>	X					
River shiner	<i>Notropis blennioides</i>	X					
Rosyface shiner	<i>Notropis rubellus</i>	X					
Sand shiner	<i>Notropis stramineus</i>	X					
Sicklefin chub	<i>Macrhybopsis meeki</i>	X					
Silver chub	<i>Macrhybopsis storeriana</i>	X					
Silverband shiner	<i>Notropis shumardi</i>	X					
Silverjaw minnow	<i>Notropis buccatus</i>	X					
Southern redbelly dace	<i>Phoxinus erythrogaster</i>	X					
Speckled chub	<i>Macrhybopsis aestivalis</i>	X					
Spotail shiner	<i>Notropis hudsonius</i>	X					
Spotfin shiner	<i>Cyprinella spiloptera</i>	X					
Striped shiner	<i>Luxilus chrysocephalus</i>	X					
Sturgeon chub	<i>Macrhybopsis aestivalis</i>	X					

(Sheet 2 of 5)

Table 2 (Continued)

Families, Species		Indigenous	Introduced	Probable Stray	Known to Move Through UMR Dams	Known to be Migratory in UMR	Probably Migratory in UMR
CYPRINIDAE (Cont)							
Suckermouth minnow	<i>Phenacobius mirabilis</i>	X					
Weed shiner	<i>Netropis texanus</i>	X					
Western silvery minnow	<i>Hybognathus nuchalis</i>	X					
CASTOSTOMIDAE							
Bigmouth buffalo	<i>Ictiobus cyprinellus</i>	X			X		X
Smallmouth buffalo	<i>Ictiobus bubalus</i>	X			X		X
Black buffalo	<i>Ictiobus niger</i>	X					
Black redhorse	<i>Moxostoma duquesnei</i>	X					X
Blue sucker	<i>Cycleptus elongatus</i>	X				X	
Golden redhorse	<i>Moxostoma erythrurum</i>	X					X
Greater redhorse	<i>Moxostoma valenciennesi</i>	X					
Highfin carpsucker	<i>Carpiodes velifer</i>	X					X
Longnose sucker	<i>Catostomus catostomus</i>	X		X			
Northern hog sucker	<i>Hypentelium nigricans</i>	X					X
Quillback	<i>Carpiodes cyprinus</i>	X					X
River carpsucker	<i>Carpiodes carpio</i>	X					
River redhorse	<i>Moxostoma carinatum</i>	X					
Shorthead redhorse	<i>Moxostoma macrolepidotum</i>	X					X
Silver redhorse	<i>Moxostoma anisurum</i>	X					X
Spotted sucker	<i>Minytrema melanops</i>	X					X
White sucker	<i>Catosomus commersoni</i>	X					X
ICTALURIDAE							
Black bullhead	<i>Ameiurus melas</i>	X					
Blue catfish	<i>Ictalurus furcatus</i>	X				X	
Brown bullhead	<i>Ameiurus nebulosus</i>	X					
Channel catfish	<i>Ictalurus punctatus</i>	X			X	X	
Flathead catfish	<i>Pylodictis olivaria</i>	X			X	X	
Freckled madtom	<i>Noturus nocturnus</i>	X					
Stonecat	<i>Noturus gyrinus</i>	X					
Tadpole madtom	<i>Noturus gyrinus</i>	X					
White catfish	<i>Ameiurus catus</i>		X				
Yellow bullhead	<i>Ameiurus natalia</i>	X					
ESOCIDAE							
Grass pickerel	<i>Esox americanus vermiculatus</i>	X					
Muskellunge	<i>Esox masquinongy</i>			X			
Northern pike	<i>Esox lucius</i>	X			X		X
UMBRIDAE							
Central mudminnow	<i>Umbra limi</i>	X					

(Sheet 3 of 5)

Table 2 (Continued)

Families, Species		Indigenous	Introduced	Probable Stray	Known to Move Through UMR Dams	Known to be Migratory in UMR	Probably Migratory in UMR
OSMERIDAE							
Rainbow smelt	<i>Osmerus mordax</i>		X				
SALMONIDAE							
Brook trout	<i>Salvelinus fontinalis</i>			X			
Brown trout	<i>Salmo trutta</i>		X	X			
Lake trout	<i>Salvelinus namaycush</i>		X	X			
Rainbow trout	<i>Oncorhynchus mykiss</i>		X	X			
PERCOPSIDAE							
Trout-perch	<i>Percopsis omiscomaycus</i>	X					
GADIDAE							
Burbot	<i>Lota lota</i>	X					
APHREDODERIDAE							
Pirate perch	<i>Apredoderus sayanus</i>	X					
CYPRINODONTIDAE							
Blackspotted topminnow	<i>Fundulus olivaceus</i>	X					
Blackstripe topminnow	<i>Fundulus notatus</i>	X					
Northern studfish	<i>Fundulus catenatus</i>	X					
Starhead topminnow	<i>Fundulus dispar</i>	X					
POECILIDAE							
Western mosquitofish	<i>Gambusia affinis</i>	X					
ATHERINIDAE							
Brook silverside	<i>Labidesthes sicculus</i>	X					
Inland silverside	<i>Menidia berylina</i>	X					
GASTEROSTEIDAE							
Brook stickleback	<i>Culaea inconstans</i>	X					
COTTIDAE							
Banded sculpin	<i>Cottus carolinae</i>	X					
PERCICHTHYIDAE							
Hybrid striped bass	<i>Morone saxatilis x chrysops</i>		X		X		
Striped bass	<i>Morone saxatilis</i>		X				
White bass	<i>Morone chrysops</i>	X			X	X	
Yellow bass	<i>Morone mississippiensis</i>	X					X

(Sheet 4 of 5)

Table 2 (Concluded)

Families, Species		Indigenous	Introduced	Probable Stray	Known to Move Through UMR Dams	Known to be Migratory in UMR	Probably Migratory in UMR
CENTRARCHIDAE							
Flier	<i>Centrarchus macropterus</i>	X					
Green sunfish	<i>Lepomis cyanellus</i>	X					
Longear sunfish	<i>Lepomis megalotis</i>	X					
Pumpkinseed	<i>Lepomis gibbosus</i>	X					
Warmouth	<i>Lepomis gulosus</i>	X					
Orangespotted sunfish	<i>Lepomis humilis</i>	X					
Bluegill	<i>Lepomis macrochirus</i>	X			X		
Redear sunfish	<i>Lepomis microlophus</i>	X					
Rock bass	<i>Ambloplites rupestris</i>	X					
Shadow bass	<i>Ambloplites ariommus</i>	X					
Smallmouth bass	<i>Micropterus dolomieu</i>	X			X		X
Largemouth bass	<i>Micropterus salmoides</i>	X				X	
Spotted bass	<i>Micropterus punctatus</i>	X					
White crappie	<i>Pomoxis annularis</i>	X					
Black crappie	<i>Pomoxis nigromaculatus</i>	X					
PERCIDAE							
Banded darter	<i>Etheostoma zonale</i>	X					
Blackside darter	<i>Percina maculata</i>	X					
Bluntnose darter	<i>Etheostoma chlorosumum</i>	X					
Dusky darter	<i>Percina sciera</i>	X					
Fantail darter	<i>Etheostoma flabellare</i>	X					
Iowa darter	<i>Etheostoma exile</i>	X					
Johnny darter	<i>Etheostoma nigrum</i>	X					
Logperch	<i>Percina caprodes</i>	X					
Mud darter	<i>Etheostoma aspringene</i>	X					
Orangethroat darter	<i>Etheostoma spectabile</i>	X					
Rainbow darter	<i>Etheostoma caeruleum</i>	X					
River darter	<i>Percina shumardi</i>	X					
Sauger	<i>Sander canadense</i>	X			X	X	
Walleye	<i>Sander vitreum</i>	X			X	X	
Slenderhead darter	<i>Percina phoxocephala</i>	X					
Western sand darter	<i>Ammocrypta clara</i>	X					
Yellow perch	<i>Percina flavescens</i>	X					
SCIAENIDAE							
Freshwater drum	<i>Aplodinotus grunniens</i>	X			X		X
MUGILIDAE							
Striped mullet	<i>Mugil cephalus</i>			X			

(Sheet 5 of 5)

Fish Migrations

Major annual movements of populations of migratory fishes to spawning, foraging, and winter habitats occurred within the river system prior to impoundment (Coker 1914, Forbes and Richardson 1920, Coker 1930, Jordan and Evermann 1923). The historical migratory runs of lake sturgeon and skipjack herring in the Upper Mississippi River were spectacular in their abundance, and were noted in the journals of explorers and early travelers.

Each migratory fish species has its own behavioral response to environmental cues for initiating migrations. Many fishes undergo pre-spawning migrations to spawning habitats, spawn in the spring, disperse to feeding habitats, and migrate to winter habitats in the fall (Figure 2). The timing of these movements varies considerably among species, and appears to be generally controlled by water temperature, photoperiod, and river flow (Table 3). The timing of these conditions has to be precise for some species, such as paddlefish, to successfully reproduce (Russell 1986).

Behavior of UMRS Migratory Fishes

Table 3 provides information on reproductive strategy, timing of migration, migration behavior, and size and age at maturity of UMRS migratory fishes. Most of the UMRS migratory fishes are rheophils or rheo-limnophils (Poddubny and Galat 1995) and have non-guarder lithophil or litho-pelagophil reproductive strategies (Balon 1977). Many UMRS fishes, like white bass (Finke 1966), travel widely within the river system between feeding areas.

Skipjack herring, Alabama shad, blue sucker, and blue catfish had major annual northward migrations in the spring, followed by downriver migrations to overwinter in warmer water (Coker 1930). Channel catfish (Newcomb 1989; Hawkinson and Gruenwald 1979; Pellet et al. 1998), flathead catfish (Hawkinson and Gruenwald 1979), walleye (Paragamian 1989), largemouth bass (Pitlo 1992) and smallmouth bass (Todd and Rabeni 1989) return to winter habitat areas. Most catostomids move upriver or into tributaries to spawning areas (Becker 1983, Currie and Spacie 1979). Many fishes move in downriver drift as eggs, larvae, and juveniles (Northcote 1984, Holland et al. 1984b). One catadromous species, the American eel, returns to the Atlantic Ocean to spawn. One anadromous species, the Alabama (formerly named Ohio) shad migrates from the sea to spawn in the Mississippi River system (Coker 1930; Pflieger 1975; Robison and Buchanan 1988). Many species, including nonmigratory ones, move laterally within the river system, seeking suitable habitats as the seasons and river discharge change.

The seasonal timing of migrations of most UMR migratory fishes remains poorly defined. Although the water temperature range during spawning has been reported for most migratory UMR fishes, the water temperature range during pre-spawning movements and the timing of migration to and departure from wintering areas has not. The onsets of prespawning movements for some fishes may be

**Table 3
Behavioral and Reproductive Characteristics Fishes in the UMRS That are Known to be or are Probably Migratory**

Species	Confirmed Upriver Movements Through UMRS Dams	Reproductive Strategy (16)	Spawning Time and Water Temperature During Spawning	Migration Behavior	Size (TL) and Age at Maturity
Silver lamprey <i>Ichthyomyzon unicuspis</i>	No	Non-guarder lithophil	April, May, early June 10 - 18.4 °C ⁴	Migrates upstream to spawn in riffles	225 to 326 mm I (April) ⁴
Lake sturgeon <i>Acipenser fulvescens</i>	Yes	Non-guarder litho-pelagophil	May, early June ¹⁸ 11.7 - 15.0 °C ¹⁹	Moves upstream to spawn ^{18, 19}	Males: 114 cm X to XVII ⁴ Females: 140 cm XXIV to XXVI
Shovelnose sturgeon <i>Scaphyrhynchus platorhynchus</i>	Yes	Non-guarder litho-pelagophil	May, early June 19.5 - 21.1 °C ^{2, 3}	Moves upstream to spawn ^{6, 18, 24} Swims near surface during spawning migration ⁵	Males: 551 mm V ⁴ Females: 605 mm VII
Pallid sturgeon <i>Schaphyrhincus albus</i>	No	Non-guarder litho-pelagophil ?	June through August ³⁷	Spawning migration during spring flood ³⁸	Males: 533 mm III ³⁹ Females: 850 mm FL XV
Paddlefish <i>Polyodon spathula</i>	Yes	Non-guarder litho-pelagophil	April, May ⁷ 10.0 - 17.0 °C	Moves upstream to spawn ⁸ Random feeding movements ⁴	Males: 1020 mm VII ⁹ Females: 1070 mm IX or X
Longnose gar <i>Lepisosteus osseus</i>	No	Non-guarder litho-phytophil	May, June ⁴ 19.5 - 21.0 °C	Ascends rivers to spawn over weed beds of shallower waters ⁴ Ascends streams to spawn on gravel ³⁴	Males: 500 mm III or IV ⁴ Females: 711 mm VI ³⁴
Goldeye <i>Hiodon alosoides</i>	No	Non-guarder pelagophil	May - July ¹⁷ 10.0 - 12.8 °C	Migrates upstream to spawn ^{17, 18}	Males: 200 mm II - III ⁴ Females: 229 mm III
Mooneye <i>Hiodon tergisus</i>	No	Non-guarder pelagophil	April, May ⁴	Migrates upstream in large numbers to spawn in swift water in clear streams ⁴	Males: 255 mm III Females: 362 mm V ^{4, 17}
American eel <i>Anguilla rostrata</i>	Yes	Non-guarder pelagophil (marine)	Unknown	Catadromous. Female elvers move upstream at night along bank or in shallow water. Able to surmount most obstacles to upstream migration. Adult females return to sea to spawn ⁴	Elvers: 65 - 90 mm ¹⁷ Female adults: >900 mm
Alabama shad <i>Alosa alabamae</i>	No	Non-guarder lithophil	May - July ²⁴	Anadromous. Migrates from sea to Gulf Coast rivers, UMR and tributaries to spawn ²⁴	Males: 254 mm Females: 275 mm ³³

(Sheet 1 of 3)

¹ Holland et al. (1984a)	¹⁶ Balon (1977)	³¹ Reynolds (1965)
² Christenson (1975)	¹⁷ Scott and Crossman (1973)	³² Nord (1967)
³ Hurley et al. (1983)	¹⁸ Eddy and Underhill (1974)	³³ Lee et al. (1980)
⁴ Becker (1983)	¹⁹ Priegel and Wirth (1971)	³⁴ Pflieger (1977)
⁵ Jordan and Evermann (1923)	²⁰ Horall (1962)	³⁵ White (1974)
⁶ Helms (1974)	²¹ Finke (1966)	³⁶ Kranz (1978)
⁷ Purkett (1961)	²² Priegel (1969)	³⁷ Forbes and Richardson (1920)
⁸ Southall (1983)	²³ Magnuson and Horall (1977)	³⁸ USFWS (1993)
⁹ Adams (1942)	²⁴ Coker (1930)	³⁹ Keenlyne and Jenkins (1993)
¹⁰ Gates and Gruenwald (1986)	²⁵ Harlan and Speaker (1956)	⁴⁰ Trautman (1957)
¹¹ Von Ruden and Holzer (1989)	²⁶ Shields (1957)	⁴¹ Currie and Spacie (1979)
¹² Hasler et al. (1958)	²⁷ Priegel (1975)	⁴² Pitlo (1992)
¹³ Olson et al. (1978)	²⁸ Franklin and Smith (1963)	⁴³ McMahon and Terrell (1982)
¹⁴ Holzer and Von Ruden (1983)	²⁹ Wright (1973)	⁴⁴ Pellet et al. (1998)
¹⁵ Gebken and Wright (1972)	³⁰ Paragamian and Coble (1975)	

Table 3 (Continued)

Species	Confirmed Upriver Movements Through UMRS Dams	Reproductive Strategy (16)	Spawning Time and Water Temperature During Spawning	Migration Behavior	Size (TL) and Age at Maturity
Skipjack herring <i>Alosa chrysochloris</i>	Yes	Unknown	April - July ²⁵	Upriver movements, probably related to spawning, return to wintering areas ²⁶	254 - 305 mm ²⁶
Blue sucker <i>Cycleptus elongatus</i>	No	Non-guarder lithophil	May - June ²⁴ 10 - 15.6 °C ²⁵	Spring and fall movements, probably related to spawning, return to wintering areas ²⁴	487 mm IV ⁴
Bigmouth buffalo <i>Ictiobus cyprinellus</i>	Yes	Non-guarder phytophil	April - May 15.6 - 18.3 °C ⁴	Upriver movements to dams in spring, also in September and October if flooding ⁴	393 mm III ⁴
Smallmouth buffalo <i>Ictiobus bubalus</i>	Yes	Non-guarder phytophil	April - June 15.6 - 18.3 °C ⁴	Sometimes ascends small streams to spawn ²⁴	324 mm III ⁴
Quillback <i>Carpionodes cyrinus</i>	No	Non-guarder psammophil	May - September 19.0 - 28.0 °C ⁴	Ascends small creeks in spring ⁴	300 mm III (assumed)
Highfin carpsucker <i>Carpionodes velifer</i>	No	Non-guarder psammophil	Mid-May - July ⁴	Upstream migration during May, downstream movement in late August, September ⁴⁰	249 mm III ^{4, 25}
Spotted sucker <i>Minytrema melanops</i>	No	Non-guarder lithophil	May 12.2 - 19.4 °C ⁴	Migrates upstream to spawn in riffles ^{35, 36}	270 mm III (assumed) ⁴
Black redbhorse <i>Moxostoma duquesnei</i>	No	Non-guarder lithophil	April 13.3 - 22.2 °C ⁴	Migrates upstream or downstream to reach spawning riffles ⁴ Ascends headwater streams to spawn ⁴¹	230 mm III ⁴
Golden redbhorse <i>Moxostoma erythrurum</i>	No	Non-guarder lithophil	May 22.2 - >15.6 °C ⁴	Ascends smaller streams in spring, moves downstream in summer and fall, winters in larger streams ⁴⁰	265 mm III ⁴
Silver redbhorse <i>Moxostoma anisurum</i>	No	Non-guarder lithophil	April and May 13.3 °C ⁴	Gathers in large schools over shallow gravel riffles to spawn ³⁴	450 mm V ⁴
Shorthead redbhorse <i>Moxostoma macrolepidotum</i>	No	Non-guarder lithophil	April and May 8.3 - 16.0 °C ⁴	Ascends tributaries to spawn ⁴¹	295 mm III ⁴
Northern hogsucker <i>Hypentelium nigricans</i>	No	Non-guarder lithophil	April and May 15.6 °C ⁴	Upstream movement into tributaries for spawning ⁴¹	Males: 135 mm II ⁴ Females: 170 mm III
White sucker <i>Catostomus commersoni</i>	No	Non-guarder lithophil	April to early May >7.2 °C ⁴	Migrates upstream to spawn ²⁴	Males: 320 mm II - III ⁴ Females: 330 mm III - IV
Blue catfish <i>Ictalurus furcatus</i>	No	Guarder, spelophil	June ³⁴	Seasonal movements in response to water temperature ^{24, 5}	508 mm (V)
Channel catfish <i>Ictalurus punctatus</i>	Yes	Guarder, spelophil	April - October >23.9 °C ⁴	Random feeding movements ¹ Movements to and from wintering areas ^{43, 44}	330 mm IV+ ⁴
Flathead catfish <i>Pylodictus olivaris</i>	Yes	Guarder, spelophil	April 22.2 - 23.9 °C ⁴	Dispersal to spawning areas, summer residence, wintering areas ¹⁰ Limited feeding movements ¹	457 mm IV or V ⁴
Northern pike <i>Esox lucius</i>	No. Probably moves upriver through dams.	Non-guarder phytophil	March - April ²⁸ 1.1 - 2.8 °C	Migrations to spawning areas ²⁸	Males: 617 mm I - II ²⁹ Females: 630 mm II - III

(Sheet 2 of 3)

Table 3 (Concluded)

Species	Confirmed Upriver Movements Through UMRS Dams	Reproductive Strategy (16)	Spawning Time and Water Temperature During Spawning	Migration Behavior	Size (TL) and Age at Maturity
White bass <i>Morone chrysops</i>	Yes	Non-guarder, litho-pelagophil	April - June 12.5 - 26.1 °C ²⁰	Homing to spawning areas ²⁰ Extensive feeding movements ²¹	313 - 363 mm III ⁴
Yellow bass <i>Morone mississippiensis</i>	No	Non-guarder litho-pelagophil	May - June 15 - 22 °C ²⁷	Moves into tributaries to spawn ⁴	234 mm III ^{27,28}
Largemouth bass <i>Micropterus salmoides</i>	Yes	Guarder lithophil	April - July ⁴ 16.7 - 18.3 °C	Movements to and from wintering areas ^{11,42}	254 - 305 mm III - IV ⁴
Smallmouth bass <i>Micropterus dolomieu</i>	Yes	Guarder lithophil	May, June ⁴ 12.8 - 23.9 °C	Possible upstream pre-spawning movements ³⁰ , pre-spawning movements into tributaries ³¹ , movements to and from wintering areas	200 mm ⁴ III - IV ³²
Walleye <i>Sander vitreum</i>	Yes	Non-guarder lithophil	March - April ⁴ 3.3 - 6.7 °C (pre-spawning movements) 5 - 10 °C (spawning)	Adult-learned homing to spawning areas ¹³ Dispersal, possible homing to summer feeding areas ^{13,14} Movements to and from feeding areas	Males: 454 mm IV - V ¹⁵ Females: 589 mm VII or VIII
Sauger <i>Sander canadense</i>	Yes	Non-guarder lithophil	April - May ²² 6.1 - 11.7 °C	Downstream movements, probably related to spawning ¹	Males: 249 mm II ^{22,23} Females: 284 mm III or IV
Freshwater drum <i>Aplodinotus grunniens</i>	No	Non-guarder pelagophil	May, June ⁴ 18.9 - 22.2 °C	Possible upstream pre-spawning movements ¹	Males: 351 mm III ⁴ Females: 386 mm IV

(Sheet 3 of 3)

Note: Reproductive Guilds Definitions for Table 3 (from Balon 1977).
 Open Substrate Spawners
 Pelagophil
 Non-guarder-open substrate
 Nonadhesive eggs are released and scattered in the open water column. Near neutral or positive buoyancy or positively buoyant eggs. Larvae swim constantly and are positively phototropic.
 Litho-pelagophil
 Non-guarder-open-substrate
 Eggs are deposited on rocks or gravel, but larvae become buoyant and water current carry them downstream
 Lithophil
 Non-guarder-open-substrate
 Eggs are deposited on rocks, etc. Larvae are highly photophobic.
 Guarder-nest-spawner
 Eggs are deposited in a single layer or multi layer on cleaned areas of rocks or in pits in gravel.
 Phyto-lithophil
 Non-guarder-open substrate
 Eggs are deposited on submerged vegetation, logs, gravel, or rocks. Many of these species have larvae with cement glands. Larvae usually associated with vegetation.
 Phytophil
 Non-guarder-open substrate
 Eggs are adhesive and attach to vegetation, logs, etc. Larvae have cement glands and are not photophobic.
 Guarders
 Substrate choosers
 Lithophils, phytophils
 Adhesive eggs are scattered or attached to vegetation. Male guards the nest. No cement glands. Larvae swim instantly to avoid anoxic mud bottoms.
 Guarder-nest spawner
 Members are adapted to nesting above or on a mud bottom.

as early as late fall or winter. Walleyes and saugers congregate in UMR tail-waters in late fall and winter, then spawn nearby in spring (Thorn 1984). In addition to the seasonal progression of water temperature and day length, turbidity and photoperiod, changes in river discharge, level of river discharge,

wind-driven currents, olfactory response to influx of materials during runoff, and availability of food resources may influence the timing of fish movements (Northcote 1984, 1998).

