



Mississippi River Between the Missouri River
and Minneapolis, 9-Foot Channel Project -
Measures for Managing Zebra Mussels
Reconnaissance Report

August 2003

Table of Contents

<u>Item</u>	<u>Page</u>
1.0 STUDY BACKGROUND AND AUTHORITY	1
2.0 STUDY PURPOSE	2
3.0 STUDY AREA	2
4.0 PLANNING PROCESS	3
5.0 PRIOR STUDIES, REPORTS AND EXISTING WATER PROJECTS	3
6.0 PROBLEMS AND NEEDS	4
6.1 Higgins' Eye and the Effects of Zebra Mussels	4
6.2 Introduction and Spread of Zebra Mussels in UMRS	5
7.0 ALTERNATIVES CONSIDERED IN RECONNAISSANCE STUDY	7
7.1 No Action	7
7.2 Managing Transport/Dispersal of Zebra Mussels in the UMRS	10
7.2.1 <i>Dispersal barriers</i>	10
7.2.2 <i>Closing all or a portion of the UMRS</i>	11
7.2.3 <i>Inspecting commercial/recreational vessels</i>	12
7.2.4 <i>Cleaning commercial vessels and recreational craft</i>	12
7.2.5 <i>Other active control technology</i>	13
7.2.6 <i>Coatings</i>	14
7.2.7 <i>Cleaning/coating exposed surfaces of locks and dams</i>	15
7.3 Managing Existing Zebra Mussel Populations in the UMRS	15
7.3.1 <i>Systemic extermination</i>	15
7.3.2 <i>Alter the hydrodynamic/hydraulic regime of the UMRS</i>	15
7.4 Federal Regulations to Prevent Future Invasions	17
8.0 RECOMMENDED ACTIONS TO ADDRESS PROBLEMS	18
8.1 Federal Interest	18
8.2 Proposed Study	18
8.3 Feasibility Study Goals and Objectives	20
8.4 Alternatives in the Federal Interest	21
8.5 Potential Additional Benefits of Zebra Mussel Management	24
8.6 Information and Planning Tools Needs	25
8.7 Issues Affecting Feasibility Study Scope	27
8.8 Estimated Time and Cost for Feasibility Study	27
8.9 Feasibility Study Coordination	27
9.0 FINDINGS AND RECOMMENDATIONS	28
REFERENCES	30

Table of Contents (cont)

<u>Item</u>	<u>Page</u>
Tables	
1. Population Estimates for Higgins' Eye in Essential and Secondary Habitat Areas	22
2. Estimated Habitat Restoration and Stocking Required	23
3. Estimated Costs and Benefits of Small Scale Habitat Restoration and Stocking	24

Figures

1. Upper Mississippi River System
2. Estimated Schedule and Budget for Completing a Feasibility Study

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1.0 STUDY BACKGROUND AND AUTHORITY

The formal authorization for the U.S. Army Corps of Engineers (USACE) to perform operation and maintenance activities on the Upper Mississippi River System (UMRS) was given in the Rivers and Harbors Act of 1927; as modified by the Rivers and Harbors Acts of 1930, 1932, and 1935; and a Resolution of the House Committee on Flood Control of September 19, 1944. Original authority for the USACE to work on the Mississippi River was provided in the Rivers and Harbors Act of 1878. These Acts and Resolution authorize the construction, operation, and maintenance of the 9-foot navigation channel on the Mississippi River between the mouth of the Missouri River and St. Paul, Minnesota, the Illinois Waterways and other tributaries.

Section 216 of the Rivers and Harbors and Flood Control Act of 1970 authorizes investigations for modification of completed projects or their operation when found advisable for improving the quality of the environment in the overall public interest. Large-scale ecosystem restoration projects linked to existing Civil Works projects (e.g., reducing the significant ecological and economic impacts of the exotic zebra mussel on the UMRS) are appropriate for study under the Section 216 authority (ER 1105-2-100, paragraph 3-10.b).

In 1993, a Navigation Feasibility Study was initiated to study potential navigation improvements on the Upper Mississippi River System by the USACE. In April 1998, the USACE and the U.S. Fish and Wildlife Service (Service) agreed that the USACE needed a system-wide analysis of operation and maintenance (O&M) impacts upon threatened and endangered species for use as a baseline for the Navigation Study. No previous biological assessments of impacts on threatened and endangered species for continued operation of the 9-Foot Navigation Channel Project on the UMRS had been completed, although some limited biological assessments were done for maintenance activities. As a result, USACE prepared a biological assessment for continued O&M and transmitted it in May 1999 along with a request for the initiation of formal consultation. The biological assessment covered direct effects (e.g., operation and maintenance of the 9-foot channel and direct USACE management of project lands); interrelated and interdependent effects (e.g., management of project lands by State and tribal fish and wildlife agencies); and indirect effects (navigation related and recreation effects). This consultation covered the following species: Indiana bat (*Myotis sodalis*), decurrent false aster (*Boltonia decurrens*), bald eagle (*Haliaeetus leucocephalus*), Higgins' eye pearlymussel (*Lampsilis higginsii*), winged mapleleaf mussel (*Quadrula fragosa*), least tern (*Sterna antillarum*), and pallid sturgeon (*Scaphirynchus alba*).

In April 2000, the Service issued a final Biological Opinion for the operation and maintenance of the 9-Foot Navigation Channel Project on the UMRS in Illinois, Iowa, Minnesota, Missouri, and Wisconsin. In this Biological Opinion, the Service stated that it was "reasonably certain that operation and maintenance of the navigation pools and project-dependent commercial barge transportation will facilitate zebra mussel persistence in the UMR [Upper Mississippi River] to the extent that the likelihood of recovery and survival of Higgins' eye is appreciably reduced." The Service's Biological Opinion is "that the action, as proposed, is likely to jeopardize the continued existence of Higgins' eye pearlymussel".

The Service identified a Reasonable and Prudent Alternative that if implemented by the USACE would avoid the likelihood of jeopardizing the continued existence of Higgins' eye pearlymussels. The reasonable and prudent alternative identified by the Service required the USACE to (1) develop a Higgins' eye pearlymussel relocation action plan and (2) conduct a reconnaissance/feasibility study of measures to control zebra mussels in the UMRS.

By letter dated June 12, 2000, the USACE provided an initial response to the Biological Opinion. In this response, the USACE agreed with the findings and recommendations of the Biological Opinion for the Indiana bat, decurrent false aster, Higgins' eye pearlymussel, winged mapleleaf mussel, and bald eagle. Additionally, this letter stated that the USACE "...will begin implementing the recommended actions for these species..."

By letter dated August 11, 2000, the USACE provided a description of the USACE's proposal to proceed with implementation of the Service's recommendations pertaining to the pallid sturgeon and the interior population of the least tern.

By letter dated September 15, 2000, the Service replied to the USACE's previous two letters acknowledging that the actions proposed by the USACE were "the appropriate path to remain in compliance with Section 7(a)(2) (Consultation Requirements) and Section 9 (Prohibited Acts) of the Endangered Species Act."

2.0 STUDY PURPOSE

The purpose of this reconnaissance study is to determine the likely Federal Interest in pursuing further detailed feasibility studies of alternatives for reducing the impacts of zebra mussels on Higgins' eye pearlymussels. This report identifies the nature of such zebra mussel management feasibility studies and the approximate cost and schedule for conducting these studies.

3.0 STUDY AREA

The 9-Foot Channel Navigation Project on the UMRS includes the commercially navigable portions of the Mississippi, Illinois, Kaskaskia, Minnesota, St. Croix, and Black Rivers. The USACE is Congressionally mandated to maintain navigation by means of a series of 37 locks and dams, channel training structures, and dredging on over 1,200 miles of navigable waterway (see Figure 1). Aquatic resources within the 9-Foot Channel Navigation Project include the entire Illinois Waterway from its confluence with the Mississippi River at Grafton, Illinois (River Mile 0.0), to the T. J. O'Brien Lock in Chicago, Illinois (River Mile 327.0); the Mississippi River from its confluence with the Ohio River (River Mile 0.0) to the Upper St. Anthony Falls Lock in Minneapolis-St. Paul, Minnesota (River Mile 854.0); and the navigable portions of the Kaskaskia, Minnesota, Black, and St. Croix Rivers.

Four USACE Districts are responsible for operation and maintenance of the 9-Foot Navigation Channel Project and the Chicago Sanitary and Ship Canal. Portions of the project operated and maintained by the St. Louis District include the UMRS from the confluence of the Mississippi and Ohio Rivers (River Mile 0.0) to near Saverton, Missouri (River Mile 300.1); the navigable portion of the Kaskaskia River; and the Illinois River from its confluence with the Mississippi River at Grafton, Illinois, to immediately below La Grange Lock and Dam at River Mile 79.8. Portions of the project operated and maintained by the Rock Island District include the UMRS (River Mile 300.1) near Saverton, Missouri, to Guttenberg, Iowa (River Mile 615); and the Illinois River from the junction of the Calumet-Sag Channel and the Chicago Sanitary and Ship Canal (River Mile 303.4) to the La Grange Lock and Dam (River Mile 79.8). Portions of the project operated and maintained by the St. Paul District include the UMRS from Guttenberg, Iowa (River Mile 615), to Minneapolis-St. Paul, Minnesota (River Mile 854.0), as well as the navigable portions of the Minnesota, Black, and St. Croix Rivers. The Chicago District is responsible for operation and maintenance of the Chicago Sanitary and Ship Canal. The Chicago Sanitary and Ship Canal provides a navigable channel from Lake Michigan to the Illinois River.

4.0 PLANNING PROCESS

This reconnaissance report is the first phase of a two-phase planning process. This first phase is funded entirely by the Federal Government. Traditionally, the second phase, referred to as the feasibility phase, is cost-shared with a non-Federal sponsor(s). It is proposed that feasibility studies be fully federally funded without a non-Federal cost-share sponsor as a Section 216 Study. Section 216 of the River and Harbor and Flood Control Act of 1970 authorizes the Chief of Engineers to review the operation of completed projects when found advisable due to significantly changed physical or economic conditions and to report thereon to Congress with recommendations on the advisability of modifying the structures or their operation for improving the quality of the environment in the overall public interest (see Section 8.1 for further discussion of Section 216). However, Federal funding for the feasibility study does not mean that the USACE is solely responsible for the introduction, spread, or management of zebra mussels in the UMRS. Funding under the Section 216 authority in this instance is analogous to the 1995 Galveston District Gulf Intracoastal Waterways Study of Aransas National Wildlife Refuge, Texas. The purpose of that study was the preservation and restoration of critical habitat for the endangered whooping crane.

The purpose of future feasibility studies would be to identify, evaluate, and recommend actions or alternatives for managing zebra mussels in the UMRS. By necessity, feasibility studies would be interdisciplinary/interagency efforts and would likely identify alternatives that could be pursued under existing USACE authorities. However, it is also likely that zebra mussel management alternatives identified during feasibility studies would include actions that the USACE has no authority to implement. For these alternatives, the feasibility study would identify local, State and/or other Federal agencies with the necessary authority to effectively implement these alternatives. The USACE would seek the assistance of these other agencies and non-governmental groups in pursuing actions deemed necessary to manage zebra mussels in the UMRS.

5.0 PRIOR STUDIES, REPORTS AND EXISTING WATER PROJECTS

The primary sources used in developing this report are listed below. Many additional relevant reports on zebra mussels, endangered mussel species, and the 9-Foot Channel Navigation Project are available.

U.S. Fish and Wildlife Service. 1983. Higgins' eye mussel recovery plan. Ft. Snelling, Minnesota.

The Higgins' eye recovery plan describes the current status of this endangered species and provides recommendations on actions needed to recover and eventually delist the species. Essential habitats are identified in the report.

Hornbach, D.J. 1999. Technical/Agency draft revised Higgins' eye pearl mussel recovery plan.

The revised recovery plan reevaluates the current status of Higgins' eye pearl mussels and provides recommendations on actions needed to recover the species.

U.S. Army Corps of Engineers. 1999. Biological assessment for operation and maintenance of the Upper Mississippi River Navigation Project within the St. Paul, Rock Island, and St. Louis Districts. Mississippi Valley Division, Vicksburg, Mississippi.

The USACE's biological assessment serves as the baseline for the ongoing Upper Mississippi River System Navigation Study by evaluating the effects of continued operation and maintenance of the 9-foot channel project on threatened and endangered species. In reference to the Higgins' eye pearl mussel, the USACE determined that continued operation and maintenance of the project was likely to affect Higgins' eye pearl mussels.

U.S. Fish and Wildlife Service. 2000. *Final biological opinion for the operation and maintenance of the 9-foot navigation channel on the Upper Mississippi River System.*

The Biological Opinion provides the Service's response to the USACE's biological assessment. The Biological Opinion describes the existing conditions and provides a determination that continued operation and maintenance of the 9-foot channel project is likely to jeopardize the continued existence of Higgins' eye pearlymussels. The Biological Opinion provides "reasonable and prudent alternatives" for the USACE to undertake to avoid jeopardy.

