Technical Report M26

SEDIMENTATION STUDY OF THE MIDDLE MISSISSIPPI RIVER AT RED ROCK RIVER MILES 93.0 TO 86.0

HYDRAULIC MICRO MODEL INVESTIGATION

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INTRODUCTION

The U.S. Army Corps of Engineers, St. Louis District initiated an environmental enhancement study of the Middle Mississippi River between Miles 93.0 and 86.0. The purpose of the study was to evaluate and propose environmental design modifications to existing stone dike structures and the possible introduction of new structures for the purpose of biological enhancement in the Mississippi River.

The study was conducted between July 2002 and September 2002 by Mrs. Dawn Lamm, Hydraulic Engineer, Mr. Edward Riiff, Engineering Technician and Mr. James Hunn Engineering Intern, under direct supervision of Mr. David Gordon, Hydraulic Engineer and Mr. Robert Davinroy, District Potamologist. Other personnel also involved with the study included: Mr. Dan Erickson, the Project Manager for the Biological Opinion Project, and Mr. Thomas Keeven, Mr. Brian Johnson and Mr. Eric Laux from the Environmental Branch of the Planning, Programs, and Project Management Division. Personnel from other agencies involved in the study included: Mr. Robert Hrabik from the Missouri Department of Conservation, Mr. Scott Stuewe and Mr. Butch Atwood from the Illinois Department of Natural Resources, and Ms. Joyce Collins, Mr. Greg Conover and Mr. Mike Thomas from the U.S. Fish and Wildlife Service.

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BACKGROUND

Micro modeling methodology was used to evaluate the existing sediment transport conditions and the impact of various structural design measures to improve environmental conditions in the Red Rock Reach of the Middle Mississippi River. The study was funded as part of the Biological Opinion for the Middle Mississippi River.

The goal of this study was to create island and side channel aquatic habitat along with deep scour holes and shoaling within the dike fields, while maintaining the integrity of the navigation channel

1. Study Reach

The study reach was located approximately 8-miles downstream of Chester, Illinois and comprised a 7-mile stretch of the Middle Mississippi River, between Miles 93.0 and 86.0. Plate 1 is a location and vicinity map of the study reach. The study area was located in Perry County, Missouri and Jackson County, Illinois.

Plate 2 is a 1998 aerial photograph illustrating the characteristics, configuration, and nomenclature of the Mississippi River between Miles 93.0 and 86.0. The reach included a rock bluff along the right descending bank (RDB) and eleven small tributaries that are shown on Plates 3 and 4. The majority of the RDB was covered with rock, contained moderate slopes, and was heavily vegetated. The rock appeared to be natural deposits and/or was revetment placed to protect the railroad track located along the top of the bankline. The left descending bank (LDB) had some natural deposits of rock, but the majority of the bankline was a sand, silt, and clay mix and was heavily vegetated. The only floodplain in this reach was located along the LDB. The Illinois side of the project area contained the Degonia and Fountain Bluff L & D District and had a drainage ditch that emptied into the Mississippi River just downstream of the project area (Plate 4).

There were no functioning fleeting areas or loading/unloading facilities located in this section of the river. An abandoned loading facility was located just downstream of the study reach along the LDB and is shown in Plate 4.

At the time of this study, the Red Rock study area was comprised of four dike fields, containing a total of 27 structures. All dike structures were of stone construction. No remnant pile structures were visible in the four dike fields.

Dike Field 1 was located along the LDB and contained 6 dikes shown on Plate 5. The dikes were located at Miles 93.0 L, 92.6 L, 92.3 L, 92.05 L, 91.8 L and 91.6 L. Dikes 92.6 L, 92.05 L, and 91.8 L appeared to have small notches or degraded sections. Structure lengths ranged from 250 feet to 500 feet.

Dike Field 2 was located along the RDB and contained 6 dikes, one with a trail (Plate 6). The dikes were located at Miles 91.6 R, 91.4 R, 91.1 R, 90.9 R, 90.7 R, and 90.5 R. Structure lengths ranged from 280 feet to 460 feet. Dike 91.6 R included a 400-foot trail.

Dike Field 3 was located along the LDB and contained 11 dikes shown on Plate 7. The dikes were located at Miles 89.3 L, 89.0 L, 88.2 L, 87.8 L, 87.5 L, 87.3 L, 87.0 L, 86.7 L, 86.5 L, 86.2 L, and 86.0 L. Structure lengths ranged from 330 feet to 980 feet.

Dike Field 4 was located along the RDB and contained 3 dikes shown on Plate 8. The dikes were located at Miles 86.4 R, 86.0 R, and 85.9 R. Dike 86.0 R appeared to have a small notch or degraded section. Structure lengths ranged from 250 feet to 430 feet.

The following table details the specific dimensions and characteristics of the dikes in each dike field. (Note: All bed elevations described in this report are referenced to the Low Water Reference Plane (LWRP). The LWRP represents a theoretical water

surface elevation profile based upon a low flow of 54,000 cfs. The reference elevation of 0 feet LWRP is based upon the probability that this stage and flow will be exceeded 97% of the time annually.)

Dike Field	Dike/Mile	Elevation (Feet LWRP)	Dike Length (Feet)	Trail Length (Feet)	Year Dike Was Built or Last Modified
1	93.0 L	+16	250		1927
1	92.6 L	+16	430		1992
1	92.3 L	+16 - Buried	350		1992
1	92.05 L	+16	490		1992
1	91.8 L	+19 to +12	500		1975
1	91.6 L	+12 to +10	300		1992
2	91.6 R	+15 to +10	330	400	1950
2	91.4 R	+19 to +15	460		1950
2	91.1 R	+17 to +12	300		1975
2	90.9 R	+17	280		1975
2	90.7 R	+20 to +16	300		1975
2	90.5 R	+19 to +15	350		1975
3	89.3 L	+15	500		1975
3	89.0 L	+15 to +13	560		1929
3	88.2 L	+18 to +15	980		1930
3	87.8 L	+20 to +13	660		1937
3	87.5 L	+20 to +10	460		1930
3	87.3 L	+17 to +10	380		1933
3	87.0 L	+20 to +13	470		1934
3	86.7 L	+17 to +11	440		1933
3	86.5 L	+20 to +10	330		1942
3	86.2 L	+15 to +11	380		1933
3	86.0 L	+15 to +10	420		1926
4	86.4 R	+10 - Buried	280		1933
4	86.0 R	+11	280		1975
4	85.9 R	+15	430		1975
4	85.7 R	+15	300		1975

2. Problem Description

This reach of the Middle Mississippi River contained numerous rock bluffs and geological controls but did not contain a significant backwater area or side channel. The reach has been repeatedly identified as an area in need of aquatic enhancement and habitat diversity. This reach was chosen for enhancement due to the large number of un-notched dikes and the very minimal dredging that has been required in the navigation channel. Minimal dredging indicated that dike modification for environmental enhancement could possibly be conducted without compromising the integrity of the navigation channel.

