Feasibility Study to Limit the Invasion of Asian Carp into the Upper Mississippi River Basin

(Final Report – March 15, 2004)

Prepared for the Minnesota DNR in cooperation with the Wisconsin DNR and the U.S. Fish and Wildlife Service (Region 3)

Prepared By:

FISHPRO
Consulting Engineers & Scientists
Affiliated with Cochran & Wilken, Inc.
5201 South Sixth Street Road
Springfield, IL 62703-5143
Phone: (217) 585-8333 FAX: (217) 585-1890

With Assistance From:

AYRES ASSOCIATES Engineers Architects Scientists Photogrammetrists

HDR ONE COMPANY | Many Solutions™

THE CADMUS GROUP, INC.

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Feasibility Study Project Team:
Matt Cochran –FishPro/Cochran & Wilken, Inc.
Gary Wilken- FishPro/Cochran & Wilken, Inc.
Peter Berrini- FishPro/Cochran & Wilken, Inc.
Jim Bakken- Ayers Associates
David Johnson- HDR Engineering, Inc.
Steve Bartell- The Cadmus Group
Ed Donahue- FishPro a Division of HDR

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I. Introduction

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I. Introduction

Purpose

In 1963, fish farmers introduced the first of four Asian carp species into the United States in an attempt to control aquatic vegetation in aquaculture ponds. Since that introduction, three (3) additional Asian carp species have been imported for use in aquaculture ponds and have escaped into the native waters of the United States. In an effort to limit the invasion of these Asian carp into the upper reaches of the Mississippi River, the Minnesota Department of Natural Resources (MN DNR) and the Wisconsin Department of Natural Resources (WI DNR) through the U.S. Fish and Wildlife Service (USFWS) funded this feasibility study entitled **Feasibility Study to Limit the Invasion of Asian Carp into the Upper Mississippi River Basin**.

This issue has been a serious concern for natural resource managers for over ten (10) years. A great deal of time and effort dedicated to research, field studies, technical and regulatory symposiums, and a public stand to stop the Asian Carp from migrating into Lake Michigan and the Great Lakes system have drawn regional and national attention to this environmental crisis.

"The longer you put off solving a problem, the more it costs you in the long run. An aggressive solution to a problem is almost always cheaper than repairing the damage later. Sometimes we have to be bold about it and not be afraid of taking some active steps protecting us against invasive species" according to Chicago Mayor Richard M. Daley, who recently launched a comprehensive water agenda initiative that included protecting the Great Lakes from harmful invasive species including Asian Carp.

In a broader and more complex manner, the MN DNR has adopted a strong commitment to do all within its power to protect the natural resources of the State of Minnesota and hopefully the entire Upper Mississippi River Basin against the invasion of these detrimental species.

Scope of Work

At this time, Asian carp are moving northward in the Mississippi River towards Minnesota and a single bighead carp has been found in Lake Pepin, just south of the Twin Cities. This fast-track study evaluated potential and available technologies that may be effective in limiting or stopping the northward movement of these carp into the Upper Mississippi River and adjacent tributaries from both an environmental and engineering point of view. This included an assessment of the potential impacts of Asian carp, the effectiveness of the technology in limiting invading fish species, the environmental impact of the technology on native species, the pluses and minuses of each technology, and the potential of the engineering task to be successfully completed.

Additionally, a risk assessment framework on the potential effects of these nonindigenous species on the UMR waters has been completed as a part of this Study.

Prior Studies

Past and on-going research and technical studies have been completed in the past 15 years to address a wide range of issues dealing with Asian Carp. Appendix C of this report cites the literature reviewed and included by reference in this report. The following list of agencies have been involved to varying degrees in prior studies:

- U.S. Fish and Wildlife Service
- U.S. Geological Survey
- U.S. Army Corps of Engineers
- National Park Service
- MN Department of Natural Resources
- WI Department of Natural Resources
- IL Department of Natural Resources
- IA Department of Natural Resources
- WI Sea Grant Institute
- IL Natural History Survey
- Mississippi Interstate Cooperative Resources Association

The type of prior and current studies include:

- Habitat – Biodiversity
- Spawning Activities
- Attract/Repel – Responses
- Sound sensitivity/Audiogram per target species
- Catchability
- Life Stages
- Food Source & Food Chain
- Movement – Tracking
- Marketability
- Fish Passage Issues

Project Authorization

This Feasibility Study was authorized by the US Fish and Wildlife Service under Project Supplement No. 1, dated December 22, 2003 (Contract No. 301812D04, Task Order No. 301814Y037) to Ayres and Associates with a subcontract to FishPro/Cochran and Wilken, Inc. with a sub-subcontract to HDR Engineering, Inc. and the Cadmus Group, Inc. A kick-off meeting was held on January 14 in St. Paul, Minnesota to officially start the project.

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II. Executive Summary and Recommendations

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II. EXECUTIVE SUMMARY AND RECOMMENDATIONS

STUDY OVERVIEW

The purpose of this study was to provide direction and focus on the feasibility of limiting the invasion of Asian carp (bighead, silver, grass and black) into the Upper Mississippi River (UMR). The report evaluated existing and new technologies that may be effective in limiting or stopping the northward movement of these species. The rate of the upstream movement of Asian carp in major rivers of the United States has been estimated and observed to be approximately 50 miles (80 km) per year and can become established approximately two (2) years after the first individual arrives (USFWS, pers. comm.). Based on this estimated and observed upstream movement rate, it is anticipated that bighead and silver carp will be reaching Lock and Dam 8 near the south edge of the Minnesota state line in two to three years. Therefore, it is imperative that immediate action is taken to implement alternatives to limit this rapid upstream movement.

Evaluation was based on an environmental and engineering view and recommended technologies that may be worthy of implementation. A risk assessment framework for the potential effects of these nonindigenous species on the UMR waters was completed.

The invasion of these carp species is not a Minnesota problem, or even an Upper Mississippi River problem. This is a National problem that is on the brink of becoming an environmental crisis of tremendous significance. Regional panels of the Aquatic Nuisance Species (ANS) Task Force help coordinate ANS efforts and identify priorities in their respective regions. The Mississippi River Basin Regional Panel held a meeting in January 2004 and the panel members identified Asian carp as the top basin-wide concern. The Minnesota Department of Natural Resources (MN DNR) the U.S. Fish and Wildlife Service (USFWS) (Region 3), and the Wisconsin DNR (WI DNR) have funded this study with cooperation and technical support from a wide array of Federal and State natural resource agencies. The Feasibility Study provides the basis and framework to assist MN DNR, WI DNR, USFWS and others in developing future operational and technology implementation planning to address this critical environmental problem.

Through a contract with the U.S. Geological Survey (USGS), the USFWS is nearing the completion of an "Ecological Risk Assessment for the Black Carp" and are in the process of completing similar assessments on the silver and bighead carp. Should these assessments determine that these species are "injurious" as defined by the Lacey Act (Amend. 1981) they will be eligible for strict regulation and enforcement by USFWS. This scientific process and legislative authority for regulation is a very important component in determining the potential success for limiting the invasion of Asian Carp into the UMR. Even without an injurious listing, the Asian Carp species pose a significant threat to the native habitat, species and economic value of the UMR.

FINDINGS AND RECOMMENDATIONS

The study provides an overview of the UMR (Section III) and reviews the current Asian Carp monitoring and research work in the Basin. Section IV sets forth a recommended framework for an Asian carp ecological risk assessment as it relates to the possible success of potential barriers, deterrents, and management alternatives, as well as the risk of colonization, spread potential, and economic impact.

A review of the current technologies available reveals that, while physical and behavioral barriers are in widespread use for intake screens and smaller scale waterway openings, there are no current installations of the magnitude required for the Upper Mississippi River. The Chicago Sanitary & Ship Canal Electrical Fish Barrier is attempting to address the same problems (preventing Asian Carp from migrating into Lake Michigan and the Great Lakes). The Corps of Engineers (COE) has installed a temporary electrical barrier and is currently constructing a "permanent" barrier for a total construction cost of about $10 million. The barrier is located in a channel 150 feet wide with a maximum 20 feet of water depth, which is considerably smaller in magnitude than the Upper Mississippi River.

Several technologies are available that merit further consideration for planning, permitting design and construction. These "engineering" solutions coupled with "environmental" operations and management solutions appear to have the most potential for success. This report recommends the following components be considered for implementation as soon as funding can be secured:

1. Education – Develop an aggressive national, regional, state and local integrated plan to educate the general public, environmentalists, water sport enthusiasts, regulators and legislators of the great threat posed by Asian Carp with specific recommendations to help reduce the risk of introduction and dispersal of these aquatic nuisance species. Continue to use existing ANS Task Force groups to provide the latest recommendations and information.

2. Research and Monitoring – Continue existing research of all Asian Carp species currently being conducted by the USGS, USFWS, COE, universities, and State natural resource agencies to further define species tendencies including:

   - Habitat – Biodiversity
   - Spawning Activities
   - Attract/Repel – Responses
   - Sound sensitivity/Audiogram per target species
   - Catchability
   - Life Stages
   - Food Source & Food Chain
   - Movement – Tracking
   - Marketability
   - Fish Passage Issues

3. Regulation and Enforcement – Continue to work with USFWS and USGS to complete Risk Assessments on all four Asian Carp Species. If determined to be injurious species, develop proposed rules in conformance with the Lacey Act. Once adopted, assist USFWS to develop an integrated Federal/State monitoring and enforcement program. If this option is unsuccessful or consumes too much time, work concurrently with all

UMRB states (MN/WI/IL/IA/MO) and/or all 28 states involved with the Mississippi Interstate Cooperative Resource Association (MICRA) to develop uniform individual State regulatory requirements regarding Asian Carp.

4. Management – Currently the USFWS is developing an integrated, multi-jurisdictional Asian Carp Management and Control Plan for the Aquatic Nuisance Species Task Force that can serve as a model for any watershed, state or region. Continue to provide support and assistance to this effort and work to get all UMRB and/or MICRA states, and Mississippi River Basin Panel Members to adopt and implement the strategies and actions in the plan.

5. Barriers and Deterrents - Based on the technology review (Section V) and alternatives analysis (Section VI) completed for this study, it was determined that the following general recommendations should be considered for planning, permitting, design and implementation.

   A. Location - Any major barrier/deterrent system should be considered either in or immediately downstream of a COE Lock and Dam. The location of the selected Lock and Dam is dependent upon physical features, confirmed establishment of the targeted carp species, and the estimated length of time required to implement the barrier/deterrent technology versus the northward migration of the Asian carp. Based on these criteria, we recommend that further consideration be given to locations at Lock and Dams 19; 8 or 11, and/or 14 or 15. These structures are located near river miles 364; 679 or 583; and 493 or 483 respectively. Section VI provides more detailed rationale as to why these locations are recommended. In addition, major tributaries to the UMR should be considered for isolated watershed protection at a state level should a major river barrier system not be installed in time to protect the smaller ecosystems.

   B. Implementation – Section VI provides an analysis of several options. Electrical barriers have been proven to be an effective management tool, and possibly the most effective deterrent system currently available. However, due to the extremely high initial construction cost and monthly operating cost, safety concerns and negative public perception, the electrical barrier does not rank as highly for this particular application.

   Based on the results of the prioritization and ratings matrix analysis (Table VI-3), it appears that an acoustic deterrent such as a Sound Projector Array (SPA) based acoustic bubble curtain (SPA/BAFF) downstream of a lock entrance location perhaps in conjunction with habitat/attractants (i.e. pheromones, plankton, lights, habitat, etc.) and an integrated management/harvest plan may provide the most feasible opportunity to limit or slow the upstream invasion of Asian Carp. The hybrid system improves the versatility and effectiveness of a standard BAFF system since the SPA based sound source can be calibrated to approximate an Asian carp specific audiogram. Preliminary cost projections range from $1.2 to

$1.6 million for an installed system at a typical lock approach entrance, including site preparation, engineering and permitting.

In addition, a Sound Projector Array (SPA) based acoustic deterrent system should be considered for installation within close proximity to the spillway gates for protection during open gate conditions. This system would be activated prior to full flow conditions so as to limit the habituation potential and essentially "turned off" after floodwaters subside and the gates are closed. Preliminary cost projections range from $8.5 to $10.5 million for an installed spillway gate protection system at the recommended locations, including site preparation, engineering and permitting.

The cost of habitat/attractant staging areas downstream of a lock and dam spillway could be in the $0.5 to $3.0 million range depending upon location. Controlled fish harvesting may have additional costs associated with agency staff time and/or subsidies to commercial fish operators to effectively remove the targeted species.

6. Ecological Risk Assessment **-** As discussed in Section IV, these components should be developed in the context of an interactive, computer-based decision support system (DSS) that can be readily accessed by risk assessors and risk managers to (1) describe and understand the current distributions of Asian Carp in the Upper Mississippi River Basin; (2) estimate the future spread, establishment, and consequences of these species in the absence of control technologies; (3) identify locations where specific barrier technologies may prove useful in controlling the spread of Asian Carp; and (4) evaluate the overall effectiveness and net benefits afforded by alternative technical control measures proposed for specific locations.

IMPLEMENTATION

Items #1 through #3 are on-going and it is recommended that Education, Research and Monitoring, and Regulation and Enforcement be expanded and coordinated either through USFWS, UMRCC or the MRBP, which is the entity to assist the ANSTF in implementing Federal efforts. Information exchange and communications regarding state regulation and enforcement must be more structured and interrelated. The National Asian Carp Management Plan (Item #4) scheduled for completion within the next year must be peer-reviewed, adopted and implemented by all Federal and State agencies as well as private/commercial operators.

It is recommended that appropriate funding be obtained to implement the planning, design, permitting and ultimately the installation of a coordinated barrier and deterrent system (Item #5). Based on the rate of northward movement of the Asian Carp, this system needs to be in-place within the next 24 months (prior to spawning migration in 2006). Lastly, a full-scale Ecological Risk Assessment (Item #6) should be contracted, designed and completed within the next 12 months to provide all decision makers with a logical, non-political evaluation system. This Assessment will build on the soon to be completed USFWS/USGS risk assessment to determine "injurious" status per the Lacey Act and provide a tool to determine specific impacts, risks, and probabilities for the success of implementing all six components recommended in this Study.

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III. Overview of the Upper Mississippi River (UMR)

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III. OVERVIEW OF THE UPPER MISSISSIPPI RIVER (UMR)

PHYSICAL AND HYDROLOGICAL CHARACTERISTICS

From its beginning at Lake Itasca, Minnesota to its entry into the Gulf of Mexico in Louisiana, the Mississippi River stretches approximately 3,782 km (2,350 miles) and is the third largest drainage basin in the world, draining approximately 41% of the contiguous United States (USCOE, 2004). The navigable portions of the river have been divided into two systems known as the Upper Mississippi River (UMR) and the Lower Mississippi River (LMR).

The Upper Mississippi River System (UMRS) represents a 1,381 km (858 mile) portion of the entire UMR and is defined as the natural floodplain between the head of navigation at Minneapolis, Minnesota (Lock and Dam 1) and the confluence with the Ohio River at Cairo, Illinois (UMRCC, 2000). The Upper Mississippi River Basin (UMRB) includes the entire drainage area from the source at Lake Itasca to its confluence with the Ohio River. **Figure III-1** delineates the UMRB boundary. The UMRB and the species that inhabit the basin have long been considered an important resource. In 1986, the U.S. Congress in the Water Resources Development Act reemphasized the importance of the UMRS by formally declaring the system a nationally significant ecosystem (UMRCC, 2000).

The floodplain and surface water of the UMRS and its major tributaries including the entire Illinois River, and navigable portions of the St. Croix, Minnesota, Black and Kaskaskia Rivers, cover more than 570,000 acres of land (UMRCC, 2000). Collectively, this system drains approximately 189,000 square miles of the upper Midwest of the United States.

A series of 29 navigation locks and dams are used to manage water levels on approximately 1,033 km of the northern reach of the UMR (**Figure III-2**). The majority of these locks and dams were constructed between 1895 and 1968 (Wilcox et al., 2003). With the exception of structures at St. Anthony Falls, Lock and Dam 1, Lock and Dam 19 and Lock 27, all of the navigation dams on the UMR are similar in design with Tainter gates and roller gates to control water flows. The gates extend down to a bottom sill that can be raised entirely out of the water during high flow conditions. The hydraulic head at the dams during low flow ranges from about 2.0 m to 11.6 m, but approaches zero at most dams during high flows.

The 29 locks and dams create flat areas or pools upstream of each dam area. A pool is defined as the area between two navigational lock and dams and is named according to the downstream dam name. Navigation miles define location along the main channel of the river. For the UMRS, the navigational miles begin at the confluence of the Ohio River (0.0) and proceed upstream.

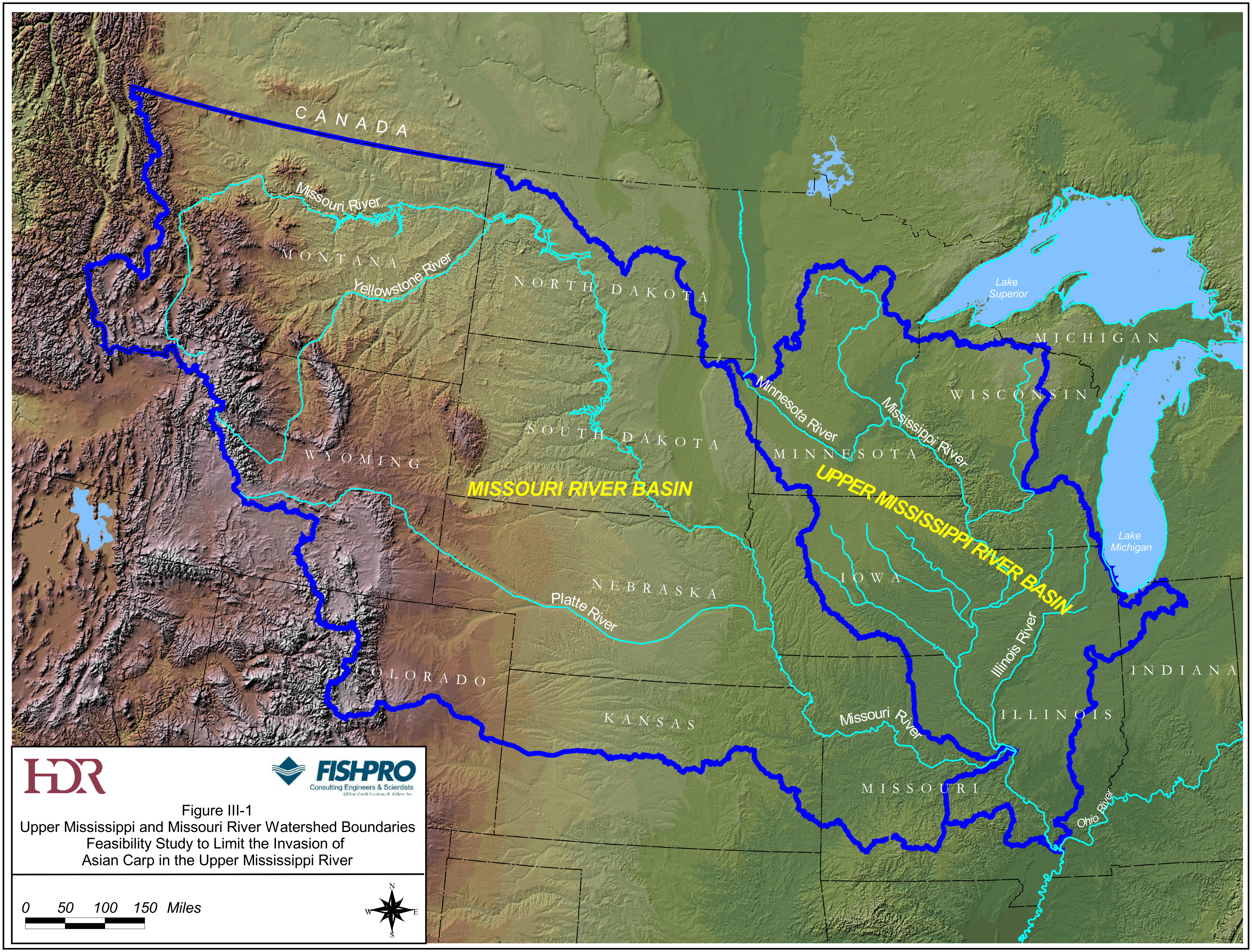

Figure III-1
Upper Mississippi and Missouri River Watershed Boundaries
Feasibility Study to Limit the Invasion of
Asian Carp in the Upper Mississippi River

Figure III-2 - Upper Mississippi River Basin Plan
Feasibility Study to Limit the Invasion of
Asian Carp in the Upper Mississippi River

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Review of Water Quality Conditions

Water Flows

River flow or discharge rate is an important factor that influences water quality in riverine systems. Periods of high flow reflect times of increased precipitation and runoff from the basin's tributary streams that may account for substantial non-point source pollutant inputs, especially from watersheds where agricultural land use is prevalent. Conversely, periods of low flow in times of drought may amplify the impacts of point source discharges, since there is less river water available for dilution of wastewater inputs. River flow also has a significant influence on the hydraulic residence time (i.e., flushing) of Lake Pepin and the UMR navigational pools. The amount of hydraulic residence time influences mixing, sedimentation, nutrient cycling, phytoplankton production, and the other physical, chemical and biological processes. As a result of these factors, most water quality parameters are correlated with river flow, which needs to be considered when interpreting water quality data from large river systems.

Water Temperature

Water temperature typically ranges from 15 to 30 degrees centigrade (^{o}C) in the study area during the summer season. Temperatures increase approximately 5 ^{0}C from the upper reaches to the lower reaches of the UMR, which are consistent with climatic differences along this latitudinal gradient. Summer dissolved oxygen (DO) concentrations generally range from 5 to 12 mg/l in the Upper Mississippi River. DO levels below 5 mg/l have been reported and were most apparent below the Twin Cities Metropolitan Area in the 1980's. In the 1990's, significant improvement in wastewater treatment technology translated into higher, more stable DO concentrations in this river reach. However, from 1995 to 1999, there were periods of low DO levels (< 5 mg/l) between pool 9 and pool 14, possibly as a result of zebra mussel expansion, increased biochemical oxygen demand, and reduced algal productivity.

Specific Conductivity

Specific conductivity, which is a measure of water's capacity to conduct an electrical current, typically increases below the Minnesota River as a result of the high dissolved solids concentrations generally present. Further downstream, conductivity levels drop where the St. Croix, Chippewa and Black Rivers enter the Upper Mississippi River system as a result of generally low dissolved solids concentrations. Conductivity then increases below the entry points of the Illinois and Missouri Rivers due to substantially higher dissolved solids loads.

pH

Most summer pH values in the UMR range from 7.0 to 9.0, which is sufficient to fully support fish and aquatic life. There are various locations along the UMR where summer pH values may periodically exceed 9.0 as a result of high levels of photosynthetic activity. However, historical data suggests that there are no consistent longitudinal patterns within the UMR.

Nitrogen

Total nitrogen values are comprised of inorganic (nitrite+nitrate), organic and ammonia nitrogen components. Total nitrogen concentrations in the UMR generally increase in Pool 2 as a result of agricultural inputs from the Minnesota River and point source inputs from the Twin Cities. It is typical for nitrogen concentrations to decrease further downstream as a result of dilution from tributaries with lower nitrogen levels. Downstream of Le Claire, Iowa, there is normally an increase due to high nitrogen loadings from Illinois and Iowa tributaries. Total inorganic nitrogen (NOX) concentrations generally range from 1.0 to 10.0 mg/l in the UMR and follow a similar longitudinal trend as total nitrogen, since inorganic nitrogen comprises a significant percentage of total nitrogen. Total ammonia nitrogen concentrations upstream of Pool two (2) have decreased in recent years as a result of reduced loadings from wastewater treatment plants. Further downstream, ammonia concentrations continue to decrease as a result of nitrification, utilization by aquatic plants and dilution.

Phosphorus

Total phosphorus concentrations are generally high within the entire UMR, with values frequently in excess of 0.5 mg/l at many sites. Increased phosphorus levels can generally be associated with high total suspended solids (TSS) concentrations and flood events, particularly in the lower half of the UMR. The highest TSS concentrations (> 500 mg/l) in the UMR are generally found downstream of the Illinois and Missouri Rivers and the lowest concentrations are found at the mouth of Lake Pepin, which is a 25-mile long natural riverine lake, which functions as a sediment and nutrient trap.

Chlorophyll

Chlorophyll measurements for the UMR have not been obtained on a consistent basis during the 1980’s and 1990’s. However, available summertime data indicates that chlorophyll concentrations ranging from 25 to 50 mg/l and higher are found throughout the UMR and reflect an abundance of nutrients, particularly dissolved forms of phosphorus, nitrogen and silica that are important for riverine algae. Low to moderate flow periods typically exhibit the highest algal productivity and chlorophyll concentrations as a result of reduced mixing and increased hydraulic retention time. Similarly, high flow periods can generally be correlated with the lowest concentrations due to the increased flushing and reduced water clarity.

Critical Habitat and Areas of Biodiversity Significance

Connection to critical habitat including main channel areas, secondary channels, floodplain waterbodies and tributaries is important for UMR species and should be considered when approaching alternatives to limiting migrations of fish and other species. Natural rivers contain a heterogeneous mosaic of aquatic habitats that are very dynamic in both a spatial and temporal sense (Wilcox et al., 2003). Identification of these habitats can be crucial and often involves tracking, species life histories and above all, professional judgment. NatureServe, together with The Nature Conservancy, recently published a document summarizing the thoughts and opinions of countless professionals on the location and ranking of these critical habitats (Weitzell et al., 2003). Within the document, a series of UMRB subdivisions were made to organize and aid in identifying areas of critical habitat. The following text and excerpts briefly summarize the subdivisions and processes outlined by NatureServe and The Nature Conservancy (see Weitzell et al., 2003 for full text).

The UMRB was divided into three major subdivisions termed Aquatic Zoogeographical Units (AZUs). These units identified major patterns of endemism and fish community structure within the UMRB. Variability within each of the three AZUs was accounted for by a further subdivision of the basin into Ecological Drainage Units (EDUs) that had unique assemblages of species and habitat.

Twenty-two (22) EDUs were identified in the UMRB. A still finer subdivision was the aquatic ecological systems that were characterized by distinct combinations of key ecological factors, including determination of macrohabitats.

Collectively, the system classification and basin subdivision data were compiled by "experts" and a list of freshwater Areas of Biodiversity Significance (ABS) was generated. In all, 186 sites were identified, that combined, covered 77 targeted species while identifying 131 total species with spatial concern (Weitzell et al., 2003). The 186 sites were narrowed down to a prioritized list of the top fifty sites for freshwater ABS. The prioritized list would capture 72% of aquatic area system types (e.g., small river, medium big river, large river and headwater/creek), 94 of the 131 species with spatial concern (including fish, mussels, insects, snails and amphipods, crayfish and herps) and would achieve 42% of the conservation goals for species (Wietzell et al., 2003 overview).

As was noted in the document (Weitzell et al., 2003), both the freshwater ABS list and the prioritized list contained the main stem of the Upper Mississippi River and the mouths of its major tributaries (termed big river habitat). Maintaining connectivity with the big rivers was important since most of the identified imperilment occurred in the big rivers (Weitzell et al., 2003).

Summary of Native Species

The UMRS provides habitat to 485 species of fish, mussels, birds, mammals, amphibians and reptiles (UMRCC, 2000). The 260 fish species that have been reported in the system represent 25% of all fish species in North America (UMRCC, 2000). In addition to fish, the UMRS provides habitat for 62 species of freshwater mussels, is a critical flyway for 326 bird species (60% of all North American Species), is habitat for 45 species of amphibians and reptiles and 50 mammal species, and represents a migratory pathway for 40% of American Waterfowl (UMRCC, 2000). The balance of the URMB as a system depends greatly upon the interactions of both terrestrial and aquatic species. Disruption to this balance by the addition of nonindigenous species or subtraction/extirpation of key native species could further alter the UMRB ecosystem.

Mussels

There are 62 species of mussels in the UMRB (Weitzell et al., 2003). Of the 62 species, five species are listed as federally endangered and sixteen species are listed as imperiled. Collectively, 26 of the 62 species are considered to be endangered, threatened, or species of special concern by resource professionals (Weitzell et al., 2003). The life history and ecology of these mussels rely heavily on fish species as hosts to complete larval stages. When hosts are not available, the species cannot complete their life cycles. A great majority of mussel species collected in the UMRB are adults rather than a mix of adults and juveniles (Weitzell et al., 2003). This observation suggests that suitable hosts are not being utilized and recruitment of mussel species in the upper reaches has been impacted by such things as lack of regional connectivity for the mussel and host species, competitive interaction with other species, loss of habitat for the mussels and host species, and/or the loss of a specific host necessary to complete life cycles. A listing of mussel species known to occur in the UMRB is provided in Appendix B.

Crayfish

Twenty-two (22) species of crayfish are found in the UMRB (Wietzell et al., 2003). Although none of the 22 species are federally listed, resource professionals list two as concerned and two species as vulnerable (Weitzell et al., 2003). Overall, the level of crayfish imperilment is considered to be low. A list of crayfish species known to occur in the Upper Mississippi River Basin is listed in Appendix B.

Fish

A total of 260 fish species have been reported in the UMRB, including its tributaries (UMRCC, 2000). Of the 260 reported species, 200 are native and are regularly occurring species (Weitzell et al., 2003). For the 1,381 km (858 mile) navigable portion of the UMRS alone, there are 156 fish species that have been reported. One hundred and forty-three (143) of the 156 reported species are considered indigenous to the UMRS. Collectively, 25% of all known North American fish species occur in the UMRS and the UMRB. A partial listing of the species occurring in the navigable portion (UMRS) is provided in Appendix B. Included with the listings are brief summaries of ecological characteristics for each species.

Fifty-one (51) Mississippi River fish species have been listed on state and federal threatened and endangered (T&E) lists. Many of these species naturally occur in the UMR portion of the river. The state and federal listings include:

Alabama shad	Grass pickerel	Pirate perch
Alligator gar	Gravel chub	Pugnose minnow
American eel	Greater redhorse	Pugnose shiner
Bigeye shiner	Highfin carpsucker	Redfin shiner
Blacknose shiner	Iowa darter	River darter
Blue sucker	Lake sturgeon	River redhorse
Blue catfish	Longear sunfish	Shovelnose sturgeon
Bluntnose darter	Miss. silvery minnow	Sicklefin chub
Brown bullhead	Mooneye	Silver jaw minnow
Burbot	Mud darter	Skipjack herring
Central mudminnow	Northern pike	Speckled chub
Chestnut lamprey	Orangethroat darter	Starhead topminnow
Crystal darter	Ozark minnow	Sturgeon chub
Flathead chub	Paddlefish	Trout-perch
Freckled madtom	Pallid shiner	Weed shiner
Ghost shiner	Pallid sturgeon	Western sand darter
Goldeye	Pearl dace	Yellow base

NatureServe and The Nature Conservancy (Weitzell et al., 2003) have classified several species of fish as imperiled or classified them as species of special concern. These classifications are independent of state and federal T&E listings and include twelve species of fish in the UMRB. An additional seven species are identified as “species of special concern” by fisheries professionals (Weitzell et al., 2003). Consideration of threatened and endangered status as well as the species of special concern should be made when evaluating impacts to the Mississippi River and when evaluating alternatives to reduce impacts.

Fish movement on the UMRS has been previously summarized before lock and dam construction (Coker, 1914 in Wilcox et al., 2003; Forbes and Richardson, 1920 in Wilcox et al., 2003; Coker, 1930 in Wilcox et al., 2003; Jordan and Evermann, 1923 in Wilcox et al.) and after lock and dam construction (Pitlo et al., 1995; Wilcox et al., 2003). An estimated number of 34 species are believed to migrate within areas of the UMRB; however, the number is thought to be an underestimation due to insufficient data on all species occurring in the UMR (Wilcox et al., 2003). Fish movement is critical for dispersal of fish to native breeding grounds, critical habitat and over-wintering areas. In addition to movement related to life history stages, UMRB fish may also serve as important hosts (see mussels above) for larval stages of species native to the UMRB. Movement of key host species into a critical habitat may determine the fate of some mussels. Similarly, downstream movement of species can be critical. For example, many species native to the river are pelagic spawners that produce buoyant eggs. These eggs become part of the icthyoplanktonic drift and are carried downstream. Knowledge of these stages is key to understanding the ecology of the river and the potential impacts to native species.

Aquatic Nuisance Species (ANS)

Nonindigenous species (NIS), also called exotic, alien or nonnative species, are generally referred to as those plants and animals that are found beyond their natural geographical ranges (US Congress, OTA 1993). It is estimated that as many as 50,000 nonindigenous species (plants, animals, invertebrates, microbes, etc.) have been introduced into the United States (Pimentel, Lach, Zuniga and Morrison, 2000). Not all nonindigenous species are harmful; some are beneficial including many food crops (US Congress, OTA 1993; Pimentel et al., 2000). In more specific terms, an invasive species is one category of nonindigenous species that is defined as 1) non-native (or alien) to the ecosystem under consideration and 2) whose introduction causes or is likely to cause economic or environmental harm or harm to human health (Executive Order 13112, 1999). Invasive species can cause direct harm to species and habitat by directly competing for resources and competitively interacting with native, indigenous species. Additionally, invasive species can result in indirect impacts to species and the general ecology of a system such as the UMRB. In either case, the impacts are often irreversible and costly. In a 1993 study produced by the United States Congress, Office of Technology Assessment, it was estimated that 79 nonindigenous species had caused approximately $97 billion in damages from a period of 1906 to 1991. However, more current estimates indicate that some nonindigenous species in the United States may cause as much as $137 billion of damage per year (Pimentel et al., 2000).

Most plant and vertebrate introductions were intentional, compared to invertebrate and microbe introductions that are mainly unintentional (Pimentel et al., 2000). Although intentional, not all introductions were malicious attempts to directly alter ecosystems but rather attempts to biologically control or enhance environments. Despite the introduction intentions, some nonindigenous species are spreading at alarming rates and threaten ecologically significant areas such as the Upper Mississippi River Basin.

A sub-classification of invasive species are the Aquatic Nuisance Species (ANS) described as nonindigenous species that threaten the diversity or abundance of native species; the ecological stability of infested waters; commercial, agricultural, aquacultural and recreational activities dependent on waters (ANS, 2000). The threat of ANS species has prompted action at local, state and federal levels. In 1990, The Nonindigenous Aquatic Nuisance Prevention and Control Act created a Task Force with three primary goals aimed at stopping or slowing the spread of ANS species. Reauthorized in 1996, the primary goals of the Task Force have remained:

1) To prevent introduction and dispersal of aquatic nuisance species
2) To monitor, control and study such species
3) To educate and inform the general public and program stakeholders about the prevention and control of these species

Regional panels of the ANS Task Force help coordinate ANS efforts and identify priorities in their respective regions. The Mississippi River Basin Regional Panel held a meeting in January 2004 and the panel members identified Asian carp as the top basin-wide concern (J. Rendall, pers. comm.). The increase in concern and need for prevention and control of ANS is exhibited by the establishment of state ANS programs and efforts. Minnesota, Wisconsin, Iowa, Missouri and Illinois all have established and/or expanding ANS programs.

Approximately 185 fish species occurring in U.S. waters have been identified as nonindigenous that originated from outside the U.S. (Fuller et al., 1999). Of the 185, seventy-five (75) are unique species with the remainder consisting of hybrid species (Fuller et al., 1999).

The introduction of ANS fish species has the potential to alter ecosystems and food webs (Pflieger, 1997) and cause extinction of some species (Taylor et al., 1984). Similarly, it is estimated that 44 species native to the Untied States are threatened or endangered by nonindigenous species (Wilcove and Bean, 1994 in Pimentel et al., 2000). While some nonindigenous fish species have been associated with positive economic benefits, the majority of nonindigenous, exotic fish species are associated with an estimated $1 billion per year economic loss (Pimentel et al., 2000). Concern about the spread of ANS, including Asian carp has been expressed by states (MN DNR Exotic Species Program 2002) and regional entities (MICRA River Crossings) for several years. Four species of Asian carp are among the 40+ nonindigenous species that pose a threat to waters in the United States. These Asian species include grass carp, bighead carp, silver carp and black carp. An overview of each species is provided below.

Review of Current Asian Carp Monitoring and Research

Multiple state and federal agencies are actively researching, monitoring and funding projects related to the introduction of Asian carp into the Mississippi River Basin. **Figure III-3** briefly highlights key locations for research, monitoring points and experimental project locations associated with Asian carp in the UMRB.

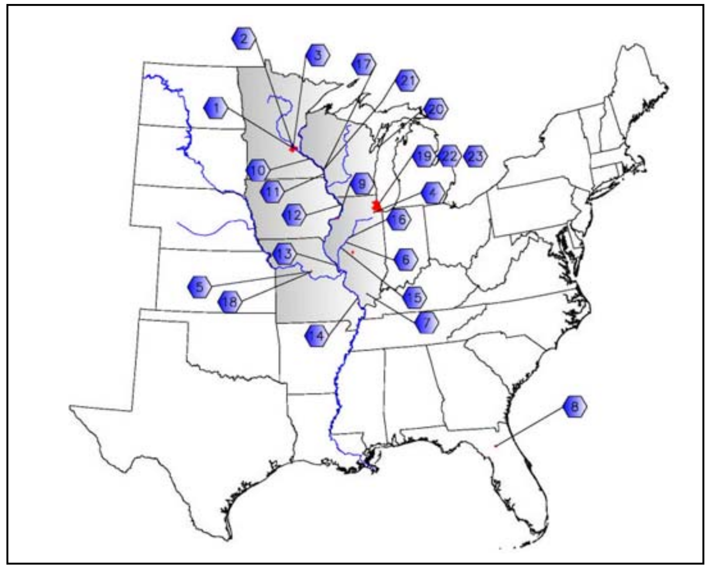


Figure III-3. Key Asian Carp Activity Areas Associated within the UMR

1. Minnesota DNR, St. Paul, MN
2. U.S. Fish and Wildlife Service- Region 3, Fort Snelling, MN
3. St. Paul District USCOE, St. Paul, MN
4. COE Experimental Electrical Barrier Site, Romeoville, IL
5. U.S. Geological Survey – Columbia Environmental Research Center, Columbia, MO
6. IL Natural History Survey-Illinois River Biological Station, Havana, IL
7. U.S. Fish and Wildlife Service-Carterville Fishery Resources Office, Marion, IL
8. U.S. Geological Survey/BRD Nonindigenous Aquatic Species Program, Center for Aquatic Resources Studies, Gainesville, FL
9. U.S. Fish and Wildlife Service, Rock Island, IL - Mississippi Interstate Cooperative Resources Association (MICRA) Coordinator
10. Mississippi River Pool #4 LTRMP Monitoring Location 1
11. Mississippi River Pool #8 LTRMP Monitoring Location 2
12. Mississippi River Pool #13 LTRMP Monitoring Location 3
13. Mississippi River Pool #26 LTRMP Monitoring Location 4
14. Mississippi River Open River (OR) LTRMP Monitoring Location 5
15. Illinois River La Grange Range (LG) Pool LTRMP Monitoring Location 6
16. Jake Wolf Memorial Fish Hatchery (INHS-Electrical and Acoustical Barrier Experiments)
17. U.S. Fish and Wildlife Service-La Crosse Fishery Resources Office, Onalaska, WI
18. U.S. Fish and Wildlife Service-Columbia Fishery Resources Office, Columbia, MO
19. Metropolitan Water Reclamation District of Greater Chicago
20. University of Wisconsin Sea Grant Institute
21. USGS – Upper Midwest Environmental Science Center, LaCrosse, WI
22. Chicago District USCOE, Chicago, IL
23. USEPA Region 5, Chicago, IL

In addition to the numbered areas, the shaded states have key Department of Natural Resource personnel devoted to Asian carp monitoring, management and control in the UMR. The key areas of Asian carp activity have been briefly summarized below and are arranged by species in order to provide an overview. Additional references, personal communications and database links are cited within the text and in the reference list located in Appendix C. Included with the summaries are accounts of movement and distribution by species. Three data sources were used to track movement and distribution: 1) commercial fishing data published by the Upper Mississippi River Conservation Committee (UMRCC); 2) Upper Mississippi River Long Term Resource Monitoring Program (LTRMP) data distributed by the United States Geological Survey (USGS) Upper Midwest Environmental Services Center; and 3) the Nonindigenous Species Database maintained by the USGS, Center for Aquatic Resource Studies (USGS, 2004). All three databases were accessible via the Internet. Where possible, the most current and verified data were used to create the species accounts and were obtained directly from the data coordinator. For example, the most current USGS distribution data was submitted directly to FishPro and is cited as Bensen, pers. comm. and Fuller, pers. comm. While multiple sources of distribution data exist, including personal accounts, the three major sources were utilized in an effort to provide standardized and documented records of the species. Coordination of future species occurrences as well as their status should be coordinated through the established framework of these systems to avoid misinterpreted accounts of the species. Further, coordination and verification of the data listed in these sources by the key personnel from each state and/or region is needed in order to provide the most accurate source of data. Additional accounts identifying key research topics and the facilities conducting this research are included in Appendix G. These areas include such things as research on life history stages, competitive impacts with native species, effectiveness of technology as barriers and general ecology. Finally, hybridization is known to occur in between closely related species (Jenkins and Burkhead, 1994 in Fuller et al., 1999). While it is possible that hybrid and back-crossed hybrids of these species have occurred, documentation of hybridization is difficult and is not included in the distribution summaries. However, Fuller et al. (1999) commented that hybridization and introgression between introduced and native species is an issue of increasing concern.

The data collection and reporting methods for each of the three sources vary greatly. The commercial fishing data provided by UMRCC is a summary of reported pounds of harvest from within each pool along the Mississippi River from 1997-2001. Individual states report commercial fishing harvest to the UMRCC for summary and publishing in annual proceedings. These states include Illinois, Iowa, Minnesota, Missouri and Wisconsin. Tables containing commercial fish harvest data for 1997-2001 are provided in Appendix F. The data was obtained from the UMRCC and sorted for analysis in Microsoft Excel.

Data collection for the LTRMP was authorized by the United States Corps of Engineers (USCOE) as outlined in the USCOE Environmental Management Program. The program originally provided funding to sample for ten years with authorization under the Water Resources Act of 1986. The program was extended five additional years by Section 405 of the Water Resources Development Act of 1990 and extended indefinitely by Section 509 of the Water Resources Act of 1999 (USGS, 2004). The program established six field stations operated by the states located within the UMR. These stations include:

1. (Lake City, MN) Mississippi Pool 4, Sampled 1990 to present
2. (Onalaska, WI) Mississippi Pool 8, Sampled 1989 to present
3. (Bellevue, IA) Mississippi Pool 13, Sampled 1989 to present
4. (Alton, IL) Mississippi Pool 26, Sampled 1989 to present
5. (Cape Girardeau, MO) Mississippi Open River, Sampled 1991 to present
6. (Havana, IL) Illinois, Mississippi La Grange, Sampled 1990 to present, (also sampled Pool 26 in 1995)

LTRMP data was downloaded from the LTRMP database (USGS, 2004), imported into Microsoft Access and analyzed with Access and Microsoft Excel.