Miller, A., B. Payne and J. Miller. 2001. *A preliminary evaluation of possible strategies to reduce or eliminate zebra mussels, and their associated impacts to *Lampsilis higginsii*, from the Upper Mississippi River Navigation System. Engineer Research and Development Center, Vicksburg, MS 39180.*

This report provides a synthesis of potential zebra mussel control measures and their likelihood for reducing zebra mussel effects on *Lampsilis higginsii*.

6.0 PROBLEMS AND NEEDS

6.1 Higgins' Eye and the Effects of Zebra Mussels – The Service listed the Higgins' eye pearlymussel (*Lampsilis higginsii*) as an endangered species on June 14, 1976 (Federal Register, 41 FR 24064). The major reasons for listing of the Higgins' eye were the decrease in abundance and range of the species. As stated in the original recovery plan, the Higgins' eye pearlymussel was not abundant and was becoming increasingly rare around the turn of the twentieth century. The fact that there were few records of live specimens from the early 1900s until the enactment of the Endangered Species Act in 1973 was a major factor in its listing by the Service in 1976.

The historical distribution of Higgins' eye pearlymussels is not known with certainty. Although nowhere abundant, the Higgins' eye is believed to have been widely distributed, inhabiting the UMRS from just north of St. Louis, Missouri, to Minneapolis-St. Paul, Minnesota. It was also found along the main stem of the UMRS and several of its tributaries including the Ohio, Illinois, Sangamon, Iowa, Cedar, Wapsipinicon, Rock, Wisconsin, Black, Minnesota, and St. Croix Rivers. The range of Higgins' eye has been reduced approximately 50 percent from its historic distribution to a 302-mile reach of the UMRS and is now found only in the UMRS upstream of Lock and Dam 19 at Keokuk, Iowa; in the St. Croix River between Wisconsin and Minnesota; in the Wisconsin River, Wisconsin; and in the lower Rock River in Illinois. The southernmost population is believed to exist in pool 19 at River Mile 407. Nearly all of the remaining habitat for Higgins' eye is within the 9-Foot Channel Project.

The Higgins' Eye Recovery Team designated seven "Essential Habitat Areas" for Higgins' eye. The Essential Habitat Areas are believed to contain viable reproducing Higgins' eye populations. The seven Essential Habitat Areas are (1) the St. Croix River at Hudson, Wisconsin (River Mile 16.2 - 17.6); (2) the UMRS at Whiskey Rock, at Ferryville, Wisconsin, Pool 9 (River Mile 655.8 - 658.4); (3) the UMRS at Harpers Slough, Pool 10 (River Mile 639.0 - 641.4); (4) the UMRS Main and East Channels at Prairie du Chien, Wisconsin, and Marquette, Iowa, Pool 10 (River Mile 633.4 - 637); (5) the UMRS at McMillan Island, Pool 10 (River Mile 616.4 - 619.1); (6) the UMRS at Cordova, Illinois, Pool 14 (River Mile 503.0 - 505.5); and (7) the UMRS at Sylvan Slough, Quad Cities, Illinois, Pool 15 (River Mile 485.5 - 486.0). The Higgins' Eye Recovery Team has proposed three additional Essential Habitat Areas – the St. Croix River at Prescott, Wisconsin, and near Taylors Falls, Minnesota (Interstate Park), and the Wisconsin River near Muscoda, Wisconsin (Orion mussel assemblage).

The reasons for the long-term decline in distribution and abundance of Higgins' eye are largely unknown. Significant changes in the UMRS watershed, from extensive urban development and

conversion of prairie and forested areas into heavy agricultural use, have greatly affected both water quantity and quality. Contaminants and other pollutants may have had a role in the long-term decline in Higgins' eye distribution and abundance and may still be affecting Higgins' eye abundance, distribution, and welfare. The thousands of channel structures built for the 4½- and 6-Foot Navigation Channel Projects and the construction, operation, and maintenance of the 9-Foot Channel Project may also have contributed to this long-term decline. However, these impacts are largely unknown, and most occurred nearly a century ago.

Studies before 1993 found no recent significant declines in the distribution and abundance of Higgins' eye on the UMRS. Since completion of the original Recovery Plan in 1983, the known range of Higgins' eye has been extended by 180 river miles, and the Higgins' Eye Recovery Team tentatively proposed an additional three Essential Habitat Areas. For this species, the outlook was cautiously optimistic; it seemed plausible to consider that Higgins' eye populations were stable and perhaps recovering. Following the Flood of 1993, the Higgins' Eye Recovery Team reassembled and began updating the original recovery plan.

The recent invasion of the exotic zebra mussel has changed this scenario. Because of upstream transport by commercial barges and recreational craft, zebra mussels are now found throughout the UMRS and have had a substantial adverse impact on Higgins' eye and other native freshwater mussels. On the basis of data on freshwater mussels from the Prairie du Chien Essential Habitat Area, and observations and recommendations of the Higgins' Eye Recovery Team, it is evident that zebra mussels are a threat to native freshwater mussels on the UMRS, including Higgins' eye.

Zebra mussels have been found throughout the UMRS and have the potential to kill or otherwise eliminate native mussels, including Higgins' eye. Adult zebra mussels attach to natural substrates, such as rocks, native mussels, wood, aquatic plants, and other zebra mussels. Zebra mussels affect native mussels by competing for food and by attaching to the shells of native mussels in such numbers that the infested mussel cannot travel or burrow. When infested by approximately 100 or more zebra mussels, native mussels cannot open their shells to respire, feed, burrow, or move, nor can they close their shells for protection. Perhaps even more problematic is the accumulation of dead and rotting zebra mussel flesh and shell debris within the native mussel bed. This accumulation creates sustained anoxic conditions at the substratum-water interface that ultimately are intolerable to native mussels and to fish species that might serve as intermediate hosts for the glochidial life-stage of native mussels. Such conditions prevent successful recruitment of native mussels. These direct and indirect impacts or combinations of impacts can lead to the death of the infested mussel and to impaired or no reproduction. Section 7.1 provides a more complete description of the impacts of zebra mussels on Higgins' eye and the likely future without action.

6.2 Introduction and Spread of Zebra Mussels in UMRS – Zebra mussels were first discovered in Lake St. Clair in 1988 and in all the Great Lakes a year later. They were found in the Chicago Sanitary and Ship Canal in June 1989 and in the main stem of the Illinois River in June 1991. The first zebra mussel collected from the UMR was in September 1991 south of La Crosse, Wisconsin.

Male zebra mussels release sperm directly to the water to fertilize eggs released to the water by the females. Large females release up to 1 million eggs per season. Eggs are released when water temperatures reach 52 to 54 °F. Immature zebra mussels (veligers) spread via passive drift on water currents. Adults and veligers attach to boat hulls or to wet compartments, containers, and equipment in boats. Commercial and recreational boats are the main vectors carrying this species upstream and between water bodies, while currents carry veligers and juveniles downstream for further dispersal.

The Chicago Sanitary and Ship Canal provided an abundant source of zebra mussel veligers from Lake Michigan to the Illinois River. Despite only being detected as being present in 1991 in the

Illinois River, by 1993, density had increased dramatically; at River Mile 5.5 (at Grafton, Illinois) densities as high as 61,126/m² were reported. However, by fall 1993, zebra mussel mortality in the Illinois River was apparent. By late 1994, it was estimated that a 99-percent reduction in zebra mussels had occurred at River Mile 5.5 as well as at River Mile 66.8. In 1995, investigators collected 34 1-m quadrats in the lower 120 miles and found only 109 adult zebra mussels greater than 20 mm long. Since 1995, adult zebra mussels continue to be present at low levels in the Illinois River, despite the fact that the Chicago Sanitary and Ship Canal continues to provide millions of zebra mussel veligers from Lake Michigan.

Unlike the Illinois River (via Lake Michigan and the Chicago Sanitary and Ship Canal), the UMRS did not have an upriver source of veligers to spread downriver with the currents. On the basis of the zebra mussel's current distribution within the UMRS, it appears tow traffic is the main transportation vector of upstream spread in the UMRS upstream of the Illinois River, while river currents are responsible for its downstream spread from the UMRS/Illinois River confluence. While recreational boats may transport zebra mussels on the UMRS, commercial barge transportation is a much more reliable vector of transport. Barges have larger submerged surface areas than recreational craft for mussel attachment. The majority of large recreational vessels in the upper reaches of the river are dry-docked during the winter, which kills any zebra mussels attached. Smaller recreational craft are also dry-docked during the winter and are frequently stored out of the water during the growing season. Barges usually remain in the water year-round, increasing exposure to drifting veligers and opportunities for attachment. Barges travel long distances within the UMRS, from below Lock and Dam 26 to the head of navigation at Minneapolis, Minnesota. The Navigation study traced barges and found that 100% of the barges that locked through Lock and Dam 8 (located upstream of some of the prime Higgins' eye essential and secondary habitat areas) in 1992 also locked through Lock and Dam 26 and the locks on the Illinois River, a constant source of zebra mussel veligers from Lake Michigan to the UMRS. The fact that UMR tributaries that have no commercial tow traffic, yet support recreational craft traffic, have not been infested or have been infested at very low levels by zebra mussels further supports the contention that commercial and large recreational vessels were the main upstream dispersal mechanism.

With a less abundant upriver source, UMRS zebra mussel populations grew at a slower pace than those in the Illinois River. Despite a slower population growth rate, recent reports from Lake Pepin (pool 4) and pools 8 through 10 indicate high adult zebra mussel numbers and densities (>20,000/m²). Studies conducted by Minnesota and Wisconsin resource agencies since 1996 indicate Lake Pepin is the likely source population for the increasing zebra mussels in pools 7 and 8. Lake Pepin may be a substantial and long-term source of zebra mussels to the downstream UMRS. Research has found zebra mussel densities to be higher in the UMRS downstream of Lake Pepin than upstream of Lake Pepin.

The continued upstream transport of zebra mussels occurs through use of the 9-foot channel project by commercial barge traffic and larger recreational traffic infested with zebra mussels. The upstream transport of zebra mussels will continue to add an unknown contribution to the populations of zebra mussels in the UMRS, encompassing all UMRS main stem Higgins' eye Essential Habitat Areas, and the existing/proposed Essential Habitat Areas on the lower St. Croix and lower Wisconsin Rivers. While the lower Wisconsin River site is currently not infested, the lower St. Croix River site was declared "infested" by the State of Minnesota in 2000. However, surveys completed by the U.S. Fish and Wildlife Service, the National Park Service, and the Minnesota and Wisconsin Departments of Natural Resources in 2001-2002 found only a few individual zebra mussels in the St. Croix River.

Zebra mussels are now found throughout the UMRS. Continued use of the 9-Foot Channel Project by commercial barges, towboats, recreational boats, and other equipment infested with zebra mussels facilitates the upstream transportation of zebra mussels, thus increasing the risk of establishing zebra mussels at currently uninfested mussel beds containing Higgins' eye in the St. Croix River above Stillwater, Minnesota, and in the lower Wisconsin River.

Since there are no known significant upriver sources of zebra mussels above Lake Pepin, zebra mussel control in upper reaches of the UMRS is more likely to be successful than attempting to control zebra mussels in infested areas downstream of Lake Pepin. The upper pools (pools 2 and 3 specifically) are considered good candidates for relocation/reestablishment of *L. higginsii*, and the St. Croix River is an extremely important resource for *L. higginsii*. In its Biological Opinion, the Service emphasized the need for controlling upriver transport of zebra mussels above Lock and Dam 3. Therefore, priority should be given to developing measures for controlling/preventing the proliferation of zebra mussels above Lake Pepin.

Lake Michigan is the source of zebra mussels for the Illinois River. It is unlikely the zebra mussel population within the Illinois River could sustain itself without the continual repopulation source (see Section 7 for further discussion). There is an opportunity to investigate measures for preventing veligers from entering the Illinois River from Lake Michigan.

Three 9-foot channel project-related indirect effects may be exacerbating the impact of zebra mussels and other exotics on Higgins' eye. Impoundment of the UMR has created more favorable habitat for the zebra mussels, a species that is ecologically developed and thrives in lentic conditions. Second, navigation traffic in the UMR has been shown to be an upstream dispersal vector for the zebra mussel. And third, the likelihood of additional exotic species, such as the quagga mussel (*Dreissena bugensis*), invading the UMR by using this same vector is still present. The impact of another exotic species invasion to the UMR upon the currently stressed Higgins' eye populations is unknown but could be significant. The potential causal factors and projected future without action are discussed further in Section 7.

7.0 ALTERNATIVES CONSIDERED IN RECONNAISSANCE STUDY

Four broad alternatives were identified during this reconnaissance study. An assessment of the effectiveness of these alternatives is discussed below.