3. History

1881 and 1908

A historical study of the Red Rock reach of the Middle Mississippi River revealed that the channel in the upstream portion in the study area contained a dramatically different alignment 100-years ago. According to the 1881 and 1908 topographic, hydrographic and land cover surveys (Plates 9 and 10), the channel was significantly wider and contained large sandbars and islands between Miles 92.5 and 88.0. Significant channel and island movement occurred between 1881 and 1908 suggesting that heavy deforestation and increased channel sedimentation had caused unstable and eroding banklines. Channel depths could not be determined from these surveys. The channel upstream of Wilkinson Island was located along the RDB. The channel then split, with the thalweg located along the LDB where it remained for approximately 3.5 miles before crossing to the RDB again.

1928

Plate 11 is a 1928 aerial photograph of the reach. The channel had widened considerably since 1908, with multiple islands forming between Miles 92.5 and 89.5. The channel thalweg appeared to be located along the RDB throughout the study reach. In addition, the photograph indicated numerous proposed dike locations along the LDB, between Miles 93.0 and 92.0.

1956

The 1956 Hydrographic Survey is shown on Plate 12. In this survey the alignment of the channel thalweg was approximately the same as the 2002 thalweg alignment. Descriptions on the hydrographic survey sheet indicated that Pile Dikes 93.0 L, 92.7 L, 92.5 L, 92.2 L, 91.0 L, 90.2 L, and 89.3L had been constructed along the previous channel alignment shown on the 1928 aerial photograph. These dikes were in all probability placed to train the channel towards the RDB and rock bluff. It was not evident when these pile dikes were constructed or when the channel moved to the 1956 alignment. The 1956 hydrograph indicated the area where the channel was previously aligned was now land. Small remnant channels and scars on the land are still visible today.

The survey also indicated that Pile Dikes 91.8 R, 91.4 R, 89.0 L, 88.5 L, 88.2 L, 87.8 L, 87.5 L, 87.3 L, 87.0 L, 86.7 L, 86.5 L, 86.2 L, and 86.0 L had been constructed in the channel. All of these dikes, with the exception of Dike 88.5 L, are presently still functioning in the river but have since been covered with stone. On the 1956 Hydrographic Survey, the channel thalweg in the beginning of the study reach was located along the RDB, with depths down to –20 feet LWRP. At Mile 91.5, a crossing existed. The crossing was shallow, with the majority of channel depth down to –10.0 feet LWRP. The thalweg then remained along the LDB for over a mile before crossing at Mile 89.8 towards the RDB. The thalweg stayed along the RDB for the remainder of the study reach. Thalweg depths from Mile 92.0 to the end of the study reach were –20 feet LWRP with some areas reaching depths of –30 feet LWRP.

1969

The 1969 Hydrographic Survey is shown on Plate 13. In this survey, a majority of the bathymetry was similar to the 1956 survey. The only changes observed in the channel thalweg were a deepening at Mile 93.0 and a shift towards the LDB at Mile 86.6. No new dike construction appeared to have occurred between 1956 and 1969.

1977

The 1977 Hydrographic Survey is shown on Plate 14. The bathymetry in this survey was slightly different then shown on the previous surveys. The crossing at Mile 91.5 migrated upstream to Mile 91.8. This crossing was also deeper, with depths down to –20 feet LWRP. Shoaling was observed in the crossing at Mile 86.6. Deposition in the channel may have been attributed to the construction of 5 new dikes within the study reach. The new dikes were located at Miles 91.8 L, 91.1 R, 90.9 R, 90.7 R, and 90.5 R.

1982

The 1982 Hydrographic Survey is shown on Plate 15. The reach experienced slight changes but maintained the same general channel alignment and bathymetry. The most noticeable bed change was decreased depths at the beginning of the Mile 91.8 crossing and deepening and widening of the channel at Mile 86.6. Changes in this reach were attributed to the construction of four new dikes. The new dikes were located at Miles 92.3 L, 89.3 L, 86.4 R, and 86.0 R.

1988

The 1988 Hydrographic Survey is shown on Plate 16. The same areas that have been experiencing changes in previous years, the Mile 91.8 and Mile 86.6 crossings, were still fluctuating according to this survey. The crossing at Mile 91.8 had deepened and depths in the crossing at Mile 86.6 appeared to have decreased. The only other obvious change to the reach was the construction of a trail on Dike 91.6 R.

1993

The 1993 Hydrographic Survey is shown on Plate 17. The survey indicated that the channel became wider throughout the study reach, with many of the sandbars diminishing in size. This was probably a factor of three measures: 1) The construction of nine Bendway Weirs in the Red Rock Bend of the Middle Mississippi River from Mile 94.6 to Mile 93.7 (Plate 18). The specific influence of these weirs on

the channel in this reach is not known but they may have been a factor for general channel improvement. 2) Dredging in the navigation channel. Records indicate that the crossing at Mile 91.8 had been repeatedly dredged to maintain the navigation channel. Minor dredging also occurred at Mile 88.1 and 88.3. There has not been any additional dredging in the study reach since 1992. 3) The raising of Dike 92.3 L, and the construction of Dikes 92.05 L, and 91.6 L in 1992. These dikes may have improved channel depths slightly.

1998

The 1998 hydrographic survey is shown on Plate 19. No significant changes were indicated from the previous survey. Minor changes included a small shoaling at Mile 86.4 and a deeper thalweg at Mile 91.1

2001

The 2001 Hydrographic Sweep Survey is shown on Plate 20. This survey displayed the same channel alignment of previous surveys but with much greater detail. At the time of the survey, there was a large shoal located at Mile 93.0. The thalweg was still located along the RDB with significant depth observed at approximately Mile 92.7. The thalweg still crossed to the LDB at Mile 91.8. There were scour holes located off of the ends of Dikes 91.6 R and 91.4 R as well as along the LDB at Mile 91.4. The channel deepened at Mile 90.7 and crossed to the RDB at Mile 90.2. A small sandbar extended from the RDB downstream of Dike 90.5 R. The large sandbar in the region of Dike Field 3 developed upstream of Dike 89.3 L and continued to Dike 86.0 L. From Mile 89.6 to 86.6 the channel was located along the RDB with the majority of the thalweg at or below depths of –18 feet LWRP. The channel crossed to the LDB at Mile 86.6. A large shoal with depths to –8 feet LWRP was located near the RDB from Mile 86.6 to 86.0.

4. Field Observations

Personnel from the Applied River Engineering Center inspected the study reach by both helicopter and shallow draft boat. These reconnaissance missions allowed the site to be photographed and studied. The site visit is described below with the water surface elevation referenced to LWRP at the Red Rock Landing, Missouri gage.

+13.60 feet LWRP (July 24, 2002)

The study reach was first visited by helicopter to video-record bankline, dike and channel conditions. At this stage the crowns of all dikes within the study reach were visible above the water surface. Plates 5 through 8 are photographs taken of each dike within the study reach.