Data collected from the Nonindigenous Species Database represents a collection of "sightings" or "occurrences" of species. The database is intended to be an accurate accounting of nonindigenous species and includes categories such as: common name, date of observation, location description, location by eight digit hydrological unit code (HUC8) name and number, state of collection, county and a determination of status (e.g., collected, established, stocked and unknown). Determination of the species status was made by the USGS based on the available records. Updates or corrections to the status of each species should be coordinated through the Gainesville office. Data was obtained directly from the Nonindigenous Species Database coordinators in Gainesville, FL. The data was analyzed using Microsoft Excel and Geographic Information System (GIS) software.

Bighead Carp (*Hypophthalmichthys nobilis*)

Overview: Bighead carp (see **Figure III-4**) have been described as a large-bodied planktivore native to Eastern China (Schrank, Braaken and Guy, 2001; Schrank and Guy, 2002; Rasmussen 2002; USFWS, 2002) that was introduced into the United States in the early to mid 1970s (Chick, 2001; Rasmussen 2002; Schrank and Guy, 2002). The original introduction of the species has been linked to private aquaculture farms in Arkansas (Fuller et al., 1999; Koel et al., 2000) that imported the species to improve water quality in fish culture ponds (Fuller et al., 1999; Schrank and Guy, 2002).


Photo: Courtesy D. Chapman - USGS

Figure III-4. Bighead carp collected in the Missouri River

Bighead carp can pose a significant threat to the ecosystems of large river systems by altering food webs, decreasing plankton abundance and competing with native species (Pflieger, 1997). The species are currently moving upstream in the major rivers of the United States and have attracted considerable attention.

Phylogeny:
Class: Actinopterygii
Order: Cypriniformes
Family: Cyprinidae
Name: *Hypophthalmichthys nobilis* also *Aristichthys nobilis*

Physical Description (source USFWS – see Appendix E for Entire Key to Identification): Deep bodied, somewhat latterly compressed with back and upper sides dark gray grading to off-white on lower side and belly, many dark to black irregularly shaped blotches scattered over entire body.

- Maximum Observed Weight – 41 kg (90 lbs) (Pflieger, 1997)
- Maximum Observed Length – 150 cm (59 in) (Laird & Page 1996)

Pflieger (1997) described the species as large, heavy-bodied fish with an exceptionally large head, an upturned mouth and small scales. He noted the eyes were located far forward in the lower part of the head and are turned downward as if the fish was looking down.

Biology: Bighead carp are known to occur in open waters in a variety of temperatures ranging from 3.4^{o}C to 26.1^{o}C (Rasmussen, 2002) but have more recently been reported with full guts at temperatures as low as 2.5^{o}C in the Missouri river indicating active feeding at lower temperatures (D. Chapman, pers. comm.). Known to occur in open river water during spawning (Schrank et al., 2001, Rasmussen, 2002), Pflieger (1997) noted the "affinity for the lower reaches of tributary streams and overflow waters on the river floodplains". D. Chapman (pers. comm.) added that large populations are found behind wingdam areas of the Missouri River.

Feeding primarily on zooplankton, these benthopelagic filter feeders have been known to consume algae, aquatic insects and detritus (Robinson & Buchanan 1988 in Rasmussen 2002). Bighead carp have also been seen below dams on the Missouri River feeding on organic surface scum (D. Chapman, pers. comm.; Stancill, pers. comm.). The preferred diet of bighead carp may be zooplankton with cladocernas, copepods and rotifers as important food sources (Schrank and Guy, 2003). Bighead carp may switch to phytoplankton when zooplankton densities are low as reported in Schrank and Guy (2003). Bighead are capable of trapping food as small as 20 microns in diameter (Pflieger, 1997) with gill raker spacing 0.07 to 0.08 mm (Schrank and Guy, 2003). A mucus secretion aids the fish in trapping small particles (Pflieger, 1997)

Photo: Courtesy MN DNR

Figure III-5. Bighead carp collected in Lake Pepin, MN

Bighead carp (see **Figure III-5**) typically reach sexual maturity by the third year in the United States (Schrank and Guy, 2002) and have a fecundity that ranges from 226,213 to 769,964 eggs (Schrank and Guy, 2002), which is similar to reports in Russia (Sukhanova, 1996 in Rasmussen, 2002) indicating some similarity between species occurring in other countries. Maximum egg size is 1.8 mm (Schrank and Guy, 2002). Spawning is generally associated with water level rises in the early to late spring (Verigin et al., 1978; Pflieger, 1997). As the river water levels rise, the species begin to migrate upstream to spawn. Spawning has also been reported at the confluence of two rivers, behind sandbars, stonebeds or islands (Rasmussen, 2002). These areas are characterized by rapid flow (>79.2 cm/sec) and mixing water (Huet, 1970 in Rasmussen, 2002 and in Schrank et al., 2001). In addition to flow, spawning is also correlated with water temperatures. The optimum spawning temperature range for the species is between 22^{o}C and 26^{o}C but 18^{o}C represents the lowest spawning limit (Jennings, 1988). Schrank et al., (2001) report that increasing flows and temperatures above 22^{o}C are needed for bighead carp to spawn in the Lower Missouri River. Bighead carp are pelagic spawners requiring a flow to carry buoyant eggs downstream. Eggs are semi-buoyant and larvae hatch about 1 day after fertilization (Jennings, 1988). Floating larvae become part of the ichthyoplankton drift (Etiner and Starne, 1993) and after approximately seven days will migrate to shore to seek nursery areas created by high water levels (Huet 1970 in

Rasmussen 2002). Multiple spawning times in a given year are widely reported (Pflieger 1997; Jennings 1988; 2002).

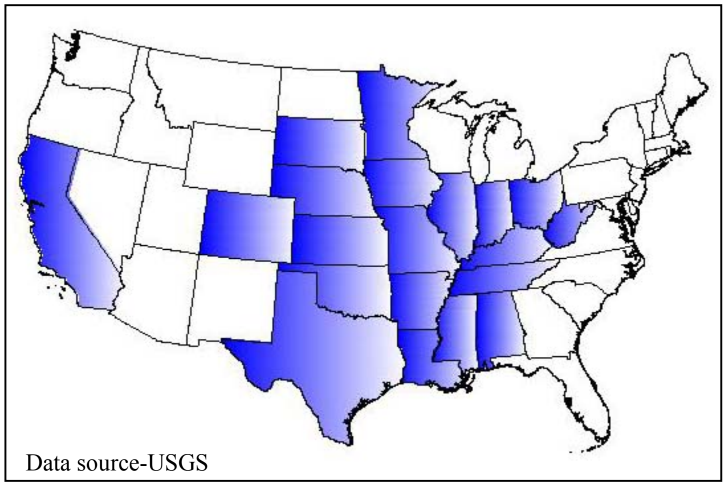


Figure III-6. States with Reported Bighead Carp Collections

Distribution and Movement: Bighead carp are believed to have escaped from private aquaculture ponds and entered the Ohio and Mississippi Rivers (Fuller et al., 1999; Koel et al., 2000) and the Missouri River (Schrank and Guy 2002) in the early to mid-1980s. Pflieger (1997) reports that bighead carp were present in the Mississippi and Missouri Rivers by 1982 with the first confirmation of spawning in 1989. Since introduction into the wild, bigheads have been reported in 20 states and one Canadian Province (see **Figure III-6**, USGS, pers. comm.). Occurrences of the species in the wild (versus captive stocks in aquaculture) have been recorded 141 different times since 1984 when the first reported sighting in the wild was logged by the USGS (A. Benson, pers. comm.). While the records maintained by USGS indicate 1984 as the first reported collection of bighead, other reports indicate the species was already present in the Mississippi River as early as 1982 (Freeze & Henderson, 1982; Plieger, 1997).

Current data indicate the species is expanding its distribution upstream in the major rivers of the United States as evidenced by the increasing number of reported occurrences and the increasing number of 8-Digit hydrologic units codes (HUC8) with documented sightings (Benson, pers. Comm.). In the first month of 2004 alone, 17 occurrences of the species have been logged by the USGS compared to 10 occurrences in all of 2003. The number of reported occurrences of the species in the wild has increased, which is due, in part, to increased awareness of the species when sampling. It should also be noted that traditional river sampling techniques utilized by river biologists are not an efficient means of Asian carp species collection (D. Chapman, pers. comm.; J. Milligan, pers. comm.; W. Stancill, pers. comm.). Bighead carp are more easily startled and scatter from approaching boats than native fish species collected with the same techniques (D. Chapman, pers. comm.; Sifa and Senlin, 1995). Modification of techniques is often needed to collect the species for proper identification and enumeration (D. Chapman, pers. comm.; J. Milligan, pers. comm.; W. Stancill, pers. comm.). Despite the increased awareness, large numbers of the species may still be unreported and estimates of populations may be underestimates of the standing biomass present in the rivers of the United States (USFWS, pers. comm.).

Figure III-7 represents LTRMP bighead carp total fish caught per year for the monitoring points along the Upper Mississippi River only. Bighead carp have not been sampled within Pools #4, #8 and #13 as part of the LTRMP monitoring efforts. Bighead carp have been detected as part of other sampling programs in very small numbers (see below) but not as part of LTRMP monitoring. Pools #26 and the Open River locations have significant numbers of bigheads established. The first LTRMP sampling of bighead occurred in 1993 at Pool 26 and presumably the Open River location (1993 Open River Data was not available). Both locations have increased in total number caught by all gear utilized in the LTRMP. Large spikes in the number caught were detected at the Open River location (1998) and Pool #26 (2000). Additionally, large numbers were also caught in the LaGrange Range of the Illinois River in 2000 (data not shown). These increases are documented in the literature (Chick, 2001) but the explanation for the increase in still under investigation.

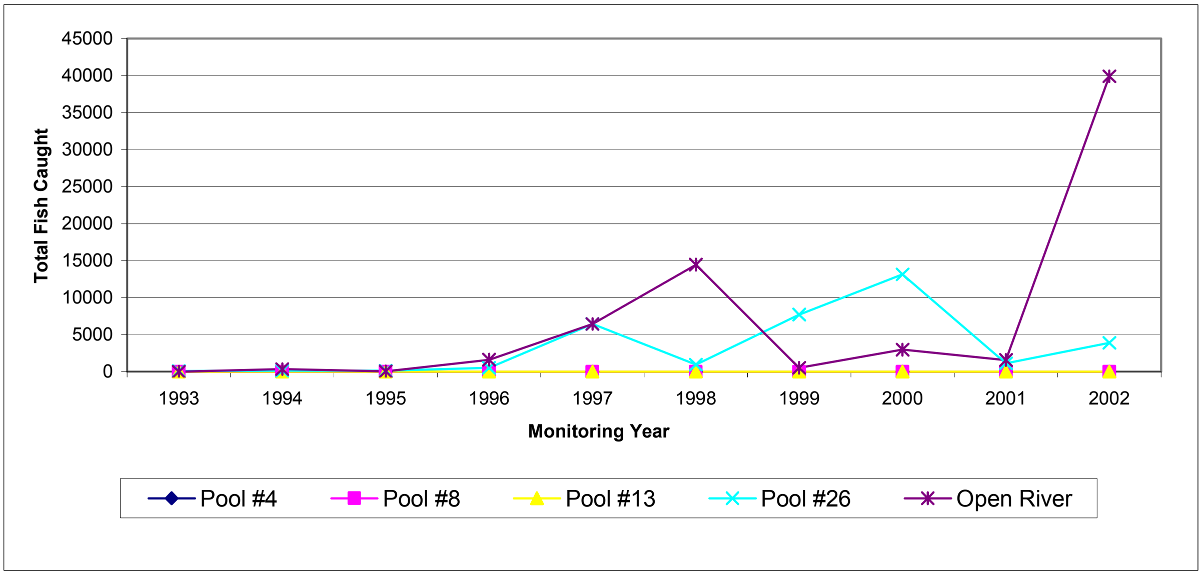


Figure III-7. Bighead Carp LTRMP Total Catch per Year

Movement in miles traveled per year for the species has not been thoroughly documented; however, a single bighead was tracked for 260 km (162 miles) in the Lower Missouri River main river channel (D. Chapman, pers. comm.). The distance covered by that particular fish represents only main river channel distance and does not include the likely travel in minor tributaries of the Missouri. Estimates of upstream population movement in major rivers of the United States have been estimated to be approximately 50 miles per year for species of Asian carp with a population becoming established approximately two (2) years after the first individual arrives (USFWS, pers. comm.).

Figure III-8 depicts bighead carp occurrences by HUC indicating where the species has been collected or has attained established status. Data obtained from the USGS Nonindigenous Aquatic Species Program document occurrences of bighead within HUC8-70801010, which is located in northwestern Illinois. The HUC, which includes Lock and Dam #13-#17 indicates the most northward advance of observed individuals that is supported by current data (February 2004). Commercial fishing data released by the UMRCC collaborate these sightings as far north as Pool #15. There were two individuals collected from Pool 4 and the St. Croix River that are reflected in Figure III-8 with a lighter shade of red to reflect a collected status. The extent of the shading encompasses the entire HUC8 area that the fish were collected from. **Figure III-9** depicts the commercial harvest in pounds reported for each pool in the UMRS. Asian carp harvest from above Lock and Dam 19 is reported as early as 1997. Based on available data, commercial harvest of Asian carp (both bighead and silver) have been reported in Pool #19 in 1997, Pool #18 in 1998, and Pools #15 and #17 in 1999. Commercial harvest reports from 2001 indicate Asian carp presence in Pool #15; however, no Asian carp were reported from Pools #15 and #16 in 2000. While the data suggests movement as far north as Pool #15, the small number of reported commercial harvest from Pool #15 and the years with no reported commercial harvest in Pools #15 and #16 indicate the populations in Pool #15 have not reached a critical mass as of 2001.

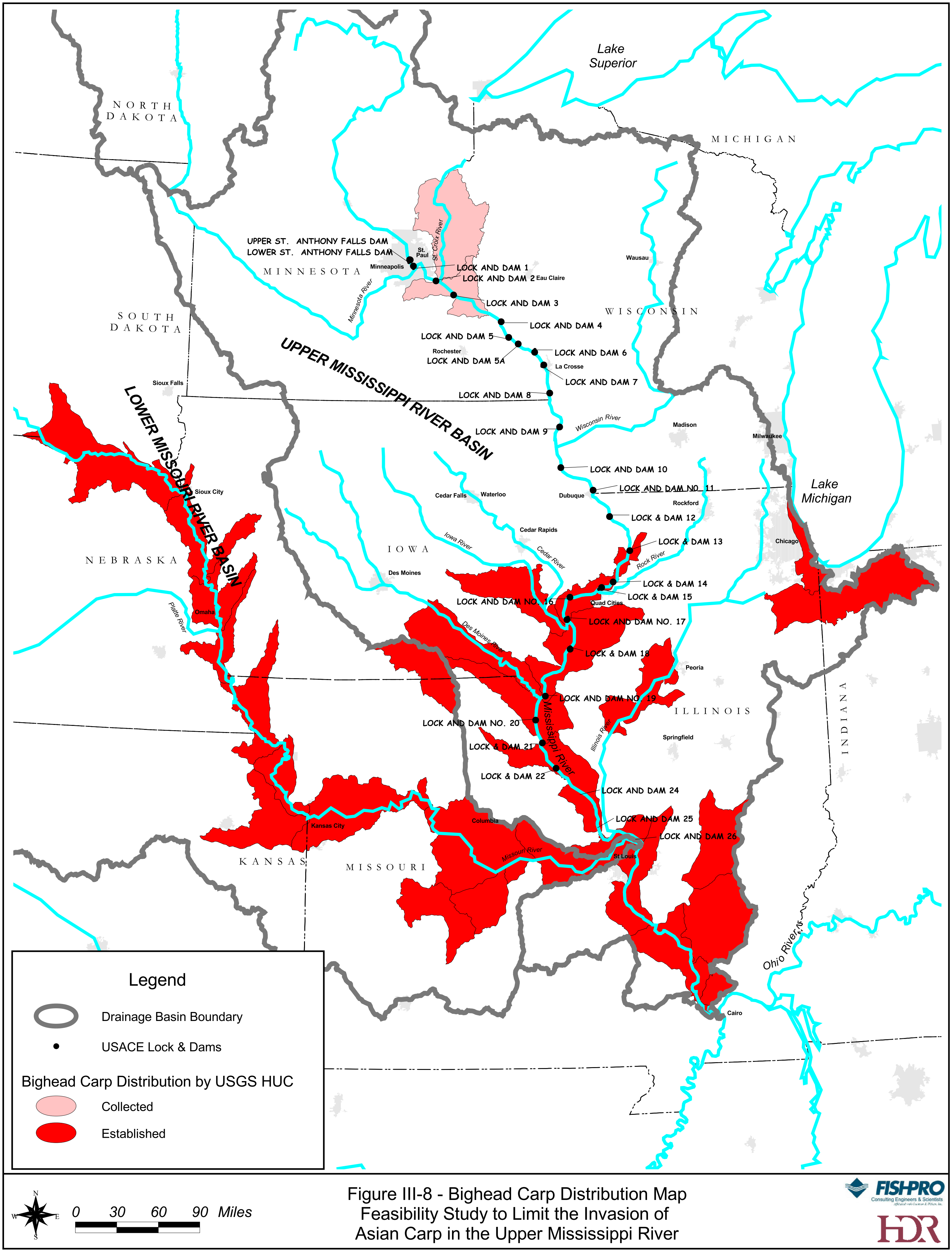


Figure III-8 - Bighead Carp Distribution Map
Feasibility Study to Limit the Invasion of
Asian Carp in the Upper Mississippi River

FISHPRO Consulting Engineers & Scientists

HDR

It should also be noted that in 2000, a total of 6.8 kg (15.0 lbs) were reported in Pool #14. In no other year prior two or after 2000 are Asian carp reported in Pool 14. Also in 2000, no Asian carp were reported in the commercial harvest for Pools #15 and #16, which are below Pool #14. This observation raises question about the reporting of Pool #14 in 2000 and should be confirmed. All summaries from commercial harvest were based on available data from 1997 through 2001. Similarly, it should be noted that sampling conducted by Pitlo et al. (1995) indicate the occurrence in Pool #10 and classify it as rare. However, the authors cautioned against the use of the document as the ultimate source in species occurrence and abundance. For this reason, the occurrence is not documented on **Figure III-8**.

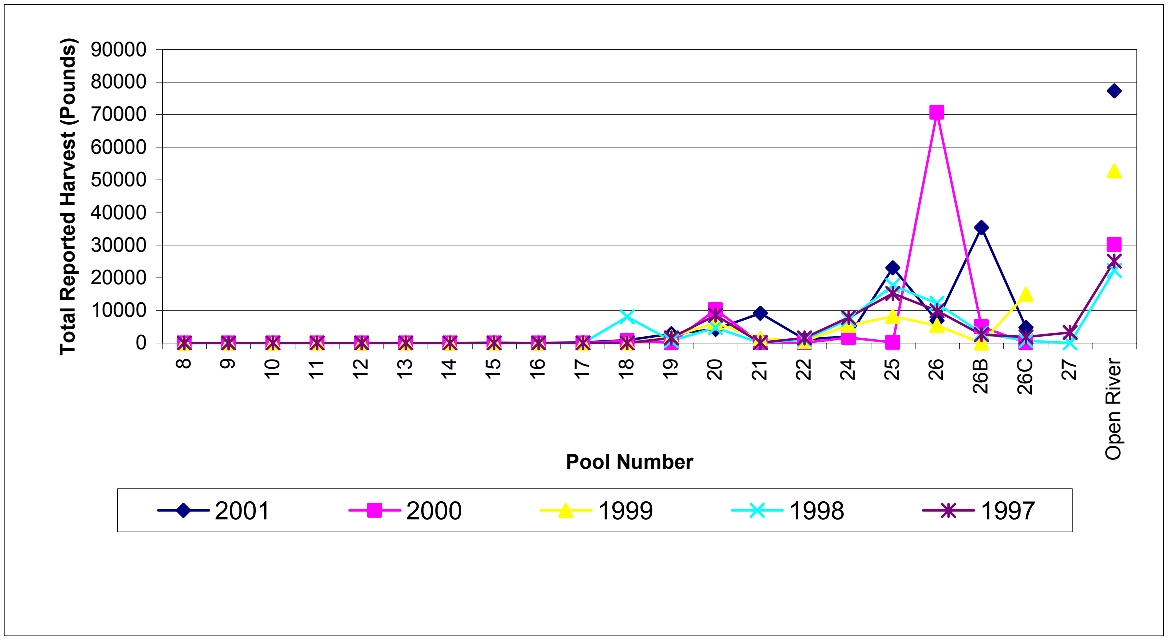


Figure III-9. Commercial Harvest of Asian Carp in UMR Pools #8 - #27

Silver Carp (*Hypophthalmichthys molitrix*)

Overview: Silver carp (see **Figure III-10**) are native to eastern China, portions of eastern Russia and possibly portions of northern Vietnam (Fuller et al., 1999). Very similar in size and shape to the bighead, the silver carp have been described as the "flying carp" due to its unmistakable jumping and leaping behavior exhibited when the species becomes startled (Skelton, 1993; Plieger, 1997). This leaping ability has gained the species an unsavory reputation in many major news media outlets (Rather, 2003; Lien, 2003; Tribune, 2002) and has been blamed for near death encounters for humans (Brant, 2004). Silver carp were brought to the United States in an attempt to aid private fish farmers in controlling aquatic vegetation in the early 1970s (Freeze and Henderson, 1982; Rasmussen, 2003; Koel et al., 2000).

Reports of silver carp being raised at state, federal and private hatcheries as well as being stocked in wastewater treatment ponds have been documented (Robinson and Buchanan, 1988 in Rasmussen, 2003). Silver carp have been documented in many parts of the world. In Europe, established populations are in areas of the Danube River. The species has been imported to over 40 countries mainly for the purposes of aquaculture (Welcomme, 1988 in Costa-Pierce, 1992).

Compared to native fish species in the Mississippi River, little is known about silver carp and their potential impacts. However, silver carp are adapting to the conditions of the temperate climates of the United States (Rasmussen, 2002) and should be perceived as a potential threat.

Figure III-10. Silver Carp Species

Phylogeny:
Class: Actinopterygii
Order: Cypriniformes
Family: Cyprinidae
Name: *Hypophthalmichthys molitrix*

Physical Description (source USFWS – see Appendix E for Entire Key to Identification):
Deep-bodied, laterally compressed body, very silvery in color in young with back and upper sides changing to olivaceous (greenish), grading to silver below the lateral line in adults.

- Maximum Observed Weight: 50 kg (110 lbs) (Rasmussen, 2002)
- Maximum Observed Length: 102 cm (40 in) (Rasmussen, 2002)

Pflieger (1997) described the species as similar to bighead carp but with a keel on belly midline extending forward from anus nearly to throat. Rakers on the first gill are fused.

Biology: As alluded to above, information on silver carp is difficult to come by and often still transmitted by word of mouth. Despite not having large amounts of published data on the species, there are some traits that have been published by a select few and a general understanding is developing. Further research is needed to confirm data in the United States and to fill in gaps of knowledge on the species.

Photo: Leonard L. Lovshin

Figure III-11. Silver Carp Species

Silver carp (see **Figure III-11**) prefer standing or slow flowing water near or behind impoundments and in backwater areas (Rasmussen, 2002; D. Chapman, pers. comm.) and are known to school (Pflieger, 1997). The species occur in a similar thermal range as bighead, but have been known to prefer a slightly warmer overall temperature range, 6.1^{o}C to 28.0^{o}C (Rasmussen, 2002). In addition to bighead carp, silver carp have also been reported with full guts at temperatures as low as 2.5^{o}C in the Missouri river indicating active feeding at lower temperatures (D. Chapman, pers. comm.). These fish are Planktivorous and feed primarily on phytoplankton and zooplankton, but will also feed on detritus (Costa-Pierce, 1992). Silver carp are not exclusively plankton feeders, but considerable debate has remained as to the specific feeding niche of the species in varying environments. In native silver carp waters, the species feeds primarily on zooplankton at the fry stage switching to epibenthic browsing and detritus rather than exclusive pelagic and phytoplankton feeding (Costa-Pierce, 1992; Pflieger, 1997). Silver carp and bighead carp feeding niches overlap causing competition for food sources (Hao-Ren, 1982 in Costa-Pierce, 1992). Similar to bighead carp, silver carp are reported to vary their diet depending on available food source and may consume any suspended material (Shan et al., 1985 in Costa-Pierce, 1992). Silver carp also have a notable netlike covering or spongelike porous matrix (USFWS, 2002) that allows the species to filter suspended materials as small as four (4) microns in diameter. The species also has the ability to reject unwanted material and has been observed "spitting" during blue-green algae blooms (Savina, 1965 in Costa-Pierce, 1992). Silver carp feed by sucking water and suspended materials through the mouth and over the spongelike gills. Large mucus secretions are also reported in silver carp similar to bighead carp (Pflieger, 1997). These modified gill rakers and ability to filter to four (4) microns may support suggestions that silver carp are nonselective feeders (Spataru and Gophen, 1985 in Costa-Pierce, 1995) and explain the reported differences observed in gut content analysis from silver carp species by varying authors as reported in Costa-Pierce (1995).

Spawning in silver carp is very similar to spawning in bighead carp as outlined above. In general, temperatures exceeding 18^{o}C trigger spawning when combined with a rise in water level and velocity increases (Costa-Pierce, 1992; Pflieger, 1997). Spawning conditions in native ranges as reported in Costa-Pierce (1992) indicate that temperatures may be as low as 16^{o}C and as high as 23^{o}C. Flow rates during spawning in native habitats ranged from 0.8 m/s to 1.8 m/s. Water level increases ranged from 0.5 m to 2.5 m and could occur in as little as 12 hours before the spawning (Costa-Pierce, 1992). Silver carp can reach maturity at 46 cm (18 in) with fecundity between 50,000 and 200,000 eggs (Rasmussen, 2002). Spawning can also occur multiple times per year (D. Chapman, pers. comm.) and can be spontaneous (Costa-Pierce, 1992). Growth potential in temperate climate rivers is good. A single silver carp species can gain as much as five or six pounds in one year (Pflieger, 1997).

Distribution and Movement: Similar to bighead, silver carp are believed to have escaped from private aquaculture ponds with the first occurrences recorded in Arkansas in 1981 (Rasmussen, 2002). Commercial fishing reports indicate the species was being captured during commercial harvest as early as 1980 (Costa-Pierce, 1992; Pflieger, 1997). Silver carp have been reported in 14 of the contiguous states, Hawaii and eastern Puerto Rico (A. Benson, pers. Comm.; P. Fuller, pers. Comm.). **Figure III-12** displays the states with documented occurrences. It should be noted that Mississippi currently (Feb., 2004) does not list any occurrences of silver carp in the USGS Nonindigenous Species Database. This is more than likely due to lack of a documented occurrence in the Nonindigenous Species Database denoted as collected in Mississippi and not due to the lack silver carp in that area.

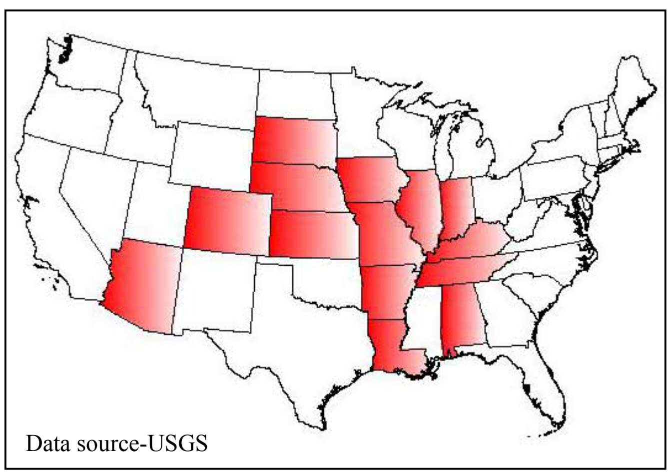
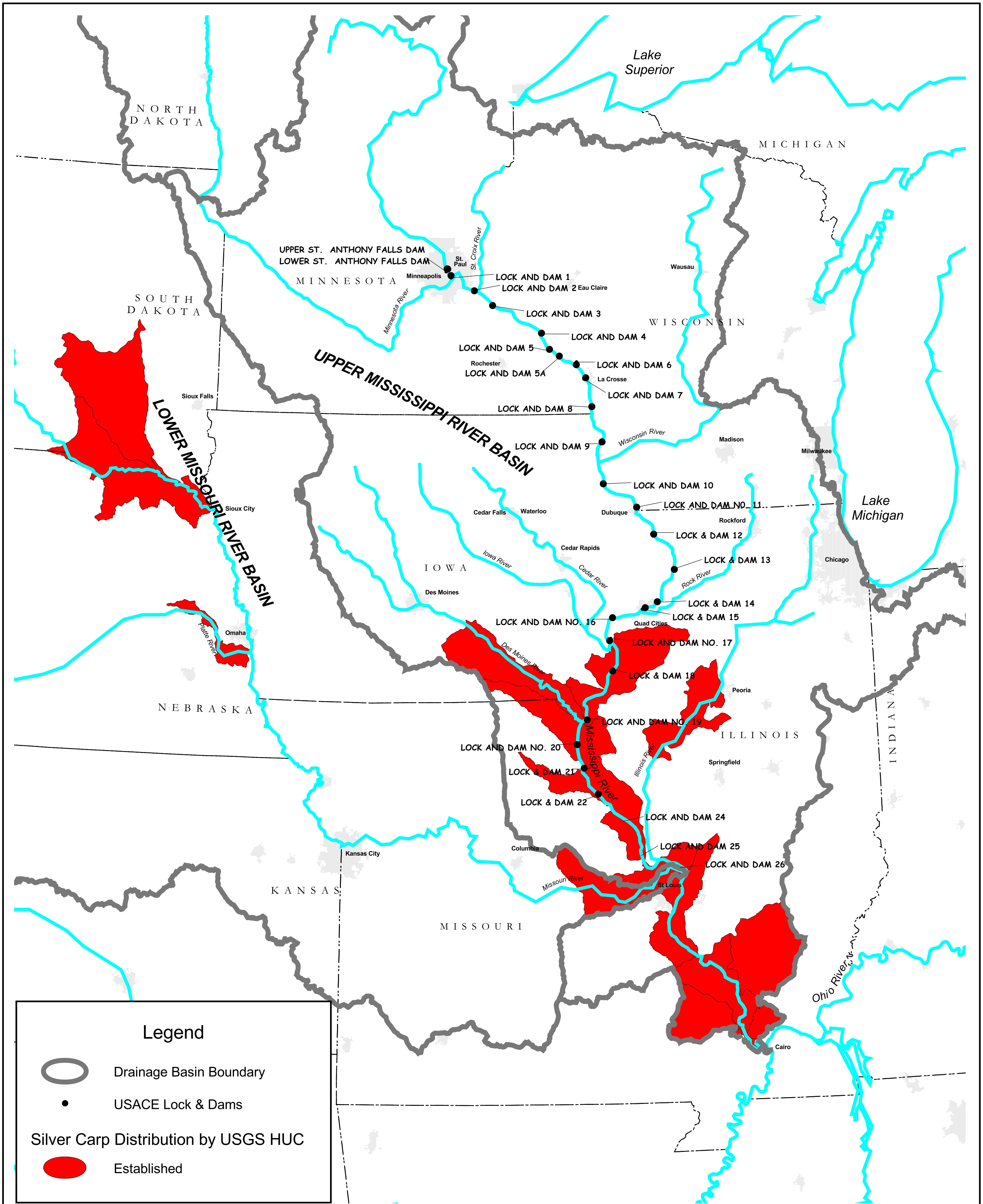


Figure III-12. States with Reported Silver Carp Occurrences

Silver carp occurrences have been recorded in the Nonindigenous Species Database 91 separate times since first being logged in the database in 1972. Silver carp are expanding and continue to march northward in the Mississippi River, but generally do not appear to establish populations before or as fast bighead carp (D. Chapman, pers. comm.). This supports the rapid movement of the species based on the known current distribution (2004). These observations are supported by the silver carp distribution data (**Figure III-13**). The northward occurrence of the silver carp is HUC8 7080104, south of the northernmost bighead occurrence. As was noted with bighead carp above, traditional river sampling techniques utilized by river biologists are not an efficient means of Asian carp species collection (D. Chapman, pers. Comm.; Sifa and Senlin, 1995; Costa-Pierce, 1992). The leaping ability of the species and the extreme sensitivity to disturbance often make the silver carp species difficult to catch using traditional techniques (D. Chapman, pers. comm.; J. Milligan, pers. comm.; W. Stancill, pers. comm.). For these reasons, distribution data and density estimates may be underestimating the total extent of species distribution.

Figure III-14 represents LTRMP silver carp total fish caught per year for the monitoring points along the Upper Mississippi River only. Similar to bighead, silver carp have not been sampled within Pools #4, #8 and #13 as part of the LTRMP monitoring efforts. Pools #26 and the Open River location have significant numbers of silver carp established but at much smaller densities than the bighead carp. The first documented catch of silver carp as part of the LTRMP was in Pool #26 in 1998. Since that time, the numbers of silver carp caught each year has steadily increased. In addition, the Open River location has been reporting increasing numbers since 2000 (**Figure III-14**).

Commercial data for both species of Asian carp are included in **Figure III-9**. Commercial fishing data does not separate harvest by bighead versus silver carp but instead reports them together. The lack of specific LTRMP sampling points between Pool #26 and Pool #13 make the separation of this data into bighead carp versus silver carp difficult. However, data recorded in the Nonindigenous Species Database indicate that the northernmost occurrences of silver carp are below Lock and Dam #17 versus bighead distribution that has occurrences within the area (HUC8) of Lock and Dams #13, #14, #15, #16 and #17 (see **Figures III-8** and **III-13**). Based on the Nonindigenous Species Database, commercial fishing harvest data between Pools #15 and #17 are estimated to contain mostly bighead carp. Further monitoring is needed to verify this assumption. One exception to the Nonindigenous Species Database was the collection of a silver carp captured by commercial fisherman in 2003 (R. Maher, pers. comm.)



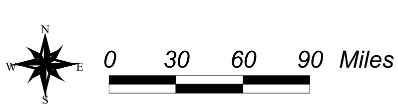


Figure III-13 - Silver Carp Distribution Map
Feasibility Study to Limit the Invasion of
Asian Carp in the Upper Mississippi River

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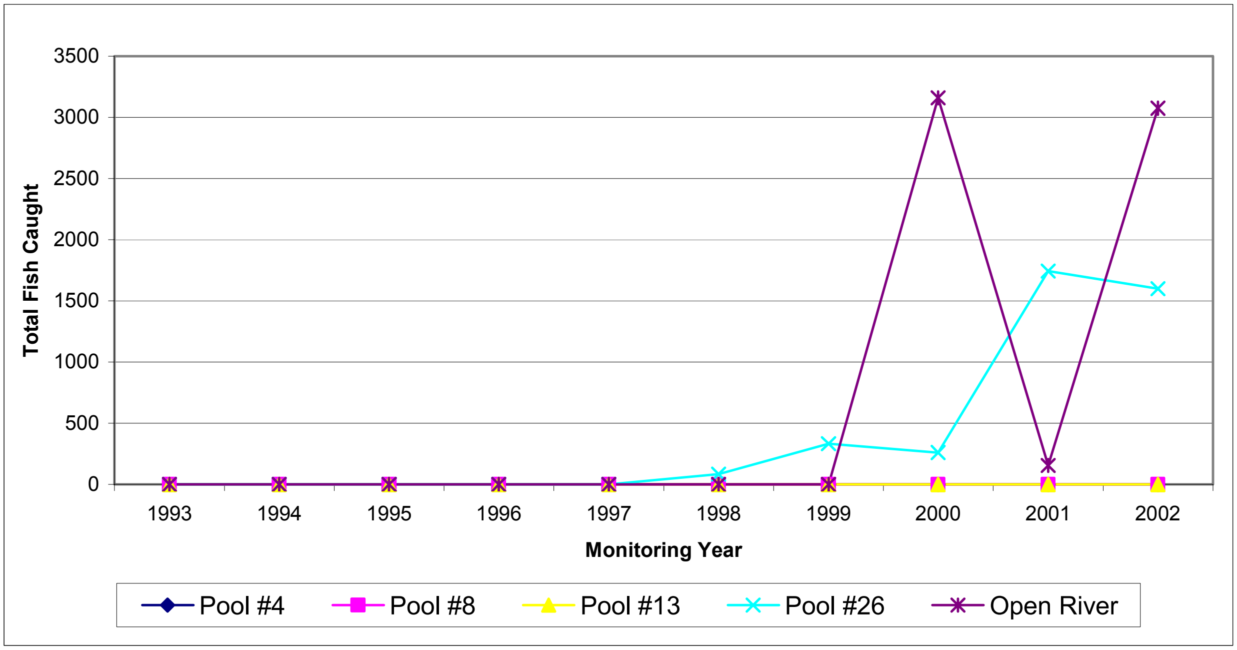


Figure III-14. Silver Carp LTRMP Total Catch per Year

Black Carp (*Mylopharyngodon piceus*)

Overview: Also from eastern Asia, the black carp was introduced into the Untied States as a contaminant in imported grass carp stockings during the 1970's (Nico and Willams, 1996). The species was re-imported intentionally in the mid 1980's to control the spread of trematode parasite (*Clinostomum margaritum*) in catfish culture (Nico and Williams, 1996 in Rasmussen, 2002). The only known escape of black carp occurred in Missouri in 1996 when an estimated 30 or more individuals and an unknown number of bighead carp escaped into the Osage River (Rasmussen, 2002).

The black carp (see **Figure III-15**) are known for their ability to crush the shells of mussels and extract the contents (USEPA, 2002). In 2000, the US Fish and Wildlife Service received a request from the Mississippi Interstate Cooperative Resources Association (MICRA) to list the species as injurious in the United States under the Lacey Act. The listing of the species as injurious would prohibit interstate sale or shipment of the species.

Photo source: fishbase.org

Figure III-15. Black Carp Species

Phylogeny:

Class: Actinopterygii
Order: Cypriniformes
Family: Cyprinidae
Name: *Mylopharyngodon piceus*

Physical Description (source USFWS – see Appendix E for Entire Key to Identification): The black carp is described as having a thick, elongate body with a broad, blunt head. The species also has golden/dark grey/brown color with scales on back and sides showing a prominently dark-edge, giving a characteristic cross-hatched effect. Juveniles closely resemble grass carp (*Ctenopharyngodon idella)*

- Maximum Observed Weight – 68 kg (150 lbs) –(USEPA, 2002)
- Maximum Observed length – 152 cm (60 in) (USEPA, 2002)

Biology: Black carp are known to occur in rivers but specific temperature ranges for the species are not known (Froese and Pauly, 2003; Rasmussen, 2003). Black carp feed primarily on zooplankton and fingerlings in fry and juvenile stages, and primarily mollusks and crustaceans as adults (USEPA, 2002; Rasmussen, 2003). Modified pharyngeal teeth that are fused and hardened allow the species to crack the shells of most mollusks native to rivers in the United States. The species has also been known to feed directly on freshwater shrimp, crawfish and insects and is known to handle almost any item it can get into its mouth (USEPA, 2002). Maturity is reached from 6 to 11 years (USEPA, 2002) and the species spawns at temperatures similar to silver and bighead (18.6^{o}C to 26^{o}C, USEPA, 2002). Fecundity estimates for black carp are 129,000 to 1,180,0000 eggs per year (USEPA, 2002). Black carp are rheophilic and pelagic spawners similar to bighead and silver carp as outlined above.

Distribution and Movement: Black carp distribution in the wild is limited. However, documentation of species collections are listed in the Nonindigenous Species Database. Collections indicate occurrences in Missouri and Illinois (see **Figures III-16 and Figure III-17**). The occurrences in Missouri are linked to escapement from a private fish farm in 1994 into the Osage River (Rasmussen, 2003). While the status of black carp in the Cache River is listed as unknown, the collection of a single adult species by a commercial fisherman in March of 2003 was the first black carp caught in the wild (USGS, 2004). The species was determined to be triploid but the origin of the fish was not listed. While these distributions in the wild are sparse, multiple captured or contained occurrences are known to occur in the United States (USEPA, 2002). No other occurrences have been documented in any of the data sources utilized in this report including the LTRMP and commercial fishing data.