7.1 No Action – Under the no action alternative, zebra mussels would continue to be transported into and within the UMRS on barges and recreational vessels. From an endangered species standpoint, this alternative means allowing zebra mussel-native mussel interactions to take their natural course. On the practical side, it must be recognized that zebra mussels are adapted to lacustrine (lake-like) habitats, and most native mussel species do best in lotic (riverine) systems. In many rivers (notably the Ohio and Illinois Rivers), zebra mussel densities increased rapidly after initial infestation, peaked at very high densities within 3 to 5 years, and appear now to be stabilizing at moderate densities that native species can tolerate. Many of the Higgins' eye pearlymussel essential habitats previously considered marginal, such as Whiskey Rock or McMillan Island, have not yet been heavily infested with zebra mussels. However, most of the former areas considered prime Higgins' eye pearlymussel habitat such as Harpers Ferry Slough and the East Channel have now been heavily infested with zebra mussels.

Higgins' eye pearlymussels have been affected by zebra mussel infestation in two main ways. The first is through direct competition for resources and mortality caused by high zebra mussel densities attached to individual Higgins' eye pearlymussels. Second, high zebra mussel densities have changed UMRS substrates from the sand and gravels preferred by Higgins' eye to thick layers of zebra mussels with silt and clay interstices.

Zebra mussels were first noted in the East Channel of the UMRS near Prairie du Chien, Wisconsin (approximately at River Mile 635), in 1993. In 1994, mean zebra mussel density was less than 100 individuals/m². In 1996, mean density increased to more than 10,000 individuals/m², and between then and 2001, mean density was variable but remained high, typically much more than 1,000 individuals/m². While densities of live organisms remained high, the quantity of dead shell material in the substratum, and associated silt and detritus, increased. In the summer of 2001, divers

reported that shells and detritus were 50 cm thick in some parts of the East Channel. Twenty-five to 50 percent of samples consisted of dead zebra mussel shells. In addition, divers reported considerable hydrogen sulfide production associated with dead zebra mussels and detritus. However, observations by resource managers have indicated that a partial die-off of zebra mussels might have occurred on portions of the UMR during late summer of 2001. Also in late summer of 2001, accumulations of dead zebra mussels were found in some lock chambers. Veliger drift below most of the locks and dams has been monitored since 1998 and an apparent reduction in number of veligers was observed in 2002. General observations by resource managers in 2003 have also indicated that adult zebra mussel densities may have been reduced throughout much of the UMRS, including Lake Pepin. The magnitude, geographical extent, and effects on future UMR zebra mussel densities of this apparent reduction in zebra mussels are unknown. The more lentic environment of the UMR, in contrast to the Illinois and Ohio Rivers, may prevent or reduce the reductions in zebra mussels that have been observed for these rivers.

The extended period of high zebra mussel density in the East Channel, from 1996 to 2002, is in marked contrast to conditions at a dense and species-rich mussel bed in the lower Ohio River near Paducah, Kentucky. Zebra mussels were first observed there in 1991; densities were estimated at 190/m² by 1993. By early 1994, mean density was 100,000 individuals/m² at some sites on the mussel bed. By late 1995, the 1994-year class of zebra mussels began to die, and by late October 1995, virtually all of the live zebra mussels had perished. Mean density was less than 100 individuals/m², and most were less than 15 mm total shell length. Since that time, zebra mussel densities in the lower Ohio River have remained moderate, ranging from 200 to 7,000 individuals/m².

In the Illinois River, adult zebra mussel densities peaked and then declined rapidly, much as they did in the lower Ohio River. Zebra mussels were first noted in the Illinois River in 1992. By 1993, density had increased dramatically; at River Mile 5.5 (at Grafton, Illinois) densities as high as 61,126/m² were reported. However, by fall 1993, zebra mussel mortality in the Illinois River was apparent. By late 1994, it was estimated that a 99-percent reduction in zebra mussels had occurred at River Mile 5.5 as well as at River Mile 66.8. In 1995, investigators collected 34 1-m quadrats in the lower 120 miles and found only 109 adult zebra mussels greater than 20 mm long. Since 1995, adult zebra mussels continue to be present at low levels in the Illinois River, despite the fact that the Chicago Sanitary and Ship Canal continues to provide millions of zebra mussel veligers from Lake Michigan.

Prior to zebra mussel infestation, mussel density and species richness in the East Channel of the UMRS were relatively high. The endangered Higgins' eye pearl mussel composed approximately 0.5 percent of the mussel assemblage and was collected regularly in the East Channel. *Lampsilis teres*, *Ellipsaria lineolata*, and *Quadrula nodulata* were uncommon but present. Mean total live native mussel density was routinely greater than 50 individuals/m². Although the mussel bed was infested with zebra mussels in 1993/1994, the native mussel assemblage remained unaffected for several years. In 1996, zebra mussel densities were approximately 10,000/m²; however, the majority of native unionids were still alive. In 1998, total live unionid density had declined to 20 individuals/m², and in 1999 through 2003, it had decreased to less than 5 individuals/m². Unionid density may have started to decline in 1997, although no data were collected that year.

Within the unionid community, evidence of recent recruitment was measured in terms of total individuals less than 30 mm total shell length or the number of species with at least one individual less than 30 mm total shell length. Prior to 1999, the number of species with at least one individual less than 30 mm total shell length varied from less than 40 to nearly 80 percent. Prior to 1999, the percentage of individuals less than 30 mm total shell length varied from 10 percent to more than 40 percent. However, evidence of recent recruitment declined abruptly after 1998. No evidence of recent recruitment was noted in 1999 through 2002. These parameters provide an indication of recruitment success 1 to 2 years previously, since individuals in the community less than 30 mm total shell length were not necessarily produced in that year. Although the high zebra mussel

infestation starting in 1996 obviously inhibited recruitment, it did not immediately cause mortality of small unionids. Small unionids were found in the assemblage in 1996, probably in 1997, and in 1998. It was not until 1999 that the high-density zebra mussel populations had a noticeable effect on unionid recruitment in the East Channel.

There is evidence that the zebra mussel has had severe impacts on native mussels in the Great Lakes and in large rivers in this country. However, not all areas in the UMRS are equally infested by zebra mussels. The East Channel of the UMRS has been/is being more severely affected by zebra mussels than more lotic reaches such as the lower Ohio River near Paducah, Kentucky, or some native mussel beds in pool 7 or 9. An area near Guttenberg, Iowa, in pool 10, is another important case in point. Although it is downriver of the East Channel and therefore likely to receive zebra mussel larvae from upriver, the substratum was not significantly infested by adult zebra mussels. Substratum is sandy, and the river reach is more lotic than the East Channel. The native mussel community there has not been affected greatly by zebra mussels, and abundance of Higgins' eye pearl mussels has not changed measurably in the last 10 years.

Unlike zebra mussels, many unionid species are specifically adapted to large rivers; hence, they may have a competitive advantage over zebra mussels throughout much of their range (see Section 7.3.2 for further discussion). Zebra mussels do not sustain themselves well in medium-size to small rivers which are likely to provide refugia for many (although certainly not all) native unionids.

Many native unionids live 30 years or more, tolerate long periods of desiccation, have an extremely strong shell, and can move about to a limited extent. Most zebra mussels live 1 to 2 years, are virtually intolerant of desiccation, and have a weak, relatively fragile shell. Although they can break loose from the substratum and be carried to new habitats on water currents, zebra mussels typically do not move about in response to reduced water levels, as do some unionids. The extreme tolerance to zebra mussel infestation exhibited by some unionids is noteworthy. In the summer of 2000 in the East Channel of the UMRS, many large unionids (specifically *Megaloniais nervosa*) were found still alive after 5 years (1996 - 2000) in substratum heavily infested with zebra mussels.

The likelihood for another exotic species invasion into the UMR is very high, but the degree of impact upon the native fauna is impossible to determine. One potential species that could affect Higgins' eye in the same fashion as the zebra mussel is the quagga mussel (*Dreissena bugensis*). The quagga mussel is presently outcompeting and replacing the zebra mussel in the Great Lakes and could be the next species to invade the UMRS through the Chicago Sanitary and Ship Canal. It is uncertain why the quagga has replaced the zebra mussel, but the quagga appears suited to outcompete the zebra mussel because it survives at deeper depths and spawns in colder weather. Introduction and spread of the quagga mussel could have significant consequences on the northern reaches of the UMRS, including the few remaining Higgins' eye essential habitat areas on the St. Croix River that have not been severely affected by zebra mussels.

It is reasonable to assume that without action to control/manage zebra mussels, declines in Higgins' eye pearl mussel numbers/populations are probable. Local extinctions, such as that which has apparently occurred in the East Channel of the UMRS at Prairie du Chien, Wisconsin, have significantly reduced the long-term viability of this species. Thus, the no action alternative would jeopardize the continued existence of the Higgins' eye pearl mussel. However, the current conditions at several of the essential habitat areas in terms of zebra mussel infestation and effects on Higgins' eye pearl mussels indicate that remnant Higgins' eye pearl mussel populations are persisting in the UMRS despite heavy zebra mussel infestations. Estimating the long-term viability of these remnant populations is speculative at best; however, even if the remnant populations of Higgins' eye pearl mussels remain viable and self-sustaining, the condition of Higgins' eye populations as a whole in the UMRS would be uncertain. The alternative and most conservative view would hold that remnant populations of Higgins' eye pearl mussels are not viable, and this species could be destined for possible extinction without immediate and emergency intervention.

7.2 Managing Transport/Dispersal of Zebra Mussels in the UMRS – Until the late 1800's, the Great Lakes and the Illinois/Mississippi River watersheds were isolated from each other. In the late 1800's, the two ecosystems were connected through construction of the Chicago Sanitary and Ship Canal. This connection provided the conduit for transfer of zebra mussels from the Great Lakes into the UMRS. With reproducing populations of zebra mussels well established in Lake Michigan, this connection allows for a continuous supply of zebra mussel veligers into the Illinois River. As stated previously in this report, it is unlikely zebra mussel populations in the Illinois River could sustain themselves without the continual influx of zebra mussel veligers from Lake Michigan. Eliminating the supply of veligers from Lake Michigan, by itself, would not likely change the zebra mussel distribution in the UMR. However, it may be an important step in the long-term control of zebra mussels in the UMRS.

While the Chicago Sanitary and Ship Canal provided the aquatic connection for zebra mussels to establish in the Illinois and Mississippi Rivers, the use of the lock and dam system has facilitated the upriver movement of zebra mussels on the UMRS. However, it is unlikely that zebra mussels would be eliminated from the UMRS below Lake Pepin if no more were brought in from the Chicago Sanitary and Ship Canal and/or transported upstream by commercial or recreational vessels. The populations of zebra mussels in the UMRS below Lake Pepin are now likely self-sustaining, and continued upriver transport is unlikely to be a critical factor in their long-term existence in the UMRS. However, similar high densities of zebra mussels do not exist above Lake Pepin in the Upper Mississippi River or in the St. Croix, Minnesota, Black, Wisconsin and Chippewa Rivers. Zebra mussel surveys conducted in the spring of 2001 and 2002 found few zebra mussels above Lake Pepin and in the St. Croix River. Commercial and recreational craft continue to be the main vector for upstream transport above Lake Pepin. Measures to contain zebra mussels within their existing infestation boundaries and protect uninfested waters are likely to be more feasible than attempting to eliminate zebra mussels from the UMRS by active/passive dispersal control measures.

Methods for controlling the upriver transport of zebra mussels fall in two broad categories: active and passive. Active control measures could include broad-scale control measures such as construction of a zebra mussel dispersal barrier on the Illinois Waterway or closing all or a portion of the UMRS to navigation traffic. Additional active measures could include hull inspections and manual removal (scraping, high pressure wash), thermal treatments (steam injection, hot water > 32 °C), electrical currents, dewatering/desiccation (freezing, heated air), acoustical vibration, ultraviolet light, etc. Active measures could be employed on individual barge hulls or on a larger scale; for instance, on a lock and dam or lock chamber.

Passive control methods would include treatments that prevent zebra mussels from attaching to barge hulls. The application of toxic coatings (copper, zinc) or non-stick surfaces (silicone-based) is included in passive control techniques.

7.2.1 Dispersal barriers – As part of the effort to slow or stop the spread of invasive species between the Great Lakes and the Mississippi River drainage basins, the U.S. Army Engineer District, Chicago, is examining methods for creating a dispersal barrier in the Chicago Sanitary and Ship Canal for the exotic round goby (*Neogobius melanostomus*), a small invasive fish. Up to \$750,000 was authorized by the National Invasive Species Act of 1996 for the Corps of Engineers to carry out a demonstration study of this project.

Construction of a demonstration dispersal barrier to control movement of *N. melanostomus* is planned. A micro-pulsed DC electric array would be placed on the floor of the canal. While the electrical field would extend throughout the full water column, the effective barrier zone would be concentrated near the floor of the canal. Such a system is useful only for organisms that move along the river bottom, such as *N. melanostomus*.

The demonstration barrier would have virtually no effect on zebra mussel veligers, which passively drift with river currents, or on adult mussels attached to barges and other vessels. A barrier that would effectively kill all life stages of zebra mussels is needed. Potential barriers could include 1) establishment of a lethal anoxic zone on the waterway (an anoxic zone occurred on the waterway prior to sewage treatment upgrades), 2) establishment of a lethal zone by other means using electricity, heated water, hydraulic jets, toxicants, etc., 3) treatment of all water diverted from Lake Michigan to kill zebra mussels, or 4) reestablishment of the former watershed boundaries by construction of barriers, levees, or lock chambers to isolate Lake Michigan from UMRS waters.