The study reach was also visited by boat to record field observations and measurements. The data collected at the site included sediment samples, velocity profiles and general observations about the channel. The following is a description of the data collected:

General observations indicated that banklines within the study area were very stable. On the Missouri side the bankline was bordered by a railroad embankment and rock bluffs. The majority of these banklines were stable due to natural cobbles, boulder deposits, and heavy vegetation. Other areas had been stabilized with stone by the railroad. There were a limited number of banklines that consisted of only a sandy silt or clay. However, these banklines contained moderate slopes and were not experiencing excessive erosion. On the Illinois side the bankline consisted of sand and silt with some stone deposits along moderate slopes. The Illinois side was also heavily vegetated with no banklines experiencing excessive erosion.

Sediment samples taken in Dike Field 2 were as follows: Upstream of Dike 91.6 R, the river bottom consisted of large gravel. Along the upper reach of Dike Field 2, near the bankline and between the dikes, the river bottom consisted of consolidated clay that was difficult to obtain samples from. Sediment samples of the riverbed

along the bankline of the lower reach of Dike Field 2 consisted of a silty sand and clay mix. The riverbed off of the end of the dikes was consistently sampled as sand.

Sediment samples taken in Dike Field 3 were as follows: The riverbed in the upper reaches of Dike Field 3 was mostly made up of sand. The middle and lower reached of Dike Field 3 contained a silt and sand mix along the bankline. The outer perimeter of the dike field was tested as containing mostly sand. Some sampling off of the ends of the dikes along the edge of the channel thalweg yielded a course gravel.

Additional features in the study reach along the RDB, Plate 3, included eight unnamed tributaries and one named tributary, Clines Branch. Also observed was a possible high water boat ramp. Along the LDB, there was another unnamed tributary and a remnant channel from the 1928 channel alignment (Plate 4). In addition, there was a drainage ditch outlet and an abandoned loading facility located just downstream from the study reach (Plate 4).

MICRO MODEL DESCRIPTION

1. Scales and Bed Materials

In order to investigate the sediment transport issues and habitat development described previously, a physical hydraulic micro model was designed and constructed. Plate 21 is a photograph of the hydraulic micro model used in this study. The model employed a horizontal scale of 1 inch = 500 feet, or 1:6000, and a vertical scale of 1 inch = 80 feet, or 1:960, for a 6.25 to 1 distortion ratio of linear scales. This distortion supplied the necessary forces required for the simulation of sediment transport conditions similar to those of the prototype. The bed material was granular polyester urea, Type II, with a specific gravity of 1.47.

2. Appurtenances

The micro model insert was constructed according to the 1998 high-resolution aerial photography of the study reach shown on Plate 3. The insert was then mounted in a standard micro model hydraulic flume. The riverbanks of the model were constructed from dense polystyrene foam, and modified during calibration with oil-based clay. The slope of the model was negligible. River training structures in the model were made of galvanized steel mesh.

Flow into the model was regulated by customized computer hardware and software interfaced with an electronic control valve and submersible pump. This interface was used to automatically control the flow of water and sediment into the model. Discharge was monitored by a magnetic flow meter interfaced with the customized computer software. Water stages were manually checked with a mechanical three-dimensional point digitizer. Resultant bed configurations were measured and recorded with a three-dimensional laser digitizer.

MICRO MODEL TESTS

1. Model Calibration

The calibration of the micro model involved the adjustment of water discharge, sediment volume, model slope, and entrance conditions of the model. These parameters were refined until the measured bed response of the model was similar to that of the prototype.

A. Micro Model Operation

In all model tests, a standard repeatable discharge hydrograph was simulated in the channel. This hydrograph served as the average design energy response of the river. Due to constant variation experienced in the prototype, this standard hydrograph was used to theoretically analyze the ultimate expected sediment response. Each hydrograph simulated a discharge range between extreme low flow to high "within-channel" flow. (Flow rates in the model ranged between 1.0 to 2.1 gallons per minute.) The most important factors during the modeling process are the establishment of an equilibrium condition of sediment transport and the simulation of high and low energy conditions. High flow in the model simulated a peak energy condition representative of the river's bed forming flow and sediment transport potential at bankfull conditions. The time increment or duration of each hydrograph cycle (peak to peak) was four minutes. Plate 22 shows the typical, sinusoidal hydrograph used in the study.

B. Prototype Data and Observations

To determine the general bathymetric characteristics and sediment response trends that existed in the prototype, several present and historic hydrographic surveys were examined. Plates 12 through 19 are plan view hydrographic survey maps of the Mississippi River from 1956, 1969, 1977, 1982, 1988, 1993, and 1998 respectively. A 2001 detailed channel sweep survey of the study reach, between Miles 93.0 and 86.0, is shown on Plate 20. In the latest surveys, the thalweg of the main channel

was located in the same general alignment. However, the shoals observed in the Mile 91.8 and Mile 86.6 crossings were not present on all surveys.

The bathymetry of the most recent prototype surveys (1993, 1998, and 2001) were very similar to each other and were used to calibrate the micro model. The thalweg maintained depths below –14 feet LWRP throughout the study reach with some areas experiencing depths below –20 feet and –30 feet LWRP. At the study reach entrance, the thalweg was located along the RDB until Mile 91.8 with depths between –14 feet and –20 feet LWRP. The thalweg then crossed to the LDB, with depths below –16 feet LWRP. The thalweg remained along the LDB for approximately 1.5 miles with depths below –16 feet LWRP. At Mile 90.1 the thalweg crossed back again to the RDB, with depths below –16 feet LWRP. The channel remained along the RDB until Mile 86.8. The thalweg depths between Mile 90.0 and 86.8 fluctuated significantly on each survey between –14 feet and –30 feet LWRP. At the end of the study reach the channel crossed towards the LDB where a slight shoal was indicated on the 1998 and 2001 surveys.

Dike Field 1 contained a significant shoal located directly across and upstream from Dike 93.0 L that was present only on the 2001 Sweep Survey. This dike field was located in a depositional area with scour holes observed off Dikes 93.0 L, 92.6 L, 92.05 L, and 91.8 L. These scour holes were observed on all three surveys.

In Dike Field 2, Dikes 91.6 R and 91.4 R had significant scour holes. However, the lower 75% of the dike field was a depositional area with a sandbar extending towards the channel.

Dike Field 3 was located in a large depositional area along the LDB. The sandbar extended from upstream of Dike 89.3 L to Dike 86.0 L. The sandbar was widest at Dike 88.2 L, extending 1500 feet into the channel. Scour was also observed downstream of Dikes 89.3 L, 89.0 L, 88.2 L, 87.8 L, 87.0 L, 86.7 L, 86.5 L, and 86.2L.