Data source-USGS

Figure III-16. States with Reported Black Carp Occurrences

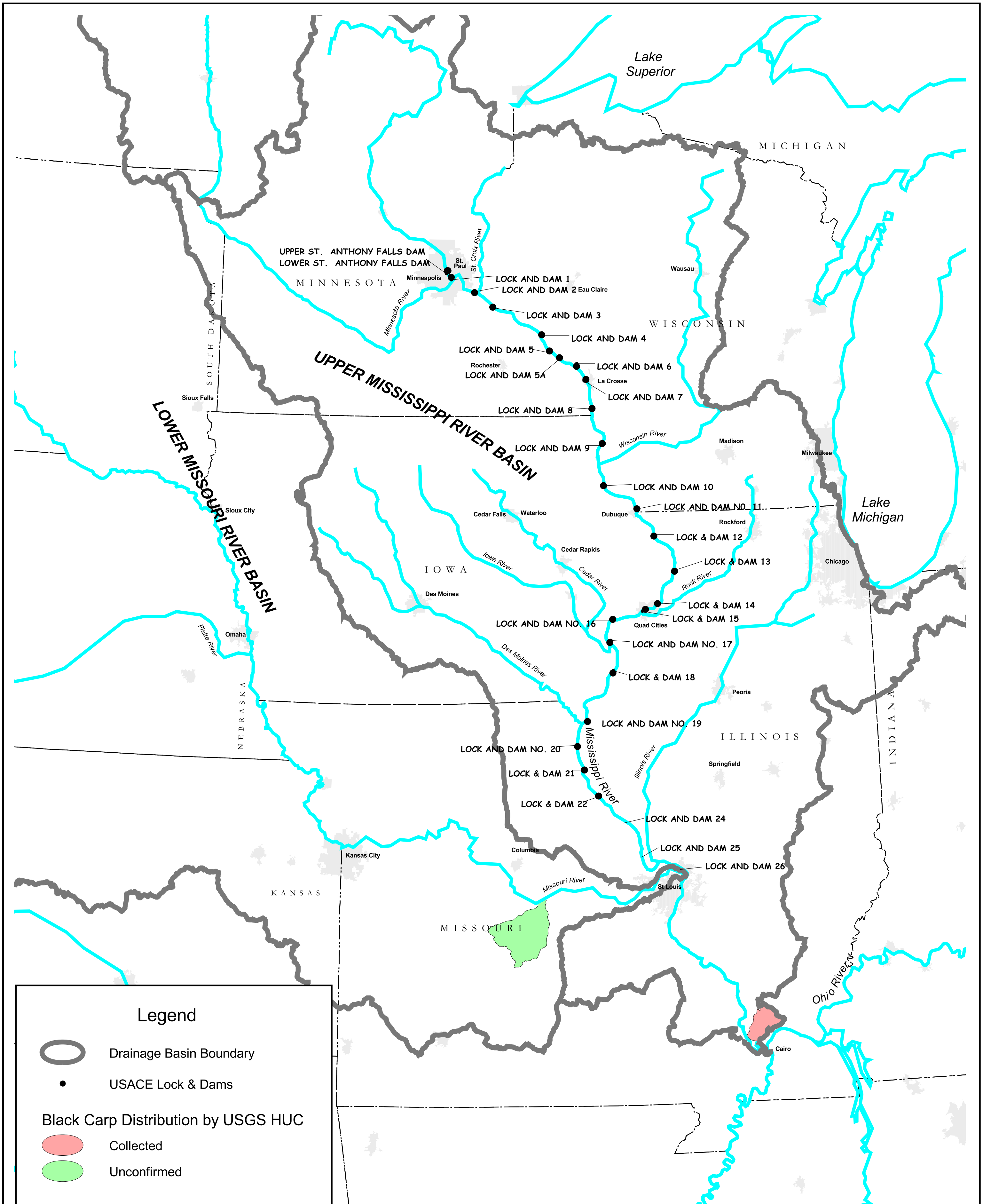


Figure III-17 - Black Carp Distribution Map
Feasibility Study to Limit the Invasion of
Asian Carp in the Upper Mississippi River

Grass Carp (*Ctenopharyngodon idella*)

Overview: Grass carp (see **Figure III-18**) were originally introduced into the United States from eastern Asia in 1963 to aid in the control of aquatic vegetation (Burr et a., 1996; Koel et al., 2000). Stocking of the species in the early 1960s included Alabama and Arkansas (Fuller et al., 1999). Introductions in the wild have been traced to Stuttgart, Arkansas and occurred shortly after import in 1963 (Fuller et al.; Pflieger, 1997).

Photo Source: fishbase.org

Figure III-18. Grass Carp Species

The use of the species for control of aquatic vegetation and research has aided the quick spread of this species throughout the United States. In addition, stocking by many state resources agencies and private aquaculture facilities is reported (Fuller et al., 1999). Due to the large amounts of data established on the species, a reduced summary is provided for comparison to the species above.

Phylogeny:

Class: Actinopterygii
Order: Cypriniformes
Family: Cyprinidae
Name: *Ctenopharyngodon idella*
Common name alternatives: White Amur

Physical Description (source USFWS – see Appendix E for Entire Key to Identification):
The grass carp is similar to the black carp and has been described as having a thick, elongate body with a broad, blunt head. The species also has silver/pale grey color with scales on back and sides showing a prominently dark-edge, giving a characteristic cross-hatched effect.

- Maximum Observed Weight – 45 kg (99 lbs) (Froese and Pauly, 2003)
- Maximum Observed Length – 150 cm (59 in) (Froese and Pauly, 2003)

Biology: Grass carp are known to occur in large rivers, which is similar to its native range (Pflieger, 1997) and are considered strong swimmers. The species has also been reported to prefer backwater areas and standing water with vegetation and are tolerant of temperatures from 0^{o}C to 38^{o}C (Froese and Pauly, 2003). Juvenile grass carp feed on small invertebrates and crustaceans (Smith, 1979; Pflieger, 1997) while adults have an affinity for aquatic vegetation. It has been further reported that grass carp eat a wide variety of plants and some animal material (Pflieger, 1997). Spawning in grass carp is similar to the other Asian species with females depositing eggs in flowing water. Larvae of grass carp have been observed in the Missouri River from May through July (Pflieger, 1997) and similar to the other Asian carp species, are believed to have an extended spawning period. Grass carp grow extremely fast adding in excess of 24.5 cm per year. Pflieger (1997) reported specimens that added 53.3 cm in one year on the Missouri River. Grass carp species can also consume large quantities of vegetation as reported by Fuller et al. (1999). A single species can consume 45 kg of vegetation per day. However, it is also reported that approximately half of the material consumed is not digested (Fuller et al., 1999). The expelled vegetation can lead to increased algal productivity due to the release of nutrients (Rose, 1972 in Fuller et al., 1999).

Distribution and Movement: Grass carp are very extensively distributed in the United States. Occurrences of the species have been logged in the Nonindigenous Species Database approximately 484 times (Benson, pers. comm.). The species has been recorded in all but three of the contiguous United States, Hawaii, and Puerto Rico (**Figure III-19 and Figure III-21**). Grass carp have been regularly caught as part of LTRMP monitoring (see **Figure III-20**) within the Open River location, Pool #26 and the Lagrange Range of the Illinois River (data not shown). Grass carp have also been collected as far north as Pool #4 but in very small numbers (3 total) and on a limited number (1) of occasions (Benson, pers. comm.).

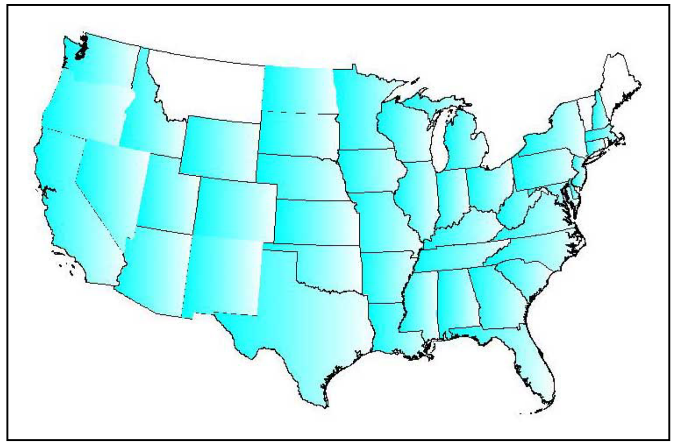


Figure III-19. States with Reported Grass Carp Occurrences

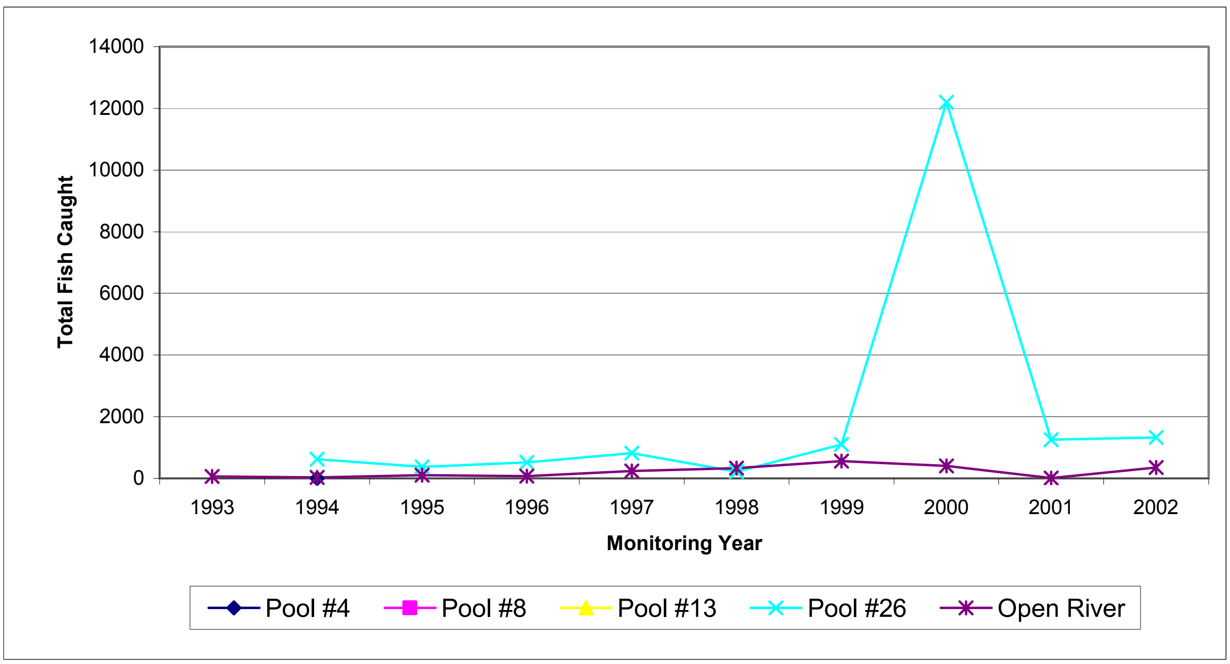
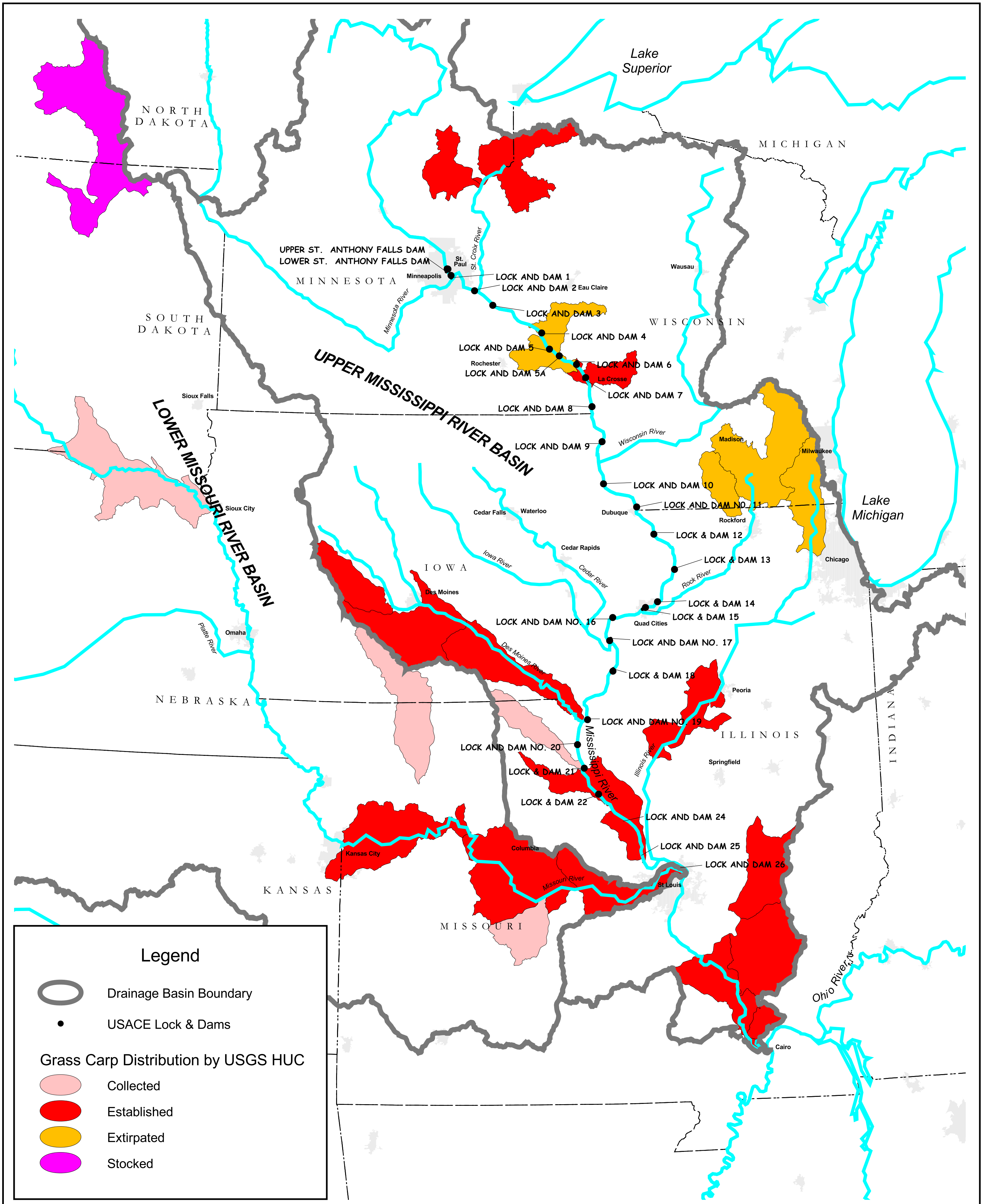


Figure III-20. Grass Carp LTRMP Total Catch per Year

In contrast to the LTRMP data, grass carp have been harvested as far north as Pool #9 and appear in most pools below Pool #9 in most years between 1997 and 2001 and are in large abundance (see **Figure III-22**). Similar commercial fishing harvest were reported in Missouri (Pflieger, 1997) where recent data at the time of publication represented approximately 4% of the commercial harvest in the Missouri River.



N S W E
0 30 60 90 Miles

Figure III-21 - Grass Carp Distribution Map
Feasibility Study to Limit the Invasion of
Asian Carp in the Upper Mississippi River

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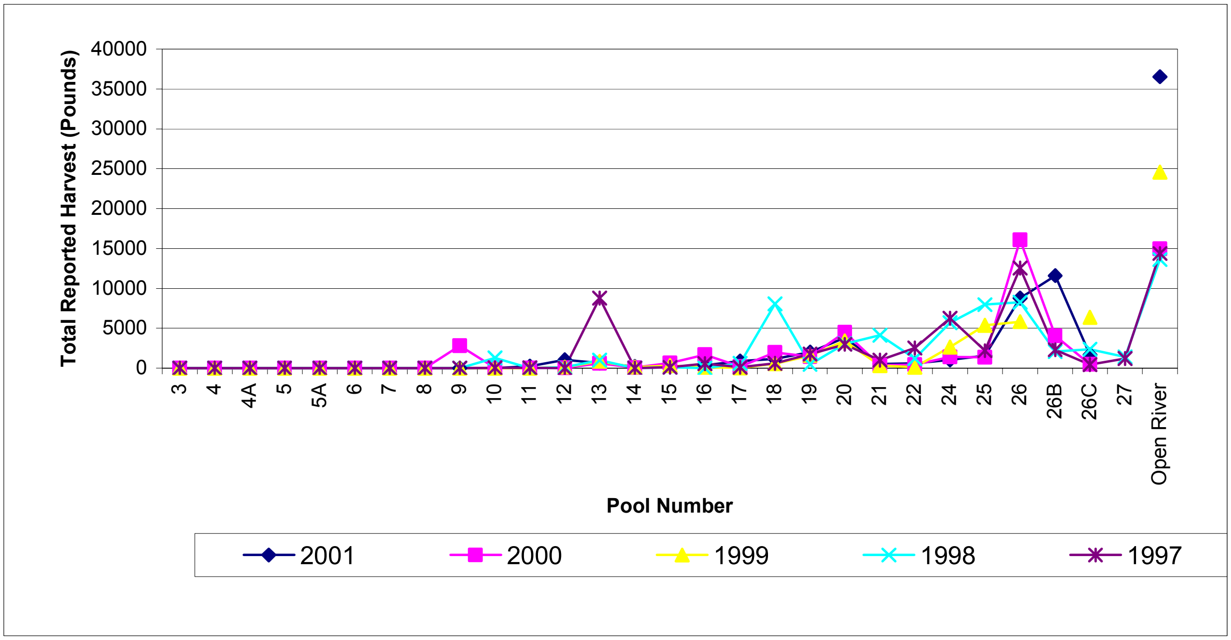


Figure III-22. Commercial Harvest of Asian Carp from UMR Pool #3 to Open River

Feasibility Study

To Limit the Invasion of Asian Carp into the Upper Mississippi River Basin

IV. Ecological Risk Assessment Framework

FISHPRO

IV. ECOLOGICAL RISK ASSESSMENT FRAMEWORK (S.M. BARTELL)

Kaplan and Garrick (1981) introduced a simple model of risk that comprises three fundamental components:

$$risk \sim (x, p, c)$$

where,

- x identifies adverse impacts of concern (What can go wrong?)
- p the probability of x (How likely is it that something will go wrong?)
- c the consequences of x, if it occurs (So what?)

This generalized model of risk can also be described in terms of answering the above three questions. In practice, there are usually many possible impacts of concern, each with its own probability of occurrence and associated consequences. Correspondingly, the risk model parameters x, p, and c are commonly described as vector quantities.

An ecological risk is the probability that an undesired ecological impact will occur in relation to one or more environmental stressors (Sergeant, 2002; Bartell, 1996; Bartell, et al. 1992; USEPA, 1992). Ecological impacts of concern to natural resource managers might include the local extinction of an ecologically important species, reduced population size in a commercial fishery, or reduced species diversity. Impacts of concern might also include the increase in population of undesired species, such as blue-green algae that are responsible for noxious blooms in coastal water bodies. Ecological risk analysis examines the probability of undesired environmental impacts, evaluates their associated consequences, and addresses uncertainties inherent to complex ecological systems. In this assessment, the undesired ecological impacts focus on the spread, colonization, and establishment of invasive species of Asian carp. These species may pose an imminent threat to the ecological and economical integrity of the Upper Mississippi River, including surface waters in Minnesota (Koel et al., 2000).

Ecological risk assessment provides a conceptual and operational framework for characterizing the responses of complex ecological systems to natural and human-induced disturbances. Ecological risk assessment, through quantification and evaluation of uncertainty in estimating probable impacts, can serve as the basis for informed and adaptive management of natural resources. A recommended approach to assessing risks posed by the spread and establishment of Asian carp in the UMR, lakes and reservoirs reflects an integration of the highly quantitative and probabilistic USEPA framework for ecological risk assessment and the more qualitative Risk Assessment Model developed for nuisance species by the Aquatic Nuisance Species Task Force (ANS, 1996). The recommended approach for assessing Asian carp risks begins by considering the USEPA methodology and continues with a description the ANS assessment model. Possible implementations are suggested for each assessment methodology in relation to risk assessment and management of Asian carp in the Upper Mississippi River Basin, including valued Minnesota surface waters. Section IV concludes with a discussion of using the results of the risk assessment in combination with knowledge concerning the implementation of alternative control technologies to reduce risk.

USEPA Framework for Ecological Risk Assessment

The United States Environmental Protection Agency (USEPA) has devoted significant effort in the derivation of a framework to guide the assessment of ecological risks (USEPA, 1998; 1992). Concerns for the potential toxic effects of industrial and agrochemicals on natural populations of plants, fish, and wildlife originally motivated the development of this methodology for assessing ecological risk. However, the USEPA methodology has proven sufficiently general to assess risks posed by other environmental stressors, including alterations in hydrology, climate, and physical habitat.

The risk assessment process according to the USEPA framework consists of four major components augmented by considering sources and impacts of uncertainties inherent to risk assessment (Figure IV-1). The four major components are problem formulation, exposure analysis, effects assessment, and risk characterization. The following paragraphs briefly describe the USEPA framework for ecological risk assessment and outline how this framework might be usefully implemented to assess risks of Asian carp establishment in UMR surface waters.

Problem Formulation

The problem formulation component of an ecological risk assessment is perhaps the most important step in the overall USEPA approach to risk assessment. This step identifies the environmental stressors of concern, specifies the resulting ecological effects (e.g., spread, colonization, and establishment) identifies relevant data (e.g., current distribution through Upper Mississippi River) and methods of analysis (e.g., monitoring, modeling) and finally, describes the approach for risk characterization (e.g., qualitative, quantitative). Problem formulation generates a conceptual model of the overall assessment. A plan of analysis follows from the conceptual model and prescribes the process for making the conceptual model operational, performing the assessment, and ultimately estimating risk.

Exposure Analysis

In estimating ecological risks posed by toxic chemicals, exposure analysis refers to the quantification of the concentration of toxic chemical in various environmental media (e.g., water, sediments, contaminated prey) likely encountered by the species of concern. Key components of exposure analysis include the magnitude, frequency, and duration of exposure.

In assessing the spread, colonization, and establishment of Asian carp, exposure analysis requires an estimate of the numbers of individuals located in selected surface waters, especially reaches of the mainstream Upper Mississippi River and its tributaries. The underlying assumption is that the rate of spread and likelihood of successful colonization and establishment is proportional to the number (i.e., concentration) of Asian carp at any point in space and time. Analysis to chemical exposures, the frequency of Asian carp entries, the number of individual carp associated with each entry, and the duration of time that an area uninhabited by these species is exposed to entry will in combination describe an "exposure scenario" for surface waters previously not occupied by these species.

Empirical and modeling approaches should prove useful in analyzing the spread of Asian carp throughout the Upper Mississippi River and Minnesota surface waters. Depending on the availability of data that describe the current and previous locations where Asian carp have been collected or reported, the rate of spread can be estimated using available data.

Alternatively, models of the spread of other pest species (and perhaps even models of disease) can be implemented to estimate the future distributions of Asian carp (e.g., Murray, 1989. Metz and de Roos, 1992) describe an individual-based approach to forecast the dynamics of invasive species. Spatially explicit models of population dynamics can be integrated with landscape models to estimate future patterns of Asian carp distribution and abundance. All of these modeling approaches should be examined for possible applications in assessing "exposure" to Asian carp.

Effects Assessment

The direct ecological effect of spread and successful colonization of UMR surface waters by Asian carp is establishment of reproducing, viable populations. Indirect effects associated with the establishment of viable carp populations include the possibility of ecosystem degradation, economic impacts, and effects on recreational use of UMR surface waters that become infested with these fish.

The assessment of these direct and indirect ecological effects requires the derivation of quantitative relationships (i.e., stressor-response functions) between the concentration of Asian carp and the likelihood of establishment, as well as the degree of ecological, economic, and recreational impacts. Initially, the development of the necessary stressor-response functions will be constrained by the availability of species-specific information for the Asian carp. Preliminary functions might be derived from information on taxonomically or ecologically similar species (e.g., common carp) with the recognition that physiology and ecology of the Asian species may differ from the selected surrogate species.

Risk Characterization

The integration of the exposure analysis and the effects assessment produces estimates of ecological risk. Risks of spread, entry, colonization, and establishment can be estimated for surface waters up-river from the location of control technologies (e.g., barriers). Risks can be correspondingly estimated for tributaries to the Upper Mississippi River, as well as streams, rivers, lakes, and reservoirs subject to entry by Asian carp.

Risks can be estimated qualitatively, especially given the sparse data describing the biology and ecology of these fish species. However, it would be technically desirable and scientifically defensible to estimate risks in a quantitative manner.

Importantly, the risk estimates will serve as a baseline for evaluating the effectiveness of alternative control technologies. Each technology (or combinations) can be evaluated in terms of risk reduction compared to the baseline risks. The estimates of risk reduction can be used to determine which technologies, either individually or in combination, appear to be most effective in controlling the rate of spread, colonization, and establishment of Asian carp in UMR surface waters.

Analysis of Uncertainty

The explicit consideration of uncertainty distinguishes ecological risk assessment from the more traditional assessment of environmental impacts, as in the NEPA process (Bartell, 1998). The limited availability of data and the incomplete understanding of Asian carp biology and ecology contribute substantial uncertainty in assessing risks of establishment and associated consequences. Inferences drawn from consideration of surrogate species should include assessment of possible bias and imprecision introduced to the assessment caused by the absence of data specific to Asian carp. Natural variability, imperfect understanding, and sparse data describing the aquatic ecosystems of concern also introduce uncertainty to the assessment of Asian carp spread and establishment.

These sources of uncertainty can be effectively examined, for example, by representing parameter values in models of spread and establishment as statistical distributions and using stochastic modeling techniques (e.g., Monte Carlo simulation) to propagate these uncertainties through the model calculations. Estimates of risk produced in this manner can be similarly described as distributions, which can be statistically evaluated. There are methods for developing distributions of model input parameters depending on the availability of data and other sources of uncertainty:

- uniform distribution – estimates of upper and lower bounds are available, but no information exists concerning a central value within the implied range,
- triangular distribution – data are available that define a model value, as well as upper and lower bounds,
- normal distribution – sufficient data exist to justify selection of this distribution, or central limit theorem applies to the parameter being estimated,
- lognormal distribution – many water quality parameters are highly variable in space and time and can be accurately characterized using this distribution,
- fitted distribution – data are sufficient to permit identification of a distribution using several methods for fitting distributions to data.

The limited availability of data directly relevant to Asian carp may preclude the empirical derivation of parametric statistical distributions. Given this circumstance, it may prove necessary to use combinations of data and best professional judgment to define fuzzy sets (Kaufmann and Gupta, 1991) in order to characterize parameter uncertainty. Fuzzy arithmetic can be used to propagate uncertainties described in this manner. The resulting expression of risks of spread, colonization, and establishment as fuzzy sets can enter into the risk management process (i.e., selection and application of control technologies) in much the same fashion as statistical distributions of risk described previously.

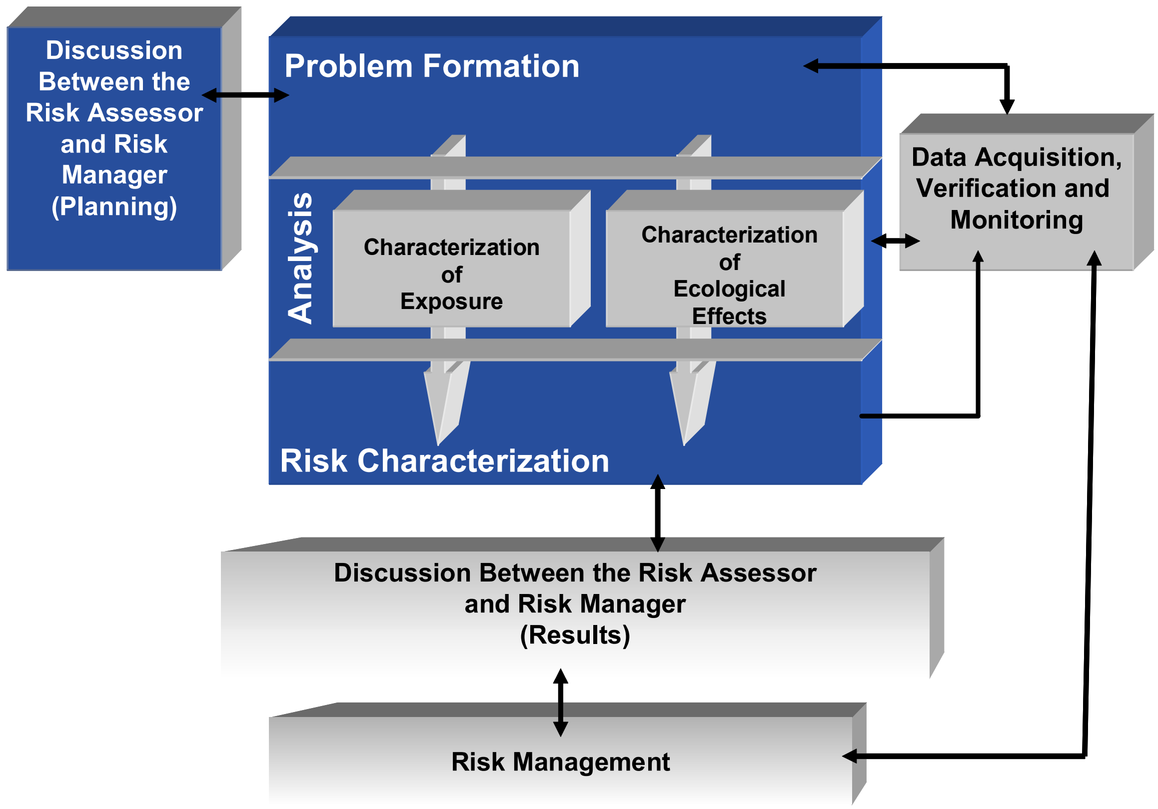


Figure IV-1. Schematic Illustration of USEPA Framework for Ecological Risk Assessment (adapted from USEPA 1998).

Aquatic Nuisance Species Task Force Risk Assessment Model

The Aquatic Nuisance Species Task Force developed a model to assess risks associated with the introduction of exotic species (ANS, 1996). The ANS risk assessment model consists of seven elements collected into two groups – Group 1 elements address issues associated with entry, establishment, and spread; group 2 elements examine possible consequences of establishment.

The following sections use the ANS organism and pathway risk assessment model to outline approaches that might be used to estimate the probability of Asian carp spread and establishment throughout the Upper Mississippi River, including Minnesota rivers, lakes, and reservoirs. The discussion also addresses possible methods for evaluating the economic, ecological, and socio-political (e.g., recreation) consequences of viable populations of Asian carp in UMR surface waters.

Group 1: Assess Probability of Organism Establishment

1. Nonindigenous aquatic organisms associated with pathway (at origin)

The relevant pathways for Asian carp introduction to UMR surface waters focus on (1) the Mississippi River and associated tributaries that provide connected lotic and lentic habitats that facilitate Asian carp migration throughout the surface waters of concern, (2) the purposeful introduction of Asian carp into rivers, lakes, and reservoirs and 3) incidental/accidental movement (e.g. with bait harvest transfer).

The collection of individual silver and bighead carp from various locations in the Upper Mississippi and Illinois Rivers demonstrates the viability of this particular pathway for subsequent spread and invasion of UMR surface waters. With this pathway established, managing the rate of spread can focus on the selection and location of various technological barriers to future carp migration.

The second and third pathways, those of human-abetted introduction, may prove the most difficult to characterize and manage in relation to future infestation of the UMR. It should be noted that failing to address the first pathway would increase the risk from the second and third pathways. Therefore, it is important to have a comprehensive approach and address all three pathways.

2. Entry potential

Current descriptions (e.g., Koel et al., 2000) of the presence and limited estimates of abundance can be used to characterize the potential for entry of Asian carp into UMR surface waters. Clearly, for locations where these fish have been reported and/or collected, entry potential is not an issue.

The natural potential for Asian carp entering the remaining surface waters of concern is primarily a function of the connectedness of currently uninhabited waters to locations where Asian carp are known to inhabit. Entry potential is also likely determined by specific habitat requirements of these fish (e.g., physical habitat, water temperature, dissolved oxygen, food resources).

Entry may be further augmented by the introduction of these species either accidentally in the form of discarded bait that, unknown to the fisherman, includes Asian carp or through the intentional introduction of Asian carp by people with some vested interest (e.g., commercial fishing) in the wide-scale, successful establishment of these species. These forms of introduction will likely pose one of the greatest sources of uncertainty in assessing risk of spread and establishment. Importantly, the impacts of these pathways might reduce the larger-scale effectiveness of the technical control of Asian carp to the point that such controls become useless in the longer term. Under such circumstances, the efforts to control spread and establishment might well be replaced by programs directed at eradication of established Asian carp populations. Estimating the timing and location of Asian carp entry via these pathways (accidental, intentional) will likely emerge as the greatest challenges in assessing the risk of establishment. However, if there are strong Allee or founder effects (e.g., Murray, 1989), the risk of successful colonization and establishment might be low as the result of introducing a comparatively small number of individuals in single (or even multiple) introductions.

In addition to building upon existing data, an informative framework for assessing this component of risk should include further investigation to describe the specific habitat requirements and critical dimensions of the ecological niche for each carp species of concern. Correspondingly, existing data and future surveys of UMR surface waters should focus on the habitat suitability of rivers, lakes, and reservoirs as determined by continued elaboration of the niche requirements of these carp. Habitat suitability can be effectively analyzed and summarized using GIS technologies, wherein habitat quality of specific aquatic environments of concern can be visualized in relation to currently known locations of Asian carp species.

3. Colonization potential

Somewhat similar to entry potential in concept, the likelihood of Asian carp colonizing surface waters currently uninhabited by these species depends upon many of the same physical, chemical, and biological factors also important in determining entry. Knowledge of the biological and ecological requirements of the species of Asian carp will increase the ability to assess colonization potential. These requirements can be evaluated in relation to the specific characteristics of UMR surface waters to determine the degree of overlap between the carp requirements and the nature of the receiving environment (e.g., inhabitable, uninhabitable).

In addition, the probability of successful colonization will be influenced by natural (e.g., predators) and human-induced (e.g., fishing pressure, toxic chemicals, harvesting) sources of mortality specific to Asian carp. Evaluating the potential for colonization may require estimation, even qualitatively, of these various sources of mortality in addition to impacts of the control technologies.

Successful colonization implies the development of a reproducing, viable population within newly inhabited surface waters. Thus, reproductive requirements (e.g., habitat, temperature, dissolved oxygen) and other factors (e.g., egg hatching success, larval survivorship) that determine reproductive success will importantly influence the likelihood of colonization within newly entered surface waters.

A framework for assessing the risk of colonization should provide for continued research directed at understanding the life history and ecological requirements (e.g., preferred food resources, susceptibility to predators and disease) of each of the invading carp species. Population (and perhaps ecosystem) models should be developed to estimate the likely success of these species in colonizing new areas in the Upper Mississippi River and Minnesota surface waters. These models should be integrated with the GIS data base described above to provide location-specific models that quantitatively estimate the potential for entry and colonization throughout the Upper Mississippi River and Minnesota rovers, lakes, and reservoirs.

4. Spread potential

Previous experience with aquatic invasive species suggests a high likelihood that Asian carp will continue to spread throughout the Upper Mississippi River Basin. Therefore, the risk assessment process will also focus on estimating the rate of spread, both under current circumstances and circumstances changed by the location and effectiveness of different control technologies.
As suggested in the exposure assessment of the USEPA methodology, the potential for spread can be estimated empirically using data from existing (e.g., LTRMP) and future monitoring programs. Alternatively, models that forecast the spread of invasive species may also prove useful in characterizing the rate of Asian carp spread throughout the Upper Mississippi River Basin, especially given the limited current data and the comparative difficulty in collecting these species of Asian carp using conventional methods (Koel et al., 2000).

Given the current data limitations, a logical path towards progress in assessing risks of establishment includes the continuation of existing monitoring programs, the design and implementation of new monitoring programs, and the development and application of models that simulate the spread of Asian carp throughout the Upper Mississippi River and potentially threatened Minnesota surface waters. The models of spread should be integrated with the previously mentioned models of entry and colonization potentials.

Group 2: Assess Consequences of Establishment

The previously described approaches emphasize the spread and establishment of viable populations of Asian carp in Minnesota surface waters. The second group of considerations in an overall risk assessment based on the ANS Task Force model addresses the consequences of establishment – or answers the "So what?" question in the Kaplan and Garrick (1981) model of risk. Clearly, if there were no consequences associated with the presence of these fish in aquatic ecosystems, the risks would correspondingly be zero (Kaplan and Garrick, 1981). Interestingly, the USEPA methodology is comparatively silent concerning the characterization of the consequences of undesired ecological impacts. The severity of the potential consequences are used mainly to identify the ecological effects of concern that become the focal points (i.e., assessment endpoints) of the USEPA ecological risk analysis process. In contrast, the ANS (1996) risk assessment model explicitly addresses the consequences of successful establishment of invasive species.

Pimentel et al. (2002) estimate the annual economic costs associated with invasive fish species in the United States as more than $1 billion. The consequences of concern for the establishment of Asian carp include economic, environmental, and socio-political impacts. Using the ANS Task Force risk assessment model as a point of departure, the following sections describe possible methods for characterizing these impacts in relation to Asian carp establishment in UMR surface waters.

5. Economic impact potential

The framework for ecological risk assessment should include provisions for estimating the economic consequences of the spread and establishment of Asian carp. These costs might be estimated as reduced numbers of fishing licenses, fishing days, cabin or resort rentals, fishing equipment and bait purchases, and similar recreational impacts for areas surrounding specific surface waters that become heavily dominated by Asian carp. Application of contingent valuation methods, surveys, and other methods should be explored in order to estimate the economic consequences of Asian carp establishment (e.g., Jansson et al., 1994, Kopp and Smith, 1993).

In evaluating the consequences of successful establishment, it is important to be mindful that some consequences might be positive (e.g., commercial fishery). Thus, if economic benefits result from the establishment of Asian carp, methods for quantifying these benefits should be incorporated into the development and application of the risk assessment framework.

Importantly, the economic consequences of establishment can be used in a benefit-cost analysis of implementing different technical measures (barriers) to control the spread of Asian carp throughout the Upper Mississippi River surface waters. Such benefit-cost analyses appear as integral components of an overall framework for assessing technological approaches to risk reduction.

6. Environmental impact potential

Many of the economic consequences of Asian carp invasions reflect ecological impacts of these fish on the structure and function of aquatic ecosystems. Depending on the degree of overlap in ecological function and any competitive advantages the invasive carp might have over native species, the establishment of Asian carp might result in unacceptable reductions or loss of native fish species. Asian carp might also impair ecosystem function, for example, by increasing suspended sediment concentrations and reducing light availability for attached algae or rooted aquatic plants. The foraging or reproductive behavior of these carp species might also physically disrupt habitat critical to the viability of native species. The ability of infested aquatic ecosystems to provide natural ecological goods (e.g., recreational fishery) and services (e.g., waste assimilation) might be reduced by large populations of Asian carp. Thus, a key component in the risk assessment framework will include capabilities to interpret risk in the context of ecosystem valuation (Bartell, 1997).

An effective framework for risk assessment and risk management will include a combination of modeling and monitoring to evaluate the ecological consequences of Asian carp spread and establishment. Aquatic ecosystem models (e.g., Bartell et al., 1999) should be examined for applications in forecasting the probable ecological consequences of Asian carp in surface waters of the Upper Mississippi River Basin. Selected ecological models should be developed in a probabilistic framework consistent with quantitative ecological risk assessment (Bartell et al., 1992). The forecasting models should be capable of incorporating the various sources of uncertainty (e.g., natural variability, parameter uncertainty) in projecting the likely impacts of Asian carp on ecosystem structure and function. The models should be subject to numerical sensitivity and uncertainty analyses in order to identify key contributors to uncertainties in ecological forecasting. The results of the uncertainty analyses can be used to develop monitoring programs that focus on these important sources of uncertainty in characterizing the ecological consequences of Asian carp in aquatic ecosystems.

The framework for risk assessment should include monitoring programs that quantitatively describe the impacts of established populations of Asian carp on aquatic ecosystems. Monitoring results should estimate the population size and age-structure of each species of carp. Changes in food web structure of native fishes and invertebrates, as well as measures of the distribution and abundance of valued aquatic resources (e.g., freshwater mussels, walleye, wild rice) might reasonably be included in a monitoring program that supports ecological risk assessment. Importantly, monitoring programs should be based on a sampling intensity that will provide sufficient statistical power to (1) detect spatial-temporal trends in the parameters selected for measurement, (2) unequivocally relate any measured changes to the invasive carp, and (3) provide information in a timely manner for risk assessment and management.

7. Perceived impacts (socio-political)

The successful introduction of the common carp (*Cyprinus carpio*) into surface waters of the United States has historically been perceived negatively by society. Despite some minimal commercial and recreational benefits, considerable efforts have been devoted by various states to "un-introduce" this species from some highly valued or priority rivers, lakes and reservoirs with characteristically large carp populations. If the ecological and economic consequences associated with establishment of Asian carp are similar to those of the common carp, a similar, largely negative public perception will likely develop. Surveys designed to characterize public perceptions of Asian carp establishment (and management) should be an important component in a comprehensive framework for assessing risks and consequences posed by these species.

In addition to public perception, the establishment of additional species of Asian carp might impede the ability of States, including Minnesota to meet the USEPA designated use criteria (e.g., fishable, swim-able) for carp infested surface waters. The monitoring programs included in the Asian carp risk assessment framework should be designed to address the potential impacts of these species in relation to achieving/maintaining designated uses in relation to the Clean Water act.

Table IV-1 indicates how the USEPA and ANS approaches to ecological risk assessment might be understood in relation to each other. Such reconciliation is not a critical issue, however, and the eventual framework for Asian carp invasion might benefit simply by adopting the strengths of each approach in relation to this specific challenge in ecological risk assessment. For example, borrowing the concept of stressor-response functions from the USEPA methodology may help to provide more quantitative rigor to the more qualitative evaluations of entry, colonization, and spread as described in the ANS (1996) risk assessment model. In addition, the quantitative description and numerical propagation of uncertainty emphasized in the USEPA approach importantly extends the more qualitative evaluation of uncertainty outlined in the ANS model. At the same time, the ANS risk assessment model focuses more directly on the evaluation of economic, ecological, and socio-political consequences of establishment, while the USEPA framework minimally addresses these key components in constructing a comprehensive model of risk (i.e., Kaplan and Garrick, 1981). Thus, integration of the two conceptual models for assessing ecological risks may produce a powerful and effective approach for Asian carp risk assessment and risk management (i.e., risk reduction). Finally, the development of the risk assessment framework for Asian carp might benefit from considering concepts and methods developed by the international community (e.g., Canada, Europe, Japan) of ecological risk assessors (Bartell, 1996).

Table IV-1. Comparison of USEPA (1992) Framework for Ecological Risk Assessment and ANS (1996) Risk Assessment Model.

USEPA Framework	ANS Risk Assessment Model
Problem formulation	Organism associated with pathway
Exposure analysis	Potential for entry, colonization, and spread
Effects assessment	Establishment
Risk characterization	Probability of establishment
(Not applicable)	Consequences of establishment

Risk Reduction

In the overall risk assessment of Asian carp, the process of risk reduction estimates decreases in the probabilities of spread and establishment in relation to the implementation and effectiveness of selected control technologies. Figure IV-2 schematically illustrates an example of evaluating a control technology to reduce the rate of spread. The "stress-response" function characterizes the cumulative probability of different hypothetical rates of spread for a species of carp at some specified location. (The shape of the cumulative probability function is determined from the risk assessment methods used to assess the rate of spread). In the absence of the control technology (i.e., "without-barriers), the rate of cumulative spread has some probability (p_β) of being at least 50 km/y. In this hypothetical example, implementing control technologies as barriers has some probability (p_τ) of reducing the rate of spread to approximately 15 km/y. Thus, the overall process entails estimating p_τ for alternative control technologies or combinations of these potential barriers to spread. Analogous stress-response functions can be used to address reductions in the risk of colonization and establishment.

The implicit assumptions and underlying motivations for risk reduction are the anticipated avoidance or at least diminished economic, environmental, and socio-political consequences of further spread and establishment of Asian carp throughout the Upper Mississippi River Basin.

Recommended Framework for an Asian Carp Ecological Risk Assessment

The ANS (1996) risk assessment model relies mainly on informed opinion to qualitatively assess risks of establishment and subsequent consequences for invasive species. In the absence of sufficient information, a framework for assessing ecological risks posed by Asian carp might begin with such a qualitative orientation. However, the framework should be developed in a form that facilitates the efficient use of existing and newly acquired data and information in generating quantitative estimates of risk. The resulting framework should ultimately be quantitative, repeatable, and transparent to risk assessors and risk managers (e.g., Kolar and Lodge, 2002).