Behavioral reaction of UMR fishes to the presence of the navigation dams and associated hydraulic conditions is largely unknown. Teleost fish use their vision, olfactory and tactile senses, their lateral line system and their otoliths and vestibular organ to obtain sensory information about their surrounding environment and to make volitional movements. Recent acoustic tagging and tracking experiments coupled with high-resolution three dimensional numerical hydraulic modeling have indicated that fish detect and respond to certain hydraulic conditions around them in a predictable way (J. Nestler, U.S. Army Engineer Research and Development Center, Environmental Laboratory, Vicksburg, MS, personal communication, 2003; Goodwin et al. 2004). Fish may have behavioral inhibitions to passing through or over the UMRS navigation dams that could restrict their upriver and downriver movements.

Swimming Performance of UMRS Fishes

McPhee and Watts (1976) defined swimming performance as the capability plus the behavioral motivation to swim at a maximum rate of speed. Brett (1964, 1967) provided a suitable framework for fish locomotor studies by distinguishing principal swimming activity levels on the basis of duration of activity for a given speed. Blaxter (1969) defined these levels as burst, prolonged, and sustained speed. Burst speed can be sustained for less than about 15 s. Burst speeds may be 3 or 4 times as fast as prolonged speed, and this level of activity is primarily fueled by hypoxic catabolism of carbohydrates (Farlinger and Beamish 1977). Prolonged swimming, with periods of cruising and occasional bursts, can be maintained for 15 s to 200 min. Sustained swimming activity can be maintained for longer than 200 min.

Fish ascending UMR dams are most likely to be swimming at prolonged speed levels. Fish must swim faster than the ambient velocity to make upstream progress. For example, a fish that can swim on average 10 cm/sec faster than the ambient current velocity would take about 5.6 min to swim upriver across a UMR dam through a Tainter gate opening (33.8 m across the dam sill), and about 11.9 min to swim upriver across a dam through a roller gate opening (71.3 m across the dam sill). In addition to the higher current velocities over the sills of the dams, fish must also negotiate the higher velocities in the tailwater and immediately upriver of the dams. Therefore, although fish may swim at burst speed for short times to pass through the areas of highest velocity, fish ascending through UMR dams must swim for an extended period, and are probably swimming at prolonged levels of activity. Some fish, such as the suckers and sturgeon, are morphologically adapted to maintaining position on the bottom in high current velocities. These fish may be able to pass upriver through UMRS dams by employing a swim and rest strategy.

Many factors influence the swimming performance of fishes. Species, body length, form, physiological condition, conditioning to currents, motivation and behavior, water temperature, concentration of dissolved gasses, turbidity, and

light all influence fish swimming performance (Gray 1957; Bainbridge 1960; Farlinger and Beamish 1977; McPhee and Watts 1976; Hocutt 1973; Dahlberg et al. 1968).

Investigations of the swimming performance of UMRs fishes have been relatively few, in contrast with the considerable testing done with salmonids and marine species. Critical swimming speed is the maximal swimming speed that can be maintained without exhaustion over a specified period of time. Critical velocity is the velocity through which a fish cannot or will not swim, thus creating a velocity barrier. Bainbridge (1960) found that the critical swimming speed-to-length relation varied considerably within and among species. Jones et al. (1974) and Tunink (1975) subjected individuals of various coolwater fish species and sizes to performance trials in test chambers to determine a critical velocity for prolonged swimming activity, sustainable for 10 min. Both Jones et al. and Tunink modeled the critical swimming speed-to-length relationship for each species they tested. The reliability of the experimentally determined critical swimming speed models and their applicability to UMR fishes is limited by the species tested, sizes and numbers of test fish, water temperatures used during the swimming performance tests, and statistical results of the swimming performance trials. The critical swimming speed estimates (U_{crit}) for adult UMR migratory fishes listed in Table 4, which range from 120 cm/sec for white bass to 42 cm/sec for northern pike, must therefore be treated with extreme caution. The swimming performance trials listed in Table 4 were for 10 min duration (prolonged swimming mode of activity) except where noted.

The UMR fishes with the fastest estimated U_{crit} speeds include the lake sturgeon (89 cm/sec), shovelnose sturgeon (82 cm/sec), paddlefish (86 cm/sec), bigmouth buffalo (63 cm/sec), blue sucker (78 cm/sec), blue catfish (69 cm/sec), channel catfish (84 cm/sec), flathead catfish (68 cm/sec), white bass (120 cm/sec), yellow bass (90 cm/sec), largemouth bass (71 cm/sec), walleye (83 cm/sec), sauger (79 cm/sec), and freshwater drum (81 cm/sec). All of these fishes except largemouth bass are rheophilic species. The sturgeons, paddlefish, bigmouth buffalo, blue sucker, large catfishes, white bass, sauger, walleye, and freshwater drum are found in fast current channel habitat within the UMR (Gutreuter and Theiling 1998).

The longnose gar, goldeye, mooneye, smallmouth buffalo, white sucker, spotted sucker, northern pike, and probably silver lamprey, American eel, Alabama shad, and skipjack herring are slower swimmers with estimated critical swimming speeds of under 60 cm/sec. Northern pike have a high burst speed and are commonly seen leaping in attempts to ascend low-head dams. Longnose gar may be faster swimmers than indicated by surrogate swimming performance of northern pike. Longnose gar are often seen swimming rapidly near the surface chasing prey. Skipjack herring may be much faster swimmers than the surrogate model for goldeye indicates. Early reports of skipjack herring noted their speed, "Even in perfectly clear water its movements are so extremely swift that the eye can seldom follow them" (Eddy and Underhill 1974). The goldeye surrogate model may also underestimate the critical swimming speed for Alabama shad, a long-distance migrant. Silver lamprey may not swim quickly, but they attach to

Table 4
Estimates of Prolonged Swimming Performance of Upper Mississippi River System Migratory Fishes

Species	Length mm TL TL or FL / SL	Ucrit Model (cm/sec)	n test fish	Reference	Estimated adult fish Ucrit (cm/sec)	Estimated adult fish Ucrit (ft/sec)	Comments on Ucrit	
Silver lamprey	225	none found					unknown	
Lake sturgeon	1140 (FL)	1.09	2.45+0.23TL	10	8	143	4.7	small test fish (Mean TL = 15.7 cm) 3 min. Ucrit
			16.0+(0.479TL)+(0.0138 T x TL) (T = temperature, degrees C, assume 12 C)	63	9	89	2.9	58 small fish (12 - 55 cm TL) 5 large fish (106 - 132 cm TL)
Shovelnose sturgeon	551 (FL)	1.08	1.6 SL	9	1, 5	82	2.7	adult fish from 46 cm to 50.9 cm SL
			none - tests of individual fish	5	10	65 to 116	2.1 - 3.8	adult fish from 53 cm to 64 cm SL
Pallid sturgeon	533	1.08 (estimate)	1.6 SL (surrogate: shovelnose sturgeon)	0	1, 5	79	2.6	surrogate
Paddlefish	1020 (FL)	1.182	1.0 SL	1	1, 5	86	2.8	1 immature fish (65.4 cm SL)
			1.5 SL	4	1, 5	129	4.2	test fish (37.2 cm - 38.1 SL)
Longnose gar	500	TL = FL	4.9FL^0.55 (surrogate: northern pike)	0	3	21	0.7	surrogate, probably low
Goldeye	200	1.25 (estimate)	2.9 SL	16	1, 5	46	1.5	test fish (24.5 cm - 29.6 cm SL)
			none- field tests of individual fish	2	3	60	2.0	test fish (Mean 22.5 FL)
Mooneye	255	1.25 (estimate)	2.9 SL (surrogate: goldeye)	58	1, 5	59	1.9	surrogate
American eel	900	1.0	none found					unknown
Alabama shad	254	1.25 (estimate)	2.9 SL (surrogate: goldeye)	58	1, 5	59	1.9	surrogate, probably low
Skipjack herring	254	1.25 (estimate)	2.9 SL (surrogate: goldeye)	58	1, 5	59	1.9	surrogate, probably low
Blue sucker	487	1.19	1.9 SL	11	1, 5	78	2.6	test fish (33.9 cm to 48.5 cm SL)
Bigmouth buffalo	393	1.25	2.0 SL	9	1, 5	63	2.1	test fish (16.9 cm to 43.5 cm SL)
			Mean of 3 min. Cv tests	2	7	59	1.9	test fish (mean 40.8 cm SL)

(Sheet 1 of 3)

Table 4 (Continued)

Species	Length mm TL	TL or FL / SL	Ucrit Model (cm/sec)	<i>n</i> test fish	Reference	Estimated adult fish Ucrit (cm/sec)	Estimated adult fish Ucrit (ft/sec)	Comments on Ucrit
Smallmouth buffalo	324	1.21	2.0 SL	5	1, 5	54	1.8	test fish (28.4 cm to 32.7 cm SL)
			25.5 + 0.97 SL	31	2	51	1.7	test fish (14 cm to 33 cm SL)
			Mean of 3 min. Ucrit tests	33	8	64	2.1	test fish (Mean 36.4 cm SL) 3 min. Cv
Quillback	300 (estimate)	1.22	25.5 + 0.97 SL (surrogate: smallmouth buffalo)	0	2	49	1.6	surrogate
Highfin carpsucker	249	1.22 (estimate)	25.5 + 0.97 SL (surrogate: smallmouth buffalo)	0	2	45	1.5	surrogate
Spotted sucker	270	1.18 (FL=1.1SL estimate)	10.03FL ^{0.55} (surrogate: white sucker)	0	3	56	1.8	surrogate
Black redhorse	230	1.23 (FL=1.1SL estimate)	10.03FL ^{0.55} (surrogate: white sucker)	0	3	50	1.6	surrogate
Golden redhorse	265	1.28 (FL=1.1SL estimate)	10.03FL ^{0.55} (surrogate: white sucker)	0	3	56	1.8	surrogate
Silver redhorse	450	1.10 (FL=1.1SL estimate)	10.03FL ^{0.55} (surrogate: white sucker)	0	3	81	2.7	surrogate
Shorthead redhorse	295	1.25 (FL=1.1SL estimate)	10.03FL ^{0.55} (surrogate: white sucker)	0	3	60	2.0	surrogate
Northern hogsucker	175	1.25 (FL=1.1SL estimate)	10.03FL ^{0.55} (surrogate: white sucker)	0	3	45	1.5	surrogate
White sucker	320	1.18 (FL=1.1SL)	10.03FL ^{0.55}	20	3	65	2.1	pooled field test data test fish (17 cm to 37 cm SL)
Blue catfish	508	1.2 (estimate)	3.05SL (surrogate: channel catfish)	0	1, 5	129	4.2	surrogate
			Mean of 3 min. Ucrit tests	3	7	69	2.3	test fish (Mean 44.3 cm SL)
Channel catfish	330	1.2	3.05SL	28	1, 5	84	2.7	test fish (14.2cm to 41.5 cm SL)
			3.0TL at 20 degrees C	25	11	99	3.2	temperature response test test fish (14.0cm to 15.4 cm TL)
			Mean of 3 min. Ucrit tests	4	7	57	1.9	test fish (Mean 36.25 cm SL)
Flathead catfish	457	1.15	3.05 SL	0	1, 5	121	4.0	surrogate

(Sheet 2 of 3)

Table 4 (Concluded)

Species	Length		Ucrit Model (cm/sec)	n test fish	Reference	Estimated adult	Estimated adult	Comments on Ucrit
	mm TL	TL or FL / SL				fish Ucrit (cm/sec)	fish Ucrit (ft/sec)	
Northern pike	617	1.15 (TL = 1.06 FL)	4.9FL ^{0.55}	192	3	46	1.5	test fish (12 cm to 62 cm FL)
White bass	313	1.2 (estimate)	4.6SL	13	1, 5	120	3.9	test fish (9.8 cm to 21.8 cm SL)
Yellow bass	234	1.2 (estimate)	4.6 SL (surrogate: white bass)	0	1, 5	90	2.9	surrogate
Largemouth bass	254	1.215	5.0TL @ 20 degrees C	15	11	127	4.2	temperature response test test fish (5.2 cm to 6.4 mm)
			3.41SL	50	12	71	2.3	conditioning response test test fish (10.9 cm to 14.2 cm FL)
			4.5 TL	>100	13	114	3.8	temperature, D.O. response test test fish (Mean 8.2 cm TL)
			3.84SL	21	14	80	2.6	performance repeatability test test fish small (Mean 9.4 cm FL)
Smallmouth bass	200	1.2	3.41SL (surrogate: largemouth bass)	0		63	2.1	surrogate
Walleye	454	1.2 (estimate)	3.04SL	6	1, 5	115	3.8	test fish (15.4 cm to 40.8 SL)
			13.07FL ^{0.51}	54	3	83	2.7	test fish (8 cm to 38 cm FL)
Sauger	249	1.2 (estimate)	3.8SL	15	1, 5	79	2.6	test fish (5.1 cm to 41.5 cm SL)
Freshwater drum	351	1.3 (estimate)	3.0SL	11	1, 5	81	2.7	test fish (17.7 cm to 30.2 cm SL)
References:								
1 - Tunink (1975)	6 - Parsons and Smiley (1994)	11 - Hocutt (1973)						
2 - Adams and Parsons (1995)	7 - Parsons and Bartlett (1997)	12 - Farlinger and Beamish (1977)						
3 - Jones, Kiceniuk, and Bamf	8 - Webb (1986)	13 - Dalberg et al. (1968)						
4 - Videler (1993)	9 - Peake et al. (1995)	14 - Kolok (1992)						
5 - Schmulbach et al. (1981)	10 - Adams et al. (1997)							

(Sheet 3 of 3)

larger fish such as catfish and paddlefish (Becker 1983). Younger life stages of all these migratory species have slower swimming speeds, given their shorter length.

Fish that swim higher in the water column when migrating (e.g., paddlefish, mooneye, skipjack herring, white bass) may have an advantage in upriver passage through the UMR dams, because lower current velocities occur near the surface in the gate bay openings. Pelagic schooling fish (e.g., white bass, gizzard shad, skipjack herring) may be behaviorally adapted to detect and travel through zones of lower velocity. Schooling fish have hydromechanical advantage and may be able to make progress against faster currents as a school than when swimming individually.

Owing to the uncertainty of swimming performance of UMRS fishes, given the limited available information, additional experimentation is needed to estimate burst and U_{crit} swimming speeds. This information would be very useful in design of fish passage improvements on the UMRS.

4 Unionid Mussels in the UMRS

Present Distribution of Mussel Species

Mussel species present, historical distribution, and relative abundance were determined for the UMRS by navigation pool (Appendix B). Also included were the lower Minnesota and lower St. Croix Rivers in part because the data were readily available. An attempt was made to identify any disjunct mussel populations and locks and dams that may impede fish hosts from these populations.

Historical Distribution of Mussel Species

Historically, 53 mussel species have been documented from the Upper Mississippi, Illinois, lower Minnesota, and lower St. Croix rivers (Appendix B, Table 1). Of these, 16 species do not have migratory fish hosts or the fish host is unknown (see Appendix B, Table 2) (Watters 1994; personal communication with Michelle Bartsch, U.S. Geological Survey Upper Midwest Environmental Science Center, La Crosse, WI, 2003; and various literature sources, primarily Parmalee and Bogan 1998 and the Ohio State University mussel database). Of the 37 species that have at least one migratory fish host, 17 appear to have disjunct or isolated populations, although for the most part they are widely distributed (and occurred historically) throughout the drainage. Two possible exceptions are *Anodonta suborbiculata*, which has recently expanded its historical range into the UMR, and *Lasmigona costata*, which may be naturally patchily distributed. The mussel species accounts in Appendix B lists all known migratory fish species (nonmigratory fish hosts not listed). Species appearing to have disjunct populations are in bold.

These 17 species may benefit from increased migratory fish movement through locks and dams in general but it is difficult to identify a single, or even a few, locks and dams where fish passage improvements could benefit a majority of these species. However, there appear to be some instances where multiple species show similar discontinuity in their present distribution, possibly a result of fish host impediment. The locks and dams identified for fish passage improvements that might have the most impact on mussel populations were those that had the largest number of mussel species associated with them. Possible species that benefited from fish passage improvements at Locks and Dams 3, 6, 8, 19, 21, and the Illinois River Marseilles Lock and Dam are discussed below. Six additional

locks and dams are identified as possibly being beneficial to mussels with increased fish passage.

5 Navigation Dams on the UMRS

Locations and Designs

There are 29 navigation dams on the Upper Mississippi River and 8 navigation dams on the Illinois Waterway (Figure 1). The dams were built over a period between 1895 and 1968. Prior to construction of the navigation project, St. Anthony Falls at Minneapolis, Minnesota, was the only barrier to upriver fish movements on the UMR (Fremling et al. 1989). A connection did not exist between Lake Michigan and the Illinois River until completion of the Chicago Sanitary and Ship Canal in 1900. A series of rock and brush channel training structures (wing dams, closing dams, and shoreline revetments) were built starting in the 1870s to stabilize and deepen the UMR main channel for navigation. Although construction of channel training structures changed main channel geometry, they did not impose much longitudinal restriction on fish passage. The wing dams extend across the main channel borders but do not extend across the main channel. The rock and brush wing dams act as shallow rock riffles, and have relatively low velocities over them especially near the shorelines. The closing dams similarly impose a minor but passable velocity barriers between the main channel and secondary channels.

In 1895, the Lower Dam was constructed about 800 m downriver from St. Anthony Falls. This hydropower dam has an overflow spillway that prevents upriver fish passage. The original Lock and Dam 2 (Meeker Island Dam) was completed in 1907, 6.1 km downriver from St. Anthony Falls. The Meeker Island Dam had a fixed-crest spillway, which presented a barrier to upriver fish passage. The Meeker Island Dam was removed in 1912 to accommodate hydropower development at St. Anthony Falls. Lock and Dam 19 was built at Keokuk, Iowa, in 1913 to provide hydropower generation and a navigation pool over the Keokuk rapids. In 1917, Lock and Dam 1 was completed 8.2 km downriver from St. Anthony Falls.

Locks and Dams 2 through 26 were built in the 1930s, with similar designs, including Tainter (radial) and roller (cylindrical) gates that extend from the water surface to dam sills on the riverbed. Lock and Dam 27 (Chain of Rocks Canal and submerged weir in the main channel) was completed in 1953 to ensure adequate water depth over the lock sill of Lock and Dam 26. Upper and Lower St. Anthony Falls Locks and Dams were built in 1958 and 1963 respectively. The single lock and dam on the Kaskaskia River was completed in 1968. Lock and

Dam 26 was replaced by the Melvin Price Locks and Dam in 1990 about 3 km downriver, and the original lock and dam were removed.

Except for the structures at St. Anthony Falls, Lock and Dam 1, Lock and Dam 19, and Lock 27 (Chain of Rocks Canal), the navigation dams on the UMR are all of similar design, with Tainter gates (Figure 3) and roller gates (Figure 4) that extend to a sill on the river bottom and that can be raised entirely out of the water during high flow (Table 3). There are 24 dams of this type on the UMR. Most of the UMR navigation dams have combinations of roller and Tainter gates. Locks and Dams 2, 19, 24, and Melvin Price Locks and Dam have only Tainter gates, and Locks and Dams 3 and 15 have only roller gates.

Seventeen of the UMR navigation dams have fixed-crest spillways in the earthen dike sections of the dams (Table 5), which are designed to pass flow during periods of high river discharge. Most of the spillways have crests at the project pool elevations. The spillways overflow when open river conditions occur and dam gates are raised from the water. Most of the spillways have an ogee crest design. The Lock and Dam 7 spillway has been rebuilt with a straight ramp on the downstream side. Some of the spillways are notched or have culverts through them to pass flow during periods of lower river discharge. Lock and Dam 3 has a series of rock overflow structures that pass flow except during periods of low river discharge. Melvin Price Locks and Dam has a rock overflow section that passes flow during periods of high river discharge.

