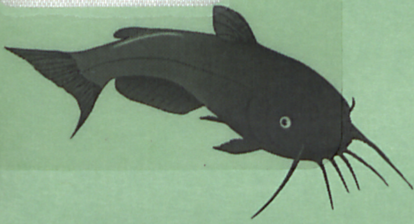
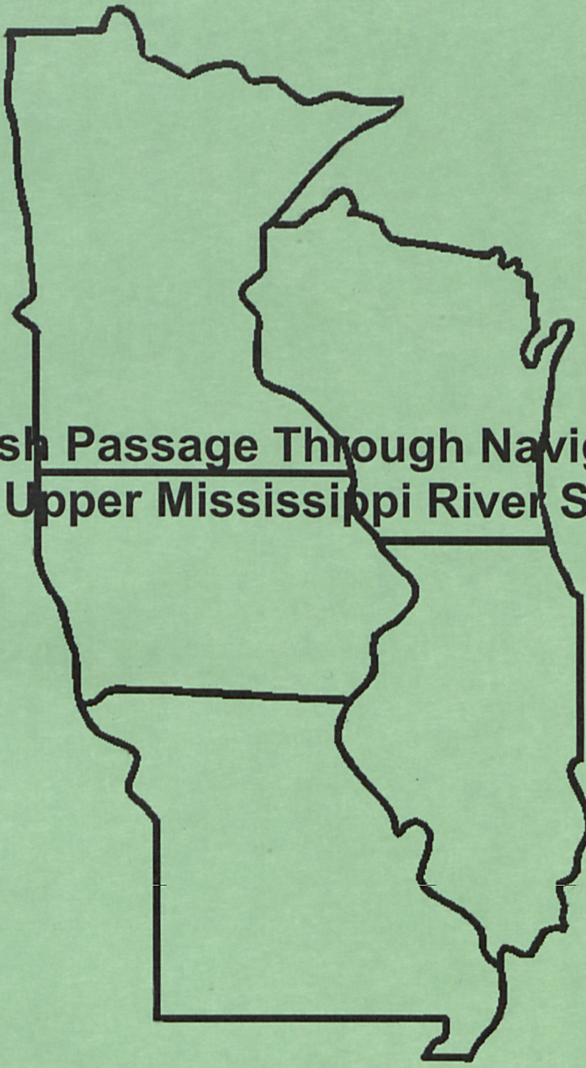
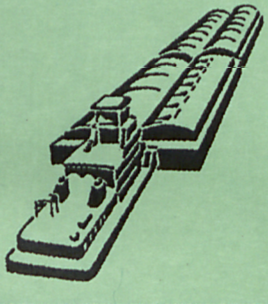
ENV Report 54

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





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



October 2004

Rock Island District
St. Louis District
St. Paul District

US Army Corps
of Engineers

Upper Mississippi River - Illinois Waterway System Navigation Study

ENV Report 54
October 2004

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

Daniel B. Wilcox, Elliott L. Stefanik, Daniel E. Kelner

U.S. Army Engineer District, St. Paul
190 5th Street East
St. Paul, MN 55101-1638

Mark A. Cornish, Daniel J. Johnson, Isaac J. Hodgins

U.S. Army Engineer District, Rock Island
Clock Tower Building
P.O. Box 2004
Rock Island, IL 61204-2004

Steven J. Zigler

U.S. Geological Survey
Upper Midwest Environmental Science Center
2630 Fanta Reed Road
La Crosse, WI 54603

Brian L. Johnson

U.S. Army Engineer District, St. Louis
1222 Spruce Street
St. Louis, MO 63103-2833

Interim report

Approved for public release; distribution is unlimited.

Prepared for U.S. Army Engineer District, Rock Island
Rock Island, IL 61204-2004
U.S. Army Engineer District, St. Louis
St. Louis, MO 63103-2833
U.S. Army Engineer District, St. Paul
St. Paul, MN 55101-1638

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.

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 32

- Present Distribution of Mussel Species 32
- Historical Distribution of Mussel Species 32

5—Navigation Dams on the UMRS 34

- Locations and Designs 34
- Illinois River Dams 37
- Dam Operation and Hydraulic Conditions 37
- Hydraulic Conditions at Illinois River Dams 39
- Hydraulic Conditions Over Spillways 40
- Hydraulic Conditions in Lock Chambers 40

6—Fish Passage Through UMRS Dams 42

- Downstream Fish Passage 42

Fish Passage Through Lock Chambers........42
Fish Passage Through Dam Gates........44
Fish Passage Over Spillways........45
Existing Opportunity for Upriver Fish Passage Through Navigation Dams........45

7—Fish Passage to and from the Floodplain........47

8—Fish Access to Tributaries........49

9—Nonindigenous Fishes in the UMRS........55

History and Presence of Nonindigenous Fish Species in the UMRS........55
Potential for Invasion by Nonindigenous Species........56
Nonindigenous Species Movement........57
Potential Effects of Improving Nonindigenous Fish Passage Through UMRS Dams........58

10—Alternatives for Improving Fish Passage Through UMRS Dams........59

Assisted Lockage........59
Modified Dam Gate Operation........60
Modified Dam Gate Bay Configuration........61
Technical Fishways........61
Nature-Like Fishways at Main Channel Navigation Dams........61
Small-Scale Fishways at Overflow Spillway Sections........62
Large-Scale Fish Passageways........63
Evaluation of Alternative Fishway Types........63

11—Alternatives for Limiting Dispersal of Nonindigenous Species........64

Dams Without Fish Passage........65
Dams With Fish Passage – Capture and Sorting........67

12—Benefits of Improving Fish Passage Through UMRS Dams........68

Increased Access to Habitats........68
  Access to main stem river habitats........68
  Fish access to tributaries........69
Effects of Improved Passage Through Dams on Fish Populations........72
Benefits of Improved Fish Passage to Sport and Commercial Fisheries........74
Other Benefits of Improved Fish Passage........74
Benefits of Improved Fish Passage to Mussels........74
  Lock and Dam 3........74
  Lock and Dam 6........75
  Lock and Dam 8........75
  Lock and Dam 19........75
  Lock and Dam 21........75
  Illinois River (Marseilles Lock and Dam)........76
  UMR Locks and Dams 2, 5, 9, 14, 22, 24........76
Potential for Whitewater Recreation........76

13—Priority of Fish Passage Improvements........77

Existing Opportunity for Fish Passage........77
Access to Habitat........77

Serial continuity of habitat between navigation pools 77
Access to main stem river habitat.. 78
Access to tributaries – Longitudinal Connectivity Index (LCI) 78
Access to tributaries with hard substrate, high velocities, and cool water 79
Identification of Potential Fish Passage Improvements at Each Lock and Dam.. 80
Cost of Fish Passage Improvements 80
Identification of the Most Practicable Fish Passage Improvements 81
Identification of Priority Sites for Fish Passage Improvements 81

14—Monitoring and Evaluating the Effectiveness of Fish Passage Improvements 87

Setting Objectives for Restoration 87
Monitoring Fish Passage Through Dam Gates 88
Fish Passage Through Locks 88
Fish Passage Through Fishways 88
Effects on Fish Populations 89
Effects on Threatened and Endangered Species 89
Movements of Nonindigenous Species 90
Effects on Sport and Commercial Fisheries... 90
Effects on Mussels 90
Operation, Maintenance, and Modifications to Fishways.............................. 90

15—Conclusions and Recommendations.. 92

Conclusions.. 92
Recommendations... 92

References 94

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 35

Figure 4. Cross section of a typical roller gate on an Upper Mississippi River navigation dam 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 38

Figure 6. Percentage of time that gates are raised out of the water at Upper Mississippi River navigation dams 40

Figure 7. Contiguous and isolated floodplain areas of the Upper Mississippi and Illinois rivers 48

Figure 8. Dams on tributaries to the Missouri, Upper Mississippi, and Illinois rivers with capacity greater than 6.1 million m^3 (5,000 acre-ft) 49

Figure 9. Total length (km) of fish-accessible tributaries by navigation pool and stream order for the Upper Mississippi River 53

Figure 10. Total length (km) of fish-accessible tributaries by navigation pool and stream order for the Illinois Waterway 54

Figure 11. Water area (ha) of Upper Mississippi River navigation pools 69

Figure 12. Length (km) of major tributaries to the first dam or natural barrier, by Upper Mississippi River navigation pool 73

List of Tables

Table 1. Fish Passage Team Members 3

Table 2. Upper Mississippi River Fishes 17

Table 3. Behavioral and Reproductive Characteristics of 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 Migratory Fishes 28

Table 5. Design Data for Upper Mississippi River Navigation Dams 36

Table 6. Tributaries to the Upper Mississippi and Illinois Rivers 50

Table 7. Initial Cost Estimate for Locking Fish Through UMRS Dams 60

Table 8. Aquatic Nuisance Species of Concern in the UMRS 64

Table 9. Potential Measures to Control the Movement of Invasive Aquatic Species 66

Table 10. Aquatic Habitat Types and Areas (ha) Associated with Upper Mississippi River Navigation Dams 70

Table 11. Aquatic Habitat Types and Areas (ha) Associated with the Illinois River Navigation Dams 72

Table 12. Longitudinal Connectivity Index for Each Navigation Pool of the UMRS 80

Table 13. Estimated Cost of Fishways at UMRS Dams 81

Table 14. Comparison of Upper Mississippi River Dams for Priority for Fish Passage Improvement 84

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 86

Preface

The 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 Daniel 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; Steven 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 Killgore, 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 report. Dr. Piotr Parasiewicz of Cornell University, Ithica, NY, and Dr. Alexander Haro of the U.S. Geological Survey S. O. Conte Anadromous Fish Laboratory, Turners Falls, MA, 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 1,033 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).

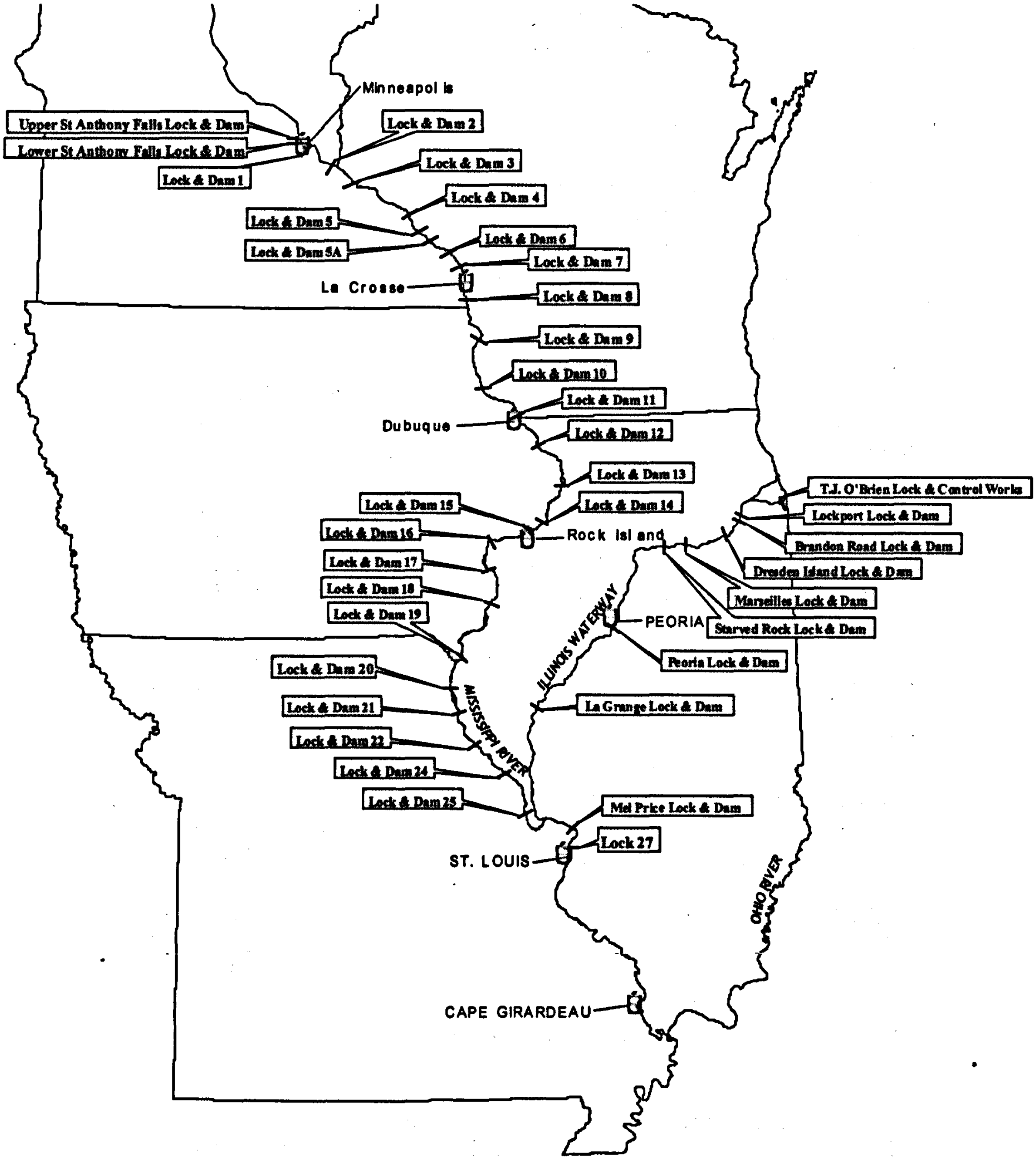


Figure 1. Upper Mississippi River – Illinois Waterway locks and dams

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.

Table 1
Fish Passage Team Members

Luther Aadland	MN DNR	218-739-7449	Luther.Aadland@dnr.state.mn.us
Butch Atwood	IL DNR	618-664-2330	eatwood@dnrmail.state.il.us
Ron Benjamin	WI DNR	608-785-9012	benjar@dnr.state.wi.us
Bernard Schonhoff	IA DNR	563-263-5062	fishiowa@muscanet.com
Ken Brummett	MO DOC	573-248-2530	brummk@mdc.state.mo.us
Aaron Buesing	Corps St. Paul	651-290-5627	Aaron.W.Buesing@usace.army.mil
Mark Cornish	Corps Rock Island	309-794-5385	Mark.A.Cornish@usace.army.mil
Isaac Hodgins	Corps Rock Island	309-794-5688	Isaac.J.Hodgins@usace.army.mil
Dan Johnson	Corps Rock Island	309-794-5857	Daniel.J.Johnson@usace.army.mil
Kenneth Brenner	Corps Rock Island	309-794-5842	Kenneth.J.Brenner@usace.army.mil
Brian Johnson	Corps St. Louis	314-331-8146	Brian.L.Johnson@usace.army.mil
Gary Lee	Corps St. Louis	314-331-8245	Gary.J.Lee@usace.army.mil
Mike Cox	Corps Rock Island	309-793-5558	Michael.D.Cox@usace.army.mil
~~Kari Layman~~	~~Corps St. Paul~~	~~651-290-5424~~	~~Kari.L.Layman@usace.army.mil~~
Ken Cook	Corps Rock Island	309-794-5285	Kenneth.M.Cook@usace.army.mil
John Nestler	Corps ERDC	601-634-3870	John.M.Nestler@usace.army.mil
Dan Johnson	Corps Rock Island	309-794-5857	Daniel.J.Johnson@usace.army.mil
Elliott Stefanik	Corps St. Paul	651-290-5260	Elliott.L.Stefanik@usace.army.mil
Dan Wilcox	Corps St. Paul	651-290-5276	Daniel.B.Wilcox@usace.army.mil
Bob Clevenstine	USFWS Rock Isl.	309-793-5600	Robert_Clevenstine@fws.gov
Gary Wege	USFWS St. Paul	612-725-3348	Gary_Wege@fws.gov
Greg Conover	USFWS Marion IL	618-997-6869	Greg_Conover@fws.gov
Chuck Surprenant	USFWS Marion IL	619-997-3344	Chuck_Surprenant@fws.gov
Scott Yess	UFWS La Crosse	608-783-6221	Scott_Yess@fws.gov
Brian Ickes	USGS La Crosse	608-783-6221	brian_ickes@usgs.gov
Steve Zigler	USGS La Crosse	608-783-8431	steven_zigler@usgs.gov

History of Concern About Fish Passage Through UMRS 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 (*Cycleptus 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., Bahr 1977; Finke 1966; Holzer and Von Ruden 1983; Hubley and Jergens 1959; Hubley 1963; Hurley 1983; reviewed by Holland et al. 1984a; Kuehn 1959;). 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, Inc. 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 Consultants, 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 alimental (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).

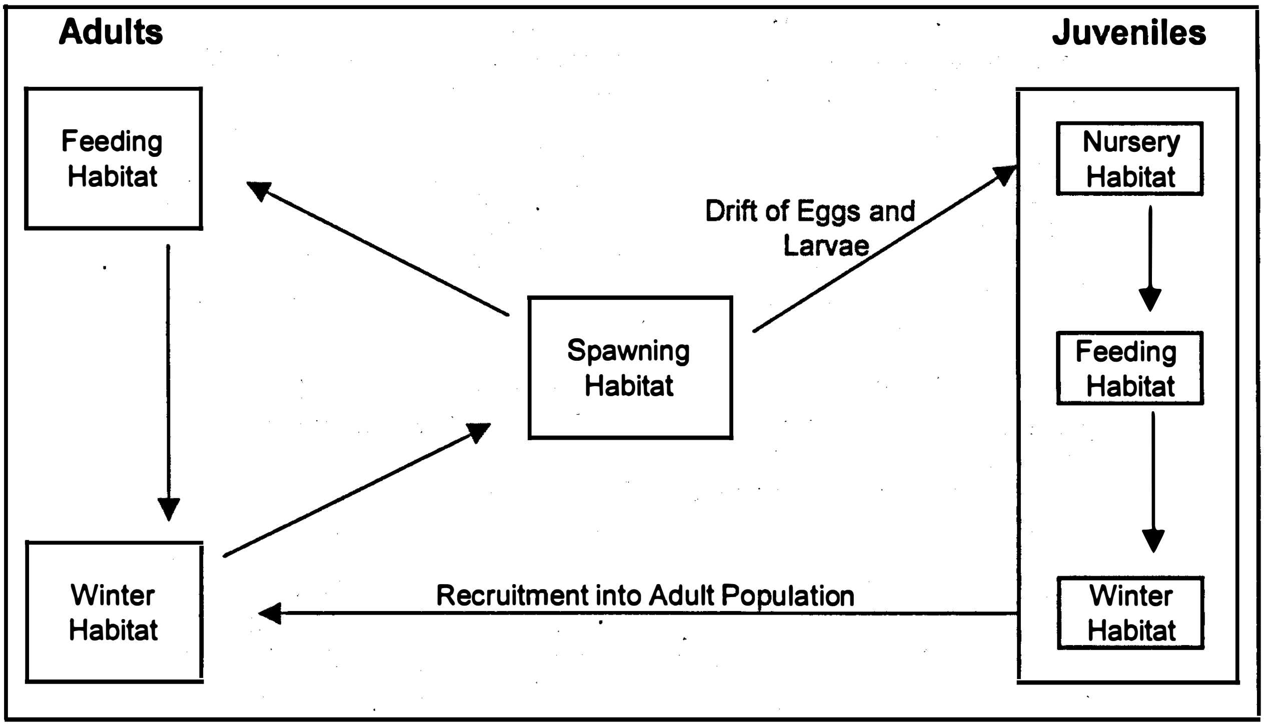


Figure 2. Pattern of seasonal movements of many Upper Mississippi River System fishes (after McKeown 1984)

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 (Osborn and Schupp 1985; Pitlo 1992). 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 owing to 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 (*Ascipenser 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 efforts, 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 (Becker 1983; Pitlo et al. 1995). 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 (*Scaphyrhyncus 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 (Berg 1981; USFWS 1993b), 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	*Ichtyomyzon castaneus*	X					
Silver Lamprey	*Ichtyomyzon unicuspis*	X					X
CARCHARHINIDAE							
Bull shark	*Carcharhinus leucas*			X			
ACIPENSERIDAE							
Lake sturgeon	*Acipenser fulvescens*	X			X	X	
Pallid sturgeon	*Scaphirhynchus albus*	X					X
Shovelnose sturgeon	*Scaphirhyncus platorynchus*	X			X	X	
POLYDONTIDAE							
Paddlefish	*Polyodon spathula*	X			X	X	
LEPISOSTEIDAE							
Alligator gar	*Lepisosteus spatula*	X					
Longnose gar	*Lepisosteus ossaus*	X					X
Shortnose gar	*Lepisosteus platostomus*	X					
Spotted gar	*Lepisosteus oculatus*	X					
AMMIIDAE							
Bowfin	*Amia calva*	X					
HIODONTIDAE							
Goldeye	*Hiodon alosoides*	X					X
Mooneye	*Hiodon tergisus*	X					X
ANGUILLIDAE							
American eel	*Anguilla rostrata*	X			X	X	
CLUPEIDAE							
Alabama shad	*Alosa alabamae*	X				X	
~~Gizzard shad~~	~~*Dorosoma cepedianum*~~	~~X~~					
Skipjack herring	*Alosa chrysochloris*	X			X	X	
Threadfin shad	*Dorosoma petenense*	X					
CYPRINIDAE							
Bigeye shiner	*Notropis boops*	X					
Bighead carp	*Hypopthalmichthys nobilis*		X				
Bigmouth shiner	*Notropis dorsalis*	X					
Blacknose dace	*Rhinichthys strartulus*	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	*Cyprinella venusta*	X					
Bluntnose minnow	*Pimephales notatus*	X					
Brassy minnow	*Hybognathus hankinsoni*	X					
Bullhead minnow	*Pimephales vigilax*	X					
Central stoneroller	*Campostoma anomalm*	X					
Channel shiner	*Notropis wickliffi*	X					
Common carp	*Cyprinus carpio*		X				
Common shiner	*Luxilus comutus*	X					
Creek chub	*Semotilus atromaculatus*	X					
Emerald shiner	*Notropis atherinoides*	X					
Fathead minnow	*Pimephales promelas*	X					
Flathead chub	*Platgobio gracillis*	X					
Ghost shiner	*Notropis buchanani*	X					
Golden shiner	*Notemigonus crysoleucas*	X					
Goldfish	*Carrassius auratus*		X				
Grass carp	*Ctenopharyngodon idella*		X				
Gravel chub	*Erimystax x-punctatus*	X					
Hornyhead chub	*Nocomis biguttatus*	X					
Mimic shiner	*Notropis volucellus*	X					
Mississippi silvery minnow	*Hybognathus nuchalia*	X					
Northern redbelly dace	*Phoxinus eos*	X					
Ozark minnow	*Notropis nubilus*	X					
Pallid shiner	*Notropis amnis*	X					
Pearl dace	*Margariscus margarita*	X					
Plains minnow	*Hybognathus nuchalia*	X					
Pugnose minnow	*Opsopoedus emiliae*	X					
Pugnose shiner	*Notropis anogenus*	X					
Red shiner	*Cyprinella lutrensis*	X					
Redfin shiner	*Lythrurus umbratilla*	X					
River shiner	*Notropis blennius*	X					
Rosyface shiner	*Notropis rubellus*	X					
Sand shiner	*Notropis stramineus*	X					
Sicklefin chub	*Macrhybopsis meekl*	X					
Silver chub	*Macrhybopsis stoeriana*	X					
Silverband shiner	*Notropis shumardi*	X					
Silverjaw minnow	*Notropis buccatus*	X					
Southern redbelly dace	*Phoxinus erythrogaster*	X					
Speckled chub	*Macrhybopsis aestivalis*	X					
Spotail shiner	*Notropis hudsonius*	X					
Spotfin shiner	*Cyprinella spiloptera*	X					
Striped shiner	*Luxilus chrysocephalus*	X					
Sturgeon chub	*Macrhybopsis aestivalis*	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	*Phenacobius mirabillis*	X					
Weed shiner	*Netropis texanus*	X					
Western silvery minnow	*Hybognathus nuchalis*	X					
CASTOSTOMIDAE							
Bigmouth buffalo	*Ictiobus cyprinellus*	X			X		X
Smallmouth buffalo	*Ictiobus bubalus*	X			X		X
Black buffalo	*Ictiobus niger*	X					
Black redhorse	*Moxostoma duquesnei*	X					X
Blue sucker	*Cycleptus elongatus*	X				X	
Golden redhorse	*Moxostome erythrurum*	X					X
Greater redhorse	*Moxostoma valenciennesi*	X					
Highfin carpsucker	*Carpiodes velifer*	X					X
Longnose sucker	*Catostomus catostomus*	X		X			
Northern hog sucker	*Hypentelium nigricans*	X					X
Quillback	*Carpiodes cyprinus*	X					X
River carpsucker	*Carpiodes carpio*	X					
River redhorse	*Moxostoma carinatum*	X					
Shorthead redhorse	*Moxostoma macrolepidotum*	X					X
Silver redhorse	*Moxostoma anisurum*	X					X
Spotted sucker	*Minytrema melanops*	X					X
White sucker	*Catosomus commersoni*	X					X
ICTALURIDAE							
Black bullhead	*Ameiurus melas*	X					
Blue catfish	*Ictalurus furcatus*	X				X	
Brown bullhead	*Amelurus nebulosus*	X					
Channel catfish	*Ictelurus punctatus*	X			X	X	
Flathead catfish	*Pylodictis olivaria*	X			X	X	
Freckled madtom	*Noturus nocturnus*	X					
Stonecat	*Noturus gyrinus*	X					
Tadpole madtom	*Noturus gyrinus*	X					
White catfish	*Ameiurus catus*		X				
Yellow bullhead	*Amelurus natalia*	X					
ESOCIDAE							
Grass pickerel	*Esox americanus vermiculatus*	X					
Muskellunge	*Esox masquinongy*			X			
Northern pike	*Esox luclus*	X			X		X
UMBRIDAE							
Central mudminnow	*Umbra limi*	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	*Osmerus mordax*		X				
SALMONIDAE							
Brook trout	*Salvelinus fontinalis*			X			
Brown trout	*Salmo trutta*		X	X			
Lake trout	*Salvelinus namaycush*		X	X			
Rainbow trout	*Oncorhynchus mykiss*		X	X			
PERCOPSIDAE							
Trout-perch	*Percopsis omiscomaycus*	X					
GADIDAE							
Burbot	*Lota lota*	X					
APHREDODERIDAE							
Pirate perch	*Apredoderus sayanus*	X					
CYPRINODONTIDAE							
Blackspotted topminnow	*Fundulus olivaceus*	X					
Blackstripe topminnow	*Fundulus notatus*	X					
Northern studfish	*Fundulus catenatus*	X					
Starhead topminnow	*Fundulus dispar*	X					
POECILIDAE							
Western mosquitofish	*Gambusia affinis*	X					
ATHERINIDAE							
Brook silverside	*Labidesthes sicculus*	X					
Inland silveside	*Menidia berylina*	X					
GASTEROSTEIDAE							
Brook stickleback	*Culaea inconstans*	X					
COTTIDAE							
Banded sculpin	*Cottus carolinae*	X					
PERCICHTHYIDAE							
Hybrid striped bass	*Morone saxatilis x chrysops*		X		X		
Striped bass	*Morone saxatilis*		X				
White bass	*Morone chrysops*	X			X	X	
Yellow bass	*Morone mississippiensis*	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	*Centrarchus macropterus*	X					
Green sunfish	*Lepomis cynanellus*	X					
Longear sunfish	*Lepomis megalotis*	X					
Pumpkinseed	*Lepomis gibbosus*	X					
Warmouth	*Lepomis gulosus*	X					
Orangespotted sunfish	*Lepomis humilis*	X					
Bluegill	*Lepomis macrochirus*	X			X		
Redear sunfish	*Lepomis microlophus*	X					
Rock bass	*Ambloplites rupestris*	X					
Shadow bass	*Ambloplites ariommus*	X					
Smallmouth bass	*Micropterus dolomieu*	X			X		X
Largemouth bass	*Micropterus salmoides*	X				X	
Spotted bass	*Micropterus punctatus*	X					
White crappie	*Pomoxis annularis*	X					
Black crappie	*Pomoxis nigromaculatus*	X					
PERCIDAE							
Banded darter	*Etheostoma zonale*	X					
Blackside darter	*Percina maculata*	X					
Bluntnose darter	*Etheostoma chlorosumum*	X					
Dusky darter	*Percina sciera*	X					
Fantail darter	*Etheostoma flabellare*	X					
Iowa darter	*Etheostoma exile*	X					
Johnny darter	*Etheostoma nigrum*	X					
Logperch	*Percina caprodes*	X					
Mud darter	*Etheostoma aspringene*	X					
Orangethroat darter	*Etheostoma spectabile*	X					
Rainbow darter	*Etheostoma caeruleum*	X					
River darter	*Percina shumardi*	X					
Sauger	*Sander canadense*	X			X	X	
Walleye	*Sander vitreum*	X			X	X	
Slenderhead darter	*Percina phoxocephala*	X					
Western sand darter	*Ammocrypta clara*	X					
Yellow perch	*Percina flavescens*	X					
SCIAENIDAE							
Freshwater drum	*Aplodinotus grunniens*	X			X		X
MUGILIDAE							
Striped mullet	*Mugil cephalus*			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, 1930; Forbes and Richardson 1920; 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 (Hawkinson and Gruenwald 1979; Newcomb 1989; 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 (Holland et al. 1984b; Northcote 1984). 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 pre-spawning movements for some fishes may be

Table 3
Behavioral and Reproductive Characteristics of 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 *Ichthyomyzon unicuspis*	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 *Ascipenser fulvescens*	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 *Scaphyrhinchus platorhynchus*	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 *Schaphyrhincus albus*	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 *Polyodon spathula*	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 *Lepisosteus osseus*	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 VI [34]
Goldeye *Hiodon alosoides*	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 *Hiodon tergisus*	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 *Anguilla rostrata*	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 *Alosa alabamae*	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)
[2] Christenson (1975)
[3] Hurley et al. (1983)
[4] Becker (1983)
[5] Jordan and Evermann (1923)
[6] Helms (1974)
[7] Purkett (1961)
[8] Southall (1982)
[9] Adams (1942)
[10] Gates and Gruenwald (1986)
[11] Von Ruden and Holzer (1989)
[12] Hasler et al. (1958)
[13] Olson et al. (1978)
[14] Holzer and Von Ruden (1983)
[15] Gebken and Wright (1972)
[16] Balon (1977)
[17] Scott and Crossman (1973)
[18] Eddy and Underhill (1974)
[19] Priegel and Wirth (1971)
[20] Horall (1962)
[21] Finke (1966)
[22] Priegel (1969)
[23] Magnuson and Horrall (1977)
[24] Coker (1930)
[25] Harlan and Speaker (1956)
[26] Shields (1957)
[27] Priegel (1975)
[28] Franklin and Smith (1963)
[29] Wright (1973)
[30] Paragamian and Coble (1975)
[31] Reynolds (1965)
[32] Nord (1967)
[33] Lee et al. (1980)
[34] Pflieger (1997)
[35] White (1974)
[36] Kranz (1978)
[37] Forbes and Richardson (1920)
[38] USFWS (1993a)
[39] Keenlyne and Jenkins (1993)
[40] Trautman (1957)
[41] Currie and Spacie (1979)
[42] Pitlo (1992)
[43] McMahon and Terrell (1982)
[44] Pellet et al. (1998)

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 *Alosa chrysochloris*	Yes	Unknown	April - July [25]	Upriver movements, probably related to spawning, return to wintering areas [26]	254 - 305 mm [26]
Blue sucker *Cycleptus elongatus*	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 *Ictiobus cyprinellus*	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 *Ictiobus bubalus*	Yes	Non-guarder phytophil	April - June 15.6 - 18.3 °C [4]	Sometimes ascends small streams to spawn [24]	324 mm III [4]
Quillback *Carpiodes cyprinus*	No	Non-guarder psammophil	May - September 19.0 - 28.0 °C [4]	Ascends small creeks in spring [4]	300 mm III (assumed)
Highfin carpsucker *Carpiodes velifer*	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 *Minytrema melanops*	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 redhorse *Moxostoma duquesnei*	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 redhorse *Moxostoma erythrurum*	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 redhorse *Moxostoma anisurum*	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 redhorse *Moxostoma macrolepidotum*	No	Non-guarder lithophil	April and May 8.3 - 16.0 °C [4]	Ascends tributaries to spawn [41]	295 mm III [4]
Northern hogsucker *Hypentelium nigricans*	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 *Catostomus commersoni*	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 *Ictalurus furcatus*	No	Guarder, spelophil	June [34]	Seasonal movements in response to water temperature [24, 5]	508 mm (V)
Channel catfish *Ictalurus punctatus*	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 *Pylodictus olivaris*	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 *Esox lucius*	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 *Morone chrysops*	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 *Morone mississippiensis*	No	Non-guarder litho-pelagophil	May - June 15 - 22 °C [27]	Moves into tributaries to spawn [4]	234 mm III [27, 28]
Largemouth bass *Micropterus salmoides*	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 *Micropterus dolomieui*	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 *Sander vitreum*	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 *Sander canadense*	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 *Aplodinotus grunniens*	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 tailwaters in late fall and winter, then spawn nearby in spring (Thorne 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 sec. 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 sec 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 (Bainbridge 1960; Dahlberg et al. 1968; Farlinger and Beamish 1977; Gray 1957; Hocutt 1973; McPhee and Watts 1976).

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 Migratory Fishes

Species	Length mm TL	TL or FL/SL	U_{crit} Model (cm/s)	*n* test fish	Reference	Estimated adult fish U_{crit} (cm/s)	Estimated adult fish U_{crit} (ft/s)	Comments on U_{crit}
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. U_{crit}
			16.0+(0.479 TL) +(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 (46 cm to 50.9 cm SL)
			none - tests of individual fish	5	10	65 to 116	2.1 - 3.8	adult fish (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	4.9 FL^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	U_{crit} Model (cm/s)	*n* test fish	Reference	Estimated adult fish U_{crit} (cm/s)	Estimated adult fish U_{crit} (ft/s)	Comments on U_{crit}
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. U_{crit} 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=1.1 SL estimate)	10.03 FL^0.55 (surrogate: white sucker)	0	3	56	1.8	surrogate
Black redhorse	230	1.23 (FL=1.1 SL estimate)	10.03 FL^0.55 (surrogate: white sucker)	0	3	50	1.6	surrogate
Golden redhorse	265	1.28 (FL=1.1 SL estimate)	10.03 FL^0.55 (surrogate: white sucker)	0	3	56	1.8	surrogate
Silver redhorse	450	1.10 (FL=1.1 SL estimate)	10.03 FL^0.55 (surrogate: white sucker)	0	3	81	2.7	surrogate
Shorthead redhorse	295	1.25 (FL=1.1 SL estimate)	10.03 FL^0.55 (surrogate: white sucker)	0	3	60	2.0	surrogate
Northern hogsucker	175	1.25 (FL=1.1 SL estimate)	10.03 FL^0.55 (surrogate: white sucker)	0	3	45	1.5	surrogate
White sucker	320	1.18 (FL=1.1 SL)	10.03 FL^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)	3.05 SL (surrogate: channel catfish)	0	1, 5	129	4.2	surrogate
			Mean of 3 min. U_{crit} tests	3	7	69	2.3	test fish (Mean 44.3 cm SL)
Channel catfish	330	1.2	3.05 SL	28	1, 5	84	2.7	test fish (14.2cm to 41.5 cm SL)
			3.0 TL 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. U_{crit} tests	4	7	57	1.9	test fish (Mean 36.25 cm SL)
Flathead catfish	457	1.15 (estimate)	3.05 SL (surrogate: channel catfish)	0	1, 5	121	4.0	surrogate
			Mean of 3 min. U_{crit} tests	5	7	68	2.2	test fish (Mean 43.5 cm SL)

(Sheet 2 of 3)

Table 4 (Concluded)

Species	Length mm TL	TL or FL/SL	U_{crit} Model (cm/s)	n test fish	Reference	Estimated adult fish U_{crit} (cm/s)	Estimated adult fish U_{crit} (ft/s)	Comments on U_{crit}
Northern pike	617	1.15 (TL = 1.06 FL)	4.9 FL^0.55	192	3	46	1.5	test fish (12 cm to 62 cm FL)
White bass	313	1.2 (estimate)	4.6 SL	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	5.0 TL @ 20 degrees C	15	11	127	4.2	temperature response test test fish (5.2 cm to 6.4 mm)
			3.41 SL	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)
			3.84 SL	21	14	80	2.6	performance repeatability test test fish small (Mean 9.4 cm FL)
Smallmouth bass	200	1.2	3.41 SL (surrogate: largemouth bass)	0		63	2.1	surrogate
Walleye	454	1.2 (estimate)	3.04 SL	6	1,5	115	3.8	test fish (15.4 cm to 40.8 SL)
			13.07 FL^0.51	54	3	83	2.7	test fish (8 cm to 38 cm FL)
Sauger	249	1.2 (estimate)	3.8 SL	15	1, 5	79	2.6	test fish (5.1cm to 41.5 cm SL)
Freshwater drum	351	1.3 (estimate)	3.0 SL	11	1, 5	81	2.7	test fish (17.7 cm to 30.2 cm SL)

(Sheet 3 of 3)

References:

1 - Tunink (1975)
2 - Adams and Parsons (1995)
3 - Jones et al. (1974)
4 - Videler (1993)
5 - Schmulbach et al. (1981)
6 - Parsons and Smiley (1994)
7 - Parsons and Bartlett (1997)
8 - Webb (1986)
9 - Peake et al. (1995)
10 - Adams et al. (1997)
11 - Hocutt (1973)
12 - Farlinger and Beamish (1977)
13 - Dalberg et al. (1968)
14 - Kolok (1992)

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 (Table 1; Appendix B). Of these, 16 species do not have migratory fish hosts or the fish host is unknown (see Table 2; Appendix B) (Watters 1994; Michelle Bartsch, U.S. Geological Survey Upper Midwest Environmental Science Center, La Crosse, WI, personal communication, 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.