2. Base Test

Model calibration was achieved once it was determined through qualitative comparisons that the prototype surveys were similar to several surveys of the model. The resultant bathymetry of this calibrated bed response served as the base test of the micro model (Plate 23). This base test survey served as the comparative bathymetry for all design alternative tests.

Results of the micro model base test bathymetry and a comparison to the 1993 through 2001 prototype surveys indicated the following trends:

- The thalweg was located along the RDB at Mile 91.8 and crossed toward the LDB in a pattern similar to the prototype. The scour depth off the ends of Dikes 91.6 R and 91.4 R was slightly greater in the base test then observed in the base test.

- The LDB downstream of Mile 91.5 had depths below –20 feet LWRP which was very similar to the three prototype surveys. The sandbar through Dike Field 2 was similar in size.

- The crossing at Mile 89.5 was in the same general location as the prototype but was slightly shallower, with depths of –8 feet to –14 feet LWRP in the model as compared to depths of –10 feet to –18 feet LWRP in the prototype.

- The channel thalweg between Miles 89.2 and 86.5 was located along the RDB and was similar to the prototype. However, the thalweg in the model maintained a continuous depth below –20 feet LWRP whereas the prototype surveys indicated that the thalweg in the river fluctuated between depths of –14 feet to below –20 feet LWRP.

- The bar development within the dike field off the LDB, between miles 89.3 L and 86.5 L, was very similar to the prototype in height and width.

Overall, the trends of the model as observed in the base test were similar to those observed from the prototype surveys.

3. Design Alternative Tests

All design alternatives studied in the micro model utilized the existing dike configurations in the prototype surveys. Modifications to the dikes included notches and the addition of trails. Some design alternatives included the addition of chevrons and multiple round hard points. Thirteen design alternative plans were model tested to examine methods of modifying the sediment transport response trends that would create biological diversity within this reach of the Middle Mississippi River. The effectiveness of each design was evaluated by comparing the resultant bed configuration to that of the base condition. Impacts or changes induced by each alternative were evaluated by observing the sediment response of the model.

Alternative 1: *In an attempt to create a side channel within Dike Field 3, two of the existing dikes were notched with the invert elevations equal to that of the riverbed. Dike heights were unaltered*

- *Dike 89.3 L: 500 feet in Length, 150-foot notch located 200-feet from the bankline.*
- *Dike 89.0 L: 560 feet in Length, 100-foot notch located 200-feet from the bankline.*
- *All remaining dikes unaltered.*

Plate 24 is a plan view map of the resultant bed configuration of Alternative 1. The test results indicated that this design was not effective in creating a continuous side channel through Dike Field 3. Some side channel development did occur from Dike 89.3 L to approximately Mile 88.7 with depths between –15 feet and 0 feet LWRP. The majority of thalweg depths were unaffected and remained similar to that of the base test. However, some areas of the thalweg appeared to be slightly deeper.

The Dike Field 3 sandbar appeared to have slightly receded towards the bankline. The height of the Dike Field 3 sandbar also appeared marginally shallower.

Alternative 2: *In an attempt to create a side channel within Dike Field 3, two of the existing dikes were notched with the invert elevations equal to that of the riverbed. In addition a trail was added to Dike 89.3L. Dike heights were unaltered*

- *Dike 89.3 L: 500 feet in Length, 150-foot notch located 200-feet from the bankline, 250-foot trail perpendicular to the end of the dike and parallel to channel flow placed at +15 foot LWRP.*
- *Dike 89.0 L: 560 feet in Length, 100-foot notch located 200-feet from the bankline.*
- *All remaining dikes unaltered.*

Plate 25 is a plan view map of the resultant bed configuration of Alternative 2. The test results indicated that this design was not effective in creating a continuous side channel through Dike Field 3. A partial side channel did develop between Dike 89.3 L and Mile 88.7. Depths reached down to –20 feet LWRP downstream of Dike 89.3 L and between –15 feet and 0 feet LWRP in the remainder of the side channel. The majority of thalweg depths were unaffected and remained similar to that of the base test. The Dike Field 3 sandbar appeared to have slightly receded towards the bankline.

Alternative 3: *In an attempt to create a side channel within Dike Field 3, two of the existing dikes were notched with the invert elevations equal to that of the riverbed. Trails were added to Dikes 89.3L and 89.0L. Dike heights were unaltered.*

- *Dike 89.3 L: 500 feet in Length, 150-foot notch located 200-feet from the bankline, 250-foot trail perpendicular to the end of the dike and parallel to channel flow placed at +15 foot LWRP.*

- *Dike 89.0 L: 560 feet in Length, 100-foot notch located 200-feet from the bankline, 250-foot trail perpendicular to the end of the dike and parallel to channel flow placed at +13 foot LWRP.*
- *All remaining dikes unaltered.*

Plate 26 is a plan view map of the resultant bed configuration of Alternative 3. The test results indicated that this design was not effective in creating a continuous side channel through Dike Field 3. A partial side channel development was observed between Dikes 89.3 L and 89.0 L, with depths between –15 feet and 0 feet LWRP. Some shoaling was present adjacent to the channel thalweg between Dikes 89.3 L and 89.0 L and Dikes 88.2 L and 86.5 L. The majority of thalweg depths were unaffected and remained similar to that of the base test.

Alternative 4: *In an attempt to create a side channel within Dike Field 3, two of the existing dikes were notched with the invert elevations equal to that of the riverbed. Trails were added to Dikes 89.3L and 89.0L. Chevrons were placed upstream of Dikes 89.3 L and 89.0 L. Dike heights were unaltered*

- *Mile 89.55: 150-foot by 150-foot chevron located 300-feet from the bankline, placed at +10 feet LWRP.*
- *Dike 89.3 L: 500 feet in Length, 150-foot notch located 200-feet from the bankline, 250-foot trail perpendicular to the end of the dike and parallel to channel flow placed at +15 feet LWRP.*
- *Mile 89.15: 150-foot by 150-foot chevron located 200-feet from the bankline, placed at +10 feet LWRP.*
- *Dike 89.0 L: 560 feet in Length, 100-foot notch located 200-feet from the bankline, 250-foot trail perpendicular to the end of the dike and parallel to channel flow placed at +13 feet LWRP.*
- *All remaining dikes unaltered.*

Plate 27 is a plan view map of the resultant bed configuration of Alternative 4. The test results indicated that this design was not effective in creating a continuous side channel through Dike Field 3. A partial side channel development was observed between Dike 89.3 L and Mile 88.6, with depths between –18 feet and 0 feet LWRP.

Scouring with depths reaching below –20 feet LWRP was observed downstream of the thalweg side of the chevron placed at Mile 89.55. The majority of thalweg depths were unaffected and remained similar to that of the base test.