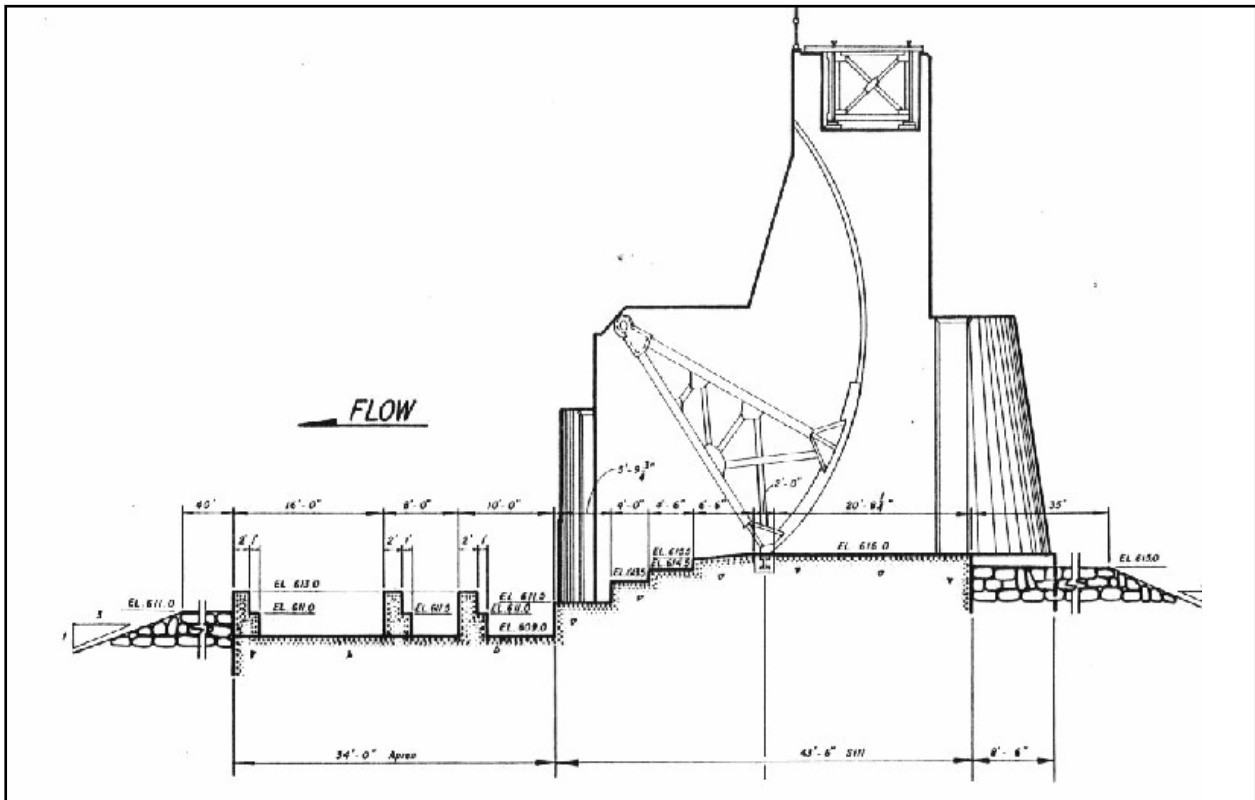


Figure 3. Cross section of a typical Tainter gate on an Upper Mississippi River navigation dam. Dimensions are in feet

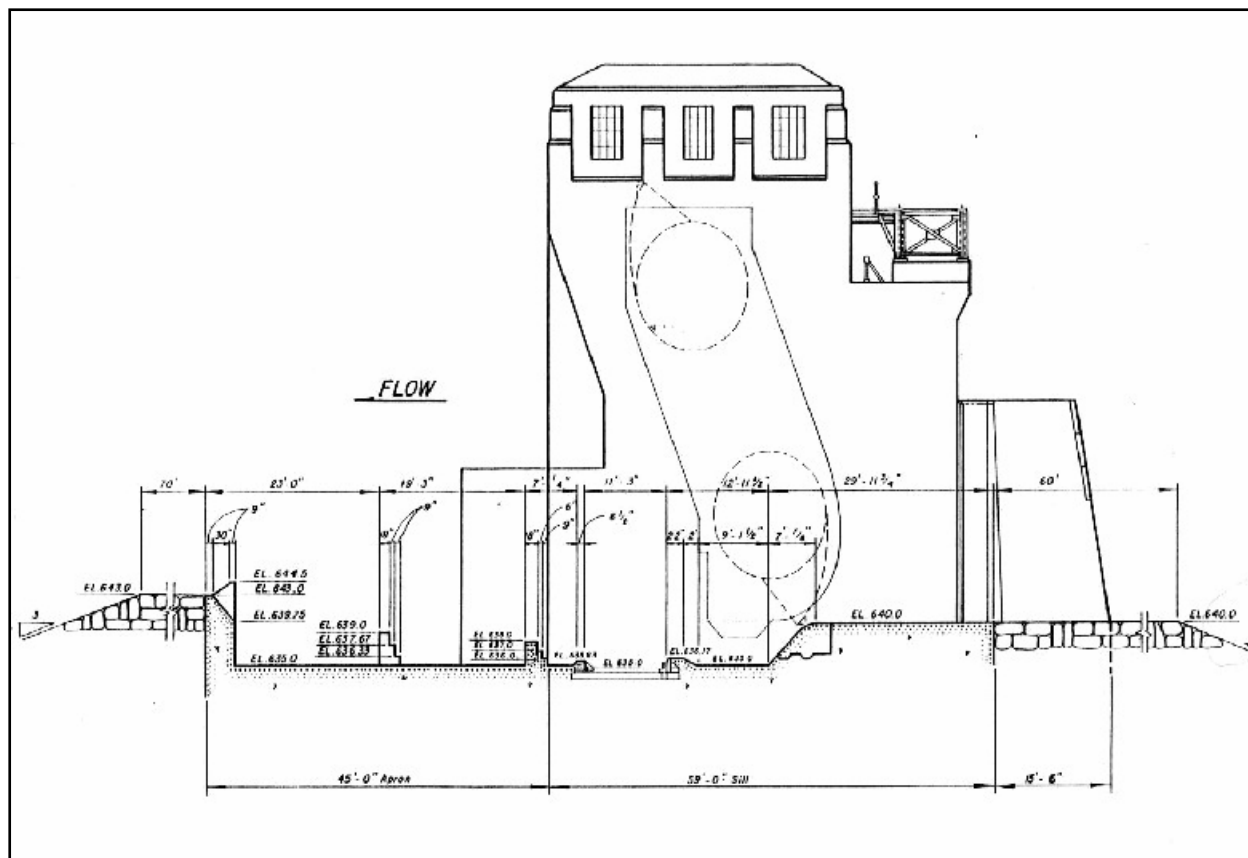


Figure 4. Cross section of a typical roller gate on an Upper Mississippi River navigation dam. Dimensions are in feet

St. Anthony Falls is now armored with a timber and concrete ramp to prevent further upriver erosion of the falls. A fixed-crest horseshoe-shaped dam topped by flashboards extends across the river above the falls. St. Anthony Falls remains a barrier to upriver fish passage. Lower St. Anthony Falls dam includes three Tainter gates in the moveable dam portion and Tainter gates in the upriver ends of the main and auxiliary locks, which can be used to pass higher levels of river discharge. At higher levels of river discharge, the Tainter gates at Lower St. Anthony Falls Dam are raised from the water, and open river conditions may allow upriver fish passage to the base of the falls just upriver. Lock and Dam 1 is an Ambersen-type concrete fixed-crest spillway topped by an inflatable dam, which prevents upriver fish passage. Lock and Dam 19 is a relatively high hydro-power dam with normal head of about 11.1 m (36.3 ft) and with 119 vertical sliding gates across the top. Lock and Dam 19 presents an impassable (except through the lock) obstacle to the upriver passage of fish because of its high head and the large number of gates. All the gates at Lock and Dam 19 have been open at the same time only once, during the 1993 flood, but there was still about 20 ft of head and the gated section of the dam remained impassable to fish moving upriver. Lock 27 (Chain of Rocks Canal) includes a submerged rock weir in the main channel, a bypass canal, and navigation locks. The submerged rock weir is notched in the middle, and more than 3 m of water always flows over it, probably providing continuous opportunity for upriver fish passage.

**Table 5
Design Data for Upper Mississippi River Navigation Dams**

Lock and Dam	Roller Gates			Tainter Gates			Head (m)			Type of Spillway
	Number	Height (m)	Width (m)	Number	Height (m)	Width (m)	Normal Head at Dam (m)	When Gates Open	Project Pool Elevation (m)	
Upper St. Anthony Falls	0			0			15.0		243.6	flashboards on horseshoe dam
Lower St. Anthony Falls	0			3	6.25	17.07	7.6		228.6	none
1	0			0			11.6		221.0	inflatable crest Ambersen dam
2	0			19	6.10	9.14	3.7	0.15	209.5	none
3	4	6.10	24.38	0			2.4	0.09	205.7	overflow dikes
4	6	6.10	18.29	22	4.57	10.67	2.4	0.15	203.3	none
5	6	6.10	18.29	28	4.57	10.67	2.7	0.15	201.2	none
5A	5	6.10	24.38	5	4.57	10.67	2.0	0.15	198.4	fixed spillway
6	5	6.10	24.38	10	4.57	10.67	2.0	0.15	196.6	fixed spillway
7	5	6.10	24.38	11	4.57	10.67	2.0	0.06	194.8	fixed spillway
8	5	6.10	24.38	10	4.57	10.67	2.4	0.21	192.3	fixed spillway
9	5	6.10	24.38	8	4.57	10.67	3.4	0.21	189.0	fixed spillway
10	4	6.10	24.38	8	6.10	12.19	2.7	0.15	186.2	fixed spillway
11	3	6.10	30.48	13	6.10	18.29	2.4	0.11	183.8	none
12	3	6.10	19.60	7	6.10	18.29	3.4	0.12	180.4	fixed spillway
13	3	6.10	30.48	10	6.10	19.51	2.7	0.12	177.7	fixed spillway
14	4	6.10	30.48	13	6.10	18.29	3.3	0.64	174.3	none
15	11	7.92	30.48	0			4.9	0.24	171.0	none
16	4	6.10	24.38	15	6.10	12.19	2.7	0.15	166.1	fixed spillway
17	3	6.10	30.48	8	6.10	19.60	2.4	0.09	163.4	fixed spillway
18	3	6.10	30.48	14	6.10	18.29	3.0	0.15	160.9	fixed spillway
19	0			119	3.35	9.75	11.1		157.9	none
20	3	6.10	18.29	40	6.10	12.19	3.0	0.15	146.4	none
21	3	6.10	30.48	10	6.10	19.51	3.2	0.24	143.3	fixed spillway
22	3	7.62	30.48	10	8.23	18.29	3.1	0.21	140.1	fixed spillway
24	0			15	7.62	24.38	4.6	0.24	136.9	fixed spillway
25	3	7.62	30.48	14	7.62	18.29	4.6	0.15	132.6	fixed spillway
Melvin Price	0			9	12.80	33.53	7.3	0.15	127.7	overflow dike
Kaskaskia	0			2			3.6			none
La Grange	0			1	6.58	23.16	1.5		130.8	weir/earth dike
Peoria	0			1	6.58	23.16	1.8		134.1	weir/earth dike
Starved Rock	0			10	5.79	15.24	5.2		139.9	head gates
Marseilles	0			8 ¹	4.88	18.30	7.3		147.2	fixed spillway
Dresden Island	0			9	4.88	18.3	6.1		153.8	fixed spillway
Brandon Road	0			21	0.70	15.2	10.4		164.1	Concrete/Earth
Lockport	0			0			12.2		175.9	Sluice Gate
T.J. Obrien	0			0			1.5		176.6	Sluice Gates

¹ Marseilles dam has 3 additional tainter gates on side channels (11 total).

Illinois River Dams

On the Illinois River, the La Grange and Peoria dams have wicket gates, with panels that are raised and lowered mechanically from a crane barge. During moderate to higher levels of river discharge, the wicket gates are lowered and boats and fish can pass over the dam freely. The Lockport, Starved Rock, Marseilles, and Dresden Island dams are higher head hydropower dams, where upriver fish passage can only occur through the locks.

Dam Operation and Hydraulic Conditions

At a typical UMR navigation dam, hydraulic conditions through the gate openings change from submerged orifice flow to open channel flow as the gates are lifted out of the water. Calculated average velocities do not fully describe hydraulic conditions through the dam gate openings and over the sill of the dam because flow conditions there are complex. The results of the physical hydraulic model tests (Osvalt and Grace 1984) and acoustic Doppler profiling (Figure 5; B. Johnson, U.S. Army Engineer District, St. Louis, personal communication, 2003) indicate the complexity of the flow over the sills of the UMR navigation dams.

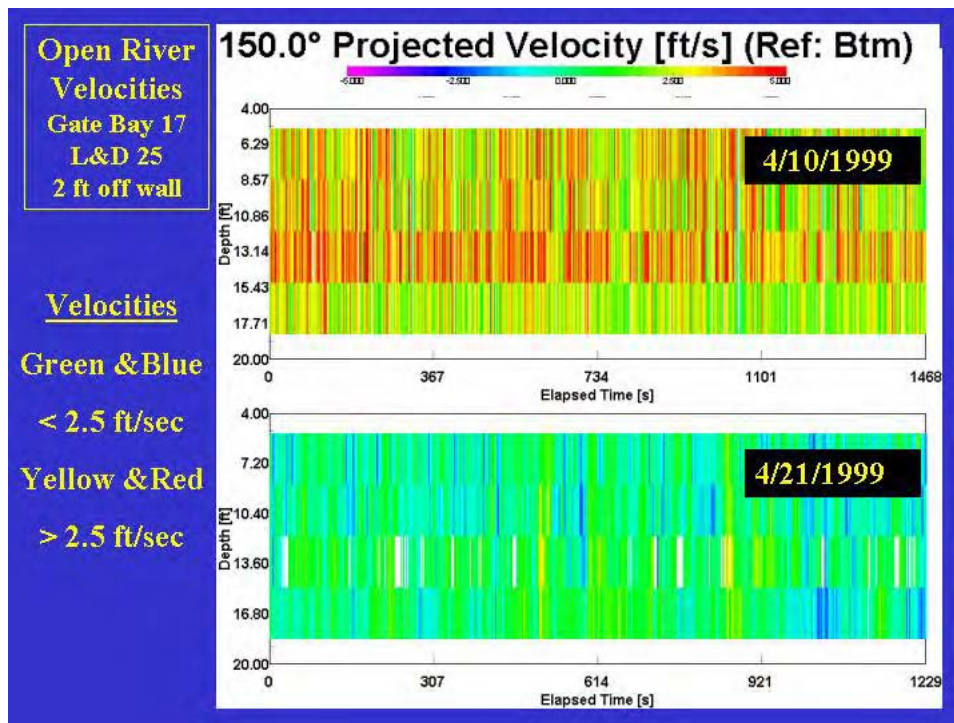


Figure 5. Current velocity near a pier in the end gate bay at Lock and Dam 25 during uncontrolled conditions with dam gates raised out of the water. On 4/10/99, dam gates had just been raised from the water. On 4/21/99, at higher level of river discharge when the overflow section of Lock and Dam 25 was overtopped

When the dam gates are raised out of the water, open channel flow conditions occur in the gate bays, with highest velocities generally occurring at about 0.6 of the depth of water in the gate bays. Velocities through the gate bays are generally under 2 m/sec in the Tainter and roller gate openings, but portions of the gate bay cross section have lower current velocity, under 1 m/sec. Velocities are probably lower near the gate bay walls and sill, but these near-structure velocities are difficult to model or to measure. Fish that swim higher in the water column and that can detect zones of lower velocity in the dam gate bays could have an advantage in upriver passage through the dam. Pelagic schooling fish such as white bass may be behaviorally adapted to detect and travel through zones of low velocity.

At high levels of river discharge under uncontrolled conditions, current velocity through the dam gate bays increases to generally more than 2 m/sec.

Under controlled (gates in the water) conditions with submerged orifice flow, velocity increases in the upstream approach to the gate opening. Downstream of the gate opening, the flow under the gate contracts to a jet then expands, and a reverse current exists in the upper part of the water column above the expanding jet of water emerging from the dam gate opening. This reverse current causes the “back roller” condition that presents a hazard to boaters in the immediate tail-water area. Although it was not possible to estimate velocities in the gate openings under controlled conditions with the physical model (Osvalt and Grace 1984), it appears from the velocities simulated for downstream of the Tainter gates and roller gates that velocities in the gate openings are probably greater than 2 m/sec.

During winter, the UMR dams are operated with the roller gates and some Tainter gates submerged. Water flowing over these gates cascades, and would not allow fish passage, although upriver fish passage is unlikely during winter.

In summary, velocities through the gated sections of the dams are highest when dam gates are in the water, and a submerged orifice flow hydraulic condition occurs in the gate openings. When the dam gates are raised entirely out of the water, open channel flow conditions occur in the gate bays. It is likely that the opportunity for upriver fish passage through UMR dams gate openings can occur only during uncontrolled conditions when the dam gates are raised out of the water. The lowest velocities through the dam gate openings generally occur at the level of river discharge when the dam gates are first raised out of the water. Depending on the dam, the geometry of the navigation pool, and if the dam includes fixed crest spillways, the lowest velocities through the dam gate openings may occur at a slightly higher level of river discharge when the spillways are first overtopped.

Some dams, such as Lock and Dam 25, have flow patterns in the upper approach to the landward gate bays that result in low (and sometimes reversed) velocities through the gate bays during uncontrolled conditions. Hydroacoustic monitoring in the landward gate bay at Lock and Dam 25 revealed that fish were swimming upriver through the gate bay during uncontrolled conditions (dam gates out of the water) (Figure 6). The highest rates of fish passage occurred with

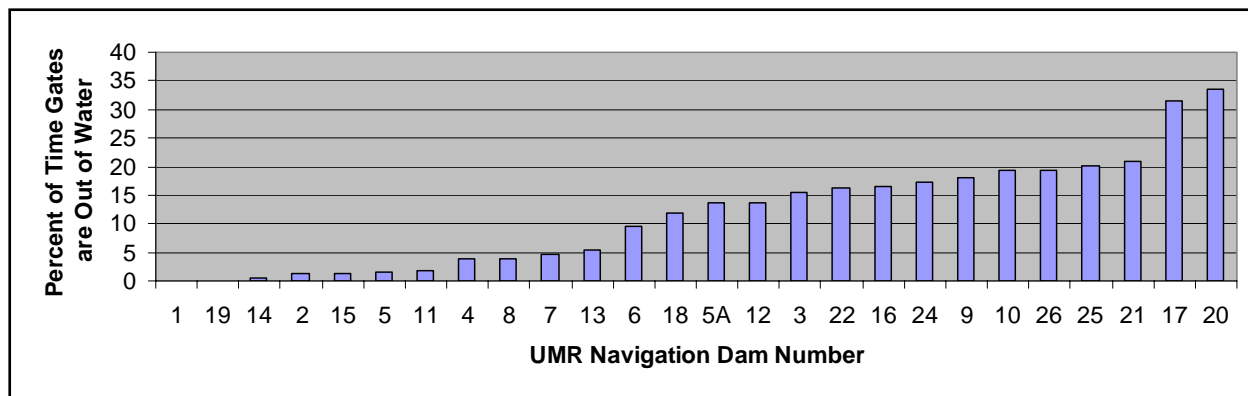


Figure 6. Percentage of time that gates are raised out of the water at Upper Mississippi River navigation dams

the dam gate out of the water, and essentially stopped when the gates went back into the water (B. Johnson, U.S. Army Engineer District, St. Louis, personal communication, 2003).

Hydraulic Conditions at Illinois River Dams

On the Illinois River, the wicket gate dams at Peoria and La Grange allow open river passage to fish most of the time. The dam at Starved Rock, however, rarely goes to an open river condition and presents a barrier to upriver fish passage most of the time. Although some fish may find their way upriver through the lock chambers, the upper Illinois River dams (Marseilles, Dresden Island, Brandon Road, and T.J. O’Brien) all present complete barriers to upriver fish passage.

Hydraulic Conditions Over Spillways

Upper St. Anthony Falls, Lower St. Anthony Falls, Lock and Dam 1, and Lock and Dam 19 have fixed-crest spillways with gates on top. All of these dams are impassable to fish moving upriver except through the locks. Seventeen of the UMR navigation dams have spillways in the dam embankments. These spillways are low, generally at or slightly higher than project pool level, and overflow at higher levels of river discharge. These spillways do not allow fish passage until they overflow. Their design (some are ogee crest, some are wider crest with grouted rock) results in a cascade and a wide, thin sheet of flow until they become submerged during higher levels of river discharge. Some of the spillways are notched to provide more continuous flow to downstream backwaters to maintain water quality. The notches may allow upriver fish passage at lower levels of river discharge than the other parts of the spillways. The spillways are generally located in the paths of former secondary channels, so they serve as secondary sites for upriver fish passage.

Hydraulic Conditions in Lock Chambers

Lock chambers in most of the UMRS dams are 33.5 m (110 ft) by 182.9 m (600 ft). Melvin Price Locks and Dam and Lock 27 in St. Louis (on the Chain of Rocks Canal) have 365.8-m (1,200-ft) by 33.5-m (110-ft) locks, as well as a 33-by 182.8-m lock. Lock 19 at Keokuk Iowa is 33.5 m (110 ft) by 365.8 m (1,200 ft) long. Upper and Lower St. Anthony Falls and Lock and Dam 1 have 121.9-m (400-ft) by 33.5-m (110-ft) locks.

The locks are filled and drained by gravity, through gated filling/emptying conduits within the landward and intermediate lock walls. A typical lock with a head of 2.4 m (8 ft) exchanges a volume of 14,924 m³ (527,036 ft³) and takes about 10 min to drain or fill. Water flows through the filling conduits at a rate of about 25 m³/sec (880 ft³/sec). The flow rate starts out high, then declines as the lock fills or drains. Flow into the lock passes through the filling conduits on each side of the lock chamber and discharges through a series of ports in the lock walls at the floor of the chamber. Flow out of the lock passes through the ports, through the conduits, and discharges through the lock walls downstream of the lower miter gates.

In addition to the flows associated with filling and emptying the lock chambers, towboats entering and exiting entrain most of the water in the lock chambers through the propellers and create turbulent conditions.

Most of the UMRS dams have auxiliary lock chambers, with partially constructed lock walls and only an upper set of miter gates. Melvin Price Locks and Dam has a 365.8-m (1,200-ft) long main lock and a second 182.9-m (600-ft) long lock. Locks and Dams 14 and 15 have functioning auxiliary locks that are used to pass recreational and (at Dam 15) commercial vessels. Except for Lower St. Anthony falls, where the auxiliary lock chamber is used to pass flood flows, all the partially constructed auxiliary lock chambers remain closed.

6 Fish Passage Through UMRS Dams

Downstream Fish Passage

Migratory fish in rivers need to travel both upstream and downstream. The gates on all UMRS navigation dams are never all closed, providing continuously available pathways for downstream fish passage. Opportunity for downstream fish passage by adult fish may be limited by behavioral avoidance of the structures, hydraulic conditions, noise, and lights at the dams. Ichthyoplankton (eggs, larvae) of many fish species passes downstream through the UMRS navigation dams. No research has been done to determine mortality of fish eggs and larvae due to pressure changes and shear forces that occur upon passage through the dam gate openings. The hydraulic stresses on ichthyoplankton passing through dam gate openings are probably less than those encountered on entrainment through commercial towboat propellers. Research on the hydraulic conditions near commercial tows and effects of propeller entrainment on ichthyoplankton in the UMRS (Maynord 2000a, 2000b and 2000c; Keevin et al. 2000; Keevin et al. 2002) indicates that ichthyoplankton mortality on passage through the dam gates is probably low. Ichthyoplankton, juvenile and small adult fish passing downstream through the dam gates may become stressed or disoriented by the hydraulic conditions within the dam gate openings, and may become more vulnerable to predation by piscivorous fish and birds that concentrate in the tailwaters.

Downstream migrating fish can also pass over the spillways at higher levels of river discharge and through the lock chambers. Fish passing over the spillways and through the lock-filling conduits may also suffer stress or mortality from pressure change and shear forces. Construction of fishways could improve opportunity for downstream migrations. The larger the fishways are, the greater is the potential for downstream-migrating fish to find and pass through them.

Fish Passage Through Lock Chambers

Fish frequently occur in lock chambers (Keyes and Klein 1984) and can move upriver and downriver past dams through shipping locks (Carter 1954; Scott and Hevel 1991; Klinge 1994). Keyes and Klein (1984), reporting on a rotenone study in the Willow Island Lock chamber on the Ohio River, collected 69,000 fish weighing nearly 10,000 pounds. Zigler et al. (in press) located a

paddlefish in a lock chamber that was tagged with a radio transmitter. Navigation Study hydroacoustic tracking and netting of fish at Lock and Dam 25 revealed that many fish occur in the lock chamber and very few are injured or killed by towboat propellers (B. Johnson, U.S. Army Engineer District, St. Louis, personal communication, 2003). Modified lock operation has been used to reintroduce sauger to the upper Allegheny River (P. Dodgion, U.S. Army Engineer District, Pittsburg, PA, personal communication, 2002).

Upriver and downriver fish passage through lock chambers undoubtedly occurs, but the locks at most of the UMRS dams do not provide a suitable pathway for upriver migrations of fish populations. Attracting flows into the lock chamber are minimal compared to the attracting flows at the dam gates. Upon entering through the lower miter gates of a lock, a fish going upriver would have to swim about 200 m through the lock chamber through currents not oriented in the direction of river flow, and exit the upper miter gate area before being subjected to entrainment in the lock emptying conduits during the following downlocking cycle. Fish may accumulate in lock chambers because it may be difficult for them to find their way out as they avoid being entrained in towboat propellers and the lock emptying conduits.