7.2.2 Closing all or a portion of the UMRS – Closing all of the UMRS to navigation traffic is unlikely to affect the long-term existence of zebra mussels in the UMRS. Additionally, the USACE does not have authority to permanently close the congressionally mandated navigation system on the UMRS. There is the possibility, however, that closing a portion of the Mississippi River upstream of Lake Pepin to all river traffic could stop the continued transport of adult zebra mussels attached to commercial/recreational vessels into the upper river. If such closure were congressionally authorized, it could be done as an alternative to, or in conjunction with, lowering the pools and returning the river to more riverine conditions. Stopping traffic in the upper river would also protect the St. Croix River from infestation, as well as other sensitive areas such as the Minnesota River.

Zebra mussels have been present in the UMRS since at least 1991 and have been continuously transported upriver on vessels ever since. However, adult zebra mussel populations above Lock and Dam 3 have not reached infestation levels even remotely similar to levels observed downstream of Lake Pepin. The influence of the Minnesota River with its contribution of heavy suspended sediments, and the relatively more lotic conditions present, are both factors that may be affecting zebra mussels in the upper pools. Large turbid rivers represent a difficult growth environment for zebra mussels because of high suspended inorganic sediment concentrations that hinder efficient feeding processes and disrupt the energetic balance of zebra mussels. The Minnesota River enters pool 2 just below Lock and Dam 1 and delivers a tremendous suspended sediment load that remains in the river until reaching Lake Pepin. This suspended sediment likely makes conditions in pool 2 and below unfavorable for zebra mussels. Additionally, veligers spawned in navigation pools upstream of Lock and Dam 3 may not settle out of the water column until they have drifted downstream into Lake Pepin. Since there is currently no known source population of zebra mussels above the Head of Navigation on the UMRS, population growth in the upper pools is likely limited to adults transported upstream by vessels. Further evaluation of the suitability of the upper pools of the UMRS for zebra mussels, as well as the population dynamics of zebra mussels in these pools, is needed.

Both commercial and recreational interests would be affected by a lock closure. Currently, approximately 12 to 15 million tons of commodities are shipped annually upriver and downriver in this reach of the UMRS. A large number of barges pass through Lock 4, located immediately downstream of Lake Pepin. If the upper river were closed to commercial traffic, these commodities would have to be shipped by other means (rail or truck) or to other markets. Instead of shipping the grain outside the area, a portion of it might stay in the area and be converted to alcohol products. The estimated economic costs would need to be investigated further during feasibility studies. When costs of commodity movements are considered, it does not really matter whether traffic is simply stopped, or the river hydrodynamics are altered to a point that commercial traffic is no longer possible.

Because of the recreational values of the St. Croix River, and the presence of a large metropolitan area within 50 miles, the most recreational lockages in the St. Paul District occur at Lock 3 near Red Wing, Minnesota. The impacts of a lock closure on recreational use and other socioeconomic factors would need to be evaluated and documented as part of any proposed feasibility studies.

In 1992, a Task Force was assembled to formulate policies and actions that could slow the spread of zebra mussels into the St. Croix River. During the 1990s, the Task Force evaluated and

prepared several management options including a voluntary vessel turnaround/quarantine system. The voluntary turnaround/quarantine system was ultimately selected as the preferred method for controlling upriver transport of zebra mussels from the UMRS to the St. Croix River. Throughout the 1990s, zebra mussels were not found in much of the river; however, large numbers of adult and juvenile zebra mussels were collected at multiple locations in the lower river in 2000. The State of Minnesota declared the St. Croix River “infested” with zebra mussels in 2000. However, surveys completed by the U.S. Fish and Wildlife Service, the National Park Service, and the Minnesota and Wisconsin Departments of Natural Resources in the spring of 2001 found only a few individual zebra mussels in the St. Croix River. Apparently, the large number of juvenile zebra mussels observed in 2000 had not survived and been recruited into the population. While it now appears that voluntary restrictions on vessel movements into the lower St. Croix River are unlikely to prevent infestation of the lower St. Croix River, many questions remain. As of 2002, zebra mussel populations appear to be established in the St. Croix River and may be sustained by adults within the system.

The lower St. Croix River is somewhat lacustrine because of backwater effects from the Mississippi River. However, north of Stillwater, Minnesota, the river narrows and becomes more lotic. At this location, known locally as the Arcola sandbar area, an opportunity exists to implement a mandatory restriction on vessel movement to keep zebra mussels from infesting the upper river. Although this would not guarantee zebra mussels would be kept out of the upper river, it could certainly slow their spread and protect native mussel stocks. However, even without the mandatory restriction of vessel movement, it is unlikely the habitat upriver of Stillwater would support large numbers of zebra mussels. Bivalve habitat in that reach is similar to those areas in pools 7, 9, and 10 that were fairly lotic and supported low populations of zebra mussels. Therefore, native species upriver of the Stillwater area are probably not in much jeopardy from zebra mussels. Regardless of this fact, it appears that the mandatory restriction on vessel movement in the upper St. Croix River has potential as a “pilot” study for examining the effectiveness of active control measures in preventing upriver transport of zebra mussels.

7.2.3 Inspecting commercial/recreational vessels – As an alternative to river closure, an initial active measure for controlling upriver transport of zebra mussels in the UMRS would be to inspect vessels. On the basis of previous discussions in this report, the logical location for a vessel inspection platform would be Lock 3 near Red Wing, Minnesota. Commercial barge/tow inspections could be done in water with divers and it would not be necessary to dry-dock the vessels. Recreational craft could be inspected by removal from the water, so no divers would be needed; however, larger craft would require divers. Inspection of smaller recreational craft would be safer and easier; however, the volume of smaller craft using the UMRS is much larger. After inspection, it is assumed that infested vessels would be cleaned, painted, or quarantined as needed.

7.2.4 Cleaning commercial vessels and recreational craft – Cleaning of commercial vessels/barges would likely require dry-docking of the vessel at a shipyard and then hull cleaning with a hydroblaster. The hulls (as well as propellers and rudders) of all recreational vessels could be cleaned to remove zebra mussels. For small craft, this could be relatively simple and inexpensive; the boat could be taken to a car wash and cleaned. Alternatively, it could be allowed to sit in the sun for several days to kill all the mussels. Costs associated with small fishing boats would be minimal, and would mainly be an aggravation to the owner. Costs to clean a large boat that would have to be pulled out of the water and put on a hoist could run from \$5,000 to \$10,000 per vessel. There are literally thousands of large recreational craft in the UMRS. Notwithstanding the relatively small individual expense of cleaning recreational craft, the overall costs and difficulty of instituting such a program and enforcing it would be monumental.

An alternative method for “cleaning” barges/recreational craft could lie in the construction of a hot water wash station, associated with a lock or similar facility, specially built for such a purpose (perhaps associated with heated effluent from a power plant). Infested boats and barges could be exposed to water sufficiently hot to kill all attached zebra mussels.

The greatest challenge for such a system would be during ice-free but cold seasons, when the energy required to heat water would be the greatest. Upper limits of water temperatures lethal to zebra mussels decline slightly with acclimation temperature. Thus, mussels in early spring, late fall, or early winter are killed at a lower temperature than mussels in summer. However, at acclimation temperatures of 5 and 10 °C, it is still necessary to expose zebra mussels to 37.5 and 38.2 °C in order to achieve 100 percent mortality (LT_{100}) instantaneously. Assuming exposure will last for perhaps 15 minutes, these temperatures are probably 1 or 2 degrees higher than is actually required. Regardless, the difficulty of creating a lock-size water bath approximately 25 to 30 °C warmer than the surrounding river is impractical.

Alternatively, slightly warmer lethal temperatures might be created in mid-summer. Assuming an acclimation temperature of 25 °C, water heated to approximately 40 °C would kill all mussels in a “lock-through” water bath. Thus, the temperature differential required falls to 15 °C – still an enormous engineering challenge. At an acclimation temperature of 30 °C (appropriate for the lowermost parts of the UMRS system in mid-summer), LT_{100} is still approximately 40 °C. Thus, a 10 °C temperature differential must be overcome simply to kill mussels in a reach where ambient water temperature is 30 °C in midsummer. Furthermore, temperature required for 100 percent mortality decreases slightly as contact time increases.

The possibility of creating a pass-through system that maintains water 10 to 15 °C warmer than ambient conditions in summer may be feasible. Use of the heated discharge of a power plant, additional heating capability, and a structural design that minimizes loss of heated water during opening and closing of gates deserve at least preliminary feasibility study. Each barge might have to pass through such a system only once or twice per season for effective control. The costs of constructing and operating such a system are likely to compare favorably with periodic dry-docking and physical cleaning of barges. A drawback on this method would be the subsequent environmental effects of the release of heated water.

As with inspecting commercial vessels, a logical location for a cleaning/treatment site might be Lock 3. A nuclear power plant exists just upstream of Lock 3 and could be a source of heated water.

7.2.5 Other active control technology – Pulse-power technology has the potential to control zebra mussels proactively; however, its history is limited. Pulse-power systems typically derive their input energy from a continuous source of electricity that ultimately delivers short, discrete bursts of relatively high energy rather than a continuous flow. The relatively high voltage discharge can be routed to electrodes, from which the energy is output to the environment as a pulsed electric field. Alternatively, the electrical pulse from the capacitors can be directed to the terminals of a transducer, which converts the electrical energy to another form before delivery to the environment. Small-scale results indicate that compromised systems can produce control efficiencies of 43 to 92 percent, but larger-scale controlled studies are still needed to refine the technology. The advantage of pulse-power systems is that they can deliver high-energy pulses, while remaining cost-effective compared with systems delivering a continuous energy output at the same or lower peak amplitude. The potential for negative effects is minor; however, a full-scale system should be engineered with health and safety problems in mind. Other studies have also shown that low levels of continuous currents as low as 6 volts/in. not only prevented attachment but also caused detachment of zebra mussels. A field scale study at the Naticoke Thermal Generating Station concluded that 8 volts/in. and an electrode separation of 12.7 cm were the minimum combination to be used that would provide total biofouling protection.

Ultraviolet light works well in a closed setting, such as a pipe; however, it cannot be used in a large area such as the UMRS. High-intensity sound, such as that produced by explosives or the plasma sparker, can prohibit settlement of juveniles or kill adult zebra mussels. However, these work only in local areas such as a pumping well or pipe. They could not be used in a river system.

Hot air can be forced over adult zebra mussels that are exposed to the atmosphere. This method can be used in pipes, and could even be used to kill zebra mussels on a lock wall or other surfaces. However, given the enormous magnitude of suitable surface area for zebra mussels on all the locks and dams, it is unrealistic to consider using this method throughout the UMRS to control zebra mussels. In addition, there is no guarantee that once the surfaces were treated, zebra mussels would not come back into the UMRS and require subsequent periodic treatment. This is also the case with many of the other temporary active control treatments discussed above.

7.2.6 Coatings – Paints and coatings impregnated with copper have been shown to prevent post-veliger settlement, while coatings impregnated with other metals have been less effective. These metals can be applied directly to metal surfaces as hot metallic sprays. They are more commonly applied to a variety of surfaces (metal, concrete, wood) as paints or other types of coatings. However, the current technology requires replacement of these coatings every 2 to 5 years, and application is relatively expensive.

There is evidence that some nonpolluting and nontoxic coatings can be maintained relatively free of zebra mussel fouling by occasional “gentle” cleaning. Either light abrasion brushing or hydraulic cleaning at low pressure can be used without substantially damaging the coating and without leaving behind byssal plaques or threads. Methyl-silicate coatings have such foul-release and easy release properties. However, these softer coatings have short lives and require frequent overcoating. For example, marine power plants that have used such coatings to protect intake structures from blue mussel fouling report a service life of approximately 5 years. Soft silicones are highly unlikely to be effective on barges and towboats used in the inland navigation system – abrasion against lock walls, other barges, and large woody debris would quickly compromise such coatings. However, relatively soft coatings may be of some use with respect to recreational craft that are pulled out of the water annually. Antifoulant waxes are potentially useful for small craft that are launched and then trailered after each use.

Harder nontoxic coatings such as polyethylene and polyvinyl coating support stronger attachment by zebra mussels, necessitating harder brushing or hydraulic cleaning leaving behind byssal plaques and threads. The marine power plant experience has been that such coatings are not effective at preventing fouling.

Thus, hard toxic coatings such as copper epoxy paints, other copper-based coatings, and flame sprayed metal coatings (very expensive) are the only coatings likely to be useful in protecting commercial barges and towboats.

All commercial vessels in the UMRS could be treated with an antifoulant coating. For these estimates, a cost of \$50/gallon of paint was used, and it was assumed that a gallon would cover 250 feet of the vessel surface. The cost for painting a vessel, which includes transportation to the shipyard, dry-docking, preliminary work, cost of paint, and the painting, would be approximately \$33,000 per vessel. The entire fleet could be painted for nearly \$200 million. This is a one-time cost that includes only a single treatment. As indicated above, the treatment would need to be repeated every 2 to 5 years.