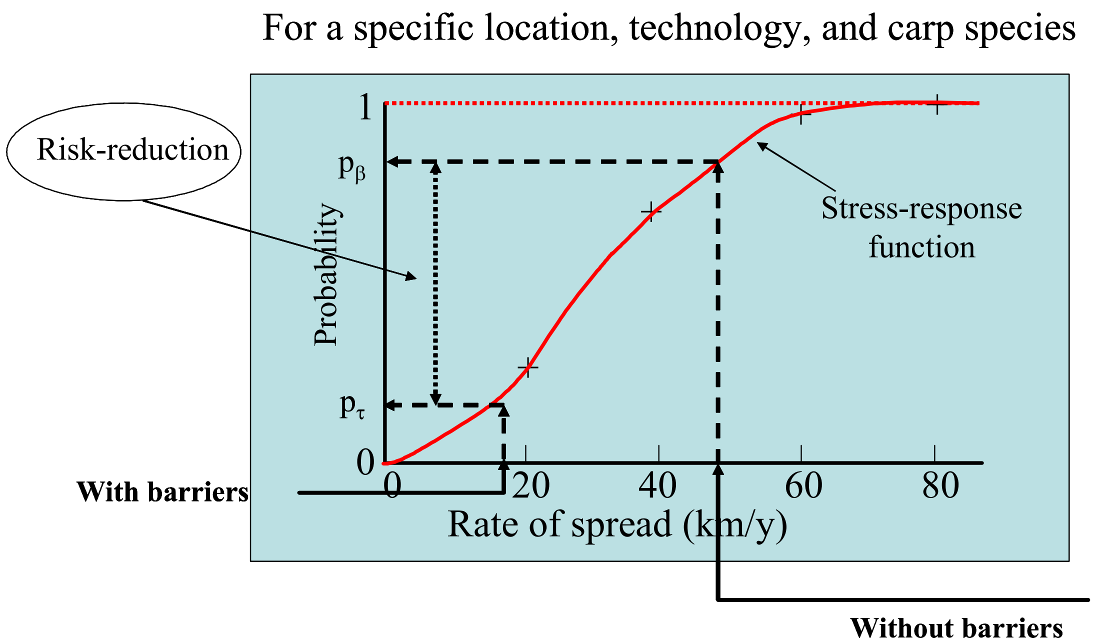


Figure IV-2. Schematic Illustration of Risk Reduction for Asian carp based on Cumulative Probability of Estimated Rate of Spread.

A risk assessment framework for assessing the potential for entry, colonization, spread, and establishment of Asian carp should include at least the following components:

- A relational data base that provides for the efficient storage and retrieval of existing and newly developed data that describe the life history traits, physiology, biology, and ecology of the species of Asian carp.

- A similar database that describes the ecological and environmental characteristics of UMR rivers, lakes, and reservoirs in relation to the habitat needs and ecological requirements of Asian carp.

- A geographic information system (GIS) linked to the above data bases. This GIS will provide for convenient analysis and visual display of the spread (and control) of Asian carp throughout the Upper Mississippi Basin, including Minnesota surface waters of concern.

- Spatially explicit models that can forecast the potential entry and likely success of colonization of currently non-infested waters by Asian carp.

- Aquatic ecosystem models that can estimate (including uncertainties) the likelihood of establishing viable Asian carp populations and the ecological consequences of established populations on system structure and function.

- Programs that monitor the spread and establishment of Asian carp throughout the Upper Mississippi River (e.g., LTRM program) and Minnesota surface waters. These programs should also be designed and implemented to measure ecological impacts of established Asian carp populations.

- The capability to monitor and survey the economic impacts of established Asian carp populations. Such surveys should also address public perceptions of the impacts of Asian carp.

- A risk-based decision process that integrates existing data, model forecasts, and the results of surveys and monitoring to usefully evaluate the efficacy of alternative control technologies in reducing risks posed by Asian carp.

These components should be developed in the context of an interactive, computer-based decision support system (DSS) (e.g., Reinert et al., 1998) that can be readily accessed by risk assessors and risk managers to (1) describe and understand the current distributions of Asian carp in the Upper Mississippi River Basin, (2) estimate the future spread, establishment, and consequences of these species in the absence of control technologies, (3) identify locations where specific barrier technologies may prove useful in controlling the spread of Asian carp, and (4) evaluate the overall effectiveness and net benefits afforded by alternative technical control measures proposed for specific locations.

Anticipated Impacts of Asian Carp

The anticipated impacts of non-indigenous Asian carp are extensive and vary by species due to differences in behavioral characteristics, habitat and feeding preferences. However, the collective impacts of these species can lead to habitat loss, reduction of food resources for native species, reduction or displacement of native species as a direct result of predation, the altering of ecosystems, displacement of wildlife adjacent to the river system and even human safety concerns. In a document prepared for the U.S. Congress by the Office of Technology Assessment (US Congress, OTA 1993), it was concluded that the combined impact of NIS species was creating an "environmental and economic burden for the country". Often, the burdens placed by NIS species are not fully realized until it's too late. The means of introduction of a NIS species is termed pathway (National Invasive Species Council, 2001). While the pathways of each of the Asian carp species are known, the impacts of those introductions may take years to document. An understanding of the species, continued research and documented cases studies are needed to provide a comprehensive understanding of the potential threats.

In addition to ecological impacts, NIS species such as Asian carp could have a profound impact on the $6.6 billion dollars in revenue generated by the 12,000,000 visitor-days for hunting, fishing, boating and sightseeing along the Upper Mississippi River (UMRCC, 2000). These impacts could be related to loss of sport fish species and the habitat to support them, the loss of adjacent wildlife common to the floodplains, and even serious injury to recreational users caused by leaping fish. The economic fall-out of the species could also be severe. Asian carp species averaged $0.17 less per pound in Illinois and Missouri than the average for all species according to data released by the UMRCC (2000) and have steadily increased in total pounds harvested in a period from 1997 to 2001. Since 1997, the reported kilograms of Asian carp harvested has more than doubled from 35,131 kg (77,451 lbs) harvested in 1997 to 75,933 kg (167,403 lbs) in 2001. In this same time period, the total amount of commercial fishing revenue has decreased slightly from $2,265,395.07 in 1997 to $2,001,864.73 in 2001 (data source, UMRCC). The presence of Asian carp in the pools utilized for commercial fishing are increasing in total number and are expanding northward (see also Section III).

The rate of the upstream movement of Asian carp in major rivers of the United States has been estimated to be approximately 50 miles per year and becoming established approximately two (2) years after the first individual arrives (USFWS, pers. comm.). It has been observed via telemetry tracking that a single bighead carp traveled 260 km (162 miles) in one year along the unrestricted Lower Missouri River (D. Chapman, pers. comm.). It is important to note that the distance covered by that particular fish represents only main river channel distance and does not include the likely travel in minor tributaries of the Missouri River. Based on the estimated and observed upstream movement rate of approximately 50 miles per year, bighead and silver carp will be reaching Lock and Dam 8 near the south edge of the Minnesota state line in two to three years.

In an effort to further the understanding of the destructive potential on native river species and habitat, the anticipated impacts of the Asian carp species have been concisely summarized in the following paragraphs.

Bighead Carp Impacts: The full realization of bighead carp impacts are not yet known, however, it is speculated that bighead carp could negatively impact native planktivors by altering food webs and decreasing plankton (Pflieger, 1997). The loss of phytoplankton resources could lead to an altering of the river ecosystem and loss of the fragile and unique wildlife supported by the river. Bighead could also negatively affect growth in native species such as paddlefish by out competing for food resource as demonstrated under experimental settings (Schrank & Guy, 2003). In addition to competition with paddlefish, bighead carp could also be direct competition for other planktivores such as gizzard shad and bigmouth buffalo (Pflieger, 1997). Koel et al., (2000) theorized that if left unaddressed, populations of Asian carp will likely result in more introductions leading to harmful effects on native species and that lessons learned from the introduction of the common carp may provide an example of what lies ahead if efforts to control are not employed.

Silver Carp Impacts: The impacts of silver carp are similar to bighead carp. The increased competition for food sources with native species has the potential to alter food webs (Pflieger, 1997) and cause declines in planktivorous species due to competition for resources (Pflieger, 1997; Rasmussen, 2003). Laird and Page (1996) added that the potential depletion of food sources by silver carp necessary for many native mussels could cause enormous damage. Aside from impacts to native river species and wildlife, silver carp pose a human safety threat due to their leaping ability. These large, leaping fish have caused numerous injuries (D. Chapman, pers. Comm.; INHS, pers. Comm.) and near fatalities (Brant, 2004).

In addition, the displacement of native species by silver carp has been documented. In 1999, a fish kill near Wilkinson Island revealed a fish population dominated by silver carp species (USFWS, 1999). On that occasion, thousands of silver carp were observed in the Wilkinson Island area indicating an ability to dominate the population structure. This type of population restructuring has a detrimental impact on native species, the general ecology of the river and the adjacent wildlife that it supports.

Black Carp impacts: It is believed that survival in United States rivers would be likely and the chance for established populations is good (USEPA, 2002). With no known factors to limit them, spread is likely once established (USEPA, 2002). Since black carp are molluscivores, spreading populations would impact native species such as fish, turtles, waterfowl and vertebrates such as raccoons, otters and muskrats by competing for food resources at all life stages. Direct impact on mussel and snail populations would occur as well as probable impact to other aquatic ecosystems by transferring pathogens (i.e., parasites, bacterial and viral diseases, etc.). Threatened and endangered fish, mollusks, turtles and birds that rely on mollusks and snails as a food source would also be impacted (Nico et al., 1996). Black carp escapement and establishment is believed to be inevitable as noted by biologists familiar with the species (Rasmussen, 2003) and would likely follow similar distribution patterns as the silver carp and bighead carp.

Grass Carp impacts: Due to their wide distribution, the threat of these species spreading has already been realized, however, not all areas of establishment sustain reproductive populations. Species are listed as established in many areas for extended periods of time due to stocking and due to the long lifespan of the species (Fuller et al., 1999). Negative impacts of this species include direct competition with native species such as crustaceans (Fuller et al., 1999). Pflieger (1997) noted the potential impact to native species and commented that effects of grass carp have not been fully realized. In addition to direct competition with other species, changes in aquatic plant and phytoplankton communities are possible impacts of grass carp (Fuller et al., 1999). The grass carp species are capable of consuming large amounts of aquatic vegetation (see also Section III) in a destructive manner. It is estimated that a single grass carp can consume 45 kg (99 lbs) of vegetation per day while only utilizing half of what it takes in (Fuller, et al., 1999). This destructive feeding pattern not only results in a loss of aquatic vegetation habitat but can also lead to an altering of the trophic state. The undigested portion left by the grass carp can result in changes in the phytoplankton structure resulting from the release of nutrients in the uneaten and partially digested vegetation.

Feasibility Study

To Limit the Invasion of Asian Carp into the Upper Mississippi River Basin

V. Technology Review of Potential Alternatives

FISHPRO

V. TECHNOLOGY REVIEW OF POTENTIAL ALTERNATIVES

Overview of Barrier and Deterrent Alternatives

Potential barrier and deterrent systems that may be suitable for use in the Upper Mississippi River System to limit the upstream movement and establishment of Asian carp are described briefly below and summarized in Table V-1. There are two barrier and deterrent classifications presented; behavioral and physical. Behavioral guidance technologies include any of the various methods that employ sensory stimuli to elicit behaviors that will result in migrating fish avoiding, or moving away from, areas that may potentially impair fish survival. In all cases, the purpose is to discourage fish from entering a particular area and to make it desirable and possible to move someplace else. Examples of potential behavioral systems include strobe lights, air bubble curtains, acoustic deterrents, electrical disbursal barriers, hydrodynamic louver screens, and combination systems that may utilize two or more systems or hybrids to provide a more effective barrier or deterrent. Physical barriers have been utilized in numerous locations to prevent fish movement through the use of rotating drum screens, traveling screens, floating curtains, vertical drops (existing and constructed), velocity barriers, etc.

Strobe Lights

The strobe light (see Figure V-1 below) has been extensively evaluated as a fish deterrent in both laboratory and field situations and has been used in conjunction with other behavioral devices to increase the level of fish diversion. Combinations with bubble curtains may enhance the effectiveness of both, as the light can be projected onto the bubble sheet. Strobe lights can repel fish by producing an avoidance response. A strobe light system at Saunders Generating Station in Ontario was found to be 65 to 95 percent effective at repelling or diverting eels (Stone and Webster, 1986). Turbidity levels in the water can affect strobe light efficiency. The intensity and duration of the flash can also affect the response of the fish; for instance, an increase in flash duration has been associated with diminished avoidance response. Strobe lights also have the potential for long distance fish attraction, since they appear as a constant light source due to light attenuation over a long distance.

Effective levels of deterrence have been achieved with a number of species, but the lights have worked most extensively and effectively with American shad juveniles. Successful fish deterrence with strobe lights has often been site specific, which indicates that hydraulic and environmental conditions, along with project design and operation, are factors that must be considered for a successful system installation.

Figure V-1. Typical Strobe Light System

Table V-1. Summary of Potential Alternatives to Limit the Invasion of Asian Carp

Control Method	Type of Alternative	Optimum Diversion Efficiency [1]	Probable Risk of Failure	Navigational Impact	Construction and/or Implementation Complexity	Operational and/or Maintenance Issues	Public Safety Concerns	Probable Cost Range (Installed)	Comments
Behavioral Barriers and Deterrents	Strobe Lights	~50 - 95%	Moderate to High: Species and size specific; location & day/night specific; effectiveness varies with time of year (water temperature, flow, etc.)	None to minimal	Moderate: Packaged unit	Low: Lamp and power delivery system maintenance	None	$0.5 million to $1.0 million	Only considered to be appropriate as a lock entrance channel deterrent
	Air Bubble Curtain	~50 - 95%	High: Does not work in high water velocity and turbulence	None to minimal	Moderate: Air piping in varying depths	Moderate : Compressor and air line maintenance	None	$0.5 million to $1.0 million	Only considered to be appropriate as a lock entrance channel deterrent. Not effective under high flow conditions.
	Acoustic Deterrent: Sound Projector Array (SPA) at Lock Entrance	~60 - 90%	Moderate to High : Species and size specific; location & day/night specific; effectiveness varies with time of year (water temperature, flow, etc.)	None to minimal	Moderate: Packaged unit	Low : Transducer and power delivery system maintenance	None	$1.2 million to $1.4 million	Potentially feasible as a deterrent for lock entrance channels
	Acoustic Deterrent: Sound Projector Array (SPA) at Spillway gates	~60 - 90%	Moderate to High: Species and size specific; location & day/night specific; effectiveness varies with time of year (water temperature, flow, etc.)	None to minimal	Moderate: Packaged unit	Low: Transducer and power delivery system maintenance	None	$8.5 million to $10.5 million	Potentially feasible as a deterrent for spillway gate areas opened under full flow conditions
	Acoustic Deterrent: Pneumatic Acoustic Bubble Curtain (BAFF) at Lock Entrance	~60 - 90%	Moderate to High: Species and size specific; location & day/night specific; effectiveness varies with time of year (water temperature, flow, etc.); does not work in high water velocity	None to minimal	Moderate: Packaged unit; air piping in varying depths	Low: Transducer and power delivery system maintenance; compressor and air line maintenance	None	$1.0 million to $1.4 million	Potentially feasible as a deterrent for lock entrance channels
	Acoustic Deterrent: SPA Based Acoustic Bubble Curtain (SPA/BAFF) at Lock Entrance	~90%+	Moderate to High: Species and size specific; location & day/night specific; effectiveness varies with time of year (water temperature, flow, etc.); does not work in high water velocity; enhances the overall effectiveness of a standard BAFF in areas with intermittent turbulence and barge traffic.	None to minimal	Moderate: Packaged unit; air piping in varying depths	Low: Transducer and power delivery system maintenance	None	$1.2 million to $1.6 million	Potentially feasible as a deterrent for lock entrance channels. Enhances the overall effectiveness of a standard BAFF system; SPA component allows utilization of Asian carp specific audiogram.
	Hybrid Comb. System (Strobe light/acoustic)	~60 - 95%	Moderate to High: Species and size specific; location & day/night specific; effectiveness varies with time of year (water temperature, flow, etc.)	None to minimal	Moderate: Packaged unit	Low: Transducer and power delivery system maintenance	None	$1.6 million to $2.2 million	Potentially feasible as a deterrent for lock entrance channels. Combination systems have generally proven to be more effective
	Hybrid Comb. System (Str. light/bubble curt.)	~60 - 95%	Moderate to High: Species and size specific; location & day/night specific; effectiveness varies with time of year (water temperature, flow, etc.); does not work in high water velocity	None to minimal	Moderate: Packaged unit; air piping in varying depths	Moderate: Compressor, air line and power delivery system maintenance	None	$1.2 million to $2.0 million	Potentially feasible as a deterrent for lock entrance channels. Combination systems have generally proven to be more effective
	Electrical Barrier (Main stem or at spillway gates/culverts)	~90 - 99%	Moderate: Variable depth for electrical field, silt, maintenance, size dependent	None to minimal	High: Electrode installation in water	High Power outages, maintenance, debris, etc.	High: Safety issues; negative Perception	$15.0 million to $25.0 million	Technically feasible for a large main stem river installation. Significant power requirement and public safety concerns.
	Electrical Barrier (Inside Lock)	~90 - 99%	Moderate: Variable depth for electrical field, silt, maintenance, size dependent	None to minimal	High: Electrode installation in water	High: Safety	High: Safety issues; negative Perception	$8.0 million to $10.0 million	Technically feasible for a large main stem river installation. Significant power requirement and public safety concerns.
	Electrical Deterrent (Lock Channel Entr.)	~90 - 99%	Moderate: Variable depth for electrical field, silt, maintenance, size dependent	None to minimal	High: Electrode installation in water	High: Safety	High: Safety issues; negative Perception	$8.0 million to $10.0 million	Technically feasible for a large main stem river installation. Significant power requirement and public safety concerns.
	Hyb.Comb. System (Electric Barrier & SPA/BAFF) at Lock	~90 - 99%	Moderate: Variable depth for electrical field, silt, maintenance, size dependent	None to minimal	High: Electrode installation in water	High: Safety	High: Safety issues; negative Perception	$9.6 million to $12.2 million	Technically feasible for a large main stem river installation. Significant power requirement and public safety concerns.
	Hydrodynamic Louver Screens	~86 - 97%	High: Fouling problems; species and size specific	Significant	Moderate : Anchor system in water	High: Icing and fouling by debris	Slight to Moderate	$1.0 million to $2.0 million	Not a suitable technology due to navigational impact, high maintenance requirement and a tendency to clog with silt and debris
Physical Barriers	Vertical Drop (Existing Overflow Spillways)	~95 - 100%	Low: Site dependent	Significant at spillway; Access through locks	Site dependent	Low	Existing Spillway	Existing Spillway	Locating a barrier or deterrent system at an existing lock and dam with a high head spillway can provide partial barrier benefits.
	Rotating Drum &/or Traveling Screens, Floating Curtains	~95 - 100%	Low to Medium	Significant Impact at locks	Extreme: Extensive civil works; Cofferdams	High: Icing; Fouling	Varying; not applicable	Varying; not applicable	Physical barrier alternatives not considered to be practical or feasible for the UMR due to magnitude of installation and/or navigational requirements
	High Velocity (Point Release)	Unknown; species specific	Low: Site dependent	None if installed at spillway gates	Site and species dependent	Moderate; debris may clog or damage	Unknown Site dependent	Site dependent	Although potentially retrofitted into an existing lock and dam spillway, swimming capabilities of Asian carp may preclude feasibility

1. Optimum efficiency ranges obtained from existing references in literature for species specific case studies, site specific installations and reported field-test results. Actual diversion efficiencies may vary according to site conditions and species targeted for deterrence.

High Pressure Sodium and Mercury Lights

High pressure sodium lights (1,000 watts) have been used to attract and hold blueback herring to slow water areas located near a powerhouse spillway. These lights are similar to those used by commercial fisherman to concentrate blueback herring for harvest. Preliminary studies have shown that blueback herring and other fishes can be attracted to high-pressure sodium or mercury vapor lights. (Nestler, Ploskey, Weeks and Schneider, 1995).

Mercury lights have been used as attractants for species-specific applications. Alewives have been attracted to a zone of filtered mercury light, whereas Coho salmon and rainbow trout displayed no attraction (Stone and Webster, 1986). Insufficient data are available to determine whether mercury lights are life-stage specific. Attractants may be used in combination to congregate fish that are avoiding other behavioral barriers or deterrents.

Hybrid barriers or combinations of different barriers have been found to increase the effectiveness of individual behavioral barriers such as strobe lights and bubble curtains. Underwater strobe lighting and bubble curtains have been found to successfully divert/deter 77 to 80 percent of all fish normally approaching hydroelectric turbine forebay areas.

Bubble Curtains

The bubble curtain is the most elementary form of behavioral fish barrier, which in its simplest form consists of a perforated tube laid across a river bed through which compressed air is forced. The rising curtain then forms a wall that will deflect fish under optimal conditions such as the reflection of light and the generation of underwater noise and vibration by the bubbles. Solomon (1992) cited fish deflection efficiencies for bubble barriers in laboratory tests of up to 98%, falling to a range of 51% to 80% in darkness or high turbidity levels. The cost of a bubble barrier is relatively low, although large, deep-water installations can be expensive, both in terms of capital costs of the compressor and housing, and of power requirements.

Air bubble curtains are created by pumping compressed air through a diffuser to create a continuous dense curtain of bubbles, which can cause an avoidance response in fish. Many factors affect the response of fish to air bubble curtains; including temperature, turbidity, light intensity, water velocity and orientation in the channel. Bubbler systems should be constructed from materials that are resistant to corrosion and rusting. Installation of bubble curtain systems should consider positioning of diffusers in areas where siltation is not likely to clog air ducts or in areas where bubble curtain disruption may occur as a result of barge or flow related turbulence.

Acoustic Barriers or Deterrents

Fish vary in their sensitivity to underwater sound, which will clearly influence the potential efficiency of an acoustic barrier. When considering audible range frequencies, hearing sensitivity is determined by the presence or absence of a swim bladder and by any anatomical specializations that improve the conduction of sound from the swim bladder to the inner ear

(Hawkins, 1986). Fish size is also an important factor in relation to acoustic deterrence efficiency. Observations have confirmed that smaller sized fish may be more tolerant and could require stronger, higher frequency sound in order to be effective. Habituation to sound is generally not a problem with migratory fish, since they are not typically in contact with the sound for a long period. Nevertheless, it must be considered with resident fish populations, where fish may be in contact with the sound for extended periods and therefore develop a tolerance. Acoustic deterrent systems are generally designed to minimize the risk of habituation by altering the deterrent signals on a daily basis.

Deflection is generally the most effective course of action for an acoustic deterrent system, where the fish are diverted away from the river structure and into a targeted area. Blocking like a barrier perpendicular to river flow can be more difficult if the fish are not diverted away from the protected area because the risk of habituation to the sound signal increases. Although regularly changing the signal pattern can minimize habituation, acoustic systems are not considered to be as effective as electrical barriers for blocking movement. Therefore, it is considered necessary to provide a desirable flow regime or habitat for the fish to be guided towards. The ideal sound field should form a steep acoustic gradient approaching the entrance, free from acoustic nulls (voids) caused by destructive interference within the sound field. The presence of such nulls could cause fish to be guided into instead of away from the river structure.

The hearing range of most fish falls within the audible range of humans, with maximum sensitivity lying in the sub-3 kHz band (Hawkins, 1981). Audible frequency deterrent systems typically exploit hearing sensitivity in the 20 to 500 kHz range. The key factors for successful fish deflection are: 1) the sound signal should be within the 20 to 500 kHz frequency spectrum; 2) the nature of the signal should be a repellant to fish; and 3) the sound level received by the fish at the required point of deflection should be sufficiently above ambient noise level (Lambert et al, 1997). Some of the common causes of acoustic deterrent system failure include: 1) emission of sounds at frequencies outside the main hearing band of fish (0 to 600 kHz); 2) ineffective signal types; 3) inadequate sound levels; 4) failure to compensate for background noise; 5) unsuitable or inadequate sound generation equipment; 6) unusual sound propagation patterns caused by interference; 7) excessive water velocities; 8) failure to provide a clear escape route or diversion area; or, 9) poor design.

Two methods of generating an acoustic barrier are presently in use. One uses arrays of underwater loudspeakers or sound projectors to produce a diffuse omni-directional field of sound that can block fish movement. The other uses sound sources coupled to a bubble curtain to produce a discrete “wall of sound” (known as an “evanescent” or rapidly decaying field) that can be used for more precise guidance of fish.

A Sound Projector Array (SPA) low frequency acoustic deflection system consists of an electronic signal generator, one or more power amplifiers and an array of underwater sound projectors (see Figure V-2 courtesy of FGS Ltd.). A typical arrangement of sound projectors includes a maximum 3-meter spacing along the diversion line. The depth can vary with conditions. The optimum number and positioning can be determined using an acoustic model such as PriSM (Subacoustic, Ltd.) to predict the resulting sound pressure. In most SPA systems, it is necessary to acoustically model the proposed installation site to ensure there are no nulls created by reflections from surrounding structures. This can lead to weak points in a system, and can in fact increase the number of fish entering a protected area or river structure entrance. The SPA system uses underwater sound projectors powered by audio amplifiers and electronic signal generators to create a repellant field ahead of a structure. Annual maintenance requirement involves removing the underwater units to check moving components and repair if necessary. It is also recommended that the units are raised and cleaned periodically to remove silt buildup or fouling. In order to provide protection during cleaning or system maintenance, a secondary system is recommended also for redundancy.

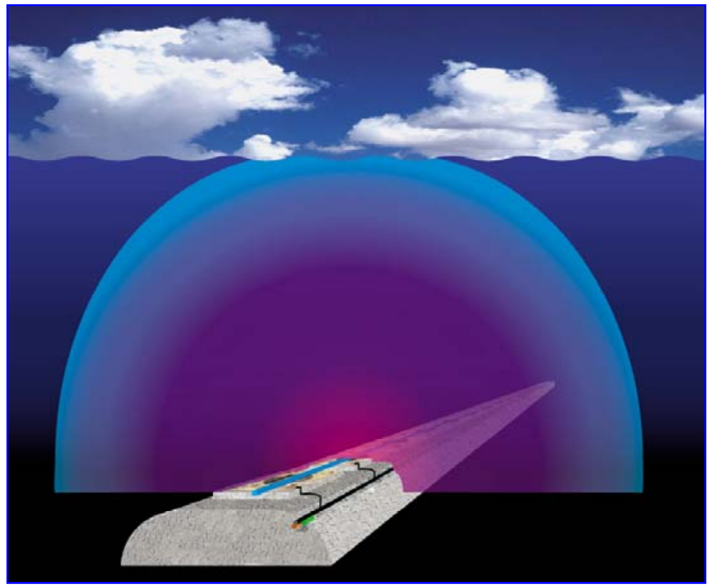


Figure V-2. SPA System and Multi-Directional Sound Field (courtesy of FGS Ltd.)

The disadvantage of a SPA is that the sound is not concentrated as with a BAFF (introduced below). A SPA is more suited to covering an intake where there is a flow past the intake and the SPA system pushes the fish away from the intake and into the main flow of the river. In applications, where it is necessary to deflect fish swimming 'head long' into the barrier, a higher and more concentrated sound field (as in a BAFF) is required to deflect the fish.

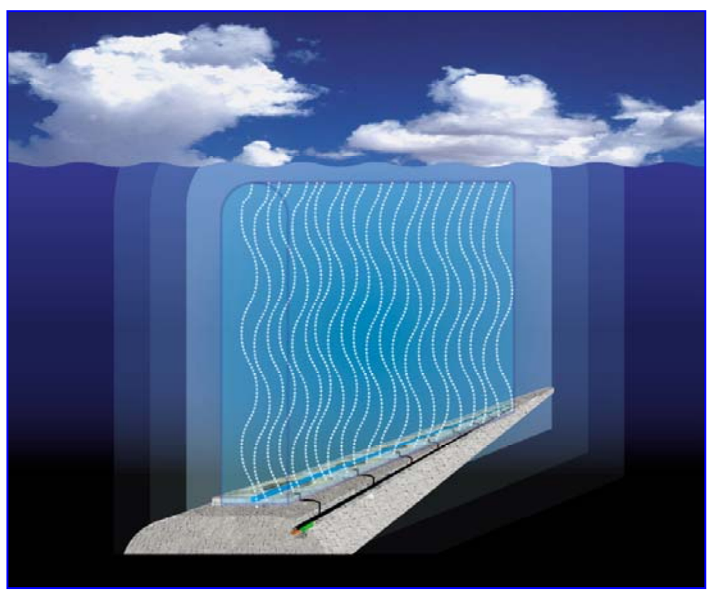


Figure V-3. Bio-Acoustic Fish Fence System (courtesy of Fish Guidance Systems, Ltd.)

The Bio-Acoustic Fish Fence (BAFF) is a proprietary product that uses a combination of a sound source and a bubble curtain to create a field that is largely contained within the bubble sheet (see Figure V-3 courtesy of FGS Ltd.). Physically, the system consists of an electromagnetic or pneumatic sound transducer coupled to a bubble-sheet generator, causing sound waves to propagate within the rising curtain of bubbles.

Operating costs for a BAFF are generally higher than for an equivalent SPA system, since it requires an air blower or compressor. However, the compressed air demand is less than an equivalent stand-alone bubble curtain system since a smaller volume of air is typically required.

The BAFF is typically used to divert fish from a particular flow area and may be regarded as analogous to a conventional angled fish screen. It utilizes an air bubble curtain to contain a sound signal through refraction that essentially becomes a "wall of sound" (an evanescent sound field) that can guide fish around and /or away from river structures. The sound level inside the bubble curtain may be as high as 170 dB and decaying to as much as 5% of this value within 0.5 to 1.0 meters away from the bubble curtain. The disadvantage of the conventional BAFF is that it is less capable of being tailored directly to the audiogram of the carp (depending on the audiogram frequencies).

A hybrid system has been recently developed by FGS that utilizes the SPA based sound projection system coupled with an air driven bubble curtain. This system differs from the conventional BAFF system in that the SPA projectors can be calibrated to produce a sound signal that matches a particular fish deterrent audiogram, whereas the pneumatically driven sound source of the conventional BAFF system cannot. In addition to the enhanced sound calibration capability, the omni-directional sound projectors would couple with the bubble curtain as a focus medium for the sound projection.

A conventional BAFF has an audio driver unit that produces the sound pneumatically, directly into the air supply for the bubble curtain, so in a conventional 'pneumatic BAFF' the sound is contained within the bubbles at very high sound levels. The sound drops off very quickly from the bubble curtain, which makes it ideal for guiding fish. With a SPA, the sound field is more widespread, but acoustic modeling would ensure that a smooth even sound field is produced from a SPA based system.

The hybrid SPA driven BAFF has an advantage over either conventional system since it combines both the ease of signal selection of an SPA, and the concentrated sound field of a BAFF. It will be important to insure that the sound from the sound projector array 'couples' with the bubble curtain, which could be incorporated in the design of the deployment system, and could be field-tested before the system went into functional operation.

The Illinois Natural History Survey has conducted SPA driven BAFF barrier experiments within concrete raceways at the Jake Wolf Memorial Fish Hatchery near Manito, IL, which is located near the Illinois River where established populations of bighead and silver carp currently exist. It was determined that the system was 57% effective in repelling 3,219 attempts of adult bighead carp under raceway-scale conditions (Taylor, Pegg and Chick, 2003). However, it should also be noted that the number of attempts decreased consistently on the 2^{nd} and 3^{rd} day of the experiment and the percentage of repels versus attempts also increased significantly, possibly as a result of a learned response. Although the test barrier was somewhat effective in restricting the movement of the captured bighead carp, it was observed that the fish were capable of crossing the barrier when frightened and that further testing and sound calibration will be required. It is important to note that the design of the experiment did not allow for fish to disperse to another area.

A high frequency sound field generated by an eight-transducer array, diverted blueback herring out of an intake plume at the Richard B. Russell Dam and Lake along the South Carolina and Georgia border. Different configurations were tested and a final system approach included sequential transducers and variable signal frequency (changing every 15 minutes to minimize habituation). The total cost for the system was $325,000. High-pressure sodium lights were used as an attractant ($490,000). Fixed aspect acoustics showed that 70 times more fish were in lit areas than unlit areas. The 81% reduction in hourly entrainment was similar to the 78% reduction observed in previous tests (Nessler and Ploskey, 1996).

Evolution of the bio-engineering approach has resulted in several valuable lessons that can benefit future efforts to achieve maximum efficiency in acoustical barriers and deterrents. The first lesson is that there are no overnight successes. A second lesson is that fish response to sound varies among species and that environmental conditions, including factors such as morphology of the site, water current patterns, seasonal stratification and turbidity, among others, can influence performance of a system both from the standpoint of the physics of sound in water and the physiological response of fish to sound. The third lesson is that field scale testing and monitoring is absolutely necessary throughout all phases of development, such as acquisition of baseline information, typical behavior of the target species, installation and testing of the full scale system. It has been observed that smaller, less mature fish generally appear to have lower sensitivity to sound than larger, more mature fish. Differences in basic sensory capability such as this could be very important in determining the specifications of sound behavior modification and/or deterrent systems.

Electrical Barriers and Deterrents

The electrical fish barrier or deterrent can function either as an impassable barricade or as a fish guidance system. In either case, the system consists of a series of metal electrodes submersed in water to create an electrical field capable of repelling fish. A modern version of the electric fish screen, which was developed in the 1950's, is the Graduated Field Fish Barrier (GFFB) manufactured by Smith Root, Inc. (SRI). The GFFB has been primarily used to prevent upstream movements of fish, where a minimum water velocity of 0.6 to 0.9 m/s is required to carry fish downstream out of the field. One of the most important features of this fish barrier/deterrent is the graduated electric field. As fish advance into a graduated field, they feel an increasingly unpleasant sensation. When the sensation becomes too intense, fish are unable to advance any further and cannot keep their body oriented with the water flow. They turn perpendicular to the field and are either swept clear by water flow or swim in the opposite direction of the increasing electric field.

The graduated field barrier uses a series of pulse generators to provide ascending levels of field intensity. The pulsators (pulse generators) have their outputs connected to an array of evenly spaced electrodes placed across a stream or river bottom (see Figure V-4 courtesy of SRI). Each pulsator can be adjusted to provide an increasing voltage between successive electrode pairs. This creates a gradually increasing electric field along the array. Longer fish receive more head-to-tail voltage and are affected at an earlier stage, while smaller fish can generally penetrate the barrier further before being overcome or repelled.

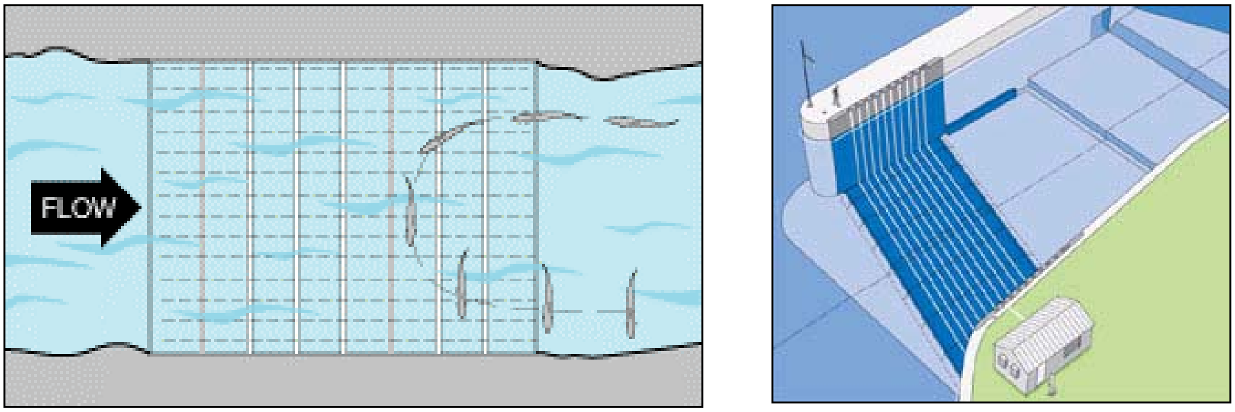


Figure V-4. Graduated Field Fish Barrier Schematics (courtesy of Smith-Root, Inc.)

In the year 2000, SRI designed and produced a new series of more powerful pulse generators capable of providing a full water column barrier in the Chicago Sanitary and Ship Canal with a 20 ft. maximum depth. This new series of pulse generators are able to be parallel connected in a series to handle even greater depths and wider water columns. Additionally, a more sophisticated operating system has been designed to handle the additional power required to generate the necessary pulse generator commands and the associated monitoring necessary to meet these requirements. This recent SRI development has made it technically possible to implement an effective electrical fish barrier on a river as large as the Mississippi.

Since the barrier electrodes would be bottom mounted and would extend from shore to shore, a major site requirement for a river wide electrical barrier installation would require a location where all of the water column would pass over the electrodes during a major flood event. Other important considerations would include the availability of sufficient electrical power, suitable distance from densely populated areas, and in a location where silt and debris accumulation would be minimal.

The Illinois Natural History Survey has conducted electric barrier experiments within concrete raceways at the Jake Wolf Memorial Fish Hatchery. Using two SRI Fish Barrier Pulsators, an eight electrode graduated field array was created to better simulate actual Chicago Sanitary and Ship Canal conditions. In addition to the graduated field electric barrier, a SPA driven BAFF acoustic-bubble curtain system was utilized simultaneously to create a hybrid, integrated system. It was determined that the hybrid, integrated system was 83% effective in repelling the attempts of adult bighead carp under raceway-scale conditions (Taylor et al., 2003). Although the test barrier was highly effective in restricting the movement of the captured bighead carp, it was observed that the fish were capable of crossing the barrier when frightened and that further testing will be required. Concerns have been raised about the feasibility of any electric barrier in a river as large as the Mississippi. Sediment and debris could cover electric cables or damage them, and high floodwaters may interrupt the curtain of electricity. Safety issues and negative public perception has also raised concern.

Hydrodynamic Louver Screens

Hydrodynamic louver screens are basically fins angled to the flow direction that are structurally supported in panels across the channel. Although a structure, the louvers cause a velocity increase that would repel some fish. They would generate a head to produce the increased velocity, would require a uniform channel, and are species and size specific for a given flow. Because of the potential for debris loading, navigational impact and the variable flow patterns present; louvers are not considered to be viable for applications on Upper Mississippi River locks and dams.

Physical Barriers

Physical barrier options that were evaluated include vertical drops, rotating drum screens, traveling screens, floating curtains, and high velocity structures. It should be noted that upstream physical barriers must also consider navigational impacts and downstream passage constraints, including impingement and bypass criteria.

The vertical drop barrier is basically an overflow weir as a component of a dam, which would provide a hydraulic drop over the structure higher than the leaping ability of the target species. Spatial geometry of the downstream pool would incorporate the consideration of creating hydraulic conditions that would prevent good staging behavior of the fish, prior to the jump, from occurring. This may be a possibility for a partial barrier/guide wall at existing Lock and Dams 8, 14 and19. Although a new vertical drop structure for the main stem of the Upper Mississippi River may not be feasible or practical, smaller scale tributary installations may warrant further consideration.

Rotating drum screens continuously rotate to pass debris over the top of the drum to the downstream side, where flow through the screen can carry it away. A set of drum screens could be oriented perpendicular to or at a slight angle to the flow, depending on the site configuration. Provisions are typically made for lifting individual drums out for maintenance. Rotating drum screens are well-proven systems for smaller applications under the proper conditions. Because wetted screen elements are constantly exposed to air, drum screens will not function in severely cold weather with a completely enclosed structure above the water surface. Sizing screens to accommodate downstream passage is not practical.

Traveling screens have been most commonly used in the past for smaller river diversion barriers. The unit would continuously rotate, lifting debris over the top and depositing it on the downstream side, similar to the rotating drum concept. As with the rotating drum, continuous exposure to wetted elements would make cold weather operation difficult or impossible without a completely enclosed structure above the water surface. Traveling screens would be subject to the same approach velocity and surface area requirements as for a stationary, or rotating self-cleaning screen, and would also appear impractical for use on Upper Mississippi River locks and dams.

Floating curtain systems generally consist of a piling or float supported cable with nylon nets or hanging chains attached. Utilizing a net or hanging chains as a barrier for major structures on the Upper Mississippi River with the high water velocities, substantial depths and debris loading would not be practical. There may, however, be a possibility to use smaller floating barriers to guide fish to a control area.

High velocity barriers are commonly configured as a flat apron below or part of a dam spillway, which generally has a high water velocity at variable flows. The velocity of the water must exceed the burst, or by distance, the sustained swimming speed of the target species. While these high velocity barriers may not be feasible or practical for the UMR, there may be potential for consideration on smaller tributary scale applications.

Overview of Management Alternatives

Potential management alternatives that may be suitable for use in the Upper Mississippi River System to limit the upstream movement and establishment of Asian carp are described briefly below and summarized in Table V-2. These alternatives include prevention through education, regulation, enforcement and deterrents; monitoring and detection; rapid response alternatives; attractants (i.e., pheromones, plankton, light and sound, etc.) and repellents (i.e, fright pheromones); constructed and enhanced habitat, controlled harvesting and removal, daughterless carp technology, sterile male release, etc.

