FINAL ENVIRONMENTAL ASSESSMENT

WITH

FINDING OF NO SIGNIFICANT IMPACT

REGULATING WORKS PROJECT
MOSENTHEIN/IVORY LANDING PHASE 4
MIDDLE MISSISSIPPI RIVER MILES 175-170
ST. CLAIR COUNTY, IL
ST. LOUIS CITY, MO

APRIL 2014

US Army Corps
of Engineers
St. Louis District

U.S. Army Corps of Engineers, St. Louis District
Regional Planning and Environment Division North
1222 Spruce St.
St. Louis, MO 63103-2833

TABLE OF CONTENTS

Contents

TABLE OF CONTENTS i
1. Purpose of and Need for Action 1
2. Alternatives Including the Proposed Action 5
3. Affected Environment 11
Physical Resources 11
Biological Resources 13
Socioeconomic Resources 16
Historic and Cultural Resources 18
4. Environmental Consequences 19
Physical Resources 19
Biological Resources 21
Socioeconomic Resources 24
Historic and Cultural Resources 24
Climate Change 25
Cumulative Impacts 27
Mitigation 32
5. Relationship of Proposed Action to Environmental Requirements 32
6. Conclusion 33
7. List of Preparers 33
8. Literature Cited. 34
FINDING OF NO SIGNIFICANT IMPACT (FONSI) 38
Appendix A. Summary of Research on the Effects of River Training Structures on Flood Levels .....
Appendix B. Biological Assessment .....
Appendix C. Cumulative Impacts Analysis .....
Appendix D. Clean Water Act Section 404(b)(1) Evaluation .....
Appendix E. Public Comments and Responses .....
Appendix F. Agency and Tribal Government Coordination .....
Appendix G. Distribution List .....

1. Purpose of and Need for Action

The Congress of the United States, through the enactment of a series of Rivers and Harbors Acts beginning in 1824, authorized the Secretary of the Army, by and through the U.S. Army Corps of Engineers St. Louis District (District), to provide a safe and dependable navigation channel, currently 9 feet deep and not less than 300 feet wide, with additional width in the bends as required, on the Middle Mississippi River (MMR).[1] The MMR is defined as that portion of the Mississippi River that lies between its confluence with the Ohio and the Missouri rivers (hereinafter referred to as the Project; Figure 1). This ongoing Project is also commonly referred to as the Regulating Works Project. The Regulating Works Project utilizes bank stabilization and sediment management to maintain bank stability and ensure adequate navigation depth and width. Bank stabilization is achieved by revetments, while sediment management is achieved by river training structures, i.e. dikes. Other activities performed to obtain the navigation channel are rock removal and construction dredging. The Project is maintained through dredging and any needed maintenance to already constructed features. The long-term goal of the Project, as authorized by Congress, is to provide a sustainable and safe navigation channel and reduce federal expenditures by alleviating the amount of annual maintenance dredging and the occurrence of vessel accidents through the construction of regulating works. Therefore, pursuant to the Congressionally authorized purpose of the Project, the District continually monitors areas of the MMR that require frequent and costly dredging to determine if a long-term sustainable solution through regulating works is reasonable.

---

[1] Congress originally authorized the project of improving navigation of the Mississippi River from the mouth of the Missouri to New Orleans in the Rivers and Harbors Act dated May 24, 1824, by the removal of trees that were endangering the safety of navigating the river. In the Rivers and Harbors Act dated June 10, 1872, Section 2, Congress mandated that an examination and/or survey be completed of the Mississippi River between the mouth of the Missouri River and the mouth of the Ohio River, providing the first Congressional action to define this portion of the Mississippi River as distinct from the rest of the Mississippi River. Congress authorized the specific improvement of the Mississippi River between the mouth of the Missouri River and the mouth of the Ohio River in the Rivers and Harbors Act dated March 3, 1873. Between 1874-1892, Congress expanded this section of the Mississippi River to include that portion between the mouth of the Missouri and the mouth of the Illinois, but in the Rivers and Harbors Act dated July 13, 1892, Congress removed this additional section of the river and once again referred to it as the Mississippi River between the mouth of the Ohio River and the mouth of the Missouri River. In the Rivers and Harbors Act dated June 25, 1910, Congress provided exactly how this Project was to be carried out by authorizing the construction, completion, repair, and preservation of "[i]mproving [the] Mississippi River from the mouth of the Ohio River to and including the mouth of the Missouri River: Continuing improvement in accordance with the plan adopted in [1881], which has for its object to eventually obtain by regularization works and by dredging a minimum depth." The 1881 plan called for the removal of rock hindering navigation, the contraction of the river to compel the river to scour its bed (now known as regulating works), and to be aided by dredging, if necessary. The 1881 plan also provided for bank protection improvements (now known as revetment) wherever the river is causing any serious caving of its banks. (Letter from the Secretary of War, dated November 25, 1881, 47th Congress, 1st Session, Ex. Doc. No. 10). The Project's current dimensions of the navigation channel were established in the Rivers and Harbors Acts dated January 21, 1927 and July 3, 1930. The Rivers and Harbors Act dated January 21, 1927 modified the Project pursuant to the Chief of Engineers recommendations, which further detailed the purpose of the Project to construct the channel through regulating works and augment this by dredging, stating that dredging should be reduced to a minimum. The Project was also later modified to provide for the Chain of Rocks Canal and Lock 27 in the Rivers and Harbors Acts dated March 2, 1945 to address the rock formation hindering navigation in this area, and the rock filled low water dam at the Chain of Rocks was authorized in the Rivers and Harbors Act dated July 3, 1958 to assure adequate depth over the lower gate sills at Locks and Dam 26.

To the extent possible under existing authorities, environmental laws, regulations, and policies, the District considers the environmental consequences of its activities as it constructs and operates the Project and acts accordingly. An important component of each activity is the use of scientific, economic, and social knowledge to understand the environmental context and effects of District actions in a collaborative manner, employing an open, transparent process that respects the views of Federal and State stakeholders, individuals, and groups interested in District activities.

Frequent dredging has been required in the area of the proposed Regulating Works, Mosenthein/Ivory Landing Phase 4 Construction work area (Mosenthein/Ivory Landing Phase 4 work area; see a detailed discussion of this in Section 3, Affected Environment.) Therefore, after analysis of this area, the District concluded that construction of the Mosenthein/Ivory Landing Phase 4 work area is reasonable and necessary to address the repetitive channel maintenance dredging in order to provide a sustainable, less costly navigation channel in this area. Bankline failures and associated channel widening have contributed to navigation channel shoaling (shallowing) and loss of private land in the area. The District has concluded through analysis and modeling that construction of a river training structure and revetments would provide a sustainable alternative to repetitive maintenance dredging. Construction of the Mosenthein/Ivory Landing Phase 4 work area is proposed to begin in 2014.

The planning of specific construction areas, including the Mosenthein/Ivory Landing Phase 4 work area, requires extensive coordination with resource agency partners and the navigation industry. The U.S. Fish and Wildlife Service, Missouri Department of Conservation, Illinois Department of Natural Resources, and multiple navigation industry groups were involved in the planning of the Mosenthein/Ivory Landing Phase 4 work area to avoid and minimize any impacts on the navigation industry and environmental resources.

Prior Reports - This site-specific Environmental Assessment (EA) is tiered off of the 1976 Environmental Impact Statement (1976 EIS) covering the District's Regulating Works Project – *Mississippi River between the Ohio and Missouri Rivers (Regulating Works),* (USACE 1976). The 1976 EIS was recently reviewed by the District to determine whether or not the document should be supplemented. The District has concluded that the Regulating Works Project has not substantially changed since 1976 but that there are significant new circumstances and information on the potential impacts of the Regulating Works Project on the resources, ecosystem and human environment to warrant the preparation of a Supplemental EIS (SEIS).

The significant new circumstances and information on the potential impacts of the Regulating Works Project relevant to this EA include the following:

- New federally threatened and endangered species have been listed since preparation of the 1976 EIS. Information on threatened and endangered species and impacts on those species can be found in Section 3, Section 4, and Appendix B of this document.
- New information exists on the changes in average river planform width (the river's outline or morphology as defined by the tree line) in response to river training structure placement. Information on recent studies of planform width can be found in Section 3 of this document.

- New information exists on the impacts of river training structures and dredging on fish and macroinvertebrates. Information on fish and macroinvertebrates and projected impacts can be found in Sections 3 and 4 of this document.
- The District has implemented new programs to restore fish and wildlife habitat on the MMR. Information on the Biological Opinion Program and the Avoid and Minimize Program can be found in Section 4 of this document.
- New information exists on the effects of navigation on fish and wildlife resources. Information on navigation effects can be found in Appendix C, Cumulative Impacts Analysis.

The Mosenthein/Ivory Landing Phase 4 EA has incorporated new information and circumstances relevant to the impacts of the action on the environment to the greatest extent possible. Should the analyses undertaken as part of the SEIS process reveal any new impacts on the resources, ecosystem, and human environment not accounted for in this EA, measures will be taken within our authority to avoid, minimize, and/or compensate for the impacts during that process as appropriate. Information on the SEIS can be found on the District's SEIS web site:

http://www.mvs.usace.army.mil/Missions/Navigation/SEIS.aspx

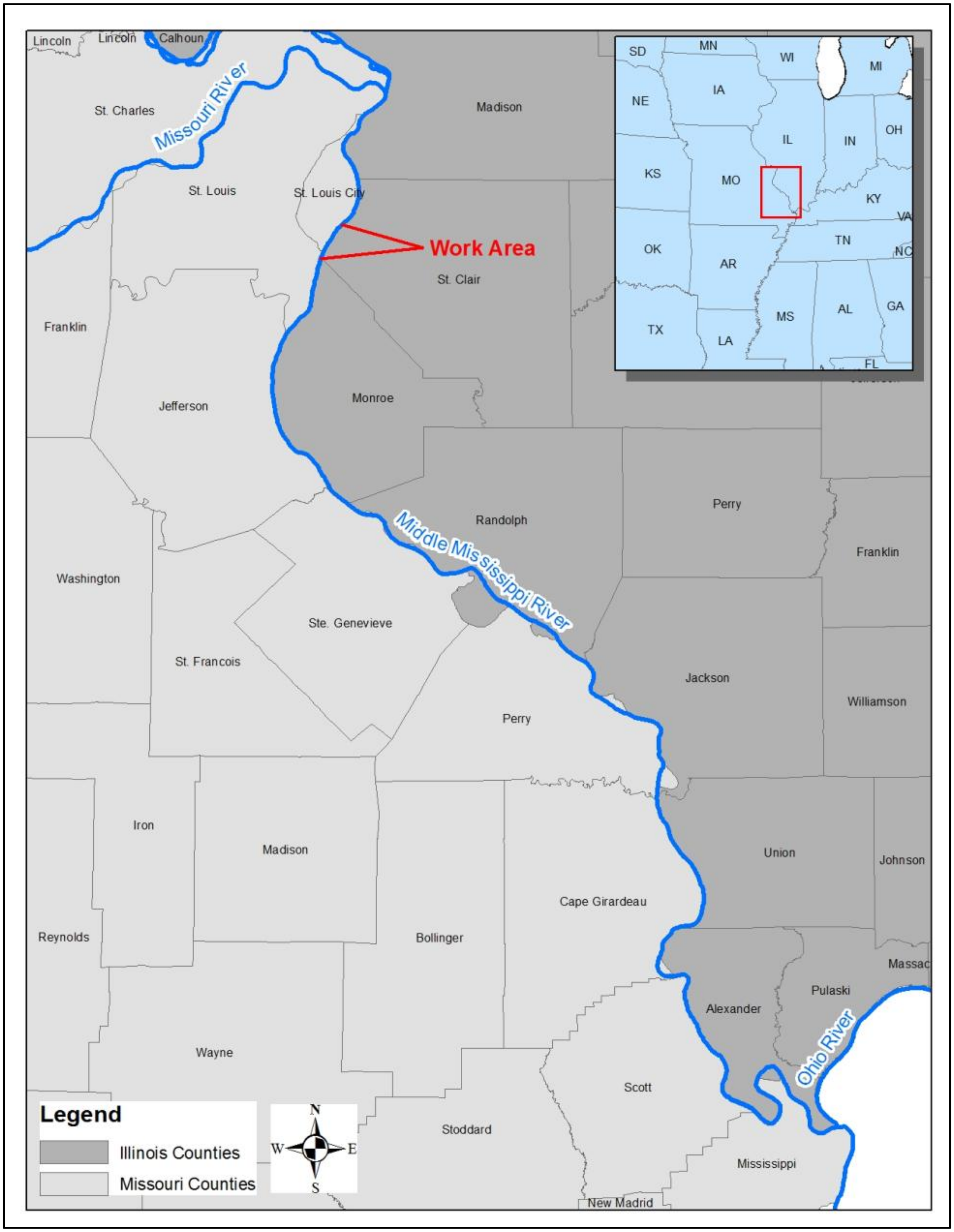


Figure 1. Work area location.

2. Alternatives Including the Proposed Action

This section describes the alternatives or potential actions that were considered as ways to address the issues with maintaining the authorized depth and width of the navigation channel at the Mosenthein/Ivory Landing Phase 4 work area. Alternatives will be described and their environmental impacts and usefulness in achieving the Project objectives will be compared.

Alternative 1: No Action Alternative. The No Action Alternative consists of not constructing any new river training structures or revetment in the work area but continuing to maintain the existing river training structures. Dredging would continue as needed to address the shoaling issues in the work area to fulfill the Project's navigation purpose. Future loss of land due to bankline erosion would affect privately-owned property along the river, which includes agriculture, commercial, industrial, and residential. Flood protection infrastructure could also be impacted.

Alternative 2: Proposed Action. The Proposed Action consists of constructing rootless dike[2] 173.4L and placing bankline revetment at four locations on the left descending bank (L) from RM 175 to 171 (see Table 1 and Figures 2 and 3 below).

Table 1. Features associated with the Proposed Action.

Location by river mile	Proposed Feature	Purpose
173.4 (L)	Construct new rootless dike 550 feet long. Top elevation will be 389 feet (+15 feet Low Water Reference Plane).	Needed to constrict the channel and increase capacity to transport sediment.
175 – 171 (L)	Place approximately 11,500 linear feet of new revetment intermittently from RM 175-171.	Needed to prevent bankline erosion and associated channel widening and shoaling.

[2] A rootless dike is a dike that does not tie in to the bankline.

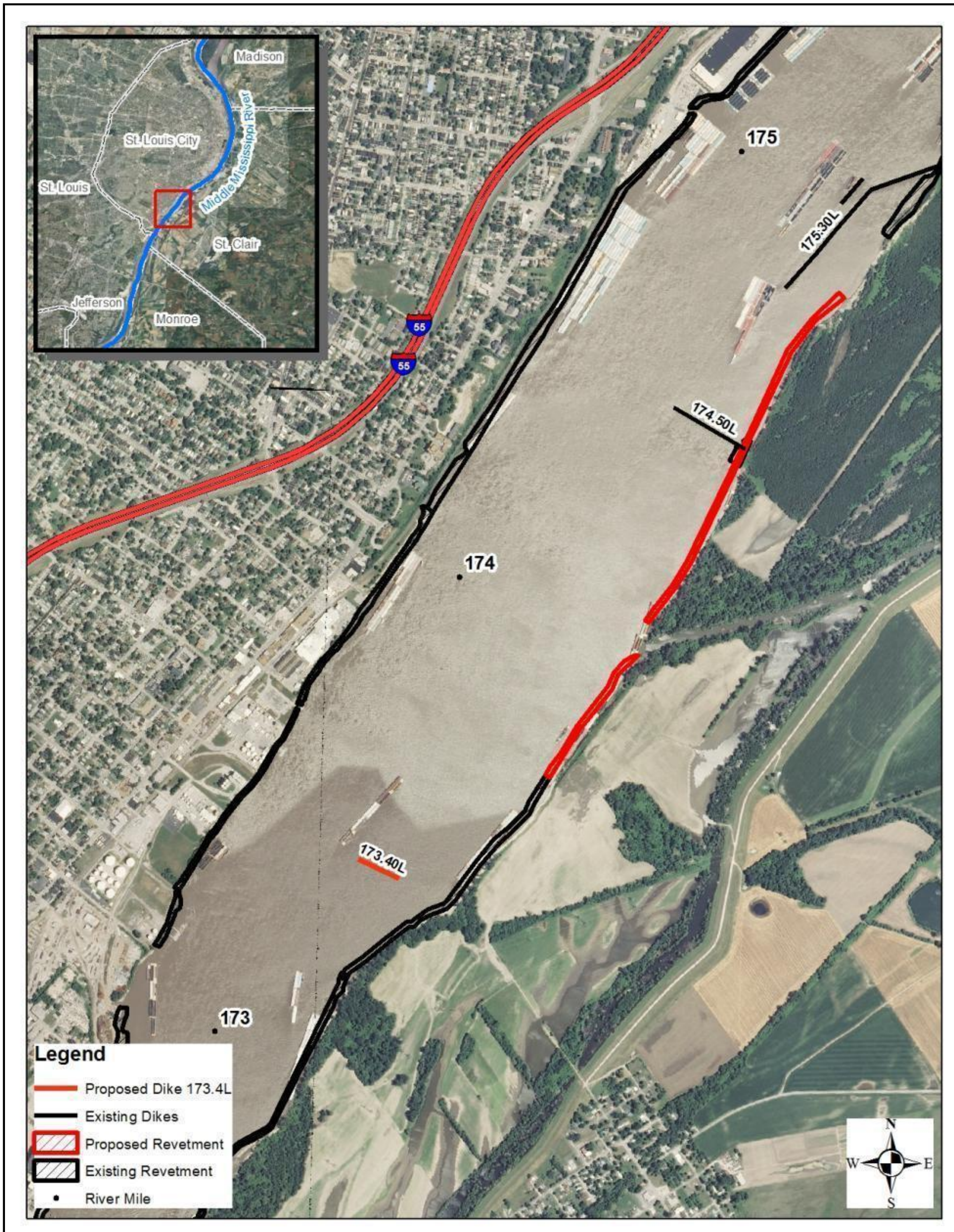


Figure 2. Locations of proposed revetment and proposed dike 173.4L.

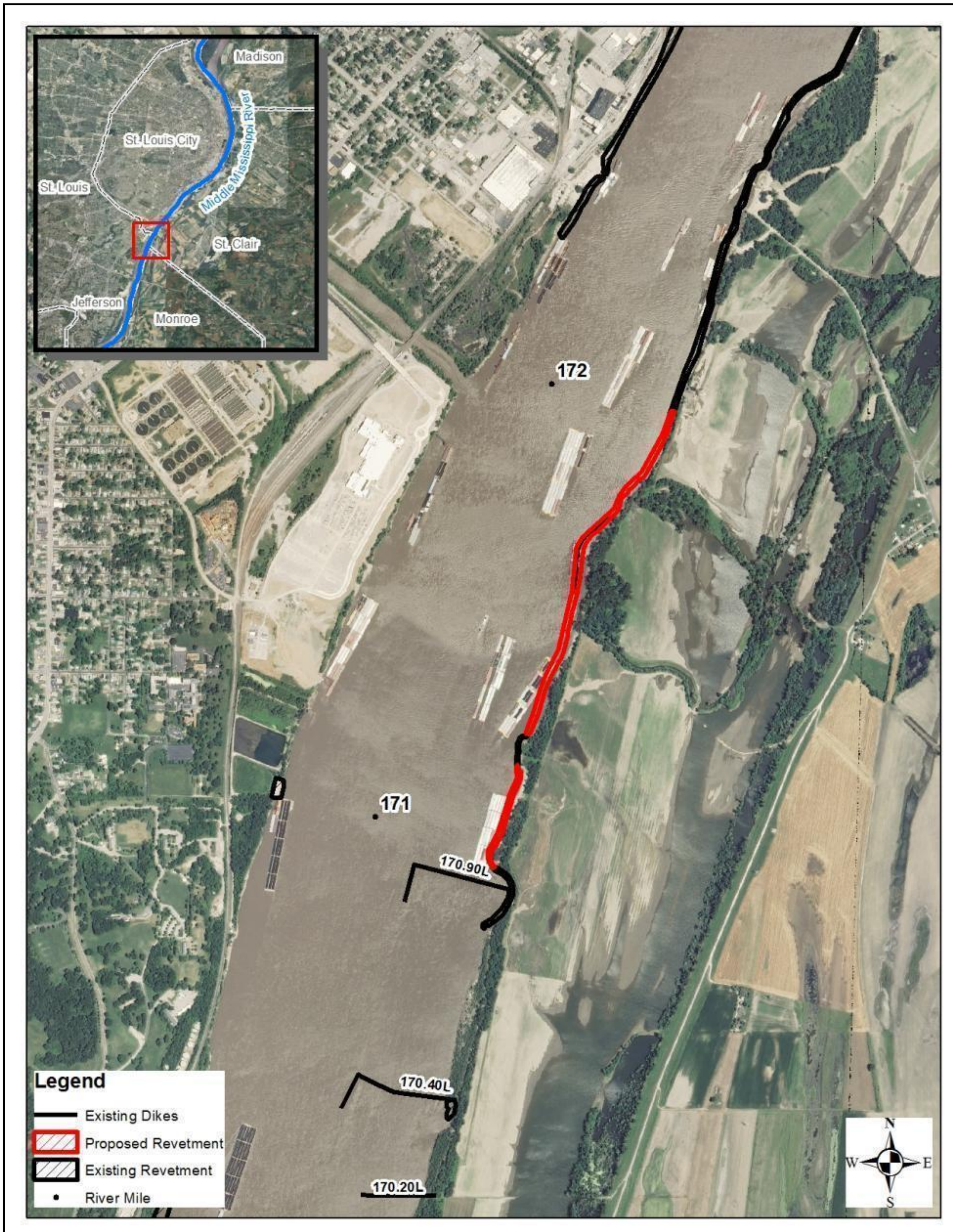


Figure 3. Locations of proposed revetment between river miles 172 and 171.

Development of Alternatives - The District has concluded Alternatives 1and 2 are the only reasonable alternatives that meet the Project purpose and should be extensively evaluated. The District's alternative evaluation process considered only those alternatives that will obtain and maintain a safe and reliable 9-foot navigation channel in the work area to be consistent with the objectives and the authority of the Middle Mississippi River Regulating Works Project. The only reasonable, feasible, and authorized methods to keep the navigation channel open is through continued maintenance dredging or construction of regulating works to minimize the dredging required. Some of the other alternatives considered but deemed unreasonable include those discussed in the 1976 EIS. The 1976 EIS adequately addresses why some alternatives are not reasonable, such as ceasing all activity or building locks and dams. Maintenance of the navigation channel in this reach of the river requires frequent, costly dredging. Therefore, pursuant to the Project's authority, the District began developing alternatives to include regulating works to minimize the dredging in this reach of the river, thereby providing a less costly and more reliable navigation channel.

The District developed alternatives using widely recognized and accepted river engineering guidance and practice, and then screened and analyzed 31 different configurations of regulating works with the assistance of a Hydraulic Sediment Response model (HSR model). HSR models are small-scale physical sediment transport models used by the District to replicate the mechanics of river sediment transport. HSR models allow the District to develop multiple configurations of river training structures for addressing the specific objectives of the work area in question in a cost-effective and efficient manner. The process of alternatives development using HSR models starts with the District calibrating the model to replicate work area conditions. Various configurations of river training structures are then applied to the models to determine their effectiveness in addressing the needs of the work area. For the Mosenthein/Ivory Landing Phase 4 work area the District utilized the Carondelet HSR model study. The Carondelet HSR model study analyzed 31 different configurations of river training structures to determine the best combinations for reducing the need for dredging in the lower Mosenthein/Ivory reach while minimizing environmental impacts and not impacting fleeting areas in the vicinity. Ultimately, construction of a new dike at RM 173.4L was determined to provide the best results for the work area. Detailed information on the Alternatives considered can be found in the on-line Carondelet HSR model study report:

http://mvs-wc.mvs.usace.army.mil/arec/Reports_HSR_Model.html

The revetment associated with the Proposed Action is necessary in order to prevent channel widening in the area. The left descending bank in the area has eroded up to 140 feet in the past 20 years. Channel widening has reduced the river's energy and ability to transport sediment in the area, resulting in sediment deposition and repetitive dredging requirements in the navigation channel. The addition of revetment in the proposed locations would maintain current channel planform and prevent future channel widening.

During the alternative evaluation process, the District worked closely with industry and natural resource agency partners to further evaluate potential alternatives in this reach of the river, including the 31 configurations analyzed in the HSR model. The primary concern voiced was the need to avoid impacts to existing barge fleeting locations in the area. Ultimately all partner concerns were satisfactorily resolved and consensus was reached on a path forward. This process resulted in the Proposed Action, which reasonably met the Project purpose while also avoiding/minimizing environmental impacts. Based on this extensive evaluation of alternatives, the District determined that the Proposed Action was the only reasonable alternative to dredging at the current level and that more extensive analysis of any of the additional configurations of regulating works in the EA would be unnecessary. Detailed information on the Alternatives development process, partner agency coordination, and alternatives eliminated from further consideration can be found in the on-line HSR model study report.

Summary of Environmental Consequences - The impacts of each Alternative on the human environment are covered in detail in Section 4, Environmental Consequences. Table 2 below provides a summary of the impacts of each Alternative by resource category.

Table 2. Summary of impacts of the No Action Alternative and the Proposed Action.

	No Action Alternative	**Proposed Action**
Achievement of Project objectives	Does not reduce the need for repetitive maintenance dredging or address bankline erosion in the area, and, therefore, does not meet the Project objectives.	Is expected to reduce the amount of repetitive maintenance dredging and stabilize banklines in the area, thereby reducing federal expenditures and meeting Project objectives.
Impacts on Stages	No impacts anticipated.	No impacts anticipated at average and higher flows. Trend toward slightly lower stages at low flows expected to continue.
Impacts on Water Quality	Localized, temporary increase in suspended sediment concentrations at discharge sites.	Localized, temporary increase in suspended sediment concentrations during construction activities. Decrease in suspended sediment in immediate vicinity of revetment long-term due to reduction in bankline erosion.
Impacts on Air Quality	Minor, local, ongoing impacts due to use of dredging equipment.	Minimal air quality impacts; below de minimis levels.
Impacts on Fish and Wildlife	Entrainment of fish and macroinvertebrates at dredge locations. Avoidance of dredge and disposal areas by mobile organisms. Loss of fish and macroinvertebrates at disposal sites.	Avoidance of sites during construction. No conversion of aquatic habitat to terrestrial. Increased fish and macroinvertebrate use of structure locations due to increased bathymetric, flow, and substrate diversity. Some loss of fish and macroinvertebrate habitat due to reduced woody debris inputs.
Impacts on Threatened and Endangered Species	May affect but not likely to adversely affect threatened and endangered species.	No significant impacts to threatened and endangered species anticipated.
Impacts on Navigation	Increasing requirement for repetitive maintenance dredging due to continued bankline erosion; increasing potential for barge groundings	Reduction in the amount and frequency of repetitive maintenance dredging in the area; reduction in barge grounding rates
Impacts on Historic and Cultural Resources	Impacts to historic and cultural resources unlikely.	No known historic resources would be affected. Impacts to unknown historic and cultural resources unlikely.

3. Affected Environment

This section presents details on the historic and existing conditions of resources within the work area that would potentially be affected by Project-related activities. The section is broken into four resource categories: physical resources, biological resources, socioeconomic resources, and historic and cultural resources. This section does not address impacts of the Alternatives, but provides a background against which Alternatives can be compared in Section 4, Environmental Consequences.

Physical Resources

Stages - Rated gages, locations where both discharge and stage is collected and combined to create a rating curve, are good sources of long term stage and discharge data. Only three rated gages exist on the MMR: St. Louis, Chester and Thebes. Due to backwater effects from the Ohio River the gage at Thebes is not a good indicator of changes in stage over time. Throughout the period of record (1866 to present) the two agencies that have been responsible for the collection of gage data on the MMR are the Corps of Engineers and U.S. Geological Survey (USGS). The USGS has been the primary agency responsible for stream gaging since 1933. Due to discrepancies in methodology and instrumentation used by the Corps and USGS it is impossible to analyze the entire period of record with confidence; therefore, only data collected by the USGS will be used here to describe the changes in stage for fixed discharges over time (Watson et al. 2013a; Watson et al. 2013b; Huizinga 2009; Munger et al. 1976).

Stages have been decreasing over time for flows below 200,000 cfs at the St. Louis gage (see Figure 4 below). For other in-bank flows between 200,000 cfs and 500,000 cfs there has been no change over time. There is a slight upward but statistically insignificant trend for stages at the overbank flow of 700,000 cfs. Stages at Chester for lower in-bank flows up to 200,000 cfs have decreased with time. There was no change in stages at flows of 200,000 cfs and 400,000 cfs. There was a slightly increasing trend at 300,000 cfs. For overbank flows of 500,000 cfs and 700,000 cfs, there were slight increasing trends observed at the Chester gage.

In general, at both the St. Louis and Chester gages there has been a decrease in stage over time for lower flows, no change in stages over time for flows between midbank and bankfull, and a slight increase in stages for high overbank flows (Huizinga 2009). Huizinga (2009) and Watson et al. (2013a) attributed the slight increase in out of bank flows to the construction of levees and the disconnection of the river from the floodplains. Both Watson et al. (2013a) and Huizinga (2009) observed a shift occurring in the out of bank flows in the mid-1960s and attributed it to the completion of the Alton to Gale levee system which paralleled the entire MMR. At these high flows navigation structures are submerged by 7 to 10 feet.

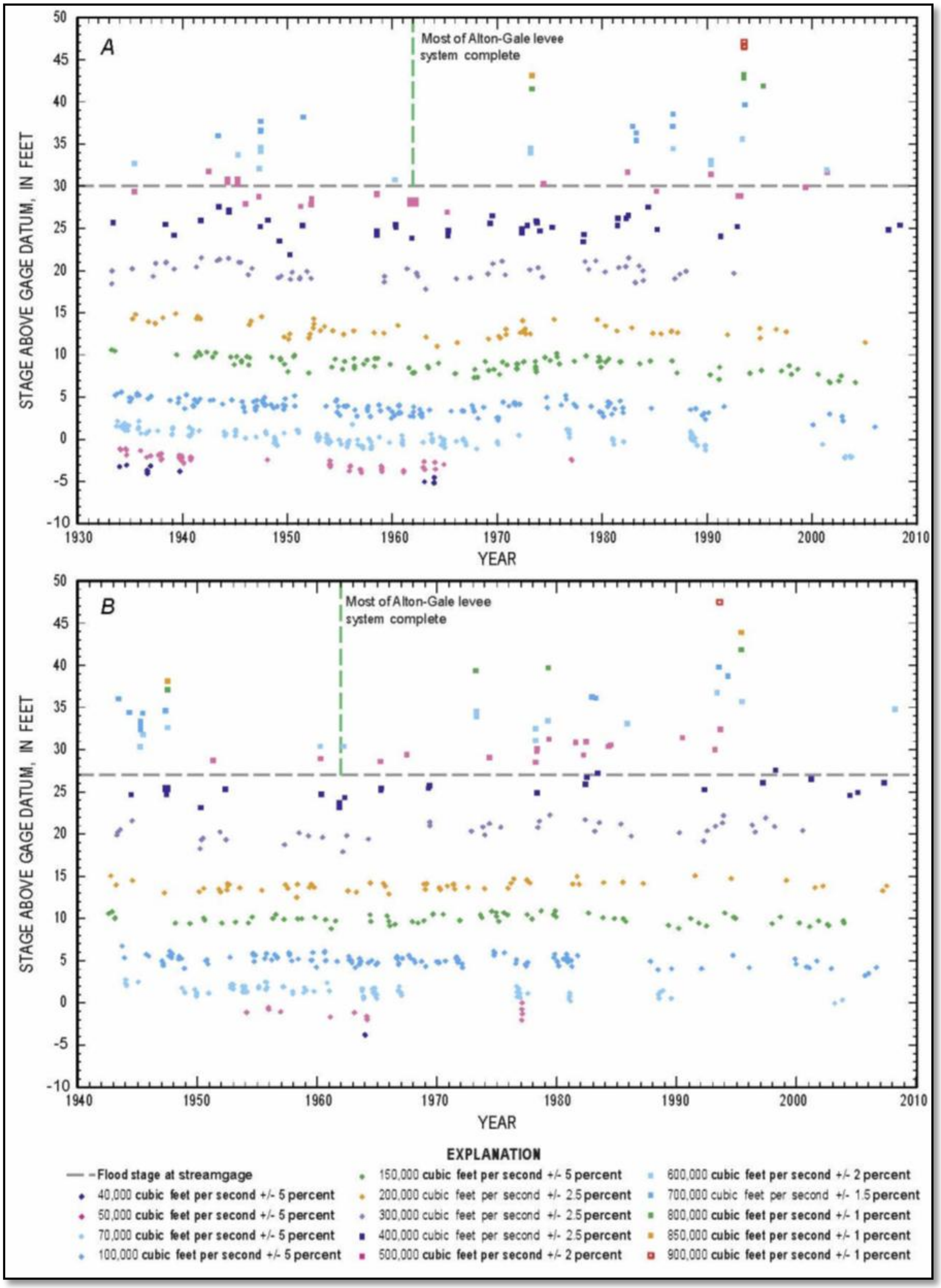


Figure 4. Stage for a given discharge range with time from measurements made at the streamgages at (A) St. Louis, Missouri, and (B) Chester, Illinois, on the Middle Mississippi River (from Huizinga 2009).

Water Quality – Consideration of water quality encompasses a wide range of physical, hydrologic, and biological parameters. Watershed influences, including tributary streams, point and non-point pollution sources, flow alteration due to navigation structures, and drought and flood events all influence water quality. Variations in land use practices, cover types, and watershed area will determine the level and type of sediment, nutrient, and contaminant inputs into the Mississippi River and its tributaries. The Mississippi River has a long history of water quality impairment due to contamination from industrial, residential, municipal, and agricultural sources. Recent changes in wastewater treatment laws and technologies, regulation of point source discharges, and changes in public awareness have contributed to overall improvements in water quality.

Section 303(d) of the Clean Water Act requires states to generate lists of impaired water bodies every two years. Impaired water bodies are those that do not meet state water quality standards for the water bodies' designated uses. On the 2012 303(d) list for Illinois, the Mississippi River in the vicinity of the work area was listed as impaired for fish consumption due to mercury and PCB contamination and impaired for public and food processing water supplies due to manganese concentration. The Mississippi River is not on the 2012 303(d) list for Missouri.

Illinois has fish consumption advisories for the Mississippi River for channel catfish (one meal per week), common carp (one meal per week), and sturgeon (one meal per month) due to PCB contamination. Missouri has fish consumption advisories for the Mississippi River for shovelnose sturgeon (1 per month) due to PCB and chlordane contamination, and for flathead catfish, blue catfish, channel catfish, and common carp (1 per week) due to PCB, chlordane, and mercury contamination.

Air Quality – The Clean Air Act requires the Environmental Protection Agency (EPA) to set National Ambient Air Quality Standards (NAAQS) for six criteria air pollutants: ozone, particulate matter, carbon monoxide, nitrogen oxides, sulfur dioxide, and lead. EPA regulates these pollutants by developing human health-based or environmentally-based permissible pollutant concentrations. EPA then publishes the results of air quality monitoring, designating areas as meeting (attainment) or not meeting (nonattainment) the standards or as being maintenance areas. Maintenance areas are those areas that have been redesignated as in attainment from a previous nonattainment status. A maintenance plan establishes measures to control emissions to ensure the air quality standard is maintained in these areas. On the Missouri side, the Mosenthein/Ivory Landing Phase 4 work area is designated as a nonattainment area for 8-hour ozone (1997 and 2008 standards) and particulate matter and is designated as a maintenance area for 1-hour ozone and carbon monoxide (USEPA 2013). On the Illinois side, the work area is designated as a nonattainment area for 8-hour ozone (2008 standard) and particulate matter and is designated as a maintenance area for 1-hour ozone and 8-hour ozone (1997 standard; USEPA 2013).

Biological Resources

Fish and Wildlife – The changes in fish and wildlife habitat in the Mississippi River Basin that have occurred over the past 200 years are well documented. Many studies have analyzed the historic changes in habitat in the Mississippi River Basin from pre-colonization times to present day (e.g., Simons et al. 1974; UMRBC 1982; Theiling et al. 2000; WEST 2000; and Heitmeyer

2008). A variety of actions have impacted the makeup of the Mississippi River basin since colonization including urbanization, agriculture, levee construction, dam construction, and river training structure placement. Many of the changes in the Middle Mississippi River planform are attributable to improvements made for navigation including river training structure placement and associated sedimentation patterns.

An analysis of changes in river planform in the MMR was recently conducted by the District (Brauer et al. 2005; Brauer et al. 2013). The analysis utilized historic and modern maps, surveys, and aerial photography to calculate changes through time in planform width, channel width, channel surface area, side channel width, etc. The analysis demonstrates that the MMR went through a period of planform widening in the mid-nineteenth century followed by a period of planform narrowing from the end of the nineteenth century through the mid-twentieth century. The period of narrowing corresponded to the widespread use of river training structures and bank protection for navigation improvements. The first training structures were mainly permeable wooden structures which focused the river's energy into the main channel by reducing the velocities between the structures, causing sediment to deposit in channel border areas. This sediment deposition caused a significant narrowing effect on the channel. Since 1968, however, the channel width appears to have reached dynamic equilibrium with very little change (see Figure 5 below). In the 1960s, the Corps began constructing impermeable dikes primarily out of stone. The use of impermeable dikes reduced the rate of deposition between the structures when compared to the previously used permeable structures. Another change was the reduction of the design elevation of dike fields. Unlike in the past, the area between the structures did not fill with sediment, grow vegetation and become part of the floodplain. In the 43 years between 1968 and 2011 the average planform width remained relatively steady with a net reduction in average planform width of 167 feet. This was the result of the changes in structure material, structure elevation, and bank protection.

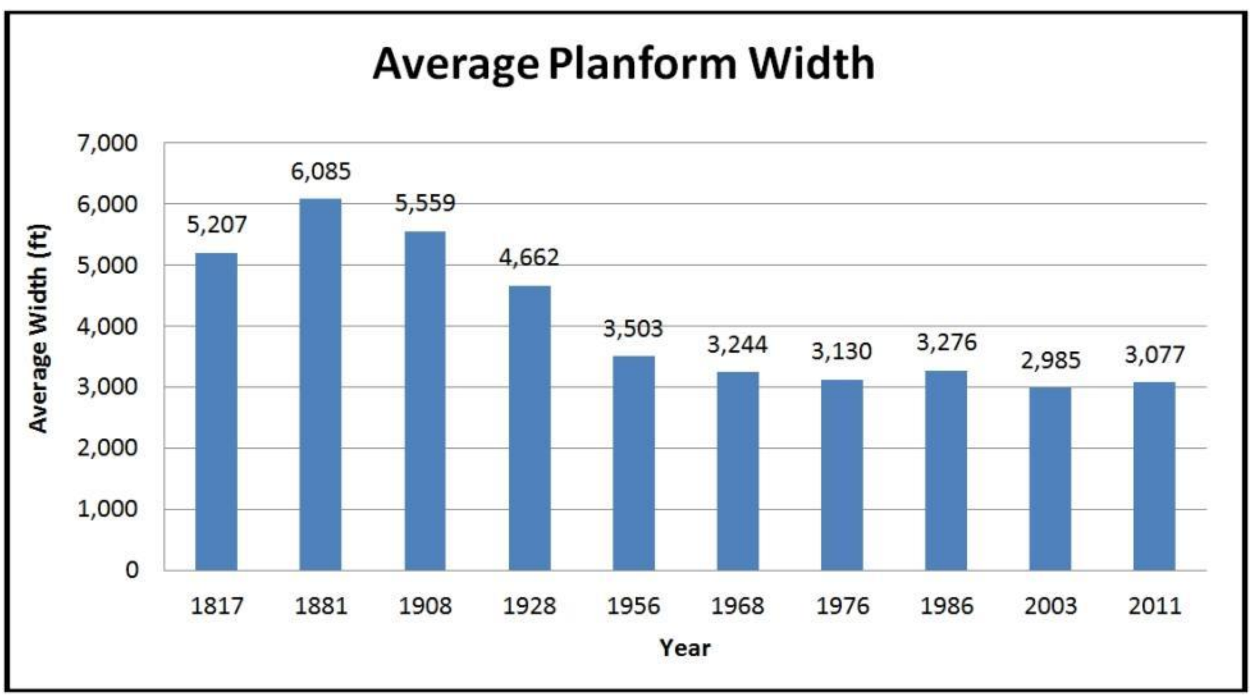


Figure 5. Average planform width of the MMR from 1817 to 2011.

In response to natural resource agency partner concerns about the potential impacts of traditional dikes on fish and wildlife habitat, the St. Louis District began to experiment with innovative dike configurations that attempt to achieve the navigational objectives of a safe and dependable navigation channel in an environmentally sensitive manner. The District has designed and implemented many different dike configurations including notched dikes, rootless dikes, L-dikes, W-dikes, chevron dikes, multiple roundpoint structures, etc. The intent of the innovative dike designs is to provide bathymetric (depth) and flow diversity compared with the traditional structures constructed since the 1960s while maintaining the function of deepening the navigation channel. The District currently builds very few traditional wing dike structures in the MMR.

The fish community in the area is expected to be typical of the Middle Mississippi River fish community in general. Fish community monitoring in the area conducted from 2003 to 2007 (RM 183 to 182; Schneider 2012) collected a total of 35 species of fish representing 14 families. The most commonly encountered native species included channel catfish (*Ictalurus punctatus*), freshwater drum (*Aplodinotus grunniens*), gizzard shad (*Dorosoma cepedianum*), goldeye (*Hiodon alosoides*), blue catfish (*I. furcatus*), shoal chub (*Macrhybopsis hyostoma*), smallmouth buffalo (*Ictiobus bubalus*), and flathead catfish (*Pylodictis olivaris*). These species accounted for approximately 85% of the fish captured, by number. Also included in the collections were 5 species of non-native fish including silver carp (*Hypophthalmichthys molitrix*), grass carp (*Ctenopharyngodon idella*), common carp (*Cyprinus carpio*), goldfish (*Carassius auratus*), and bighead carp (*Hypophthalmichthys nobilis*). These species accounted for approximately 5% of the fish captured, by number. Silver carp were likely under-represented in the collection due to the sampling methodologies employed. The Middle Mississippi River sees some commercial and recreational fishing pressure. Commercial fishermen typically target common carp, bigmouth and smallmouth buffalo, catfish, freshwater drum, and recently silver carp. Recreational fishermen typically target catfish.

Macroinvertebrates are an important part of the river ecosystem as they serve as a food source for a variety of fish and wildlife species. Common macroinvertebrate fauna encountered in the MMR consist of a variety of oligochaete worms, flies, mayflies, caddisflies, and stoneflies. Sampling by Battle et al. (2007) near Cape Girardeau, Missouri showed densities of macroinvertebrates in fine substrates downstream from wing dikes ranging from approximately 3,700 to 11,700 individuals per square meter. Sixty-eight taxa were collected from fine sediments with the dominant groups being oligochaete worms, midges, and mayflies. Densities on rocks on the upstream side of wing dikes ranged from 57,800 to 163,000 individuals per square meter. Fifty taxa were collected from rock substrate with the dominant group being caddisflies.

Threatened and Endangered Species – Based on coordination with the U.S. Fish and Wildlife Service, eight federally threatened or endangered species could potentially be found in the area. The eight species, federal protection status, and habitat can be found in Table 3. No critical habitat is located in the work area.

Table 3. Federally listed threatened and endangered species potentially occurring in the work area.

Species	**Status**	**Habitat**
Indiana bat (*Myotis sodalis)*	Endangered	Hibernacula: Caves and mines; Maternity and foraging habitat: small stream corridors with well developed riparian woods; upland and bottomland forests
Least tern (interior population) (*Sterna antillarum*)	Endangered	Large rivers - nests on bare alluvial and dredge spoil islands
Pallid sturgeon (*Scaphirhynchus albus*)	Endangered	Mississippi and Missouri Rivers
Gray Bat *(Myotis grisescens)*	Endangered	Caves and mines; forages over rivers and reservoirs adjacent to forests
Spectaclecase *(Cumberlandia monodonta)*	Endangered	Medium to large rivers with coarse sand and gravel
Sheepnose *(Plethobasus cyphyus)*	Endangered	Medium to large rivers with gravel/mixed sand and gravel
Pink Mucket *(Lampsilis abrupta)*	Endangered	Medium to large rivers with strong currents
Decurrent False Aster *(Boltonia decurrens)*	Threatened	Recently disturbed areas within wet prairies, shallow marshes, and shores of open rivers, creeks, and lakes

Socioeconomic Resources

Navigation - The Middle Mississippi River is a critically important navigation corridor that provides for movement of a wide variety of commodities of local, national, and international importance. The St. Louis Harbor is the third busiest inland port in the nation. Approximately 106 million tons of cargo passed through the MMR in 2011, the most recent year with data available (USACE 2013). Food and farm products (37 million tons), coal (26 million tons), crude materials (14 million tons), fertilizers (12 million tons), and petroleum products (10 million tons) accounted for the majority (93%) of shipments in 2011.

Repetitive channel maintenance dredging occurs regularly in the area from RM 173.5 to 170.5 (see Figure 6). The area has required dredging 35 times since 2000 at an average cost of $240,000 per dredging event, or approximately $650,000 per year.

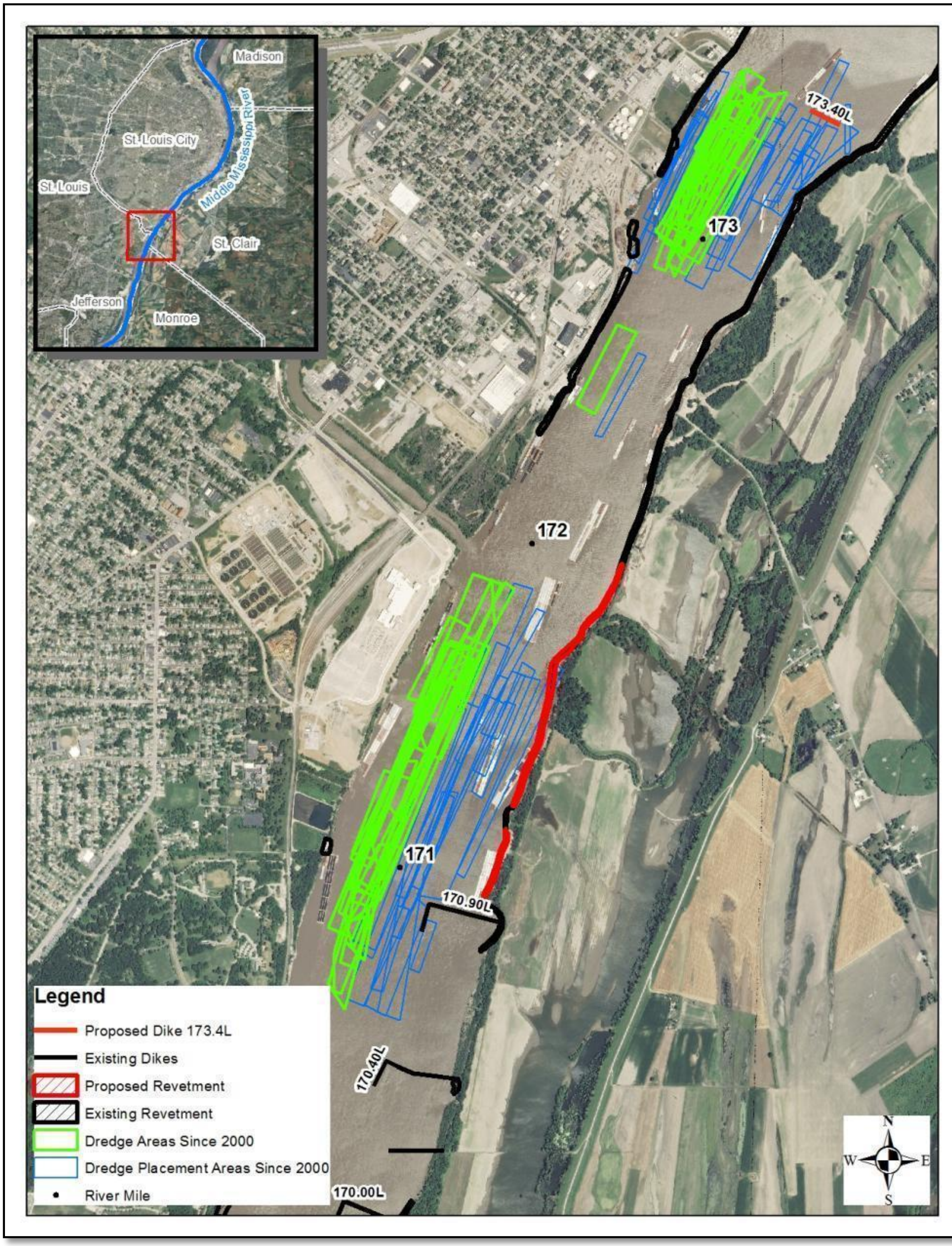


Figure 6. Repetitive dredging areas between river miles 173.5 and 170.5 since 2000.

Historic and Cultural Resources

During the summer of 1988 when the Mississippi River was at one of its lowest levels on record, the St. Louis District Corps of Engineers conducted an aerial survey of exposed shipwrecks on 300 miles of the Mississippi River, within the St. Louis District, between Saverton, Missouri, and the mouth of the Ohio River. The nearest wreck to the proposed features was located approximately at RM 176. No cultural resource was visible on the exposed riverbed at the location. In 2010 and 2013 high resolution multi-scan hydro-surveys of the area were conducted and no topographic anomalies were detected.

The proposed revetments are located on relatively recently accreted lands. The location of the Illinois bank of the Mississippi River between RM 171 and 175 has changed appreciably in the last 150 years. River regulating structures and practices have led to a significant narrowing of the MMR with accretion of land along the Illinois bank. Much of this transformation at this location was due to the "capture" of Arsenal Island. Originally formed upstream on the Missouri side of the river in the first half of the nineteenth century, this ephemeral landform continuously shifted downstream and, moreover, in 1874, the navigation channel shifted from the east to the west of the island. Between 1878 and 1882 the Federal government constructed a dike from the northeastern tip of the island, and then a closing structure south of the dike, which led to rapid land accretion largely closing the eastern channel. Maps and historical narratives indicate that the riverbank generally stabilized near its current location in the 1880s. A pedestrian archaeological survey was conducted along the proposed revetment alignment in 2013 to ensure that no historical structures or features would be adversely affected. Two District archaeologists conducted the survey over the course of two days and no significant resources were encountered.

4. Environmental Consequences

The Environmental Consequences Section of this report details the impacts of the Alternatives on the human environment. The section is organized by resource, in the same order in which they were covered in Section 3, Affected Environment. Within each resource category, impacts will be broken out by Alternative. The No Action Alternative consists of not constructing any new river training structures or revetment in the area but continuing to maintain the existing river training structures. Dredging under the No Action Alternative would continue as needed to address the shoaling issues in the area, presumably at increasing levels due to continued bankline erosion. The Proposed Action consists of constructing rootless dike 173.4L and placing bankline revetment at four locations on the left descending bank from RM 175 to 171.

Physical Resources

Stages

Impacts of the No Action Alternative on Stages – Stages in the vicinity of the work area and the Middle Mississippi River would be expected to be similar to current conditions under the No Action Alternative.

Impacts of the Proposed Action on Stages – With implementation of the Proposed Action, stages at average and high flows both in the vicinity of the work area and on the Middle Mississippi River are expected to be similar to current conditions. An abundance of research has been conducted analyzing the impacts of river training structures on water surfaces dating to the 1940s. This research has analyzed historic gage data, velocity data, and cross sectional data. Physical and numerical models have also been used to determine the effects of dikes on water surfaces. It should be noted that some published research supports the contention that river training structures raise flood heights. A summary of research on the effects of river training structures on flood heights can be found in Appendix A. Based on an analysis of this research by the Corps and other external reviewers, the District has concluded that river training structures do not affect water surface elevations at higher flows.

With respect to water surface elevations at low flows, analysis of the data shows a trend of decreasing stages over time. This decrease could be a result of river training structure placement and/or a decrease in the sediment load in the river due to construction of reservoirs on Mississippi River tributaries (Huizinga 2009). The same conclusion regarding decreasing stages at low flows was reached in the 1976 Regulating Works EIS (USACE 1976). The 1976 EIS concluded that, as a result of stage decreases, many of the remaining side channels in the MMR might be lost at some point in the future due to sedimentation. While much research has been performed on the impacts of river training structures at high flows, similar research has not been performed on the impacts at low flows. However, since the 1976 EIS, there has been an increasing recognition of the importance of side channel habitat on the MMR and increased emphasis on side channel restoration. Through the District's Biological Opinion Program (http://mvs-wc.mvs.usace.army.mil/arec/Bio_Op.html), Avoid and Minimize Program (http://mvs-wc.mvs.usace.army.mil/arec/AM.html), innovative river training structure design, and other restoration initiatives, side channel restoration and preservation on the MMR has occurred and will continue to occur for the foreseeable future, resulting in a substantial preservation of the side channels that existed in 1976. While the Proposed Action may have some minor local effect on water surface elevations at lower flows, any impacts locally or cumulatively are being minimized through the use of innovative river training structures and through other District programs, which have currently seen success in restoring and preserving side channels affected by river training structures.

Water Quality

Impacts of the No Action Alternative on Water Quality – Periodic dredging activities would continue to cause re-suspension of river sediments at the point of discharge, causing turbidity, increased suspended sediment concentration, and decreased light penetration. The impact would be localized and would dissipate quickly. Dredged sediments in the area are typically sand with little associated fines and would, therefore, not be expected to release contaminants into the water column at concentrations that alone or in combination with other contaminants would cause toxic effects to aquatic organisms.

Impacts of the Proposed Action on Water Quality – Construction activities would cause temporary increases in turbidity and suspended sediment concentrations in the immediate vicinity of the structure locations. The impact would be localized and would dissipate quickly. Sediments in the area are typically sand with little associated fines and would, therefore, not be expected to release contaminants into the water column at concentrations that alone or in combination with other contaminants would cause toxic effects to aquatic organisms.

The proposed dike structure is designed to change the sedimentation patterns in the area and would, therefore, cause some minor temporary changes in the suspended sediment concentration in the immediate area. The proposed revetment is designed to reduce bankline erosion in the area and would, therefore, reduce suspended sediment concentration in the immediate vicinity.

Limestone material used for construction could potentially affect local water chemistry (e.g., alkalinity, hardness, and pH). However, given the prevalence of limestone in the watershed geology and the quick dissipation of any associated fine materials in the water column, the impact is likely to be negligible.

The District is currently in the process of obtaining authorization for the work under sections 404 and 401 of the Clean Water Act. All permits necessary for completion of the work have been applied for and will be obtained prior to implementation.

Air Quality

Impacts of the No Action Alternative on Air Quality – Air quality in the vicinity of the work area would be expected to be similar to current conditions. Equipment used for repetitive dredging activities would generate emissions on an occasional, ongoing basis from the use of petroleum products. Impacts would be minor and local in nature.

Impacts of the Proposed Action on Air Quality – When a federal action is being undertaken in a nonattainment area, the federal agency responsible for the action is required to determine if its action conforms to the applicable State Implementation Plan (SIP). A SIP is a plan that provides for implementation, maintenance, and enforcement of the National Ambient Air Quality Standards (NAAQS) and includes emission limitations and control measures to attain and maintain the NAAQS. An analysis was conducted to determine the conformity of the Mosenthein/Ivory Landing Phase 4 work to the SIPs for the states of Missouri and Illinois. As a result of the analysis, the District has concluded that the work would have minimal air quality impacts and they would be below the de minimis levels for the area.

Biological Resources

Fish and Wildlife

Impacts of the No Action Alternative on Fish and Wildlife – Periodic maintenance dredging and dredged material disposal operations would have the potential to affect fish and wildlife resources through direct removal of individual organisms (entrainment) at the dredging site. The degree to which fish and wildlife resources are impacted is largely a factor of the density of the organisms in the area of the dredge cut at the time of dredging operations. Macroinvertebrate densities tend to increase with greater sediment stability, lower water velocities, and higher silt and organic matter concentrations (Galat et al. 2005). Given the shifting nature of the sediments, high water velocities, and low silt concentrations in the main channel of the MMR, the area is not ideal habitat for colonization by bottom-dwelling macroinvertebrates (Koel and Stevenson 2002; Sauer 2004), but likely provides habitat for low densities to exist. Various fish species likely utilize the habitat as well and could be impacted at dredge sites. The Corps' Engineer Research and Development Center published a Technical Note in 1998 that summarized existing literature regarding potential impacts to aquatic organisms from dredging operations (Reine and Clarke 1998). Fish entrainment rates varied widely among species and studies and were reported as ranging from <0.001 to 0.594 fish/cubic yard of material dredged.

The St. Louis District recently contracted a dredge monitoring study for the Chain of Rocks East Canal Levee Project (Blodgett 2010). The project involved the use of sand dredged from the main channel of the MMR for construction of a seepage berm on the Chain of Rocks Canal Levee. Because there was concern that dredging operations could entrain endangered pallid sturgeon in the project area, monitoring of dredged material was conducted to quantify impacts of dredging operations on the fish community. A total of approximately 1,000,000 cubic yards of material was dredged during the project, and fish entrainment monitoring was conducted during approximately 15% of the operation. No pallid sturgeon were captured during the study. Nine shovelnose sturgeon and 38 other fish representing 6 species were captured during the study.

Aside from direct impacts from dredge entrainment, fish and wildlife could also be impacted directly by disposal of dredged material. Organisms in the vicinity of the disposal area could be affected by changes in water quality including increased suspended solids and could be covered by settling sediments. Increased suspended solids in the water column could cause abrasion of body and respiratory surfaces. Most mobile organisms in the vicinity of the disposal location, however, would likely avoid the area during dredging operations. Changes in water quality would be short-lived and localized in extent.

Recovery of fish and wildlife resources at the dredge and disposal location occurs over a period of weeks, months, or years, depending on the species in question (USACE 1983). Areas with unstable sediment such as those in the main channel of the MMR are much more likely to have associated fish and wildlife species more adapted to physically stressful conditions and, therefore, would be more likely to withstand stresses imposed by dredging and disposal and recover more quickly (USACE 1983).

In summary, the amount of dredging going forward would increase due to continued bankline erosion. Dredging and disposal impacts would include potential entrainment of aquatic species as well as behavioral changes associated with noise and turbidity levels. Some mortality of individual fish and invertebrates would be anticipated. Overall impacts to the fish and invertebrate communities in the area would be expected to be localized, minor, and short-term in nature.

Impacts of the Proposed Action on Fish and Wildlife

Dike Effects – The hydrodynamics around training structures are complex and vary greatly depending upon the type of training structure in question and where it is located within the river channel. A traditional wing dike constructed perpendicular to flow and tied in to the river bank would be expected to deepen the adjacent navigation channel, cause a scour hole to develop at the dike tip, and cause sediment accretion downstream from the structure near the river bank. Shields (1995) studied 26 groups of traditional dikes in the Lower Mississippi River and determined that the aquatic volume and area of associated low-velocity habitat (important aquatic habitat) were reduced by 38% and 17%, respectively. Most of the changes occurred shortly after construction, and after initial adjustment, habitat area and volume fluctuated around a condition of dynamic equilibrium. As detailed in Section 3 above, dike construction on the MMR has, historically, caused a narrowing of the river planform over time due to this sediment accretion process followed by growth of terrestrial vegetation. However, the analysis of changes in river planform in the MMR recently conducted by the District (Brauer et al. 2005; Brauer et al. 2013) demonstrates that channel widths in the MMR appear to have reached a state of dynamic equilibrium where very little conversion to terrestrial habitat is occurring subsequent to river training structure placement. In addition, innovative structures such as the proposed rootless dike are intended to provide bathymetric diversity, flow refuge, and split flow conditions that differ from traditional wing dikes. Based on the model studies conducted for the work area and District experience with similar river training structures, the proposed dike is expected to deepen the adjacent navigation channel, create bathymetric diversity in the immediate vicinity of the structure, provide flow refuge immediately downstream, and create split-flow conditions at certain river stages.

Regardless of the specific configuration of the river training structures utilized, rock structures can provide improved habitat for fish by providing areas of reduced flow, a more diverse substrate, and additional cover. In addition, they can provide more suitable substrate for a wide variety of benthic organisms. Barko et al. (2004) found that species richness was greatest at wing dikes in the Middle Mississippi River for both adult and age-0 fishes when compared with main channel borders. However, they did find differences in species composition. Hartman and Titus (2009) studied dikes and reference sites on the Kanawha River, West Virginia and found that fish used dikes as much as or more than sites without dikes and that differences in taxonomic composition occurred. A study of larval fish use of dike structures on the Kanawha River found significantly higher capture rates of larval fish at dike sites than at reference sites (Niles and Hartman 2009). The difference in capture rates was attributed to reduced velocities provided by dikes. On the Upper Mississippi River, Madejczyk et al. (1998) found that fish abundance and diversity measures differed little among channel border habitat types in Pool 6, but significantly larger fish were present at locations with structure (wing dikes, woody snags) than at sites with bare shorelines.

Limited sampling conducted by the St. Louis District at an offset dike field in the MMR at RM 60.0 to 57.5 (USACE 2012) showed an increase in bathymetric, flow, and sediment diversity from pre-construction to post-construction and showed similar fish community composition pre- and post-project. Schneider (2012) investigated fish community and habitat changes associated with chevron dike construction in the MMR St. Louis Harbor and found increased fish and habitat diversity associated with chevrons dikes as compared to pre-construction conditions and open water control sites.

In summary, the proposed rootless dike 173.4L is not expected to result in a loss of aquatic habitat due to sedimentation and conversion to terrestrial habitat. The structure is expected to increase bathymetric, flow, and sediment diversity in the immediate vicinity of the structure. Fish response to these changes in habitat is difficult to predict quantitatively, but, based on prior studies, fish use of the area may increase after construction related disturbance ends.

Revetment Effects – The proposed revetment is designed to prevent the continued erosion and migration of the associated bankline in the area. Preventing bankline erosion could have a minor negative impact on the fish community in the area. Bankline erosion frequently leads to woody debris inputs to the system. Woody debris is an important habitat component in the MMR, providing nutrient inputs, macroinvertebrate colonization substrate, and habitat diversity for fish and wildlife resources. Although woody debris inputs through bankline erosion would be prevented, woody debris would still enter the system from the area during overbank flow events.

Similar to rock dike structures, revetment can improve fish habitat by providing substrate diversity, additional cover, and more suitable substrate for a wide variety of benthic macroinvertebrate colonization (Beckett et al. 1983; Bingham 1982; Dardeau et al. 1995; Fischenich 2003; Nord and Schmulbach 1973; Payne et al. 1989; White et al. 2010). Farabee (1986) studied fish at two revetted and two natural main channel border sites in Pool 24 over a 3-year period. Although the number of species at each bankline type were similar, total fish collected was greater on banklines with revetments, especially where larger stone was present. On the Lower Mississippi River, Pennington et al. (1983) found that the numbers of fish species taken from natural and revetted banks were similar. However, the relative abundance of individual species was different in the two habitats, with sport and commercial species more abundant by weight on revetted banks.

In summary, the proposed revetment is likely to reduce the amount of beneficial woody debris entering the system from the area through bankline erosion. However, woody debris would continue to enter the system during overbank flow events, and revetment would benefit fish and wildlife by providing rock substrate.

Threatened and Endangered Species
A programmatic (Tier I) consultation (USACE 1999), conducted under Section 7 of the Endangered Species Act, considered the systemic impacts of the operation and maintenance of the 9-Foot Channel Navigation Project on the Upper Mississippi River System (including the MMR) and addressed listed species as projected 50 years into the future (USFWS 2000). The consultation did not include individual, site specific effects or new construction. It was agreed that site specific impacts and new construction impacts would be handled under separate Tier II consultation. Although channel structure impacts were covered under the Tier I consultation, other site and species specific impacts could occur. As such, the Mosenthein/Ivory Landing Phase 4 work requires Tier II consultation. Accordingly, the District has prepared a Tier II Biological Assessment to determine the potential impacts of the work on federally threatened and endangered species (see Appendix B). No significant impacts to threatened or endangered species are anticipated.

Although the bald eagle was removed from the federal list of threatened and endangered species in 2007, it continues to be protected under the Migratory Bird Treaty Act and the Bald and Golden Eagle Protection Act (BGEPA). The BGEPA prohibits unregulated take of bald eagles, including disturbance. The U.S. Fish and Wildlife Service developed the National Bald Eagle Management Guidelines (USFWS 2007) to provide landowners, land managers, and others with information and recommendations regarding how to minimize potential project impacts to bald eagles, particularly where such impacts may constitute disturbance. No bald eagle nest trees are known to occur in the immediate vicinity of the work area at this time. If any nest trees are identified in the work area, the National Bald Eagle Management Guidelines will be implemented to minimize potential impacts and appropriate coordination with the U.S. Fish and Wildlife Service will be conducted.

Socioeconomic Resources

Navigation
Impacts of the No Action Alternative on Navigation – With the No Action Alternative, the potential for barge groundings would be expected to increase. Repetitive maintenance dredging activities would be expected to continue and increase as the unstable banks continue to fail. Recent dredging costs in the area have averaged approximately $650,000 per year. These expenditures would be expected to continue and increase in the future.

Impacts of the Proposed Action on Navigation – Implementation of the Proposed Action is expected to reduce the amount and frequency of repetitive maintenance dredging necessary in the area. Barge grounding rates would also be expected to decrease in the area. Extensive coordination with navigation industry partners was conducted. Accordingly, impacts to fleeting areas and other navigation concerns have been avoided. The cost of the Proposed Action is not expected to exceed $5,000,000.

Historic and Cultural Resources

Impacts of the No Action Alternative on Historic and Cultural Resources – Continued dredging and disposal operations under the No Action Alternative are not anticipated to impact any known historic and cultural resources in the area. Any undocumented historic and cultural resources that may have existed in the area likely would have been destroyed by previous dredging activities. Future maintenance dredging and disposal under the No Action Alternative would likely occur in the same locations as previous dredging and disposal, and, therefore, would be unlikely to impact undocumented historic and cultural resources.

Impacts of the Proposed Action on Historic and Cultural Resources – All construction work on the dike will be carried out via barge, without recourse to land access; therefore, any effects are limited to submerged cultural resources. Primary among these are historic period shipwrecks. Given the continual river flow and associated sedimentary erosion, deposition, and reworking, it is highly unlikely that any more ephemeral cultural material remains on the river bed.

As with other training structures, construction of revetment would be conducted via barge, without recourse to land access. The placement of the rock, however, has the potential to damage or destroy any resource on the bankline. With all revetment segments, historical research was conducted on the proposed location. The proposed work was determined to be on recently accreted land. Recently accreted land is highly unlikely to contain deeply buried cultural resources. A pedestrian archaeological survey was also conducted at the proposed placement sites. No significant resources were encountered.

Given the features' construction method (with no land impact), the recent age of the landform, and the lack of any survey evidence for existing wrecks or other significant cultural resources, it is the District's opinion that the proposed undertaking will have no significant effect on cultural resources. The Illinois State Historic Preservation Officers (SHPO) concurred that the proposed actions would not affect listed or eligible historic properties. A copy of the correspondence is included in Appendix F. If, however, cultural resources were to be encountered during construction, all work would stop in the affected area and further consultation would take place.

Twenty-eight federally recognized tribes affiliated with the St. Louis District were consulted and no objections to the work were raised. Copies of the consultation letter and response are included in Appendix F.

Climate Change. To date, no official guidance applicable to the Middle Mississippi River Regulating Works Project has been established for federal agencies in determining impacts of proposed actions on climate change or the impacts of climate change on proposed actions. Nonetheless, a general assessment of climate trends and the most likely future climate conditions can assist decision makers in characterizing the potential impacts of their actions on climate change and the potential impacts of climate change on water resources and the future efficacy of infrastructure.

As part of the requirements of the Global Change Research Act enacted in 1990, the United States Global Change Research Program periodically conducts National Climate Assessments. National Climate Assessments are intended to evaluate, integrate, and assess the most current climate change information available and make it available to the public. National Climate Assessments were prepared in 2000 and 2009 and a draft of the third report was released in 2013 and is expected to be completed in 2014. The information below (Kunkel et al. 2013a; Kunkel et al. 2013b) comes from the technical reports prepared in support of the third National Climate Assessment and represents the most up-to-date information available on climate trends and forecasts for the area.

For the National Climate Assessment analysis, the Midwest was defined as Minnesota, Wisconsin, Michigan, Iowa, Illinois, Indiana, Ohio, and Missouri. Despite a large degree of interannual variability, analyses of recent trends for annual precipitation totals and extreme precipitation events in the Midwest show upward trends (Kunkel et al. 2013a; Karl et al. 2009). Predictions of future precipitation characteristics for the Midwest are characterized by a high degree of variability and uncertainty (Winkler et al. 2012; Kunkel et al. 2013a), but the following conclusions about simulated future precipitation in the Midwest were drawn (Kunkel et al. 2013a):

- *The greatest simulated increases in average annual precipitation are seen in the far north, while a decrease is indicated in the southwestern corner of the region. Seasonal changes are generally upward in winter, spring, and fall and downward in summer in the south. However, the range of model-simulated precipitation changes is considerably larger than the multi-model mean change. Thus, there is great uncertainty associated with future precipitation changes in these scenarios.*

- *Simulated changes in the number of days with precipitation exceeding 1 inch are upward for the entire Midwest region, with increases of up to 60% (for the A2 scenario at mid-century). The largest changes are seen in the states bordering Canada. The increases are statistically significant generally in the north, but not in the south.*

- *Statistically significant decreases in the number of consecutive days with less than 0.1 inches of precipitation are simulated for the north (for the A2 scenario at mid-century). Elsewhere changes are not statistically significant.*

- *Many of the modeled values of decadal precipitation change are not statistically significant, with respect to 2001-2010, out to 2091-2099.*

Precipitation trends for the Great Plains watershed are also important considerations for the Middle Mississippi River given the contribution of the Missouri River to Middle Mississippi River flows. For the National Climate Assessment analysis, the Great Plains was defined as Montana, North Dakota, South Dakota, Wyoming, Nebraska, Kansas, Oklahoma, and Texas (Kunkel et al. 2013b). The following general conclusions about simulated future precipitation in the Great Plains were drawn (Kunkel et al. 2013b):

- *Southern regions show the largest simulated decreases in average annual precipitation, while northern areas show increases. NARCCAP models show increases across most of the region in all seasons except summer. For the most part, these changes are either not statistically significant or the models do not agree on the sign of the change. An exception is the modeled changes in the far northern and far southern portions of the region for 2070-2099 under the high (A2) emissions scenario where the models simulate statistically significant increases and decreases, respectively. For most time periods and* *locations, the range of model-simulated precipitation changes is considerably larger than the multi-model mean change. Thus, there is great uncertainty associated with future precipitation changes in these scenarios.*

- *Nearly the entire region is simulated to see increases (up to 27%) in the annual number of days with precipitation exceeding 1 inch (for the A2 scenario at mid-century), with small areas in the far western portions of the region simulated to see slight decreases (up to 23%). However, these changes are mostly not statistically significant.*

- *Consecutive days with little or no precipitation (less than 0.1 inches) are simulated to increase in the south by 3-13 days per year and decrease in parts of the north by up to 8 days per year (for the A2 scenario at mid-century). The decreases in Texas and Oklahoma are mostly statistically significant.*

- *Many of the modeled values of decadal precipitation change are not statistically significant, with respect to 2001-2010, out to 2091-2099.*

Given the high degree of variability and uncertainty in weather patterns in general and in predictions of future weather patterns in particular, quantifying future Project impacts is inexact. However, if the assumption is made that changes in future precipitation in the Middle Mississippi River watershed are going to be characterized by increased average annual precipitation, more frequent extreme rainfall events, and consequently more frequent and greater flood events, then the basic functionality of river training structures and their ability to change sedimentation patterns should not be affected going forward. Also, given that the District has concluded that river training structures do not increase flood heights (see Section 4, Environmental Consequences and Appendix A), river training structures would not contribute any increase to potential future flood events. Nonetheless, climate change could impact navigation by changing sedimentation patterns and associated impediments to navigation, increasing the need for dredging, and decreasing the dependability of the navigation channel due to floods and droughts (Moser et al. 2008; Karl et al. 2009).

With respect to impacts on climate change, implementation of the Proposed Action would result in some minor greenhouse gas emissions due to equipment used for construction activities, rock transportation, etc. However, the Proposed Action would result in an overall decrease in greenhouse gas emissions due to the reduction in the amount of repetitive maintenance dredging required in the work area.

Cumulative Impacts

Council on Environmental Quality (CEQ) regulations define cumulative impacts as “the impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions regardless of what agency (Federal or non-Federal) or person undertakes such other actions. Cumulative impacts can result from individually minor but collectively significant actions taking place over a period of time.” (40 CFR §1508.7). In order to assist federal agencies in producing better cumulative impact analyses, CEQ developed a handbook, “Considering Cumulative Effects under the National Environmental

Policy Act" (CEQ 1997). Accordingly, the Mosenthein/Ivory Landing Phase 4 EA cumulative impact analysis generally followed the steps laid out by the handbook.

As detailed in Appendix C and summarized in Table 4 below, the cumulative impact analysis involved determining the incremental impact of the Alternatives on resources in the area in the context of all of the other past, present, and reasonably foreseeable future actions that might also impact each resource category. The analysis looked beyond the footprint of the work area to include impacts to the resources throughout the Middle Mississippi River. Clearly the human environment in the Middle Mississippi River has been, and will continue to be, impacted by a wide range of actions. The cumulative impact analysis evaluates the same resources (Physical Resources [River Stages, Water Quality, and Air Quality]; Biological Resources [Fish and Wildlife: Dike Effects, Revetment Effects, Threatened & Endangered Species, and Climate Change]; Socioeconomic Resources [Navigation]; and Historic & Cultural Resources) that were evaluated in the Environmental Consequences section. In addition, the cumulative impacts for the No Action Alternative and Action Alternative were evaluated for navigation effects and side channel impacts.

The Regulating Works Project, in combination with the other actions throughout the watershed, has had past impacts, both positive and negative, on the human environment. However, this analysis is meant to characterize the incremental impact of the current action in the broader context of other actions affecting the same resources. Although past actions associated with the Regulating Works Project have impacted these resources, the current method of conducting business for the Project – involving partner agencies throughout the planning process, avoiding and minimizing impacts during the planning process, and utilizing innovative river training structures to provide habitat diversity while still providing benefits to the navigation system – has been successful in accomplishing the desired effect of avoiding significant environmental consequences. Although our understanding of the actions that bear upon the resources of the Middle Mississippi River continues to evolve, an equilibrium in habitat conditions appears to have been reached. Accordingly, no significant impacts to the human environment are anticipated for the Regulating Works, Mosenthein/Ivory Landing Phase 4 construction.

Table 4. Summary of cumulative impacts.

Resource	Past Actions	Present Actions	Future Actions	No Action Alternative	Proposed Action
Stages	Flows and stages impacted by watershed land use changes, levee construction, mainline and watershed dam construction, consumptive water use, climate change	Continued impacts due to land use changes in watershed, consumptive water use, levee construction, climate change	Continued impacts due to land use changes in watershed, consumptive water use, levee construction, climate change	No impacts on stages anticipated	No impacts on stages anticipated at average and high flows. At low flows, current trend of decreasing stages expected to continue.
Water Quality	Increasing human populations and industrialization result in increased water quality problems. Establishment of Clean Water Act, NEPA, USEPA, state environmental agencies and associated regulations greatly improve conditions.	Continued population growth and development result in increased potential for water quality impacts. Continued regulation enforcement and societal recognition prevent water quality degradation.	Continued regulation enforcement and societal recognition. Continued population growth and development result in increased potential for water quality impacts.	Localized, temporary increase in suspended sediment concentrations at dredge material discharge sites	Localized, temporary increase in suspended sediment concentrations during construction activities; decrease in suspended sediment in immediate vicinity of revetment long-term due to reduction in bankline erosion
Air Quality	Increasing human populations and industrialization result in deterioration of air quality. Establishment of Clean Air Act, NEPA, USEPA, air quality standards improve conditions. Non-attainment status in work area.	Continued population growth and development result in increased potential for air quality impacts. Continued regulation enforcement and societal recognition. Continued non-attainment status in work area.	Continued population growth and development result in increased potential for air quality impacts. Continued regulation enforcement and societal recognition. Possible achievement of attainment status through implementation of State Implementation Plans.	Minor and local impacts due to use of dredging equipment	Minimal air quality impacts; below de minimis levels

Table 4. (cont.)

Resource	Past Actions	Present Actions	Future Actions	No Action Alternative	Proposed Action
Fish and Wildlife (including threatened and endangered species)	Transformation of river system from natural condition to pooled lock and dam system above Chain of Rocks; in MMR, loss of floodplain habitat due to levees, agriculture, urbanization; loss of natural river habitat – loss of dynamic habitat due to river channel stabilization with dikes/ revetment; loss of side channel habitat; dredging impacts; navigation impacts; USACE, other federal, state, and private habitat restoration and land mgmt programs reverse habitat loss; introduction of exotic species/reduced native species biomass; implementation of innovative river training structures to provide habitat diversity; recognition of T&E species through Endangered Species Act; listing of multiple T&E species in MMR; implementation of District Biological Opinion Program and Avoid and Minimize Program	Maintenance of current habitat conditions due to maintenance of lock and dam system above Chain of Rocks and existing dikes/revetment; continued implementation of Regulating Works Project; continued use of innovative river training structures to provide habitat diversity; habitat restoration and land mgmt through USACE, other federal, state, and private programs; habitat changes associated with recent and current innovative dike construction; maintenance of current floodplain habitat conditions due to continued agriculture use/ maintenance of existing levees/ urbanization; dredging impacts; navigation impacts; native species continue to be impacted by exotic species; continued implementation of Biological Opinion Program and Avoid and Minimize Program; restoration/maintenance of side channel habitat	Continued maintenance of habitat conditions due to maintenance of lock and dam system above Chain of Rocks and maintenance of existing dikes/revetment; dredging impacts; navigation impacts; continued implementation of Regulating Works Project; continued use of innovative river training structures to provide habitat diversity; continued habitat restoration and land mgmt through USACE, other federal, state, and private programs; maintenance of current floodplain habitat conditions due to continued agriculture use/ maintenance of existing levees/ urbanization; new exotic species likely to be introduced; continued implementation of Biological Opinion Program and Avoid and Minimize Program; restoration/maintenance of side channel habitat	Entrainment of some fish and macroinvertebrates at dredge locations; avoidance of dredge and disposal areas by mobile organisms; some loss of fish and macroinvertebrates at disposal sites; may affect but not likely to adversely affect threatened and endangered species	Avoidance of sites during construction; no conversion of aquatic habitat to terrestrial; increased fish and macroinvertebrate use of structure locations due to increased bathymetric, flow, and substrate diversity; some loss of fish and macroinvertebrate habitat due to reduced woody debris inputs; no significant impacts to threatened and endangered species anticipated

Table 4. (cont.)