A small 12- to 16-foot boat could probably be cleaned and painted for a few hundred dollars. Most of the work could be done by hand with inexperienced labor. The vessel would be taken out of the water, turned upside down on sawhorses, cleaned, dried, and then spray-painted. Larger boats would cost substantially more. The 45-foot-long Tawas Bay, a Bay Class tug, was coated with an antifoulant for approximately \$2,500. Dry-docking and cleaning the vessel prior to painting cost an additional \$2,500. As discussed previously in this section, it is doubtful that the total numbers of zebra mussels in the UMRS would be reduced by any measurable extent by cleaning and coating recreational and commercial vessels.

7.2.7 Cleaning/coating exposed surfaces of locks and dams – Concrete walls, metal gates, pipes, culverts, and screens all provide suitable habitat for zebra mussels in the UMRS. These surfaces could be physically cleaned of zebra mussels and/or treated with antifoulant coatings.

Zebra mussels in the UMRS cannot be eliminated by cleaning all exposed surfaces (lock walls, gates, screens, culverts, and pipes) associated with USACE projects. Such physical cleaning could not eliminate zebra mussels from the large expanses of natural substratum in the navigation pools, and even if this could be done, the zebra mussels would likely recolonize.

Exposed surfaces at locks and dams could be treated with an antifoulant. This would eliminate habitat for zebra mussels in the UMRS and could reduce the number of immature zebra mussels in the system. However, there are likely significantly larger numbers of zebra mussels on natural substratum in the UMRS that successfully reproduce each year. Eliminating zebra mussels from the locks and dams would probably have an insignificant effect on the total population of zebra mussels in the UMRS.

7.3 Managing Existing Zebra Mussel Populations in the UMRS – Zebra mussels have currently reached infestation levels in the UMRS that jeopardize the continued existence of the Higgins' eye pearly mussel. Measures for managing or reducing zebra mussel populations to levels where co-existence with native mussels is possible are discussed in the following sections.

7.3.1 Systemic extermination – The ultimate control of zebra mussels would occur if a species-specific biocide, pathogen, or disease could be identified. Research to find a “silver bullet” that would wipe out zebra mussels in the UMRS is limited; however, zebra mussel specific pathogens or diseases are being investigated.

If present in large enough numbers, zebra mussel specific pathogens or diseases would offer potential for significantly reducing zebra mussel populations on a systemic basis. Research is currently under way to identify and mass produce zebra mussel specific pathogens; however, it will likely be many years before this technology becomes advanced enough for broad applications to the UMRS.

Chemical control has been found to be most suitable for application to problems in closed systems and internal piping. It is much less effective in the treatment of external surfaces where it may be impossible to maintain required treatment concentrations and contact times of the compound. Thus, current chemical options are not available for treating and reducing densities of zebra mussels in source waters, such as lakes, rivers, and streams. It is quite unrealistic to consider treating all water within a lock chamber with a biocide in an attempt to reduce the number of zebra mussels in the UMRS. In addition, it does not make much sense to try to treat a river reach with a biocide. The environmental effects of such a treatment could be worse than the effects of zebra mussels.

7.3.2 Alter the hydrodynamic/hydraulic regime of the UMRS – There is some evidence to suggest that native mussel species (which are adapted to lotic or riverine conditions) have a competitive advantage over zebra mussels (which are adapted to lacustrine or lake-like conditions) in more natural riverine environments. Zebra mussels are not found in large numbers in streams or small rivers. Once firmly attached, adult zebra mussels are able to withstand water velocity up to approximately 1.5 m/sec. In this sense, they appear highly adapted to lotic conditions. However, when the life history of zebra mussels is considered, full adaptability to lotic life is much more doubtful. All other bivalves that have been successful in rivers, including native unionids, *Corbicula*, and some fingernail clams, do not exhibit external fertilization or produce planktonic larvae as does the zebra mussel. In unionids, sperm released by males are brought into the mantle cavity on inhalant water currents produced by the female. Eggs held in marsupial chambers of the gill are fertilized, and development proceeds to the production of glochidia larvae. These larvae are released, then attach to fish fins, skin, or gills, and undergo metamorphosis; and a miniature version of the adult drops to the river bottom. Both *Corbicula* and fingernail clams

brood embryos in gill marsupia until an essentially benthic individual has developed. Reliance on external fertilization and planktonic larvae has not been a successful design for bivalves in truly lotic habitats with nearly continuous downstream flow.

Lakes and run-of-river reservoirs along large rivers are the primary habitats of zebra mussels. Zebra mussel settlement is restricted by water velocity. Settlement is most successful in slow-moving water (<10 cm/sec) and, further, within velocity refuges of such slow-moving water. Successful colonization of smaller river systems by zebra mussels may depend on lakes, large pools, and impoundments along the river's course. Although impoundments along a smaller river enhance conditions for successful zebra mussel colonization, the overall susceptibility of such river systems to heavy infestation by zebra mussels is much lower than for lakes and long, low-velocity sections of large rivers.

As discussed previously, in the Ohio and Illinois Rivers, zebra mussel densities increased rapidly after initial infestation, peaked at very high densities within 3 to 5 years, and appear now to be stabilizing at moderate densities that native species can tolerate. Additionally, in Higgins' eye pearl mussel essential habitat areas where higher velocity, more river-like conditions exist, native mussels appear to be "doing better" than in areas where lower velocity conditions are prevalent. Density of live zebra mussels in the UMRS is not markedly higher than in the lower Ohio River. However, in the lower Ohio River, native mussels have been much less severely affected than in the UMRS. High mortality of native mussels has characterized much of the UMRS, while mortality effects have been far less in the lower Ohio River. Indeed, native mussels continue to recruit successfully to these beds, despite occasionally high adult zebra mussel density (4,000 to 7,000 individuals per m²), and density of settling zebra mussels each year now measures in the range of several thousand per m². However, substratum is more scoured in the lower Ohio River, and extensive buildup of zebra mussel debris does not occur as it does in the UMRS. It appears that areas with moderately scoured sandy substratum tend to support the remaining living unionids in the UMRS. Prior to zebra mussel infestation, these more erosional locations in the UMRS were considered to be of marginal value to native mussels. Thus, it is possible that more frequent or continuous scour of zebra mussel debris at selected locations in the UMRS could be used as a successful management tool to protect native mussels, including Higgins' eye pearl mussels. Altering the hydrodynamic/hydraulic conditions of the 9-foot channel project may provide conditions favoring native mussels over zebra mussels.

Run-of-river reservoirs, such as those in the UMRS, provide extensive areas with ideal conditions for zebra mussels – slow flow during much of the reproductive season, yet sufficient scour on a seasonal basis to provide hard substratum. These conditions are not dissimilar to the sublittoral zone of the Great Lakes where zebra mussels have thrived. More lotic conditions in the upper and middle reaches of each navigation pool are probably not as favorable for zebra mussels as the more lentic conditions in the lower reaches of each pool. Although the run-of-river reservoir system provides significant amounts of habitat favorable for the zebra mussel, even if the river were returned to a natural state, there would still be habitat that could be used successfully by the species.

Converting the UMRS from a series of run-of-river reservoirs to a more natural riverine habitat would have great adverse economic impacts on recreational and commercial usage of the UMRS. Many more recreational vessels use the lock system than commercial vessels. The large expanses of backwaters, used by fishermen and boaters, would be lost or so shallow that they could be used only by small boats. The fish fauna would change from those adapted to lentic conditions (largemouth bass and bluegill) to species with less recreational interest and value. The ecological impacts of converting the system to a free-flowing river would be significant.

Short of dam removal, it may be feasible to place cobble, gravel, and sand at selected locations in the more lotic reaches of existing pools (typically the upper one-third of each pool). It would be difficult, if not impossible, to create conditions of rapid water flow deleterious to adult zebra mussels but not to native mussels. Gravel and sand substratum typically used by native unionids would be

eroded by flow swift enough to preclude adult zebra mussels. However, sustained and moderately scouring conditions, or frequent scouring conditions, may be beneficial to unionids by removing debris that otherwise accumulates when zebra mussels die. Native mussels are threatened not just by dense infestation of living, attached zebra mussels. Perhaps even more problematic is the accumulation of dead and rotting zebra mussel flesh and shell debris. This accumulation creates sustained anoxic conditions at the substratum-water interface that are unsuitable to native mussels. Successful recruitment of native mussels may be prevented by such conditions.

Altered river hydraulics on a more limited scale could benefit native mussels now faced with dense infestations of zebra mussels. At particular sites or within restricted river reaches, it may be possible to create conditions of flow sufficiently rapid and sustained to prevent heavy settlement of zebra mussels. The upper reaches in each pool tend not to have sufficiently depositional and stable substratum suitable for colonization by native unionids. A combination of river training structures and substratum placement may provide a way of creating conditions in which unionids can live but accumulations of zebra mussel debris will be swept away. In addition, with altered dam operations, it may be possible to maintain more scouring conditions than presently exist during at least parts of the settlement season (May through October in the UMRS) for zebra mussels. Creation of more lotic conditions may be feasible in the UMRS by dam removal, altered dam operations, use of river training structures, or substratum manipulation. Combinations of the latter three methods, although a difficult hydraulic task, probably are the practical approach.

Biologists and hydraulic engineers working as a team should be able to identify existing sites (perhaps associated with wing dams) or design new sites that would provide appropriately stable substratum for unionids, yet still provide enough scour to prevent sustained accumulations of zebra mussel debris. Such sites might first be tested using a common species, such as *Amblema plicata*, and soon thereafter be used as translocation sites for Higgins' eye pearl mussels. Although less than ideal from a biological perspective, such sites subject to more erosional conditions may provide critical refuge habitat for native mussels.

Habitat alterations alone may not achieve the desired restoration of Higgins' eye mussel populations. Some level of natural recruitment may happen, but it may take many years to occur and in many instances may not be at a level to achieve sustainable populations. Higgins' eye propagation and stocking of habitat-altered areas may be required. The ongoing Higgins' eye Relocation Plan developed to address the Service's Reasonable and Prudent Alternative 1 has demonstrated that Higgins' eye can be propagated effectively. In addition to the habitat alterations and stocking, it may be possible to reestablish Higgins' eye populations at sites within their historical range that have not been infested with zebra mussels or that have experienced only low levels of infestation. Higgins' eye mussels were extirpated from these areas for a variety of reasons. Water quality conditions and other factors have improved in many of these areas, and the native mussel communities have rebounded. However, these areas remain a relatively high risk for reestablishment of Higgins' eye, because it remains uncertain whether the factors that led to the extirpation in these areas still exist. In addition, many of these areas are at the fringe of the range of Higgins' eye and may never have had many Higgins' eye due to a variety of natural limiting factors. The ongoing Higgins' Eye Relocation Plan may provide information on how feasible this option is, but at this time, stocking within the Higgins' eye historical range where zebra mussels are absent or at relatively low levels is not considered an effective long-term solution as a stand-alone alternative.

7.4 Federal Regulations to Prevent Future Invasions – A broader approach to controlling invasive species introductions to the United States involves regulations to control ballast water discharge. Regulations and guidelines have been issued by the U.S. and Canadian Coast Guards and the international community to minimize and prevent the dispersal of zebra mussels and other nonindigenous species from contaminated ballast waters of ocean-going vessels. This approach is considered critical to preventing invasive species introductions.

8.0 RECOMMENDED ACTIONS TO ADDRESS PROBLEMS

A feasibility study to evaluate zebra mussel management measures is recommended. The potential control measures to be addressed in the study are described further in this section of the reconnaissance report. Additionally, the Federal interest in completing a study, estimated cost and schedule, and potential partners are also summarized. A Project Management Plan for the feasibility report is attached. The feasibility study would be initiated in the spring of 2005.

8.1 Federal Interest – Section 7(a)(2) of the 1973 Endangered Species Act (ESA) requires Federal agencies to insure that actions authorized, funded, or carried out by them are not likely to jeopardize the continued existence of endangered or threatened species. In addition, the ESA establishes as Federal policy that “*all Federal departments and agencies shall seek to conserve endangered species and threatened species.*” In keeping with this ESA requirement and policy, it is within the Federal Interest to implement the Biological Opinion’s Reasonable and Prudent Alternative of conducting a reconnaissance/feasibility study of measures for controlling zebra mussels in the UMRS. Additionally, the Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990 broadly requires Federal agencies to implement measures to prevent the proliferation of nonindigenous aquatic species. This act provides further Federal interest for conducting reconnaissance/feasibility studies.

Section 216 of the River and Harbor and Flood Control Act of 1970 authorizes the Chief of Engineers to review the operation of completed projects when found advisable due to significantly changed physical or economic conditions and to report thereon to Congress with recommendations on the advisability of modifying the structures or their operation for improving the quality of the environment in the overall public interest. The introduction and subsequent population expansion of zebra mussels has significantly changed the aquatic environment of the UMRS. Specific to concerns expressed previously in this report, zebra mussels pose a direct threat to the continued existence of Higgins’ eye pearlymussels in the UMRS. It would appear that feasibility studies of methods for controlling zebra mussels could be undertaken using the Section 216 authority.