Alternative 5: *In an attempt to create a side channel within Dike Field 3, two of the existing dikes were notched with the invert elevations equal to that of the riverbed. Trails were added to Dikes 89.3L and 89.0L. Chevrons were placed upstream of Dikes 89.3 L, 89.0 L and 88.2 L. Dike heights were unaltered*

- *Mile 89.55: 150-foot by 150-foot chevron located 300-feet from the bankline, placed at +10 feet LWRP.*
- *Dike 89.3 L: 500 feet in Length, 150-foot notch located 200-feet from the bankline, 250-foot trail perpendicular to the end of the dike and parallel to channel flow placed at +15 feet LWRP.*
- *Mile 89.15: 150-foot by 150-foot chevron located 200-feet from the bankline, placed at +10 feet LWRP.*
- *Dike 89.0 L: 560 feet in Length, 100-foot notch located 200-feet from the bankline, 250-foot trail perpendicular to the end of the dike and parallel to channel flow placed at +13 feet LWRP.*
- *Mile 88.6: 150-foot by 150-foot chevron located 200-feet from the bankline, placed at +10 feet LWRP.*
- *All remaining dikes unaltered.*

Plate 28 is a plan view map of the resultant bed configuration of Alternative 5. The test results indicated that this design was not effective in creating a continuous side channel through Dike Field 3. A partial side channel development was observed between Dike 89.3 L and Mile 88.5, with depths between –14 feet and 0 feet LWRP. Scouring with depths reaching below –20 feet LWRP was observed downstream of the thalweg side of the chevron placed at Mile 89.55. The additional chevron at Mile 88.6 did not significantly extend the length of the side channel. The majority of thalweg depths were unaffected and remained similar to that of the base test. However, some areas of the thalweg appeared to be slightly deeper. The height of the Dike Field 3 sandbar also appeared marginally shallower.

Alternative 6: *In an attempt to create a side channel within Dike Field 3, two of the existing dikes were notched with the invert elevations equal to that of the riverbed. Trails were added to Dikes 89.3L and 89.0L. Chevrons were placed upstream of Dikes 89.3 L and 89.0 L. Dike heights were unaltered*

- *Mile 89.55: 150-foot by 150-foot chevron located 300-feet from the bankline, placed at +10 feet LWRP.*
- *Dike 89.3 L: 500 feet in Length, 150-foot notch located 200-feet from the bankline, 250-foot trail perpendicular to the end of the dike and parallel to channel flow placed at +15 feet LWRP.*
- *Mile 89.15: 150-foot by 150-foot chevron located 200-feet from the bankline, placed at +10 feet LWRP.*
- *Dike 89.0 L: 560 feet in Length, 150-foot notch located 250-feet from the bankline, 250-foot trail perpendicular to the end of the dike and parallel to channel flow placed at +13 feet LWRP.*
- *All remaining dikes unaltered.*

Plate 29 is a plan view map of the resultant bed configuration of Alternative 6. The test results indicated that this design was somewhat effective in creating a continuous side channel through Dike Field 3. Side channel development was observed between Dike 89.3 L and Mile 88.5, with depths between –16 feet and 0 feet LWRP. Scouring with depths reaching below –20 feet LWRP was observed downstream of the thalweg side of the chevron placed at Mile 89.55. The bar that formed between the side channel and the thalweg became wider and extended farther into the river channel. This would create additional shoal areas but could possible impede navigation. Some areas of the thalweg appear to be wider and deeper. The height of the Dike Field 3 sandbar also appears marginally shallower.

Alternative 7: *In an attempt to create a side channel within Dike Field 3, two of the existing dikes were notched with the invert elevations equal to that of the riverbed. Trails were added to Dikes 89.3L and 89.0L. Chevrons were placed upstream of Dikes 89.3 L and 89.0 L with two additional chevrons placed between Dikes 89.0 L and 88.2 L. Dike heights were unaltered*

- *Mile 89.55: 150-foot by 150-foot chevron located 300-feet from the bankline, placed at +10 feet LWRP.*
- *Dike 89.3 L: 500 feet in Length, 150-foot notch located 200-feet from the bankline, 250-foot trail perpendicular to the end of the dike and parallel to channel flow placed at +15 feet LWRP.*
- *Mile 89.15: 150-foot by 150-foot chevron located 200-feet from the bankline, placed at +10 feet LWRP.*
- *Dike 89.0 L: 560 feet in Length, 150-foot notch located 250-feet from the bankline, 250-foot trail perpendicular to the end of the dike and parallel to channel flow placed at +13 feet LWRP.*
- *Mile 88.6: 150-foot by 150-foot chevron located 300-feet from the bankline, placed at +10 feet LWRP.*
- *Mile 88.4: 150-foot by 150-foot chevron located 300-feet from the bankline, placed at +10 feet LWRP.*
- *All remaining dikes unaltered.*

Plate 30 is a plan view map of the resultant bed configuration of Alternative 7. The test results indicated that this design was somewhat effective in creating a continuous side channel through Dike Field 3. Side channel development was observed between Dike 89.3 L and Mile 88.3, with depths between –18 feet and 0 feet LWRP. Scouring with depths reaching below –20 feet LWRP was observed downstream of the thalweg side of the chevron placed at Mile 89.55. Some areas of the thalweg appeared to be slightly wider and deeper. The height of the Dike Field 3 sandbar also appeared marginally shallower

Alternative 8: *In an attempt to create a side channel within Dike Field 3, three of the existing dikes were notched with the invert elevations equal to that of the riverbed. Trails were added to Dikes 89.3L and 89.0L. Chevrons were placed upstream of Dikes 89.3 L and 89.0 L with two additional chevrons placed between Dikes 89.0 L and 88.2 L. Dike heights were unaltered*

- *Mile 89.55: 150-foot by 150-foot chevron located 300-feet from the bankline, placed at +10 feet LWRP.*

- *Dike 89.3 L: 500 feet in Length, 150-foot notch located 200-feet from the bankline, 250-foot trail perpendicular to the end of the dike and parallel to channel flow placed at +15 feet LWRP.*
- *Mile 89.15: 150-foot by 150-foot chevron located 200-feet from the bankline, placed at +10 feet LWRP.*
- *Dike 89.0 L: 560 feet in Length, 150-foot notch located 250-feet from the bankline, 250-foot trail perpendicular to the end of the dike and parallel to channel flow placed at +13 feet LWRP.*
- *Mile 88.6: 150-foot by 150-foot chevron located 300-feet from the bankline, placed at +10 feet LWRP.*
- *Mile 88.4: 150-foot by 150-foot chevron located 300-feet from the bankline, placed at +10 feet LWRP.*
- *Dike 88.2 L: 980 feet in Length, 150-foot notch located 325-feet from the bankline*
- *All remaining dikes unaltered.*

Plate 31 is a plan view map of the resultant bed configuration of Alternative 8. The test results indicated that this design was somewhat effective in creating a continuous side channel through Dike Field 3. Side channel development was observed between Dike 89.3 L and Mile 88.3, with depths between –18 feet and 0 feet LWRP. Side channel flows did not go through the notch in Dike 88.2 L, instead flows dissipated into the main channel. Scouring with depths reaching below –20 feet LWRP was observed downstream of the both sides of the chevron placed at Mile 89.55. The bar that formed between the side channel and the thalweg became wider and longer. This created additional shoal areas, but could possible impede navigation. The majority of thalweg depths were unaffected and remained similar to that of the base test. However, some areas of the thalweg appeared to be slightly deeper. The height of the Dike Field 3 sandbar also appeared marginally shallower.