Resource	Past Actions	Present Actions	Future Actions	No Action Alternative	Proposed Action
Navigation	1927 River and Harbor Act authorized USACE to provide 9-foot Nav channel on MMR; USACE transformed free-flowing Mississippi River system into navigable waterway with 37 lock and dam complexes above Chain of Rocks, some dredging, dikes, revetment; growth of port facilities and inland waterways and traffic throughout Mississippi River system provided for movement of commodities with local, national, and international importance	Operation of lock and dam system above Chain of Rocks continues; traditional and innovative stone dike, revetment construction, rock removal, and dredging continue to provide safe and dependable navigation channel; navigation continues to be an important part of local / national / international transportation and commerce activities	Operation of lock and dam system above Chain of Rocks continues; traditional and innovative stone dike, revetment construction, rock removal, and dredging continue to provide safe and dependable navigation channel; navigation continues to be an important part of local / national / international transportation and commerce activities	Increasing requirement for repetitive maintenance dredging due to continued bankline erosion; increasing potential for barge groundings	Reduction in the amount and frequency of repetitive maintenance dredging in the area; reduction in barge grounding rates
Historic and Cultural Resources	Historic and cultural resources subjected to natural processes and manmade actions (e.g., erosion, floodplain development); recognition of importance of historic and cultural resources through National Historic Preservation Act (and others)	Historic and cultural resources continue to be impacted by human activities as well as natural processes; continued societal recognition of importance of historic and cultural resources	Historic and cultural resources continue to be impacted by human activities as well as natural processes; continued societal recognition of importance of historic and cultural resources	Impacts to historic and cultural resources unlikely.	No known historic resources would be affected. Impacts to unknown historic and cultural resources unlikely.

Mitigation

Mitigation measures are used to avoid, minimize, or compensate for adverse impacts to environmental resources. The Mosenthein/Ivory Landing Phase 4 work has avoided and minimized adverse impacts throughout the alternative development process. No adverse impacts have been identified that would require compensatory mitigation.

5. Relationship of Proposed Action to Environmental Requirements

Federal Policy	Compliance Status
Bald Eagle Protection Act, 16 USC 668-668d	Full
Clean Air Act, 42 USC 7401-7542	Full
Clean Water Act, 33 USC 1251-1375	Partial 1*
Comprehensive Environmental Response, Compensation, and Liability Act, 42 USC 9601-9675	Full
Endangered Species Act, 16 USC 1531-1543	Full
Farmland Protection Policy Act, 7 USC 4201-4208	Full
Fish and Wildlife Coordination Act, 16 USC 661-666c	Full
Land and Water Conservation Fund Act, 16 USC 460d-461	Full
Migratory Bird Treaty Act of 1918, 16 USC 703-712	Full
National Environmental Policy Act, 42 USC 4321-4347	Full
National Historic Preservation Act, 16 USC 470 et seq.	Full
Noise Control Act, 42 USC 7591-7642	Full
Resource Conservation and Recovery Act, 42 USC 6901-6987	Full
Rivers and Harbors Act, 33 USC 401-413	Partial 1*
Water Resources Development Acts of 1986 and 1990	Full
Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations (EO 12898)	Full
Floodplain Management (EO 11988 as amended by EO 12148)	Full
Prevention, Control, and Abatement of Air and Water Pollution at Federal Facilities (EO 11282 as amended by EO's 11288 and 11507)	Full
Protection and Enhancement of Environmental Quality (EO 11991)	Full
Protection and Enhancement of the Cultural Environment (EO 11593)	Full
Protection of Wetlands (EO 11990 as amended by EO 12608)	Full
Responsibilities of Federal Agencies to Protect Migratory Birds (EO 13186)	Full

1* Full compliance will be obtained prior to construction.

6. Conclusion

The St. Louis District has assessed the impacts of the Proposed Action on the physical, biological, socioeconomic, and historic and cultural resources of the work area and determined that the proposed work would have no significant direct, indirect, or cumulative impacts upon the human environment.

7. List of Preparers

Name	Role	Experience
Mike Rodgers	Project Manager	12 years, hydraulic engineering
Jasen Brown	Project Manager	12 years, hydraulic engineering
Eddie Brauer	Engineering Lead	12 years, hydraulic engineering
Kip Runyon	Environmental Lead	16 years, biology
Francis Walton	Threatened and Endangered Species	13 years, environmental compliance
Tim George	Air Quality	23 years, ecology
Tom Keevin	Cumulative Impacts	33 years, aquatic ecology
Kevin Slattery	HTRW	15 years, environmental science
Mark Smith	Historic and Cultural Resources	20 years, archaeology
Danny McClendon	Regulatory	27 years, regulatory compliance and biology
Keli Broadstock	Legal Review	2 years USACE, 6 years private sector law

8. Literature Cited.

Barko, V.A., D.P. Herzog, R.A. Hrabik, and J.S. Scheibe. 2004. Relationship among fish assemblages and main channel border physical habitats in the unimpounded Upper Mississippi River. Transactions of the American Fisheries Society, 133:2, 371-384.

Battle, J.M., J.K. Jackson, B.W. Sweeney. 2007. Annual and spatial variation for macroinvertebrates in the Upper Mississippi River near Cape Girardeau, Missouri. Fundamental and Applied Limnology. 168/1: 39-54.

Beckett, D.C., C.R. Bingham, and L.R Sanders. 1983. Benthic macroinvertebrates of selected habitats of the lower Mississippi River. Journal of Freshwater Ecology 2: 247-261.

Bingham, C.R. 1982. Benthic macroinvertebrate study of a stone dike. Environmental and Water Quality Operational Studies Information Exchange Bulletin, Bol. E-82-4.

Blodgett, N. 2010. Final Report: Monitoring of Dredged Material for Fish Entrainment with Special Emphasis on the Pallid Sturgeon, Phase III North Berms Dredging, Chain of Rocks Canal, Mississippi River, Madison County, IL. Prepared by Ecological Specialists, Inc. for the U.S. Army Corps of Engineers, St. Louis District, St. Louis, MO.

Brauer, E.J., R.D. Davinroy, L. Briggs, and D. Fisher. 2013. Draft Supplement to *Geomorphology Study of the Middle Mississippi River (2005)*. U.S. Army Corps of Engineers, St. Louis District, Applied River Engineering Center, St. Louis, Missouri. 12 pp.

Brauer, E.J., D.R. Busse, C. Strauser, R.D. Davinroy, D.C. Gordon, J.L. Brown, J.E. Myers, A.M. Rhoads, and D. Lamm. 2005. Geomorphology Study of the Middle Mississippi River. U.S. Army Corps of Engineers, St. Louis District, Applied River Engineering Center, St. Louis, Missouri. 43 pp.

CEQ. 1997. Considering Cumulative Effects under the National Environmental Policy Act. Council on Environmental Quality, Executive Office of the President, Washington, D.C.

Dardeau, E.A., Jr., K.J. Killgore, Jr., and A.C. Miller. 1995. Using riprap to create or improve riverine habitat. Pp. 609-620 in C. R. Thorne, S.R. Abt, F.B.J. Barends, S.T. Maynord, and K.W. Pilarczyk (eds.). River, coastal and shoreline protection: Erosion control using riprap and armourstone. John Wiley & Sons Ltd.

Farabee, G. F. 1986. Fish species associated with revetted and natural main channel border habitats in Pool 24 of the Upper Mississippi River. North American Journal Fisheries Management 6: 504-508.

Fischenich, J.C. 2003. Effects of riprap on riverine and riparian ecosystems. ERDC/EL TR-03-4, U.S. Army Engineer Research and Development Center: Vicksburg, MS.

Galat, D. L., C. R. Berry, Jr., E. J. Peters, and R. G. White. 2005. Missouri River Basin. Pp. 427–480 in A. C. Benke and C. E. Cushing (eds.). Rivers of North America, Elsevier, Oxford.

Hartman, K.J. and J.L. Titus. 2009. Fish use of artificial dike structures in a navigable river. River Research and Applications. 26: 1170-1186.

Heitmeyer, M.E. 2008. An evaluation of ecosystem restoration options for the Middle Mississippi River Regional Corridor. Greenbrier Wetland Services Report 08-02, Advance, MO.

Huizinga, R.J. 2009. Examination of direct discharge measurement data and historic daily data for selected gages on the Middle Mississippi River, 1861-2008. U.S. Geological Survey Scientific Investigations Report 2009-5232. 60pp. (Available at http://pubs.usgs.gov/sir/2009/5232/)

Karl, T.R., J.M. Melillo, and T.C. Peterson, (eds.). 2009. Global Climate Change Impacts in the United States, Cambridge University Press.

Koel, T. M., and K. E. Stevenson. 2002. Effects of dredge material placement on benthic macroinvertebrates of the Illinois River. Hydrobiologia 474:229-238.

Kunkel, K.E, L.E. Stevens, S.E. Stevens, L. Sun, E. Janssen, D. Wuebbles, S.D. Hilberg, M.S. Timlin, L. Stoecker, N.E. Westcott, and J.G. Dobson. 2013a. Regional Climate Trends and Scenarios for the U.S. National Climate Assessment. Part 3. Climate of the Midwest U.S., NOAA Technical Report NESDIS 142-3, 95 pp.

Kunkel, K.E, L.E. Stevens, S.E. Stevens, L. Sun, E. Janssen, D. Wuebbles, M.C. Kruk, D.P. Thomas, M.D. Shulski, N.A. Umphlett, K.G. Hubbard, K. Robbins, L. Romolo, A. Akyuz, T.B. Pathak, T.R. Bergantino, and J.G. Dobson. 2013b. Regional Climate Trends and Scenarios for the U.S. National Climate Assessment. Part 4. Climate of the U.S. Great Plains, NOAA Technical Report NESDIS 142-4, 82 pp.

Madejczyk, J.C., N.D. Mundahl, and R.M. Lehtinen. 1998. Fish assemblages of natural and artificial habitats within the channel border of the Upper Mississippi River. American Midland Naturalist, Vol. 139, No. 2, pp. 296-310.

Moser, H., P.J Hawkes, K.D. White, S. Mai, O.A. Arntsen, P. Gaufres, and G. Pauli. 2008. Waterborne transport, ports and waterways—A review of climate change drivers, impacts, responses and mitigation: Brussels, PIANC, 58 p.

Munger, P.R., G.T. Stevens, S.P. Clemence, D.J. Barr, J.A. Westphal, C.D. Muir, F.J. Kern, T.R. Beveridge, and J.B. Heagler, Jr. 1976. SLD Potamology Study (T-1). University of Missouri-Rolla, Institute of River Studies, Rolla, Missouri.

Niles, J.M. and K.J. Hartman. 2009. Larval fish use of dike structures on a navigable river. North American Journal of Fisheries Management. 29: 1035-1045.

Nord, A.E., and J.C. Schmulbach. 1973. A comparison of the macroinvertebrate attached communities in the unstabilized and stabilized Missouri River. Proceedings, South Dakota Academy of Science 52:127-139.

Payne, B.S., C.R. Bingham, and A.C. Miller. 1989. Life history and production of dominant larval insects on stone dikes in the Lower Mississippi River. Lower Mississippi River Environmental Program Report 18. U.S. Army Corps of Engineers, Mississippi River Commission, Vicksburg, Mississippi.

Pennington, C.H., J.A. Baker, and M.E. Potter. 1983. Fish populations along natural and revetted banks on the Lower Mississippi River. North American Journal of Fisheries Management 3: 204-211.

Reine, K., and D. Clarke. 1998. "Entrainment by hydraulic dredges–A review of potential impacts." Technical Note DOER-E1. U.S. Army Engineer Research and Development Center, Vicksburg, MS.

Sauer, J. 2004. Multiyear synthesis of the macroinvertebrate component from 1992 to 2002 for the Long Term Resource Monitoring Program. 2004. Final report submitted to U.S. Army Corps of Engineers from the U.S. Geological Survey, Upper Midwest Environment Sciences Center, La Crosse, Wisconsin, December 2004. Technical Report LTRMP 2004-T005. 31 pp. + Appendixes A–C.

Schneider, B. 2012. Changes in fish use and habitat diversity associated with placement of three chevron dikes in the Middle Mississippi River. M.S. thesis, Southern Illinois University Edwardsville.

Shields, Jr., F. D. 1995. Fate of Lower Mississippi River habitats associated with river training dikes. Aquatic Conservation and Freshwater Ecosystems 5:97-108.

Simons, D.B., S.A. Schumm, and M.A. Stevens. 1974. Geomorphology of the Middle Mississippi River. Report DACW39-73-C-0026 prepared for the U.S. Army Corps of Engineers, St. Louis District, St. Louis, Missouri. 110 pp.

Theiling, C.H., C. Korschgen, H. De Haan, T. Fox, J. Rohweder, and L. Robinson. 2000. Habitat Needs Assessment for the Upper Mississippi River System: Technical Report. U.S. Geological Survey, Upper Midwest Environmental Sciences Center, La Crosse, Wisconsin. Contract report prepared for U.S. Army Corps of Engineers, St. Louis District, St. Louis, Missouri. 248 pp.

UMRBC. 1982. Comprehensive Master Plan for the Management of the Upper Mississippi River System. Upper Mississippi River Basin Commission, Minneapolis, Minnesota. 193pp.

USACE. 1976. Environmental Statement, Mississippi River between the Ohio and Missouri Rivers (Regulating Works). U.S. Army Corps of Engineers, St. Louis District, St. Louis, Missouri.

USACE. 1983. Dredging and dredged material disposal. Engineer Manual 1110-2-5025. U.S. Army Corps of Engineers, Washington, DC.

USACE. 1999. Tier I of a two tiered Biological Assessment - Operation and Maintenance of the Upper Mississippi River Navigation Project within St. Paul, Rock Island, and St. Louis Districts. Mississippi Valley Division, Vicksburg, MS.

USACE. 2012. Devils Island offset dikes: pre- and post-construction monitoring completion report. U.S. Army Corps of Engineers, St. Louis District, St. Louis, MO.

USACE. 2013. Waterborne commerce of the United States. U.S. Army Corps of Engineers Navigation Data Center Waterborne Commerce Statistics Center. http://www.navigationdatacenter.us/wcsc/wcsc.htm . Accessed 21 August 2013.

USEPA. 2013. U. S. Environmental Protection Agency green book nonattainment areas for criteria pollutants as of July 31, 2013. http://www.epa.gov/airquality/greenbk/ . Accessed 13 August 2013.

USFWS. 2007. National Bald Eagle Management Guidelines. U.S. Fish and Wildlife Service, Arlington, VA.

USFWS. 2000. Biological opinion for the operation and maintenance of the 9-foot navigation channel on the Upper Mississippi River System. U. S. Department of the Interior, Fort Snelling, Minnesota.

Watson, C.C., D.S. Biedenharn, and C.R. Thorne. 2013a. Analysis of the impacts of dikes on flood stages in the Middle Mississippi River. Journal of Hydraulic Engineering 139:1071-1078.

Watson, C.C., R.R. Holmes, and D.S. Biedenharn. 2013b. Mississippi River streamflow measurement techniques at St. Louis, Missouri. Journal of Hydraulic Engineering 139:1062-1070.

WEST Consultants, Inc. 2000. Upper Mississippi River and Illinois Waterway Navigation Feasibility Study – Cumulative Effects Study, Volumes 1-2. Prepared by WEST Consultants, Inc. for the U.S. Army Corps of Engineers, Rock Island District, Rock Island, Illinois.

White, K., J. Gerken, C. Paukert, and A. Makinster. 2010. Fish community structure in natural and engineered habitats in the Kansas River. River Research and Applications 26: 797-805.

Winkler, J.A., R.W. Arritt, and S.C. Pryor. 2012. Climate Projections for the Midwest: Availability, Interpretation and Synthesis. In: *U.S. National Climate Assessment Midwest Technical Input Report*. J. Winkler, J. Andresen, J. Hatfield, D. Bidwell, and D. Brown, coordinators. Available from the Great Lakes Integrated Sciences and Assessment (GLISA) Center, http://glisa.msu.edu/docs/NCA/MTIT_Future.pdf.

FINDING OF NO SIGNIFICANT IMPACT (FONSI)
MOSENTHEIN/IVORY LANDING PHASE 4 REGULATING WORKS
MIDDLE MISSISSIPPI RIVER MILES 175-170
ST. CLAIR COUNTY, IL
ST. LOUIS CITY, MO

I. In accordance with the National Environmental Policy Act, I have reviewed and evaluated the documents concerning the Regulating Works, Mosenthein/Ivory Landing Phase 4 construction, St. Clair County, Illinois and St. Louis City, Missouri. As part of this evaluation, I have considered:

a. Existing resources and the No Action Alternative.

b. Impacts to existing resources from the Proposed Action.

II. The possible consequences of these alternatives have been studied for physical, environmental, cultural, social and economic effects, and engineering feasibility. My evaluation of significant factors has contributed to my finding:

a. The work would address repetitive dredging in the area. This would be accomplished by the construction of a rootless dike and placement of revetment.

b. No significant impacts to federally listed threatened or endangered species are anticipated.

c. No significant impacts are anticipated to natural resources, including fish and wildlife resources. The proposed work would have no effect upon significant historic properties or archaeological resources. There would be no appreciable degradation to the physical environment (e.g., stages, air quality, and water quality) due to the work.

d. The "no action" alternative was evaluated and determined to be unacceptable as repetitive dredging expenditures would continue.

III. Based on the evaluation and disclosure of impacts contained within the Environmental Assessment, I find no significant impacts to the human environment are likely to occur as a result of the proposed action. Therefore, an Environmental Impact Statement will not be prepared prior to proceeding with the proposed Regulating Works, Mosenthein/Ivory Landing Phase 4 construction, St. Clair County, Illinois and St. Louis City, Missouri.

4-17-14

(Date)

CHRISTOPHER G. HALL
COL, EN
Commanding

FINAL ENVIRONMENTAL ASSESSMENT

WITH

FINDING OF NO SIGNIFICANT IMPACT

REGULATING WORKS PROJECT
MOSENTHEIN/IVORY LANDING PHASE 4
MIDDLE MISSISSIPPI RIVER MILES 175-170
ST. CLAIR COUNTY, IL
ST. LOUIS CITY, MO

APRIL 2014

APPENDICES

Appendix A. Summary of Research on the Effects of River Training Structures on Flood Levels

Summary of Research on the Effects of River Training Structures on Flood Levels

1. Introduction

With implementation of the Proposed Action, stages at average and high flows both in the vicinity of the project area and on the Middle Mississippi River are expected to be similar to current conditions. An abundance of research has been conducted analyzing the impacts of river training structures on water surfaces dating to the 1930s. This research includes numerical and physical models as well as analyses of historic gage data, velocity data, and cross sectional data. In addition to continued monitoring and analysis, the U.S. Army Corps of Engineers (Corps) has conducted a literature review of all available literature on the impact of river traning structures on flood levels. A summary of research on the topic is detailed below. Based on an analysis of this research by the Corps and other external reviewers, the District has concluded that river training structures do not impact flood levels.

2. Studies concluding no impact on flood levels

2.1 Historic Research

One of the early studies specifically addressing the effect of river training structure construction on water surfaces was conducted during the extreme high water of June and July 1935 (Ressegieu 1952). This study was prompted by the differences in observed streamflow for equal stages following the transfer of streamgaging responsibility from the Corps to the United States Geological Survey (USGS) in March 1933. When observed field data showed a major change in the stage for which a specific discharge was passing, the Corps and USGS initiated a study to determine the cause. This study addressed the accuracy of the standard equipment and method of observation between the two agencies. Similar simultaneous streamflow studies were conducted between 1935 and 1948. In 1952, the results of all of the studies were analyzed and it was concluded that, on average, the discharges measured by the Corps generally exceeded those measured by the USGS by zero percent at mean stage to slightly more than ten percent at high stages. Ressegieu (1952) concluded that "the reduction in floodway capacity was not an actual physical reduction but an apparent reduction caused by a discrepancy in the accuracy of measuring streamflow by older methods and equipment". The conclusions by Ressegieu (1952) were analyzed along with new information and confirmed by Watson et al. (2013a).

Monroe (1962) conducted a comprehensive analysis of all factors which are believed to have had some effect on the St. Louis rating curve including: accuracy of discharge measurements, man-made obstructions and hydrology and hydraulic changes. Monroe (1962) observed a spread in stage for equivalent discharge at flows with stages of about 35 and 40 ft on the St. Louis gage. The analysis concluded that the change in stage for higher flows was due to the construction and raising of levees between 1935 and 1951. In an analysis of river training structures, Monroe (1962) found that “the contraction by permeable dikes has had a negligible effect on the increase in flood heights.” A number of natural factors were found to affect stages for equivalent discharge including: season (water temperature), rapidity of rise of the flood wave, amount of flow contribution by the upper Mississippi River and the amount of bed material carried by the Missouri River.

In a comprehensive study of hydrologic, hydraulic, geologic and morphologic factors which relate to the Mississippi River downstream of Alton, IL, Munger et al. (1976) studied the changes in hydraulics on the Mississippi River resulting from river confinement by levees and the construction of river training structures. As was the case in previous studies using gage data, the reliability of early discharge data collected by the Corps was brought into question. In a study of velocity, stage and discharge data, Munger et al. (1976) concluded that “generalizations about the effect of dikes on stage-discharge relations are not justified.” When examining cross section shape and velocity distributions at the St. Louis gage, it was observed that there had been no striking changes in cross-section shape or velocity distributions at the section between 1942 and 1973.

Dyhouse (1985, 1995) found through numerical and physical modeling that published discharges for historic floods, including 1844 and 1903, were overestimated by 33 and 23 percent, respectively. Dyhouse concluded that the use of early discharge data collected by the Corps, including historic peak flood discharges in conjunction with streamflow measurements by the USGS, will result in incorrect conclusions.

Other reach scale numerical and physical models studying the effect of river training structures on water surfaces include USACE (1996) which used a Hydrologic Engineering Center (HEC-2) model used to analyze pre- and post- construction water surface elevations for the Nebraska Point Dike field on the Lower Mississippi River. For each cross section analyzed, the dike field construction lowered water surface elevations and reduced overbank discharges for the 50%, 20%, and 10% annual chance exceedance events. Xia (2009) used an Adaptive Hydraulics (AdH) model to study the changes in water surface resulting from the construction of a dike field. In this fixed bed analysis, Xia found that changes in water surface elevation due to the dikes was greatest at average flows and decreased with increasing and decreasing river flow. Azinfar and Kells (2007) developed a multiple function model to predict the drag coefficient and backwater effect of a single spur dike in a fixed bed. This study concluded that increasing submergence levels resulted in a decreasing backwater effect.

In a moveable bed model study conducted to develop structural alternatives for a power plant on the Minnesota River, Parker et al. (1988) measured water surface changes from a baseline for a series of dikes and determined that construction of the structures had a negligible effect on flood stages compared to calibration values. Yossef (2005) used a 1:40 scale fixed bed physical model of the Dutch River Waal to study the morphodynamics of rivers with groynes (dikes are referred to as groynes in other parts of the world including the Netherlands) including their effect on water surface. Yossef found that on the River Waal, the effect of groynes decreased with increasing submergence. It was also observed that the maximum possible water level reduction of the design flood (378,000 cfs) by lowering all of the groynes in the system was 0.06 meters (2.4 inches).

Other international research supports the conclusion that river training structures do not impact flood levels. An international technical working group made up of experts from around the world organized by PIANC, the World Association for Waterborne Transport Infrastructure, analyzed the impact of dikes on high discharges. It was determined that dikes can be designed to avoid high water impacts by having a top elevation below mean high water (similar to what is used on the Middle Mississippi River (MMR). The report describes that although dikes may increase hydraulic resistance, the erosion of the low water bed may compensate for the water level upset entirely. The report also cites conventional practice that requires dikes to be designed so they do not increase stage during high discharges (PIANC 2009). As an engineering organization, the Corps follows this conventional practice and ethical code to ensure that dike construction does not cause an impact to public safety.

2.2 Updated Evaluations

2.2.1 Watson & Biedenharn

To update ongoing evaluations of the physical effects of river training structures, the Corps initiated a new study on the possible effect of these structures on water surfaces in 2008. This series of studies included an analysis of past research, an analysis of the available gage data on the MMR, an analysis of historic measurement technique and instrumentation and its effect on the rating curve, specific gage analysis, numerical and physical modeling. In addition to the research conducted by the Corps, the St. Louis District engaged with external technical experts in the fields of river data collection, river engineering, geomorphology, hydraulics and statistics.

In a review of historic streamflow data collected prior to the USGS, Watson & Biedenharn (2010) determined that pre-USGS data should be omitted for the following reasons: (1) It has been confirmed through simultaneous measurement comparisons that there is much uncertainty in the historic data due to differences in methodology and equipment; (2) there is much uncertainty with respect to the location of the discharge range; (3) there is insufficient measured data at the higher flow ranges to produce reliable specific gage records; and (4) the homogeneous data set containing all discharges collected by the USGS provides an adequate long-term, consistent record of the modern-day river system including periods of significant dike construction. A more detailed description of the limitations of early discharge measurements can be found in Watson et al. (2013a).

In their analysis, Watson & Biedenharn (2010) studied the specific gage records at the three rated gages on the MMR: St. Louis, Chester and Thebes. A summary of the analysis techniques used and a detailed analysis of the specific gage record at St. Louis can be found in Watson et al. (2013b). The analysis for the gage at Thebes was omitted due to the effect of backwater from the Ohio River. For each streamgage studied, the specific gage record was analyzed and compared with a record of river training structure construction for a reach extending 20 river miles downstream. All data used in their study were collected by the USGS and retrieved from the USGS website (http://www.usgs.gov).

Bankfull stage at the St. Louis gage is approximately +30 feet with a corresponding discharge of approximately 500,000 cubic feet per second (cfs). Flows below 400,000 cfs are contained within the top bank and flows above 700,000 cfs are well above the top-bank elevation. The time period 1933-2009 was studied. The top elevation of training structures in this reach was between +12 and +16 feet referenced to the St. Louis gage. All structures are completely submerged at discharges exceeding 280,000 cfs. In their analysis, Watson and Biedenharn (2010) found a statistically significant slightly decreasing trend in streamflows below 200,000 cfs. In streamflows between 300,000 cfs and 500,000 cfs, a statistically significant horizontal trend in stages was observed. At 700,000 cfs a non-statistically significant, slightly increasing trend in stages was observed. The slight upward trend in stages at 700,000 cfs had considerable variability in the data and was strongly influenced by the 1993 flood.

Bankfull stage at the Chester gage is approximately +27 feet with a corresponding discharge of approximately 420,000 cfs. The time period 1942-2009 was studied. The top elevation of navigation structures in this reach was +14 to +17 feet referenced to the Chester gage. All structures are completely submerged at discharges exceeding 280,000 cfs. The only statistically significant trend found was a slightly decreasing trend for streamflows below 100,000 cfs. There was a horizontal trend for 200,000 and 400,000 cfs. There was a slightly increasing trend at 300,000 cfs. For both overbank flows, 500,000 cfs and 700,000 cfs, there were slight increasing trends.

After a closer examination of the specific gage trends it was apparent that the long term trends for both St. Louis and Chester were not continuous and there was a shift in stages that occurred in 1973. This year was significant because (1) 1973 was marked by the occurrence of a major flood event that is documented as having significant impacts on the morphology of the MMR, (2) the year 1973 marked the end of a remarkably flood free period and (3) the pre-1973 period was characterized by extensive dike construction whereas the post-1973 period saw 50% less dike construction. When the record was broken into pre- and post-1973 sections, different trends were observed. Prior to 1973 at all gages studied, there were no increasing trends for any of the flows. Post-1973 there were no increasing stage trends for within-bank flows at any of the gages. A slightly increasing stage trend occurred for overbank flows of 500,000 cfs (statistically significant) and 700,000 cfs (not statistically significant) at the Chester gage. A majority of the construction of river training structures on the Middle Mississippi was performed prior to 1973.

In conjunction with the specific gage record, Watson & Biedenharn (2010) and Watson et al. (2013) analyzed the record of training structure construction including an analysis of the top elevation of the structures. The typical top elevation of the structures was 10-16 feet below the top bank. Since the top elevation is so far below top-bank elevations, the most dramatic impacts of the structures should be in the low to moderate stages below top bank where the specific gage analysis revealed decreasing or no trends (Sukhodolov, 2013; Watson & Biedenharn 2010; USGAO 2011, PIANC 2009, Azinfar & Kells 2007, Stevens et al. 1975, Chow 1959).

Watson & Biedenharn (2010) concluded that, "based on the specific gage records, there has been no significant increase in stages for within-bank flows that can be attributable to river training structure construction. Any increase in overbank flood stages may be the result of levees, floodplain encroachments, and extreme hydrologic events; and cannot be attributed to river training structures based solely on specific gage records."

2.2.2 United States Geological Survey

Huizinga (2009) conducted a specific gage analysis using the direct step method on only data collected by the USGS for the gages at St. Louis and Chester. Similar to Watson & Biedenharn (2010), an apparent decrease of stage with time for smaller, in bank discharges was observed at both the St. Louis and Chester gages. This decrease in stage was attributed to the construction of river training structures and/or a decrease in sediment load available for transport on the Mississippi River due to the construction of reservoirs on the main stem tributaries of the Mississippi River, particularly the Missouri River.

Huizinga (2009) found a slight increase in stage over time for higher flows at both St. Louis and Chester over the entire period of record. The transitional discharge was 400,000 cfs and 300,000 cfs for the St. Louis and Chester gages respectively. These discharges correspond to stages of +25 feet at St. Louis and +22 feet at Chester. At these stages the navigation structures are submerged by 5-13 feet. Huizinga (2009) attributed the slight increase in out of bank flows to the construction of levees and the disconnection of the river to the floodplains. Similar to Watson & Biedenharn (2010), Huizinga (2009) observed a shift occurring in the out of bank flows in the mid-1960s and attributed it to the completion of the Alton to Gale levee system which paralleled the entire Middle Mississippi River.

In an analysis of cross sectional data collected at the St. Louis and Chester gages, it was found that although the shape of the cross section had changed, the cross sectional area for moderate (400,000 cfs) and high (600,000 cfs) flows remained relatively constant throughout the period of record. The construction of river training structures immediately upstream of the Chester gage provided a case study on the effect of the absence and construction of structures on the cross section over time. Prior to the construction of the structures, the channel thalweg repeatedly shifted between the left and right banks. Following the construction of the structures, the cross sections displayed much less variability. An overall stabilizing effect of the structures was seen on the cross section for discharges of 100,000 cfs and 400,000 cfs. The cross sectional area for the first and last measurements of the period of record remained similar despite the river training structure construction upstream for all discharges.

Huizinga (2009) conducted a study of all rating curves developed for St. Louis and Chester, including those developed prior to 1933 by the Corps. When comparing daily values from the Corps from 1861-1927 to the original USGS rating in 1933 there appeared to be an abrupt change in the upper end of the ratings used before 1933. When these daily values developed by the Corps were adjusted to compensate for the overestimation of Corps discharge measurements detailed in the simultaneous discharge measurement studies between the Corps and USGS, the adjusted daily discharge values plotted in line with the original USGS rating. This study is further evidence of the overestimation of early discharges.

2.2.3 *Statistical Evaluation*

A critical review of the statistical analysis used to support specific gage analyses by Pinter et al., (2001) and Pinter and Thomas (2003) was conducted by V.A. Samaranayake (2009) from the department of Mathematics and Statistics at Missouri University of Science and Technology. Samaranayake (2009) concluded that the analysis presented by Pinter et al., (2001) and Pinter and Thomas (2003) did not support the conclusions that river training structures are increasing stages for higher discharges. In an evaluation of the two types of specific gage analysis, Samaranayake (2009) concluded that the direct step method was the most appropriate on the MMR. This is due to the data points being more homogeneous than those obtained from the rating method as far as variance is concerned and therefore they can be considered devoid of simultaneity bias and other such artifacts.

Samaranayake (2009) also found that, when using computed daily discharge values, the researcher is essentially recreating the original USGS rating curves used to obtain the daily discharges. The computed daily discharge data lacks the natural variability found in measured streamflow and can lead to conclusions that are due to artifacts created by errors in the original rating curves. This error is compounded by the fact that the USGS uses the same rating curves for several years producing results that, rather than being independent, are correlated across several years.

Samaranayake (2009) questioned the cause and effect relationship concluded by Pinter et al., (2001). The straight trend lines concluded by Pinter et al. (2001) revealed an increasing trend in stages reflecting a smooth gradual increase. Dike construction was not constant throughout history. The history of dike construction revealed much variability in magnitude throughout the period of record and did not directly correlate with the trends observed by Pinter (2001). Pinter et al., (2001) failed to prove that the relationship between stage trends on the MMR and dike construction was statistically significant.

2.2.4 Numerical and physical modeling studies

The Iowa Institute of Hydraulic Research (IIHR) at the University of Iowa performed a series of hydrodynamic simulations of a recently constructed chevron field and dike extension using the United States Bureau of Reclamation Sedimentation and River Hydraulics Two-Dimensional (SRH-2D) modeling software (Piotrowski et al. 2012). Simulations studied the impact of the construction on water surfaces and the magnitude of natural variation on water surfaces. The results indicated that structures did not cause significant differences in reach-scale water surface elevations. The simulations also found that the differences in pre- and post-construction water surface elevations were less than the differences resulting from natural variability in two post-construction scenarios.

A physical sediment transport model at the University of Illinois, Urbana-Champaign was used to test the effect of submerged dikes and dike fields on water surfaces (Brauer 2013). The study tested flows and stages along a rating curve from ½ bankfull to a flow with a 0.5% annual chance exceedance. The study concluded that the magnitude of the effect of dikes on water surfaces was smaller than the natural variability in the stage and discharge relationship and decreased with increasing flow/submergence. The study also found that there was no direct cumulative effect for up to four structures.

2.2.5 Analysis of Updated Evaluations

Dike elevation information relative to the gages at St. Louis, Chester and Thebes are important in the interpretation of the specific gage results. On the MMR, dike elevations are well below the top-bank elevations and are submerged by over thirty feet during major floods. The most dramatic impacts of the dikes are expected to be observed in the low to moderate stages below top bank (Sukhodolov, 2013; Watson & Biedenharn, 2010; USGAO, 2011; PIANC, 2009; Azinfar & Kells, 2007; Stevens et al., 1975; Chow 1959). Once the flows spill overbank, the specific gage trends are impacted by changes in the floodplain including bridge abutments, levee construction, vegetation changes, etc. (Huizinga 2009, Heine and Pinter 2012). The effect of levees on the stages of larger floods is more pronounced than at lesser floods due to the additional conveyance loss of the floodplain (Simons et al. 1975, Heine and Pinter 2012).

The magnitude of the stage changes for overbank discharges observed by Watson & Biedenharn (2010), Watson et al. (2013), and Huizinga (2009) are consistent with the expected changes due to the construction of levees along the MMR. The Upper Mississippi River Comprehensive Plan (USACE 2008) calculated that levees contributed an increase of up to 2.9 feet at St. Louis, Missouri and up to 7.3 feet at Chester, Illinois of the 1% annual chance exceedance flood (100-year). The Floodplain Management Assessment of the Upper Mississippi River and Lower Missouri Rivers and Tributaries report (USACE 1995) calculated that agricultural levees contributed an average peak stage increase of up to 4.9 feet on the MMR between St. Louis and Cape Girardeau. The Mississippi Basin Model (MBM) tests showed an increase of up to 4 feet compared to 1820 conditions, depending on discharge and location of flooding (Dyhouse 1995). The magnitude of levee impact is dependent on the roughness of the floodplain being protected. The values detailed above generally assume agricultural land.

Through the use of numerical and physical models, Piotrowski (2012) and Brauer (2013) reinforced the conclusion that river training structures do not impact flood flows. Additionally, Piotrowski (2012) and Brauer (2013) quantified the impact of natural variability in the channel on stage. Brauer (2013), through the use of a moveable bed model, demonstrated the importance of sediment transport and bed changes when analyzing how river training structures influence stages.

3. Analysis of research proposing a link between instream structures and an increase in flood levels.

The Corps has researched and analyzed all available literature that either purports or has been claimed to purport that river training structures increase flood heights. Comments received on the draft Environmental Assessment have provided a list of 51 studies claimed to link the construction of instream structures to increases in flood levels. However, only 21 of the 51 journal articles, technical notes, book chapters, and conference papers cited attempt to link the construction of instream structures to increases in flood levels. The remaining thirty studies cited do not discuss the construction of instream structures and/or increases in flood levels. Some of the cited papers simply reference the research of others as background information. Others discuss the topics of flow frequency, physical modeling and model scale distortion, and levee construction. Others are on topics unrelated to instream structures and/or flood levels.

This appendix only discusses in detail the journal articles, technical notes, book chapters, and conference papers whose conclusions claim a link between instream structure construction and an increase in flood levels. Some of the analyses are presented in multiple papers. Since the analysis in Pinter et al. (2000) is the basis for Pinter et al. (2001a), Pinter et al. (2001b), Pinter et al. (2002), Pinter et al. (2003), Pinter and Heine (2005), Pinter et al. (2006b) and Szilagyi et al. (2008), only Pinter et al. (2000) will be discussed in detail. Similarly, the analysis in Jemberie et al. (2008) is the basis for Pinter et al. (2008), Pinter (2009), and Pinter et al. (2010). Only Jemberie et al. (2008) will be discussed in detail.

The studies whose conclusions claim a link between instream structure construction and an increase in flood levels have been grouped below into three categories: specific gage analysis, numerical simulations and physical fixed bed modeling.

3.1 Specific Gage Analysis

Fifteen of the journal articles, technical notes, book chapters, conference papers and editorials proposing a link between instream structures and an increase in flood levels rely on the use of specific gage analysis.

3.1.1 Description

Specific gage analysis is a graph of stage for a specific fixed discharge at a particular gaging location plotted against time (Watson et al 1999). The use of specific gage analysis is a simple and straightforward method to illustrate aggradation and degradational trends in a river or the response of a river to various alterations in the channel. Similar to most engineering analyses, the interpretation of specific gage records can be complex.

Specific gage analysis is an analysis of field data collected at gage locations along a river. The measurements that are collected at the gage locations are stage (water height), velocity (speed of the water) and cross sectional area (area of the channel). Velocity and area are multiplied together to calculate the discharge which is the volume of water passing a fixed location. It is important to ensure that the methodology and instrumentation used to collect velocity and cross sectional area has not changed during the period of record being examined. If it has changed, it is important to understand how those changes in instrumentation and methodology impact the results. As detailed above, the period of record on the MMR includes two distinctly different data sets.

3.1.2 Papers using specific gage analysis to link instream structure construction to flood level increases

The first use of specific gage analysis to link instream structures to apparent changes to the stage-discharge relationship on the Middle Mississippi River dates back to Stevens et al. (1975) and Belt (1975). Flaws in the source data, methodology and analysis used by Stevens et al. (1975) were addressed by Stevens (1976), Dyhouse (1976) Strauser & Long (1976) and Westphal & Munger (1976). These include the following: use of limited cross-sectional data from one highly engineered reach of the MMR (St. Louis harbor) to represent the entire Middle Mississippi River; use of the unmeasured 1844 flood discharge and the 1903 flood discharge, which was measured only at Chester and Thebes using a different analysis to draw sweeping conclusions; use of early inaccurate and overestimated discharge measurements in conjunction with more accurate contemporary measurements; and the lack of a direct correlation between dike construction and trends in water surface changes.

Through a comparison of trends in stage and streamflow measurements from floods from 1862-1904 to those after the 1980s, Criss & Shock (2001) concluded that stages have increased over time on rivers due to the construction of river training structures. Criss & Shock (2001) also analyzed rivers with and without river training structures to determine the impact structures have on water surfaces. The conclusions of Criss & Shock (2001) are driven by the comparison of two distinctly different data sets: early discharges collected by the Corps and contemporary discharges collected by the USGS. As detailed above, combining early Corps discharge measurements with contemporary USGS discharge measurements without appropriately accounting for the differences in accuracy of those measurements can result in flawed conclusions.

Pinter et al. (2000) used specific gage analysis to study changes to the stage-discharge relationship, cross-sectional area and velocity on the Middle Mississippi River. A specific gage trend was developed using daily stage and discharge data from the Middle Mississippi River gages at St. Louis, Chester, and Thebes. Pinter et al. (2000) concluded that engineering modifications on the Middle Mississippi River have caused changes in the cross-sectional geometry and flow regime leading to a decrease in stages for low discharges and rising stages for water levels starting at 40%-65% of bankfull discharge and above. Since their analysis shows rises in stages are greater for larger discharges, the authors conclude that the impact of the changes is greatest for large flood events.

One limitation of specific gage analysis is that it can only be performed on rated gages (gages with a discharge record). Jemberie et al. (2008) developed a refined specific gage approach attempting to overcome this limitation by developing "synthetic discharges" at stage only gages. The synthetic discharges were created by interpolating discharge values at nearby gages to create a stage- discharge relationship at stage only gages. Rare discharges were created using "enhanced interpolation" to formulate a continuous specific gage time series for large, rare discharges. The results of the refined specific gage study were that stages that correspond to flood discharges increased substantially at all stations consistent with what was documented by Pinter (2001).

3.1.3 Errors in specific gage papers

3.1.3.1 Use of a non-homogeneous data set

The analysis in Pinter et al. (2000) and Jemberie et al. (2008) includes data, assumptions and analysis techniques that have been brought into question by engineers and scientists within the Corps, USGS and academia. The period of record data set used by Pinter et al. (2000) and Jemberie et al. (2008) combines daily discharge measurements from rating curves developed by both the Corps of Engineers and USGS. The use of daily discharge data from the entire period of record implies the assumption that the rating curves have been developed using the same methods throughout the period of record and the measured discharges used to develop the rating curves were collected similarly throughout the period of record. On the MMR, this assumption is not valid since the period of record of discharge measurements is two distinctly different data sets as discussed above.

In an effort to disprove the long standing joint conclusion of the Corps and USGS that Corps measurements overestimated discharges compared to the USGS standard used after 1933 (Ressegieu 1952, Huizinga 2009, Watson et al. 2013a, Dyhouse 1976, Dyhouse 1985, Dyhouse 1995, Dieckmann & Dyhouse 1998), Pinter (2010) analyzed 2,015 measurements collected by the Corps on the Middle Mississippi River. The author concluded that early Corps discharges were not overestimated but were, in fact, underestimated. Based on this faulty conclusion, the author questions the adjustment of early data in the Upper Mississippi River System Flow Frequency Study and the flood frequencies and flood profiles used by the Corps on the Middle Mississippi River.

Pinter (2010) did not analyze a data set sufficient to prove his hypothesis. The source data used by the author, *Corps of Engineers, 1935, Stream-flow measurements of the Mississippi River and its Tributaries between Clarksville, MO., and the Mouth of the Ohio River 1866-1934*, included only early Corps measurements using different instruments and methodologies employed by the Corps. The author did not analyze any measurements collected using USGS instruments and methodology or compare any early Corps measurements to ones collected by the USGS.

3.1.3.2 Use of Daily Discharge Values

The analysis by Pinter et al. (2000) used daily discharge values instead of measured discharges. Daily discharge values are values of discharge that are extracted from the rating curve using a measured value of stage for a specified gage location. A rating curve is a relationship between stage and discharge that is developed by creating a smooth equation using observed measured data. Rating curves usually incorporate data from multiple years to develop their relationship and therefore are not reflective of the river for one particular year.

The use of daily discharge data over direct measured discharges for the creation of a specific gage record is discouraged by many experts including Stevens (1979), Samaranayake (2009), Huizinga (2009) and Watson and Biedenharn (2010). Stevens (1979) recommended that "measured discharges should gain quick acceptance over estimates obtained from rating curves because they reveal the relationship that exists between discharge and the controlling variables at the time of measurement." Samaranayake (2009) cautioned against the use of data obtained from rating curves since "such data lacks the natural variability one finds in actual data and can lead to conclusions that are due to the artifacts created by errors in the original rating curves." Watson and Biedenharn (2010) acknowledged that it is often tempting to use the computed daily discharge values since they increase the number of data points and improve the statistics of the rating curve, but caution that these values are not valid and risk masking actual trends.

3.1.3.3 Analysis of early Corps and USGS rating curve development

Compounding the issues with using daily discharge measurements is the use of rating curves developed by multiple agencies using different standards and practices. Over the sixty-six years between 1861-1927, the Corps created five independent rating curves for the St. Louis gage. Curves were developed for the time periods 1861-1881, 1882-1895, 1896-1915, 1916-1918 and 1919-1927. Each curve was created with discharges collected within that time period. In most cases, the discharge measurements were not collected continuously through the rating period. For example, the first rating period which spans 1861 to 1881 was created using only 181 discharge measurements. All but four of the measurements were made in 1880 and 1881 (Huizinga 2009).

The rating curves employed by the USGS (starting in 1933 in St. Louis) are not as static as the early ratings used by the Corps. USGS rating curves are often shifted and changed to account for changes in the shape, size, slope and roughness of the channel. To keep the ratings accurate and up to date, USGS technicians visit each streamgage about once every 6 weeks to measure flow directly. The USGS also emphasizes measuring extreme high and low flows since they are less common and can greatly impact the ends of the rating curve.

Regardless of whether the early Corps or contemporary USGS rating curves are used, daily discharge measurements extracted from a rating curve do not represent the characteristics of the river at the gage location for a particular year. To analyze changes over time it is recommended to create independent annual rating curves using measured discharges all collected in a specific year or analyze measured discharges for specific discharge ranges over time.

3.1.3.4 Statistical Errors

There are significantly fewer points associated with the larger discharge values of the specific gage records than the more frequent discharges. For example, as of March 2014 there have been approximately 3,435 discharge measurements collected at the St. Louis gage since 1933. Only 253 measurements (7.4 percent) have been collected for flows above bankfull (500,000 cfs). Only 80 measurements (2.3 percent) have been collected for flows above 700,000 cfs. Forty percent of the measurements observed for flows greater than 700,000 cfs were collected during the 1993 flood.

When using the direct step method of specific gage analysis, the uncertainty for the flows with limited data is revealed in the statistics (Watson & Biedenharn 2010). Pinter et al. (2000) used the rating curve method of specific gage analysis using daily discharge which the author called "a powerful tool for reducing scatter in hydrologic time-series" (Pinter 2001). As with most dependent variable values predicted using a regression equation, the error in the regression equation is less close to the mean of the independent variable and increases toward the more extreme values (small and large discharge values). The net result is that Pinter et al. (2000) generated data that has varying degrees of error variance and the use of ordinary least squares estimation under such circumstances has lead to incorrect results (Samaranayake 2009).

3.1.3.5 Physical Changes on the MMR

Inherent in the use of a specific gage that spans a long time period is the understanding that errors and inconsistencies associated with the measurement of discharge and stage are captured in the record. Substantial changes in the river, if not accounted for, would all render the specific gage record unreliable.

For example, Pinter et al. (2000) uses a single linear regression to represent the trend for a given discharge value curve. This is problematic since it does not accurately represent all the time periods in the record. There are shorter periods of time observed in the presented specific gage records when stages are decreasing rather than increasing, and the linear trend sorely misrepresents the observed changes. Other problems with this approach are there were major physical changes that occurred throughout the period of record which are reflected by changes in the stage-discharge record. These include the capture of the Kaskaskia River which shortened the MMR by 5 miles, the construction of reservoirs which reduced the sediment load in the MMR, and the construction of levees throughout the period of record including the completion of the Alton to Gale levee system.

3.1.3.6 Creation and use of "Synthetic Discharges" and "enhanced interpolation"

Much of the analysis of Jemberie et al. (2008) is similar to the analysis of Pinter et al. (2000) and has the same issues as described above. The new contributions of Jemberie et al. (2008) are the development of 'synthetic discharges' for unrated gages and 'enhanced interpolation' to calculate continuous specific-stage time series for rare discharges.

The development of 'synthetic discharges' is simply the development of a discharge record for gages where discharge was not measured by interpolating between rated gages. The purpose of creating a discharge record is so a specific gage analysis can be performed at that gage. Since the discharge record at the 'synthetic gages' is inherently dependent on the discharge record at the legitimately rated gages, the data at the 'synthetic' gages are not independent and should not be treated as such. The creation of a rating for the 'synthetic gages' incorporates an abundance of uncertainty due to the many assumptions that need to be made.

Compounding the problems with interpolating between gages to create a discharge value at an unrated gage is the use of daily discharges as the source data for the interpolation. As detailed above, daily discharges are not measured values. The use of daily discharge values incorporates more error and uncertainty into the fabricated rating at the 'synthetic gages'.

For rare high flows, the true rating curve for an unrated gage may be heavily influenced by levee overtopping or other phenomena which would only be reflected through discharge measurements. The author does not detail or account for the impact of the assumptions made on the 'data' created for the 'synthetic gages'.

The practice of using 'enhanced interpolation' to generate a continuous time series for a particular fixed discharge is not supported by the Corps and many other engineers and scientists. Similar to the 'synthetic gage' data, the data created using 'enhanced interpolation' is based off of an interpolation scheme and is not measured data. The fabricated values are dependent on the other values used to create the time series trend.

To create the data using 'enhanced interpolation' one must assume that the time series for Q and Q_t^* is continuous and linear. Watson et al. (2013b), Watson and Biedenharn (2010), Huizinga (2009) and Brauer (2009) have all shown that this assumption is not valid. Another assumption necessary is that there is only one specific stage value for each independent discharge, specifically at the highest and lowest discharges. Analyses of measured discharges have shown that stage is dependent not only on discharge but other physical characteristics of the channel (bed roughness, vegetation, sediment load, temperature, etc.). The use of 'enhanced interpolation' masks the natural variability in the relationship between stage and discharge.

Jemberie et al. (2008) does not make any attempt to verify the validity of the 'enhanced interpolation' technique by proving the relationship using stage and discharge relationships at rated gages.

3.1.4 Summary

A majority of the journal articles, technical notes, book chapters, and conference papers whose conclusions claim a link between instream structure construction and an increase in flood levels rely on specific gage analysis. The specific gage analyses that conclude that instream structures impact flood levels are all driven by the use of source data and methodology not supported by many engineers and scientists in the fields of river data collection, river engineering, geomorphology, hydraulics and statistics. Specific gage analysis studies conducted on the MMR also conclude that instream structures do not impact flood levels (Huizinga 2009, Watson & Biedenharn 2010 and Watson et al. 2013). The Corps does not give credibility to the conclusions of the specific gage analysis studies that attempt to link instream structures with increases in flood level due to the methodology and data use errors.

3.2 Papers using numerical simulations to link instream structure construction to flood level increases

3.2.1"Retro-Modeling"

Remo and Pinter (2007) developed a one-dimensional unsteady-flow "retro-model" of the Middle Mississippi River using historical hydrologic and geospatial data to assess the magnitude and types of changes in flood stages associated with twentieth century river engineering.

Comparison of the retro-model results with the 2004 Upper Mississippi River System Flow Frequency Study (UMRSFFS) revealed increases in flood stages of 0.7 – 4.7 m. The difference in flood stages between the UMRSFFS and retro-model increased with increasing discharge.

3.2.1.1 Errors in "Retro-Modeling" studies

3.2.1.1.1 Source Data

The large stage differences between current and early discharge estimates are partly due to the use of incorrect discharge values for historic hydrographs and floods occurring prior to 1933 as discussed above. The retro-modeling period of 1900-1904 includes one major flood in 1903 and a small one in 1904. The original estimated historic discharge of 1,020,000 cfs at St. Louis is used for the peak of the 1903 flood. This flow was originally developed for St. Louis from discharge measurements made at Chester. Tests conducted with the Mississippi Basin Model in the late 1980s found that a match of the 1903 high water marks through the entire reach of stream at St. Louis occurred for a discharge of about 790,000 cfs. The actual value of the 1903 discharge at St. Louis is likely to be approximately 230,000 cfs (or 23 percent) less than the value used by Remo and Pinter (2007) in the model calibration.

3.2.1.1.2 Channel Roughness

Manning's 'n' is the value most often modified to achieve a calibration of the model results to known stages. Manning's 'n' represents the relative roughness of a channel. The larger the Manning's 'n' the more resistance there is to flow. Forcing a calibration of the high and incorrect discharge of the 1903 flood would require a surprisingly low 'n' value for the channel of about 0.02, as used by Remo and Pinter (2007). The authors observe that the 'n' values for the historical period were systematically at the lower end of the published ranges. In practice, this usually indicates a problem with the model geometry or input data.

The authors describe HEC-RAS as only allowing a single roughness coefficient value in the channel and separate values for the floodplains. The limitation of having "fixed" values was described as a source of model uncertainty. This statement by the authors is untrue — not only does HEC-RAS have the ability to vary the 'n' value horizontally across the cross sections, but it can also be varied for flow or season. All of these techniques are standard hydraulic engineering practice. Horizontal variation of the roughness may be necessary to generate reasonable model results and has a solid foundation in the literature, as noted by Remo and Pinter (2007).

3.2.1.1.3 Model Assumptions

One assumption that could affect model results is the absence of flows from tributaries in the model calibration. Another problematic model assumption is that land use in unmapped areas was forested. Large tracts of timber in the Mississippi Valley were harvested in the late 1800s and early 1900s. The 'retro-model' also does not appear to consider how under the natural (before levee construction) conditions, flood water entering the floodplain over natural levees likely returned to the channel through a series of backwater swamps and channels. This may explain the apparent tendency of the model to over predict stages on the falling limb of the hydrograph. This natural drainage system was likely altered during conversion of the floodplain to agricultural production.

3.2.1.2 Corps Conclusions and Analysis

The calibration of the "retro-model" has been questioned by the Corps due to the use of early Corps discharges, surprisingly low 'n' values used, and other model assumptions detailed above. The Corps believes that the surprisingly low Manning's roughness values were necessary to compensate for the overestimated flows used in the model and are not representative of the characteristics of the historic channel.

The Corps takes the conclusions of Remo & Pinter (2007) very seriously and has attempted to work with the authors to verify the model results and gain a full understanding of the physical processes driving their concluded increase in flood stage. This research was carried out with support from the US National Science Foundation (NSF) grants EAR-0229578 and BCS-0552364. National Science Foundation policy states that, "Investigators are expected to share with other researchers, at no more than incremental cost and within a reasonable time, the primary data, samples, physical collections and other supporting materials created or gathered in the course of work under NSF grants." However, to date, the authors have refused to provide the model, data or any other supporting materials to the Corps' St. Louis District, although multiple requests for this information have been made.

3.2.2 Retro and Scenario Modeling

Remo et al. (2009) is an expansion of Remo and Pinter (2007). In addition to the comparison of the 'retro-model' to the UMRSFFS, Remo et al. (2009) run a series of scenario models to quantify the impact of levees, channel change and land cover. Remo et al. (2009) concluded that on the MMR in the "St. Louis Reach" levees accounted for 0.1 – 1.0 m of increase in stage, changes in channel geometry accounted for a stage increase of 0.1-2.9 m, changes in total roughness accounted for a stage increase of 0.1 – 1.4 m, and changes in land cover accounted for a stage increase of up to 0.4 m.

Similar to the model effort of Remo and Pinter (2007), the Corps has attempted to work with the authors to verify the model results and gain a full understanding of the physical processes driving their concluded increase in flood stage. To date the authors have refused to provide a copy of the model and associated data used to develop the conclusions of Remo et al. (2009) for review by the Corps in spite of the NSF policy requirements detailed above. This research was funded by NSF Grants EAR-0229578 and BCS-0552364.

Remo et al. (2009) concludes that "changes in total roughness (channel and floodplain Manning's n) between the ca. 1900 retro-model and the values used in the UMRSFFS UNET model explained much of the increases in stage observed along St. Louis Study reach." The Corps believes these stage changes are due to errors in the modeling process as detailed above and are not representative of physical changes on the MMR.

3.2.3 Theoretical Analysis

Huthoff et al. (2013) used a simplified theoretical analysis to test the impact of wing dikes on flood levels. This analysis used a simplified cross section to test three scenarios: with no wing dikes, with wing dikes without bed response, and with wing dikes including bed response. The overall channel discharge is calculated for each stage using Manning's equation for steady uniform flow. The discharge for separate flow compartments is calculated using the divided channel method. The Manning's roughness for the dike region is calculated using a flow resistance equation from Yossef (2004, 2005). The author concludes that although the roughness in the dike reach decreases with increasing water levels, the submergence is not great enough for the roughness to return to the base roughness. The authors conclude that the increase in stage for four times the average flow ($4Q_{ave}$) due to the wing dikes is 0.6 m, 0.7 m, 1.1 m and 0.6 m at St. Louis, Chester, Grand Tower and Thebes, respectively.

3.2.3.1 Errors in Theoretical Analysis

3.2.3.1.1 Applicability of Effective Roughness Equation

The theoretical analysis proposed by Huthoff et al. (2013) is an oversimplified method to quantify an extremely complex and dynamic hydraulic problem. The basis of this analysis is the effective 'n' value formula developed by Yossef (2004, 2005) which was developed using a fixed bed physical model scaled to represent a reach of the Dutch River Waal which has much different geometry, dike size, and dike spacing than those used on the Middle Mississippi River. Although this relationship can be used to give insight into the effective roughness in the dike zone and submergence, it is only suitable to deduce trends rather than quantify accurate magnitudes of change.

3.2.3.1.2 Bank Roughness

As detailed in the editor's note, Huthoff et al. (2013) initially submitted a manuscript with an error in the calculation of Manning's roughness which resulted in an overestimation of the roughness by a factor of 10. Due to the theoretical model's sensitivity to the bank roughness value, this overestimation was the primary driver for the stage changes concluded. A simple correction of the calculation error with no additional manipulation in input data results in stage changes of -0.12 m at St. Louis, +0.21 m at Chester, +0.84 m at Grand Tower, and -0.00 m at Thebes for $4Q_{ave}$. In addition to correcting the error, the authors changed the input values of bank roughness, mean dike crest elevation, and assumed bed level changes. The impact of each of these input changes in the model was an increase in stage for $4Q_{ave}$.

The bank roughness values used in Huthoff et al. (2013) were much lower than what is typically used for the MMR and much lower than those used for the main channel. The authors used a combination of 'n' values from different sources: the bank values were arbitrarily taken from literature whereas the values for other zones were taken from a hydraulic model. This resulted in velocity distribution in the channel that had high velocities along the bank and lower velocities in the channel at high flow. This is contrary to observed and theoretical velocity patterns in an open channel (Chow 1959).

3.2.3.1.3 Model Verification

The model used in this analysis did not have adequate validation to prove that it has the ability to reproduce empirical results. The attempt of validation showed that the model matched the empirical values which it was calibrated to. The author did not validate the model to an independent observed flow which is customary engineering practice. The author also did not attempt to verify the ability of the model to reproduce any flood flows.

3.2.3.2 Discussion

Since the relationship by Yossef (2004, 2005) was developed studying a river whose geometry and structures are very different to those used on the MMR, it cannot be used to quantify accurate magnitudes of change on the MMR. Although the model used by Huthoff et al. (2013) has many limitations preventing it from being used quantitatively, insight can be gained by the shape of the relationship between water level and dike roughness. The reduction of roughness with an increase in submergence is consistent with what has been observed by many scientists and engineers (Sukhodolov 2013; Watson & Biedenharn 2010; GAO 2011; PIANC 2009; Azinfar & Kells 2007; Stevens et al. 1975; Chow 1959) and in conflict with what has been concluded by Pinter (2000) and Remo & Pinter (2007).

3.3 Physical Fixed Bed Modeling

Azinfar and Kells (2009, 2008, and 2007) use the results of fixed bed physical model studies to analyze flow resistance and backwater effect of a single dike. The authors use the conclusions of Criss & Shock (2001), Pinter et al. (2001) and Pinter (2004) as a foundation for their research. The purpose of the analysis in Azinfar and Kells (2009, 2008, and 2007) was to "quantify the amount of backwater effect that occurs so that the impacts of spur dike construction can be determined by those charged with managing the river system."

Azinfar and Kells (2007) developed a multi-functional backwater model calibrated to fixed bed physical model studies by Oak (1992) to study the backwater effect due to a single spur dike in an open-channel flow. Parameters analyzed using the model include the spur dike aspect ratio (height/length), spur dike opening ratio (1-length/channel width), spur dike submergence ratio (water depth/height) and upstream Froude number. Azinfar and Kells (2007) found that the parameter that has the greatest effect on the drag coefficient of a spur dike was the submergence ratio— the more the structure is submerged, the less the drag coefficient and therefore the less impact it has on water surfaces. This conclusion is contrary to the conclusion of Pinter (2000) and Remo & Pinter (2007) that conclude that the impact of dikes on water surfaces increases with increasing discharge and are highest at flood stage.

Azinfar and Kells (2008) propose a predictive relationship developed in Azinfar and Kells (2007) that can be used to obtain a first-level estimate of the backwater effect due to a single, submerged spur dike in an open channel flow. Azinfar and Kells (2009) conclude that in a rigid flume an increase in blockage due to a spur dike is the main parameter responsible for an increase in the drag coefficient and associated flow resistance.

There is no debate that in a fixed bed scenario any channel blockage will produce a backwater effect. This is due to the decrease in cross sectional area resulting from the presence of the structure. The conclusions of Azinfar and Kells (2009, 2008, and 2007) reinforce why incorporating sediment transport is critical in having a full understanding of the impacts of dikes on water surfaces, particularly flood levels. The purpose of dikes is to induce bed scour and deepen the channel. Analysis of cross sectional changes on the Mississippi River has shown that once equilibrium is reached, although the dimensions of the channel may be different (i.e., deeper and narrower), the cross sectional area is preserved.

4. Studies cited that do not link the construction of instream structures to increases in flood levels

Other journal articles, editorials and conference papers have been incorrectly referenced as linking the construction of instream structures to increases in flood levels:

1. Chen and Simmons (1986), Roberge (2002), Pinter et al. (2006a), Sondergaard and Jeppesen (2007), Theiling and Nestler (2010), and Borman et al. (2011) simply reference the research detailed in the aforementioned papers as background but do not present any new analysis.

2. Bowen et al. (2003), Wasklewicz et al. (2004), Ehlmann and Criss (2006), Criss and Vinston (2008), Criss (2009) and Pinter et al. (2012) analyze flow frequency and/or propose changes to the way flow frequency is calculated. They do not present any new analysis linking instream structures to increasing flood levels.

3. Struiksma and Klaasen (1987), Ettema and Muste (2004), and Maynord (2006), are about physical modeling and model scaling and distortion and do not discuss instream structure construction or flood levels.

4. Pinter (2005) and Van Ogtrop et al. (2005) present arguments linking the construction of levees to increases in flood levels. These papers do not present any analysis on instream structures and how they impact flood levels.

5. Maher (1964) presents changes in river regime of the Mississippi River and the variations in rating curves with respect to time and stage. The analysis includes causes for some of the stage-discharge relationship changes. The author analyzes the changes of three reaches of the MMR over three different time periods. Maher (1964) concludes that “the construction of levees in the Mississippi River floodplain during the period 1908-1927 has been the main factor in reducing floodway capacity to approximately 54% of the 1908 area. Between 1927 and 1943, when no additional levees were constructed, the floodway capacity remained practically constant, being reduced in area by only an additional ½ of 1%.” Maher (1964) does not attempt to link the construction of instream structures to increases in flood levels.

6. Paz et al. (2010) describes a HEC-RAS model study of the Paraguay River and its tributaries with limited data.

7. Doyle and Havlick (2009) examines current infrastructure and current understanding of environmental impacts for different types of infrastructure. This paper discusses the impact of levees on flooding.

8. Remo et al. (2008) discusses a database compiled by the authors with hydrologic and geospatial data on the Mississippi, lower Missouri and Illinois rivers. No analysis is conducted or conclusions drawn.

9. Remo and Pinter (2007) is a conference paper that discusses the database compiled by the authors detailed in Remo et al. (2008) and summarizes “retro-modeling” as a tool to analyze historic changes.

10. O’Donnell and Galat (2007) discusses river enhancement projects on the Upper Mississippi River and recommends improvement in management practices and project data collection, entry, management, and quality control/assurance across agencies.

11. Jai et al. (2005) used CCHE3D, a three-dimensional model for free surface turbulent flows developed at the National Center for Computational Hydroscience and Engineering, to study the helical secondary current and near-field flow distribution around one submerged weir. The model was validated using flow data measured during a physical model study conducted at the Coastal and Hydraulic Laboratory of ERDC. The models used in this study did not simulate sediment transport and channel change. Although water surface elevation contours are discussed near the submerged weir, the paper does not present a detailed analysis of the structures’ impact on water surfaces.

12. Pinter et al. (2004) provides an evaluation of dredging on a particular reach of the Middle and Upper Mississippi River based on dredging records obtained from the USACE St. Louis District. Although references to the impact of river training structures on flood stages are made several times, Pinter et al. (2004) does not have any analysis, discussion or conclusions on the topic.

13. Smith and Winkley (1996) examine the response of the Lower Mississippi River to a variety of engineering activities. This paper presents a brief history of engineering investigation on the Lower Mississippi River, analyzes the impact of artificial cutoffs on the channel geometry and water surface profiles, analyzes the impact of channel alignment activities on channel morphology and the apparent impact of all of the Lower Mississippi River engineering activities on sediment dynamics in the channel. There is no discussion or analysis by Smith and Winkley (1996) on how the construction of river training structures impacts flow levels.

14. Huang and Ng (2006) use a CCHE3D model calibrated to a fixed bed physical model to study basic flow structure around a single submerged weir in a bend. Conclusions are made on the near field changes in water surface. With the weir installed, the water surface elevation reflected the existence of the weir in the whole channel with an increase in the water surface elevation upstream of the weir due to an increase in resistance when the flow approaches the weir. Downstream of the weir the model found a decrease in water surface due to the acceleration of the flow after passing through the weir. Huang and Ng (2006) describe the changes in water

surface as a “local effect.” The scenario analyzed in Huang and Ng (2006) is for a single weir added to a fixed bed channel with no change in channel bathymetry, thus presenting an obstruction to flow. The author does not test flood flows or attempt to extrapolate his results to conclude that instream structures raise flood levels.

5. Studies the Corps was unable to gain access to

The Corps was unable to retrieve copies of the following study and therefore was unable to use it in their analysis of the impact of instream structures on flood levels:

Clifford, N.J., Soar, P.J., Gurnell, A.M., Petts, G.E., 2002. Numerical flow modeling for eco-hydraulic and river rehabilitation applications: a case study of the River Cole, Birmingham, U.K.. In River Flow 2002, Bousmar D, Zech Y (eds). Swets & Zeitlinger/Balkema: Lisse; 1195-1204.

6. Conclusion

Based upon all of the available research analyzed above, the Corps has concluded that river training structures do not impact flood levels. The research efforts, as detailed in the published papers, book chapters, editorials and conference proceedings that conflict with the Corps’ conclusions all rely on analysis, assumptions and data that is not supported by engineers and scientists within the Corps, other Federal Agencies with expertise in water resources, and academia.

The claims in the literature detailed above that river training structures have an impact on flood flows are not new. The Corps was concerned in the 1930s that the construction of dikes may have reduced the floodway capacity of the MMR (Ressegieu 1952). The Corps worked with the USGS and other experts to understand the issue and determined that there was not a change in floodway capacity rather a change in the way data was collected. Through the incorrect use of early Corps discharge data (Watson et al. 2013a) scientists in the 1970s again claimed that dikes have increased flood levels. In response, the Corps worked with experts from academia to understand the issue and study the problem using the latest technology. The conclusions of the experts reinforced previous conclusions that river training structures do not increase flood levels.

Recently, the Corps worked with experts from other agencies and academia to evaluate the impact of river training structures on flood levels. The conclusions of these studies reinforce the previous conclusions that river training structures do not increase flood levels. As has been the case throughout the history of the Regulating Works Project, the Corps will continue to monitor and study the physical effects of river training structures using the most up-to-date methods and technology as it becomes available.

The majority of research attempting to link river training structures to an increase in flood heights is based off of a handful of research efforts primarily by researchers from three academic institutions: Washington University (Criss, Shock), Southern Illinois University –Carbondale (Pinter, Remo, Jemberie, Huthoff), and University of Saskatchewan (Azinfar, Kells). The Corps takes the claims of these researchers very seriously and has made repeated attempts to engage and collaborate with them to fully understand their conclusions that link river training structures to increases in flood levels. These efforts have had limited success (USGAO 2011).

7. References

Azinfar, H., and J.A. Kells, 2009. Flow resistance due to a single spur dike in an open channel. Journal of Hydraulic Research, 47: 755-763.

Azinfar, H., J.A. Kells, 2008. Backwater prediction due to the blockage caused by a single, submerged spur dike in an open channel. Journal of Hydraulic Engineering, 134: 1153-1157.

Azinfar, H., and J.A. Kells, 2007. Backwater effect due to a single spur dike. Canadian Journal of Civil Engineering, 34: 107-115.

Belt, C.B. 1975. The 1973 flood and man's constriction of the Mississippi River. Science, 189: 681-684.

Brauer, E.J., and Duncan, D.L., in press. Discussion of "Theoretical Analysis of Wing Dike Impact on River Flood Stages" by Fredrik Huthoff, Nicholas Pinter and Jonathan W.F. Remo. Journal of Hydraulic Engineering

Brauer, E.J. 2009. The limitations of using specific gage analysis to analyze the effect of navigation structures on flood heights in the Middle Mississippi River. Vienna, Austria, Proceedings of the 4th international congress of Smart Rivers '21. Sept 6-9. p156-163.

Brauer, E.J. 2012. The effect of river training structures on flood heights on the Middle Mississippi River. San Jose, Costa Rica. Proceedings of the 6th edition of the International Conference on Fluvial Hydraulics. Sept 5-7. CRC Press.

Brauer, E.J. 2013. The Effect of Dikes on Water Surfaces in a Mobile Bed. MS Thesis. University of Illinois, Urbana-Champaign.

Bormann, H., N. Pinter, and S. Elfert, 2011. Hydrological signatures of flood trends on German Rivers: Flood frequencies, flood heights, and specific stages. Journal of Hydrology 404 (2011) 50–66.

Bowen, Z.H., Bovee, K.D., Waddle, T.J. 2003. Effects of Regulation on Shallow-Water Habitat Dynamics and Floodplain Connectivity. Transactions of the American Fisheries Society 132, 809-823.

Chen Y.H., and Simmons D.B., 1986. Hydrology, hydraulics, and geomorphology of the Upper Mississippi River system. Hydrobiologia 136, 5-20.

Chow, V.T., 1959. Open-channel hydraulics: New York, McGraw-Hill.

Clifford, N.J., Soar, P.J., Gurnell, A.M., Petts, G.E., 2002. Numerical flow modeling for eco-hydraulic and river rehabilitation applications: a case study of the River Cole, Birmingham, U.K.. In River Flow 2002, Bousmar D, Zech Y (eds). Swets & Zeitlinger/Balkema: Lisse; 1195-1204.

Criss, R.E., 2009. Increased flooding of large and small watersheds of the central USA and the consequences for flood frequency predictions. In R. E. Criss and Timothy M. Kusky (Eds.), Finding the Balance between Floods, Flood Protection, and River Navigation, pp. 16-21. Saint Louis University, Center for Environmental Sciences.

Criss, R.E., and W.E. Vinston, 2008. Public Safety and Faulty Flood Statistics. Environmental Health Perspectives, 116: A516.

Criss, R. E., & Shock, E. L. 2001. Flood enhancement through flood control. Geology , 29 (10), 875-878.

Doyle, M.W., D.G. Havlick, 2009. Infrastructure and the Environment. Annual Review of Environment and Resources, 34: 349-373.

Dieckmann, R.J., Dyhouse, G.R. 1998. Changing history at St. Louis – adjusting historic flows for frequency analysis. First Federal Inter-Avency Hydrologic Modeling Conference, April 20-22, 1998. Las Vegas, NV.

Dyhouse, G.R. 1995. Effects of Federal Levees and Reservoirs on 1993 Flood Stages in St. Louis. Washington, DC. National Research Council, Transportation Research Board, Record No. 1483. 7p.

Dyhouse, G.R. 1985. Comparing flood stage-discharge data- Be Careful! In Hydraulics and Hydrology in the Small Computer Age: Proceedings of the Specialty Conference. Waldrop WR (ed.) American Soc. Of Civil Engineers Hydraulics Divison: New York; 73-78.

Dyhouse, G.R. 1976. Discussion of "Man-induced changes of Middle Mississippi River". Journal of the waterways harbors, and coastal engineering division. Proceedings of the American Society of Civil Engineers. 102(WW2). 277-279.

Ehlmann, B.L., and R.E. Criss, 2006. Enhanced stage and stage variability on the lower Missouri River benchmarked by Lewis and Clark. Geology, 34: 977-980.

Ettema, R., Muste, M. 2004. Scale effects in flume experiments on flow around a spur dike in a flat bed channel. Journal of Hydraulic Engineering. 130 (7), 635-646.

Heine, R.A., Pinter, N. 2012. Levee effects upon flood levels: an empirical assessment. Hydrological Processes, 26, 3225-3240. DOI: 10.1002/hyp.8261.

Huang, S.L., Ng C. 2007. Hydraulics of a submerged weir and applicability in navigational channels: Basin flow structures. International Journal for Numerical Methods in Engineering 69, 2264-2278.

Huizinga, R.J. 2009. Examination of measurement and historic daily data for several gaging stations on the Middle Mississippi River, 1861-2008. U.S. Geologicial Survey Scientific Investigations Report 2009-5232. 60p. (Also available at http://pubs.usgs.gov/sir/2009/5232/)

Huthoff, F., N. Pinter, J.W.F. Remo, 2013. Theoretical analysis of wing dike impact on river flood stages. Journal of Hydraulic Engineering. 139(5), 550-556. DOI: 10:1061/(ASCE)HY.1943-7900.0000698.

Jai, Y., Scott S., Xu, Y., Huang, S. and Wang, S.S.Y. 2005. Three-dimensional numerical simulation and analysis of flow around submerged weir in a channel bendway. Journal of Hydraulic Engineering. 131, 682-693.

Jemberie, A.A., N. Pinter, and J.W.F. Remo, 2008. Hydrologic history of the Mississippi and Lower Missouri Rivers based upon a refined specific-gage approach. Hydrologic Processes, 22: 7736-4447, doi:10.1002/hyp.7046.

Maher, T.F. 1964. Study of regulation works on stream flow. Paper presented at ASCE Meeting, Cincinnati, Ohio, February, 1-24.

Maynord, S.T. 2006. Evaluation of the Micromodel: An Extremely Small-Scale Movable Bed Model. Journal of Hydraulic Engineering 132, 343-353.

Monroe, R.H. 1962. U.S. Geological Survey, unpublished data.

Munger, P.R., Stevens, G.T., Clemence, S.P., Barr, D.J., Westphal, J.A., Muir, C.D., Kern, F.J., Beveridge, T.R., and Heagler, Jr., J.B. 1976. SLD Potamology Study (T-1). University of Missouri-Rolla, Institute of River Studies, Rolla, Missouri.

O’ Donnell, K.T. Galat D.L., 2007. River Enhancement in the Upper Mississippi River Basin: Approaches Based on River Uses, Alterations, and Management Agencies. Restoration Ecology, 15, 538-549.

Parker, G., Garcia, MH, Joannesson, J. and Okabe, K. 1988. Model Study of the Minnesota River near Wilmarth Power Plant, Minnesota, Project Report No. 284, Saint Anthony Falls Hydraulic Laboratory, University of Minnesota.

Paz, A.R., J.M. Bravo, D. Allasia, W. Collischonn, and C.E.M. Tucci, 2010. Large-scale hydrodynamic modeling of a complex river network and floodplains. Journal of Hydrologic Engineering, 15: 152-165.

PIANC, 2009. Sustainable waterways within the context of navigation and flood management. Envi-Com Report n°107-2009.

Pinter, N., J. Dierauer, and J.W.F. Remo, 2012. Flood-loss modeling for assessing impacts of flood-frequency adjustment, Middle Mississippi River, USA. Hydrologic Processes, doi:10.1002/hyp.9321.

Pinter, N., A.A. Jemberie, J.W.F. Remo, R.A. Heine, and B.A. Ickes, 2010. Cumulative impacts of river engineering, Mississippi and Lower Missouri Rivers. River Research and Applications, 26: 546-571.

Pinter, N., 2010. Historical discharge measurements on the Middle Mississippi River, USA: No basis for "changing history." Hydrological Processes, 24: 1088-1093.

Pinter, N., 2009. Non-stationary flood occurrence on the Upper Mississippi-Lower Missouri River system: Review and current status. In R. E. Criss and Timothy M. Kusky (Eds.), Finding the Balance between Floods, Flood Protection, and River Navigation, pp. 34-40. Saint Louis University, Center for Environmental Sciences.

Pinter, N., A.A. Jemberie, J.W.F. Remo, R.A. Heine, and B.S. Ickes, 2008. Flood trends and river engineering on the Mississippi River system, Geophysical Research Letters, 35, L23404, doi:10.1029/2008GL035987.

Pinter, N., R.R. van der Ploeg, P. Schweigert, and G. Hoefer, 2006. Flood Magnification on the River Rhine. Hydrological Processes, 20: 147-164.

Pinter, N., B.S. Ickes, J.H. Wlosinski, and R.R. van der Ploeg, 2006. Trends in flood stages: Contrasting trends in flooding on the Mississippi and Rhine river systems. Journal of Hydrology, 331: 554-566.

Pinter, N., 2005. Policy Forum: One step forward, two steps back on U.S. floodplains. Science, 308: 207-208.

Pinter, N., and R.A. Heine, 2005. Hydrodynamic and morphodynamic response to river engineering documented by fixed-discharge analysis, Lower Missouri River, USA. Journal of Hydrology, 302: 70-91.

Pinter, N., K. Miller, J.H. Wlosinski, and R.R. van der Ploeg, 2004. Recurrent shoaling and dredging on the Middle and Upper Mississippi River, USA. Journal of Hydrology, 290: 275-296.

Pinter, N., and R. Thomas, 2003. Engineering modifications and changes in flood behavior of the Middle Mississippi River. In R. Criss and D. Wilson, (eds.), At The Confluence: Rivers, Floods, and Water Quality in the St. Louis Region, pp. 96-114.

Pinter, N., R. Thomas, and J.H. Wlosinski, 2002. Reply to U.S. Army Corps of Engineers Comment on "Assessing flood hazard on dynamic rivers." Eos: Transactions of the American Geophysical Union, 83(36): 397-398.

Pinter, N., J.H. Wlosinski, and R. Heine, 2002. The case for utilization of stage data in flood-frequency analysis: Preliminary results from the Middle Mississippi and Lower Missouri River. Hydrologic Science and Technology Journal, 18(1-4): 173-185.

Pinter, N., R. Thomas, and N.S. Philippi, 2001b. Side-stepping environmental conflicts: The role of natural-hazards assessment, planning, and mitigation. E. Petzold-Bradley, A. Carius, and A. Vincze (eds.), Responding to Environmental Conflicts: Implications for Theory and Practice, p. 113-132. Dordrecht: Kluwer Academic Publishers.

Pinter, N., R. Thomas, and J.H. Wlosinski, 2001a. Flood-hazard assessment on dynamic rivers. Eos: Transactions of the American Geophysical Union, 82(31): 333-339.