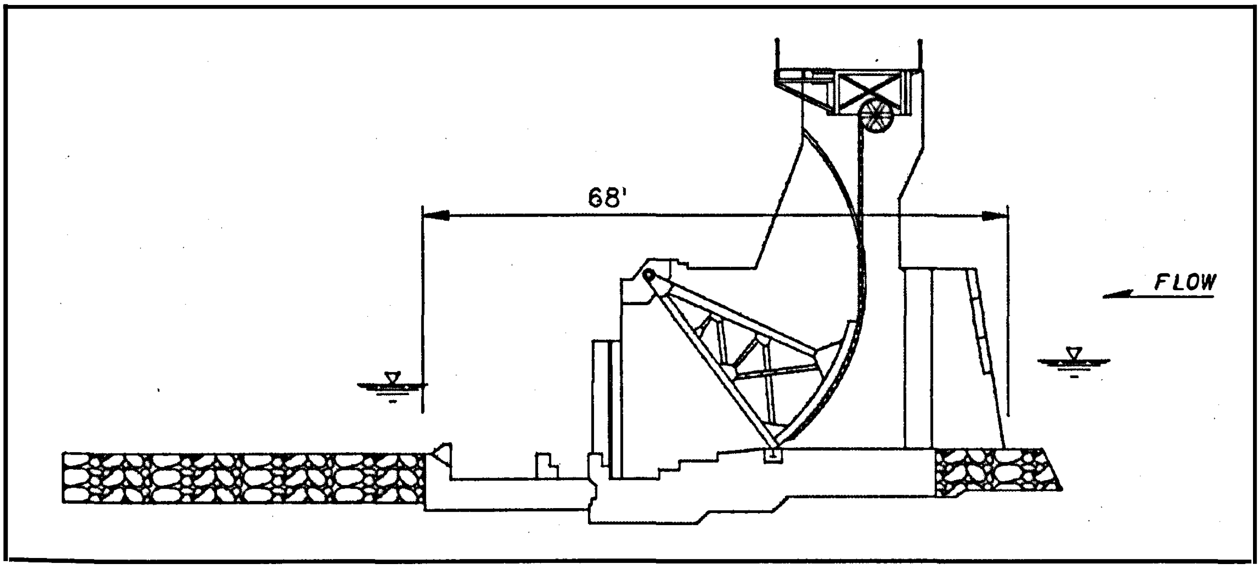


Figure 3. Cross section of a typical Tainter gate on an Upper Mississippi River navigation dam

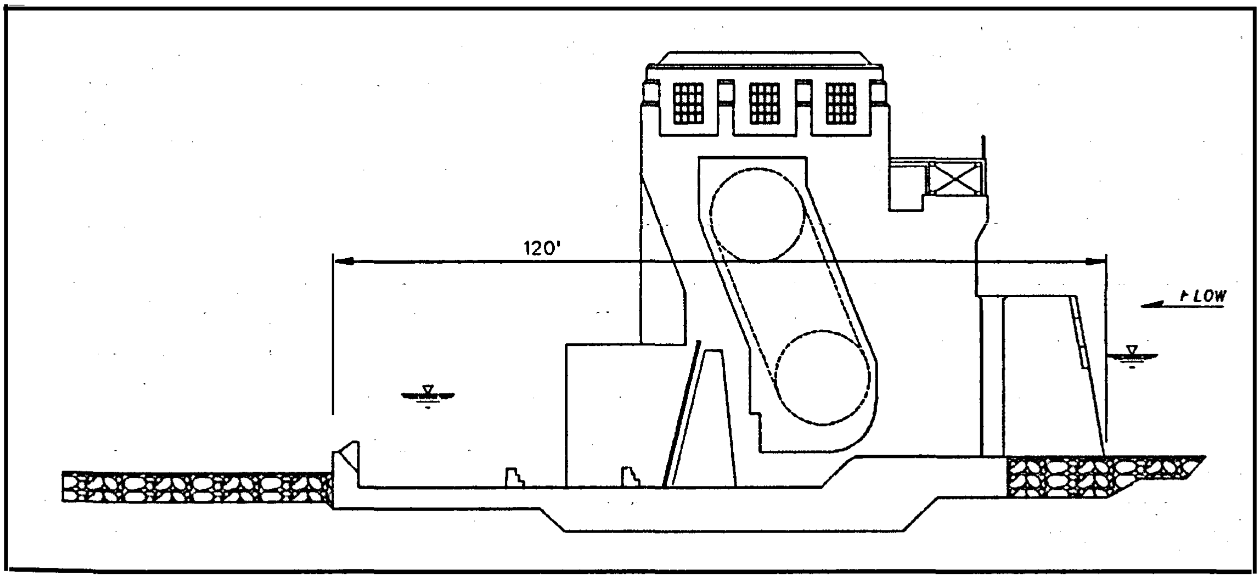


Figure 4. Cross section of a typical roller gate on an Upper Mississippi River navigation dam

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

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).

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.

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 concrete fixed-crest spillway topped by an inflatable dam, which prevents upriver fish passage. Lock and Dam 19 is a relatively high hydropower 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 6 m (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.

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

The UMRS navigation system is regulated according to master plans of operation for the Upper Mississippi River and the Illinois Waterway (U.S. Army Corps of Engineers 1980 and 1996, respectively). Water levels are regulated by opening and closing the moveable gates on the navigation dams to maintain sufficient depth in the navigation channels.

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, St. Louis, MO, personal communication, 2003) indicate the complexity of the flow over the sills of the UMR navigation dams.

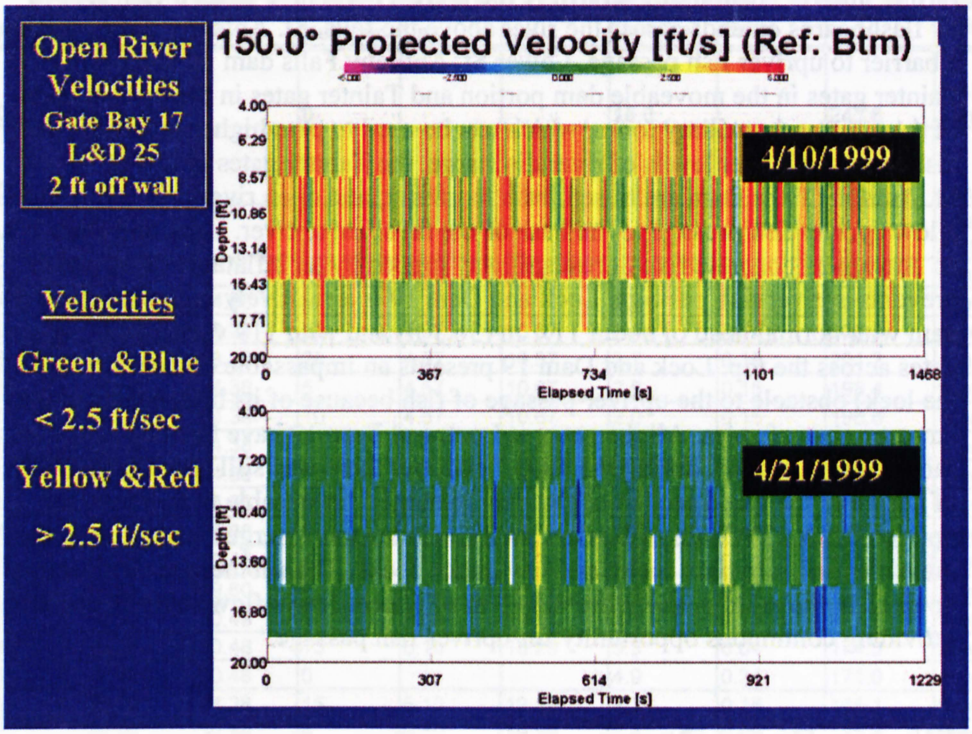


Figure 5. Current velocity near a pier in the end gate bay at Lock and Dam 25 during uncontrolled conditions with dam gates raised out of the water. On 4/10/99, dam gates had just been raised from the water. On 4/21/99, at higher level of river discharge when the overflow section of Lock and Dam 25 was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

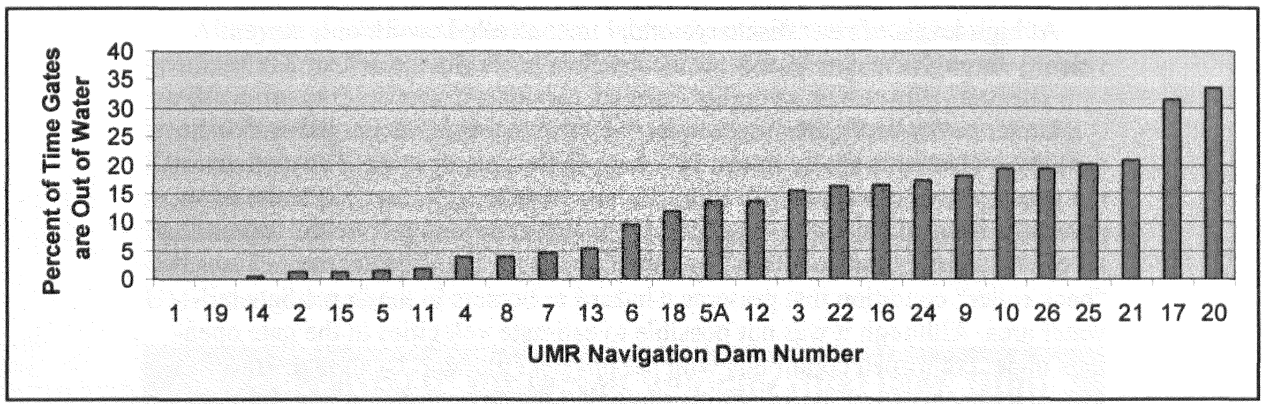


Figure 6. Percentage of time that gates are raised out of the water at Upper Mississippi River navigation dams

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 m^3 (527,036 ft^3) and takes about 10 min to drain or fill. Water flows through the filling conduits at a rate of about 25 m^3/sec (880 ft^3/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 ichtyoplankton 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. Ichtyoplankton, 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, 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, IL, 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 hydroacoustic 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, IA, is a high dam built in 1913 for hydropower. 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), show 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 Consultants, 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.

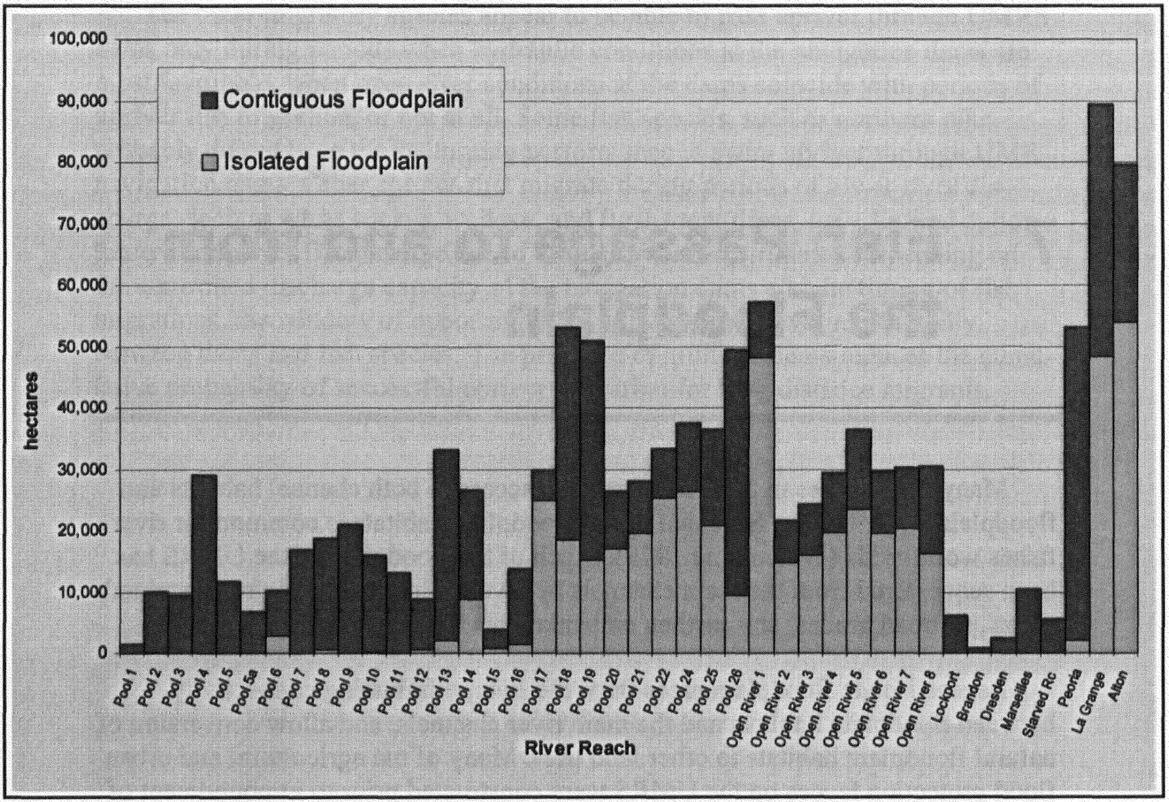


Figure 7. Contiguous and isolated floodplain areas of the Upper Mississippi and Illinois rivers

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 or 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 48,280 km (30,000 miles) of rivers and streams within the UMRS basin, except the headwaters of the Mississippi, St. Croix, Chippewa, Wisconsin, and Black rivers where falls imposed natural barriers to upriver fish movements. There are 266 larger dams impounding reservoirs of over 6.1 million m^3 (5,000 acre-ft) exist on UMRS tributaries (FEMA 1996; Figure 8).

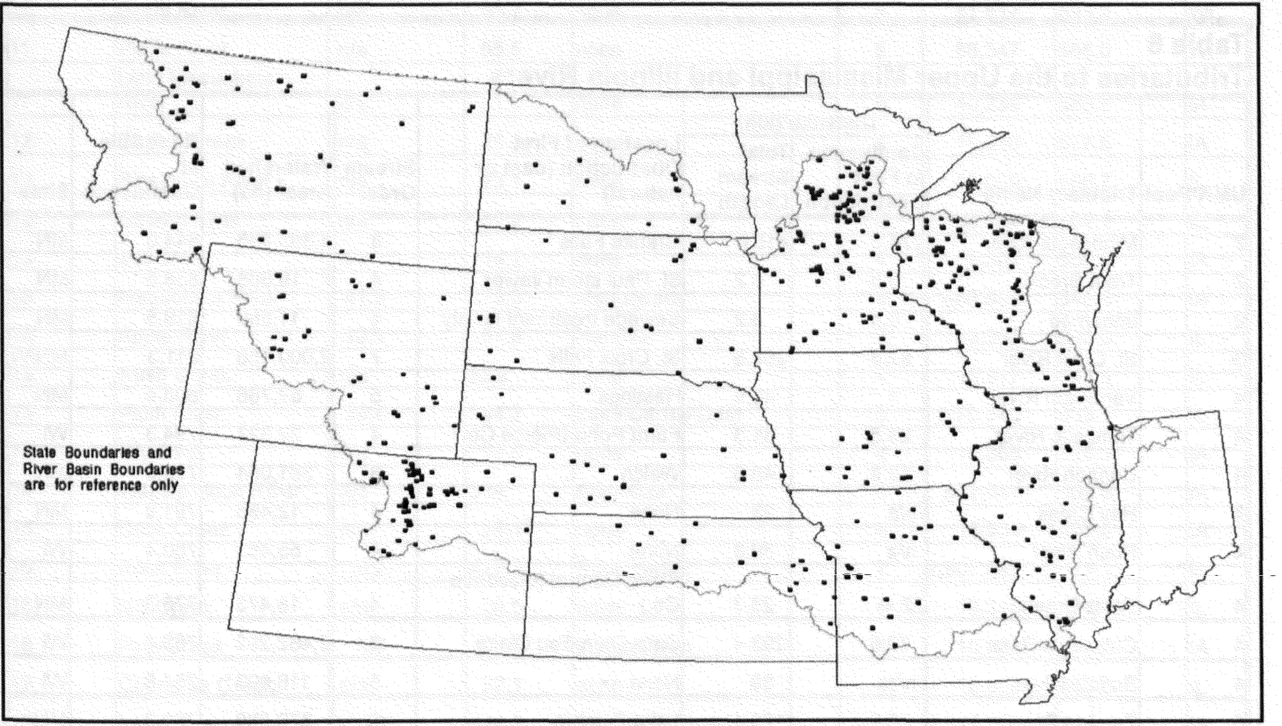


Figure 8. Dams on tributaries to the Missouri, Upper Mississippi, and Illinois rivers with capacity greater than 6.1 million m^3 (5,000 acre-ft)

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 129 km (80 miles) of lower Illinois River in that navigation pool.

Table 6
Tributaries to the Upper Mississippi and Illinois Rivers

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) Confluence to First Obstruction	Distance (km) Total Stream Length	Location of First Obstruction (dam or natural)	Stream Order[1]	Watershed Area[2] (ha)	River Mile at Confluence	State
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

(Sheet 4 of 4)

[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.

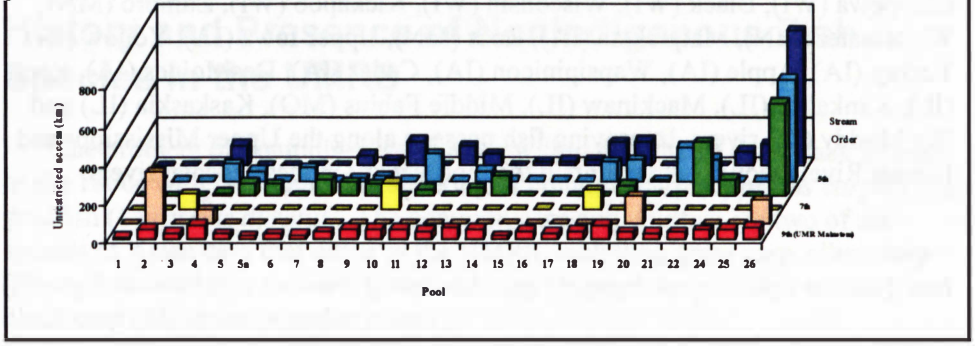


Figure 9. Total length (km) of fish-accessible tributaries by navigation pool and stream order for the Upper Mississippi River

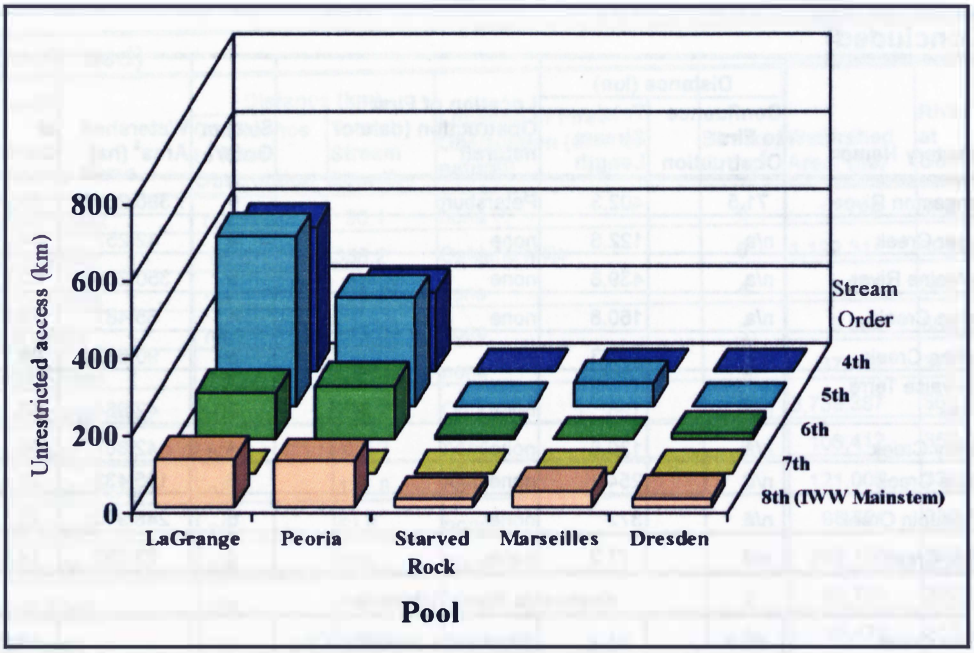


Figure 10. Total length (km) of fish-accessible tributaries by navigation pool and stream order for the Illinois Waterway

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 melanstomus*). 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 (*Oncorhinchus 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 by 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 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 passageways, 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).

Table 7
Initial Cost Estimate for Locking Fish Through UMRS Dams

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; Schwalme 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 microhabitats 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 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 (DVWK 1996; Gaboury et al. 1995).

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	Mylopharyngodon piceus	Asia
bighead carp*	*Hypophthalmichthys nobilis*	Asia
silver carp	*Hypophthalmichthys molitrix*	Asia
grass carp*	*Ctenopharyngodon idella*	Asia
common carp*	*Cyprinus carpio*	Asia
goldfish*	*Carassius auratus*	Asia
Ruffe	*Gymnocephalus cernuus*	Eurasia
round goby	*Neogobius melanostomus*	Europe
tubenose goby	*Proterorhinus marmoratus*	Europe
Asian weatherfish	Misgurnus anquillicaudatus	Asia
Plants		
Eurasian watermilfoil*	*Myriophyllum spicatum*	Eurasia
Purple loosestrife*	*Lythrum salicaria*	Eurasia
Common reed*	*Phragmites australis*	Europe/United States
Reed canarygrass*	*Phalaris arundinacea*	Europe/United States
Mussels		
Zebra mussel*	*Dreissena polymorpha*	Europe
Quagga mussel	*Dreissena bugensis*	Europe
Asian clam*	*Corbicula fluminea*	Asia
Plankton		
Spiny water fleas	*Bythotrephes cederstroemi and Ceropagis pengoi*	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 repellant
Sound projection array (SPA) acoustic barrier	Combination of acoustic and tactile repellants
Active capture	Trawling or netting and physical removal
Screening	Physical obstruction
Light	Visual repellant
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 triflouromethyl-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.

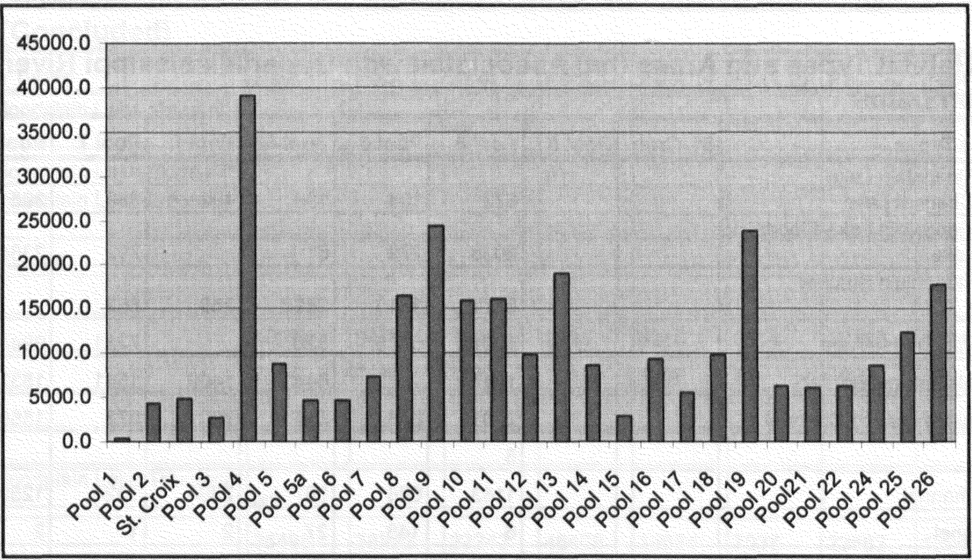


Figure 11. Water area (ha) of Upper Mississippi River navigation pools

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 identifies 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	Pool21	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.

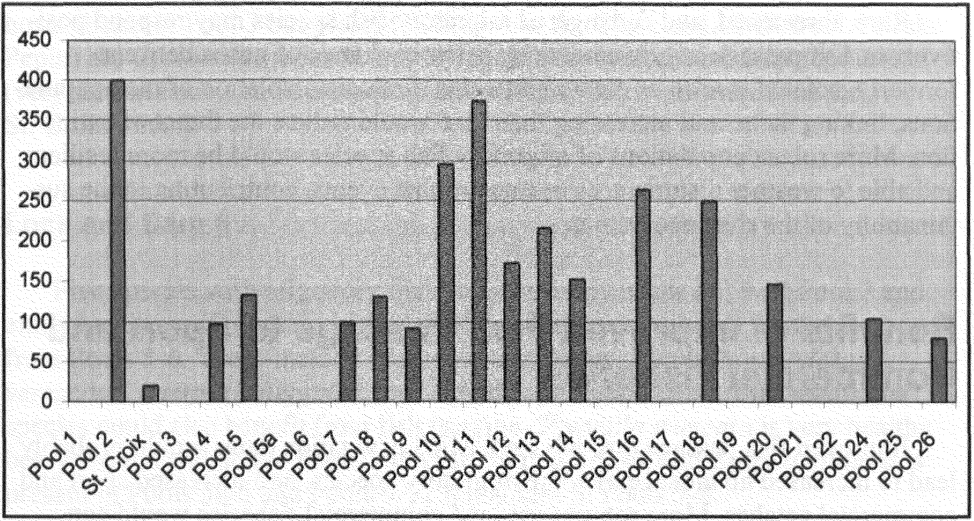


Figure 12. Length (km) of major tributaries to the first dam or natural barrier, by Upper Mississippi River navigation pool

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 nonmonetary 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 cyphyus, 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. cyphyus, 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 hosts may benefit from fish passage at Lock and Dam 21: *P. cyphyus, T. verrucosa, A. confragosus,* and *A. ligamentina. Plethobasus cyphyus, 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:

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

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.

Table 13
Estimated Cost of Fishways at UMRS Dams

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 beneficial and most cost-effective (see Appendix D, Potential Fishway Sites). The location of fishway entrances close 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 beneficial 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 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 Trimbelle, 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 higginsi* 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						
Medium	🟨	10 to 20 %			2			2				2	2		2				2		2				2	2		2
High	🟥	20 + %																		1			1	1			1	

Rank

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
Medium	🟨	5,000 to 15,000 ha			2		2			2					2		2		2	2	2		2	2	2	2	2	
Low	🟥	>5000 ha	1	1				1	1									1										
		Rank	1	1	2	3	2	1	1	2	3	3	3	3	2	3	2	1	2	2	2	3	2	2	2	2	2	3

Hard substrate spawning habitat: ■

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		2209							1978								2113	2089			2576			9982
Medium	🟨	1000 - 2000									1110	1049		1393		1263	1068						1513	1143		1255		
Low	🟥	<1000	93		845		863	497	529	697					886			251	536	419							923	
		Rank	1	3	1	3	1	1	1	1	2	2	3	2	1	2	2	1	1	1	3	3	2	2	3	2	1	3

Hard substrate spawning habitat: ■

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	–		3	3	3	3	3	3	3	3	3	3	3	3	3		3	3	3		3	3	3	3	3	
Medium	🟨	$20 M - $30 M	–	2														2										2
High	🟥	> $30 M	–																			1						
		Estimated Cost (M)	=	$26.3	$10.9	$14.9	$15.3	$13.2	$14.9	$15.3	$16.9	$16.5	$14.5	$15.5	$16.3	$17.0	$15.0	$20.5	$14.5	$14.7	$19.5	$47.5	$15.2	$16.2	$15.5	$17.4	$17.0	$25.0
		Rank		2	3	3	3	3	3	3	3	3	3	3	3	3	3	2	3	3	3	1	3	3	3	3	3	2

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	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: Becker (1983), Burr and Page (1986), Carlander (1954), Eddy and Underhill (1974), 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 geographical 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 m^2 of each fishway cross section, annual erosion loss of less than 1 m^2 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 towboats 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. Amy 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.

References

Adams, L. A. (1942). "Age determination and rate of growth in *Polyodon spathula* by means of the growth rings of the otoliths and dentary bone," *American Midland Naturalist* 28, 617-630.

Adams, S. R., and Parsons, G. R. (1995). "Swimming performance of the smallmouth buffalo, *Ictiobus bubalus*," Report to the U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Adams, S. R., Parsons, G. R., Hoover, J. J., and Killgore, K. J. (1997). "Observations of swimming ability in shovelnose sturgeon (*Scaphirhynchus platorynchus*)," *Journal of Freshwater Ecology* 12, 631-633.

Anfinson, J. O. (1994). "A brief history of navigation and the environment of the Upper Mississippi River." *Proceedings of the Upper Mississippi River Conservation Committee*, Fiftieth Anniversary Conference, Upper Mississippi River Conservation Committee, Rock Island, IL.

__________. (2003). *The river we have wrought. A history of the Upper Mississippi River*. University of Minnesota Press.

Auer, N. A. (1996). "Importance of habitat and migration to sturgeons with emphasis on lake sturgeon," *Canadian Journal Fisheries and Aquatic Science* 53 (Supplement 1), 152-160.

Bahr, D. M. (1977). "Homing, swimming behavior, range, activity patterns, and reaction to increasing water levels of walleyes (*Stizostedion vitreum vitreum*) as determined by radio-telemetry in Navigation Pool 7 and 8 of the Upper Mississippi River during spring, 1976," M.S. thesis, University of Wisconsin, La Crosse.

Bainbridge, R. (1960). "Speed and stamina in three fish," *Journal of Experimental Biology* 37, 129-153.

Balon, E. K. (1977). "Reproductive guilds in fishes: A proposal and definition," *Journal of the Fisheries Research Board of Canada* 32, 821-864.

Beamish, F. W. H. (1978). "Swimming capacity." *Fish physiology*. W. S. Hoar and D. J. Randall, eds., Volume VII, *Locomotion*, Academic Press, New York, 101-187.

Becker, G. C. (1983). *Fishes of Wisconsin.* The University of Wisconsin Press, Madison.

Benjamin, R. L. (1989). "Assess the status of the walleye population in Pool 5 of the Mississippi River," Mississippi River Work Unit Annual Report, 1989, Wisconsin Department of Natural Resources, La Crosse.

Berg, R. K. (1981). "Fish populations of the wild and scenic Missouri River, Montana," Montana Department of Fish, Wildlife and Parks. Restoration Project FW-3-R. Job 1-A.

Bertrand, B., and Sallee, D. (1985). "Pool 18 walleye, sauger harvest study," Illinois Department of Conservation, Aledo, IL.

Blaxter, J. H. S. (1969). "Swimming speeds of fish," *FAO Fisheries Report* 62(2), 69-100.

Blaxter, J. H. S., and Dickson, W. (1958). "Observations on the swimming speeds of fish," *Journal du Conseil International pour le Exploration de la Mer* 24, 472-479.

Boland, T., and Ackerman, G. (1982). "Investigation of tailwater walleye and sauger fisheries of the Upper Mississippi River," Fish Management Job Completion Report, 1981-82. Iowa Conservation Commission, Des Moines.

Brett, J. R. (1964). "The respiratory metabolism and swimming performance of young sockeye salmon," *Journal of the Fisheries Research Board of Canada* 21, 1183-1226.

__________. (1965). "The relation of size to rate of oxygen consumption and sustained swimming speed of sockeye salmon (*Oncorhynchus nerka*)," *Journal of the Fisheries Research Board of Canada* 22, 1491-1501.

__________. (1967). "Swimming performance of sockeye salmon (*Oncorhynchus nerka*) in relation to fatigue time and temperature," *Journal of the Fisheries Research Board of Canada* 24, 1731-1741.

Burr, B. M., and Page, L. M. (1986). "Zoogeography of fishes of the Lower Ohio-Upper Mississippi River Basin." *The Zoogeography of North American Freshwater Fishes.* C. H. Hocutt and E. O. Wiley, eds., John Wiley and Sons, Inc., New York, 287-324.

Cada, G. F., and Francfort, J. E. (1995). "Examining the benefits and costs of fish passage and protection measures," *Hydro Review*, February, 44-45.

Caley, J., and Schluter, D. (1997). "The relationship between local and regional diversity," *Ecology* 78(1), 70-80.

Carlander, H. B. (1954). "A history of fish and fishing in the Upper Mississippi River," Upper Mississippi River Conservation Committee, Rock Island, IL.

Carlander, K. D. (1969). *Handbook of freshwater fishery biology.* Volume 1. Iowa State University Press, Ames.

__________. (1977). *Handbook of freshwater fishery biology.* Volume 2. Iowa State University Press, Ames.

Carlson, B. D., Propst, D. B., Stynes, D. J., and Jackson, R. S. (1995). "Economic impact of recreation on the upper Mississippi River," Technical Report EL-95-16, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS. NTIS No. AD A294 201.

Carter, B. T. (1954). "The movement of fishes through navigation lock chambers in the Kentucky River," *Transactions of the Kentucky Academy of Science* 15(3), 48-56.

Christenson, L. M. (1975). "The shovelnose sturgeon, *Scaphirynchus platorynchus* (Rafinesque), in the Red Cedar–Chippewa river system, Wisconsin," Wisconsin Department of Natural Resources, Research Report 82.

Christenson, L. M., and Smith, L. L. (1965). "Characteristics of fish populations in Upper Mississippi River backwater areas," U.S. Bureau of Sport Fisheries and Wildlife, Circular 212.

Coker, R. E. (1914). "Water-power development in relation to fishes and mussels of the Mississippi," U.S. Department of Commerce, Bureau of Fisheries, Document 805.

__________. (1929). "Keokuk Dam and the fisheries of the Upper Mississippi River," *Bulletin of the U.S. Bureau of Fisheries* 45(1063), 87-139.