Alternative 9: *In an attempt to create a side channel within Dike Field 3, two of the existing dikes were notched with the invert elevations equal to that of the riverbed. Trails were added to Dikes 89.3L and 89.0L. Chevrons were placed*

upstream of Dikes 89.3 L and 89.0 L. An additional dike was added between Dikes 89.0 L and 88.2 L. Dike heights were unaltered

- *Mile 89.55: 150-foot by 150-foot chevron located 300-feet from the bankline, placed at +10 feet LWRP.*
- *Dike 89.3 L: 500 feet in Length, 150-foot notch located 200-feet from the bankline, 250-foot trail perpendicular to the end of the dike and parallel to channel flow placed at +15 feet LWRP.*
- *Mile 89.15: 150-foot by 150-foot chevron located 200-feet from the bankline, placed at +10 feet LWRP.*
- *Dike 89.0 L: 560 feet in Length, 150-foot notch located 250-feet from the bankline, 250-foot trail perpendicular to the end of the dike and parallel to channel flow placed at +13 feet LWRP.*
- *Mile 88.5 L: 200-foot long dike added at a height of +10 feet LWRP.*
- *All remaining dikes unaltered.*

Plate 32 is a plan view map of the resultant bed configuration of Alternative 9. The test results indicated that this design was somewhat effective in creating a continuous side channel through Dike Field 3. Side channel development was observed between Dike 89.3 L and Mile 88.3, with depths between –14 feet and 0 feet LWRP. Scouring with depths reaching below –30 feet LWRP was observed downstream of both sides of the chevron placed at Mile 89.55. The bar that formed between the side channel and the thalweg became longer, creating additional shoal areas. The majority of thalweg depths were unaffected and remained similar to that of the base test. The height of the Dike Field 3 sandbar also appeared marginally shallower.

Alternative 10: *In an attempt to create a side channel within Dike Field 3, two of the existing dikes were notched with the invert elevations equal to that of the riverbed. Trails were added to Dikes 89.3L and 89.0L. Chevrons were placed upstream of Dikes 89.3 L and 89.0 L. An additional dike was placed between Dikes 89.0 L and 88.2 L. Dike heights were unaltered*

- *Mile 89.55: 150-foot by 150-foot chevron located 300-feet from the bankline, placed at +10 feet LWRP.*
- *Dike 89.3 L: 500 feet in Length, 150-foot notch located 200-feet from the bankline, 250-foot trail perpendicular to the end of the dike and parallel to channel flow placed at +15 feet LWRP.*
- *Mile 89.15: 150-foot by 150-foot chevron located 200-feet from the bankline, placed at +10 feet LWRP.*
- *Dike 89.0 L: 560 feet in Length, 150-foot notch located 250-feet from the bankline, 250-foot trail perpendicular to the end of the dike and parallel to channel flow placed at +13 feet LWRP.*
- *Mile 88.5 L: 400-foot long dike added at a height of +10 feet LWRP.*
- *All remaining dikes unaltered.*

Plate 33 is a plan view map of the resultant bed configuration of Alternative 10. The test results indicated that this design was somewhat effective in creating a continuous side channel through Dike Field 3. Side channel development was observed between Dike 89.3 L and Mile 88.5, with depths between –14 feet and 0 feet LWRP. Scouring with depths reaching below –30 feet LWRP was observed downstream of both sides of the chevron placed at Mile 89.55. The bar that formed between the side channel and the thalweg was similar in size when compared to present day conditions. The majority of thalweg depths were unaffected and remained similar to that of the base test. However, some areas of the thalweg appeared to be slightly deeper. The height of the Dike Field 3 sandbar also appeared marginally shallower.

Alternative 11: *In an attempt to create a side channel within Dike Field 3, two of the existing dikes were notched with the invert elevations equal to that of the riverbed. Trails were added to Dikes 89.3L and 89.0L. Chevrons were placed upstream of Dikes 89.3 L and 89.0 L. An additional dike was placed between Dikes 89.0 L and 88.2 L. In an attempt to create additional habitat in Dike Field 2 a dike was added at Mile 90.4 along the RDB. Dike heights were unaltered*

- *Mile 90.4: Dike was placed along the RDB, 250-feet from bankline. Dike length was 300 foot with a 100-foot notch midway across the dike. Notch invert was equal to that of the riverbed. Dike height was +10 feet LWRP*
- *Mile 89.55: 150-foot by 150-foot chevron located 300-feet from the bankline, placed at +10 feet LWRP.*
- *Dike 89.3 L: 500 feet in Length, 150-foot notch located 200-feet from the bankline, 250-foot trail perpendicular to the end of the dike and parallel to channel flow placed at +15 feet LWRP.*
- *Mile 89.15: 150-foot by 150-foot chevron located 200-feet from the bankline, placed at +10 feet LWRP.*
- *Dike 89.0 L: 560 feet in Length, 150-foot notch located 250-feet from the bankline, 250-foot trail perpendicular to the end of the dike and parallel to channel flow placed at +13 feet LWRP.*
- *Mile 88.5 L: 400-foot long dike added at a height of +10 feet LWRP.*
- *All remaining dikes unaltered.*

Plate 34 is a plan view map of the resultant bed configuration of Alternative 11. The test results indicated that this design was somewhat effective in creating a continuous side channel through Dike Field 3. A shallow side channel development was observed between Dike 89.3 L and Mile 88.4, with depths between –10 feet and 0 feet LWRP. Scouring with depths reaching below –30 feet LWRP was observed downstream of both sides of the chevron placed at Mile 89.55. The bar that formed between the side channel and the thalweg was similar in size but shallower then present day conditions. Some shoaling was observed adjacent to the end of Dike 88.2 L. The dike placed at Mile 90.4 R experienced downstream scouring with depths below –40 feet LWRP. Along the RDB a large sandbar formed from Mile 90.2 to 89.2. Small shoals formed in the center of the river channel at Mile 86.9. The majority of thalweg depths were unaffected and remained similar to that of the base test. The height of the sandbar in Dike Field 3 also appeared marginally shallower.