Pinter, N., R. Thomas, and J.H. Wlosinski, 2000. Regional impacts of levee construction and channelization, Middle Mississippi River, USA. In J. Marsalek, W.E. Watt, E. Zeman, and F. Sieker (eds.), Flood Issues in Contemporary Water Management, p. 351-361. Dordrecht: Kluwer Academic Publishers.

Piotrowski, J.A., Young, N.C., Weber, L.J. 2012. Supplemental Investigatoin of the Influence of River Training Structures on Flood Stages From River Mile 179.5 to 190.0 of the Middle Mississippi River. Submitted to the U.S. Army Corps of Engineers, St. Louis, Missouri.

Remo, J.W.F., N. Pinter, and R.A. Heine, 2009. The use of retro- and scenario- modeling to assess effects of 100+ years river engineering and land cover change on Middle and Lower Mississippi River flood stages. Journal of Hydrology, 376: 403–416.

Remo, J.W.F., N. Pinter, B. Ickes, and R. Heine, 2008. New databases reveal 200 years of change on the Mississippi River System. Eos, 89(14): 134-135.

Remo, J.W.F, and Pinter, N., 2007. The use of spatial systems, historic remote sensing and retro-modeling to assess man-made changes to the Mississippi River System. In: Zaho, P. et al. (eds.), Proceedings of International Association of Mathematical Geology 2007: Geomathematics and GIS Analysis of Resources, Environment and Hazards. State Key Laboratory of Geological Processes and Mineral Resources, Beijing, China, pp. 286-288.

Remo, J.W.F., and N. Pinter, 2007. Retro-modeling of the Middle Mississippi River. Journal of Hydrology. doi: 10.1016/j.hydrol.2007.02.008.

Ressegieu, F.E. 1952. Comparative discharge measurements, Mississippi River by USGS and Corps of Engineers. St. Louis District, U.S. Army Corps of Engineers.

Roberge, M., 2002. Human modification of the geomorphically unstable Salt River in metropolitan Phoenix. Professional Geographer, 54: 175-189.

Samaranayake, V.A. 2009. The statistical review of three papers on specific gage analysis. Report to U.S. Army Corps of Engineers, St. Louis District.

Smith, L. M., and Winkley, B.R. 1996. The response of Lower Mississippi River to river engineering . Engineering Geology. 45, 433-455.

Sondergaard, M., and E. Jeppesen, 2007. Anthropogenic impacts on lake and stream ecosystems, and approaches to restoration. Journal of Applied Ecology, 44: 1089-1094.

Stevens, M. A., Simons, D. B., & Schumm, S. A. 1975. Man-induced changes of Middle Mississippi River. Journal of the Waterways Harbors and Coastal Engineering Division , 119-133.

Stevens, G.T. 1976. Discussion of “Man-induced changes of Middle Mississippi River”.Journal of the waterways, harbors, and costal engineering division. Proceedings of the American Society of Civil Engineers. 102(WW2). 280.

Strauser, C.N. and N.C. Long. 1976. Discussion of “Man-induced changes of Middle Mississippi River”. Journal of the waterways, harbors, and costal engineering division. Proceedings of the American Society of Civil Engineers. 102(WW2). 281-282.

Struiksma, N. Klaasen, G.J., 1987. On scale effects in moveable river models. Communication No. 381, Delft Hydralics Laboratory, Delft, The Netherlands.

Sukhodolov, A.N. 2014. Hydrodynamic of groyne fields in a straight river reach: insight from field experiments. Journal of Hydraulic Research. 52:1, 105-120. DOI: 10.1080/00221686.2014.880859.

Szilagyi, J., N. Pinter, and R. Venczel, 2008. Application of a routing model for detecting channel flow changes with minimal data. Journal of Hydrologic Engineering, 13: 521-526.

Theiling, C.H., and J.M. Nestler, 2010. River stage response to alteration of Upper Mississippi River channels, floodplains, and watersheds. Hydrobiologia, 640: 17-47.

USACE. 1996. Barfield Bend Potomology Study Update, Mississippi River, Hydraulics and Hydrology Branch.

USACE. 2008. Upper Mississippi River Comprehensive Plan. U.S. Army Corps of Engineers Rock Island District, St. Louis District, St. Paul District.

USACE. 1995. Floodplain Management Assessment of the Upper Mississippi River and Lower Missouri Rivers and Tributaries.

USACE. 1942. Mississippi River flood discharge capacity. Prepared by U.S. Army Engineer District, St. Louis.

USACE. 1935. Stream-flow measurements of the Mississippi River and its Tributaries between Clarksville, MO and the Mouth of the Ohio River 1866-1934, Hydrologic Pamphlet No. 1, U.S. Engineer Office, St. Louis, MO. U.S. Government Printing Office: Washington, D.C.

U.S. Government Accountability Office (USGAO). 2011. "Mississippi River: Actions are needed to help resolve environmental and flooding concerns about the use of river training structures". Rep. GAO-12-41, Washington, DC.

Van Ogtrop, F.F., A.Y. Hoekstra, and F. van der Meulen, 2005. Flood management in the Lower Incomati River Basin, Mozambique: Two alternatives. Journal of the American Water Resources Association, 41: 607-619.

Wasklewicz T.A., J. Grubaugh, and S. Franklin, 2004. 20th century stage trends along the Mississippi River. Physical Geography, 25: 208-224.

Watson, C.C. and Biedenharn, D.C. 2010. Specific gage analyses of stage trends on the Middle Mississippi River. Report to U.S. Army Corps of Engineers, St. Louis District.

Watson, C.C., R.R. Holmes, D.S. Biedenharn. 2013a. Mississippi River Streamflow Measurement Techniques at St. Louis, Missouri. J. Hydraulic Engineering: 139:1062-1070.

Watson, C.C., Holmes, R.R., Jr., and Biedenharn, D.S., 2013a. Mississippi River streamflow measurement techniques at St. Louis, Missouri. Journal of Hydraulic Engineering., 139(10), 1062-1070.

Watson, C.C., D.S. Biedehnarn, C.R. Thorne. 2013b. Analysis of the Impacts of Dikes on Flood Stages in the Middle Mississippi River. J. Hydraulic Engineering. 139:1071-1078.

Watson, C.C., and Biedenharn, D.S. 2010. Specific gage analysis of stage trends on the Middle Mississippi River. Report to U.S. Army Corps of Engineers, St. Louis District.

Watson, C.C, Biedenharn, D.S., Scott, S.H., 1999. Channel Rehabilitation: Process, Design, and Implementation. U.S. Army Corps of Engineers.

Westphal, J.A. and P.R. Munger. 1976. Discussion of "Man-induced changes of Middle Mississippi River". Journal of the waterways, harbors, and costal engineering division. Proceedings of the American Society of Civil Engineers. 102(WW2). 283-284.

Xia, R. 2009. "Using computational model- ADH to evaluate relationship of water surface elevation to wing dikes". World Environmental and Water Resource Congress. ASCE.

Yossef, M.F. 2002. The effect of groynes on rivers: Literature review. Delft Cluster project no. 03.03.04.

Yossef, M.F.M. 2005. Morphodynamics of rivers with groynes, Delft University Press, Delft.

Appendix B. Biological Assessment

APPENDIX B

TIER II BIOLOGICAL ASSESSMENT:

REGULATING WORKS PROJECT
MOSENTHEIN/IVORY LANDING PHASE 4
MIDDLE MISSISSIPPI RIVER MILES 175-170
ST. CLAIR COUNTY, IL
ST. LOUIS CITY, MO

U.S. Army Corps of Engineers
Regional Planning and Environmental Division North (CEMVP-PD-C)
1222 Spruce Street
St. Louis, Missouri 63103-2833
Commercial Telephone Number: (314) 331-8102

October 2013

Introduction

The tier I of a two-tiered biological assessment for the Operation and Maintenance of the 9-Foot Navigation Channel on the Upper Mississippi River System was prepared by the U.S. Army Corps of Engineers in April 1999 (USACE 1999a). This tier II biological assessment discusses the site-specific impacts of a proposed regulating works project on federally listed species known to occur in the Mosenthein/Ivory Landing Phase 4 reach, River Miles (RMs) 175-170: pallid sturgeon, Indiana bat, interior least tern, decurrent false aster, gray bat, pink mucket mussel, sheepnose mussel and spectaclecase mussel. USACE has proposed placing over 11,500 feet of revetment on the left descending bank (LDB) between RMs 175 and 171, and constructing a rootless dike at RM 173.4(L).

Problem Description:

Navigation through the St. Louis Harbor (RMs 182 to 170) has been described as one of the most treacherous on the entire Mississippi River (USACE 2004). Seven bridges cross over the Mississippi River between RMs 184 and 168.0. The navigation spans of nearly all of the bridges do not match the alignment of the main channel. Modification of regulating works are needed in this area of the Middle Mississippi River (MMR) in order to safely and effectively operate and maintain the 9-Foot Navigation Channel on the Upper Mississippi River System. Between RMs 182.0 and 170.0, approximately 6 million cubic yards of dredge material were relocated during the period 2002 through 2012, and 3.2 million cubic yards from 2008 to 2012. This reach of the river includes a long narrow bend of the Mississippi River. Because of this, the channel thalweg meanders back and forth between the Missouri and Illinois banks creating many crossing and shoaling problems. The shoaling occurring at RM 173 has necessitated numerous dredge cuts and was investigated in the 2013 Carondolet Hydraulic Sediment Response (HSR) model study (USACE 2013).

St. Louis Harbor, which is the third largest inland port of the United States, handles more than 110 million tons of freight each year. In terms of the river, fleeting is defined as the storing and moving of barges. Fleeting areas are numerous within the reach due to the St. Louis Harbor’s close location to the Illinois River, Missouri River, Kaskaskia River, and Interstates 70, 64, 55, and 44. Furthermore, Locks 27, which is just upstream of the St. Louis Harbor, is the most downstream lock on the system. Once below Locks 27, tows can be reconfigured from 15 barges (3 wide by 5 long) to larger barge configurations that are more efficient on the open river.

The project area is located in St. Clair County, Illinois and St. Louis City, Missouri. Plate 1 is an aerial map of the study reach with nomenclature. At the present time, the St. Louis Harbor has a total of 11 dikes and 12 bendway weirs. Also, the majority of the banklines in the reach are revetted. Plate 2 is an aerial photograph illustrating the dredging locations of the study reach.

Alternatives:

The U.S. Army Corps of Engineers St. Louis District recently conducted an HSR study of the flow and sediment transport regime of the Carondelet reach of the MMR between RMs 181.0 and 165.0 near Saint Louis, Missouri (USACE 2013). This study was funded by the Regulating Works Project and was conducted between October 2011 and March 2013 using a physical HSR model at the Applied River Engineering Center in St. Louis, Missouri. The objective of the model study was to produce a report that outlined the results of an analysis of various river engineering measures intended to reduce or eliminate the need for repetitive maintenance dredging within the Mosenthein/Ivory Landing Phase 4 reach. The Carondolet HSR model study also looked at the shoaling occurring at the RM 173 location, shown on Plate 3. In order to determine the best alternative, certain criteria, based on the study purpose and goals, were used to evaluate each alternative. The first and most important consideration was that the alternative had to reduce or eliminate the need for repetitive maintenance dredging within the Mosenthein/Ivory Landing Phase 4 reach. The second condition was that the alternative had to maintain the navigation channel requirements of at least 9-foot depth and 300-foot width. Third, the alternative should avoid and minimize impacts to fleeting areas within the reach. Finally, the alternative should avoid and minimize impacts to environmental areas, i.e., bathymetry that supports good aquatic habitat. There were a number of alternatives that showed minimal improvements to the repetitive dredging locations while maintaining the navigation channel requirements, although most involved placing structures within existing fleeting locations.

A rootless dike at RM 173.4, elevation 389.5 feet (+15 feet Low Water Reference Plane (LWRP)), was included as Alternative 31 in the Carondolet investigation. Alternative 31, shown on Plate 4, was recommended as the most desirable alternative because of its observed ability in the model to reduce or eliminate the need for repetitive maintenance dredging within the Carondelet reach. In addition, this alternative maintained the navigation channel requirements of at least 9-foot depth and 300-foot width and the structure was not placed directly within an existing fleeting location. The dike was within the immediate vicinity of two existing fleeting locations, but the operator of the fleeting area stated that they were agreeable with the proposed alternative being placed between the two existing fleeting locations. Finally, the alternative did not impact the existing river bars near RM 174.0 or between RMs 171.0 and RM 168.5. These river bars provide aquatic and terrestrial habitat for many organisms. Overall, this alternative, as modeled, enhanced navigation by providing a channel that would not require repetitive maintenance dredging, which has financial impacts on the navigation industry. It also protects valuable environmental habitat (USACE 2004).

The proposed revetment between RMs 175 and 171 is designed to prevent the continued erosion and migration of the associated bankline in the project area. The left descending bank in the project area has eroded up to 140 feet in the past 20 years. Channel widening has reduced the river's energy and ability to transport sediment in the area, resulting in sediment deposition and repetitive dredging requirements in the navigation channel. The addition of revetment in the proposed locations would maintain current channel planform and prevent future channel widening.

Project construction locations are shown on Plates 5, 6 and 7.

Recommendations

The Mosenthein/Ivory Landing Phase 4 Project would involve the following actions in order to attain the desired conditions based on the Carondolet HSR model investigation:

- Place revetment along the LDB at RMs 173.5 to 175 and RMs 172 to 171 as indicated on Plates 6 and 7. No grading or tree removal will be required. The revetment will help reduce erosion along the river bank and reduce sediment load in the river.

- Construct a 500-foot rootless dike with a top elevation of 389.5 feet (+15 feet LWRP) at RM 173.4 (L). This will help to reduce the shoaling and the need for repeated dredge cuts at RM 173.

Conservation Measures

The following measures will be implemented at the time of construction.

1. Construction will be conducted from the river in order to avoid impacting the adjacent shoreline and riparian habitat.
2. The dike proposed at RM 173.4 (L) is rootless and will not be attached to the riverbank, which should allow for secondary channel development and less sediment downstream of the dike.

Biological Assessment:

According to the U.S. Fish and Wildlife Service Endangered Species Midwest Region website on 17 September 2013 (USFWS 2013), the following species may occur in the project area (St. Louis Co.

MO and St. Louis, MO and St. Clair Co., IL): pallid sturgeon, Indiana bat, interior least tern, decurrent false aster, gray bat, pink mucket, sheepnose mussel and spectaclecase mussel. Several species listed on the website including Illinois cave amphipod, Eastern prairie fringed orchid, scaleshell, snuffbox, Mead's milkweed and running buffalo clover are not likely to be found within the project area and are not addressed.

Pallid Sturgeon (Scaphirhynchus albus) – Federally Endangered It is the position of the U.S. Fish and Wildlife Service (2000) that over time, channel training structures have adversely affected pallid sturgeon by affecting the quality and quantity of habitats in the MMR to which the species is adapted (e.g., braided channels, irregular flow patterns, flood cycles, extensive microhabitat diversity, and turbid waters). According to the Service, this loss of habitat has reduced pallid sturgeon reproduction, growth, and survival by (1) decreasing the availability of spawning habitat; (2) reducing larval and juvenile pallid sturgeon rearing habitat; (3) reducing the availability of seasonal refugia; and (4) reducing the availability of foraging habitat (USFWS 2000). Additionally, some authors believe that loss of habitat contributes to the hybridization of pallid and shovelnose sturgeon (Carlson *et al*. 1985, Keenlyne *et al*. 1993, Campton *et al*. 1995, USFWS 2000) although a study by Hartfield and Kuhajda (Hartfield et al. 2009) disputes that conclusion. The Service also asserts that these habitat changes have also reduced the natural forage base of the pallid sturgeon, and is another likely contributing factor in its decline (Mayden and Kuhajda 1997, USFWS 2000). The Service states that channel training structures have also altered the natural hydrograph of the MMR by contributing to higher water surface elevations at lower discharges than in the past and to a downward trend in annual minimum stages (Simons *et al*. 1974, Wlosinski 1999, USFWS 2000). Thus, as a result, previously aquatic habitats are now dry at low discharges (Wlosinski 1999). According to the Service, this has potentially reduced the availability of pallid sturgeon spawning habitat through the loss of habitat complexity (USFWS 2000).

Dikes are prominent channel regulating features common in the main channel and they are used to concentrate flow in order to reduce the need for dredging. Dikes are usually constructed in groups called dike fields. These areas are depositional zones that often fill from the bank outward toward the channel. Notching dikes, lowering dike profiles, adding trails to dikes, or altering dike angles to the channel are some actions that can be used to increase habitat diversity through the creation of new scour holes, sandbars, and flow refugia. When dike alteration is done on the dike field level, or in association with new structure placements, new side channels, islands, and off-channel areas can be created (USFWS 2004a). This project involves revetment placement and rootless dike construction. Rootless dike construction should increase habitat diversity in the area by creating scour holes and a secondary channel. The dike's rock would provide suitable habitat for epilithic macroinvertebrates.

Dikes and dike fields within the MMR are currently utilized by pallid sturgeon, including the project study area between RMs 195.0-154.0 (Sheehan and Heidinger 2001). Most notably, pallids congregate in the vicinity of the Chain of Rocks, with numerous detections documented between RMs 190.4 and 188.0 (J. Killgore, pers. comm.). Deep scour holes that develop in association with dikes and chevron dikes provide seasonal refugia, particularly during winter. Pallid sturgeon also utilize the sand bar habitat that accretes between dikes and chevron dikes. Although their preference for this habitat is poorly understood, at a minimum it is believed these areas provide important foraging habitat (USFWS 2004a). Though outside the Mosenthein/Ivory Landing Phase 4 project area, the Carterville Fisheries Research Office, prior to 2005, collected juvenile sturgeon in high concentrations over the flooded sandbar on the western shore of Rockwood Island between RMs 102 and 101. Juvenile sturgeon were also collected from Liberty Chute below the rock closing structure at RM 101.1, and juvenile shovelnose were collected within Liberty Chute (Colby Wrasse, pers. comm.). Juvenile sturgeon were also collected over flooded portions of the Mile 100 Islands during the spring of 2005 (Teri Allen, pers. comm.). While the 2000 Biological Opinion Reasonable Prudent Alternatives (RPA) identified modification of channel training structures as a medium priority for pallid sturgeon, dike alterations are critical to improving habitat diversity in the MMR for a wide range of species (USFWS 2004a).

Preventing bankline erosion by revetment placement could have a minor negative impact on the fish community in the area. Bankline erosion frequently leads to woody debris inputs to the system. Woody debris is an important habitat component in the MMR, providing nutrient inputs, macroinvertebrate colonization substrate, and habitat diversity for fish and wildlife. The proposed revetment is likely to reduce the amount of beneficial woody debris entering the system from the project area. However, woody debris would continue to enter the system during overbank flow events, and revetment would benefit fish and wildlife by providing rock substrate.

Construction activities may result in short-term adverse effects for pallid sturgeon. Activities that impact any existing deepwater habitat may result in displacement of pallid sturgeon. Disruption of existing sand bar habitat may impact foraging habitat. However, these adverse effects are expected to occur at a local, individual dike scale. By completing regulating works projects with incorporated modifications to increase habitat diversity at the scale of the dike field, long-term beneficial effects for pallid sturgeon should result. The creation of scour holes and secondary channel and associated shallow water habitat through dike construction is expected to create additional larval/juvenile rearing habitat and seasonal refugia, and improve forage food production (USFWS 2004a).

It is the position of the St. Louis District that short-term adverse impacts that may occur are limited, and the long-term impacts associated with reduced dredging and increased habitat diversity, which is expected as a consequence of river training structure modification, are predicted to be beneficial to pallid sturgeon. Dredging disturbs main channel habitat, killing the resident benthic macroinvertebrates and temporarily leveling the dune and swale bed forms.

Thus, dike construction which results in the creation of diverse aquatic habitats would be beneficial to fish in general, and "may affect but is not likely to adversely affect" the pallid sturgeon.

Indiana Bat (Myotis sodalis) – Federally Endangered The range of the Indiana bat includes much of the eastern half of the United States, including Missouri and Illinois. Indiana bats migrate seasonally between winter hibernacula and summer roosting habitats. Winter hibernacula include caves and abandoned mines. Females emerge from hibernation in late March or early April to migrate to summer roosts. During the summer, the Indiana bat frequents the corridors of small streams with well-developed riparian woods, as well as mature upland forests. It forages for insects along stream corridors, within the canopy of floodplain and upland forests, over clearings with early successional vegetation (old fields), along the borders of croplands, along wooded fencerows, and over farm ponds in pastures. Females form nursery colonies under the loose bark of trees (dead or alive) and/or cavities, where each female gives birth to a single young in June or early July. A maternity colony may include from one to 100 individuals. A single colony may utilize a number of roost trees during the summer, typically a primary roost tree and several alternates. Some males remain in the area near the winter hibernacula during summer months, but others disperse throughout the range of the species and roost individually or in small numbers in the same types of trees as females.

Disturbance and vandalism, improper cave gates and structures, natural hazards such as flooding or freezing, microclimate changes, land use changes in maternity range, and chemical contamination are the leading causes of population decline in the Indiana bat (USFWS 2000, 2004a). To avoid impacting this species, tree clearing activities should not occur during the period of 1 April to 30 September.

Modification measures resulting in aquatic habitat improvement should contribute to the species' forage base. Dike construction and revetment placement is anticipated to be primarily performed by river-based equipment and has minimal potential to affect Indiana bats because forested habitats would not be affected by placement of revetment. Additionally, creation of a secondary channel and associated shallow water habitat is expected to provide bathymetric diversity necessary to provide habitat for a range of aquatic species and life stages. Thus, dike construction which creates diverse aquatic habitats "may affect but is not likely to adversely affect" the Indiana bat.

Gray Bat (Myotis grisescens) – Federally Endangered The gray bat (Myotis grisescens) is listed as endangered and occurs in several Illinois and Missouri counties where it inhabits caves both summer and winter. This species forages over rivers and reservoirs adjacent to forests. No caves or forested areas would be impacted by the proposed action; therefore, this project will have “no effect” on the gray bat.

Interior Least Tern (Sterna antillarum) – Federally Endangered The least tern is a colonial, migratory waterbird, which resides and breeds along the Mississippi River during the spring and summer. Least terns arrive on the Mississippi River from late April to mid-May. Reproduction takes place from May through August, and the birds migrate to the wintering grounds in late August or early September (USACE 1999b). Sparsely vegetated portions of sandbars and islands are typical breeding, nesting, rearing, loafing, and roosting sites for least terns along the MMR. Nests are often at higher elevations and well removed from the water’s edge, a reflection of the fact that nesting starts when river stages are relatively high (USACE 1999b). In alluvial rivers, sandbars are dynamic channel bedforms. Individual sandbars typically wax and wane over time as fluvial processes adjust channel geometry to varying sediment load and discharge, the construction of river engineering works, and other influences. There is limited data on site fidelity for Mississippi River least terns. Given the highly dynamic bed and planform of the historic river, ability to return to previously used colony sites is not likely a critical life history requirement. The availability of sandbar habitat to least terns for breeding, nesting, and rearing of chicks from 15 May to 31 August is a key variable in the population ecology of this water bird. Only portions of sandbars that are not densely covered by woody vegetation and that are emergent during the 15 May to 31 August period are potentially available to least terns (USACE 1999b). A 1999 report (USACE 1999b) estimated that there were approximately 20,412 acres of non-vegetated sandbar habitat above the MMR LWRP. About 4,975 acres (111 ac/RM) were located between the Mouth of the Ohio and Thebes Gap (RM 0-45) and 15,437 acres (103 ac/RM) between Thebes Gap and the Mouth of the Missouri River (RM 45-195). Currently, reoccurring nesting is known at Marquette Island (RM 50.5), Bumgard Island (RM 30), and Brown’s Bar (RM 24.5-23.5) (USFWS 2004a). Some nesting attempts have also been made at Ellis Island (RM 202), however these are not considered to be reoccurring.

Least terns are almost exclusively piscivorous (Anderson 1983), preying on small fish, primarily minnows (Cyprinidae). Prey size appears to be a more important factor determining dietary composition than preference for a particular species or group of fishes (Moseley, 1976; Whitman, 1988, USACE 1999b). Fishing occurs close to the nesting colonies and may occur in both shallow and deep water, in main stem river habitats or backwater lakes or overflow areas. Radiotelemetry studies have shown that terns will travel up to 2.5 miles to fish (Sidle and Harrison, 1990, USACE 1999b). Along the Mississippi River, individuals are commonly observed hovering and diving for fish over current divergences (boils) in the main channel, in areas of turbulence and eddies along natural and revetted banks, and at “run outs” from floodplain lakes where forage fish may be concentrated (USACE 1999b).

Although south of the project area, the least tern population surveys between Cape Girardeau, MO and Baton Rouge, LA were contracted by the USACE Memphis District from 1985 to 2012. These casual observance surveys have revealed a five to six-fold increase in individuals along the Lower Mississippi River from the initial survey years. Numbers of nesting sites have generally more than doubled. Since 2003, the number of individual birds has remained above 8,000, with five of those years being over 10,000. In 2010, over 18,000 birds were counted (Jones 2011).

According to the Service (USFWS 2000), existing dikes have the ongoing effect of altering natural river habitat processes, thereby reducing the quality, quantity, and diversity of habitat in the MMR. The Service asserts that continued disruption of natural processes will affect least terns by (1) reducing the availability of bare sandbar nesting habitat; (2) reducing the availability of foraging habitat; and (3) reducing the abundance of forage food.

The rock dike substrate provides habitat for epilithic macroinvertebrates that are capable of colonizing in very high densities and providing an important food source for fish (USFWS 2000). The construction of the Dike at 173.4 (L) should reduce shoaling at RM 173, but will not affect the bar at RM 174. By completing regulating works projects at a local scale, long-term beneficial effects for least tern should accrue from the incorporation of structure modifications resulting in the creation of additional side channels and sandbars. Such activities may create additional nesting and rearing habitat and improve forage food production. Placement of revetment along the riverbank at RM 175 – 173.5 and RM 172-171 would not impact any least tern nesting habitat, i.e., isolated sand bars.

Thus, dike construction, which results in the diversification of aquatic habitats, including formation of a secondary channel and shallow water habitat in this project area would be beneficial to the least tern, as well as fish in general (the species' forage base), and "may affect but is not likely to adversely affect" the Interior Least Tern.

Spectaclecase (Cumberlandia monodonta) – Federally Endangered This mussel is "known to occur in the Meramec River and may potentially occur in the Mississippi River north of Monroe County, Illinois" (USFWS undated). In an assessment of the status of population viability at known locations of occurrence across its range, USFWS (undated) considered all spectaclecase populations in the Mississippi River in Illinois and Missouri to be either extirpated or "non-viable or unknown." None were classified as having "some evidence of viability."

Habitat destruction and degradation are the chief causes of imperilment, including reservoir construction, channelization, chemical contamination, mining, and sedimentation. Habitats are found in medium to large rivers with low to high gradients, and include shoals and riffles with slow to swift currents over coarse sand and gravel. Substrates sometimes consist of mud, cobble, and boulders (USFWS 2011).

The spectaclecase is not known to exist in any nearby mussels beds. The proposed construction and alteration of the dikes as well as revetment placement "may affect, but is not likely to adversely affect" the spectaclecase mussel because evidence suggests that it is likely extirpated from the project area.

Sheepnose (Plethobasus cyphyus) – Federally Endangered Sheepnose mussel is listed as a federally endangered species and occurs in Missouri in the Mississippi, Meramec, Bourbeuse, and Osage Fork (Gasconade) Rivers. This species inhabits gravel and mixed sand and gravel habitats in medium to large rivers.

The sheepnose is thought to be extant in five Mississippi River pools (3, 5, 15, 20 and 22) in very low numbers. In the upper Mississippi River, the sheepnose is an example of a rare species becoming rarer. Despite the discovery of juvenile recruitment in Mississippi River Pool 7, the sheepnose population levels in the upper Mississippi River appear to be very small and of questionable long-term viability. The sheepnose and other mussel populations in the upper Mississippi River are seriously threatened by zebra mussels. Even if some level of sheepnose recruitment was documented, the status of this species in the Mississippi River is highly jeopardized, with imminent extirpation a distinct possibility (USFWS 2003). This project could potentially benefit this species by providing some of its necessary habitat features, i.e. shallow shoal habitats and flow refugia. The sheepnose is not known to occur in any nearby mussel beds. This project "may affect but is not likely to adversely affect" the sheepnose mussel.

Pink Mucket (Lampsilis abrupta) – Federally Endangered The pink mucket is a medium-sized (reaching up to approximately 100 mm in length) freshwater mussel with a smooth, yellow or yellowish green shell and faint green rays. The life span of the species exceeds 50 years. Like other freshwater mussels, the pink mucket feeds by filtering food particles from the water column. The specific food habits of the species are unknown, but other juvenile and adult freshwater mussels have been documented to feed on detritus, diatoms, phytoplankton, and zooplankton.

The pink mucket has undergone a substantial range reduction. It was historically distributed in 25 rivers and tributaries in the Ohio, Cumberland, Mississippi, and Tennessee River systems. The species is likely extirpated in Ohio, Pennsylvania, and Illinois (NatureServe 2003). Records from 1990 indicate that the species remained in only 16 rivers and tributaries at that time (NatureServe 2003).

The pink mucket typically inhabits medium to large rivers with strong currents; however, it has also been able to survive and reproduce in areas of impounded reaches with river/lake conditions, but not in standing water (NatureServe 2003, USFWS 1985). Substrate preferences include sand, gravel, and pockets between rocky ledges in high velocity areas and mud and sand in slower moving waters. Individuals have been found at depths up to one meter in swiftly moving currents and in much deeper waters with slower currents (Gordon and Layzer 1989). No pink mucket population is known in the project area; therefore the project "may affect, but is unlikely to adversely affect" the pink mucket.

Decurrent False Aster (Boltonia decurrens) – Federally Threatened Decurrent false aster is a threatened floodplain species that is considered to potentially occur in St. Clair County, Illinois and St. Louis City, Missouri, bordering the Mississippi River. It is a perennial, early successional plant found on moist, sandy, floodplains and prairie wetlands along the Illinois River. It relies on periodic flooding to scour away other plants that compete for the same habitat (USFWS 2011). Without disturbance, other plant species can outcompete decurrent false aster and eliminate it in 3 to 5 years from any given area. Decline in this species is due to several factors including excessive silting of habitat due to topsoil run-off, conversion of natural habitat to agriculture, drainage/development of wetlands, altered flooding patterns, and herbicide use. No critical habitat rules have been published for the decurrent false aster.

Decurrent false aster is not known to occur within the project area. Most of the known populations of this species occur north of the project area below the confluence of the Illinois River. Due to the placement of revetment and the loss of potential suitable habitat in the area, the project "may affect, but is not likely to adversely affect" the decurrent false aster.

Literature Cited

Anderson, E.A. 1983. "Nesting Productivity of the interior or Least Tern in Illinois." Unpublished Report. Cooperative Wildlife Research Laboratory, Southern Illinois University, Carbondale, Illinois, 19 pp.

Campton, D.E., A.I. Garcia, B.W. Bowen, and F.A. Chapman. 1995. Genetic evaluation of pallid, shovelnose and Alabama sturgeon (*Scaphirhynchus albus*, *S. platorhynchus*, and *S. suttkusi*) based on control Region (D-loop) sequences of mitochondrial DNA. Report from Dept. of Fisheries and Aquatic Sciences, Univ. of Florida, Gainesville, Florida.

Carlson, D.M., W.L. Pflieger, L. Trial, and P.S. Haverland. 1985. Distribution, biology, and hybridization of *Scaphirhynchus albus* and *S. platorhynchus* in the Missouri and Mississippi Rivers. Environmental Biology of Fishes. 14:51-59.

Gordon, M.E. and Layzer, J.B. 1989. Mussels (Bivalvia: Unionoidea) of the Cumberland River review of life histories and ecological relationships. Biological Report 89(15): 1-99.

Hartfield, P., and B.R. Kuhajda. 2009. Threat Assessment: Hybridization between pallid sturgeon and shovelnose sturgeon in the Mississippi River. U.S. Fish and Wildlife Service, Jackson, Mississippi. Unpubl. Report.

Jones, K. H. 2011. Population Survey of the Interior Least Tern on the Mississippi River from Cape Girardeau, Missouri to Baton Rouge, Louisiana. Under contract with Choctaw Transportation Company, Inc. Dyersburg, Tennessee. 18 pp. with appendix.

Keenlyne, K.D., L.K. Graham, and B.C. Reed. 1993. Natural hybrids between two species of Scaphirhynchinae sturgeon. U.S. Fish and Wildlife Service, Pierre, South Dakota. Unpubl. Report.

Mayden, R.L., and B.R. Kuhajda. 1997. Threatened fishes of the world: *Scaphirhynchus albus* (Forbes and Richardson, 1905) (Acipenseridae). Environmental Biology of Fishes. 48:420-421.

Moseley, L.J. 1976. "Behavior and Communication in the Least Tern (Sterna albifrons)." Ph.D. Dissertation, University of North Carolina, Chapel Hill. 164 pp.

NatureServe. 2003. NatureServe Explorer: An online encyclopedia of life [web application]. Version 1.8. NatureServe, Arlington, Virginia. Available http://www.natureserve.org/explorer. (Accessed: December 3, 2003).

Sheehan, R.J., and R. C. Heidinger. 2001. Middle Mississippi River Pallid Sturgeon Habitat Use Project. In: Upper Mississippi River Basin, Mississippi River Missouri and Illinois, Progress Report 2000, Design Memorandum Number 24, Avoid and Minimize Measures, June 2001.

Sidle, J.G. and W.F. Harrison, 1990. "Recovery Plan for the Interior Population of the Least Tern (*Sterna antillarum*)." U.S. Fish and Wildlife Service, Twin Cities, Minnesota. 90 pp. (1)

Simons, D.B., S.A. Schumm, and M.A. Stevens. 1974. Geomorphology of the Middle Mississippi River. Report DACW39-73-C-0026 prepared for the U.S. Army Corps of Engineers, St. Louis District, St. Louis, Missouri. 110 pp.

U.S. Army Corps of Engineers. 1999a. Tier I of a Two Tiered Biological Assessment. Operation and Maintenance of the Upper Mississippi River Navigation Project within St. Paul, Rock Island, and St. Louis Districts. U.S. Army Corps of Engineers. April 1999.

U.S. Army Corps of Engineers. 1999b. Biological Assessment, Interior Population of the Least Tern, *Sterna Antillarum,* Regulating Works Project, Upper Mississippi River (River Miles 0-195) and Mississippi River and Tributaries Project, Channel Improvement Feature, Lower Mississippi River (River Miles 0-954.5, AHP). U. S. Army Corps of Engineers, Mississippi Valley Division/Mississippi River Commission, Vicksburg, Mississippi, December 1999.

U.S. Army Corps of Engineers. 2004. Sedimentation and Navigation Study of the Middle Mississippi River in the St. Louis Harbor River Miles 192.0 TO 172.0 Hydraulic Micro Model Investigation, St. Louis District, U.S. Army Corps of Engineers.

U.S. Army Corps of Engineers. 2013. Sedimentation and Navigation Study of the Middle Mississippi River in the Carondolet HSR Model River Miles 181.0 TO 165.0 Hydraulic Micro Model Investigation, St. Louis District, U.S. Army Corps of Engineers.

U.S. Fish and Wildlife Service. 1985. Recovery Plan for the Pink Mucket Pearly Mussel (*Lampsilis orbiculata*). Atlanta, GA. 52 pp

U.S. Fish and Wildlife Service. 2011. Decurrent False Aster Fact Sheet. Available http://www.fws.gov/midwest/Endangered/plants/decurrfa.html. (Accessed: August 31, 2011).

U.S. Fish and Wildlife Service. 2000. Biological Opinion for the Operation and Maintenance of the 9-Food Navigation Channel on the Upper Mississippi River System, May 15, 2000.

U.S. Fish and Wildlife Service. 2003 Status Assessment Report for the sheepnose, *Plethobasus cyphyus*, occurring in the Mississippi River system (U.S. Fish and Wildlife Service Regions 3, 4, and 5)

U.S. Fish and Wildlife Service. 2004a. Final Biological Opinion for the Upper Mississippi River-Illinois Waterway System Navigation Feasibility Study, August 2004.

U.S. Fish and Wildlife Service. 2005. Letter dated 10 December 2004 from the U.S. Fish and Wildlife Service, Marion Illinois Suboffice (ES) to the U.S. Army Corps of Engineers, St. Louis District.

U.S. Fish and Wildlife Service. 2011. Spectaclecase Fact Sheet. Available http://www.fws.gov/midwest/endangered/clams/spectaclecase/SpectaclecaseFactSheetJan2011.html. (Accessed: August 31, 2011).

U.S. Fish and Wildlife Service. 2013. Midwest Endangered Species Website. Available http://www.fws.gov/midwest/endangered/ml. (Accessed: September 17, 2013).

U.S. Fish and Wildlife Service. Undated. Status assessment for three imperiled mussel species: spectaclecase (Cumberlandia monodonta,), sheepnose (Plethobasus cyphyus), and rayed bean (Villosa fabalis). Mollusk Subgroup, Ohio River Valley Ecosystem Team. Available http://www.fws.gov/orve/online_symposium_three_mussels.html. (Accessed: August 31, 2011).

Whitman, P.L. 1988. "Biology and Conservation of the Endangered Interior Lest Tern: A Literature Review." Biological Report 88(3). U.S. Fish and Wildlife Service, Division of Endangered Species, Twin Cities, Minnesota.

Wlosinski, J. 1999. Hydrology. Pages 6-1 to 6-10 in USGS, ed., Ecological status and trends of the Upper Mississippi River system. USGS Upper Midwest Environmental Sciences Center, LaCrosse, Wisconsin. 241 pp.

Plate 1 – 2007 Aerial Photograph Mosenthein/Ivory Landing Reach

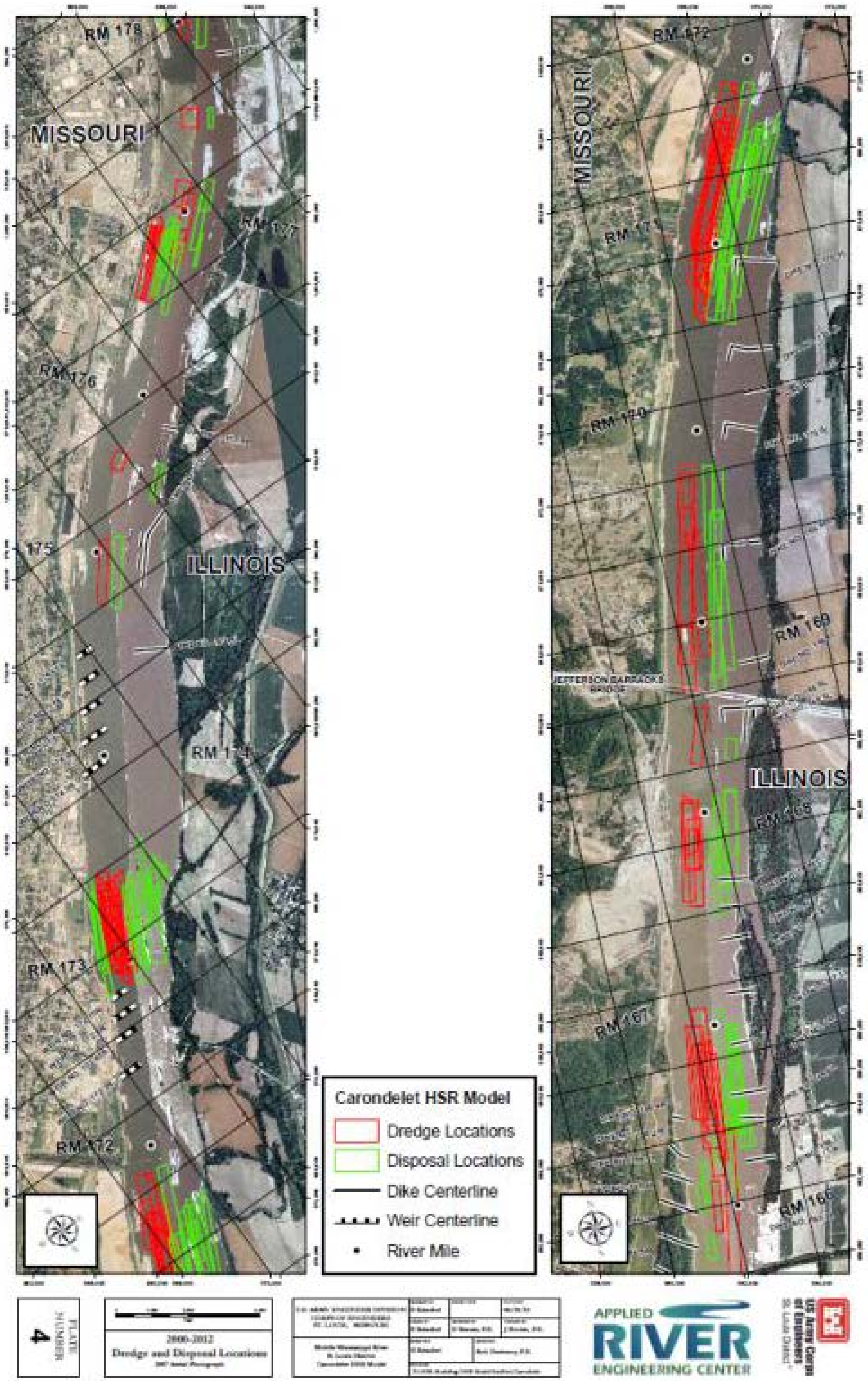


Plate 2 - Dredge and Disposal Locations

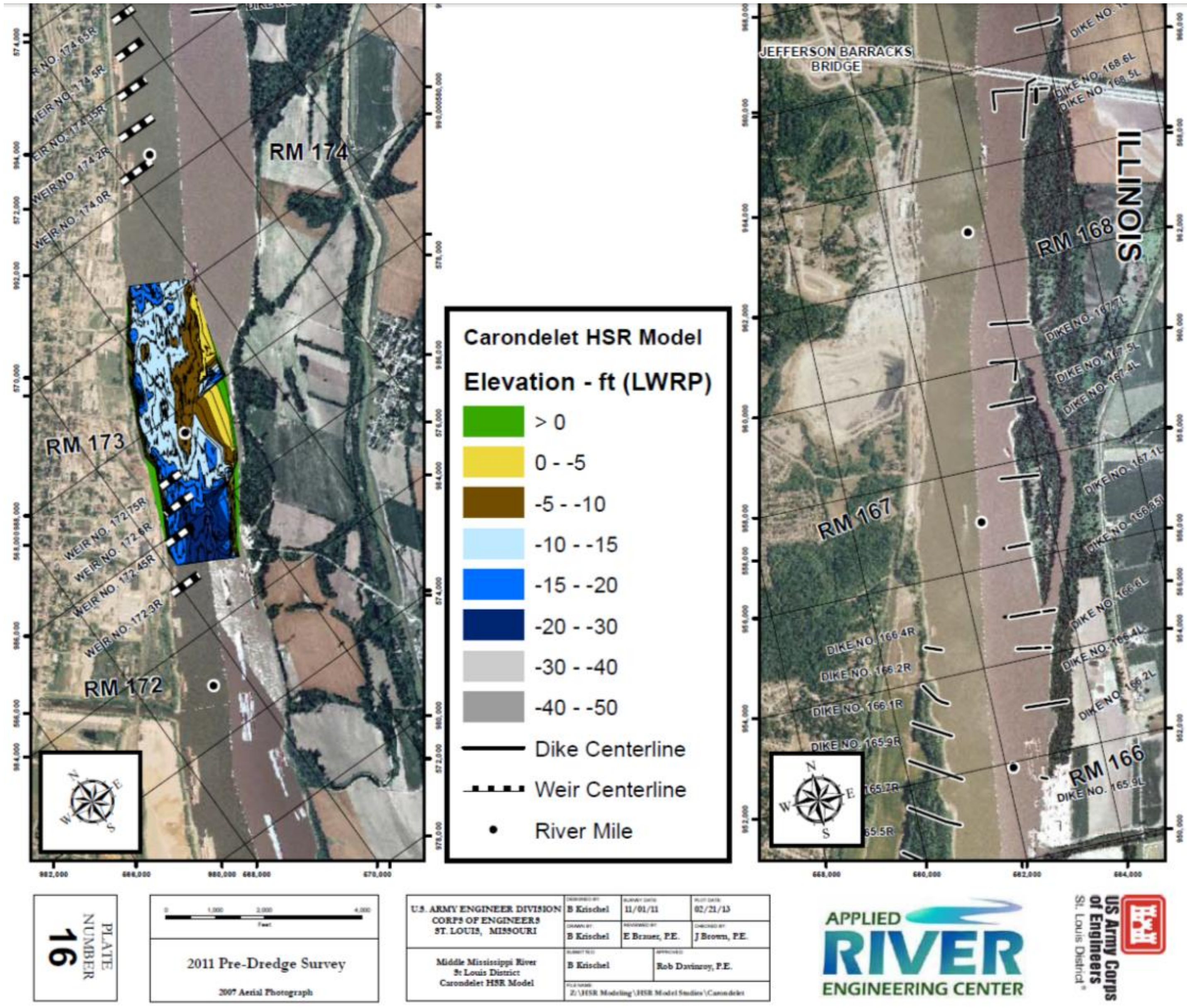


Plate 3 – Dredge Survey Showing Elevation and Shoaling at RM 173

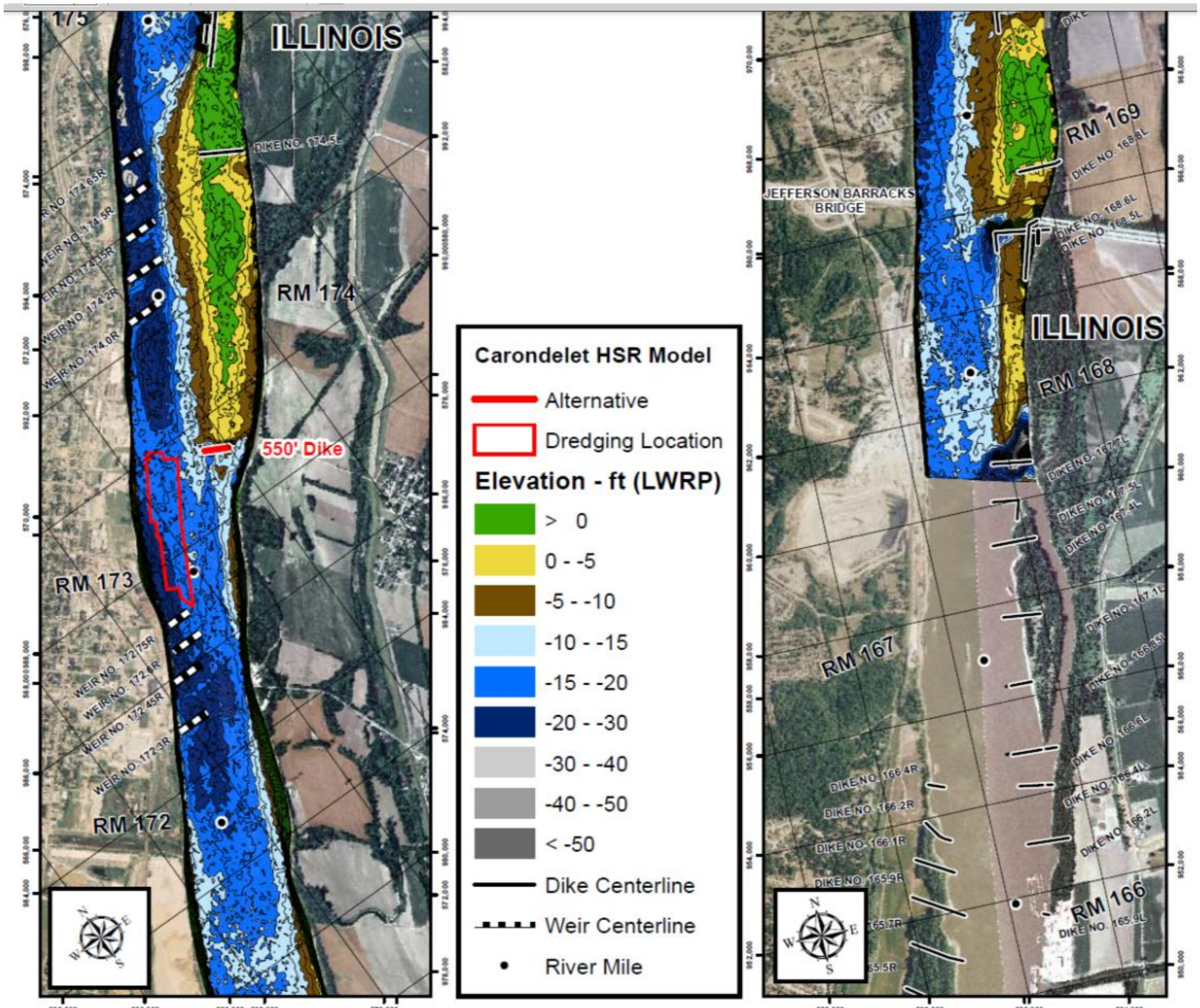


Plate 4 – Alternative 31

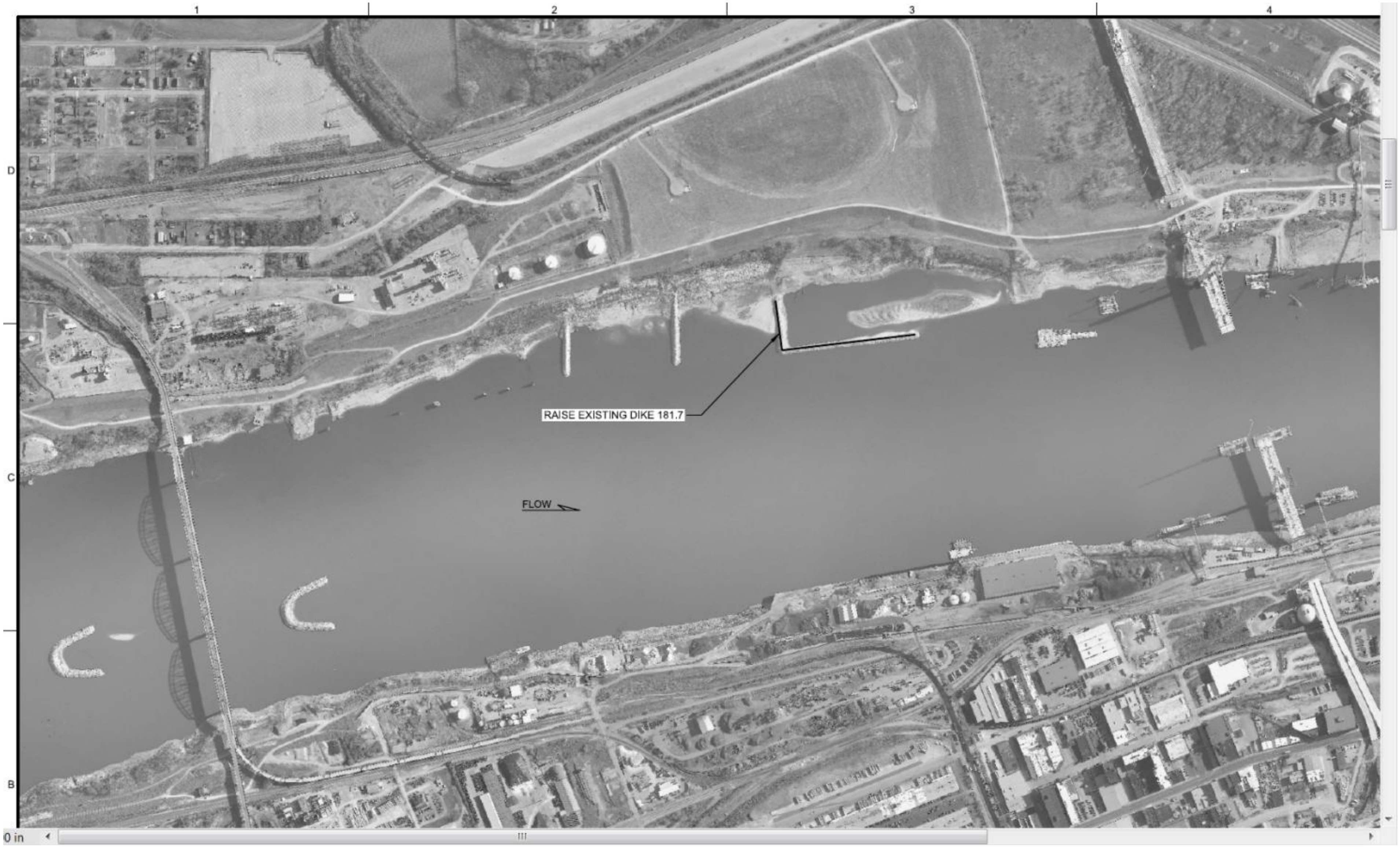


Plate 5 – Proposed Construction

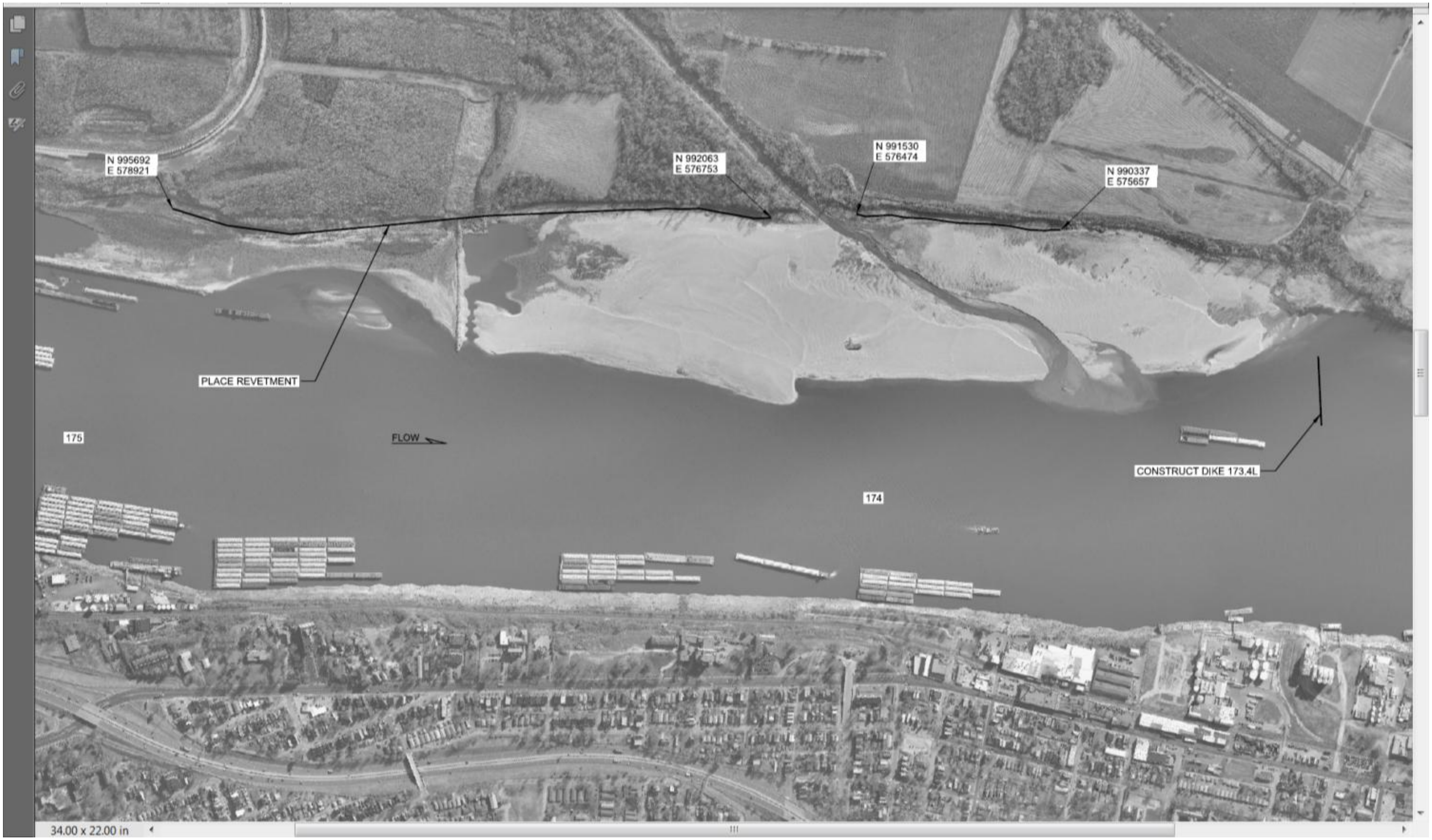


Plate 6 – Proposed Construction

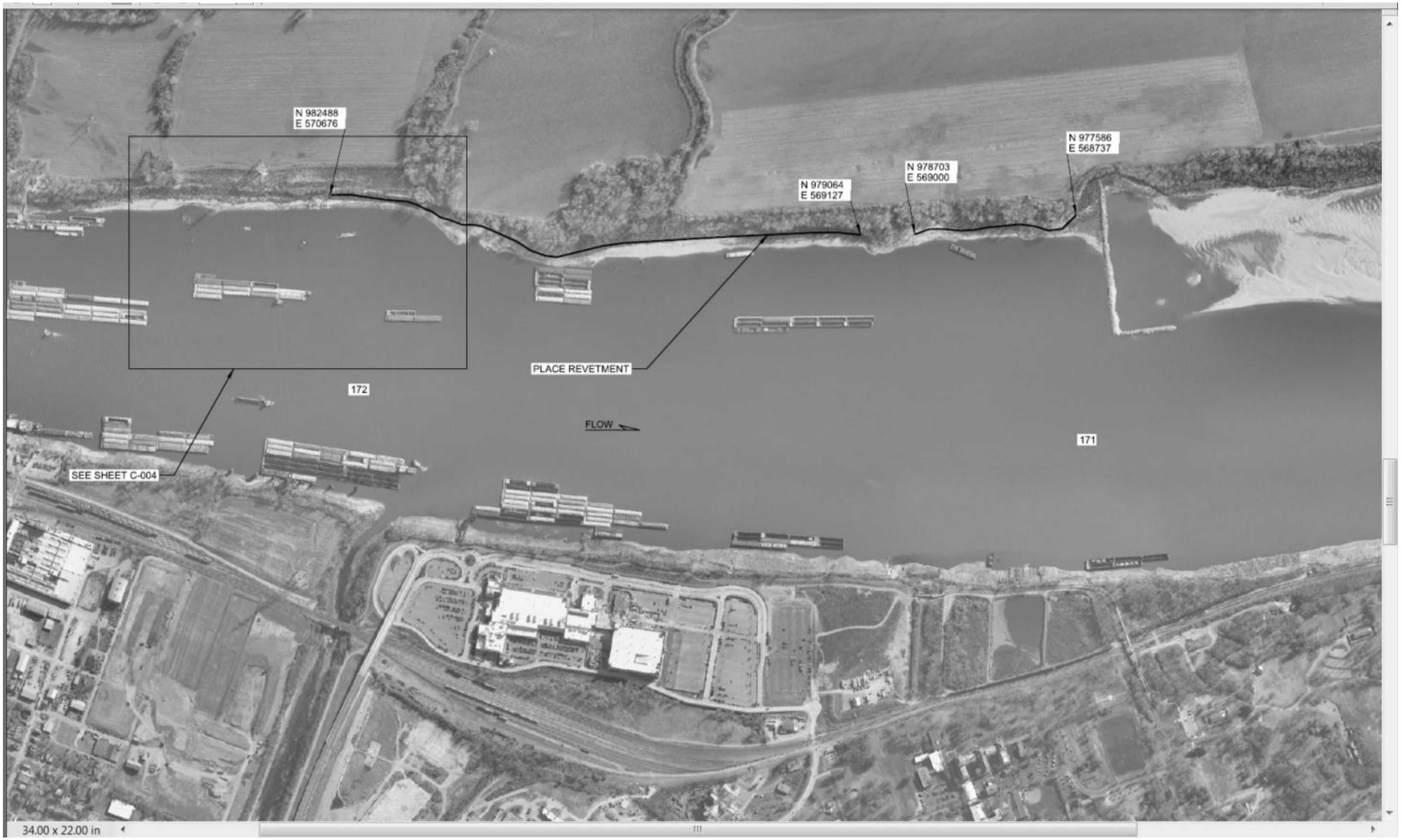


Plate 7 – Proposed Construction

Appendix C. Cumulative Impacts Analysis

Cumulative Impacts Analysis

The Council on Environmental Quality (CEQ) regulations define cumulative impacts as "the impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions regardless of what agency (Federal or non-Federal) or person undertakes such other actions. Cumulative impacts can result from individually minor but collectively significant actions taking place over a period of time." (40 CFR §1508.7). In order to assist federal agencies in producing better cumulative impact analyses, CEQ developed a handbook, "Considering Cumulative Effects under the National Environmental Policy Act" (CEQ 1997). Accordingly, the Mosenthein/Ivory Landing Phase 4 EA cumulative impact analysis generally followed the steps laid out by the handbook.

Cumulative impact analysis involved determining the incremental impact of the Alternatives on resources in the area in the context of all of the other past, present, and reasonably foreseeable future actions that might also impact each resource category. The analysis looked beyond the footprint of the work area to include impacts to the resources throughout the Middle Mississippi River. Clearly the resources, ecosystem and human environment in the Middle Mississippi River have been, and will continue to be, impacted by a wide range of actions. The cumulative impact analysis evaluates the same resources (Physical Resources [River Stages, Water Quality, and Air Quality]; Biological Resources [Fish and Wildlife: Dike Effects, Revetment Effects, Threatened & Endangered Species, and Climate Change]; Socioeconomic Resources [Navigation]; and Historic & Cultural Resources) that were evaluated in the Environmental Consequences section. In addition, the cumulative impacts for the No Action Alternative and Action Alternative were evaluated for navigation effects and side channel impacts.

The Regulating Works Project, in combination with the other actions throughout the watershed, has had past impacts, both positive and negative, on the resources, ecosystem and human environment. However, this analysis is meant to characterize the incremental impact of the current action in the broader context of other actions affecting the same resources. Although past actions associated with the Regulating Works Project have impacted these resources, the current method of conducting business for the Project – involving partner agencies throughout the planning process, avoiding and minimizing impacts during the planning process, and utilizing innovative river training structure configurations to provide habitat diversity while still providing benefits to the navigation system – has been successful in accomplishing the desired effect of avoiding significant environmental consequences. Although our understanding of the actions that bear upon the resources of the Middle Mississippi River continues to evolve, equilibrium in habitat conditions appears to have been reached. Accordingly, no significant impacts to the resources, ecosystem and human environment are anticipated for the Mosenthein/Ivory Landing Phase 4 work area.

Physical Resources

River Stages

A summary of research on the effects of river training structures on flood heights is provided in Appendix A. As noted in the Environmental Consequences (Physical Resources, River Stages) section, the District has concluded that river training structures do not affect water surface elevations at higher flows. With respect to water surface elevations at low flows, analysis of data show a trend of decreasing stages. It is not known if this is a result of construction of river training structures or the reduction of sediment load due to the construction of reservoirs on Mississippi River tributaries (Huizinga 2009). Reduced stages was acknowledged in the 1976 Regulating Works EIS (USACE) and the potential loss of side channels was discussed. The District acknowledges the importance of side channels and has continued to monitor the changes in the morphology and geometry of existing side channels. To offset potential impacts to side channels the District has initiated side channel restoration planning (USACE 1999; Nestler et al. 2012) and has conducted a number of restoration projects. The number of side channels has been substantially preserved through these monitoring and restoration efforts combined with natural processes within the side channels.

Based on this analysis, the impacts of No Action and the Proposed Action, when evaluated in relation to past and present stage heights, are not anticipated to rise above what would occur naturally. The potential reduction in stages and impacts on side channels were addressed in the 1976 EIS. Potential impacts, if they are being caused by river training structures, should be offset by side channel restoration/enhancement features constructed in the future by the District under various authorities and the use of innovative river training structure configurations designed to divert flow into existing side channels.

Water Quality

Prior to the implementation of the Clean Water Act, the MMR was an open sewer and a convenient place to dump solid waste (Bi-State Development Agency 1958; U.S. Public Health Service 1958). Raw sewage, untreated industrial waste, and ground garbage were discharged into the MMR (in 1952, approximately 212 tons/day of garbage [animal and vegetable waste] were collected in St. Louis, ground, and discharged.) This resulted in high oxygen demand; extremely high fecal coliform levels; low dissolved oxygen levels (< 5 mg/l); transport of toilet paper, animal entrails, and other solid wastes; elimination of aquatic life below St. Louis and reduction of aquatic life for a large portion of the MMR; and unpalatable fish where they did exist (Ellis 1931; Ellis 1943; Platner 1943; Bi-State Development Agency 1954; U.S. Public Health Service 1958; Baldwin 1970). Severely degraded water quality conditions in the MMR rose to the level of a human health hazard and a conference was convened in St. Louis (U.S. Public Health Service 1958) to discuss remedies.

Water quality in the MMR has improved dramatically since the implementation of the Clean Water Act. Although the MMR has improved, it currently exceeds suggested nutrient (total nitrogen and phosphorus) guidelines either part of the time (nitrogen) or most of the time (phosphorous) (Johnson and Hagerty 2008). As discussed in the affected environment section, there are also fish consumption advisories for PCB, chlordane, and mercury contamination.

During major storm events, raw sewage enters the river because of sewage treatment plant overloads due to combined (sewage/stormwater) sewage systems. Crites et al. (2012) found that water quality conditions in Buffalo Chute (River Mile 26) during isolation (mid-June through March during their study) from the river channel were not conducive to supporting healthy native fish communities. Thermal and chemical stratifications coupled with high water temperatures and anoxic conditions were observed during the summer months during two years of study.

Johnson and Hagerty (2008) indicated that future changes in nutrient inputs to the river are difficult to predict, and largely a function of outputs from sewage treatment plants and runoff from fertilizer application on land. There are ongoing efforts in the St. Louis area to improve wastewater treatment and alleviate the problems associated with combined sewage systems. These efforts should improve nutrient loading and eventually eliminate raw sewage overflow events. It is not anticipated that nutrients from agriculture will rise; however, this is driven by agricultural economics. The St. Louis District has conducted side channel restoration planning (USACE, 1999; Nestler et al. 2012) and has been restoring side channels under various authorities. Water quality and aquatic ecosystem improvement are basic goals of these restoration efforts. So, water quality conditions in the MMR are expected to improve with time.

The No Action Alternative would have no additional impacts (existing level of dredging associated short-term turbidity plume) on water quality. The Proposed Action would have only minor, short-term construction impacts on water quality. Navigation traffic levels and associated turbidity pulses will remain the same under both the No Action and Proposed Action. As such, the impacts of No Action and the Proposed Action, when evaluated in relation to past, present, and future water quality impacts, are not anticipated to rise to the level of a significant impact.

Air Quality

The work area is currently designated as attainment areas for all six criteria air pollutants (ozone, particulate matter, carbon monoxide, nitrogen oxides, sulfur dioxide, and lead) (USEPA 2013). There are no known foreseeable projects in the work area that would adversely impact air quality. The No Action Alternative would have no additional impacts on air quality. The Proposed Action would have only minor, short-term, air quality impacts associated with the use of construction equipment. Navigation traffic levels and associated engine exhaust will remain the same under both the No Action and Action Alternatives. As such, the impacts of No Action and the Proposed Action, when evaluated in relation to past, present, and future air quality, are not anticipated to rise to the level of a significant impact.

The Missouri side of the Mosenthein/Ivory Landing Phase 4 work area is designated as a nonattainment area for 8-hour ozone (1997 and 2008 standards) and particulate matter and is designated as a maintenance area for 1-hour ozone and carbon monoxide (USEPA 2013). On the Illinois side of the MMR, the work area is designated as a nonattainment area for 8-hour ozone (2008 standard) and particulate matter and is designated as a maintenance area for 1-hour ozone and 8-hour ozone (1997 standard; USEPA 2013). There are no known foreseeable projects in the work area that would adversely impact air quality.

The No Action Alternative would have no additional impacts on air quality. The Proposed Action would have only minor, short-term, air quality impacts associated with the use of construction equipment. This would be equivalent to putting an additional towboat in the harbor and operating a crane during construction. Navigation traffic levels and associated engine exhaust will remain the same under both the No Action and Action Alternatives. As such, the impacts of No Action and the Proposed Action, when evaluated in relation to past, present, and future air quality, are not anticipated to rise to the level of a significant impact.

Biological Resources (Fish & Wildlife)

Dike & Revetments (Dikes, Bendway Weirs, and Revetment)

Currently, there are 1,375 river training structures on the MMR, which include wing dikes, bendway weirs, chevrons, and other configurations. Of this total, 175 are bendway weirs. The pace of construction has changed over time and the shape, size, elevation and configuration of river training structures has also changed. The St. Louis District built approximately 450 river training structures in the late 19th century and another 250 in the 1930s. The District constructed 150 bendway weirs from 1990 to 2000. Table 1 lists work areas that are considered likely to be constructed in the reasonably foreseeable future.

Table 1. List of Regulating Works work areas showing location and structure type that are considered likely to be constructed in the reasonably foreseeable future (USACE 2012a; USACE 2012b; USACE 2013a; USACE 2013b).

Major Reach	Localized Reach	Work in Reach
Mosenthein-Ivory Landing Phase 4 (RM 195-154)	St. Louis Harbor	Revetment RM (175-171)
		Raise Dike 181.7L
		Dike 173.4L
Eliza Point/Greenfield Bend Phase 3 (RM 20 - 0)	Bird's Point (RM 4 - 0)	Rootless Dike 3.0L
		Weir 2.6R
		Weir 2.5R
		Weir 2.3R
		Weir 2.2R
Grand Tower Phase 5 (RM 90 - 67)	Crawford Towhead (RM 75 - 71)	Chevron 73.6L
		Dike Extension 72.9L
		Chevron 72.5L
	Vancil Towhead (RM 70-66)	Weir 69.15L
		Weir 68.95L
		Weir 68.75L
		Diverter Dike 68.10L
		Diverter Dike 67.80L
		Diverter Dike 67.50L
		Repair Dike 67.80L
		Shorten Dike 67.30L
		Shorten Dike 67.10L
		600 ft revetment
Dogtooth Bend Phase 5 (RM 40-20)	Bumgard (RM 33-27)	Weir 34.20L Weir 34.10L Weir 32.50L Weir 32.40L Weir 32.30L Weir 32.20L Dike 31.60R Weir 30.80R Weir 30.70R

The St. Louis District has three Regulating Works HSR model studies that are ongoing and will likely result in future construction. They are the Mouth of the Meramec HSR Model Study, the Gray’s Point HSR Model Study, and the Upper Brown’s Bar HSR Model Study. The Mouth of the Meramec HSR Model Study is intended to identify a river engineering design that will reduce or eliminate the need for repetitive dredging at approximately UMR 161. The Gray's Point HSR Model Study is intended to identify a river engineering design that will reduce or eliminate the need for repetitive dredging at approximately UMR 46. The Upper Brown’s Bar

HSR Model Study is intended to identify a river engineering design that will reduce or eliminate the need for repetitive dredging at approximately UMR 24. Specific designs for construction are dependent on the modeling efforts which are anticipated to be available by September 30, 2014. Success of the Regulating Works Project is dependent on careful evaluation of conditions on the Middle Mississippi River over time while incrementally implementing river training structures to provide a safe and dependable navigation channel while reducing the need for repetitive dredging. Future needs are based on priority work locations that are determined by examining repetitive dredging problems on the Middle Mississippi River. The District then develops alternatives using widely recognized and accepted river engineering guidance and practice, and then screens and analyzes different configurations of regulating works with the assistance of a Hydraulic Sediment Response (HSR) model. During the alternative evaluation process, the District works closely with industry and natural resource agency partners to further evaluate potential alternatives, including configurations analyzed in the HSR model. This process results in alternatives which reasonably meet the project purpose while also avoiding/minimizing environmental impacts. The timing of future construction is heavily dependent on Congressional funding and modeling results.

A discussion of the environmental impacts of dike and revetments is contained in Section 4 Environmental Consequences (**Physical Resources**: River Stages and **Biological Resources**: Dike Effects and Revetment Effects). Potential cumulative impacts of the Regulating Works Project on biological resources fall into a number of general categories: 1. Biological effects of training structures and their construction, and the biological implications of existing and reduced dredging; 2. Potential impacts of reduced channel migration; and, 3. Potential effects of changed flow patterns.

1. Construction impacts (actual construction related impacts) would be minimal under the no action alternative because no new construction (no construction impacts) would occur and structure repair would have minimal impacts. Under the no action alternative, dredging frequency, quantity, and area dredged would remain similar to what it is today. Benthic invertebrates in the dredged area would be killed and dredged material disposal would cover and kill benthic invertebrates in the disposal area. These areas would recover at a rate that is most likely site specific, but the cycle would continue the next time dredging is required (Koel and Stevenson 2002).

   Under the action alternative, benthic invertebrates in any future construction areas would be covered by the structure (rock) and killed. The area under the structures would be covered and unavailable for future colonization by benthic invertebrates. The environmental effects of training structures have been described in detail in Section 4 – Environmental Consequences. Although the benthic fauna type will change, rock is far more attractive to benthic invertebrates than shifting sand and the density (numbers/meter) will increase dramatically. This increase in benthic invertebrate density will also be more attractive to fish species. Construction of dikes has been suggested as a method for ecological enhancement (Radspinner et al. 2010) of river ecosystems and construction guidelines have been developed for revetment to benefit the environment (Shields and Tesa III et al. 1995). The St. Louis District has worked with partner agencies to develop innovative training structure configurations that fully serve their intended navigation function while providing environmental benefits at the same time.

The structures themselves directly create/enhance aquatic habitat and provide fishery benefits. For example, chevron dike construction in St. Louis Harbor provided increased habitat diversity and increased fish use (Schneider 2012); off-bank dike notching has been used for island creation (River Mile 100 Islands) which has benefited the fishery (Allen 2010); wing dikes provide adult (Barko et al. 2004) and larval fish (Niles and Hartman 2009) habitat, wing dike tips provide summer habitats for juvenile rheophilic fishes (Bischoff and Wolter 2001) and dike scour holes provide fish habitat, especially during the winter. Under the action alternative, future dredging and associated impacts to the benthic fauna would be reduced in frequency and quantity.

Following a period of widening and instability on the MMR, historic dike construction caused a narrowing of the river planform due to sediment accretion followed by terrestrial vegetation growth (Brauer et al. 2005; Brauer et al. 2013). Continued operation and maintenance of the training structures has maintained the narrowed channel. Table 7 in the EA shows the average planform width of the MMR from 1817 through 2011. Since 1968, the channel width appears to have reached a dynamic equilibrium with very little change occurring. It is anticipated that dynamic equilibrium in channel width will be maintained with little change resulting from additional training structure construction. As such, the impacts of No Action and the Proposed Action, when evaluated in relation to past, present, and future biological impacts of structure construction and operation and maintenance of the structures, are not anticipated to rise to the level of a significant impact.

2. As noted in Cumulative Impact Analysis (Side Channels), the potential for the natural development of new MMR side channels, which is a natural geomorphic process in fluvial river systems (Grenfell et al., 2012), has been restricted by the placement of stone revetment on the bankline as part of the Regulating Works Project. Bankline revetment restricts channel migration and has fixed the MMR in place, thus eliminating the potential for new natural side channel development. Since no new natural side channels are being created, it is essential to engineer new side channels through the manipulation of existing river training structures and new innovative river training structure configurations as well as maintain and restore those that remain through other programs authorized to so. Based on the analysis conducted in the Side Channel Section, the impacts of No Action and the Proposed Action, when evaluated in relation to past, present, and future condition of MMR side channels, are not anticipated to rise beyond the levels previously described in the 1976 EIS.

3. Dikes change flow patterns and increase both velocity and turbulence near the structure (Yossef and de Vriend 2011; Jia et al. 2009; and Ouillon and Dartus 1997 and others). McElroy et al. (2012) have recently found that fish use particular paths for migrations that take advantage of flow velocities (both high and low velocities) to reduce their energy output during migrations. Currently, the extent of this potential impact in the MMR is unknown, and the means to obtain a full understanding of how this information may or may not impact the MMR is not known as this would be scientifically difficult to evaluate. The Corps continues to remain apprised, analyze, and consider any research or potential issues with respect to the impact of changing flow patterns on fish and wildlife.

Navigation Traffic

The movement of commercial navigation traffic has both physical and biological effects (Table 2) that affect the ecosystem health of the MMR. These impacts are discussed in greater detail in USACE (2004) and Söhngen et al. (2008). With respect to cumulative impacts (past, present, and future actions), the impacts of commercial navigation traffic resulted from the original development of the navigation project and subsequent operation and maintenance of the navigation channel. Because none of the actions associated with operation and maintenance will increase traffic and associated impacts, the impacts of the No Action Alternative and the Action Alternative are identical. In other words, only an action (construction project) that would increase traffic would also increase impacts beyond what we have today.

Table 2: Potential Aquatic Impacts Associated with the Movement of Tows on the Middle Mississippi River

Impact	**Reference**
Fish Recruitment	(Nielsen et al. 1986; Arlinghaus et al. 2002; Huckstorf et al. 2010)
Propeller Mortality	
Adult Fish	(Gutreuter et al. 2003; Killgore et al. 2005; Killgore, et al. 2011; Miranda & Killgore 2013)
Adult Fish during Lockage	(Keevin et al. 2005)
Larval Fish	(Holland and Sylvester 1983; Holland 1987; Odum et al, 1992; Killgore et al. 2001; Bartell & Campbell 2000)
Fish Disturbance (Displacement from Channel)	(Todd et al. 1989; Wolter and Bischoff 2001; Gutreuter et al. 2006)
Wave Wash	
Physical	(Bhowmik et al 1999)
Fish	(Sheehan et al. 2000a, 2000b; Wolter & Arlinghaus 2003; Wolter et al. 2005; Kucera-Hirzinger et al. 2009; Gabel et al. 2011b)
Invertebrate	(Bishop & Chapman 2004; Gabel et al. 2008; Gabel et al. 2011a, 2011b)
Shoreline Drawdown/Dewatering	(Adams et al 1999; Maynord 2004; Maynord & Keevin 2005)
Towboat Induced Turbidity	

Channel	(Smart et al. 1985; Savino et al. 1994; Garcia et al. 1999; In addition, there are numerous publications on the adverse effects of turbidity on benthic invertebrates and fish.)
Phytoplankton	(Munawar et al. 1991)
Side Channel/Backwaters	(Pokrefke et al. 2003)
Hull Sheer	
Larval Fish	(Morgan II, et al. 1976; Maynord 2000; Keevin et al. 2002)
Turbulence	(Killgore et al. 1987; Mazumder et al. 1993; Deng et al. 2005)
Towboat Dispersal of Exotic Species	(Keevin et al. 1992)
Towboat Noise & Fish Disturbance	(Wysocki et al. 2006)
Bank Erosion	(Bhowmik et al. 1999; Nanson et al. 1993)
Risk of Accidents & Hazardous Spills	(University of Memphis 1998; Marmorstein 2000)
Changed Velocities	(Maynord 2000; Sheehan et al. 2000a; Sheehan et al .2000b

Although, there are many potential impacts associated with the movement of towboats through the system as described in USACE (2004) and Söhngen et al. (2008) and summarized in Table 2, the impact of greatest concern in the MMR is larval and adult fish mortality associated with towboat propeller entrainment.