__________. (1930). "Studies of the common fishes of the Mississippi River at Keokuk," U.S. Department of Commerce, Bureau of Fisheries, Document 1072, 141-225.

Collins, M. R. (1985). "Species profiles: Life histories and environmental requirements of coastal fishes and invertebrates (South Florida). Striped mullet," U.S. Fish and Wildlife Service Biological Report 82(11.34). U.S. Army Corps of Engineers Technical Report EL-B2-4. http://www.nwrc.gov/publications/specindex.html

Cowx, I. G., and Welcomme, R. L., eds. (1998). "Rehabilitation of rivers for fish," European Inland Fisheries Advisory Commission of the Food and Agriculture Organization of the United Nations. Fishing News Books, Blackwell Science Ltd. Oxford, U.K.

Currie, K. D., and Spacie, A. (1979). "The importance of tributary streams to the reproduction of catostomids and sauger," Purdue University, Water Resources Research Center, Technical Report 126, West Lafayette, IN.

Curtis, G. L. (1990). "Habitat use by shovelnose sturgeon in Pool 13, Upper Mississippi River, Iowa," M.S. thesis. Iowa State University, Ames.

Daget, J. (1960). "Les migrations des poissons dans les eaux douces tropicales africaines," *Proc. IPFC* 8(3), 79-82.

Dahlberg, M. L., Shumway, D. L., and Doudoroff, P. (1968). "Influence of dissolved oxygen and carbon dioxide on swimming performance of large-mouth bass and coho salmon," *Journal of the Fisheries Research Board of Canada* 25, 49-70.

Daughtery, R. L., and Franzini, J. B. (1977). *Fluid mechanics with engineering applications.* McGraw Hill, New York..

Delaney, R. L., and Craig, M. R. (1997). "Longitudinal changes in Mississippi River floodplain structure. Project Status Report," Upper Mississippi River System Long Term Resource Monitoring Program. U.S. Geological Survey, Onalaska, WI.

DeHaan, H. C., McVay, N. M., Theiling, C. H., and Soileau, R. S. (2003). "Upper Mississippi River - Illinois Waterway System Environmental Objectives Planning Workshops," U.S. Army Engineer District, Rock Island, Rock Island, IL.

DeHaan, H. C., Fox, T. J., Korschgen, C. E., Theiling, C. H., and Rohweder, J. J. (2000). "Habitat needs assessment GIS query tool for the Upper Mississippi River System, User's Manual," U.S. Geological Survey Upper Midwest Environmental Sciences Center, La Crosse, WI. Report prepared for the U.S. Army Engineer District, St. Louis.

DVWK (German Association for Water Resources and Agriculture). (1996). "Upstream fish passage facilities, dimensioning, configuration, and operational checks," *Instructional Bulletins on Water Research* 232/1996.

Eddy, S., and Surber, T. (1943). *Northern fishes. With special reference to the Upper Mississippi Valley.* The University of Minnesota Press, Minneapolis.

Eddy, S., and Underhill, J. C. (1974). *Northern fishes.* University of Minnesota Press, Minneapolis.

Ellis, M. M. (1932). "Report on surveys of Lake Keokuk, Lake Pepin, and certain other portions of the Mississippi River, conducted by the United States Bureau of Fisheries for the Corps of Engineers, United States Army, in connection with the proposed 9-foot channel, during the summer of 1930." War Department. 1932. Correspondence from the Secretary of War transmitting a report from the Chief of Engineers on a survey of the Mississippi River between the Missouri River and Minneapolis, with a view to securing a channel depth of 9 feet at low water, with suitable widths. Part 1-Report. House Document 137. 72nd Congress, 1st session. U.S. Government Printing Office, Washington, DC. (letter).

Farlinger, S., and Beamish, F. W. H. (1977). "Effects of time and velocity increments on the critical swimming speed of largemouth bass (*Micropterus salmoides*)," *Transactions of the American Fisheries Society* 106, 436-439.

Fausch, K. D., Torgersen, C. E., Baxter, C. V., and Li, H. W. (2002). "Landscapes to Riverscapes: Bridging the gap between research and conservation of stream fishes," *Bioscience* 52, 483-498.

Federal Emergency Management Agency (1996). "National Inventory of Dams." Compact Disc NID 1995-1995. Washington, DC.

Finke, A. H. (1966). "White bass tagging study–Upper Mississippi River," Wisconsin Conservation Department Division of Fisheries Management Report 6.

Forbes, S. A., and Richardson, R. E. (1905). "On a new shovelnose sturgeon from the Mississippi River," *Bulletin Illinois State Laboratory Natural History* 7, 37-44.

__________. (1920). "The fishes of Illinois," *Illinois Natural History Survey Bulletin* 3.

Franklin, D. R., and Smith, L. L. (1963). "Early life history of the northern pike (*Esox lucius* L.) with special reference to the factors influencing strength of year classes," *Transactions of the American Fisheries Society* 92, 91-110.

Fremling, C. R., and Claflin, T. O. (1984). "Ecological history of the Upper Mississippi River." *Contaminants in the Upper Mississippi River*. J. G. Wiener, R. V. Anderson, and D. R. McConville, eds., Butterworth Publishers, Stoneham, MA, 5-24.

Fremling, C. R., Rasmussen, J. L., Sparks, R. E., Cobb, S. P., Bryan, C. F., and Claflin, T. O. (1989). "Mississippi River fisheries: A case history," *Proceedings of the International Large River Symposium* (*LARS*). D. P. Dodge, ed. Canadian Special Publication of Fisheries and Aquatic Sciences 106, 309-351.

FishPro, Inc. (2004). "Feasibility study to limit invasion of Asian carp into the Upper Mississippi River," Report prepared for the Minnesota Department of Natural Resources and the U.S. Fish and Wildlife Service, St. Paul, MN.

Fuller, S. L. (1980). "Freshwater mussels (Mollusca: Bivalva: Unionidae) of the Upper Mississippi River. Observations at selected sites within the Nine-Foot Navigation Channel Project for the St. Paul District, U.S. Army Corps of Engineers, 1977-1979," Report 79-24F, Academy of Natural Sciences of Philadelphia, Philadelphia, PA.

Gaboury, M. N., Newbury, R. W., and Erickson, C. M. (1995). "Pool and riffle fishways for small dams," Manitoba Natural Resources Branch, Winnipeg, Manitoba, Canada.

Gebken, D., and Wright, K. (1972). "Walleye and sauger spawning areas study, Pool 7, Mississippi River 1960-1970," Wisconsin Department of Natural Resources Bureau of Fisheries Management Report 60.

Gerking, S. D. (1959). "The restricted movements of fish populations," *Biological Reviews of the Cambridge Philosophical Society* 34, 221-242.

Goodwin, R. A., Anderson, J. J., and Nestler, J. M. (2004). "Decoding 3-D movement patterns of fish in response to hydrodynamics and water quality for forecast simulation." Presentation to the 6th International Conference on Hydroinformatics, Singapore. http://www.cbr.washington.edu/papers/goodwin-anderson-nestler2004.pdf

Gray, J. (1957). "How fishes swim," *Scientific American* 192, 48-54.

Gutreuter, S., and Theiling, C. (1998). "Fish life on the Mississippi," *Ecological status and trends of the Upper Mississippi River System.* U.S. Geological Survey, Environmental Management Technical Center, Onalaska, WI, 12-1 to 12-25.

Harden-Jones, F. R. (1968). *Fish navigation.* Edwin Arnold (Publishers) Ltd., London.

Harlan, J. R., and Speaker, E. B. (1956). "Iowa fish and fishing," Iowa Conservation Commission.

Hasler, A. D., Horrall, R. M., Wisby, W. J., and Braemer, W. (1958). "Sun orientation and homing in fishes," *Limnol. Oceanography* 3, 353-361.

Havera, S. P., Yetter, A. P., Hine, C. S., and Georgi, M. M. (1995). "Some misconceptions about conflicts between waterfowl and fisheries management," *Proceedings of the Fifty-First Annual Meeting of the Upper Mississippi River Conservation Committee*, Rock Island, IL, 26-40.

Hawkinson, B., and Gruenwald, G. (1979). "Observation of a wintertime concentration of catfish in the Mississippi River," Minnesota Department of Natural Resources, Division of Fish and Wildlife, Fisheries Section Investigational Report 365. St. Paul, MN.

Helms, D. R. (1974). "Shovelnose sturgeon in the Mississippi River, Iowa," Iowa Conservation Commission Fisheries Research Technical Series 74-3.

Henitz, A. J. (1986). "Discharge ratings for control gates. Mississippi River Lock and Dam 11, Dubuque, Iowa," U.S. Geological Survey Water Resources Investigations Report 85-4105.

Hocutt, C. H. (1973). "Swimming performance of three warmwater fishes exposed to rapid temperature change," *Chesapeake Science* 14(1), 11-16.

Holland, L. (1984). “Literature summary of fish movements between UMR Pools 3-15,” *Proceedings of the fortieth annual meeting of the Upper Mississippi River Conservation Committee.* Upper Mississippi River Conservation Committee, Rock Island, IL.

Holland, L., Huff, D., Littlejohn, S., and Jacobson, R. (1984a). “Analysis of existing information on adult fish movements through dams on the Upper Mississippi River,” Report to the St. Paul District, U.S. Army Corps of Engineers, by the U.S. Fish and Wildlife Service, National Fishery Research Laboratory, La Crosse, WI.

Holland, L., Hornung, T., Huston, M., and Duval, M. (1984b). “Analysis of existing information on ichthyoplankton drift through dams on the Upper Mississippi River,” Report to the St. Paul District, U.S. Army Corps of Engineers, by the U.S. Fish and Wildlife Service, National Fishery Research Laboratory, La Crosse, WI.

Holzer, J. A. (1989). “A Mississippi River telemetry study of largemouth bass movement patterns following release from a bass tournament,” *Mississippi River Work Unit Fisheries Summary Reports, 1990.* Wisconsin Department of Natural Resources, La Crosse, WI, 24-61.

Holzer, J. A., and Von Ruden, K. L. (1983). “Determine walleye spawning movements in Pool 8 of the Mississippi River,” *Mississippi River Work Unit Annual Report 1982-1983.* Wisconsin Department of Natural Resources, La Crosse, WI, 1-78.

Horall, R. M. (1962). “A comparative study of two spawning populations of the white bass, *Roccus chrysops* (Rafinesque), in Lake Mendota, Wisconsin, with special reference to homing behavior,” Ph.D. dissertation, University of Wisconsin, Madison.

Hubley, R. C., Jr. (1963). “Movement of tagged channel catfish in the Upper Mississippi River,” *Transactions of the American Fisheries Society* 92, 165-168.

Hubley, R. C., Jr., and Jergens, G. D. (1959). “Walleye and sauger tagging investigation on the Upper Mississippi River,” Wisconsin Conservation Department, Fish Management Division, West Central Area, Progress Report 1958, Investigational memorandum No. 1.

Hurley, S. T. (1983). “Habitat associations and movements of shovelnose sturgeon in Pool 13 of the Upper Mississippi River.” M.S. thesis, University of Iowa, Iowa City.

Hurley, S. T., Hubert, W. A., and Nickum, J. G. (1983). “Habitat associations and movements, with reference to spawning, of shovelnose sturgeon in Pool 13 of the Upper Mississippi River,” Cooperative Fisheries Research Unit, Iowa State University, Ames, IA.

Ickes, B. S. (2000). "Fish passage as a management goal in the Upper Mississippi River: Results of a recent survey," Project Status Report PSR 2000-06. U.S. Geological Survey, Upper Midwest Environmental Sciences Center, La Crosse, WI. http://www.umesc.usgs.gov/reports_publications/psrs/psr_2000_06.html

Ickes, B. S., Wlosinski, J. H., Knights, B. C., and Zigler, S. J. (2001). "Fish passage through dams in large temperate floodplain rivers: an annotated bibliography." U.S. Geological Survey, Upper Midwest Environmental Sciences Center, La Crosse, WI. http://www.umesc.usgs.gov/ltrmp_fish/fish_passage_biblio.html

Jones, D. R., Kiceniuk, J. W., and Bamford, O. S. (1974). "Evaluation of the swimming performance of several fish species from the Mackenzie River," *Journal of the Fisheries Research Board of Canada* 31, 1641-1647.

Jordan, D. S., and Evermann, B. W. (1923). *American food and game fishes.* Doubleday, Page and Co., Garden City, New York.

Jungwirth, M., Schmutz, S., and Weiss, S., eds. (1998). *Fish migration and fish bypasses.* Fishing News Books, Blackwell Science Ltd, Oxford, U.K.

Keenlyne, K. D., and Jenkins, L. G. (1993). "Age at sexual maturity of the pallid sturgeon." *Transactions of the American Fisheries Society* 122, 393-396.

Keevin, T. M., Adams, S. R., and Killgore, K. J. (2000). "Effects of pressure changes induced by commercial navigation traffic on mortality of early life stages of fish," ENV Report 34, U.S. Army Engineer District, Rock Island, Rock Island, IL.

Keevin, T. M., Maynord, S. T., Adams, S. R., and Kilgore, K. J. (2002). "Mortality of fish early life stages resulting from hull shear associated with passage of commercial navigation traffic," ENV Report 35, U.S. Army Engineer District, Rock Island, Rock Island, IL.

Keller, R. J., and Haupt, L. J. (2000). "The influence of rock ramp fishways on the hydraulic characteristics of weirs," *Fish migration and passage symposium proceedings*. Physiological Section, J. Cech, Jr., S. McCormick, and D. MacKinlay, eds., American Fisheries Society, Bethesda, MD, 123-131.

Keyes, J. L., and Klein, W. L. (1984). "Lock rotenoning—A technique used to sample fish population trends on the Ohio River," *Proceedings of the fortieth annual meeting of the Upper Mississippi River Conservation Committee.* Rochester, Minnesota, March 13-15, 1984.

Klinge, M. (1994). "Fish migration via the shipping lock at the Hagenstein Barrage: Results of an indicative study," *Water Science Technology* 29(3), 357-361.

Kolok, A. S. (1992). "The swimming performance of individual largemouth bass (*Microperus salmoides*) are repeatable," Short communication. *Journal of Experimental Biology* 170, 265-270.

Knights, B. C., Valazza, J. M., Zigler, S. J., and Dewey, M. R. (2002). "Habitat and movement of lake sturgeon in the Upper Mississippi River System, U.S.A," *Transactions of the American Fisheries Society* 131, 507-522.

Knowlton, M. F., and Jones, J. R. (1997). "Trophic status of Missouri River floodplain lakes in relation to basin type and connectivity," *Wetlands* 17(4), 468.

Kranz, V. R. (1978). "Intake siting study for Tyrone Energy Park," Report prepared for the Northern States Power Company, Eau Claire, WI. NUS Corporation Northern Environmental Services Division, Pittsburgh, PA.

Kuehn, J. H. (1959). "Mississippi River fisheries survey," Job 1, Minnesota Department of Natural Resources, St. Paul, MN.

Lee, D. S., Gilbert, C. R., Hocutt, C. H., Jenkins, R. M., McAllister, D. E., and Stauffer, J. R., Jr. (1980). *Atlas of North American freshwater fishes.* North Carolina State Museum of Natural Sciences, Raleigh.

Leopold, L. B., Wolman, M. G., and Miller, J. P. (1964). *Fluvial processes in geomorphology.* W. H. Freeman and Company, San Francisco, CA.

Loar, J. M., and Hildebrand, S. G. (1980). "A comparison of environmental issues related to development of small hydropower resources at new versus existing sites," *Proceedings of the third Miami International Conference on Alternative Energy Sources, Clean Energy Research Institute,* T. N. Vesirogln, ed., University of Miami, Coral Gables, FL, 681-683.

Magnuson, J. J., and Horrall, R. M. (1977). "University of Wisconsin 1977-1978 proposal to the National Sea Grant Program for continuing Sea Grant College support," Vol. 2, University of Wisconsin Sea Grant College Program, Madison.

Markussen, J. V., and Wilhelms, S. C. (1987). "Scour protection for Locks and Dams 2-10, Upper Mississippi River hydraulic model investigation," Technical Report HL-87-4, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Maynord, S. T. (2000a). "Shear stress on shallow-draft barge hulls," ENV Report 24, U.S. Army Engineer District, Rock Island, Rock Island, IL.

__________. (2000b). "Concentric cylinder experiments of shear mortality of eggs and larval fish," ENV Report 23, U.S. Army Engineer District, Rock Island, Rock Island, IL.

__________. (2000c). "Physical forces near commercial tows," ENV Report 19, U.S. Army Engineer District, Rock Island, Rock Island, IL.

Mays, L. W. (2001). *Water resources engineering.* John Wiley and Sons, Inc., New York.

McCarthy, T. (1990). "An evaluation of hybrid striped bass stocking in the Upper Mississippi River, Pool 14, 1985-1990," Iowa Department of Natural Resources, Illinois Department of Conservation, and Commonwealth Edison.

McCleave, J. D. (1980). "Swimming performance of European eel (*Anguilla anguilla* L.) elvers," *Journal of Fish Biology* 16, 445-452.

McKeown, B. A. (1984). *Fish migration.* Timber Press, Portland, OR.

McLeod, A. M., and Nemenyi, P. (1939). "An investigation of fishways," University of Iowa Studies in Engineering Bulletin 24, State University of Iowa, Iowa City, IA.

McMahon, T. E., and Terrell, J. W. (1982). "Habitat suitability models. Channel catfish," FWS/OBS-82/10.2, U.S. Fish and Wildlife Service.

McPhee, C., and Watts, F. J. (1976). "Swimming performance of Arctic grayling in highway culverts," U.S. Fish and Wildlife Service Bulletin 13, Anchorage, Alaska.

Meyers, G. S. (1949). "Use of anadromous, catadromous and allied terms for migratory fishes," *Copeia* 89-97.

Moen, C. T. (1989). "Paddlefish movements and habitat use in Pool 13 of the Upper Mississippi River during low water conditions," M.S. thesis, Iowa State University, Ames.

Moen, C. T., and Scarnecchia, D. L. (1992). "Paddlefish movement and habitat use in Pool 13 of the Upper Mississippi River during abnormally low river stages and discharges," *North American Journal of Fisheries Management* 12, 744-751.

Newcomb, B. A. (1989). "Winter abundance of channel catfish in the channelized Missouri River, Nebraska," *North American Journal of Fisheries Management* 9, 195-202.

Nord, R. C. (1967). "A compendium of fishery information on the Upper Mississippi River," Upper Mississippi River Conservation Committee, Rock Island, IL.

Northcote, T. G. (1978). "Migratory strategies and production in freshwater fishes." *Ecology of freshwater fish production.* S. D. Gerking, ed., Halsted Press, New York, 326-359.

__________. (1984). "Mechanisms of fish migration in rivers," *Mechanisms of migration in fishes.* J. D. McCleave, G. P. Arnold, J. J. Dodson, and W. H. Neill, eds., NATO Advanced Research Institute on Mechanisms of Fish Migration, Plenum Press, New York, 317-355.

Northcote, T. G. (1998). "Migratory behavior of fish and its significance to movement through riverine fish passage facilities." *Fish migration and fish bypasses.* M. Jungwirth, S. Schmutz, and S. Wiess, eds., Fishing News Books, Blackwell Science Ltd, Oxford, U.K., 3-18.

Noss, R. F. (1990). "Indicators for monitoring biodiversity. A hierchical approach," *Conservation Biology* 4, 355-364.

Olson, D. E., Schupp, H. H., and Macins, V. (1978). "A hypothesis of homing behavior as related to observed patterns of passive and active movement," *American Fisheries Society Special Publication* 11, 52-57.

Osborn, T. C., and Schupp, D. H. (1985). "Long-term changes in the Lake Winnibigoshish walleye sport fishery," Minnesota Department of Natural Resources, Fisheries Investigational Report 381.

Osvalt, R., and Grace, J. (1984). "Velocity field in roller/tainter gate bays of Upper Mississippi River Structures," June 13, 1984, Letter Report from the U.S. Army Engineer Waterways Experiment Station, Hydraulics Laboratory, Vicksburg, MS, to St. Paul District, U.S. Army Corps of Engineers, St. Paul, MN.

Paragamian, V. L. (1989). "Seasonal habitat use by walleye in a warmwater river system, as determined by radiotelemetry," *North American Journal of Fisheries Management* 9, 392-401.

Paragamian, V. L., and Coble, D. W. (1975). "Vital statistics of smallmouth bass in two Wisconsin rivers, and other waters," *Journal of Wildlife Management* 39, 201-210.

Parsons, G. R., and Bartlett, J. (1997). "Swimming performance of selected freshwater fish species," Report to the U.S. Army Engineer Waterways Experiment Station, Environmental Laboratory, Vicksburg, MS. University of Mississippi, Oxford.

Parsons, G. R., and Smiley, R. (1994). "Swimming performance of white crappie, *Pomoxis annularis*. The effect of environmental change," Freshwater Fisheries Report 136. University of Mississippi, University.

Parasiewicz, P., Eberstaller, J., Weiss, S., and Schmutz, S. (1998). "Conceptual guidelines for nature-like bypass channels." *Fish migration and fish bypasses.* M. Jungwirth, S. Schmutz, and S. Weiss, eds., Blackwell Science Inc., Malden, MA, 348-362.

Parmalee, P. W., and Bogan, A. E. (1998). *The freshwater mussels of Tennessee.* The University of Tennessee Press, Knoxville, TN.

Peake, S., Beamish, F. W. H., McKinley, R. S., Katopodis, C., and Scruton, D. A. (1995). "Swimming performance of lake sturgeon *Acipenser fulvescens*," Canadian Technical Report of Fisheries and Aquatic Sciences 2063, Canada Department of Fisheries and Oceans, St. Johns, Newfoundland.

Pellett, T. D., and Fago, D. (1984). "An evaluation of catfish populations and the catfish fisheries in the Lower Wisconsin River," Wisconsin Department of Natural Resources, Research Progress Report, SFR Project F-83-R, Study Number 507, Madison, WI.

Pellett, T. D., Van Dyck, G. J., and Adams, J. V. (1998). "Seasonal migration and homing of channel catfish in the lower Wisconsin River," *North American Journal of Fisheries Management* 18, 85-95.

Petts, G. E. (1989). "Perspectives for the ecological management of regulated rivers." *Alternatives in regulated river management.* J. A. Gore and G. E. Petts, eds., CRC Press, Inc., Boca Raton, FL, 3-24.

Pflieger, W. L. (1997). "The fishes of Missouri," Missouri Department of Conservation, Jefferson City. 343pp.

Phillip, D. P., and Claussen, J. C. (1995). "Loss of genetic diversity among managed populations," *Our Living Resources. A report to the nation on the distribution, abundance, and health of U.S. plants, and animals, and ecosystems,* U.S. Department of Interior National Biological Service. http://biology.usgs.gov/s+t/noframe/e221.htm

Pimental, D., Lach, L., Zuniga, R., and Morrison, D. (2000). "Environmental and economic costs of nonindigenous species in the United States," *BioScience* 20(1).

Pitlo, J., Jr. (1989). "Walleye spawning habitat in Pool 13 of the Upper Mississippi River," *North American Journal of Fisheries Management* 9, 303-308.

__________. (1992). "An evaluation of largemouth bass populations in the Upper Mississippi River," Mississippi River Investigations, Completion Report, Federal Aid to Fisheries Restoration, Project No. F-109-R, Iowa Department of Natural Resources, Des Moines.

Pitlo, J., Jr., Van Vooren, A., and Rasmussen, J. (1995). "Distribution and relative abundance of Upper Mississippi River fishes," Upper Mississippi River Conservation Committee Fish Technical Section, Rock Island, IL.

Poddubny, A. G., and Galat, D. L. (1995). "Habitat associations of upper Volga River fishes; effects of reservoirs," *Regulated Rivers Research and Management* 11, 67-84.

Priegel, G. R. (1969). The Lake Winnebago sauger-age, growth, reproduction, and early life history," Wisconsin Department of Natural Resources Technical Bulletin 43.

__________. (1975). "Age and growth of the yellow bass in Lake Poygan, Wisconsin," *Transactions of the American Fisheries Society* 104, 513-515.

Priegel, G. R., and Wirth, T. L. (1971). "The lake sturgeon, its life history, ecology and management," Wisconsin Department of Natural Resources Publication, 240-270.

Pringle, C. M., Freeman, M. C., and Freeman, B. J. (2000). "Regional effects of hydrologic alterations on riverine macrobiota in the new world: Tropical-temperate comparisons," *Bioscience* 50, 807-823.

Purkett, C. A., Jr. (1961). "Reproduction and early development of the paddlefish," *Transactions of the American Fisheries Society* 90, 125-129.

Reynolds, J. B. (1965). "Life history of smallmouth bass, *Micropterus dolomieu* Lacepede, in the Des Moines River, Boone County, Iowa," *Iowa State Journal of Science* 39, 417-436.

Robison, H. W., and Buchanan, T. M. (1988). *The fishes of Arkansas.* University of Arkansas Press, Fayetteville, AR.

Romano, M. A., Markillie, D. B., and Anderson, R. V. (1991). "Electrophoretic analysis of the host–parasite relationship between flathead catfish (*Pylodictus olivaris*) and the mapleleaf mussel (*Quadrula quadrula*)," *Proceedings of the Mississippi River Research Consortium, Inc.*, Vol 23.

Rouse, H. (1938). *Fluid mechanics for hydraulic engineers.* McGraw-Hill, New York.

Rosgen, D. (1996). *Applied river methodology.* Wildland Hydrology Books, Jacksonville, FL.

Russell, T. R. (1986). "Biology and life history of the paddlefish - A review," *The Paddlefish: Status, Management and Propagation.* J. G. Dillard, L. K. Graham, and T. R. Russell, eds., American Fisheries Society, North Central Division. Special Publication 7, Bethesda, MD, 2-21.

Scientific Assessment and Strategy Team. (1995). "Science for floodplain management into the 21st century. A blueprint for change. SAST dataset, levees." http://edc.usgs.gov/sast/

Scarpino, P. V. (1985). *Great river. An environmental history of the Upper Mississippi, 1890-1950.* University of Missouri Press, Columbia.

Schmulbach, J. C., Tunink, D. H., and Zittel, A. E. (1981). "Swimming performance of fishes endemic to the Missouri River in South Dakota," U.S. Department of the Interior.

Schlosser, I. J. (1991). "Stream fish ecology: A landscape perspective," *Bioscience* 41, 704-712.

Schoumacher, R. (1963). "Results of a walleye and sauger tagging study in Iowa waters of the Mississippi River," Quarterly Biological Report, Iowa Conservation Commission, Des Moines.

Schwalme, K., and Mackay, W. C. (1985). "Suitability of vertical slot and Denil fishways for passing north-temperate, nonsalmonid fishes," *Canadian Journal Fisheries Aquatic Science* 42, 1815-1822.

Scott, E. M., and Hevel, K. W. (1991). "Upstream migration of sauger past Tennessee River dams via navigation locks," Tennessee Valley Authority, Water Resources Aquatic Biology Department.

Scott, W. B., and Crossman, E. J. (1973). "Freshwater fishes of Canada," Bulletin 184, Fisheries Research Board of Canada, Ottawa, Ontario, Canada.

Shields, J. T. (1957). "Report of fisheries investigations during the second year of impoundment of Gavins Point Reservoir, South Dakota, 1956," South Dakota Department of Game Fish Parks.

Southall, P. D. (1982). "Paddlefish movement and habitat use in the Upper Mississippi River," M.S. thesis, Iowa State University, Ames.

Southall, P. D., and Hubert, W. A. (1984). "Habitat use by adult paddlefish in the Upper Mississippi River," *Transactions of the American Fisheries Society* 113, 125-131.

Stang, D. A., and Nickum, J. G. (1985). "Radio tracking of catfish and buffalo in Pool 13 Upper Mississippi River," Iowa Department of Natural Resources, Bellevue.

Strahler, A. N. (1957). "Quantitative analysis of watershed geomorphology," *American Geophysical Union Transactions* 38, 913-920.

Talbot, M. (1984). "Determine largemouth bass population dynamics and angler harvest in Pool 4, Upper Mississippi River," Mississippi River Work Unit Annual Report, 1983-984, Wisconsin Department of Natural Resources, La Crosse, WI.

Theiling, C. H., Korschgen, C., DeHaan, H., Fox, T., Rohweder, J., and Robinson, L. (2000). "Habitat Needs Assessment for the Upper Mississippi River System: Technical Report," U.S. Geological Survey, Upper Midwest Environmental Science Center, La Crosse, WI. Contract report prepared for the U.S. Army Corps of Engineers, St. Louis District, St. Louis, MO. www.umesc.usgs.gov/habitat_needs_assessment/emp_hna.html

Thorne, W. C. (1984). "Effects of continuous fishing on the walleye and sauger population in Pool 4, Mississippi River," Minnesota Department of Natural Resources Section of Fisheries Investigational Report 378, St. Paul, MN

Todd, B. L., and Rabeni, C. F. (1989). "Movement and habitat use by stream-dwelling smallmouth bass," *Transactions of the American Fisheries Society* 118, 229-242.

Toltz, King, Duvall, Anderson and Associates, Inc. (1996). “Discharge ratings for control gates at Mississippi River Lock and Dam 8,” Genoa, Wisconsin, St. Paul District, Corps of Engineers. St. Paul, Minnesota.

Townsend, C. H. (1902). “Statistics of the fisheries of the Mississippi River and tributaries,” U.S. Fish Commission Report for 1901, Government Printing Office, Washington, DC, 659-701.

Trautman, M. B. (1957). *The fishes of Ohio.* Ohio State University Press. Columbus. 683 pp. (Revised edition 1981).

Tunink, D. H. (1975). “The swimming performance of fishes endemic to the middle Mississippi River,” M.S. thesis, University of South Dakota.

Upper Mississippi River Conservation Committee. (1994). “Upper Mississippi River commercial fisheries statistics for 1992 and 1993,” *Proceedings of the Fiftieth Annual Meeting of the Upper Mississippi River Conservation Committee*, Rock Island, IL, 112-126.

__________. (2001). “A working river and a river that works,” Upper Mississippi River Conservation Committee, Rock Island, IL.

U.S. Army Corps of Engineers. (1980). “Master water control manual for the Mississippi River Nine-Foot Channel Navigation Project,” Appendixes for Locks and Dams at St. Anthony Falls through Melvin Price Locks and Dam, U.S. Army Corps of Engineers, Mississippi Valley Division, Vicksburg, MS.

__________. (1996). “Master water control manual for the Upper Mississippi River Basin Illinois Waterway,” U.S. Army Corps of Engineers, Rock Island District, Rock Island, IL.

U.S. Fish and Wildlife Service. (1993a). “Operating plan for the Upper Mississippi River Long Term Resource Monitoring Program,” EMTC 91-P002R, Environmental Management Technical Center, Onalaska, WI.

__________. (1993b). “Pallid sturgeon (*Scaphirhynchus albus*) recovery plan,” Region 6, USFWS, Denver.

U.S. Geological Survey. (1999). “Nonindigenous aquatic species,” Biological Resources Division, Florida Caribbean Science Center, Gainesville, FL. http://www.fcsc.usgs.gov/nas/.

Vennard, J. K., and Street, R. L. (1982). *Elementary fluid mechanics.* Sixth Edition. John Wiley & Sons, New York.

Videler, J. J. (1993). “Fish swimming.” *Biological Implications.* Chapman and Hall, London, 207-240.

Von Ruden, K. L., and Holzer, J. A.. (1989). "Determine the angler harvest, angler exploitation and total mortality of the largemouth bass population in Lake Onalaska, Pool 7, of the Mississippi River," Wisconsin Department of Natural Resources. La Crosse, WI.

Walden, H. T. (1964). *Familiar freshwater fishes of America.* Harper and Row, New York.

Ward, J. V., Tockner, K., and Schiemer, F. (1999). "Biodiversity of floodplain river ecosystems: ecotones and connectivity," *Regulated Rivers: Research and Management* 15, 125-139.

Watters, G. T. (1994). "An annotated bibliography of the reproduction and propagation of the Unionoidea (primarily of North America)," Ohio Biological Survey, Miscellaneous Contributions No 1.

War Department. (1932). "Correspondence from the Secretary of War transmitting a report from the Chief of Engineers on a survey of the Mississippi River between the Missouri River and Minneapolis, with a view to securing a channel depth of 9 feet at low water, with suitable widths," Part 1-Report, House Document 137, 72nd Congress, 1st session. U.S. Government Printing Office, Washington, DC (letter).

Webb, P. W. (1986). "Kinematics of lake sturgeon, *Acipenser fulvescens*, at cruising speeds," *Can. Journal of Zool.* 64, 2137-2141.

Weitzell, R. E., Khoury, M. L., Gagnon, P., Schreurs, B., Grossman, D., and Higgins, J. (2003). "Conservation priorities for freshwater biodiversity in the Upper Mississippi River Basin," Nature Serve and The Nature Conservancy.

Welcomme, R. L. (1979). *Fisheries ecology of floodplain rivers.* Longman Group Limited, London, England.

__________. (1985). "River fisheries," FAO Fisheries Technical Paper 262. Rome.

West Consultants, Inc. (2000). "Upper Mississippi River and Illinois Waterway cumulative effects study," Volume 2, *Ecological assessment.* Report prepared for the Rock Island District, U.S. Army Corps of Engineers, Rock Island, IL.

White, D. S. (1974). "The biology of *Minytrema melanops* (Rafinesque) the spotted sucker," Ph.D. dissertation, University of Louisville, Louisville, Kentucky.

Wilcox, D. B. (1987). "Opportunity for fish passage through Lock and Dam 3, Mississippi River," Appendix I, Draft Environmental Impact Statement, Lock and Dam 3 Navigation Safety Study, St. Paul District, U.S. Army Corps of Engineers, St. Paul, MN.

Wilcox, D. B. (1990). "Fish passage through dams on the Upper Mississippi River," Mississippi River Research Consortium Annual Meeting, La Crosse, WI. (abstract).

Wildman, L., Parasiewicz, P., Katopodis, C., and Dumont, U. (2003). "An illustrated handbook on nature-like fishways – Summarized version," American Rivers, Washington, DC. http://www.amrivers.org/doc_repository/AFS_Paper.pdf

Wlosinski, J. H., Hansen, D. E., and Hagedorn, S. R. (1995). "Long term resource monitoring program procedures: Water surface elevation and discharge," Program Report 95-P002-4.

Wlosinski, J. H., Wilcox, D. B., and Surprenant, C. (in press). "Fish passage through dams on the Upper Mississippi River System, Fisheries Compendium for the Upper Mississippi River System, Upper Mississippi River Conservation Committee, Rock Island, IL.

Wright, K. J. (1973). "An assessment of fish abundance, habitat, and fishing in a portion of Pool 8, Mississippi River, subject to highway intrusion," Wisconsin Department of Natural Resources, Bureau of Fisheries Management Report 63.

Zigler, S. J., Dewey, M. R., Knights, B. C., Runstrom, A. L., and Steingraeber, M. T. (2003). "Movement and habitat use by radio-tagged paddlefish in the Upper Mississippi River and tributaries," *American Journal of Fisheries Management* 23, 189-205.

__________. (in press). "Hydrologic and hydraulic factors affecting passage of paddlefish through dams in the Upper Mississippi River," accepted for publication in *Transactions of the American Fisheries Society.*

Zigler, S. J., Rust, P. J., Dewey, M. R., Knights, B. C., Steingraeber, M. T., and Runstrom, A. L. (1998). "Evaluation of passage of paddlefish through dams on the Upper Mississippi River," *Proceedings of the Mississippi River Research Consortium* 30.