Alternative 12: *In an attempt to create a side channel within Dike Field 3, two of the existing dikes were notched with the invert elevations equal to that of the riverbed. Trails were added to Dikes 89.3L and 89.0L. Chevrons were placed upstream of Dikes 89.3 L and 89.0 L. An additional dike was placed between Dikes 89.0 L and 88.2 L. In an attempt to create additional habitat in Dike Field 2 a chevron was added at Mile 90.4 along the RDB. Dike heights were unaltered*

- *Mile 90.4: 150-foot by 150-foot chevron located 250-feet from the RDB, placed at +10 feet LWRP.*
- *Mile 89.55: 150-foot by 150-foot chevron located 300-feet from the bankline, placed at +10 feet LWRP.*
- *Dike 89.3 L: 500 feet in Length, 150-foot notch located 200-feet from the bankline, 250-foot trail perpendicular to the end of the dike and parallel to channel flow placed at +15 feet LWRP.*
- *Mile 89.15: 150-foot by 150-foot chevron located 200-feet from the bankline, placed at +10 feet LWRP.*
- *Dike 89.0 L: 560 feet in Length, 150-foot notch located 250-feet from the bankline, 250-foot trail perpendicular to the end of the dike and parallel to channel flow placed at +13 feet LWRP.*
- *Mile 88.5 L: 400-foot long dike added at a height of +10 feet LWRP.*
- *All remaining dikes unaltered.*

Plate 35 is a plan view map of the resultant bed configuration of Alternative 12. The test results indicated that this design was somewhat effective in creating a continuous side channel through Dike Field 3. Side channel development was observed between Dike 89.3 L and Mile 88.5, with depths between –14 feet and 0 feet LWRP. Scouring with depths reaching below –30 feet LWRP was observed downstream of both sides of the chevron placed at Mile 89.55. The bar that formed between the side channel and the thalweg was similar in size but shallower then present day conditions. The chevron placed at Mile 90.4 R experienced downstream scouring with depths below –20 feet LWRP. Upstream of the Mile 90.4 R Chevron the channel had small shoals form. Along the RDB a sandbar formed from Mile 90.3 to 89.6. Small shoals also formed in the center of the river channel

at Mile 86.5. The majority of thalweg depths were unaffected and remained similar to that of the base test. The height of the Dike Field 3 sandbar also appeared marginally shallower.

Alternative 13: *In an attempt to create a side channel within Dike Field 3, two of the existing dikes were notched with the invert elevations equal to that of the riverbed. Trails were added to Dikes 89.3L and 89.0L. Chevrons were placed upstream of Dikes 89.3 L and 89.0 L. An additional dike was placed between Dikes 89.0 L and 88.2 L. In an attempt to create additional habitat in Dike Field 2 a chevron was added at Mile 90.4 along the RDB. Dike heights were unaltered*

- *Mile 90.4: 150-foot by 150-foot chevron located 250-feet from the RDB, placed at +10 feet LWRP.*
- *Mile 89.55: 150-foot by 150-foot chevron located 300-feet from the bankline, placed at +10 feet LWRP.*
- *Dike 89.3 L: 500 feet in Length, 150-foot notch located 200-feet from the bankline, 250-foot trail perpendicular to the end of the dike and parallel to channel flow placed at +15 feet LWRP.*
- *Mile 89.15: 150-foot by 150-foot chevron located 200-feet from the bankline, placed at +10 feet LWRP.*
- *Dike 89.0 L: 560 feet in Length, 150-foot notch located 250-feet from the bankline, 250-foot trail perpendicular to the end of the dike and parallel to channel flow placed at +13 feet LWRP.*
- *Mile 88.5 L: 200-foot long dike added at a height of +10 feet LWRP.*
- *All remaining dikes unaltered.*

Plate 36 is a plan view map of the resultant bed configuration of Alternative 13. The test results indicated that this design was effective in creating a continuous side channel through Dike Field 3. Side channel development was observed between Dike 89.3 L and Mile 88.5, with depths between –16 feet and 0 feet LWRP. Scouring with depths reaching below –30 feet LWRP was observed downstream of both sides of the chevron placed at Mile 89.55. The bar that formed between the side channel and the thalweg was similar in size but shallower then present day

conditions. The chevron placed at Mile 90.4 R experienced downstream scouring with depths below –20 feet LWRP. Along the RDB a sandbar formed from Mile 90.3 to 89.6. The majority of thalweg depths were unaffected and remained similar to that of the base test. The height of the Dike Field 3 sandbar also appeared marginally shallower.

CONCLUSIONS

1. Summary and Recommendations

Several alternative design tests were conducted in this particular study. Each alternative was tested with the intention of creating new island, side channel and deep scour hole aquatic habitat within the dike fields of the study reach. Additional bathymetric diversity was desired while not negatively influencing the integrity of the adjacent navigation channel.

Alternatives 1 through 10 focused on improving habitat within Dike Field 3, and alternatives 11 through 13 focused on improvements within Dike Field 2 and 3.

Alternatives 1 through 5 were successful in creating a partial, non-continuous side channel in the upper end of Dike Field 3. Of these 5 tests, results indicated that the addition of two chevrons, two trails, and dike notching produced the most side channel depth and bathymetric diversity in the dike field. With these plans, the integrity of the navigation channel was not affected.

Alternatives 6 through 10 were successful in creating a continuous side channel in the upper portion of Dike Field 3. With these alternatives, a new bar or shoaling area was developed in the channel off the ends of the upper 3 dikes, between Mile 89.3 and 88.5. The bar encroached approximately 400 feet to 500 feet into the navigation channel near Mile 89.0. However, the navigation channel was still approximately 400 feet to 500 feet wide in this area.

Alternatives 11 through 13 were successful in creating a continuous side channel in the upper portion of Dike Field 3 in addition to creating habitat diversity in the lower portion of Dike Field 2. With these alternatives, localized scouring occurred downstream of the tested structure at Mile 90.4 and a bar formed downstream of Dike Field 2.

All design tests are viable options for enhancing the aquatic habitat in the Red Rock reach of the Mississippi River.

If the recommended plan is eventually constructed in the river, revetment of the bankline should also be carried out along the LDB, in the immediate area of Dikes 89.3 L and 89.0 L. This measure will ensure protection of adjacent private floodplain lands and preserve flow energy necessary for the formation of the side channel.

2. Interpretation of Model Test Results

In the interpretation and evaluation of the results of the tests conducted, it should be remembered that the results of these model tests were qualitative in nature. Any hydraulic model, whether physical or numerical, is subject to biases introduced as a result of the inherent complexities that exist in the prototype. Anomalies in actual hydrographic events, such as prolonged periods of high or low flows are not reflected in these results, nor are complex physical phenomena, such as the existence of underlying rock formations or other non-erodible variables. Flood flows were not simulated in this study.

This model study was intended to serve as a tool for the river engineer to guide in assessing the general trends that could be expected to occur in the actual river from a variety of imposed design alternatives. Measures for the final design may be modified based upon engineering knowledge and experience, real estate and construction considerations, economic and environmental impacts, or any other special requirements.