Table V-2. Summary of Potential Management Alternatives

Type of Management Alternative	Implementation and/or Maintenance Issues	Comments
Prevention through Regulation, Enforcement, Education and Deterrents	Important to educate public and regulators that the Asian carp population must be contained.	Coordination and acceptance from a national audience is required to insure a level playing field. It is important to prevent or restrict Asian carp aquaculture, live fish transport and sales, catch and release fishing and sustainable commercial harvest.
Monitoring and Detection	Proper equipment and training must be provided to appropriate personnel for early detection and consistent monitoring.	Since the Asian carp is generally difficult to detect and monitor using traditional fish population sampling equipment, it will be important to develop and maintain a coordinated, well staffed and appropriately trained personnel.
Rapid Response Alternatives	A coordinated rapid response plan must be developed in the event of detection and or establishment of Asian carp in critical areas to be determined.	A rapid response plan has been developed for the Chicago Sanitary and Ship Canal project that may be applicable to the UMR

Attractants and Repellants (Pheromones)	In development; Regular management required to maintain pheromone supply and subsequent removal of fish by controlled harvest	USEPA has recently approved the first field-scale testing of vertebrate pheromones to attract and control sea lampreys in selected Great Lakes tributaries.
Attractants (Plankton)	Unknown: field-testing will be required. Regular management required to maintain plankton supply and removal of fish by controlled harvest	Since the bighead and silver carp are primarily plankton feeders, enhancing a protected area with nutrients sufficient to stimulate appropriate plankton blooms could be considered as a means of attracting higher densities for removal
Attractants (Light, sound, etc.)	Species and size specific; Location & day/night specific; Effectiveness varies with time of year (water temperature, flow, etc.); Regular management required to maintain system operation and removal of fish	Field scale testing would be required to determine suitability for effectiveness on Asian carp
Constructed and Enhanced Habitat	Site dependent; Inundation during flood events, maintenance of structures, habitat, etc.	Wing dams, side channel areas, habitat based traps, etc. designed to concentrate fish density for efficient removal, in addition to enhancement and restoration of native species habitat
Controlled Harvesting and Removal	Regular management required to maintain system operation and removal of fish, particularly downstream of spillway gates where a deterrence system has been installed at lock entrances	It is likely that finite contractual harvesting may be required for specific locations to eliminate potential for sustainable population; An investigation into the impacts of harvest on recruitment may be necessary
Daughterless Carp Technology	Regular management required to maintain genetically altered carp for release; long time frame for results	Involves genetic manipulation to produce an inheritable "daughterless carp" in an effort to reduce the number of breeding females may be controversial
Sterile Male Release	Regular management required to maintain sterile males for release	Currently being tested on sea lamprey to reduce spawning success
Life Stage Management	Site dependent; Inundation during flood events, maintenance of structures, habitat, etc.	Shallow water habitat modification; capture of downstream egg drift; exclusion of YOY from seasonal wetlands; additional research required

Prevention through Regulation and Enforcement, Education and Public Outreach

Based on the priorities of the Great Lakes and other regional panels as addressed in the National Aquatic Invasive Species Act (1996), it can be inferred that an Asian carp prevention and control program will require coordination in areas of policy and legislation, research and management, in addition to information, education and public outreach. It will be essential to empower state, regional and national entities with the authority and resources to implement the necessary legislative mandates as well as incentives to operate on a cooperative basis.

It will be equally important to increase public awareness and understanding of Asian carp and their impacts to the ecological and economic health of the Upper Mississippi River. Outreach programs that promote commercial and recreational practices to prevent the spread of Asian carp should be implemented. These practices include the proper disposal of live bait, particularly since young-of-year silver and bighead carp fingerlings closely resemble gizzard shad. For example, a program entitled "Stop Aquatic Hitchhikers" has been initiated by the ANS Task Force public awareness campaign in an effort to control recreational spread of aquatic nuisance species and could be applied to Asian carp (see Figure V-4).

Based on a review of available information, there does not appear to be a great deal of "regulatory coordination" between states bordering the Upper Mississippi River. Minnesota apparently has the most stringent laws on the books with regard to the four species of Asian Carp. Only Illinois lists the Black Carp as injurious. Although it is not currently illegal to import Asian Carp into Wisconsin, the Wisconsin DNR is actively working towards changing the regulation to make importation illegal. Iowa law prohibits the introduction of live fish into any Waters of the State with the exception that private waters may be stocked with live fish, which probably provides a potential pathway for the introduction of Asian Carp.

The ***Model Rapid Response Plan for Great Lakes Aquatic Invasions*** (Draft: July 17, 2003) represents the development of a model rapid response plan for Great Lakes aquatic invasions. The goal of this project was to develop a model rapid response plan as part of an overall regional effort to enhance ability to anticipate, prevent and respond to new aquatic invasions of non-indigenous species in the Great Lakes-St. Lawrence region and could be modified and adapted for limiting the movement of Asian carp into the Upper Mississippi River System.

Integral to rapid response planning is a communication and organizational structure that determines how to disseminate information, as well as authority and leadership roles, coordination, cooperation and partnerships. Legislative authority and policy also need to be taken into consideration under this component. A clearly defined communication structure will facilitate timely information exchange among the appropriate entities in the rapid response network. If a rapid response is deemed appropriate, information needs to be communicated to appropriate stakeholders to engage them in the process. Other states, provinces, agencies, the media and the public need to be made aware of the situation and associated activities as appropriate.

Monitoring and Detection

Early detection and monitoring efforts are critical to the discovery of new introductions of non-indigenous aquatic species such as Asian carp and in accurately tracking the spread of existing invasions. Efforts related to early detection and monitoring may include such activities as priority setting, identification of high priority species and at-risk sites; routinely monitoring certain areas (LTRMP-Long Term Resource Monitoring Program already in place may need to be supplemented with additional monitoring sites); prevention and containment efforts; surveillance, detection and reporting activities including data collection and management; the collection, identification and storage of voucher specimens; and training volunteers and professionals in detection, identification and removal techniques.

Rapid Response Alternatives

As part of the process of rapid response, there is a definite need for a compilation of management options regarding control measures and tools available to managers to apply in response to the Asian carp invasion. In addition to mechanical/physical, biological and chemical responses, the process should provide direction on how to obtain pre-approval and permitting for control measures, quarantine establishment and enforcement, and an assessment of specific control measures and management tools for high priority species. Several of the most common control measures that are applicable to several invasive species should be pre-approved for specific situations. Management tools should be assessed based on the species, location and extent of the infestation. The tools for response include mechanical methods (i.e., trapnets, trawling, etc), chemical methods (i.e., rotenone, etc.), and biological control such as increasing predators and introducing pathogens (Wiley and Wydoski, 1993). Mechanical methods may be the most specific and selective while chemical methods tend to have wide-ranging effects on the ecosystem. Biological control methods are often controversial and take longer periods of time to attain permitting for implementation.

Implementation efforts need to be highly coordinated to limit redundancy and to ensure that the appropriate stakeholders are involved and informed of actions. It is particularly important that this coordination and planning is incorporated into the state and federal ANS management plans. Because authority and leadership roles are critical to the implementation of a rapid response, the communication and organizational structure described above should be well developed on a state and federal level. Implementation of a response to an invasive species will most likely be conducted by the agency with the authority to respond or the agency with jurisdictional responsibility/rights over the infested area. Securing and appropriating adequate funding for the implementation of a rapid response may be the largest potential obstacle to overcome.

An adaptive management scheme is crucially important to the implementation of a rapid response. Ideally, adaptive management will include an evaluation of plan effectiveness, mitigation and/or restoration of treatment areas, an assessment of re-introduction risks, and post-procedure monitoring. Additionally, education and outreach efforts should continue during the adaptive management phase of the rapid response plan. The evaluation of the chosen management option should determine if the desired outcomes have occurred and whether or not the goals and objectives set during the initial phases of plan implementation were met. If the preferred management option is not producing the desired outcomes and meeting goals, there needs to be a mechanism in place to make the decision quickly to move to another option. The adaptive *Model Rapid Response Plan for Great Lakes Aquatic Invasions* (Draft: July 17, 2003) management phase of the plan allows for the assessment of what strategies worked and those that did not.

The Great Lakes Rapid Response Plan developed for the Chicago Sanitary and Ship Canal barrier to prevent Asian carp from entering Lake Michigan included the evaluation of several control measures that could be implemented as a last resort method of control/eradication. Although several of these rapid control measures (i.e., increased electrical strength, thermal discharge, nitrogen stripping, piscicides such as rotenone, etc.) are environmentally drastic measures, they may very well be required in the event the Chicago Sanitary and Ship Canal electric barrier is reached and compromised by Asian carp. Many of these same rapid response control measures may also be necessary in the UMR, particularly if Asian carp are detected in the vicinity of Lock and Dam 2. The Rapid Response Control Measures that were evaluated for the Chicago Sanitary and Ship Canal Barrier include:

1) Increased Electrical Barrier Strength: An electric barrier (if implemented in UMR) could be increased to stop the fish's heart, but not enough to kill. If the fish were retained in the electric field long enough, the fish could then suffocate. This was a concept attempted with a round goby trap and intensified barrier. Considering Asian carp are not confined to the bottom and would float with the current, it is unlikely this approach would be effective.

2) Thermal Discharge: Large volumes of heated water (> 40.5 ^{0}C) may be effective, but consistency and availability of sufficient volumes to discharge with minimum variability are questionable. It is also probable that significant environmental impact would occur.

3) Sonic Disruption: Very strong acoustic pulses may be used to kill or disorient the fish or other organisms. There is concern regarding impact to structure walls. There may be seismic devices capable of providing the desired level of sonic disruption.

4) Nitrogen Stripping: There are currently two physical methods of stripping dissolved oxygen from river water (in a confined space); one is based on vacuum removal and the other is based on inert gas (nitrogen) stripping. There is some concern that the resulting anaerobic (oxygen free) environment may promote the production of hydrogen sulfide, which is a toxic gas. The biological effectiveness, practicality and economics of oxygen removal need to be determined and demonstrated at river scale applications. Using nitrogen to strip oxygen from the water column in a UMR lock chamber may be economically unfeasible with current technology at an estimated $250,000 or more per day for operating expenses.

5) Pesticides: The USGS lab in LaCrosse (WI) has proposed to complete a 6-year research program to develop an Asian carp specific pesticide for an estimated $800,000. The only two pesticides currently available for rapid response use are rotenone and antimycin. The Rapid Response committee requested a reduced cost magnitude and a much faster timeline.

Herding into a more defined area with deterrent stimuli will be desirable to concentrate fish and allow pesticides to be more effective. Flouricene dye to define flow patterns (eddies, dead pockets, etc.) in the river is also recommended to plan for optimum piscicide application efficiency.

According to the Great Lakes Fishery Commission, the primary method to control sea lampreys uses the lampricide TFM, which kills sea lamprey larvae in streams with little or no impact on other fish and wildlife at the recommended concentration. Approximately 175 Great Lakes streams are treated at regular intervals with TFM to kill larval sea lampreys. Another lampricide, granular Bayluscide, is used in areas where TFM has not been effective. TFM (3-trifluoromethyl-4-nitrophenol) was developed in 1958 after testing almost 6,000 compounds. Extensive research is typically required to understand the chemical and physical conditions of the stream being treated.

Attractants and Repellents: The likelihood of finding/developing a chemical attractant or repellent in the near future (< 2 years) is unlikely. It may be more feasible to develop an acoustic or visual stimulus in conjunction with other methods to deter and/or herd fish. The USGS is currently conducting research to develop sex pheromones and fright pheromones for Asian carp. It is anticipated that a minimum of three years will be required for development (E. Little, pers. Comm.). The research effort includes an investigation of pheromone persistence in the environment, other substances that may be available or suitable, and then attempting to concentrate it into a field-stable application.

It is well established that fish rely on highly developed chemical signaling systems to find each other and reproduce. This is particularly true for freshwater species as a result of the typically high turbidity conditions of most inland waters. It is therefore felt that hormonal pheromones have great potential in the efforts to manage and control nuisance invasive species. The University of Minnesota Fisheries and Wildlife Dept. is currently conducting research in the development of pheromones as a technology to control fish populations. The project will examine the specificity and potency of fish pheromones to determine whether and how they can be applied to attract unwanted invasive species to traps for removal and/or male sterilization and release. The USEPA has approved the field-testing of sea lamprey specific migratory and sex pheromones to demonstrate the effectiveness of attracting the lampreys into traps and/or suitable spawning habitat in various Great Lakes tributaries. USGS scientists were instrumental in obtaining the first ever experimental use permits issued by the EPA for vertebrate pheromones.

Constructed and Enhanced Habitat

Various approaches to habitat construction and/or enhancement should be considered that would either provide desirable in-river conditions for attracting and/or concentrating Asian carp for higher efficiency harvesting and removal, or to enhance and expand native species habitat not normally preferred by Asian carp. It will be important to research spawning and habitat requirements in order to prevent deterioration of healthy native species habitats and/or to maximize attraction and harvesting efforts. Examples of constructed or enhanced habitat include wing dams, existing and/or side channel areas, habitat based structure, and traps specifically designed for Asian carp.

A fish by-pass channel capable of allowing migrating fish to pass into a confined area for selective removal and disposal, with native fish being allowed to continue could also be considered. This alternative would be management and labor intensive, but would provide improved connectivity for native fish species.

Controlled Harvesting and Removal

It is important to note that any control option that includes harvesting should be implemented and controlled in such a manner that sustainable commercial harvesting is **not** an option. The sole objective of strategic harvesting operations will be to significantly reduce the population density of Asian carp in key areas of the UMR that are determined to be critical habitat areas or where attractant areas are managed for the purpose of providing high density collection zones. The harvesting and removal component must be carefully managed and regulated to eliminate the possibility of allowing sustainable harvesting operations.

Since the late 1960s, seines and trawl nets have been operated in Chinese reservoirs for the purpose of commercially harvesting silver and bighead carp. A fishing method that combines blocking, driving, gill-netting, and seining has been developed based on an understanding of the habits of silver carp and bighead carp (Sifa and Senlin, 2004**.** Like many other stocked species, silver carp and bighead carp tend to move in schools. However, their movements appear to vary depending on the developmental stage of the fish and on environmental conditions.

The joint fishing method, which combines blocking, driving, gill netting, and seining, is a large-scale operation used specifically to catch silver carp and bighead carp. This fishing method was developed in the mid-1960s and has been constantly improved. It is now widely applied in most of the large and medium reservoirs in China (Sifa and Senlin, 2004). Several types of fishing gear are jointly operated in the same water body. In this way, the fishing gear can be used for different functions and passive fishing gears can be turned into active gear. The joint fishing method can be applied and adapted to reservoirs and rivers with complicated bottom topography, large surface areas, and scattered fish populations. In actual operation, the blocking and driving operations are conducted simultaneously with capture so that all of the silver carp and bighead carp are forced to aggregate in a certain place and are caught. The joint fishing method is such a large-scale operation that it can be used for a fishing area ranging from a hundred to thousands of hectares.

The joint fishing method uses several types of fishing gear. The driving gear includes net and non-net driving gear and provides the best results when they are used jointly. However, they can also be used separately. Net-driving gear is mostly gill nets, such as trammel nets, frame gill nets, and simple gill nets. But, beach seines can be used to drive fish in shallow, riverine and backwater areas. The trammel net is used mainly to drive the fish schools. The frame gill net and simple gill net are the most common fishing gears for capture, but are not popular for driving operations. When operated in combination with trammel nets, the driving effect is greatly increased and other species can also be caught.

A compressor can be used to introduce air into the water through several tubes to form an air curtain. The fish are frightened by the bubble sound and low frequency oscillations and move rapidly in the desired direction. This device includes an engine-driven compressor that forces compressed air into a steel manifold and then through rubber pipes. Electricity can also be used to drive fish. Compared with net driving, electricity requires less investment and labor. However, its effect is not as predictable as other methods, particularly in large reservoirs. Therefore, electric driving is operated in combination with netting.

Blocking nets are one of the main fishing devices used in joint fishing and provide several functions. At the start of the harvest, all escape routes are secured with blocking nets to form an enclosure. Blocking nets are usually set in combination with trammel nets and other fishing gear to force the fish to aggregate in the enclosure. When fixed filters accompany blocking nets, the net can prevent fish from returning and guide the fish toward the fixed filter net where they are caught. If the mesh size and twine diameter of the net are designed appropriately, the net can be used to block fish and to eliminate predators. In the joint fishing method, the fixed filter net is the final chamber used to harvest the fish. It is usually set at a specific location with the harvest area. The fish are driven by the trammel nets, blocking nets, and other fishing gear and are forced to the filter net for harvesting (Sifa and Senlin, 2004).

Although these harvesting techniques have been developed to optimize the harvesting success of Asian carp in Chinese reservoirs and rivers, it is clear that an integrated and coordinated approach will be required for optimal efficiency in the Upper Mississippi River System. Ultimately, the harvesting of Asian carp as a means of population reduction and control will have to be a well-planned and coordinated effort that utilizes appropriate equipment and personnel necessary to maximize removal efficiencies.

The issue of intensive harvesting of adult and sub-adult Asian carp versus the potential for recruitment and which age class may have the most negative impact on the river ecosystem, habitat and native species must be addressed by additional research. This investigation could evaluate the potential of creating new habitat "slots" for juvenile fish as a result of the removal of adult fish, which is not desirable.

Daughterless Carp Technology

This technology has involved manipulating the genes of common carp to produce an inheritable "daughterless carp". This restricts all offspring to males and can be introduced into the carp population. Despite breeding normally, fewer and fewer females are produced with every generation until the carp population is mostly male. With fewer and fewer females in the population, it is predicted this technology will sharply reduce the carp numbers in the Murray-Darling River Basin (Australia) within 20 to 30 years of release. The technology must first be considered as ecologically safe, socially acceptable and cost effective. It is anticipated that a final decision on the release of the carriers will not be made until 2009. (Murray Darling Basin Commission).

Sterile Male Release

The Great Lakes Fishery Commission is conducting research on large-scale sea lamprey sterilization. The sterile male (triploid) release technique aims to reduce the success of sea lamprey spawning. Assessment indicates that fewer sea lamprey eggs hatch in streams where the sterile male technique has been used. On average, 40,000 sterilized sea lampreys are released annually into the St. Mary's River near Sault Ste. Marie, Michigan to compete with normal males during the spawning season. The released males have been effectively moving in to spawning areas and competing as expected.

Life Stage Management

Additional research and field investigation is required to determine if other control measures may be successful in limiting and/or reducing the expansion of Asian carp by focusing on various life stages. Potential management concepts to be considered include:

- Shallow water habitat modification; USGS studies have shown that approximately 40 percent of Asian carp biomass on the Missouri River is found on or near shallow sand bar habitat.

- Control, capture and destruction of the one to five day downstream egg drift after spawning.

- Limiting the young of year (YOY) use of seasonal wetlands either by exclusion or eradication.

Feasibility Study

To Limit the Invasion of Asian Carp into the Upper Mississippi River Basin

VI. Alternative Analysis and Recommendations

FISHPRO

VI. ALTERNATIVES ANALYSIS AND RECOMENDATIONS

Analysis of Potential Barrier and Deterrent Locations

The Upper Mississippi River System (UMRS) includes a portion of the Upper Mississippi River (UMR) that extends approximately 1,356 km from the mouth of the Ohio River at Cairo, Illinois, to the upstream limits of navigation at Minneapolis, Minnesota (see Figure III-2). The Illinois River and the Illinois Waterway is part of the UMRS and extends from its 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 are used to manage water levels on approximately 1,033 km of the northern reach of the UMR. With the exception of structures at St. Anthony Falls, Lock and Dam 1, Lock and Dam 19 and Lock 27, all of the navigation dams on the UMR are similar in design with Tainter gates and roller gates to control water flows. The gates extend down to a bottom sill that can be raised entirely out of the water during high flow conditions. The head at the dams during low flow ranges from about 2.0 m to 11.6 m, but approaches zero at most dams during high flows.

It is an accepted fact that dams restrict fish movements in regulated rivers throughout the world (Petts, 1989). On the UMRS, the existing navigational dams impose at least partial barriers to fish passage (Fremling et al. 1989). The construction of Lock and Dam 19, which is a major impounding structure on the UMR, may have contributed to greatly reduced abundance of long distance migratory species such as skipjack herring, Alabama shad, lake sturgeon, paddlefish, blue sucker and blue catfish (Wilcox et al., 2003).

Several previous studies have provided important data regarding the potential location of fish barriers or deterrents on the UMRS. A DRAFT Report by the US Corps of Engineers (Wilcox et al., 2004) addresses the need, opportunity and probable costs associated with increasing upstream and downstream fish passage on the UMRS. In order to assess potential barrier/deterrent sites, the document was used in “reverse” to direct attention to evaluating the lock and dam locations that currently restrict fish passage the most effectively. By identifying and reviewing these selected locations, the project team was able to direct its focus to a limited number of prime locations to implement an analysis of alternative options.

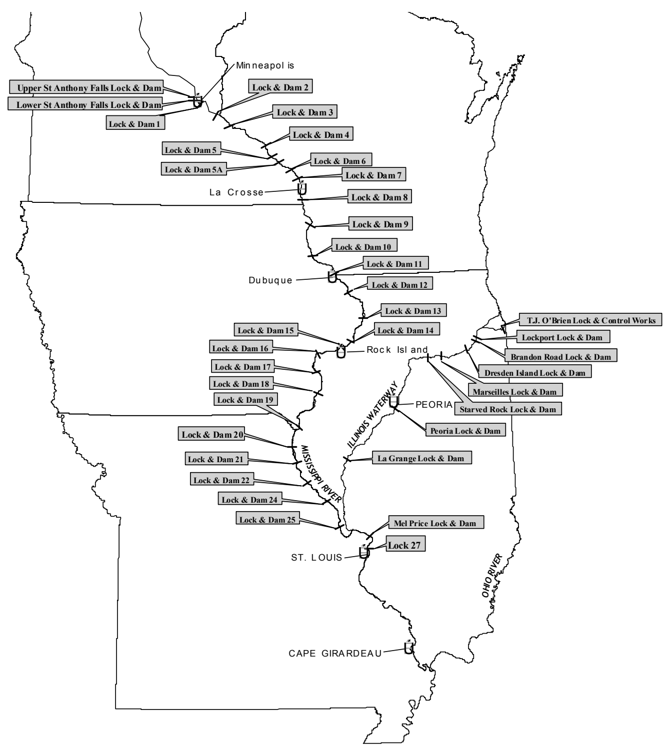
A second document prepared for the Minnesota Department of Natural Resources by Smith-Root, Inc. entitled “Preliminary Conceptual Report on the Feasibility of an Electrical Fish Barrier on the Mississippi River” in October 2003, reviewed several possible locations for electrical barriers on the UMRS within the boundaries of Minnesota (Smith et al., 2003). This study reviewed seven (7) locations from Lock & Dam #6 (River Mile 714) to Highway Bridge 61 at Hastings (River Mile 814) or approximately 100 miles. As discussed in Section V, the SRI study focused more on “natural” main-stem river locations and less on lock and dam locations due to the nature and characteristics of electrical barriers in high traffic areas. The SRI report indicated that the most important factors for a main stem electrical barrier site selection in order of importance were:

1. Water containment during flood events is the prime requisite
2. Location where barge traffic and high volume of public boating is at a minimum.
3. Low population areas, to protect the public from exposed electrodes near shore.
4. Bottom stability in a straight run area not subject to scouring.
5. Site location furthest downstream consistent with listed criteria and still allow enough time for design and construction in advance of population spread.
6. Availability of electric power, preferably separate power grids for redundancy.
7. Sufficient water velocity to sweep fish and animals clear of electrified areas.

This feasibility study has attempted to use both the documents cited above as well as known physical and hydrological characteristics of the UMRS discussed in Section III and apply the known (and potential) technologies, methodologies and management practices reviewed in Section V to develop a series of potential locations suitable for implementing barrier/deterrent technology alternatives. The COE Fish Passage Report (Wilcox et al., 2004) was reviewed to help identify the most likely candidates for lock and dam locations. Parameters considered to be important criteria for selecting potential barrier locations included the following:

1. Physical location (River Mile) of a Lock and Dam relative to confirmed sighting of the various Asian Carp species (Figure VI-1).

Figure VI-1. Upper Mississippi River and Illinois Waterway locks and dams



(Source: COE Fish Passage Report's Figure 1)

2. Based on location (above), the time required by normal migration for the various species to naturally advance upstream versus the time estimated to plan, design, permit and construct any barriers.
3. The normal head differential of the dam from upstream to downstream pool elevation; the type of gates and/or spillways (Table VI-1).
4. The percent of time the gates are out of the water, which indicates the periods that upstream migration could occur through the dam gates, in addition to the periods where water temperatures are historically sufficient to stimulate migratory movement are shown (Figure VI-2).

	Roller Gates			Tainter Gates			Head (m)			
Lock and Dam	Number	Height (m)	Width (m)	Number	Height (m)	Width (m)	Normal head at dam (m)	when gates open	Project pool elevation (m)	Type of Spillway
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 Ambursen 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
LaGrange	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*	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	Concret/Earth
Lockport	0			0			12.2		175.9	Sluice Gate
T.J. Obrien	0			0			1.5		176.6	Sluice Gates

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

Table VI-1. Design data for Upper Mississippi River System dams
(Source: COE Fish Passage Report's Table 5)

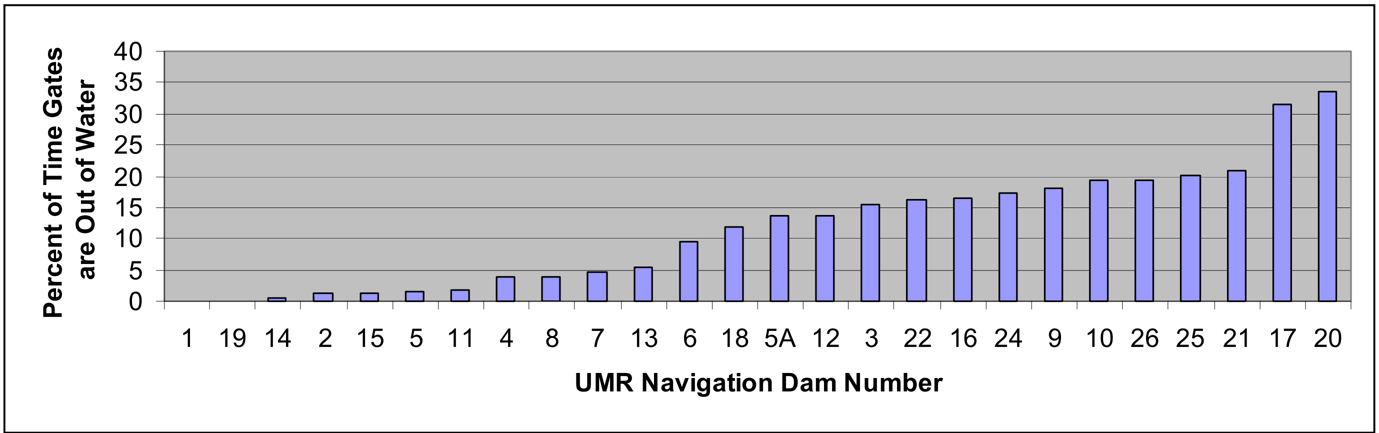


Figure VI-2. Percent of time that gates are raised out of the water at Upper Mississippi River navigation dams (Source: COE Fish Passage Report's Figure 6)

5. Regional fish passage connectivity potential within the river reaches located between each of the targeted locations.

Based on this analysis, five possible locations appear to provide the physical criteria required for fish barrier/deterrent technology to be most efficiently implemented (see Figure VI-3), while still providing opportunity for regional fish passage connectivity:

Site Location	Air Photo Page Location	Approx. River Mile	Normal Head	% of Time Gates out of the Water *
L/D #19	VI-13	364	11.1 m	0
L/D #14	VI-14	493	3.3 m	1
L/D # 8	VI-15	679	2.4 m	4

Second tier locations include:

Site Location	Air Photo Page Location	Approx. River Mile	Normal Head	% of Time Gates out of the Water *
L/D #15	VI-16	483	4.9 m	2
L/D #11	VI-17	583	2.4 m	3

* See Table VI-2 for the probability by week of the year that the open gate conditions could allow migratory fish passage.

The potential control measures discussed in Section V were reviewed based on the above recommended physical locations. It was determined that measures to prevent the upstream movement of Asian carp could be implemented within the lock chamber, immediately downstream of the lock gates at the entrance to the approach areas, and/or across the width of the river downstream of the spillway gates, and near the mouths of significant tributaries. The percentages of open gate conditions listed in Table VI-2 were compared with the weekly average water temperatures. Weeks where average water temperatures were 18^{o}C or higher were shaded to indicate probable Asian carp spawning/upstream migration periods.

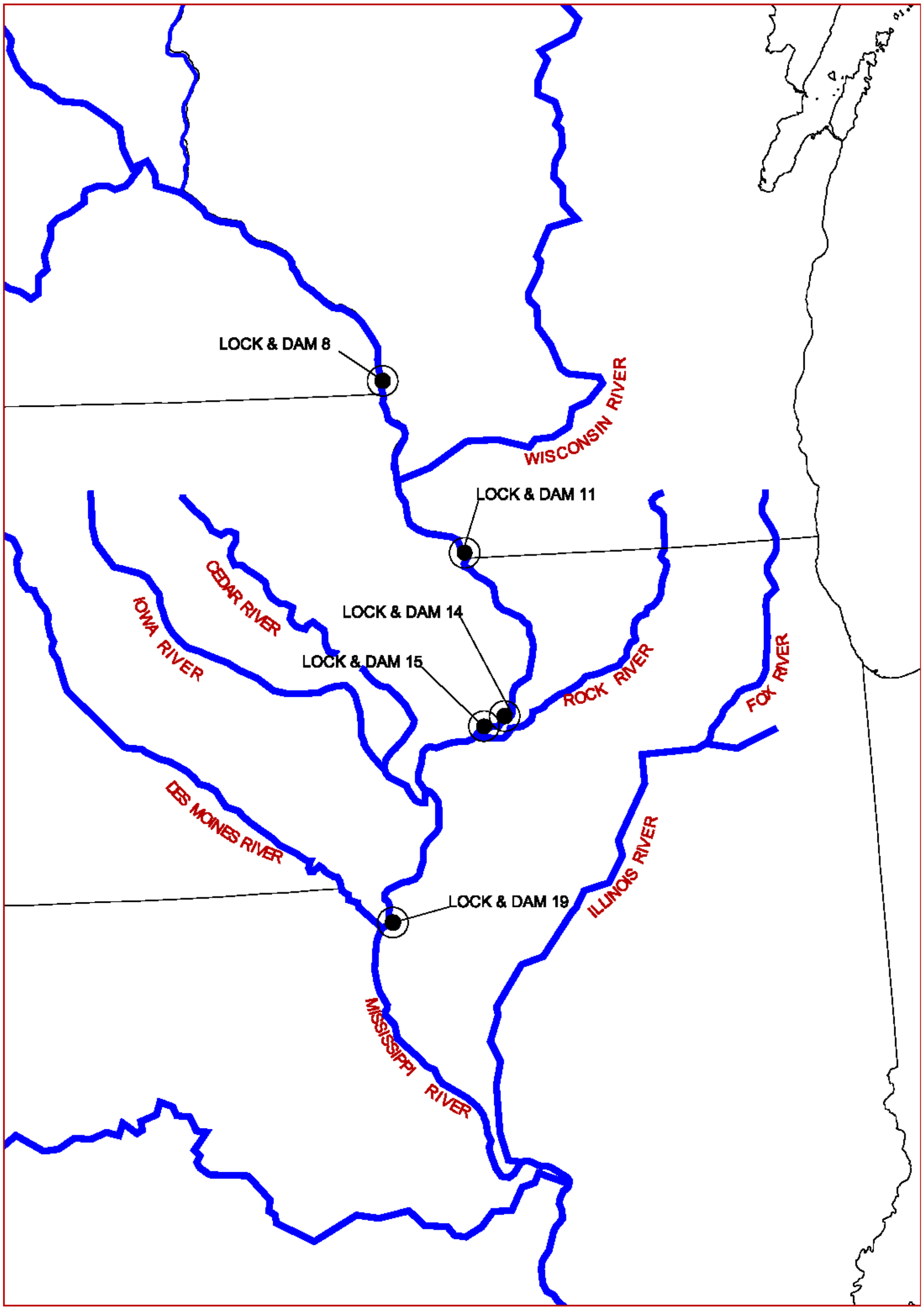


Figure VI-3. Location Map of Recommended Alternatives

Month	Week of Year	Lock & Dam Number 8	11	14	15	19
	1	0.0	0.0	0.0	0.0	0.0
	2	0.0	0.0	0.0	0.0	0.0
	3	0.0	0.0	0.0	0.0	0.0
	4	0.0	0.0	0.0	0.0	0.0
	5	0.0	0.0	0.0	0.0	0.0
	6	0.0	0.0	0.0	0.0	0.0
	7	0.0	0.0	0.0	0.0	0.0
	8	0.0	0.0	0.0	2.8	0.0
	9	0.0	0.0	0.0	0.0	0.0
	10	1.4	0.0	0.0	0.0	0.0
	11	6.5	3.9	0.0	0.0	0.0
	12	6.5	5.2	0.9	3.2	0.0
	13	6.9	1.9	0.9	2.3	0.0
	14	13.8	1.0	0.0	0.0	0.0
	15	25.3	9.1	0.5	3.2	0.0
	16	27.6	14.8	0.9	6.5	0.0
	17	27.6	16.2	6.5	12.9	0.0
M	18	21.2	14.8	4.6	7.9	0.0
A	19	17.5	8.1	4.6	6.5	0.0
Y	20	6.9	2.9	0.0	2.8	0.0
	21	4.6	0.0	0.0	0.0	0.0
J	22	0.5	0.0	0.0	0.0	0.0
U	23	0.0	0.0	0.0	0.0	0.0
N	24	0.0	0.0	0.0	0.0	0.0
	25	3.7	0.5	0.0	0.0	0.0
J	26	6.5	3.4	1.8	3.2	0.0
U	27	5.5	3.3	3.3	3.3	0.0
L	28	4.1	3.3	3.2	3.3	0.0
	29	3.2	3.3	3.2	3.3	0.0
A	30	1.8	1.0	0.5	2.8	0.0
U	31	1.4	0.0	0.0	0.0	0.0
G	32	0.5	0.0	0.0	0.5	0.0
	33	0.0	0.0	0.0	0.0	0.0
S	34	0.0	0.0	0.0	0.0	0.0
E	35	0.0	0.0	0.0	0.0	0.0
P	36	0.0	0.0	0.0	0.0	0.0
	37	0.0	0.0	0.0	0.0	0.0
O	38	0.0	0.0	0.0	0.0	0.0
C	39	3.2	0.0	0.0	0.0	0.0
T	40	3.2	0.0	0.9	2.8	0.0
	41	4.1	0.0	1.4	2.8	0.0
	42	2.8	0.0	0.0	0.0	0.0
	43	0.0	0.0	0.0	0.0	0.0
	44	0.0	0.0	0.0	0.0	0.0
	45	0.0	0.0	0.0	0.0	0.0
	46	0.0	0.0	0.0	0.0	0.0
	47	0.0	0.0	0.0	0.0	0.0
	48	0.0	0.0	0.0	0.0	0.0
	49	0.0	0.0	0.0	0.0	0.0
	50	0.0	0.0	0.0	0.0	0.0
	51	0.0	0.0	0.0	0.0	0.0
	52	0.0	0.0	0.0	0.0	0.0

[shaded] Weeks in which average daily Mississippi River water temperature was at or above 18^{o}C*. Date from USGS water quality monitoring stations with linear interpolation by river miles from USGS to dams.

* Known minimum trigger temperature for Asian carp spawning. See Section III.

Table VI-2. Opportunity for upriver passage by Asian Carp through UMR locks and dams. (Numbers indicate percent probability of dam gates out of water by week of year.)

ANALYSIS OF MEASURES TO PREVENT/SLOW INVASION

Using the same matrix as Table V-1 in Section V, a numerical value has been assigned to each of the listed alternatives based on implementation at one of the primary locations. A simple one to three (most desirable to least desirable) ranking system for each criteria was implemented (see Table VI-3).

Table VI-3. Prioritization and Ratings Matrix for Potential Control Alternatives

Control Method	Type of Alternative	Optimum Diversion Effic.	Prob. of Success	Navigat. Impact	Constr. and/or Implem. Complex.	Oper. and/or Maint. Issues	Public Safety Concerns	Probable Cost Range (Installed)	Impacts to Upstream/ Downstrm. Species Movement	Total Rating Points
Behavioral Barriers and Deterrents	Strobe Lights	3	2 - 3	1	2	1	1	1	1 - 2	12 - 14
	Air Bubble Curtain	3	3	1	2	2	1	1	1	14
	Acoustic Deterrent: Sound Projector Array(SPA) at Lock Entrance	2	2	1	2	1	1	2	1	12
	Acoustic Deterrent: Sound Projector Array (SPA) at Spillway gates	2	2	1	2	1	1	3	1	13
	Acoustic Deterrent: Pneumatic Acoustic Bubble Curtain (BAFF) at Lock Entrance	2	2	1	2	1	1	2	1	12
	Acoustic Deterrent: SPA Based Acoustic Bubble Curtain SPA/BAFF) at Lock Entrance	1 - 2	2	1	2	1	1	2	1	11 - 12
	Hybrid Comb. System (Strobe light & acoustic)	3	2	1	2	1	1	2	1	13
	Hyb.Comb. System (Strobe Light & bubble curtain)	3	2	1	2	2	1	2	1	14
	Electrical Barrier (Main stem and/or spillway gates & culverts)	1	2	1	3	3	3	3	3	19
	Electrical Barrier (Inside Lock)	1	2	1	3	3	3	3	2	18
	Electric Deterrent (Lock Channel Entrance)	1	2	1	3	3	3	3	2	18
	Hyb.Comb. System (Electric Barrier & SPA/BAFF) at Lock	1	1 – 2	1	3	3	3	3	2	17 - 18
	Hydrodynamic Louver Screens	2	2	3	2	3	2	2	2	18
Physical Barriers	Vertical Drop (Existing Overflow Spillways)	1	1	3	2	1	2	*	2	*
	Rotating Drum &/or Traveling Screens, Floating Curtains	1	1	3	3	3	2	3	3	20
	High Velocity (Point Release)	2	2	2	2	2	2	2 – 3	2	16-17

Key Rating Criteria
Optimum Diversion Efficiency: 1 = 95-100%; 2 = 80-95%; 3 = <80%
Probability of Success: 1 = High; 2 = Moderate; 3 = Low
Probable Cost Range: 1=Low ($1.0 million or less); 2 = Medium ($1.01-6.99 million); 3 = High ($7.0 and greater)
All other Criteria: 1 = Low (Best); 2 = Moderate; 3 = High (Worst)

Based on the results of the prioritization and ratings matrix analysis, it appears that an acoustic deterrent such as a Sound Projector Array (SPA) based acoustic bubble curtain (SPA/BAFF) downstream of a lock location perhaps in conjunction with attractants (i.e. pheromones, plankton, lights, etc.) and an integrated management/harvest plan may provide the most feasible opportunity to limit or slow the upstream invasion of Asian Carp. The hybrid system improves the versatility and effectiveness of a standard BAFF system since the SPA based sound source can be calibrated to approximate an Asian carp specific audiogram. The omni-directional sound field produced by an SPA is not only focused along the bubble curtain, but can maintain sound field effectiveness in the event a passing barge or lock discharge disrupts the integrity of the bubble curtain. In addition to the criteria evaluated in the Prioritization and Ratings Matrix, the acoustic based system received additional prioritization due to silver and bighead carp being easily startled and scattering away from approaching boats and engine noise. Preliminary cost projections range from $1.2 to $1.6 million for an installed system at a typical lock approach entrance, including site preparation, engineering and permitting.

Since several of the lock and dam locations targeted for control alternative implementation have a low enough total head (L/D 8 and 14) that upstream passage may be possible during gate-open full flow river conditions, a SPA based acoustic deterrent system should be considered for installation within close proximity to the spillway gates. This system would be activated prior to full flow conditions so as to limit the habituation potential and essentially “turned off” after flood waters subside and the gates are closed. Preliminary cost projections range from $8.5 to $10.5 million for an installed spillway gate protection system, including site preparation, engineering and permitting. An electric barrier may also be considered for the gate/spillway deterrent system, but the $15 to $25 million initial cost combined with safety and public perception concerns make this option less feasible. In addition, there are culverts through some lock and dam structures that could allow invasive species passage and will also require protection.

Other technologies, including electrical barriers within the lock chamber or in the downstream entrance channel should also be considered although their construction and operating costs are significantly higher and there are significant safety/operation concerns. Based on this broad based analysis of technology and physical location it is the recommendation of this report to develop a strategy that includes Prevention, Detection, and Control. Previous sections have discussed alternatives for “prevention” and “detection”. The “control” options should ultimately be determined within a risk-based decision process that integrates existing data, model forecasts, and the results of surveys and monitoring to usefully evaluate the efficacy of alternative control technologies in reducing risks posed by Asian Carp.

The behavioral guidance systems recommended for: 1) selected lock entrance and spillway deterrent locations; combined with 2) potential habitat areas (natural or enhanced) for attracting and concentrating (potentially with pheromones, plankton, lights, etc.); followed by 3) controlled harvesting and removal; and 4) continued education and 5) monitoring and detection is an integrated system that can increase the probability of limiting upstream Asian carp movement. The estimated cost of a habitat/attractant staging area may be in the $0.5 to $3.0 million range depending upon location. Controlled harvesting may have additional costs associated with staff time and/or controlled harvesting operations designed to effectively remove the targeted species.

Analysis of Potential Barriers and/or Deterrents for Tributaries

In addition to the alternatives recommended for limiting Asian carp upstream via the main-stem Mississippi River Lock and Dam system, tributary scale barrier/deterrent systems (i.e., SPA/BAFF acoustic bubble curtain and/or graduated field electric barrier/deterrent systems) should be considered to limit the movement into key tributaries such as the Minnesota River, the St. Croix River, the Chippewa River, the Wisconsin River, the Rock River and the Iowa River. These tributaries are all Stream Order Classifications 7 or 8 (Wilcox et al., 2004). There are also nine (9) rivers of Stream Order 6 upstream of Lock and Dam 19 that could be considered for tributary-scale protection against upstream Asian carp movement. See Appendix I for a complete listing of Stream Order 6, 7 and 8 tributaries upstream of Lock and Dam 19.

As discussed in Section IV, these components should be developed in the context of an interactive, computer-based decision support system (DSS) that can be readily accessed by risk assessors and risk managers to (1) describe and understand the current distributions of Asian Carp in the Upper Mississippi River Basin, (2) estimate the future spread, establishment, and consequences of these species in the absence of control technologies, (3) identify locations where specific barrier technologies may prove useful in controlling the spread of Asian Carp, and (4) evaluate the overall effectiveness and net benefits afforded by alternative technical control measures proposed for specific locations.

In addition to the barrier/deterrent alternatives for limiting upstream movement as discussed above, it is imperative that an integrated approach be implemented with suitable long and short term management alternatives that include regulation, education and public outreach, research and the implementation of population control approaches such as constructed and enhanced native species habitat, controlled harvesting and removal, daughterless carp technology, sterile male release, etc.

As described in Section V, the methods for optimum harvesting and removal should include methods of blocking; driving and netting will have to be a well coordinated effort in order to be successful. The methods of species-specific attraction (i.e., pheromones, artificially enhanced food sources, habitat modification, etc.) will have to be further developed and refined, the seasonal and life-cycle behavior needs to be better understood and the approach to removal will require timely coordination and cooperation from all state and federal agencies impacted by the Asian carp invasion of the Upper Mississippi River.

Probable Operational and Construction Costs

The anticipated operational and construction costs for the recommended systems include probable cost ranges for the installed systems, engineering design and permitting costs, anticipated contingencies, operation and maintenance costs. A concise summary of the anticipated costs has been provided for the various systems recommended for implementation. Management options such as monitoring, research, education and outreach, regulatory coordination, pheromone development and implementation, harvesting, daughterless carp technology, sterile male release, etc. have not been included in estimation of probable cost for this report. Additional analysis and research will be required in order to more accurately determine these cost ranges.