Congressional authority and funding for a Federal/USACE study is another option for securing funding for feasibility studies. Legislation authorizing and funding the study would need to be included in a Congressional appropriations bill or in a Water Resources Development Act.

Pursuit of a feasibility study to manage zebra mussels is consistent with USACE Environmental Operating Principles. As stated in the February 2003 Program Management Plan for Integrating the Environmental Operating Principles within USACE, USACE will: “Strive to achieve Environmental Sustainability. An environment maintained in a healthy, diverse, and sustainable condition is necessary to support life.” Zebra mussels threaten the environmental sustainability of the UMRS. There appears to be a strong Federal Interest in terms of resolving the impacts of zebra mussels on Federally threatened and endangered species and on the nationally significant Upper Mississippi River Ecosystem.

8.2 Proposed Study – The preliminary analysis provided in this report suggests the following:

- 1) native mussels are better adapted to lotic (riverine) environments than zebra mussels,
- 2) controlling upstream transport of zebra mussels above Lock and Dam 3 is a potential measure for protecting the St. Croix River and pools 1, 2, and 3 from further zebra mussel infestation,
- 3) cleaning or coating commercial/recreational vessels is a potential measure for minimizing the spread of zebra mussels into uninfested waters, and
- 4) barriers and regulations to stop the introduction of invasive species are needed.

The proposed feasibility studies would address the major evaluation areas listed below. The USACE does not have the authority or responsibility to implement all feasible zebra mussel management measures identified and to be addressed in the feasibility study. The likely entities with authority and potential lead responsibilities are identified below for each major evaluation area.

- Evaluation of large-scale alterations of the hydrodynamics of the UMRS
 - o Systemic pool drawdowns (USACE)
 - o Pool specific drawdowns (USACE)
- Evaluation of smaller-scale alterations of the hydraulics and substrate of the UMRS
 - o Flowing channel restoration (USACE)
 - o Wing dam or other structural modifications (USACE)
 - o Substrate modifications (USACE)
- Higgins' eye propagation and stocking

Several Habitat Rehabilitation and Enhancement Projects are currently being planned for construction in the UMRS under the Environmental Management Program. Consideration of potential measures for altering the hydraulics of the UMRS to benefit native mussels could be incorporated into these projects. Monitoring the effectiveness of restoration measures would provide invaluable information for completing task two outlined above.

- Evaluation of Barriers to Introductions of Exotics
 - o Dispersal barrier on Chicago Sanitary and Ship Canal (USACE & City of Chicago)
 - o Ballast water regulations (U.S. and Canadian Coast Guard)
- Evaluation of Closing the UMRS above Lock and Dam 3 (Congress)
 - o Economic impacts
 - o Environmental impacts
- Evaluation of Closing the Wisconsin River (and other tributaries) (National Park Service, States, U.S. Fish and Wildlife Service)
 - o Economic impacts
 - o Environmental impacts

Protecting the St. Croix River is critical to preserving the Higgins' eye pearl mussel, while pools 1, 2, and 3 could provide relocation/refuge areas. Closing the Wisconsin River to protect Higgins' eye populations from zebra mussels would also be investigated.

- Evaluation of Cleaning Alternatives (USACE, States, National Park Service, U.S. Fish and Wildlife Service, private)
 - o Hot water wash
 - o Hydro-acoustic technologies
 - o Manual scraping
 - o Others
- Evaluation of Coating Alternatives (USACE for USACE facilities, U.S. Coast Guard, States, private for non-public facilities or vessels)
 - o Toxic-release antifoulants
 - o Non-toxic self-cleaning

When viewed as an alternative to closing portions of the UMRS, cleaning/coating alternatives are preliminarily attractive. Since many of the alternatives that would be considered in the feasibility study have the potential to have significant impacts on the quality of the human environment, an Environmental Impact Statement would be prepared as part of the feasibility study.

8.3 Feasibility Study Goals and Objectives – The overall goal of the feasibility study is to identify cost effective and environmentally sustainable alternatives for managing zebra mussel populations in the UMRS. The feasibility study's level of detail must be sufficient to determine preferred alternatives and to meet the requirements of the National Environmental Policy Act (NEPA) and other pertinent environmental laws.

Objectives of the study include the following:

- Evaluate existing data; identify data gaps.

This objective will focus on an examination of existing data and studies that have been undertaken in the basin targeted at zebra mussel management and control. Analysis and interpretation of existing data will help to provide direction for analyses proposed for this study. The objective will also identify incongruities in the database and outline mechanisms to acquire the needed data.

- Acquire and analyze data.

Data gaps identified above and data needed for objectives listed below will be gathered, interpreted, and analyzed during the study. Predictive models for evaluating future conditions with and without alternatives will be developed.

- Identify zebra mussel management alternatives.

Management of zebra mussels may need to include a number of actions, such as measures to control/manage dispersal of zebra mussels in the UMRS, measures to reduce/manage zebra mussel populations in the UMRS, and measures to prevent future introductions of zebra mussels and/or other exotics into the UMRS.

- Evaluate alternatives for managing zebra mussels.

This objective requires analysis of alternatives identified above for managing zebra mussels in the UMRS. This objective will be accomplished by detailed analyses of the economic costs associated with identified alternatives, the potential effectiveness of the alternative in managing zebra mussels and risks associated with alternative implementation, and the environmental costs and benefits associated with the alternative. An Ecological Risk Assessment approach will be used to evaluate the future without action and alternative management measures.

- Formulate alternative plans.

Alternatives will include such things as large-scale alterations of the hydrodynamics of the UMRS to manage zebra mussels, small-scale alterations of the hydraulics of the UMRS, closing portions of the UMRS, cleaning/coating technologies, and barriers to prevent transport of zebra mussels.

- Develop criteria for alternative evaluation.

Existing data and data collected during the study will be used to assess whether the alternative measures will or will not result in reductions in zebra mussels in the UMRS or at least in areas of the UMRS considered important to native mussels. The assessments will result in specific evaluation criteria that will be used to determine if alternatives can/should be implemented. Potential roadblocks (e.g., economic costs, environmental costs, etc.) will be identified and documented. Beneficial and adverse impacts of each alternative on the environment, society, and economy will be compared.

- Produce draft and final feasibility reports and appropriate NEPA documents regarding the study's conclusions and recommendations.

A preliminary draft feasibility report and Environmental Impact Statement will be prepared and reviewed by an Independent Group, with no vested interest in the outcome of the study. Based on the review by the Independent Group, a draft feasibility report and Environmental Impact Statement will be prepared. After policy review and other feasibility study review processes, the draft will be submitted to the appropriate Federal agencies, State and local participants, and the general public for review and comment. This draft document will outline the preferred plan and the environmental, economic, and social impacts/costs of potential alternatives. The study team will address the review comments in the final feasibility report and Environmental Impact Statement.

8.4 Alternatives in the Federal Interest – To evaluate whether at least one of the above alternatives appears to be in the Federal Interest to pursue, the alternative of smaller-scale alterations of the hydraulics and substrate of the UMRS, with subsequent stocking of Higgins' eye, has been developed in greater detail. Note that larger scale alterations of the hydraulic conditions or a combination of smaller and large scale habitat restoration projects may be more cost effective, but the study level needed to evaluate these larger scale measures exceeds the scope of a reconnaissance study. The goal will be to reestablish Higgins' eye populations to pre-zebra mussel invasion levels through small-scale habitat restoration measures and stocking.

In order to estimate the level of effort needed to reach this goal, pre-zebra mussel and future without action estimates of Higgins' eye populations are needed. Table 1 summarizes the estimated pre-zebra mussel and likely population changes that might occur without action and the approximate number of acres of available Higgins' eye habitat. The confidence limits around these estimates are rather large and are also dependent on the estimated boundaries of the suitable habitat as defined by the individual investigator. Assumptions used in the development of this estimate are as follows:

- The St. Croix and Wisconsin River Higgins' eye populations would be unaffected by zebra mussels in the future and would maintain existing levels.
- The prime essential habitat areas (i.e., East Channel Prairie du Chien, Harpers Slough, Cordova, Sylvan Slough) have experienced heavy prolonged infestations by zebra mussels, and Higgins' eye mussels are likely to be extirpated or remain at very low levels.
- Some of the essential and secondary habitats, generally considered moderate in habitat quality for Higgins' eye, have not been affected by zebra mussels to the same extent and have maintained good Higgins' eye numbers. However, mussel densities and Higgins' eye abundance were and are approximately half those of the prime essential habitat areas.
- The population levels of Higgins' eye outside the designated secondary or essential habitat areas are unknown. These areas are also likely to not have been significantly affected by zebra mussels. For the purpose of this analysis, populations outside secondary and essential habitat areas are assumed to have and will continue to remain at similar levels.

Table 1. Population Estimates for Higgins' Eye in Essential and Secondary Habitat Areas

Site	Estimated amount of available habitat (acres) in 1990's	1990's population estimate	2000's population estimate	2015 w/o action population estimate	2015 population interim objective	2065 population long-term objective
Essential Habitat Areas						
Interstate – St. Croix River	216	4,000 ¹	4,212 ⁴	4,212	4,212	4,212
Hudson – St. Croix River	47	ND	8,424 ⁴	8,424	8,424	8,424
Prescott – St. Croix River	8	ND	4,939 ⁵	4,939	4,939	4,939
Orion – Wisconsin River	320	2,273 ²	ND	2,273	2,273	2,273
Pool 9 Whiskey Rock – UMR	183	38,881 ⁵	65,512 ^{5,6}	38,881	38,881	38,881
Pool 10 Harpers Slough – UMR	492	215,039 ⁵	10,967 ⁵	0	0	0
Pool 10 East & West Channel – UMR	937	143,106 ⁵	11,433 ⁵	0	0	0
Pool 10 McMillian Island – UMR	440	43,050 ⁵		43,050	43,050	43,050
Pool 14 Cordova – UMR	212	213,987 ⁵	9,511 ⁵	0	0	0
Pool 15 Sylvan Slough – UMR	64	2,562 ⁵	793 ⁵	0	0	0
Secondary Habitat Areas						
Pool 7 Winters Landing – UMR	38	ND	10,661 ⁵	10,661	10,661	10,661
Pool 11 Goetz Island – UMR	25	5,690 ³	ND	5,690	5,690	5,690
Pool 11 Cassville	13	ND	3,049 ⁶			
Pool 13 Bellevue – UMR	3	ND	1,165 ⁵	1,165	1,165	1,165
Pool 17 Muscatine – UMR	27	ND	932 ⁵	932	932	932
Other habitat areas outside essential and secondary habitat areas						
Miscellaneous	Unknown	Unknown	Unknown	same level	same level	same level
Habitat Restoration and Stocking - Target Levels						
Habitat alteration & stocking	1,700	0	0	0	231,012	288,766
Stocking only	1,700	0	0	0	231,012	288,766
Total in secondary and essential habitat without action and with habitat restoration and stocking						
Total in secondary & essential habitat	3,025	697,758	182,611	120,227	582,252	697,758

¹ Hornbach et al. 1995

² Heath 1995

³ Miller and Payne 1997

⁴ Heath et al. 2001

⁵ Miller and Payne 2001

⁶ Farr et al. 2002

ND – No data. It was assumed that populations had not changed between the 1990's and 2000's for purposes of determining total numbers in secondary and essential habitat areas.

Zebra mussels are likely to adversely affect approximately 1,700 acres of prime Higgins' eye habitat and eliminate 573,000 Higgins' eye or 83 percent of the total known populations in essential and secondary habitat areas. The population model RAMAS developed by Applied Biomathematics (Akcakaya 1998) was used to estimate the stocking effort and associated costs needed to reach the project objective of replacing the more than 0.5 million Higgins' eye that will be lost. The RAMAS model indicates that it will take stocking of approximately 460,000 age 2 Higgins' eye to achieve the long-term self-sustaining target population level. Producing this number of age 2 Higgins' eye will involve raising over one-half million fish, infesting them with Higgins' eye glochidia, raising the juveniles in cages, and subsequent relocation of age 2 Higgins' eye to the final destination area. Based on the experiences gained from similar efforts on the ongoing Higgins' eye Relocation Plan, it is estimated that it would cost \$33.33 to produce each age 2 Higgins' eye.

The target from a habitat acreage standpoint would be geared toward achieving habitat quality conditions similar to the essential and secondary habitat areas where Higgins' eye appears to be maintaining population levels. Approximately 3,400 acres of medium quality habitat conditions would be needed to replace the loss in 1,700 acres of prime essential habitat. Zebra mussels have generally maintained high levels in the UMRS from Lake Pepin in pool 4 to approximately pool 19. Pools 1 to upper pool 4, pools 20 through 24, and many of the tributaries within the historical range of Higgins' eye have not experienced the high levels of zebra mussel infestation, and native mussels appear to be maintaining population levels. It is assumed that it will be possible to find approximately half of the target habitat acres (1,700) that will be suitable for stocking Higgins' eye in these historic areas. No habitat modifications would be required. Within the zone of heavy zebra mussel infestation, Lake Pepin to pool 19, a combination of habitat enhancement (1,700 acres) and stocking would be required. Two potential mussel habitat improvement projects have recently been developed for potential funding under the Environmental Management Program or Natural Resource program for the 9-foot Channel Project. Both proposals involved a combination of modifying hydraulic conditions and substrate. The estimated average cost per acre of habitat created for these proposals is \$13,465. Table 2 presents the potential costs of this alternative to reach the goal of restoring Higgins' eye habitat and populations. These costs are preliminary and would be refined in the feasibility study.