Existing (2000) traffic in the Middle Mississippi River was responsible for the annual equivalent adult mortality of 262,853 fish, based on the number of larval fish killed passing through towboat propellers (USACE 2004, page 91). Annual equivalent adult mortality resulting from the incremental increase in traffic due to the construction of 1,200 foot locks on the Upper Mississippi River (USACE 2004 – a project not funded for construction) was projected to be between 11,612 and 79,274 fishes in the Middle Mississippi River for the year 2040 (USACE 2004, 396-397).

Killgore et al. (2011) published a towboat propeller entrainment paper for adult fish for the pooled portion of the Upper Mississippi River. It indicated that fish entrainment was low (< 1 fish/km) in wide, deep and fast sections of the river, while it was variable and occasionally high (> 30 fish/km) in narrow, shallow, and slow reaches of the UMR. If you used the value of 1 fish/km injured or killed (the MMR is wide, deep and fast), then approximately 151,161 fish would be injured or killed per year (313.822 km x 19,938 towboats/year x .024 injury-mortality rate) in the Middle Mississippi River under existing traffic conditions. This number overestimates mortality, because only a fraction of towboats/year actually navigate the entire length of the system (only 7,750 locked through Locks 27).

Additionally, another 34,972 adult fish are killed per year locking through Locks 27 (4.5125 average fish mortality per lockage x 7,750 commercial lockages in 2001) (Keevin et al. 2005). Entrainment mortality of some fish species, for example the shovelnose sturgeon, combined with other mortality factors (commercial fishing) may be responsible for unsustainable population levels in the Upper Mississippi River (Miranda and Killgore 2013).

In addition to the above projected mortality numbers, an unknown number of fish would be killed due to egg mortality from propeller entrainment (Holland and Sylvester 1983; Odum et al, 1992), shoreline dewatering (Adams et al 1999; Maynord & Keevin 2005), hull shear (Morgan II, et al. 1976; Maynord 2000; Keevin et al. 2002), and fish being washed out of protected areas (especially during the winter) due to wave wash (Sheehan et al. 2000a, 2000b; Wolter and Arlinghaus 2003; Wolter et al. 2005; Kucera-Hirzinger et al. 2009).

Based on this analysis, the impacts of No Action and the Proposed Action (no increases in navigation traffic), when evaluated in relation to past, present, and future impacts associated with the movement of navigation traffic, are not anticipated to rise beyond the existing conditions and projected traffic increases which have been addressed in USACE (2004).

Side Channels

With the draining of floodplain lakes for agricultural development and the reduction of overbank flooding during high flows due to levee construction, side channels represent the major source of off-channel water bodies on the MMR. Secondary channels typically provide a well-defined gradient between flowing to non-flowing water depending on their level of connectivity to the main channel. Based on the level of water flow, secondary channels can function as wetlands, isolated backwaters, connected backwaters, isolated secondary channels (at low stages), and flowing secondary channels. Level of connectivity also affects substrates, water quality conditions (Crites et al. 2012), benthic invertebrate communities (Bij de Vaate et al. 2007; Paillex et al. 2009) and fish faunas (Barko and Herzog 2003; Barko et al. 2004). Flowing secondary channels, those connected to the main channel, generally have course bottom substrates (i.e., sand and gravel) and support large river aquatic species (suckers, minnows, and darters) tolerant of current and/or turbidity. Disconnected secondary channels generally have finer substrate types (sand and silt) and support lentic species that prefer moderate to low current and low turbidity levels (Barko and Herzog 2003). This diversity of habitat provides important feeding, spawning, nursery, and overwintering habitat for fish (Lowery et al. 1987; Scheaffer and Nickum 1986; Grift et al. 2001), and habitat for other environmentally sensitive invertebrates, fish, and wildlife (Eckblad et al. 1984; Siegrest and Cobb 1987; Barko and Herzog 2003). Secondary channels also export nutrients, detritus, plankton, invertebrates, and fish to the main channel and the Gulf of Mexico (Eckblad et al. 1984; Cellot 1996; Simons et al. 2001; Hein et al. 2004; Preiner et al. 2008).

Secondary channels are also important because they are a refuge for fish escaping navigation related disturbances. Galat and Zweimuller (2001) and Wolter and Bischoff (2001) hypothesized that commercial navigation traffic may push fish toward the littoral zone or into secondary channels. Gutreuter et al. (2006) estimated the magnitude of traffic-induced reduction of fishes in the main channel of the Upper Mississippi River by comparing fish abundance in the navigation channel relative to abundance in secondary channels. They found the presence of some species was unaffected by traffic disturbances; whereas, the presence of others was reduced. Thus, secondary channels contribute to the overall health of the riverine system (Baker et al. 1991; Simons et al. 2001).

Due to the placement of rock closing structures, almost all MMR side channels are isolated from the main channel based on river stages and the crown elevation of the closing structure. The purpose of closing structures is to shunt water to the main channel to support navigation flows. Of the extant thirty-two side channels, only one (Cottonwood Side Channel) does not have closing structures. The remaining MMR side-channels are in various successional stages, including wetlands, isolated backwater, connected backwaters, isolated side channels (at low stages), and flowing side channels. The successional stage is related to ground elevation and river discharge, which translate into the level of connectivity to the main channel. The current median level of connectivity on a monthly basis for MMR side channels is shown in Table 3.

Table 3: A visual representation of flow conditions for Middle Mississippi River side channels showing months when channels are connected to the river and flowing (green) and when they are not flowing (red) based on median monthly stages and 2011 bathymetric data. Yellow represents side channels with high barriers restricting flow during all but extremely high water events (Modified from Keevin et al. 2014).

Table 3 (cont.)

Side Channel (River Mile)	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Bumgard (31)												
Buffalo (26)												
Browns (25)												
Thompson (19)												
Sister (14)												
Boston (10)												
Angelo (5)												

The 1976 MMR Regulating Works EIS indicated that most of the side channels would be lost "Based on Colorado State University studies of man-induced changes in the Middle Mississippi River, most of the side channel and main channel border habitat will eventually become filled with sediment (Simons, Schumm, and Stevens, 1974), unless artificial means, i.e., dredging, are employed to maintain side channels (page 216)." This is supported by the findings of Theiling et al. (2000) who found that, based on a GIS analysis of land cover change, MMR side channels were showing trends toward filling with sediment. Contrary to these conclusions, an analysis of MMR geomorphology by Brauer (2013) found that, similar to main channel widths, side channel widths have reached a dynamic equilibrium and remained relatively steady since 1968. These trends were found both in average trends and reach scale trends. These trends were also found in Guntren 2011. This study found that while some side channels decreased over the course of the study, others were increasing, suggesting that side channels in the MMR are dynamic. Further, since the 1976 EIS, there has been an increasing recognition of the importance of side channel habitat on the MMR and increased emphasis on side channel restoration. Through the District's Biological Opinion Program (http://mvs-wc.mvs.usace.army.mil/arec/Bio_Op.html), Avoid and Minimize Program (http://mvs-wc.mvs.usace.army.mil/arec/AM.html), innovative river training structure design, and other restoration initiatives, side channel restoration and preservation on the MMR has occurred and will continue to occur for the foreseeable future, resulting in a substantial preservation of the side channels that existed in 1976.

The potential for the natural development of new MMR side channels, which is a natural geomorphic process in fluvial river systems (Grenfell et al., 2012), has been restricted by the placement of stone revetment on the bankline as part of the navigation system's Regulating Works Project. Bankline revetment restricts channel migration and has fixed the MMR in place, thus eliminating the potential for new natural side channel development. Since no new natural side channels are being created, it is essential to engineer new side channels as well as maintain and restore those that remain.

The reduced potential for the natural formation of new side channels and the current degree of connectivity to the main channel is the existing condition. Any future construction of bankline revetment will not impact the potential for major channel migration and the creation of a new side channel complex. There are no plans to build new closing structures on any side channels. The St. Louis District understands the biological importance of side channels and has conducted environmental planning, in coordination with our agency partners, for side channel restoration in the MMR (USACE, 1999; Nestler et al., 2012). A number of side channel projects have been completed to improve flow and create more diverse aquatic habitat (i.e., environmental dredging of Sister Chute to provide more open water; environmental engineering to create/restore habitat in Santa Fe Chute, Marquette Chute, Jones Chute, and Establishment Chute) under a variety of authorities outside of the Regulating Works Project. It is anticipated that more side channel restoration will occur in the future as discussed above.

Based on this analysis, the impacts of No Action and the Proposed Action, when evaluated in relation to past, present, and future condition of MMR side channels, are not anticipated to rise to the level of being significant.

Threatened and Endangered Species

Section 7 consultation, under the Endangered Species Act, and compliance with the Act has a very structured coordination process between an action agency (the St. Louis District for this work area) and the U.S. Fish and Wildlife Service. In 1999, a Biological Assessment was prepared for the operation and maintenance of the 9-foot navigation project on the Upper Mississippi River (USACE 1999). The U.S. Fish & Wildlife Service prepared a Biological Opinion in response to the BA (USFWS 2000). The Service made a jeopardy determination for a number of species and provided Reasonable and Prudent Alternatives to avoid jeopardy. The Service also prepared an Incidental Take Statement and provided Reasonable and Prudent Measures for a number of species. The Biological Opinion assessed the impacts of past and on-going operation and maintenance activities. An agreement was made that Tier II Biological Assessments would be prepared to address potential future site specific impacts of construction projects related to the operation and maintenance of the navigation project. This coordination and compliance process has been followed since 2000.

Recently, four Biological Assessments were prepared for construction of regulating works (USACE 2012a; USACE 2012b; USACE 2013a; USACE 2013b) on the MMR. For these work areas, the U.S. Fish and Wildlife Service conducted a Tier II Formal Consultation. The Service determined that the work falls within the scope of the programmatic BO issued for Operation and Maintenance of the 9-Foot Navigation Channel on the Upper Mississippi River System and that incidental take was considered programmatically in the BO. As such no new incidental take statement was included with the opinions. It was the Service's biological opinion that the Proposed Actions are not likely to jeopardize the continued existence of the pallid sturgeon.

The impacts of the Proposed Actions, when considered in relation to the past and present (2000 study evaluation baseline) did not rise to the level that any of the species being evaluated would be jeopardized or that the existing incidental take criteria were exceeded. In addition, the St. Louis District has implemented a number of projects under a variety of authorities to benefit the pallid sturgeon (e.g., placement of large woody structures; incorporation of woody debris into dikes; environmental dredging of Sister Chute; environmental engineering to create/restore habitat in Santa Fe Chute, Marquette Chute, Jones Chute, and Establishment Chute; dike modification to create habitat; design and utilization of innovative dike configurations to create habitat diversity; testing of flexible dredge pipe for future habitat creation; etc.) and least tern (e.g., modification of island tip at Ellis Island to create nesting habitat; creation of nesting habitat on floating barges; sandbar isolation from shoreline in the MMR to provide nesting habitat) These types of restoration/rehabilitation/enhancement projects will continue into the future to benefit threatened and endangered species in the MMR.

Climate Change

A cumulative impact assessment of the impact of climate changes on the MMR is highly speculative because the projected trends are so general and can be offsetting predictions (one area receives more rain while another receives less). Should climate change result in more frequent and more severe storms, then there is a potential for more sediment input into the system which “might” result in more dredging (under the No Action Alternative and the Proposed Action), depending on the level of increase. The Proposed Action should offset some of the need for additional dredging in the existing repetitive dredging area, but the nature and extent of future dredging requirements under different climate change scenarios is nearly impossible to predict. If flow levels rise, there is a possibility that the side channels would be connected to the main channel more often (under both the No Action and Action Alternatives), depending on the level and duration of stage increase. Although highly speculative based on the existing data, the past, present, and future impacts of both the no action and the Proposed Action, are not anticipated to rise to the level of being significant.

Socioeconomic Resources

The Mississippi River is essential to the economies of the counties and states that border it. The people living and working in those places rely on the river system for their livelihood. Water transportation supports thousands of jobs throughout the river corridor, and the Nation, in a variety of industries. Agricultural, mining, and manufacturing industries; public utilities; waterside commercial development; and water-based recreational activities depend on the inland waterway for their livelihood. The Regional Economic Development study conducted as part of the Upper Mississippi River-Illinois Waterway System Navigation Feasibility Study (USACE 2004) traced expenditures and transportation cost savings throughout the economy in terms of additional full-time employment, wage and salary income, and output of the value of the goods produced. The analysis reported that within the study area States of Illinois, Iowa, Minnesota, Missouri, and Wisconsin, 21,891 man-years of employment are generated by water based industries. This benefit also has an impact on other regions as well as the entire United States. In the states bordering the study area, income generated by these business activities was estimated to be over $509 million, and for the entire United States it was estimated to be over $1.2 billion. Inland water transportation generates thousands of jobs and millions of dollars in taxes for State and Federal governments.

The Middle Mississippi River Regulating Works Project is an integral part of the inland water transportation system. The long-term goal of the Project, as authorized by Congress, is to provide a sustainable and safe navigation channel and reduce federal expenditures by alleviating the amount of annual maintenance dredging and the occurrence of vessel accidents through the construction of regulating works. Past Regulating Works Project actions have been successful in providing a sustainable and safe navigation channel, reducing vessel accidents, and reducing the average annual dredging requirements in the MMR. Present and reasonably foreseeable future actions are expected to continue this trend.

Historic and Cultural Resources

Historic and cultural resources within and in proximity to the Middle Mississippi River have been, and continue to be, subjected to natural riverine processes (e.g., bankline and riverbed erosion). Anthropogenic changes to the system have also impacted those resources since at least the 18th century. As Euro-American settlements developed along the river, levee systems began to be constructed by landowners and communities for flood control. Beginning in the mid-19th century, structures were constructed in the river to modify water-flow to either decrease or increase sedimentation in specific locations. Dikes, for example, directed the water current to eliminate sandbars, and hurdles were used to close off chutes between towheads and riverbanks causing them to fill with sediment, and effectively narrow the river. While specific cultural resources might be adversely impacted by increased waterflow and resulting erosion, others were protected by increased sedimentation. In 1879 the Mississippi River Commission (MRC) was created by Congress to promote commerce and prevent flooding. Part of the MRC mission was to permanently locate and deepen the navigation channel and stabilize river banks. The construction of dikes and embankments has greatly reduced bankline erosion and halted river migration, thereby protecting cultural resources, both known and unknown, from destruction.

All construction and modification work on dikes and weirs is carried out using barges, without recourse to land access; therefore, any potential effects are limited to submerged cultural resources. Primary among these are historic period shipwrecks. Given the continual river flow and associated sedimentary erosion, deposition, and reworking, it is highly unlikely that any more ephemeral cultural material remains on the river bed. Historic research and bathymetric surveys are conducted to determine if any wrecks are likely to be present prior to construction.

The construction of revetments can potentially have adverse effects on cultural resources. As with other training structures work is conducted via barge, without recourse to land access. The placement of the rock, however, has the potential to damage or destroy any resource on the bankline. With all revetment segments, historical research is conducted on the proposed location to determine if it is on recently accreted land or cut-banks in an existing, older, landform. Recently accreted land is highly unlikely to contain deeply buried cultural resources. If necessary terrestrial surveys are conducted to determine if any cultural resources are present.

Long term impacts of the river training structures is continued bankline stability, reducing the likelihood of cultural resources being damaged or destroyed by erosion.

Continued dredging operations under the No Action Alternative are not anticipated to impact any known historic and cultural resources in the work area. Any undocumented historic and cultural resources that may have existed in the work area likely would have been destroyed by previous dredging and disposal activities. Future maintenance dredging and disposal under the No Action Alternative would likely occur in the same locations as previous dredging, and, therefore, would be unlikely to impact undocumented historic and cultural resources.

The Proposed Action would have no impact on known historic resources and impacts to unknown resources are very unlikely. As such, the past, present, and future impacts to historic and cultural resources of No Action and the Proposed Action, are not anticipated to rise to the level of being significant.

References

Adams, S.R., T.M. Keevin, K.J. Killgore, and J.J. Hoover. 1999. Stranding potential of young fishes subjected to simulated vessel-induced drawdown. Transactions of the American Fisheries Society 128:1230-1234.

Allen, T. C. 2010. Middle Mississippi River islands: historical distribution, restoration planning, and biological importance. Ph.D. Dissertation, University of Missouri-St. Louis. 170 pp.

Arlinghaus, R., C. Engelhardt, A. Sukhodolov, and C. Wolter. 2002. Fish recruitment in a canal with intensive navigation: implications for ecosystem management. Journal of Fish Biology 61:1386-1402.

Baker, J.A., K.J. Killgore, and R.L. Kasul. 1991. Aquatic habitats and fish communities in the Lower Mississippi River. CRC Reviews in Aquatic Sciences 3:313-414.

Baldwin, R. E. 1970. Palatability of three species of fish and aroma of water from sites on the Mississippi River. Journal of Food Science 35:413-417

Barko, V.A., and D.P. Herzog. 2003. Relationship among side channels, fish assemblages, and environmental gradients in the unimpounded Upper Mississippi River. Journal of Freshwater Ecology 18:377-383.

Barko, V.A., M.W. Palmer, and D.P. Herzog. 2004. Influential environmental gradients and spatiotemporal patterns of fish assemblages in the unimpounded Upper Mississippi River. American Midland Naturalist 152:369-385.

Bartell, S.M., and K. Campbell. 2000. Ecological risk assessment of the effects of incremental increase in commercial navigation on fish. Upper Mississippi River-Illinois Waterway System Navigation Study ENV 16.

Bhowmik, N.D. Soong, T. Nakato, M. Spoor, J. Anderson, and D. Johnson. 1999. Bank erosion field survey report of the Upper Mississippi River and Illinois Waterway. Upper Mississippi River-Illinois Waterway System Navigation Study ENV Report 8.

Bij de Vaate, A., A.G. Klink, M. Greijdanus-Klaas, L.H. Jans, J. Oosterbaan, and F. Kok. 2007. Effects of habitat restoration on the macroinvertebrate fauna in a foreland along the River Waal, the Main distributary in the Rhine Delta. River Research and *Applications* 23:171-183.

Bischoff, A., and C. Wolter. 2001. Groyne-heads as potential summer habitats for juvenile rheophilic fishes in the lower order, Germany. Limnologica 31:17-26

Bishop, M.J., and M.G. Chapman. 2004. Managerial decisions as experiments: an opportunity to determine the ecological impacts of boat-generated waves on macrobenthic infauna. Estuarine Coastal and Shelf Science 61:613-622.

Bi-State Development Agency. 1954. Mississippi River water pollution investigation. St. Louis Metropolitan Area. 378 pp.

Brauer, E.J., R.D. Davinroy, L. Briggs, and D. Fisher. 2013. Draft Supplement to *Geomorphology Study of the Middle Mississippi River (2005)*. U.S. Army Corps of Engineers, St. Louis District, Applied River Engineering Center, St. Louis, Missouri. 12 pp.

Brauer, E.J., D.R. Busse, C. Strauser, R.D. Davinroy, D.C. Gordon, J.L. Brown, J.E. Myers, A.M. Rhoads, and D. Lamm. 2005. Geomorphology Study of the Middle Mississippi River. U.S. Army Corps of Engineers, St. Louis District, Applied River Engineering Center, St. Louis, Missouri. 43 pp.

Cellot, B. 1996. Influence of side-arms on aquatic macroinvertebrate drift in the main channel of a large river. Freshwater Biology 35:149-164.

Chipps, S. R., D. H. Bennett, and T. J. Dresser, Jr. 1997. Patterns of fish abundance associated with a dredge disposal island: Implications for fish habitat enhancement in a large reservoir. North American Journal of Fishery Management 17:378-386

Crites, J. W., Q. E. Phelps, K. N. S. McCain, D. P. Herzog, and R. A. Hrabik. 2012. An investigation of fish community and water quality composition in an isolated side channel of the Upper Mississippi River. Journal of Freshwater Ecology 27:19-29.

Deng, Z., G.R. Guensch, C A. McKinstry, R.P. Mueller, D.D. Dauble, and M C. Richmond. 2005. Evaluation of fish-injury mechanisms during exposure to turbulent shear flow. Canadian Journal of Fisheries and Aquatic Sciences 62:1513-1522.

Ellis, M. M. 1931. A survey of conditions affecting fisheries in the Upper Mississippi River. U.S. Bureau of Fisheries. Fishery Circular 5. 18 pp.

Ellis, M. M. 1943. A study of the Mississippi River from Chain of Rocks, St. Louis, Missouri, to Cairo, Illinois, with special reference to the proposed introduction of ground garbage into the river by the City of St. Louis. U.S. Fish and Wildlife Service Special Science Report 8. 22 pp.

Eckblad, J.W., C.S. Volden, and L.S. Weilgart. 1984. Allochthonous drift from backwaters to the main channel of the Mississippi River. American Midland Naturalist 111:16-22.

Gabel, F., M.T. Pusch, P. Breyer, V. Burmester, N. Walz, and X.-F. Garcia. 2011a. Differential effect of wave stress on the physiology and behavior of native versus non-native benthic invertebrates. Biological Invasions 13:1843-1853.

Gabel, F. S. Stoll, P. Fischer, M.T. Pusch, X.-F. Garcia. 2011b. Waves affect predator-prey interactions between fish and benthic invertebrates. Oecologia 165:101-109.

Gabel, F., X.-F. Garcia, M. Brauns, A. Sukhodolov, M. Leszinski, and M.T. Pusch. 2008. Resistance to ship-induced waves of benthic invertebrates in various littoral habitats. Freshwater Biology 53:1567-1578.

Galat, D.L., and I. Zweimuller. 2001. Conserving large-river fishes: is the highway analogy an appropriate paradigm? Journal of the North American Benthological Society 20:255-265.

Garcia, M.H., D.M. Admiraal, and J.F. Rodriguez. 1999. Laboratory experiments on navigation-induced bed shear stresses and sediment resuspension. Int. J. Sed. Res. 14:303-317.

Grenfell M, Aalto R, Nicholas A. 2012. Chute channel dynamics in large, sand-bed meandering rivers. Earth Surface Processes and Landforms 37:315-331.

Grift, R.E., A.D. Buijse, W.L.T. Van Densen, and J.G.P. Klein Breteler. 2001. Restoration of the river-floodplain interaction: benefits for the fish community in the River Rhine. Archiv für Hydrobiologie 12:173-185.

Guntren, E. M. 2011. Modeling Planform Changes Over Time in Middle Mississippi River Side Channels to Determine General Trends and Impacts on Aquatic Habitats. M.S. Thesis, Southern Illinois University Edwardsville.

Gutreuter, S., J.M. Dettmers, and D.H. Wahl. 2003. Estimating mortality rates of adult fish from entrainment through the propellers of river towboats. Transactions of the American Fisheries Society 132:646-661.

Gutreuter, S., J.M. Vallazza, and B.C. Knights. 2006. Persistent disturbance by commercial navigation alters the relative abundance of channel-dwelling fishes in a large river. Canadian Journal of Fisheries and Aquatic Sciences 63:2418-2433.

Hein, T., C. Baranyi, W. Reckendorfer, and F. Schiemer. 2004. The impact of surface water exchange on nutrient and particle dynamics in side-arms along the River Danube, Austria. Science of the Total Environment 328:207-218.

Holland, L.E. 1986. Effects of barge traffic on distribution and survival of ichthyoplankton and small fishes in the Upper Mississippi River. Transactions of the American Fisheries Society 115:162-165.

Holland, L.E. 1987. Effects of brief navigation-related dewatering on fish eggs and larvae. North American Journal of Fisheries Management 7:145-147.

Holland, L.E., and J.R. Sylvester. 1983. Distribution of larval fishes related to potential navigation impacts on the upper Mississippi River, Pool 7. Transactions of the American Fisheries Society 112:293-301.

Huckstorf, V., W.-C. Lewin, T. Mehner, and C. Wolter. 2011. Impoverishment of YOY-fish assemblages by intensive commercial navigation in a large lowland river. River Research and Applications 27:1253-1263.

Huizinga, R.J. 2009. Examination of direct discharge measurement data and historic daily data for selected gages on the Middle Mississippi River, 1861-2008. U.S. Geological Survey Scientific Investigations Report 2009-5232. 60pp. (Available at http://pubs.usgs.gov/sir/2009/5232/)

Jia, Y., S Scott, Y. Xu, and S. Wang. 2009. Numerical study of flow affected by bendway weirs in Victoria Bendway, the Mississippi River. Journal of Hydraulic Engineering 135:902-916.

Johnson, B.L., and K.H. Hagerty, editors. 2008. Status and trends of selected resources of the Upper Mississippi River System. U.S. Geological Survey,Upper Midwest Environmental Sciences Center, La Crosse, Wisconsin, December 2008. Technical Report LTRMP 2008-T002. 102 pp + Appendixes A-B.

Keevin, T.M., B.L. Johnson, E.A. Laux, T.B. Miller, K.P. Slattery, and D.J. Schaeffer. 2005. Adult fish mortality during lockage of commercial navigation traffic at Lock and Dam 25, Upper Mississippi River. Upper Mississippi River-Illinois Waterway System Navigation Study ENV Report 58. 14 pp.

Keevin, T.M., E. Marks Guntren, and R. Barkau. 2014. Middle Mississippi River side channels: Existing hydraulic connectivity to the river with implications for restoration planning. Report, in preparation.

Keevin, T.M., R.E. Yarbrough, and A.C. Miller 1992. Long-distance dispersal of zebra mussels (*Dreissena polymorpha*) attached to hulls of commercial vessels. Journal of Freshwater Ecology 7: 437.

Keevin, T.M., S.T. Maynord, S.R. Adams, and K.J. Killgore. 2002. Mortality of fish early life stages resulting from hull shear stress associated with passage of commercial navigation traffic. Upper Mississippi River - Illinois Waterway System Navigation Study ENV Report 35. 17 pp.

Killgore, K.J., A.C. Miller, and K.C. Conley. 1987. Effects of turbulence on yolk-sac larvae of paddlefish. Transactions of the American Fisheries Society 116:670-673.

Killgore, K.J., L.W. Miranda, C.E. Murphy, D.M. Wolff, J.J. Hoover, T.M. Keevin. S. T.Maynord, and M.A.Cornish. 2011. Fish entrainment through towboat propellers in the Upper Mississippi-Illinois Waterway System. Transactions of the American Fisheries Society 140:570-581.

Killgore, J., C. Murphy, D. Wolff, and T. Keevin. 2005. Evaluation of towboat propeller-induced mortality of juvenile and adult fishes. Upper Mississippi River-Illinois Waterway System Navigation Study ENV Report 56. 14 pp.

Killgore, K. J., S. T. Maynord, M. D. Chan, and R. M. Morgan II. 2001. Evaluation of propeller-induced mortality on early life stages of selected fish species. North American Journal of Fisheries Management 21:947-955.

Koel, T. M., and K. E. Stevenson. 2002. Effects of dredge material placement on benthic macroinvertebrates of the Illinois. Hydrobiologia 474:229-238.

Kucera-Hizinger, V., E. Schludermann, H. Zornig, A. Weissenbacher, M. Schabuss, and F. Schiemer. 2009. Potential effects of navigation-induced wave wash on the early life history stages of riverine fish. Aquatic Science 71:94-102.

Lowery, D. R., Pasch, R. W., and E. M. Scott. 1987. Hydroacoustic survey of fish populations of the lower Cumberland River. Final Report to the U.S. Army Corps of Engineers. U.S. Army Corps of Engineers, Nashville, TN.

Marmorstein, J. 2000. Analysis of the impact of infrastructure improvements on the risk of accidents and hazardous spills. Report Prepared for the U.S. Army Corps of Engineers.

Maynord, S. T. 2000. Velocity patterns downstream of Mississippi River dikes with and without tow traffic. Upper Mississippi River-Illinois Waterway System Navigation Study ENV Report 21.

Maynord, S. T. 2004. Decay of tow-induced drawdown in backwaters and secondary channels. Upper Mississippi River-Illinois Waterway System Navigation Study ENV Report 45.

Maynord, S. T., and T. M. Keevin. 2005. Commercial navigation traffic induced shoreline dewatering on the Upper Mississippi River: Implications for larval fish stranding. Upper Mississippi River - Illinois Waterway System Navigation Study ENV Report 55. 14 pp.

Mazumder, B. S., N. G. Bhowmik, and T. W. Soong. 1993. Turbulence in rivers due to navigation Traffic. Journal of Hydraulic Engineering 119:581-597.

McElroy, B., A. DeLonay, and R. Jacobson. 2012. Optimum swimming pathways of fish spawning migrations in rivers. Ecology 93:29-34.

Miranda, L.E., and K.J. Killgore. 2013. Entrainment of shovelnose sturgeon by towboat navigation in the Upper Mississippi River. Journal of Applied Ichthyology 29:316-322.

Morgan II, R.P., R.E. Ulanowicz, V.J. Rasin, Jr., L.A. Noe, and G.B. Gray. 1976. Effects of shear on eggs and larvae of striped bass, *Morone saxatilis*, and white perch, *M. Americana*. Transactions of the American Fisheries Society 105:149-154.

Munawar, M., W.P. Norwood, and L.H. McCarthy. 1991. A method for evaluating the impacts of navigationally induced suspended sediments from the Upper Great Lakes Connecting Channels on primary productivity. Hydrobiologia 219:325-332.

Nanson, G.C., A. von Krusenstierna, E.A. Bryant, and M.R. Renilson. 1993. Experimental measurements of river-bank erosion caused by boat-generated waves on the Gordon River, Tasmania. Regulated Rivers: Research and Management 9:1-14.

Nestler J.M., D.L Galat, and R.A.Hrabik. 2012. Side channels of the impounded and Middle Mississippi River: Opportunities and challenges to maximize restoration potential. Report of a Workshop held 10-14 January 2011 for the Corps of Engineers Navigation & Environmental Sustainability Program (NESP) and Water Operations Technology Support Program (WOTS), and Missouri Department of Conservation.

Nielsen, L.A.R.J. Sheehan, D.J. Orth. 1986. Impacts of navigation on riverine fish production in the United States. Polish Archives of Hydrobiology 33:277-294.

Niles, J.M. and K.J. Hartman. 2009. Larval fish use of dike structures on a navigable river. North American Journal of Fisheries Management. 29:1035-1045.

Odum, M.C., D.J. Orth, and L.A. Nielsen. 1992. Investigation of barge-associated mortality of larval fishes in the Kanawha River. Virginia Journal of Science 43:41-45.

Ouillon, S. and D. Dartus. 1997. Three-dimensional computation of flow around groyne. Journal of Hydraulic Engineering 123: 962–970.

Paillex, A, S. Dolédec, E. Castella, and S. Mérigoux. 2009. Large river floodplain restoration: predicting species richness and trait responses to the restoration of hydrological connectivity. Journal of Applied Ecology 46:250-258.

Penczak, T., K. O'Hara, and J. Kostrzewa. 2002. Fish bioenergetics model used for estimation of food consumption in a navigation canal with heavy traffic. Hydrobiologia 479:109-123.

Platner, W. S. 1946. Water quality studies of the Mississippi River. U.S. Fish and Wildlife Service Special Science Report 30. 77 pp.

Pokrefke, T.J., C. Berger, J.P. Rhee, S.T. Maynord. 2003. Tow-induced backwater and secondary channel sedimentation, Upper Mississippi River System. Upper Mississippi River-Illinois Waterway System Navigation Study ENV Report 41.

Preiner, S., I. Drozdowski, M. Schagerl, F. Schiemer, and T. Hein. 2008. The significance of side-arm connectivity for carbon dynamics of the River Danube, Austria. Freshwater Biology 53:238-252.

Radspinner, R. R., P. Diplas, A. F. Lightbody, and F. Sotiropoulos. 2010. River training and ecological enhancement potential using in-stream structures. Journal of Hydraulic Engineering 136:967-980.

Savino, J.F., M.A. Blouin, B.M. Davis, P.L. Hudson, T.N. Todd, and G.W. Fleischer. 1994. Effects of pulsed turbidity and vessel traffic on lake herring eggs and larvae. Journal Great Lakes Research 20:366-376.

Scheaffer, W.A., and J.G. Nickum. 1986. Backwater areas as nursery habitats for fishes in Pool 13 of the Upper Mississippi River. Hydrobiologia 136:131-140.

Schneider, B. 2012. Changes in fish use and habitat diversity associated with placement of three chevron dikes in the Middle Mississippi River. M.S. thesis, Southern Illinois University Edwardsville.

Sheehan, R.J., P.S. Willis, M.A. Schmidt, and J.M. Hennessy. 2000a. Determination of the fate of fish displaced from low-velocity habitats at low temperatures. Upper Mississippi River-Illinois Waterway System Navigation Study ENV Report 32.

Sheehan, R.J., P.S. Willis, M. Schmidt, and J.M. Hennessy. 2000b. Determination of tolerance of fish in low-velocity habitats to hydraulic disturbance at low temperatures. Upper Mississippi River-Illinois Waterway System Navigation Study ENV Report 33.

Shields, F. D., Jr., C. M. Commer, and S. Tesa III. 1995. Toward greener riprap: environmental considerations from microscale to macroscale. Pp. 557-574. *In*: River, Coastal and Shoreline Protection: Erosion Control Using Riprap and Armourstone, Thorne, C. R. et al. (eds). John Wiley and Sons: Chichester.

Siegrest, J.M., and S.P. Cobb. 1987. Evaluation of bird and mammal utilization of dike systems along the Lower Mississippi River. USACE Lower Mississippi River Environmental Program. Report 10.

Simons, J.H. E.J., C. Bakker, M.H.J. Schropp, L.H. Jans, F.R. Kok, and R.E. Grift. 2001. Man-made secondary channels along the River Rhine (The Netherlands): results of post-project monitoring. Regulated Rivers: Research & Management 17:473-491.

Smart, M.M., R.G. Rada, D.N. Nielsen, and T.O. Clafin. 1985. The effect of commercial and recreational traffic on the resuspension of sediment in navigation pool 9 on the Upper Mississippi River. Hydrobiologia 126:263-274.

Söhngen, B., J. Koop, S. Knight, J. Rythönen, P. Beckwith, N. Ferrari, J. Iribarren, T. Keevin, C. Wolter, S. Maynord. 2008. Considerations to Reduce Environmental Impacts of Vessels. Permanent International Navigation Congress (PIANC) Report Series #99: 113 pp. + CD Appendices.

Theiling, C., M.R. Craig, and K.S. Lubinski. 2000. Side channel sedimentation and land cover change in the Middle Mississippi River reach of the Upper Mississippi River System. U.S. Geological Survey Report. 82 pp.

Todd, B.L., F.S. Dillon, and R.E. Sparks. 1989. Barge effects on channel catfish. Illinois Natural History Survey, Aquatic Ecology Technical Report 89/5, Champaign, Illinois.

University of Memphis. 1998. Accidents and hazardous spills analysis for Upper Mississippi River Basin. Transportation Studies Institute, prepared for the U.S. Army Corps of Engineers, Rock Island District.

USACE. 1999. Middle Mississippi River side channels: A habitat rehabilitation and conservation initiative. U.S. Army Corps of Engineers, Rock Island District. 31 pp. + Appendicies.

USACE. 1999. Tier I of a two tiered Biological Assessment - Operation and Maintenance of the Upper Mississippi River Navigation Project within St. Paul, Rock Island, and St. Louis Districts. Mississippi Valley Division, Vicksburg, MS.

USACE. 2004. Final Integrated Feasibility Report and Programmatic Environmental Impact Statement for the UMR-IWW System Navigation Feasibility Study. U.S. Army Corps of Engineers, St. Paul, Rock Island, and St. Louis Districts.

USACE. 2006. Environmental Assessment with Draft Finding of No Significant Impact: Explosive Removal of Rock Pinnacles and Outcroppings Considered to be Navigation Obstructions During Low-Flow Periods on the Middle Mississippi River. St. Louis District, U.S. Army Corps of Engineers. 31 pp.

USACE. 2009. Tier II Supplemental Environmental Assessment with Draft Finding of No Significant Impact: Removal of Rock Pinnacles and Outcroppings Considered to be Navigation Obstructions During Low-Flow Periods on the Middle Mississippi River. 10 pp.

USACE. 2012. Supplemental Environmental Assessment with Draft Finding of No Significant Impact: Removal of Rock Pinnacles and Outcroppings Considered to be Navigation Obstructions During Low-Flow Periods on the Middlle Mississippi River. 26 pp.

USACE. 2012a. Tier II Biological Assessment: Grand Tower, Crawford Towhead, Vancill Towhead (Grand Tower Phase V Regulating Works), MRM 80.6-67, Operation and Maintenance of the 9-foot Navigation Channel on the Upper Mississippi River System. U.S. Army Corps of Engineers, St. Louis District. 16 pp.

USACE. . 2012b. Tier II Biological Assessment: Regulating Works Project, Eliza Point/Greenfield Bend Phase 3, MRM 20.0-0, Alexander County, Illinois, Mississippi County, Missouri, on the Middle Mississippi River. U.S. Army Corps of Engineers, St. Louis District. 12 pp.

USACE. 2013a. Tier II Biological Assessment: Dogtooth Bend Phase 5, River Miles 40-20, Alexander County, Illinois, Scott and Mississippi Counties, Missouri, on the Middle Mississippi River. U.S. Army Corps of Engineers, St. Louis District. 14 pp.

USACE. 2013b. Tier II Biological Assessment: Regulating Works Project, Mosenthein/Ivory Landing Phase 4, Middle Mississippi River Miles 175-170, St. Clair County, IL, St. Louis City, MO. U.S. Army Corps of Engineers, St. Louis District. 16 pp.

USEPA. 2013. U. S. Environmental Protection Agency green book nonattainment areas for criteria pollutants as of July 31, 2013. http://www.epa.gov/airquality/greenbk/ . Accessed 13 August 2013.

USFWS. 2000. Biological opinion for the operation and maintenance of the 9-foot navigation channel on the Upper Mississippi River System. U. S. Department of the Interior, Fort Snelling, Minnesota.

U.S. Public Health Service. 1958. Transcript of conference. Pollution of interstate waters: Mississippi River, St. Louis Metropolitan Area. 121 pp + Appendix.

Wolter, C., and R. Arlinghaus. 2003. Navigation impacts on freshwater fish assemblages: the ecological relevance of swimming performance. Reviews in Fish Biology and Fisheries 13:63-89.

Wolter, C., and A. Bischoff. 2001. Seasonal changes of fish diversity in the main channel of the large lowland river Oder. Regulated Rivers: Research and Management 17:595-608.

Wolter, C., R. Arlinghaus, A. Sukhodolov, and C. Engehardt. 2005. A model of navigation-induced currents in inland waterways and implications for juvenile fish displacement. Environmental Management 34:656-668.

Wysocki, L.E., J P. Dittami, and F. Ladich. 2006. Ship noise and cortisol secretion in European freshwater fishes. Biological Conservation 128:501.508.

Yossef, M., and H. de Vriend. 2011. Flow details near river groynes: experimental investigation. Journal of Hydraulic Engineering 137:504-516.

Appendix D. Clean Water Act Section 404(b)(1) Evaluation

REGULATING WORKS PROJECT
MOSENTHEIN/IVORY LANDING PHASE 4
MIDDLE MISSISSIPPI RIVER MILES 175-170
ST. CLAIR COUNTY, IL
ST. LOUIS CITY, MO

APRIL 2014

APPENDIX D
CLEAN WATER ACT
SECTION 404(b)(1) Evaluation

CONTENTS

1. PROJECT DESCRIPTION 1

   A. Location. 1
   B. General Description. 1
   C. Authority and Purpose. 1
   D. General Description of the Fill Material 1
   E. Description of the Proposed Placement Site 2
   F. Description of the Placement Method. 2

2. FACTUAL DETERMINATIONS 2

   A. Physical Substrate Determinations 2
   B. Water Circulation, Fluctuation, and Salinity Determinations 3
   C. Suspended Particulate/Turbidity Determinations 3
   D. Contaminant Determinations. 4
   E. Aquatic Ecosystem and Organism Determinations 4
   F. Proposed Placement Site Determinations 5
   G. Determinations of Cumulative Effects on the Aquatic Ecosystem. 6
   H. Determinations of Secondary Effects on the Aquatic Ecosystem. 6

3. FINDINGS OF COMPLIANCE OR NON-COMPLIANCE WITH THE RESTRICTIONS ON PLACEMENT 6

APPENDIX D
CLEAN WATER ACT
SECTION 404(b)(1) Evaluation

1. PROJECT DESCRIPTION

A. Location. The Mosenthein/Ivory Landing Phase 4 work area is located in the Middle Mississippi River (MMR) between river miles (RM) 175 and 171 in St. Louis City, Missouri and St. Clair County, Illinois. The MMR is defined as that portion of the Mississippi River that lies between the confluences of the Ohio and Missouri rivers.

B. General Description. The Corps of Engineers St. Louis District is proposing to construct the Mosenthein/Ivory Landing Phase 4 work as part of its Regulating Works Project. The Regulating Works Project utilizes bank stabilization and sediment management to maintain bank stability and ensure adequate navigation depth and width. Bank stabilization is achieved by revetments, while sediment management is achieved by river training structures, i.e. dikes. The Mosenthein/Ivory Landing Phase 4 work is designed to address repetitive maintenance dredging conditions in the area. The work involves construction of rootless dike 173.4 (L), and placement of bankline revetment at four locations on the left descending bank from river mile 175 to 171.

C. Authority and Purpose. The Middle Mississippi River Regulating Works Project is specifically and currently authorized pursuant to Rivers and Harbors Acts beginning in the mid-1800's. These authorize USACE to provide a 9-foot-deep by minimum of 300-foot-wide, with additional width in bends, navigation channel at low river levels.

The purpose of this work is to provide a sustainable, safe and dependable navigation channel through regulation works to reduce the need for repetitive channel maintenance dredging in the area.

D. General Description of the Fill Material.
Fill material would include quarry run limestone consisting of graded "A" stone. Size requirements for graded "A" stone are shown below. Stone (260,000 tons) required for construction would be obtained from commercial stone quarries in the vicinity of the work area capable of producing stone which meets USACE specifications.

GRADED "A" STONE	
Stone Weight (LBS)	Cumulative % Finer by Weight
5000	100
2500	70-100
500	40-65
100	20-45
5	0-15
1	0-5

E. Description of the Proposed Placement Site.
The proposed work would consist of the following:

Construction of rootless dike at river mile 173.4 (L)
- 550 feet long
- Top elevation of 389 feet (+15 feet LWRP)

Placement of revetment on the bankline at 4 locations from river mile 175 to 171
- Approximately 11,500 linear feet
- Top elevation of approximately 404 feet (+30 feet LWRP) or existing high bank elevation, whichever is lower

F. Description of the Placement Method.
Placement of material would be accomplished by trackhoe or dragline crane. Stone would be transported to placement sites by barges. All construction would be accomplished from the river and all work would be performed below ordinary high water. No grading of banks for revetment placement will be performed.

2. FACTUAL DETERMINATIONS

A. Physical Substrate Determinations

I. **Elevation and Slope.** There would be an immediate change in substrate elevation and slope over the areal extent of the placement location of rootless dike 173.4 (L). The rootless dike would consist of a rock mound of uniform shape, 550 feet long, placed approximately 450 feet off the existing bankline and extending toward the navigation channel. The top elevation of the rootless dike would be 389 feet. Side slopes would be approximately 1 vertical on 1.5 horizontal. After placement, sediment patterns in the immediate vicinity of the structure would change with scour occurring off both ends of the dike. Areas immediately downstream of the dike would experience some areas of accretion and some areas of scour.

There would be an immediate change in elevation over the areal extent of the revetment placement locations. Elevation change associated with revetment placement will be 30 inches minimum. In areas with steep, caving banks, elevation changes will be greater as enough revetment will be placed to bring the slope to 1 vertical on 1.5 horizontal. After placement, sedimentation patterns in the immediate vicinity of the revetment will change as bankline erosion is prevented.

II. **Sediment Type.** The work area is located entirely within the existing channel of the Middle Mississippi River. The Middle Mississippi River channel is comprised mainly of sands with some gravels, silts, and clays. The stone used for construction would be Graded “A” limestone.

III. **Fill Material Movement.** No bank grading or excavation would be required for placement of stone. Draglines and/or trackhoes would pull rock from floating barges and place the material into the river and on the banks. Fill materials would be subject to periodic high flows which may cause some potential movement and dislodging of stone. This may result in the need for minor repairs; however, no major failures are likely to occur.

IV. **Physical Effects on Benthos.** Material placement should not significantly affect benthic organisms. Shifting sediments at structure placement sites likely harbor oligochaetes, chironomids, caddisflies, turbellaria, and other macroinvertebrates. High densities of hydropsychid caddisflies and other macroinvertebrates would be expected to colonize the large limestone rocks after construction. Fish would temporarily avoid the area during construction. Greater utilization of the location by fish is expected after construction due to the expected increase in densities of macroinvertebrates.

V. **Actions Taken to Minimize Impacts.** Best Management Practices for construction would be enforced.

B. Water Circulation, Fluctuation, and Salinity Determinations

I. **Water.** Some sediments (mostly sands) would be disturbed when the rock used for construction is deposited onto the riverbed. This increased sediment load would be local and minor compared to the natural sediment load of the river, especially during high river stages.

II. **Current Patterns and Circulation.** The rootless dike 173.4 (L) would create split flow conditions at river stages below the top structure elevation of 389 feet. The rootless dike would increase channel depth in the thalweg and along the adjacent bankline. Revetment is not expected to appreciably change current and circulation patterns.

III. **Normal Water Level Fluctuations.** Stages at average and high flows both in the vicinity of the work area and on the MMR are expected to be similar to current conditions. Stages at low flows on the MMR show a decreasing trend over time and this trend is expected to continue with implementation of the Proposed Action.

IV. **Actions Taken to Minimize Impacts.** Best Management Practices for construction would be enforced.

C. Suspended Particulate/Turbidity Determinations

I. **Expected Changes in Suspended Particles and Turbidity Levels in Vicinity of Placement Site.** Increases in suspended particulates and turbidity due to construction activities are expected to be greatest within the immediate vicinity of the rock structures. The increased sediment load would be local and minor compared to the natural sediment load of the river. This would cease soon after construction completion. Revetment is designed to prevent bankline erosion, thereby reducing suspended particulate and turbidity levels in the immediate vicinity in the future.

II. **Effects on Chemical and Physical Properties of the Water Column**

a. Light Penetration. There would be a temporary reduction in light penetration until sediments suspended as part of construction activities settled out of the water column. There would be a minor increase in light penetration in the immediate vicinity of revetment locations in the future due to reduced bankline erosion.
b. Dissolved Oxygen. No adverse effects expected.
c. Toxic Metals and Organics. No adverse effects expected.
d. Aesthetics. Aesthetics of work sites are likely to be adversely affected during construction, but are expected to return to normal after construction.

III. **Effects on Biota.** The work would likely result in some short-term displacement of biota in the immediate vicinity of construction activities due to temporary decreases in water quality and disturbance by construction equipment.

IV. **Actions Taken to Minimize Impacts.** Impacts are anticipated to be minimized by the use of clean, physically stable, and chemically non-contaminating limestone rock for construction.

D. Contaminant Determinations. It is not anticipated that any contaminants would be introduced or translocated as a result of construction activities.

E. Aquatic Ecosystem and Organism Determinations

I. **Effects on Plankton.** The work could have a temporary, minor effect on plankton communities in the immediate vicinity of the work area. This would cease after construction completion.

II. **Effects on Benthos. S**ediments at structure placement sites likely harbor oligochaetes, chironomids, caddisflies, turbellaria, and other macroinvertebrates. Construction activities would eliminate some of these organisms. High densities of hydropsychid caddisflies and other macroinvertebrates would be expected to colonize the large limestone rocks after construction. Fish would be expected to temporarily avoid the area during construction. Greater utilization of the location by fish is expected after construction due to the expected increase in densities of macroinvertebrates. Fish habitat is expected to improve at the dike placement site due to improved flow, bathymetry, and prey resource conditions. A minor decrease in woody debris inputs into the system is anticipated due to decreased bankline erosion associated with revetment sites. Decreased woody debris would have a minor negative impact on fish and macroinvertebrate communities that utilize this resource for foraging and refuge.

III. **Effects on Nekton.** Nekton would be temporarily displaced during construction activities, but would return shortly after completion. Greater utilization of the area by fish may occur after construction due to the expected increase in densities of macroinvertebrates and areas of improved flow and bathymetry. Decreased woody debris inputs due to decreased bankline erosion would have a minor negative impact on fish and macroinvertebrate communities that utilize this resource for foraging and refuge.

IV. **Effects on Aquatic Food Web.** Temporary reductions in macroinvertebrate and fish communities during construction in the relatively small work area should not significantly impact the aquatic food web in the Middle Mississippi River. Improvements in lower trophic levels (macroinvertebrates) subsequent to completion should benefit the aquatic food web. Minor negative impacts on fish and macroinvertebrate communities due to reduced woody debris should not significantly impact the aquatic food web.

V. **Effects on Special Aquatic Sites.** There are no special aquatic sites within the work area.

VI. **Threatened and Endangered Species.** Presence of, or use by, endangered and threatened species is discussed in the Environmental Assessment and Biological Assessment. No significant adverse impacts to threatened and endangered species are expected to result from this work.

VII. **Other Wildlife.** The work would likely result in some very localized, short-term displacement of wildlife in the immediate vicinity of construction activities. Displacement would end immediately after construction completion.

VIII. **Actions Taken to Minimize Impacts.** Best Management Practices for construction would be enforced.

F. Proposed Placement Site Determinations

I. **Mixing Zone Determinations.** The fill material is inert and would not mix with the water. The lack of fine particulate typically contained in rock fill and main channel sediments indicates negligible chemical or turbidity effects resulting from the proposed action.

II. **Determination of Compliance with Applicable Water Quality Standards.** Section 401 water quality certifications have been obtained from the states of Illinois and Missouri (see Appendix F). All other permits necessary for the completion of the work have been applied for and will be obtained prior to implementation.

III. **Potential Effects on Human Use Characteristics.** The proposed work would have no adverse impact on municipal or private water supplies; water-related recreation; aesthetics; or parks, national and historic monuments, national seashores, wilderness areas, research sites or similar preserves. During construction the area would not be available for recreational and commercial fishing.

G. Determinations of Cumulative Effects on the Aquatic Ecosystem. Dikes and revetment have been used extensively throughout the Lower, Middle, and Upper Mississippi River System to provide a safe and dependable navigation channel. Due to concerns from natural resource agency partners about the potential cumulative impacts of river training structures, and other actions within the watershed, on the aquatic ecosystem, the St. Louis District has been utilizing innovative river training structures such as offset dikes to increase habitat diversity in the Middle Mississippi River while still maintaining the navigation channel. The District conducts extensive coordination with resource agency and navigation industry partners to ensure that implementation is accomplished effectively from an ecological and navigation viewpoint. Although minor short-term construction-related impacts to local fish and wildlife populations are likely to occur, no significant cumulative impacts on the aquatic ecosystem are identified for the Mosenthein/Ivory Landing Phase 4 work.

H. Determinations of Secondary Effects on the Aquatic Ecosystem. No adverse secondary effects would be expected to result from the proposed action.

3. FINDINGS OF COMPLIANCE OR NON-COMPLIANCE WITH THE RESTRICTIONS ON PLACEMENT

A. No significant adaptations of the 404(b)(1) guidelines were made relative to this evaluation.

B. Alternatives that were considered for the proposed action included:

1. No Action Alternative - The No Action Alternative consists of not constructing any new structures in the area but continuing to maintain the existing river training structures. Dredging would continue as needed to address the shoaling issues in the area.
2. Proposed Action - The Proposed Action consists of construction of a rootless dike at RM 173.4 (L) and placement of revetment at four locations from RM 175 (L) to 171 (L).

C. Certification under Section 401 of the Clean Water Act has been obtained from the Missouri Department of Natural Resources and the Illinois Environmental Protection Agency (see Appendix F).

D. The proposed fill activity is in compliance with Applicable Toxic Effluent Standards of Prohibition under Section 307 of the Clean Water Act.

E. No significant impact to threatened or endangered species is anticipated from this work. Prior to construction, full compliance with the Endangered Species Act would be documented.

F. No municipal or private water supplies would be affected by the proposed action, and no degradation of waters of the United States is anticipated.

G. The work area is situated along an inland freshwater river system. No marine sanctuaries are involved or would be affected by the proposed action.

H. The materials used for construction would be chemically and physically stable and non-contaminating.

I. The proposed construction activity would not have a significant adverse effect on human health and welfare, recreation and commercial fisheries, plankton, fish, shellfish, wildlife, or special aquatic sites. No significant adverse effects on life stages of aquatic life and other wildlife dependent on aquatic ecosystems are expected to result. The proposed construction activity would have no significant adverse effects on aquatic ecosystem diversity, productivity, and stability. No significant adverse effects on recreational, aesthetic, and economic values would occur.

J. No other practical alternatives have been identified. The proposed action is in compliance with Section 404(b)(1) of the Clean water Act, as amended. The proposed action would not significantly impact water quality and would improve the integrity of an authorized navigation system.

4-17-14

(Date)

CHRISTOPHER G. HALL
COL, EN
Commanding

Appendix E. Public Comments and Responses

Appendix E. Public Comments and Responses

TABLE OF CONTENTS

Comments of the National Wildlife Federation	E1
Attachment A	E5
Attachment B	E21
Attachment C	E33
Attachment D	E38
District Responses to National Wildlife Federation Comments	E102

NATIONAL WILDLIFE FEDERATION®
83 Valley Road
San Anselmo, CA 94960
415-762-8264 (office)
415-577-9193 (cell)
sametm@nwf.org

November 15, 2013

Via Email: Danny.D.Mcclendon@usace.army.mil

Danny D. McClendon
Chief, Regulatory Branch
U.S. Army Corps of Engineers
St. Louis District
1222 Spruce Street
St. Louis, Missouri 63103

Re: Comments on Draft Environmental Assessment with Unsigned Finding of No Significant Impact, Mosenthein/Ivory Landing Phase 4 Regulating Work Projects; Public Notice P-2853 (2013-619)

Dear Mr. McClendon:

The National Wildlife Federation appreciates the opportunity to submit these comments on the Draft Environmental Assessment with Unsigned Finding of No Significant Impact, Mosenthein/Ivory Landing Phase 4 Regulating Work Projects (the Environmental Assessment).

The National Wildlife Federation (NWF) is the Nation's largest conservation education and advocacy organization. NWF has more than four million members and supporters and conservation affiliate organizations in forty-seven states and territories. NWF has a long history of interest and involvement in the programs of the U.S. Army Corps of Engineers (Corps) and the management and protection of the Mississippi River. NWF is a strong supporter of ecologically sound efforts to restore the Mississippi River and the nation's many other damaged rivers, coasts, and wetlands; and was a strong advocate for the comprehensive restoration program authorized in 2007 as part of the Navigation and Ecosystem Sustainability Program.

A. The Corps Should Prepare a Supplemental Environmental Impact Statement to Evaluate All Operations and Maintenance Activities

The construction of river training structures and placement of revetment are activities carried out under the Corps' authority to operate and maintain the Upper Mississippi River-Illinois Waterway Navigation System (UMR-IWW). As discussed in detailed in a February 16, 2012 letter to the Assistant Secretary of the Army for Civil Works, these operation and maintenance (O&M) activities are causing significant environmental harm, increasing flood risks for riverside communities, and undermining the work carried out under the Corps' restoration and flood protection authorities. A copy of this letter is attached to these comments at Attachment A. NWF incorporates the February 16, 2012 letter by reference herein and we request that the Corps consider the contents of that letter as though fully set forth in the text of these scoping comments.

As also discussed in detail in the February 16, 2012 letter, the National Environmental Policy Act (NEPA) requires preparation of a supplemental Environmental Impact Statement to evaluate all O&M activities and to identify alternatives that could cause less harm to the environment. The Environmental Assessment, which evaluates construction of only one set of new river training structures, cannot satisfy the requirements of NEPA as it would constitute an impermissible piecemeal assessment of just one of many O&M activities designed to maintain a 9 foot navigation channel in one portion of the UMR-IWW.

As also discussed below, the Environmental Assessment does not effectively evaluate the significant risks to public safety created by river training structures in the Mississippi River and does not meaningfully evaluate alternative approaches to reducing those risks. Extensive peer-reviewed science demonstrates that river training structures constructed to reduce navigation dredging costs have increased flood levels by up to 15 feet in some locations and 10 feet in broad stretches of the Mississippi River where these structures are prevalent.[1] The flood height inducing effects of river training structures are so well recognized that the Dutch have "begun lowering dozens of wing dikes along a branch of the Rhine River and [have] plans to lower hundreds more as part of a nationwide effort to reduce flood risk in that river's floodplain." [2] The Environmental Assessment, however, denies the validity of this science without providing a reasonable explanation for doing so.

Instead of the proposed Environmental Assessment, the National Wildlife Federation urges the Corps to:

1. Initiate a comprehensive reassessment of the activities carried out by the Corps to operate and maintain the UMR-IWW. This reassessment should be carried out through preparation of a comprehensive supplemental environmental impact statement and a general reevaluation of the Corps' O&M planning studies. This would help ensure that future O&M activities comply with current law, planning criteria and policies, including the requirements established by the Clean Water Act, the Endangered Species Act, the Water Resources Development Act of 2007, and the Fish and Wildlife Coordination Act.

2. Initiate a National Academy of Sciences study on the effect of river training structures on flood heights to inform the reassessment. A National Academy of Sciences review is critical for ensuring that the reassessment is based on the best possible scientific understanding of the role of river training structures on increasing flood heights, and for ensuring that the reassessment produces recommendations that will provide the highest possible protection to the public.

3. Impose a moratorium on the construction of new river training structures pending completion of the reassessment process. As noted above, extensive peer-reviewed science demonstrates that river training structures have increased flood levels by up to 15 feet in some locations and

[1] Pinter, N., A.A. Jemberie, J.W.F. Remo, R.A. Heine, and B.A. Ickes, 2010. Empirical modeling of hydrologic response to river engineering, Mississippi and Lower Missouri Rivers. River Research and Applications, 26: 546-571; Remo, J.W.F., N. Pinter, and R.A. Heine, 2009. The use of retro- and scenario- modeling to assess effects of 100+ years river engineering and land cover change on Middle and Lower Mississippi River flood stages. Journal of Hydrology, 376: 403-416.

[2] Government Accountability Office, GAO-12-41, Mississippi River, Actions Are Needed to Help Resolve Environmental and Flooding Concerns about the Use of River Training Structures (December 2011) (GAO Study on River Training Structures) (concluding that the Corps is out of compliance with both the National Environmental Policy Act and the Clean Water Act).

10 feet in broad stretches of the Mississippi River where these structures are prevalent. It is critical that additional structures are not constructed unless and until a comprehensive reassessment establishes that such construction will not contribute to increased flood risks to communities.

To comply with NEPA, the supplemental environmental impact statement must evaluate, among other things: the impacts and cumulative impacts of operations and maintenance activities on the Upper Mississippi River and Illinois River ecosystems; the effect of those activities on flood heights and public safety; alternatives to those activities that could cause less harm to the environment, including alternative water level management regimes and removal and/or modification of river training structures; and mitigation for those impacts that cannot be avoided. An Environmental Assessment would likewise have to evaluate these impacts and alternatives.

The National Wildlife Federation urges the Corps to defer consideration of construction of the Eliza Point project until it carries out a comprehensive supplemental environmental impact statement for operations and maintenance of the Mississippi River navigation system. The Environmental Assessment is far too limited to adequately assess the risks to public safety and does not comply with the requirements of NEPA.

B. The Environmental Assessment Fails to Properly Evaluate Alternatives and Impacts

The Environmental Assessment provides only a limited analysis that does not comply with the requirements of NEPA. The Environmental Assessment reviews only two alternatives, utilizes inappropriate studies, and fails to provide a reasonable explanation between the information presented and the conclusions drawn. Among other problems:

1. The Environmental Assessment examines only two alternatives, the no action alternative and the proposed alternative. This is legally insufficient. A legally adequate environmental assessment must examine a full range of reasonable alternatives.

2. The proposed alternative was developed using a Hydraulic Sediment Response model (HSR model). "An HSR model is a small-scale physical sediment transport model used by the District to replicate the mechanics of river sediment transport." Environmental Assessment at 5. However, such models cannot be relied upon to provide accurate planning information as they lack "predictive capability". Stephen T. Maynord, Journal of Hydraulic Engineering, *Evaluation of the Micromodel: An Extremely Small-Scale Movable Bed Model* (April 2006). Maynord concludes that because of the "lack of predictive evidence, the micromodel should be limited to demonstration, education, and communication." A copy of this study is attached to these comments at Attachment B.

3. The Environmental Assessment and Appendix A fail to analyze the full range of scientific studies that address the role of river training structures in raising flood heights. A list of 47 studies assessing the role of instream structures on increasing flood heights is attached to these comments at Attachment C. NWF requests that these studies be carefully reviewed and considered by the Corps and included in the record for this project. The Environmental Assessment also does not provide a reasonable explanation as to why it rejected the conclusions

in those few studies related to increased flood heights from river training structures that it did evaluate.

4. The Environmental Assessment fails to adequately evaluate the environmental impacts of the proposed revetment. The project recommended in the Environmental Assessment includes 2.178 miles of revetment (11,500 linear feet). The Environmental Assessment, however, refers to only six studies on the impacts of revetment, the most recent of which was published in 1989 – 24 years ago. As the Corps itself has documented, a host of more recent studies are available. *See, e.g*, Fischenich, J.C. (2003), "Effects of Riprap on Riverine and Riparian Ecosystems", ERDC/EL TR-03-4, U.S. Army Corps of Engineer Research and Development Center. A copy of this report, which is itself already a decade old, is attached to these comments at Attachment D. Up to date science must be utilized to evaluate the adverse impacts of more than 2 miles of revetment.

C. Conclusion

For the reasons set forth above, the Environmental Assessment is legally deficient and cannot be relied upon to satisfy the requirements of NEPA for the proposed project. The National Wildlife Federation urges the Corps to defer consideration of construction of the Eliza Point project until it carries out a comprehensive supplemental environmental impact statement for operations and maintenance of the Mississippi River navigation system. The Environmental Assessment is far too limited and flawed to adequately assess the risks to public safety and the impacts on the environment, and it does not comply with the requirements of NEPA.

Very truly yours,

Melissa Samet
Senior Water Resources Counsel

Attachments

Attachment A
Comments of the National Wildlife Federation

February 16, 2012

Via Email and U.S. Mail

The Honorable Jo-Ellen Darcy
Assistant Secretary of the Army (Civil Works)
Department of the Army
108 Army Pentagon, Room 3E446
Washington, DC 20310

Re: Operations and Maintenance of the Upper Mississippi River – Illinois Waterway Navigation System

Dear Assistant Secretary Darcy:

The National Wildlife Federation respectfully requests that you initiate a comprehensive reassessment of the activities carried out by the U.S. Army Corps of Engineers (Corps) to operate and maintain the Upper Mississippi River – Illinois Waterway Navigation System. These activities are causing significant environmental harm, increasing flood risks for riverside communities, and undermining the work carried out under the Corps' restoration and flood protection authorities.

This reassessment should be carried out through preparation of a comprehensive supplemental environmental impact statement, and a general reevaluation of the Corps' operations and maintenance (O&M) planning studies to ensure that future O&M activities comply with current law, planning criteria and policies. This would also trigger, and thus ensure compliance with, the requirements of other applicable federal laws, including the Clean Water Act, the Endangered Species, the Water Resources Development Act of 2007, and the Fish and Wildlife Coordination Act.

To comply with the National Environmental Policy Act (NEPA), the supplemental environmental impact statement must evaluate, among other things: the impacts and cumulative impacts of operations and maintenance activities on the Upper Mississippi River and Illinois River ecosystems; the effect of those activities on flood heights and public safety; alternatives to those activities that could cause less harm to the environment, including alternative water level management regimes and removal and/or modification of river training structures; and mitigation for those impacts that cannot be avoided.

To ensure that the reassessment produces recommendations for O&M activities that will provide the highest possible protection to the public, the National Wildlife Federation also urges you to initiate a National Academy of Sciences study on the effect of river training structures on flood heights to inform the reassessment, and to impose a moratorium on the construction of new river training structures pending completion of the reassessment process.

The National Wildlife Federation and others in the environmental and scientific communities have raised the issues set forth in this letter with the Corps' military and civilian leadership both prior to your confirmation and under previous administrations. As you know, I have submitted an official request to meet with you to discuss our concerns and to explore opportunities for modernizing the Corps' O&M activities to protect people, wildlife, and the environment. I hope that such a meeting will be possible.

A. O&M Activities Cause Significant Harm to People and Wildlife

The Upper Mississippi River – Illinois Waterway (UMR-IWW) navigation system includes 1,200 miles of 9-foot navigation channel, 37 lock and dam sites, and thousands of channel training structures. This system requires "continuous regular operations and maintenance" at a cost of more than $120 million each year.[1] These operations and maintenance (O&M) activities include: dredging and disposal of dredged material, water level regulation, construction of river training structures (wing dikes, bendway weirs, chevrons), construction of revetment, and operation and maintenance of the system's 37 locks and dams.

These O&M activities are a significant cause of the severe decline in the ecological health of the UMR-IWW system and have completely altered the natural processes in the Upper Mississippi River.[2] Construction of river training structures has also resulted in significant increases in flood heights along the Mississippi River. These adverse impacts also undermine the effectiveness of work carried out under the Corps' restoration and flood protection authorities for the Mississippi River

In a 1999 report on the Status and Trends of the Upper Mississippi River System, the U.S. Geological Survey concluded that the Corps' O&M activities in the UMR-IWW system were: destroying critical habitats including the rivers' backwaters, side channels and wetlands; altering water depth; destroying bathymetric diversity; causing nonnative species to proliferate; and severely impacting native species.[3] The 1999 Status and Trends Report also rated the health of the Mississippi River System as follows:

1. The Lower Reach of the Illinois River is degraded for all 6 criteria of ecosystem health evaluated by the report.[4]
2. The Unimpounded Reach of the Mississippi River is degraded for 3 criteria, heavily impacted for 2 criteria, and moderately impacted for 1 criterion.
3. The Lower Impounded Reach of the Mississippi River (Pools 14-26) is degraded for 2 criteria, heavily impacted for 3 criteria, and moderately impacted for 1 criterion.
4. The Upper Impounded Reach of the Mississippi River (Pools 1-13) is degraded for 1 criterion

[1] USACE Brochure, Upper Mississippi River – Illinois Waterway System Locks and Dams (September 2009) available at http://www.mvr.usace.army.mil/brochures/documents/UMRSLocksandDams.pdf; Congressional Research Service, *Inland Waterways: Recent Proposals and Issues for Congress* (July 14, 2011) at 15.
[2] U.S. Geological Survey, Ecological Status and Trends of the Upper Mississippi River System 1998: A Report of the Long Term Resource Monitoring Program (April 1999) (1999 Status and Trends Report).
[3] *Id*.
[4] "Degraded" is the lowest possible grade issued by the report and is defined as a condition where the factors associated with the criteria "are now below ecologically acceptable levels" and where "[m]ultiple management actions are required to raise these conditions to acceptable levels." 1999 Status and *Trends Report* at 16-2.

and moderately impacted for 5 criteria.

The 1999 Status and Trends report further concluded that no segment of the Upper Mississippi River system was unchanged from historic conditions, or deemed to require no management action to maintain, restore or improve conditions. Equally important, no segment of the system was improving in quality.[5]

In December 2008, the U.S. Geological Survey issued a second report on the status and trends of selected resources in the Upper Mississippi River system which also found that the Corps' O&M activities were causing significant adverse impacts.[6] For example:

> The current condition of the UMRS is heavily influenced by its agriculture-dominated basin and by the dams, channel training structures, dredging, and levees that regulate flow distribution during most of the year. Although substantial improvements in some conditions have occurred since the 1960s because of improvements in sewage treatment and land use practices, the UMRS still faces substantial challenges including
>
> 1. High sedimentation rates in some backwaters and side channels;
> 2. An altered hydrologic regime resulting from modifications of river channels, the floodplain, and land use within the basin, and from dams and their operation;
> 3. Loss of connection between the floodplain and the river, particularly in the southern reaches of the UMRS;
> 4. Nonnative species (e.g., common carp [*Cyprinus carpio*], Asian carps [*Hypophtalmichthys* spp.], zebra mussels [*Dreissena polymorpha*]);
> 5. High levels of nutrients and suspended sediments; and
> 6. Degradation of floodplain forests.[7]

The 2008 Status and Trends report also recognized that there has been "a substantial loss of habitat diversity"[8] in the system over the past 50 years due in large part to excessive sedimentation and erosion:

> In all reaches, sedimentation has filled-in many backwaters, channels, and deep holes. In the lower reaches, sediments have completely filled the area between many wing dikes producing a narrower channel and new terrestrial habitat. Erosion has eliminated many islands, especially in impounded zones.[9]

In addition to this significant environmental harm, an extensive body of peer-reviewed scientific literature also demonstrates that river training structures constructed by the Corps to help maintain the

[5] 1999 Status *and Trends Report at* 16-1 to 16.-2.
[6] Johnson, B. L., and K. H. Hagerty, editors. 2008. U.S. Geological Survey, *Status and Trends of Selected Resources of the Upper Mississippi River System,* December 2008, Technical Report LTRMP 2008-T002. 102 pp + Appendixes A–B (Upper Midwest Environmental Sciences Center, La Crosse, Wisconsin) (2008 Status and Trends Report).
[7] *Id*. at 3.
[8] *Id*. at 6.
[9] *Id*. at 6.

9 foot navigation channel are significantly increasing the risks of floods for riverside communities.[10] These structures, constructed by the Corps to reduce navigation dredging costs, have increased flood levels by up to 15 feet in some locations and 10 feet in broad stretches of the river where these structures are prevalent.[11] While the Corps continues to deny the validity of this science, the flood height inducing effects of river training structures are so well recognized that the Dutch have "begun lowering dozens of wing dikes along a branch of the Rhine River and [have] plans to lower hundreds more as part of a nationwide effort to reduce flood risk in that river's floodplain." [12]

B. The Corps Should Conduct a Comprehensive Reevaluation of its O&M Activities and Develop Alternatives that Cause Less Harm to the Environment

The law is clear that a supplemental environmental impact statement (EIS) must be prepared when there "are significant new circumstances or information relevant to environmental concerns and bearing on the proposed action or its impacts" or when the agency makes "substantial changes in the proposed action that are relevant to environmental concerns." 40 C.F.R. § 1502.9(c); 33 C.F.R. § 230.13(b).

The Supreme Court has ruled that:

> If there remains 'major Federal actio[n]' to occur, and if the new information is sufficient to show that the remaining action will 'affec[t] the quality of the human environment' in a significant manner or to a significant extent not already considered, a supplemental EIS must be prepared.

Marsh v. Oregon Natural Resources Council, 490 U.S. 360, 374 (1989) (emphasis added).

New information requires preparation of a supplemental EIS if the information "'presents a picture of the likely environmental consequences associated with the proposed action not envisioned by the original EIS'" and "'raises new concerns of sufficient gravity such that another, formal in-depth look at the environmental consequences of the proposed action is necessary'" *Louisiana Wildlife Federation v. York*, 761 F.2d 1044, 1051 (5th Cir. 1985) (quoting *Wisconsin v. Weinberger*, 745 F.2d 412, 418 (7th Cir. 1984) (a supplemental EIS must be prepared when "new information provides a *seriously* different picture of the environmental landscape such that another hard look is necessary")).

The Corps is not free to ignore the possible significance of new information. The Corps must "take a hard look" at any new information (*i.e.*, information that did not exist when the original environmental

[10] See Attachment A listing 47 peer reviewed studies linking instream structures to increased flood heights.

[11] Pinter, N., A.A. Jemberie, J.W.F. Remo, R.A. Heine, and B.A. Ickes, 2010. Empirical modeling of hydrologic response to river engineering, Mississippi and Lower Missouri Rivers. River Research and Applications, 26: 546-571; Remo, J.W.F., N. Pinter, and R.A. Heine, 2009. The use of retro- and scenario- modeling to assess effects of 100+ years river engineering and land cover change on Middle and Lower Mississippi River flood stages. Journal of Hydrology, 376: 403-416.

[12] Government Accountability Office, GAO-12-41, Mississippi River, Actions Are Needed to Help Resolve Environmental and Flooding Concerns about the Use of River Training Structures (December 2011) (GAO Study on River Training Structures) (concluding that the Corps is out of compliance with both the National Environmental Policy Act and the Clean Water Act).

impact statement was prepared) to determine whether a supplemental environmental impact statement is required. *Marsh*, 490 U.S. at 385. Where, as here, an EIS is "more than 5 years old," it should be "carefully reexamined" to determine if a supplement is required. 46 Fed Reg. 18026 (March 23, 1981), as amended, 51 Fed. Reg. 15618 (April 25, 1986), Question 32; *see also Oregon Natural Resources Council v. U.S. Forest Serv*., 445 F. Supp. 2d 1211, 1232 (D. Or. 2006) (recognizing passage of time likely warrants supplemental NEPA analysis).

Despite these clear requirements, the Corps has failed to update the woefully out of date and piecemeal environmental reviews that it is relying on to justify its O&M activities and has failed to develop less environmentally damaging alternatives. The Corps has long been aware that alternative methods exist for maintaining the system's navigational capacity while also improving the system's ecological health, making the failure to adopt such alternatives even more troubling.[13]

The Corps has never prepared a single, comprehensive environmental impact statement evaluating the full range of impacts, including the cumulative impacts, of O&M activities on the UMR-IWW system. Instead, the Corps continues to rely on a series of five outdated and piecemeal environmental impact statements that do not satisfy the requirements of NEPA. Four of these EISs are more than 35 years old – two were written in 1974, one in 1975, and one in 1976.[14] Another assessment that reviews only a portion of O&M activities carried out in one Corps District was written in 1997, 15 years ago.[15]

Each of these EISs is limited to examining activities carried out within a single district. Each of these EISs is based on stale and outdated scientific and ecological information. None of these EISs evaluate the cumulative impacts of O&M activities.[16] None of these EISs evaluate the impact of the thousands of river training structures constructed by the Corps on flood heights or on the safety of river communities.[17]

[13] For example, in 1997, the Donald J. Barry, Deputy Assistant Secretary for Fish and Wildlife and Parks, U.S. Department of Interior wrote a letter to the Martin Lancaster, Assistant Secretary of the Army for Civil Works advising the Corps of the new information that has been developed by the Corps and FWS regarding the impacts of the Corps' O&M activities on the Upper Mississippi River System and that the Corps' activities "can be managed to achieve the goals of navigation and a healthy river system." (Letter dated April 12, 1997). Similarly, the Upper Mississippi Water Level Management Task Force advised the Corps in 1996 that "[w]ater level management experiences from around the world amply demonstrate that opportunity exists for improving the ecological conditions of the Upper Mississippi River." Upper Mississippi Water Level Management Task Force, Problem Appraisal Report for Water Level Management (1996) at 3-3.

[14] The St. Paul District prepared an EIS in 1974 for the operation and maintenance of a 9-foot channel on the Upper Mississippi River from the head of navigation to Guttenberg, Iowa. The Rock Island District prepared an EIS in 1974 for the operation and maintenance of a 9-foot navigation channel on the Upper Mississippi River. The St. Louis District prepared an EIS in 1975 and 1976 for the operation and maintenance of pools on the Mississippi and Illinois Rivers and the regulating works for the Mississippi River between the Ohio and Missouri River.

[15] The St. Paul District issued a fifth EIS in 1997 that evaluated navigation maintenance activities within that district (1997 EIS). As acknowledged in the 1997 EIS, that document did not evaluate "operations" and did not examine cumulative impacts.

[16] The duty to discuss cumulative impacts in an EIS is mandatory and not within the agency's discretion. 40 C.F.R. §§ 1502.16, 1508.7; *see also Oregon Natural Resources Council v. Marsh*, 52 F.3d 1485 (9th Cir. 1995) (holding that the Corps violated NEPA by narrowly limiting the scope of the discussion of cumulative impacts).

[17] GAO Study on River Training Structures.

The St. Louis District appears intent on continuing to assess O&M activities in a piecemeal fashion. In response to the recent Government Accountability Office report outlining the Corps' failure to comply with NEPA and the Clean Water Act in connection with the use of river training structures, the St. Louis District has announced that it will prepare an environmental assessment on that single O&M activity.[18] Such a limited assessment, however, is legally insufficient and cannot adequately assess the risk to public safety.

C. Significant New Circumstances and Information Relating to Environmental Impacts Require Preparation of a Supplemental EIS

The Corps must prepare a supplemental EIS because significant new circumstances have arisen and significant new information has become available since completion of the existing EISs that bear on the environmental impacts of the O&M activities. This information could not have been, and was not, evaluated in the original EISs and has not been taken into account to develop less damaging approaches to the Corps' O&M activities. As discussed in section D below, the Corps also must prepare a supplemental EIS because the agency has made substantial changes to its O&M activities that are relevant to environmental concerns.

1. Dramatic decline in the ecological health of the system

Since the EISs were completed, the federal government has documented a dramatic decline in the ecological health of the Mississippi and Illinois Rivers and the species that rely on them. This decline is recognized as resulting in large part from the Corps' O&M activities.

For example, in December 1997, the Corps issued a report to Congress which concludes that "conditions at even the most healthy sites within the [Upper Mississippi River System] are at least partially artificial, non-sustainable, and in a recognized state of degradation."[19]

As discussed in Section A above, the 1999 Status and Trends report issued by the U.S. Geological Survey concludes that the Corps' O&M activities have completely altered the natural processes in the Upper Mississippi River and are destroying critical habitats including the rivers' backwaters, side channels and wetlands; altering water depth; destroying bathymetric diversity; causing nonnative species to proliferate; and severely impacting native species.[20] That report also concludes that each segment of the river is degraded, heavily impacted, or moderately impacted for some or all of a series of 6 criteria of ecosystem health evaluated by the report.[21] Importantly, no segment of the Upper Mississippi River system is unchanged from historic conditions, or deemed to require no management action to maintain, restore or improve conditions; and no segment of the system is improving in quality.[22]

[18] GAO Study on River Training Structures.
[19] Rock Island District, U.S. Army Corps of Engineers, *Report to Congress, An Evaluation of the Upper Mississippi River System Environmental Management Program* (December 1997) at 2-3.
[20] 1999 Status and Trends Report.
[21] "Degraded" is the lowest possible grade issued by the report and is defined as a condition where the factors associated with the criteria "are now below ecologically acceptable levels" and where "[m]ultiple management actions are required to raise these conditions to acceptable levels." 1999 Status and Trends Report at 16-2.
[22] 1999 Status and Trends Report at 16-1 to 16-12.