Preliminary cost projections range from \$1.2 to \$1.6 million for an installed Sound Projector Array (SPA) based acoustic bubble curtain (SPA/BAFF) system at a typical lock approach entrance, including site preparation, engineering and permitting.

Preliminary cost projections for a SPA based acoustic deterrent system range from \$8.5 to \$10.5 million for an installed spillway gate protection system, including site preparation, engineering and permitting. An electric barrier may also be considered for the gate/spillway deterrent system, but the \$15.0 to \$25.0 million initial cost combined with safety and public perception concerns make this option less feasible.

The estimated cost of a habitat/attractant staging area may be in the \$0.5 to \$3.0 million range depending upon location. Controlled harvesting may have additional costs associated with staff time and/or harvesting operations designed to effectively remove the targeted species.

Although preliminary cost ranges have been provided in this feasibility study for planning and budgeting purposes, we feel that additional site-specific evaluation and preliminary design efforts should be completed in order to more accurately determine specific requirements and to estimate the probable costs for the alternatives selected.

Figure VI-4. Lock and Dam 19 with Proposed Alternative Locations

Figure VI-5. Oblique Aerial View of Lock and Dam 19

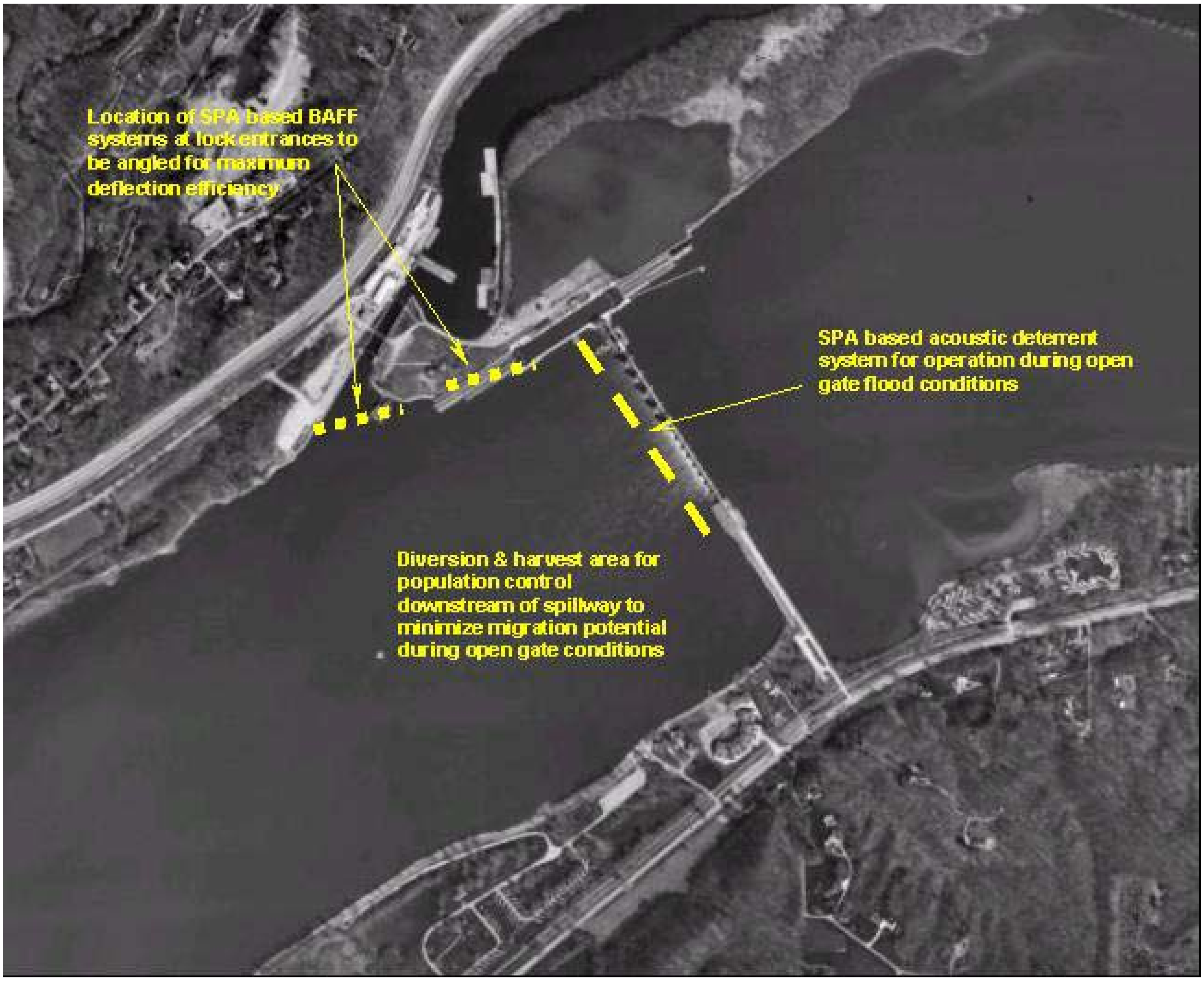


Figure VI-6. Lock and Dam 14 with Proposed Alternative Locations

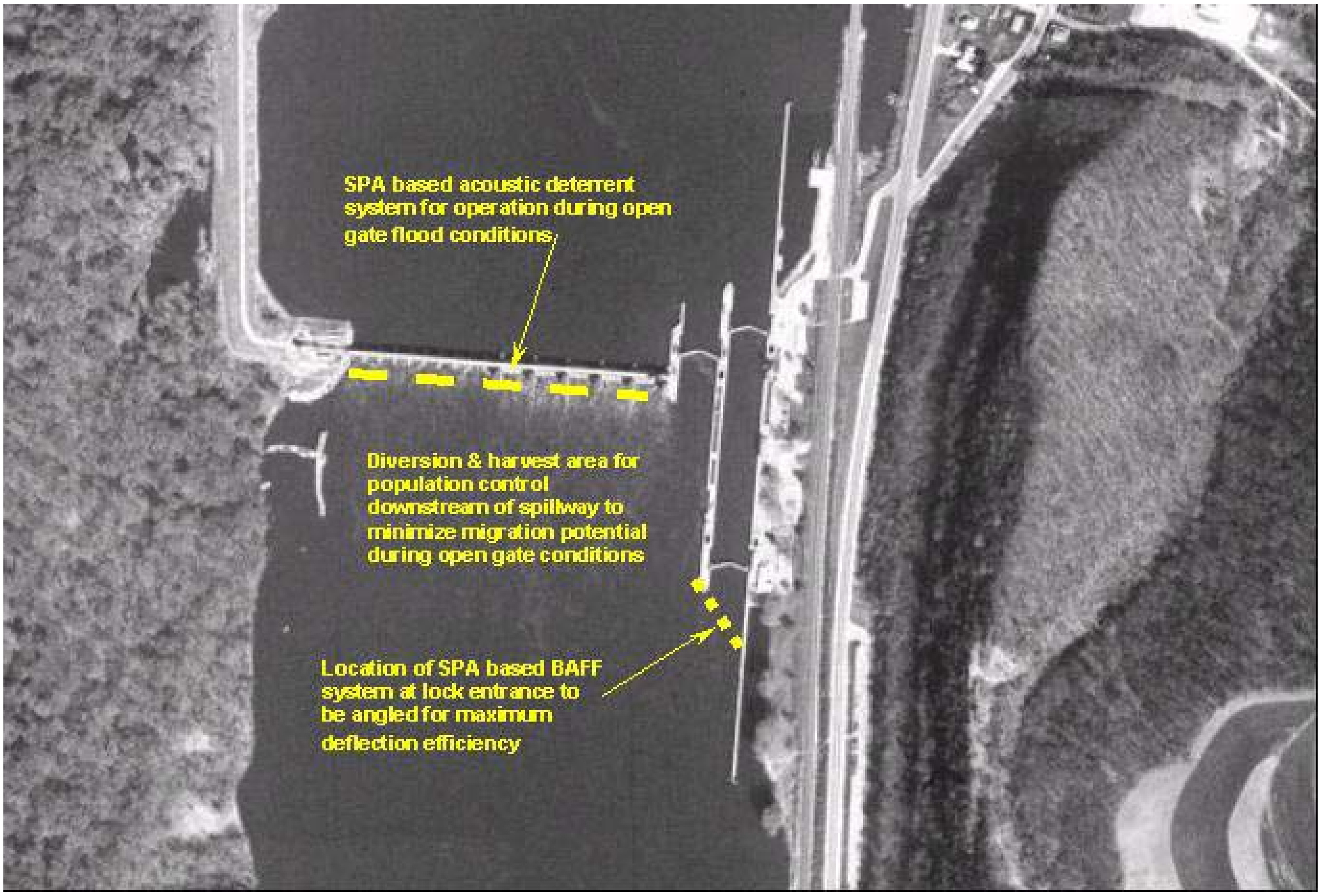


Figure VI-7. Lock and Dam 8 with Proposed Alternative Locations

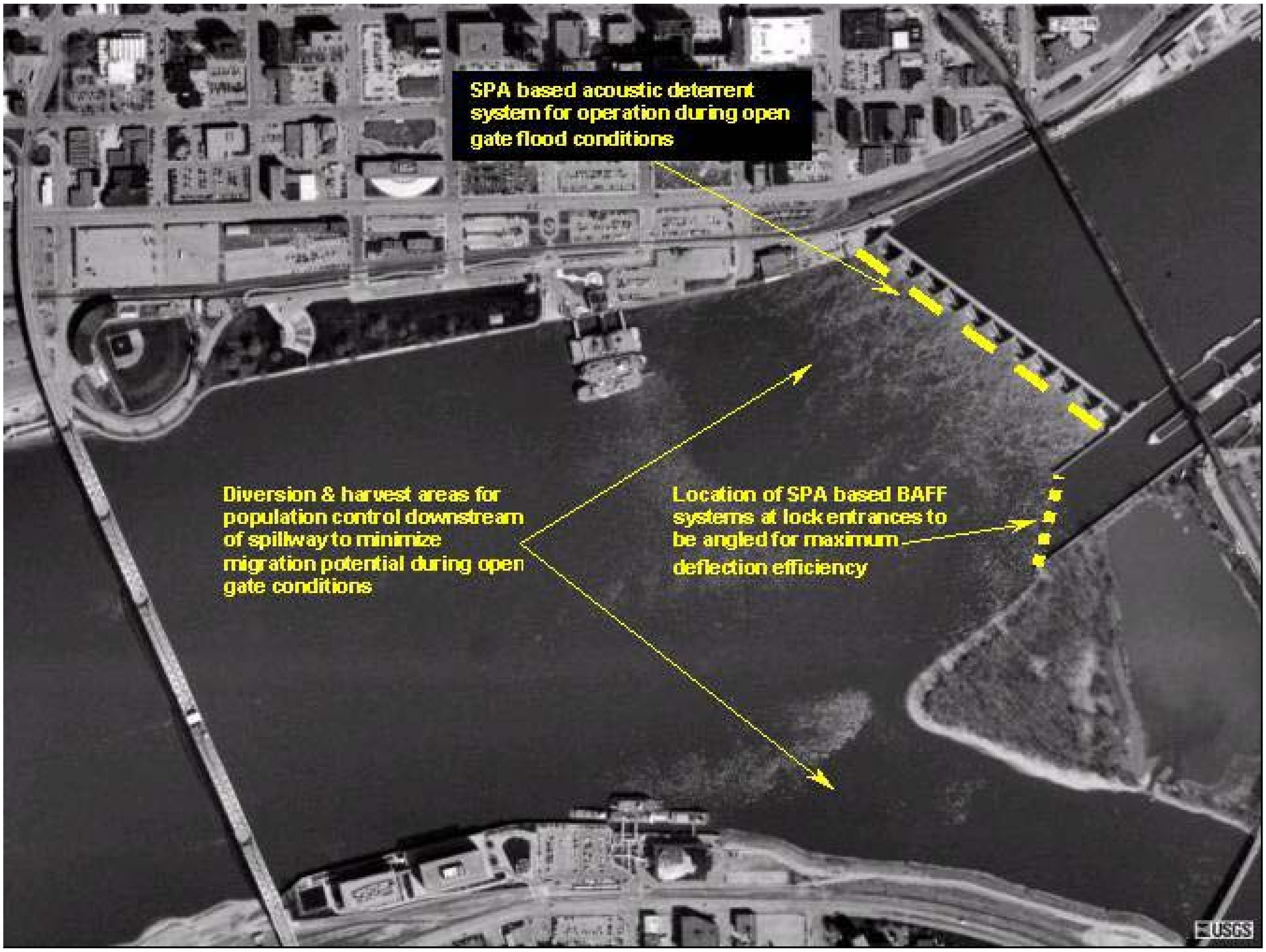


Figure VI-8. Lock and Dam 15 with Proposed Alternative Locations

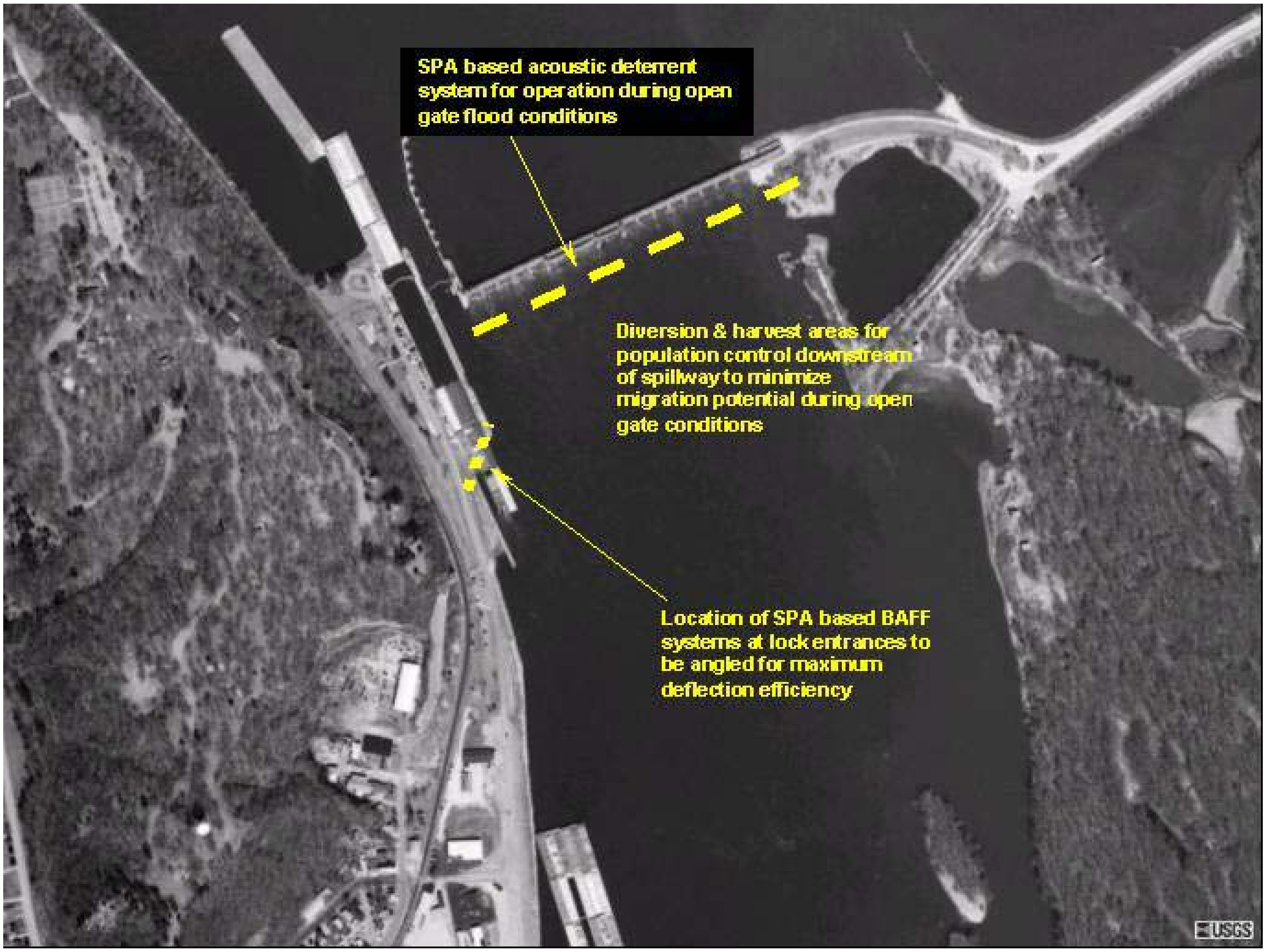


Figure VI-9. Lock and Dam 11 with Proposed Alternative Locations

Feasibility Study

To Limit the Invasion of Asian Carp into the Upper Mississippi River Basin

VII. Appendices

A. Regulatory Review
B. List of Species Occurring in the Mississippi River
C. Literature Review
D. Meeting Summaries
E. Key to Asian Carp Identification
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FISHPRO

Feasibility Study

To Limit the Invasion of Asian Carp into the Upper Mississippi River Basin

VII–A. Regulatory Review

FISHPRO

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METHOD OF INVESTIGATION

HDR reviewed the permitting and regulatory information available on websites of the U.S. Army Corps of Engineers, St. Paul District (Corps), the U.S. Fish and Wildlife Service (USFWS) the Minnesota Department of Natural Resources (MNDNR), the Minnesota Pollution Control Agency (MPCA), the Wisconsin Department of Natural Resources (WDNR), the Iowa Department of Natural Resources (IDNR), the Illinois Department of Natural Resources (ILDNR), the Missouri Department of Natural Resources (MODNR) and the Missouri Department of Conservation (MODC). Information on regulations pertaining to new construction, modifications to existing structures and application of chemical and/or biological projects was reviewed and summarized as it relates to the control of the spreading Asian Carp population in the Mississippi River.

SUMMARY OF REGULATIONS

Federal

U.S. ARMY CORP OF ENGINEERS

If a project to install and/or modify structures at the existing locks and dams or at new river locations is proposed to be undertaken by the Corps of Engineers, no state or local permits are required. In addition, the Corps does not issue permits to itself to implement projects. The implementation of a project by the Corps may require environmental review under NEPA regulations as well as a Chapter 106 historic and cultural resources review.

If the proposed fish barrier project is going to be implemented at the State level, an Army Corps permit will be required of that State Agency. The following summarizes Corps permit authority and requirements:

Under Section 10, a Corps' permit is required to do any work in, over or under a Navigable Water of the U.S. (these are generally called the "Section 10 waters") or to do any work that affects the course, location or condition of the waterbody in such a manner as to impact on its navigable capacity. Waterbodies have been designated as Section 10 waters based on their past, present, or potential use for transportation for interstate commerce. These waters include many of the larger rivers and lakes, such as the Minnesota, St. Croix, Wisconsin and Mississippi rivers along with Lake Superior, Lake Michigan and the Mississippi headwaters and many other rivers and lakes.

The U.S. Army Corps of Engineers routinely applies for state waters permits out of comity. The Corps is required to obtain State Water Quality Certification for projects involving fill in waters of the United States as part of Section 404(b) of the Clean Water Act. In addition to the Section 10 Rivers and Harbors Act requirements described in the report, any work in proximity to the navigation dams would require planning in consultation with the appropriate Corps of Engineers District, and approval by the Corps. This would be needed to ensure compatibility with the operations and maintenance of the navigation project.

Activities such as dredging and construction of docks, bulkheads and utility lines require review under Section 10 of the Rivers and Harbors Act of 1899 to ensure that they will not cause an obstruction to navigation and are not contrary to the public interest.

Under Section 404, a Corps' permit is required for the discharge of dredged or fill material into waters of the U.S., which include wetlands. Regulated discharges include filling wetlands for development, grading or pushing material around within a wetland, disturbing wetland soil during land clearing, etc. The general rule is that for an activity to receive a 404 permit it must comply with the EPA's Section 404(b)(1) guidelines.

In general, the guidelines require that the activity be the least environmentally damaging alternative that is feasible, and that adverse impacts are avoided, then minimized, and then compensated for (such as creating or restoring wetlands to replace those that would be filled). Activities also must not be contrary to the public interest, as determined by the Corps.

Certain discharges for some farm, forestry, maintenance and other purposes are exempt from Section 404 regulation. Exempt discharges must be for defined purposes and must satisfy certain conditions. You should obtain confirmation from the Corps to avoid a potential violation of Federal law before conducting any discharge you believe is exempt.

Some general permits can be confirmed or issued in a day, while other general permits and Letters of Permission may require a 30-day agency and public review process depending on the nature and location of the project and will take 45 days or more. Standard individual permits typically require a 30-day agency and public review and take 60 to 120 days or more.

U.S. FISH AND WILDLIFE SERVICE

The U.S. Fish and Wildlife Service is mandated with protecting and preserving the nations fish and wildlife habitats. Likely roles for the USFWS in the control of the spread of Asian Carp include NEPA review for any Environmental Assessment or Environmental Impact Statements needed for implementation of projects or programs to stop the spread and/or attempts to eradicate exotic species of fish. The USFWS service also leads the management of aquatic nuisance species for the Federal government, an example of which is the management of sea lamprey in the great lakes.

The USFWS does not issue fishing and hunting permits. Individual fishing licenses and commercial fishing permits are issued by the respective state governments. The USFWS service would be involved in permitting in an instance in which a rare, threatened or endangered species would be adversely impacted by a potential project.

State

MINNESOTA

Minnesota DNR: Projects Requiring Public Waters Work Permits

Under Minnesota Statutes 103G.245, Subdivision 1 (except as provided in Subdivisions 2, 11, and 12), the state, a political subdivision of the state, a public or private corporation, or a person, must have a MNDNR Public Waters Work Permit to: construct, reconstruct, remove, abandon, transfer ownership of, or make any change in a reservoir, dam, or waterway obstruction on public waters; or change or diminish the course, current, or cross section of public waters, entirely or partially within the state, by any means, including filling, excavating, or placing of materials in or on the beds of public waters. The installation of new structures or modification of existing, state or locally owned structures would require a MNDNR Protected Waters Permit.

Minnesota DNR: Projects Requiring Fisheries Permits

The MNDNR Division of Fisheries administers the States fisheries programs. Through the MNDNR, permits are issued to commercial fishermen for the harvesting of carp and other species via nets and other mechanical devices.

Minnesota Pollution Control Agency Water Quality Permit Application

Under Minnesota Statutes Chapter 7000, and in particular, Chapter 7050, the MPCA water quality permits establish specific limits and requirements to protect Minnesota's surface and ground water quality for a variety of uses, including drinking water, fishing and recreation. Permits are regularly reviewed and updated as they expire, allowing the MPCA to incorporate new information about the impacts of pollutants to the environment in subsequent permits.

Permits are enforced through a combination of self-reporting (reports to the MPCA, U.S. EPA or both) and compliance monitoring.

WISCONSIN

Wisconsin DNR Waterway and Wetland Permits

Wisconsin State Statutes Chapters 30 and 31 govern work in navigable waters and the placement and/or modification of structures. Similar to MNDNR requirements, the WDNR requires permits for activities that will modify a watercourse. Unlike the State of Minnesota, the WDNR also regulates activities that may impact water quality. The placement of a new structure(s) or modification of existing structures by a State or Local agency will require a WDNR permit.

Wisconsin DNR Fishing Permits

The WIDNR issues permits for the commercial netting of carp and other rough fish in the Mississippi River.

IOWA

Iowa Department of Natural Resources Sovereign Lands Construction Permits

Any person wishing to conduct construction activities on, above or under state-owned water and land is required to have a sovereign lands construction permit. Chapter 461A of the Iowa Code states:

> "*A person, association, or corporation shall not build or erect any pier, wharf, sluice, piling, wall, fence, obstruction, building or erection of any kind upon or over any state-owned land or water under the jurisdiction of the commission, without first obtaining from the commission a written permit. A permit, in matters relating to or in any manner affecting flood control, shall not be issued without approval of the environmental protection commission of the department. A person shall not maintain or erect any structure beyond the line of private ownership along or upon the shores of state-owned waters in a manner to obstruct the passage of pedestrians along the shore between the ordinary high-water mark and the water's edge, except by written permission of the commission.*"

The application form that the Department uses for Sovereign Lands Construction Permits is the joint application form created by the Iowa Department of Natural Resources and the US Army Corps of Engineers.

Iowa DNR Fishing Regulations

The Iowa DNR regulates the commercial harvest of rough fish in state waters. The IDNR does allow for the harvest of carp and other rough fish in the Mississippi River and tributaries. Iowa Code also allows for promiscuous fishing in certain circumstances:

Promiscuous Fishing

When there is imminent danger of fish loss through natural causes, the Iowa Natural Resources Commission can order the taking of fish from any area and by such means they deem advisable to salvage such fish.

Iowa Department of Natural Resources Environmental Reviews

Environmental reviews consist of a record of review for protected species (state listed endangered or threatened), rare natural communities, state lands and waters in the project area, including review by personnel representing state parks, preserves, recreation areas, wetlands, fisheries and wildlife. An environmental review does not constitute a permit and before proceeding with a construction project you may need to obtain permits from the IDNR or other state or federal agencies. The Department of Natural Resources receives many requests for environmental reviews from individuals, companies and public agencies that wish to proceed with new construction.

ILLINOIS

Illinois DNR: Permit Programs of the Division of Water Resource Management

The Division of Water Resource Management (DWRM) issues permits to demonstrate compliance with its regulatory programs. The Division issues permits for work in and along the rivers lakes and streams of the state, including Lake Michigan, for activities in and along the public waters, and for the construction and maintenance of dams. Prior to 1995, DWRM was part of the Illinois Department of Transportation. All permits for work in water issued by the Department of Transportation are now administered by DWRM.

Generally, the division issues an individual formal permit to the applicant to demonstrate compliance with the rules. In some cases, the division has issued statewide, regional and general permits to reduce paperwork for the applicant. The statewide and regional permits describe a general project type and set limits on the scope of the work. If the proposed work meets all the specified limits, the project is approved under the statewide or regional permit. FOR PROJECTS

COVERED BY A STATEWIDE OR REGIONAL PERMIT, YOU DO NOT NEED TO CONTACT THE DIVISION. General permits similarly cover a specific type of project and are limited in scope. For projects covered by a general permit an application submittal is still required.

The division has four regulatory permit programs. They are referenced by their administrative code section numbers as well as the program name:

Part 3700 - Construction in Floodways of Rivers, Lakes and Streams

The division issues permits for construction projects that may impact the flood carrying capacity of the rivers, lakes and streams. These rules affect all streams and lakes except those regulated under Part 3708. All construction activities, except dams regulated under Part 3702, in the floodway of streams draining more than one square mile in an urban area or ten square miles in a rural area must be permitted by the division prior to construction. Floodways are defined for many of these streams and appear on the federal flood insurance program's flood hazard boundary maps. Those maps are available for viewing at the local building and /or zoning office. If a floodway has not been previously delineated, division staff will determine whether the work is in the floodway.

Part 3702 - Construction and Maintenance of Dams

The division issues permits for the construction, operation and maintenance of new dams and the operation and maintenance of dams which existed prior to September 2, 1980. Dams are classified by the division based on both size and hazard potential. There are three hazard classifications. All dams in the two higher classifications are required to have a permit under these rules. Dams in the lower hazard classification require a permit for construction or modification if they meet certain size criteria. Anyone proposing to construct a new dam is recommended to submit a preliminary design report to the division as early as possible.

Part 3704 - Regulation of Public Waters

The division issues permits for activities in and adjacent to the public waters of the state. The public waters may generally be described as the commercially navigable lakes and streams of the state and the backwater areas of those streams. A list of the public waters is included in the rules. There are certain public rights in the public waters that are reserved for the citizens of the state. The division reviews proposed activity in and adjacent to the public waters to ensure that the public's rights are not diminished by the activity. Activities that require review are not limited to construction. A permit is issued to demonstrate that the activity does not diminish the public's rights. A construction project in the public waters will require review under both 3704 and 3700, 3702 or 3708.

Illinois DNR Fishing Regulations

Under State Rules Part 830, the Illinois Department of Natural Resources regulates the commercial harvest of fish and mussels. The commercial harvesting of carp and other rough fish by nets and other mechanical practices is allowed under Illinois State Codes.

MISSOURI

Missouri Department of Natural Resources Permits

Under Missouri State Code, the Missouri Department of Natural Resources issues permits for dams and dam safety and for water pollution control and water quality. The placement of a new structure(s) or modification of existing structures by a State or Local agency will require a MODNR permit.

SUMMARY

The Federal government owns and operates a system of 26 locks and dams on the Mississippi River. Based on review of available on-line permit guidance, modification of these structures by a federal agency in an attempt to stop or contain the spread of exotic fish species would not require federal permits. Depending upon the proposed activity, environmental review (EA and/or EIS) may be required along with a historic resources review under the Chapter 106 National Historic Resources Preservation Act. The federal government does not seek state permits when implementing federal projects. During the implementation of a federal water resources project, State agencies are afforded the opportunity to provide review and comment to the Federal agency that is proposing to build a project.

The implementation of a “structural” project by a state or local agency will require federal, as well as state permits by the various natural resources agencies, dependent upon where in the Mississippi Basin the project is proposed to be located. The States of Minnesota, Iowa, Wisconsin and Illinois all have a combined State/Federal permit application for working in protected water bodies. It is highly recommended that this joint state/federal permit application and review process be utilized for any proposed barrier solutions.

Likewise, the commercial harvesting of carp and other rough fish will require a permit from each of the respective State natural resources agencies. Based on review of available on-line

Regulatory Summaries

Based on review of available information, there does not appear to be a great deal of "regulatory coordination" between the states on the Mississippi River. Minnesota probably has the toughest laws on the books as regards the four species of Asian Carp. Illinois lists only the Black Carp as injurious. It is not illegal to import Asian Carp into Wisconsin. Iowa law prohibits the introduction of live fish into any Waters of the State with the exception that private waters may be stocked with live fish, which probably provides a pathway for the introduction of Asian Carp.

Needs:

- Need all states to consistently list all four species of Asian Carp as injurious and/or exotic
- Need all states to consistently ban export and/or import of live fish with the exception of native game species by respective DNRs and USFWS

State	Summary of Regulations Regarding Exotic Species and Bait
Minnesota	• Defines Bighead, Black, Grass and Silver Carp as a "prohibited exotic species" • It is unlawful (misdemeanor) to possess, import, purchase, transport or introduce these species except under a permit for disposal, control, research or education • It is illegal for anglers to transport live fish • Using whole or parts of carp for bait is illegal • Unwanted minnows can not be dumped in the water • It is illegal to use imported live minnows for bait
Illinois	• Lists Black Carp as an injurious species (live specimen, progeny, viable eggs, gametes) • Injurious species shall not be possessed, propagated, bought, sold or bartered without a DNR permit • Injurious species shall not be released • Possession of federally listed injurious species shall be in accordance with provisions of the Lacey Act (18 USC 42) and 50 CFR 16 • The IDNR is offering a free "Protect Our Waters - Don't Dump Bait" sticker for anglers to apply to their bait buckets. • Illinois is addressing the ANS issue through outreach, management and research. These activities are administered by the Illinois ANS Program, • Section 10-105. Fish Importation Permits: You must possess all required permits, particularly a fish importation permit, to import live fish, viable fish eggs, or viable sperm of any species or hybrid of salmon or trout into Illinois. • Section 10-100. Release of Aquatic Life: It is illegal to release any aquatic life into Illinois waters without permission of the Illinois

	Department of Natural Resources (DNR). However, aquatic life captured by sportfishing may be released immediately back into waters from which they were taken. The owner of a body of water may also release into waters entirely on his/her own property aquatic life that are indigenous to Illinois. The DNR has the right to regulate possession, transportation, and shipping of aquatic life non-indigenous to Illinois. • 810.35 Statewide Sportfishing Regulations--Daily Catch and Size Limits: There are no catch and size limits for species listed in 17 Ill. Adm. Code 805, Injurious Species. Live possession is prohibited. • 810.50 Bait Fishing: The use of live injurious species as bait is prohibited. • 890.20 Permit Requirements: To remove undesirable fish from waters under personal control using chemicals, a "To Remove Undesirable Fish" permit must be obtained from the DNR. Fish toxicants covered by this permit must be applied by DNR personnel;
Iowa	• Identifies Black, Bighead, Silver and Grass Carp as nuisance species • Carp may not be used for bait on any Iowa water • Gizzard shad taken for bait purposes must be killed immediately • 481A.142 Licensed aquaculture units -- activities allowed. A holder of an aquaculture unit license may: 1. Possess, propagate, buy, sell, deal in, and transport the aquatic organisms produced from breeding stock legally acquired, including minnows. 2. Sell fish for stocking purposes within or outside the state. Fish which are nonindigenous to Iowa shall not be received or sold in the state unless the aquaculture unit has obtained an importation permit from the department. The department shall establish, by rule, requirements governing importation, and shall include a list of approved aquaculture species. Failure to comply with this subsection will result in loss of license and a violator is subject to the scheduled fine provided in section 805.8B. 3. Hold, feed, and sell carp, buffalofish, and other fish legally taken by commercial fishers. • Capture and sale of minnows requires a bait license • Licensed bait dealers can not sell carp • You cannot stock or introduce into the waters of the state any live fish, except for hooked bait, without the permission of the director of the DNR. • You can stock privately owned ponds and lakes.
Wisconsin	• Lists Carp (Cyprinus carpio) as a non-native fish • The WDNR has developed a draft policy on the unintentional introduction of aquatic and terrestrial invasive species. The policy needs to be approved by the Natural Resources Board before it becomes official WDNR policy. The purpose of the policy is to minimize the impacts of invasive species to the natural resources of the state. Carp and Asian Carp are not on the Species of Concern List for this policy.

	• A permit from the Department of Natural Resources (DNR) is required to import **non-native** species of fish or fish eggs, under Section 29.735, Wisconsin Statutes. • No person may bring into this state any fish or fish eggs, of a species that is **non-native** to this state, for the purpose of introduction into the waters of the state: for use as bait, or for rearing in a fish farm without having a permit issued by the DNR. • No person may introduce, stock or plant any fish in the waters of the state unless all of the following apply: The person has a permit issued by the Department of Natural Resources. The fish have been certified by a qualified inspector to meet the fish health standards and requirements as determined by the Department of Agriculture, Trade and Consumer Protection, under Section 95.60, Wisconsin Statutes. The fish is not a species of lake sturgeon. • It is illegal to release unused bait into Wisconsin's lakes, ponds, rivers and streams • It is illegal to transport live rough fish into or within the state without a permit from the DNR

Feasibility Study

To Limit the Invasion of Asian Carp into the Upper Mississippi River Basin

VII-B. List of Species Occurring in the Mississippi River

FISHPRO

Fish of the Mississippi River

T/E/SC*	Common Name	Scientific Name	Primary Food Source	Preferred Habitat	Spawning Habitat	Adult Size Range	Adult Swimming
IST	Chesnut lamprey	*Icthyomyzon castaneus*	various fish i.e suckers, catfish, sturgeon; larvae algae and protozoa	Any, ammocetes in soft silt much of quite water with aquatic vegetation	May and June in tributaries of gravel and sand bottoms of medium current	8-10"	
SC	Northern brook lamprey	*Ichthyomyzon fossor*	Small, one-celled plants and animals	Clean headwater areas of creeks and small rivers with coarse gravel to rock bottoms	May and June, shallow water of creeks and small rivers during	up to 6"	
	silver lamprey	*Ichthyomyzon unicuspis*	attach themselves to larger fish and feed	small to moderate streams	June, moderate to small streams with moderate current levels	9-14"	
IST	American brook lamprey	*Lampetra appendix*	adult does not eat, larvae filter-feed	cool, spring fed streams bottom of sand or small-sized gravel	April-May stream with sand/gravel bottom	<10"	
SC, ISE	Lake sturgeon	*Acipenser fulvescens*	bottom dwelling orgs including small clams, snails, crayfish, sideswimmers, aquatic insects, algae, and other plant matter	deeper part of channels or deep pools	April-June migrate to areas with gravel bottoms	up to 2.5 m	
	Shovelnose sturgeon	*Scaphirhynchus platorynchus*	biting midge, midge, caddisfly, mayfly, stonefly larvae; snails; small clams; waterfleas	open, flowing channels with sand or gravel bottoms	May-June over gravel or rocks in an area with fast current	up to 24"	
ST	paddlefish	*Polyodon spathula*	Planktivore	large river areas and riverine lakes	early spring when water levels are on the rise from snowmelt and spring rains in stream gravel bars in water 10 ft or less deep	48-52"	
	longnose gar	*Lepisosteus osseus*	Piscivores - carp, brook silversides, minnows, bluegill, largemouth and smallmouth bass, northern pike, cisco, yellow perch, walleye, and other gar	large rivers with backwaters with little to no current and in weedy floodplain lakes	late May-June; migrate to smaller tributaries and seek out weed beds over a gravel bottom	up to 1 meter	
	shortnose gar	*Lepisosteus platostomus*	Insects, crayfish and fish	large rivers with backwaters, little to no current and weedy floodplain lakes	May or June as water temperatures reach the mid 60s, in quiet shallow water over aquatic plants or other submerged objects	up to 31"	
	bowfin	*Amia clava*	Most anything including fish, frogs, snakes, turtles, small mammals	large, slow rivers especially backwaters; clear water with little current and lots of vegetation	May to early June; weedy areas with sand and gravel	24-39"	
	goldeye	*Hiodon alosoides*	Most anything, commonly aquatic insect larvae and fish	turbid rivers, marshy backwaters	Late April; shallow, turbid pools and backwaters	commonly 1.4-1.7", up to 17"	
	mooneye	*Hiodon tergisus*	insects, crustaceans, small fish, mollusks	slow moving large rivers and their backwaters	medium to large-sized rivers from March through May eggs are deposited over rocks in swift water areas	11-15"	
	American eel	*Anguilla rostrata*	fish, frogs, crayfish, insects, snails, earthworms	medium to large streams and lakes with muddy bottoms and quiet waters	Sargasso Sea late winter/early spring	female 3'; male 1.5'	very long distances
SC	skipjack herring	*Alosa chrysochloris*	plankton, minnows and larvae of mayflies and caddisflies	clear, fast waters over sand and gravel in large rivers	April to mid June	12-16"	
	gizzard shad	*Dorosoma cepedianum*	phytoplankton and zooplankton	deep, openwater of medium to large rivers, lakes, and impoundments	late April and early Augus, over sandy and rocky substrates	9-14"	
	central stoneroller	*Campostoma anomalum*	bottom feeder, living on insect larvae, small mollusks, and filamentous algae	riffle areas of small to medium-sized streams of moderate gradient	Spring, small tributary streams	up to 8"	
	largescale stoneroller	*Campostoma oligolepis*	Scrapes detritus, diatoms, inorganic material, and green and blue-green algae	Medium to large streams with cool clear water, moderate to swift current, and gravel bottom	rocky riffles and runs of clear creeks and small to medium rivers	up to 8"	
	goldfish	*Carassius auratus*	plants, insects, small crustaceans, zooplankton, detritus	slow-moving, freshwater bodies of water	Late spring and summer	4-8"	
	redside dace	*Clinostomus elongatus*	aquatic insects	headwater streams	mid-May, move from pools to gravel spawning beds in or above a riffle	3-4"	
	grass carp	*Ctenopharyngodon idella*	Soft aquatic vegetation	areas (ponds, small lakes) that include soft aquatic vegetation such as filiform, Ziz's pondweed, pondweed, hornwort, spiked milfoil, duckweed and water thyme	May thru July	up to 49"	
	red shiner	*Cyprinella lutrensis*	small invertebrates, plant material, microorganisms	Perennial creeks and small to medium rivers, canals, lakes, ponds, and ephemeral habitats with high turbidity	Spring and summer, shallow water over gravel and sand	up to 4.5"	
	spotfin shiner	*Cyprinella spiloptera*	insects, decapods, microcrustaceans, mites, plants, and detritus	clear streams, reservoirs and lakes over most substrates	Mid-June to mid-August, near logs and tree roots	1-3"	
	carp	*Cyprinus carpio*	invertebrates that live in the sediments	larger, slower-moving bodies of water with soft sediments	spring and early summer depending upon the climate, shallow waters with dense macrophyte cover	11-24"	
SC	gravel chub	*Erimystax x-punctatus*	desmids, diatoms, plant debris and other vegetation	Clear to moderately turbid waters of large creeks and small to large rivers	Spring	up to 4"	
	brassy minnow	*Hybognathus hankinsoni*	plant eater, feeding heavily on algae	small streams and ponds, apparently preferring those with boggy, acid waters	early spring in quiet water	2.5"	
	Mississippi silvery minnow	*Hybognathus nuchalis*	algae and other organic materials	Pools and backwaters of creeks and small to large rivers with low or moderate gradient	Spring and summer	up to 7"	
SC	pallid shiner	*Hybopsis amnis*	unknown	Medium to large rivers, quiet waters over sandy-silty bottoms, often at end of sand and gravel bars	Late winter and early spring	up to 3.25"	
	bighead carp	*Hypophthalmichthys nobilis*	zooplankton, phytoplankton and detritus	Native to large rivers	Large rivers when the temperature reaches 77F-86F	up to 42"	
	common shiner	*Luxilus cornutus*	aquatic inscts, filamentous algae, and other plant matter	downstream ends riffles, pools, beaver ponds with turbid water and bottoms of gravel, sand, and mud	late May; pebble and gravel bottoms at heads of riffles	3-5" up to 12"	