Appendix A
Assessment of Existing Fish Passage Opportunity by Species

Silver Lamprey

Silver lamprey move upriver to spawn in gravel riffles in late April through early June. Spawning schools of silver lamprey have been observed in the Chippewa River, a large UMR tributary, in May. A swimming performance model for silver lamprey was not found. Given their relatively short length as adults and mode of swimming, silver lamprey probably cannot swim fast enough to pass upriver through UMR navigation dams. Silver lamprey attach to larger fish, and may "hitchhike" their way upriver through UMR dams. This form of passage through dams may not contribute to the pre-spawning upriver migration. The dams probably restrict silver lamprey from reaching suitable shallow, clear water, gravel-substrate spawning habitat, which is found in tributaries to the UMR.

Lake Sturgeon

Lake sturgeon are strong swimmers adapted to high current velocity channel habitats as well as to lakes. Adult lake sturgeon probably swim fast enough (C_v = 89 cm/sec) to pass upriver through UMR dams when the dam gates are out of the water. Lake sturgeon occur throughout the UMR main stem and in a number of tributaries. Missouri has been stocking lake sturgeon in the Mississippi River (K. Brummett, Missouri Department of Conservation, personal communication, 2003). Lake sturgeon probably spawn in the Wisconsin, Black, Chippewa, and St. Croix rivers in Wisconsin (all UMR tributaries), and move annually to and from spawning areas (Knights et al. 2002). Locks and Dams 1 and 19 present complete barriers to lake sturgeon upriver migrations. Locks and Dams 2, 5, 7, 11, 14, and 15 present barriers to upriver migrations in most years. Locks and Dams 1, 2, and Lower St. Anthony Falls dam prevent lake sturgeon from spawning in the fast current and rock substrate at St. Anthony Falls. Lake sturgeon have relatively good passage opportunities through Lock and Dam 3, which allows access to and between the St. Croix River, Lake Pepin, and the Chippewa River.

Lock and Dam 5 probably prevents lake sturgeon in Pools 6 and 7 from migrating upriver to favorable spawning habitat in the Chippewa River. Lock and Dam 11 probably prevents sturgeon in Pools 12, 13, and 14 from migrating upriver to spawning habitat in the Wisconsin River. Lake sturgeon are much less abundant now than before construction of the navigation system. Their decline in abundance may be due in part to restrictions to upriver migrations imposed by the navigation dams.

Shovelnose Sturgeon

Shovelnose sturgeon are also strong swimmers ($C_v = 82$ cm/sec) adapted to high current velocity channel habitats, and the adults can probably pass upriver through UMR navigation dams when the gates are out of the water. Shovelnose sturgeon are relatively common and widely distributed throughout the UMR and larger tributaries. We did not find information on the seasonal timing of their pre-spawning migration, which may occur later in spring before their spawning period. If shovelnose sturgeon have a short pre-spawning migration period, they may have relatively poor opportunity for upriver passage through UMR dams in most years, because the spring flood is usually declining at that time and dam gates are lowered into the water.

Pallid Sturgeon

Pallid sturgeon are morphologically similar to shovelnose sturgeon, but only limited information is available about their life history and swimming performance. Pallid sturgeon are migratory, and are probably strong swimmers. Pallid sturgeon have not been found upriver from the Missouri River confluence since the early 1900s (Pflieger 1997).

Paddlefish

Paddlefish are strong swimmers ($C_v = 86$ cm/sec) that migrate upriver to spawn in fast water over gravel bars in April and May. Paddlefish are known to inhabit the mainstem Mississippi River as well as the St. Croix, Chippewa, Black, Wisconsin, DesMoines, Iowa-Cedar, Illinois, Kaskaskia, and Missouri rivers (P. Thiel, U.S. Fish and Wildlife Service, La Crosse, WI, personal communication, 2002; Zigler et al. 2003, in press). Adult paddlefish probably have good opportunity for upriver passage through UMR dams when dam gates are out of the water. The timing of their spawning period coincides with the spring high river discharge period when dam gates are most often out of the water. Paddlefish move in the river system to feeding areas after the spawning period. Feeding-related movements between navigation pools are probably restricted in most years. The paddlefish population in the UMR is probably fragmented by restrictions to upriver migration imposed by Locks and Dams 2, 5, 7, 11, 14, and 15, in the same way as previously described for lake sturgeon.

Goldeye

Goldeye migrate up rivers in spring to spawn (Scott and Crossman 1973; Eddy and Underhill 1974), continue upriver to feed after spawning, and migrate downstream in fall (Scott and Crossman 1973). They are relatively slow swimmers (C_v = 46 cm/sec), and may not be able to pass upriver through UMR dams even when the gates are out of the water. Their spawning period coincides with the spring high river discharge period.

Mooneye

Mooneye migrate upriver in large schools to spawn in April and May. They are modest swimmers (C_v = 59 cm/sec) as indicated by the goldeye model. They rapidly swim to exhaustion when hooked. Their spawning period coincides with the spring period of high river discharge. Mooneye are fairly abundant and widely distributed in the UMR. The opportunity for upriver passage through dams may not be a factor limiting the mooneye population in the UMR.

American Eel

Female American eel migrate upriver from the ocean as elvers (leptocephali), then metamorphose and grow to adulthood in fresh water. Elvers migrate upriver at night in shallow water. Elvers can travel out of the water on wet grass or on the surface of wet rocks. They can ascend rivers by crawling over or around barriers (Becker 1983). McCleave (1980) found that elvers of the European eel (*Anguilla anguilla*) could make no progress against current greater than 50 cm/sec and that they could swim only 10-45 m in still water before exhaustion. Eels found in the UMR are adult females, >50 cm TL. There have been no reports of migrating elvers in the UMR, and eels in the Mississippi River probably metamorphose into adult form before they reach the UMR during their upriver migration. We found no information on swimming performance of adult American eels, but they are probably strong swimmers, given their long-distance migratory life history. Despite the effectively complete barrier to upriver fish movements presented by Lock and Dam 19, American eels have been occasionally found in the UMR and tributaries as far north as Lake St. Croix. Adult eels may travel over land when necessary to ascend barriers on rivers. This behavior of adults or occasional upriver passage through lock chambers may explain the continued reports of eels upriver from Lock and Dam 19.

Alabama Shad

The Alabama shad was a common anadromous species in the UMR, with annual migrations from the sea to the upper river (Coker 1930). The construction of Lock and Dam 19 blocked continued migrations northward, and the species is now rare or absent in the UMR. Downriver from Lock and Dam 19, Alabama shad should be able to pass upriver through the locks and dams, with better opportunities for passage through dams present early in their spawning period.

Although information on swimming performance of Alabama shad is not available, the model for the morphologically similar goldeye indicates that adult shad are moderately fast swimmers (C_v = 59 cm/sec, Table 5). Alabama shad may swim faster than goldeye, given their long distance migratory life history.

Skipjack Herring

Skipjack herring was an abundant potadromous species in the UMR, with upriver migration in spring and early summer to spawn, followed by a return migration downriver in the fall (Coker 1930). The construction of Lock and Dam 19 blocked upriver migrations by skipjack herring, leading to the near-extirpation of the ebonyshell mussel (*Fusconaia ebena*), for which skipjack herring serve as glochidial host (Fuller 1980). Skipjack herring are rare or absent in Pools 1 through 19. Skipjack herring were found in the UMR north of Lock and Dam 19 during the 1993 flood, as far as far upriver as Lake Pepin in Pool 4. Young of year skipjack herring were found there in 1993, indicating that adults had migrated that far north and successfully reproduced. Some skipjack herring adults have been found in the upper pools during flood years (Walter Popp, Minnesota Department of Natural Resources, Lake City, MN, personal communication, 2003). Head at Lock and Dam 13 was 4.3 m at the peak of the 1993 flood, so they didn't go through the dam gates. Some skipjack herring apparently got by Lock and Dam 19, perhaps through the lock chamber, then took advantage of the high water and uncontrolled dams to make their way upriver. Skipjack herring probably swim faster than indicated by the C_v = 59 cm/sec from the goldeye model. They swim high in the water column (Coker 1930), and can probably pass upriver through UMR dams when dam gates are out of the water. The timing of their upriver migrations is not well documented, but seems to coincide with the time of the declining spring flood. The opportunity for skipjack herring to pass through Locks and Dams 20 through 26 seems to exist in most years. Conditions at any one navigation dam can restrict upriver movement of these long-distance migrants, however. The time of arrival at dams and the schooling behavior of migrating skipjack herring may determine the northward limits of their migration in any year. The effects of the dams on the downriver herring migration is unknown.

Bigmouth and Smallmouth Buffalo

Bigmouth and smallmouth buffalo move upriver to spawn in flooded vegetation during a brief period in spring. Buffalo fish may ascend tributaries to spawn (Coker 1930). Both species are moderately fast swimmers, with C_v = 63 cm/sec for bigmouth buffalo and C_v = 51 cm/sec for smallmouth buffalo. Although their spawning period is brief, it does typically correspond with the time of the declining spring flood, when dam gates are often out of the water. Both species are relatively abundant and widely distributed throughout the UMR, indicating that the opportunity for passage through navigation dams may not be limiting their populations.

Blue Sucker

Large numbers of blue suckers once migrated northward in the UMR in the spring before spawning, and returned southward in the fall (Jordan and Evermann 1923). The blue sucker is a streamlined fish adapted for high current velocities in channel habitat. The blue sucker is a relatively fast swimmer (C_v = 78 cm/sec). Blue suckers spawn during the spring flood, and adults should be able to pass upriver through dams when the gates are out of the water. Blue sucker populations may be fragmented by the presence of the UMR navigation dams, resulting in fewer individuals available for upriver migrations and spawning activity.

Other Catostomids

Other Catostomids (quillback, highfin carpsucker, spotted sucker, black redhorse, golden redhorse, silver redhorse, shorthead redhorse, northern hogsucker, white sucker) ascend rivers to spawn on riffles in April and May (Table 3). They are slow to moderate swimmers, (C_v ranging from 45 cm/sec for highfin carpsucker and northern hogsucker to 81 cm/sec for silver redhorse, Table 4). Upriver passage through UMR dams may be difficult for these species, although some may make use of their streamlined form and pectoral fins to maintain position in high current velocity and employ a burst-and-stop mode of swimming along the bottom to ascend. White suckers are early spawners that make annual spawning runs in smaller tributaries to the UMR. Their spawning period coincides with the early part of the spring flood in the UMR. Some Catostomids, such as the northern hogsucker, spawn later in the spring following the spring flood and probably have very limited opportunity for upriver passage through UMR dams. In navigation pools with accessible spawning habitat in tributaries, the Catostomid populations may not be limited by restricted passage through the navigation dams. Access to suitable riffle spawning habitat in tributaries may be constraining populations of some of the Catostomid species in the UMR. Some of the Catostomids such as spotted suckers feed on variety of small benthic macroinvertebrates common in clear rivers with hard substrate (White 1974). Spotted suckers may migrate between the UMR and tributaries, depending on foraging conditions.

Blue Catfish

Blue catfish once had seasonal migrations in the UMR in response to water temperature, moving northward in spring for spawning and feeding and returning southward in fall (Jordan and Evermann 1924). Lock and Dam 19 now blocks upriver migration of blue catfish from more southerly parts of the river. Blue catfish are large inhabitants of deep channels and fast water. They are strong swimmers (C_v = 69 cm/sec) and can probably move upriver through UMR dams when dam gates are out of the water. Blue catfish are at the northern limits of their range in the UMR. They have not been reported north of Pool 11 in recent years, and may never have occurred throughout the UMR. The seasonal timing of their upriver migration is not well known. Their June spawning period occurs when most of the locks and dams are operated in a controlled condition, indicating little opportunity for upriver migration by blue catfish during most years.

Channel Catfish

Channel catfish move to and from wintering areas, and travel widely in the UMR. Holland et al. (1984a) observed that there does not appear to be large concerted migrations of channel catfish in the UMR, although they have been recaptured up to 345 km from their tagging sites (Hubley 1963; Stang and Nickum 1985). Pellet et al. (1998) reported that channel catfish occupy small summer home ranges in the Wisconsin River (a large UMR tributary), migrate to the UMR in autumn to spend the winter, return to the Wisconsin River in the spring to spawn, then return to the same summer home ranges that they previously occupied. Channel catfish congregate in deep holes with low current velocity to overwinter (McMahon and Terrell 1982). Channel catfish are streamlined, strong swimmers (C_v = 84 cm/sec, Table 5), and adapted to high current velocity channel habitat. Channel catfish can move upriver through UMR dams when the gates are out of the water. Their spawning period is in June and July, coinciding with lower river discharge and controlled dam operation. Channel catfish spawn in cavities in the bank or in woody debris jams, habitats that are generally present throughout the UMR. Channel catfish are relatively abundant and widely distributed in the UMR.

Flathead Catfish

Flathead catfish, like channel catfish, disperse from winter habitat to spawning areas, and summer residence areas, and return to winter habitat. Flathead catfish, unlike blue catfish, do not undergo long-distance seasonal migrations, but migrate more locally (Holland et al. 1984a). Unlike channel catfish, flathead catfish do not seem to travel far during the summer after spawning, and may return to specific patches of summer habitat with cover. Adult flathead catfish are streamlined residents of deep holes and debris jams adjacent to fast current in large channel habitat. They are large fish when sexually mature, and are strong swimmers (C_v = 121 cm/sec). Flathead catfish are probably able to swim upriver through UMR navigation dams when the dam gates are out of the water. Their spawning period occurs late in June. Depending on when flathead catfish undergo dispersal from winter habitats and pre-spawning movements, they may not have good opportunity for upriver passage through UMR dams.

Northern Pike

Northern pike are ambush predators with high burst speed, but they are relatively weak swimmers in a current (C_v = 42 cm/sec). Northern pike migrate upriver and into tributaries to spawn in flooded vegetation shortly after ice-out (Scott and Crossman 1973; Becker 1983). This early migration and spawning in the UMR occurs before the spring flood in most years. Adult northern pike are territorial and spend their summers within specific patches of feeding habitat.

Their relatively weak swimming ability, combined with pre-spawning movements that usually occur during late winter when dams are operating in the controlled condition, result in poor opportunity for upriver movements by northern pike through UMR dams.

White Bass

White bass are strong-swimming (C_v = 120 cm/sec), schooling fish that travel widely within the river system (Finke 1966). White bass move upriver and into tributaries to spawn in April through June. Their pre-spawning movements and spawning period coincide with periods of high river discharge when UMR dam gates are most often open. Adult white bass are probably able to move upriver through UMR dams when the dam gates are out of the water. White bass are pelagic spawners. Their eggs and larvae are common in the main channel ichthyoplankton drift. Although they prefer tributary rivers for spawning, white bass can also spawn successfully on windswept shores of lakes and reservoirs (Becker 1983). White bass are relatively abundant and widely distributed in the UMR (Pitlo et al. 1995).

Yellow Bass

Yellow bass move to and from wintering areas and spawn in tributary rivers or lake littoral zones. They are a southern species, and at the northern limit of their range where reported from the Chippewa River, a UMR tributary in Wisconsin (Becker 1983). Unlike white bass, yellow bass have not been reported to undergo concerted upriver spawning runs. Yellow bass have not been tested for swimming performance. The surrogate model (white bass) indicates that adult yellow bass are strong swimmers (C_v = 90 cm/sec) and should be able to swim upriver through UMR dams when the gates are out of the water. Their pre-spawning movements and spawning period coincide with the spring flood in the southern pools of the UMR when the gates at many of the dams are out of the water more than 50 percent of the time.

Largemouth Bass

Largemouth bass move to and from specific winter and summer areas in the UMR. Largemouth bass moved up to 14.5 km to winter areas, indicating a potential scarcity of suitable winter habitat (Pitlo 1992). Largemouth bass do not undergo concerted migrations in the UMR, but seem to migrate locally. Although largemouth bass are strong swimmers (C_v = 71 cm/sec), they select low current velocity areas most of the time. Spawning occurs over a short period in May and June. Dispersal from winter habitat and pre-spawning movements may coincide with the period of spring river discharge when dam gates are most often open. Restricted ability to pass upriver through UMR dams may limit largemouth bass access to suitable winter habitat areas, possibly constraining overwinter survival of adults and size of the largemouth bass population in the UMR.

Smallmouth Bass

Smallmouth bass disperse from winter habitat areas, move upriver in spring before spawning, have well-defined summer home ranges, and return to winter habitat areas. Most smallmouth bass movements in rivers are local, with few marked fish traveling great distances (Keuhn 1959; Becker 1983). Smallmouth bass are strong swimmers ($C_v = 63$ cm/sec), and are probably able to swim upriver through UMR dams when the dam gates are open. Pre-spawning movements may coincide with the latter part of the spring flood on the UMR in most years, when dam gates are most often open.

Walleye

Walleye migrate upriver to spawning areas in lake and river systems, possibly a learned migration behavior as first-year spawners follow older adults to traditional spawning locations (Olson et al. 1978). In the UMR, walleyes have been found to spawn on gravel, rock, and flooded vegetation, often near tailwaters below dams on the UMR (Pitlo 1989). After spawning, walleyes disperse to summer feeding areas and move about in search of food, then return to winter habitat areas. Walleye begin to assemble below locks and dams on the UMR in late fall and become concentrated in tailwater areas over winter and before spawning. Their apparent preference for tailwaters as winter habitat and pre-spawning staging areas results in concentrations of walleyes in the tailwaters of the UMR navigation dams. These winter concentrations of walleye in tailwaters provide a popular and economically important sport fishery (Thorne 1984), and render walleyes vulnerable to exploitation by winter-hardy anglers. Walleyes are strong swimmers ($C_v = 83$ cm/sec). Walleyes can swim upriver through UMR navigation dams when the gates are raised from the water. Walleyes spawn early, usually in early April before the spring flood, resulting in generally poor opportunity for upriver passage through the UMR navigation dams. The flexibility of walleye in using a variety of spawning habitats indicates that the UMR walleye population is adapted to the river and can successfully reproduce, although suitability of spawning habitat at any one location may vary markedly from one year to the next. One of the largest, most popular, and well-studied walleye fisheries in the UMR is in Pool 4. The Pool 4 walleye population has relatively frequent access upriver through Lock and Dam 3 to Pool 3 of the UMR and the St. Croix River, as well as downriver to Lake Pepin and the Chippewa River. This relatively large present range of accessible habitat within the UMR undoubtedly contributes to the recruitment success and fast growth of the walleye population and to the continued success of the fishery.

Sauger

Sauger spawn in lakes and migrate up rivers to spawn (Becker 1983). In the UMR, saugers concentrate in tailwaters during winter, then spawn in tailwaters during April and May. Saugers are often found in the scour holes below the UMRS navigation dams and between wing dams in the channel border areas near the navigation dams. Sauger in the UMR spawn on rock riprap in tailwater areas

(Gebken and Wright 1972), and on gravel between wing dams in tailwater areas (Larry Gates, Tim Schlagenhaft, and Alan Stevens, Minnesota Department of Natural Resources, Lake City, MN, personal communication, 2001). Sauger spawn usually in late April and May, coinciding with high river discharge when dam gates are most often open. Sauger are strong swimmers (C_v = 79 cm/sec) and can probably swim upriver through UMR dams when the gates are raised out of the water. Sauger probably benefit from the relatively large extent of river channel habitat available to them. Sauger are widely distributed in the UMR, becoming more abundant than walleye in the southern navigation pools.

Freshwater drum

Freshwater drum migrate in schools into tributaries to spawn in May and June. Large concentrations of spawning freshwater drum occur below dams on the Willow River (tributary to the St. Croix River in Wisconsin), and in the tailwaters of UMR dams. Freshwater drum have pelagic eggs and larvae and are common in the ichthyoplankton drift in the UMR main channel. They are strong swimmers for their size (C_v = 81 cm/sec), and can probably swim upriver through UMR dams when the gates are raised from the water. Large freshwater drum occur in fast-current channel habitat. Their pre-spawning movements in late May coincide with the decline of the spring flood in most years, providing relatively poor opportunity for upriver passage through dams with gates out of the water. Freshwater drum are common and widely distributed throughout the UMR and are probably not constrained by ability to pass upriver through dams.

Appendix B
Unionid Mussels

Mussel Species Accounts

Species in **bold** exhibit disjunct populations that require at least one migratory fish host species.

Subfamily Cumberlandinae

Cumberlandia monodonta. Fish host unknown. Historically patchily distributed predominantly below Pool 14 and the lower Illinois River. Currently rare in UMR Pools 10, 15-26, and the St. Croix River. Absent from its historical range in the Illinois River and above Pool 15, except Pool 10. Disjunct populations in Pool 10 and the St. Croix River.

Subfamily Ambleminae

Amblema plicata. Black and golden redhorse, northern hogsucker, largemouth bass, northern pike, flathead and channel catfish, white bass, sauger, freshwater drum. Present everywhere within its historical range except the Minnesota River. Abundant in most pools, rare only in Lower St. Anthony Falls Pool.

***Cyclonaias tuberculata.* Channel and flathead catfish. Species has always been rare in the UMR and may be near extirpation. Currently exists in pools 4, 20, 25, and the St. Croix River.**

***Elliptio crassidens.* Skipjack herring. Historically widespread throughout the UMR and its major tributaries, but currently only isolated relict population exists in the St. Croix River and possibly Pool 17. Very near extirpation from impediment of Skipjack upstream migration from Lock and Dam 19.**

***Elliptio dilatata.* Flathead catfish. Historically distributed throughout the UMR drainage. Healthy populations exist in the St Croix River and Pool 4 (Lake Pepin) and Pool 9. Rare in Pool 3, 5a, 6, 10, 11, 14, 17, and 20. Absent in the UMR above the St. Croix River including the Minnesota River. Perhaps several disjunct populations exist, one from the St. Croix River to Pool 6, one from Pools 9-11, and three in Pools 14, 17, and 20.**

***Fusconaia ebena.* Skipjack herring. Historically widespread and very abundant in the UMR and its main tributaries, but currently only isolated relict populations exist in the St. Croix River, Pools 9 and 18, and below Lock and Dam 19 including the Alton Pool of the Illinois River. Very near extirpation above Lock and Dam 19 from impediment of Skipjack upstream migration at Lock and Dam 19. Possibly two relict disjunct population exist; one on the St. Croix River and one below Lock and Dam 19 and lower Illinois River. The St. Croix River population probably has not reproduced for many years.**

Fusconaia flava. No migratory fish hosts. Present everywhere within its historical range except the Minnesota River. Common to abundant in most pool. Expanded its historical range above St. Anthony Falls where it is now abundant in the Upper St. Anthony Falls Pool.

***Megalonaias nervosa.* American eel, flathead and channel catfish, longnose gar, white bass, freshwater drum. Historically widespread, healthy populations in lower UMR reaches: Pools 9-26 and the lower Illinois River, rare in the St. Croix and from Pools 3-8. Absent in the UMR above the St. Croix and Pool 5a.**

Plethobasus cyphyus. Sauger. Historically distributed throughout UMR and it main tributaries and probably never common. May be near extirpation in the UMR. Several disjunct populations may exist: St. Croix River and Pools 7, 10, 15-17, 20, and 22-24.

Pleurobema rubrum. No migratory fish hosts. Historically possibly occurred in the lower Illinois River Alton and La Grange Pools. Currently does not occur in the UMR Drainage.

***Pleurobema sintoxia.* No migratory fish hosts. Historically occurred throughout the UMR drainage. Currently common in the St. Croix River and Pool 11. Rare in most pools, absent within its historical range from the Minnesota and Illinois rivers and Pools 5a, 12, 14, and 22. The species has expanded its historical range above St. Anthony Falls where it is rare.**

Quadrula fragosa. Fish host unknown. Historically occurred in the Minnesota and St. Croix rivers and probably the UMR from St. Anthony Falls to at least Pool 10. Currently only exists in the upper reaches of the lower St. Croix River.

***Quadrula metanevra.* Sauger. Historically occurred throughout the UMR drainage. Currently common in pools 15, 17, and 19 and rare in most other pools. Absent from its historical range in the Minnesota and Illinois River and Pools 3 and 5a.**

***Quadrula nodulata.* Largemouth bass, channel and flathead catfish. Historically occurred throughout most of the UMR drainage. Common in Pools 1-3, 18-20, and 22-24, rare in Pools 4, 7, 9-17, 21, 25-middle river, and the lower Illinois River. Two disjunct populations may exist: one from Pools 1-3 and another from Pools 18-24.**

Quadrula pustulosa. Shovelnose sturgeon, channel and flathead catfish. Common to abundant in most pools. Absent from its historical range only from the Minnesota River. No disjunct populations are apparent.

Quadrula quadrula. Flathead catfish. Historically occurred throughout most of the UMR drainage. Probably has increased in abundance and become more widespread due to its opportunistical nature with impoundments. Currently common in most pools, abundant in the Upper St. Anthony Falls Pool where it has expanded it historical range and in Pool 1 and the entire Illinois River. Rare in the St. Croix River, Lower St. Anthony Falls Pool, and Pools 5a and 6. Probably no disjunct populations exist.

Tritogonia verrucosa. Flathead catfish. Historically occurred throughout UMR and its major tributaries. Currently occurs only in a few pools and may be near extirpation in the UMR. Rare in the St. Croix River and Pools 2, 4, 7-10, 19, 22-24, Peoria Pool, and Marseilles Pool. A few small disjunct populations may exist: St. Croix River, Pools 2 and 4, Pools 7-10, Pools 22-24, and the upper Illinois River.

Uniomerus tetralasmus. No migratory fish hosts. Historically only occurred in the Middle UMR and the Illinois River Alton Pool. Currently rare in the Middle UMR and absent in the lower Illinois River.

Subfamily Anodontinae

Alasmidonta marginata. White sucker, shorthead redhorse, northern hogsucker. Typically a smaller river species, but did historically occur in the Minnesota, Illinois, and the upper reaches of the UMR (Pools 2-13), but probably never common. May be near extirpation from the UMR proper. Currently rare and n the St. Croix River and Pools 2-3, 6, 8, and 11.

Alasmidonta viridis. No migratory fish hosts. Only historical records from UMR Pool 12, and the upper Illinois River (Starved Rock and Marseilles pools).

Anodonta suborbiculata. **Largemouth bass. Probably has expanded its range northward into the UMR as far as Pool 4. Currently rare in UMR Pools 4-6, 8-10, 13, 15-17, 20, 25-Middle UMR, and the Illinois River (Alton, La Grange, and Starved Rock pools). Possibly three disjunct populations: Pools 4-10, Pools 13-17, and the lower UMR (Pool 25-Middle UMR) and Illinois River (Alton, LaGrange, and Starved Rock pools).**

Anodontoides ferussacianus. White sucker, largemouth bass. Typically a smaller river or headwater species. Historical records only from the Minnesota River, UMR Pool 4, and the Illinois River (Peoria, Starved Rock, and Marseilles pools).

Arcidens confragosus. Freshwater drum. Historically occurred throughout the UMR, and its major tributaries. Currently rare in the St. Croix River and most UMR pools, common in the lower Illinois River (Alton Pool). Absent from the UMR above Pool 2 including the Minnesota River, UMR Pools 4, 5a, 21, and the upper Illinois River (Marseilles Pool). A healthy disjunct population exists in Pools 2-3.

***Lasmigona complanata*. Largemouth bass, longnose gar, sauger. Historically present throughout the UMR and its tributaries. Currently rare in most UMR pools and the Minnesota, St. Croix, and the upper Illinois rivers. Common in UMR Pool 13 and the lower Illinois River (Alton to Starved Rock). Absent from a few pools in the upper reaches of the UMR: Lower St. Anthony Falls, Pool 1, and Pools 4-5a. Possibly two disjunct populations: one above and one below UMR Pools 4-5a, respectively.**

Lasmigona compressa. No migratory fish hosts. Typically a smaller river or headwaters species. Rare in the St. Croix River, only historical records from UMR Pools 14 and 15.

***Lasmigona costata*. Smallmouth and largemouth bass, northern pike, walleye. Typically a smaller river species but historically occurred in the Minnesota River, St. Croix River, Illinois River, most UMR pools between Pools 2 and 15, and Pool 22. Currently rare in the St. Croix River, Pools 2, 8, 14, 22, and the Marseilles Pool of the Illinois River. Possible disjunct populations in the St. Croix River, Upper Illinois River, and mid reaches of the UMR (Pools 8-14).**

Pyganodon grandis. White sucker, largemouth bass, skipjack herring, longnose gar, white bass, freshwater drum. Historically occurred throughout the UMR drainage. Currently rare or common in every UMR pool and its tributaries. No apparent disjunct populations exist.

Simpsonaias ambigua. No migratory fish hosts. Historical records from the St. Croix River, UMR Pools 3, 10, 12, and 26. Currently rare in the St. Croix River and UMR Pools 10 and 12. Perhaps these two areas harbor disjunct populations.

***Strophitus undulatus*. Largemouth bass, walleye. Historically occurred throughout most of the UMR drainage, except the lower reaches. Currently abundant in the Upper St. Anthony Falls Pool where it has expanded its historical range, and common in UMR Pools 1, 2, and 9. Rare in the St. Croix River and upper Illinois River (Marseilles Pool), Lower St. Anthony Falls Pool, and UMR Pools 3-4, 5a-8, 19-17, 19-20, and 24. Absent within its historical range from the Minnesota and lower Illinois rivers, UMR Pools 5 and 18. May never have been present in UMR Pools 21, 22, 25-Middle UMR. Possible disjunct population in the upper Illinois River.**

Utterbackia imbecillis. Largemouth bass. Historically occurred throughout the UMR drainage. Currently abundant in UMR Pool 19, common in UMR Pool 17, and rare in most reaches: Minnesota River, St. Croix River, Lower St. Anthony Falls, UMR Pools 1-5, 6-16, 18, 20-Middle UMR, Alton Pool, and Peoria Pool. Absent within its historical range from the Illinois River La Grange, Starved Rock and Marseilles pools, and UMR Pool 5a. No apparent disjunct populations.

Subfamily Lamsilinae

Actinonaias ligamentina. American eel, smallmouth bass, largemouth bass, white bass, sauger. Historically occurred throughout the UMR and it tributaries. Probably never common in the UMR proper. Currently common in UMR Pool 14 and the Illinois River Marseilles Pool. Rare in the St. Croix River, UMR Pools 2-4, 7-13, 15-20, 22-22, 26, and Illinois River Alton-Starved Rock pools. Absent within its historical range from the Minnesota River, UMR Pools 5-6, and 25. Two disjunct populations may exist above and below UMR Pools 5-6, respectively.

Ellipsaria lineolata. Sauger, freshwater drum. Historically occurred throughout the UMR and its major tributaries. Currently abundant in UMR Pools 15, 20, 22, 24, and common in UMR Pools 11-12, 14, 16-19, 25-26. Rare in the St. Croix River, UMR Pools 3-4, 5a-10, 13, 21, and the Middle UMR. Absent from its historical range in the Minnesota and Illinois rivers, and UMR Pools 2 and 5. No apparent disjunct populations.

Epioblasma triquetra. No migratory fish hosts. Historically occurred in the St. Croix River and Illinois River (La Grange, Starved Rock, and Marseilles pools), and UMR Pools 3-4, 5a-6, and 14-16. Currently only occurs in the upper portion of the lower St. Croix River, where it is rare.

Lampsilis cardium. **Smallmouth and largemouth bass, sauger, walleye. Historically occurred throughout the UMR drainage. Currently abundant in the Upper St. Anthony Falls Pool, common in UMR Pools 2-3, 6-9, 11-15, 17-19, 24-25. Rare in the Minnesota and St. Croix rivers, Lower St. Anthony Falls Pool, UMR Pools 1, 4-5a, 10, 16, 20-22, 26, Middle UMR, and the Alton and Marseilles pools of the Illinois River. A Possible disjunct population occurs in the upper Illinois River (Marseilles Pool).**

Lampsilis higginsii. **Smallmouth and largemouth bass, northern pike, sauger, walleye, freshwater drum. Historically occurred in the UMR from below St. Anthony Falls to Pool 24 and its major tributaries. Currently rare in the St. Croix River, UMR Pools 7-17 and 19. Absent from its historical range in the Minnesota and Illinois rivers, and UMR Pools 2-6, 22, and 24. Possible disjunct populations exist in the St. Croix River and from Pools 7-17.**

Lampsilis siliquoidea. **White sucker, smallmouth and largemouth bass, white bass, sauger, walleye. Historically occurred in the UMR above Pool 18 and its tributaries. Probably never abundant in the UMR proper. Currently common in the Upper St. Anthony Falls Pool, rare in the St. Croix River, Lower St. Anthony Falls Pool, UMR Pools 1-5, 6-13, 17, and the Illinois River Peoria and Marseilles pools. Absent within its historical range from the lower Minnesota River, UMR Pools 5a, 14-15, and Illinois River Alton, La Grange, and Starved Rock pools. Possible disjunct population exists in the Illinois River.**

Lampsilis teres. Shovelnose sturgeon, largemouth bass, longnose gar. Historically occurred throughout the UMR and its tributaries. Currently common in the lower UMR (Pools 25 to Middle UMR), rare in UMR Pools 4, 7, 9-11, 14, 15, 17, 19-24, and the lower Illinois River (Alton and La Grange pools). Absent within its historical range from the Minnesota, St. Croix, and upper Illinois rivers, and UMR Pools 2, 3, 5-6, 8, 13, 16, and 18. No apparent disjunct populations.

Leptodea fragilis. Freshwater drum. Historically occurred throughout the UMR and its tributaries. Currently abundant in Upper St. Anthony Falls Pool where it has expanded its historical range, UMR Pool 11, 19, Middle UMR, and the Illinois River Marseilles Pool. Common in the Minnesota, St. Croix, and lower Illinois (Alton, La Grange, Peoria) rivers. Rare in UMR Pools 1, 3, 5-7, 10, 13, 14, 16, 20-22, and the Illinois River Starved Rock Pool. Only absent within its historical range from the Lower St. Anthony Falls Pool. No apparent disjunct populations.

Leptodea leptodon. No migratory fish hosts. Historically occurred in the Minnesota River and UMR Pools 2, 10, and 13. Currently does not exist within the UMR proper or its tributaries above the Middle UMR. Nearest known population occurs in the Meremac River, which enters the Middle UMR.

Ligumia recta. Largemouth, sauger, walleye. Historically occurred throughout the UMR and its tributaries. Currently common in the Upper St. Anthony Falls Pool and UMR Pools 2, 9, 11, 13, and 14. Rare in the St. Croix and lower Illinois (Alton Pool) rivers, and UMR Pools 1, 3-8, 10, 12, and 15-26. Absent within its historical range from the Minnesota and upper Illinois rivers and the Lower St. Anthony Falls Pool. No apparent disjunct populations.

Ligumia subrostrata. Largemouth bass. Historically occurred in UMR Pools 16-19. Currently does not occur with the UMR.

Obliquaria reflexa. No migratory fish hosts. Historically occurred throughout the UMR drainage. Currently abundant in most pools including the Upper St. Anthony Falls Pool where it has expanded its historical range. Absent within its historical range from the Minnesota and upper Illinois (Starved Rock and Marseille pools) rivers. No apparent disjunct populations.

Obovaria olivaria. Shovelnose sturgeon. Historically occurred throughout the UMR and its major tributaries. Currently abundant in UMR Pools 7 and 22, common in UMR Pools 6, 10-14, 17-20, 24-Middle UMR. Rare in the St. Croix River and two Illinois River pools (Alton and Peoria), and in UMR Pools 2-5a, 8, 9, 15, 16, 21. Absent within its historical range from the Minnesota River, Illinois River La Grange, Starved Rock, and Marseilles pools. There appears to be no disjunct populations.

Potamilus alatus. Freshwater drum. Historically occurred throughout the UMR and its tributaries. Currently abundant in the Upper St. Anthony Falls Pool where it has expanded its historical range. Common in the St. Croix River, UMR Pools 1-3, 7, 9, 10, 14, 16, 17, 19, 25, and 26. Rare in the Minnesota River, Lower St. Anthony Falls Pool, lower Illinois River (Alton, La Grange, Peoria pools), and UMR Pools 4, 5, 6, 8, 11-13, 15, 18, 21-24, and Middle UMR. There appears to be no disjunct populations.