In May 2000, the U.S. Fish and Wildlife Service issued a Final Biological Opinion on the Corps' O&M activities which concludes that the "continued operation and maintenance of the 9-foot Navigation project will jeopardize the continued existence of the Higgins eye pearly mussel (*Lampsilis higginsi*) and the pallid sturgeon (*Sacphirhynchus albus*)."[23] The Biological Opinion also concludes that the Project will result in the incidental take of the least tern (*Sterna antillarum*) and winged mapleleaf mussel (*Quadrula fragosa*). The Biological Opinion also concludes that the Project will likely adversely affect the bald eagle (*Haliaeetus leucocephalus)*, the Indiana bat (*Myotis sodalis*), and the decurrent false aster (*Boltonia decurrens*).[24]

As discussed in Section A above, in December 2008, the U.S. Geological Survey issued a second report on the status and trends of selected resources in the Upper Mississippi River System which found that that the Corps' O&M activities continue to create long term adverse impacts, including high sedimentation rates, altered hydrologic regimes, loss of connection between the river and its floodplain, nonnative species, and degradation of floodplain forests.[25] That report also recognizes that there has been "a substantial loss of habitat diversity"[26] in the system over the past 50 years due in large part to excessive sedimentation and erosion, and that "sedimentation has filled-in many backwaters, channels, and deep holes" and has "completely filled the area between many wing dikes producing a narrower channel and new terrestrial habitat."[27]

2. Significant new scientific information

Since the EISs were completed there has been a deluge of new scientific studies that bear directly on the environmental impacts of the Corps' O&M activities. This new information must be fully evaluated and taken into account to develop less damaging approaches to O&M.

For example, since 1976, hundreds of studies have been published addressing large river sediment transport and deposition.[28] As discussed above, sedimentation in the navigation pools, side channels, and backwater areas is well recognized as one of the most critical ecological problems affecting the Upper Mississippi River ecosystem.

Since 1986, at least 44 scientific studies have been published linking the construction of river training structures to increased flood heights. More than 15 studies published from 2000-2010 demonstrate the role of river training structures on flood heights in the Mississippi River. River training structures

[23] U.S. Fish and Wildlife Service, *Biological Opinion for the Operation and Maintenance of the 9-Foot Navigation Channel on the Upper Mississippi River System* (finding jeopardy for pallid sturgeon and Higgins eye pearly mussel) at 1.
[24] *Id*.
[25] 2008 Status and Trends Report.
[26] *Id*. at 6.
[27] *Id*. at 6.
[28] E.g., DeHaan, H.C. 1998, *Large River Sediment Transport and Deposition: An Annotated Bibliography,* U.S. Geological Survey, Environmental Management Technical Center, Onalaska, Wisconsin, April 1998, LTRMP 98-T002. 85 pp. (identifying more than 250 scientific studies addressing large river sediment transport and deposition published since 1976): Pierre Y. Julien and Chad W. Vensel, Department of Civil and Environmental Engineering Colorado State University, *Review of Sedimentation Issues on the Mississippi River***,** DRAFT Report Presented to the UNESCO: ISI, November 2005 (referencing more than 100 studies published between 1979 and 2005).

constructed by the Corps to reduce navigation dredging costs on the Mississippi River have increased flood levels by 10 to 15 feet and more in some locations during large floods. The flood height increases caused by these structures far exceed the flood height increases caused by levees and land use changes.[29] As noted in Section A, the scientific support for the flood height inducing effect of river training structures is so strong that the Dutch are expending a significant amount of resources to modify hundreds of river training structures to reduce flood risks.[30]

3. Significant changes in rainfall, streamflow, and climate patterns

Since the EISs were completed there have been documented changes in rainfall, streamflow, and climate within the Mississippi River basin. This new information must be fully evaluated and taken into account to develop less damaging approaches to the O&M activities.

For example, in March 2005, the U.S. Geological Survey released a study showing upward trends in rainfall and streamflow for the Mississippi River.[31] In 2009, the U.S. Global Change Research Program issued a report showing that the Midwest experienced a 31% increase in very heavy precipitation events (defined as the heaviest 1% of all daily events) between 1958 and 2007.[32] That study also reports that during the past 50 years, "the greatest increases in heavy precipitation occurred in the Northeast and the Midwest."[33] Models predict that heavy downfalls will continue to increase:

> Climate models project continued increases in the heaviest downpours during this century, while the lightest precipitation is projected to decrease. Heavy downpours that are now 1-in-20-year occurrences are projected to occur about every 4 to 15 years by the end of this century, depending on location, and the intensity of heavy downpours is also expected to increase. The 1-in-20-year heavy downpour is expected to be between 10 and 25 percent heavier by the end of the century than it is now. . . . Changes in these kinds of extreme weather and climate events are among the most serious challenges to our nation in coping with a changing climate.[34]

4. Significant changes in applicable law and policy

Since the EISs were completed there have been significant changes to the laws and policies applicable to the Corps' O&M practices. These new laws and policies must be fully evaluated and strictly complied with to develop less damaging approaches to the O&M activities. For example:

(a) New Executive Orders: Executive Orders issued in 1977 direct agencies to protect wetlands and floodplains. Executive Order 11990 (Protection of Wetlands) directs each federal agency to provide leadership and take action to minimize the destruction, loss or degradation of wetlands, and to preserve and enhance the natural and beneficial values in carrying out agency policy. Executive Order 11988 (Floodplain Management) directs each federal agency to avoid, to the extent possible, the long and short-term adverse impacts associated with the occupancy and

[29] See studies cited in attachment A; GAO Study on River Training Structures.
[30] GAO Study on River Training Structures at 41.
[31] USGS Fact Sheet 2005-3020, Trends in the Water Budget of the Mississippi River Basin, 1949-1997.
[32] *Id*. at 32.
[33] *Id*.
[34] *Id*.

modification of floodplains; to avoid direct and indirect support of floodplain development wherever there is a practicable alternative; and "to restore and preserve the natural and beneficial values served by flood plains in carrying out its responsibilities."

(b) NEPA Implementing Regulations: In 1978, the Council on Environmental Quality promulgated regulations for implementing NEPA. The Corps' own regulations implementing NEPA were promulgated in 1988.

(c) Clean Water Act Regulations: In 1980, the Clean Water Act's Section 404(b)(1) guidelines were promulgated. These guidelines must be followed for the Corps' civil works activities. In 1990 the Corps and EPA signed a Memorandum of Agreement on mitigation that establishes priorities and procedures to be used in implementing mitigation under the Clean Water Act § 404. In 2008, the Corps and EPA issued new mitigation requirements applicable to the Clean Water Act § 404 program. Corps civil works projects are subject to these new mitigation requirements (and to the mitigation requirements established by the Water Resources Development Act of 2007, discussed below). 33 U.S.C. § 2283(d). These mitigation requirements must be satisfied for both new projects and existing projects that are reevaluated under NEPA. *Id*.

(d) Water Resources Development Acts: The Water Resources Development Act (WRDA) of 1986 authorizes the Corps to modify existing water resources projects and operations to improve the quality of the environment. WRDA 1990 changed the Corps' fundamental mission to "include environmental protection as one of the primary missions of the Corps of Engineers in planning, designing, constructing, operating, and maintaining water resources projects." 33 U.S.C. § 2316. WRDA 2007 created a new federal water policy that requires all Corps projects to protect and restore the environment and imposes new and important mitigation requirements for Corps projects, including existing projects that are re-evaluated through an EIS or supplemental EIS. 33 U.S.C. § 2283(d).

D. Substantial Changes to O&M Activities that are Relevant to Environmental Concerns Require Preparation of a Supplemental EIS

The Corps must prepare a supplemental EIS because it has made substantial changes to the O&M activities evaluated in the existing EISs that are relevant to environmental concerns. 40 C.F.R. § 1502.9(c)(1). As discussed in section C above, the Corps also must prepare a supplemental EIS because significant new circumstances have arisen and significant new information has become available that bear on the environmental impacts of O&M activities.

For example, the Corps is constructing new types of river training structures that could not have been – and were not – evaluated in the original EISs. For example, while the EISs prepared in the 1970s provide a cursory review of the impacts of wing dikes, those EISs did not evaluate bendway weirs and chevrons as those types of river training structures had not yet been developed. The first bendway weirs were constructed in the Mississippi River in 1990 and the first blunt nose chevrons were constructed in the Mississippi River in 1993. Scientific evidence shows that these types of structures raise flood heights significantly higher than the older wing dikes.

The use of river training structure has also increased significantly over time, and the cumulative impact of the large number of structures has ever been evaluated. Independent scientists who have studied the effects of river training structures report that as of 2001, the Corps had constructed 1.5 miles of river training structures for each mile of the Middle Mississippi River (river miles 180 to 37). At least 380 river training structures were constructed in this portion of the river between 1980 and 2009. More than 40,000 feet of "wing dikes" and "bendway weirs" were constructed in the Mississippi during the 3 years prior to the great flood of 1993 contributing to record crests in 1993, 1995, 2008, and again in 2011.

The Government Accountability Office reports that Corps documents show more than 1,375 wing dikes, bendway weirs, chevrons, and similar structures in the 195 miles that constitute the Middle Mississippi River. The Corps constructed at least 150 of the bendway weirs between 1990 and 2000, and constructed 23 chevrons in this portion of the river between 2003 and 2010.[35]

In December 2011, the Government Accountability Office informed Congress that the Corps has not complied with the requirements of either NEPA or the Clean Water Act in constructing river training structures to help operate and maintain the UMR-IWW system.[36] Instead, the Corps has continued to rely on a 1976 environmental impact statement despite the fact that the river and the Corps' design of river training structures has changed significantly since that time.[37]

The National Wildlife Federation also understands that the Corps is dredging the Mississippi River channel to at least 11.5 feet rather than the authorized depth of 9-feet. However, the Corps has not evaluated the environmental impacts of dredging the channel 2.5 feet deeper than the authorized depth. The Corps must analyze the environmental impacts of the actual dredging that it is conducting.

E. Conclusion

For the reasons discussed above, the National Wildlife Federation urges the Corps to conduct a comprehensive reassessment of its O&M activities on the Upper Mississippi River – Illinois Waterway Navigation System. This reassessment should be carried out through preparation of a comprehensive supplemental environmental impact statement, and a general reevaluation of the Corps' operations and maintenance (O&M) planning studies to ensure that future O&M activities comply with current law, planning criteria and policies.

To ensure that the reassessment produces recommendations for O&M activities that will provide the highest possible protection to the public, the National Wildlife Federation also urges you to initiate a National Academy of Sciences study on the effect of river training structures on flood heights to inform the reassessment, and to impose a moratorium on the construction of new river training structures pending completion of the reassessment process.

The National Wildlife Federation looks forward to working with your office and with the Corps to ensure a comprehensive reassessment of O&M activities for the UMR-IWW Navigation System and to

[35] GAO Study on River Training Structures at 9-10.
[36] *Id*. at 26-27.
[37] *Id*.

implement changes to those activities that will protect and restore the environment and protect the public from unintended increases in flood risks.

Sincerely,

Melissa Samet
Senior Water Resources Counsel

Attachment

Attachment A

February 16, 2012 National Wildlife Federation Letter to the Honorable Jo-Ellen Darcy

Studies Linking the Construction of Instream Structures to Increases in Flood Levels

1. Pinter, N., A.A. Jemberie, J.W.F. Remo, R.A. Heine, and B.A. Ickes, 2010. Empirical modeling of hydrologic response to river engineering, Mississippi and Lower Missouri Rivers. River Research and Applications, 26: 546-571.

2. Paz, A.R., J.M. Bravo, D. Allasia, W. Collischonn, and C.E.M. Tucci, 2010. Large-scale hydrodynamic modeling of a complex river network and floodplains. Journal of Hydrologic Engineering, 15: 152-165.

3. Pinter, N., 2010. Historical discharge measurements on the Middle Mississippi River, USA: No basis for "changing history." Hydrological Processes, 24: 1088-1093.

4. Theiling, C.H., and J.M. Nestler, 2010. River stage response to alteration of Upper Mississippi River channels, floodplains, and watersheds. Hydrobiologia, 640: 17-47.

5. Remo, J.W.F., N. Pinter, and R.A. Heine, 2009. The use of retro- and scenario- modeling to assess effects of 100+ years river engineering and land cover change on Middle and Lower Mississippi River flood stages. Journal of Hydrology, 376: 403–416.

6. Azinfar, H., and J.A. Kells, 2009. Flow resistance due to a single spur dike in an open channel. Journal of Hydraulic Research, 47: 755-763.

7. Doyle, M.W., D.G. Havlick, 2009. Infrastructure and the Environment. Annual Review of Environment and Resources, 34: 349-373.

8. Pinter, N., 2009. Non-stationary flood occurrence on the Upper Mississippi-Lower Missouri River system: Review and current status. In R. E. Criss and Timothy M. Kusky (Eds.), Finding the Balance between Floods, Flood Protection, and River Navigation, pp. 34-40. Saint Louis University, Center for Environmental Sciences.

9. Criss, R.E., and W.E. Vinston, 2008. Public Safety and Faulty Flood Statistics. Environmental Health Perspectives, 116: A516.

10. Pinter, N., A.A. Jemberie, J.W.F. Remo, R.A. Heine, and B.S. Ickes, 2008. Flood trends and river engineering on the Mississippi River system, Geophysical Research Letters, 35, L23404, doi:10.1029/2008GL035987.

11. Jemberie, A.A., N. Pinter, and J.W.F. Remo, 2008. Hydrologic history of the Mississippi and Lower Missouri Rivers based upon a refined specific-gage approach. Hydrologic Processes, 22: 7736-4447, doi:10.1002/hyp.7046.

12. Szilagyi, J., N. Pinter, and R. Venczel, 2008. Application of a routing model for detecting channel flow changes with minimal data. Journal of Hydrologic Engineering, 13: 521-526.

13. Remo, J.W.F., N. Pinter, B. Ickes, and R. Heine, 2008. New databases reveal 200 years of change on the Mississippi River System. Eos, 89(14): 134-135.

14. Azinfar, H., and J.A. Kells, 2007. Backwater effect due to a single spur dike. Canadian Journal of Civil Engineering, 34: 107-115.

15. Remo, J.W.F, and Pinter, N., 2007. The use of spatial systems, historic remote sensing and retro-modeling to assess man-made changes to the Mississippi River System. In: Zaho, P. et al. (eds.), Proceedings of International Association of Mathematical Geology 2007: Geomathematics and GIS Analysis of Resources, Environment and Hazards. State Key Laboratory of Geological Processes and Mineral Resources, Beijing, China, pp. 286-288.

16. O' Donnell, K.T. Galat D.L., 2007. River Enhancement in the Upper Mississippi River Basin: Approaches Based on River Uses, Alterations, and Management Agencies. Restoration Ecology, 15, 538-549.

17. Sondergaard, M., and E. Jeppesen, 2007. Anthropogenic impacts on lake and stream ecosystems, and approaches to restoration. Journal of Applied Ecology, 44: 1089-1094.

18. Remo, J.W.F., and N. Pinter, 2007. Retro-modeling of the Middle Mississippi River. Journal of Hydrology. doi: 10.1016/j.hydrol.2007.02.008.

19. Azinfar, H., J.A. Kells, 2007. Backwater prediction due to the blockage caused by a single, submerged spur dike in an open channel. Journal of Hydraulic Engineering, 134: 1153-1157.

20. Maynord, S.T. 2006. Evaluation of the Micromodel: An Extremely Small-Scale Movable Bed Model. Journal of Hydraulic Engineering 132, 343-353.

21. Pinter, N., B.S. Ickes, J.H. Wlosinski, and R.R. van der Ploeg, 2006. Trends in flood stages: Contrasting trends in flooding on the Mississippi and Rhine river systems. Journal of Hydrology, 331: 554-566.

22. Ehlmann, B.L., and R.E. Criss, 2006. Enhanced stage and stage variability on the lower Missouri River benchmarked by Lewis and Clark. Geology, 34: 977-980.

23. Pinter, N., R.R. van der Ploeg, P. Schweigert, and G. Hoefer, 2006. Flood Magnification on the River Rhine. Hydrological Processes, 20: 147-164.

24. Huang, S.L., Ng C. 2006. Hydraulics of a submerged weir and applicability in navigational channels: Basin flow structures. International Journal for Numerical Methods in Engineering 69, 2264-2278.

25. Pinter, N., 2005. Policy Forum: One step forward, two steps back on U.S. floodplains. Science, 308: 207-208.

26. Jai, Y., Scott S., Xu, Y., Huang, S. and Wang, S.S.Y. 2005. Three-dimensional numerical simulation and analysis of flow around submerged weir in a channel bendway. Journal of Hydraulic Engineering. 131, 682-693.

27. Van Ogtrop, F.F., A.Y. Hoekstra, and F. van der Meulen, 2005. Flood management in the Lower Incomati River Basin, Mozambique: Two alternatives. Journal of the American Water Resources Association, 41: 607-619.

28. Pinter, N., and R.A. Heine, 2005. Hydrodynamic and morphodynamic response to river engineering documented by fixed-discharge analysis, Lower Missouri River, USA. Journal of Hydrology, 302: 70-91.

29. Ettema, R., Muste, M. 2004 Scale effects in flume experiments on flow around a spur dike in a flat bed channel. Journal of Hydraulic Engineering. 130 (7), 635-646.

30. Pinter, N., K. Miller, J.H. Wlosinski, and R.R. van der Ploeg, 2004. Recurrent shoaling and dredging on the Middle and Upper Mississippi River, USA. Journal of Hydrology, 290: 275-296.

31. Wasklewicz T.A., J. Grubaugh, and S. Franklin, 2004. 20th century stage trends along the Mississippi River. Physical Geography, 25: 208-224.

32. Pinter, N., and R. Thomas, 2003. Engineering modifications and changes in flood behavior of the Middle Mississippi River. In R. Criss and D. Wilson, (eds.), At The Confluence: Rivers, Floods, and Water Quality in the St. Louis Region, pp. 96-114.

33. Bowen, Z.H., Bovee, K.D., Waddle, T.J. 2003. Effects of Regulation on Shallow-Water Habitat Dynamics and Floodplain Connectivity. Transactions of the American Fisheries Society 132, 809-823.

34. Pinter, N., R. Thomas, and J.H. Wlosinski, 2002. *Reply* to U.S. Army Corps of Engineers *Comment* on "Assessing flood hazard on dynamic rivers." Eos: Transactions of the American Geophysical Union, 83(36): 397-398.

35. Clifford, N.J., Soar, P.J., Gurnell, A.M., Petts, G.E., 2002. Numerical flow modeling for eco-hydraulic and river rehabilitation applications: a case study of the River Cole, Birmingham, U.K.. In River Flow 2002, Bousmar D, Zech Y (eds). Swets & Zeitlinger/Balkema: Lisse; 1195-1204.

36. Pinter, N., J.H. Wlosinski, and R. Heine, 2002. The case for utilization of stage data in flood-frequency analysis: Preliminary results from the Middle Mississippi and Lower Missouri River. Hydrologic Science and Technology Journal, 18(1-4): 173-185.

37. Roberge, M., 2002. Human modification of the geomorphically unstable Salt River in metropolitan Phoenix. Professional Geographer, 54: 175-189.

38. Pinter, N., R. Thomas, and J.H. Wlosinski, 2001. Flood-hazard assessment on dynamic rivers. Eos: Transactions of the American Geophysical Union, 82(31): 333-339.

39. Criss, R. E., & Shock, E. L. (2001). Flood enhancement through flood control. Geology , 29 (10), 875-878.

40. Pinter, N., R. Thomas, and N.S. Philippi, 2001. Side-stepping environmental conflicts: The role of natural-hazards assessment, planning, and mitigation. E. Petzold-Bradley, A.

Carius, and A. Vincze (eds.), Responding to Environmental Conflicts: Implications for Theory and Practice, p. 113-132. Dordrecht: Kluwer Academic Publishers.

41. Pinter, N., R. Thomas, and J.H. Wlosinski, 2000. Regional impacts of levee construction and channelization, Middle Mississippi River, USA. In J. Marsalek, W.E. Watt, E. Zeman, and F. Sieker (eds.), Flood Issues in Contemporary Water Management, p. 351-361. Dordrecht: Kluwer Academic Publishers.

42. Smith, L. M., and Winkley, B.R. 1996. The response of Lower Mississippi River to river engineering . Engineering Geology. 45, 433-455.

43. Struiksma, N. Klaasen, G.J., 1987. On scale effects in moveable river models. Communication No. 381, Delft Hydralics Laboratory, Delft, The Netherlands.

44. Chen Y.H., and Simmons D.B., 1986. Hydrology, hydraulics, and geomorphology of the Upper Mississippi River system. Hydrobiologia 136, 5-20.

45. Belt, C.B. 1975. The 1973 flood and man's constriction of the Mississippi River. Science, 189: 681-684.

46. Stevens, M. A., Simons, D. B., & Schumm, S. A. (1975). Man-induced changes of Middle Mississippi River. Journal of the Waterways Harbors and Coastal Engineering Division , 119-133.

47. Maher, T.F. 1964. Study of regulation works on stream flow. Paper presented at ASCE Meeting, Cincinnati, Ohio, February, 1-24.

Attachment B
Comments of the National Wildlife Federation

Evaluation of the Micromodel: An Extremely Small-Scale Movable Bed Model

Stephen T. Maynord, A.M.ASCE[1]

Abstract: The micromodel is an extremely small physical river model having a movable bed, varying discharge, and numerous innovations to achieve quick answers to river engineering problems. In addition to its size being as small as 4 cm in channel width, the vertical scale distortion up to 20, Froude number exaggeration up to 3.7, and no correspondence of stage in model and prototype, place the micromodel in a category by itself. The writer was assigned to evaluate the micromodel's capabilities and limitations to ensure proper application. A portion of this evaluation documents the deviation of the micromodel from similarity considerations used in previous movable bed models. The primary basis for this evaluation is the comparison of the micromodel to the prototype. The writer looked for comparisons that had (1) a reasonable calibration of the micromodel and (2) about the same river engineering structures constructed in the prototype that were tested in the micromodel and (3) a prediction by the micromodel of the approximate trends in the prototype. Evaluation of these comparisons shows a lack of predictive capability by the micromodel. Differences in micromodel and prototype likely result from uncertainty in prototype data and the large relaxations in similitude. Based on the lack of predictive evidence, the micromodel should be limited to demonstration, education, and communication for which it has been useful and should be of value to the profession.

DOI: 10.1061/(ASCE)0733-9429(2006)132:4(343)

CE Database subject headings: Scale models; Channel flow; Sediment; River beds; Water discharge.

Introduction

The micromodel is an extremely small physical river model having a movable bed and varying discharge. It was developed in 1994 by the St. Louis District (Davinroy 1994) of the U.S. Army Corps of Engineers (USACE). Horizontal scales of up to 1:20,000 result in micromodel channel widths as small as 4 cm. Previous Mississippi River micromodels typically reproduced about 20 km of the river on the standard 1.9-m-long micromodel table. The micromodel has been used to predict the bathymetry and flow pattern trends for proposed river training structures for purposes of navigation and environmental effects. To date, over 20 reports have been published detailing micromodel studies. The writer was assigned to a USACE team in 1999 to evaluate the capabilities and limitations of the micromodel. The two other members of the evaluation team were developers and present users of the micromodel. The team could not reach a consensus on the capabilities of the micromodel and the USACE had the USACE Committee on Channel Stabilization (CCS) provide an evaluation of the micromodel based on a meeting with the team members. The CCS (USACE 2004) report concluded that the micromodel is not a detailed design tool but that the micromodel can be used for screening alternatives except for study types where human life or the overall project are at risk. For such critical study types, the CCS concluded micromodel use should be "limited." The CCS report states that "During the discussions, it became apparent to some that there is a considerable gap between the pure academic/scientific views of the micromodel technology and the practical use of the micromodel as a tool in an overall river engineering process which has been used on large rivers in MVD (Mississippi Valley Division of the USACE)." The inability to resolve the issue of whether to evaluate the river engineering process that uses a micromodel, or only the micromodel, was a major impediment to the evaluation. The proper evaluation parameter for the river engineering process is whether the project was a success. The proper evaluation parameter for the micromodel is comparison of bathymetric and flow features to the prototype. This writer is evaluating one component of the river engineering process, the micromodel, and whether it can approximately predict the bathymetric and flow features of a large river like the Mississippi.

Some observers of micromodel technology have been critical of its use. Falvey (1999) stated "*Civil Engineering* and the St. Louis District are doing the profession a disservice by implying that a micro-model is a tool that can be used for serious engineering investigations." Yalin, an expert in movable bed modeling, was able to observe and discuss the micromodel with the evaluation team. Yalin stated in a letter to this writer, "I regret that such a 'model' cannot be used for predictive purposes." Both criticisms were almost certainly the result of the micromodel's small size and lack of adherence to similarity principles used in movable bed modeling. From early in the team evaluation, this writer felt that if the size and similarity issues were significant, their effects would be seen in attempts to use the micromodel to predict response in the river. For that reason, this writer spent a large portion of the multiyear study evaluating micromodel-prototype comparisons, particularly predictions.

The objective of this paper is to present results of an evaluation funded by the USACE Research and Development Program

[1]Research Hydraulic Engineer, U.S. Army Corps of Engineers, Engineering Research and Development Center, Coastal and Hydraulics Laboratory, 3909 Halls Ferry Rd., Vicksburg, MS 39180.

Note. Discussion open until September 1, 2006. Separate discussions must be submitted for individual papers. To extend the closing date by one month, a written request must be filed with the ASCE Managing Editor. The manuscript for this paper was submitted for review and possible publication on October 18, 2004; approved on February 3, 2005. This paper is part of the ***Journal of Hydraulic Engineering***, Vol. 132, No. 4, April 1, 2006. ©ASCE, ISSN 0733-9429/2006/4-343–353/$25.00.

to determine the capabilities and limitations of the micromodel. Specific focus is directed at critical study types where human life or the overall project is at risk if the model is not correct.

Movable Bed Modeling

Yalin (1971) states that a model can be scientifically valid only if measured quantities in the model are related to their counterparts in the prototype by scale ratios that satisfy the criteria of similarity. Ettema (2001) presents the dimensionless parameters associated with flow of water and sediment in channels with a bed of cohesionless particles including movable bed models (MBMs) as

$$\Pi_A = f_A\left[D\left(\frac{g(\rho_s-\rho)}{\rho\nu^2}\right)^{1/3}, \frac{\rho Ri}{D(\rho_s-\rho)}, \frac{\rho_s}{\rho}, \frac{D}{R}, \frac{B}{R}, \frac{\sigma}{\rho g i R^2}\right] \quad (1)$$

where the dependent variable A in Π_A might be flow resistance, thalweg sinuosity, sediment transport, or some other variable in alluvial channels; D=particle size; g=gravity; ρ_s=particle density; ρ=water density; ν=kinematic viscosity of water; R=hydraulic radius; i=slope; B=channel width; and σ=surface tension. Scale distortions arise when the dimensionless parameters on the right side of the equation are not the same in model and prototype. However, some of the dimensionless ratios, under certain conditions, do not cause significant effects when model and prototype values differ. For example, in a model of sufficient size, the last parameter on the right side of Eq. (1) will not be the same in model and prototype but the effects of differences in surface tension in model and prototype will be negligible. It remains to be determined if the surface tension term can be neglected in a micromodel. The first term on the right hand side is a particle density term which shows that if a lightweight bed material is used, the particle size in the model will be larger than in the prototype. The second term is the Shields parameter that is present in almost all movable bed model criteria and defines the amount of movement of sediment. The third term (ρ_s/ρ) is often ignored because density effects are addressed in the first and second terms of the right side of the equation. The fourth term on the right hand side, D/R, is the relative roughness that is rarely equal in model and prototype of sand bed streams and is often assumed to have negligible effects on model results. However, Ettema et al. (1998) have shown significant scale effects of D/R on bridge pier scour. The fifth term on the right side is the aspect ratio that is another term that can rarely be maintained the same in MBM and prototype of sand bed rivers.

Three techniques have been used in MBM (and are used in the micromodel) to increase model Reynolds number and sediment mobility in the model and, in some MBMs, to achieve equal Shields parameter in model and prototype. In the Shields parameter, the water density ρ is fixed, prototype sediment density ρ_s is relatively constant, and the model particle size D cannot be scaled down due to particle cohesion problems and will be roughly the same in model and prototype when dealing with sand bed alluvial streams. Therefore, if the model Shields parameter is to be increased or made equal to the prototype, the only parameters that can be varied in the model are ρ_s, R, and i. Adjustment of these three parameters has led to three techniques often used jointly in MBMs as follows.

1. *Lightweight sediment*. Minimum specific gravity of MBM sediment has been about 1.05 but sediment this light has to be carefully handled and model flooding and startup are difficult. Walnut shells having a specific gravity of 1.3 have been used. Coal having a specific gravity of 1.3 is common. A wide range of plastics are available. ASCE (2000) describes some of the various sediment types used in MBM.
2. *Vertical scale distortion*. Vertical scale distortion is the second technique used to achieve correct sediment movement. Vertical scale distortion results in attempting to model a prototype channel with a model that has an aspect ratio (width/depth) that is less than the prototype. Jaeggi (1986) concludes that morphological processes are highly dependent on the aspect ratio and that a distorted model should be avoided. Glazik (1984) stated that distortion should be avoided in movable bed river models but that a value of 1.5 (ratio of model horizontal scale to vertical scale) provided adequate results. Suga (1973) reports that distortions used in his laboratory's MBM studies were 5 or less and concludes that distortion should not be used when scour depth and location are the main subjects. Foster (1975) presented cross section plots of velocity from a model with a distortion of 3 and an undistorted model of the St. Lawrence River. Foster concluded "The velocities in the distorted model shifted several hundred feet (prototype) toward the outside of the bend from those in the undistorted model." Channel width in this reach was 360–460 m (1,200–1,500 ft). Zimmerman and Kennedy (1978) conducted research on curved channels to determine the transverse bed slope in bends and concluded distorted models can be used if distortion is limited to no more than 2 or 3. ASCE (2000) suggests a limit of 6. While these previous studies consider distortion to be a necessary evil and have recommended limitations, application of regime theory to MBM requires distortion.
3. *Increased model slope*. Increased model slope is the third technique used to achieve correct sediment movement. This leads to a Froude number in the model that is greater than that of the prototype, which then raises concerns about the ability of the model to reproduce flow patterns. Einstein and Chien (1955) allow some exaggeration of model Froude number but do not recommend a limit. In an example presented by Gujar (1981), a Froude number exaggeration of $\mathsf{F}_m/\mathsf{F}_p$=2.5 was classified as large whereas 1.67 was classified as acceptable. Latteux (1986) reported that a Froude number exaggeration of 2.5 was unsatisfactory but 2.2 provided acceptable results. Vollmers (1986) used Froude number exaggeration of 1.4 in the MBM of the Elbe estuary, which had a vertical scale distortion of 8. Froude number exaggeration is based on the concept that the Froude number has limited significance for low values typical of alluvial streams. A problem arises when the Froude number is exaggerated to the point where it is no longer insignificant in the model.

Calibration versus Validation and Base Test

The terms calibration and validation must be defined as used herein. Based on ASCE (2000), "Model calibration is the tuning of the model to reproduce a single known event. Tuning the model to reproduce the prototype behavior in this event does not ensure that the model will reproduce different or future events. However, if the model cannot reproduce a known event, little confidence can be maintained that the model will reproduce future events." Vernon-Harcourt [in Freeman (1929)] used the validation concept in which he calibrated his model until it reproduced a known prototype condition. He then tested the model against a different set of prototype boundary conditions (validation) to see if it could reproduce these known changes. If satisfactory in the validation, Vernon-Harcourt then declared the model ready for prediction. The same validation concept is used herein to evaluate predictive/screening capability of the micromodel.

The micromodel uses the concept of a base test in which the calibrated model is run with a hydrograph and the resulting bathymetry and flow patterns are referred to as the base test. All plans/project alternatives are run with the same base test hydrograph and all plan results are compared to the base test results. Changes from base test results to plan results are assumed indicative of what changes will occur in the prototype. The use of a base test may reduce the required accuracy of the model somewhat but there should be some resemblance of model predictions to what occurs in the prototype.

Types of Physical Movable Bed Models

Graf (1971) categorizes MBMs as rational models that are semi-quantitative and empirical models that are qualitative. The Graf categories generally correspond to the degree to which the Eq. (1) parameters are equal in model and prototype.

Rational Movable Bed Models

Graf (1971) credits Einstein and Chien (1955) with development of the rational method of MBMs. Yalin (1965) and de Vries and van der Zwaard (1975) also developed methods that fall under Graf's category of a rational MBM. The rational method is simply a more rigorous adherence to the similarity criteria in Eq. (1) and generally requires large models to apply the method. Rational models are characterized by low vertical scale distortion, low Froude number exaggeration, and equality of Shields parameters in model and prototype.

Empirical Movable Bed Models

Graf's second category, empirical MBMs, places less reliance on similarity requirements and allows greater relaxation of the Eq. (1) parameters. Warnock (1949) states, "Instead of arranging the various hydraulic forces involved to meet definite requirements laid down in any law of similitude, the successful prosecution of a movable-bed model study requires that the combined action of the hydraulic forces bring about similitude with respect to the all-important phenomenon of bed movement, which is the essence of this type of model study." Although less rigorous than the rational MBM, most empirical models attempt to limit vertical scale distortion and Froude number exaggeration. Empirical MBMs have a Shields parameter that is generally less than the prototype that is required in order to limit model size, vertical scale distortion, and Froude number exaggeration. Empirical MBMs previously used at the Engineering Research and Development Center (ERDC, formerly Waterways Experiment Station) employed coal as the model bed material and had a model Shields parameter of less than 0.1, whereas the prototypes being studied had Shields parameters in excess of 1. Glazik and Schinke (1986) describe MBM experience using a model Shields parameter significantly less than the prototype. Due to the importance of the equality of the Shields parameter in the model and prototype, empirical models are generally limited to assessing bathymetric response.

Other Movable Bed Models

Some MBMs do not fit into the two categories delineated by Graf (1971). Freeman (1929) discusses early studies by Reynolds and Vernon-Harcourt, which were similar to the empirical model but used Froude scale velocities and simulated water levels in models with large vertical scale distortions. Reynolds conducted a study of the Mersey estuary in England in a model with a vertical distortion of 27.

Pertinent Features of the Micromodel

Micromodel Description and Operation

Gaines and Maynord (2001) provide details of the design and operation of the micromodel and only a brief summary is presented herein. Past micromodel studies have selected horizontal scales so that the modeled reach will fit on a standard 0.9-m-wide by 1.9-m-long flume table that is equipped with a recirculating pump, sump, and regulating valves. Sediment is recirculated in the micromodel. Horizontal scales range up to 1:20,000 and minimum model channel widths of 4 cm are employed in the main channel and lesser model widths in side channels or tributaries. The model banks are cut vertically and the channel is filled with granular plastic that ranges in size from 0.25 to 1.2 mm and has a specific gravity of 1.48. Some recent experiments have explored using lower density model sediment. The downstream end of the channel has a fixed free overfall. Islands are simulated with solid boundaries and vertical banks in the model. After having problems of exaggerated scour with solid river training structures typically found in MBMs, river training structures in the micromodel such as dikes or bendway weirs are represented by pervious steel mesh having 3×3 mm^2 openings. A typical micromodel is shown in Fig. 1.

In the calibration process, the micromodel bed is not premolded to a specific bed condition as done in other types of MBMs. Calibration of the model begins with selection of the high and low flow used to simulate the effects of the variable hydrograph in the prototype. High flow is based on a visual assessment of both the amount of sediment movement and the energy level in the model. Low flow is based on the model producing a slight amount of sediment movement. Model hydrograph cycle times have ranged from 1.8 to 6 min with 3 to 5 min being typical. To assess whether the model is calibrated, the model is run for numerous hydrograph cycles until the bed reaches equilibrium. The model is surveyed using an innovative laser profiler and the model bathymetry is compared to the trends of available prototype surveys. If the trends are replicated in the model, the model is declared calibrated and ready for screening alternatives. If the trends are not replicated in the model, adjustments are made to one or more of the following: (1) flume table slope; (2) amount of sediment in the model; (3) size, shape, and elevation of the fixed free overfall at the downstream end; (4) inflow baffling; (5) discharge hydrograph; and (6) vertical scale and datum. Various vertical scales and vertical datum are used to convert model bathymetry to corresponding prototype numbers throughout the calibration process to achieve the best agreement of model and prototype bathymetry.

Micromodel Contrasted with Previous Movable Bed Models

Of the two Graf (1971) categories, the micromodel is closest to the empirical MBM category. While similarity laws are not fol-

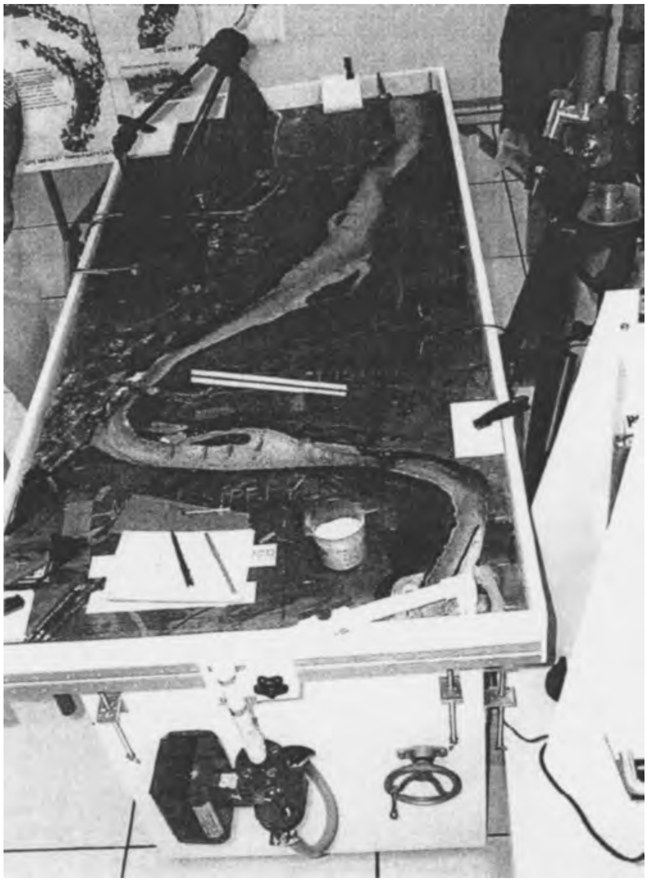


Fig. 1. Micromodel of Vicksburg Front, Mississippi River. Micromodel scale = 1 : 14,400 horizontal, 1:1,200 vertical.

lowed closely in empirical MBMs, there are definite differences between the micromodel and most previous empirical models as follows.

1. Small size. The micromodel is one to two orders of magnitude smaller than most empirical models. Model channel widths are as low as 4 cm. Model channel depths as low as 1 cm are an order of magnitude less than the minimum of 10 cm recommended in Gujar (1981). No requirements for minimum Reynolds number are used in the micromodel. The small model depths result in large distortion of relative roughness.
2. Large vertical scale distortion. With a few exceptions, distortion ratios used in the micromodel are at least twice that in most empirical models. Micromodels commonly use distortions of 8 to 15.
3. No correspondence of stage in micromodel and prototype. Most empirical models relate stage to a corresponding stage in the prototype.
4. Low stages run in micromodel. Typical alluvial streams have dominant or channel forming discharges that are roughly at a bank-full stage. Maximum stages in the micromodel are about 2/3 of bank full.
5. Calibration of micromodel based on equilibrium bed. Previous MBMs conduct calibration by starting with a known bed configuration, running representations of the subsequent stage and discharge hydrographs, and comparing the ending bed topography in model and prototype (Franco 1978). The micromodel starts with an unmolded bed, runs a generic hydrograph for many repetitions until the bed reaches equilibrium, and compares the equilibrium bed to as many prototype hydrographic surveys as possible to see if the correct trends are reproduced.
6. The small size of the micromodel and the relatively heavy (heavy for plastic) bed material (specific gravity 1.48) results in steep slopes in the micromodel. Water-surface slopes of the few micromodels that have been measured are about 1%. Steep slopes result in significant exaggeration of the Froude number. Froude numbers in the two micromodel studies where appropriate measurements were taken, are 2.7 and 3.7 times the prototype Froude number.
7. Model sediment, when scaled to prototype dimensions using a typical vertical scale, is 0.6–1.2 m in diameter.
8. No similarity of friction in the micromodel. Even with the large exaggeration of the relative roughness, the large distortion in the micromodel results in the model being too smooth, which is typical of highly distorted models. This smoothness is possibly the reason the micromodel cannot be used to simulate high stages.
9. Micromodel uses porous dikes to solve the exaggerated scour problems around dikes that occur in distorted models.
10. Due to short duration hydrographs, no bed molding, and automated bathymetry measurement, the micromodel can evaluate an enormous number of conditions in a short period of time.

The most significant differences in the micromodel compared to empirical models are small size, large vertical scale distortion, large Froude number/slope distortion, and no correspondence of stages. These differences place the micromodel in the third category of “other” in addition to rational and empirical models. Rational models are designed and operated with similarity considerations and only small deviations are allowed. Empirical models often do not follow similarity criteria, but the manner in which they are operated results in the existence of significant but limited deviations from similarity criteria. In like manner, the operation of micromodels results in even larger departures from similarity criteria.

Proposed Uses of the Micromodel

The categorization of micromodel and other MBM capabilities can be dealt with in a variety of ways. One option is to categorize based on structure type such as bendway weirs versus traditional dikes. Another option is to categorize based on problem type such as minimization of maintenance dredging in the main navigation channel versus rehabilitation of side channels for environmental enhancement. Ettema (2001) differentiates MBMs based on the degree of freedom of lateral movement, with micromodels of a long constriction having a greater chance of success than those in which lateral movement of the thalweg is relatively unrestricted. The categorization adopted herein is based on the categorization developed in CCS (ASCE 2004) as follows.

1. Demonstration, education, and communication. This includes demonstration of river engineering concepts including the generic effects of structures placed in the river.
2. Screening tool for alternatives to reduce maintenance and dredging of the navigation channel. Failure to perform as predicted would not be damaging to the overall project or endanger human life.
3. Screening tool for alternatives of channel and navigation alignments. This category does not include navigable bridge approaches. Failure to perform as predicted would not be

damaging to the overall project or endanger human life.

4. Screening tool for environmental evaluation of river modifications, side channel modifications, notches in dikes, etc. Failure to perform as predicted would not be damaging to the overall project or endanger human life.
5. Screening tool for major navigation problems, around structures such as lock approaches, bridge approaches, confluences, etc. Failure to perform as predicted could be damaging to the overall project or endanger human life.

For category 1, the micromodel has proven to be useful and beneficial as a demonstration, education, and communication tool, and the developers have presented a valuable tool to the profession. Many of the benefits of the micromodel to the river engineering process have been a result of its value in demonstration, education, and communication. The micromodel has allowed diverse groups to reach a consensus on controversial projects. All parties in this evaluation agreed that the micromodel is effective for demonstration, education, and communication. A demonstration tool shows the generic effects of a river training structure such as traditional contracting dike causing a shoaling area to reduce or a redirection of the currents and no specific dimensions are attached to the dike characteristics or the observations from the micromodel.

Categories 2–5 require greater capability than a demonstration tool. Any conclusions about the screening capabilities of the micromodel should answer the following three questions: (1) What is a screening tool? (2) What does it take to show any model is a screening tool? (3) What facts show the micromodel is a screening tool? A screening tool is able to identify likely or unlikely solutions or rank/compare alternatives. Screening tools are used to discard some alternatives and select others for further study. Some view a screening tool as quantitative relative to model inputs like dike length, elevation, location, orientation, etc. Others view a screening tool as completely qualitative with model inputs such as dike characteristics having little or no quantitative significance. A screening tool does not always predict the correct trends but should be correct some or most of the time. A screening tool is different from a demonstration tool because it crosses the threshold between nonprediction and prediction or, stated otherwise, the threshold between telling the user information he/she might not have known. To show that any model is a screening tool requires a modest record of an approximate prediction of trends that occurred in the prototype.

The CCS concluded that screening in categories 2–4 can be based on analysis of both bathymetry and surface flow patterns but screening for category 5 can only be based on bathymetry because surface flow patterns are not considered adequate for category 5 problems. This CCS criterion is a major limitation for category 5 problems because this writer has not seen a category 5 problem that could be addressed without analysis of surface flow patterns.

Model/Prototype Comparisons

General

The previous discussion shows that the micromodel is operated with large differences from similarity principles. The remaining question is whether these differences are significant. This writer presents model-prototype comparisons to address this question of significance. Although the primary question is whether the micromodel can predict prototype response in a calibrated model, the

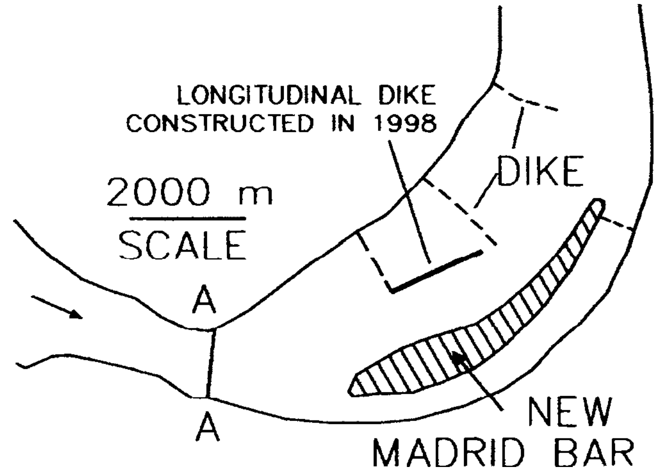


Fig. 2. Schematic of New Madrid, Mississippi River. Micromodel scale = 1 : 19,000 horizontal, 1:1,200 vertical.

ability of the micromodel to be adequately calibrated, i.e. replicate existing conditions, is the only information available in many micromodel studies. The reports from previous micromodel studies were evaluated to determine the ability of the micromodel regarding both calibration and prediction but the selected comparisons focus on projects that provide insight into the predictive capabilities of the micromodel. Some of the project comparisons were selected because those projects have been cited as evidence of micromodel success. Other micromodels achieved reasonable calibrations while some did not. These other micromodels are not discussed herein because these models did not provide information on predictive capabilities and because of page limitations in this paper.

New Madrid, Mississippi River

The New Madrid, Mississippi River micromodel study (Davinroy 1996) was conducted to develop a structural solution to repetitive maintenance dredging in the main navigation channel. The calibration has large departures in depth within the problem area compared to the prototype. Fig. 2 shows the channel schematic and the location of cross section AA about one channel width upstream of New Madrid Bar. Section AA is the location of some of the structures used in alternative tests. As shown in Fig. 3, scour reached an elevation of about 21 m below the low water reference plane (LWRP) in the prototype compared to 6 m below

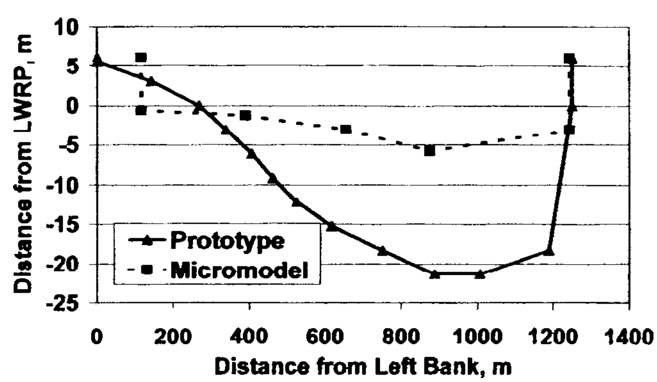


Fig. 3. Prototype and micromodel cross sections at New Madrid

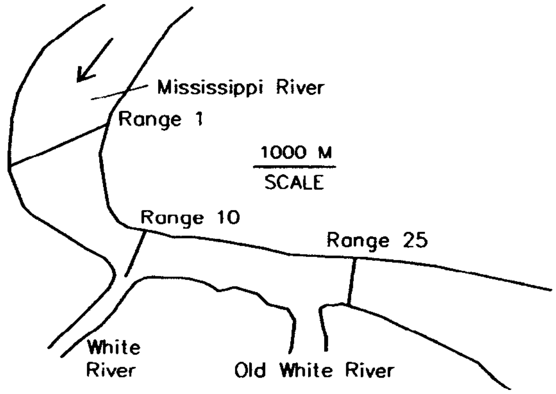


Fig. 4. Schematic of the Mouth of the White River, Mississippi River. Micromodel scale=1:12,000 horizontal, 1:1,200 vertical.

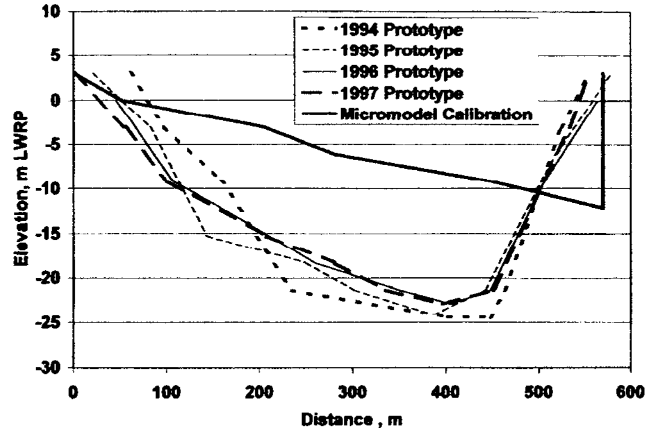


Fig. 6. Cross section at the Mouth of the White River, Range 17

the LWRP in the calibrated model. The LWRP is the stage in the Mississippi River that is exceeded about 97% of the time. The channel cross section area below LWRP=0.0 is roughly 1/3 of bank-full cross section area. The bank-full stage is about 9–10 m above the LWRP. The New Madrid study also provides information on prediction. The longitudinal dike shown in Fig. 2 was constructed in 1998. The longitudinal dike was studied in the 1996 micromodel study but was not one of the two recommended plans. The 1996 report stated that tests with a longitudinal dike indicated (1) slight channel deepening and (2) the navigation channel narrowed approximately 120 m. Subsequent prototype experience with a similar longitudinal dike in place has shown reduced dredging and an increase in the width of the navigation channel. While the project appears to be successful, the micromodel did not predict the trends of the prototype.

Mouth of the White River

The primary objective of the Mouth of the White River (MOWR) study (Gordon et al. 1998) was to evaluate design alternatives that would provide improved conditions for navigation near the MOWR (Fig. 4). The MOWR study involved navigation conditions at the confluence of two navigable rivers, the Mississippi and White Rivers. The micromodel calibration test comparison with the prototype was satisfactory upstream of the mouth, but at and downstream of the mouth, the model bathymetry differed significantly from the prototype. Fig. 5 shows the hydraulic depth (area/top width) at the LWRP along the reach. Differences in hydraulic depth in the calibration are up to 10 m at Range 19. Fig. 6 shows a cross section plot from the calibration at about Range 17 where the bed of the micromodel is up to 15 m higher than the average of 4 years of relatively consistent prototype survey data. The MOWR study is pertinent to this evaluation because (1) the micromodel procedure allows many attempts at calibration; (2) 4 years of prototype data used for calibration were relatively consistent; and (3) the best calibration was unsatisfactory. In addition to large differences in the calibration, the micromodel plan closest to the plan constructed in the prototype had top elevation of the bendway weirs at elevation −4.6 m LWRP compared to an average elevation of −7.6 m LWRP as surveyed in the prototype. The difference in calibration and in the bendway weir elevations means that the Mouth of the White River provides little information about the predictive capabilities of the micromodel.

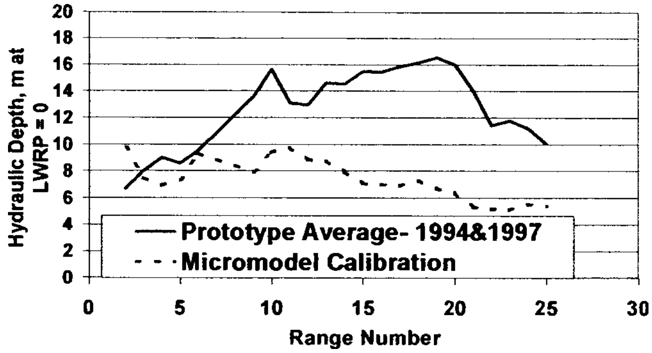


Fig. 5. Hydraulic depth at Mouth of the White River

Vicksburg Front

The Vicksburg Front comparison addresses the validity of bathymetry trends and surface currents in a calibrated micromodel and does not provide any information on prediction/validation. Maynord (2002) presents results of a comparison of surface currents in the Vicksburg Front micromodel and the prototype. Confetti streaks and particle image velocimetry (PIV) were used to determine surface velocities in the Vicksburg Front micromodel. Recording global positioning system (GPS) units used in differential mode were placed on surface floats in the bend of the Mississippi River at Vicksburg, Mississippi. The GPS floats were placed at various locations across the channel upstream of the bend at Vicksburg and retrieved at the lower end of the bend. The average stage in the river during the 4-day measurement period and the stage in the micromodel were almost identical. Fig. 7 shows a schematic of the Vicksburg bend and the location of a cross section at river mile 439.5 where velocities were compared from the GPS prototype and the PIV micromodel. Fig. 8 shows the cross section velocity plot from the micromodel and prototype. Velocities in the micromodel were converted to prototype using the square root of the vertical scale ratio that is the ratio typically applicable to distorted models. The plot shows the exaggeration of velocity that is typical of MBMs. In this case the exaggeration is large, about 3.7 times the Froude scale velocities. The plot also shows velocities in the micromodel are concentrated on the left descending bankline when compared to the prototype data. The concentration of flow on the left bank in the

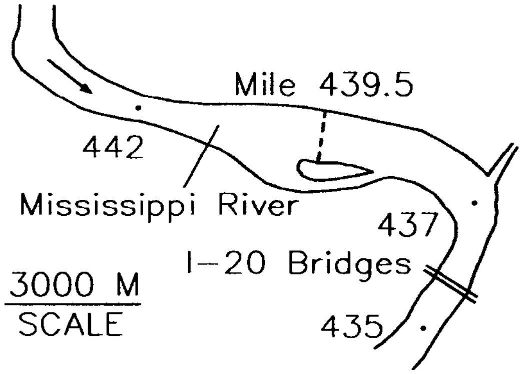


Fig. 7. Schematic of Vicksburg Front, Mississippi River. Micromodel scale=1:14,400 horizontal, 1:1,200 vertical.

micromodel is consistent with the incorrect sediment deposition in the micromodel along the right bank at river mile 437.5 that does not occur in the prototype.

Kate Aubrey

The Kate Aubrey reach of the Mississippi River has experienced shoaling problems that required repeated dredging. Two micromodels of the Kate Aubrey reach were constructed as part of the USACE micromodel evaluation to validate or test predictive capability. The Kate Aubrey models were a major component of the team evaluation. The two micromodels included a traditional size micromodel having a 1:16,000 horizontal scale and 1:900 vertical scale and a larger (2×) micromodel having a 1:8,000 horizontal scale and 1:600 vertical scale. Both micromodels were calibrated to 1975 and 1976 bathymetry. The predicted micromodel bathymetry was compared to the 1998 bathymetry (Fig. 9) and was not similar to the prototype in both the 1:8,000 (Fig. 10) and 1:16,000 (Fig. 11) micromodels. The problem area is centered at about mile 791–792. Extensive dredging was conducted in this reach in 1988 and may have contributed to some of the differences between model and prototype. However, the high flows during the mid-1990s would likely minimize the effects of dredging ten years earlier in 1988 and the dredging impacts would not show up in the 1998 bathymetry. The Kate Aubrey comparisons leads to the conclusion that a micromodel can be calibrated yet not be validated and thus, cannot be used for prediction of alternative effects.

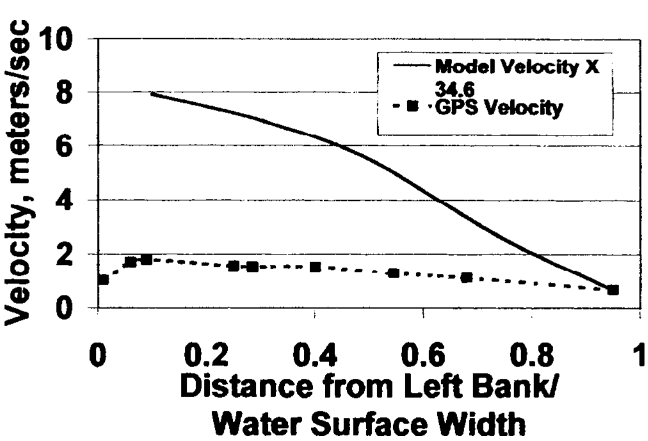


Fig. 8. Prototype GPS and micromodel velocities at Vicksburg Front

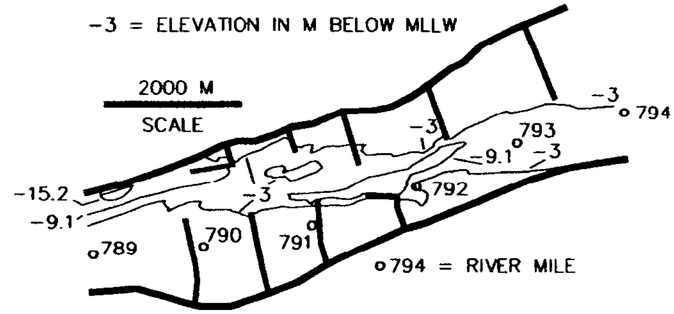


Fig. 9. Kate Aubrey, Mississippi River, 1998 prototype bathymetry. Flow from right to left.

Bolter's Bar

The Bolter's Bar micromodel study was conducted to evaluate alternatives to alleviate dredging in the main channel without adversely affecting side channels. A schematic of the reach with the dikes that were present in 1997–1998 is shown in Fig. 12. The dredging problem was primarily between river miles 225 and 226. Fig. 13 shows the plan constructed in the prototype in 2002 that includes four chevron dikes on the right side of the navigation channel between river miles 225 and 226, a longitudinal dike on the right bank at river mile 226, and raising and notching the existing closure dike. The four left bank dikes between river miles 226 and 225.4 were removed from the micromodel but remain in the prototype. Little is known about the characteristics of the left bank dikes. The micromodelers have stated they believe the left bank dikes have little impact on the bathymetry. Since the 2002 construction of the improvement plan, dredging has been reduced in the reach and survey data show an improved navigation channel through the problem dredging reach. However, the difference in model and prototype because of the left bank dikes and the limited time since construction make it difficult to evaluate this validation/prediction.

Lock and Dam 24

The Lock and Dam 24 micromodel was conducted to evaluate means of reducing outdraft. Outdraft results from the cross currents in the upstream lock approach that cause a tow to move toward the dam rather than into the lock (Fig. 14). Outdraft is a dangerous condition at many locks and dams and has resulted in numerous accidents. The guardwall in the Lock and Dam 24 micromodel was solid but the guardwall in the prototype was ported which means that it has openings at the bottom to pass flow out of

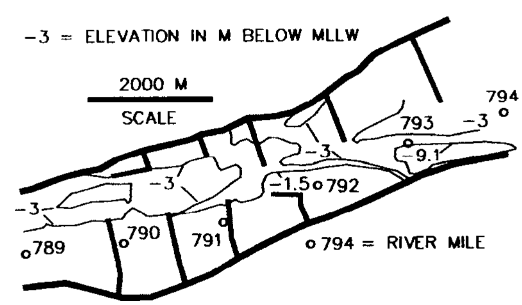


Fig. 10. Kate Aubrey, Mississippi River, 1:8,000 micromodel prediction of 1998 conditions. Flow from right to left. Upper end of model at mile 803.

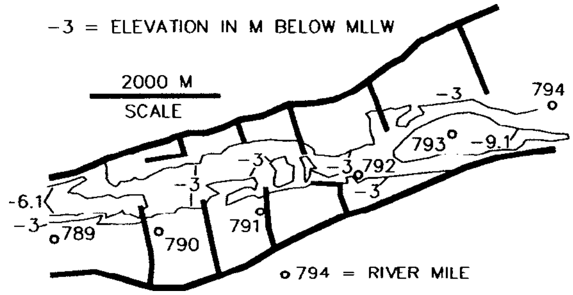


Fig. 11. Kate Aubrey, Mississippi River, 1:16,000 micromodel prediction of 1998 conditions. Flow from right to left. Upper end of model at mile 803.

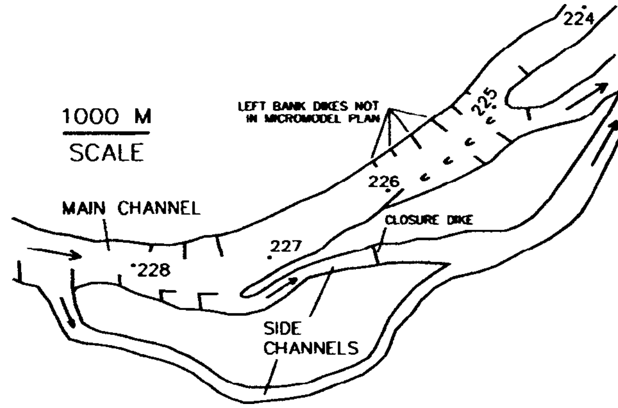


Fig. 13. Schematic of Bolter's Bar, Mississippi River, with project. Micromodel scale=1:9,600 horizontal, 1:600 vertical. Upper end of model at mile 231.5.

the lock approach. A solid guardwall was used in the micromodel to represent a worst case and because the guardwall ports often clog with debris. The currents behind the guardwall in the prediction of the micromodel did not agree with the currents measured in the prototype. The micromodel showed slackwater just upstream of the area between the upper end of the guardwall and the bank. The prototype showed significant currents in this area. This raises two possibilities. If the ports were clogged at the time of prototype measurement, the model predicted incorrect currents. If the ports were open during prototype measurement, the difference in guardwall configuration could explain all or part of the difference in flow patterns and the Lock and Dam 24 comparison provides no information about the predictive capabilities of the micromodel.

Comparison of Micromodel and ERDC Coal Bed Models

In addition to the Kate Aubrey micromodels built and studied by the evaluation team, another major portion was an evaluation of micromodels relative to coal bed models previously used at ERDC. This component of the evaluation began with the objective of using comparison of model and prototype cross section areas, channel widths, and other bathymetric parameters to determine if a MBM was calibrated rather than using the subjective/visual comparisons that have been used traditionally. Several modelers were skeptical about quantifying whether a model was calibrated.

The techniques developed for determining calibration were also used to compare the coal-bed model and the micromodel. For example, the ratio of difference in model and prototype cross section area to cross section area in the prototype was determined for each cross section. A mean squared error (MSE) measure of dispersion of the data was defined as the square of this ratio for each cross section that was averaged over the length of the model (except for entrance and exit reaches). For cross sectional area, the MSE for 16 coal bed models ranged from 0.014 to 0.33 with an overall average MSE for all models of 0.12. The MSE for area in 14 micromodels ranged from 0.024 to 0.456 with an overall average MSE for all models of 0.16. The MSE for area in the MOWR micromodel discussed previously was 0.16. An MSE of 0.16 for area means that prototype and model area differed by an average of 40% of the prototype area over the length of the model. Other bathymetric parameters used in the comparison were (1) thalweg location had overall MSE=0.11 in the coal bed and 0.05 in the micromodel; (2) width had the same overall MSE=0.06; and (3) hydraulic depth had overall MSE=0.09 in the coal bed and 0.14 in the micromodel. Because of limited prototype data, the bathymetry parameters were evaluated at an elevation of 0.0 LWRP that is a low stage. Consequently, these error measures are somewhat larger than would be the case had data been available at higher stages. An LWRP of 0.0 is significant for navigation purposes because it roughly corresponds to the width

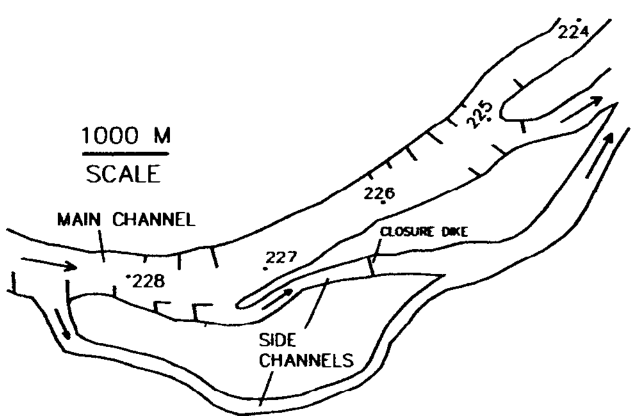


Fig. 12. Schematic of Bolter's Bar, Mississippi River, without project. Micromodel scale=1:9,600 horizontal, 1:600 vertical. Upper end of model at mile 231.5.

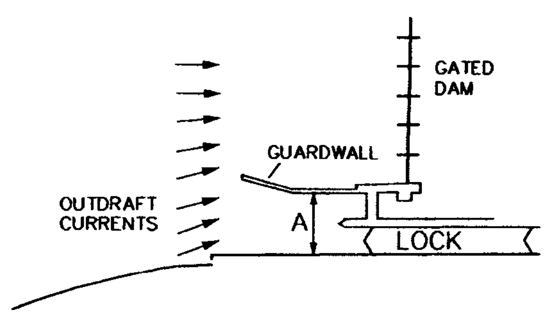


Fig. 14. Schematic of Lock 24 outdraft at upstream lock approach on Mississippi River. Micromodel scale=1:9,600 horizontal, 1:600 vertical. Dimension "A" in micromodel is about 0.8 cm versus a prototype distance of about 80 m.

of the navigable portion of the channel. With the exception of one model (Kate Aubrey), the comparison micromodels were all different projects than the comparison coal-bed models. Gaines (2002) used similar geometric techniques with only the Kate Aubrey coal-bed and micromodels and concluded that "Therefore, there is no advantage in using the larger scale models (coal-bed models) to evaluate river training structures over the small-scale models (micromodels)." This writer does not place significant weight on the comparison of coal-bed models and micromodels because of the following.

1. The comparison was based on calibration only. As stated in ASCE (2000), calibration does not ensure the model will predict. As stated previously, the micromodel is significantly different from previous empirical models like the ERDC coal-bed models and equivalency based only on calibration is not valid.
2. The adjustment of vertical scale and vertical datum in the calibration process should insure that reach averaged values will be close in micromodel and prototype. To a lesser extent, this same factor is true in the coal bed model because of other adjustments.

Basis of Unsatisfactory Calibration and Validation

Why are the previous calibrations and validations (predictions) of micromodels unsatisfactory? Some of the differences can be attributed to variability and uncertainty in the prototype bathymetry data. The large relaxations in similarity criteria must also be a primary factor. Ettema and Muste (2004) conducted scale effect fixed-bed flume experiments and found that thalweg alignment and extent of separation around spur dikes do not scale with model length scale for a range of small models. Ettema and Maynord (2002) note that in hydraulic models, the usual causes of scale effects are (1) large length scales; (2) distortion of vertical scale relative to horizontal scale; (3) inflation of bed sediment size; and (4) amplification of channel slope. All of these scale effect causes are present in the micromodel as discussed previously. In addition to these four causes, the micromodel does not have correspondence of stage in model and prototype. Since all four causes plus the stage issue are present in the micromodel and there are unknown interactions, it is not possible to state which specific causes are responsible for the differences in model and prototype shown previously. At the small dimensions of flow in the micromodel, Reynolds and Weber numbers are sufficiently different than at full scale as to influence flow behavior and distribution (Ettema 2001). Froude number exaggerations up to 3.7 and vertical scale distortion up to 20 are likely causes of poor agreement of lateral velocity distribution and thus bathymetry in the model. Struiksma and Klaasen (1987) report scale effect problems resulting from exaggerations in Froude number and from bed roughness not being reproduced. Ettema (2001) and Ettema and Muste (2002) conclude that micromodels can be useful in situations where the thalweg is constrained to only vertical movement such as in a long constriction. In cases where the thalweg can move laterally, model utility diminishes quickly.

Is the Micromodel Capable of Quantitative Inputs?

Quantitative inputs describe dikes or other river engineering structures by their length, elevation, location, etc. River engineering often uses contraction of the channel to achieve a desired navigation channel. The amount of contraction of a proposed plan and thus dike characteristics cannot be specified when the water levels and thus the channel area are not modeled. The effectiveness of a dike cannot be assumed equal in model and prototype when the model velocities are roughly 2.7 to 3.7 times higher than scaling by Froude criteria. While the porous dikes used in the micromodel have some significant advantages, they have not been shown to address the problems of incorrect water level and high velocities regarding quantitative inputs.

Conclusions and Recommended Capabilities and Limitations

The micromodel, because of its small size and large deviations from similarity considerations, is different from previous MBMs and does not fit into either of Graf's categories of empirical or rational models. In addition to its size being as small as 4 cm channel width, large vertical scale distortion, large Froude number exaggeration, and no correspondence of stage in model and prototype, place the micromodel in a category by itself.

The micromodel is effective for demonstration, education, and communication and the developers have provided a valuable tool to the profession.

The disagreement over the micromodel concerns screening capability and can best be resolved by answering the following three questions: (1) What is a screening tool? (2) What does it take to show any model is a screening tool? (3) What facts show the micromodel is a screening tool? A screening tool is able to identify likely or unlikely solutions or rank/compare alternatives. A screening tool is used for prediction in order to eliminate some alternatives and keep others for further study. To show that any model is a screening tool requires a modest record of prediction of the approximate trends that occurred in the prototype. The pertinent facts regarding screening capability in the micromodel are as follows.

1. The two Kate Aubrey models provided unsatisfactory predictions of bathymetry.
2. The New Madrid micromodel predicted narrowing of navigation channel but widening occurred in the prototype. New Madrid is one of the examples of a successful project not being a successful model-prototype comparison.
3. Bolter's Bar appears to come closest to a successful prediction but the comparison has uncertainty because the left bank dikes are present in the prototype and not present in the micromodel prediction.
4. The calibrated Vicksburg Front model had velocity and sedimentation trends that did not agree with the prototype.
5. No prediction evidence is provided by the Mouth of the White River micromodel because the calibration differs greatly from the prototype and the bendway weirs have a different elevation in model and prototype.
6. Predicted model velocities did not agree with the prototype at Lock and Dam 24. Depending on whether the guardwall ports were clogged during the time of prototype measurement, the micromodel predictions were either incorrect or can be explained by the difference in micromodel and prototype ports.
7. The micromodel achieves calibration similar to coal-bed models used at ERDC based on bathymetric parameters averaged over most of the length of the model. Data were not available to evaluate prediction using these same parameters.
8. The large departures from similarity principles in the micro-

model and no correspondence of water level in the micromodel and prototype are of concern.

This writer found successful projects that had been micromodeled but looked for micromodel-prototype comparisons that had (1) a reasonable calibration; (2) about the same river engineering structures constructed in the prototype that were tested in the model; and (3) a prediction of the correct trends in the prototype. The evidence is not overwhelming (because there are relatively few studies providing information on prediction) but shows a lack of predictive capability. Based on the lack of predictive evidence, the micromodel should be limited to demonstration, education, and communication for which it is effective and useful. This conclusion differs from the CCS (ASCE 2004) report that concluded screening capability for all but category 5 problems.

Quantitative inputs have little significance in the micromodel because the water level is not correct and the velocities are 2.7 to 3.7 times greater than given by Froude scaling.

Screening for category 5 studies that are complex and where human life or the overall project are at risk such as navigation near structures, bridge approaches, and confluences is of particular importance to this evaluator. In this writer's opinion, the micromodel should not be used for category 5 problems. This conclusion is consistent with the recommendations of the CCS (ASCE 2004) for category 5 problems.

Acknowledgments

The study described herein was funded by the USACE. The views expressed herein are the writer's. Diverse views of micromodel capability exist within the USACE.

Notation

The following symbols are used in this paper:

B = channel width;
D = particle size;
F_m = Froude number in model;
F_p = Froude number in prototype;
g = gravitational acceleration;
i = slope;
R = hydraulic radius;
ν = kinematic viscosity;
ρ = water density;
ρ_s = particle density; and
σ = surface tension.

References

ASCE Task Committee on Hydraulic Modeling, Environmental and Water Resources Institute. (2000). "Hydraulic modeling: Concepts and practice." *Manual and Report No. 97*, ASCE, Reston, Va.

Davinroy, R. D. (1994). "Physical sediment modeling of the Mississippi River on a micro scale." Ph.D. thesis, Univ. of Missouri–Rolla, Mo.

Davinroy, R. D. (1996). "Sedimentation study of the Mississippi River, New Madrid Bar Reach, miles 891 to 883, hydraulic micro model investigation." *USACE Rep.*, U.S. Army Engineer District, St. Louis, Mo.

de Vries, M., and van der Zwaard, J. J. (1975). "Movable-bed river-models." *Publication No. 156*, Delft Hydraulics Laboratory, Delft, The Netherlands.

Einstein, H. A., and Chien, N. (1955). "Similarity of distorted river models with movable beds." *Paper No. 2805*, Transactions of the ASCE.

Ettema, R. (2001). "A framework for evaluating micro-models." *Limited Distribution Report No. 295*, Iowa Institute of Hydraulic Research, The Univ. of Iowa, Iowa City, Iowa.

Ettema, R., and Maynord, S. T. (2002). "Framework for evaluating very small hydraulic models of channel-control works." *Hydraulic Measurements and Experimental Methods 2002*, ASCE, Reston, Va.

Ettema, R., Melville, B. W., and Barkdoll, B. (1998). "Scale effect in pier-scour experiments." *J. Hydraul. Eng.*, 124(6), 639–642.

Ettema, R., and Muste, M. (2002). "Scale-effect trends on flow thalweg and flow separation at dikes in flat-bed channels." *IIHR Technical Rep. No. 426*, Iowa Institute of Hydraulic Research, Iowa City, Iowa.

Ettema, R., and Muste, M. (2004). "Scale effects in flume experiments on flow around a spur dike in flatbed channel." *J. Hydraul. Eng.*, 130(7), 635–646.

Falvey, H. T. (1999). Letter to Editor, "Misuse of term model." *Civil Engineering Magazine*, ASCE, Reston, Va., Vol. 69, No. 12, December.

Foster, J. E. (1975). "Physical modeling techniques used in river models." *Symposium on Modeling Techniques*, ASCE, Reston, Va.

Franco, J. J. (1978). "Guidelines for the design, adjustment and operation of models for the study of river sedimentation problems." *Instruction Rep. No. H-78-1*, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss.

Freeman, J. R. (1929). *Hydraulic laboratory practice*, American Society of Mechanical Engineers, New York.

Gaines, R. A. (2002). "Micro-scale moveable bed physical model." PhD dissertation, Univ. of Missouri–Rolla, Mo.

Gaines, R. A., and Maynord, S. T. (2001). "Microscale loose-bed hydraulic models." *J. Hydraul. Eng.*, 127(5), 335–338.

Glazik, G. (1984). "Influence of river model distortion on hydraulic similarity of structures arranged at the channel." *Symp. on Scale Effects in Modeling Hydraulic Structures*, Germany, International Association for Hydraulic Reserch, Esslingen, Germany.

Glazik, G., and Schinke, H. (1986). "Demonstration of scale effects in river models with movable bed by means of comparison of prototype and model family." *Symp. on Scale Effects in Modelling Sediment Transport Phenomenon*, supplement, International Association for Hydraulic Research, Toronto.

Gordon, D. C., Davinroy, R. D., and Riiff, E. H. (1998). "Sedimentation and navigation study of the Lower Mississippi River at the White River Confluence, miles 603 to 596." *USACE Rep.*, U.S. Army Engineer District, St. Louis, Mo.

Graf, W. H. (1971). *Hydraulics of sediment transport*, McGraw-Hill, New York.

Gujar, V. G. (1981). "Determination of scales for mobile bed models with special reference to river models." *Irrig. Power*, 38(2), New Delhi, India.

Jaeggi, M. N. R. (1986). "Non distorted models for research on river morphology." *Symp. on Scale Effects in Modelling Sediment Transport Phenomenon*, International Association for Hydraulic Research, Toronto.

Latteux, B. (1986). "The LNH experience in modelling sediment transport under combined wave and current action." *Symp. on Scale Effects in Modelling Sediment Transport Phenomenon*, supplement, International Association for Hydraulic Research, Toronto.

Maynord, S. T. (2002). "Comparison of surface velocities in micro-model and prototype." *Hydraulic measurements and experimental methods 2002*, ASCE, Reston, Va.

Struiksma, N., and Klaasen, G. J. (1987). "On scale effects in movable-bed river models." *Communication No. 381*, Delft Hydraulics Laboratory, Delft, The Netherlands.

Suga, K. (1973). "Some notes on hydraulic model tests of river channels." *IAHR Int. Symp. on River Mechanics*, Bangkok, Thailand.

U.S. Army Corps of Engineers (USACE). (2004). *Rep. on the 68th Meeting, Micromodeling*, Committee on Channel Stabilization, Mississippi Valley Division, Vicksburg, Miss.

Vollmers, H. J. (1986). "Physical modelling of sediment transport in coastal models." *Third Int. Proc., Symp. on River Sedimentation*, S. Y. Wang, H. W. Shen, and L. Z. Ding, eds., Jackson, Miss.

Warnock, J. E. (1949). "Chapter 2: Hydraulic similitude." *Engineering hydraulics*, Hunter Rouse, ed., John Wiley, New York.

Yalin, M. S. (1965). "Similarity in sediment transport by currents." *Hydraulics Research Paper No. 6*, Hydraulics Research Station, Wallingford, U.K.

Yalin, M. S. (1971). *Theory of hydraulic models*, McMillan, London.

Zimmerman, C., and Kennedy, J. F. (1978). "Transverse bed slopes in curved alluvial streams." *J. Hydraul. Div., Am. Soc. Civ. Eng.*, 104(1), 33–48.

Attachment C
Comments of the National Wildlife Federation

Studies Linking The Construction Of Instream Structures To Increases In Flood Levels

1. Pinter, N., A.A. Jemberie, J.W.F. Remo, R.A. Heine, and B.A. Ickes, 2010. Empirical modeling of hydrologic response to river engineering, Mississippi and Lower Missouri Rivers. River Research and Applications, 26: 546-571.

2. Paz, A.R., J.M. Bravo, D. Allasia, W. Collischonn, and C.E.M. Tucci, 2010. Large-scale hydrodynamic modeling of a complex river network and floodplains. Journal of Hydrologic Engineering, 15: 152-165.

3. Pinter, N., 2010. Historical discharge measurements on the Middle Mississippi River, USA: No basis for "changing history." Hydrological Processes, 24: 1088-1093.

4. Theiling, C.H., and J.M. Nestler, 2010. River stage response to alteration of Upper Mississippi River channels, floodplains, and watersheds. Hydrobiologia, 640: 17-47.

5. Remo, J.W.F., N. Pinter, and R.A. Heine, 2009. The use of retro- and scenario- modeling to assess effects of 100+ years river engineering and land cover change on Middle and Lower Mississippi River flood stages. Journal of Hydrology, 376: 403–416.

6. Azinfar, H., and J.A. Kells, 2009. Flow resistance due to a single spur dike in an open channel. Journal of Hydraulic Research, 47: 755-763.

7. Doyle, M.W., D.G. Havlick, 2009. Infrastructure and the Environment. Annual Review of Environment and Resources, 34: 349-373.

8. Pinter, N., 2009. Non-stationary flood occurrence on the Upper Mississippi-Lower Missouri River system: Review and current status. In R. E. Criss and Timothy M. Kusky (Eds.), Finding the Balance between Floods, Flood Protection, and River Navigation, pp. 34-40. Saint Louis University, Center for Environmental Sciences.