The frequency and seasonal timing of lock operation also limits the potential for the locks to be effective pathways for fish migration. The lock chambers are operated only to pass navigation traffic and are only intermittently available for fish passage. In the southern reaches of the UMR and on the Illinois River, navigation occurs all year. In the northern reaches of the UMR, generally north of Lock and Dam 15 at Rock Island Illinois, navigation closes for the winter in late November. On average, Lock and Dam 10 at Guttenberg, IA, first opens on March 11 and the first towboats reach St. Paul on March 19. The number of lockages each year varies from about 2800 (both upbound and downbound) at Lock and Dam 1 to about 7400 at Melvin Price Locks and Dam (Lock and Dam 26) near St. Louis. An average of between about 6 and 11 upbound lockages per day during the navigation season at UMR navigation dams provides only a limited amount of time each day for fish use the lock chambers for upriver passage. The availability of locks for upriver fish passage is further limited by seasonal timing of navigation traffic, which generally is greater in the summer and fall, vs. the seasonal timing of upriver fish migrations, which mostly occur in the spring.

An exception may be the Kaskaskia Lock and Dam, which has only two Tainter gates located immediately adjacent to the lock, and has low traffic rates. That lock may be operated to effectively pass fish.

Fish swim into lock chambers and are carried in live wells on sport fishing boats. Holzer (1989) reported that fish caught in bass tournaments are occasionally released in adjacent pools after being transported in boat live wells. D. Sallee (Illinois Department of Natural Resources, personal communication) noted that walleye and sauger were transported through three sets of locks in live wells during fishing tournaments. Bertrand and Sallee (1985) found indications that walleye and sauger may have passed through lock chambers transported by fishermen in the live wells of their boats.

Fish Passage Through Dam Gates

Most of the navigation dams on the UMR allow some upriver fish passage due to their unique design and operating characteristics. With gates that extend to sills on the river bed, most of the UMR dams were designed to maintain minimum water levels to allow navigation during periods of low to moderate flow. The dams were designed to allow river flow to pass unrestricted with gates raised entirely from the water during periods of high river discharge.

Estimates of velocities in the dam gate openings made using a physical hydraulic model indicate that velocities are sufficiently low for upriver passage by some UMR migratory fish species (under 1 m/sec) during uncontrolled discharge conditions, when the dam gates are raised entirely out of the water. Flow through the dam gate openings is then open channel flow. Larger fish have been confirmed to swim upriver through UMR dam gates by telemetry and hydro-acoustic tracking. Open channel hydraulic conditions through the dam gate openings occur during periods of higher river discharge. These relatively low current velocities (under 1 m/sec) during uncontrolled conditions through the dam gates openings are probably too fast for many of the smaller and weaker swimming migratory fish species in the UMRS.

Velocities through the gate bay openings are much higher during periods of lower river discharge under controlled conditions when the dam gates are in the water, and upriver fish passage during periods of low river discharge is unlikely. Hydraulic conditions through the dam gate openings during controlled conditions are orifice flow, with the plane of highest velocity occurring just downstream of the lip of the dam gate.

The lowest velocities through the dam gate openings occur when the gates are first raised from the water. At dams with overflow spillways, the lowest velocities through the dam gates may occur when the spillways are first overtopped.

Lock and Dam 19 at Keokuk, Iowa, is a high dam built in 1913 for hydro-power. Lock and Dam 19 has gone to open river conditions (gates out of the water) only once since it was constructed, during the extreme flood of 1993. Lock and Dam 1 in Minneapolis is also a high dam. These two dams are complete barriers to upriver fish movements. Lock and Dam 1 is 8 km downriver from St. Anthony Falls, which is a natural barrier to upriver fish movements. Lock and Dam 19, however, denies fish access to 776 km of mainstem UMR and numerous tributaries.

Locks and Dams 3, 5a, 9, 10, 12, 16, 17, 20, 21, 22, 24, 25, and 26 go to uncontrolled conditions early in the discharge hydrograph and may provide opportunity for upriver fish passage during most years (Figure 6). Locks and Dams 2, 5, 7, 11, 14, and 15 have high controlled discharge capacity for their sites, have low probability for uncontrolled conditions, and present barriers to upriver fish passage during most years.

Recent evidence of fish movements through UMRS dams (Zigler et al., in press; B. Johnson, U.S. Army Engineer District, St. Louis, personal communication, 2003), fish swimming speeds (Table 4), analyses of historic mark-recapture and telemetry studies (Wlosinski et al., in press; Holland et al. 1984b), and telemetry work with fast-swimming adult lake sturgeon (Knights et al. 2002) and paddlefish (Zigler et al. 2003), shows that upstream movements of fish through dam gates is highly unlikely except under uncontrolled conditions.

Each navigation dam reaches controlled discharge capacity at a different level of river discharge, when the dam gates are raised out of the water, and the dam is in an “open river” or “uncontrolled” condition. Opportunities for upriver fish passage through UMRS dam gates vary by dam and by year because they are closely linked to uncontrolled conditions (Zigler et al., in press; B. Knights, U.S. Geological Survey Upper Midwest Science Center, La Crosse, WI, personal communication, 2003.). Dams with low controlled discharge capacity may therefore present more frequent and longer opportunities for upriver fish passage than other dams with high discharge capacity.

The opportunity for upriver passage through UMR dams requires that physiologically capable and behaviorally motivated fish find their way to a portion of the dam where hydraulic conditions allow passage. The favorable hydraulic conditions at the navigation dams must occur during the period of seasonal migration for the fish populations. Because most UMRS dams are out of control 15 percent of the time or less (only two dams are open more than 30 percent of the time), upriver fish passage through UMRS dam gates is restricted during most periods of all years with some dams entirely blocking fish passage through the gates during most or all years. Many of the navigation dams in the northern reaches of the UMR are at open river conditions during cold-water periods that are not conducive to fish passage.

An evaluation of the existing potential for upriver passage by migratory fish species in the UMRS is provided in Appendix A.

Fish Passage Over Spillways

See the discussion of hydraulic conditions at spillways, above.

Existing Opportunity for Upriver Fish Passage Through Navigation Dams

The migratory fish species in the UMR with the highest swimming speeds appear to have the best opportunity for upstream passage through most UMRS dams during most years, based on their swimming performance, timing of upriver movements, and hydraulic conditions at the dams (see Fish Species Accounts, Appendix A). Lake sturgeon, shovelnose sturgeon, paddlefish, white bass, yellow bass, and possibly skipjack herring are strong swimmers and tend to migrate high in the water column (skipjack herring are restricted to the UMR below Lock and Dam 19).

The other migratory species appear to be able to pass upriver through UMRS dams only during periods when hydraulic conditions at the navigation dams are most favorable, when open river conditions at the dams coincide with periods of upriver fish migration, or not at all. Some fish species, such as northern pike, probably do not have the swimming performance to swim upriver through UMR navigation dams. Other species that migrate during periods of lower river discharge, such as white sucker, walleye, and freshwater drum, have limited opportunity for upriver fish passage due to timing of their migrations. Depending on the controlled discharge capacity of the navigation dams and the timing of fish migrations, the window of opportunity for upriver passage varies markedly between dams and fish species. The presence of multiple dams reduces the cumulative probability of successful upriver migration for long distance migrants.

7 Fish Passage to and from the Floodplain

Many fish species in the UMRS require access to both channel habitats and floodplain water bodies. Seasonal use of floodplain habitats is common for river fishes world-wide (Welcomme 1979). Much of the floodplain of the UMRS has been sequestered from the main channels by levees, floodwalls, highway embankments, railroad grades, and earthen embankments at the navigation dams.

Levees isolate floodplain areas from the river, eliminating connectivity between floodplain habitats and the main river channels, and allow conversion of natural floodplain habitats to other land uses. Many of the agricultural and urban flood protection levees on the UMRS were constructed prior to impoundment of the navigation system. The locations of levee and drainage districts on UMRS floodplains are presented in West, Inc. (2000) and in the Scientific Assessment and Strategy Team database (1995). Levees are most prevalent in the Mississippi River south of Rock Island and in the La Grange and Alton pools on the Illinois River. The majority of levees were constructed to protect agricultural areas from moderate floods. Although little of the floodplain has been sequestered from the river by levees in Pools 4 through 14, over half of the floodplain area of the UMR from the Quad Cities to Cairo and most of the Illinois River floodplain is isolated from the river by levees (Figure 7; Delaney and Craig 1997).

The environmental impacts of levees and induced floodplain development are extensive. Natural vegetation in leveed areas has been removed and largely converted to agriculture. Wetlands were filled and the floodplain behind levees has been drained and leveled. Floodplain lakes have been isolated from the river and tributaries have been channelized. The areas protected by levees have lost most of their habitat value.

The isolation of most of the floodplain from the river channels in the southern reaches of the UMR and Illinois River has denied river fishes access to floodplain habitat. The fish community of the Open River reach (Lock and Dam 26 to Cairo Illinois) is largely composed of rheophilic species, given the isolation of the river from the floodplain by levees in this reach.

Lentic species such as Centrarchids have few places to reproduce or spend the winter in these reaches of the UMRS.

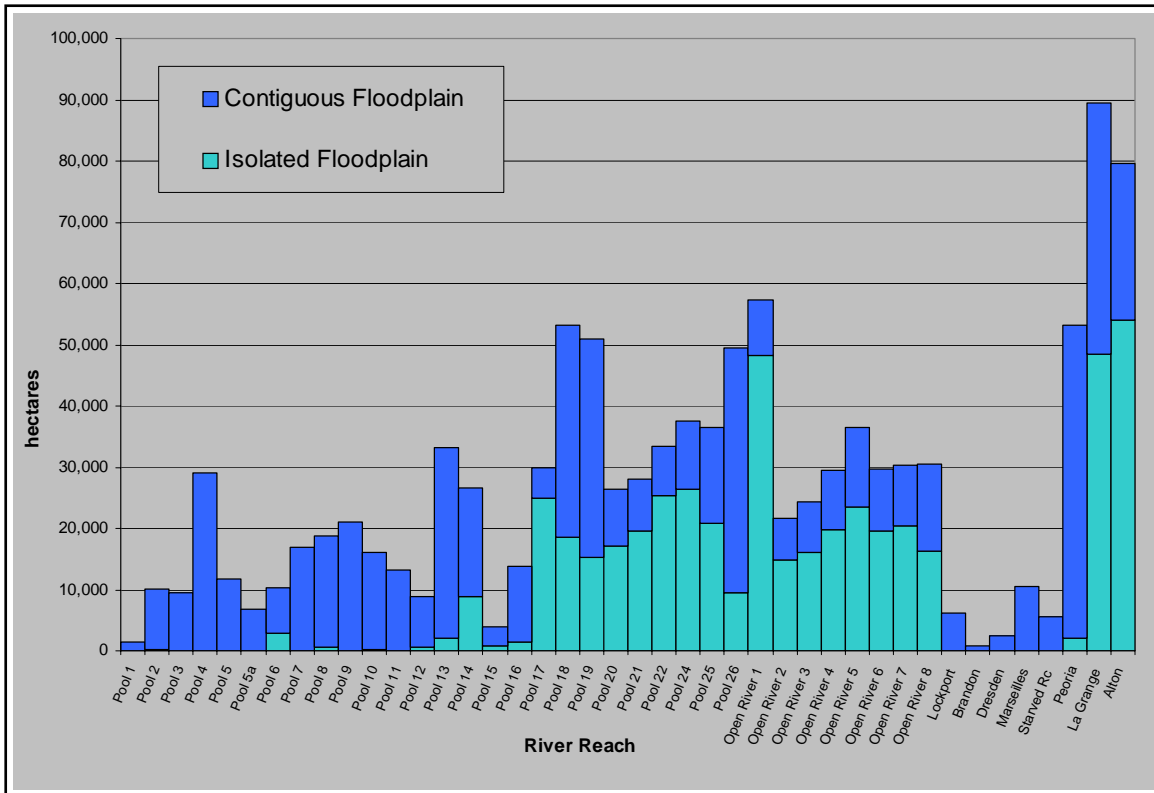


Figure 7. Contiguous and isolated floodplain areas of the Upper Mississippi and Illinois Rivers

The states and the U.S. Fish and Wildlife service manage shallow floodplain impoundments on the UMRS for waterfowl. Called moist soil units, these typically sequester portions of contiguous and impounded backwaters behind low 1- to 2-m (3- to 6-ft) levees. Most are overtopped during typical spring floods and many have water level management capabilities through the use of gravity drains, pumps, or both. Drains and pumps are used to lower water levels to pre-impoundment, low flow water surface elevations. The technique allows managers greater control to prevent small hydrological variations that can limit emergent aquatic plant production. Public and private management areas with water control capabilities affect about 10 percent on the nonleveed Illinois River Floodplain and about 7 percent of the nonleveed Mississippi River between Pool 12 and Pool 26 (Havera et al. 1995).

The operation of moist soil management units for avian wildlife is detrimental to fisheries because they trap young-of-the-year fish produced in the units, they cause mass die-offs of adults trapped by dewatering, they can entrain and kill fish in pumps, they sequester valuable backwater areas and prevent fish movements, and they may reduce water quality in the river when water low in dissolved oxygen is pumped out of the unit and into the river. Fisheries impacts and management opportunities in moist soil units, however, have not been adequately assessed. There may be water control structure designs and operating strategies for isolated floodplain water bodies that could be applied to restore aquatic habitat connectivity as well as the abundance of emergent aquatic plants.

8 Fish Access to Tributaries

Dams on tributary rivers have also reduced connectivity of UMRS aquatic habitats. Prior to construction of the UMR navigation system and tributary dams, fish had access to most of the more than 30,000 miles of rivers and streams within the UMRS basin, except the headwaters of the Mississippi, St. Croix, Chippewa, WI, and Black rivers where falls imposed natural barriers to upriver fish movements. There are 266 larger dams impounding reservoirs of over 6.1 million m³ (5,000 acre-ft) exist on UMRS tributaries (FEMA 1996; Figure 8).

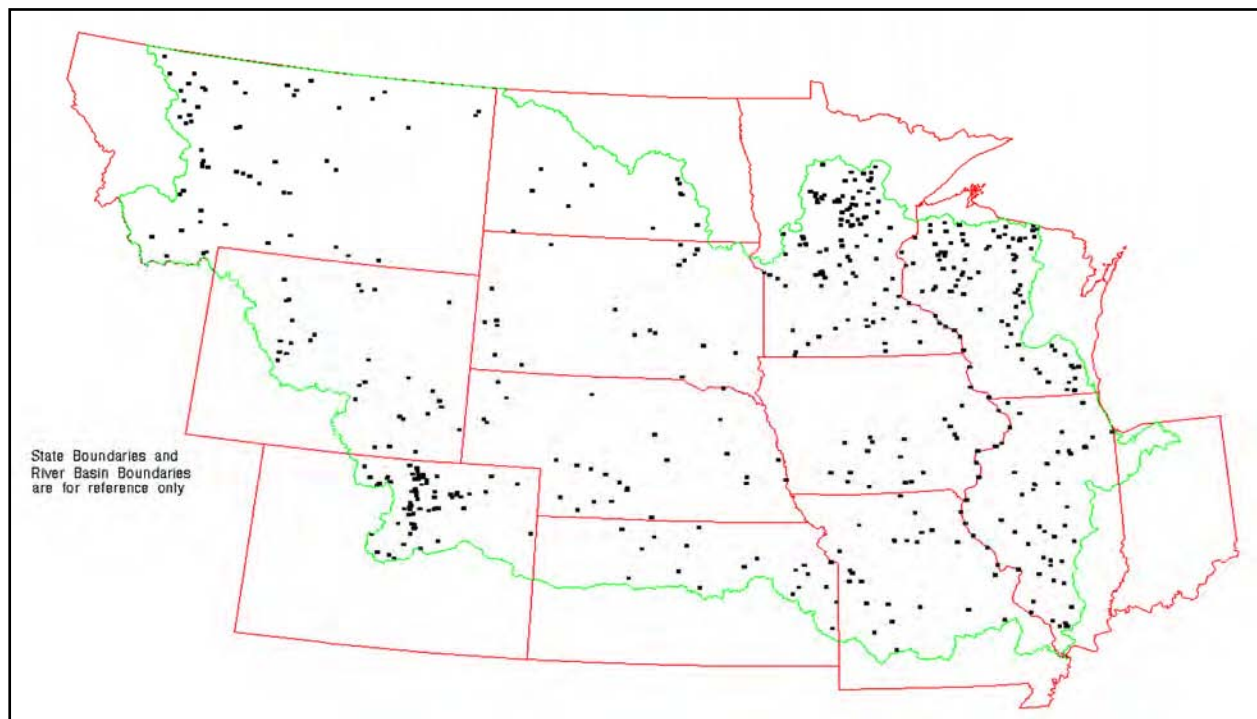


Figure 8. Dams on tributaries to the Missouri, Upper Mississippi, and Illinois Rivers with capacity greater than 6.1 million m³ (5,000 acre-ft)

In addition to the large dams, there are about 3,000 smaller dams in the UMRS Basin. Many UMRS tributary dams are small, low-head former mill and hydropower dams that remain barriers to fish movements. The Chicago Sanitary and Ship Canal and the diversion of water from Lake Michigan into the Illinois River extended aquatic habitat connectivity between the Great Lakes and the UMRS, allowing the introduction of Great Lakes and nonindigenous species (see

below). Table 6 provides information on UMRS tributaries, natural barriers, and dams. The effect of reduced access by UMRS migratory fishes to the tributary river network has probably reduced the population size of a number of species due to limited access to more optimal spawning, nursery, foraging, and winter habitats. Also, fish communities in the impounded tributary streams are no longer affected by the seasonal presence of migratory fish from the main stem rivers.

Table 6 identifies tributaries confluent with each UMRS navigation pool, stream orders (Strahler 1957), first barriers, and the length of tributary rivers currently accessible to fish from the main stem rivers. Figures 9 and 10 illustrate the distribution and stream order of tributaries to Upper Mississippi River and Illinois Waterway navigation pools, respectively. Removing or providing fishways at tributary dams would restore access to important habitat for UMRS migratory fishes.

It is important to note that the Illinois River main stem is a tributary to the Mississippi River, confluent to the navigation pool formed by the Melvin Price Locks and Dam (often referred to as Pool 26). There are 80 miles of lower Illinois River in that navigation pool.

UMR Pool	Tributary Name	Distance (km)		Location of First Obstruction (dam or natural)	Stream Order ¹	Watershed Area ² (ha)	River Mile at Confluence	State
		Confluence to First Obstruction	Total Stream Length					
2	Minnesota River	274.3	415.4	Granite Falls	8	4,363,136	844.0	MN
2	Trout Brook	0.5	6.2	St. Paul storm sewer	4	19,608	838.5	MN
2	unnamed	0.5	3.2	Sewage treatment facility	4	11,559	819.5	MN
3	St. Croix River	82.8	268.5	St. Croix Falls	7	2,000,156	811.3	MN/WI
4	Vermillion River	1	46.9	Hastings	5	67,786	808.4	MN
4	Trimbelle River	28.5	31.3	Farm Pond (Pierce Co.)	4	22,327	794.3	WI
4	Cannon River	12.8	148.8	Welch	6	381,054	792.9	MN
4	Hay Creek	n/a	23	None	4	12,465	791.8	MN
4	Rush River	n/a	39.8	None	4	55,453	780.4	WI
4	Wells Creek	22.4	23.7	Flood Control (Goodhue Co.)	4	18,473	778.3	MN
4	Chippewa River	73.5	293.4	Dells Dam Eau Claire	8	2,462,292	763.4	WI
4	Buffalo River	n/a	89	None	5	116,093	754.8	WI
5	Zumbro River	65.2	128.4	Lake Zumbro	6	370,589	750.2	MN
5	Whitewater River	n/a	51.7	none	5	83,441	743.7	MN
5a	Waumandee Creek	n/a	38.1	none	5	44,563	733.2	WI
5a	Garvin Brook	6.4	21	Near Minnesota City	5	25,587	730.6	MN
6	Trempealeau River	65	82.2	Blair Mill	5	185,568	717.0	WI
7	Black River	88	236.1	Black River Falls	6	583,980	709.4	WI

(Sheet 1 of 4)

Table 6 (Continued)

UMR Pool	Tributary Name	Distance (km)		Location of First Obstruction (dam or natural)	Stream Order ¹	Watershed Area ² (ha)	River Mile at Confluence	State
		Confluence to First Obstruction	Total Stream Length					
8	La Crosse River	18.3	62.5	Neshonoc Dam	5	121,767	698.1	WI
8	Pine Creek	n/a	24.7	none	4	14,877	696.8	MN
8	Root River	72.8	130.3	South Branch	6	429,911	693.7	MN
8	Coon Creek	21.3	35.9	Coon Creek, Vernon Co.	4	36,423	684.5	WI
9	Bad Axe River	25.4	30	Sidie Hollow	5	48,625	674.3	WI
9	Upper Iowa River	57.1	158.6	near Decorah	6	290,398	670.9	IA
9	Village Creek	n/a	16.8	none	4	18,871	662.1	IA
9	Rush Creek	n/a	15	none	4	26,794	653.5	WI
10	Paint Creek	n/a	29.7	none	4	21,800	640.6	IA
10	Yellow River	n/a	50.8	none	4	62,591	637.7	IA
10	Wisconsin River	139.7	609.5	Prairie du Sac	7	3,080,924	630.6	WI
10	Buck Creek	n/a	50.8	none	4	8,799	618.0	IA
11	Turkey River	35.8	181.4	Elkader	6	435,585	608.5	IA
11	Grant River	n/a	55.7	none	5	81,517	593.3	WI
11	Platte River	n/a	55.5	none	5	86,347	588.0	WI
11	Little Maquoketa River	n/a	31.3	none	5	40,239	585.5	IA
12	Catfish Creek	n/a	25.3	none	4	18,980	577.5	IA
12	Sinsinawa River	n/a	23.1	none	4	12,699	566.7	IL
12	Galena River	n/a	57.8	none	4	52,644	564.1	IL
13	Mill Creek	n/a	14.2	none	4	8,387	556.0	IA
13	Maquoketa River	41.5	173.3	Maquoketa	6	480,689	548.6	IA
13	Apple River	13.1	57.8	Hanover	5	65,363	543.0	IL
13	Rush Creek	n/a	32.2	none	4	16,917	541.8	IL
13	Plum River	39.4	44.2	Lake Carroll Dam	5	70,340	533.1	IL
13	Elk River	n/a	17.6	none	4	19,365	528.1	IA
14	Wapsipinicon River	103	314	Anamosa	6	652,547	506.6	IA
15	Duck Creek	n/a	25.1	none	4	15,934	487.8	IA
16	Rock River	6.2	427.3	Rock Island	7	2,807,657	479.1	IL
16	Mill Creek	n/a	26.5	none	4	16,248	477.7	IL
16	Pine Creek	3.6	9.5	Wildcat Den	4	10,701	465.7	IA
17	Copperas Creek	n/a	32.1	none	4	18,809	450.8	IL
18	Iowa River	105.6	444.7	Iowa City/Waterloo	7	3,272,701	434.1	IA
18	Eliza Creek	n/a	25.2	none	4	8,435	433.0	IL
18	Edwards River	n/a	97.4	none	5	111,501	431.3	IL
18	Pope Creek	n/a	68.2	none	4	42,498	427.7	IL
19	Henderson Creek	n/a	75.7	none	5	335,954	409.8	IL
19	Flint River	n/a	35.3	none	5	38,734	405.3	IA
19	Ellison Creek	n/a	37	none	4	22,718	400.9	IL