***Potamilus capax*. Freshwater drum. Historically occurred primarily in the lower reaches of the UMR (below Pool 17) and lower Illinois River, but has been documented from upper UMR Pools: Lower St. Anthony Falls, 4, 5a, 10, 13, 16. Currently only reported from UMR Pools 20 and 24 where it is rare. This species may be near extirpation in the UMR. These populations may be disjunct from Lower Mississippi River Drainage populations.**

Potamilus ohiensis. Freshwater drum. Historically occurred throughout UMR and its tributaries. Currently common in the Minnesota River and the Illinois River Starved Rock Pool, and UMR Pools 3, 17, 19, and 22. Rare in the St. Croix River, Illinois River Alton, La Grange, Peoria, Marseilles pools, Upper St. Anthony Falls Pool (expanded historical range), Pools 1, 2, 4-16, 18, 20, 21, and 24-Middle UMR. There appears to be no disjunct populations.

Potamilus purpuratus. Freshwater drum. Historically occurred in the Middle UMR but has been documented in Pool 19. Currently rare in the Middle UMR.

Toxolasma parvus. No migratory fish hosts. Historically occurred throughout the UMR drainage. Currently common in UMR Pools 5, 6, 10, and 11. Rare in the Minnesota and St. Croix rivers, Illinois River La Grange Pool, Upper St. Anthony Falls (expanded historical range), UMR Pools, 2-4, 7, 8, 12-19, 25, and the Middle UMR. Within its historical range the species is absent from UMR Pool 9 and 26, and from Illinois River Alton, Peoria, and Marseilles pools. The species is absent and probably never was present in Lower St. Anthony Falls Pool and UMR Pools 1, 20-24, and Illinois River Starved Rock Pool. Two disjunct populations may exist as result of the gap in the species presence in UMR Pools 20-24.

Toxolasma texasiensis. No migratory fish hosts. Only historical record is from the Middle UMR, which is near the northern most extent of this species range. Currently does not occur within the UMR drainage including the Middle UMR.

Trincilla donaciformis. Sauger, freshwater drum. Historically occurred throughout the UMR drainage. Currently abundant in UMR Pool 5 and common in UMR Pools 5a, 6, 13, 15, 17-19, 22, 24. Rare in the St. Croix River, Illinois River Alton and Peoria pools, Upper and Lower St. Anthony Falls pools, and in Pools 1-4, 7-12, 14, 16, 20, 21, 25-Middle UMR. Absent within its historical range in the Minnesota River and the Illinois River La Grange and Starved Rock pools. No disjunct populations appear.

Truncilla truncata. Sauger, freshwater drum. Historically occurred throughout the UMR drainage. Currently abundant in Upper St. Anthony Fall Pool where it has expanded its historical range, and in UMR Pools 1-2, 4, 8, 10-11, 15, 24, and Illinois River La Grange Pool. Common in the St. Croix River, UMR Pools 3, 5, 7, 9, 12-14, 17-20, 22, 25-26, and in the Illinois River Alton and Peoria pools. Rare in the Minnesota River, Lower St. Anthony Falls Pool, Illinois River Marseilles Pool, and in UMR Pools 5a-6, 16, 21, and the Middle UMR. Absent within its historical range only from the Illinois River Starved Rock Pool.

Venustaconcha ellipsiformis. No migratory fish hosts. Historical records from the St. Croix River and UMR Pools 3-4, and 15, but probably never very well established in the UMR proper. Currently does not exist in the UMR or its major tributaries.

Villosa iris. No migratory fish hosts. Historically only occurred in the upper Illinois River in the Starved Rock and Marseilles pools. Currently does not exist in the UMR proper.

Appendix C
Cost Estimates for Fish Passage Improvements on the Upper Mississippi River and Illinois Waterway

---

This initial set of cost estimates was prepared to enable reconnaissance-level comparison of the relative costs of fish passage improvements at UMRS navigation dams. A set of assumptions was made to provide a system-wide basis for estimating costs of fish passage improvements. More detailed work on fish passage improvements at each site could reveal more ecologically effective and less costly designs. Space available for construction, head at the dam, access needs, foundation conditions, and many other site-specific factors would be considered in identifying more optimal designs for fishways than those used here for the initial cost estimates.

Fish Lockage

The following assumptions were used to estimate the cost of locking fish through UMRS navigation dams:

a. Fish lockage would occur during the primary migration periods for UMRS fish, which are April through June and October through November (152 days total or approximately 40 percent of the year).

b. All commercial and recreational navigation traffic would have precedence. Fish lockage would occur during low traffic periods.

c. A maximum of five fish lockages would be done each day at each lock.

d. Each fish lockage cycle would take 1 hour to complete.

At the start of a fish lockage cycle, both the lower and upper miter gates of the lock would be closed. The water level in the lock would be lowered to the tailwater elevation. The lower end miter gates would be opened completely into the miter gate recesses. The Tainter gates in the lock filling culverts would be cracked opened. To attract fish, water would then flow out of the completely opened lock chamber at a no-head condition. After a period of 1/2 hour, the Tainter gates would be closed to stop the flow out of the lower end of the lock. The lower miter gates would be closed to trap the fish in the lock. The lock water level would be raised to the upper pool elevation. The upper miter gates would be opened completely into the miter gate recesses to allow the fish into the upper pool for approximately 1/2 hour. The lock draining conduits would be opened to set up currents in the lock chamber that would induce fish to leave the lock. (Opening the lock-draining conduits with the upper miter gates open is possible, but may require modifications to the lock operating controls to accomplish routinely.) The upper miter gates would be closed, completing the process.

Estimating cost of fish lockage

Table C1 summarizes the estimated costs of locking fish at UMRS dams. Assumptions include: Two lock operators would be needed to cover additional duties.

Table C1
Estimated Cost of Locking Fish Through UMRS Navigation Dams

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

The effective rate for a lock operator is approximately $125,000 per year based on 1 shift, 7 days a week. Since 40 percent of the lock operator's time would be dedicated to fish lockage, the result is $50,000 per year for each lock operator. One lock operator would be needed to cover additional duties. The effective rate for a lock repairman is approximately $110,000 per year based on 1 shift, 7 days a week.

Since 40 percent of the lock repairman's time would be dedicated to fish lockage, the result is $44,400 per year for each lock repairman.

Lock maintenance and rehabilitation would be needed. The period of time between major rehabilitation cycles (without fish lockage) currently is approximately 25 years and rehabilitation costs have averaged between $10 and $30 million at most lock and dam sites. Assuming that fish lockage would require additional maintenance by adding approximately 10 percent of the above cost in 60 percent of the above time frame, the result is fish lockage maintenance and rehabilitation would cost approximately $1 to $3 million every 15 years, or a estimated annual rate of $200,000 ($3 million divided by 15 years equals $200,000 per year).

Adding the three items above gives a subtotal cost of $344,400 per year at each lock. With a 25 percent contingency due to a large uncertainty in the estimates, the total cost is $430,500 per year at each lock. Fish lockage would proceed at five lockages per day and 152 days per year, or 760 times per year. The resulting average cost would be approximately $566 per lockage at each lock. It is important to note that the cost estimates are based upon fish lockage occurring in addition to boat lockage, not occurring with or during boat lockage.

Fish Lockage - Conclusion

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 when no other fish passage improvement alternative is found to be practicable at a site.

Fishways

Nature-like fishways appear to be the most promising alternative for the UMRS. Nature-like fishways are gradually sloping open channels with rough bottoms or a series of riffles and pools. For developing initial cost estimates for nature-like fishways on the UMRS, we assumed a fishway design with a slope 100:1 that passes 5 percent or less of the river's total flow with a minimum width of 25 m. These standard assumptions were adopted to allow a reconnaissance-level estimate of relative cost for fishways at UMRS dams system-wide. Detailed design work could reveal that longer, lower slope, and larger cross-section fishways would be more ecologically beneficial and cost-effective. The following discussion describes the assumptions and methods for estimating the costs of fishways at UMRS navigation dams.

Channel Cross Section Design

The assumed channel cross section was modeled as an asymmetrical V-notch to yield a varied velocity profile for passage of many species of fish (Figure C1). For purposes of the standard designs for estimating costs, the maximum channel width was assumed to be 30.48 m (100 ft), which is the maximum possible width of most readily available control structures (i.e., bulkheads or Tainter gates). (Fishways could be constructed at some UMRS dams without upstream control structures.) Minimum channel depth would be 0.9 m (3 ft) to allow passage of large sized fish species.

Flow through the channel is modeled with Manning's equation:

$$Q = \frac{1.49}{n} A R^{2/3} S_O^{1/2}$$

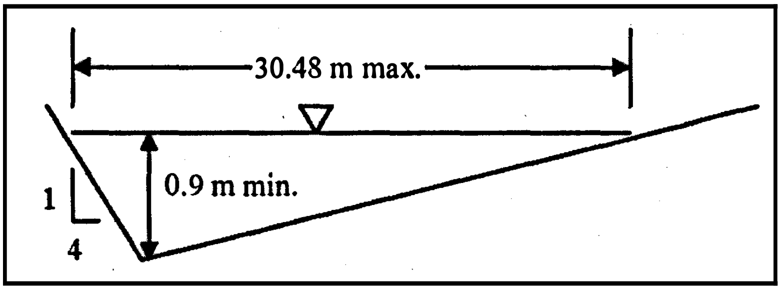


Figure C1. Typical fishway cross-section

where

Q = flow through the cross-section of the channel (m/sec)
n = roughness coefficient (selected as 0.050 for a rock lined channel).
A = channel cross-sectional area.
R = hydraulic radius (cross-sectional area divided by the wetted perimeter).
S_o = bed slope of the channel.

Using Manning's equation with the specified parameters and a bed slope of 1 percent (100:1), we calculate the flow to be approximately 16.6 m/sec (585 ft/sec). Preliminary design requirements called for 5 percent of the annual river discharge. The above calculated flow value is often much less than 5 percent of the annual river discharge at many locks and dams along the UMR/IWW.

The channel would be lined with 0.9 m (3 ft) of riprap and 0.6 m (2 ft) of bedding (Figure C2).

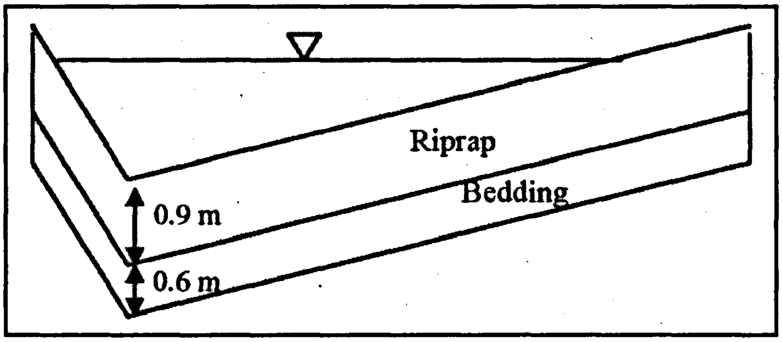


Figure C2. Fishway riprap and bedding cross section

Alternative Fishway Designs - Natural Meander

Nature-like fishways built to simulate natural river channels would have a hydraulic environment more suited to passing fish than technical fishways, flumes, or conventional bypass channels. An important aspect of the geometry of alluvial channels is the meander pattern. Fishways designed with a natural meander pattern would probably have a more natural hydraulic environment, be more effective in passing fish, and would tend to remain more stable, requiring less maintenance and repair.

Design of the meander is based on the following equations (Leopold et al. 1964).

The meander wavelength, L is a function of the channel width, B: $L = 10.9\,B^{1.01}$ (see Figure C3). The radius of curvature, R_c is a function of the meander wavelength, L: $R_c = (L/4.7)^{(1/098)}$ (see Figure C3). Varying the meander belt width controls the meander length (Figure C3).

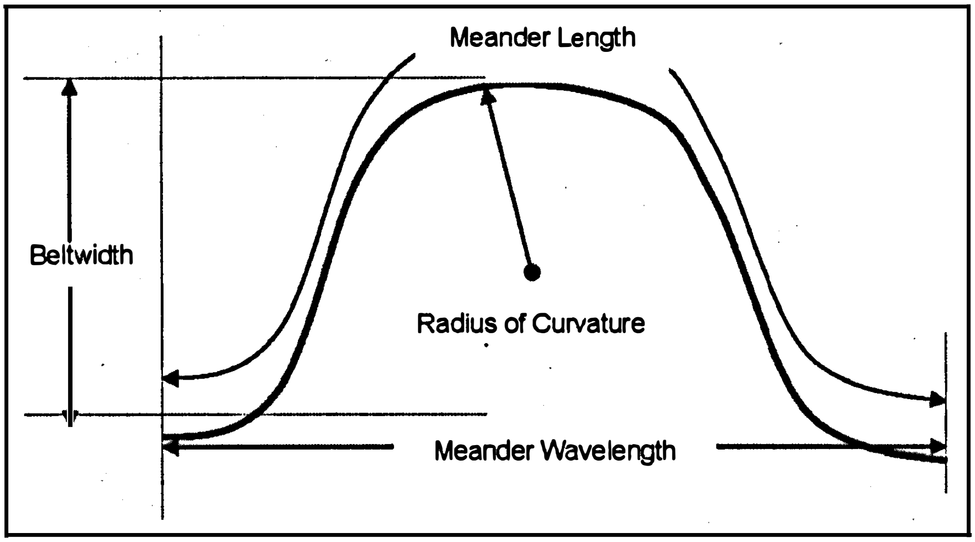
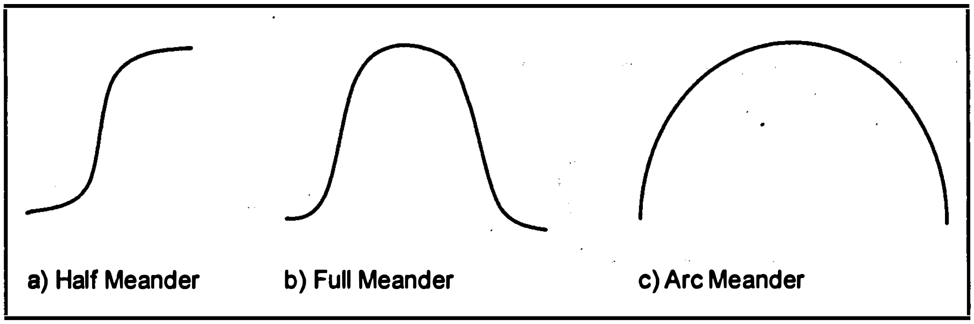


Figure C3. Natural meander layout

Meander fishways would have an overall 1 percent slope along the profile. The required meander length (not the meander wavelength) is calculated from the flat pool to flat pool head difference (i.e., a dam with a head difference of 3 m (10 ft) would have a required meander fishway length of 305 m (1,000 ft). Based on the natural meander layout, three meander alternatives are possible (Figure C4). With a channel width of 30.5 m (100 ft), the half-meander alternative is valid for flat pool head difference greater than or equal to 1.8 m (6 ft). With a channel width of 30.5 m (100 ft), the full-meander alternative is valid for a flat pool head difference greater than or equal to 3.5 m (11.5 ft). With a channel width of 30.5 m (100 ft), the arc meander alternative is valid for flat pool head difference less than or equal to 2.6 m (8.5 ft).



a) Half Meander b) Full Meander c) Arc Meander

Figure C4. Fishway meander alternatives

Riffle/pool features would be constructed of riprap along the fishway (Figure C5). They would be spaced at a distance of 5 times the channel width, approximately 0.61 m (2 ft) thick at their crest, with a 4:1 upstream slope and a 20:1 slope downstream. The riffle features would have a U-shaped symmetrical plan shape to direct the flow toward the center of the fishway channel.

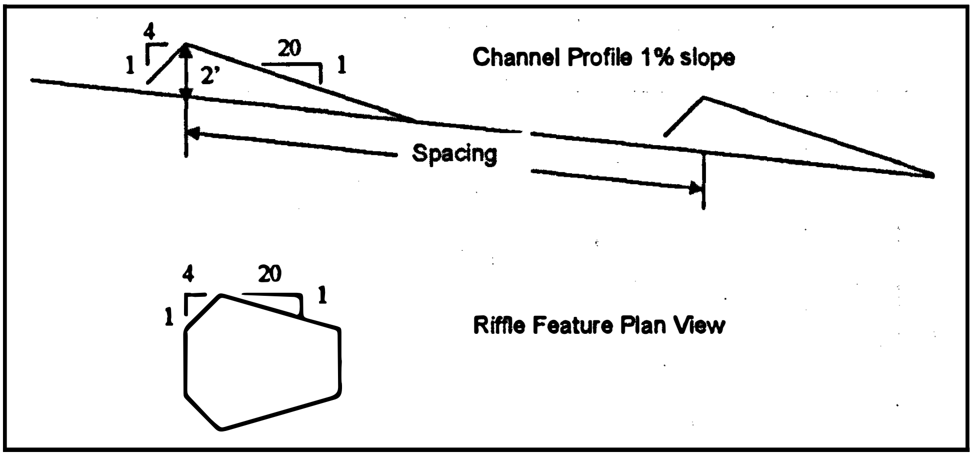


Figure C5. Fishway riffle and pool features

Alternative Designs - Island Fishways

This alternative fishway design would be used when one is built through an earthen embankment or fixed crest spillway of the dam. The fishway entrance would be located as close to the gated section of the dam as possible. The island would be constructed of hydraulically dredged sand. The island would have 4:1 slopes on the banks (Figure C6). The banks would be lined with 0.6-ft- (2-ft-) thick bedding and 0.9-m- (3-ft-) thick riprap to prevent erosion. After the island is built, the fishway channel would be excavated into the island. The entire surface would be covered with fine-grained sediment, and a seeding mat seeded to prevent erosion. Type PZ-27 sheet pile would be used to line the fishway channel on both sides and the ends at a depth of 3.5 times the island thickness (the island would extend to the river bed).

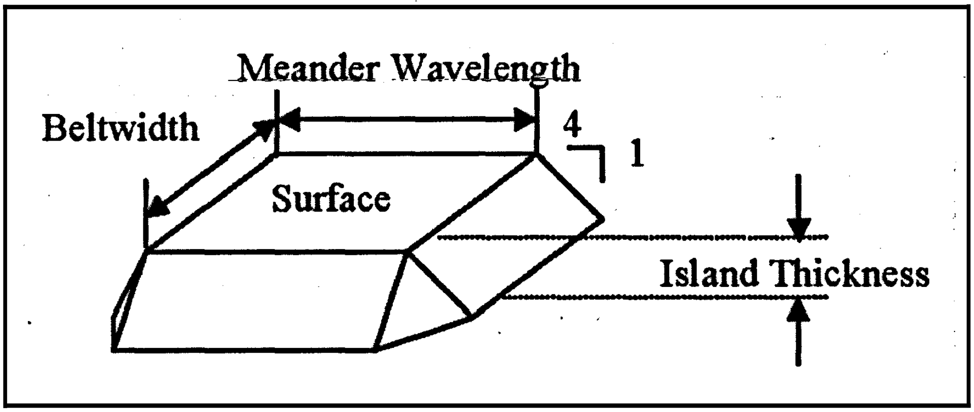


Figure C6. Fishway island isometric view

Alternative Designs – Fishways Through Land

At some sites, a fishway could be excavated through existing land. It was assumed that type PZ-27 sheet pile would be used to line the fishway channel on both sides and the ends to a depth of 3.5 times the channel depth. The island and through land fishway alternatives were assumed to have gated control structures or bulkhead closure at the fishway entrances. Upstream water control structures may not be needed at all sites, but were included in the initial cost estimates. We assumed that a Tainter gate and piers would be needed for the upstream water control structures. If a fishway is built through an emergency spillway, any existing service crane rail system would need to be extended across the fishway. Service bridges over fishways may be needed at some sites. Inclusion of upstream water control structures and service bridges over the fishways approximately doubled the initial cost estimates.

Alternative Designs - Rock Ramps In Auxiliary Lock Chambers

Auxiliary locks could be transformed into rock ramps for fish passage (Figure C7). Flow from the fishway would need to be directed in a way to avoid interference with navigation. The miter gates would be removed and replaced with an upstream hydraulic control. For estimating cost, it was assumed that a spillway dam, Tainter gate, and control structure (i.e., Tainter gate, bulkhead, etc.) would be included. The rock ramp would have a 20:1 profile slope. Rock ramp length is calculated from the flat pool to flat pool head difference (i.e., a dam with a head difference of 3 m (10 ft) would have a rock ramp length of 61 m (200 ft)). The cross-section of the rock ramp would be similar to the natural meander fishway alternative (Figure C1). Type PZ-27 sheet pile would possibly be used to line the rock ramp on both sides and the in the spillway at a depth of 3.5 times the channel depth.

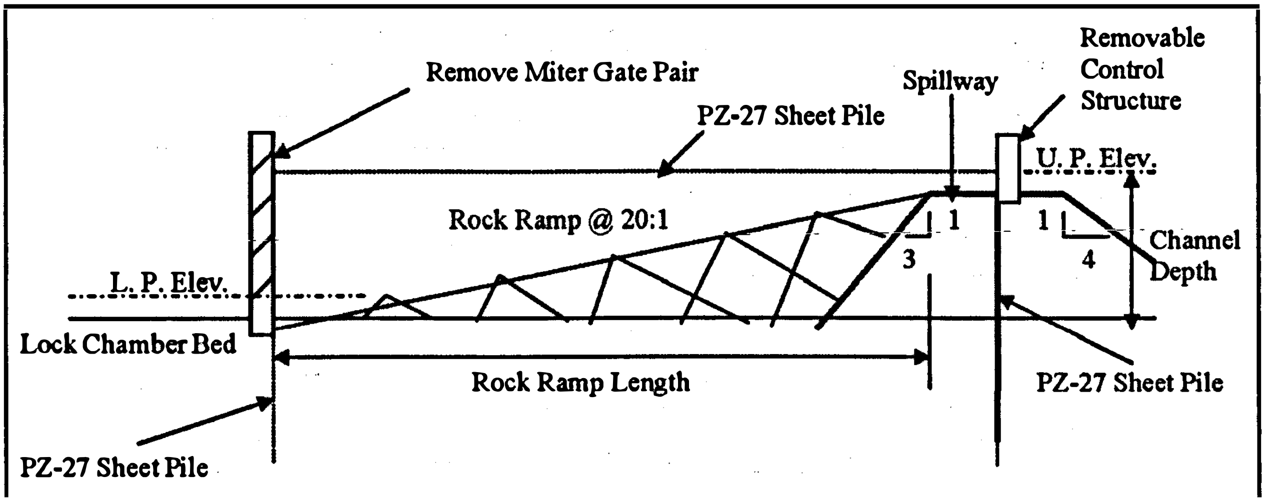


Figure C7. Typical rock ramp profile in auxiliary lock

Custom Alternatives

A few sites exist that could have fishways that would not follow the general designs described above. These sites are noted and documented separately (Tables C2, C3, and C4).

Fishway Costs

Tables C2, C3, and C4 provide the estimated costs for fishways at UMRS locks and dams, using the design alternative that is most appropriate to each site.

We calculated quantities based on the alternative design chosen, the flat pool head difference, and the average river depths in the immediate area of each lock and dam determined from recent bathymetric surveys. All items were either modeled as ideal geometric shapes or quantified individually to allow for ease and generalization in calculations.

Table C2
Estimated Cost of Island-type Fishways at UMRS Locks and Dams

		Island Fishway		
Lock and Dam	**Head (m)**	**Alternative #1**	**Alternative #2**	**Alternative #3**
2	3.7	X	X	X
3	2.4	X	X	X
4	2.1	X	X	X
5	2.7	X	X	X
5A	1.8	X	X	X
6	1.8	X	X	X
7	2.4	X	X	X
8	3.4	X	X	X
9	2.7	X	X	X
10	2.4	X	X	X
11	3.4	$61,208,359	X	X
12	2.7	$60,250,358	X	X
13	3.4	$61,208,359	X	X
14	3.4	$43,690,800	X	X
15	4.9	X	X	X
16	2.7	$46,148,842	X	X
17	2.4	$45,162,167	X	$38,306,224
18	3.0	$59,133,682	X	X
19	11.6	X	X	X
20	3.0	$42,887,301	X	X
21	3.2	$51,372,307	X	X
22	3.0	$53,113,965	X	X
24	3.7	$43,515,556	$38,369,421	X
25	3.8	$44,665,611	$39,866,531	X
26	5.5	$57,106,988	$52,195,100	X
Starved Rock	5.5	$57,705,083	$52,723,254	X
Marseilles	7.4	X	X	X
Dresden Island	6.7	$81,975,380	$74,150,727	X
Kaskaskia	3.7	X	X	X

Table C3
Estimated Cost of Fishways Constructed Through Land at UMRS Locks and Dams

		Through Land Fishway		
Lock and Dam	**Head (m)**	**Alternative #1**	**Alternative #2**	**Alternative #3**
2	3.7	$26,287,315	$26,326,849	X
3	2.4	X	X	X
4	2.1	$15,369,433	X	$15,373,914
5	2.7	$15,802,262	X	X
5A	1.8	X	X	X
6	1.8	$14,881,540	X	$14,883,491
7	2.4	$15,900,999	X	$15,907,073
8	3.4	$17,793,551	X	X
9	2.7	$16,502,262	X	X
10	2.4	$15,200,999	X	$15,907,073
11	3.4	X	X	X
12	2.7	X	X	X
13	3.4	X	X	X
14	3.4	X	$15,392,943	X
15	4.9	$21,776,009	$20,523,531	X
16	2.7	X	X	X
17	2.4	X	X	X
18	3.0	X	X	X
19	11.6	X	X	X
20	3.0	X	X	X
21	3.2	X	X	X
22	3.0	X	X	X
24	3.7	X	X	X
25	3.8	X	X	X
26	5.5	X	X	X
Starved Rock	5.5	X	X	X
Marseilles	7.4	$29,510,476	X	X
Dresden Island	6.7	X	X	X
Kaskaskia	3.7	X	X	X

Unit costs for materials were calculated using the June 2003 price level. Unit prices were assumed to be the same throughout the UMRS. The cost estimates include overhead and profit for construction, but do not include planning, design, and construction management, or any necessary real estate acquisition. Due to the uncertainty in the quantities and unit prices estimated, an overall contingency for the cost estimate is about 25 percent. Water control and access structures included for each alternative (i.e., bulk heads and Tainter gates) accounted for a large proportion of the cost of each alternative (over 50 percent in some cases). Detailed information about the initial fishway cost estimates is available from the Rock Island District upon request.

Table C4
Estimated Costs of Fishways In Auxiliary Lock Chambers and for 'Custom' Alternative Fishways at UMRS Locks and Dams

Lock and Dam	Head Difference (ft)*	Auxiliary Lock Chamber	Custom Alternatives**
2	3.7	16,234,785	X
3	2.4		10,880,000
4	2.1	14,962,269	X
5	2.7	15,312,372	X
5A	1.8	13,219,550	14,831,140
6	1.8	14,913,764	X
7	2.4	15,261,712	16,511,712
8	3.4	16,875,856	X
9	2.7	18,299,093	X
10	2.4	14,543,928	15,793,928
11	3.4	15,546,775	X
12	2.7	16,290,146	20,903,937
13	3.4	17,038,126	34,079,855
14	3.4	15,031,966	X
15	4.9	X	23,576,753
16	2.7	14,477,629	X
17	2.4	14,656,261	X
18	3.0	19,538,799	X
19	11.6	X	47,520,886
20	3.0	15,233,949	X
21	3.2	16,227,399	X
22	3.0	15,495,036	X
24	3.7	17,436,098	X
25	3.8	16,968,015	X
26	5.5	24,986,281	X
Starved Rock	5.5	X	X
Marseilles	7.4	X	X
Dresden Island	6.7	X	X
Kaskaskia	3.7	X	42,672,622

* The difference recorded is the flat pool to flat pool head difference, except for the following sites:

Lock and Dam 18: The flat pool to flat pool head difference was rounded from 9.8 ft to 10.0 ft.

Lock and Dam 24: The head difference is the difference between the low tailwater and high headwater elevations.

Lock and Dam 25: The head difference is the difference between the low tailwater and high headwater elevations.

Lock and Dam 26: The head difference is the difference between the low tailwater and high headwater elevations.

Kaskaskia Lock and Dam: The head difference is the difference between the low tailwater and high headwater elevations.

**The following describes the 'custom' alternatives:

Initial design and cost estimation for the Lock and Dam 3 custom alternative were done as part of a separate embankments study. The fishway would be a riffle and pool fishway. Sheet pile would not be continuous along both sides of the fishway. There would not be an upstream water control structure. The entire channel would not be lined with riprap, only at the riffles.

Lock and Dams 5A, 7, 10, 12, and 13 custom alternatives are rock ramps similar to the Auxiliary Lock Chamber Rock Ramp Alternative (see Figure C7), except they notch through the emergency spillway of the dam (or similar structure) instead of the auxiliary lock chamber.

Lock and Dam 15 custom alternative is a rock ramp that would be retrofitted onto the Moline Power Dam located on the East end of the Sylvan Slough. The adjacent downstream channel would be completely lined with rock to cause a "rapids like" environment for fish passage. It is important to note that the estimated cost does not incorporate any real estate acquisition associated with the Moline Power Dam.

Lock and Dam 19 custom alternative is a rock ramp that would be replace the abandoned lock adjacent to the currently utilized lock.

Kaskaskia Lock and Dam alternative is a rock ramp that would connect the existing side channel with the upper pool. The channel would be completely lined with rock to cause a "rapids like" environment for fish passage.

Appendix D
Alternative Fish Passage Improvements at Upper Mississippi River System Locks and Dams

This appendix includes a brief description of the potential fishway sites at UMRS locks and dams and figures illustrating them. The descriptions are based on a workshop held in Rock Island District Corps of Engineers office in May 2003, when Fish Passage Team members reviewed the layout of each UMRS lock and dam and identified alternative fish passage improvements. Representatives from the three UMRS Corps Districts including lock and dam specialists, fisheries biologists, and hydraulic engineers participated. The marked-up hard copy aerial photos of each site were converted into diagrams for each site used in this appendix.

All estimated costs for fishway construction given here do not include costs for water control structures at the upstream end of the fishways or for access facilities like bridges. These fishway features may be needed at many sites. The estimates also do not include costs for operation and maintenance of the fishways. Appendix C describes how costs of fish passage improvements were estimated.

Given the reconnaissance level of planning and design detail in this report, these potential fishway sites should be considered preliminary. Further information about each site should be used to select the most ecologically beneficial and cost-effective alternative for fish passage improvements when more detailed planning and design is conducted. Fishway design should be adapted to the existing site conditions. “Right” and “left” below refer to the right and left river banks, looking downstream.

Lock and Dam 1

Lock and Dam 1 is located in the gorge of the Mississippi River in St. Paul (Figure D1). The dam is an Amberson-type fixed crest spillway with an inflatable dam on the crest. The Ford Motor Company owns and operates a hydropower facility, with a powerhouse on the left end of the dam. The lock is located on the right bank. Lock and Dam 1 is the highest dam on the UMRS. Normal head at the dam is 11.6 m. The Corps Fish Passage Team members decided that a fishway at this site would be impracticable, given the high head, constrained site conditions, and the limited amount (340 ha) of upriver habitat (despite the rock substrate) to which a fishway would provide access. St. Anthony Falls, located 8.2 km upstream of Lock and Dam 2, is a natural barrier to upriver fish movements.

Figure D1. Lock and Dam 1, Upper Mississippi River

Lock and Dam 2

Lock and Dam 2 at Hastings, Minnesota, is also a difficult site for a fishway. Lock and Dam 2 has relatively high head of 3.7 m. The right bank of the dam connects to railroad grade and a cliff. On the left end of the dam are the lock and a hydropower plant owned and operated by the City of Hastings. One potential fishway location would be through Lake Rebecca Park on the right bank (Figure D2). Estimated cost of a fishway there, constructed through land with an entrance downstream of the lock would be approximately $14,749,000. Flow from a fishway entrance downstream of the lock may not be very effective at attracting fish into a fishway at this location. A fishway in the auxiliary lock chamber is estimated to cost approximately $3,833,000. Because the auxiliary lock chamber is separated from the main lock by a strip of land, flow out of a fishway at this location may not interfere with navigation traffic.

Figure D2. Potential fish passage improvements at Lock and Dam 2, Upper Mississippi River

Lock and Dam 3

Lock and Dam 3 is located about 10 km upstream of Red Wing, Minnesota, and has a relatively low head of 2.4 m. A fishway is being considered as an ecosystem restoration feature of a project to strengthen the Wisconsin embankments and to improve navigation safety. One potential location would be through the left (Wisconsin) embankment (Figure D3). A fishway there is estimated to cost $10,880,000. Additional dredging would be required to provide a travel pathway upstream through the peninsula that separates the shallow bay where the fishway would exit from the main channel. Because a fishway channel would exit onto a point bar, sediment accumulation could be a problem there. Another potential location for a fishway would be in the auxiliary lock chamber, which is estimated to cost $1,348,000. A fishway in the auxiliary lock chamber would probably not be very effective because the lock is located in an excavated channel, separated from the main channel by an island. The embankments at Lock and Dam 3 are mostly natural high ground and are not constructed embankments such as other dams on the Upper Mississippi River possess. Because both the Wisconsin and Minnesota embankments have overflow weirs (spot dikes) that routinely overflow, fish passage over these embankments is relatively unrestricted.

Figure D3. Potential fish passage improvements at Lock and Dam 3, Upper Mississippi River

Lock and Dam 4

Lock and Dam 4 at Alma, Wisconsin, also has a relatively low head of 2.4 m. A bypass channel fishway could be constructed through land on the right (Minnesota) bank (Figure D4). This fishway is estimated to cost approximately $3,831,000. A fishway in the auxiliary lock chamber is estimated to cost $2,560,000.

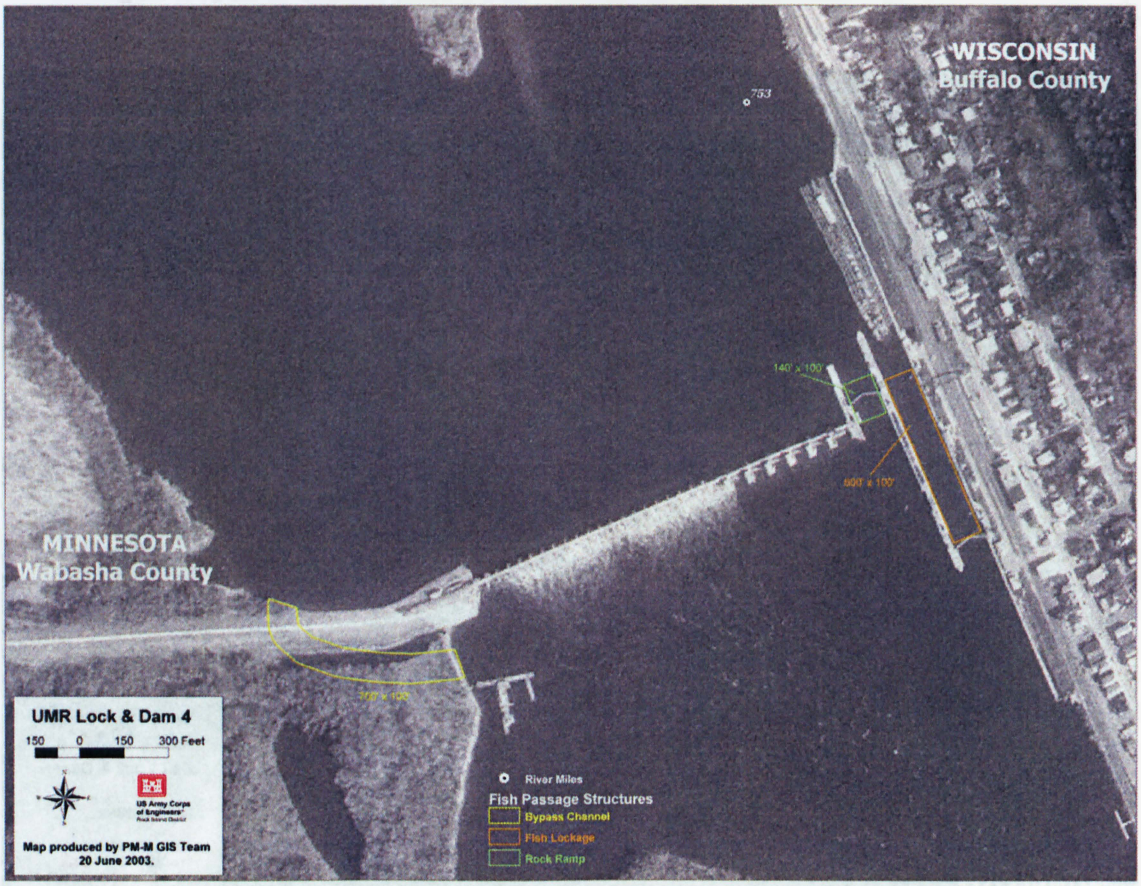


Figure D4. Potential fish passage improvements at Lock and Dam 4, Upper Mississippi River

Lock and Dam 5

Lock and Dam 5 at Whitman, Minnesota, has a head of 2.7 m. A bypass channel fishway could be constructed through the right (Wisconsin) embankment at an estimated cost of $4,264,000 (Figure D5). A fishway through the auxiliary lock chamber is estimated to cost $2,910,000 to construct. Potential exists for smaller fishways through the Wisconsin embankment at the upper end of Fountain City Bay where culverts provide flow to the Indian Creek system and at the "Hole in the Wall" culverts (not shown in Figure D5).