9. Criss, R.E., and W.E. Vinston, 2008. Public Safety and Faulty Flood Statistics. Environmental Health Perspectives, 116: A516.

10. Pinter, N., A.A. Jemberie, J.W.F. Remo, R.A. Heine, and B.S. Ickes, 2008. Flood trends and river engineering on the Mississippi River system, Geophysical Research Letters, 35, L23404, doi:10.1029/2008GL035987.

11. Jemberie, A.A., N. Pinter, and J.W.F. Remo, 2008. Hydrologic history of the Mississippi and Lower Missouri Rivers based upon a refined specific-gage approach. Hydrologic Processes, 22: 7736-4447, doi:10.1002/hyp.7046.

12. Szilagyi, J., N. Pinter, and R. Venczel, 2008. Application of a routing model for detecting channel flow changes with minimal data. Journal of Hydrologic Engineering, 13: 521-526.

13. Remo, J.W.F., N. Pinter, B. Ickes, and R. Heine, 2008. New databases reveal 200 years of change on the Mississippi River System. Eos, 89(14): 134-135.

14. Azinfar, H., and J.A. Kells, 2007. Backwater effect due to a single spur dike. Canadian Journal of Civil Engineering, 34: 107-115.

15. Remo, J.W.F, and Pinter, N., 2007. The use of spatial systems, historic remote sensing and retro-modeling to assess man-made changes to the Mississippi River System. In: Zaho, P. et al. (eds.), Proceedings of International Association of Mathematical Geology 2007: Geomathematics and GIS Analysis of Resources, Environment and Hazards. State Key Laboratory of Geological Processes and Mineral Resources, Beijing, China, pp. 286-288.

16. O' Donnell, K.T. Galat D.L., 2007. River Enhancement in the Upper Mississippi River Basin: Approaches Based on River Uses, Alterations, and Management Agencies. Restoration Ecology, 15, 538-549.

17. Sondergaard, M., and E. Jeppesen, 2007. Anthropogenic impacts on lake and stream ecosystems, and approaches to restoration. Journal of Applied Ecology, 44: 1089-1094.

18. Remo, J.W.F., and N. Pinter, 2007. Retro-modeling of the Middle Mississippi River. Journal of Hydrology. doi: 10.1016/j.hydrol.2007.02.008.

19. Azinfar, H., J.A. Kells, 2007. Backwater prediction due to the blockage caused by a single, submerged spur dike in an open channel. Journal of Hydraulic Engineering, 134: 1153-1157.

20. Maynord, S.T. 2006. Evaluation of the Micromodel: An Extremely Small-Scale Movable Bed Model. Journal of Hydraulic Engineering 132, 343-353.

21. Pinter, N., B.S. Ickes, J.H. Wlosinski, and R.R. van der Ploeg, 2006. Trends in flood stages: Contrasting trends in flooding on the Mississippi and Rhine river systems. Journal of Hydrology, 331: 554-566.

22. Ehlmann, B.L., and R.E. Criss, 2006. Enhanced stage and stage variability on the lower Missouri River benchmarked by Lewis and Clark. Geology, 34: 977-980.

23. Pinter, N., R.R. van der Ploeg, P. Schweigert, and G. Hoefer, 2006. Flood Magnification on the River Rhine. Hydrological Processes, 20: 147-164.

24. Huang, S.L., Ng C. 2006. Hydraulics of a submerged weir and applicability in navigational channels: Basin flow structures. International Journal for Numerical Methods in Engineering 69, 2264-2278.

25. Pinter, N., 2005. Policy Forum: One step forward, two steps back on U.S. floodplains. Science, 308: 207-208.

26. Jai, Y., Scott S., Xu, Y., Huang, S. and Wang, S.S.Y. 2005. Three-dimensional numerical simulation and analysis of flow around submerged weir in a channel bendway. Journal of Hydraulic Engineering. 131, 682-693.

27. Van Ogtrop, F.F., A.Y. Hoekstra, and F. van der Meulen, 2005. Flood management in the Lower Incomati River Basin, Mozambique: Two alternatives. Journal of the American Water Resources Association, 41: 607-619.

28. Pinter, N., and R.A. Heine, 2005. Hydrodynamic and morphodynamic response to river engineering documented by fixed-discharge analysis, Lower Missouri River, USA. Journal of Hydrology, 302: 70-91.

29. Ettema, R., Muste, M. 2004 Scale effects in flume experiments on flow around a spur dike in a flat bed channel. Journal of Hydraulic Engineering. 130 (7), 635-646.

30. Pinter, N., K. Miller, J.H. Wlosinski, and R.R. van der Ploeg, 2004. Recurrent shoaling and dredging on the Middle and Upper Mississippi River, USA. Journal of Hydrology, 290: 275-296.

31. Wasklewicz T.A., J. Grubaugh, and S. Franklin, 2004. 20th century stage trends along the Mississippi River. Physical Geography, 25: 208-224.

32. Pinter, N., and R. Thomas, 2003. Engineering modifications and changes in flood behavior of the Middle Mississippi River. In R. Criss and D. Wilson, (eds.), At The Confluence: Rivers, Floods, and Water Quality in the St. Louis Region, pp. 96-114.

33. Bowen, Z.H., Bovee, K.D., Waddle, T.J. 2003. Effects of Regulation on Shallow-Water Habitat Dynamics and Floodplain Connectivity. Transactions of the American Fisheries Society 132, 809-823.

34. Pinter, N., R. Thomas, and J.H. Wlosinski, 2002. *Reply* to U.S. Army Corps of Engineers *Comment* on "Assessing flood hazard on dynamic rivers." Eos: Transactions of the American Geophysical Union, 83(36): 397-398.

35. Clifford, N.J., Soar, P.J., Gurnell, A.M., Petts, G.E., 2002. Numerical flow modeling for eco-hydraulic and river rehabilitation applications: a case study of the River Cole, Birmingham, U.K.. In River Flow 2002, Bousmar D, Zech Y (eds). Swets & Zeitlinger/Balkema: Lisse; 1195-1204.

36. Pinter, N., J.H. Wlosinski, and R. Heine, 2002. The case for utilization of stage data in flood-frequency analysis: Preliminary results from the Middle Mississippi and Lower Missouri River. Hydrologic Science and Technology Journal, 18(1-4): 173-185.

37. Roberge, M., 2002. Human modification of the geomorphically unstable Salt River in metropolitan Phoenix. Professional Geographer, 54: 175-189.

38. Pinter, N., R. Thomas, and J.H. Wlosinski, 2001. Flood-hazard assessment on dynamic rivers. Eos: Transactions of the American Geophysical Union, 82(31): 333-339.

39. Criss, R. E., & Shock, E. L. (2001). Flood enhancement through flood control. Geology , 29 (10), 875-878.

40. Pinter, N., R. Thomas, and N.S. Philippi, 2001. Side-stepping environmental conflicts: The role of natural-hazards assessment, planning, and mitigation. E. Petzold-Bradley, A. Carius, and A. Vincze (eds.), Responding to Environmental Conflicts: Implications for Theory and Practice, p. 113-132. Dordrecht: Kluwer Academic Publishers.

41. Pinter, N., R. Thomas, and J.H. Wlosinski, 2000. Regional impacts of levee construction and channelization, Middle Mississippi River, USA. In J. Marsalek, W.E. Watt, E. Zeman, and F. Sieker (eds.), Flood Issues in Contemporary Water Management, p. 351-361. Dordrecht: Kluwer Academic Publishers.

42. Smith, L. M., and Winkley, B.R. 1996. The response of Lower Mississippi River to river engineering . Engineering Geology. 45, 433-455.

43. Struiksma, N. Klaasen, G.J., 1987. On scale effects in moveable river models. Communication No. 381, Delft Hydralics Laboratory, Delft, The Netherlands.

44. Chen Y.H., and Simmons D.B., 1986. Hydrology, hydraulics, and geomorphology of the Upper Mississippi River system. Hydrobiologia 136, 5-20.

45. Belt, C.B. 1975. The 1973 flood and man's constriction of the Mississippi River. Science, 189: 681-684.

46. Stevens, M. A., Simons, D. B., & Schumm, S. A. (1975). Man-induced changes of Middle Mississippi River. Journal of the Waterways Harbors and Coastal Engineering Division , 119-133.

47. Maher, T.F. 1964. Study of regulation works on stream flow. Paper presented at ASCE Meeting, Cincinnati, Ohio, February, 1-24.

Attachment D
Comments of the National Wildlife Federation

ERDC/EL TR-03-4

US Army Corps
of Engineers®
Engineer Research and
Development Center

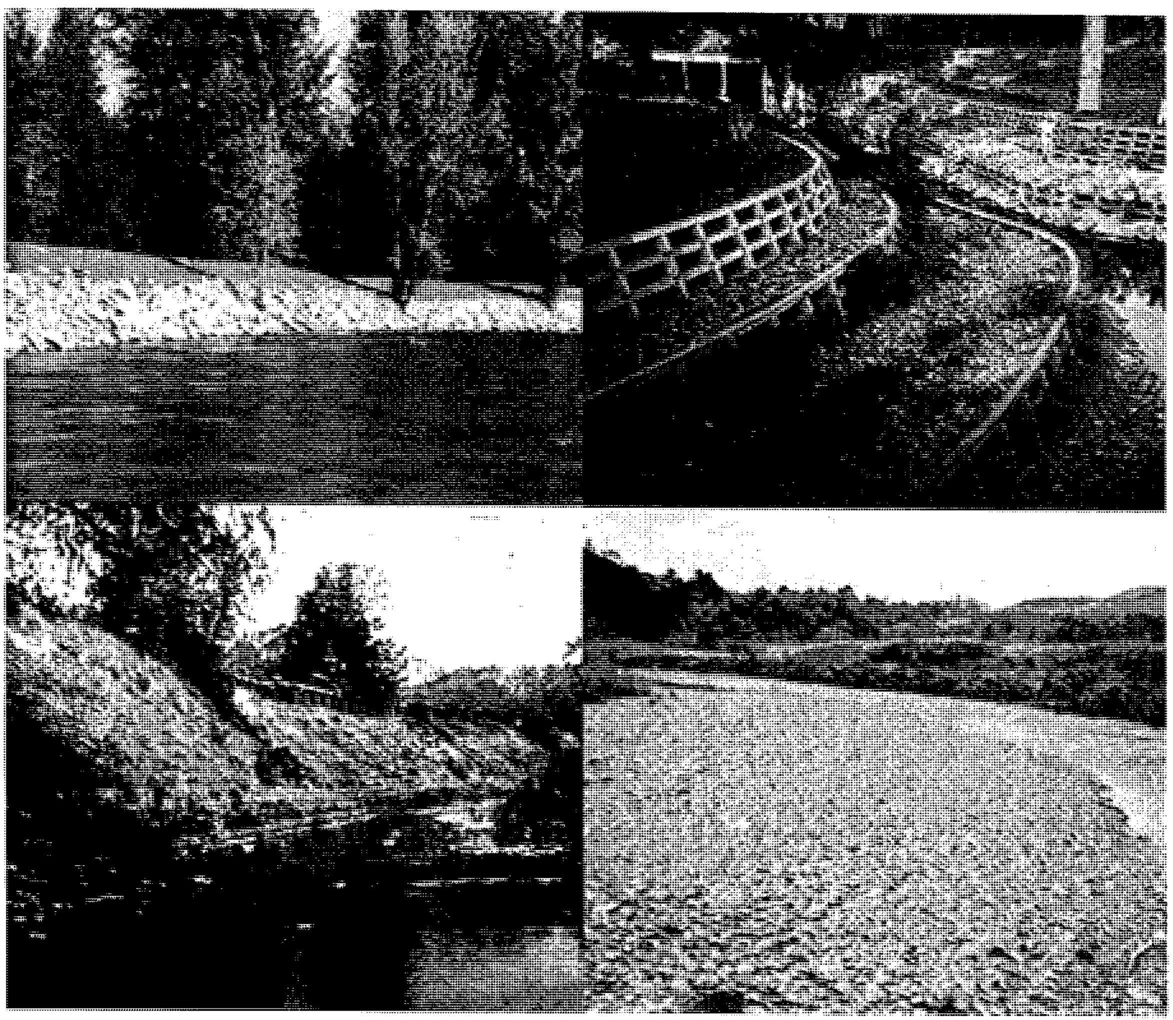
20030623 016

Wetlands Regulatory Assistance Program

Effects of Riprap on Riverine and Riparian Ecosystems

J. Craig Fischenich

April 2003



Environmental Laboratory

Wetlands Regulatory
Assistance Program

ERDC/EL TR-03-4
April 2003

Effects of Riprap on Riverine and Riparian Ecosystems

by J. Craig Fischenich

Environmental Laboratory
U.S. Army Engineer Research and Development Center
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

Final report

Prepared for U.S. Army Corps of Engineers
Washington, DC 20314-1000

Contents

Preface iv

Executive Summary v

1—Overview 1

2—Impacts of Riprap 3

Summary of the Literature 4
Impacts Based Upon Function 6
Impacts on morphologic evolution 8
Impacts on hydrologic balance 9
Impacts on sediments 9
Impacts on habitat 10
Impacts on chemical and biological processes 11

3—Avoidance and Minimization of Impacts 13

Practicable Alternatives 13
No-action alternative 13
Comparison of techniques 14
Measures to Avoid and Mitigate Impacts 17
Stone size 17
Revetment dimensions 19
Deflection structure design 20
Incorporation of vegetation 24
Grade control 26
Construction 28

4—Summary 30

5—Annotated Bibliography 32

6—Additional References 50

7—Internet References/Resources 52

SF 298

Preface

This report was authorized and funded by Headquarters, U.S. Army Corps of Engineers, as part of the Wetlands Regulatory Assistance Program (WRAP). HQUSACE representatives for this report are Mr. Charles Hess, Chief, Operations Division; Mr. Charles Stark, Acting Chief, Regulatory Branch; Mr. Mark Sudol, Chief, Regulatory Branch; Mr. Ted Rugiel, Regulatory Branch; and Ms. Katherine Trott, Senior headquarters Regulatory Program Manager. Mr. Robert L. Lazor, U.S. Army Engineer Research and Development Center (ERDC), Environmental Laboratory (EL), was the WRAP Program Manager. General supervision of this effort was provided by Dr. Mike Passmore, Chief, Ecological Resources Branch; Dr. Dave Tazik, Chief, Ecosystem Evaluation and Engineering Division; and Dr. Edwin Theriot, Director, EL.

This report was prepared by Dr. Craig Fischenich, ERDC, EL. The assistance of Michael Waring, ERDC, EL (retired), and Michael Scuderi, U.S. Army Corps of Engineers, Seattle District, in compiling this list of references is gratefully acknowledged.

At the time of publication of this report, Dr. James R. Houston was Director of ERDC, and COL John W. Morris III, EN, was Commander and Executive Director.

This report should be cited as follows:

Fischenich, J. C. (2003). "Effects of riprap on riverine and riparian ecosystems," ERDC/EL TR-03-4, U.S. Army Engineer Research and Development Center, Vicksburg, MS.

Executive Summary

Streambank stabilization affects many of the structural characteristics and functions of a stream. These impacts can be viewed as either adverse or beneficial, depending upon the perspective of the individual assigning values to the system. The prevailing philosophy in ecosystem management is that physical alterations of the structure and character of an ecosystem are most significant if they also impact process-based functions. A series of 15 river and riparian functions are presented in five categories, against which the impacts of riprap stabilization treatments are assessed.

Among the general categories, erosion control measures are most likely to impact morphological evolution, sediment processes, and habitat. They are least likely to impact the stream's hydrologic character and the chemical processes and pathways. Of the 15 specific functions, stream evolution, riparian succession, sedimentation processes, habitat, and biological community processes are most likely to be impacted.

Riprap is a material consisting of graded stone. The stone source may vary, but is typically blasted, grizzled, and screened at a quarry. This material can be used in a variety of ways to stabilize streambanks. Distinctions among various bank stabilization measures can be made on the basis of 1) how they work, 2) the materials used, 3) their geometry and position in the landscape, and (in some cases), 4) the character of stream system to which they are applied. Stabilization measures in four basic categories were evaluated for the likely impact to the basic functions.

Relative to the other categories of stabilization alternatives, *energy reduction* measures, which include a variety of techniques to lower the energy gradient of the stream, have the greatest potential impacts. Intermittent *flow deflection* structures that extend outward from the bank and force the higher velocities streamward generally have the least overall potential impact. *Slope stabilization* and *armor* measures, which include placing stone along the bank parallel to the flow, have intermediate impact potential.

Functions most likely to be impacted by stabilization measures include stream evolution processes, riparian succession, sedimentation processes, habitat, and biological community interactions. Those least likely to be impacted include the functions related to hydrologic balance and chemical and biological processes. The nature and significance of the impacts depend upon the specific measure employed, and the characteristics of the stream system on which it is used.

Many of the impacts associated with erosion control measures are independent of the material used to accomplish the erosion control. Most of the impacts associated with an armor structure, for example, are the same regardless of whether the armor material is riprap, concrete, vegetation, or a synthetic product. Material-related impacts are generally associated with the habitat characteristics of the structure, and the influence of the structure on riparian vegetation.

The impacts associated with the use of riprap can be minimized by modification of structures used to provide for erosion control. When used as an armor material, riprap impacts can be minimized by reducing the height of the protection, by increasing the slope of the embankment, and by sizing the riprap in order to afford adequate habitat within the aquatic environment. Planting the interstices of a riprap revetment with woody vegetation can also reduce impacts. Similar modifications can be employed to minimize the impacts associated with riprap used as toe protection in a slope stabilization project.

Measures to reduce the impacts associated with flow deflection structures incorporating riprap include carefully locating the structures so as to minimize impacts to the riparian corridor, and modifying the structure design in order to generate desired habitat characteristics within the aquatic environment. Structure designs that result in diverse conditions or that restore or generate necessary habitat can have generally positive impacts. Some research suggests that the size and gradation of stone for both flow deflection and armor structures can be adjusted to reduce impacts.

Most impacts caused by energy reduction structures are related to the height of the structure. High structures significantly decrease the energy and water surface slope, induce sediment deposition upstream and scour downstream, and can present a barrier to the migration of aquatic organisms. These impacts can be minimized by replacing single structures with a series of low-head structures, and by incorporating structural modifications to improve sediment continuity and fish passage.

Thorough impact assessments should contrast the existing and future with- and without-project conditions, for various stabilization alternatives. These assessments should help the reviewer determine the impacts of riprap relative to other practical alternatives and, in some cases, the absolute impacts of the proposed measure to determine mitigation needs.

1 Overview

Riprap (graded stone or crushed rock) is the most common material used in the stabilization of streambanks and shorelines. The continued use of this material as fill has been challenged in many locations by resource agencies due to concern for potential environmental impacts. Moratoriums on the use of riprap have been established or are being pursued by the National Marine Fisheries Service (NMFS), the U.S. Fish and Wildlife Service (USF&WS), and several State Environmental Quality offices. U.S. Army Corps of Engineer Districts currently invest considerable manpower interacting with applicants and resource agencies on this issue. These efforts are hampered by a number of factors including inconsistencies in the literature, differences among ecosystems, conflicting agency missions and directives, and insufficient knowledge. Lacking a sound procedure for the objective evaluation of potential impacts and given the ambiguous nature of the literature on the matter, decisions are often clouded by biased judgment.

To address this problem, research was initiated under the Wetlands Regulatory Assistance Program (WRAP) to develop guidelines for the evaluation of the environmental impacts and benefits of riprap. The first step in this research was the formulation of an annotated bibliography of related publications that could serve as a basis for regional and site-specific evaluations, and that characterizes the current state of knowledge on this subject.

This document presents the results of the literature review. Citations are presented in the following sections, with an annotation summarizing the study findings. Each citation is appended with one or more category numbers that indicate the major thrust of the reference, based on the following:

1. Methods of construction/engineering aspects.

2. General impact considerations.

3. Salmonid-specific impacts.

4. Salmonid habitat/life requisites.

5. Evaluation of riprap pros and cons.
6. Assessment methods for riprap and riverine habitat.
7. Case studies/literature review.

2 Impacts of Riprap

Riprap, or graded stone, has been used in a variety of ways to prevent streambank erosion in the United States for more than a century. Most of this work was unregulated and was executed prior to the recognition of the potential environmental impacts of such activities. Consequently, thousands of miles of stream have been stabilized with riprap, and it is clear that the nation's waters have been impacted.

Section 404 of the Clean Water Act (CWA), enacted in 1976, established a permit program and technical guidelines to regulate discharges of fill material such as riprap in waters of the United States, and the USACE has the primary responsibility for the Section 404 program execution. The basic premise of the program is that no discharge of fill material can he permitted if a practicable alternative exists that is less damaging to the aquatic environment or if the nation's waters would be significantly degraded.

USACE's evaluation of a Section 404 permit application involves determining whether the proposed project complies with the Guidelines (40 CFR 230) and USACE permit regulations (33 CFR 320-330), which require a "public interest" review of the project. To comply with the Guidelines, projects must (a) represent the least environmentally damaging, practicable alternative, (b) conform with established legal standards, (c) not result in significant aquatic ecosystem degradation, and (d) utilize all practicable means to minimize adverse environmental impacts.

No permit is granted if the proposal is found to be contrary to the public interest. The public benefits and detriments of all relevant factors are carefully evaluated and balanced by the Corps in the review process. The decision whether to authorize a proposal, and if so, the conditions under which it will be allowed to occur, are therefore determined by the outcome of this general balancing process. That decision should reflect the national concern for both protection and utilization of important resources.

Execution of the Section 404 program in a manner consistent with the public interest thus requires that the regulatory personnel evaluating a proposed fill project understand the impacts of that activity upon the environment and upon other users of the resource. These impacts must be assessed both individually and in combination with known and/or probable impacts of other activities affecting the ecosystems of concern.

Despite the pervasive and historic use of riprap for stabilizing streambanks, relatively little is known about the impacts of such activities. This is due in part to the narrow focus of previous impact studies, but is also attributable to the complexities of stream and riparian ecosystems. The interrelationships among the physical, chemical, biological, and socio/economic characteristics of these systems are not well understood, so a full accounting of potential impacts from fill projects involving riprap is yet to be formulated. However, public interest reviews and compliance with the guidelines for projects using riprap as fill require an objective and thorough investigation of impacts.

Summary of the Literature

The annotated bibliography to this report contains 103 citations addressing the impacts of riprap placed in a stream environment. A majority of these publications deal with the impacts of riprap upon habitat for fish species and, more specifically, for certain life stages of salmonids. Despite the limited focus of these previous efforts, there is no consensus on the impacts of riprap upon habitat for fish and other aquatic organisms, and the existing publications present conflicting evidence of the nature and degree of impacts.

Table 1 summarizes the findings presented in the literature with respect to the impacts of riprap upon aquatic organisms. Roughly an equivalent number of "adverse," "beneficial," and "no" impacts are cited by the studies. The impacts cited for coldwater fisheries are predominantly adverse, whereas impacts for warmwater organisms are overwhelmingly beneficial. Although a number of variables are involved, this general trend appears to be related to the character of the habitat afforded by the riprap relative to the habitat it replaces and the other habitat in nearby reaches. In most of the warmwater systems studied, coarse hard substrate was very limited, so the addition of riprap provided a habitat niche that was rapidly exploited by a number of species. In contrast, most of the coldwater systems studied had abundant hard substrate, and the riprap replaced some other habitat type (e.g. cut banks, overhanging vegetation, etc.) that may have been limited.

Table 1
Impacts of Riprap Upon Aquatic Organisms Cited in the Literature

	Impact			
Species/Life stage	**Adverse**	**None**	**Benefit**	**Reference**
Juvenile Chinook Salmon		X		California Department of Fish and Game (1983)
	X			Beamer and Henderson (1998)
	X			Michny and Deibel (1986)
	X			U.S. Fish and Wildlife Service (1992)
	X			Roper and Scarnecchia (1994)
Yearling Chinook Salmon		X		Ward et al. (1994)
Winter-Run Chinook Salmon	X			Ecos, Inc. (1991)
Coho Salmon	X			Beamer and Henderson (1998)
			X	House and Boehne (1986)
Juvenile Coho Salmon	X			Knudsen and Dilley (1987)
			X	Shirvell (1990)
Salmonid Habitat		X		Harvey and Watson (1988)
Juvenile Salmonid			X	Lister et al. (1995)

(Continued)

Table 1 (Concluded)				
			Impact	
Species/Life stage	Adverse	None	Benefit	Reference
Salmon	X			*http://swr.ucsd.edu/fmd/citguide.htm*
	X			Buer et al. (1989)
Juvenile Steelhead Trout	X			Roper and Scarnecchia (1994)
		X		Ward et al. (1994)
	X			Knudsen and Dilley (1987)
			X	Shirvell (1990)
		X		Hamilton (1989)
Juvenile Brown Trout	X			Shuler, Nehring, and Fausch (1994)
Adult Brown Trout	X			Shuler, Nehring, and Fausch (1994)
Rainbow Trout		X		Beamer and Henderson (1998)
		X		Meyer and Griffith (1997)
Juvenile Cutthroat Trout	X			Knudsen and Dilley (1987)
Caddisflies			X	Dardeau, Killgore, and Miller (1995)
Midges			X	Dardeau, Killgore, and Miller (1995)
Mussels			X	Dardeau, Killgore, and Miller (1995)
Lithophils			X	Dardeau, Killgore, and Miller (1995)
Sturgeon			X	Dardeau, Killgore, and Miller (1995)
Paddlefish			X	Dardeau, Killgore, and Miller (1995)
Striped bass			X	Dardeau, Killgore, and Miller (1995)
Walleye			X	Dardeau, Killgore, and Miller (1995)
Blue Sucker			X	Dardeau, Killgore, and Miller (1995)
Flathead Catfish			X	Dardeau, Killgore, and Miller (1995)
Blue Catfish			X	Dardeau, Killgore, and Miller (1995)
Bluegill			X	Dardeau, Killgore, and Miller (1995)
Brook Silverside			X	Dardeau, Killgore, and Miller (1995)
Freshwater Drum			X	Dardeau, Killgore, and Miller (1995)
Larval Fishes	X			Li, Schreck, and Tubb (1984)

Several inconsistencies are evident in the literature. For example, of six authors studying the impacts of riprap upon juvenile steelhead trout, two concluded the impacts were adverse, two that they were beneficial, and two deemed the riprap to have no material impact upon habitat. Similarly inconsistent findings are evident for a number of the species studied. The different conclusions are likely attributable to several factors:

a. Differences in the physical character of the systems studied.

b. Differences in the study methods employed.

c. Differences in seasons studied.

d. Different preferences of life stages or subpopulations.

e. Influence from other species.

f. Bias.

g. Different size or configuration of the riprap.

h. Differences in the scale of the projects.

i. Different project ages.

Each of these factors influences the overall impact of riprap upon habitat for aquatic organisms, so study results tend to be highly empirical and should be extrapolated to other situations only with care. A thorough investigation of potential impacts from proposed riprap projects should include an assessment of the impacts cited in the literature, but must also include many factors in addition to the habitat impacts. Foremost among these are the potential impacts of the proposed work upon the processes and conditions that create and maintain the habitat, and that characterize the ecosystem.

Impacts Based Upon Function

Although their specific characteristics vary both spatially and temporally, all rivers support common *functions* – the physical, chemical, and biological components and processes that interact to form and maintain streams and riparian zones. The basic functions that rivers support have been divided into five categories:

a. Evolution through morphologic processes.

b. Maintenance of hydrologic balance.

c. Continuity of sediment processes.

d. Provision of habitat.

e. Maintenance of chemical processes and pathways.

Within each of these categories, three key functions have been identified (Table 2). It is important to note that not all functions will be of equal importance in every river, so interpretation of this framework will be required for each situation. In addition, other equally important functions may be identified for certain situations.

Table 2
Summary of Primary Functions

Morphologic Evolution	Hydrologic Balance	Sediment Continuity	Habitat Provision	Chemical Process & Pathways
Stream Evolution Processes	Surface Water Storage Processes (short & long-term)	Full Sedimentation Processes	Biological Communities and Processes	Water and Soil Quality Processes
Energy Processes	Surface/Subsurface Water Exchange Processes	Substrate and Structural Processes	Necessary Habitats for all Life Cycles	Chemical Processes and Nutrient Cycles
Riparian Succession	Hydrodynamic Character	Quality and Quantity of Sediments	Trophic Structures and Pathways	Landscape Pathways and Processes

The conditions and character of each river system, reach, site, or riparian corridor are a consequence of these functions, so the potential impacts to each should be evaluated when reviewing permit applications. It is helpful to determine which functions are currently limiting, are functioning inappropriately, or are acting as stressors, etc. to the system, because an impact may be either adverse or desirable, depending upon whether the change results in the degradation or the restoration of necessary functions or conditions. In evaluating relevant functions, it is also important to remain cognizant of the interrelated nature of the functions, namely that several functions have similar indicators and direct measures, and impacts to one are not necessarily independent of all others. This concept, and its value in terms of analysis efficiency, is expanded upon in another document in preparation under the Wetlands Regulatory Assistance Program (Fischenich 2003).

Streambank stabilization affects many of the structural characteristics and functions of a stream. The basic purpose of any stabilization project is to interrupt erosion processes where they are deemed to conflict with social needs or ecological requirements. These efforts also interrupt or affect other processes and alter the physical environment. Because of the strong interrelations among the structural components and functions of a stream/riparian system, a number of secondary and tertiary impacts are associated with bank stabilization measures.

Knowledge of the direct and ancillary impacts of stabilization can be used, for example, to select measures and develop a design that restores or enhances the structure or function of a degraded ecosystem. For example, erosion that results in the widening of a stream reach to the degree that sediment continuity, bed sediment character, and local hydrodynamics are adversely impacted can be compensated by stabilization measures that narrow the reach width to one that provides for the proper functioning of these conditions. If the stabilization measure also restores critical riparian and aquatic habitat, so much the better. But the selected measure may still impact other important processes such as channel evolution, riparian succession, and landscape pathways.

Few alterations to the structure or function of the environment are universally adverse or universally beneficial. Most measures benefit some components of the ecosystem at the expense of others. Thus, regulatory decisions must seek to optimize upon the likely outcomes by maximizing benefits and minimizing adverse impacts. This may involve "weighting" the functions, or considering them in the context of both short- and long-term impact.

The following sections present an overview of likely impacts from common bank stabilization practices. These impacts are based on the review of the materials summarized in the attached bibliography, along with extensive written works reviewed by the author and his experiences in research, design, construction, and monitoring thousands of bank stabilization structures. In this report, the term "impact" denotes a measurable change, without regard for the significance or value of the change. These changes or impacts are, by nature, very site-dependent; thus, generalizations provided herein may run contrary to some observations.

Stabilization measures composed of riprap are divided into four basic categories for presentation in this report. *Armor* techniques include the placement of riprap along the bank face to prevent erosion due to the shear force of the flowing water. *Flow deflection* structures extend outward from the bank, normal or angled to the flow, and function by forcing the higher velocity flows away from the bank for some distance downstream. *Slope stabilization* measures include placing large stone sections at the toe of the bank slope to resist translational or rotational failures. *Energy reduction* measures include a wide array of techniques that reduce the energy gradient of the stream and, thus, its ability to induce erosion.

Impacts on morphologic evolution

Morphologic evolution refers to the natural changes in stream characteristics, energy processes, and riparian succession that occur in healthy stream and riparian ecosystems. Stream lateral migration and riparian succession are necessary processes in maintaining appropriate energy levels in a system. They also promote diversity and ecological vigor by initiating change, which is important to long-term adaptation of ecosystems. Energy flow, predominately in the form of organic carbon, is governed by thermodynamics and aquatic chemical equilibrium. The ability of a stream to convert energy between its potential and kinetic forms through changes in physical features, hydraulic characteristics, and sediment transport processes is important in creating complex habitats generating heat for biochemical reactions, and reoxygenating flows. Stream and riparian management activities often impact this energy gradient. Impacts on morphologic evolution are summarized in Table 3.

Table 3
Impacts on Morphologic Evolution

Category	Impacts
General	The only applicable generalization of the impacts of bank stabilization on morphological evolution through a project reach is that all stabilization measures are intended to prevent or reduce lateral stream migration. The extent to which this migration is reduced relative to "normal" bank migration for a particular system defines the degree of this impact.
Armor Techniques	In addition to preventing lateral migration (a form of channel evolution), armor techniques typically impact riparian succession processes. On systems with a high sediment load and where the slope of the revetment face is gentle, sediments may deposit in the interstices of the riprap and some succession processes may proceed, but these may differ substantially from those that would occur in the absence of the revetment. Armor layers of riprap seldom have a significant impact upon energy processes.
Deflection Techniques	Deflection techniques generally have more limited effects than armor structures upon succession processes because the bank between the structures is largely unaffected. However, sediment deposition between structures may lead to the establishment of uncharacteristic riparian complexes. Deflection structures, depending upon their size, can reduce or localize the kinetic energy in a system, leading to other related impacts.
Slope Stabilization Techniques	Slope stabilization techniques, in general, have impacts similar to those for armor techniques. They reduce channel evolution through migration, and can reduce most riparian succession processes unless they incorporate vegetation as a component of the slope stabilization. Even in that instance, large woody debris recruitment may be limited if the stabilization measure persists for a long period of time. Energy impacts are typically minor.
Energy Reduction Techniques	Energy reduction techniques generally reduce velocity, shear stress and stream power, converting kinetic energy to potential energy. Their impacts upon riparian succession processes and channel migration can be less significant than the impacts associated with other stabilization techniques, but energy reduction through the use of dams and weirs can significantly impact these functions as well.

Impacts on hydrologic balance

Stabilization practices can alter the hydrologic balance of a river reach in several ways. Examples include (1) increased storage by changing the resistance characteristics (either form or friction) of the reach or by altering the channel geometry (slope or cross section); (2) modifying surface/subsurface water exchange by creating a barrier to flow; and (3) modifying the hydrodynamic character by altering flow fields or through the creation of backwater conditions. These changes can be direct (e.g., adding a weir to change channel slope), or indirect (e.g., structures that may cause a sorting of bed materials, resulting in a coarser surface fraction with higher resistance). Variables that influence stabilization impacts upon hydrologic balance include 1) the materials (affect resistance, turbulence and porosity), 2) structure geometry and location (affect slope, degree of expansion or contraction, flow convergence or separation, and secondary currents), and 3) structure type. Impacts on hydrologic balance are summarized in Table 4.

Table 4
Impacts on Hydrologic Balance

Category	Impacts
General	No generalization can be made on the impacts of bank stabilization using riprap on the hydrologic balance of a stream reach.
Armor Techniques	Riprap armor, in general, has little local or cumulative effect on water storage or exchange processes, and its impact upon hydrodynamics is generally associated with change in resistance. Exceptions may occur when the measure requires an alteration to the channel cross-sectional area. Impacts from resistance or cross section changes can be readily quantified through the application of the de Saint Venant Equations and resistance techniques. Expansions and contractions of less than 10 percent generally result in negligible impacts. Impacts from changes to resistance, which depend on the magnitude and length of the change, are greatest for streams with a width/depth ratio less than 20.
Deflection Techniques	Deflectors, which create form roughness and reduce the cross-sectional area of the channel, have the potential to increase water surface elevations, generate local scour, concentrate flows and generate backwater due to form roughness, impacting hydrodynamics and storage. Unfortunately, techniques to quantify these impacts are generally lacking. The impacts depend on the flow condition, character of the channel, and geometry of the deflector. Any deflector field that reduces channel width by more than 15 percent or cross section area more than 10 percent should be carefully reviewed.
Slope Stabilization Techniques	The impacts from slope stabilization techniques upon storage, water exchange, and hydrodynamics are similar to those for armoring techniques. Slope stabilization often employs vegetation, which can increase resistance relative to riprap.
Energy Reduction Techniques	Energy reduction techniques reduce kinetic energy, which is usually converted to potential energy in the form of increased water surface elevation. This increases storage, and generally reduces velocities in the backwater zone. During low-flow periods, the exchange of water between the surface and shallow groundwater may increase. Methods to quantify impacts to water surface elevations and velocities are straightforward, and generally consist of backwater analyses. Techniques to predict the impacts upon exchange can be complex, but this issue is typically of concern only for dams and very large weir structures.

Impacts on sediments

All stabilization structures and measures impact sedimentation processes. They reduce or eliminate sediment yield and tend to generate local scour, usually at the toe or immediately downstream. Sediment sorting and armoring tends to increase in stabilized reaches. Measures can affect local transport capacity by affecting resistance or channel geometry. The primary variables that influence sedimentation processes are the sediment yield, sediment characteristics, and the effects of the stabilization measure on velocity, stream power, and shear stress. Algorithms for computing erosion, deposition, and scour are often inaccurate and of limited value in assessing the true impacts and localized nature of these processes associated with bank stabilization. Impacts on sediments are summarized in Table 5.

Table 5
Impacts on Sediments

Category	Impacts
General	All bank stabilization measures at least temporarily change sediment yield characteristics of a channel. Most cause local scour and many induce sediment deposition. These impacts tend to be temporary, though their results may persist for long periods of time, particularly in streams with armored beds and few tributaries.
Armor Techniques	Armoring techniques generally reduce local bank erosion but induce local scour. Scour usually occurs at the toe of the armor structure and extends into the stream about two to three times the scour depth. Algorithms to compute scour and sorting are notoriously poor, but provide some means of estimating the magnitude of the impacts. Armor techniques that use materials with high resistance values can also induce local sediment deposition, usually on and within the armor material.
Deflection Techniques	Flow deflection structures reduce sediment yield from the protected bank, and also alter the flow field, which, in turn, generates zones where both scour and deposition occur in close proximity. The overall impact on scour, deposition, and sediment movement varies greatly with the channel conditions and structure configuration, and the impacts of these structures on sediment processes and character require case-specific analyses.
Slope Stabilization Techniques	The impacts of slope stabilization measures on sediment processes and character are generally the same as those for armor techniques, and the differences are generally associated with different resistance values.
Energy Reduction Techniques	Techniques used to reduce energy within a stream have a significant impact on sediment transport, scour, and deposition. Grade control measures create backwater, increasing upstream depth and reducing velocity. Sediment transport capacity is reduced, and upstream stream reaches often have finer bed materials than those found in adjacent reaches, while substrates in downstream scour pools are generally coarser. Secondary channels blocked with chute closures may become backwater zones or wetlands, trapping fine sediments during flood events. Flows in the main channel may deepen, with a corresponding coarsening of the bed material and corresponding increase in sediment transport.

Impacts on habitat

All stabilization measures affect the local habitat conditions in a reach. Riprap provides a substrate that generally differs from the parent material of the channel boundary, so offers a different habitat condition. In addition, the stabilization structure may alter the channel geometry, flow field, riparian vegetation conditions, or a host of other habitat elements. The net effect of these changes varies by species, life stage, season, flow condition, age, and the extent of coverage or structure size. Riprap can create preferential habitat for some organisms at the expense of others, and can upset one or more entire guilds or trophic levels in the system. Impacts on habitat are summarized in Table 6. The literature identified in the annotated bibliography presents a more detailed discussion of specific habitat impacts.

Table 6 Impacts on Habitat Provision	
Category	**Impacts**
General	Bank stabilization measures directly affect habitat by altering the character of the substrate and riparian/aquatic associations. Indirect impacts are usually related to alterations in the flow field, shifts in population dynamics, and pathway modifications.
Armor Techniques	Armor techniques utilizing riprap favor species that use interstitial voids of the rocks for shelter or cover. This can, in turn, result in population shifts, changes in predation, and other biological community impacts. The addition of riprap usually results in an increase in macroinvertebrate biomass and density. Most revetments result in a reduction of streamside vegetation, so riparian flora and fauna are often adversely impacted.
Deflection Techniques	Deflection techniques generally have only limited effects on habitat for riparian flora and fauna, and the interstices of the stone are not generally used to the same degree as are those in revetments. Macroinvertebrate colonization is comparable to that for stone in armor layers. The predominant influence of deflection structures on habitat is related to the diverse patterns of scour and deposition located near the deflector fields.
Slope Stabilization Techniques	The habitat impacts associated with slope stabilization techniques are similar to those for revetments, except that those measures that include vegetation as a key component of the slope stabilization generally have lower impacts on riparian flora and fauna than do revetments. Migration reduction may eliminate island habitats.
Energy Reduction Techniques	Energy reduction techniques can significantly affect habitat. Weir structures generate backwater conditions that alter the flow field, promote fine sediment deposition, increase flow depth, increase the wetted perimeter of the channel, and alter the adjacent riparian community composition. Immediately downstream of these structures, deep but concentrated scour holes typically form, creating habitat niches with deep pools and coarse substrates. Organisms often concentrate in these areas – leading to increased stress and competition. Other energy reduction measures such as channel blocks can accelerate sedimentation processes and eliminate backwater rearing areas.

Impacts on chemical and biological processes

Stream channels and their associated riparian zones help maintain soil and water quality and support important chemical processes and nutrient cycles necessary to perpetuate the long-term health of the physical and biological properties of these areas. Stream and riparian systems occupy unique landscape positions that are critical to the survival of many plant and animal species, and provide longitudinal connectivity that allows for biotic and abiotic energy pathways that link ecological processes and communities. They can also serve as important barriers, and buffers to plant and animal migration. Finally, these ecologically diverse areas often provide critical source and sink areas for maintaining population equilibrium of some plant and animal species, especially during large-scale disturbances that affect large portions of habitat. Stabilization measures generally affect these functions only indirectly. Impacts on chemical processes and pathways are summarized in Table 7.

Table 7
Impacts on Chemical Processes and Pathways

Category	Impacts
General	No generalizations can be made regarding the impacts of riprap upon soil and water quality, nutrient cycling, and the provision of pathways.
Armor Techniques	Revetments constructed of riprap generally have only minor impacts upon water quality. Long reaches of continuous riprap armor can increase stream temperatures due to solar radiation, and can diminish nutrient loading because of the elimination of riparian vegetation, but these impacts are likewise generally minor. Large amounts of limestone used as riprap can raise the pH of a stream, but such increases are also generally very slight. Revetments do, however, often serve as a barrier between the aquatic and terrestrial ecosystem, restricting biotic movement between these zones and potentially increasing predation.
Deflection Techniques	Flow deflection structures constructed of riprap generally have no influence upon soil quality or nutrient dynamics. When placed in a configuration that results in the formation of a deep thalweg, however, they can alter the low-flow pathway along the stream channel and can serve to reduce temperatures in the stream because of the increased depth and velocity.
Slope Stabilization Techniques	The impacts of slope stabilization measures upon chemical processes and pathways are essentially the same as those for an armor layer, except nutrient dynamics are less affected in slope stabilization projects when vegetation is used to stabilize the upper slopes.
Energy Reduction Techniques	Energy reduction techniques such as weirs, closures, and vanes can impact several important chemical processes and pathways. Because these measures often decrease velocity, the potential for elevated stream temperatures and reduced oxygen levels exists, particularly for low gradient systems. Increases in surface area and wetted perimeter provide more soil/water and air/water contact, so chemical processes that occur at these interfaces often increase. Weir structures often present a barrier to biotic movement along the channel, and can affect the formation and breakup of ice cover.

3 Avoidance and Minimization of Impacts

Numerous large- and small-scale negative ecological impacts are associated with riprap bank stabilization structures, and construction of structures may cause severe damage to riparian and instream habitats. Alternatives to stabilization with structures using riprap may be available, and should be evaluated. Design features can often be incorporated into riprap structures that will minimize the impacts to the functions listed in the previous section, and steps may be taken to minimize impacts from construction.

Practicable Alternatives

No-action alternative

Despite all evidence to the contrary, the perception persists that ecologically healthy streams and riparian corridors are stable. In truth, dynamic processes such as erosion, deposition, flooding, and drought occur in healthy streams, and are critical for maintaining pathways and establishing new habitats. Even in *pristine* systems, it is common to find that 10 to 50 percent of the banks are actively eroding, and the process of erosion is important to the ecological health of most systems (Figure 1). Thus, the first consideration in any permit application review involving the use of riprap should be the necessity of providing any erosion control.

Most streambank stabilization efforts are intended to protect infrastructure or other important investments, and deference must be given to these concerns when weighing public interest. However, stabilization practices are also frequently employed without clear justification for the intent or perceived benefit. In these instances, public interest may often be best served by ensuring that the proposed activity does not contribute to degradation of the ecosystem function and create future problems.

Figure 1. Some erosion is necessary for proper ecological function and the creation of new habitats such as nesting sites and spawning gravels

Successful streambank stabilization is based upon more than an understanding of the problem and the identification of techniques capable of addressing the problem. It is also based on understanding the interaction of the problem and proposed solutions with other ecosystem components, both locally and beyond the project's boundaries, and over varied temporal scales. An understanding of social and economic constraints, and the recognition that stabilization is but one component of a broader management plan that must include conservation and impact prevention strategies and the restoration of degraded systems is also required. This broader systems-level review of proposed stabilization actions may lead to the conclusion that certain stabilization practices are not in the public interest, and that the preferred alternative is to allow the erosion to continue.

Comparison of techniques

When it is clear that stabilization of an eroding or failing streambank is in the public interest, the selected technique should be the one that successfully stabilizes the system with the minimum impact to the functions listed in the preceding section of this report. To be successful, methods used to control erosion must address the underlying cause of the bank loss. Banks fail in one of four ways:

a. Hydraulic forces remove erodible bed or bank material.

b. Geotechnical instabilities result in bank failures.

c. Mechanical actions cause a reduction in the strength of the bank.

d. A combination of the above factors causes failure.

Fischenich and Allen (2000) present details of each of these mechanisms of bank loss, and list appropriate stabilization measures for each. From among the list of appropriate techniques, the one with the least impacts should be identified and selected, unless other factors such as material availability or constructability preclude the use of that option.

Table 8 summarizes the relative impacts of bank stabilization techniques upon each of the 15 functions. Among categories of stabilization measures, a clear distinction can be made only for the energy reduction techniques, which have the greatest impact on the full range of ecosystem functions. These are the only suitable techniques to address erosion caused by channel incision, but for other causal mechanisms, techniques from the other categories may be preferable.

Table 8 suggests that stabilization efforts generally have a greater impact on morphological evolution, sediment continuity, and habitat than on hydrologic balance and chemical processes. Moreover, the greatest impacts are likely to be associated with channel evolution, riparian succession, and sedimentation processes, so these should be a focal point of any assessment.

Within each of the stabilization categories, a number of different techniques can be employed. For example, a bank can be effectively armored using a revetment made of riprap, concrete, pavement blocks, rubble, or other material, or it can be armored with vegetation, erosion control fabrics, or other means. Many of the impacts associated with each category are independent of the specific technique. For example, ALL armor techniques affect stream evolution, energy processes, surface water storage, and hydrodynamic character in essentially the same manner. In most instances, the differences among the techniques relate to the materials and design details, rather than to the overall performance of the structure.

Thus, the use of riprap as a *material* should be assessed in addition to an evaluation of the overall structure type. Differences in material type primarily affect habitat, but can also influence groundwater exchange, movement of organisms, and many of the chemical and nutrient processes. The ramifications to habitat of adding riprap are often mixed – benefiting some species at the expense of others. The impacts to habitat and to other functions from the use of riprap as a material, and as a function of the characteristics of the structure itself, are addressed in the following section. The relative impacts of erosion control methods on stream and riparian functions are compared in Table 8. A variety of armor techniques are shown in Figure 2.

Table 8
Relative Impact of Erosion Control Methods on Stream and Riparian Functions (Scaled 1 to 10 with 1 Representing the Most Severe Impact)

Function	Armor Techniques	Flow Deflection	Slope Stabilization	Energy Reduction	Average	Rank
Morphologic Evolution						
Stream Evolution Processes	3	6	3	7	4.75	1
Energy Processes	9	6	9	4	7.00	9
Riparian Succession	3	6	4	6	4.75	2
Hydrologic Balance						
Surface Water Storage Processes	10	8	10	5	8.25	14
Surface/Subsurface Water Exchange	10	10	10	7	9.25	15
Hydrodynamic Character	10	7	10	4	7.75	12
Sediment Continuity						
Full Sedimentation Processes	5	5	5	4	4.75	3
Substrate and Structural Processes	8	5	7	5	6.25	6
Quality and Quantity of Sediments	7	7	7	6	6.75	8
Habitat Provision						
Biological Communities and Processes	6	5	7	5	5.75	5
Necessary Habitats for all Life Cycles	6	5	6	5	5.50	4
Trophic Structures and Pathways	8	9	8	6	7.75	13
Chemical Processes &Pathways						
Water and Soil Quality Processes	8	9	7	5	7.25	11
Chemical Processes & Nutrient Cycles	7	9	7	5	7.00	10
Landscape Pathways and Processes	4	9	5	9	6.75	7
Average	6.9	7.1	7.0	5.5		
Rank	2	4	3	1		

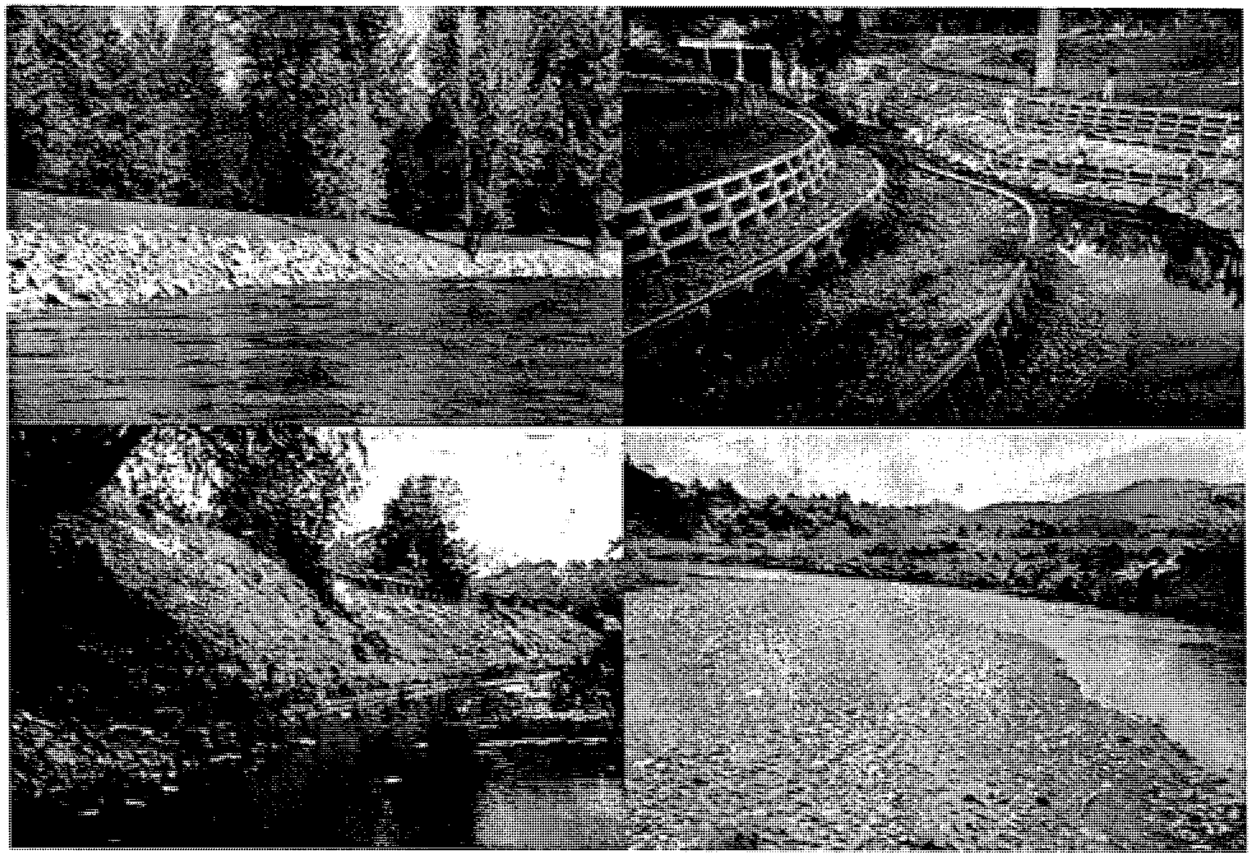


Figure 2. Impacts from each of these armor techniques are largely the same - most of the differences are associated with the direct habitat afforded by each material

Measures to Avoid and Mitigate Impacts

Stone size

The size of the stone used in riprap revetments or other riprap structures must meet certain requirements for stability, or it will be susceptible to failure. However, the gradation and size of the stones can influence the local habitat by virtue of the sizes of the interstitial spaces. In some situations, the spaces provided by large or poorly graded stone may provide greater habitat than a riprap sized strictly for the design hydraulic condition.

The size of the stone used in a riprap mix is determined by the stream's energy environment. Wave energy and boat wakes sometimes dictate this size, but it is usually determined on the basis of the stream velocity and depth at the design discharge. The design condition should represent the most adverse condition likely to occur on the stream, but this is not typically the largest flood. Generally, some intermediate discharge in the 2- to 10-year return frequency exerts the greatest force against riprap and is selected as the design discharge.

Stone size and thickness should be sufficient to withstand conditions during this design discharge, and may include some factor of safety. A failed riprap structure is generally more environmentally damaging than one that performs its stabilization function properly, so it is important that the riprap be properly sized.

Guidance for riprap in streamflow applications is found in EM-1110-2-1601, "Hydraulic Design of Flood Control Channels," and the equation for determining stone size is:

$$D_{30} = S_f C_s C_v C_T d \left[\left(\frac{\gamma_w}{\gamma_s - \gamma_w} \right)^{\frac{1}{2}} \frac{V}{\sqrt{K_1 g d}} \right]^{2.5}$$

where

D_{30} = riprap size of which 30 percent (by weight) is finer, m
S_f = safety factor, unitless
C_s = stability coefficient for incipient failure, unitless
C_v = vertical velocity distribution coefficient, unitless
C_T = blanket thickness coefficient, unitless
D = local depth of flow, m
γ_w = unit weight of water, N/m^3
γ_s = unit weight of stone, N/m^3
V = local depth-averaged velocity, m/s
g = gravitational constant, m/s^2
K_1 = side slope correction factor, unitless

Riprap thickness for most streambank protection projects is the greater of $1.0D_{100}$(max) or $1.5D_{50}$(max) and the blanket thickness coefficient (C_T) can be taken as 1.0. For riprap of this thickness and having a uniformity coefficient (D_{85}/D_{15}) between 1.7 and 5.2, the stability coefficient for incipient failure (C_s) can be estimated as:

C_s = 0.30 for angular rock
C_s = 0.375 for rounded rock

The value for the vertical velocity distribution coefficient (C_v) should be:

C_v = 1.0 for straight channels or inside of bends
C_v = 1.25 downstream of concrete channels
C_v = 1.25 at end of dikes
C_v = 1.283 - 0.2log(R/W) for outside of bends (or 1.0 for R/W > 26)

where:

R = centerline radius of bend, m
W = water surface width at upstream end of bend, m

For bank protection, $V = V_{SS}$ where V_{SS} is the depth-averaged velocity at 20 percent of the slope length up from the toe. A minimum safety factor (S_f) of 1.1 should be used. Recommended side slope correction factors (K_1) based upon slope are:

Slope	1V:1.5H	1V:2H	1V:3H	1V:4H or flatter
K_1	0.71	0.88	0.98	1.0

Revetment dimensions

The dimensions of revetments should be sufficient to provide the necessary degree of protection without overkill. The longitudinal extent of protection required for a particular bank protection scheme is highly dependent on local site conditions. In general, the revetment should be continuous for a distance greater than the length that is impacted by channel-flow forces severe enough to cause dislodging and/or transport of bank material. Although this is a vague criterion, it demands serious consideration. A common criterion suggests an upstream distance of 1.0 channel width and a downstream distance of 1.5 channel widths from the area subject to erosion, but these values must be adjusted to adapt to the conditions at each site.

The design height of a riprap installation should be set at the minimum necessary elevation, plus some allowance for freeboard. The "necessary" elevation depends upon the energy of the stream, the size of the riprap, the channel planform, and the bank angle. In general, the force exerted upon riprap by the flow decreases almost linearly from its maximum near the bed to a value of zero at the water surface. Most stabilization projects use riprap up to an elevation much higher than is needed to afford adequate stabilization (Figure 3). Although barren soils are easily eroded, a simple cover of vegetation is usually adequate to protect against shear stresses up to about 2 psf. This equates to a depth of more than 6 ft below the water surface on a stream with a 0.5-percent slope. Freeboard is provided to ensure the desired degree of protection considering uncertainties. The amount of freeboard cannot be fixed by a single, widely applicable formula but, rather, depends upon the degree of analytical certainty and acceptable risk.

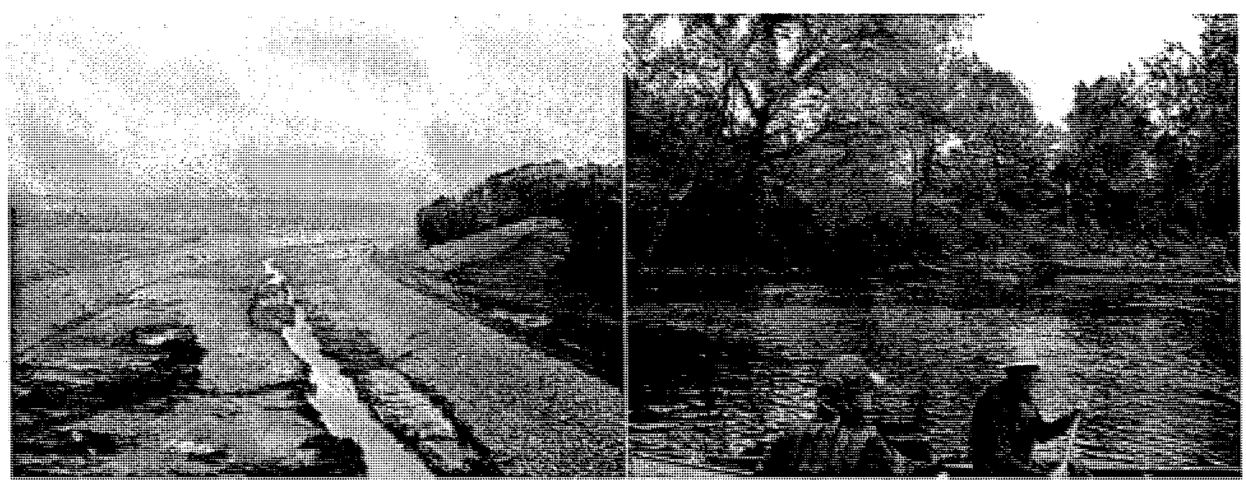


Figure 3. Common problems include setting the riprap elevation higher than needed and not extending the protection far enough downstream

The undermining of revetment toe protection has been identified as one of the primary mechanisms of riprap revetment failure. In the design of bank protection, estimates of the depth of scour are needed so that the protective layer is placed sufficiently low in the streambed to prevent undermining. The ultimate depth of scour must consider channel degradation as well as natural scour and fill processes.

When designing a riprap section to stabilize a streambank, the designer accounts for scour in one of two ways: 1) by excavation to the maximum scour depth and placing the stone section to this elevation, or 2) by increasing the volume of material in the toe section to provide a launching apron that will fill and armor the scour hole. Preference should usually be given to option (2) because of ease of construction and lower cost, and because of environmental impacts associated with excavation of the streambed.

Typical riprap bank stabilization structures are very uniform and lack the irregularities needed to provide velocity refugia for fishes or other aquatic organisms. There are, however, many design features that can be incorporated into riprap structures to improve habitat value, including the following:

a. Using larger-than-normal stone to increase size of interstitial spaces and thus increase amount of velocity refugia and cover for fishes.

b. Adding spur dikes to the structure. These features are built perpendicular to current extending from the toe toward the channel (Figure 4).

c. Adding fish groins (i.e., ridges of riprap running from the top bank to the toe of the structure) (Shields et al. 1995).

d. Incorporating indentations into the riprap structure.

e. Placing large boulders (1 to 1.5 m in diameter) along the toe of the structure.

f. Filling interstitial spaces with gravel so that the structure can serve as spawning habitat for salmonid fishes.

These features, except the last one, are designed to maximize eddies and velocity refuges for fishes and other aquatic organisms. However, they also have the potential to increase flow resistance and trap ice and debris, and thus reduce channel capacity and increase flood hazard of a stream.

Deflection structure design

Flow deflection structures extend into the stream channel, and redirect part of the flow so that hydraulic forces at the channel boundary are reduced to a non-erosive level. They include a variety of measures that differ somewhat in configuration and function and fall under names such as: groins, dikes, retards, bendway weirs, and vanes.

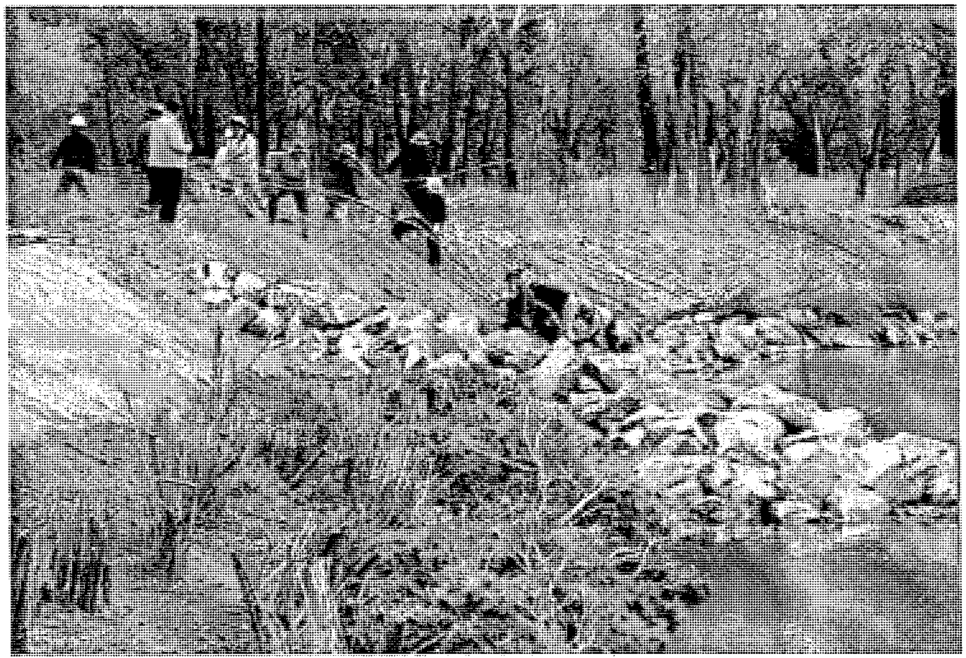


Figure 4. Incorporating irregular alignments, features such as spurs, and other habitat measures into a revetment can significantly improve habitat benefits

Although channel capacity at high flow is decreased initially with these structures, the channel will usually adjust by forming a deeper, though narrower, cross section and the ultimate effect may even be an increase in capacity. However, the extent of the adjustment cannot always be reliably predicted, even with physical or numerical models. Dikes and retards may be a safety hazard if the stream is used for recreation, and the esthetics often leave much to be desired, although vegetative growth lessens the impact in most regions.

Little or no bank preparation is involved for deflection structures. This reduces cost and riparian environmental impacts, simplifies the acquisition of rights-of-way, eliminates material disposal problems, and usually allows existing overbank drainage patterns to remain undisturbed. Existing channel alignment and geometry can be modified, although the changes may not always be beneficial or predictable. Indirect approaches usually increase geotechnical bank stability by causing deposition at the bank toe, although this process is not immediate enough or positive enough in all cases.

These structures offer the opportunity for incorporating a wide variety of environmental features. They can be designed to generate scour holes and may thus improve aquatic and terrestrial habitat by increasing diversity (Figure 5), although sometimes at the expense of shallow-water habitat. Conversely, they can be designed to trap sediments and create shallow-water areas near the streambank. In arid areas, the reduction of water surface area during low flows decreases evaporation, which is usually considered a benefit.

Figure 5. Flow deflection structures can create diverse habitats

An incidental effect of these two techniques might be to increase energy loss in bends at low flow, through both the modification of channel shape and the roughness introduced by the structures themselves. This would be beneficial on many streams, especially channelized ones that have suffered a lowering of flowlines with detrimental effects on aquatic habitat, riverside facilities, and the water table. A bend would in effect act as a very long grade control structure, without interfering with the natural flow of the stream, or if the structures are submerged below navigation depth, without interfering with navigation.

The principal design considerations for flow deflection structures are the structure length, height, orientation (angle to the bank), spacing and the type of material used for its construction. Unfortunately, little guidance is available for most of these parameters. The optimum height of flow deflection structures depends on the objectives of the project, the nature of the erosion at the site and the general channel geometry. Structures intended to generate a low-flow channel, disrupt secondary currents, protect against toe erosion, or placed along a straight reach generally need not be placed high above the bed of the stream. Many designers try to match the relative elevations of natural point bar features under these circumstances. On tight bends, or where the erosion occurs along the entire bank face, the structures generally need to be higher. They are commonly constructed with a top that slopes from nearly the top of the bank to only a fraction of the flow depth (about 20 percent) at the toe. In cases where impacts to the water surface elevation during flood flows are a concern, a balance between the structure length and height must be sought. Sand and gravel-bed streams that scour and adjust to the placement of deflectors can generally accommodate a flow blockage of only about 15 percent without experiencing impacts to the water surface profile.

Structure length is almost always determined with the objective of providing a desirable flowline for the thalweg and bank. When the structures are intended to trap sediments and promote the development of bars, natural bars on the stream can be used as a guide to help determine the necessary structure length. Structure lengths exceeding 30 percent of the channel width generally require more detailed analyses.

Spacing of deflection structures (groins, barbs, hardpoints) is generally based on the length of the structure and the width of the channel. This is one of the few parameters for which acceptable design guidelines exist. Table 9 presents guidelines found in the literature. These guidelines are intended to address the minimum necessary spacing to provide adequate stabilization.

The most contentious issue with respect to flow deflection structures seems to be the appropriate orientation. Some argue that the only effective orientation is upstream (and they may even identify a specific angle), while others point out that for every upstream-angled structure, a dozen have been constructed perpendicular to the flow or angled downstream and have worked effectively for decades. Simply put, this is an intractable issue at this point. Additional research is needed to define the limits of application and to formulate the appropriate guidance.

Incorporation of vegetation

Live plants can be incorporated into a riprap structure to enhance its habitat and aesthetic value (Figure 6). Live staking (i.e., planting live woody vegetation) of the riprap interstices is common, and root wads can be incorporated into a riprap structure. The woody vegetation enhances the habitat value of the structure, and as an added benefit, it can also increase bank stability and reduce chances of structure failure. In areas where aesthetics are especially important, the stone above the normal high water level can be covered with soil and planted in grasses.

Table 9
Recommended Groin Spacing (S) as a Function of Groin Length (L) and Stream Width (B) (from Fischenich and Allen (2000))

Author	Spacing S/L	Spacing S/B	Type of Bank	Remarks
United Nations(1953)	1		Concave	General practice
	2-2.5		Convex	General practice
Ahmad (1951)	4.29		Straight	
	<2.5		Curves	
Joglekar (1971)	2~2.5			Upstream groins
U.S. Army (1984a)	2			Mississippi River
Mathes (1956)	1.5			
Strom (1962)	3-5			
Acheson (1968)	3-4			Varies depending on curvature and stream slope
Altunin (1962)	4		Straight	$\alpha > 75°$
	3			for $0.005 \leq I \leq 0.01$
	2			for $I \geq 0.01$
Richardson et al. (1975)	2-6			For bank protection
	3-4			T- head groins for navigation channels
	1.5-2			Deep channel for navigation
Mamak (1956)	2-3	1		
Macura (1966)		0.5	Concave	
		5/4	Convex	
		3/4-1	Straight	
Jansen et al. (1979)		1-2		In constricted rivers
		0.5-1		
Blench et al. (1976)	3.5			
Copeland (1983)	> 3		Concave	
Akantisz et al. (1989)		0.9-1		For $\phi = 45°$-$50°$ R/B = 8- 13.5
				For $\phi = 55°$ R/B = 8
				For $\phi = 55°$ R/B = 13.5
Kovacs et al. (1976)	1-2			Danube River
Mohan and Agraval (1979)	5			Submerged groins of height one-third the depth
Maza Alvarez (1989)	5.1- 6.3		Straight	Sloping-crested groins for bank
	2.5- 4		Curves	Protection

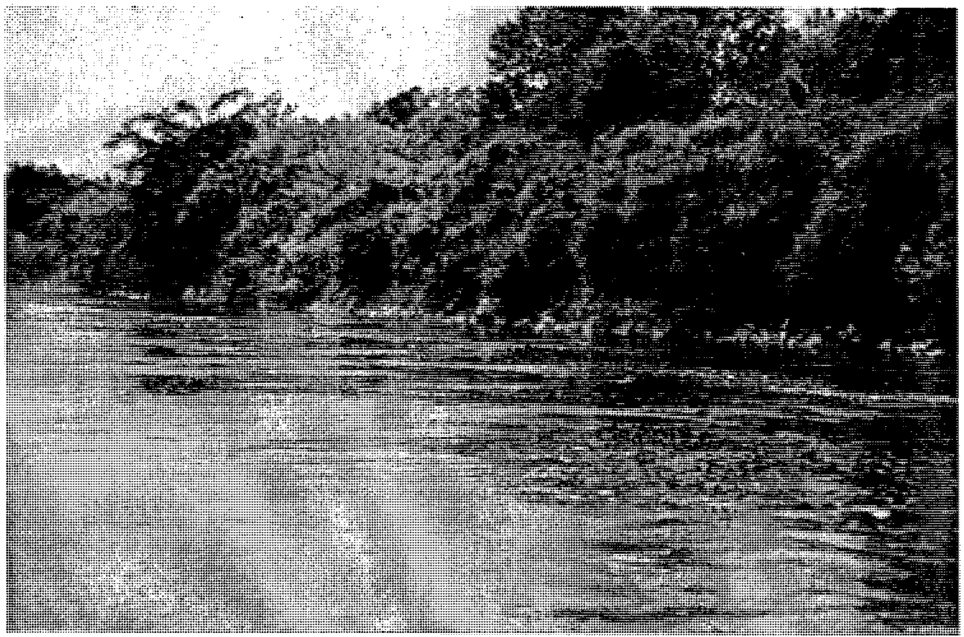


Figure 6. A combination of riprap in the toe section and woody vegetation on the upper banks often affords the best combination of stabilization and environmental benefits

Cuttings (live stakes) are the most beneficial means of adding vegetation to riprap structures. Cuttings should be prepared from woody plants that root adventitiously (e.g. Salix spp.), obtained from as near the site as possible, and should be free from obvious signs of diseases. To root effectively, cuttings must have good soil/stem contact, which can be difficult to achieve in many riprap structures, and must be placed to a depth sufficient to access groundwater during drought (Figure 7).

Woody cuttings or posts can be placed through many riprap sections using a stinger mounted on an excavator. The stinger creates a pilot hole into which the cutting is inserted. A newly patented procedure, shown in Figure 7, allows the installation through riprap of plants that are encapsulated with soil. This greatly improves survival, as a lack of soil contact within the riprap section is a leading cause of mortality for plants installed with a conventional stinger.

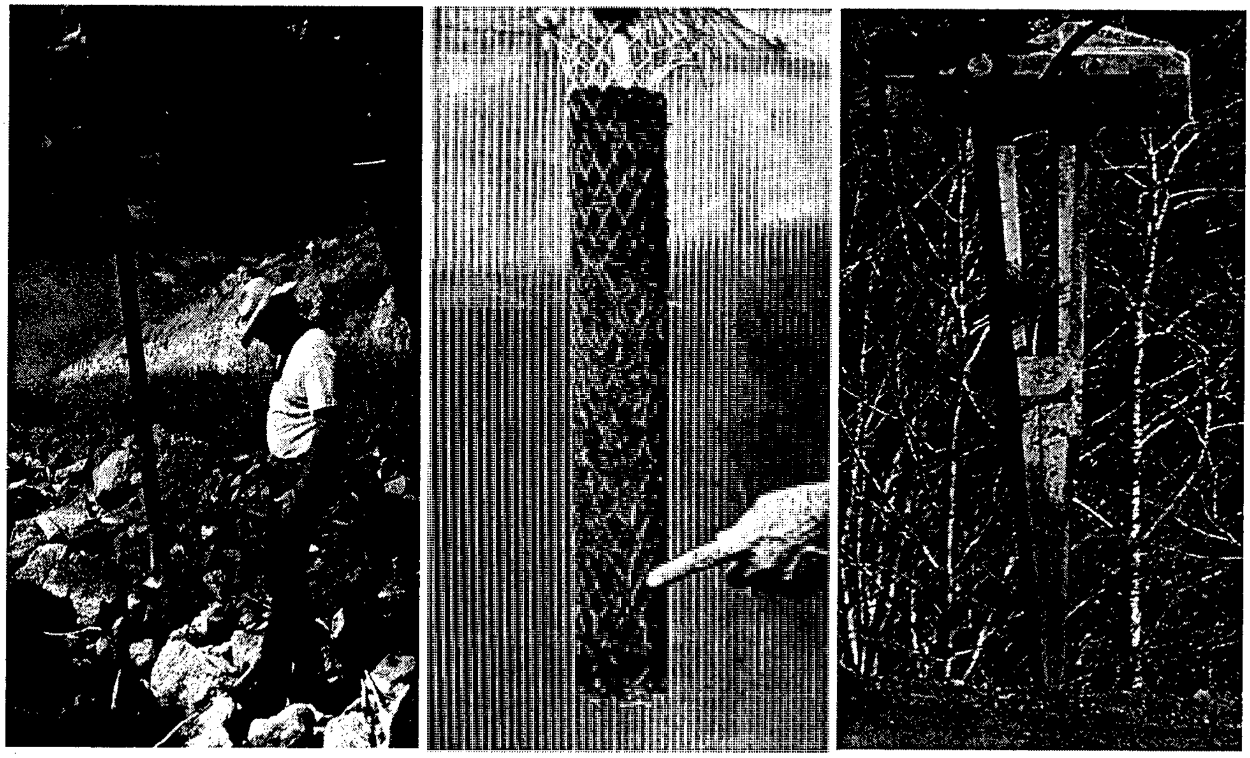


Figure 7. Conventional stinger application (left) and new stinger design (right) that uses soil-encapsulated plants (center) for insertion into riprap sections

Grade control

Low-head stone weirs (LHSW) are boulder structures that extend across the entire bed of a stream channel, and have an effective height of less than 3 ft (see Figure 8). The structures are primarily used to:

a. Prevent streambed degradation.

b. Reduce the energy slope to control erosion.

c. Create backwater for reliable water surface elevations.

d. Increase aquatic habitat diversity.

Unlike traditional grade control structures, which can adversely impact fish passage, habitat, recreation, and other environmental functions, LHSW are designed to provide stabilization and riffle and pool habitat, reoxygenate water, establish desired substrate characteristics, improve local bank stability, and enhance habitat diversity and visual appeal.

LHSW structures are flexible in that their design characteristics can be altered to achieve specific objectives and to address unique site characteristics. All LHSW structures are designed to remain stable under the full range of anticipated flow conditions, and to permit fish passage.

Figure 8. Low-head stone weir on the North Fork of the White River, Colorado

All LHSW structures obstruct the flow, creating a backwater area upstream that, at least temporarily, serves as a pool and reduces upstream erosion. Most concentrate the energy losses in a scour hole or dissipation basin immediately downstream of the structure. They can be designed to arrest bed degradation, or can have virtually no effect upon this phenomenon. The extent to which these and other characteristics are manifested depends upon the structure dimensions, shape and orientation, material, and the character of the stream.

A common configuration for conventional LHSW structures is a V-shaped structure with the apex pointing upstream, a depressed central region to serve as a low-flow notch, and boulders or riprap as a foundation with the ends keyed well into the banks. The dimensions can be varied for effect, but the structure height is commonly set at about the bankfull elevation at the banks, and is generally 0-2 ft above the bed at the apex.

The V-shape is intended to concentrate flows in the central portion of the channel and minimize the velocity gradient near the banks. The friction generated by the water flowing over the weir crest causes the streamlines to "bend" approximately perpendicular to the crest alignment. This phenomenon only persists for a narrow range of flow depths (generally less than one fifth the structure height), so on an LHSW with a sloping crest, the effect varies with discharge.

Construction

Construction methods used to place revetments should be carefully reviewed to ensure that they do not contribute to environmental degradation. Construction of a typical riprap structure requires extensive use of heavy equipment, and steps should be taken to minimize damage to riparian vegetation and instream habitats. When feasible, heavy equipment and materials should be transported to the site by barge. When barge transport is not feasible, movement of construction materials should be planned to minimize impacts to riparian vegetation outside the area of interest. Likewise, the work area at the site should be clearly defined, and no heavy equipment should be allowed outside that area. No more heavy equipment than necessary should be allowed in the streambed. Any other actions that can be taken to reduce damage to riparian or instream habitats should be considered.

When possible, riprap placement should be conducted so as to preserve existing trees along the bank that are not in danger of windthrow or toppling (Figure 9). Equipment operation on the upper banks should be regulated to minimize soil compaction in the riparian zone, which leads to plant mortality.

The common methods of riprap placement are hand placing; machine placing, such as from a skip, dragline, or some form of bucket; and dumping from trucks and spreading by bulldozer. Hand placement produces the best riprap revetment, but it is the most expensive method except when labor is unusually cheap. Steeper side slopes can be used with hand-placed riprap than with other placing methods. Where steep slopes are unavoidable (when channel widths are constricted by existing bridge openings or other structures, and when rights-of-way are costly), hand placement should be considered. In the machine placement method, sufficiently small increments of stone should be released as close to their final positions as practical. Rehandling or dragging operations to smooth the revetment surface tend to result in segregation and breakage of stone, and can result in a rough revetment surface. Stone should not be dropped from an excessive height as this may result in the same undesirable conditions. Riprap placement by dumping and spreading is the least desirable method, as a large amount of segregation and breakage can occur. In some cases, it may be economical to increase the layer thickness and stone size somewhat to offset the shortcomings of this placement method.

Timing of construction is important when managing for certain impacts. Construction activities should generally be avoided when they will disrupt spawning or nesting activities of nearby sensitive species. Designs that incorporate vegetation may require that the installation occur during the dormant season. Construction activities should generally be abandoned when flows are sufficient to heighten the risk of catastrophic failure.