Fish of the Mississippi River

T/E/SC*	Common Name	Scientific Name	Primary Food Source	Preferred Habitat	Spawning Habitat	Adult Size Range	Adult Swimming
	redfin shiner	*Lythrurus umbratilis*	aquatic and terrestrial insects and other small invertebrates	Headwaters, creeks and small to medium rivers	Spring and summer	up to 3"	
	speckled chub	*Macrhybopsis (Hybopsis) aestivalis*	immature insects, cyclopoid fish scales and some plant matter	Shallow channels of large, permanently flowing, sandy streams	May through June and continues sporadically into August, when water temperatures rise above 70^{o}	1.7-2.1"	
	silver chub	*Macrhybopsis (Hybopsis) storeriana*	aquatic insects and crustaceans	Large streams and lakes, waters with gravel or silty bottoms	late May through June in open water areas of large streams and lakes	4-7"	
ISE	pearl dace	*Margariscus margarita*	aquatic insects, free-floating animal plankton, and a variety of other small aquatic organisms	cool, boggy waters of lakes and ponds and in the cold headwater streams often associated with trout	in streams from late spring to early summer	3-4"	
	hornyhead chub	*Nocomis biguttatus*	waterfleas, small crusteaceans, small insect larvae, and some algae	small to medium streams with bottoms of sand, gravel, and boulders, numbers increase in turbid areas	late May in area of gravel with moderate current	8-12"	
	golden shiner	*Notemigonus crysoleucas*	zooplankton, crustaceans, algae, insects and small fish	medium to large bodies of slow moving or standing water, quiet, clear water over sand, gravel or organic debris covered bottoms	May to July, females deposit adhesive eggs over filamentous algae and submerged weed beds	2.5-7"	
ISE	pugnose shiner	*Notropis anogenus*	algae and cladocerans	clear, slow water areas of large streams and lakes with plenty of vegetation	Spring	<2"	
	emerald shiner	*Notropis atherinoides*	zooplankton, insects, and flying insects	large, deep rivers and large lakes or reservoirs	late spring or early summer, over sand, gravel, vegetation and other cover	2-3.5"	
	river shiner	*Notropis blennius*	aquatic insect larvae	Pools and main channels of largest rivers and lower parts of main tributaries, in water of varying clarity (usually turbid) over substrate of silt, sand, and gravel	June to late August, over sand and gravel bars	up to 2.5"	
	bigmouth shiner	*Notropis dorsalis*	Bottom feeder consuming aquatic insects, detritus, and plant material	sand bottom streams	May thru July	up to 3"	
	blackchin shiner	*Notropis heterodon*	Aquatic insects and cladocera at the water's surface	slow, clear, weedy areas of large streams and the shallow parts of lakes	July	2-3"	
	spottail shiner	*Notropis hudsonius*	insects, clams, young shiners, fish eggs, and plants	large lakes and rivers to small streams	June or July over sandy bottom and at the mouths of streams	2-3.5"	
SC	Ozark minnow	*Notropis nubilus*	green algae, blue-green algae and diatoms	clear, small-to-medium-sized streams with slow current and devoid of vegetation	May or June	2-3"	
	rosyface shiner	*Notropis rubellus*	aquatic and terrestrial insects	swifter parts of large and moderate-sized streams	June, over gravel bottom in the lower part of a riffle	up to 3"	
	sand shiner	*Notropis stramineus*	Aquatic insects, plant material, crustaceans, and detritus	moderate to large streams and in lakes where there is enough current or wave action to keep the bottom free of silt	May through August, at temperatures of 21 to 37 C	2.5"	
ISE	weed shiner	*Notropis texanus*	microscopic plants, small insects and their larvae	microscopic plants, small insects and their larvae	unknown	up to 3.5"	
IST, SC, FE	Topeka shiner	*Notropis topeka*	ominvores (insects, waterfleas, snails, clams, algae, plant stems, etc.)	low-gradient, slow-moving streams with bottoms of snad, gravel, or rubble covered in a deep layer of silt in pool-like areas outside the main channel that are in contact with groundwater and usually contain vegetation and areas of exposed gravel	mid-May to early June; share nests with orange-spotted or green sunfish	2.4-3"	
	mimic shiner	*Notropis volucellus*	Entomostracans, algae and other plant debris, and midge adults and larvae	quieter parts of streams, often around vegetation	June and July	3"	
ISC	pugnose minnow	*Opsopoeodus emiliae*	larvae of aquatic insects and zooplankton	clear water with aquatic vegetation where the bottom is comprised of organic debris or sand	Spring	2"	
	suckermouth minnow	*Phenacobius mirabilis*	Insect larvae	runs and riffles of creeks and small to medium (sometimes large) rivers with substrates ranging from sand and gravel to large boulders	Over gravel riffles	4-5"	
	northern redbelly dace	*Phoxinus eos*	filamentous algae and diatoms	small streams (fast or slow) and bog lakes with variety of bottom types	May to July in masses of fialmentous algae	up to 3"	
	southern redbelly dace	*Phoxinus erythrogaster*	algae and detritus	between wooded banks and contain long pools of moving	May	1.6-2.8"	
	finescale dace	*Phoxinus neogaeus*	small inverts (aquatic insects and fingernail clams)	smalll boggy ponds and slow-moving creeks	April and May in depressions under submerged logs and brush	60-70 mm	
	bluntnose minnow	*Pimephales notatus*	algae, aquatic insect larvae, diatoms, and small crustaceans called entomostracans	shallow areas of clear lakes and ponds with sand and gravel bottoms, in streams they prefer gravel to rock substrate	begin spawning in the spring and may continue into August	1.6-3.5"	
	fathead minnow	*Pimephales promelas*	algae, protozoa, plant matter, insects, rotifers, copepods	low-gradient, turbid streams and ditches	May to mid-August; gravel or sand bottom under a log rock, etc.	2.6-2.8"	
	bullhead minnow	*Pimephales vigilax*	Algae, insect larvae, diatoms, entomostracans, and rarely fish eggs or small fish	small creek species that is intolerant of high turbidity	spring to late summer	up to 4"	
	blacknose dace	*Rhinichthys atratulus*	Largely aquatic insects and larvae, worms, and algae	rocky runs and pools of headwaters, creeks and small rivers	late spring to early summer in riffles over gravel and rubble	up to 4"	

Fish of the Mississippi River

T/E/SC*	Common Name	Scientific Name	Primary Food Source	Preferred Habitat	Spawning Habitat	Adult Size Range	Adult Swimming
	longnose dace	*Rhinichthys cataractae*	aquatic insect larvae	prefer the riffle areas of streams, but can be found along the shoreline of lakes where the substrate is composed of small rubble	late spring through early summer on gravel bottoms of shallow riffles	3-6"	
	creek chub	*Semotilus atromaculatus*	insect larvae, terrestrial insects, small fish	small to moderat sized streams; clear to faintly cloudy waters over hard bottoms	May to July in streams of moderate current with gravel bottoms	7-10"	
	river carpsucker	*Carpiodes carpio*	primarily algae and some small insects	quiet pools over silt or mixd snad and fine gravel	May through July	16-24"	2.3 ft/s prolonged - Schmulbach
	quillback	*Carpiodes cyprinus*	detritus, algae, and insect larvae	quiet waters of medium to low gradient including sloughs and floodplain lakes - wide habitat tolerance	probably April to September in small streams in sand and mudflats in slow-moving water	15-22"	Family range 2 to 5 ft/s prolonged
	highfin carpsucker	*Carpiodes velifer*	Algae and Insects	gravel or mixed sand bottom with moderate current or adjacent to river channels	Riffles in April and May	up to 12"	Family range 2 to 5 ft/s prolonged
	white sucker	*Catostomus commersoni*	aquatic insect larvae, waterfleas, sideswimmers, snails, clams, algae, and detritus	benthic areas of slow-moving turbid rivers - wide tolerance to habitats	March to May; stream headwaters with bottoms of gravel or coarse sand	15-20"	Approximately 5.5 ft/s - Bell, 1973
SC	blue sucker	*Cycleptus elongatus*	aquatic insect larvae, crustaceans, plant material	deeper fast moving channels with bottoms of gravel or cobble	Probably May to mid June and migrate upstream to areas of moderately swift current and good gravel bottoms	20-24"	
	nothern hogsucker	*Hypentelium nigricans*	Benthic insects and mollusks	Clear, fast riffles with pebbly or sandy bottoms free of silt and algae	April to may in gravelly areas - highly migratory	12-18"	Family range 2 to 5 ft/s prolonged
	smallmouth buffalo	*Ictiobus bubalus*	insect larvae, algae and detritus	Prefers deep, clearer waters with moderate current	Spring	12-28"	
	bigmouth buffalo	*Ictiobus cyprinellus*	plankton, copepods, cladocerans, bottom plants, aquatic insects, mollusks, small fish	slow to still waters and bottoms of mud, silt, sand, and gravel especially in floodplains and oxbow lakes	April-May in sloughs and flooded marshes of large rivers over sparse vegetation, rocks, or mud with clear water	14-24"	
SC	black buffalo	*Ictiobus niger*	mollusks and insects, along with crayfish, duckweed, diatoms and bluegreen algae	Has habits similar to the smallmouth buffalo, but are more often found in deeper water and stronger currents	April to mid-June	16"	
	spotted sucker	*Minytrema melanops*	cladocerans, copepods, ostricods and plant materials that includes algae	long deep pools of small to medium rivers over clay, sand, or gravel substrates	April when water temperature is 55 degrees F and continues through May until the water temperature reaches about 67 degrees F, shallow riffles over rubble or gravel in moderate current are preferred	up to 19"	
	silver redhorse	*Moxostoma anisurum*	Algae, Immature insects, mollusks and detritus	Silty to firmed bottom pools and runs also natural lakes and impoundments	channel of turbid rivers in 1 to 3 feet of water over gravel	16-20"	Family range 2 to 5 ft/s prolonged
T	river redhorse	*Moxostoma carinatum*	Mollusks and Benthic insects	swift, gravelly riffles; intolerant of turbid waters and poor water quality	late March or early June	15-27"	Family range 2 to 5 ft/s prolonged
IST	black redhorse	*Moxostoma duquesnei*	Aquatic insects, copepods, freshwater shrimp, sideswimmers, and aquatic roundworms	clean, swift flowing creeks and rivers with bottoms of gravel, rock, or sand and has a low tolerance for pollution, siltation, or turbidity	spring when the water temperature is between 56-72 F	10-15"	
	golden redhorse	*Moxostoma erythrurum*	Benthic Insects, Mollusks and some Algae	firm bottom pools	Riffles in April and May	15-24"	Family range 2 to 5 ft/s prolonged
	shorthead redhorse	*Moxostoma macrolepidotum*	insect larvae, mollusks, some plant material	clear to moderately turbid pools and riffles with bottoms of sand, gravel, and rock	late April to early June; in areas of clean shallow, gravel riffles	12-24"	Family range 2 to 5 ft/s prolonged
E	greater redhorse	*Moxostoma valenciennesi*	midge larvae, mollusks, crustaceans and plant material	Clear waters of medium to large-sized rivers, reservoirs and large lakes at depths of less than 3 feet (1m) over sand, gravel or boulders	Spawn in May and June in moderately rapid waters of streams on gravel, sand or rubble	15-24"	Family range 2 to 5 ft/s prolonged
	black bullhead	*Ameiurus melas*	scavenger and insects, clams, snails, waterfleas	slow moving, quiet waters with soft bottoms of mud and sand	late April to early June in water 0.6-1.2 meters deep underneat matted vegetatio, wood, or a bank	6-10"	
	yellow bullhead	*Ameirurus natalis*	plant and animal material, both live and dead	Warm pools and backwaters in ponds, lakes, and reservoirs, streams and rivers	Late spring or early summer	up to 12"	
	brown bullhead	*Ameirurus nebulosus*	Crustaceans, insects, worms, algae, mollusks, fish	Shallow, weedy, muddy areas of lakes or large slow-moving streams; also impoundments, lakes, and ponds	early in spring, usually in late April or May	up to 20"	
	channel catfish	*Ictalurus punctatus*	insects, mollusks, crustaceans, fish, and some plant material	cool, deep, clean water with a sand or gravel bottom	late spring or early summer when water temperatures reach 75°F	up to 48"	
SC	slender madtom	*Noturus exilis*	caddisflies, midgeflies and other insects and algae	Clear, moderately swift waters at depths of 4-12 inches (10-30cm) over gravel and boulder substrate interspersed with fine sand	Late May and June	3-4"	
	stonecat	*Noturus flavus*	insect larvae, small crustaceans, and small fish	riffle areas composed of gravel, cobble, and bedrock	Stonecats begin spawning when water temperatures reach about 80 F	3-6"	
	tadpole madtom	*Noturus gyrinus*	aquatic insect larvae, waterfleas, and other small crustaceans and worms	shallow water 1-2 meters deep in clear to somewhat turbid water near underwater vegetation other types of plant debris	Probably June to July under submerged objects	up to 4.5"	

Fish of the Mississippi River

T/E/SC*	Common Name	Scientific Name	Primary Food Source	Preferred Habitat	Spawning Habitat	Adult Size Range	Adult Swimming
	flathead catfish	*Pylodictis olivaris*	fish	benthic habitats of deep pools, backwaters in sluggish parts of rivers	June and July under a bank or log in areas of silt and mud with gravel bottom	over 3.2'	
	northern pike	*Esox lucius*	fish and other vertebrates	shallow vegetated areas with cool to warm slow-moving water	April to early May in shallow, flooded marshlands or grassy lakes	14-31"	
	muskellunge	*Esox masquinongy*	fish and other vertebrates	warm, slow-moving rivers and backwater areas with clear water and numerous underwater weed beds	spring (April or May) in heavily vegetated sites in water 38-50" deep	45-50"	
	central mudminnow	*Umbra limi*	insect larvae, small snails and clams and sideswimmers	cool bogs and marshes and slow-moving streams with bottoms of soft sediments	spring (usually April) in spring-flooded areas with plenty of vegetation	2.8-3.2"	
	rainbow smelt	*Osmerus mordax*	Smaller fish, aquatic life, and worms	usually found in dark, cool waters offshore	Spring	7-9"	
	rainbow trout	*Oncorhynchus mykiss*	small fish, larval and adult insects	fast-running clean streams with gravel bottoms and in deep, cool, soft water lakes	Spring (mostly April) upstream in stream tributaries or shallow areas of rock or gravel	24-28"	
	brown trout	*Salmo trutta*	insects from water and land, and take larger prey such as worms, crustaceans, mollusks, fish, salamanders, and frogs as their size increases	cool clear rivers and streams with temperatures of 54F-66F	Fall and early winter in spring-fed headwaters, the head of a riffle, or the tail of a pool, selected sites have good water flows through the gravel bottom	13-16"	
	brook trout	*Salvelinus fontinalis*	aquatic insects, sideswimmers, snails, and worms	small spring-fed streams that have cool, clear waters with sand and gravel bottoms and moderate vegetation	Autumn (October through November) in riffles with gravel	6-10"	
	trout-perch	*Percopsis omiscomaycus*	waterfleas, copepods, sideswimmers, fingernail clams, and midge larvae	clear to moderately turbid water with sand and gravel bottoms	May to August; over sandbars and rocks in lakes or small streams over gravel and sand beds	3-5", up to 8"	
SC, ISC	pirate perch	*Aphredoderus sayanus*	aquatic insects, small crustaceans and occasionally on small fish	quiet pools and backwaters that are characterized by clear, warm water, absence of current and abundant aquatic plant life or organic debris for cover	February to March	3-4.5"	
IST	burbot	*Lota lota*	fish	Rocky riffles and pools under banks in water not exceeding 69 degrees	mid-winter to early spring before ice is off in shallow water less than 5 m deep over sand or gravel bottoms	28-32"	
	brook silverside	*Labidesthes sicculus*	copepods, waterfleas, and terrestrial and aquatic insects	near the surface of still or slow-moving water in clear to slightly turbid areas typically in sloughs, pools, and backwaters, but NOT with thick vegetation	May to July near water surface	3.2"	
	banded killifish	*Fundulus diaphanus*	small crusteaceans, aquatic insects, mayfly nymphs, flying insects, and plant seeds	still backwaters of large rivers where current is sluggish with shallow, clear waters with sandy to gravely bottoms and large amounts of vegeation	June to mid August in shallow water in an area of vegetation	2-3"	
	starhead topminnow	*Fundulus dispar*	terrestrial and aquatic insects, crustaceans, mollusks and delicate aquatic vegetation	Glacial lakes and clear, well-vegetated floodplain lakes, swamps and marshes. Prefer quiet, clear to slightly turbid (cloudy), shallow backwaters with an abundance of submergent vegetation	Spawn in dense beds of aquatic vegetation during late spring to early summer	1.8-2.2"	
	brook stickleback	*Culaea inconstans*	aquatic insect larvae, terrestrial insects, waterfleas, worms, snails	cool unclouded waters with large amounts of vegetation	late spring to early summer (May-June) in vegetated areas	up to 2.4 inches	
	mottled sculpin	*Cottus bairdi*	aquatic insect larvae and sideswimmers	small clear streams in riffle and pools over sand, gravel, boulders or limestone	April to May in cavities under rocks, ledges or logs	3-5"	
	slimy sculpin	*Cottus cognatus*	aquatic invertebrates	riffle areas among rocks of cold, clear streams, but it can be found along gravel beaches of lakes	Spring	2-3"	
	white bass	*Morone chrysops*	waterfleas, insect larvae, and fish	clear water, some current over sandy or rocky bottoms with little to no vegetation	spring (May) in tributaries of hard bottom of sand, gravel or rubble	up to 13"	
SC	yellow bass	*Morone misssissippiensis*	insects, crustaceans and fish	clear to slightly turbid water and a firm bottom substrate of sand, gravel, rock rubble and mud	May when the water temperature approaches 60 degrees F	4-9"	
	rock bass	*Ambloplites rupestis*	small fish, insects, crayfish and other invertebrates	hard rock and gravel bottoms	spring, when the water temperature ranges from the high 60s into the 70s	up to 10"	
	green sunfish	*Lepomis cyanellus*	zooplankton (waterfleas and copepods), insect larvae, small snails, and small fish	quiet water of shallow weedy small streams	late spring and summer (late May to early August) near shelter with gravel bottom	up to 8"	
	pumpkinseed	*Lepomis gibbosus*	aquatic insect larvae, terrestrial insects, snails, clams, leeches	slow-moving streams with clear water 1-2 meters deep with lots of vegetation	late May to August in shallow weedy bays and pools of streams with gravel bottoms.	6-8"	
	warmouth	*Lepomis gulosus*	fish, insects, crayfish, and other invertebrates	lowland species, inhabiting oxbow lakes, quiet waters of bayous and rivers, and swamps having mud and detritus bottoms	Multiple spawns of warmouth begin in the summer months as the water temperature exceeds 70° F	5-8"	
	orangespotted sunfish	*Lepomis humilis*	aquatic insects, crustaceans and other small fish	Clearer, cool streams, rivers, lakes, ponds,and impoundments of clearer creeks, rivers, and streams	Spawning begins when the water reaches 65-70 degrees F	2-6"	
	bluegill	*Lpomis macrochirus*	aquatic insect larvae	slow moving parts of streams and rivers with a lot of aquatic plants and warmer water	late May to early August in areas of gravel and coarse sand	3.5-12"	
	smallmouth bass	*Micropterus dolomieu*	fish	clear, strong-flowing streams and rivers with with grave or boulder shores	mid-May through end of June in a gravel bed near a log or boulder	12-20"	

Fish of the Mississippi River

T/E/SC*	Common Name	Scientific Name	Primary Food Source	Preferred Habitat	Spawning Habitat	Adult Size Range	Adult Swimming
	largemouth bass	*Micropterus salmoides*	fish and zooplankton	backwaters of warm waters, sandy shorelines with numerous weed beds	May to June in shallow water near bulrushes, water lilies, and other submerged plants with a bottom of gravel, sand or mud.	10-13"	
	white crappie	*Pomoxis annularis*	insect larvae and small fish	They prefer larger ponds, reservoirs, and rivers	May and June	8-12"	
	black crappie	*Pomoxis nigromaculatus*	minnows and small fish	moderate to large streams, backwaters in clear, calm, warm water with abundant vegetation	May and June in areas of fine gravel, sand or mud next to submerged pants in water 0.3-2 meters deep	10-12"	
IST	western sand darter	*Ammocrypta clara*	include small or immature aquatic insects and midge larvae	medium to large rivers that have moderate to swift currents, primarily over extensive areas of sandy substrate	may occur in mid-summer	up to 2.75"	
SC	crystal darter	*Crystallaria asprella*	mayflies, midgeflies, caddisflies, water scavenger beetles and nematodes	Larger, deeper rivers in clear to slightly turbid (cloudy) waters and moderate to strong currents. Prefer extensive sandy riffles, bars and pool bottoms that are clean and at least 2 feet (60cm) under water	unknown	5-6"	
	mud darter	*Etheostoma asprigene*	mayflies and midge larvae	rivers; also lowland lakes	April and May	up to 2.75"	
	rainbow darter	*Etheostoma caeruleum*	aquatic insect larvae, zooplankton, and small crustaceans	clear, moderate to fast current with gravel and bounder bottom over sand	May to early June riffles of medium current in gravel	2.2-2.4"	
ISE	bluntnose darter	*Etheostoma chlorosoma*	chironomid and blackfly larvae, cyclops and daphnia by darting around from one perching site to another among the organic debris in sand, mud or clay along the benthic (bottom) surface	Quiet waters of oxbows, ponds, sloughs, creeks, pools and sluggish currents	May	1.5-2"	
	Iowa darter	*Etheostoma exile*	zooplankton	still or slow-moving water with clear to moderately turbid water with plenty of sumberged aquatic plants and algae	late April to June in shallow water 10-12 cm deep among submerged vegetation, algae, or exposed roots.	2.5"	
	fantail darter	*Etheostoma flabellare*	larvae, amphipods and other aquatic insects	riffle areas of streams where there are cobbles and gravel. They are especially abundant in streams where there are chunks or slabs of limestone or shale	late April to mid-June	up to 2"	
SC, ISE	least darter	*Etheostoma microperca*	zooplankton	shallow (less than 1.5 m) clear waters with little current in or near weedy areas over bottoms of gravle, sand, and silt	late May through July on aquatic weeds at edge of pools and slow runs in streams	up to 1.5"	
	johnny darter	*Etheostoma nigrum*	zooplankton	clear water with sandy or gravely bottoms and slow or still waters	May to June in pools, slow runs where there is debris to lay eggs under	up to 2.5"	
	banded darter	*Etheostoma zonale*	aquatic insects	algae-covered boulders of rocky deep riffles in streams having permanent strong flow	Spring	up to 2.25"	
	yellow perch	*Perca flavescens*	fish and zooplankton	backwater areas of large rivers	after ice-out in April and early May in shallow, slower protected weedy areas of streams	up to 15"	
	logperch	*Percina caprodes*	aquatic insects, zooplankton	clear, slow moving to medium swift waters with bottoms of sand, gravel, and boulders; also found in some turbid rivers (Mississippi)	late April to early June in area of clean sand or gravel in water 2-200 cm deep	4.5-5.1"	
SC	gilt darter	*Percina evides*	caddisfly larvae, diptera larvae and mayfly nymphs	clear, moderate to large-sized streams with strong flow in rubble riffles and cobble or boulders where currents are moderate to swift	May to July over gravel and sand in cobble and cobble-boulder raceways of moderate but persistant flow	50 mm at maturity	
	blackside darter	*Percina maculata*	aquatic insect larvae	rocky riffles to pebbly and sandy runs of small to large rivers	May through early July over fine gravel and sometimes coarse sand in raceways and edges of slow riffles	3-4.3"	
	slenderhead darter	*Percina phoxocephala*	caddisfly and mayfly larvae	medium sized creeks and small rivers with gravel bottoms and a strong flow	late March and early May	3-4"	
	river darter	*Percina shumardi*	aquatic insects	deep, lower ends of riffles in streams of moderate to large size	in strong current over scattered rubble	up to 3"	
	sauger	*Sander canadense*	Opportunistic feeder primarily feeds on other fish and large insects	Backwater areas; tolerant of silty bottom	April in gravel or rubble (short spawning season)	12-18"	
	walleye	*Sander vitreus*	Opportunistic feeder - primarily fish and large insects	clear, cool and calm waters also turbid, warm and flowing water if a cooler quieter water retreat in late summer is available	April and early May after ice-out; migrate into small streams of shallow gravel beds or areas of flooded vegetation	15-30"	2.7 ft/s Prolonged - Jones 1974
	freshwater drum	*Aplodinotus grunniens*	bottom dwelling creatures especially aquatic insect larvae	large rivers with slow-moving turbid water with bottoms of mostly mud or a mixture of mud and sand	May to June in deep open waters near the surfae of the water	12-24"	

*SC = Minnesota Special Concern species, ST = Minnesota Threatened species, SE = Minnesota Endangered species, ISC = Iowa Special Concern species, IST = Iowas Threatened species, ISE = Iowa Endangered species, FT = Federal Threatened species, FE = Federal Endangered species

Freshwater Mussels of the Mississippi River Pools 1-19

T/E/SC*	Common Name	Scientific Name	Preferred Habitat	A**	C**	R**	H**
ISE, ST	spectaclecase	Cumberlandia monodonta	Large rivers with swiftly flowing water, among boulders in patches of sand, cobble, or gravel in areas where current is reduced.			10, 15, 16, 17, 19	3, 9, 14
	threeridge	Amblema plicata	Small to large rivers and impoundments in mud, sand, or gravel.	1-19			
ST, IST	purple wartyback	Cyclonaias tuberculata	Medium to large rivers in gravel or mixed sand and gravel			4	2, 3, 6-8, 10, 11, 13-16
SE	elephant ear	Elliptio crassidens	Large rivers in mud, sand, or fine gravel			17	2-16
SC	spike	Elliptio dilatata	Small to large streams and occasionally lakes in mud or gravel.		4	3, 5a, 6, 10, 11, 14, 17	
SE	ebonyshell	Fusconaia ebena	Large rivers in sand and gravel			9, 18	2-8, 10-17, 19
	Wabash pigtoe	Fusconaia flava	Creeks to large rivers in mud, sand, or gravel	1, 3, 4, 11	2, 5, 5a, 6-8, 10, 12-14, 16-18	9, 15, 19	
ST	washboard	Megalonaias nervosa	Primarily large rivers with a good current; occasionally medium-sized streams in mud, sand, or gravel.	15-17	9, 10, 14, 18, 19	3-5, 6-8, 12, 13	2
SE	sheepnose	Plethobasus cyphyus	Medium to large rivers in gravel or mixed sand and gravel			7, 10, 15-17	2-6, 8, 13, 14, 18
ST	round pigtoe	Pleurobema sintoxia	Medium to large rivers in mud, sand, or gravel		11	2-5, 6-10, 13, 15-17	5a, 12, 14
SE, FE	winged mapleleaf	Quadrula fragosa	Medium to large rivers in mud, sand, or gravel				2-4, 6, 8, 10
ST	monkeyface	Quadrula metanevra	Medium to large rivers in gravel or mixed sand and gravel.		15, 17, 19	2, 4, 5, 6-14, 16, 18	3, 5a
SE	wartyback	Quadrula nodulata	Large rivers or in the lower sections of medium-sized rivers in sand or fine gravel.		1-3, 18, 19	4, 7, 9-17	8
	pimpleback	Quadrula pustulosa	Medium to large rivers in mud, sand, or gravel.	15-17, 19	2-7, 9-14, 18	1, 8	
	mapleleaf	Quadrula quadrula	Medium to large rivers and reservoirs with a mud, sand, or gravel bottom.	1	2-4, 8-19	5-6	
ST	pistolgrip	Tritogonia verrucosa	Medium to large rivers in mud, sand, or gravel.			2, 4, 7-10, 19	3, 5-6, 11, 13-18
ST	elktoe	Alasmidonta marginata	Medium-sized streams in gravel or mixed sand and gravel.			2, 3, 6, 8, 11	4, 5a, 7, 9, 10, 13

Freshwater Mussels of the Mississippi River Pools 1-19

T/E/SC*	Common Name	Scientific Name	Preferred Habitat	A**	C**	R**	H**
ISE, ST	slippershell mussel	Alasmidonta viridis	Creeks and the headwaters of large rivers in sand, mud, or fine gravel				12
	flat floater	Anodonta suborbiculata	Ponds, lakes, or sluggish mud-bottomed pools of creeks and rivers.			4-6, 8-10, 13, 15-17	14
	cylindrical papershell	Anodontoides ferussacianus	Small creeks and the headwaters of larger streams in sand and mud				4
SE	rock pocketbook	Arcidens confragosus	Medium to large rivers in pools and areas of reduced flow in mud and sand.			2, 3, 5, 6-19	4, 5a
	white heelsplitter	Lasmigona complanata	Pools or sluggish streams with a mud, sand, or fine gravel bottom.		13	2, 3, 6-12, 14-19	1, 4-5a
SC, IST	creek heelsplitter	Lasmigona compressa	Creeks and the headwaters of small to medium rivers in fine gravel or sand. Rarely found in larger rivers.				14, 15
SC	fluted shell	Lasmigona costata	Medium to large rivers in sand, mud, or fine gravel in areas with slow to moderate flow.			2, 8, 10, 14	4, 5, 6, 7, 9, 13, 15
	giant floater	Pyganodon grandis	Typically, ponds, lakes, and sluggish mud-bottomed pools of creeks and rivers; can be found in a variety of other habitats as well.		1-3, 9, 11, 12, 18	4-8, 10, 13-17, 19	
	salamander mussel	Simpsonaias ambigua	Medium to large rivers on mud or gravel bars and under flat slabs or stones.			10, 12	3
IST	strange floater	Strophitus undulatus	Small to medium-sized streams and occasionally large rivers in mud, sand, or gravel.		1, 2, 9	3, 4, 5a-8, 10-17, 19	5, 18
	paper pondshell	Utterbackia imbecillis	Ponds, lakes, and sluggish mud-bottomed pools of creeks and rivers.	19	17	1-5, 6-16, 18	5a
ST	mucket	Actinonaias ligamentina	Medium to large rivers in gravel or mixed sand and gravel.		14	2-4, 7-13, 15-19	5-6
ST, IST	butterfly	Ellipsaria lineolata	Large rivers in sand or gravel	15	11, 12, 14, 16-19	3, 4, 5a-10, 13	2, 5
ST	snuffbox	Epioblasma triquetra	Medium to large rivers in clear, gravel riffles.				3, 4, 5a, 6, 10, 14-16,
	plain pocketbook	Lampsilis cardium	Small creeks to large rivers in mud, sand, or gravel.		2, 3, 6-9, 11-15, 17-19	1, 4-5a, 10, 16	
ISE, SE, FE	Higgins eye	Lampsilis higginsii	Mississippi River and some of its larger northern tributaries in gravel or sand.			7-17, 19	2-6
	fatmucket	Lampsilis siliquoidea	Lakes and small to medium-sized streams in mud, sand, or gravel.			1-5, 6-13, 17	5a, 14, 15

Freshwater Mussels of the Mississippi River Pools 1-19

T/E/SC*	Common Name	Scientific Name	Preferred Habitat	A**	C**	R**	H**
ISE, SE	yellow sandshell	Lampsilis teres	Medium to large rivers in sand or fine gravel.			4, 7, 9-11, 14, 15, 17, 19	2, 3, 5-6, 8, 13, 16, 18
	fragile papershell	Leptodea fragilis	Streams of all sizes in mud, sand, or gravel.	11, 19	2, 4, 8, 9, 12, 15, 17, 18	1, 3, 5-7, 10, 13, 14, 16	
	scaleshell	Leptodea leptodon	Large rivers in mud.				2, 10, 13
SC	black sandshell	Ligumia recta	Medium to large rivers in riffles or raceways in gravel or firm sand		2, 9, 11, 13, 14	1, 3-8, 10, 12, 15-19	
	threehorn wartyback	Obliquaria reflexa	Large rivers in sand or gravel; may be locally abundant in impoundments.	1-4, 6-8, 10, 12-15	5, 5a, 9, 11, 16-19		
SC	hickorynut	Obovaria olivaria	Large rivers (rarely in medium or small streams) in sand or mixed sand and gravel.	7	6, 10-14, 17-19	2-5a, 8, 9, 15, 16	
	pink heelsplitter	Potamilus alatus	Medium to large rivers in mud or mixed mud, sand, and gravel.		1-3, 7, 9, 10, 14, 16, 17, 19	4, 5, 6, 8, 11-13, 15, 18	5a
FE	fat pocketbook	Potamilus capax	Large rivers in slow-flowing water in mud or sand.				4, 5a, 10, 13, 16, 18, 19
	pink papershell	Potamilus ohiensis	Medium to large rivers in silt, mud, or sand.		3, 17, 19	1, 2, 4-16, 18	
	bleufer	Potamilus purpuratus	Large rivers in mud or mixed mud and gravel.				19
	lilliput	Toxolasma parvus	Ponds, lakes, and creeks to large rivers in mud, sand, or fine gravel.		5, 6, 10, 11	2-4, 5a, 7, 8, 12-19	
	fawnsfoot	Truncilla donaciformis	Large rivers or the lower reaches of medium-sized streams in sand or gravel.	5	5a, 6, 13, 15, 17-19	1-4, 7-12, 14, 16	
ST, IST	ellipse	Venustaconcha ellipsiformis	Small to moderate streams in gravel or mixed sand and gravel				
	deertoe	Truncilla truncata	Medium to large rivers in mud, sand, or gravel.	1, 2, 4, 8, 10, 11, 15	3, 5, 7, 9, 12-14, 17-19	5a, 6, 16	

*SC = Minnesota Special Concern species, ST = Minnesota Threatened species, SE = Minnesota Endangered species, ISC = Iowa Special Concern species, IST = Iowas Threatened species, ISE = Iowa Endangered species, FT = Federal Threatened species, FE = Federal Endangered species

**H = Records of occurrence but no live collections have been documented in the past ~25 years.
R = Rare, does not usually appear in sample collections, populations are small either naturally or have declined and may or may not be near extirpation.

Crayfish of the Mississippi River

Scientific Name	Common Name
CAMBARUS DIOGENES	DEVIL CRAWFISH
CAMBARUS HUBRICHTI	SALEM CAVE CRAYFISH
CAMBARUS TENEBROSUS	
CAMBARUS MACULATUS	FRECKLED CRAYFISH
CAMBARELLUS SHUFELDTII	CAJUN DWARF CRAYFISH
CAMBARELLUS PUER	A DWARF CRAYFISH
ORCONECTES LANCIFER	
ORCONECTES PROPINQUUS	NORTHERN CLEARWATER CRAYFISH
ORCONECTES HARRISONII	BIG RIVER CRAYFISH
ORCONECTES HYLAS	WOODLAND CRAYFISH
ORCONECTES MEDIUS	SADDLEBACKED CRAYFISH
ORCONECTES PALMERI	GREY-SPECKLED CRAYFISH
ORCONECTES ILLINOIENSIS	
ORCONECTES IMMUNIS	CALICO CRAYFISH
ORCONECTES LUTEUS	
ORCONECTES VIRILIS	VIRILE CRAYFISH
PROCAMBARUS ACUTUS	WHITE RIVER CRAWFISH
PROCAMBARUS VIAEVIRIDIS	
PROCAMBARUS GRACILIS	PRAIRIE CRAYFISH
PROCAMBARUS CLARKII	RED SWAMP CRAWFISH
FALLICAMBARUS FODIENS	
ORCONECTES PUNCTIMANUS	SPOTHANDED CRAYFISH

Feasibility Study

To Limit the Invasion of Asian Carp into the Upper Mississippi River Basin

VII-C. Literature Review

FISHPRO

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Feasibility Study

To Limit the Invasion of Asian Carp into the Upper Mississippi River Basin

VII-D. Meeting Summaries

FISHPRO

MEETING SUMMARY

for

Feasibility Study to Limit the Invasion of
Asian Carp in the Upper Mississippi River

FP/CWI No. 04004

A kick-off meeting for the feasibility study was held at 10:00 a.m. on January 14, 2004 at the Minnesota Department of Natural Resources headquarters in St. Paul, MN. The purpose of the meeting was to bring together the project team and key members of the scientific community and agencies involved with the movement of Asian carp species. Provided below is a brief outline of the meeting and the topics covered. The following were in attendance:

Jack Wingate- MN DNR
Ron Payer- MN DNR
Lee Pfannmuller- MN DNR
Gerry Jackson- USFWS
Mike Oetker- USFWS
Mike Hoff- USFWS
Pam Thiel- USFWS
Greg Conover- USFWS
Jerry Rasmussen- MICRA
Phil Moy- WI Sea Grant
Duane Chapman- USGS
Edward Little- USGS
Dan Wilcox- COE
Randy Ferrin- NPS St. Croix NRS
Ron Benjamin- WI DNR
Matt Cochran –FishPro\Cochran & Wilken, Inc.
Gary Wilken- FishPro\Cochran & Wilken, Inc.
Peter Berrini- FishPro\Cochran & Wilken, Inc.
Jim Bakken- Ayers Associates
David Johnson- HDR
Steve Bartell- Cadmus (via phone conf.)

(Project directory is attached)

1. The meeting began with an address from Deputy Commissioner Mark Holsten. Mr. Holsten providing some background on his agency's knowledge of the problem, outlined the involvement of the Minnesota DNR and emphasized their commitment to work on limiting the invasion of Asian carp. Gerry Jackson added to the statements by emphasizing the problem as a nationwide issue that deserves national attention.

2. Following the introduction by Mark Holsten, Jack Wingate provided additional comment about the project and the MN DNR perspective and officially kicked-off the meeting. Jack summarized the project into three broad categories: (1) to provide an objective analysis of the technology available; (2) address the potential impact of technology on native species; (3) provide estimates for anticipated establishment of the species related to timeline of arrival, impact on native species, impact on recreation, etc. Jack also highlighted the importance of the project and the timeline limitations available to complete this study. A Smith-Root report dated October 2003 was discussed. It was the consensus of all parties attending that due to the capitol costs, operating costs, safety, public perception, flooding, etc. that an electrical barrier is not

practical on the Upper Mississippi River. The study may consider some use of electrical barriers in conjunction with other systems.

3. Following Jack's comments, the meeting was turned over to Gary Wilken. Gary highlighted the points made by Jack related to the project scope and deliverables and emphasized the importance of the meeting for information exchange. Gary commented on the level of expertise in the room related to Asian carp and emphasized the need for FishPro to acquire valuable information and points of contact from the attendees.

4. After Gary's remarks, each represented agency was given a few minutes to summarize their involvement and/or to provide comment on the movement of Asian Carp. The following agencies and/or groups provided comment:

a. US Fish and Wild Life Service (USFWS)
b. Mississippi Interstate Cooperative Resource Association (MICRA)
c. US Geological Survey (USGS)
d. US Army Corps of Engineers (USACE)
e. National Park Service (NPS) St. Croix NSR
f. Wisconsin Department of Natural Resources (WI DNR)
g. Upper Mississippi River Conservation Committee (UMRCC) (Represented by WI DNR)
h. Wisconsin Sea Grant
i. Minnesota Department of Natural Resources (MN DNR)

5. During the discussion, several specific points of contact were established and/or information requests were made. The following outline summarizes comments, points of contact and requests for information:

A. USFWS –
1. Multi-million dollar issue
2. Integrated approach to problem is needed – Need to focus on the problems and options
    i. Physical
    ii. Chemical
    iii. Biological
3. Economic and ecological issues are important
    i. Impacts to species
    ii. Impacts to potential commerce
4. Legislation written into National Invasive Species Act to include feasibility studies on barriers outside of Chicago area was noted.
5. All pathways important beyond Mississippi River (i.e., bait, aquaculture, etc…)
6. Mike Hoff – Point of contact for USFWS
7. People not exposed to problem tend to ignore or reduce the significance
8. Some states feel that Asian carp are not a problem
9. Legal action may be a possibility over issues in future
10. Lacey Act was mentioned

   i. Gerry Jackson – three of the four Asian carp species being investigated for listing as "Injurious" species. Gerry to get names of people in D.C. area to talk to related to Lacey Act and EIS (economic)
11. National Management Control Plan for Asian carp being developed by end of year – Greg Conover is point of contact. Plan can be modified for regional application.
12. Risk Assessment for Asian carp being completed (USFWS Funded)
   i. Black Carp
   ii. Silver Carp – Cindy Kolar
   iii. Bighead – USGS in Gainesville
   iv. Mike Hoff inquired with USGS about Literature Review – Status pending
   v. Steve Bartell from project team will contact and inquire – Need to provide Steve with contact for Cindy Kolar in order to obtain draft copies of reports
13. Samples of carp – Dr. Becky Lasee – LaCrosse Fish Health Center Contact
14. Mike Oetker – Point of contact for issues – Asked to Consolidate information for the Region 3 office by Gerry Jackson
15. Commercial harvest may become an issue – some commercial fisherman now target Asian carp. Agencies do not want to manage for sustainable harvest
16. Asian carp could reverse the years of effort spent restoring native species
17. Bob Adair – Conduit to Region 3 monitoring in Great Lakes area
18. Greg Conover to provide FishPro a copy of St. Louis area business plan for carp protein commercial development.

B. USGS-
1. Studies ongoing
   i. Telemetry (movement distances)
   ii. Habitat Characterization (Missouri River)
   iii. Diet Study (stomach analysis)
   iv. Chemical Resistance – (e.g., Rotenone)
   v. Pheromone Research – Ed Little
   vi. Traditional capture
2. Distribution data available online. Contacts are Amy Benson/Pam Fuller USFWS Gainsville
   i. Database has some drawbacks or limitations – Reported versus confirmed
   ii. Efforts to improve database inputs are pending
3. Life cycle conditions needed
   i. Spawning conditions needed (e.g., floating time for eggs or larvae)
   ii. Bottlenecks in life cycle
4. Traditional capture techniques need to be modified for Asian carp – Net shy
5. Large numbers of fish being found on Missouri River by USGS staff
6. DO Sags – species may be more vulnerable than others – research needed
7. High risk to boaters

C. UMRCC
1. Capture data available through commercial fisherman – Ron Benjamin WI DNR incoming UMRCC Chair

D. NPS –
1. Lacey Act may be an integral part in the long-term management of Asian Carp

E. USACE
1. Marking and recapture studies on species has been done (non-Asian carp)
2. Lock and Dam locations provide some physical barrier (e.g., Lock and Dam 19 full barrier. Lock and Dam 15, 14,2 and 1 partial barriers)
3. USACE working with lock operators to modify gate management (i.e., leaving downstream gates closed between locking by boats)
4. Possible funding source for continued work – Section 206 money 65% Federal/35% non-federal
5. Conducting long-term (18 month) feasibility study that will draw upon the MN DNR funded
   short-term study (this MN DNR funded study)
   i. Same study goal –evaluate limiting northern advance of Asian carp species
6. Other Districts are aware of the problem
7. Point of contact for acoustical barrier work – Dr. John Nessler – Vicksburg office
8. Point of contact – Al Parsons Mississippi State University
9. Jan Hover – Swimming performance
10. Fish Passage Study – Interim Report for the Upper Mississippi River – Illinois Waterway Navigation Stud was introduced. Draft available online ftp://ftp.mvp.usace.army.mil/Fishpass

F. WI Sea Grant
1. Phil Moy – point of contact for Chicago Sanitary and Ship Canal Barrier projects
2. Work and data collected on the experimental barrier may aid this study
3. Study being funded to create audiograms of Asian carp by Fish Guidance Systems, LTD.

6. Following the overviews by each agency represented, the draft outline/table of contents developed by MN DNR with input from the representatives listed above was reviewed. During the review, specific areas outlined that were not addressed or identified previously during the meeting were discussed. Clarification for each area in question on the draft outline was provided to the project team when needed. Included with the clarification were discussions related to terminologies and their impacts on the risk assessment approach addressed by Steve Bartell. Risk assessment components to include framework for determining (1) rate of spread; (2) consequences of new invasion; (3) establishment of new population. Steve Bartell will only be providing framework of models needed to make these assessments. Draft framework from Steve is anticipated by February 16.