Table 2. Estimated habitat restoration and stocking required

Measure	Goal		Habitat Costs/acre	Propagation costs/acre	Habitat Costs	Propagation Costs	Total Costs
	Acres	Higgins' eye numbers					
Habitat & Stocking	1,700	231,012	\$13,459	\$4,530	\$22,880,503	\$7,700,400	\$30,580,903
Stocking Only	1,700	231,012		\$4,530		\$7,700,400	\$7,700,400
Total	3,400	462,024	NA	NA	\$22,880,503	\$15,400,800	\$38,281,303

Customarily, the U.S. Fish and Wildlife Service's 1980 version of Habitat Evaluation Procedures (HEP) is used to quantify and evaluate the potential project effects and benefits. The HEP methodology uses a Habitat Suitability Index (HSI) to rate habitat quality on a scale of 0 to 1 (1 being optimum). The HSI is multiplied by the number of acres of available habitat to obtain Habitat Units (HU's). One HU is defined as 1 acre of optimum habitat. By comparing the projected HU's available without a proposed action to HU's projected to be gained with a proposed action or alternative, the benefits of different alternatives can be quantified. There is no Habitat Suitability model for Higgins' eye. For the purposes of this preliminary analysis, it is assumed that the East Channel at Prairie du Chien in pool 10 and other prime essential habitat areas represented optimal conditions or an HSI of 1.0 and the medium quality essential and secondary habitats represent an HSI value of 0.5. The target would be to create habitat conditions similar to the medium quality essential and secondary habitats for an HSI increase of 0.5. Table 3 provides the costs on per acre and average annual habitat unit gain basis. Stocking alone produces the best cost per average annual habitat unit gained. However, the costs per average annual habitat unit gained, with and without the inclusion of habitat restoration measures, are well within the range of what is

normally considered acceptable under the Upper Mississippi River Environmental Management Program. There would also be substantial additional unquantified habitat benefits associated with this plan. The costs per average annual habitat unit seem reasonable and in the Federal Interest to pursue a more detailed feasibility study, especially when viewed from the standpoint of restoring habitat conditions and populations for the federally endangered Higgins' eye under jeopardy for its continued existence.

Table 3. Estimated cost and benefits of small scale habitat restoration and stocking

Measure	Total Costs	Annualized cost (50 years)	Average annual cost per acre	Average annual cost per habitat unit gained **
Habitat & Stocking	\$30,580,903	\$1,906,414	\$1,121	\$2,242.84
Stocking Only	\$7,700,400	\$480,043	\$282	\$564.76
Total	\$38,281,303	\$2,386,456	\$702	\$1,403.80

* Discount rate of 0.06234

** Assumes Habitat Suitability Index Increase of 0.5

8.5 Potential Additional Benefits of Zebra Mussel Management – The

feasibility study will focus on zebra mussel management measures that might directly benefit Higgins' eye mussels. However, there are many other potential ecological, economic, and social benefits that would accrue from many of the zebra mussel management measures to be investigated in the feasibility study. To the extent practical, these additional ecological and economic benefits will be quantified and included in the feasibility evaluation of the various management measures.

In addition to addressing the problems with zebra mussels and the effects they are having on Higgins' eye, most of the management measures identified in Section 8.2 have the potential to have many other ecological benefits. For instance, pool or system-wide drawdowns could be an effective tool in managing zebra mussels. However, these drawdowns are presently being investigated as a means to mimic the occurrence of low water conditions that would occur naturally on the Upper Mississippi River if it were not impounded and regulated to maintain adequate water depths for commercial navigation. One of the main objectives of a growing season drawdown is to expose substrates and enhance conditions for the reproduction, growth, and survival of perennial emergent species of aquatic vegetation. The role of aquatic vegetation in ecosystem function and health and its value to fish and wildlife has been well documented. Also, drawdown to expose aquatic substrate and promote the growth of emergent vegetation is a proven wildlife habitat management measure. Smaller scale alterations in hydrodynamic and substrate habitat conditions will also benefit many other species of native mussels, the endemic macroinvertebrate community, and a variety of riverine fish species.

Zebra mussels can have a variety of ecological effects within the UMRS, which would be abated with an effective zebra mussel control plan. The infestation of zebra mussels has caused dramatic shifts in the macroinvertebrate community of the UMRS. Zebra mussels are affecting populations of native unionids, including other species such as sheepsnose (*Plethobasus cyphus*) and spectacle case (*Cumberlandia monodonta*), which the Service is presently evaluating for potential listing under the Endangered Species Act. Zebra mussels also may affect other benthic invertebrates such as amphipods and other crustaceans, insects, and other organisms that live along the river bottom, which ultimately could affect the entire food web of the UMRS. In 1997, pools 9 through 11 experienced extremely low dissolved oxygen levels (< 3ppm) in the main channel and main channel border where zebra mussel populations had exceeded 15,000/m². These reduced dissolved oxygen levels can affect almost all aquatic biota, but are particularly adverse for immobile organisms. Benthic invertebrates that are immobile may be especially affected if they cannot vacate an area with low dissolved oxygen. These benthic areas are also where reductions in dissolved oxygen would likely be the greatest.

In addition to these effects, it is possible that filter feeding by zebra mussels may reduce planktonic resources that larval fish depend on for feeding and initial growth and survival. One zebra mussel can filter up to 2 pints of water per day, and such high filtration may remove large quantities of available food from the water column. However, such an effect has not been proven definitely, and may not be of concern on the UMR where zooplankton and phytoplankton are relatively abundant.

Zebra mussels have caused serious, expensive problems for private, public, and commercial users of water resources. Zebra mussels typically attach to any hard surface. When done in enormous numbers, it can cause operation and maintenance difficulties in a variety of ways. This has included the blockage of diversion and delivery pipes associated with water supplies for power plants, municipal drinking water supplies, navigation lock and dam structures, and other facilities that depend on water availability. They also have hampered recreational and commercial waterborne vessels by attaching to hulls, engines, rudders, and water intake structures. Zebra mussels also have an impact on property owners, affecting docks, boats, swimming platforms, and other property. They have deterred water use by both commercial and recreational fishermen. Zebra mussels also have affected beaches and other waterfront recreation, covering such areas with sharp-edged shells and decomposing mussel tissue.

The exact economic cost/impact of zebra mussels is difficult to estimate. The Service estimates the potential economic impact at \$5 billion over the next 10 years to U.S. and Canadian water users in the Great Lakes region. Another source estimated during the mid-1990s that zebra mussels would cause \$5 billion per year in damages and control costs to water intake pipes and water filtration and electric generating plants by the year 2000.

Lastly, the UMRS serves as a source of zebra mussels that may infest other outside water bodies. Connected water bodies may become infested through downstream drift as well as upstream movement by various commercial and private water vessels. Outside, unconnected water bodies may become infested through overland transport by recreational and or commercial watercraft. This has been evidenced near Lake Michigan, where nearby inland lakes have become infested with zebra mussels. Also Lake Zumbro, a reservoir on a tributary to the UMRS, has recently become infested with zebra mussels.

8.6 Information and Planning Tools Needs – The zebra mussel management feasibility study effort will need to be adaptive. This approach is presently being used for the UMRS Navigation Study and Comprehensive Management Plan. Some of the information or evaluation tools needed to fully evaluate some of the alternatives are not presently available and are not likely to be available within the time frame of the proposed feasibility study. Research and development for the “silver bullet” that would eradicate zebra mussels, while having acceptable ecological and economic consequences, is not likely to be completed within the feasibility study time line. Although research and development continues on barriers, cleaning, and coatings, there is or will be enough information available to evaluate these alternatives. For instance, the USACE is presently conducting preliminary studies to evaluate the effectiveness of the existing electrical barrier on the Illinois Waterway to manage zebra mussel veligers from Lake Michigan.

Development of zebra mussel population models will be critical in predicting future conditions with and without the various management measures identified in Section 8.2. Two models are presently being developed, one specifically for Lake Pepin and another to evaluate the distribution of zebra mussels as influenced by current, suspended solids, and water temperature. Zebra mussel veliger distribution studies being conducted since 2001, in partnership with the States of Wisconsin, Iowa, and Illinois, have demonstrated that Lake Pepin is a major zebra mussel recruitment source for the downstream pools. Hydraulic 2-D and 3-D models presently exist for Lake Pepin, as well as spatially explicit zebra mussel distribution maps. This information will allow us to develop a predictive model to assess the contribution of Lake Pepin and the effectiveness of zebra mussel management actions that might be employed. There is enough information on zebra mussel habitat suitability (as measured by suspended solid, water temperature, and current velocity) to

develop and verify a predictive model of the distribution of zebra mussels on the UMRS. It is anticipated that these models will be available shortly after initiation of the feasibility study. These models will also be useful in evaluating zebra mussel management measures and selecting areas and designing native mussel habitat projects.

The USACE has been monitoring native and zebra mussels in the UMRS since the issuance of the Biological Opinion to provide some basic information on the health and status of native and zebra mussels. In addition, the States, the Service and the USACE are developing a proposal for funding under the Long-Term Resource Monitoring component of the Environmental Management Program (EMP) for a native and zebra mussel large-scale inventory and long-term monitoring program for the entire UMRS. This proposal has received a high ranking by the USACE and the partner agencies. EMP funding levels for Fiscal Year 2004 and beyond are uncertain at this point. Increased funding in Fiscal Year 2004 or 2005 for EMP could mean that much of this additional mussel inventory work would be available for the feasibility study. Having a good understanding of the health and status of native and zebra mussels in the UMRS would greatly assist us in evaluating the effectiveness of potential control measures and location for mussel habitat work. The U.S. Geological Survey's Upper Midwest Environmental Science Center is also developing a predictive landscape native mussel model that will greatly assist in the feasibility study.

An ecological risk assessment approach would be used in the feasibility study to evaluate future without action and future with the various alternative management measures identified in 8.2. Risk assessment is a comprehensive process that identifies relevant information, organizes and analyzes pertinent data, states assumptions, and addresses uncertainties in estimating the probability of some undesired event (Committee on Environment and Natural Resources (1999)). Risk assessment has been used to estimate and manage human health risks to employees in the workplace, as well as to guide management responses to large-scale disasters, including earthquakes, dam failures, floods, and forest fires. By analogy, ecological risk assessment (ERA) estimates the probable occurrence of an undesired ecological impact in relation to physical, chemical, or biological stressors (USEPA 1998). ERA was originally developed to assess the probable adverse ecological effects of toxic chemicals. More recently, the ERA process has been adapted to assess risks posed by other stressors; for example, habitat degradation and the introduction of exotic species.

The basic components of an ERA include problem formulation, exposure analysis, effects assessment, and risk characterization (USEPA 1998). Fundamental to problem formulation is the development of a conceptual model that outlines the assessment, identifies the stressors and ecological impacts, and defines functional interrelationships that translate stressor exposure to estimates of risk. To perform the assessment, the conceptual model is made operational, usually through the analysis of existing information and the application of statistical or process-based ecological models, such as the models described above for zebra and native mussels. The ERA process produces a documented, transparent, and repeatable analysis of the impacts of environmental stressors, such as introduction and spread of zebra mussels. Importantly, the ERA process can also be used in the context of risk-based decision-making to evaluate the effectiveness of proposed management and mitigation plans. The risk-based decision process would not be limited in application to the ecological aspects of introduction and spread of nonindigenous species; this process could also address relevant economic and socio-political concerns as well.

Possible use of an ERA to evaluate zebra mussel spread, establishment, and impacts in the UMR. The zebra mussel is now an important component of the UMRS ecosystem. A management plan for this pest species could be developed based upon risk assessments and risk-based decision-making, including the following capabilities:

1. Estimating the risk of spread to uninfested waterbodies or tributaries such as the St. Croix River, and quantifying the risk of establishing viable reproductive populations in these systems.

2. Characterizing the importance of veliger sources such as Lake Pepin or Lake Michigan to establishing downstream adult populations of zebra mussels.
3. Contributing to the estimation of ecological and economic impacts of zebra mussels.
4. Evaluating the comparative susceptibility of different habitats, ecosystem components, and man-made facilities to infestation by zebra mussels.

The proposed ERA would estimate the probability of spread and establishment, and assess the efficacy of all potential means of controlling zebra mussels – from commonly used technologies to relatively novel or extreme measures. The secondary impacts of spread and establishment and benefits of these management measures would also be addressed.