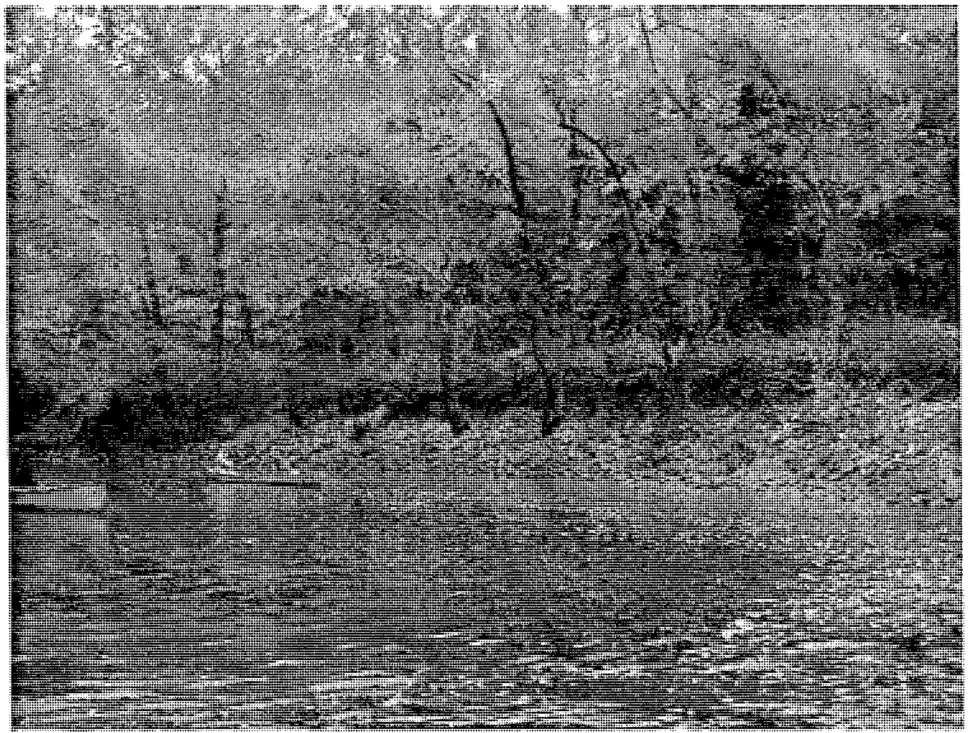


Figure 9. Careful placement of riprap can allow the preservation of mature trees along the banks and avoid impacts associated with their removal

4 Summary

Riprap usually refers to natural stone (i.e., cobbles, boulders, or broken stone), used for shoreline, streambank, or streambed armoring for erosion control. It has many advantages over other bank protection techniques including:

a. Low cost compared to other bank protection techniques.

b. Relatively simple construction with no special equipment or construction techniques necessary.

c. Easily repaired by adding stone to damaged areas.

d. Vegetation can often grow between the rocks, increasing stability of the bank and improving habitat value of the structure.

e. Riprap structures are flexible and are not impaired or weakened by settling or other minor adjustments.

When stone is readily available, riprap is one of the most economically effective bank stabilization techniques. There are numerous large- and small-scale negative ecological impacts associated with riprap bank stabilization structures, and construction of structures often results in severe damage to riparian and instream habitats.

Conversely, riprap structures also have ecological benefits and can even be used specifically to improve the quality of riverine habitat. Stabilizing stream channels with riprap can reduce sediment loads, improve water quality, and allow reestablishment of riparian vegetation. Stone used in riprap structures provides hard substrate habitat that can be important in some sand bed streams where it might be limited, and spaces between riprap stones provide velocity refuge and cover for aquatic invertebrates and small fishes.

Generally, streams with healthy riparian vegetation communities and the habitat features associated with such communities (shade, relatively stable undercut banks, large woody debris, etc.) will be harmed ecologically from the addition of riprap structures. On the other hand, habitat may be improved on streams where natural hard substrate is rare or lacking. Additionally, systems with excessive erosion due to anthropogenic causes are most likely to benefit ecologically from riprap.

Careful planning can minimize impacts due to construction, and design features can often be incorporated into riprap structures that will improve their habitat value. Although severe ecological impacts are often associated with riprap, it is still one of the most ecologically and aesthetically desirable techniques for erosion control and under certain conditions can be ecologically desirable.

The evidence presented in the literature strongly suggests that the impacts from riprap are very site-specific. The influence of riprap upon habitat even for a specific life stage of a given species depends upon the character of the system in which the riprap is placed, so care should be exercised in extrapolating habitat assessments from one system to another.

5 Annotated Bibliography[1]

Abt, S. R., Johnson, T. L., Thornton, C. I., and Trabant, S. C. (1998). "Riprap sizing at toe of embankment slopes," *Journal of Hydraulic Engineering* 124-7, 672-677.
(A pilot study was conducted to evaluate existing rock-sizing techniques for stabilizing transition toes of embankments. The results indicate that an embankment toe can be stabilized with a smaller median stone size than previously anticipated.) 1

Abt, S. R., Watson, C. C., Fischenich, J. C., and Peters, M. R. (1995). "Bank stabilization and habitat aspects of low-flow channels," *Land & Water, The Journal of the International Erosion Control Association*, January/February 1995, 10-13.
(Presents a bivariate habitat assessment technique and its application to three stream systems.) 6

Beamer, E. M., and Henderson, R. A. (1998). "Juvenile salmonid use of natural and hydromodified stream bank habitat in the mainstem Skagit River, northwest Washington," report prepared for U.S. Army Engineer District, Seattle, Skagit System Cooperative, LaConner, WA.
(This study paired natural and "Hydromodified" [riprap or other human-induced modification] over an 80-mile river length. No riprap or rubble was found in the natural banks, but woody cover was found in some of the hydromodified banks and tended to increase over time following modification. The amount of wood cover had a significant positive correlation with abundance of juvenile Chinook and coho salmon. There was also evidence that rainbow trout show a preference for riprap (but not rubble) and some woody cover, suggesting that they may not be adversely affected by hydromodification as long as the rocks are not too large). 3

[1] Each citation is appended with one or more of the following category numbers that indicate the major thrust of the reference:

1. Methods of construction/engineering aspects.
2. General impact considerations.
3. Salmonid-specific impacts.
4. Salmonid habitat/life requisites.
5. Evaluation of riprap pros and cons.
6. Assessment methods for riprap and riverine habitat.
7. Case studies/literature review.

Bingham, C. R. (1982). "Benthic macroinvertebrate study of a stone dike," *Environmental & Water Quality Operational Studies Information Exchange Bulletin*, E-82-4, Environmental Laboratory, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.
(The stone dikes of the lower Mississippi River have been shown to be high-quality environment for macroinvertebrates requiring a hard substrate. Average macroinvertebrate density of the stone dike substrate was 102,485 organisms/m^2 as opposed to an average of 865 organisms/m^2 from natural substrates.) 2,5

Binns, N. A., and Eiserman, F. M. (1979). "Quantification of fluvial trout habitat in Wyoming." *Transactions of the American Fisheries Society* 108, 215-228.
(This study developed a habitat quality index (HQI) for predicting trout standing crop in Wyoming streams. Eroding banks and stream velocity were two of nine habitat attributes that were used to develop a stream rating. Higher percentages of eroding banks and lower water velocities contributed to lower overall ratings. The HQI could be modified for other species.) 4,6

Binns, N. A. (1986). "Stabilizing eroding stream banks in Wyoming," Wyoming Game and Fish Department, Cheyenne, WY.
(This guidebook summarizes some key principles of river mechanics and details bank stabilization methods used on Wyoming streams. The structures and techniques have been successfully used to stabilize eroding banks on a wide variety of Wyoming streams.) 1,7

Bodie, R. (1998). "Waverly Park drainage channel improvements," *Land and Water* 42-6, 25.
(The Waverly Park channel, a typical vegetated drainage channel, had exceeded its flow capacity. The problem was solved with an erosion control system of modular concrete walls and articulating concrete blocks with a cost savings of 10 to 20 percent over the cost of conventional alternatives.) 1,7

Boelman, S. F., Stein, O. R., and Seal, R. (1997). "Hydraulic and geomorphic assessment of in-stream boulder clusters," *Proceedings of the Conference on Management of Landscapes Disturbed by Channel Incision*. 684-688.
(Much of the St. Regis River in western Montana has been relocated and/or channelized. Fishery improvement structures were installed in several miles of river reach between 1972 and 1982. Biological assessment in 1976 and 1982 concluded that random boulder clusters and associated scour pools were effective mitigation for loss of trout habitat.) 3,5

Boeters, R. E. A. M., Verheij, H. J., and van der Wal, M. (1991). "Environmental-friendly bank protections," *Environmental hydraulics*. Lee & Cheung (eds.), Balkema, Rotterdam, 1437-1442.
(With increased public awareness, more environmental-friendly solutions have been leading to greater attention for design criteria for protective structures allowing the presence of vegetation. This paper looks at other studies dealing with the current environmental bank protection research in the Netherlands.) 1

Buer, K., Forwalter, D., Kissel, M., and Stohler, B. (1989). "The Middle Sacramento River: Human impacts on physical and ecological processes along a meandering river," *Proceedings of the California Riparian Systems Conference Held in Davis, California on September 22-24, 1988: Protection, Management, and Restoration for the 1990's.* USDA Forest Service Gen. Tech. Rep. PSW-110, 22-32.
(This is an ongoing study that focuses on changes in bank erosion, bank composition, river length, depth, width, sinuosity, and floodplain deposition. Completed studies indicate that bank protection and dams have significantly affected the river habitat; reduction of salmon spawning gravel from freshly eroded banks was of special concern. While both the dams and riprap were implicated, it appears that the major causal effect was reduced erosion rates from lower flows associated with dam construction). 2,3

Burke, T. D., and Robinson, J. W. (1979). "River structure modifications to provide habitat diversity." *A national workshop on mitigating losses of fish and wildlife habitats.* General Technical Report RM-65, Colorado State University, 556-561.
(Discussion of beneficial and detrimental effects of Missouri River Bank Stabilization and Navigation Project and description of structure modifications used to improve fish and wildlife habitats, flood carrying capacity, and control of accretions. Methods include notched, rootless, and low elevation structures.) 1,2,5

Cabalka, D., and Trotti, J. (1996). "The grass-lined channel," *Erosion Control* 3-6, 42-50.
(Grass-lined channels (GLC's) provide a welcome alternative to conventional riprap and cast-in-place concrete linings. GLC's employ vegetation alone or in concert with other materials to cover the subgrade defining the shape of the channel.) 1

California Department of Fish and Game. (1983). "Sacramento River and tributaries bank protection and erosion control investigation – Evaluation of impacts on fisheries," Final Report.
(This study attempted to assess the potential impacts of bank protection measures on spawning, rearing, and food sources of Chinook salmon. Although no statistical difference was found between riprap and cutback areas with respect to total quantity of primary food organisms, the variability of the data was very high. Riprap areas contained only one third the number of salmon as the cutback areas. Additional studies were recommended to assess the impacts of bank protection on spawning gravels.) 3,4,7

Chamberlain, F. W., and Meyers, M. S. (1995). "A case study of the use of riprap in Rochester, Minnesota," *River, coastal and shoreline protection: Erosion control using riprap and armourstone.* John Wiley & Sons Ltd., 591-605.
(This paper presents a case study of the use of riprap for an ongoing flood control project. Primary concerns of safety, cost-effectiveness, reliability, and efficiency are addressed, along with considerations for the environmental and social aspects of the design. Design details and construction procedures are presented and discussed.) 1,2,7

Dardeau, E. A., Jr., Killgore, K. J., Jr., and Miller, A. C. (1995). "Using riprap to create or improve riverine habitat." *River, coastal and shoreline protection: Erosion control using riprap and armourstone.* John Wiley & Sons Ltd., 609-620.
(A general overview of the use of riprap is provided. Benefits include slowing or halting bank erosion thereby allowing recovery of natural vegetation, providing hard substrate for invertebrates [especially in alluvial systems], and increasing fish habitat for various life stages of many different fish species. Significant recommendations include specifying well-graded and sized riprap for each project, avoiding the use of riprap in areas of high sediment deposition, and monitoring the effectiveness of the riprap placement through quantification of changes in population and species composition.) 2,5

Derrick, D. L. (1997). "Harland Creek bank stabilization demonstration project," *Land and Water* 41-5, 22-25.
(Bendway weir, willow post, and longitudinal peaked stone toe protection bank protection methodologies were successfully applied to 14 eroding bends of a stream. Results show satisfactory project performance, with most reaches appearing stable and maturing quickly.) 1

Ecos, Inc. (1991). "Biological data report regarding Sacramento River Bank Protection Project impacts on winter-run chinook salmon," Report to U.S. Army Engineer District, Sacramento (Delivery Order No. 14, DACW05-88-D-0058).
(The purposes of this report were to 1] determine if the project will have adverse impacts on the winter run, 2] describe alternative mitigation measures that could be used in the project, and 3] identify cumulative effects of the project. Preliminary data indicated four to twelve times the density of salmon at natural banks as opposed to revetted banks. Degradation of rearing habitat is probably most attributable to reduced instream and overwater cover associated with loss of riparian vegetation and bank modification. While natural bank conservation is the preferred method for construction site review, it was recognized that an equitable balance between habitat and flood control protection must often be achieved. Six mitigation strategies and five bank protection methods are reviewed). 1,2,3,4,5

Field, J. J. (1997). "Channel modifications along an artificially constructed channel designed to provide salmon habitat." *Proceedings of the Conference on Management of Landscapes Disturbed by Channel Incision.* 822-827.
(Channel modifications along an artificially relocated reach of Schell Creek near Ferndale, WA damaged 68 percent of the 59 habitat improvement structures placed in the channel. Damage resulted from channel aggradation, bed erosion, and bank scour. All of the damage occurred in the first year during three bank-full or near-bank-full flows. Future attempts at stream location should allot time for the channel to reach a quasi-equilibrium condition before placing habitat structures in the channel. Evaluation of stream enhancement projects is critical if past mistakes are to be avoided in future projects.) 1,2

Fischenich, J. C. (1990). "Cumulative impacts analysis of a midwest fluvial system." *Proceedings, 1990 ASCE Hydraulic Engineering Conference.* San Diego, CA.
(Summarizes an analysis of the cumulative impacts of bank stabilization activities along 314 miles of the Platte River in Nebraska. The study defines limits of bank stabilization actions before causing impacts to sediment transport, bed level, and water surface elevation.) 2

Fischenich, J. C. (1991). "In-stream fish habitat improvement using structural measures: A case study on the South Platte River in Colorado." *Proceedings of the ASCE 24th Annual Water Resources Conference.* St. Paul, MN.
(Presents designs and analyses for eight streambank and instream erosion control measures and their impacts upon aquatic biota.) 1,2

Fischenich, J. C. (1994). "Design criteria for in-stream and streambank environmental features." *Proceedings of the 1994 ASCE National Conference on Hydraulic Engineering.* Buffalo, NY.
(Provides guidelines for the design of erosion control features so that environmental benefits and stability are optimized.) 1

Fischenich, J. C. (2002). "Impacts of riprap on aquatic and riparian ecosystems." In preparation, U.S. Army Engineer Research and Development Center, Wetlands Regulatory Assistance Program, Vicksburg, MS.
(Assesses the impacts of riprap in absolute terms and relative to other stabilization measures. The basis for assessment is a suite of 15 stream functions organized into categories of system dynamics, hydrologic character, sedimentation processes, biological support, and water quality.) 2, 5, 7

Fischenich, J. C., and Theriot, R. (1998). "Integrating new technologies into stream restoration." *Proceedings, Special Meeting of the Society of Ecological Engineering.* Paris, France, August 1998.
(Characterizes the state of knowledge in stream restoration, lists ongoing research efforts in the United States, and identifies future research needs). 7

Fischenich, C. J., and Allen, H. H. (2000). "Protocol for design of stream and floodplain restoration projects." *Association of State Wetland Managers Wetlands '99" Conference.* Annapolis, MD, October 25-27, 1999.
(Proposes a means for evaluating an impacted stream system to ascertain the cause, and a sequence of efforts to establish the appropriate restoration strategy. Focuses on stream instabilities.) 6

Frissell, C. A., Liss, W. J., Warren, C. E., and Hurley, M. D. (1986). "A hierarchical framework for stream habitat classification: Viewing streams in a watershed context," *Environ. Manage.* 10, 199-214.
(A general approach for classifying streams within the watersheds that surround them is articulated in this article. The framework provides a perspective that should allow a more systematic interpretation or description of watershed/individual stream relationships.) 6

Georgia Soil & Water conservation Commission. (1994). "Guidelines for streambank restoration."
(This manual was published to help owners of streamside property understand how to prevent and correct simple streambank erosion problems utilizing live plant material, structural measures, or a combination of both. The techniques described in this manual are intended for small stream systems with uncomplicated erosion problems.) 1,6

Goff, K. (1999). "Designer linings," *Erosion Control* 6-5, 58-65.
(The indiscriminate use of riprap to prevent scour and erosion, the lining of once-vegetated riverbanks with concrete, and too many locks, levees, and dams are perceived by most to be undesirable vestiges of past environmental folly. Therefore, it is time to reassess our traditional approaches to waterway stabilization and develop a systematic approach to the problem of streambank erosion. Combining armor-type protection with softer, bioengineered techniques is proving to be a viable approach to many embankment stabilization problems. In fact, the effectiveness of armoring techniques is improved when vegetation is included in stabilization projects.) 1,5

Gore, J. A., and Shields, F. D., Jr. (1995). "Can large rivers be restored," *BioScience* 45-3, 142-152.
(Although restoration of large rivers to a pristine condition is probably not practical, there is considerable potential for rehabilitation; that is, the partial restoration of riverine habitats and ecosystems. Renewal of physical and biological interactions between the main channel, backwaters, and floodplains is central to the rehabilitation of large rivers.) 7

Gore, J. A., and Hamilton, S. W. (1996). "Comparison of flow-related habitat evaluations downstream of low-head weirs on small and large fluvial ecosystems," *Regulated Rivers: Research & Management* 12, 459-469.
(The focus of within-channel restoration is the placement and construction of instream habitat structures to enhance the capture of organic detritus and aufwuchs, as well as colonization by macroinvertebrate and fish species. These instream structures also modify local hydraulic conditions to present preferred habitat to benthic invertebrates.) 1,2

Gorman, O. T., and Karr, J. R. (1978). "Habitat structure and stream fish communities," *Ecology*, 59-3, 507-515.
(Increasing community and habitat diversity followed stream-order gradients. Natural streams supported fish communities of high species diversity, which were seasonally more stable than the lower-diversity communities of modified streams. After disturbances such as channelization, seasonal peaks in species diversity attain levels typical of undisturbed streams.) 2

Haltiner, J. (1995). "Environmentally sensitive approaches to river channel management." *River, coastal and shoreline protection: Erosion control using riprap and armourstone.* John Wiley & Sons Ltd., 545-556. (Traditional engineering approaches to river channel erosion and flood hazards have focused on single-purpose, structurally intensive solutions such as monolithic riprap or concrete-lined channels, and drop structures. While often successful in reducing erosion, they provide little or no environmental, aesthetic, or recreational value. However, biotechnical approaches integrating riprap or other structural measures with vegetation provide a range of bank and channel stabilization methods consistent with a multi-objective approach.) 1

Hamilton, J. B. (1989). "Response of juvenile steelhead to instream deflectors in a high gradient stream." *Practical approaches to riparian resources management.* R. E. Gresswell, B. A. Barton, and J. L. Kershner, eds. American Fisheries Society, Montana Chapter, Bethesda, Maryland, 149-157. (This study examined the effects in high gradient streams of boulder/rock triangular wing deflectors on juvenile steelhead populations and stream channel characteristics. It was found that population increases did not occur in the high-gradient streams, whereas similar habitat improvements in low-gradient streams had been reported to show population increases. The author includes a literature review showing type of structure, population response, and gradient.) 1,3

Harvey, M. D., and Watson, C. C. (1988). "Effects of bank revetment on Sacramento River, California." Proceedings of the California Riparian Systems Conference Held in Davis, California on September 22-24, 1988: Protection, Management, and Restoration for the 1990's. USDA Forest Service Gen. Tech. Rep. PSW-110, 47-50.
(This study found that revetment of individual bends in the study area did not affect salmonid habitat adversely. It did not prevent the re-entrainment of point bar gravels or cause a coarsening of the point bar sediments. As long as an upstream source of gravel exists, then gravel recruitment from point bars will at least partially mitigate the loss of gravel sources on revetted banks). 3,5

Hemphill, C., Fischenich, J. C., Redigan, J. (1999). "Bioengineered streambank stabilization methods to reduce costs and improve habitat." *ASCE Int. Water Resources Engineering Conference, Seattle, WA.* August 8-11, 1999. (This paper describes the use of bioengineering techniques on the Sauquoit River in New York. Emphasizes the benefits of selected techniques versus conventional flood channel design and stabilization.) 5,7

Henderson, J. E., and Shields, F. D., Jr. (1984). "Environmental features for streambank protection projects," Technical Report E-84-11, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.
(This report provides guidance for incorporating environmental considerations into streambank protection projects. Each feature is discussed in terms of concept, the purpose or use of the feature, environmental considerations, limitations to use of the feature, performance history, and cost.) 1,7

Henderson, J. E. (1986). "Environmental designs for streambank protection projects," *Water Resources Bulletin* 22-4, 549-558.
(Adverse environmental impacts have been minimized and existing habitat and aesthetics have been enhanced through the development of new, innovative designs or modifications to existing designs and through use of construction and maintenance practices that promote habitat and aesthetics. Vegetation is most effective for bank protection when used in combination with structural components.) 1,2

Henszey, R. J., Wesche, T. A., and Skinner, Q. D. (1989). "Evaluation of the state-of-the-art streambank stabilization," Wyoming Department of Environmental Quality, Cheyenne, WY.
(This report reviews the current literature on streambank stabilization techniques, and compiles a state-of-the-art streambank stabilization bibliography. Classical treatments such as riprap, gabions, and tree revetments are included, but primary emphasis is on the characteristics and requirement of plant species suitable for bank revegetation in the semiarid western United States.) 1,2,5,7

House, R. A., and Boehne, P. L. (1986). "Effects of instream structures on salmonid habitat and populations in Tobe Creek, Oregon," *North American Journal of Fisheries Management* 6, 38-46.
(Differences between a young-alder stream section logged and cleared of large debris 20 years ago and a mature mixed-conifer section unlogged and containing large amounts of large woody debris were studied. Stream enhancement techniques were used to simulate large woody debris in the logged alder section to try to increase salmonid use. Large woody debris in the channel caused the development of secondary channels, meanders, pools, and undercut banks in the unlogged, mature-conifer stream section. Salmonid biomass was significantly greater in the mature-conifer than the young-alder section prior to stream enhancement. After enhancement, no significant difference was found. The study revealed that structure is most likely a more important factor than shade in governing a stream's capacity for producing salmonids.) 4,5

Inoue, M., and Nakano, S. (1999). "Habitat structure along channel-unit sequences for juvenile salmon: A subunit-based analysis of in-stream landscapes," *Freshwater Biology* 42, 597-608.
(This study examined habitat structure and habitat use by juvenile masu salmon in small streams in Northern Hokkaido, Japan. Results of the study suggest that habitat value should be determined not only by the habitat itself, but also by the characteristics of adjacent habitats. To that end, the use of the habitat by the fish should be studied in the context of the total in-stream landscape.) 4,6

Jackson, W. L., and Van Haveren, B. P. (1984) "Design for a stable channel in coarse alluvium for riparian zone restoration," *Water Resources Bulletin* 20-5, 695-703.
(Geomorphic, hydraulic, and hydrologic principles are applied in the design of a stable stream channel for a badly disturbed portion of Badger Creek, Colorado, and its associated riparian and meadow complexes. Gabion controls are recommended to help reduce the chance of lateral migration of the newly constructed channel. Controls are designed to allow for some vertical adjustment of the channel bed following increased bank stability due to revegetation.) 1

Jungwirth, M., Moog, O., and Muhar, S. (1993). "Effects of river bed restructuring on fish and benthos of a fifth order stream, Melk, Austria," *Regulated Rivers, Research and Management*, xx, 195-204.
(Studies conducted on 15 sections of seven different epipotamal streams established the impact of riverbed structures on fish communities. Reduced spatial heterogeneity due to river straightening resulted in decreasing numbers of fish species, stock density, and biomass. The variance of maximum depths used as a measure of habitat structure showed a highly significant correlation with the number and diversity of fish species.) 2

Karouna, N. (1991). "Stream restoration and bio-engineering techniques." *Restoring our home river: Water quality and habitat in the Anacostia*. College Park, MD.
(This paper is a comprehensive summary of structural methods that can be used to stabilize eroding streambanks and improve aquatic habitat within degraded urban stream systems. Many of the basic techniques were derived from work traditionally associated with the restoration of undeveloped watersheds.) 1

Keown, M. P. (1983). "Stream bank protection guidelines," U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.
(Streambank protection is a complex subject. There are no engineering manuals available with construction plans for bank protection projects that are guaranteed to work. However, this pamphlet provides general information needed to develop a systematic plan of action for solving a streambank protection problem.) 6

Klingeman, P. C. (1984). "Evaluating hydrologic needs for design of stream habitat modification structures." *Proceedings of the Pacific Northwest Stream Habitat Workshop, Arcata, CA.*
(This paper describes the needs and uses of basic hydrologic, hydraulic, and geomorphic information for designing stream habitat modification structures. Also, common types of stream habitat modification structures are described.) 1,6

Knudsen, E. E., and Dilley, S. J. (1987). "Effects of riprap bank reinforcement on juvenile salmonids in four western Washington streams," *North American Journal of Fisheries Management* 7, 351-356.
(Construction of riprap bank reinforcement, rather than the actual riprap itself, resulted in significant short-term negative effects. These effects increased as the severity of habitat alteration increased, and decreased as stream and fish size increased.) 1,3

Kondolf, G. M. (2000). "Some suggested guidelines for geomorphic aspects of anadromous salmonid habitat restoration proposals," *Restoration Ecology* 8, 48-56.
(Stream restoration projects to improve habitat for anadromous salmonids must be justified on the basis of geomorphology as well as biology. At the watershed scale, the geomorphic setting should be addressed by specifying changes in the flow regime or sediment yield; at the reach scale, geomorphic setting and process should be addressed by indicating the basis for design channel form and dimensions, calculating the frequency of bed mobilization, and assessing existing gravel quality for spawning. Provisions should be made for post-project performance evaluation.) 6

Li, H. W., Schreck, C. B., and Tubb, R. A. (1984). "Comparison of habitats near spur dikes, continuous revetments, and natural banks for larval, juvenile, and adult fishes of the Willamette River," Final Technical Completion Report, Project Number G864-05.
(Natural banks afford the best habitat for resident fishes on the mid-Willamette River because of their structural diversity. Spur dikes contain a greater diversity of habitats than continuous revetments in terms of velocities, depths, and cover. Spur dikes were intermediate between natural banks and revetments for species richness and densities of juvenile and larval fish. The number of species of adult fishes were similar in both spur dikes and continuous revetments, and greater for natural banks.) 4,7

Lisle, T. E. (1986). "Stabilization of a gravel channel by large streamside obstructions and bedrock bends, Jacoby Creek, Northwestern California," *Geological Society of America Bulletin* 97, 999-1011.
(This study showed how large obstructions and bedrock bends might affect the channel of a gravel-bed stream. The author states that the formation of bars and pools that is inherent in many gravel channels can thus be enhanced by using flow structures set up around large obstructions and bends formed of resistant materials.) 1

Lister, D. B., Beniston, R. J., Kellerhals, R., and Miles, M. (1995) "Rock size affects juvenile salmonid use of stream bank riprap," *River, Coastal and Shoreline Protection* 621-632.
(Assessment of habitat alteration included comparisons of juvenile salmonid densities along banks of large and small riprap, and natural cobble-boulder material. Densities were found to be greater along large riprap than small riprap banks. Placing large boulders along the toe of the bank appeared to increase rearing densities.) 1,4

Long, K. S., Nestler, J. M., Fischenich, J. C. (1997). "Survey of habitat-related channel features and structures in tailwaters," Technical Report EL-97-6, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS. (Summarizes a survey of instream and streambank features placed in tailwater reaches below reservoirs. Focuses on the impacts of the features to velocity and depth.) 2,7

Meyer, K. A., and Griffith, J. S. (1997). "Effects of cobble-boulder substrate configuration on winter residency of juvenile rainbow trout," *North American Journal of Fisheries Management* 17, 77-84.
(Cobble-boulder substrates were arranged in four different configurations to assess winter habitat use by rainbow trout (*Oncorhynchyus mykiss*). As the configuration was changed to create more concealment cover, the number of fish remaining in the enclosures increased significantly, even though the quantity of substrate remained unchanged. The results demonstrate the importance of the configuration of cobble-boulder substrate in determining its suitability as winter cover for rainbow trout.) 3,4

Michny, R., and Deibel, R. (1986). "Sacramento River Chico Landing to Red Bluff Project juvenile salmon study," Report prepared for U.S. Army Engineer District, Sacramento.
(This study was conducted to determine (1) the effect that rock revetment has on juvenile Chinook salmon, and (2) the usefulness of specific slope and substrate modifications, in lieu of standard revetment, as salmon rearing habitat. Salmon abundance was higher and more stable in the natural bank habitat. The revetted banks had the lowest abundance; the abundance of fish in the rearing bench habitat was higher than revetted areas, but also varied more). 3

Morrow, J. V., Jr., and Fischenich, J. C. (1999). "Habitat requirements for freshwater fish," Technical Note SR-99-6, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.
(With very few exceptions, stream restoration projects will have consequences for fish communities and the user groups associated with those communities. An organism's habitat must contain all the physical, chemical, and biological features needed for that organism to complete its life cycle. For fishes, this may include a variety of parameters such as water temperature regimes, pH, amount and type of cover, substrate type, turbidity, depth, water velocity, inorganic nutrient levels, and accessibility to migration routes. Habitat quality affects health of individual fishes, fish populations, and communities, and changes in habitat will usually result in changes to the species composition of a fish community. This technical note characterizes fish habitat and habitat requirements and preferences. It is designed to help water resource managers who may have little or no training in fishery science to better understand problems associated with freshwater fish habitat.) 2,6

Northcutt, G. (1998). "Hybrid structures turn hard armor green," *Erosion Control*, 5-7, 46-55.
(A new breed of structures blurs the distinction between hard armor and soft vegetative solutions. These hybrid solutions result in landscape features with natural-looking appearances that camouflage the structural integrity engineered into them.) 1

Nunnally, N. R., and Sotir, R. B. (1994). "Soil bioengineering for streambank protection," *Erosion* 1-5, 38-44.
(Streambank protection and stabilization measures work either by reducing the force of flowing water, by increasing the resistance of the bank to erosion, or by some combination of the two. Soil bioengineering systems are natural in appearance; they provide shade, overhanging cover, and organic debris for aquatic ecosystems; and they provide good riparian habitat.) 2,5

Pastorok, R. A., MacDonald, A., Sampson, J. R., Wilber, P., Yozzo, D. J., and Titre, J. P. (1997). "An ecological decision framework for environmental restoration projects," *Ecological Engineering* 9, 89-107.
(Ecosystem restoration projects require planning and monitoring, yet projects completed thus far have been planned on an ad hoc, consensus basis and are virtually ignored after revegetation at the site is complete. A process was developed to integrate a fundamental understanding of ecological principles into the existing project planning framework used by the U. S. Army Corps of Engineers in their growing role in restoration of aquatic habitats, but it should be applied to terrestrial habitats as well.) 6

Roper, B. B., Konnoff, D., Heller, D., and Wieman, K. (1998). "Durability of Pacific Northwest instream structures following floods," *North American Journal of Fisheries Management* 18, 686-693.
(The durability of 3,946 instream structures in 94 streams that had floods with return intervals exceeding 5 years was assessed. Overall structure durability was high. The higher magnitude of flood events resulted in reduced durability. Stream order also affected structure durability.) 6,7

Roper, B. B., and Scarnecchia, D. L. (1994). "Summer distribution of and habitat use by Chinook salmon and steelhead within a major basin of the South Umpqua River, Oregon," *Transactions of the American Fisheries Society*. 123, 298-308.
(Basin-wide summer habitat use by juvenile Chinook salmon and steelhead was determined through a combination of established stream habitat assessment methods. It was suggested that high stream temperatures in the lower reaches, habitat preferences of each species, and the interaction between the two species may have influenced the distribution and abundance of both species. The densities of the species varied substantially over the reaches, suggesting that habitat studies on streams with variable habitat and patchy fish distributions should be conducted over much larger areas of a basin than has typically been the case in past studies.) 4,6

Rosgen, D. L. (1997). "A geomorphological approach to restoration of incised rivers." *Proceedings of the Conference on Management of Landscapes Disturbed by Channel Incision*. 12-29.
(Geomorphologic concepts are described as integrated into incised river restoration projects. A range of restoration design concepts are presented, including returning the stream to its original elevation and reconnecting floodplains, widening the belt width to construct a new channel at the existing elevation, changing stream types, and stabilizing the existing incised channel in place.) 1

Schmetterling, D. A., and Pierce, R. W. (1999). "Success of instream habitat structures after a 50-year flood in Gold Creek, Montana," *Restoration Ecology* 7-4, 369-375.
(In this study, 66 structures made of natural materials (rock and wood) were constructed that resulted in 61 new pools in an attempt to restore salmonid habitat. Following an estimated 50-year recurrence interval flood, 55 (85 percent) of the structures remained intact and stable.) 1,4

Shields, F. D., Jr. (1991). "Woody vegetation and riprap stability along the Sacramento River mile 84.5-119," *Water Resources Bulletin* 27-3, 527-536.
(Stability of vegetated and bare riprap revetments along a Sacramento River reach during the flood of record was assessed. Damage rates for revetments supporting woody vegetation tended to be lower than for unvegetated revetments of the same age located on banks of similar curvature.) 6

Shields, F. D., Jr., and Hoover, J. J. (1991). "Effects of channel restabilization on habitat diversity, Twentymile Creek, Mississippi," *Regulated Rivers: Research & Management* 6, 163-181.
(Twentymile Creek was channelized prior to 1910, in 1938, and in 1966. Straightening and enlargement in 1966 resulted in channel instability, rapid bed degradation, and cross-section enlargement. Grade control structures and various types of streambank protection were constructed along the channel in the early 80's to restore stability. This paper studies the effects of restabilization of Twentymile Creek on aquatic habitats.) 7

Shields, F. D., Jr., Knight, S. S., and Cooper, C. M. (1995) "Rehabilitation of watersheds with incising channels," *Water Resources Bulletin* 31-6, 971-982.
(Rehabilitation measures, which are selected and laid out using a subjective integration of hydraulic and geotechnical stability analyses, include grade controls, bank protection, and small reservoirs. Aquatic habitat studies indicate that stone-protected stilling basins below grade-control weirs and habitats associated with drop popes and stone spur dikes are assets to erosion-damaged streams.) 2,7

Shields, F. D., Jr., Bowie, A. J., and Cooper, C. M. (1995). "Control of streambank erosion due to bed degradation with vegetation and structure," *Water Resources Bulletin* 31-3, 475-489.
(Combinations of vegetation and structure were applied to control streambank erosion along incised stream channels in northwest Mississippi. Tested configurations included eroding banks protected by vegetation alone, vegetation with structural toe protection, vegetation planted on regraded banks, and vegetation planted on regraded banks with toe protection. Designs involving riprap toe protection in the form of a longitudinal dike and woody vegetation appeared to be most cost-effective.) 1,2

Shields, F. D., Jr., Cooper, C. M., and Knight, S. S. (1995). "Experiment in stream restoration," *Journal of Hydraulic Engineering* 121-6, 494-502. (Aquatic habitats in a deeply incised sand-bed channel were modified by adding stone and planting dormant willow posts. Restoration structures were designed as complements to existing channel stabilization works. Fish numbers tripled, median fish size increased by 50 percent, and the number of species increased from 14 to 19.) 1,2

Shields, F. D., Jr., Cooper, C. M., and Testa, S., III. (1995). "Towards greener riprap: Environmental considerations from microscale to macroscale." *River, coastal and shoreline protection using riprap and armourstone*. John Wiley and Sons, Ltd., 558-573.
(Effects of riprap on riverine fish and macroinvertebrate habitats are strongly related to spatial scale. At the microscale (median stone diameter squared), riprap supports dense, diverse populations of macroinvertebrates that compare favorably to natural conditions. At the mesoscale (square of the channel width), hydraulic conditions created by the riprap can be either beneficial or detrimental to habitat quality; numerous citations support both views. Macroscale (reach) effects of riprap stabilization of the planform on the bed material size and cross-section shape have not been clearly established for all stabilized river systems. Studies were conducted on the Willamette and Sacramento Rivers regarding suggestions that extensive bank protection might reduce the gravel supply enough to impact gravel-spawning species.) 2,3,5,7

Shields, F. D., Jr., and Cooper, C. M. (1997). "Stream habitat restoration using spurs added to stone toe protection," *Proceedings of the Conference on Management of Landscapes Disturbed by Channel Incision*. 667-672.
(Longitudinal stone toe is one of the most reliable and economically attractive approaches for stabilizing eroding banks in incised channels. However, aquatic habitat provided by stone toe is inferior to that provided by spur dikes. Results indicated that spur addition resulted in modest increases in base flow, stony bank line, water width and pool habitat availability, but had only local effects on depth.) 1

Shields, F. D., Jr., Knight, S. S., and Cooper, C. M. (1997). "Rehabilitation of warmwater stream ecosystems following channel incision," *Ecological Engineering* 8, 93-116.
(A case study of two streams damaged by channel straightening and incision is presented. One stream was stabilized by using a metal sheetpiling weir and dormant willow post planting, while the other was treated with a stone weir, stone toe bank protection, and willow sprout planting.) 7

Shields, F. D., Jr., Knight, S. S., and Cooper, C. M. (1998). "Rehabilitation of aquatic habitats in warmwater streams damaged by channel incision in Mississippi," *Hydrobiologia* 382, 63-86.
(A study of incised warmwater stream rehabilitation was conducted to develop and demonstrate techniques that would be economically feasible for integration with more orthodox, extensively employed watershed stabilization techniques. During the study, two reaches were modified by adding woody vegetation and stone structure to rehabilitate habitats degraded by erosion and channelization. These experiments suggest that major gains in stream ecosystem rehabilitation can be made through relatively modest but well-designed efforts to modify degraded physical habitats.) 1,2,5

Shields, F. D., Jr., Knight, S. S., and Cooper, C. M. (1998). "Addition of spurs to stone toe protection for warmwater fish habitat rehabilitation," *Journal of the American Water Resources Association* 34-6, 1427-1436.
(Longitudinal stone toe is one of the most reliable and economically attractive approaches for stabilizing eroding banks in incised channels. However, aquatic habitat provided by stone toe is inferior to that provided by spur dikes. Test designs were performed that combined features of stone toe and spurs. Overall results indicated that spur addition resulted in modest increases in base flow stony bank line, water width, and pool habitat availability, but had only local effects on depth.) 1,5

Shirvell, C. S. (1990). "Role of instream rootwads as juvenile coho salmon (*Oncorhynchus kisutch*) and steelhead trout (*O. mykiss*) cover habitat under varying streamflows," *Canadian Journal of Fisheries and Aquatic Science* 47, 852-861.
(The effect of abundance and position of rootwads on their function as cover habitat for juvenile salmonids was investigated, primarily in relation to stream flow. Results of the study show that rootwads can provide both shelter and protection simultaneously for fish with different motives. It was suggested that the fish were not selecting positions because of an affinity for the rootwads themselves, but rather for the conditions caused by the rootwads.) 3,4,6

Shuler, S. W., Nehring, R. B., and Fausch, K. D. (1994). "Diel habitat selection by brown trout in the Rio Grande River, Colorado, after placement of boulder structures," *North American Journal of Fisheries Management* 14-1, 99-111.
(Brown trout distribution and microhabitat use were measured in 10 study sections on the Rio Grande River, Colorado, where three types of structures make from large boulders had previously been placed. On average, 65 percent of the adult brown trout and 69 percent of the juvenile brown trout observed were holding positions near structures.) 4

Sotir, R. B., and Nunnally, N. R. (1995). "Use of riprap in soil bioengineering stream bank protection." *River, coastal and shoreline protection: Erosion control using riprap and armourstone.* John Wiley & Sons Ltd., 577-589. (Streambank protection systems that incorporate woody vegetation provide additional benefits over those that do not. Soil bioengineering employs woody vegetation as the major structural component in streambank protection designs. Although in some applications adequate protection against erosion can be provided by vegetation systems alone, most applications require the use of some rock in conjunction with vegetation to prevent damage to the system that would impair its effectiveness or reduce its environmental benefit.) 1,5 *http://www.sotir.com/pubs/publist/riprap/riprap.html*

Sotir, R. B. (1998). "Soil bioengineering takes root," *Civil Engineering* July, 50-53.
(Soil bioengineering is a natural way to restore, rehabilitate, and reclaim watersheds that suffer from erosion. But it should be used in conjunction with other methods such as riprap, articulated block systems, geogrids, geotextiles, gabions, and cellular confinement systems.) 1

Stern, D. H., Stern, M. S., and Missouri Institute of River Studies. (1980). "Effects of bank stabilization on the physical and chemical characteristics of streams and small rivers: An annotated bibliography," U.S. Fish and Wildlife Service, Office of Biological Services, Report 80/12.
(This annotated bibliography contains 213 references indexed by key subject headings. It provides sources of information on the impacts of bank stabilization on small rivers and streams.) 2

Streubel, D. N., and Griffith, J. S. (1993). "Use of boulder pocket habitat by rainbow trout in Fall River," *Great Basin Naturalist* 53-2, 194-198.
(Abundance of rainbow trout in relation to characteristics of pockets created by boulders was studied in Fall River, southeastern Idaho. Results showed that maximum water depth and pocket surface area were both positive factors affecting trout density.) 4

Thorne, C. R., Reed, S., and Doornkamp, J. C. (1996). "A procedure for assessing river bank erosion problems and solution," R&D Report 28, National Rivers Authority, Almondsbury, Bristol BS12 4UD.
(The purpose of this report is to provide operational level guidance on the management of riverbank erosion problems for individuals concerned with flood defense, land drainage, local drainage, local planning, recreation, conservation, and navigation. Where a structural solution that involves physically protecting the bank is appropriate, there is now a wide range of designs and materials that may be used. These range from hard engineering materials to softer materials and combinations of the two.) 6

U.S. Army Corps of Engineers. (1989). "Environmental engineering for local flood control channels," Engineer Manual 1110-2-1205, Washington, DC. (This manual provides guidance for incorporating environmental considerations in the planning, engineering, design, and construction of flood control channels, levees, and associated structures. Channel modifications for flood and erosion control include clearing and snagging; channel straightening; channel enlargement; streambank protection; channel lining; and construction of grade control structures, culverts, levees, and floodwalls.) 1

U.S. Army Engineer District, Omaha and the State of Colorado (Colorado Water Conservation Board). (1992). "Colorado Erosion Control Manual." (This manual provides the necessary information for a local or regional planner or engineer to effectively address streambank erosion, either through design of remedial measures or by providing insight into the selection and oversight of a company consultant. In addition, the processes of evaluating an erosion problem, selecting appropriate solutions, designing structures, and performing monitoring and maintenance are described in this manual.) 1,6

U.S. Army Engineer Waterways Experiment Station and the Committee on Channel Stabilization of the U.S. Army Corps of Engineers. (1990). "Stability of flood control channels." (This document provides guidance for determining potential channel instability in flood control projects. It is intended to facilitate consideration of: the type and severity of erosion and sedimentation problems; the need for and scope of further hydraulic studies to address those problems; and design features to promote channel stability.) 6

U.S. Department of Transportation. (1979). "Restoration of fish habitat in relocated streams," FHWA-IP-79-3. (This manual provides guidelines for the design and construction of relocated channels, and describes measures that will lead to rapid recovery of new channels by natural processes. Good design and implementation of these measures can greatly reduce the adverse effects of stream relocation.) 1,2

U.S. Fish and Wildlife Service. (1992). "Juvenile salmon study, Butte Basin Reach, Sacramento River Bank Protection Project," report prepared for U.S. Army Corps of Engineers, Sacramento, California. (The main focus of this study was to determine the impact of various riprap modifications on the relative abundance of juvenile Chinook salmon. Four techniques were evaluated, with natural banks as the control: typical riprap protection with no mitigation features, riprap combined with gravel, riprap with rock fish groins, and riprap with gravel fish groins installed. Of the four, the gravel groins/riprap technique provided the best replacement value for juvenile salmon. However, all of the techniques were inferior in value to natural bank conditions). 1,3,5

Vannote, R. L., Minshall, G. W., Cummins, K. W., Sedell, J. R., and Cushing, C. E. (1980). "The river continuum concept," *Canadian Journal of Fisheries and Aquatic Science* 37,130-137.
(Physical variables within a river system present a continuous gradient of physical conditions. The river continuum concept provides a framework for integrating predictable and observable biological features of the lotic systems. Although the model was developed specifically in reference to natural, unperturbed stream ecosystems, it should accommodate many unnatural disturbances, as well.) 6

Ward, D. L., Nigro, A. A., Farr, R. A., and Knutsen, C. J. (1994). "Influence of waterway development on migrational characteristics of juvenile salmonids in the Lower Willamette River, Oregon," *North American Journal of Fisheries Management* 14, 362-371.
(Effects of development on the migration and behavior of juvenile salmonids were investigated in Portland Harbor in the Lower Willamette River. The waterway developments presented few risks to the migrating salmonids. It was suggested, however, that activities such as dredging and construction be avoided in the spring when juvenile salmon are in abundance.) 3

Wesche, T. A. (1985). "Stream channel modifications and reclamation structures to enhance fish habitat." *The restoration of rivers and streams*. Chapter 5, Butterworth Publishers.
(Many of the detrimental effects of channelization can be avoided, with little compromise in channel efficiency, by employing channel design guidelines that do not destroy the hydraulic and morphologic equilibrium that natural streams possess. These guidelines include minimal straightening; promoting bank stability by leaving trees, minimizing channel reshaping, and employing bank stabilization techniques; and, emulating the morphology of natural stream channels.) 1,2

White, R. J. (1991). "Resisted lateral scour in streams-its special importance to salmonid habitat and management." *American Fisheries Society Symposium*. 10, 200-203.
(The resisted lateral scour forms zones of high shear stress of current against streambanks in association with undercut banks, large backside rocks, and accumulations of large woody debris. Development and maintenance of the lateral scour pools and related features usually depend on the binding and roughening of banks by abundant riparian vegetation.) 1,3,4,5

6 Additional References

Abt, S. R., Johnson, T. L., Thornton, C. I., and Trabant, S. C. (1998). "Riprap sizing at toe of embankment slopes," *Journal of Hydraulic Engineering*, American Society of Civil Engineers 124(7), July.

Bisson, P. A., Nielson, J. L., Palmason, R. A., and Grove, L. E. (1982). "A system of naming habitat types in small streams, with habitat utilization by salmonids during low streamflow." *Acquisition and utilization of aquatic habitat inventory information.* N.B. Armantrout, ed., American Fisheries Society, 62-73.

Bottom, D. L., Howell, P. J., and Rogers, J. D. (1985). "The effects of stream alteration on salmon and trout habitat in Oregon," Oregon Department of Fish and Wildlife, Final Report, Fish Research Project 000-217, Portland, OR.

Buer, K. Y., Eaves, J. N., Scott, R. G., and McMillan, J. R. (1984). "Basin changes affecting salmon habitat in the Sacramento River." *Proceedings of the Pacific Northwest Stream Habitat Management Workshop*. T. J. Hassler, ed., Humboldt State University, Arcata, CA, 14-50.

Everest, F. H., and Sedell, J. R. (1984). "Evaluating effectiveness of stream enhancement projects." *Proceedings, Northwest Stream Habitat Management Workshop*. T. J. Hassler, ed., California Cooperative Fishery Research Unit, Humboldt State University, Arcata, CA, 246-256.

Everest, F. H., Beschta, R. L., Scrivener, J. C., Koski, K. V., Sedell, J. R., and Cederholm, C. J. (1987). "Fine sediment and salmonid production: A paradox." *Streamside management: Forestry and fishery interactions*. E. O. Salo, and T. W. Cundy, eds., University of Washington, Institute of Forest Resources, Contribution 57, Seattle.

Hall, J. D. (1984). "Evaluating fish response to artificial stream structures: Problems and progress." *Proceedings, Northwest Stream Habitat Management Workshop*. T. J. Hassler, ed., California Cooperative Fishery Research Unit, Humboldt State University, Arcata, CA, 214-221.

Knight, S. S., and Cooper, C. M. (1991). "Effects of bank protection on stream fishes." *Proceedings of the Fifth Federal Interagency Sedimentation Conference (FIASC)*. Federal Energy Regulatory Commission, Washington, DC, 13-34 – 13-39.

Lichatowich, J. A. (1989). *Habitat alteration and changes in abundance of coho (Oncorhynchus kisutch) and chinook salmon (0. tshawytscha) in Oregon's coastal streams.* Canadian Special Publication of Fisheries and Aquatic Sciences 105, 92-99.

Marcus, M. D., Young, M. K., Noel, L. E., and Mullen, B. A. (1990). "Salmonid-habitat relationships in the Western United States: A review and indexed bibliography," U.S. For. Ser. Gen. Tech. Rep. RM-188.

McCain, M., Fuller, D., Decker, L., and Overton, K. (1989). "Stream habitat classification and inventory procedures for Northern California," *FHR Currents: The Fish Habitat Relationships Technical Bulletin No. 1*, U.S. Forest Service, Pacific Southwest Region, Arcata, CA.

Mussetter, R. A. (1983). "Equilibrium slopes above channel control structures." *D. B. Simons Symposium on Erosion and Sedimentation.* In cooperation with Colorado State University and the American Society of Civil Engineers, Chapter 2, Bookcrafters, Inc., Chelsea, MI.

Reeves, G. H., and Roelofs, T. D. (1982). "Rehabilitating and enhancing stream habitat: Field applications," U.S. Forest Service General Technical Report PNW- 140.

Reichard, N. (1984). "Riparian habitat restoration: some techniques for dealing with landowners, livestock, and eroding stream banks." *Proceedings, Northwest Stream Habitat Management Workshop.* T. J. Hassler, ed., California Cooperative Fishery Research Unit, Humboldt State University, Arcata, CA, 128-137.

Tockner, K. (1991). "Riprap: An artificial biotope (impounded area of the River Danube)," *Internationale Vereinigung fuer Theoretische und Angewandte Limnologie* 24, 1953-1956.

Ward, B. R., and Slaney, P. A. (1981). "Further evaluation of structures for the improvement of salmonid rearing habitat in coastal streams of British Columbia." *Proceedings, Northwest Stream Habitat Management Workshop.* T. J. Hassler, ed., California Cooperative Fishery Research Unit, Humboldt State University, Arcata, CA, 99-108.

Warren, C. E. (1979). "Toward classification and rationale for watershed management and stream protection," U.S. Environmental Protection Agency, Ecological Research Series EPA-600/3-79-059.

7 Internet References/ Resources

http://swr.ucsd.edu/fmd/citguide.htm

(This link is to A Citizen's Guide to the 4(d) Rule for Threatened Salmon and Steelhead on the West Coast, published by the National Marine Fisheries Service Northwest and Southwest Regions, June 20, 2000. Provides information on compliance with the Endangered Species Act with reference to salmonids. Also provides links for additional information at the Federal and local levels.)

http://www.4sos.org/

(Provides sources of information and links to additional information for stream restoration and salmonid-specific issues. Primarily layman/activist oriented.)

http://www.cityofbellevue.org/utilities/shorezone/potential.htm

(The Utilities Department for the City of Bellevue, Washington published the Final Report on Effects of Shorezone Development - Potential Impacts of Shoreline Development. This particular site discusses the potential impacts of various types of shoreline development. It contains links to fish ecology, conclusions, and the Utilities homepage.)

http://nepa.eh.doe.gov/eis/eis-0265/Table_of_Contents.htm

(This link is to the Table of Contents page for the Bonneville Power Administration Watershed Management Program Final Environmental Impact Statement [DOE/EIS-0265].)

http://www.americanrivers.org/

(The AmericanRivers home page is primarily a layman-oriented site for obtaining information on, and becoming active in, a number of river issues nationwide, including the Columbia and Snake River systems. The "Tools and Additional Links" button provides access to both scientific and popular literature.)

http://www.epa.gov/OWOW/NPS/MMGI/Chapter6/ch6-2a.html

(This is Chapter 6 of the EPA Office of Water manual. This contains information on channelization and channel modification measures, including a discussion of riprap. Also contains links to other areas of interest on non-point source issues.)

http://www.epa.gov/OWOW/NPS/urbanize/report.html

(EPA Office of Water site with information on the hydrologic impacts associated with the urbanization of streams. Provides a literature cited section.)

http://www.state.ak.us/adfg/habitat/geninfo/webpage/liepitz.htm

(Executive summary of "An Assessment of the Cumulative Impacts of Development and Human Uses on Fish Habitat in the Kenai River" by Gary S. Liepitz. The purpose of the study was to identify and evaluate the cumulative impacts of development on Kenai River fish habitat.)

http://www.epa.gov/owow/estuaries/coastlines/spring98/rockbarb.html

(This site provides information from the EPA Office of Water on the use of rock barbs for enhancing fish habitat and water quality in the Tillamook Bay watershed. It provides a good "how-to" discussion of the use and construction of barbs in conjunction with riprap and vegetation. A discussion of pros and cons is provided.)

http://www.critfc.org/handbook/Bibliography.html

(The link is to a bibliography produced by the Columbia River Inter-Tribal Fish Commission. Many titles refer to salmonids, habitat, impacts, riparian and stream enhancements, etc. The home page of the Commission can also be accessed from this site.)

http://www.ijc.org/boards/wqb/hab_summ.html

(Provides extended abstracts for a number of presentations from the Habitat Session of the Practical and Cost-Effective Watershed Management Conference, Livonia, Michigan, May 3, 1996. Streambank stabilization, sediment control, and habitat enhancement are included among the topics.)

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)* April 2003	**2. REPORT TYPE** Final report	**3. DATES COVERED** *(From - To)*
4. TITLE AND SUBTITLE Effects of Riprap on Riverine and Riparian Ecosystems		**5a. CONTRACT NUMBER** **5b. GRANT NUMBER** **5c. PROGRAM ELEMENT NUMBER**
6. AUTHOR(S) J. Craig Fischenich		**5d. PROJECT NUMBER** **5e. TASK NUMBER** **5f. WORK UNIT NUMBER**
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army Engineer Research and Development Center Environmental Laboratory 3909 Halls Ferry Road Vicksburg, MS 39180-6199		**8. PERFORMING ORGANIZATION REPORT NUMBER** ERDC/EL TR-03-4
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Army Corps of Engineers Washington, DC 20314-1000		**10. SPONSOR/MONITOR'S ACRONYM(S)** **11. SPONSOR/MONITOR'S REPORT NUMBER(S)**

12. DISTRIBUTION / AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

Riprap (graded stone or crushed rock) is the most common material used in the stabilization of streambanks and shorelines. The continued use of this material as fill has been challenged in many locations by resource agencies due to concern for potential environmental impacts. U.S. Army Corps of Engineer Districts currently invest considerable manpower "interacting" with applicants and resource agencies on this issue. These efforts are hampered by a number of factors including inconsistencies in the literature, differences among ecosystems, conflicting agency missions and directives, and insufficient knowledge. Lacking a sound procedure for the objective evaluation of potential impacts and given the ambiguous nature of the literature on the matter, decisions are often clouded by biased judgment.

To address this problem, research was initiated under the Wetlands Regulatory Assistance Program (WRAP) to develop guidelines for the evaluation of the environmental impacts and benefits of riprap. The first step in this research was the formulation of an annotated bibliography of related publications that could serve as a basis for regional and site-specific evaluations, and that characterizes the current state of knowledge on this subject.

(Continued)

15. SUBJECT TERMS

Ecosystem	Riparian functions	Streambank stabilization
Riparian ecosystem	Riprap	
	Riverine ecosystems	

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			**19b. TELEPHONE NUMBER** *(include area code)*
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED		60	

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

14. (Concluded).

This document presents the results of the literature review. Citations are presented in the following sections, with an annotation summarizing the study findings. In addition to the annotation, each citation is appended with one or more category numbers that indicate the major thrust of the reference, based on the following:

1. Methods of construction/engineering aspects.
2. General impact considerations.
3. Salmonid-specific impacts.
4. Salmonid habitat/life requisites.
5. Evaluation of riprap pros and cons.
6. Assessment methods for riprap and riverine habitat.
7. Case studies/literature review.

Responses to November 15, 2013 National Wildlife Federation Comments

Comment 1: *The Corps Should Prepare a Supplemental Environmental Impact Statement to Evaluate All Operations and Maintenance Activities*

Response: The District is currently preparing a Supplemental Environmental Impact Statement (SEIS) for Regulating Works on the Middle Mississippi River. The SEIS will address river training structures, bankline revetments, dredging, the Chain of Rocks Canal and Locks (Locks 27), and the Low Water Dam (Dam No. 27).

Comment 2: *The construction of river training structures and placement of revetment are activities carried out under the Corps' authority to operate and maintain the Upper Mississippi River-Illinois Waterway Navigation System (UMR-IWW).*

Response: While these activities may be carried out throughout the Mississippi and Illinois Rivers under various authorities, the Regulating Works Project on the Middle Mississippi River has its own specific authority, separate from the rest of the UMR-IWW. The Environmental Assessment is being prepared in accordance with the authority for the Middle Mississippi River Regulating Works Project. Additional information on the authority for the Middle Mississippi River Regulating Works Project has been added to Section 1 of the EA, Purpose of and Need for Action.

Comment 3: *The Environmental Assessment, which evaluates construction of only one set of new river training structures, cannot satisfy the requirements of NEPA as it would constitute an impermissible piecemeal assessment of just one of many O&M activities designed to maintain a 9 foot navigation channel in one portion of the UMR-IWW.*

Response: Per NEPA, the Environmental Assessment is a site-specific analysis tiered off of the Programmatic 1976 Environmental Impact Statement (EIS) for the Middle Mississippi Regulating Works Project. The 1976 EIS is being supplemented due to new information and circumstances. New information and circumstances were considered in preparation of the Environmental Assessment. Additional information on the new information and circumstances considered has been added to Section 1 of the EA, Purpose of and Need for Action under Prior Reports.

Comment 4: *As also discussed below, the Environmental Assessment does not effectively evaluate the significant risks to public safety created by river training structures in the Mississippi River and does not meaningfully evaluate alternative approaches to reducing those risks. Extensive peer-reviewed science demonstrates that river training structures constructed to reduce navigation dredging costs have increased flood levels by up to 15 feet in some locations and 10 feet in broad stretches of the Mississippi River where these structures are prevalent. The flood height inducing effects of river training structures are so well recognized that the Dutch have "begun lowering dozens of wing dikes along a branch of the Rhine River and [have] plans* *to lower hundreds more as part of a nationwide effort to reduce flood risk in that river's floodplain." The Environmental Assessment, however, denies the validity of this science without providing a reasonable explanation for doing so.*

Response: The Corps of Engineers considers public safety to be of paramount importance when designing and evaluating projects. The agency believes strongly that the best available science shows that this project will not increase flood heights, and consequently the project does not pose a significant risk to public safety. The Corps, other federal agencies and academic institutions have performed extensive research dating back to at least the 1930s on the physical effects of river training structures, including their impact on flood heights, and have concluded that river training structures do not raise flood heights. These evaluations have fully considered all available literature and science. In an effort to update this research, the Corps commissioned independent technical reviews to examine if river training structures had measureable impacts on flood stages within the Middle Mississippi River. The conclusions of the independent technical reviews reaffirmed that river training structures do not raise the stage of the river and do not increase flood risk. Appendix A of the EA, Summary of Research on the Effects of River Training Structures on Flood Levels, has been expanded to more clearly articulate the District's position on the existing body of research on the topic.

Dikes (referred to in the Netherlands as 'groynes') are being modified in the Netherlands in conjunction with other measures including the lowering of the floodplain, deepening of the summer bed, creation of storage basins, levee relocation, creation of high water diversion channels, and obstacle removal as part of the "Room for the River" program. The structures used on the Middle Mississippi River are much different in size, spacing, and top elevation than those used by the Dutch; our structures have greater spacing, smaller crown width and are constructed to a much lower top elevation. Unlike the structures in the Netherlands, which have a crest elevation of top of bank, the structures on the Middle Mississippi River are constructed to an elevation of approximately one-half bankfull. Structures used on the Middle Mississippi River will still be lower than the modified structures in the Netherlands and research shows they have no impact on flood levels. The Corps continues to work with engineers from the Netherlands to monitor and study the impacts of dikes both in the Netherlands and the United States.

Comment 5: *Initiate a comprehensive reassessment of the activities carried out by the Corps to operate and maintain the UMR-IWW. This reassessment should be carried out through preparation of a comprehensive supplemental environmental impact statement and a general reevaluation of the Corps' O&M planning studies. This would help ensure that future O&M activities comply with current law, planning criteria and policies, including the requirements established by the Clean Water Act, the Endangered Species Act, the Water Resources Development Act of 2007, and the Fish and Wildlife Coordination Act.*

Response: The Regulating Works Project on the Middle Mississippi River has its own specific authority, separate from the rest of the UMR-IWW. The District is currently preparing a Supplemental Environmental Impact Statement for Regulating Works on the Middle Mississippi River. The Environmental Assessment is in compliance with all applicable laws and policies.

Comment 6: *Initiate a National Academy of Sciences study on the effect of river training structures on flood heights to inform the reassessment. A National Academy of Sciences review is critical for ensuring that the reassessment is based on the best possible scientific understanding of the role of river training structures on increasing flood heights, and for ensuring that the reassessment produces recommendations that will provide the highest possible protection to the public.*

Response: See response to Comment 4 above and the revised Appendix A. The Corps recognizes that a few academics do not agree with the conclusions of the Corps, other federal agencies, and academic institutions. Due to the extensive research supporting the conclusions of the Corps, we do not believe that there is sufficient evidence to warrant funding costly and time-consuming research efforts at this time. The Corps welcomes and will participate in any independent reviews or research funded by an outside agency or organization that will further the science and understanding of the impacts of river training structures on flood heights.

Comment 7: *Impose a moratorium on the construction of new river training structures pending completion of the reassessment process. As noted above, extensive peer-reviewed science demonstrates that river training structures have increased flood levels by up to 15 feet in some locations and 10 feet in broad stretches of the Mississippi River where these structures are prevalent. It is critical that additional structures are not constructed unless and until a comprehensive reassessment establishes that such construction will not contribute to increased flood risks to communities.*

Response: See responses to Comments 4 and 6 above. We have concluded that river training structures do not raise river stages and do not pose a significant risk to public safety. Therefore, we do not believe that a moratorium on the construction of new river training structures is warranted. Further, the 1976 EIS is being supplemented due to new information and circumstances, not due to substantial changes to the project. The fact that the 1976 EIS is being supplemented does not invalidate the document. New information and circumstances were considered in preparation of the Environmental Assessment to reach the conclusion that the project will not have a significant impact on the environment. Additional information on the new information and circumstances considered has been added to Section 1 of the EA, Purpose of and Need for Action under Prior Reports.

Comment 8: *To comply with NEPA, the supplemental environmental impact statement must evaluate, among other things: the impacts and cumulative impacts of operations and maintenance activities on the Upper Mississippi River and Illinois River ecosystems; the effect of those activities on flood heights and public safety; alternatives to those activities that could cause less harm to the environment, including alternative water level management regimes and removal and/or modification of river training structures; and mitigation for those impacts that cannot be avoided. An Environmental Assessment would likewise have to evaluate these impacts and alternatives.*

Response: The Environmental Assessment includes a cumulative impact assessment, addresses impacts on river stages, addresses reasonable alternatives for the project purpose, and concluded that no compensatory mitigation is required. Likewise, the Supplemental Environmental Impact Statement for Regulating Works on the Middle Mississippi River will provide an evaluation of all of these issues.

Comment 9: *The Environmental Assessment examines only two alternatives, the no action alternative and the proposed alternative. This is legally insufficient. A legally adequate environmental assessment must examine a full range of reasonable alternatives.*

Response: Section 2 of the EA, Alternatives Including the Proposed Action, has been expanded to more clearly articulate the alternatives analysis process utilized.

Comment 10: *The proposed alternative was developed using a Hydraulic Sediment Response model (HSR model). "An HSR model is a small-scale physical sediment transport model used by the District to replicate the mechanics of river sediment transport." Environmental Assessment at 5. However, such models cannot be relied upon to provide accurate planning information as they lack "predictive capability". Stephen T. Maynord, Journal of Hydraulic Engineering, Evaluation of the Micromodel: An Extremely Small-Scale Movable Bed Model (April 2006). Maynord concludes that because of the "lack of predictive evidence, the micromodel should be limited to demonstration, education, and communication."*

Response: The screening of alternatives using an HSR model is one of many steps in the river engineering process used to solve complex river engineering problems. Alternatives tested in the HSR model or other river engineering tools are initially developed by experienced river engineers using accepted river engineering guidance and practice. The alternatives considered are coordinated directly with all project partners including resource agencies, navigation industry, and other interested stakeholders to develop the recommended alterative. The recommended alternative proposed is then subject to technical review both within the District and Division before the final design.

HSR models have proven to be an effective tool to compare and analyze bathymetry and velocity trends of multiple alternatives. The purpose of HSR models is to predict the hydraulic response of the tested alternatives, not to analyze hydrologic impacts including water surface changes. HSR model technology has been used successfully in solutions for over 50 complex sediment transport problems on 9 different rivers spanning 10 Corps districts. Monitoring of approximately 20 constructed projects has demonstrated the predictive capability of HSR models.

HSR modeling technology and projects developed using HSR models have gained recognition through numerous design awards from the Corps, environmental and navigation organizations and the engineering community. Projects developed using HSR models have been the subject of national and international technical papers and presentations.

Comment 11: *The Environmental Assessment and Appendix A fail to analyze the full range of scientific studies that address the role of river training structures in raising flood heights. A list of 47 studies assessing the role of instream structures on increasing flood heights is attached to these comments at Attachment C. NWF requests that these studies be carefully reviewed and considered by the Corps and included in the record for this project. The Environmental Assessment also does not provide a reasonable explanation as to why it rejected the conclusions in those few studies related to increased flood heights from river training structures that it did evaluate.*

Response: See response to Comment 4 above and the revised Appendix A.

Comment 12: *The Environmental Assessment fails to adequately evaluate the environmental impacts of the proposed revetment. The project recommended in the Environmental Assessment includes 2.178 miles of revetment (11,500 linear feet). The Environmental Assessment, however, refers to only six studies on the impacts of revetment, the most recent of which was published in 1989 – 24 years ago. As the Corps itself has documented, a host of more recent studies are available. See, e.g, Fischenich, J.C. (2003), "Effects of Riprap on Riverine and Riparian Ecosystems", ERDC/EL TR-03-4, U.S. Army Corps of Engineer Research and Development Center. A copy of this report, which is itself already a decade old, is attached to these comments at Attachment D. Up to date science must be utilized to evaluate the adverse impacts of more than 2 miles of revetment.*

Response: More recent references, including Fischenich (2003), have been added to the Revetment Effects section of the Environmental Assessment. The updated information does not change the conclusions of the analysis.

Responses to February 16, 2012 National Wildlife Federation Comments to Assistant Secretary of the Army for Civil Works that were incorporated by reference into the November 15, 2013 National Wildlife Federation comment letter. Note: only those comments from the February 16, 2012 letter that differ substantially from the above comments and that are relevant to the Environmental Assessment are addressed here.

Comment 13: *O&M Activities Cause Significant Harm to People and Wildlife*

Response: The impacts of Corps O&M activities in support of navigation as well as a host of other factors affecting the human environment in the Mississippi River have been well documented for decades in a multitude of publications (including the 1976 Middle Mississippi River Regulating Works EIS). This understanding is clearly acknowledged and addressed in the EA.The Corps works closely with the public as well as state and federal natural resource agencies in order to avoid and minimize negative impacts to the greatest extent possible and to provide habitat diversity while still providing the required benefits to the navigation system.

Comment 14: *Since the EISs were completed there have been documented changes in rainfall, streamflow, and climate within the Mississippi River basin. This new information must be fully evaluated and taken into account to develop less damaging approaches to the O&M activities.*

Response: Climate change information has been added to the EA in Section 4, Environmental Consequences.

Comment 15: *Since the EISs were completed there have been significant changes to the laws and policies applicable to the Corps' O&M practices. These new laws and policies must be fully evaluated and strictly complied with to develop less damaging approaches to the O&M activities.*

Response: The Environmental Assessment and the proposed action are in compliance with all applicable laws and policies.

Comment 16: *The Corps must prepare a supplemental EIS because it has made substantial changes to the O&M activities evaluated in the existing EISs that are relevant to environmental concerns. 40 C.F.R. §1502.9(c)(1).*

For example, the Corps is constructing new types of river training structures that could not have been – and were not – evaluated in the original EISs. For example, while the EISs prepared in the 1970s provide a cursory review of the impacts of wing dikes, those EISs did not evaluate bendway weirs and chevrons as those types of river training structures had not yet been developed. The first bendway weirs were constructed in the Mississippi River in 1990 and the first blunt nose chevrons were constructed in the Mississippi River in 1993.

Response: The District is currently preparing a Supplemental Environmental Impact Statement for Regulating Works on the Middle Mississippi River. The 1976 EIS is not being supplemented due to a change in the Regulating Works Project but due to new circumstances and information relevant to environmental concerns of the Regulating Works Project on the human environment. The 1976 EIS discussed and analyzed generally the impacts of regulating works; such analysis still applies today. The Mosenthein/Ivory Landing Phase 4 EA describes and analyzes new circumstances and information relevant to the work area and includes these new circumstances and information in the analysis of potential impacts rather than relying solely on the general analysis in the 1976 EIS. Additional information on the new information and circumstances considered has been added to Section 1 of the EA, Purpose of and Need for Action under Prior Reports.

The types of river training structures used by the Corps vary broadly in their configuration. Common dike configurations are descriptively referred to as wing dikes, wing dams, L-dikes, spur dikes, trail dikes, weirs, w-dikes, s-dikes, notched wing dikes, round points and chevrons. However, the basic construction feature is the same, namely, rock structures engineered to manage the location of sediment deposition for the purpose of maintaining the 9-foot navigation channel within the Mississippi River. These structures are periodically constructed in response to areas of specific concern regarding the deposition of sediments, and are subject to subsequent alteration or removal if more efficiency can be gained in that manner. Since the river training structures used on the MMR are variations of the shape and elevation of those evaluated in the 1976 EIS and not new types of river training structures, we do not believe that there has been a substantial change to the O&M activities of the original EIS.

Appendix F. Agency and Tribal Government Coordination

Appendix F. Agency and Tribal Government Coordination

TABLE OF CONTENTS

Illinois Historic Preservation Agency Coordination Letter September 4, 2013	F1
Illinois Historic Preservation Agency Coordination Letter September 19, 2013	F2
Missouri DNR Water Quality Certification	F3
Illinois EPA Water Quality Certification	F7
Illinois DNR Office of Water Resources Permit	F9
District Tribal Coordination Letter	F13
Comments of the Delaware Tribe	F29
Comments of the Cherokee Nation	F30
Comments of the Kickapoo Tribe of Oklahoma	F31
Comments of the United Keetoowah Band of Cherokee Indians in Oklahoma	F32
Comments of the Winnebago Tribe of Nebraska	F33
Comments of the U.S. Fish and Wildlife Service	F34
District Responses to Agency and Tribal Government Comments	F38

Illinois Historic
Preservation Agency

FAX (217) 782-8161

1 Old State Capitol Plaza • Springfield, Illinois 62701-1512 • www.illinois-history.gov

Various Counties
East Carondelet to Brooklyn
New Construction of Revetments and Dike, Raise Existing Dike - Mosenthein-Ivory Landing Phase 4 River Training Structures
Between St. Louis Harbor River Miles 171 and 175, Existing Dike - 181.7L,
Proposed Dike - 173.4L,
IHPA Log #011082013

September 4, 2013

Michael K. Trimble, Ph.D., Chief
Department of the Army
St. Louis District, Corps of Engineers
Curation and Archives Analysis Branch (EC-Z)
1222 Spruce St.
St. Louis, MO 63103-2833

Dear Chief Trimble:

We have reviewed the documentation submitted for the referenced project in accordance with 36 CFR Part 800.4. Based upon the information provided, no historic properties are affected. We, therefore, have no objection to the undertaking proceeding as planned.

Please retain this letter in your files as evidence of compliance with section 106 of the National Historic Preservation Act of 1966, as amended. This clearance remains in effect for two years from date of issuance. It does not pertain to any discovery during construction, nor is it a clearance for purposes of the Illinois Human Skeletal Remains Protection Act (20 ILCS 3440).

If you have any further questions, please contact me at 217/785-5027.

Sincerely,

Anne E. Haaker

Anne E. Haaker
Deputy State Historic
Preservation Officer

Illinois Historic
Preservation Agency

1 Old State Capitol Plaza, Springfield, IL 62701-1512

FAX 217/782-8161

www.illinoishistory.gov

Various County PLEASE REFER TO: IHPA LOG #011082013
East Carondelet to Brooklyn
Between St. Louis Harbor River Miles 171 and 175, Existing Dike - 181.7L, Proposed Dike - 173.4L
COESTL
New Construction of Revetments and Dike, Raise Existing Dike - Mosenthein-Ivory Landing Phase 4 River Training Structures

September 19, 2013

Michael K. Trimble, Ph.D., Chief
Department of the Army
St. Louis District, Corps of Engineers
Curation and Archives Analysis Branch (EC-Z)
1222 Spruce St.
St. Louis, MO 63103-2833

Dear Chief Trimble:

Acre(s): 13.7 Site(s): 0
Archaeological Contractor: COESTL/Smith

Thank you for submitting the results of the archaeological reconnaissance. Our comments are required by Section 106 of the National Historic Preservation Act of 1966, as amended, and its implementing regulations, 36 CFR 800: "Protection of Historic Properties".

Our staff has reviewed the archaeological Phase I reconnaissance report performed for the project referenced above. The Phase I survey and assessment of the archaeological resources appear to be adequate. Accordingly, we have determined, based upon this report, that no significant historic, architectural, and archaeological resources are located in the project area.

Please submit a copy of this letter with your application to the state or federal agency from which you obtain any permit, license, grant, or other assistance. Please retain this letter in your files as evidence of compliance with Section 106 of the National Historic Preservation Act of 1966, as amended. This clearance remains in effect for two years from date of issuance. It does not pertain to any discovery during construction, nor is it a clearance for purposes of the Illinois Human Skeletal Remains Protection Act (20 ILCS 3440).

Sincerely,

Anne E. Haaker

Anne E. Haaker
Deputy State Historic
Preservation Officer

STATE OF MISSOURI
Jeremiah W. (Jay) Nixon, Governor • Sara Parker Pauley, Director
DEPARTMENT OF NATURAL RESOURCES
www.dnr.mo.gov

NOV - 1 2013

Mr. Kevin P. Slattery
Engineering and Construction Branch
and Project Management Branch
St. Louis District
U.S. Army Corps of Engineers
1222 Spruce St.
St. Louis, MO 63103-2833

St. Louis City
P-2853/2013-619/CES002748

RE: Mosenthien – Ivory Landing Between Mississippi River Miles 181.7 - 171.0

Dear Mr. Slattery:

The Missouri Department of Natural Resources' Water Protection Program has reviewed your request for Clean Water Act Section 401 Water Quality Certification (WQC) to accompany the U.S. Army Corps of Engineers' (USACE) Permit No. P-2853 in which your agency and/or contractors are proposing to place approximately 14,500 linear feet of revetment along the left descending bank of the Mississippi River and construct a single 550 foot rootless dike at River Mile 173.4.

The purpose of the dike structures is to reduce repetitive dredging and enhance alignment resulting in a dependable and safe navigation channel in the reach, while the purpose of the revetment is to reduce bank erosion and stabilize the planform. This is located between Mississippi River Miles 181.7 - 171.0. Structures will be constructed in the channel at an elevation of ½ bankfull and will be submerged most of the time at normal stage. All site access is via the river and all construction is from a floating plant.

A hydraulic sediment response (HSR) model was used to test multiple alternatives to determine the most effective solution that uses the least amount of stone fill material. The model tests also helped determine the solution that most enhances or preserves the existing aquatic habitat.

Should any comments provided during the public notice period which started October 18, 2013, and concludes on November 18, 2013, identify negative water quality issues, this WQC may be amended or revoked.

This WQC is being issued under Section 401 of Public Law 95-217, The Clean Water Act of 1977 and subsequent revisions. After further review of your application, this office certifies that the ongoing activities apparently will not cause the general or numeric criteria to be exceeded nor impair beneficial uses established in Water Quality Standards, 10 CSR 20-7.031, provided the following are met:

1. Unwanted dredged material and river water extracted from only the Mississippi River may be placed back into the Mississippi River. You shall not dispose of waste materials, water, or garbage below the ordinary high water mark of any other water body, in a wetland area, or at any location where the materials could be introduced into the water body or an adjacent wetland as a result of runoff, flooding, wind, or other natural forces.

2. Operations in the Mississippi River shall be conducted such that there will be no unreasonable interference with navigation by the existence or use of the activity.

3. A Total Maximum Daily Load (TMDL) was approved for Chlordane and Polychlorinated Biphenyls (PCB) on November 3, 2006, and allocations were set at zero pounds per day. No new Chlordane or PCB loading of the Mississippi River is allowed. Any excavated Chlordane or PCB contained sediment shall be disposed of at an appropriate upland disposal facility.

4. Fuel, oil and other petroleum products, equipment, construction materials and any solid waste shall not be stored below the ordinary high water mark at any time or in the adjacent floodway beyond normal working hours. All precautions shall be taken to avoid the release of wastes or fuel to streams and other adjacent waters as a result of this operation.

5. Petroleum products spilled into any water or on the banks where the material may enter waters of the state shall be immediately cleaned up and disposed of properly. Any such spills of petroleum shall be reported as soon as possible, but no later than 24 hours after discovery to the Missouri Department of Natural Resources' Environmental Emergency Response number at (573) 634-2436.

6. Only clean, nonpolluting fill shall be used. The following materials are not suitable for bank stabilization and shall not be used due to their potential to cause violations of the general criteria of the Water Quality Standards (10 CSR 20-7.031 (3)(A)-(H)):

    a. Earthen fill, gravel, broken concrete where the material does not meet the specifications stated in the Missouri Nationwide Permit Regional Conditions (http://www.nwk.usace.army.mil/Portals/29/docs/regulatory/nationwidepermits/2012/MORegCon.pdf) and fragmented asphalt, since these materials are usually not substantial enough to withstand erosive flows;
    b. Concrete with exposed rebar;

c. Tires, vehicles or vehicle bodies, construction or demolition debris are solid waste and are excluded from placement in the waters of the state;
d. Liquid concrete, including grouted riprap, if not placed as part of an engineered structure; and
e. Any material containing chemical pollutants (including but not limited to creosote or pentachlorophenol).

7. To the maximum extent practicable, use bioengineering methods for bank stabilization that minimize the amount of sediment and other pollutants entering the water ways. As opportunity allows, limit the amount of rock or other hard points while increasing the amount of native vegetation or a combination of rock and vegetation.

8. Best Management Practices shall be used during all phases of the project to limit the amount of discharge of water contaminants to waters of the state. The project shall not involve more than normal stormwater or incidental loading of sediment caused by construction disturbances.

9. Conduct activity at low flows and water levels to limit the amount of sediment disturbance caused by the heavy equipment. Limit the duration and extent that the heavy equipment is required to be in-stream.

10. The WQC is based on the plans as submitted. Should any plan modifications occur, please contact the Department to determine whether the WQC remains valid or may be amended or revoked.