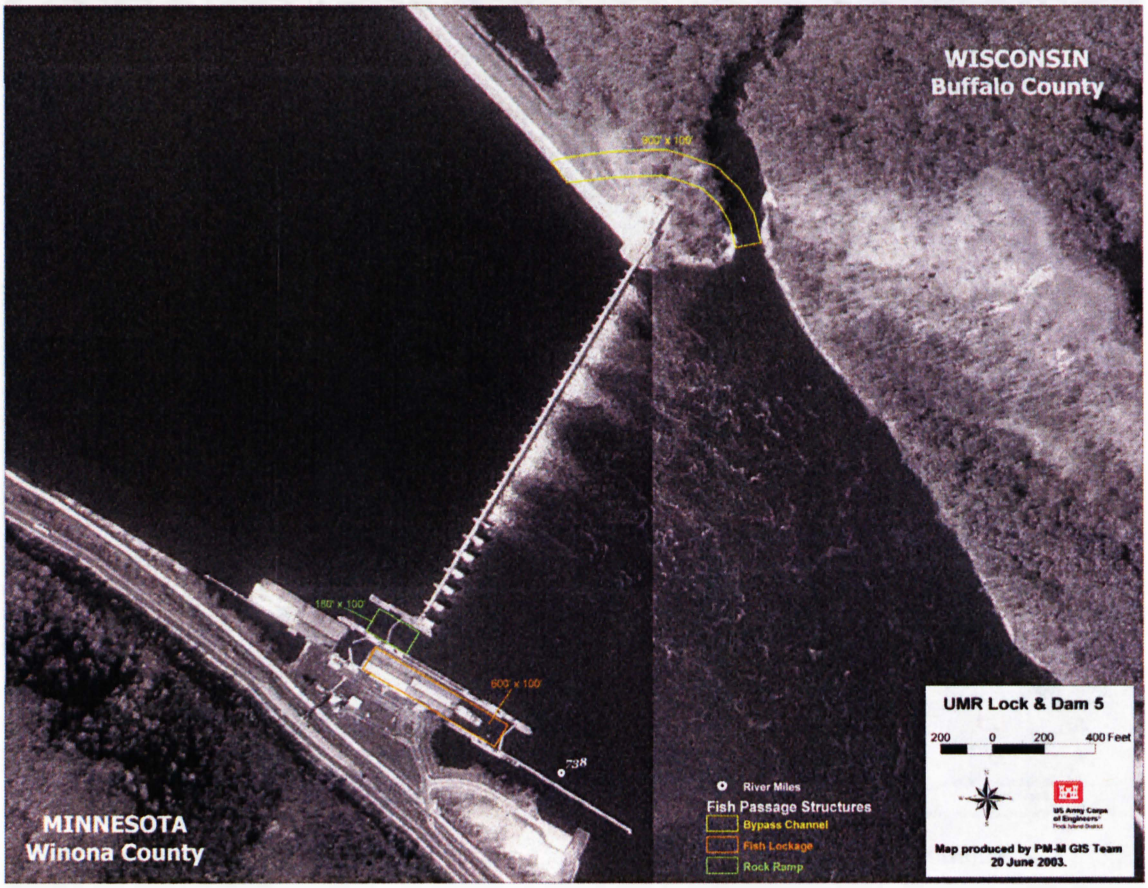


Figure D5. Potential fish passage improvements at Lock and Dam 5, Upper Mississippi River

Lock and Dam 5A

Lock and Dam 5A near Fountain City, Wisconsin, has a low head of 2.0 m. The Wisconsin side is constrained by the lock's operations area and a highway. A rock ramp type fishway could be constructed through the right (Minnesota) embankment into Polander Lake (Figure D6) for an estimated cost of $2,429,000. A fishway could be constructed through the auxiliary lock chamber at an estimated cost of $818,000, not including an upstream control structure. A smaller fishway could be constructed through the overflow spillway (not shown in Figure D6) into Polander Lake on the Minnesota side of the dam.

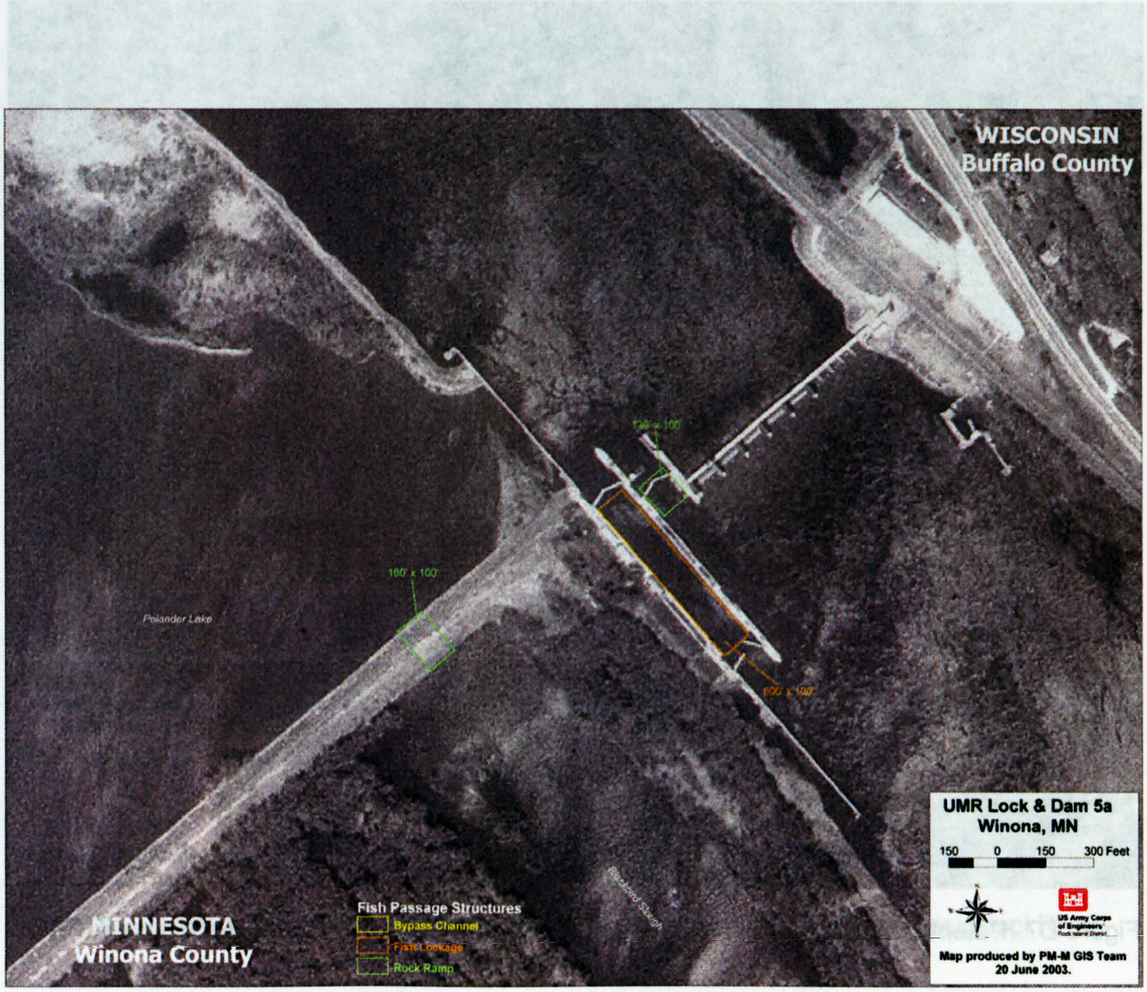


Figure D6. Potential fish passage improvements at Lock and Dam 5A, Upper Mississippi River

Lock and Dam 6

Lock and Dam 6 at Trempealeau, Wisconsin, also has a low head of 2 m. A bypass channel fishway could be constructed on the right bank through the Wisconsin embankment for an estimated cost of $3,343,000 (Figure D7). A fishway through the auxiliary lock chamber could be constructed for an estimated cost of $2,512,000. A smaller fishway could be constructed through the overflow spillway on the Minnesota end of the dam.

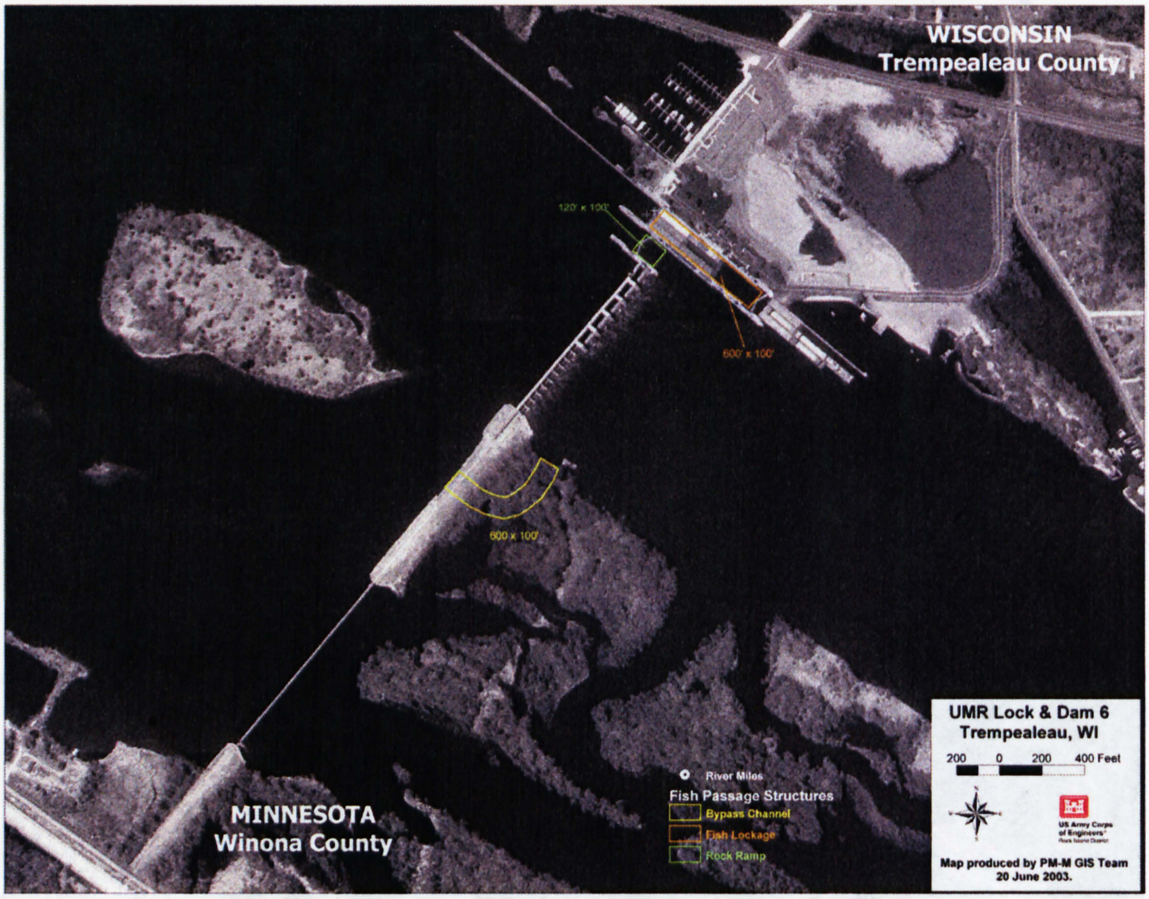


Figure D7. Potential fish passage improvements at Lock and Dam 6, Upper Mississippi River

Lock and Dam 7

Lock and Dam 7 at La Crosse, Wisconsin, has a low head of 2.0 m. A bypass channel fishway could be constructed through the left (Wisconsin) embankment (Figure D8) for an estimated cost of $4,362,000. A fishway could be constructed in the auxiliary lock for an estimated cost of $2,860,000. Smaller fishways could be constructed in the Round Lake and Black River (Onalaska) spillways for an estimated cost of $4,110,000 each.

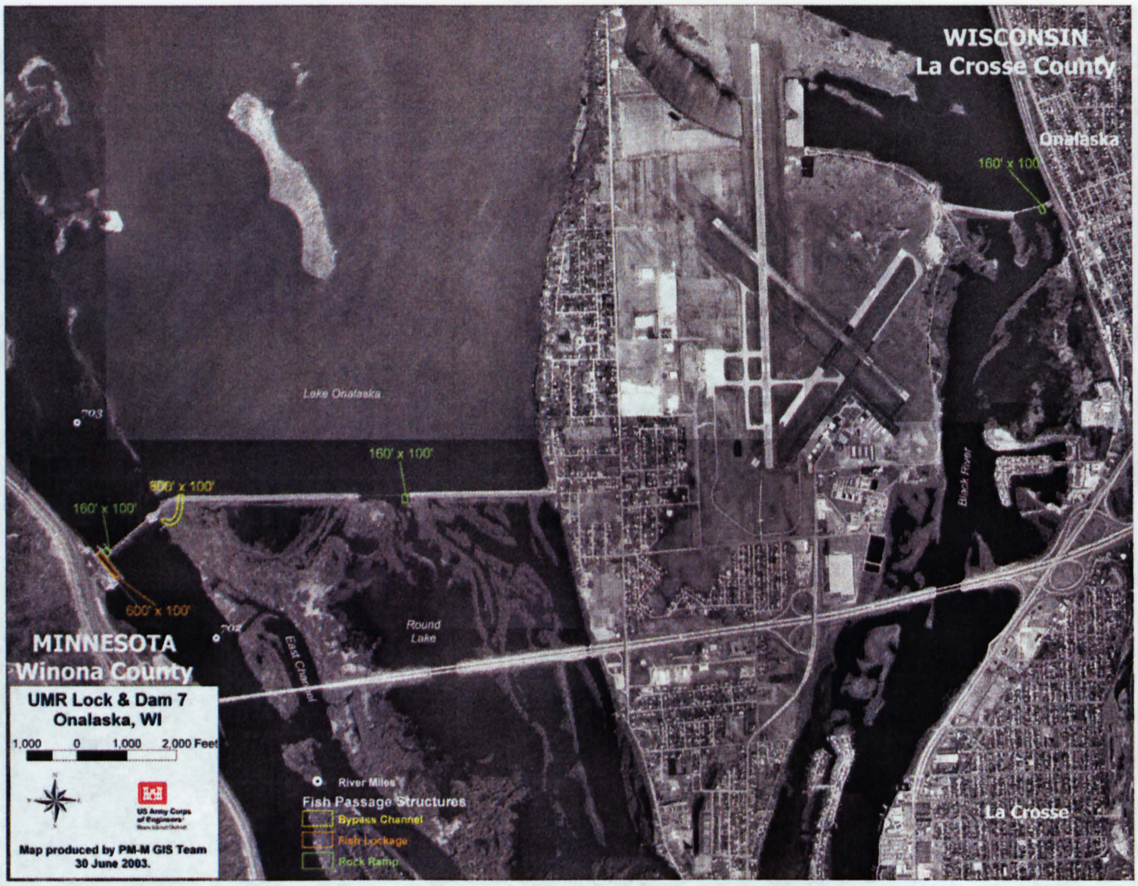


Figure D8. Potential fish passage improvements at Lock and Dam 7, Upper Mississippi River

Lock and Dam 8

Lock and Dam 8 at Genoa, Wisconsin, has a head of 2.4 m. A bypass channel fishway could be constructed through the right (Minnesota) embankment for an estimated cost of $6,255,000 (Figure D9). A fishway could be constructed through the auxiliary lock chamber at an estimated cost of $4,474,000. Smaller fishways could be constructed through the embankment on the Minnesota side, connecting Pickerel and Running Sloughs in Reno Bottoms with Pool 8 (not shown in Figure D9).

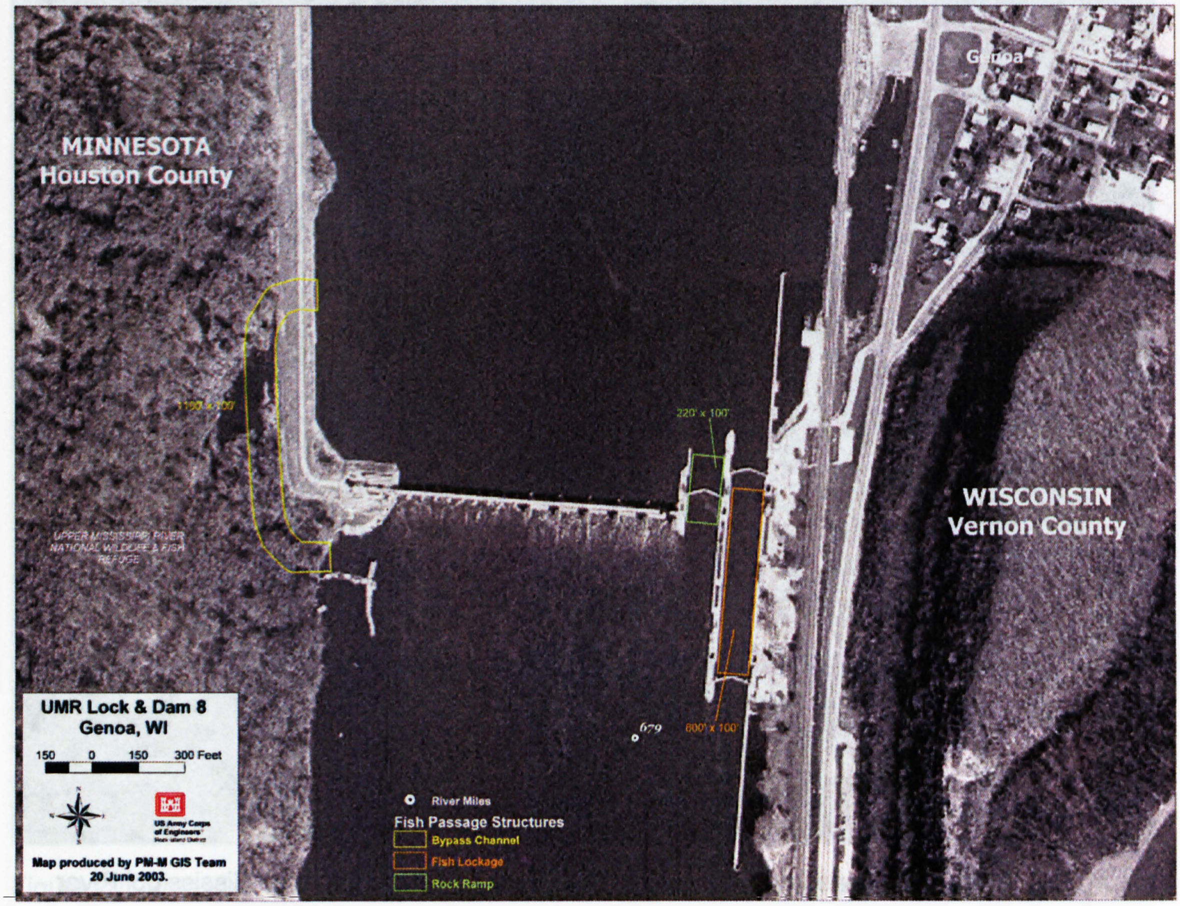


Figure D9. Potential fish passage improvements at Lock and Dam 8, Upper Mississippi River

Lock and Dam 9

Lock and Dam 9 near Harpers Ferry, Iowa, has a head of 3.4 m. A bypass channel fishway could be constructed through the right (Iowa) embankment for an estimated cost of $4,964,000 (Figure D10). A fishway through the auxiliary lock chamber is estimated to cost $5,897,000. A smaller fishway could be constructed through the overflow spillway to connect Harper Slough with Pool 9 (not shown in Figure D10).

Figure D10. Potential fish passage improvements at Lock and Dam 9, Upper Mississippi River

Lock and Dam 10

Lock and Dam 10 at Guttenberg, Iowa, has a head of 2.7 m (Figure D11). A bypass channel fishway could be constructed through the right (Wisconsin) embankment for an estimated cost of $3,662,000. A fishway could be built in the auxiliary lock for an estimated cost of $2,142,000. A rock ramp fishway could be constructed in the overflow spillway on Cassville Slough for an estimated cost of $3,392,000. A smaller, less costly fishway could be constructed at this location.

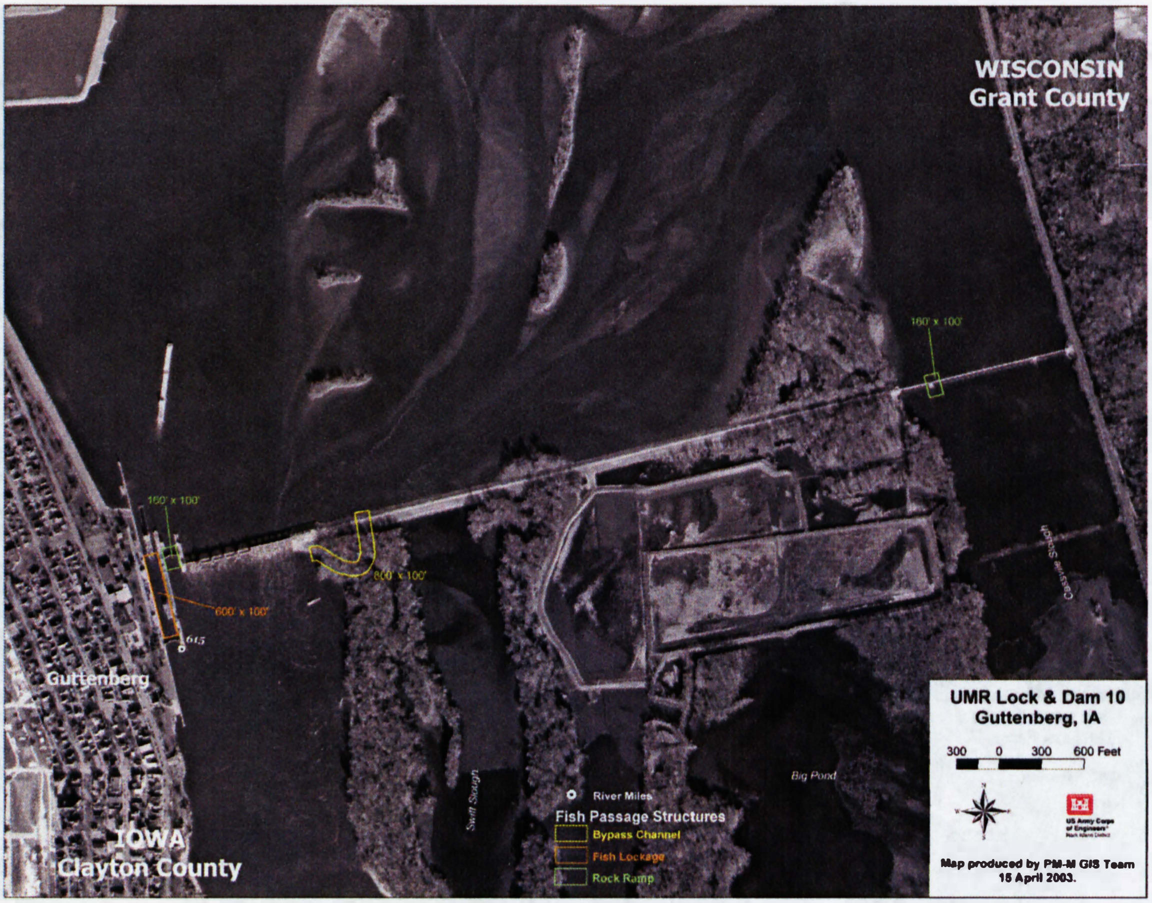


Figure D11. Potential fish passage improvements at Lock and Dam 10, Upper Mississippi River

Lock and Dam 11

Lock and Dam 11 at Dubuque, Iowa, has a head of 2.4 m (Figure D12). A bypass channel fishway could be constructed through the right (Wisconsin) embankment by adding fill to the downstream side of the embankment or by constructing an island on the upstream side of the embankment and building a fishway through it. The estimated cost of construction of an island-type fishway would be $36,569,000. A fishway could be constructed in the auxiliary lock chamber at an estimated cost of $3,145,000, not including an upstream control structure.

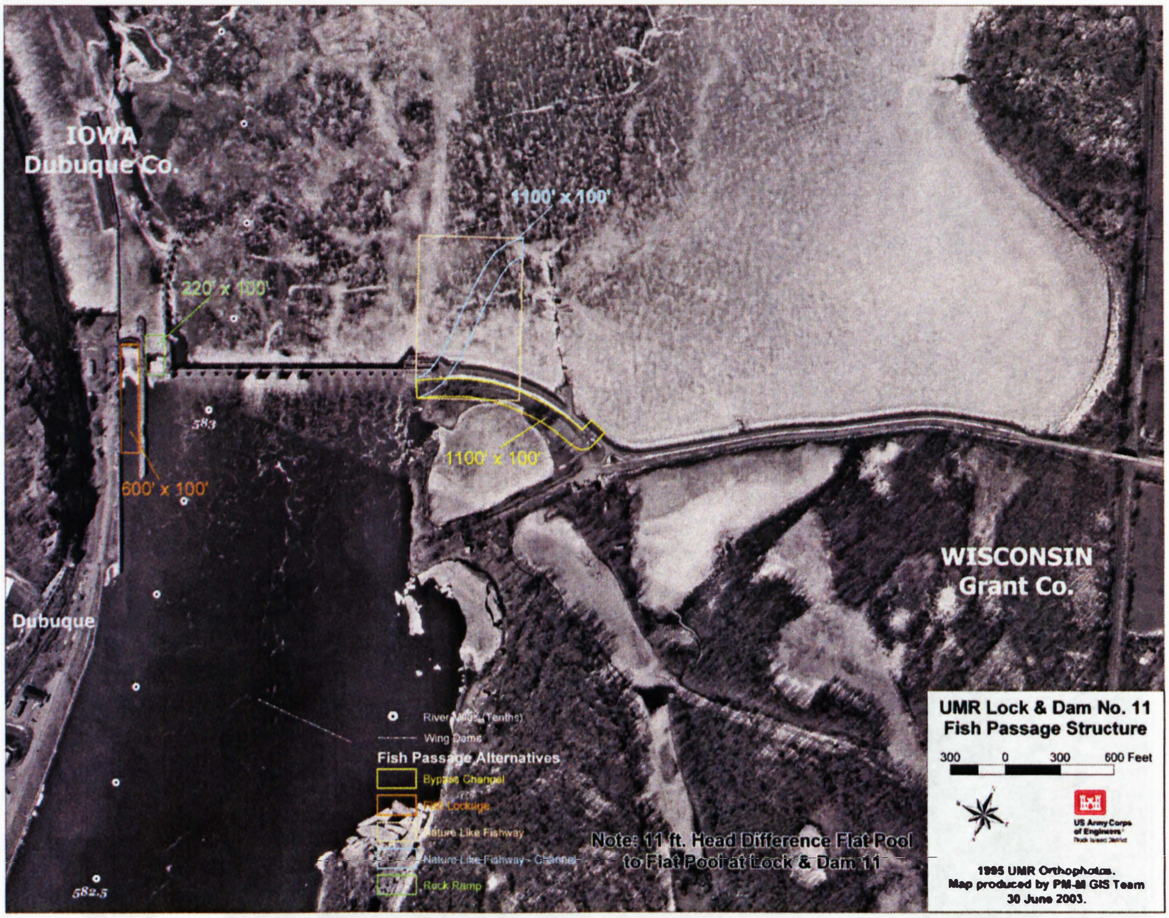


Figure D12. Potential fish passage improvements at Lock and Dam 11

Lock and Dam 12

Lock and Dam 12 at Bellevue, Iowa, has a head of 3.4 m (Figure D13). Potential fishways at this site include an island-type fishway, a bypass channel, a fishway in the auxiliary lock chamber, and a rock ramp through the left (Illinois) embankment. The island-type fishway is estimated to cost $35,611,000. A rock ramp fishway through the Illinois embankment is estimated to cost $8,502,000. A smaller less costly fishway could be constructed through the Illinois embankment to connect Crooked Slough with Pool 12. A fishway could be constructed in the auxiliary lock chamber at an estimated cost of $3,888,000, not including an upstream control structure.

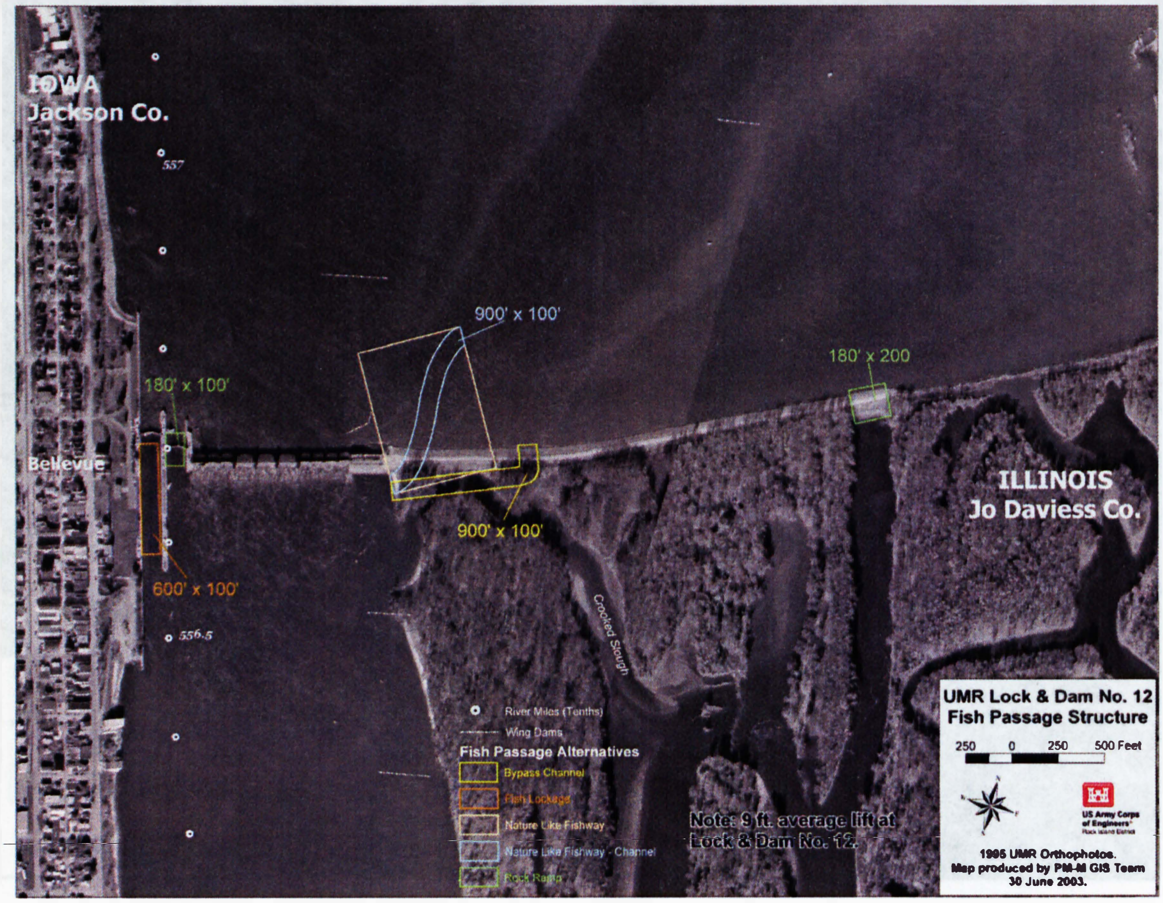


Figure D13. Potential fish passage improvements at Lock and Dam 12, Upper Mississippi River

Lock and Dam 13

Lock and Dam 13 at Clinton, Iowa, has a head of 2.7 m (Figure D14). Potential fish passage improvements at this site include an island-type fishway on the upstream side of the right (Iowa) embankment, a bypass channel on the downstream side of the right embankment, a fishway in the auxiliary lock, and a rock ramp at the overflow spillway into Lyons Chute. The island-type fishway is estimated to cost $36,569,000, the Lyons Chute rock ramp is estimated to cost $21,678,000, and a fishway in the auxiliary lock chamber is estimated to cost $4,636,000, all not including upstream control structures.