The USACE presently is developing an ERA framework (3-year Research and Development project started in Fiscal Year 2003 by USACE ERDC-EL) for assessing the potential introduction, spread, and ecological and economic consequences of golden mussels (*Limnoperna fortunei*). Golden mussels have a very similar ecology to zebra mussels, but are adapted to warmer climates. The golden mussels are rapidly expanding in South America and could become a serious problem in the southern United States. Once this ERA framework has been developed, it will be possible to modify the ERA model to address zebra mussels for the UMRS.

The feasibility study will also identify and prioritize additional research and development that needs to be completed and lay out a strategy, including identifying responsible parties, for getting this completed in future efforts.

8.7 Issues Affecting Feasibility Study Scope – Zebra mussels are an exotic species, recently introduced to the United States. Their long-term effects on the ecosystem of the UMRS are relatively unknown, but currently appear to be significant. A wide variety of issues, primarily focused on the unknowns concerning zebra mussels, have the potential to affect the scope of the feasibility study and evaluation of alternatives. These include but are not limited to the following:

- Zebra mussel populations have experienced “boom/bust” cycles of abundance in the Ohio and Illinois Rivers. They may do the same in the UMRS. A “crash” in zebra mussel numbers on the UMRS would indicate a natural control mechanism exists and could obviate the need for continued studies of control alternatives.

8.8 Estimated Time and Cost for Feasibility Study – The anticipated timeline and estimated study cost for evaluating large- and small-scale hydrodynamic alterations for managing zebra mussels, closing portions of the UMRS and other tributaries to navigation, cleaning/coating vessels to control transport of zebra mussels in the UMRS and barriers/regulations to prevent introduction of invasive species are 3 to 3½ years and \$2 million. Figure 2 contains a detailed list of feasibility and NEPA milestones. The anticipated fiscal year funding requirements are expected to be as follows: Fiscal Year 2004 would require \$50,000 (to begin zebra mussel model development), Fiscal Year 2005 would require \$810,000, Fiscal Year 2006 would require \$870,000, Fiscal Year 2007 would require \$245,000 and Fiscal Year 2007 would require \$15,000 to complete the study.

8.9 Feasibility Study Coordination – Control/management of zebra mussels will likely require the combined efforts of many resource management agencies and the general public. A multi-District team consisting of USACE representatives from the St. Paul, Rock Island, St. Louis, and Chicago Districts, as well as a representative of the Engineer Research and Development Center (ERDC), would be formed to provide general oversight and guidance for completion of the study. Tasks (and appropriate funding) would be assigned to each District for completion. The ERDC has an active zebra mussel research program that would provide information on zebra

mussel control, biology, etc. Funding would need to be provided to supplement ERDC's zebra mussel research program to allow participation in the feasibility study.

The Service, through its Biological Opinion, has stated the importance of conducting reconnaissance/feasibility studies of potential measures for controlling zebra mussels in the Upper Mississippi River. Their full support and cooperation with the proposed studies is anticipated. In addition to the multi-District team and the Service, an interagency collaborative effort would be needed to complete the feasibility study in the time frame proposed. The interagency team would be composed of agencies already actively involved with the USACE in identifying/evaluating zebra mussel control measures. In 2000, a Mussel Coordination Team (MCT) was established with a Partnership Agreement signed by the agency heads of the USACE St. Paul and Rock Island Districts; the U.S. Fish and Wildlife Service; the U.S. Geological Survey; the National Park Service; the U.S. Coast Guard; and the Departments of Natural Resources from Minnesota, Wisconsin, Iowa, and Illinois. The purpose of the MCT is to work together as a trusting, cooperative team to coordinate planned mussel studies and projects and share information on the management of native mussel resources and control of invasive nonindigenous mussel species. The MCT would be used for coordination of the feasibility study and could be used for completing portions of the feasibility study. Additionally, the feasibility study could recommend implementation of zebra mussel management alternatives that fall outside USACE existing authorities. Such alternatives would need to be implemented by other concerned agencies or the public.

Further coordination with other Federal, State, and local resources management agencies would occur during the problem identification phase of the feasibility study, and the list of agencies to be a part of this interagency collaborative effort would be expanded to represent the variety of interests in the study, including the City of Chicago, the U.S. Environmental Protection Agency, and the Federal and State Departments of Transportation, Agriculture, etc. There are also many private stakeholders, Non-Governmental Organizations (NGOs), which have a vested interest in the outcome of any feasibility study to manage zebra mussels on the UMRS. Extensive coordination and consultation with these NGOs would be done through a series of workshops. Moreover, the views of the navigation interests would be solicited, including collaboratively identifying the potential economic consequences of the alternatives being considered and identifying and evaluating potential joint private and government measures that could be implemented to manage zebra mussels.

An Independent Group, with no vested interest in the outcome of the study, would also participate in the feasibility study. The Independent Group would participate in some of the interagency and non-governmental stakeholder meetings and provide critiques at critical junctions in the planning process, including the problem identification and development and the evaluation of alternatives phases. This Independent Group would also provide an Independent Technical Review Report on the Preliminary Draft Feasibility Study Report and Environmental Impact Statement.

Extensive coordination and consultation with the public would also be completed during the feasibility study.

9.0 FINDINGS AND RECOMMENDATIONS

Based on the preliminary analysis provided in this report, altered hydrodynamic regimes offer potential for managing zebra mussel infestations. This approach probably offers its best potential within existing pools and as related to the use of substratum placement, use of river training structures, and perhaps altered dam operations to create habitat for native mussels that is less susceptible to accumulation of zebra mussel debris.

Similarly, closing of traffic and cleaning of vessels are options that might be used on a limited basis, such as to protect the lower St. Croix River. However, it is unlikely that such measures can be

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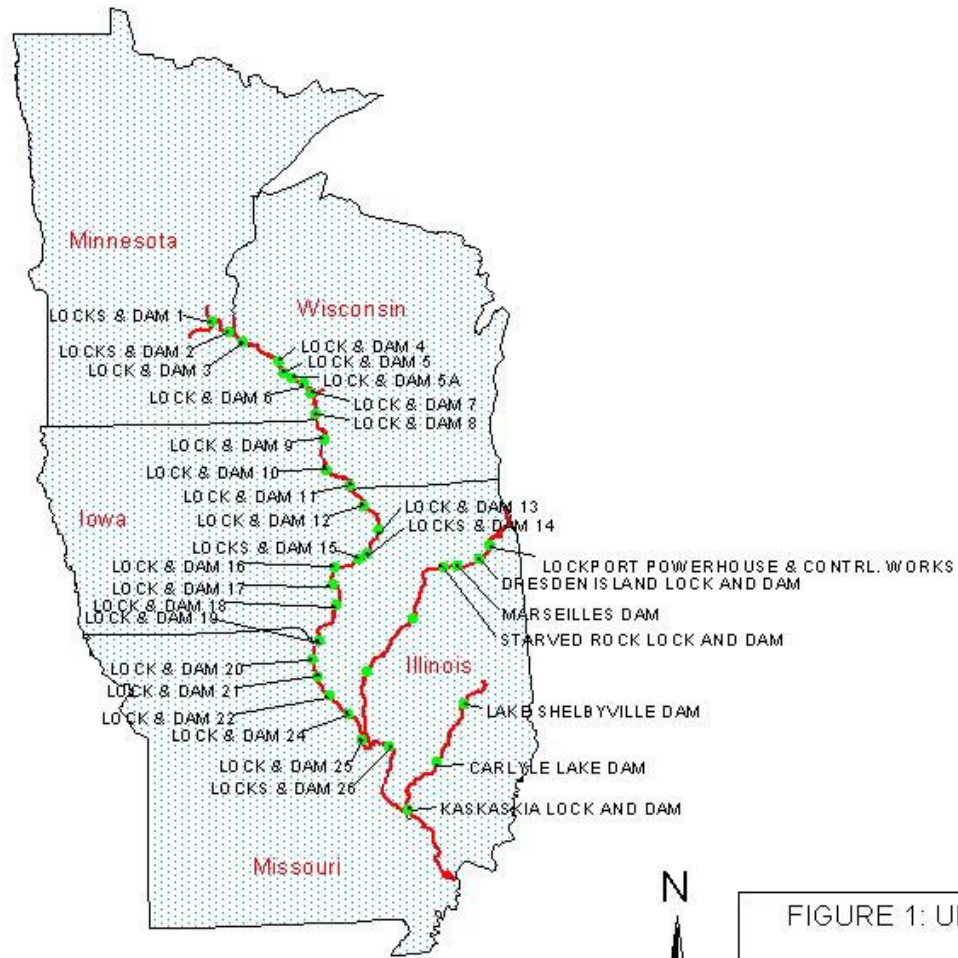


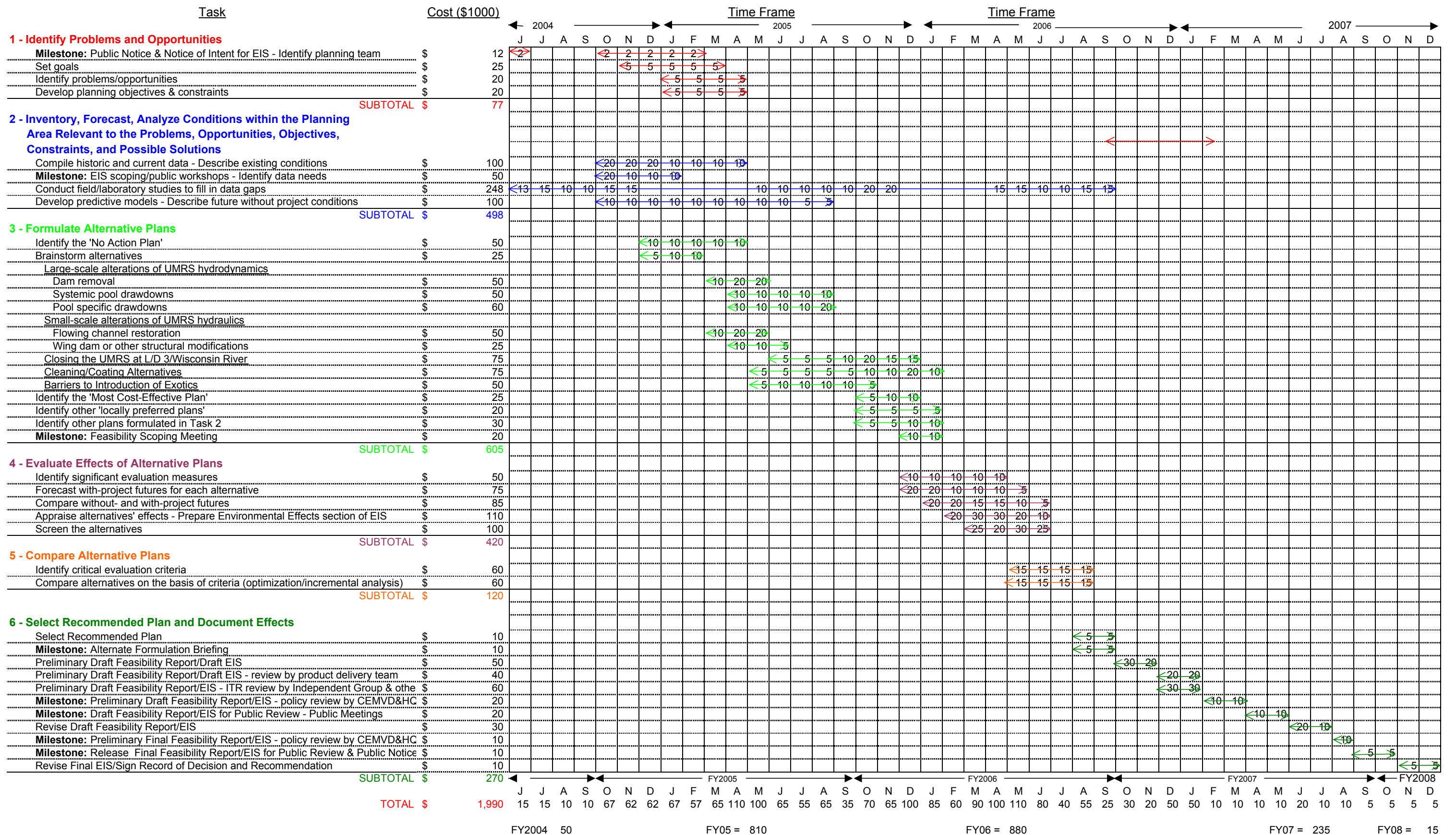
FIGURE 1: UPPER MISSISSIPPI RIVER SYSTEM

U.S. ARMY ENGINEERING DISTRICT, ST. PAUL
MISSISSIPPI RIVER DIVISION

200 0 200 400 Kilometers



Figure 2 - Estimated schedule and budget for completing a Feasibility Study of measures for managing zebra mussels in the 9-foot navigation channel of the Upper Mississippi River.



The following agencies and institutions would be actively involved and responsible during each task:

CEMVP, CEMVR, CEMVS, CEMVD, CELRC, CEERDC, USFWS, USGS, USCG, USEPA, Minnesota DNR, Wisconsin DNR, Iowa DNR, Illinois DNR, Missouri DNR, other federal, state, and local agencies, non-governmental organizations.