(Sheet 2 of 4)

Table 6 (Continued)

UMR Pool	Tributary Name	Distance (km)		Location of First Obstruction (dam or natural)	Stream Order ¹	Watershed Area ² (ha)	River Mile at Confluence	State
		Confluence to First Obstruction	Total Stream Length					
19	Honey Creek	n/a	30.1	none	4	12,729	398.7	IL
19	Skunk River	55.5	358.2	Oakland Mills	6	1,122,311	395.9	IA
19	Camp Creek	n/a	15.3	none	4	9,725	391.9	IL
19	Lost Creek	n/a	19.3	none	4	9,882	385.9	IA
19	Sugar Creek	n/a	31	none	4	37,402	377.0	IA
20	Des Moines River	148	718.7	Ottumwa	8	3,739,387	361.4	IA
20	Fox River	n/a	127.7	none	5	106,412	353.5	MO
21	Wyaconda River	n/a	122.8	none	5	121,005	337.1	MO
21	Bear Creek	n/a	52.6	none	5	98,721	330.5	IL
22	Fabius River	n/a	276	none	6	398,106	323.1	MO
22	North River	n/a	88.9	none	5	95,728	320.9	MO
22	Mill Creek	n/a	26.5	none	5	26,478	318.2	IL
24	McCraney/Hadley Creek	n/a	36.6	none	4	41,669	296.7	IL
24	Kiser Creek	n/a	26.8	none	4	15,629	289.3	IL
24	Salt River	87.7	241.4	Spalding (Reregulation dam)	6	739,148	284.1	MO
24	Buffalo Creek	n/a	18.3	none	4	11,855	280.9	MO
25	Bay Creek	n/a	61.1	none	4	54,147	270.0	IL
25	Ramsey Creek	n/a	18.9	none	4	10,266	265.6	MO
25	Guinns Creek	n/a	16.8	none	4	8,255	260.7	MO
25	Bryants Creek	17.5	18.1	Clarence Canyon (Lincoln Co.)	4	10,549	258.8	MO
26	Bobs Creek	n/a	25.5	none	4	10,274	238.0	MO
26	Cuivre River	111.2	129.6	near Louisville (Pike Co.)	6	317,483	236.6	MO
26	Peruque Creek	19.6	43.6	none	4	19,028	233.5	MO
26	Dardenne Creek	n/a	46.3	none	4	26,320	227.3	MO
26	Illinois River	125.5	439.3	La Grange	8	7,452,199	220.0	IL
26	Piasa Creek	n/a	32.5	none	4	30,978	209.2	IL
Illinois River Tributaries								
Dresden	Kankakee River	16.2	202.7	Wilmington	6	561,610	273	IL
Marseilles	Mazon River	59	119.8	Mazonia	5	134,989	263.5	IL
Starved Rock	Fox River	8.8	282.5	Dayton	6	447,713	239.7	IL
Peoria	Vermillion River	140.2	158.3	Streator	6	345,435	226.5	IL
Peoria	Little Vermillion River	n/a	124.8	none	4	32,431	225.6	IL
Peoria	Big Bureau Creek	n/a	278.5	none	5	99,159	207.8	IL
Peoria	Sandy Creek	n/a	80.1	none	4	37,221	196.2	IL
La Grange	Mackinaw River	n/a	199.1	none	4	55,016	147.9	IL
La Grange	Quiver Creek	n/a	54.7	none	4	55,148	128.6	IL
La Grange	Spoon River	51.2	202.3	Bernadotte	6	483,174	120.5	IL

(Sheet 3 of 4)

Table 6 (Concluded)								
UMR Pool	Tributary Name	Distance (km)		Location of First Obstruction (dam or natural)	Stream Order ¹	Watershed Area ² (ha)	River Mile at Confluence	State
		Confluence to First Obstruction	Total Stream Length					
La Grange	Sangamon River	71.5	402.3	Petersburg	6	1,380,235	88.9	IL
La Grange	Sugar Creek	n/a	122.6	none	4	42,257	94.4	IL
La Grange	La Moine River	n/a	439.8	none	5	350,291	83.7	IL
n/a	Indian Creek	n/a	160.8	none	4	55,487	78.8	IL
n/a	McKee Creek	n/a	278.3	none	5	90,613	66.7	IL
n/a	Mauvaise Terre Creek	n/a	198	none	4	42,984	63.1	IL
n/a	Sandy Creek	n/a	130.8	none	4	42,807	50.1	IL
n/a	Apple Creek	n/a	254.1	none	5	105,433	38.4	IL
n/a	Macoupin Creek	n/a	372	none	6	248,910	23.1	IL
n/a	Otter Creek	n/a	77.2	none	4	23,050	14.9	IL
Kaskaskia River Tributaries								
n/a	Silver Creek	59.9	91.2	Silver Lake (Madison Co.)			48.6	IL
n/a	Crooked Creek	n/a	56.7	none			60.8	IL
n/a	Sugar Creek	n/a	43.7	none			79.4	IL
n/a	Shoal Creek	95.5	109.6	Lake Lou Yeager			90.5	IL
<i>(Sheet 4 of 4)</i>								
¹ Stream orders were identified through a procedure that utilized Arc/Info GIS hydrologic modeling tools. USGS 1:250,000-scale digital elevation models were first converted to Arc/Info lattice files and merged to cover a portion of the Upper Mississippi River Basin (UMRB). The merged file was further prepared for hydrological analysis by filling in sinks and converting it to a flow grid. Next, a stream network grid and watershed outlet grid were generated. These were used with the flow data to create a watershed grid and stream order grid using the Strahler method. This grid was then converted to a vector polygon coverage and watershed boundary locations were checked using USGS 1:250,000- and 1:100,000-scale quadrangle maps. These steps were repeated for various areas of the UMRB until the entire basin was completed. The watershed polygon coverages were then merged into one final UMRB watershed GIS data layer and attribute information was added. ² The Upper Mississippi River System (UMRS) watershed data layer includes all basins larger than 60.7 ha (150 acres) that empty directly into the main stem of the UMRS. Watershed boundaries were delineated using USGS 1:250,000 scale Digital Elevation Models (DEMs) and 1:250,000- and 1:100,000-scale Quadrangle maps. The UMRS watershed database contains various attributes including watershed size, perimeter length, stream order, stream name (for basins larger than second order), and basin outlet location by navigation pool and state.								

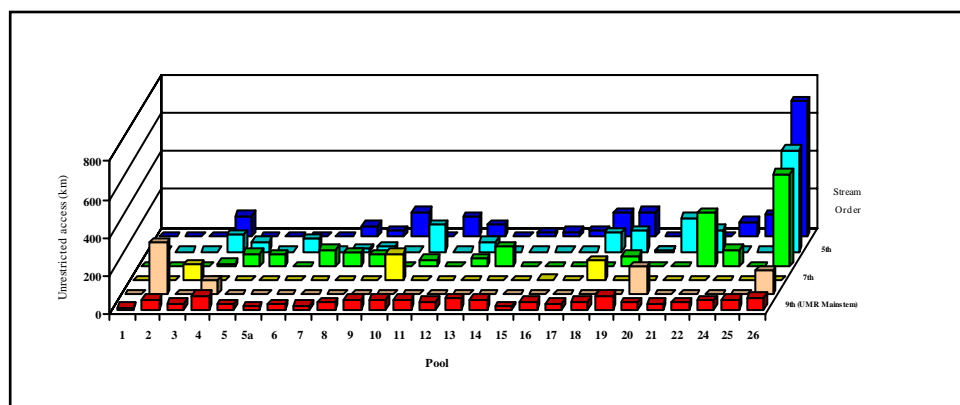


Figure 9. Total length (km) of fish-accessible tributaries by navigation pool and stream order for the Upper Mississippi River

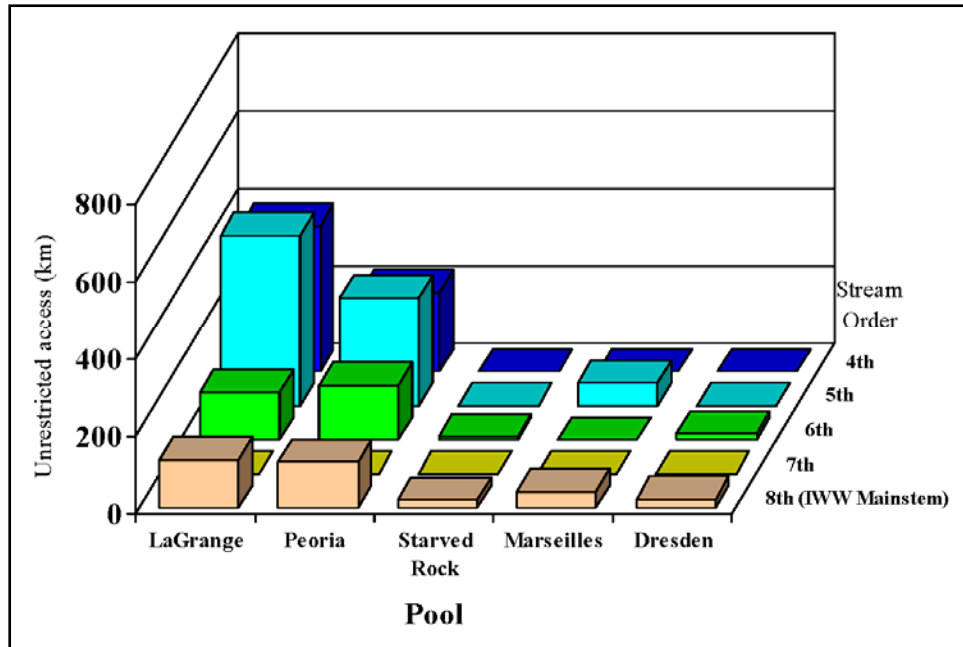


Figure 10. Total length (km) of fish-accessible tributaries by navigation pool and stream order for the Illinois Waterway

The Kaskaskia Lock and Dam impounds the Kaskaskia River near its confluence with the Mississippi River, in the open river reach about 12 km upstream of Chester, IL. The Kaskaskia River between the Kaskaskia Lock and Dam and Carlyle Lake Dam extends 151 km, and has four tributaries with a total of 255 km of channel (Table 6).

The Nature Conservancy, in cooperation with the McKnight Foundation, Nature Serve, the U.S. Environmental Protection Agency, the U.S. Geological Survey, the U.S. Fish and Wildlife Service, state natural resources management agencies, and regional expert ecologists have identified the Upper Mississippi and Illinois River main stems and a number of tributaries as conservation priority areas, because they are aquatic areas of significant biodiversity (Weitzell et al. 2003). UMRS impounded reach tributaries identified as conservation priority areas include the Minnesota (MN), Lower St. Croix (WI), Kinnickinnic (WI), Chippewa (WI), Black (WI), Wisconsin (WI), Kickapoo (WI), Zumbro (MN), Whitewater (MN), Maquoketa (IA), Root (MN), Upper Iowa (IA), Yellow (IA), Turkey (IA), Apple (IA), Wapsipinicon (IA), Cedar (IA), DesMoines (IA), Rock (IL), Kankakee (IL), Mackinaw (IL), Middle Fabius (MO), Kaskaskia (IL) and Big Muddy (IL) rivers. Improving fish passage along the Upper Mississippi and Illinois Rivers would help maintain the biodiversity in these special rivers.

9 Nonindigenous Fishes in the UMRS

A significant threat facing the integrity of the UMRS ecosystems is from nonindigenous species. The terms nonindigenous, exotic, introduced, and invasive have all been used to describe organisms that were moved by humans outside their native ranges. However, the term nonindigenous is the most broad and has included species introduced from locations within North America and overseas. The Federal Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990 (Section 1003) has defined “nonindigenous species” as “...*any species or other viable biological material that enters an ecosystem beyond its historic range, including any such organism transferred from one country into another.*”

Nonindigenous species can affect fish and aquatic community diversity through an outright loss or displacement of native species. Once established, they may be able to out-compete native species, or modify their habitat. Not all species moved outside their native range will become established or have a substantial adverse effect on aquatic communities. However, those that do may have dramatic effects on the ecosystem. For example UMR exotic species such as the grass carp (*Ctenopharyngodon idella*) and common carp (*Cyprinus carpio*) destroy aquatic vegetation, increase water turbidity, and can reduce, degrade or eliminate certain types of valuable fish and wildlife habitat. In many cases, exotic species have been introduced with positive intentions, including all but one of the nonindigenous fishes that occur in the UMRS. However, harmful effects generally outweigh any potential beneficial effects of nonindigenous species.

History and Presence of Nonindigenous Fish Species in the UMRS

The problem of nonindigenous species within the UMRS dates back at least to the 1800s with the intentional stocking of common carp (*Cyprinus carpio*) and goldfish (*Carassius auratus*). The common carp and goldfish are two of six species of Asian carp that occur in the UMRS, including grass carp, silver carp (*Hypophthalmichthys molotrix*), bighead carp (*Hypophthalmichthys nobilis*), and black carp (*Mylopharyngodon piceus*).

Common carp were originally brought to the U.S. during the 1800s and were widely propagated and intentionally distributed. Goldfish were stocked and escaped from captivity in ponds and aquaria. Common carp are now abundant

throughout the entire UMRS. Although relatively uncommon on the UMR and IWW, goldfish are frequently collected in Pools 19 and 20. Grass carp were brought from Asia in 1963 as a means to control aquatic vegetation in aquaculture ponds. They were first collected in the UMRS in 1971 and are generally considered to be uncommon to rare throughout the UMRS. Silver carp and big head carp also were brought to the U.S. from China in 1973 for use in the aquaculture industry. Their presence was documented in the UMRS as early as 1982. Population levels for both silver and bighead carp were relatively low until 1999 and 2000, when both species apparently increased in abundance. Bighead carp have been commercially harvested in Pool 19 since 1992 (UMRCC 1994). Silver carp are not abundant above Lock and Dam 19. These two species are now relatively common in the lower reaches of the Upper Mississippi and Illinois Rivers, and above Dresden Dam on the Illinois River. Adult bighead carp have been collected in Pool 9 and in Lake Pepin (Pool 4) of the Mississippi River. Black carp have recently been brought to the U.S. for use in aquaculture. The first black carp was captured from the UMR the spring of 2003 from a backwater lake within the open river reach of the Mississippi River below St. Louis, MO. Initial tests indicated this single fish may have been triploid (as used by the aquaculture industry), but this has not been confirmed.

Another nonindigenous fish species of concern is the round goby (*Neogobius melanostomus*). The round goby originates from the Black and Caspian Seas, and was first discovered in the St. Claire River (north of Detroit, MI). It has since spread through the great lakes, and has begun to move downstream from Lake Michigan through the Chicago ship and sanitary canal. It has moved into the upper IWW, and continues to move downstream towards the lower IWW and, potentially, the UMR. In addition to the round goby, the tubenose goby (*Proterorhinus marmoratus*) and the ruffe (*Gymnocephalus cernuus*) are also found in the Great Lakes and may well make their way downstream into the IWW.

Striped bass (*Morone saxtilis*) and striped bass x native white bass (“wipers,” *Morone saxtilis* x *Morone chrysops*) have been stocked in the UMRS rivers and reservoirs in the basin for sport fishing. Brown trout (*Salmo trutta*) and rainbow trout (*Oncorhynchus mykiss*) are occasional strays from tributary streams into the UMR.

Potential for Invasion by Nonindigenous Species

Nonindigenous species escape and establish in the UMR in one of three ways: intentional introductions, intentional introductions with subsequent escape, and unintentional introductions. Intentional introductions are those nonindigenous species transported beyond their native range and released into the wild with the purpose and intention that they will become established, such as the common carp. Intentional introductions with subsequent escape are those nonindigenous species transported beyond their native range and which subsequently escape into the wild; these include species such as the bighead, silver, and black carp. Unintentional introductions are those nonindigenous species that are transported, usually unnoticed or without detection, beyond their native range in the course of some unrelated activity.

Due to increased awareness of the dangers associated with release of nonindigenous species, intentional release may be less of a concern. However, such releases are still possible, especially by members of the general public who may not be educated to the dangers associated with release.

Conversely, intentional introductions with subsequent escape, and unintentional introductions certainly remain of concern for spread of undesirable fish. For example, concerns continue to exist as black carp continue to be used within the aquaculture industry. The aquaculture industry attempts to use triploid (genetically modified to be sterile) individuals to assure that any animals that escape are not capable of reproduction. However, concern exists that some black carp may not be sterile. These animals can escape into the UMRS during floods, dam or levee failures, within effluent released from aquaculture facilities, as well as other mechanisms. This type of movement will most likely where nonindigenous fish are intentionally imported and used in aquaculture.

Unintentional introductions also remain a significant concern as a pathway for introduction of nonindigenous aquatic organisms. Trans-Atlantic shipping between European ports and ports within the Great Lakes has proven to be a pathway for the unintentional introduction of undesirable aquatic species, including round goby as well as zebra mussels (*Dreissena polymorpha*), quagga mussels (*Dreissena bugensis*), spiny water flea (*Bythotrephes cederstroemi*), Eurasian ruffe (*Gymnocephalus cernuus*), and others. These species make their way into the ballast water of ships, and are discharged back into areas outside of their native range.

Nonindigenous Species Movement

Nonindigenous species can make their way from Lake Michigan into the IWW and UMR by way of the Chicago Ship and Sanitary Canal. Downstream movement is relatively easy, with survival and establishment based largely on the species' ability to adapt to conditions of the IWW. The Corps of Engineers has installed an electrical barrier to discourage fish movement between Lake Michigan and the upper IWW. Studies are currently underway to evaluate the effectiveness of this barrier.

Movement of nonindigenous species in the UMRS from downstream to upstream locations may prove more difficult. Upstream movement by fish on the UMR is slowed by the presence of navigation dams. The dams are difficult for fish to pass under most conditions, with passage through the dam gates possible only during high water periods when dam gates are lifted out of the water. Locks and Dams 19 and 1 present complete barriers to upriver fish movement through the gated parts of the dams. Upriver fish passage through these dams is limited to individuals that lock through with upbound navigation traffic. The navigation dams are not complete barriers to upriver fish movements and at best probably serve as temporary barriers to upriver invasion by nonindigenous fishes.

Upstream movement past navigation dams may be less of an issue on the IWW within areas of Alton, La Grange, and Peoria pools. Dams at Peoria and La Grange have wicket gates that are frequently down, allowing open pass, and

impede upstream fish movement much less frequently than the UMR navigation dams.

The potential ultimate range of nonindigenous fishes in the UMRS Basin is limited only by the habitat requirements and thermal tolerances of the invading species.

Potential Effects of Improving Nonindigenous Fish Passage Through UMRS Dams

Predicting potential impacts to the river ecosystems and fisheries from invasion by nonindigenous species is difficult. Fish passage structures may expedite upstream movement of undesirable species from downstream sources. The most likely sources of undesirable fish include Lake Michigan and the open river portions of the UMR. Although downstream movement would not be affected, upstream movement of nonindigenous fishes would be more rapid with improved fish passage at the navigation dams.

However, the current navigation system is not a complete barrier to upstream migration. The navigation dams may slow down but will not stop the upstream movement of undesirable species. Many of the undesirable species in the UMR are already above Lock and Dam 19, which is the primary barrier to upstream movement. Therefore, even if fish passage at UMRS dams is not improved, nonindigenous species will probably disperse upstream and affect fish communities of the UMRS.

Reduced habitat connectivity, effects of impoundment and river regulation, impoundment and channelization of tributaries, water quality degradation, and over harvest have reduced the abundance, competitiveness and resilience of native migratory fish populations in the UMRS. This indirectly supports the nonindigenous fish fauna. Therefore, the adverse effects of improving nonindigenous fish passage could be outweighed by stronger competitive pressure by native species that benefit from improved fish passage.

10 Alternatives for Improving Fish Passage Through UMRS Dams

Improving opportunity for fish passage through UMR dams via operational changes and modifications to the gated portions of the navigation dams may be possible. Assisted lockage, modified gate bay configuration, and modified flow through the dam gates could improve opportunity for upriver fish passage. Three structural fishway approaches have been considered to improve upstream passage of fish in the UMRS: a) technical fishways, including Denil trough, fish elevator, eel path, baffled trough, and pool and orifice trough; b) nature-like fish passage-ways, including rock ramp and pool and riffle bypass channels; and c) large-scale measures including dam removal and whole-river rock ramps.

Assisted Lockage

Fish could be attracted into navigation locks by first closing the upper and lower miter gates, then lowering water level in the lock chamber to the tailwater level. Opening the downstream miter gates would allow fish to enter. Partially opening the lock filling conduits would provide attracting flow to induce fish to enter the lock. After allowing fish time to enter, the lower miter gates could be closed, the lock filled, then the upper miter gates could be opened to allow the fish to leave the lock into the upstream pool. Fish could be induced to leave the lock by partially opening the lock draining conduits while leaving the upper miter gates open. This cycling of the lock chambers could be done during the late April through June and the October through November periods of fish migration in the UMRS.

To estimate the cost of assisted lockage, an assumption was made for 5 lockages each day during the fish migration periods, for a total of 760 lockages per year at each lock. Cycling the lock chambers with no navigation traffic to pass fish upriver would require lock operators and would cause wear of the lock machinery, increasing maintenance and rehabilitation costs (Table 7; Appendix C).

Item	Quantity	Unit Price	Cost / year at each lock
Lock Operator	2.00	50,000.00	\$100,000
Lock Repairman	1.00	44,400.00	\$44,400
Lock Maintenance and Rehabilitation	1.00	200,000.00	\$200,000
		Sub-Total	\$344,400
Contingency	25.00	% of Sub-Total	\$86,100
		Total / year / lock	\$430,500
		Total / lockage	\$566

Assisted lockages may not be sufficient to routinely pass large numbers or whole populations of fish in the UMRS. The limitations of using shipping locks as fishways include the considerably greater attracting flows for fish at the gated parts of the dams than at the locks, mixed rheotactic cues for fish within the lock chambers, the potential for disorientation and propeller entrainment as commercial vessels enter and leave the locks, and wear of lock machinery from additional lockage cycles.

Locking fish is definitely possible, but is relatively expensive and of questionable ecological effectiveness compared to other fish passage alternatives. Because of these considerations, locking fish should be considered at sites when no other fish passage alternative is found to be possible. One exception is the Kaskaskia Lock and Dam, which has two Tainter gates immediately adjacent to the lock and little navigation traffic. Locking fish may prove effective there.