Pursuant to Chapter 644.052.9, RSMo, commonly referred to as the Missouri Clean Water Law, this WQC shall be valid only upon payment of a fee of seventy-five dollars ($75.00). The enclosed invoice contains the necessary information on how to submit your fee. Payment must be received within fifteen (15) days of receipt of this WQC. Upon receipt of the fee, the applicable office of the USACE's will be informed that the WQC is now in effect and final.

You may appeal to have the matter heard by the Administrative Hearing Commission (AHC). To appeal, you must file a petition with the AHC within thirty (30) days after the date this decision was mailed or the date it was delivered, whichever date was earlier. If any such petition is sent by registered mail or certified mail, it will be deemed filed on the date it is mailed; if it is sent by any method other than registered mail or certified mail, it will be deemed filed on the date it is received by the AHC.

This WQC is part of the USACE's permit. Water Quality Standards must be met during any operations authorized. If you have any questions, please contact Ms. Stacia Bax by phone at (573) 526-4586, by e-mail at stacia.bax@dnr.mo.gov, or by mail at the Missouri Department of Natural Resources, Water Protection Program, Operating Permits Section, P.O. Box 176, Jefferson City, MO 65102-0176. Thank you for working with the Department to protect our environment.

Sincerely,

WATER PROTECTION PROGRAM

Chris Wieberg, Chief
Operating Permits Section

CW:sbp

Enclosure

c: Mr. Danny McClendon, U.S. Army Corps of Engineers, St. Louis District
Mr. Eddie Brauer, U.S. Army Corps of Engineers, St. Louis District
Mr. Jasen Brown, U.S. Army Corps of Engineers, St. Louis District
Ms. Donna Riebeling, St. Louis Regional Office
Mr. John Hoke, Water Protection Program, Watershed Protection Section
File Copy

ILLINOIS ENVIRONMENTAL PROTECTION AGENCY

1021 NORTH GRAND AVENUE EAST, P.O. BOX 19276, SPRINGFIELD, ILLINOIS 62794-9276 • (217) 782-2829

PAT QUINN, GOVERNOR LISA BONNETT, DIRECTOR

217/782-3362

NOV 1 4 2013

RECEIVED NOV 18 2013 BY:

St. Louis District
Corps of Engineers
Regulatory Branch
1222 Spruce Street
St. Louis, MO 63103

Re: U.S. Army Corps of Engineers (Monroe and St. Clair Counties)
Revetment Restoration and Construction of a Rootless Dike – Mississippi River Miles 165-182
Log # C-0508-13 [CoE appl. # 2013-619]

Gentlemen:

This Agency received a request on August 27, 2013 from the U.S. Army Corps of Engineers requesting necessary comments concerning the restoration of a revetment and construction of a rootless dike along the Mississippi River miles 165 to 182. We offer the following comments.

Based on the information included in this submittal, it is our engineering judgment that the proposed project may be completed without causing water pollution as defined in the Illinois Environmental Protection Act, provided the project is carefully planned and supervised.

These comments are directed at the effect on water quality of the construction procedures involved in the above described project and are not an approval of any discharge resulting from the completed facility, nor an approval of the design of the facility. These comments do not supplant any permit responsibilities of the applicant toward the Agency.

This Agency hereby issues certification under Section 401 of the Clean Water Act (PL 95-217), subject to the applicant's compliance with the following conditions:

1. The applicant shall not cause:
   a. violation of applicable water quality standards of the Illinois Pollution Control Board, Title 35, Subtitle C: Water Pollution Rules and Regulations;
   b. water pollution defined and prohibited by the Illinois Environmental Protection Act; or
   c. interference with water use practices near public recreation areas or water supply intakes.
2. The applicant shall provide adequate planning and supervision during the project construction period for implementing construction methods, processes and cleanup procedures necessary to prevent water pollution and control erosion.
3. Any spoil material excavated, dredged or otherwise produced must not be returned to the waterway but must be deposited in a self-contained area in compliance with all state statutes, regulations and permit requirements with no discharge to waters of the State unless a permit has been issued by this Agency. Any backfilling must be done with clean material and placed in a manner to prevent violation of applicable water quality standards.

4. All areas affected by construction shall be mulched and seeded as soon after construction as possible. The applicant shall undertake necessary measures and procedures to reduce erosion during construction. Interim measures to prevent erosion during construction shall be taken and may include the installation of staked straw bales, sedimentation basins and temporary mulching. All construction within the waterway shall be constructed during zero or low flow conditions. The applicant shall be responsible for obtaining an NPDES Storm Water Permit prior to initiating construction if the construction activity associated with the project will result in the disturbance of 1 (one) or more acres, total land area. An NPDES Storm Water Permit may be obtained by submitting a properly completed Notice of Intent (NOI) form by certified mail to the Agency's Division of Water Pollution Control, Permit Section.

5. The applicant shall implement erosion control measures consistent with the "Illinois Urban Manual" (IEPA/USDA, NRCS; 2012).

6. The proposed work shall be constructed with adequate erosion control measures (i.e., silt fences, straw bales, etc.) to prevent transport of sediment and materials downstream.

7. The fill material used in waters of the State shall be predominantly sand or larger size material, with <20% passing a #230 U. S. sieve.

8. Asphalt, bituminous material and concrete with protruding material such as reinforcing bar or mesh shall not be 1) used for backfill, 2) placed on shorelines/streambanks, or 3) placed in waters of the State.

This certification becomes effective when the Department of the Army, Corps of Engineers, includes the above conditions # 1 through # 8 as conditions of the requested approval issued pursuant to Section 404 of PL 95-217.

This certification does not grant immunity from any enforcement action found necessary by this Agency to meet its responsibilities in prevention, abatement, and control of water pollution.

Sincerely,

Alan Keller

Alan Keller, P.E.
Manager, Permit Section
Division of Water Pollution Control

SAK:TJF:0508-13.docx

cc: IEPA, Records Unit
IEPA, DWPC, FOS, Collinsville
IDNR, OWR, Springfield
USEPA, Region 5
Mr. Kevin Slattery, U.S. Army Corps of Engineers, St. Louis District

Illinois Department of
Natural Resources

One Natural Resources Way Springfield, Illinois 62702-1271
http://dnr.state.il.us

Pat Quinn, Governor
Marc Miller, Director

December 18, 2013

SUBJECT: Permit No. DS2013096
St. Louis Harbor Phase 4
Bank Stabilization & Sediment Control
Mississippi River (Miles 171.0 to 174.8)
St. Clair and Monroe Counties

U.S. Army Corps of Engineers
St. Louis District
ATTN: Kevin Slattery
1222 Spruce Street
St. Louis, Missouri 63103

Dear Mr. Slattery:

Enclosed is Illinois Department of Natural Resources, Office of Water Resources Permit No. DS2013096 authorizing the subject project. The proposed restoration of Dike 181.4L to its original condition is considered maintenance and repair which does not require IDNR/OWR authorization. This permit does not supersede any other federal, state, or local authorizations that may be required for the project.

If any changes of the permitted work are found necessary, revised plans should be submitted promptly to this office for review and approval. Also, this permit expires on the date indicated in Condition (13). If unable to complete the work by that date, the permittee may make a written request for a time extension.

Upon receipt and review of this permit and all of its conditions, please properly execute and return the attached acceptance blank within sixty (60) days from the date of the permit.

Please feel free to contact Jerry Bishoff of my staff at 217/558-6617 if you have any questions concerning this authorization.

Sincerely,

Michael L. Diedrichsen

Michael L. Diedrichsen, P.E.
Acting Manager, Downstate Regulatory Programs

MLD:JMB:crw
Enclosure
cc: IEPA, Permit Section, Division of Water Pollution Control

PERMIT NO. DS2013096
DATE: December 18, 2013

State of Illinois
Department of Natural Resources, Office of Water Resources

Permission is hereby granted to:

U.S. ARMY CORPS OF ENGINEERS
1222 SPRUCE STREET
ST. LOUIS, MISSOURI 63103

to construct a new rootless dike at River Mile 173.4L and place revetment on intermittent portions of the left descending bank of the Mississippi River between River Miles 171.0 and 174.8 in Sections 5, 7, 8, 18, and 19, Township 1 North, Range 10 West of the 3rd Principal Meridian in St. Clair and Monroe Counties,

in accordance with an application dated August 23, 2013, and the plans and specifications submitted with the application entitled:

ST. LOUIS HARBOR, RM 182 – 170, MOSENTHIEN – IVORY PHASE 4, LOWER MISSISSIPPI (Sheets G-003, C-001 – C-004);
TYPICAL RIVER TRAINING STRUCTURES, MISSISSIPPI RIVER MILES 300 – 0 (Sheets 1 – 1 & 2 - 2); and DESIGN JUSTIFICATION: MOSENTHIEN, MILES 181.7 – 171.0 (A four page narrative authored by Brad Krischel of the USACE, St. Louis District, Applied River Engineering Center).

Examined and Recommended:

Michael L. Diedrichsen

Michael L. Diedrichsen, Acting Manager
Downstate Regulatory Programs

Approval Recommended:

Arlan R. Juhl

Arlan R. Juhl, Director
Office of Water Resources

Approved:

Marc Miller by AJ

Marc Miller, Director
Department of Natural Resources

This PERMIT is subject to the terms and special conditions contained herein.

THIS PERMIT IS SUBJECT TO THE FOLLOWING CONDITIONS:

1) This permit is granted in accordance with the Rivers, Lakes and Streams Act "615 ILCS 5."

2) This permit does not convey title to the permittee or recognize title of the permittee to any submerged or other lands, and furthermore, does not convey, lease or provide any right or rights of occupancy or use of the public or private property on which the activity or any part thereof will be located, or otherwise grant to the permittee any right or interest in or to the property, whether the property is owned or possessed by the State of Illinois or by any private or public party or parties.

3) This permit does not release the permittee from liability for damage to persons or property resulting from the work covered by this permit, and does not authorize any injury to private property or invasion of private rights.

4) This permit does not relieve the permittee of the responsibility to obtain other federal, state or local authorizations required for the construction of the permitted activity; and if the permittee is required by law to obtain approvals from any federal or other state agency to do the work, this permit is not effective until the federal and state approvals are obtained.

5) The permittee shall, at the permittee's own expense, remove all temporary piling, cofferdams, false work, and material incidental to the construction of the project. If the permittee fails to remove such structures or materials, the Department may have removal made at the expense of the permittee.

6) In public waters, if future need for public navigation or other public interest by the state or federal government necessitates changes in any part of the structure or structures, such changes shall be made by and at the expense of the permittee or the permittee's successors as required by the Department or other properly constituted agency, within sixty (60) days from receipt of written notice of the necessity from the Department or other agency, unless a longer period of time is specifically authorized.

7) The execution and details of the work authorized shall be subject to the review and approval of the Department. Department personnel shall have the right of access to accomplish this purpose.

8) Starting work on the activity authorized will be considered full acceptance by the permittee of the terms and conditions of the permit.

9) The Department in issuing this permit has relied upon the statements and representations made by the permittee; if any substantive statement or representation made by the permittee is found to be false, this permit will be revoked; and when revoked, all rights of the permittee under the permit are voided.

10) In public waters, the permittee and the permittee's successors shall make no claim whatsoever to any interest in any accretions caused by the activity.

11) In issuing this permit, the Department does not ensure the adequacy of the design or structural strength of the structure or improvement.

12) Noncompliance with the conditions of this permit will be considered grounds for revocation.

13) If the construction activity permitted is not completed on or before December 31, 2016, this permit shall cease and be null and void.

PERMIT NO. DS2013***
U.S. ARMY CORPS OF ENGINEERS
MISSISSIPPI R., ST. CLAIR & MONROE CO.
ST. LOUIS HARBOR PHASE 4

PERMIT ACCEPTANCE

This Acceptance must be signed and returned to the address below to validate this permit. See Condition No. 8.

ILLINOIS DEPARTMENT OF NATURAL RESOURCES
OFFICE OF WATER RESOURCES
One Natural Resources Way
Springfield, Illinois 62702-1271

The undersigned permittee, personally, or if a corporation by its duly authorized officers, hereby accepts the permit bearing the above serial number subject to all conditions named therein, on this ____________day of ________________________, 20__.

____

By______________________________

By______________________________

If a corporation
affix seal here.

DEPARTMENT OF THE ARMY
ST. LOUIS DISTRICT CORPS OF ENGINEERS
1222 SPRUCE STREET
ST. LOUIS, MISSOURI 63103-2833

REPLY TO
ATTENTION OF:

August 16, 2013

Engineering and Construction Division
Curation and Archives Analysis Branch

COPY

Ms. Glenna J. Wallace, Chief
Eastern Shawnee Tribe of Oklahoma
P.O. Box 350
Seneca, Missouri 64865

Dear Chief Wallace:

This letter addresses the construction of river training structures in four major areas of the middle Mississippi River. River training structures are used to help reduce sediment deposition in the navigation channel and to limit the need for dredging. The U.S. Army Corps of Engineers proposes adding, or modifying, twenty seven (27) training structures.

This project is located along the Mississippi River from St. Louis Harbor, located in St. Clair County, Illinois, south along the Mississippi River to the counties of Alexander located in Illinois, and Mississippi located in Missouri (see Figure 1). See Figures 2–7 for the location and structure types to be constructed on both the Illinois and Missouri sides of the Mississippi River. Federal monies have been received for the river training structures. The project areas are located on private land both in Missouri and Illinois. This federal action falls under Section 106 of the National Historic Preservation Act (NHPA), in conjunction with the National Environmental Policy Act (NEPA) and the Clean Water Act (CWA). This project is being implemented to improve navigation, reduce dredging in the channel, and enhance wildlife habitat along the river.

In 1866 the Federal Government allocated funding for a 4-foot navigation channel between Minneapolis and St. Louis. In 1878 this channel was deepened to a 4.5-foot channel, and in 1907 it was once again deepened to a 6-foot channel. This was achieved using a system of wing and closing dikes in conjunction with river dredging. On July 3, 1930, the Rivers and Harbors Act was amended, and the lock and dam system along the upper Mississippi River, from Minneapolis to St. Louis, was put in place. However, the middle and lower sections of the Mississippi River, below St. Louis, remains an open river navigation channel.

Training structures will be incorporated into the pre-existing system of structures already located along the river. There are numerous types of river structures including dikes, revetments, and bendway weirs. Below is a description of the different types of training structures proposed for this project. See Table 1 for the proposed location and type of structure to be constructed.

- **Wing dikes** are the oldest form of river training structure. They are constructed from the bankline into the river generally at a perpendicular angle to the current (see Figure 2 for an example). They redirect the river's own energy to manage sediment distribution within the river channel. While the original dikes of the nineteenth century were largely pile structures, by the middle of the twentieth century many had been converted to stone-fill types.

- **L-dikes** are shaped like an L with the shorter arm extending to the bank and the longer arm parallel with the current (see Figure 2 for an example). They are used to restrict sediment-carrying bottom currents from moving into the area between a series of dikes.

- **Rootless dikes** are wing dikes that are not connected to the shore (see Figure 3 for an example). The gap between the structure and the bank promotes habitat diversity.

- **Diverter (or S-) dikes** are in-stream structures useful in creating secondary side channels as they capture water from the main channel and direct it toward areas of interest, while still providing enough roughness and constriction to maintain a navigable channel (see Figure 5 for an example). They cause minimal erosion along the bankline because eddies are formed at their downstream tip.

- **Chevrons** are blunt nosed arch-shaped structures constructed parallel to the river flow (see Figure 4 for an example). Like other dikes they utilize the energy of the river to redistribute water flow, but unlike traditional dikes that create a unidirectional deflection, they create a split flow. The riverside bank of the chevron directs flow to maintain the navigation channel while the other side directs flow toward the near bank region. These structures have been proven to be effective at promoting environmental diversity, including a low velocity habitat behind the chevron itself.

- **Revetments** are structures placed along the river bank to stabilize or protect the bank from erosion (see Figure 3 for an example). They are usually constructed out of stone, but a variety of other materials have been used including concrete-mat, willow mattresses, and gabions.

- **Bendway weirs** are submerged rock structure that are positioned from the outside bankline of a river-bend and angled upstream toward the river flow (see Figure 7 for an example). These underwater structures extend directly into the navigation channel and shift the current away from the outside bankline. This controls channel scouring, and reduces riverbank erosion, resulting in a wider and safer navigation channel through the bend without the need for periodic dredging.

Impacts to potentially significant historic properties are not anticipated during this work. River training structures are constructed via barge, without recourse to land access; therefore, any impact is limited to submerged cultural resources. Primary among these are historic period shipwrecks. Given the continual river flow and associated sedimentary erosion, deposition, and reworking, it is highly unlikely that any more ephemeral cultural material remains on the river bed. USACE has conducted shipwreck surveys during times of historic low water levels and maintains a database of known shipwrecks for the middle Mississippi. All proposed locations for river training structures are compared to the database, as well as aerial imagery from low water years, to ensure historical shipwrecks are not adversely impacted.

River embankments can potentially have adverse affects on cultural resources. As with other training structures they are conducted via barge, without recourse to land access. The placement of the rock on the shoreline, however, has the potential to affect any resources on that shoreline. With all embankment features, historical research is conducted on the proposed location to determine if the area is on recently accreted land or cut-banks in an existing, older, landform. Recently accreted land is highly unlikely to contain deeply buried cultural resources. If appropriate, pedestrian and/or shovel test surveys will be conducted to investigate all proposed locations. Should an inadvertent discovery of human remains occur, then state law will be followed, and work will stop within the area of the discovery. Tribes will be notified, and any human remains will be treated with respect and dignity. The following Federally recognized tribes are being notified of this project.

Absentee-Shawnee Tribe of Oklahoma
Eastern Shawnee Tribe of Oklahoma
Shawnee Tribe
Cherokee Nation
United Keetoowah Band of Cherokee of Oklahoma
Delaware Nation, Oklahoma
Delaware Tribe of Indians, Oklahoma
Citizen Potawatomi Nation
Forest County Potawatomi Community
Match-e-be-nash-she-wish Band of Potawatomi of Michigan
Hannahville Indian Community
Nottawaseppi Band of Huron Potawatomi
Pokagon Band of Potawatomi
Prairie Band Potawatomi Nation
Ho-Chunk Nation of Wisconsin
Winnebago Tribe of Nebraska
Iowa Tribe of Kansas and Nebraska
Iowa Tribe of Oklahoma
Kickapoo Traditional Tribe of Texas

Kickapoo Tribe of Oklahoma
Kickapoo Tribe of Indians of Kansas
Sac & Fox Nation of Oklahoma
Sac & Fox Nation of Missouri in Kansas and Nebraska

Sac & Fox Tribe of the Mississippi in Iowa
Miami Tribe of Oklahoma
Osage Nation of Oklahoma
Peoria Tribe of Oklahoma
Quapaw Tribe of Indians, Oklahoma

The U.S. Army Corps of Engineers, St Louis District is requesting you review the maps and information about this project and notify our office if you have any concerns such as a traditional cultural properties or sacred sites that are located within or near the construction sites. Please notify our office no later than October 4, 2013, if you have any areas of concern. If you have any questions regarding this matter, please contact Ms. Roberta L. Hayworth, Native American Coordinator directly at (314) 331-8833, or by electronic mail at roberta.l.hayworth@usace.army.mil. Thank you in advance for your timely review of this request.

Sincerely,

Michael K. Trimble, Ph.D.
Chief, Curation and Archives Analysis Branch

COPY

Enclosures

Copy Furnished:
Mr. Joseph Blanchard

COPY

Major Reach	Localized Reach	Work	County	State
Mosethein-Ivory Landing Phase 4 (RM 195-154)	St Louis Harbor	Revetment RM 175-171	St. Clair	IL
		Raise Dike 181.7L	St. Clair	IL
		Dike 173.4L	St. Clair	IL
Eliza Point/Greenfield Bend Phase 3 (RM20-0)	Bird's Point (RM 4-0)	Rootless Dike 3.0L	Alexander	IL
		Weir 2.6R	Mississippi	MO
		Weir 2.5R	Mississippi	MO
		Weir 2.3R	Mississippi	MO
		Weir 2.2R	Mississippi	MO
Grand Tower Phase 5 (RM90-67)	Crawford Towhead (RM 75-71)	Chevron 73.6L	Union	MO
		Dike Extension 72.9L	Union	MO
		Chevron 72.5L	Union	MO
	Vancil Towhead (RM 70-66)	Weir 69.15R	Cape Girardeau	MO
		Weir 68.95R	Cape Girardeau	MO
		Weir 68.75R	Cape Girardeau	MO
		Diverter Dike 68.10L	Union	IL
		Diverter Dike 67.80L	Union	IL
		Diverter Dike 67.50L	Union	IL
		Repair Dike 67.80L	Union	IL
		Shorten Dike 67.30L	Union	IL
		Shorten Dike 67.10L	Union	IL
		600 feet Revetment	Union	IL
Dogtooth Bend Phase 5 (RM 40-20)	Bumgard (RM 33-27)	Weir 34.20L	Alexander	IL
		Weir 34.10L	Alexander	IL
		Weir 32.50L	Alexander	IL
		Weir 32.40L	Alexander	IL
		Weir 32.3L	Alexander	IL
		Weir 32.2L	Alexander	IL
		Shorten Dike 32.0L	Alexander	IL
		Extend Dike 31.8L	Alexander	IL
		Extend Dike 31.6L	Alexander	IL
		Dike 31.6R	Scott	MO
		Extend Dike 31.4L	Alexander	IL
		Extend Dike 31.2L	Alexander	IL
		Extend Dike 31.1L	Alexander	IL
		Weir 30.80R	Scott	MO
		Weir 30.70R	Scott	MO

Table 1

Proposed FY 2014 river training structure projects

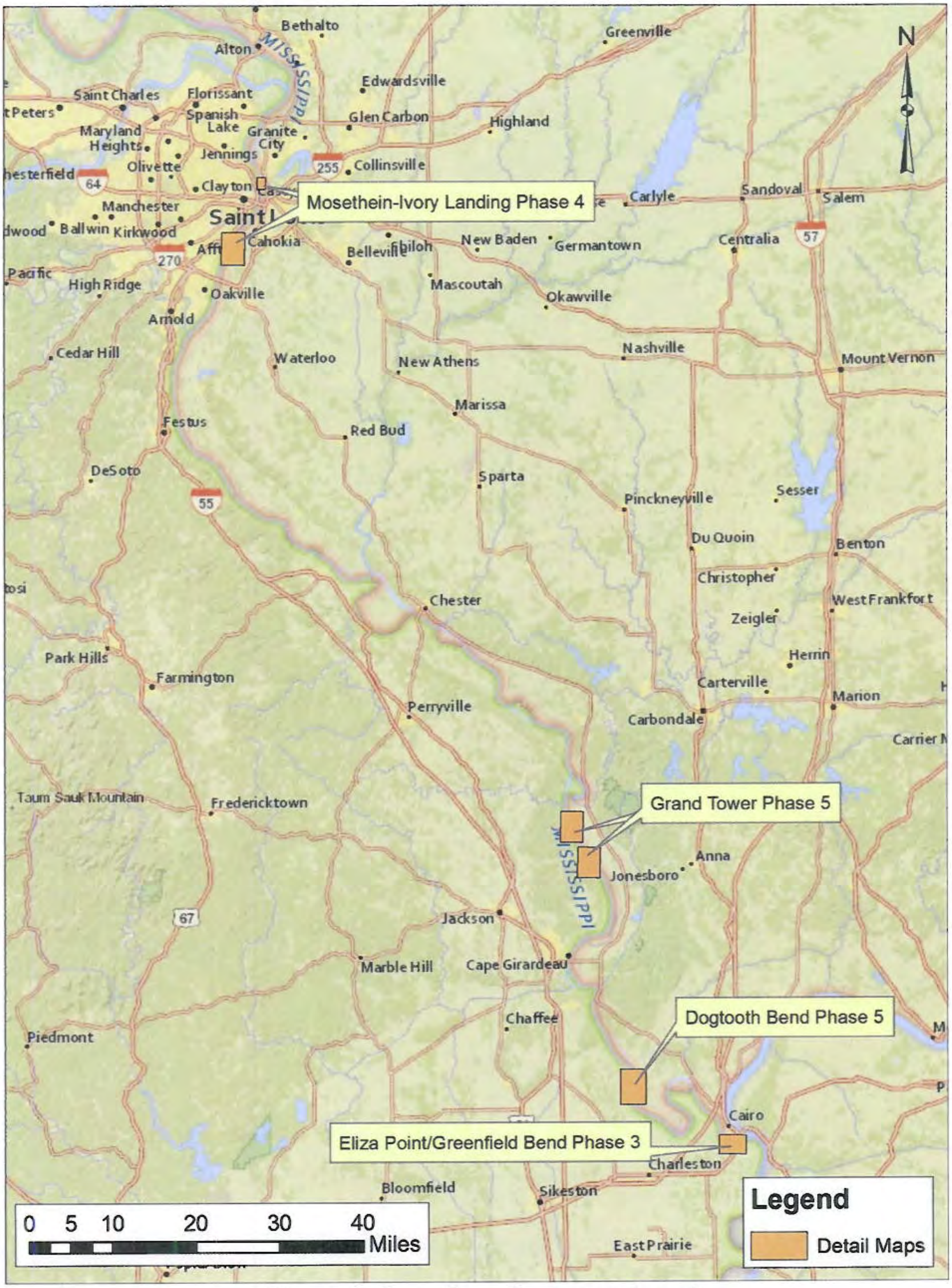


Figure 1. Location of proposed work.

Figure 2. Location of Dike 181.7L in St. Louis Harbor.

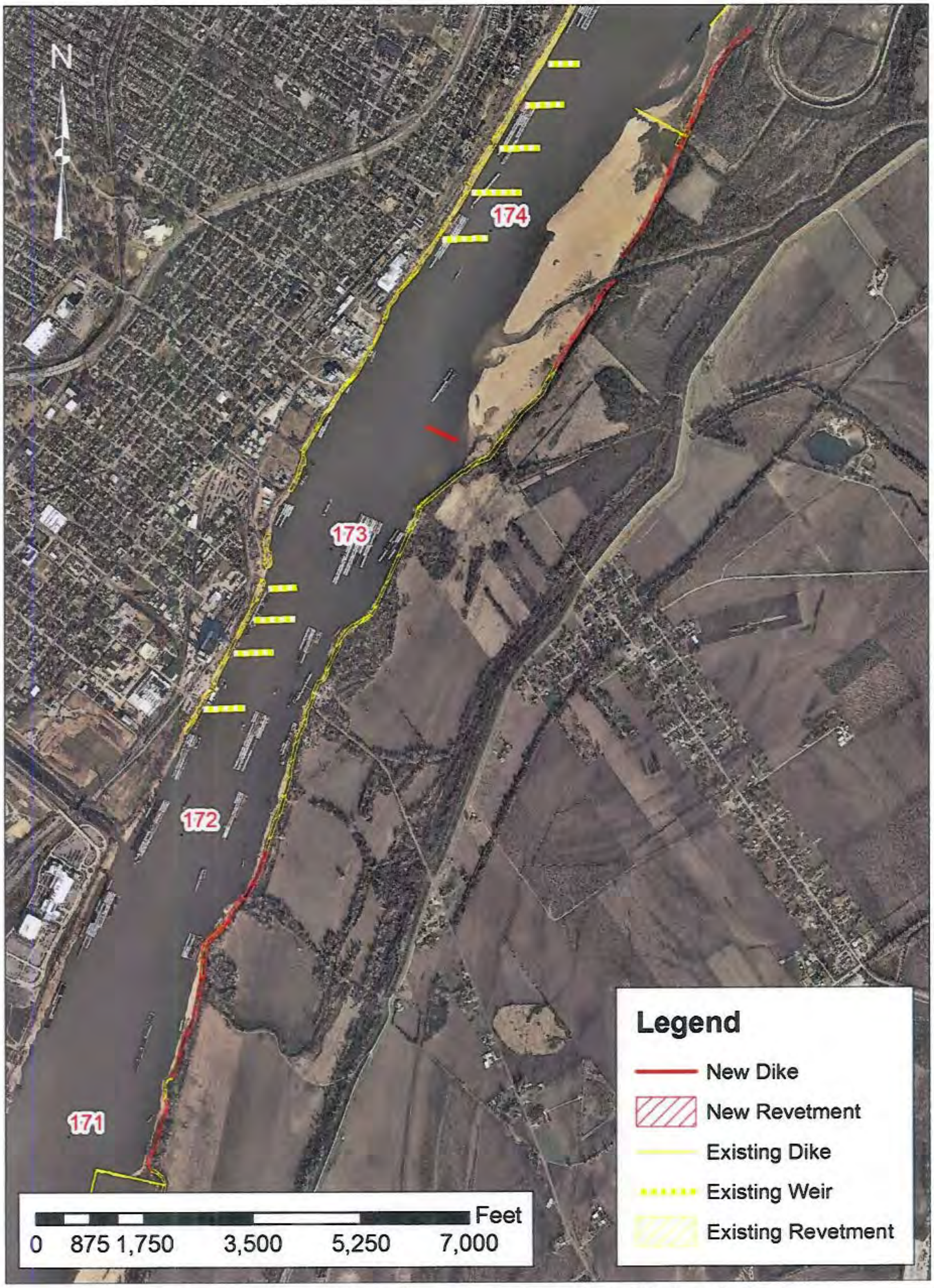


Figure 3. Location of proposed work in St. Louis harbor.

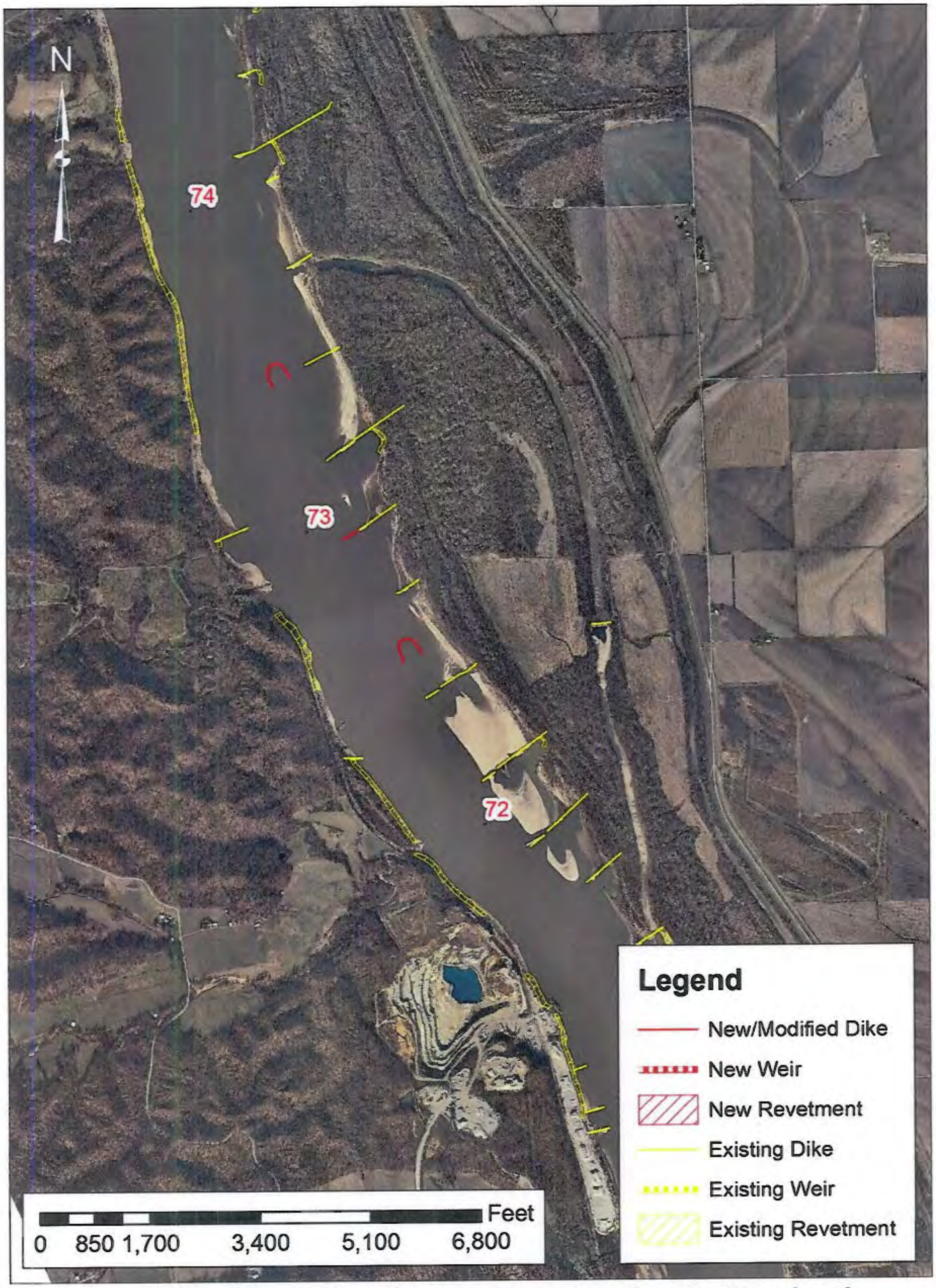


Figure 4. Location of proposed work at Crawford Towhead.

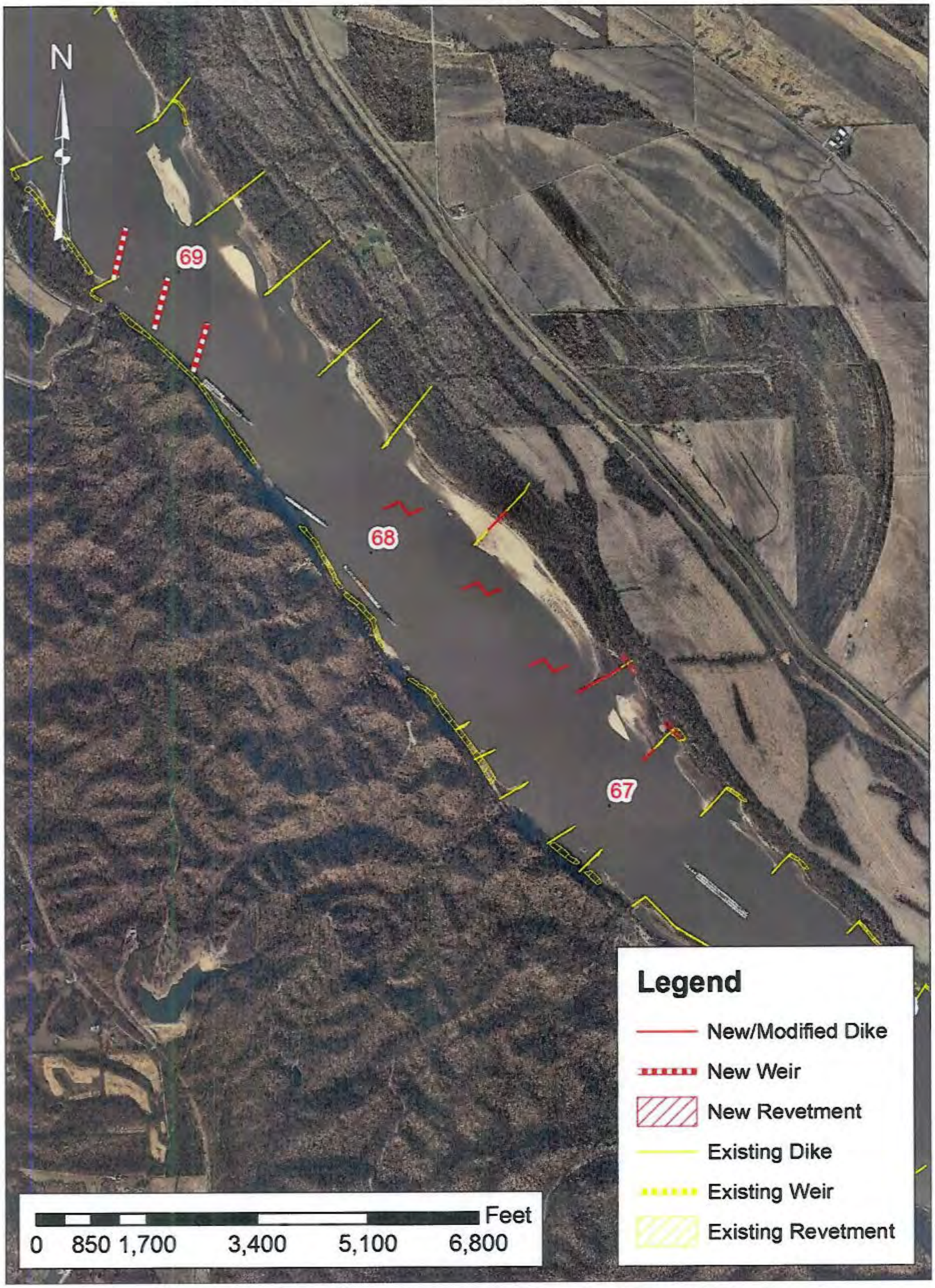


Figure 5. Location of proposed work at Vancil Towhead.

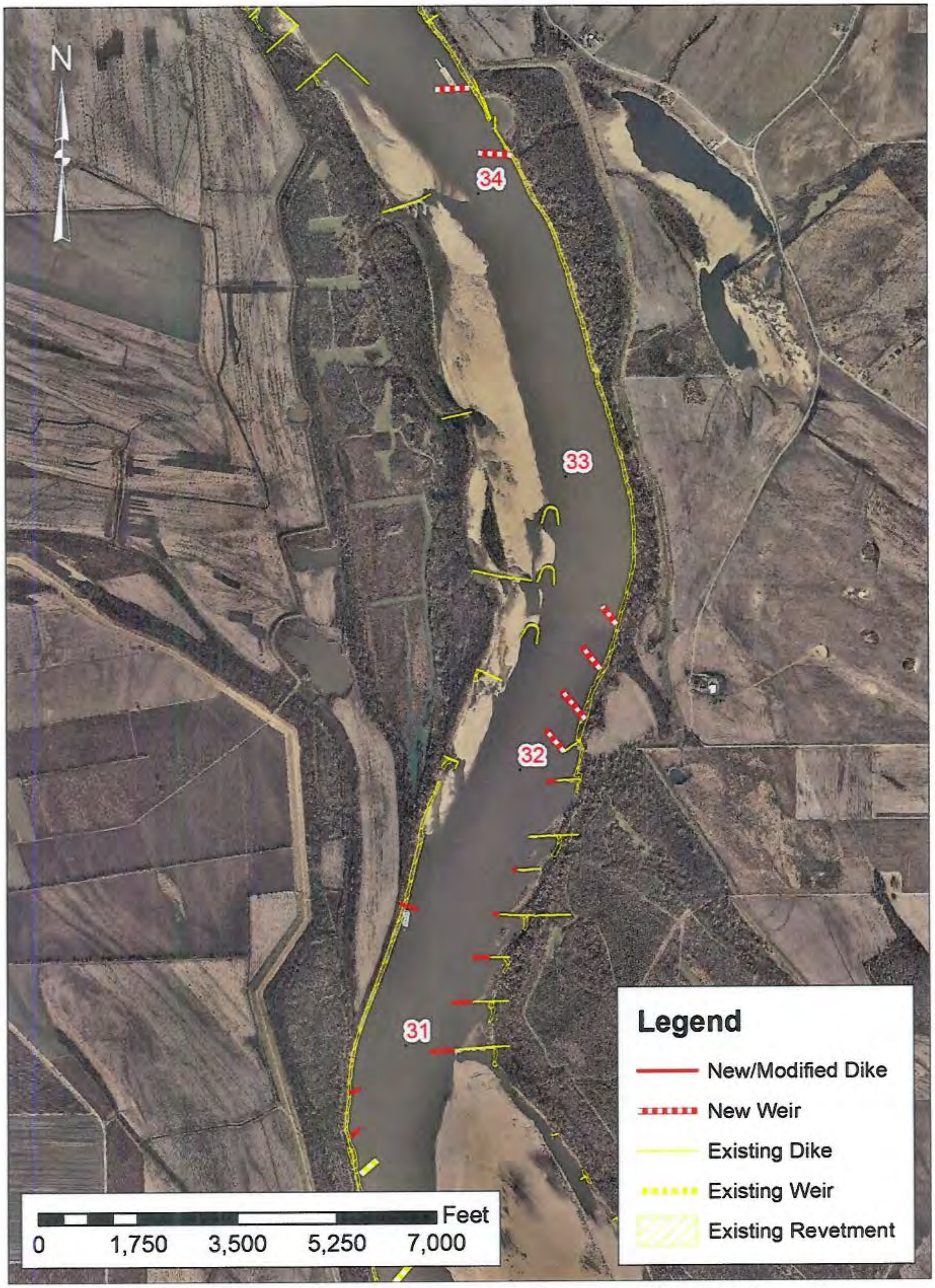


Figure 6. Location of proposed work at Bumgard reach.

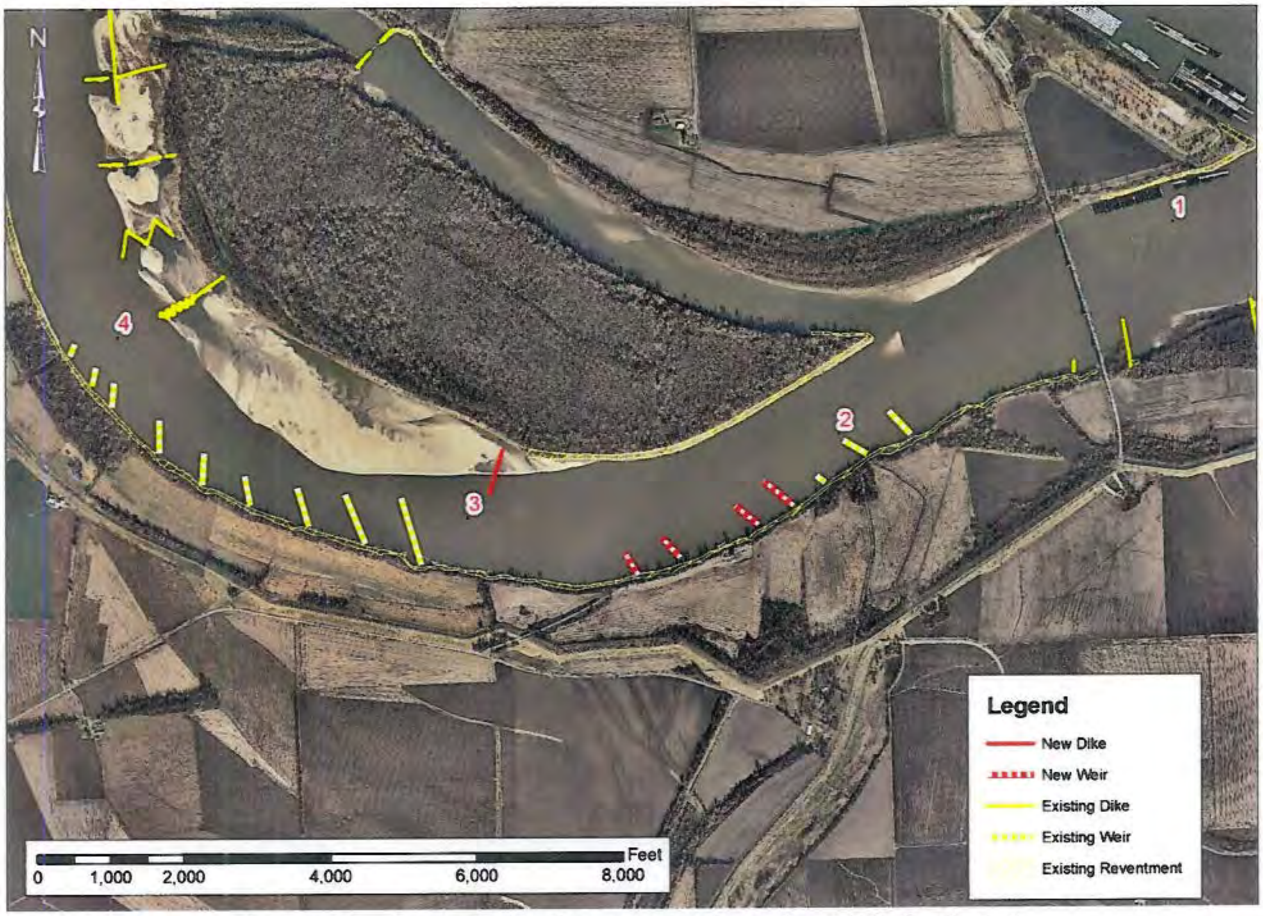


Figure 7. Location of proposed work at Birds Point.

SAME LETTER SENT
TRIBAL CHAIRPERSONS

Ms. Edwina Butler-Wolfe Governor
Absentee-Shawnee Tribe
of Indians of Oklahoma
2025 S. Gordon Cooper Drive
Shawnee, Oklahoma 74810-9381

Ms. Glenna J. Wallace, Chief
Eastern Shawnee Tribe of Oklahoma
P.O. Box 350
Seneca, Missouri 64865

Mr. Ron Sparkman, Chairman
Shawnee Tribe
P.O. Box 189
Miami, Oklahoma 74355

Mr. Bill John Baker, Principal Chief
Cherokee Nation
P.O. Box 948
Tahlequah, Oklahoma 74465

Mr. George Wickliffe, Chief
United Keetoowah Band of Cherokee
Indians of Oklahoma
P.O. Box 746
Tahlequah, Oklahoma 74464

Mr. Kerry Holton, President
Delaware Nation, Oklahoma
P.O. Box 825
Anadarko, Oklahoma 73005

Ms. Paula Pechonick, Chief
Delaware Tribe of Indians
170 N. Barbara
Bartlesville, Oklahoma 74006

Mr. John Barrett, Chairman
Citizen Potawatomi Nation, Oklahoma
1601 S. Gordon Cooper Drive
Shawnee, Oklahoma 74801

Mr. Harold Frank, Chairman
Forest County Potawatomi
Community, Wisconsin
P.O. Box 340
Crandon, Wisconsin 54520

Mr. D.K. Sprague, Chairman
Match-e-be-nash-she-wish Band of
Potawatomi Indians of Michigan
P.O. Box 218
Dorr, Michigan 49323

Mr. Kenneth Meshigand, Chairman
Hannahville Indian Community, Michigan
N14911 Hannahville Blvd. Rd.
Wilson, Michigan 49896-9728

Mr. Homer Mandoka, Chairman
Nottawaseppi Huron Band of
Potawatomi, Michigan
2221—1 ½ Mile Road
Fulton, Michigan 49052

Mr. Matthew Wesaw, Chairman
Pokagon Band of Potawatomi Indians,
Michigan and Indiana
P.O. Box 180
Dowagiac, Michigan 49047

Mr. Steve Ortiz, Chairman
Prairie Band Potawatomi Nation
Government Center
16281 Q Road
Mayetta, Kansas 66509

Mr. Jon Greendeer, President
Ho-Chunk Nation of Wisconsin
W 9814 Airport Road
Black River Falls, Wisconsin 54675

Mr. John Blackhawk, Chairman
Winnebago Tribe of Nebraska
P.O. Box 687
Winnebago, Nebraska 68071

Mr. Tim Rhodd, Chairman
Iowa Tribe of Kansas and Nebraska
3345 Thrasher Road # 8
White Cloud, Kansas 66094

Ms. Janice Rowe-Kurak, Chairwoman
Iowa Tribe of Oklahoma
Route 1, Box 721
Perkins, Oklahoma 74059

Mr. Juan Garza, Chairman
Kickapoo Traditional Tribe of Texas
HC 1, Box 9700
Eagle Pass, Texas 78853

Mr. Tony Salazar, Chairman
Kickapoo Tribe of Oklahoma
P.O. Box 70
McCloud, Oklahoma 74851

Mr. Steve Cadue, Chairman
Kickapoo Tribe of Indians of the
Kickapoo Reservation in Kansas
P.O. Box 271
Horton, Kansas 66439

Mr. George Thurman, Principal Chief
Sac & Fox Nation, Oklahoma
920883 S. Hwy. 99
Building A
Stroud, Oklahoma 74079

Mr. Michael Dougherty, Chairman
Sac & Fox Nation of Missouri in
Kansas and Nebraska
305 N. Main Street
Hiawatha, Kansas 66434

Mr. Frank Blackcloud, Chairman
Sac & Fox Tribe of the
Mississippi in Iowa
349 Meskwaki Road
Tama, Iowa 52339

Mr. Thomas E. Gamble, Chief
Miami Tribe of Oklahoma
P.O. Box 1326
202 S. Eight Tribes Trail
Miami, Oklahoma 74355

Mr. John D. Red Eagle, Principal Chief
The Osage Nation
P.O. Box 779
Pawhuska, Oklahoma 74056

Mr. John Froman, Chief
Peoria Tribe of Indians of Oklahoma
P.O. Box 1527
118 S. Eight Tribes Trail
Miami, Oklahoma 74355

Mr. John Berrey, Chairman
Quapaw Tribe of Indians
P.O. Box 765
Quapaw, Oklahoma 74363

SAME LETTER SENT
TRIBAL REPRESENTATIVE:

Mr. Joseph Blanchard
Tribal Historic Preservation Officer
Absentee-Shawnee Tribe
of Indians of Oklahoma
2025 Gordon Cooper Drive
Shawnee, Oklahoma 74810-9381

Ms. Robin DuShane
Eastern Shawnee Tribe of Oklahoma
P.O. Box 350
Seneca, Missouri 64856

Ms. Kim Jumper
Shawnee Tribe
P.O. Box 189
Miami, Oklahoma 74355

Dr. Richard Allen
Cherokee Nation
P.O. Box 948
Tahlequah, Oklahoma 74465

Ms. Lisa Larue-Baker
United Keetoowah Band of Cherokee
Indians of Oklahoma
2450 S. Muskogee Avenue
Tahlequah, Oklahoma 74464

Ms. Tamara Francis Fourkiller
Delaware Nation, Oklahoma
P.O. Box 825
Anadarko, Oklahoma 73005

Dr. Bryce Obermeyer
Delaware Tribe of Indians
Tribal Historic Preservation Office
Roosevelt Hall, Room 212
1200 Commercial Street
Emporia, Kansas 66801

Ms. Kelli Mosteller
Tribal Historic Preservation Officer
Citizen Potawatomi Nation, Oklahoma
1601 S. Gordon Cooper Dr.
Shawnee, Oklahoma 74801

Ms. Melissa Cook
Tribal Historic Preservation Officer
Forest County Potawatomi,
Community, Wisconsin
Cultural Center, Library & Museum
8130 Mishkoswen Drive, P.O. Box 340
Crandon, Wisconsin 54520

Mr. Todd Williamson
Match-e-be-nash-she-wish Band
of Pottawatomi Indians of Michigan
P.O. Box 218
Dorr, Michigan 49323

Mr. Earl Meshigaud
Hannahville Indian Community,
Michigan
N 14911 Hannahville Road
Wilson, Michigan 49896

Mr. John Rodwan
Nottawaseppi Huron Band of
Potawatomi, Michigan
2221-1&1/2 Mile Road
Fulton, Michigan 49052

Mr. Mike Zimmerman
Tribal Historic Preservation Officer
Pokagon Band of Potawatomi Indians,
Michigan and Indiana
P.O. Box 180
58620 Stink Road
Dowagiac, Michigan 49047

Ms. Jancita Warrington
Prairie Band Potawatomi Nation
Government Center
16281 Q Road
Mayetta, Kansas 66509

Mr. William Quackenbush
Tribal Historic Preservation Officer
Ho-Chunk Nation of Wisconsin
P.O. Box 667
Black River Falls, Wisconsin 54615

Ms. Emily DeLeon
Winnebago Tribe of Nebraska
Little Priest Tribal College
P.O. Box 270
Winnebago, Nebraska 68071

Mr. F. Martin Fee
Tribal Historic Preservation Officer
Iowa Tribe of Kansas and Nebraska
3345 Thrasher Road
White Cloud, Kansas 66094

Mr. Kent Collier
Kickapoo Tribe of Oklahoma
P.O. Box 70
McCloud, Oklahoma 74851

Ms. Curtis Simon
Kickapoo Tribe of Indians of the
Kickapoo Reservation in Kansas
1107 Goldfinch Road
Horton, Kansas 66439

Ms. Sandra Massey
Sac & Fox Nation, Oklahoma
920883 S. Hwy. 99
Building A
Stroud, Oklahoma 74079

Mr. Edmore Green
Sac & Fox Nation of Missouri
in Kansas and Nebraska
305 North Main Street
Hiawatha, Kansas 66434

Mr. Jonathan Buffalo
Sac & Fox Tribe of the Mississippi
in Iowa
349 Meskwaki Road
Tama, Iowa 52339

Mr. George Strack
Tribal Historic Preservation Officer
Miami Tribe
P.O. Box 1236
202 S. Eight Tribes Trail
Miami, Oklahoma 74355

Dr. Andrea Hunter
Historic Preservation Office
The Osage Nation
627 Grandview
Pawhuska, Oklahoma 74056

Mr. Frank Hecksher
Peoria Tribe of Indians of Oklahoma
118 S. Eight Tribes Trail
P.O. Box 1527
Miami, Oklahoma 74355

Ms. Jean Ann Lambert
Tribal Historic Preservation Officer
Quapaw Tribe of Indians
P.O. Box 765
Quapaw, Oklahoma 74363

Delaware Tribe Historic Preservation Office
1200 Commercial St
Roosevelt Hall, RM 212
Emporia State University
Emporia, KS 66801
(620) 341-6699
bobermeyer@delawaretribe.org

August 23, 2013

U.S. Army Corps of Engineers
St. Louis District
Attn: Michael K. Trimble, Ph.D.
1222 Spruce Street
St. Louis, Missouri 63103-2833

Re: Construction of River Training Structures along the Mississippi River

Dear Michael K. Trimble,

Thank you for informing the Delaware Tribe on the proposed construction associated with the above referenced project. Our review indicates that there are no religious or culturally significant sites in the project area. As such, we defer comment to your office as well as to the State Historic Preservation Office and/or the State Archaeologist.

We wish to continue as a consulting party on this project and look forward to receiving a copy of the cultural resources survey report if one is performed. We also ask that if any human remains are accidentally unearthed during the course of the survey and/or the construction project that you cease development immediately and inform the Delaware Tribe of Indians of the inadvertent discovery.

If you have any questions, please feel free to contact this office by phone at (620) 341-6699 or by e-mail at bobermeyer@delawaretribe.org

Sincerely,

Bruce Obermeyer

Brice Obermeyer
Delaware Tribe Historic Preservation Office
1200 Commercial St
Roosevelt Hall, RM 212
Emporia State University
Emporia, KS 66801

ᏣᎳᎩ ᎠᏰᏟ
CHEROKEE NATION®
P.O. Box 948 • Tahlequah, OK 74465-0948 • 918-453-5000 • cherokee.org

Office of the Chief

Bill John Baker
Principal Chief
ᎾᏢ ᏣᏂ ᏗᏚᏚᏇᏍᎩ
ᎤᎬᏫᏳᎯ

S. Joe Crittenden
Deputy Principal Chief
Ꮝ. ᏦᏩ ᏗᎬᎩᏍᎩ
ᎳᎵᏁ ᎠᏓᏍᏁ ᎤᎬᏫᏳᎯ

082613

Michael K. Trimble, Ph.D.
Chief, Curation and Archives / Analyses Branch
Dept. of the Army
St. Louis District, Corps of Engineers
61222 Spruce St.
St. Louis, MO 63103

Re: construction of river training structures in 4 major areas

Dr. Trimble:

The Cherokee Nation appreciates the opportunity to comment upon the "construction of river training structures in 4 major areas". The Cherokee Nation does not currently maintain records of cultural resources in this geographic area. Thus, we would request you conduct your inquiries with the Illinois and Missouri State Historic Preservation Offices and any geographically appropriate/pertinent Tribal Historic Preservation Office(s). However, if during the conduct of these projects, items of cultural significance are discovered, the Cherokee Nation requests you recontact our Offices for further consultation. If you have any questions or require further information, please contact Mr. Pat Gwin, Administration Liaison, at 918/453-5704. Thank you.

Sincerely,

Pat Gwin, Administration Liaison

Kickapoo Tribe of Oklahoma

P.O.Box 70
407 N. Hwy 102
McLoud, Oklahoma 74851

Administration Department
Phone: 405-964-7053; Fax: 405-964-7065
Email: kwilson@kickapootribeofoklahoma.com

August 29, 2013

Department of the Army
U.S. Army Corps of Engineers
St. Louis District
ATTN: Roberta L. Hayworth
Engineering and Construction Division
Curation and Archives Analysis Branch
1222 Spruce Street
St. Louis, MO 63103-2833

RE: Proposed FY 2014 River Training Structure Projects: RM 195-154; RM20-0; RM90-67 & RM 40-20

Dear Ms. Hayworth:

Thank you for consulting with the Kickapoo Tribe of Oklahoma in regard to the above referenced site(s). At this time, the Kickapoo Tribe of Oklahoma has no objections to the proposed project at the intended site(s). However, in the event burial remains and/or artifacts are discovered during the development or construction process, the Kickapoo Tribe of Oklahoma would ask for immediate notification of such findings.

Should I be of any further assistance, please contact me at (405) 964-4227.

Sincerely,

Kent Collier
NAGPRA Contact
Kickapoo Tribe of Oklahoma

Cc: File

From: Lisa LaRue-Baker - UKB THPO [ukbthpo-larue@yahoo.com]
Sent: Wednesday, September 18, 2013 1:53 PM
To: Hayworth, Roberta L MVS
Cc: verna
Subject: [EXTERNAL] Mississippi River Training Facilities

The United Keetoowah Band of Cherokee Indians in Oklahoma has reviewed your project under Section 106 of the NHPA, and at this time, have no comments or objections. However, if any human remains are inadvertently discovered, please cease all work and contact us immediately.

Thank you,

Lisa C. Baker
Acting THPO
United Keetoowah Band of Cherokee Indians in Oklahoma
PO Box 746
Tahlequah, OK 74465

TRIBAL HISTORIC PRESERVATION OFFICE

Winnebago Tribe of NE P.O. Box 687 Winnebago, NE 68071 402-878-3313

November 7, 2013

US Army Corps of Engineers
Attn: CEMVS-OD-F
1222 Spruce Street
St. Louis, MO 63103

RE: P-2853

Dear Mr. Danny McClendon,

Thank you for your recent letter to the Tribal Historic Preservation Office of the Winnebago Tribe of Nebraska. The Preservation Office would like to inform you that the Winnebago Tribe of Nebraska does have cultural properties in the area of your proposed construciton. According to oral tradition, the tribe lived in the area in the prehistoric period and still do today.

You may proceed with your proposed construction, but if there are any burial sites or other cultural properties found we would like for your office to notify us right away at (402)878-3313. Thank you.

Sincerely,

Emily DeLeon

Emily Smith-DeLeon

THPO, Winnebago Tribe of NE

Smith_deleon77@yahoo.com

United States Department of the Interior

U.S. FISH AND WILDLIFE SERVICE
Marion Illinois Sub-Office (ES)
8588 Route 148
Marion, Illinois 62959
(618) 997-3344

November 26, 2013

Colonel Christopher G. Hall
U.S. Army Corps of Engineers
St. Louis District
1222 Spruce Street
St. Louis, Missouri 63103-2833

Attn: Mr. Danny McClendon

Dear Colonel Hall:

Thank you for the opportunity to review and comment on the Environmental Assessment (EA), Unsigned Finding of No Significant Impact (FONSI), and Public Notice P-2853 addressing the Mosenthein/Ivory Landing Phase 4 Regulating Works Project located in St. Clair County, Illinois and St. Louis City, MO. The proposed project involves construction of a rootless dike and placement of bankline revetment at four locations between Upper Mississippi River Miles 170.0 and 175.0. Alternatives considered for this project included no action and a preferred alternative described above. These comments are prepared under the authority of and in accordance with the provisions of the Fish and Wildlife Coordination Act (48 Stat. 401, as amended; 16 U.S.C. 661 et seq.); the Endangered Species Act of 1973 (87 Stat. 884, as amended; 16 U.S.C. 1531 *et seq*.); and, the National Environmental Policy Act (83 Stat. 852, as amended P.L. 91-190, 42 U.S.C. 4321 et seq.).

Fish and Wildlife Resources

The purpose of constructing the proposed project is to address bankline erosion, channel widening, and a repetitive channel maintenance dredging issue to ensure adequate navigation depth and width. Information provided in the EA indicates that the proposed project is expected improve fish and macroinvertebrate habitat by increasing bathymetric, flow, and sediment diversity in the immediate vicinity of the rootless dike and by providing substrate diversity, cover, and increased macroinvertebrate colonization surface area along the revetment. While the Service does not disagree with this assessment the Service is concerned that the proposed construction is likely to reduce natural bank erosion and halt the natural meandering process of the river and potentially impact sand bar habitats utilized by larval and juvenile fisheries resources. The Service is also concerned about the cumulative loss of habitat and potential impacts on fisheries resources in the Mississippi River from past, present, and reasonably foreseeable future actions utilized to maintain the navigation channel. The Service recommends that the U.S. Army Corps of Engineers (Corps) continue to utilize its authorities and programs

(Biological Opinion Program, Avoid and Minimize Program, and Environmental Management Program) to restore/enhance habitats in the Mississippi River. The Service also recommends that the Corps seek a post authorization change to provide for environmental protection and enhancement under the Regulating Works Project as described in the 1976 Environmental Impact Statement (EIS). As stated in the 1976 EIS, "the overall effects of the attainment of a nine-foot-navigation channel upon the riverine ecosystem has not been beneficial" and "A significant amount of fish and wildlife habitat has been affected."

Threatened and Endangered Species

The EA includes a Tier II Biological Assessment (BA) which was prepared in order to comply with the requirements of the 2000 Biological Opinion for Operation and Maintenance of the 9-Foot Navigation Channel on the Upper Mississippi River System. The 2000 Biological Opinion (BO) was prepared as a result of the programmatic consultation under Section 7 of the Endangered Species Act of 1973, as amended, which evaluated the effects of operation and maintenance of the 9-foot navigation channel on federally listed threatened and endangered species. The BA evaluated the impacts of the proposed project on the endangered gray bat (*Myotis grisescens*), endangered Indiana bat (*Myotis sodalis*), endangered least tern (*Sterna antillarum*), endangered pallid sturgeon (*Scaphirynchus albus*), endangered pink mucket (*Lampsilis abrupta*), endangered sheepnose mussel (*Plethobasus cyphyus*), endangered spectaclecase mussel (*Cumberlandia monodonta*), and threatened decurrent false aster (*Boltonia decurrens*).

Information provided in the BA indicates that no caves or forest areas would be impacted by the proposed action; therefore, the Corps has determined the proposed project will have no effect on the gray bat. This precludes the need for further action on this project as required under Section 7 of the Endangered Species Act of 1973, as amended for the gray bat. Information provided in the BA indicates that the decurrent false aster, pink mucket, sheepnose, and spectaclecase are not known to occur with the project area; therefore, the Corps has determined the proposed project is not likely to adversely affect any of these species. Based on this information, the Service concurs that the proposed project is not likely to adversely affect the decurrent false aster, pink mucket, sheepnose, and spectaclecase. Information in the BA indicates that the proposed project will create aquatic habitat diversity and increase macroinvertebrate colonization surface area; therefore, the Corps has determined the proposed project is not likely to adversely affect the Indiana bat. The Service concurs that the proposed project is not likely to adversely affect the Indiana bat.

Information in the BA indicates that construction of the rootless dike is expected to create scour holes, a secondary channel, and shallow water habitat that will provide additional larval/juvenile rearing habitat and seasonal refugia, and improve forage food production which should result in long-term beneficial effects for the pallid sturgeon. The construction of the rootless dike is also expected to provide diverse habitats and improved forage food production which should be beneficial to the least tern. Thus, the Corps has determined that the proposed project is not likely to adversely affect the pallid sturgeon and least tern. It is unclear to the Service whether the river training structure modifications (with resulting hydro-geomorphologic changes) and the reduction in channel maintenance dredging can fully compensate for the project impacts. The

Service is concerned that the proposed revetment will reduce natural bank erosion and halt the natural meandering process of the river; thereby, reducing the availability of spawning habitat, larval and juvenile rearing habitat, seasonal refugia, and abundance of forage for the pallid sturgeon and availability of sandbar nesting habitat, foraging habitat, and abundance of forage food for the least tern. Therefore, the Service believes the proposed project is likely to adversely affect the pallid sturgeon and least tern and that Tier II formal consultation is necessary.

Tier II Formal Consultation

The Service has determined that the proposed project falls within the scope of the programmatic BO issued for Operation and Maintenance of the 9-Foot Navigation Channel on the Upper Mississippi River System (Section 1.2.4 River Regulatory Structures), the effects of this proposed action on the least tern and pallid sturgeon are consistent with those anticipated in the programmatic BO (Sections 4.3.1.2 and 8.3.1.2 Maintenance of the 9-Foot Channel Project), and the appropriate Terms and Conditions associated with the Reasonable and Prudent Measures (RPMs) for each species identified in the programmatic BO have been adhered to (Sections 4.5.3, 4.5.4, 8.5.3 and 8.5.4). Specifically, the Corps adhered to Term and Condition 2 and RPM 1 for the least tern by submitting the project to the Service for a 30 day review period and incorporating Service recommendations for least tern nesting/foraging habitat improvement into project construction plans. The Corps adhered to Term and Condition 2 and RPM 1 for the pallid sturgeon by submitting the project to the Service for a 30 day review period and incorporating Service recommendations for aquatic habitat improvement into project construction plans. Based on this information, it is the Service's biological opinion that the proposed project is not likely to jeopardize the continued existence of the least tern or pallid sturgeon. Incidental take was considered programmatically in the BO (Section 4.5 and 8.5 Incidental Take Statement) and will be evaluated at program level. Thus no incidental take statement is included with this opinion.

This concludes formal consultation on the proposed action. As provided in 50 CFR §402.16, reinitiation of formal consultation is required where discretionary Federal agency involvement or control over the action has been retained (or is authorized by law) and if: (1) the amount or extent of incidental take is exceeded; (2) new information reveals effects of the agency action that may affect listed species or critical habitat in a manner or to an extent not considered in this opinion; (3) the agency action is subsequently modified in a manner that causes an effect to the listed species or critical habitat not considered in this opinion; or (4) a new species is listed or critical habitat designated that may be affected by the action. In instances where the amount or extent of incidental take is exceeded, any operations causing such take must cease pending reinitiation.

Conclusion

The Service recommends the FONSI be modified to address the potential adverse effects to federally listed species as anticipated in the programmatic BO, i.e. the potential adverse effect of the proposed action on the least tern and pallid sturgeon. Provided the modifications are made, the Service concurs with the FONSI for the proposed project. Thank you for the opportunity to provide comment on the EA, FONSI, and Public Notice. For additional coordination, please contact me at (618) 997-3344, ext. 345.

Sincerely,

/s/ Matthew T. Mangan

Matthew T. Mangan
Biologist in Charge

cc: IDNR (Atwood)
MDC (Sternberg)

Response to August 23, 2013 Delaware Tribe Comment Letter

Comment 1: *Our review indicates that there are no religious or culturally significant sites in the project area. As such, we defer comment to your office as well as to the State Historic Preservation Office and/or the State Archaeologist.*

We wish to continue as a consulting party on this project and look forward to receiving a copy of the cultural resources survey report if one is performed. We also ask that if any human remains are accidentally unearthed during the course of the survey and/or the construction project that you cease development immediately and inform the Delaware Tribe of Indians of the inadvertent discovery.

Response: Coordination with the appropriate State Historic Preservation Offices has been conducted (see coordination letters in this appendix). If any human remains are unearthed, construction will cease and all appropriate parties will be notified.

Response to August 26, 2013 Cherokee Nation Comment Letter

Comment 1: *The Cherokee Nation does not currently maintain records of cultural resources in this geographic area. Thus, we would request you conduct your inquiries with the Illinois and Missouri State Historic Preservation Offices and any geographically appropriate/pertinent Tribal Historic Preservation Office(s). However, if during the conduct of these projects, items of cultural significance are discovered, the Cherokee Nation requests you recontact our Offices for further consultation.*

Response: Coordination with the appropriate State and Tribal Historic Preservation Offices has been conducted (see coordination letters in this appendix). If items of cultural significance are discovered during construction your Offices will be contacted for further consultation.

Response to August 29, 2013 Kickapoo Tribe Comment Letter

Comment 1: *At this time, the Kickapoo Tribe of Oklahoma has no objections to the proposed project at the intended site(s). However, in the event burial remains and/or artifacts are discovered during the development or construction process, the Kickapoo Tribe of Oklahoma would ask for immediate notification of such findings.*

Response: If any burial remains and/or artifacts are discovered, all appropriate parties will be notified as soon as possible.

Response to September 18, 2013 United Keetoowah Band Comment Letter

Comment 1: … *if any human remains are inadvertently discovered, please cease all work and contact us immediately.*

Response: If any human remains are discovered, construction will cease and all appropriate parties will be notified as soon as possible.

Response to November 7, 2013 Winnebago Tribe Comment Letter

Comment 1: *You may proceed with your proposed construction, but if there are any burial sites or other cultural properties found we would like for your office to notify us right away…*

Response: If any burial sites or other cultural properties are found during construction, all appropriate parties will be notified as soon as possible.

Responses to November 26, 2013 U.S. Fish and Wildlife Service Comments

Comment 1: *The Service recommends that the U.S. Army Corps of Engineers (Corps) continue to utilize its authorities and programs (Biological Opinion Program, Avoid and Minimize Program, and Environmental Management Program) to restore/enhance habitats in the Mississippi River. The Service also recommends that the Corps seek a post authorization change to provide for environmental protection and enhancement under the Regulating Works Project as described in the 1976 Environmental Impact Statement (EIS). As stated in the 1976 EIS, "the overall effects of the attainment of a nine-foot-navigation channel upon the riverine ecosystem has not been beneficial" and "A significant amount of fish and wildlife habitat has been affected."*

Response: The District will continue to utilize existing authorities and programs, including the Biological Opinion Program, Avoid and Minimize Program, and Environmental Management Program, as appropriate, to restore and enhance Mississippi River habitats. As part of the current process to supplement the 1976 Middle Mississippi River Regulating Works Environmental Impact Statement, the District will utilize the alternatives and analysis provided in the 1976 EIS, including the post authorization change, and will update and consider the information as appropriate.

Comment 2: *The Service recommends the FONSI be modified to address the potential adverse effects to federally listed species as anticipated in the programmatic BO, i.e. the potential adverse effect of the proposed action on the least tern and pallid sturgeon.*

Response: The FONSI has been modified to indicate that no *significant* impacts to federally listed species are anticipated.

Appendix G. Distribution List

The following individuals and organizations received a hard copy mailing of the Public Notice:

Governor Jay Nixon
P.O. Box 720
Jefferson City, MO 65102

The Osage Nation
Assistant Chief Scott Bighorse
627 Grandview
P.O. Box 779
Pawhuska, Ok 74056

Anne Haaker
IL State Historic Preservation Office
Springfield, IL 62701

Russell Bradley
Kickapoo Tribe in Kansas
Chairman
1107 Goldfinch Road
Horton, KS 66439

MDNR Division of State Parks
Planning and Development
PO Box 176
Jefferson City, MO 65102

Yvonne Homeyer
Webster Groves Nature Society
1508 Oriole Lane
St. Louis, MO 63144

Honorable Blaine Luetkemeyer
1118 Longworth HOB
Washington, DC 20515

Senator Gary Forby
903 West Washington, Suite 5
Benton, IL 62812

Honorable Claire McCaskill
5850 A Delmar Blvd
St. Louis, MO 63112

Advisory Council on Historic Preservation
1100 Pennsylvania Avenue NW, Suite 803
Old Post Office Building
Washington, DC 20004

Kelly Isherwood
5072 Oak Tree Lane
House Springs, MO 63051

Pat Malone
IDNR Natural Resource Review
1 Natural Resource Way
Springfield, IL 62702

Raymond Hopkins
RIAC/ARTCO
P.O. Box 2889
St. Louis, MO 63111

Mike Larson
MDNR
Land Reclamation Program
Jefferson City, MO 65102

Honorable Lacy Clay
6830 Gravois
St. Louis, MO 63116

Honorable Ann Wagner
301 Sovereign Court, Suite 201
Ballwin, MO 63011

Honorable John M. Shimkus
15 Professional Park Drive
Maryville, IL 62062

Representative Ed Schieffer
Missouri House of Representatives
201 West Capitol Avenue
Jefferson City, MO 65101-6806

US Coast Guard Marine Safety Office
Commanding Officer
225 Tully Street
Paducah, KY 42003

Rose M. Schulte
2842 Chadwick Dr.
St. Louis, MO 63121

Honorable Roy Blunt
United States Senator
2502 Tanner Drive – Suite 208
Cape Girardeau, MO 63703

Leon Campbell, Chairman
Iowa Tribe of Kansas and Nebraska
3345B Thrasher Road
White Cloud, Kansas 66094

Jack Norman
906 N. Metter Avenue
Columbia, IL 62236

Donald Rea
City of St. Louis
Water Division
10450 Riverview Drive
St. Louis, MO 63137

Nick Nichols
City of St. Louis Port Authority
1520 Market Street
St. Louis, MO 63103

Timothy V. Johnson, M.C.
IL15
202 N. Prospect Rd., Suite 203
Bloomington, IL 61704

Nellie Keo
Kickapoo Tribe in Kansas
Land/NAGPRA Office
1107 Goldfinch Road
Horton, KS 66439

Hoppies Marine
P.O. Box 44
Kimmwick, MO 63053

Environmental Coordinator
Planning and Compliance Office
Natural Park Service, Midwest Region
601 Riverfront Drive
Omaha, NE 68102-4226

Joseph Standing Bear Schranz
Midwest Soaring
5158 S. Mobile Avenue
Chicago, IL 60638

Great Rivers Environ. Law Center
705 Olive Street, Ste. 614
St. Louis, MO 63101

Southern Illinois Sand Company
P.O. Box 262
Chester, IL 62233

Russell Cissell
1075 LeSieur
Portage des Sioux, MO 63373

Mike Diedrichsen
IDNR Natural Resource Review
1 Natural Resource Way
Springfield, IL 62702

David Jones
Environmental Director
Nottawaseppi Huron Band of Potawatomi
2221 1-1/2 Mike Road
Fulton, MI 49052

Patrick J. Lamping
Executive Director
The Jefferson County Port Authority
PO Box 603
Hillsboro, MO 63050

Representative Daniel Beiser
528 Henry Street
Alton, IL 62002-2611

Governor Pat Quinn
Office of the Governor
207 State House
Springfield, IL 62706

Fay Houghton
Land Management Director
Winnebago Tribe of Nebraska
P.O. Box 687
Winnebago, NE 68071

Senator John Jones
2929 Broadway
Suite 5
Mt. Vernon, IL 62864

Honorable William Enyart
23 Public Square
Belleville, IL 62220

Mr. Ed Schieffer
183 Thornhill Cemetery Road
Troy, MO 63379

Dave Schulenburg
US EPA
Wetland and Watersheds Section
WW16J
77 W. Jackson Boulevard
Chicago, IL 60604-3590

Honorable Richard Durbin
525 South 8th Street
Springfield, IL 62703-1601

Senator Dale Righter
88 Broadway Avenue, Suite 1
Mattoon, IL 61938-4597

Senator Larry Bomke
307 Capitol Building
Springfield, IL 62706

Senator Mark Kirk
Springfield Senate Office
607 East Adams, Suite 1520
Springfield, IL 62701

Senator James Clayborne Jr.
Kenneth Hall State Office Building
#10 Collinsville Avenue
East St. Louis, IL 62201

Honorable Aaron Schock
235 S. Sixth Street
Springfield, IL 62701

Honorable Rodney Davis
2004 Fox Drive
Champaign, IL 61820

Honorable Jason Smith
2502 Tanner Drive, Suite 205
Cape Girardeau, MO 63703

Honorable Sam Graves
906 Broadway
P.O. Box 364
Hannibal, MO 63401

The following individuals and organizations received e-mail notification of the Public Notice:

Adams, R.
Adrian, D.
Amato, Joel
Andria, Kathy
Atwood, Butch
Bacon, T.
Barnes, Robert
Bax, Stacia
Beardslee, Tom
Bellville, Colette
Bensman, Jim
Boaz, Tracy
Boehm, Gerry
Brandom, Ellen
Brescia, Chris
Brown, Danny
Brown, Doyle
Buan, Steve
Buffalo, Jonathan
Burlingame, Chuck
Byer, J. R.
Caito, J.
Campbell-Allison, Jennifer
Carney, Doug
Clements, Mark
Coder, Justin S.
Crowley, Steve
Cruse, Lester
Darst, E. B.
Deel, Judith
Dewey, Dave
Dock Hardware and Marine Fabrication
Dodd, Harold
Dorothy, Olivia
Dougherty, Mark
Duncan, Cecil
Ebey, Mike
Elmestad, Gary
Enos, Tim
Erickson, Tom
Fabrizio, Christi
Favilla, Christy
Foster, Bill
Goldstein, Jeff

Genz, Greg
Glenn, S.
Goode, Peter
Goodwin, Bill
Greer, Courtney
Gross, Andrea
Hammond, Cheryl
Hanke Terminals
Hanneman, M.
Hansen, Rick
Hansens Harbor
Harding, Scott
Held, Eric
Henleben, Ed
Herschler, Mike
Herzog, Dave
Hilburn, Craig
Hogan-Smith, Shelly
Howard, Chuck
Hubertz, Elizabeth
Hughes, Shannon
Hunter, Andrea
Hussell, B.
Illinois Corn Growers Association
Illinois Department of Natural Resources
Illinois Environmental Protection Agency
Jamison, Larry
Johnson, Erick
Johnson, Frank
Johnson, Tom
Knowles, Kim
Knuth, Dave
Lauer, Steve
Leary, Alan
Leipus, Ed
Leiser, Ken
Lensing, Brian
Lipeles, Maxie
Louis Marine
Mangan, Matthew
Mannion, Clare
Mauer, Paul
Melgin, Wendy
Miller, Kenneth
Miller, Melissa
Missouri Corn Growers Association

Missouri Department of Conservation
Missouri Department of Natural Resources
Muench, Lynn
Muir, T.
Nelson, Lee
Nelson, Rick
Novak, Ron
O'Carroll, J.
Overbey, Dan
Paurus, Tim
Pehler, Kent
Phillip, C.
Pivor, Jeremy
Pondrom, Gary
Popplewell, Mickey
Porter, Jason
Red, Chief John
Reichert, Joe
Reitz, Paul
Reuters Chicago
Rickert, Ron
Roark, Bev
Rodenberg, V.
Rowe, Kelly
Samet, Melissa
Sauer, Randy
Schieffer, Ed
Shepard, Larry
Shoulberg, J.
Slay, Glen
Smith, David
Southeast Missouri Regional Port Authority
Southern Illinois Transfer
Spath, Robert
Stahlman, Bill
Staten, Shane
Sternburg, Janet
Stevens, Mark
Stout, Robert
Streight, Tom
Teah, Philip
Todd, Brian
Tow Inc.
Tyson, J.
Urban, David
U.S. Coast Guard Marine Safety Office

U.S. Environmental Protection Agency Region 7
Weber, Angie
Welge, Owen
Werner, Paul
Wilmsmeyer, Dennis
York Bridge Co.
Zupan, T.