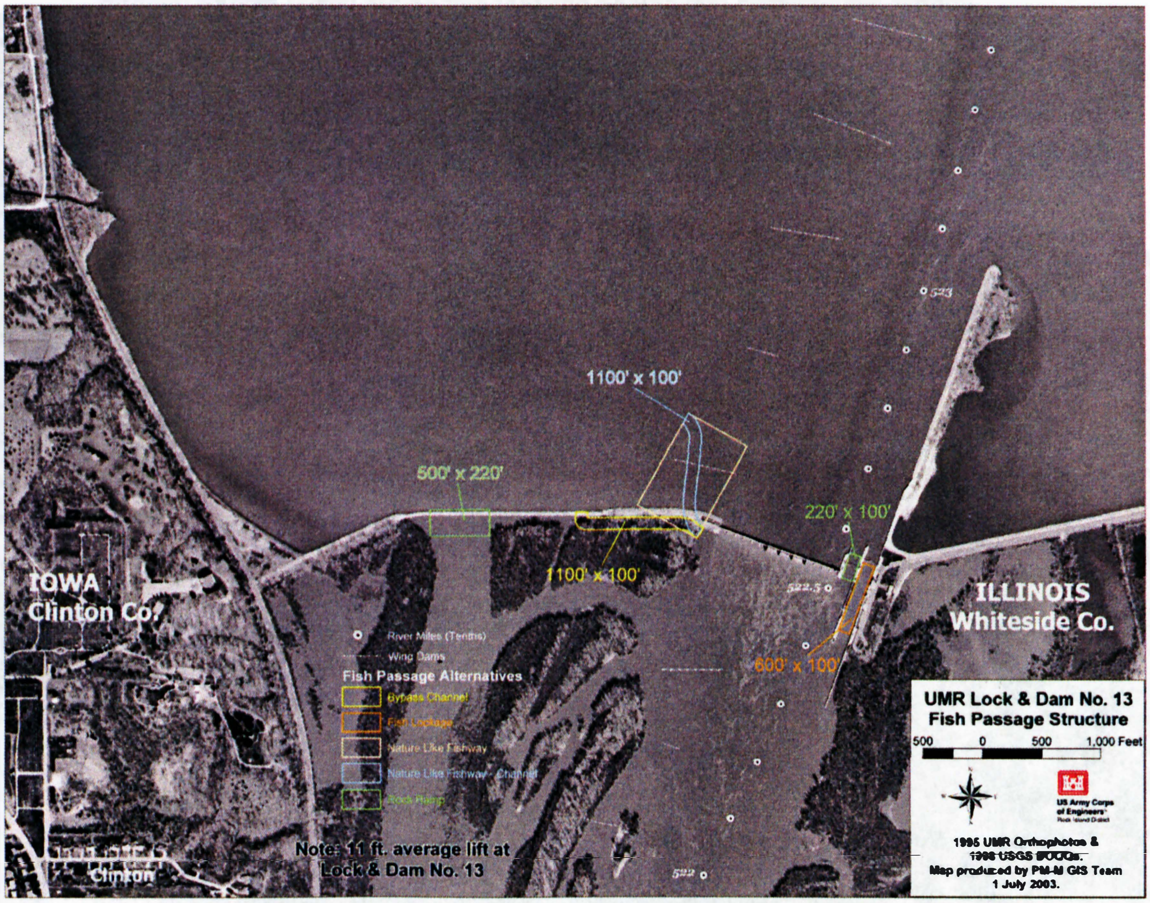


Figure D14. Potential fish passage improvements at Lock and Dam 13, Upper Mississippi River

Lock and Dam 14

Lock and Dam 14 at Hampton, Illinois, has a head of 3.3 m (Figure D15). Alternatives for fish passage improvements include an island-type fishway on the upstream side of the right (Illinois) embankment, a bypass channel on the downstream side of the right embankment, a fishway constructed through the existing peninsula on the left (Iowa) side, and a fishway in the auxiliary lock chamber. Estimated costs for constructing fishways are $19,052,000 for an island-type fishway, $3,854,000 for the peninsula fishway, and $2,630,000 for a fishway in the auxiliary lock chamber, all not including upstream control structures or access facilities.

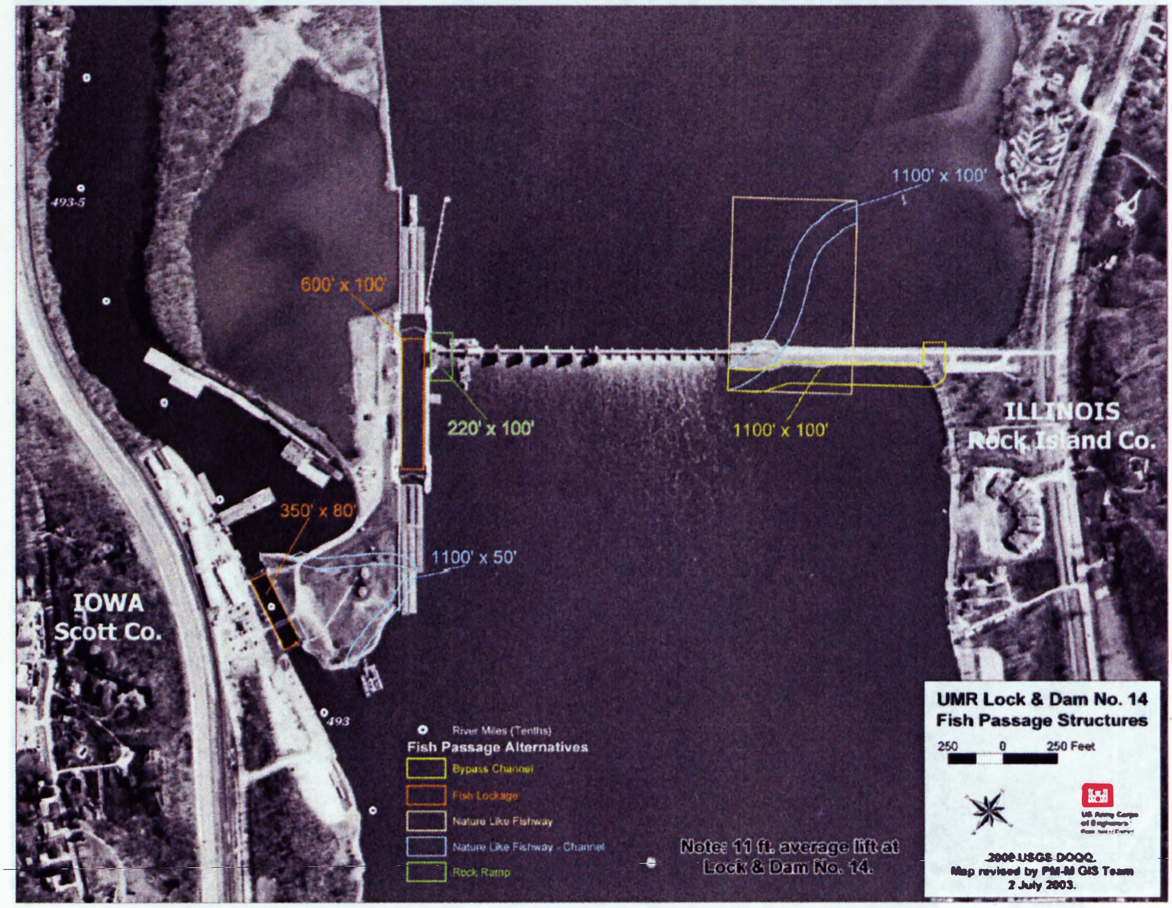


Figure D15. Potential fish passage improvements at Lock and Dam 14, Upper Mississippi River

Lock and Dam 15

Lock and Dam 15 at Davenport, Iowa, and Rock Island, Illinois, is on the main channel on the north side of Arsenal Island (Figure D16). Sylvan Slough flows on the south side of Arsenal Island. The U.S. Army operates a hydropower plant on Sylvan Slough, and there is an abandoned hydropower raceway channel through rock adjacent to the John Deere plant site. Urban development on the Davenport side of the river and the lock and military installation on the Arsenal Island side of the main channel constrain potential sites for a fishway. Lock and Dam 15 has an operating auxiliary lock chamber. Potential fishways include routes through Sylvan Island and in the abandoned John Deere hydropower channel. The estimated cost of construction of the half and full meander fishways through Sylvan Island are $8,988,000 and $8,985,000 respectively, without upstream control structures. A rock ramp-type fishway in the abandoned John Deere hydropower channel is estimated to cost $12,038,000.

The Sylvan Island and John Deere hydropower channel sites could be developed to serve as fishways as well as to provide whitewater recreation.

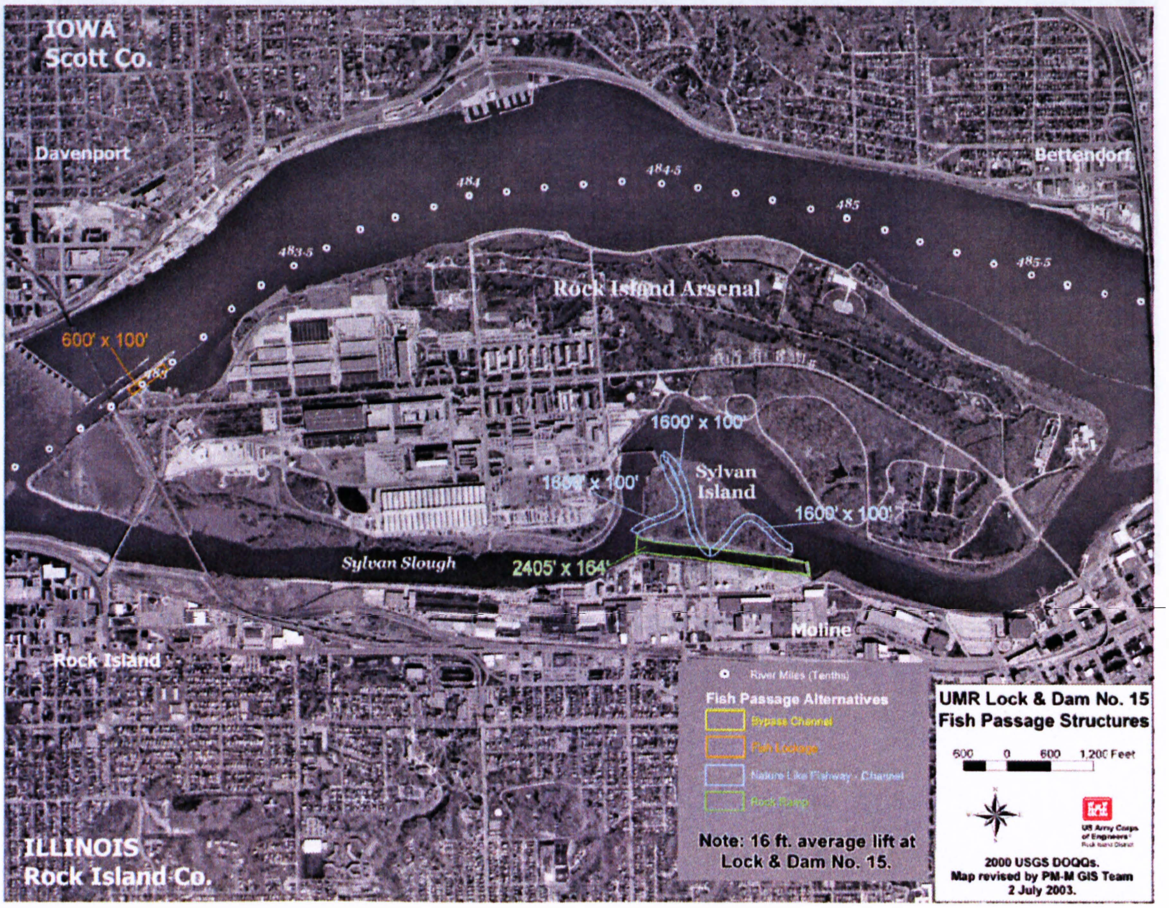


Figure D16. Potential fish passage improvements at Lock and Dam 15, Upper Mississippi River

Lock and Dam 16

Lock and Dam 16 at Muscatine, Iowa, has a head of 2.7 m (Figure D17). Potential locations for fishways include an island-type structure upstream of the right (Iowa) embankment, and in the auxiliary lock. The estimated cost of an island-type fishway is $21,510,000 and a fishway in the auxiliary lock chamber would be $2,076,000, both not including upstream control or access structures.

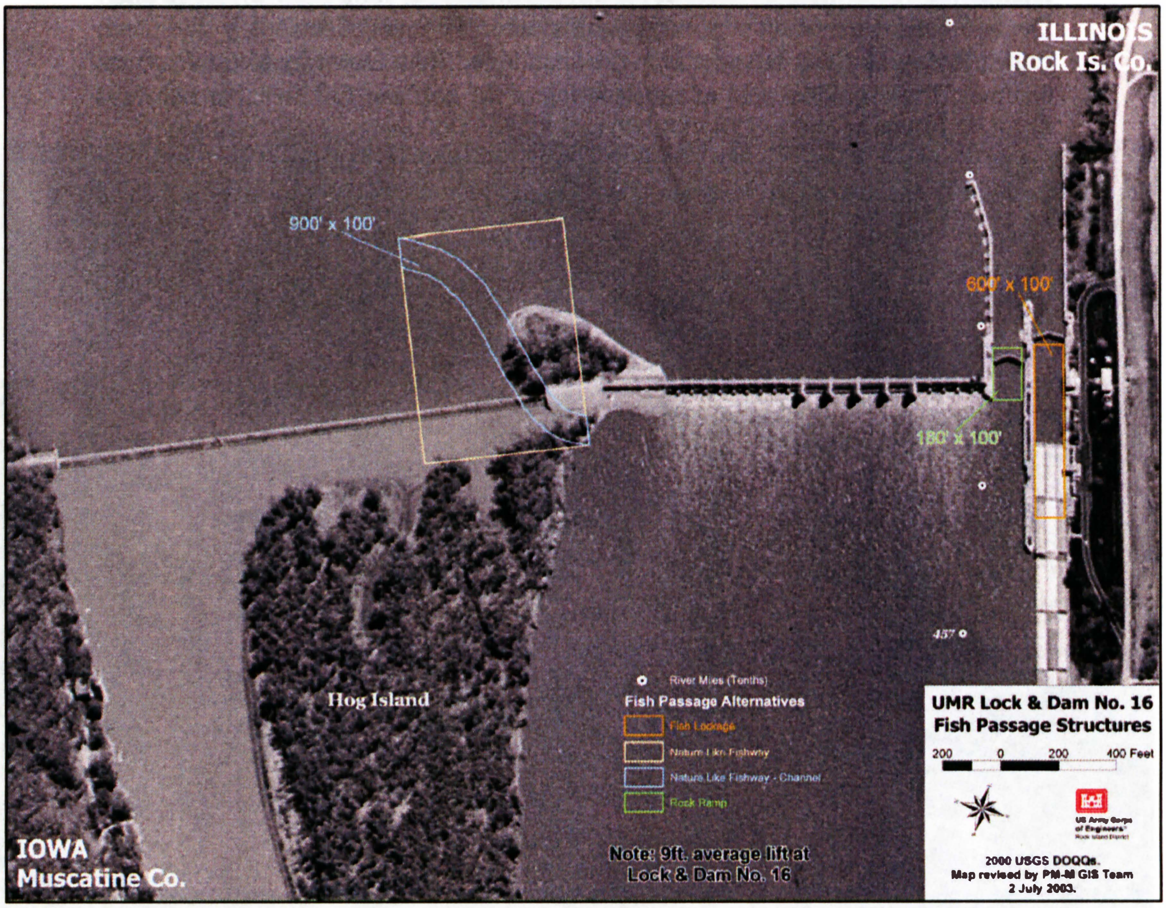


Figure D17. Potential fish passage improvements at Lock and Dam 16, Upper Mississippi River

Lock and Dam 17

Lock and Dam 17 near New Boston, Illinois, has a head of 2.4 m (Figure D18). Potential fishway locations include an island-type fishway upstream of the right (Iowa) embankment, a bypass channel on the downstream side of the right embankment, and a fishway in the auxiliary lock. The estimated cost of the island type fishway is $20,523,000, and the estimated cost of a fishway in the auxiliary lock is $2,254,000.

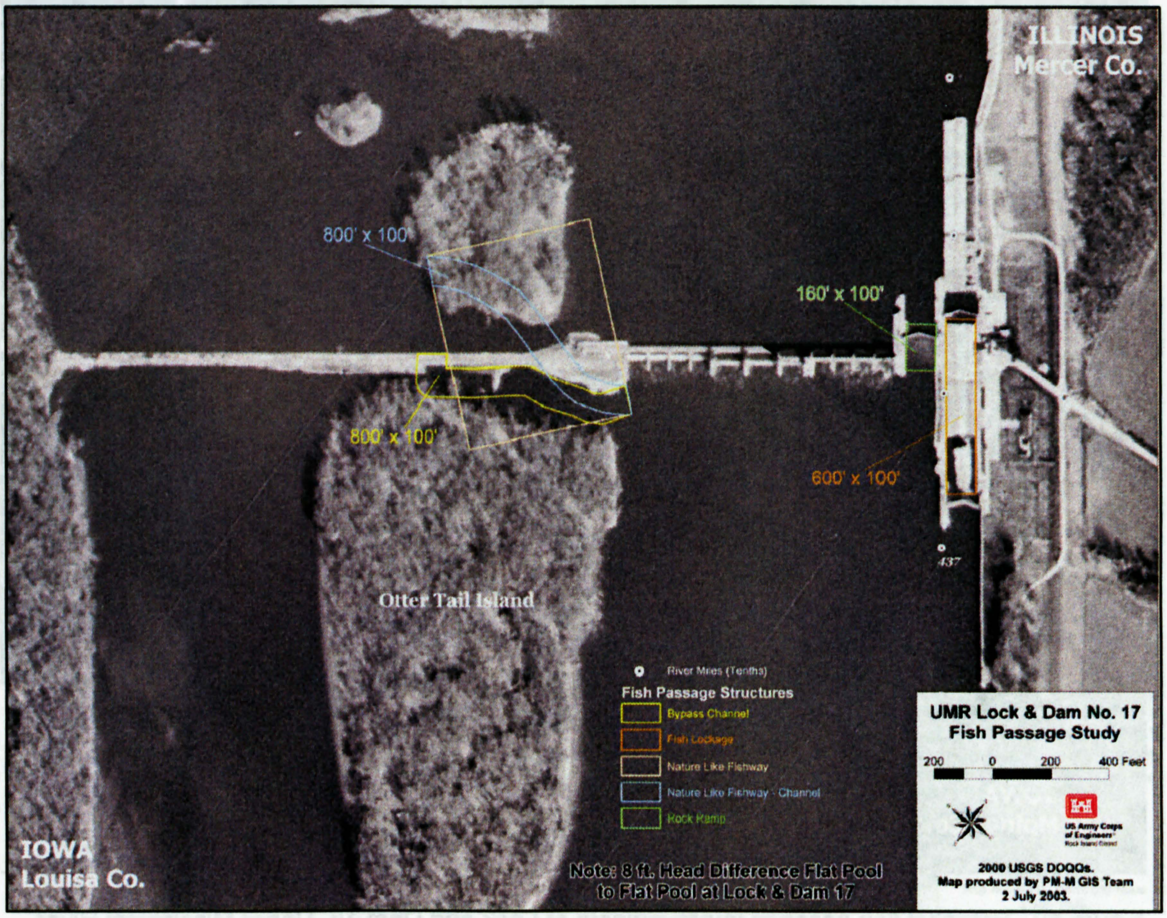


Figure D18. Potential fish passage improvements at Lock and Dam 18, Upper Mississippi River

Lock and Dam 18

Lock and Dam 18 is located near Oquawka, Illinois and has a head of 3 m (Figure 19). Potential fishways at this site include an island-type fishway upstream of the right (Iowa) overflow spillway and a fishway in the auxiliary lock chamber. Estimated cost of the island-type fishway is $34,494,000. A fishway in the auxiliary lock is estimated to cost $7,137,000.

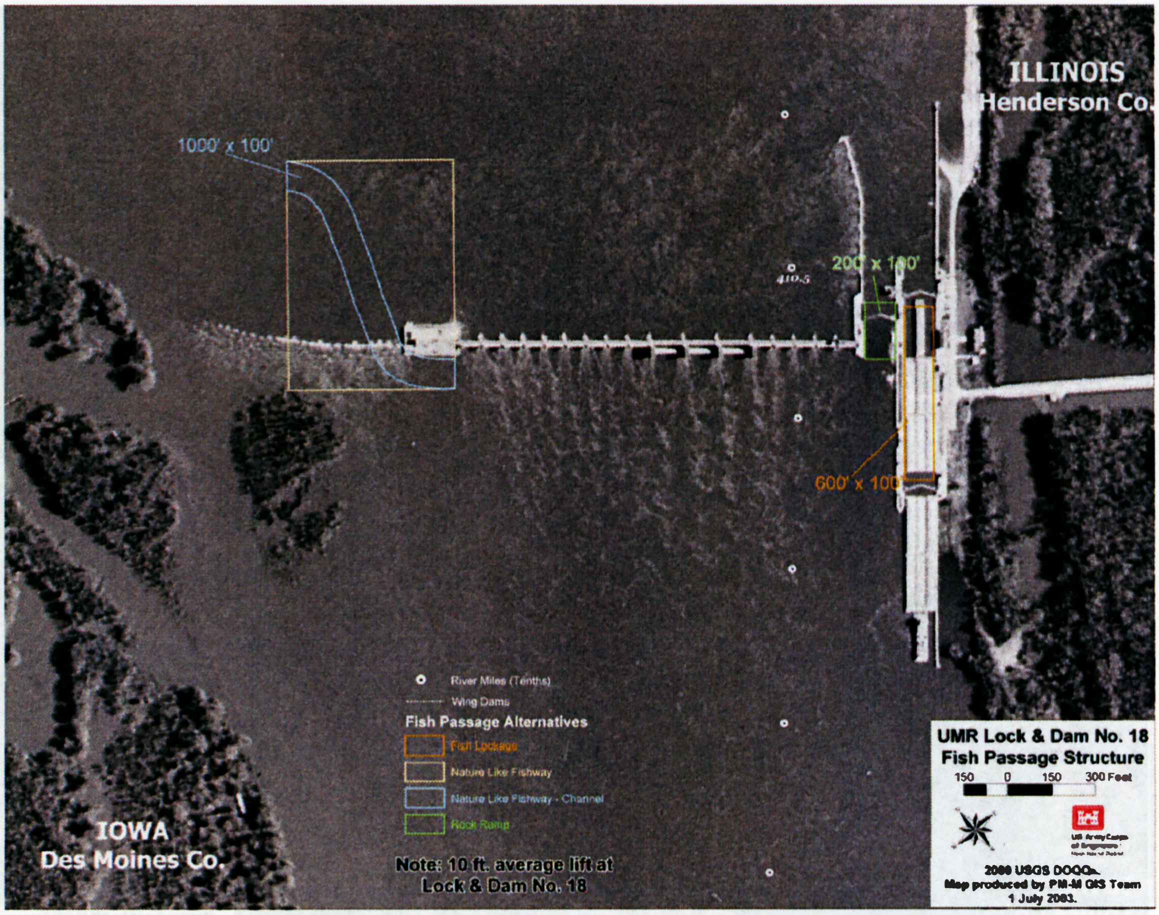


Figure 19. Potential fish passage improvements at Lock and Dam 18, Upper Mississippi River

Lock and Dam 19

Lock and Dam 19, located at Keokuk, Iowa, has high (11.1 m) head (Figure D20). It is a privately-owned hydropower dam completed in 1913. A number of alternative fishway alignments were considered earlier as part of the Navigation Study. A fishway constructed in the unused powerhouse foundation area downstream of the powerhouse appears to be the most feasible location. This fishway is estimated to cost $47,521,000.

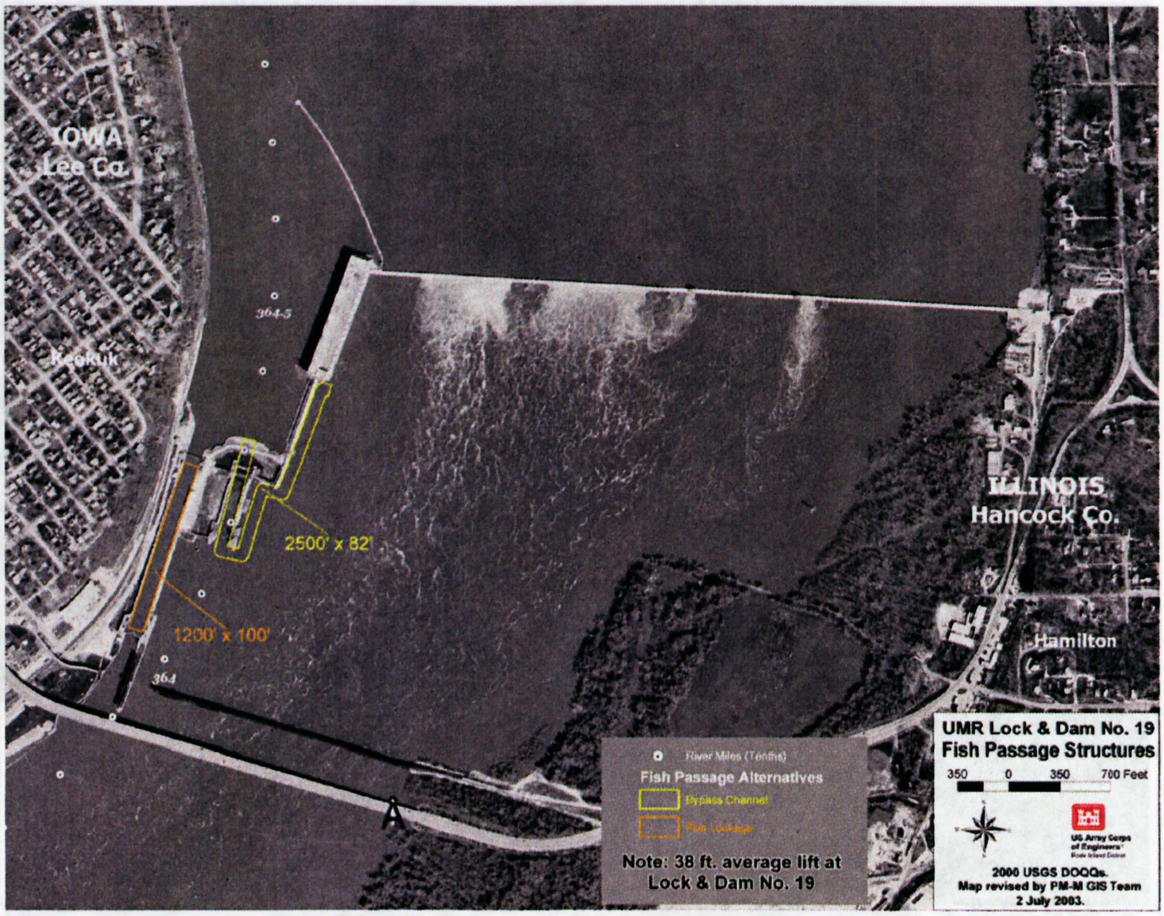


Figure D20. Potential fish passage improvements at Lock and Dam 19, Upper Mississippi River

Lock and Dam 20

Lock and Dam 20 near Canton, Missouri, has a head of 3.0 m (Figure D21). The left (Illinois) side is constrained by a highway. Potential fishway locations at this site include a bypass channel making use of Gregory Slough (Buck Run) on the Missouri side and a fishway in the auxiliary lock chamber. The cost of the bypass channel fishway is estimated to be $18,248,000. A fishway in the auxiliary lock chamber is estimated to cost $2,832,000.

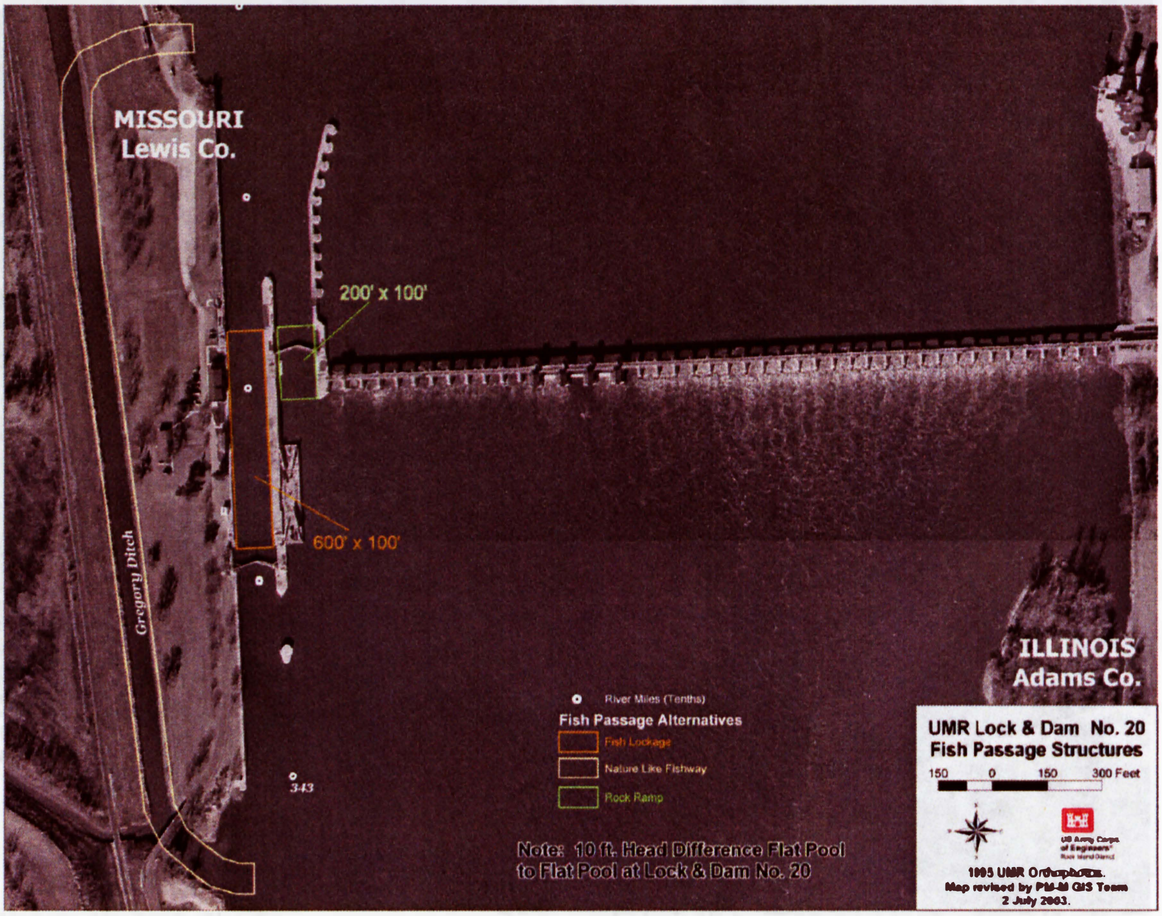


Figure D21. Potential fish passage improvements at Lock and Dam 20, Upper Mississippi River

Lock and Dam 21

Lock and Dam 21 near Quincy, Illinois, has a head of 3.2 m (Figure D22). Alternatives for fishways at this site include a nature-like bypass channel through the right (Missouri) embankment, an island-type fishway on the upstream side of the right embankment, a bypass channel on the downstream side of the right embankment, and a fishway in the auxiliary lock. Estimated cost of the island-type fishway would be $26,733,000 and the estimated cost of a fishway in the auxiliary lock would be $3,825,000.

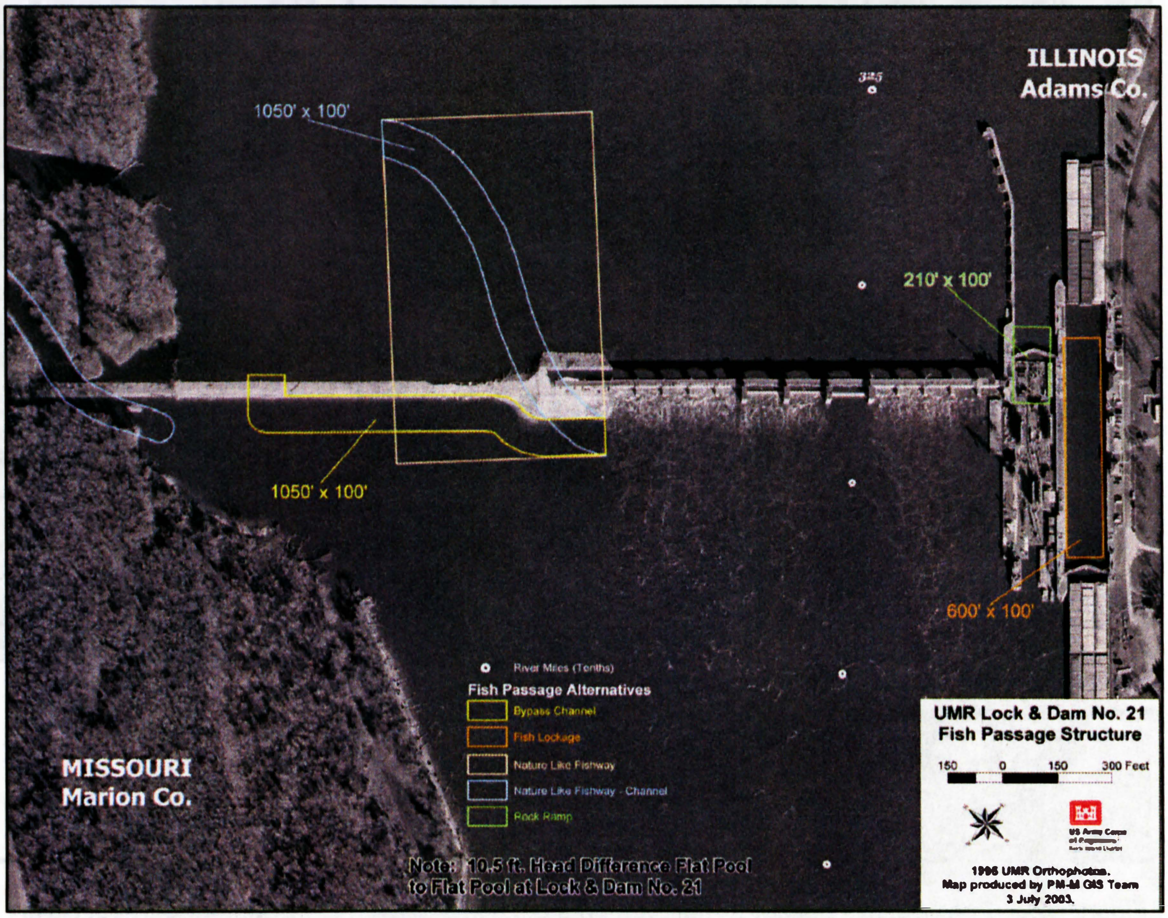


Figure D22. Potential fish passage improvements at Lock and Dam 21, Upper Mississippi River

Lock and Dam 22

Lock and Dam 11 has a head of 3.1 m and is located 12.9 km downstream from Hannibal, Missouri (Figure D23). Potential fishway locations include an island-type fishway on the upstream side of the left (Illinois) spillway, a rock ramp fishway on the left spillway, and a fishway in the auxiliary lock chamber. The estimated cost for the island-type fishway is $28,475,000, and $3,093,000 is the estimate for a fishway in the auxiliary lock chamber.

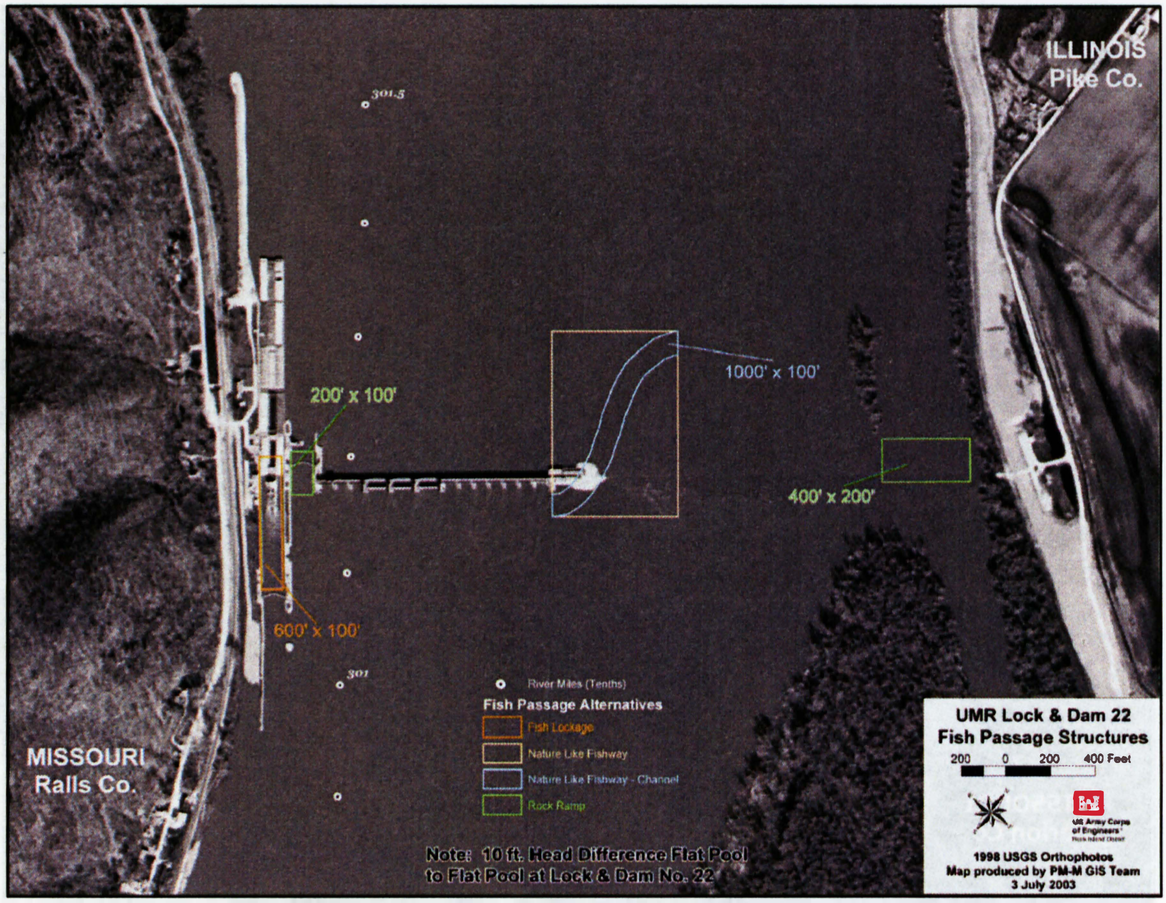


Figure D23. Potential fish passage improvements at Lock and Dam 22, Upper Mississippi River

Lock and Dam 23

This lock and dam was never built, and it remains the phantom structure in the system. Fish don't notice that it is not in the way.