7. After the review of the draft outline, a short discussion about the literature search and data collection was initiated. Several points of contact and potential sources of data were highlighted during the meeting under reports from individual agencies. In addition to those sources, the project team has requested that all available literature and data pertaining to the subject be sent to FishPro. For the literature search and data that can be made available, the project team is

requesting that each individual rank the items in terms of relevance or significance to the three major objectives outlined by Jack Wingate. This ranking will assist the project team in sorting through large amounts of data and will ensure that the key references and data sets are reviewed by the March 1st deadline. Additionally, this document may serve as a clearinghouse for current data summaries of research topics, technology and literature searches that are occurring simultaneously in multiple Regions and States. The ranking of literature and data may benefit future project efforts and may facilitate implementation of actions plans.

8. A project coordination meeting with project team, MN DNR and USFWS was established and will take place January 23rd, 2004 at 1:30 p.m. CST via conference call. Information about the meeting will be provided to the necessary attendees. The next meeting date will be scheduled after this teleconference. Closing comments were made by members of the project team, Gerry Jackson and Jack Wingate before adjourning at 2:30 p.m.

Non-Verbatim Minutes by:

Matt Cochran, FishPro/Cochran & Wilken, Inc.

cc: All in attendance
Steve Bartell- Cadmus Group

Additional cc not in attendance at the meeting:

- Rob Maher- Illinois DNR
- Ray Norrgard- Minnesota DNR
- Jay Rendall- Minnesota DNR
- Scot Johnson- Minnesota DNR
- Kevin Stauffer- Minnesota DNR
- Steven DeLain- Minnesota DNR
- Kim Bogenschutz- Iowa DNR
- Dick Larson- Congressman Gill Gutneckt (Rochester)
- Terry Birkenstock- US Army Corps of Engineers - St. Paul District
- David Loss- U.S. Army Corps of Engineers
- Lon Meixner- St. Paul District
- Cindy Kolar- UMESC-USGS
- Colleen Tollefson- Minnesota Office of Tourism
- Ed Donahue- FishPro, a division of HDR

FISHPRO

MEETING SUMMARY

for

Conference call on Feasibility Study to Limit the Invasion of
Asian Carp in the Upper Mississippi River

FP/CWI No. 04004

A conference call for the feasibility study was held at 1:30 p.m. CST on January 23, 2004. The purpose of the call was to bring together the project team, MN DNR and USFWS representatives to discuss the progress and expectations of the study. Provided below is a brief outline of the topics covered. The following were in attendance:

Jack Wingate- MN DNR
Jay Rendall- MN DNR
Mike Oetker- USFWS
Matt Cochran –FishPro/Cochran & Wilken, Inc.
Gary Wilken- FishPro/Cochran & Wilken, Inc.
Peter Berrini- FishPro/Cochran & Wilken, Inc.

1. The meeting began with an overview of the Corps of Engineers study efforts related to the barrier feasibility study. For the Corps perspective on projects, an internal process must occur before any projects can be implemented. That comment was made after FishPro inquired about a feasibility study being prepared by the Corps that was similar in scope to the FishPro report scope. While similar in scope, the Corps report will build upon the FishPro report and is therefore not a duplicate effort. References to the Corps report effort are not needed in the FishPro report and should not be made. However, a general reference to future work that may be conducted is acceptable to mention in FishPro report.

2. Gary Wilken inquired about making recommendations on construction of alternatives. Jack Wingate commented that nothing on actual construction was needed in this report. Jack went on to outline the report expectations as the following:

- Provide possibilities of what might work to limit or slow the invasion
- List the pros and cons of alternatives
- Summarize feasibility of alternatives
    - Feasibility of Construction
    - Feasibility of Operation

In general, the report will be used to aid the decision making process by MN DNR.

3. Gary Wilken inquired about the Draft Corps of Engineers report entitled **Interim Report for the Upper Mississippi River-Illinois Waterway Navigation Study, Draft 4**. Specifically, questions about MN DNR involvement were asked. It was noted that MN DNR had minor involvement in the document but was not a major contributor. DNR felt the document and the information/data within the report could be used as base document for the feasibility study.

4. Jay Rendall made some comments about barriers and noted that a barrier at each lock and dam was not appropriate. Jay stressed the importance of regional distribution. Matt Cochran commented that the discussions with Dan Wilcox of the St. Paul District Corps indicated that a combination of barriers at some locations and fish passage at others may ultimately be an effective solution for limiting the northward advance of Asian carp while still providing selective regional connectivity of native species. Mike Oetker commented on the Corps report suggesting that the document will aid USFWS in selecting which passage project to move forward with.

5. The conversation shifted to the movement of invasive species. Jay Rendall commented that the timeline for projects to limit invasion is driven by funding but also driven by species movement. Some concern was raised about the required Corps of Engineers project procedures versus the movement of the species and the timeline available to construct and implement alternatives to limit the invasion.

6. A brief discussion was held about the listing of Asian carp as injurious species. Mike Oetker commented that Congress ultimately asked for the listings which prompted the authorization of the USGS led risk assessments currently (Jan. 2004) being completed.

7. Additional questions about species tracking and distribution relative to critical habitat were asked by FishPro. It was noted that Conrad Smith is the DNR point of contact for the tracking of species and habitat, but is currently (Jan. 2004) on seasonal layoff.

8. FishPro indicated that a revised Table of Contents for the report was developed using the original DNR generated outline of topics. Jack Wingate asked for the new TOC to be cross-referenced with the original DNR outline to see where the critical topics would be discussed. FishPro will submit to DNR and USFWS.

9. Jay Rendall made an additional note that Burk O'Neil at the University of Wisconsin would be a good contact about electrofishing technology. His contact information is: (608) 263-2921

10. Before the conference call ended, February 5th at 1:30 p.m. was set as the next coordination call regarding the study.

11. The call was ended at approximately 2:20 p.m. CST

Non-Verbatim Minutes by:

Matt Cochran, FishPro/Cochran & Wilken, Inc.

cc: All in attendance
David Johnson – HDR
Jim Bakken – Ayres and Associates
Steve Bartell – Cadmus Group

FISHPRO

MEETING SUMMARY

for

Conference call on Feasibility Study to Limit the Invasion of
Asian Carp in the Upper Mississippi River

FP/CWI No. 04004

A conference call for the feasibility study was held at 1:30 p.m. CST on February 5, 2004. The purpose of the call was to bring together the project team, MN DNR and USFWS representatives to discuss progress and outstanding questions related to the report. Provided below is a brief outline of the topics covered. The following were in attendance:

Jake Wingate- MN DNR
Jay Rendall- MN DNR
Mike Oetker- USFWS

Matt Cochran –FishPro/Cochran & Wilken, Inc.
Gary Wilken- FishPro/Cochran & Wilken, Inc.
Peter Berrini- FishPro/Cochran & Wilken, Inc.

1. The meeting began with FishPro answering a series of questions that were asked by MN DNR and USFWS in response to the updated Table of Contents submitted for review. Matt Cochran addressed the questions as follows:

DNR Questions from e-mail dated 1-28-04

a. There are a couple of areas where we do have some questions. First, the new IV. (ANS) mentions an overview of Existing ANS Program. Is this intended to summarize the USFWS or Minnesota ANS program? I am unclear about what this adds to the report and would suggest that it is not needed. However, I am open to a discussion as to why one or the other needs to be included.

FishPro response – While not wanting to conduct more work than what was necessary, FishPro felt an overview of ANS topics would be beneficial to the reader. The topic was discussed and it was determined that ANS issues would be moved to Section III in the TOC and a short paragraph related to existing ANS programs (MN DNR and USFWS) could be included but an official overview of the programs will not be provided.

b. We are unclear what is intended in Part V. (Ecological Risk Assessment Framework) of the suggested Table of Contents. What will and will not be included in this section. Will the areas listed under "Potential Environmental Effects of Nonindigenous Species" in the State's original outline all be covered or is it anticipated that certain pieces are going to be dropped. Specifically, it is unclear if all the potentially impacted areas are going to be addressed such as the effects on ecosystems, recreation, and economics. These areas are critical to us as we all discussed earlier.

FishPro response – Yes, those areas will be covered in the framework that is being prepared. The USGS protocol for risk assessment is being reviewed and utilized.

c. In part VII. of your revised Table of Contents, we are unclear if there will be a longer, clear statement of what is currently appearing in the

Executive Summary as "Findings and Recommendations". In part VII, recommendations are listed in the title, but not as a specific area under the title. We would like to see a recommendations section added under this title.

FishPro response – Yes. Section VII is intended to provide the majority of the analysis, discussions and recommendations while Section II is simply an Executive Summary of the Recommendations.

d. USFWS Comments - In addition to the concerns brought up in Jack's email below, I would like to add one on Section V. I am unclear why we are using a chemical assessment framework developed by EPA for a biological assessment. A framework for developing risk assessments for non-indigenous species already exists and is used as the standard by USGS when we have contracted risk assessment reports from them. General guidelines were issued in 1996 for risk assessments by a group formed under the ANS Task Force (http://anstaskforce.gov/gennasrev.htm). Maybe a call or quick email to explain the reasoning will help me understand the logic.

FishPro response – The comments made about the chemical assessment were just made as an example or point of reference. The actual framework being applied will utilize the USGS protocol and the specific reference outline by the link in your question above. Additional references to the black carp assessment will be made if the document can be made available. To date (Feb 5,2004), we have not received a copy as requested from Kari Duncan.

2. A discussion about the potential locations was held. The importance of L&D 19 was made but it was also noted that the bighead and silver carp are now found above L&D 19. FishPro also mentioned L&D 14 and L&D 15 as potential barrier locations outside of MN. In general, the L&D locations are being considered due to their existing presence as a partial barrier. FishPro made reference to the Corps fish passage report and mentioned that teleconferences and e-mail correspondence have been conducted with Dan Wilcox as a point of contact.

3. FishPro also inquired about the locations relative to the comfort level of DNR. With the obvious answer of no more northern advance of the species, it was ultimately determined that the MN DNR will consider the ability to limit the northward advances a success if the species are kept below L&D 4. Above that location, exposure to other tributaries such as the Minnesota River and the St. Croix River are possible. Species above L&D 2 will surely reach both the St. Croix and Minnesota Rivers with the potential to expand beyond the borders of MN.

4. A short discussion about distribution was held. FishPro indicated that they had been in contact with USGS regarding movement of the species. It was also noted that there is a diverse jurisdiction on Asian carp that includes many States as well as the USFWS.

5. The timeline and distribution of the report was discussed and the following points were established.

February 23, 2004 – First Draft submitted by project team
February 27, 2004 – Comments from reviewers due to FishPro
March 3, 2004 – Final Draft due to MN DNR for use in Legislative meeting
March 15, 2004 – Final Report due

6. Jack Wingate and Mike Oetker will confirm with FishPro the list of people that are to receive and review the draft reports. A list will be provided to FishPro via e-mail.

7. The call was ended at approximately 2:10 p.m. CST

Non-Verbatim Minutes by:

Matt Cochran, FishPro/Cochran & Wilken, Inc.

cc: All in attendance
David Johnson – HDR
Jim Bakken – Ayres and Associates
Steve Bartell – Cadmus Group

MEETING SUMMARY

for

Conference call on Feasibility Study to Limit the Invasion of Asian Carp in the Upper Mississippi River

FP/CWI No. 04004

A conference call to discuss Asian carp was held at 2:30 p.m. CST on February 6, 2004. The purpose of the call was to discuss aspects of the species and potential research progress with USGS. Provided below is a brief outline of the topics covered during the call. The following were in attendance:

Duane Chapman- USGS
Ed Little- USGS
Matt Cochran –FishPro/Cochran & Wilken, Inc.
Gary Wilken- FishPro/Cochran & Wilken, Inc.
Peter Berrini- FishPro/Cochran & Wilken, Inc.

1. The call began with a series of questions for Duane Chapman regarding the behavior of the Asian carp species. Duane provide the following comments:

- Life History and General Ecology
  - Very little is confirmed to date (Feb 2004)
  - The majority of references to silver and bighead spawning is by word of mouth
  - Bighead life history is similar to grass carp in the early life stages
  - Bighead and silver carp differ in spawning times and flow timing. Silver carp appear to spawn and are active over a longer time range (i.e., more months out of the year)
  - Sally Schrank Kansas Cooperative Fish and Wildlife Research Unit– point of contact about life history
  - 1.0 to 2.5 ^{o}C may be the lower limit of feeding
  - USGS has seen both silver and bighead with full guts at 2.5 ^{o}C and above.
  - Bighead have been seen skimming surface of water eating organic type scum on water surface below dams. Duane adds that too a lesser extent silvers too but there is a great deal of uncertainty about silvers.
  - Silvers are not obligate planktivores or filter feeders
  - Duane has observed both bigheads and silvers eat in aquaria and has witnessed particles too large to be consumed being sucked in and blown out and
  - High inorganic turbidity appears to discourage feeding in both species
  - Gut observations revel nothing large enough to be identified

- Distribution and Movement
  - Movement triggered by rise in water levels
  - Spring flows increase, species takes off up the river.

- USGS has tracked silver carp swimming at approximately 1.5 miles per hour against an approximate 4 to 5 knot current.
- USGS has tracked a single silver carp species over 163 miles during the span of one year. The 163 miles included movement back and forth within a major stretch of the Missouri River. The 163 miles does not include any of the probable movements in and out of tributaries during that same time span. Actual total miles traveled would be over 200 miles.
- Bighead and silvers appear to swim away from approaching boats more than native species
- Silver and bighead carp are very adept at avoiding capture techniques. Modified capture techniques are needed to accurately sample species.
- Duane has enhanced the data collection reporting on Asian carp and suggests contacting Amy Benson to get an updated distribution list.
- Bigheads do not move as much as silver but appear to be the first (out of the two) species that will be detected in a new area.
- USGS reported seeing a bighead carp in Red Cedar River in Wisconsin.

2. Duane also provided additional comments on silver and bigheads including:
   - Grass carp do not appear to be establishing sustainable populations in Upper Mississippi, why?
   - Bighead normally are detected before silver carp, why?
   - European countries have had Asian carp present for long periods of time. Many commercial fishing operations on European rivers report that Asian carp represent as much as 90% of the harvested biomass.
   - Some countries see Asian carp as a positive impact
   - Daughterless Carp technology - a genetic alteration. Duane commented that researchers are looking at the possibility of gene alterations but he specifically does not hae experience or opinions about the subject. Since the conference call, FishPro has begun researching articles related to daughterless carp technology. The gene alterations inhibit the key enzyme necessary for the species to develop into a female. The technique has been used with common carp. Duane commented that some [other researchers/ecologists] have expressed concern for the potential of the gene alteration to spread and eventually impact Asian carp species overseas. Human populations overseas are dependent upon the biomass of Asian carp as a food source. Additionally, some [researchers/ecologists] express concern over the alteration "jumping" species and causing alterations in other species.

3. The USGS research on pheromones was addressed by Ed Little. Ed confirmed that the attractant research is ongoing and a few years (at best) from providing definitive results. The alarm pheromone research is slightly farther along. Initial hints of using pheromones indicate that sex pheromones can be effective at very small doses (parts per trillion) but that either pheromone approach will have high manpower costs related to management of deterred fish. Both pheromones can be administered with a drip dose type of application. Costs associated with the use of pheromones would be difficult to estimate at this point in the research.

4. Ed commented on the relationship to pheromone work on other species. FishPro inquired about the round goby work that is using pheromones as attractants to bedding locations for capture. While proving somewhat successful for the round goby, the spawning behavior difference between the goby and the Asian carp would not make a direct correlation very likely. Ed did comment that work with sea lampreys might more closely resemble the behavioral aspects of the Asian carp.

5. The timeline and distribution of the report was shared with Ed and Duane
   February 23, 2004 – First Draft submitted by project team
   February 27, 2004 – Comments from reviewers due to FishPro
   March 3, 2004 – Final Draft due to MN DNR for use in Legislative meeting
   March 15, 2004 – Final Report due

6. Matt Cochran asked Duane Chapman to review life history summaries that will be summarized by FishPro. Summaries will be submitted on or before 2-16-04 to USGS for review

7. The call was ended at approximately 3:40 p.m. CST

Non-Verbatim Minutes by:

Matt Cochran, FishPro/Cochran & Wilken, Inc.

cc: All in attendance
   David Johnson – HDR
   Jim Bakken – Ayres and Associates
   Steve Bartell – Cadmus Group

MEETING SUMMARY

for

Conference Call on Feasibility Study to Limit the Invasion of
Asian Carp in the Upper Mississippi River

FP/CWI No. 04004

A conference call for the feasibility study was held at 11:00 a.m. CST on February 27, 2004. The purpose of the call was to review comments regarding the first draft of the Feasibility Study to Limit the Invasion of Asian Carp into the Upper Mississippi River Basin. The following were in attendance:

Jack Wingate- MN DNR
Jay Rendall- MN DNR
Mike Oetker- USFWS
Lee Pfannmuller- MN DNR
Matt Cochran –FishPro/Cochran & Wilken, Inc.
Gary Wilken- FishPro/Cochran & Wilken, Inc.

1. The following briefly outlines the points made during the call.
   a. Maps – Difficult to read in black and white. Alright in color. Many people will be receiving this as a PDF making B&W printing critical. Adjustments of maps are needed
   b. More text is needed regarding education, regulation, etc. Outside of physical and behavioral barriers, the point needs to be made that regulation and enforcement, and the education of the public is important. Jack also gave an example of regulation not going far enough. In MN, it is illegal to import Asian carp. In WI, it is not illegal. Coordination is needed. Report should highlight that.
   c. Overview of current research topics is not in TOC
   d. Physical barrier discussion in text is needed in addition to what is presented in Section V table.
   e. USFWS Asian Carp Management Control Plan was mentioned. The report is in the very early stages but does provide some ideas on multi-jurisdictional issues related to management. If these fish are not listed as injurious, USFWS can only enforce the laws pertaining to each state.
   f. Lee added the report should bring together the issues related to management, control and prevention. FishPro commented that many areas related to tying the ends together had been done since submittal of the first draft. Should also explore other pathways (i.e., education and regulation).
   g. Jack commented that the harvest as a management tool should also consider the possibility of recruitment. Once the larger fish are gone, will juvenile fish fill the niche. Which scenario is harder on the ecosystem type of review. FishPro added that the harvest ideas are designed to reduce the "stacking of fish" below dam and lock areas as a result of a barrier or deterrent technology.

h. Locations of barriers – Missing from the discussion is an overview of tributaries. Some tributary areas would be ideal locations for other types of barriers. FishPro will provide an overview of possible technologies at major tributaries but will not make specific recommendations as to which one due to multi-jurisdictional issues and possible regional connectivity issues. Feasibility of alternatives at tributaries will be used by the states as a tool to determine location.
i. Jay added that the impacts to wildlife needs to be expanded. As an example, if plankton levels change and the ecology of the river changes, there are potential impacts to wildlife and higher food chain species that rely on the river system. These need to be briefly highlighted.
j. Effects on commercial and recreations aspects (and/or risk to economics) has not been fully realized in the report. Emphasis on the potential impacts is needed as part of the final document. This would include impacts to commercial fishing as well as recreational usage.
k. Jay also commented that the extent of habitat destruction needs to be explained. He used the impact of grass carp as an example.
l. ANS issues – ANS regional panels and their current high priority issues need to be addressed. Jay and Mike Hoff (USFWS) will provide a brief summary to include.
m. Mike Oetker commented on the operation of the dam gates. As the gates open in the spring during higher water events, the species can pass. FishPro commented that the alternatives being explored took this operational issue into consideration.
n. Mike also talked about management issues and commented on the targeting of other life stages (i.e., larval fish in search of shallow water habitat and seasonal wetlands). Targeting fish in those areas may be a possibility to consider.
o. A general comment was made about the date of information used in the species distribution summaries. The dates will be confirmed but FishPro believes the most current data available was given.

2. The overall project timeline was discussed. The following explain the expectations:
    a. Final Draft due in PDF form on March 3 (afternoon)
    b. Wide distribution of this version will be made by DNR on March 4th
    c. Comments are due back to FishPro by Wednesday, March 10th
    d. Final report due March 15th
        i. March 15th – PDF version
        ii. March 16th- Latest date for printed version in MN DNR hands
3. A tentative conference call was set for Friday, March 12 at 11:00 a.m. FishPro will determine the necessity of the meeting after reviewing the comments, but will notify MN DNR and USFWS by the 11th about the meeting.
4. Written comments on the first draft will be e-mail to FishPro
5. The call was ended at approximately 11:50 a.m. CST

Non-Verbatim Minutes by:

Matt Cochran, FishPro/Cochran & Wilken, Inc.
cc: All in attendance
David Johnson – HDR
Jim Bakken – Ayres and Associates
Steve Bartell – Cadmus Group

FISHPRO

MEETING SUMMARY

for

Conference Call on Feasibility Study to Limit the Invasion of
Asian Carp in the Upper Mississippi River

FP/CWI No. 04004

A short conference call was held at 8:45 a.m. CST on March 8, 2004 with Jack Wingate to discuss a few aspects of the report. The following were in attendance:

Jack Wingate- MN DNR
Peter Berrini- FishPro/Cochran & Wilken, Inc.
Matt Cochran –FishPro/Cochran & Wilken, Inc.

1. The following text briefly outlines the points made during the call.
   a. Page I-1, add Wisconsin to the funding source. They assisted MN DNR in funding the study.
   b. Grass Carp – several areas of the report fail to reference the grass carp in addition to the other species. In particular, Section IV lists the other three species several times but not grass carp. Jack suggests making a reference to…"Asian carp-includes: black carp, bighead carp, silver carp and grass carp". The report could then just mention "Asian carp" each time the species were mentioned rather than listing out each species.
   c. Page IV-8, under 5. Economic impact potential-Jack feels this is a good location to expand on the links to hunting and wildlife impacts.
   d. Page VI-9, first paragraph, last sentence-Appendix ## and figure were not included.
   e. Page VI-9-11, more coverage of wildlife is needed. Impacts to waterfowl are not mentioned and would be big. FishPro agrees and will add.
   f. Section IV – Provides outline but does not say enough to satisfy the goal of MN DNR. While speculative documentation exists on each species, some references to the perceived risks based on available information could be made. The impacts listed in Section VI (Pages VI-9 to VI-11) are a good start. These impact discussions could be moved to Section IV to strengthen the discussion on impacts and risk. Comments are good start but are a bit generic. Could be enhanced based on information that is available (i.e., pers. comm. in addition to published).
   g. A timeframe of arrival or estimated time of arrival is not included. FishPro will estimate based on information available.

2. General comments from entire reviewing audience- While the official comments are not due until March 10, Jack wanted to give the team a chance to get moving on some enhancements to the areas outlined above. FishPro agrees to visit each area and look at enhancing the discussions. More comments will be provided by March 10.

3. The call was ended at approximately 9:05 a.m. CST

Non-Verbatim Minutes by:

Matt Cochran, FishPro/Cochran & Wilken, Inc.

cc: Jack Wingate
Peter Berrini
Gary Wilken
Steve Bartell

MEETING SUMMARIES LIST

The following list additional meetings or conference calls were held during the short duration of the project:

1. A conference call to discuss the USFWS authorized risk assessments on bighead and silver carp was held January 22, 2004. The purpose of the call was to discuss aspects of the species and potential report progress for the developing bighead and silver carp risk assessments. Provided below is a brief outline of the topics covered during the call. The following were in attendance:

Kari Duncan- USFWS
Matt Cochran –FishPro/Cochran & Wilken, Inc.
Peter Berrini- FishPro/Cochran & Wilken, Inc.
Steve Bartell – Cadmus Group

2. A conference call to discuss the COE Draft Report for fish passage carp was held February 5, 2004. The purpose of the call was to discuss aspects of the species and potential barrier locations. General aspects of the COE report were also discussed. Provided below is a brief outline of the topics covered during the call. The following were in attendance:

Dan Wilcox- COE
Matt Cochran –FishPro/Cochran & Wilken, Inc.
Peter Berrini- FishPro/Cochran & Wilken, Inc.
Gary Wilken- FishPro/Cochran & Wilken, Inc

3. A conference call to discuss the Smith-Root reports prepared for the MN DNR held on February 10, 2004. The purpose of the call was to discuss aspects of the species and potential barrier locations. General aspects of the electrical barriers were also discussed. Provided below is a brief outline of the topics covered during the call. The following were in attendance:

Jeff Smith- Smith-Root
Matt Cochran –FishPro/Cochran & Wilken, Inc.
Gary Wilken- FishPro/Cochran & Wilken, Inc

4. A conference call to discuss the planned National Carp Management Control Plan held on February 17, 2004. The purpose of the call was to discuss aspects related to the development of the control plan by the USFWS. Provided below is a brief outline of the topics covered during the call. The following were in attendance:

Greg Conover- USFWS, Carterville FRO
Matt Cochran –FishPro/Cochran & Wilken, Inc.
Peter Berrini- FishPro/Cochran & Wilken, Inc

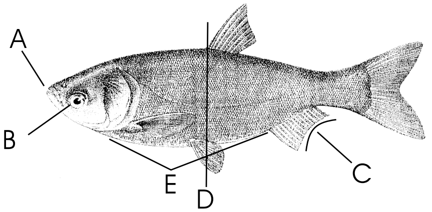
Feasibility Study

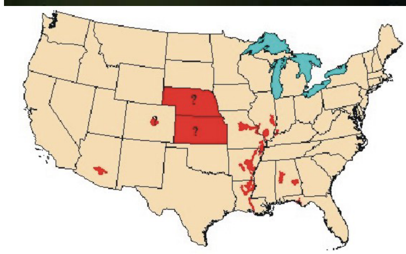
To Limit the Invasion of Asian Carp into the Upper Mississippi River Basin

VII-E. Key to Asian Carp Identification

FISHPRO

• lateral line scales approximately 95-103
• fins of small specimens without spines
• pectoral fin with 15-18 rays and stiff, hard spine having a finely serrated posterior (rear) margin
• dorsal fin with moderately stiff, nonserrate spinelike ray at origin
• anal fin (C) falcate (i.e. hooked) with 12-13 rays and slightly stiffened, nonserrate spine at origin



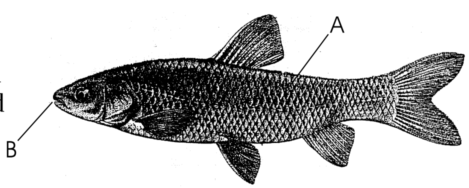


Silver carp (Hypophthalmichthys molitrix)
Drainages with introductions

• dorsal fin with 8 rays and origin of fin (D) behind pelvic insertion
• a smooth ventral keel (E) extending from base of anal fin to isthmus at the base of the gills
• gill rakers extremely numerous and fused or covered with a netlike or spongelike porous matrix
• pharyngeal teeth 4-4, moderately long and bluntly rounded
• intestine very long with many loops, its length 3-6 times longer than total fish length

Black carp

• thick, elongate body with broad, blunt head
• golden/dark grey/brown color with scales on back and sides showing a prominently dark-edged, giving a characteristic cross-hatched effect (A)
• subterminal mouth (B) with thin unspecialized lips



• dorsal fin short and pointed with 7-8 rays and situated over the pelvic fins
• anal fin closer to caudal fin than in native minnow (i.e. distance from front of anal fin base to base of caudal fin going more than 2.5 times into the distance from anal fin base forward to tip of snout)
• throat teeth fused (See Figure 2-II), molariform (i.e. knobs looking similar to human molars)

Black carp (Mylopharyngodon piceus)
Drainages with introductions

Information Sources:

Etnier, D.A. and W.C. Starne. 1993. The fishes of Tennessee. University of Tennessee Press, Knoxville. 681 pp.
Pflieger, W.L. 1975. The fishes of Missouri. Missouri Dept. of Conservation, Jefferson City. 343 pp.
Robison, H.W. and T.M. Buchanan. 1988. Fishes of Arkansas. University of Arkansas Press. Fayetteville. 536 pp.
Smith, P.W. 1979. The fishes of Illinois. University of Illinois Press. Urbana. 314 pp.
USGS Online. Nonindigenous aquatic species. http://nas.er.usgs.gov/fishes/accounts/

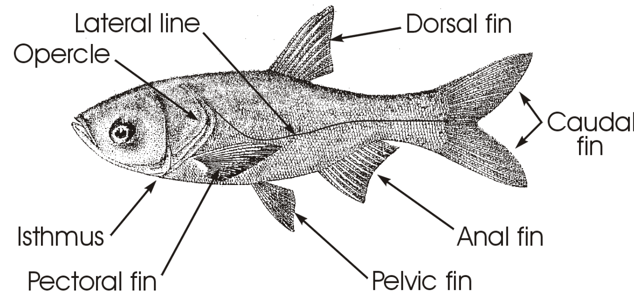
Natural Resource Agency Contacts:

U.S. Fish and Wildlife Service
La Crosse Fishery Resource Office
555 Lester Avenue
Onalaska, Wisconsin 54650
(608) 783-8434

Revised - 9 January 2002

U.S. Fish & Wildlife Service

Asian Carp



Key To Identification

Asian carp are large 39-40 in. (40-50 lb.) fish introduced into the U.S. by fish farmers in Southern states in the 1960's and 70's to control vegetation and algae blooms. Three of these species, the grass carp (***Ctenopharyngodon idella***), bighead carp (***Hypophthalmichthys nobilis***), and silver carp (***Hypophthalmichthys molitrix***) have been released or have escaped to the wild and are reproducing in many rivers and streams of the Mississippi River Basin. As they continue to expand their range, and show up in commercial and sport fish catches, a need has arisen to develop a simple key to assist fishers and resource managers in making quick and accurate field identifications.

Five species are included in this key. In addition to the grass, bighead and silver carps; the common carp (***Cyprinus carpio***) and the black carp (***Mylopharyngodon piceus***) have also been included. The black carp remains in captivity in hatcheries, fish culture facilities, and fish farm ponds, primarily in Southeastern states. But because of its similarity in appearance to the grass carp, and the possibility of its escape from captivity, resource managers and fishers are urged to be watchful for it. The key to Asian carp identification which follows assumes that the reader can readily distinquish the common carp from other fish species:

1. Dorsal fin rays 13 or more; dorsal and anal fins with a strongly serrated (barbed) anterior (front) spine..Common carp

Dorsal fin rays 9 or fewer; dorsal and anal fins lacking strongly serrated spines....................................2

2. Distance from origin of anal fin to caudal fin base equal to distance from anal fin origin to pelvic fin insertion (Figure 1-I), scales large, carp-like................*3*

Distance from origin of anal fin to caudal fin base 1.5 to 2 times distance from anal fin origin to pelvic fin insertion (Figure 1-II), scales small, trout-like.............4

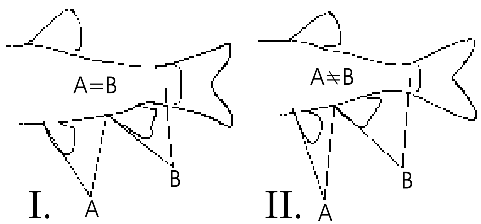


Figure 1. Relative anal fin positions of Asian carps.

3. Pharyngeal teeth 2,5-4,2 (located behind the mouth in the throat) with prominent parallel grooves (Figure 2-I.............................Grass carp

Pharyngeal teeth molariform (Figure 2-II).............Black carp

4. Ventral keel on abdomen (belly) extends forward only to the base of pelvic fins; gill rakers long and slender; body with scattered dark blotches..... ....bighead carp

Ventral keel on abdomen extends forward past pelvic fin base to isthmus (i.e. base of gills): gill rakers forming a compact mass covered by a net-like matrix; body lacking scattered dark blotches..........silver carp

I. grass carp teeth

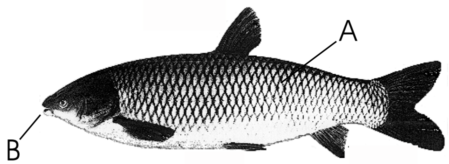
II. molariform teeth

Figure 2. Anterior view of pharyangeal arches showing teeth configurations of grass carp and black carp-like (i.e. molariform) teeth.

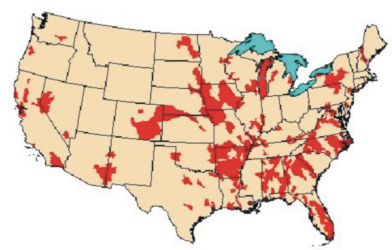
Further descriptive details by species follow:

Grass carp

- thick, elongate body with broad, blunt head
- silver/pale grey color with scales on back and sides showing a prominently dark-edge, giving a characteristic cross-hatched effect (A)
- subterminal mouth (B) with thin unspecialized lips
- dorsal fin short and pointed with 7-8 rays and situated over the pelvic fins
- anal fin closer to caudal fin than in native minnows (i.e. distance from front of anal fin base to base of caudal fin going more than 2.5 times into the distance from anal fin base forward to tip of snout)
- pharyngeal throat teeth 2,4-5-4,2 (those in principal row with deep parallel grooves (See Figure 2-I)



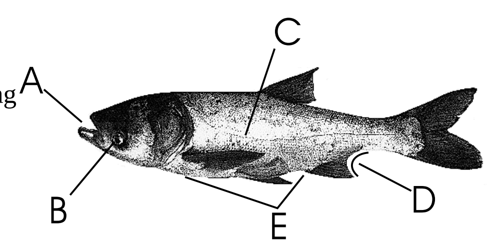
Juvenile grass carp



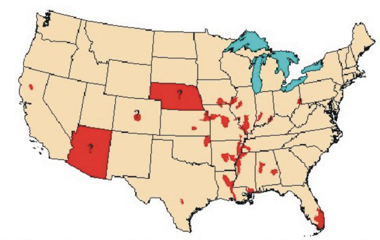
Grass carp (Ctenopharyngodon idella)
Drainages with introductions

Bighead carp

- deep bodied, somewhat laterally compressed body with back and upper sides dark gray grading to off-white on lower sides and belly, many dark to black irregularly shaped blotches scattered over entire body
- young silver in color, not developing blotches until about 8 weeks of age (see juvenile photo)
- large, scaleless head and opercle
- mouth large and terminal (A) without teeth in jaws, and with lower jaw projecting beyond upper jaw
- eyes situated far forward (B) along midline of body and projecting downward
- scales very tiny, cycloid, resembling those of trout
- lateral line complete and strongly decurved anteriorly (C) with 85-100 scales
- scale rows above lateral line 26-28
- fins of small specimens without spines
- pectoral fins with 16-21 rays and large individuals with sharp, nonserrate ridges along several of the anterior rays
- moderately stiff nonserrated spine at dorsal fin origin
- anal fin falcate (i.e. hooked) (D) with 13-14 soft rays
- smooth ventral keel (E) extending from vent forward to pelvic fin base
- gill rakers long, comblike (length 40 times width) and close-set, not fused into a porous, net-like plate
- pharyngeal teeth 4-4, moderately long and bluntly rounded
- intestine long with many loops, its length 3-5 times longer than the total fish length



Juvenile bighead carp



Bighead carp (Hypophthalmichthys nobilis)
Drainages with introductions

Silver carp

- deep-bodied, laterally compressed body, very silvery in color in young with back and upper sides changing to olivaceous (greenish), grading to silver below the lateral line in adults
- scales very tiny and cycloid, resembling those of trout
- head and opercle scaleless with relatively large, upturned mouth (A) without teeth in jaws
- eyes situated far forward (B) along the midline of the body and projecting somewhat downward

Feasibility Study

To Limit the Invasion of Asian Carp into the Upper Mississippi River Basin

VII-F. Commercial Fish Data

FISHPRO

Summary of Commercial Fishing Harvest Data for Bighead and Silver Carp (1997-2001)

Pool #	2001	2000	1999	1998	1997
3	0	0	0	0	0
4	0	0	0	0	0
4A	0	0	0	0	0
5	0	0	0	0	0
5A	0	0	0	0	0
6	0	0	0	0	0
7	0	0	0	0	0
8	0	0	0	0	0
9	0	0	0	0	0
10	0	0	0	0	0
11	0	0	0	0	0
12	0	0	0	0	0
13	0	0	0	0	0
14	0	15	0	0	0
15	105	0	30	12	0
16	20	0	0	0	0
17	177	40	20	0	0
18	800	661	0	8,000	0
19	2,757	70	1,900	700	1,600
20	4,177	10,200	6,200	4,700	8,510
21	9,010	123	1,300	0	100
22	1,120	60	599	1,000	1,600
24	1,985	1,682	5,275	7,215	7,800
25	23,014	231	8,100	17,610	15,200
26	6,798	70,804	5,390	12,129	9,918
26B	35,400	4,915	-	2,966	2,560
26C	4,750	100	14,965	650	1,835
27				0	3,200
Open River	77,290	30,142	52,764	22,248	25,128

Note - Summary data includes both silver and bighead carp only

Summary of Commercial Fishing Harvest Data for Bighead and Silver Carp (1997-2001)

	2001	2000	1999	1998	1997
3	0	0	0	0	0
4	0	0	0	0	0
4A	0	0	0	0	0
5	0	0	0	0	0
5A	0	0	0	0	0
6	0	0	0	0	0
7	0	0	18	0	0
8	0	0	0	15	0
9	13	2,794	0	0	0
10	10	29	10	1,300	21
11	255	0	0	8	47
12	1,047	35	161	105	0
13	641	625	864	1,010	8,817
14	236	71	163	0	0
15	186	650	355	100	100
16	381	1,722	100	0	570
17	902	215	30	590	121
18	1,183	1,980	569	8,067	608
19	2,006	1,440	1,592	500	1,795
20	3,848	4,523	3,430	3,070	3,010
21	550	398	355	4,140	1,022
22	600	439	126	1,200	2,535
24	1,070	1,397	2,642	5,701	6,252
25	1,547	1,361	5,400	7,965	2,185
26	8,810	16,110	5,840	8,289	12,549
26B	11,628	4,067		2,084	2,317
26C	1,700	500	6,375	2,389	446
27				1,400	1,200
Open River	36,561	14,948	24,604	13,621	14,375

Note - Summary data includes grass carp only

Feasibility Study

To Limit the Invasion of Asian Carp into the Upper Mississippi River Basin

VII-G. List of Abbreviations Used

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ABBREVIATIONS

ABS	Areas of Biodiversity Significance
ANS	Aquatic Nuisance Species
AZUS	Aquatic Zoogeographical Units
EDUS	Ecological Drainage Units
GIS	Geographic Information System
HVC	Hydrologic Unit Codes
INHS	Illinois National Historic Survey
LG	Lagrange River
LMR	Lower Mississippi River
LTRMP	Long Term Resource Monitoring Program
MICRA	Mississippi Interstate Cooperative Resources Association
NIS	Nonindigenous Species
OR	Open River
T&E	Threatened and Endangered
UMR	Upper Mississippi River
UMRB	Upper Mississippi River Basin
UMRCC	Upper Mississippi River Conservation Committee
UMRS	Upper Mississippi River System
USCOE	United States Corp of Engineers
USEPA	U.S. Environmental Protection Agency
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey

Feasibility Study

To Limit the Invasion of Asian Carp into the Upper Mississippi River Basin

VII-H. Original MN DNR Outline

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FEASIBILITY STUDY TO LIMIT THE INVASION OF ASIAN CARP INTO THE UPPER MISSISSIPPI RIVER BASIN

SUMMARY

- Listing of alternative measures
  - Description of and brief summary of pluses and minuses
  - Ranking of options
- Areas of potential controversy
- Unresolved issues

INTRODUCTION

- Study purpose and scope
- Background for doing the study
- Prior studies

OPTIONS TO PREVENT SPREAD INCLUDING LIKELIHOOD OF PREVENTION

- Alternative measures to prevent/slow invaders
  - No action
  - Electrical barriers across one or more river channels
  - Electrical barriers below locks
  - Bubble/acoustical barriers across one or more river channels
  - Bubble/acoustical barriers below locks
  - Lethal lock chambers
    - Thermal treatment
    - Toxins
    - Other technologies
  - Intensive fishing
  - Other deterrent technologies
  - Habitat enhancement for healthier native fish populations
  - Public education
  - Regulations to limit introduction, transport
- Evaluation of potential impacts of alternative measures
  - Effectiveness
  - Efficiency
  - Acceptability
  - Biological / Ecological
    - Impacts on fisheries
    - Impacts on wildlife
    - Impacts on mussels
    - Impacts on aquatic plants
    - Impacts on aquatic insects
  - Recreational
    - Impacts on angling and hunting
    - Impacts on boating and related water sports
    - Impacts on other river recreation
  - Commercial
    - Impacts on commercial fishing
    - Impacts on businesses related to water recreation
  - Alternative plan comparisons
  - Potential placement and practicality of alternative plans
  - Technology availability

POTENTIAL ENVIRONMENTAL EFFECTS OF NONINDIGENOUS SPECIES

Projection of risk if the Asian carp were to become established
- Present distribution of Asian carp in the Upper Mississippi River (UMR)
- Present distribution of other non-indigenous fish species poised to invade the UMR
- Estimated future rates and areas of invasion by species
- Effects on river ecosystem (biological/ecological)
  - Effects on native fish species and communities
  - Effects on mussels
  - Effects on aquatic plants
  - Effects on aquatic insects
  - Effects on trophic structure
  - Effects on wildlife populations
- Effects on river recreation
  - Effects on sport fisheries
  - Effects on hunting
  - Effects on boating and water related sports
  - Effects on other river related recreation
- Economic effects
  - Effects on commercial fisheries
  - Effects on businesses related to water recreation

Effects of alternative plans
- Potential construction impacts
- Projected effects of operation and maintenance
- Projected effects on future rates and areas of invasion by non-indigenous species
- Projected avoided adverse ecological effects
- Projected avoided adverse effects on recreation
- Projected avoided adverse economic effects
- Projected costs
  - Installation
  - Operation

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Recommendations
- Ranking of the options and effects of options

REFERENCES

Literature Cited

Acronyms/Abbreviations

Glossary

Feasibility Study

To Limit the Invasion of Asian Carp into the Upper Mississippi River Basin

VII-I. List of Significant Stream Order Tributaries of the UMR

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Appendix VII-I. List of Significant Stream Order Tributaries of the UMR

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
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 Cntrl (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	n/a	21	none	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
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

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					
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
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

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
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	LaGrange	8	7,452,199	220.0	IL
26	Piasa Creek	n/a	32.5	none	4	30,978	209.2	IL
Pool	**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
LaGrange	Mackinaw River	n/a	199.1	none	4	55,016	147.9	IL
LaGrange	Quiver Creek	n/a	54.7	none	4	55,148	128.6	IL
LaGrange	Spoon River	51.2	202.3	Bernadotte	6	483,174	120.5	IL
LaGrange	Sangamon River	71.5	402.3	Petersburg	6	1,380,235	88.9	IL

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					
LaGrange	Sugar Creek	n/a	122.6	none	4	42,257	94.4	IL
LaGrange	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

[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 he 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 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.

Source: Wilcox et al., 2004