Modified Dam Gate Operation

Lengthening the time that dam gates remain out of the water could improve opportunity for upriver passage by some fish species. Lengthening the time window for open river conditions could be done at landward dam gates where migrating fish might be most concentrated. The dam gates could be raised from the water slightly in advance of the normal procedure (at a slightly greater head) as river discharge increased, and the gates could be left out of the water for a slightly longer time as flow receded. The only disadvantages of this technique would be that velocities through the gate bay openings would be greater with higher head between the pool and tailwater when the gates remain out of the water. This could limit opportunity for upriver passage of some fish. The higher velocities through the gate bays could require additional rock at the toe of the dams to prevent further scour in the tailwater areas. Modifications to dam gate operation to extend the window of fish passage time would not be costly, but further rock scour protection would require expensive placement of large quarry rock at the toe of the dam below the gate bays that would be held open longer.

Because the time window when modified gate operation could be used is small and slower swimming fish species would still not be able to negotiate the

gate bay, the benefit of improved fish passage would probably be low for this operational alternative.

Modified Dam Gate Bay Configuration

If the amount of flow through landward gate bays could be reduced, lower velocities would provide better opportunity for upriver fish passage when the dam gates are out of the water. Flow through the landward gate bays could be reduced by a deflector dike or chevron structure upstream of the gate bay opening. It might be possible to roughen the dam sill upstream of the gate by placing large rock. Simple rock structures to slow flow through the dam gate openings would probably be the most effective and least costly. The disadvantage of this technique is that slowing flow through a gate opening would reduce the discharge capacity of the moveable dam, possibly raising upstream water levels. This technique could not be applied at some dams with limited gated discharge capacity.

Technical Fishways

Technical fishways are widely used and can be effective at moving fish around a barrier, particularly salmon in the northwestern United States and some species of warmwater fish (McLeod and Nemenyi 1939; Schwalm and Mackay 1985). The thought behind these structures is that adequate fish passage can be achieved through sound engineering based on the life history requirements of an individual or a small group of species. These passageways are relatively small in size, easy to site, and often have viewing windows that are useful in educating the public about fish movements. Technical fishways such as Denil troughs, eel paths, baffled troughs, and pool and orifice troughs, are limited in effectiveness to a few species; typically those that are found high in the water column, large bodied, and good swimmers. Fish locking and fish elevators are semi-successful at passing a wide variety of large and small fish. They require frequent operation and maintenance and require fish to respond to human induced cues in a human timeframe (Carter 1954; Scott and Hevel 1991). Efforts have been made to modify baffled fishways by roughening the bottom to create suitable micro-habitats to pass smaller fish but these, like other technical fishways, pass only a fraction of the total population over each dam. The likelihood of ecologically sustainable populations making it past a series of dams using only technical fishways is small, yet at some dams a technical fishway may be useful as part of a suite of fish passageway measures.

Nature-Like Fishways at Main Channel Navigation Dams

Nature-like fishways are gradually sloping open channels with rough bottoms or a series of riffles and pools (Wildman et al. 2003). The closer a nature-like fishway matches the morphological characteristics of natural river habitat for the species present, the less likely hydraulic conditions will reach thresholds that limit fish passage (Parasiewicz et al. 1998). Nature-like fishways have proven

effective for a wide range of fish species with varying swimming abilities and can be relatively inexpensive to construct (Gaboury et al. 1995; DVWK 1996).

There is potential to use both rock ramps and pool and weir fishways in the UMRS mainstem dams (Keller and Haupt 2000). Ideally, the slope of any nature-like fishway would be very gradual, with few very low vertical drops and small sized bed materials to replicate the riverbed found below the dam. Like technical fishways, nature-like fishways require some maintenance and are limited in effectiveness to those fish that can find the entrance and successfully swim up through the constructed channel.

In addition to improving fish passage past dams, nature-like fishways provide year-round habitat for fish and macroinvertebrates adapted to higher gradient river conditions. Much of the higher current velocity hard substrate habitat in the UMRS was lost due to impoundment. Rock riffles in nature-like fishways may provide important spawning habitat for a number of native species including lake sturgeon. Many resident fish species have been found in nature-like fishways in Minnesota (L. Aadland, Minnesota Department of Natural Resources, Fergus Falls, MN, personal communication, 2003).

Given the reconnaissance level of study for this system-wide report, we adopted a conservative approach to estimating cost and for identifying potential locations of fishways at the dams. The general guidelines used for the UMRS in this study to estimate costs for nature-like fishways include a slope 100:1 that passes 5 percent or less of the river's total flow with a minimum width of 25 m. Upon gaining approval to do detailed planning and design, we expect to develop a more optimal design for each site, given head at the dam and space available for construction. Longer, lower-gradient fishways that convey more flow would be more ecologically effective and may be less costly to construct than shorter, steeper fishways. The rationale, design assumptions, and methods for initial cost estimates of fishways at UMRS navigation dams are presented in Appendix C.

Small-Scale Fishways at Overflow Spillway Sections

Smaller, steeper, and less expensive fishways could be constructed in or at the ends of overflow sections in UMRS navigation dams to provide upriver fish passage in the secondary channels blocked by construction of the dam. These fish passes could be designed like the nature-like fishways described above, but smaller, and perhaps could be designed to only function at higher levels of river discharge, to save cost. These smaller, or secondary fishways would not be as ecologically effective as larger fishways with entrances located at the gated part of the dams, given the concentration of migrating fish in the main channel. Secondary fishways at the overflow sections would pass fish, however, and would provide some benefit to fish populations.

Large-Scale Fish Passageways

Large-scale passageways provide systemic fish passage by effectively removing the barrier. The rationale for large-scale fish passageways and dam removal are that smaller-scale measures are inadequate to sustain the lotic ecosystem; therefore, barriers should be removed or their effects mitigated through construction of river-wide structures. These passageways effectively eliminate the fish barrier both upstream and downstream and pass all aquatic species. Dam removal is not an option because these dams are required for navigation, but channel-wide rock ramps may be used at the spillway area and side channels at some dams on the UMRS.

Evaluation of Alternative Fishway Types

In general, nature-like fishways may provide the best opportunity of success given the physical constraints of the most dams on the UMRS, and the large number of migratory species with various swimming performance and migration behavior. Nature-like fishways are, therefore, considered the most promising fish passage improvements for the UMRS. Technical fishways would not be effective for the wide range of migratory fish species and large-scale measures are impractical as long as the dams are still being used for navigation. Discussion of these conceptual fish passage techniques has raised environmental and engineering issues with fisheries managers and scientists from Federal and state agencies. Some of these technical questions may be answered with more detailed site-specific studies. Because nature-like fishways are untested on rivers with the size and species-rich fish community of the UMRS, an adaptive management or phased approach should be used as fish passage improvements are implemented. Pre- and post-project monitoring are considered essential. Post-project studies may indicate that additional fish passage improvements or modifications are required to adequately pass fish at a site.

11 Alternatives for Limiting Dispersal of Nonindigenous Species

Aquatic nuisance species (Table 8) may continue to spread throughout the waterways of the United States without a barrier against upstream range expansion. The absence of a barrier within the UMRS could put native species at risk from competition and predation from invasive species. An invasive species is defined as one that is nonnative to the ecosystem and whose introduction causes or is likely to cause economic or environmental harm or harm to human health.

Table 8 Aquatic Nuisance Species of Concern in the UMRS		
Fish	Species	Native Region
black carp	<i>Mylopharyngodon piceus</i>	Asia
bighead carp*	<i>Hypophthalmichthys nobilis</i>	Asia
silver carp	<i>Hypophthalmichthys molitrix</i>	Asia
grass carp*	<i>Ctenopharyngodon idella</i>	Asia
common carp*	<i>Cyprinus carpio</i>	Asia
goldfish*	<i>Carassius auratus</i>	Asia
Ruffe	<i>Gymnocephalus cernuus</i>	Eurasia
round goby	<i>Neogobius melanostomus</i>	Europe
tubenose goby	<i>Proterorhinus marmoratus</i>	Europe
Asian weatherfish	<i>Misgurnus anquillicaudatus</i>	Asia
Plants		
Eurasian watermilfoil*	<i>Myriophyllum spicatum</i>	Eurasia
Purple loosestrife*	<i>Lythrum salicaria</i>	Eurasia
Common reed*	<i>Phragmites australis</i>	Europe/United States
Reed canarygrass*	<i>Phalaris arundinacea</i>	Europe/United States
Mussels		
Zebra mussel*	<i>Dreissena polymorpha</i>	Europe
Quagga mussel	<i>Dreissena bugensis</i>	Europe
Asian clam*	<i>Corbicula fluminea</i>	Asia
Plankton		
Spiny water fleas	<i>Bythotrephes cederstroemi</i> and <i>Ceropagis pengoi</i>	Europe
* Found above Lock and Dam 19		

In addition to the known invasive aquatic species listed in Table 8, a host of disease organisms exist, which could be transmitted to native fish by invasive fish species moving up the UMRS. The existing navigation dams do impede upriver fish movements and may provide the native fishes some level of protection from diseases carried by migratory fish. Improving fish passage on the UMRS could impose some ecological risk associated with the introduction of fish disease organisms.

There are three challenges for creating barriers within the UMRS. First, all the navigation dams have lock chambers that allow at least some fish passage. Second, with the exception of Lock and Dam 19 and Lock and Dam 1, all dams on the UMR reach open river condition at some time, enabling upstream passage of exotic fish species. Third, many aquatic nuisance species have already established populations in the UMRS (Table 2), some of them upstream of Lock and Dam 19.

The inter-basin connection at the Chicago Sanitary and Ship Canal is key to preventing the expansion of aquatic nuisance species. An experimental electrical barrier was constructed on the Chicago Sanitary and Ship Canal near Romeoville, IL, in 2001, with a second nearby electrical barrier scheduled for construction in 2004. These barriers are intended to separate the Mississippi River basin from the Great Lakes basin. The effectiveness of the original barrier is still being tested.

Dams Without Fish Passage

Within the UMRS, Lock and Dam 19 is the only dam that provides the opportunity for a year-round physical barrier against northward invasion by invasive species. (Lock and Dam 1 is also a complete barrier to upriver fish passage except for the lock, but is located only 10 km downstream of St. Anthony Falls near the head of navigation.) Locks and Dams 11, 14, and 15 are near-complete barriers, with dam gates that are rarely in the open river position. Because of the concern about northward dispersal of nonindigenous fishes, the locks at Locks and Dams 11, 14, 15, and 19 are also potential sites for a fish barrier to deter fish from entering the lock chamber. A fish barrier to prevent upriver movement by nonindigenous fish would also prevent passage by native migratory fishes. This issue warrants more detailed consideration.

On the Illinois River and Illinois Waterway, Starved Rock, Marseilles, Dresden Island, Brandon Road, and Lockport Locks and Dams and the T.J. O'Brien Lock and Control Works serve as barriers (except for the lock chambers) to dispersal of fish from the UMRS into Lake Michigan.

Fish barriers could be installed within or near the lock chambers entrances at Locks and Dams 14, 15, or 19 to reduce the upstream passage of aquatic nuisance species. Control mechanisms can be broken into three general categories: physical, biological, and chemical (Table 9).

**Table 9
Potential Measures to Control the Movement of Invasive Aquatic Species**

Measures	Description
Physical and Biological	
Electrical	Electrification
Closure	Close Lock 19 and build a transfer station
Thermal	Heating water beyond biological thresholds
Sonic disruption	Acoustic destruction of tissue
Bubble curtains	Tactile repellent
Sound projection array (SPA) acoustic barrier	Combination of acoustic and tactile repellents
Active capture	Trawling or netting and physical removal
Screening	Physical obstruction
Light	Visual repellent
Oxygen stripping	Suffocation
Nitrogen injection	Nitrogen super saturation (gas bubble disease)
Predation	Artificial adjustment of predator/prey ratio
Explosives	Physical destruction
Chemical	
Chlorine	Toxicant (not registered for fish use)
Rotenone and potassium permanganate	Piscicide
Antimycin	Piscicide
TFM (3 trifluoromethyl-4 nitrophenol)	Lampricide - used to control sea lampreys in the Great Lakes (not registered for fish use)
Chemical attractants (pheromones)	Species specific and unidentified
Chemical repellants	Unidentified

Stand-alone alternatives that would not effectively deter the upstream movement of aquatic nuisance species can be readily eliminated. Combinations of these alternatives may be effective fish deterrents or attractors that may be used to keep fish from entering lock chambers. Oxygen stripping and nitrogen injection require prolonged exposure, and fish may be able to avoid exposure by using seeps in the lock walls. Physical barriers such as screens would be difficult to maintain and would interfere with navigation. Thermal treatment to prevent fish entry into lock chambers could be used at sites located near steam-electric power plants.

A brief feasibility study by Smith Root Inc. conducted for the Minnesota Department of Natural Resources suggested an electrical barrier across the Mississippi River in Pool 6 near Trempealeau, Wisconsin. Concerns were raised about the feasibility of this alternative: about interference by sediment and debris, effectiveness of a fish barrier across the river during floods, interference with native fish migrations, safety, and public perception (Jay Rendall, Minnesota Department of Natural Resources, St. Paul, MN, personal communication, 2004).

Combined technologies such as light and acoustic barriers or attractors might be effective in limiting fish entry into lock chambers (J. Nestler, U.S. Army Engineer Research and Development Center, Environmental Laboratory, Vicksburg, MS, personal communication, 2003). A variety of alternatives were considered for limiting the invasion of Asian carp up the Mississippi River as part of a study funded by the Minnesota Department of Natural Resources and

the U.S. Fish and Wildlife Service (FishPro, Inc. 2004). The consulting team led by FishPro, Inc., recommended that a sound projection array/acoustic bubble curtain (SPA/BAFF) system be installed at one of the UMR dams (Locks and Dams 8, 11, 14, 15, or 19) to prevent fish from moving upriver through the locks. This would slow the eventual invasion of these fish into the UMR Basin.

Several alternatives would be too expensive to maintain or pose a threat to public safety. Alternatives for killing fish in the lock chambers would be difficult to implement with every lockage. Chemicals and heat would be expensive when treating large volumes of water over long periods of time. Chemicals also affect nontarget species and chemically treated water would have to be detoxified before release back into the river. Fish killed in lock chambers would have to be collected and disposed of. Sonic disruption and explosives within the lock bay could lead to wear of the lock chamber and could affect the stability of the dam structure. Closure of navigation at Lock and Dam 19 and construction of a transfer station at Keokuk, IA, to move materials between barges operating above and below the dam would significantly increase cargo handling and transportation costs.

Many factors should be considered before choosing to construct a barrier. Barriers are generally designed for one type of organism. Fish barriers do little to stop the spread of aquatic plants, plankton, or mollusks, yet these are serious threats to native species of the UMRS. Additionally, multiple vectors often spread aquatic nuisance species. A fish barrier may slow the range expansion of invasive fishes, but invasion by other pathways above the barrier can circumvent its effectiveness. Additional management actions such as regulation, public education, rapid response to invasion by nonindigenous species, habitat restoration for native species, and removal by intensive harvesting are needed to limit the ecological risk of invasive aquatic species in the UMRS.

A more thorough assessment of the ecological risk of Asian carp and other aquatic species invading the UMRS is needed. This would help with decision-making about investments in fish barriers and fish passage improvements. SPA/BAFF barriers at selected navigation locks may be effective in delaying the invasion of Asian carp. It would be worthwhile to improve fish passage regionally (upstream and downstream of any dam with barriers to upriver fish passage through the lock chamber) to benefit native fish and mussels.

Dams With Fish Passage – Capture and Sorting

A fishway constructed at a dam with little or no potential for upriver passage through the dam gates (e.g., Locks and Dams 11, 14, 15, or 19) could be designed with a facility to capture and sort fish by species. Invasive species would be removed and not allowed to proceed upriver. Although a fishway of this kind would be difficult to design to be effective, costly to construct and would probably require considerable labor, it could be a feasible way to impose a barrier to upriver passage by invasive species while enabling upriver passage by native migratory fish.

12 Benefits of Improving Fish Passage Through UMRS Dams

Improved fish passage through UMRS dams would improve conditions for fish, Unionid mussels, and fish-eating birds and mammals. Improving fish passage would contribute to restoring the river ecosystem. Improved fish passage through UMRS dams would result in increased production of ecosystem goods and services of value to human society, including increased availability of food, increased sport and commercial fishing opportunity, wildlife viewing, restoration of threatened and endangered species populations, and would provide the bequest value of knowing that migratory fish and mussel populations and the river ecosystem are more sustainable.

Increased Access to Habitats

The primary way that improved fish passage through UMRS dams would affect migratory fish in the UMRS would be to increase the amount and types of habitat available to them. Availability and quality of habitat are probably limiting the size and structure of many migratory fish populations in the UMRS.

Each UMRS navigation dam impounds a pool of a certain size, some with tributary rivers. If fish become able to pass a navigation dam, their range of available habitat would increase by at least one navigation pool and the confluent tributary rivers of that pool up to the first barrier (Figures 9 and 10, Tables 7 and 11).

Access to main stem river habitats

Pools 4, 9, 13, 19, and 26 are the largest in the UMR. Pool 4 includes Lake Pepin, and Pool 26 includes the lower reach of the Illinois River up to La Grange Lock and Dam. The St. Croix River is a major tributary to the Mississippi River in Pool 3, and is a navigable part of the UMRS up to Stillwater, MN. The St. Croix River was treated as a navigation pool in Figure 11 and Table 10.

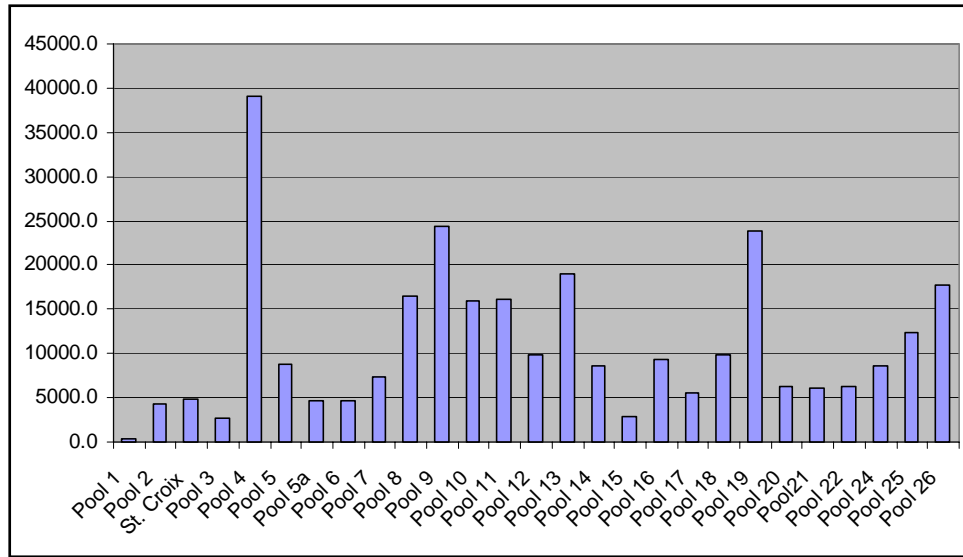


Figure 11. Water area (ha) of Upper Mississippi River navigation pools

The UMRS EMP Habitat Needs Assessment (Theiling et al. 2000) provides a GIS-based inventory of existing available habitats throughout the UMRS, a forecast of future habitat conditions, and identifier desired future conditions for the UMRS ecosystem. The Habitat Needs Assessment GIS Query Tool (DeHaan et al. 2003) enables examining available habitat areas for selected fish species and guilds, and estimating the amount of new main stem river aquatic habitats that migratory fish could occupy if they were able to pass upriver through navigation dams. The UMRS-EMP Long Term Resource Monitoring database of land use/land cover types and aquatic areas allows delineation of larger physical habitat areas. Migratory fish species need different small-scale habitat types, such as areas with specific combinations of depth, substrate type, and current velocity. There are significant differences in availability of these smaller scale habitat types among navigation pools and tributary rivers in the UMRS.

Fish access to tributaries

Over 7,400 km of tributaries remain free flowing and connected to the Upper Mississippi and Illinois Rivers (Table 6, Figure 12). The Kaskaskia River has 412 km (256 miles) of tributaries. Improving fish passage at a mainstem dam can provide migratory fish access to important tributary habitat. Many UMRS fishes require the gravel, cobble, and rock substrate and clearer, cooler water that is found in some tributary rivers.

**Table 10
Aquatic Habitat Types and Areas (ha) Associated with Upper Mississippi River
Navigation Dams**

Aquatic Area Types	St. Croix	Pool 3	Pool 4	Pool 5	Pool 5a	Pool 6	Pool 7	Pool 8	Pool 9
Contiguous Floodplain Lake-Abandoned Channel Lake			672	104	139	492	332	395	1473
Contiguous Floodplain Lake-Floodplain Depression Lake			2038	279	61		792	2384	135
Contiguous Floodplain Shallow Aquatic Area			3873	1810	2892	259	862		8091
Contiguous Impounded Area			1007	5383	820		7231	9944	12777
Main Channel-Channel Border			1107	1368	644	1409	1541	1532	2813
Main Channel-Navigation Channel			2701	843	545	760	572	1559	1615
Sandbar			5						
Secondary Channel			1143	686	367	2394	1324	1259	926
Tertiary Channel			6	146	27	2	1	2	1029
Tributary Channel			239		68	89	80	74	58
Excavated Channel									
Contiguous Floodplain Lake-Manmade Lake									
Contiguous Floodplain Lake-Borrow Pit			29						
Contiguous Floodplain Lake-Lateral Levee Lake									
Secondary Channel	594	1306							
Channel	1237	1141	5200	8704	1789	4655	140516	4425	6441
Backwater	1847	1246	30305	1914	3773	751	276823	16612	22676
Lake	8227	2953							
Contiguous Floodplain Lake-Tributary Delta Lake			22685						199
Water Total	11905	6646	71010	21238	11125	10811	430076	38185	58231
Aquatic Area Types	Pool 10	Pool 11	Pool 12	Pool 13	Pool 14	Pool 15	Pool 16	Pool 17	Pool 18
Contiguous Floodplain Lake-Abandoned Channel Lake	3668	1125	976	563	1596	5	484	566	843
Contiguous Floodplain Lake-Floodplain Depression Lake	384								
Contiguous Floodplain Shallow Aquatic Area	1279	3169	1347	4701			609		
Contiguous Impounded Area	2254	5656	2136	8786					
Main Channel-Channel Border	4079	5789	3780	2835	5304	2508	4510	1975	4622
Main Channel-Navigation Channel	1658	2042	1479	3909	1392	589	1604	1925	2085
Sandbar				64					
Secondary Channel	3815	1583	1828	1950	1481	409	3935	1992	3800
Tertiary Channel	158	23	49	260	11		93	1	93
Tributary Channel	364	34	11	78	59	8	56	0	310
Excavated Channel									

(Continued)

Note: The aquatic areas data is from the UMRS-EMP Long Term Resource Monitoring Program database. The length of tributaries to the first dam was determined using GIS. Aquatic area estimates for the St. Croix River were digitized from aerial photographs.