Lock and Dam 24

Lock and Dam 24 is located at Clarksville, Missouri, and has a head of 4.6 m (Figure D24). Three alignments for island-type fishways upstream of the left (Illinois) embankment and a fishway in the auxiliary lock chamber were identified as potential locations. A chevron-type structure could be built upstream of the left end gate of the dam to reduce velocities through the gate bay opening to facilitate upriver fish passage when the gates are out of the water. The estimated cost of the island-type fishways is $18,876,000. The estimated cost of a fishway in the auxiliary lock is $5,034,000.

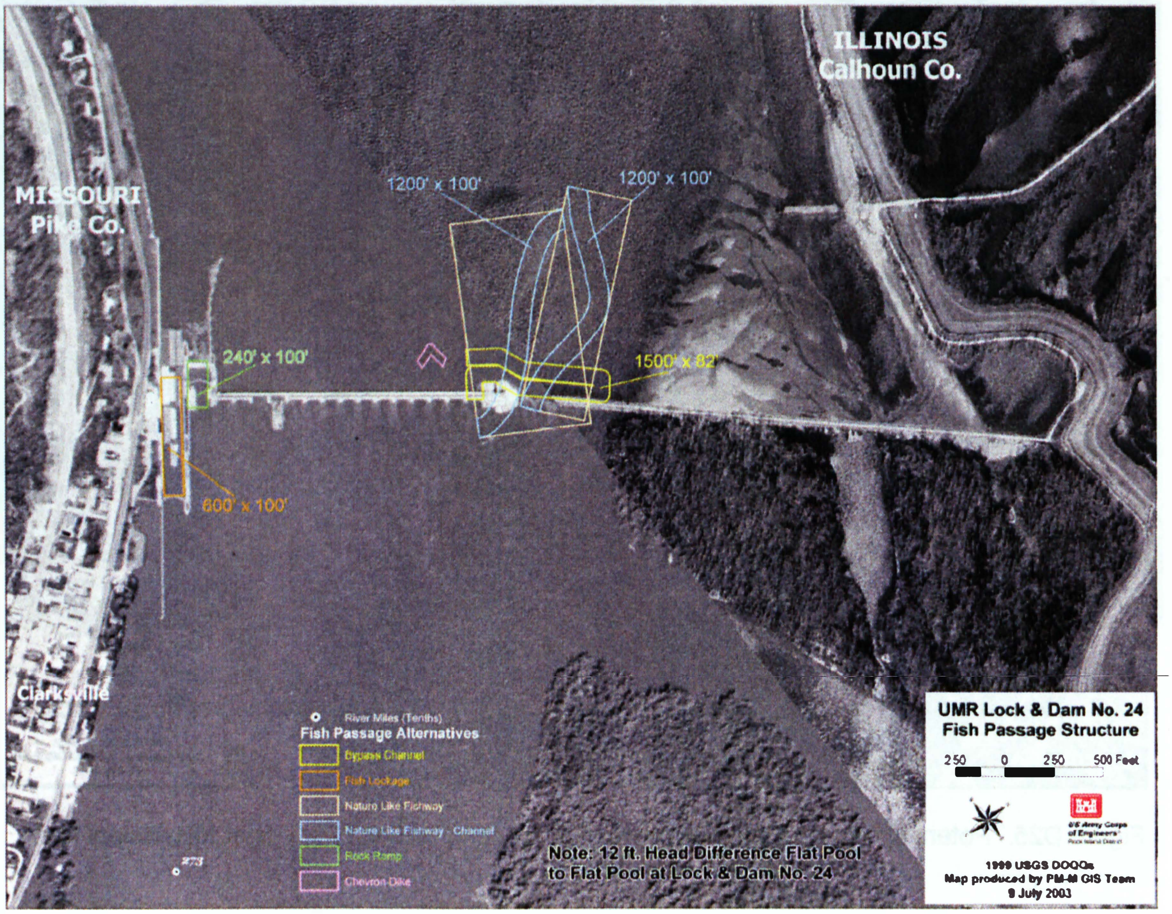


Figure D24. Potential fish passage improvements at Lock and Dam 24, Upper Mississippi River

Lock and Dam 25

Lock and Dam 25 near Winfield, Missouri, has a head of 4.6 m (Figure D25). Three alignments for island-type fishways upstream of the left (Illinois) embankment and a fishway in the auxiliary lock chamber were identified as potential locations. A chevron-type structure could be built upstream of the left end gate of the dam to reduce velocities through the gate bay opening to facilitate upriver fish passage when the gates are out of the water. Bypass channels could be built through the left embankment, making use of an existing shallow channel, and through the right embankment, making use of Sandy Slough.

The estimated cost of the island-type fishways is $20,026,000. The estimated cost of a fishway in the auxiliary lock is $4,566,000.

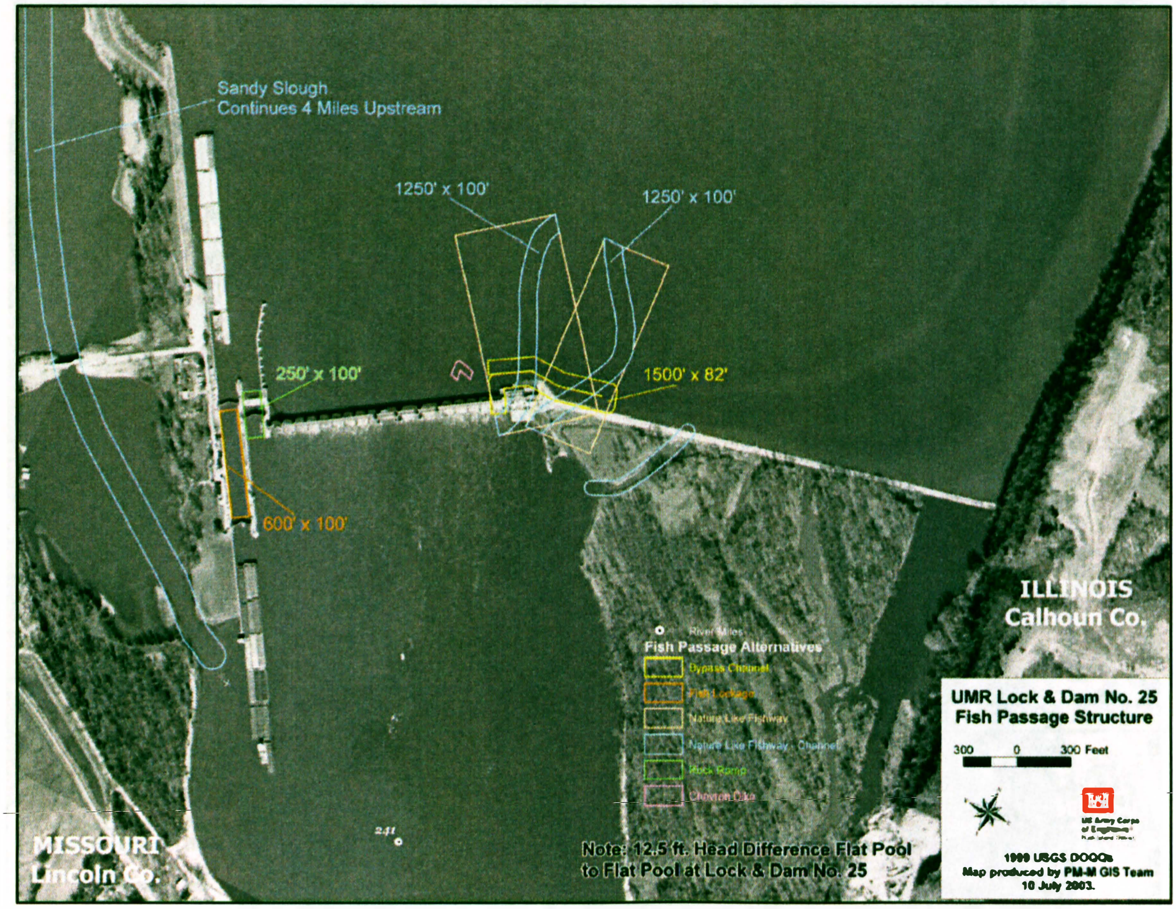


Figure D25. Potential fish passage improvements at Lock and Dam 25, Upper Mississippi River

Melvin Price Locks and Dam

Melvin Price Locks and Dam at Alton, Illinois was built to replace the original Lock and Dam 26 (Figure D26). This dam has a head of 7.3 m. Two potential island-type fishway layouts upstream of the right embankment were identified, along with a rock ramp-type fishway in the left roller gate bay. The estimated cost for an island-type fishway is $32,468,000. The estimated cost of a fishway in the roller gate bay is $12,584,000.

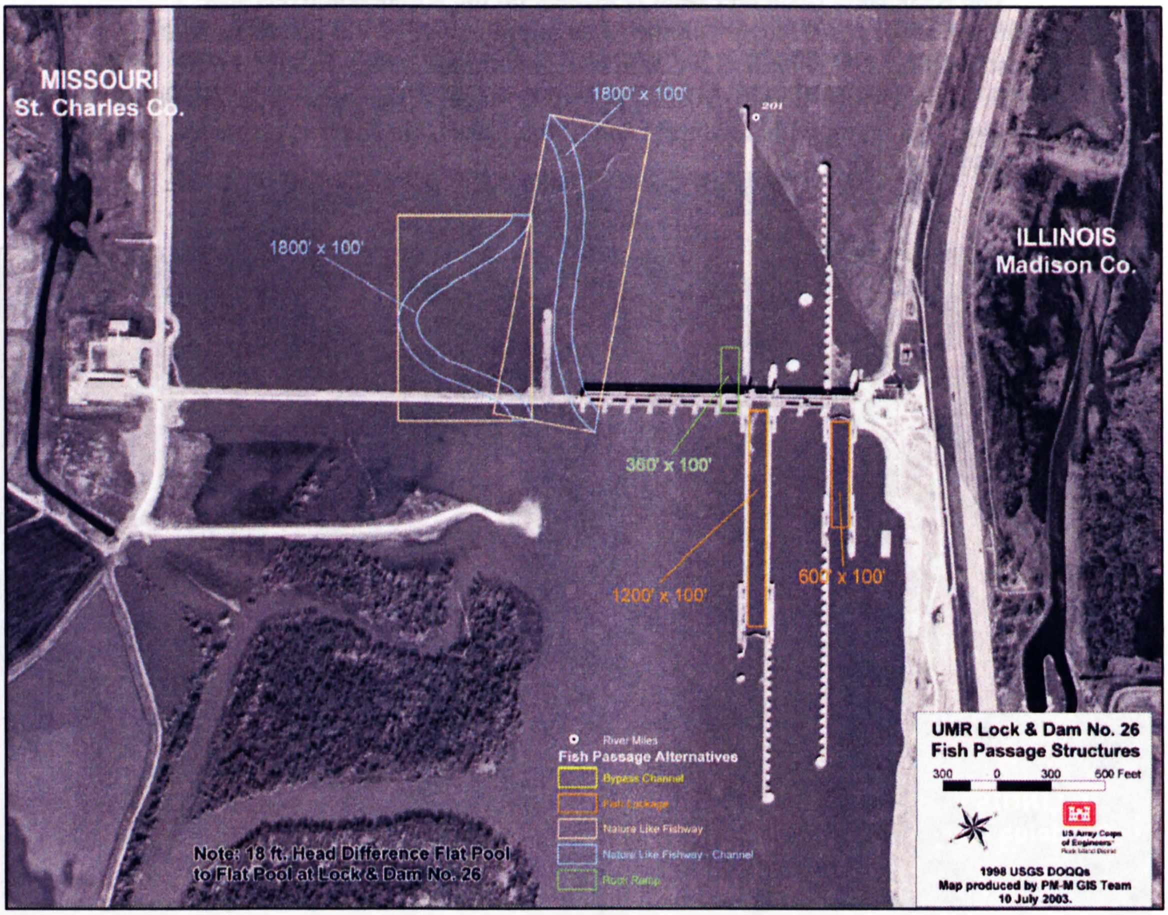


Figure D26. Potential fish passage improvements at Melvin Price Locks and Dam, Upper Mississippi River

Lock and Dam 27

The Chain of Rocks canal, lock, and weir on the main channel at St. Louis, Missouri allow upriver fish passage. No fish passage improvements are proposed for this site.

Kaskaskia Lock and Dam

The Kaskaskia Lock and Dam is located on the Kaskaskia River just upstream of the confluence with the Mississippi River, 12 km upstream from Chester, Illinois. The Kaskaskia Dam has a maximum head of about 3.6 m, which is greatly affected by Mississippi River stage. A potential bypass channel fishway connecting with a natural bend of the Kaskaskia River is estimated to cost $31,134,000.

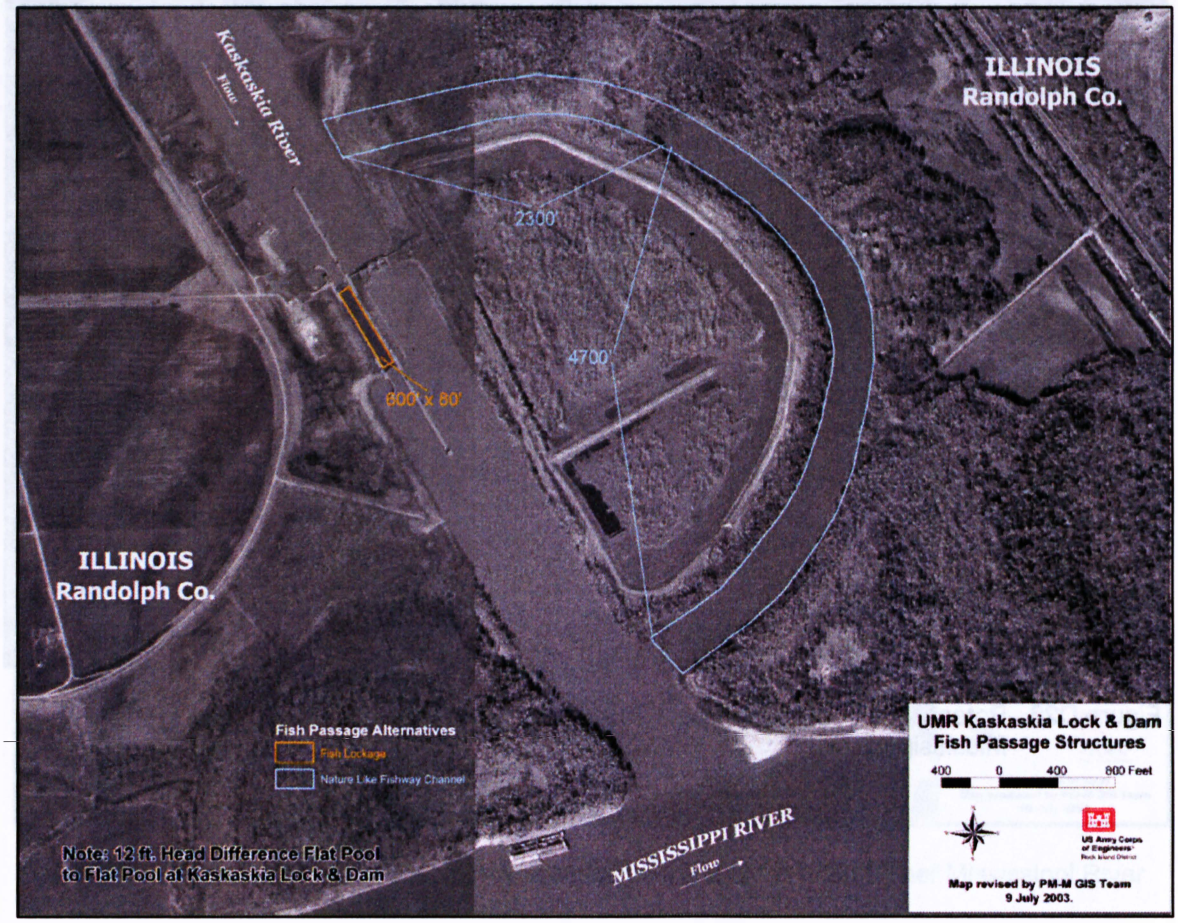


Figure D27. Potential fish passage improvements at Kaskaskia Lock and Dam

Illinois Waterway

La Grange and Peoria Locks and Dams

The locks and dams at La Grange and Peoria are significantly different from those found anywhere else on the UMRS navigation system (Figures D28 and D29). Dams at these facilities are a series of wicket gates that are raised or lowered to manipulate water elevations within a given pool. Due to the nature of the Illinois Waterway and seasonal flow conditions, these wicket gates are in a down position a significant portion of the time (Figures D28 and D29). This allows for free fish movement during much of the year, thus fish migration past these lower dams on the Illinois River is generally not of concern. For this reason, fish passage improvements are not needed at these two locks and dams.

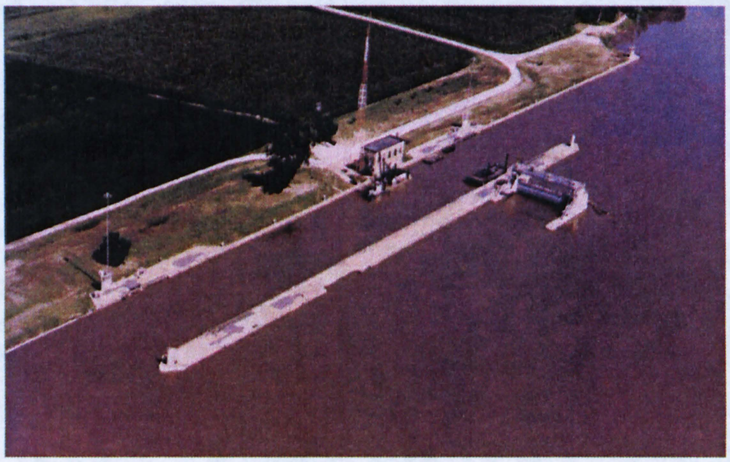


Figure D28. La Grange Lock and Dam, Illinois Waterway

Figure D29. Peoria Lock and Dam, Illinois Waterway

Starved Rock Lock and Dam

Starved Rock Lock and Dam has a relatively high head of 5.5 m. The left bank at this site is a higher bluff. Multiple passage alternatives were considered along the right bank. Various bypass channel fishway options could be constructed either below the Lock and Dam, or island-type fishways upstream of the dam (Figure D30). These fishways are conservatively estimated to cost between $28.0 and $33.0 million. A fishway is not proposed for the auxiliary lock chamber at this lock and dam.

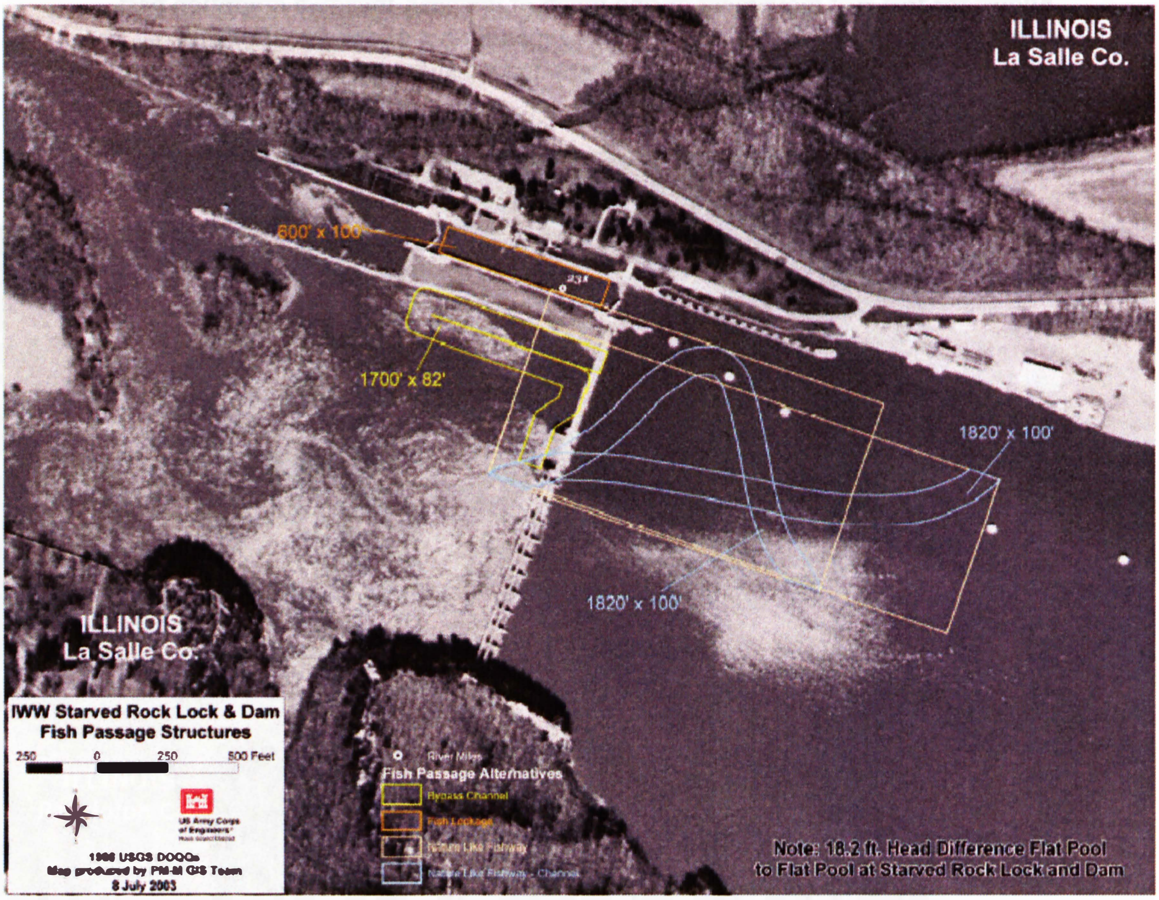


Figure D30. Potential fish passage improvements at Starved Rock Lock and Dam, Illinois Waterway

Marseilles Lock and Dam

Marseilles Lock and Dam also has a relatively high head of 7.4 m. A bypass channel fishway could be constructed through land on the left descending bank with the downstream entry directly below the Dam (Figure D31). Due to the unique features of this site, the bypass channel would route back to the west, and exit into Marseilles pool within the man-made channel above the lock structure. This fishway alternative is conservatively estimated to cost $17,972,000. No fishway is proposed for the auxiliary lock chamber.

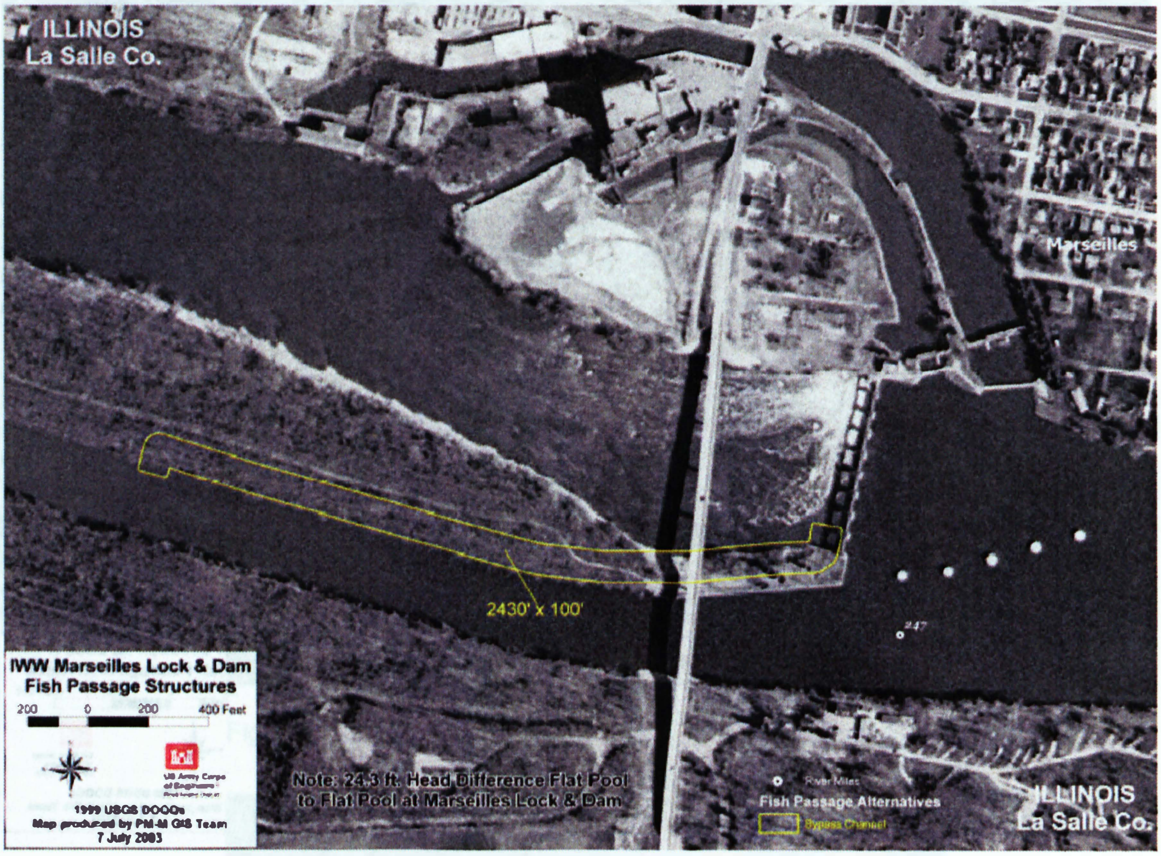


Figure D31. Potential fish passage improvements at Marseilles Rock Lock and Dam, Illinois Waterway

Dresden Lock and Dam

Dresden Lock and Dam also has a relatively high head of 6.7 m. A bypass channel fishway could be constructed along the right descending bank with the downstream entry directly below the Dam (Figure D32). This fishway alternative is conservatively estimated to cost $49,511,000. No fishway is proposed for the auxiliary lock chamber.

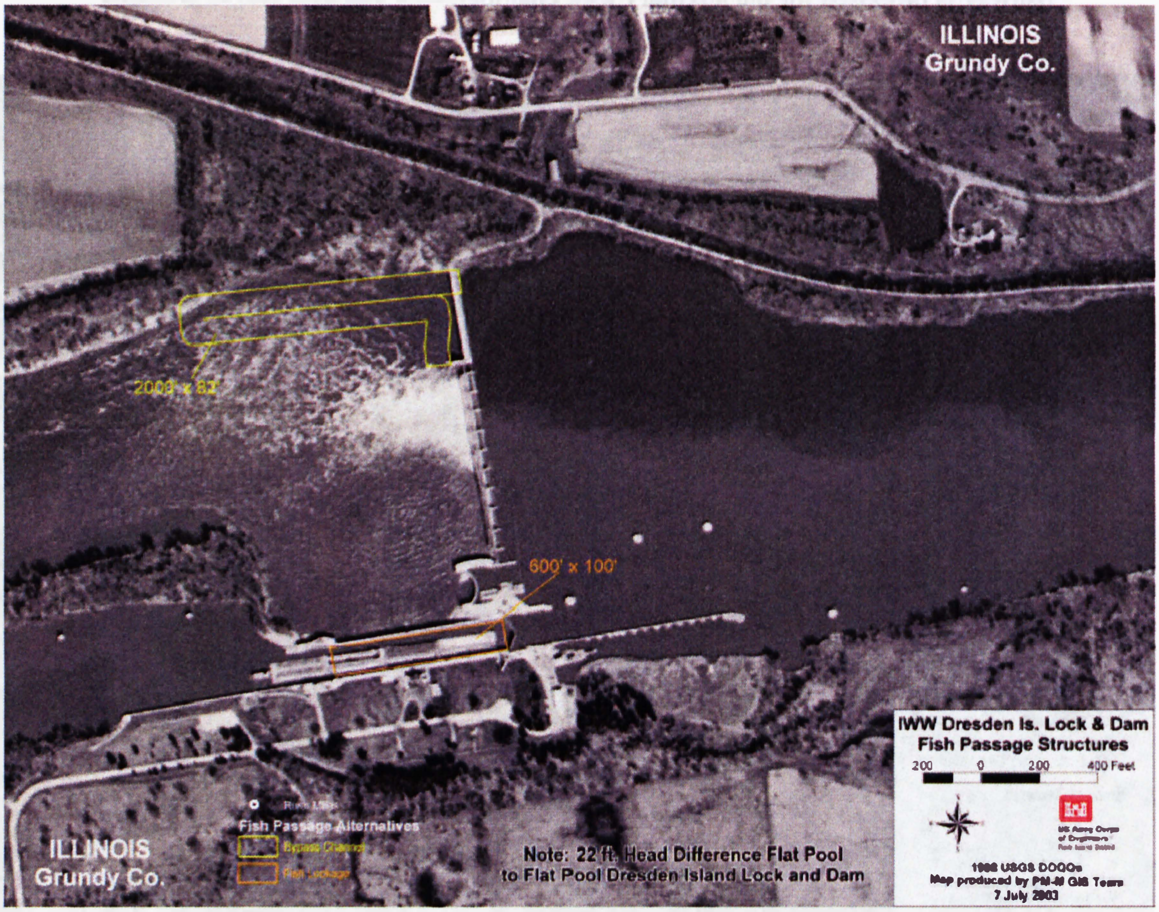


Figure D32. Potential fish passage improvements at Dresden Lock and Dam, Illinois Waterway

Brandon Road, Lockport and O'Brien Locks and Dams

Above the Dresden Lock and Dam are three additional locks and dams on the Illinois Waterway: Brandon Road, Lockport, and O'Brien (Figures D33, D34, and D35). Fish passage improvements were considered at these sites. However, due to concerns with habitat quality and contaminants near the City of Chicago, it was decided that fish passage may not be appropriate at these facilities. In addition, fishways at these sites could also prove quite costly. Moreover, these three facilities connect the Illinois Waterway with Lake Michigan. This waterway connection is not natural, and provides an undesirable avenue for movement of aquatic life between Lake Michigan and the UMRS. Providing fish passage at these facilitates could facilitate more rapid upstream movement of undesirable, non-indigenous aquatic species from the UMRS and lower Illinois Waterway to Lake Michigan. Therefore, fish passage improvements are not proposed for these sites.

Figure D33. Brandon Road Lock and Dam, Illinois Waterway

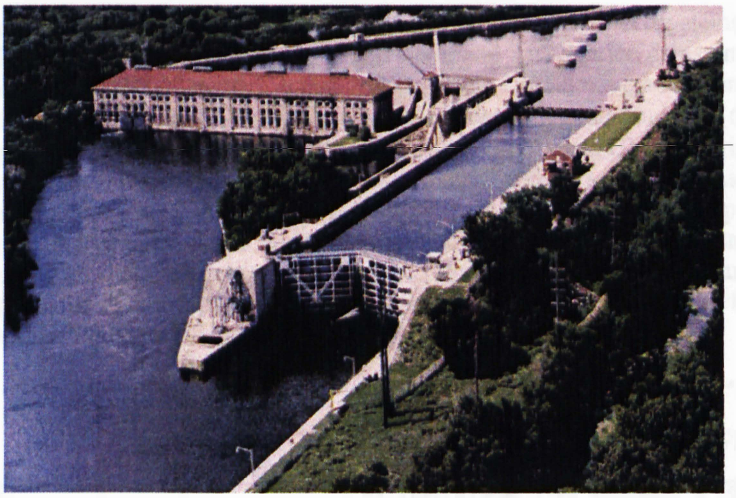


Figure D34. Lockport Lock and Dam, Illinois Waterway

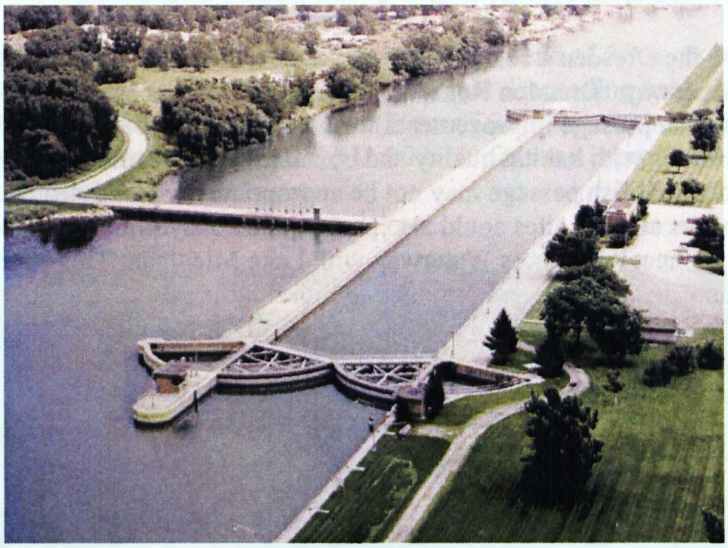


Figure D35. O'Brien Lock and Dam, Illinois Waterway

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
October 2004

2. REPORT TYPE
Final report

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE
Improving Fish Passage Through Navigation Dams on the Upper Mississippi River System

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Daniel B. Wilcox, Elliott L. Stefanik, Daniel E. Kelner, Mark A. Cornish, Daniel J. Johnson, Isaac J. Hodgins, Steven J. Zigler, Brian L. Johnson

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Engineer District, St. Paul
190 5th Street East, St. Paul, MN 55101-1638;
U.S. Army Engineer District, Rock Island
Clock Tower Building, P.O. Box 2004, Rock Island, IL 61204-2004;
U.S. Geological Survey, Upper Midwest Environmental Science Center
2630 Fanta Reed Road, La Crosse, WI 54603;
U.S. Army Engineer District, St. Louis
1222 Spruce Street, St. Louis, MO 63103-2833;

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Engineer District, Rock Island
Clock Tower Building, P.O. Box 2004, Rock Island, IL 61204-2004;
U.S. Army Engineer District, St. Louis
1222 Spruce Street, St. Louis, MO 63103-2833;
U.S. Army Engineer District, St. Paul
190 5th Street East, St. Paul, MN 55101-1638

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
ENV Report 54

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. 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.

15. SUBJECT TERMS

Dams	Illinois River	Mississippi River
Fish passage	Migratory fish	Mussels

16. SECURITY CLASSIFICATION OF:

a. REPORT	b. ABSTRACT	c. THIS PAGE
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED

17. LIMITATION OF ABSTRACT

18. NUMBER OF PAGES
181

19a. NAME OF RESPONSIBLE PERSON

19b. TELEPHONE NUMBER *(include area code)*

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. 239.18