Table 10 (Concluded)									
Aquatic Area Types	Pool 10	Pool 11	Pool 12	Pool 13	Pool 14	Pool 15	Pool 16	Pool 17	Pool 18
Contiguous Floodplain Lake-Manmade Lake			16						
Contiguous Floodplain Lake-Borrow Pit				61					
Contiguous Floodplain Lake-Lateral Levee Lake									
Secondary Channel									
Channel	10074	9472	7098	9095	8246	3514	10198	5894	10910
Backwater	7674	9929	4524	14110	1596	5	1093	589	843
Lake									
Contiguous Floodplain Lake-Tributary Delta Lake	90								
Water Total	35495	38822	23243	46409	19684	7037	22582	12966	23506
Aquatic Area Types	Pool 19	Pool 20	Pool 21	Pool 22	Pool 24	Pool 25	Pool 26	P26 to Cairo	
Contiguous Floodplain Lake-Abandoned Channel Lake	1613	57	801	168	311	1358	931		
Contiguous Floodplain Lake-Floodplain Depression Lake			369					9	
Contiguous Floodplain Shallow Aquatic Area	3169					819			
Contiguous Impounded Area	2642					417	605		
Main Channel-Channel Border	13099	4351	2744	4186	4567	5190	7832		
Main Channel-Navigation Channel	3342	1418	1682	1965	2284	2714	4063		
Sandbar									
Secondary Channel	3774	1361	1879	1275	2915	3975	3663		
Tertiary Channel	2	11	10	4	149	78	34		
Tributary Channel	229	493	35		244	102	125		
Excavated Channel									
Contiguous Floodplain Lake-Manmade Lake	54		12						
Contiguous Floodplain Lake-Borrow Pit							7		
Contiguous Floodplain Lake-Lateral Levee Lake			2						
Secondary Channel									
Channel	20446	7633	6349	7430	10159	12059	15719		
Backwater	7953	57	814	168	311	2604	4349		
Lake									
Contiguous Floodplain Lake-Tributary Delta Lake	107								
Water Total	56798	15381	14325	15196	20939	29325	40135	14663	

**Table 11
Aquatic Habitat Types and Areas (ha) Associated with the Illinois River Navigation Dams**

Aquatic Area Types	Total	Alton	La Grange	Peoria	Starved Rock	Marseilles	Brandon Rd.	Dresden	Lockport
Contiguous Floodplain Lake- Abandoned Channel Lake		68	809			98	10	55	
Contiguous Floodplain Lake- Floodplain Depression Lake		3954	12960					37	
Contiguous Floodplain Shallow Aquatic Area		395	256						
Contiguous Impounded Area			0						
Main Channel-Channel Border		3620				1028	114		
Main Channel-Navigation Channel		4866	5829			1079	168		
Sandbar									
Secondary Channel		637	442			68	37	1145	
Tertiary Channel			7						
Tributary Channel		109	687			85	11	180	
Excavated Channel			483			105	9	80	
Contiguous Floodplain Lake- Manmade Lake						545		702	
Contiguous Floodplain Lake- Borrow Pit			3						
Contiguous Floodplain Lake- Lateral Levee Lake									
Secondary Channel									
Channel									
Backwater									
Lake									
Contiguous Floodplain Lake- Tributary Delta Lake									
Water Total	99321	16121	32714	34576	3250	5220	357	2524	4270

Effects of Improved Passage Through Dams on Fish Populations

Although difficult to quantitatively predict, improving fish passage through UMRS dams would have positive benefits for some fish populations. Fish would probably make use of improved fish passage opportunities immediately. Examples of this were observed during the flood of 1993. During this flood, all UMR dams except Lock and Dam 19 were passable much of the summer. During this time, skipjack herring were reported in the northern reaches of the UMR in Wisconsin and Minnesota (USGS 1999). This indicates that skipjack that were able to pass through Lock and Dam 19 (probably by locking through) were able to continue moving upstream during the flood when upriver dam gates were out of the water.

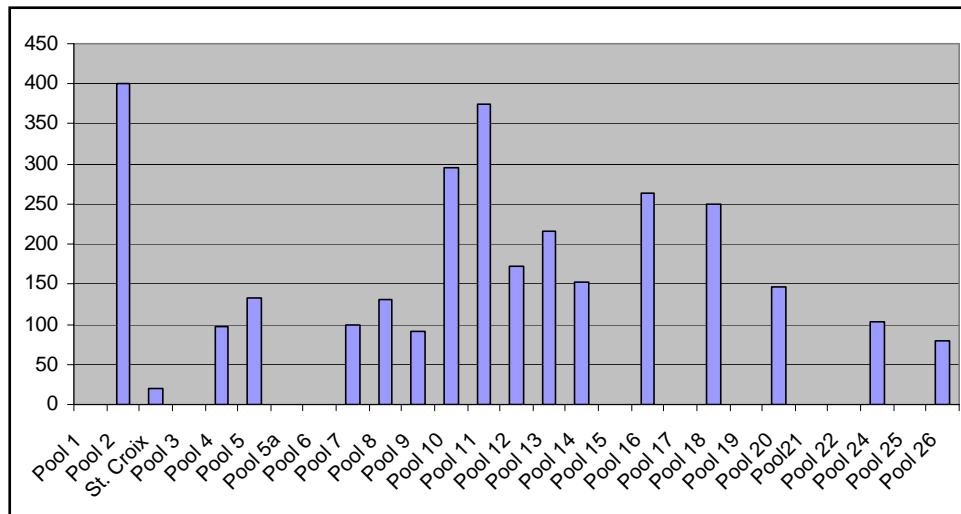


Figure 12. Length (km) of major tributaries to the first dam or natural barrier, by Upper Mississippi River navigation pool

Reproduction-limited fish species that spawn infrequently and require specific spawning habitat conditions, such as lake sturgeon, shovelnose sturgeon, and paddlefish, may increase in abundance if fish passage improvements allow more of them to reach suitable habitat areas and to spawn more successfully. Auer (1996) suggested that lake sturgeon need a barrier-free 250-300 km combined river and lake range as a minimum for a self-maintaining population.

Growth-limited fish species may increase in population size if fish passage improvements enable them to reach more suitable foraging habitats. Fish species that are limited by availability of winter habitat may have greater over-winter survival and increase in population size if fish passage improvements allow them to reach suitable winter habitat areas.

Increased population size of migratory fishes in the UMRS would be a primary benefit of fish passage improvements. Fish passage may also increase genetic diversity of migratory fish populations. Increased population size and genetic diversity would make the UMR migratory fish populations more resilient and sustainable.

Tributary fish communities could benefit from increased seasonal abundance of migratory fishes and their young-of-year.

Additional fish species other than those identified as known or probable migratory species in the UMRS could benefit from improved fish passage through the navigation dams. Many small fish species such as darters and minnows may be migratory at least within river reaches. Monitoring of nature-like fishways in Minnesota has revealed that many small fish species move through fishways, including darters, minnows, rock bass, and bullheads (L. Aadland, Minnesota Department of Natural Resources, Fergus Falls, MN, personal communication, 2003). Many fish species would make use of fishways as residence habitat, such as smallmouth bass, rock bass, and darters. Lake sturgeon may make use of the rock and higher velocity habitat in fishways for spawning.

Rare, threatened, and endangered migratory fish species may respond positively to fish passage improvements by better exchange of genes between formerly isolated stocks, or metapopulations. Reducing isolation of metapopulations, linking them, and increasing their size would reduce the threat of extinction. More robust populations of migratory fish species would be more resilient and able to weather disturbances or catastrophic events, contributing to the sustainability of the river ecosystem.

Benefits of Improved Fish Passage to Sport and Commercial Fisheries

Improved fish passage through the UMRS navigation dams would probably lead to increased abundance of some migratory species, and increased sport and commercial catches. More robust sport and commercial fisheries would contribute to the regional economy. Improved fish passage through the dams could reduce fish densities in tailwater areas seasonally, affecting the present pattern of sport fishing effort. Businesses such as fishing float operations and bait stores that rely on local tailwater sport fishing activity could be adversely affected by reduced sportfishing effort in the tailwater areas.

Other Benefits of Improved Fish Passage

Reintroducing skipjack herring above Lock and Dam 19 could expand the forage base for piscivorous fish and birds. Increasing populations of protected species, such as lake sturgeon and paddlefish, would provide substantial non-monetary benefits. These “charismatic megafauna” are legendary and popular animals. Spawning aggregations of lake sturgeon provide a fascinating wildlife viewing experience.

Benefits of Improved Fish Passage to Mussels

Owing to the timing of mussel reproduction, host fish infected with glochidia are unlikely to have significant opportunities to pass upstream through most dams. Consequently, improved fish passage could provide upstream gene flow for mussels and contribute to the sustainability of mussel populations. Improved fish passage at UMRS locks and dams could be beneficial to many mussel species by allowing migratory host fishes to gain access to navigation pools from which they were previously restricted, providing opportunity for dispersal of these populations. The following discussion identifies the mussel species that would probably benefit in different parts of the river system.

Lock and Dam 3

Fish passage through Lock and Dam 3 would allow fish upstream access to UMR Pool 3 and the St. Croix River (a critical mussel refuge), which could benefit many mussel species. Among the mussel species with migratory fish

hosts absent in Pool 3 but present in the lower St. Croix and UMR Pool 4 (Lake Pepin) are *Cyclonaias tuberculata*, *Tritogonia verrucosa*, and *Elliptio dilatata* (very rare in Pool 3 and only occurs immediately below the mouth of the St. Croix River).

Lock and Dam 6

Five species with migratory fish hosts currently occur in UMR Pool 7 and either have been extirpated in the UMR upstream or are absent for the most part from Pools 5-6. These include *Plethobasus cyphus*, *Quadrula nodulata*, *T. verrucosa*, *Lampsilis higginsii*, and *Actinonaias ligamentina*. Two additional species could also benefit from fish passage, *Truncilla truncata* is very healthy below Pool 6 and above Pool 5a but rare in Pools 5a-6, and *Elliptio dilatata* is present in Pools 5a-6 and Pools 9-11 but absent in Pools 7-8.

Lock and Dam 8

Three species that could possibly benefit from fish passage at Lock and Dam 8 are *E. dilatata*, *Q. nodulata*, and *L. costata*. *Elliptio dilatata* is common or rare in Pools 9-11 and 5a-6 but absent from Pools 7-8. *Quadrula nodulata* is rare or common in every UMR pool below Pool 8 and rare in Pool 7 but absent in Pool 8. *Lasmigona costata* is rare in Pools 8 and 10 but absent in Pool 9. A relict population of *Fusconaia ebena* exists in Pool 9 and the lower St. Croix River but it is unlikely this species would benefit from fish passage at Lock and Dam 8 alone.

Lock and Dam 19

Two obvious examples of species impacted by the impediment of their fish host have been the near extirpation of *F. ebena* and *Elliptio crassidens* in the UMR above Lock and Dam 19. Both species use skipjack herring as an obligatory fish host whose upstream migration has been all but eliminated by Lock and Dam 19. Probably only the *F. ebena* population upstream may benefit from fish passage at Lock and Dam 19 as the species is present in UMR Pools 20-26 and relict populations exist in UMR Pool 18, 9, and the Lower St. Croix River. Five additional species with migratory fish hosts that may benefit from fish passage are *C. tuberculata*, *E. dilatata*, *P. cyphus*, *A. suborbiculata*, and *Potamilus capax*. All these species presently exist in Pool 20 but are absent in Pool 19. Pool 20 is the upstream most extent of *Potamilus capax*, although the species historically occurred in the upper reaches of the UMR.

Lock and Dam 21

Four species with migratory fish host(s) may benefit from fish passage at Lock and Dam 21: *P. cyphus*, *T. verrucosa*, *A. confragosus*, and *A. ligamentina*. *Plethobasus cyphus*, *T. verrucosa*, and *A. ligamentina* currently exist in Pools 22-24 but are absent in Pool 21 and exist in either Pools 20 or 19. *Arcidens*

confragosus occurs from Pools 22 to the Middle UMR (and the Lower Illinois River) and in most pools above Pool 21, but is absent in Pool 21.

Illinois River (Marseilles Lock and Dam)

Perhaps five disjunct mussel species populations with migratory fish hosts exist in the upper Illinois River Marseilles Reach: *T. verrucosa*, *L. costata*, *Strophitus undulatus*, *Lampsilis cardium*, and *L. siliquoidea*. None of these species also exist in the Starved Rock Pool (downstream pool) so benefits of a fish passageway at the Marseilles Lock and Dam may be negligible and limited *T. verrucosa*, *L. siliquoidea* and *L. cardium*. *Tritogonia verrucosa* and *L. siliquoidea* currently exist in the Peoria Pool and *L. cardium* exists in the Alton Pool. *Strophitus undulatus* and *L. costata* do not currently exist in the Illinois River outside the Marseilles Pool.

UMR Locks and Dams 2, 5, 9, 14, 22, 24

Increased fish passage at these locks and dams could possibly benefit at least two mussel species that require migratory fish hosts.

Potential for Whitewater Recreation

Whitewater recreation (canoeing and kayaking) is rapidly increasing in popularity. Fishways could also be used for whitewater recreation. Fishways with water control capability could be designed and operated to pass fish during fish migration periods, and operated to provide whitewater recreation at other times. One potential site would be in the old John Deere hydropower channel and Sylvan Island in Rock Island Illinois (near Lock and Dam 15). Most UMRS locks and dams do not have potential for whitewater recreation at fishways, because of safety and security considerations.

13 Priority of Fish Passage Improvements

Because construction and operation of fishways are expensive, the consequent ecological benefits should be demonstrable, and the benefits should be commensurate with the costs (Cada and Francfort 1995). The sequence of sites for improving fish passage on the UMRS should be determined by the potential for ecological effectiveness and cost. Ecological effectiveness of fish passage improvements is influenced by the existing opportunity for fish passage at each site, the amount and quality of habitat that would become available to fish that pass the dam, the fish and mussel populations that would likely benefit, and the design and operation of the fish passage improvements that determine effectiveness in passing fish. The serial nature UMRS dams in restricting fish passage should be considered as well.

Existing Opportunity for Fish Passage

Dams that can be considered prime candidates for improving fish passage opportunity because of the degree to which they present barriers to upriver fish movements and block access to river habitat include: Locks and Dams 19 at Keokuk, IA, 14 and 15 near Rock Island, IL, 11 near Dubuque, IA, 8 at Genoa, WI, 7 at La Crosse, WI, 6 at Trempealeau, WI, 5 at Whitman, MN, 4 at Alma, WI, and 2 at Hastings, MN. All these dams are at open river conditions less than 10 percent of the time, or not at all (Figure 6).

Access to Habitat

Improved fish passage past UMRS navigation dams would provide fish access to additional habitat in the main stem rivers and tributaries.

Serial continuity of habitat between navigation pools

Improved fish passage opportunity at Lock and Dam 19 could restore access to the northern reaches of the UMR for long distance migrants such as the lake sturgeon, paddlefish, Alabama shad, skipjack herring (and the associated Ebony shell mussel), the American eel, blue sucker, and blue catfish.

In addition to the major barrier imposed by Lock and Dam 19, Locks and Dams 6, 7, and 8 present a serial barrier to upriver fish movements, limiting opportunity for fish from Pools 9, 10, and the Wisconsin River to reach pools 4, 5, 5a, and the Chippewa River. The Pool 10 through Pool 16 reach is fragmented by Locks and Dams 11, 14, and 15, which are rarely at open river condition.

Improved fish passage past Lock and Dam 2 would enable fish to gain access to the long reach of the Minnesota River and its tributaries, continuous with the St. Croix River and its tributaries. Improvement of fish passage opportunity at Locks and Dams 3 and 4 would provide fish access to and from the St. Croix River and Chippewa River in Wisconsin, which have an abundance of habitat for fishes that require clear water and rock and gravel substrates.

Access to main stem river habitat

Improving fish passage at dams impounding the larger navigation pools, including Pools 4, 9, 13, 19, and 26, would provide fish access to extensive main stem river habitat areas (Figure 9, Table 10). Each navigation pool has a unique mix of aquatic habitat types (Table 10) that would benefit migratory fish species.

Access to tributaries – Longitudinal Connectivity Index (LCI)

The contributions of tributaries to fisheries in the main stem rivers are a function of stream order (size, discharge) at the confluences. The ecological interplay between smaller (lower order) tributaries and the main stem rivers differs from that of larger (higher order) tributaries. In the UMRS basin, some fish populations in smaller streams annually migrate to the UMRS main stem rivers or the larger tributaries during the winter. Many fish species in larger streams are year-round residents, and are therefore less dependent upon the main stem rivers to meet life history requirements. Tributaries are needed to fulfill life cycle requirements for some migratory fish species, which rely upon larger tributaries and specific habitats for spawning and early life but live their remaining life in the main stem of the river. Considering the above, we deemed a simple comparison of tributary stream length inadequate for quantifying the influence of tributaries on the fish communities of the UMRS.

We developed a Longitudinal Connectivity Index, or LCI, as a tool to compare incremental benefits of restoring fish passage between each UMRS navigation pool because the number and size of tributaries differs for each pool (Figures 11 and 12). This index was developed to aid in identifying priority of fish passage improvements throughout the system. Tributary connectivity was calculated using stream order (Strahler 1957) and length of accessible stream from the main stem rivers (Table 6). For this analysis only fourth order and greater streams were considered because the location of the first dam was best documented for larger streams. The LCI could include smaller order streams if better systemic information existed. The LCI was calculated for each navigation pool using the formula:

$$\Sigma (\text{unobstructed stream length} \times \text{stream order}) = \text{LCI}$$

For example, the LCI for Pool 13 was calculated using information for all fourth order and larger tributaries:

UMR Pool 13 Tributary Name	Distance (km)		Location of First Obstruction (dam or natural)	Stream Order	Water shed Area (ha)	River Mile at Confluence	State
	Confluence to First Obstruction	Total Stream Length					
Mill Creek	n/a	14.2	None	4	8,387	556.0	IA
Maquoketa River	41.5	173.3	Maquoketa	6	480,689	548.6	IA
Apple River	13.1	57.8	Hanover	5	65,363	543.0	IL
Rush Creek	n/a	32.2	None	4	16,917	541.8	IL
Plum River	39.4	44.2	Lake Carroll Dam	5	70,340	533.1	IL
Elk River	n/a	17.6	None	4	19,365	528.1	IA
Pool 13 main stem	55.0	n/a	L&D 12	9	n/a	n/a	IA/IL

Fish-accessible tributary lengths were combined and multiplied by the stream order to weight their relative contribution. Only the length of tributary stream accessible to main stem fishes was used. Each order increment was then added to calculate the LCI as follows:

$$\begin{aligned}
 (14.2 + 32.2 + 17.6) \times 4 &= 256 \\
 (13.1 + 39.4) \times 5 &= 262.5 \\
 41.5 \times 6 &= 249 \\
 0 \times 7 &= 0 \\
 0 \times 8 &= 0 \\
 + 55.0 \times 9 &= 495 \\
 \hline
 \text{LCI for Pool 13} &= 1262.5
 \end{aligned}$$

LCIs were developed for each Pool (Table 12). These were then prioritized into three general categories based upon LCI: high (>2000), medium (1000-2000), and low (<1000). Exception was made for Pool 10, which was rated as high even though the LCI was 1978.3. This was done to account for a weakness within the tributary database, which did not contain the Kickapoo River and Blue River (Wisconsin River tributaries). Inclusion of these increased the LCI above the 2000 threshold and therefore Pool 10 was included in the high category.

Access to tributaries with hard substrate, high velocities, and cool water

The tributaries with high quality habitat for fish requiring higher current velocities, rock, cobble, and gravel substrates with cooler, clearer water include the St. Croix and its tributaries the Apple and Kinnickinnic, the Chippewa, Black, Wisconsin and their tributaries in Wisconsin, the Zumbro, and Whitewater in Minnesota, and the Root, Upper Iowa, Turkey, and Wapsipicon in Iowa.

Table 12 Longitudinal Connectivity Index for Each Navigation Pool of the UMRS (Pools shaded green have a high LCI, yellow moderate, and red have a low LCI)										
Pool	1	2	3	4	5	5a	6	7	8	9
LCI	93	2669	845	2209	863	497	529	697	1110	1049
10	11	12	13	14	15	16	17	18	19	20
1978	1393	806	1263	1068	251	536	419	2113	2089	1513
Illinois Waterway										
21	22	24	25	26	La Grange	Peoria	Starved Rock	Marseilles	Dresden	
1143	2576	1255	923	9982	5438	3997	228	641	284	

Identification of Potential Fish Passage Improvements at Each Lock and Dam

A workshop with Corps Fish Passage Team members, lock and dam specialists, and hydraulic engineers was held to review each UMRS lock and dam to identify potential fish passage improvements. Fish could be locked through at every UMRS lock and dam. Nature-like bypass channels, rock ramps, nature-like bypass channels built on land, nature-like bypass channels built through constructed islands upstream or downstream of the dams, rock ramp fishways, “custom” type fishways, and smaller fishways at the overflow spillways were considered for each site. Unused auxiliary lock chambers were considered potential fishway locations, even though careful design would be required to prevent interference with navigation in the lock approaches. The focus was on main channel fishways that would be most ecologically effective in passing migratory fish. Hard copy aerial photos of each lock and dam were marked up to indicate the locations of potential fish passage improvements.

Appendix D provides a brief description of potential fish passage improvements and figures illustrating where they might be located at each lock and dam. These potential improvements were identified in the reconnaissance-level workshops as the most obvious choices. Detailed planning and design for each site may reveal more practicable, cost- and ecologically effective fish passage improvements.

Cost of Fish Passage Improvements

The cost of fish passage improvements was conservatively estimated, using some standard assumptions about the cost of locking fish, the size, geometry, and materials used in structural fishways, cost of materials, and cost of construction (Appendix C). The costs of constructing potential fishways identified at each lock and dam were estimated using standard engineering techniques of estimating quantities of different materials, their unit costs, and construction costs (Mays 2001; Rosgen 1996). The assumption was made that all fishways would require

upstream water control structures and access facilities (bridges, etc.). These features approximately doubled the estimated cost of the fishways. Water control structures at the upstream end of fishways and access facilities may not be needed at each site, however. Innovative construction techniques and fishway designs may significantly lower the cost of constructing fishways at UMRS dams below the initial estimates presented in Table 13. The initial cost estimates were made in a systematic way, however, and they do provide a basis for comparing the relative cost of fishway construction between sites. The initial cost estimates do not include costs of any necessary real estate acquisition, monitoring, modifications, or operation and maintenance of fish passage improvements.

Lock and Dam	Head m	Estimated Cost	Fishway Type
2	3.7	\$26,287,315	Auxiliary lock
3	2.4	\$10,880,000	Through land
4	2.1	\$14,962,269	Auxiliary lock
5	2.7	\$15,312,372	Through land
5A	1.8	\$13,219,550	Auxiliary lock
6	1.8	\$14,881,540	Through land
7	2.4	\$15,261,712	Auxiliary lock
8	3.4	\$16,875,856	Auxiliary lock
9	2.7	\$16,502,262	Through land
10	2.4	\$14,543,928	Auxiliary lock
11	3.4	\$15,546,775	Auxiliary lock
12	2.7	\$16,290,146	Auxiliary lock
13	3.4	\$17,038,126	Auxiliary lock
14	3.4	\$15,031,966	Auxiliary lock
15	4.9	\$20,523,531	Through land
16	2.7	\$14,477,629	Auxiliary lock
17	2.4	\$14,656,261	Auxiliary lock
18	3.0	\$19,538,799	Auxiliary lock
19	11.6	\$47,520,886	Custom
20	3.0	\$15,233,949	Auxiliary lock
21	3.2	\$16,227,399	Auxiliary lock
22	3.0	\$15,495,036	Auxiliary lock
24	3.7	\$17,436,098	Auxiliary lock
25	3.8	\$16,968,015	Auxiliary lock
26	5.5	\$24,986,281	Auxiliary lock
Starved Rock	5.5	\$52,723,254	Island
Marseilles	7.4	\$29,510,476	Through land
Dresden Island	6.7	\$74,150,727	Island
Kaskaskia	3.7	\$42,672,622	Custom

Identification of the Most Practicable Fish Passage Improvements

We reviewed the potential fish passage improvements at each site and identified the ones that would probably be the most ecologically- and cost-effective (see Appendix D, Potential Fishway Sites). The location of fishway entrances in proximity to the gated part of the dams is a major consideration so that fish can find and be attracted into a fishway. Fishways with entrances close to the gated part of the dam were selected in preference to other alternative locations with more distant entrances. At some sites, the cost of bypass channel or other fishway types was significantly greater than cost of a rock ramp fishway built into the auxiliary lock chamber, so at those sites, the lock chamber alternative was selected as the most practicable. The potential fish passage improvements at each site should be more carefully considered upon initiating detailed planning and design for implementation.

Identification of Priority Sites for Fish Passage Improvements

The combination of existing opportunity for fish passage through each dam, the amount of newly accessible habitat in each pool and confluent tributaries, and

the cost of construction at each site was used to identify the most ecologically and cost-effective sites for fish passage improvements on the Upper Mississippi and Illinois Rivers (Tables 14 and 15, respectively).

We applied a simple 1 to 3 (low, medium, high) ranking system for sites using four selection criteria: existing opportunity for upriver fish passage, access to habitat in the navigation pool, access to tributaries, and estimated construction cost for fish passage improvements. The variable used to describe existing opportunity for upstream passage is the percentage of the time that the dam gates are out of the water. For O_E , existing opportunity for upriver fish passage, the dams that present more complete barriers to upriver fish passage were given a high rating, indicating priority of need for fish passage improvement. The areas of aquatic habitat in each navigation pool were used, along with the longitudinal connectivity index (LCI) for tributaries to each pool as variables for newly accessible habitat. The formula used to calculate the overall ranking R was:

$$R = \{[(O_E + H_P + H_T) 3] + C_C\} / 2$$

where

R = rank

O_E = existing opportunity for upriver fish passage (1 = high, 3 = low)

H_P = habitat area of navigation pool (3 = high, 1 = low)

H_T = habitat area of tributaries confluent to navigation pool (LCI index)
(3 = high, 1 = low)

C_C = Construction cost (1 = high, 3 = low)

This formula weights the positive aspects of the site for fish passage improvements equally against the estimated cost of construction.

Mainstem river and tributary aquatic habitat with rock and gravel substrates is noted in Table 14, based on limited knowledge of its distribution. This factor was not included in the ranking of sites for priority of fish passage improvements.

Using this simple ranking system, Locks and Dams 4, 5, 7, 8, 9, 10, 11, 13, 14, 18, 22 and 24 emerged as high priority sites for fish passage improvements on the UMR. Additional locks and dams should be considered higher priority sites for fish passage improvements for other reasons.

A fishway at Lock and Dam 2 would provide connectivity between the Minnesota River and its many tributaries, the Mississippi River, and the St. Croix River. Despite the relatively high cost, a fishway at this site would help restore migratory pathways for channel catfish, paddlefish, and lake sturgeon.

Lock and Dam 3 should be considered a higher priority site for fish passage improvement. This site did not rank highly due to the relatively low surface area of Pool 3), the relatively low total length of tributaries in Pool 3, and the 16 percent of time that the dam is out of control with gates out of the water. However, fish passage improvement at Lock and Dam 3 could be ecologically effective. The walleye and sauger sport fishery in Pools 3 and 4 is a nationally recognized

year-round fishery that is economically important in the region. Other migratory fish populations that would positively respond to improved fish passage at Lock and Dam 3 include the state-listed threatened and endangered lake sturgeon and paddlefish. Improved fish passage through Lock and Dam 3 would provide migratory fish moving upriver from Pool 4 continuity of habitat with an additional 18,551 ha of channel and river lake habitat in the Mississippi and St. Croix Rivers. Access to traditional spawning sites in tributaries with hard substrate, high current velocities, and cool water is needed for spawning by many migratory fish species, including lake sturgeon and paddlefish. Improved fish passage at Lock and Dam 3 would provide fish continuity of access to tributaries with high quality habitat, including the St. Croix River and its tributaries the Apple and Kinnickinnic Rivers, the Mississippi River, including Lake Pepin, the Trimble, Rush, Big, and Chippewa rivers in Wisconsin and the Vermillion and Cannon rivers in Minnesota, for a total of 350 km of tributary river habitat. Improved fish passage at Lock and Dam 3 would have a positive effect on the sustainability of native mussel populations. In particular, populations of the Federally endangered Higgin's Eye Pearly Mussel, *Lampsilis higginsii* and Winged Mapleleaf, *Quadrula fragosa*, could benefit from increased abundance and migratory range of their host fish species in the St. Croix River. Construction of a fishway would need to be done in conjunction with a project to strengthen the Wisconsin embankments at this site.

Pool 15 was the site of the Rock Island Rapids before the navigation dams were constructed. Consequently, Pool 15 is the steepest and shortest UMR navigation pool below St. Anthony falls. As a result of this unique geographical feature, this pool failed to rank high when prioritized against other Upper Mississippi River dams (Table 14) even though Dams 14 and 15 create a significant serial bottleneck to upriver fish passage in the system (Figure 6). The team recognized that because it is a near-complete barrier, fish passage must be addressed at this bottleneck early in the restoration process for systemic benefits to be realized. Therefore, these sites were included in the recommendation for detailed planning even though Dam 15 did not rank high using the comparison criteria.

Lock and Dam 19 should be considered a high priority site for fish passage improvement, despite the high cost of constructing a fishway there. Lock and Dam 19 is a near-complete barrier to upriver fish passage. Lock and Dam 19 is a key site for restoration long-distance migratory fish populations, such as the skipjack herring. Although a fishway at this site would be expensive, Lock and Dam 19 is the most significant bottleneck for fish movements on the UMR. Fish passage improvement at this dam would restore the essential connection for fish movements between the upper and lower.

Melvin Price Locks and Dam should also be considered a high priority site for fish passage improvement, despite the relatively high cost of constructing a fishway there. In addition to Pool 26 and the lower reach of the Illinois River up to the La Grange dam, there is a large amount of tributary habitat confluent with Pool 26. A fishway at Melvin Price Locks and Dam would provide migrating fish access upriver to Lock and Dam 19 in many years, because Locks and Dams 25, 24, 22, 21, and 20 are out of control during higher levels of river discharge.

Table 14
Comparison of Upper Mississippi River Dams for Priority for Fish Passage Improvement

Existing Opportunity for Fish Passage		Variable: Percent of time that dam gates are out of the water																										
Locks and Dams:		1	2	3	4	5	5a	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	24	25	26	
Low	0 to 10 %	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	
Medium	10 to 20 %	2																										
High	20 + %																											
Access to Habitat in Navigation Pool		Variable: Water area of navigation pool																										
Locks and Dams:		1	2	3	4	5	5a	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	24	25	26	
High	>15,000 ha				3				3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	
Medium	5,000 to 15,000 ha			2					2																			
Low	>5000 ha	3	1																									
Hard substrate spawning habitat:		Rank																										
		1	2	3	2	1	1	2	3	3	3	3	2	3	2	1	2	2	1	2	2	3	2	2	2	2	2	3
Access to Tributaries		Variable: Longitudinal Connectivity Index (LCI)																										
Navigation Pools		1	2	3	4	5	5a	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	24	25	26	
High	>2000	2669			2219						1978										2113	2089			2576		9982	
Medium	1000 - 2000								1110	1049		1393			1263	1068									1513	1143	1266	
Low	<1000	33	345	345	345	497	529	637					316				251	526	419								923	
Hard substrate spawning habitat:		Rank																										
		1	3	1	3	1	1	1	1	2	2	3	2	1	2	2	1	1	1	1	3	3	2	2	3	2	1	3
Cost of Fishways		Variable: Cost of rock ramp or bypass fishway																										
Locks and Dams:		1	2	3	4	5	5a	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	24	25	26	
Low	<\$20 M																											
Medium	\$20 M - \$30 M																											
High	> \$30 M																											
Summary		Variable: Number of high ranks from above																										
Locks and Dams:		1	2	3	4	5	5a	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	24	25	26	
High	= 2.5 to 3.0																											
Medium	= 2.0 to 2.49																											
Low	= <2.0																											
Rank Score		2.2	2.3	3.0	2.5	2.2	2.3	2.5	2.8	2.7	2.8	2.8	2.3	2.8	2.7	2.8	2.7	1.8	2.3	2.2	2.7	2.0	2.3	2.3	2.7	2.5	2.2	2.3

= Higher priority sites for fish passage improvements (Combined rank score > or = to 2.5)

Although we did not include the Kaskaskia Lock and Dam in the ranking process, fish passage improvements there could play a significant role in the ecosystem restoration efforts on 151 km of the Kaskaskia River. This site would be a good location to experiment with locking fish, and the layout of the lock and dam and the former river channel lends itself to a bypass channel fishway.

On the Illinois River, we excluded Peoria and La Grange Locks and Dams because they already allow upriver fish passage, and we excluded Lockport, Brandon Road, and T.J O'Brien Locks and Dams due to the concern about limiting dispersal of nonindigenous aquatic species between the UMRS and Lake Michigan (Table 15). Of the remaining three locks and dams on the Illinois River, Marseilles Lock and Dam emerged with the highest rank for fish passage improvements. Improving fish passage at Dresden Lock and Dam would provide fish access to the improving habitat conditions in the Kankakee River. Improving fish passage at Brandon Road would provide fish access to the DesPlaines River, but this objective could conflict with the intent to prevent dispersal of nonindigenous fish.




Many UMRS navigation dams have potential for smaller fishways through the earthen embankments or overflow spillways. Although the priority should initially be for improving main channel fish passage, smaller fishways would be helpful in passing fish in secondary channels. This ranking is not intended to exclude sites from further consideration for fish passage improvements. As fish passage improvements are implemented and proven to be effective, improvements should be considered at other sites.

Table 15

Comparison of Illinois River Dams for Priority for Fish Passage Improvements, Excluding Peoria and La Grange, Brandon Road, Lockport, and T.J. O'Brien Lock and Dams




Existing Opportunity for Fish Passage

Variable: Percent of time that dam gates are out of the water

		Locks and Dams: Dresden Marseilles Starved Rock			
Low		0 to 10 %	3	3	3
Medium		10 to 20 %			
High		20 + %			
		Rank	3	3	3




Access to Habitat in Navigation Pool

Variable: Water area of navigation pool

		Locks and Dams: Dresden Marseilles Starved Rock			
High		>2,000 ha		3	
Medium		1,000 to 2,000 ha	2		2
Low		>1000 ha			
		Rank	2	3	2




Access to Tributaries

Variable: Longitudinal Connectivity Index (LCI)

		Locks and Dams: Dresden Marseilles Starved Rock			
High		>2000			
Medium		1000 - 2000			
Low		<2000	228	641	284
		Rank	1	1	1




Cost of Fishways

Variable: Cost of rock ramp or bypass fishway

		Locks and Dams: Dresden Marseilles Starved Rock			
Low		< \$20 M			
Medium		\$20 M - \$30 M		2	
High		> \$30 M	1		1
		Cost	\$74.1	\$29.5	\$52.7
		Rank	1	2	1

Summary

Variable: Number of high ranks from above

		Locks and Dams: Dresden Marseilles Starved Rock			
High		= 2.5 to 3.0			
Medium		= 2.0 to 2.49			
Low		= <2.0			
		Rank Score	1.5	2.2	1.5

14 Monitoring and Evaluating the Effectiveness of Fish Passage Improvements

Setting Objectives for Restoration

Major investments in fish passage improvements on the UMRS warrant clear objectives for the use of fishways by fish and for the restoration of migratory fish and associated Unionid mussel populations. Monitoring of the effects of fish passage improvements would allow evaluation of the degree to which ecosystem restoration objectives are attained. In addition to ecological objectives, objectives for hydraulic conditions, structural integrity, and operation and maintenance requirements of fish passage improvements should be set in advance.

Further research on pre-impoundment migratory fish species abundance and distribution in the UMRS would be appropriate for setting targets for restoration. A number of reviews of historical fish records from the UMRS have been made: Burr and Page (1986), Carlander (1954), Eddy and Underhill (1974), Becker (1983), Fremling et al. (1989). Becker (1983), Eddy and Underhill (1974), and Pflieger (1975) made extensive use of museum collections to describe historical fish distribution in the UMR. It would be useful to thoroughly research, compile, and update this historical information prior to embarking on a system-wide program to improve fish passage through UMR dams. A geographic information system (GIS) of historical and present fish species distribution in the UMRS would be helpful in visualizing targets for restoration. Information about pre-impoundment UMRS fish population sizes are nonexistent except as anecdote and commercial landings (Coker 1914, 1929, 1930; Townsend 1902). Ecological modeling should be done to simulate the biotic potential of selected migratory UMRS fishes to set population size objectives for their restoration as well as setting objectives for restoring them to their pre-impoundment geographic range.

Monitoring the ecological effectiveness, hydraulic conditions, and structural integrity of newly constructed fishways would be an essential element of adaptive management. Performance targets should be set for physical conditions within the passage structure (e.g., current velocities less than 0.3 m/sec in at least 1 m² of each fishway cross section, annual erosion loss of less than 1 m² in any fishway cross section, etc.). Some biological performance targets may also be set (e.g., use of fishways by species, percentage of entering fish that leave the upriver end of the fishway, etc.) These targets should be further evaluated for

effectiveness and appropriateness through post-construction monitoring. Monitoring efforts should be carefully designed to obtain specific information necessary to make any needed modifications to fish passage improvements, to determine if biological objectives are attained, to make refinements to future designs, operation and maintenance, and to learn.

Monitoring Fish Passage Through Dam Gates

Fish passage through dam gates should be monitored with telemetry, mark-recapture, directional net capture, and with hydroacoustic equipment and data loggers. Telemetry can confirm movements of fish through dams. Mark-recapture experiments can provide information on the numbers of fish that pass through dams. Net capture of fish close to the dam gates would be impracticable owing to the high velocities and difficult setting for net deployment. Sophistication of hydroacoustic equipment has advanced to be able to detect the number of passing fish, their relative size (based on acoustic reflectivity from their swim bladders), direction of movement, and timing of movement. Placing instruments in all the gate bays at one lock and dam would be prohibitively expensive, but monitoring of fish passage through several of the landward gate openings would be valuable for use in estimating total numbers of fish that move through a dam in a season. Acoustic Doppler profiling equipment should be used to measure the hydraulic conditions in the dam gate openings.

Fish Passage Through Locks

Fish passage through locks during dedicated fish lockages should be estimated in controlled experiments using directional capture nets, telemetry, or hydroacoustic equipment. Fish passage through the lock chambers when tow-boats are entering and leaving would be impracticable. The numbers of fish in lock chambers can be estimated using rotenone sampling as was routinely done at Ohio River navigation locks (Keyes and Kline 1984) or by repeated net capture.

Fish Passage Through Fishways

The number and species of fish using the first fishways on the UMRS should be monitored. Hydroacoustic equipment and directional net capture of fish should be used. Directional net capture of fish moving through a fishway can be done with finer mesh near the bottom, to capture small fish where velocities are lower, and with larger mesh higher in the water column to capture larger fish (L. Aadlund, Minnesota Department of Natural Resources, Fergus Falls, MN, personal communication, 2003). Hydroacoustic or net capture monitoring would need to be conducted continuously over the potential fish passage seasons to estimate total numbers and to determine the seasonal timing of fish use of the fishways. Telemetry studies, although cost- and labor-intensive, also offer the most detailed information on fish movement and passage. There may be unique benefits to telemetry that have potential to describe not only passage but also distribution, attraction, and fallback of fishes passing dams. Acoustic Doppler

profiling equipment should be used to measure the hydraulic conditions in the fishways.

Fish captured passing through a fishway should be measured for size. Scales or spines could be obtained to estimate their age if needed. Captured fish of selected species should be marked and then released to enable subsequent recapture in conjunction with controlled experiments to determine the additional habitat areas occupied and the timing of subsequent upriver and downriver passages. Returns of tagged fish could be obtained through active capture techniques and by tag returns from anglers. The movements of fish equipped with radio transmitters can be tracked using telemetry equipment to determine their use of habitats following ascent of a fishway and the timing and pathways for downriver passage. These kind of studies are labor and cost-intensive.

Effects on Fish Populations

Effects of improved fish passage through UMRS dams on fish populations would probably occur, but would be difficult to monitor for most migratory species. The increased presence of some migratory species, such as skipjack herring, could become obvious by direct observation. Few fish stock assessments or population studies are conducted on the UMRS. The Long Term Resource Monitoring Program (LTRMP, see: <http://www.umesc.usgs.gov/ltrmp.html>) is part of Environmental Management Program for the Upper Mississippi River System (UMRS EMP). Congress funds the UMRS EMP through the U.S. Army Corps of Engineers, which has administrative and management responsibilities for the program. The U.S. Geological Survey Upper Midwest Environmental Science Center in La Crosse, WI, and five UMRS states conduct the LTRMP. Continued LTRMP fish monitoring in selected UMRS navigation pools may reveal changes in relative abundance of fish resulting from improved fish passage, but the LTRMP monitoring is not designed to detect changes in fish population size. A carefully designed mark-recapture study would be required. This kind of population-level response study would be time-, labor-, and cost-intensive.

Monitoring the genetic responses of UMR migratory fish stocks and populations to fish passage improvements could be accomplished through carefully designed experiments to characterize genetic diversity of selected fish species before and after installation of fish passage improvements.

Effects on Threatened and Endangered Species

Monitoring the effects of improved fish passage on the state-listed threatened and endangered species migratory fish species (lake sturgeon, paddlefish) should first focus on the numbers of these species passing new fishways. Given their size, we can assume that the largest fish detected by hydroacoustic equipment would be these species. Further monitoring could focus on their relative abundance in preferred spawning areas, building on historical information. This kind

of monitoring of long-lived and infrequently reproducing fishes would take decades.

Movements of Nonindigenous Species

Nonindigenous species are a major concern, with several species of Asian carp and gobies poised to invade the Upper Mississippi River Basin. Tracking of upriver invasion of these species will be done by the states, the U.S. Fish and Wildlife Service and the U.S. Geological Survey. A brief feasibility study on limiting the northward invasion of Asian carp was conducted (FishPro, Inc. 2004) with attention to potential barrier technologies to prevent fish from moving upriver through lock chambers. Decisions about implementing fish passage improvements will be done in the context of invading nonindigenous species. A barrier placed to prevent the upriver movement of nonindigenous species would probably also prevent upriver passage by native migratory species.

Effects on Sport and Commercial Fisheries

Carefully designed experiments would be needed to monitor and detect the population level response of most migratory fish species and related changes in sport and commercial fishing success. Density of fish in tailwater areas could be monitored by hydroacoustic equipment for several years before and after fish passage improvements are implemented, to address the question that many tailwater anglers are likely to have about effects of improved fish passage on their fishing opportunity.

Effects on Mussels

The response of mussel populations to greater distribution and abundance of migratory fish in the UMRS would probably be slow, given the many variables affecting their recruitment. It would be difficult to design monitoring experiments that conclusively measure the effects of fish passage improvements on mussel populations. Given the paucity of stock assessment data on mussels, continued surveys of their relative abundance are unlikely to provide evidence of the effects of improved fish passage through the navigation dams. Some responses might be obvious, such as restored range of skipjack herring and Ebony shell mussels.

Operation, Maintenance, and Modifications to Fishways

The structural integrity of fishways should be monitored through the routine periodic inspections of the Locks and Dams. Fisheries scientists and managers should participate in the periodic inspections of the fish passage facilities.

Acoustic Doppler surveys of hydraulic conditions in the fishways should reveal the need for any modifications to remove hydraulic barriers to fish passage.

15 Conclusions and Recommendations

The following conclusions and recommendations are those of a majority of the interagency Navigation Study Fish Passage Team members, and do not necessarily reflect the positions or policies of the U.S. Army Corps of Engineers, the U.S. Fish and Wildlife Service, the U.S. Geological Survey, or the Departments of Natural Resources of Minnesota, Wisconsin, Iowa, Illinois, or Missouri.

Conclusions

- There are at least 34 species of migratory native fishes in the UMRS.
- The navigation dams present near-complete to partial barriers to fish migrations.
- Fragmentation of habitat by navigation dams has adverse effects on the size and sustainability of fish populations in the UMRS.
- The reduced abundance of migratory fishes has had adverse effects on Unionid mussels in the UMRS.
- Improving fish passage through the UMRS navigation dams would provide significant ecological benefits.
- The U.S. Army Corps of Engineers had the intent at the time of navigation project construction to construct fishways if they were shown to be necessary.
- This U.S. Army Corps of Engineers has the authority to install fishways at navigation dams on the UMRS.
- Fish passage has been used as an essential component of efforts to restore river ecosystems worldwide. Effective fish passage improvements are typically well received by the public.

Recommendations

- Set clear objectives for restoration of UMRS migratory fishes and Unionid mussels, to restore them to their pre-impoundment geographic

distribution and populations sizes commensurate with their biotic potential.

- Conduct detailed planning for fish passage improvements starting with Mississippi River Locks and Dams 2, 3, 4, 5, 7, 8, 9, 10, 11, 13, 14, 15, 18, 19, 22, 24, Melvin Price Locks and Dam, and Kaskaskia Lock and Dam. An interagency interdisciplinary team should collaboratively plan and design the fish passage improvements.
- Incorporate innovative design and construction techniques to reduce the cost of fish passage improvements.
- Monitor and evaluate the ecological and engineering effectiveness of the fish passage improvements. Monitor the use of the dam gates, locks, and constructed fishways by fish, and conduct experiments to estimate biological responses of improved fish passage. Monitor operation and maintenance requirements.
- Evaluate the performance of the first fishways, and proceed to adaptively plan, design, and construct additional fishways with improved designs.
- Present the results of fish passage monitoring and planning at UMRS management conferences.
- Publish technical articles about UMRS fish passage in agency literature and in scientific journals.

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