FOR MORE INFORMATION

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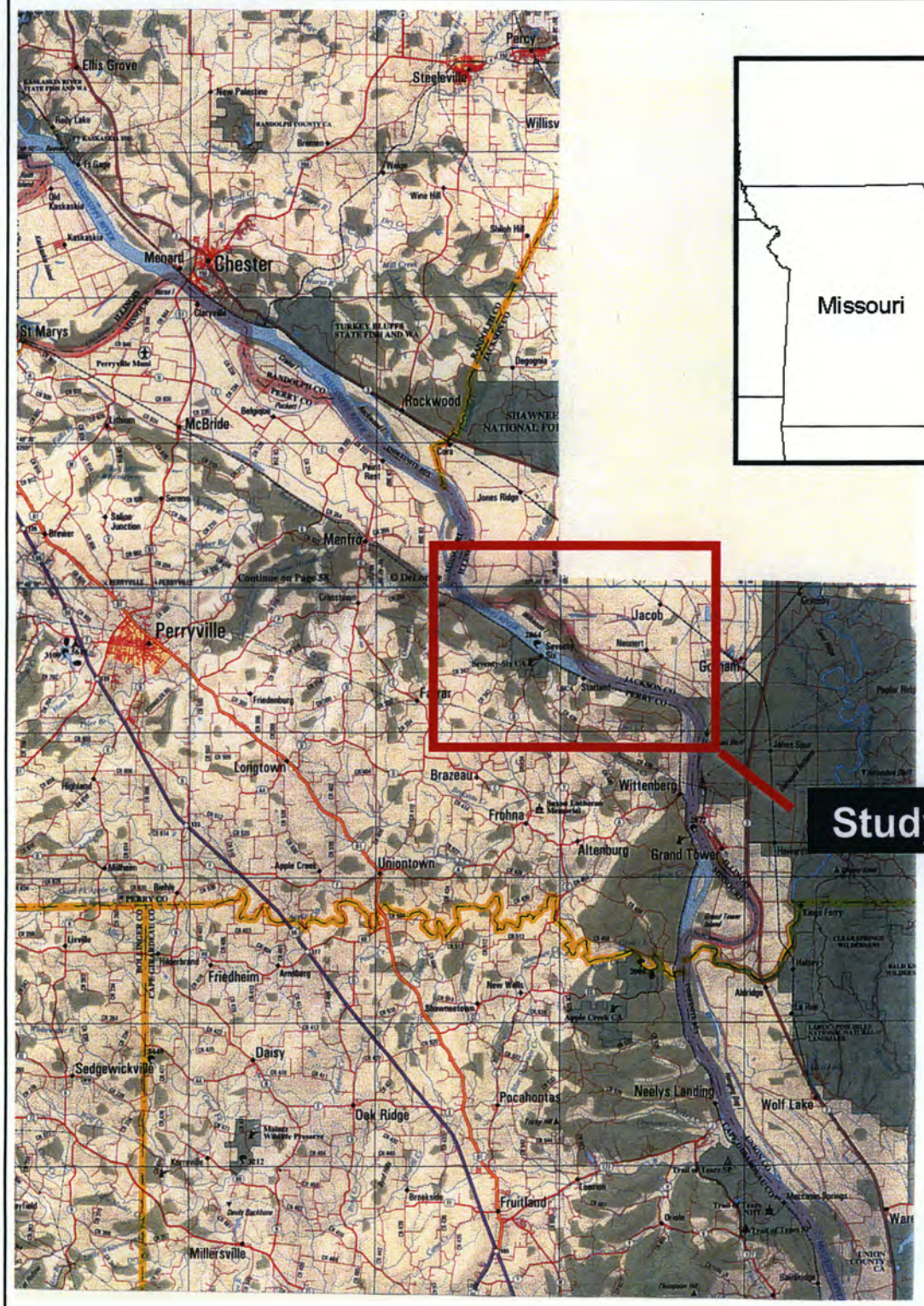
APPENDIX OF PLATES

Plate #'s 1 through 36 follow:

1. Location and Vicinity Map of the Study Reach
2. Characteristics of the Study Reach
3. Right Descending Bank Features
4. Left Descending Bank Features
5. Reach 1 Dike Information
6. Reach 2 Dike Information
7. Reach 3 Dike Information
8. Reach 4 Dike Information
9. 1881 Topographic and Hydrographic Survey with Color Coded Land Usage
10. 1908 Topographic and Hydrographic Survey with Color Coded Land Usage
11. 1928 Aerial Photograph
12. 1956 Hydrographic Survey
13. 1968 Aerial Photograph and 1969 Hydrographic Survey
14. 1976 Aerial Photograph and 1977 Hydrographic Survey
15. 1976 Aerial Photograph and 1982 Hydrographic Survey
16. 1983 Aerial Photograph and 1988 Hydrographic Survey
17. 1998 Aerial Photograph and 1993 Hydrographic Survey
18. Red Rock Bendway Weirs
19. 1998 Aerial Photograph and 1998 Hydrographic Survey
20. 1998 Aerial Photograph and 2001 Hydrographic Survey
21. Red Rock Micro Model
22. Typical Micro Model Hydrograph
23. Micro Model Base Test
24. Alternative 1
25. Alternative 2
26. Alternative 3
27. Alternative 4
28. Alternative 5

29. Alternative 6
30. Alternative 7
31. Alternative 8
32. Alternative 9
33. Alternative 10
34. Alternative 11
35. Alternative 12
36. Alternative 13



	U.S. ARMY ENGINEER DISTRICT, ST. LOUIS **CORPS OF ENGINEERS** **ST. LOUIS, MO**
PREPARED BY: E. RIIFF CHECKED BY: D. LAMM	BIOLOGICAL OPINION MICRO MODEL STUDY MILES 93.0 TO 86.0 LOCATION AND VICINITY MAP OF THE STUDY REACH
FILE NAME: RRVICINITY. / PLOT DATE: 01 OCT 02	PLATE NO. 1

Drainage Ditch for the Degonia and Fountain Bluff L & D District Located Along the LDB at Mile 85.4

Abandoned Loading Facility Located Along the LDB at Mile 85.6

Unnamed Tributary Located Along the LDB at Mile 86.4

Remnant Channel Located Along the LDB at Mile 88.3

Photographs taken on July 24, 2002 at a Red Rock gage reading of +13.60 feet LWRP

U.S. ARMY ENGINEER DISTRICT, ST. LOUIS
CORPS OF ENGINEERS
ST. LOUIS, MO

PREPARED BY: J. HUNN
DRAWN BY:D. LAMM
CHECKED BY: D. LAMM

BIOLOGICAL OPINION MICRO MODEL STUDY
MISSISSIPPI RIVER MILES 93.0 TO 86.0

LEFT DESCENDING BANK FEATURES

DESIGN FILE: LDB FEATURES | PLOT DATE: 01 OCT 02

PLATE NO. 4

Dike height is +16 Ft. LWRP
Approximate length is 250 Ft.

Dike height is +16 Ft. LWRP
Approximate length is 430 Ft.

Dike height is +16 Ft. LWRP
Approximate length is 350 Ft.

Dike height is +16 Ft. LWRP
Approximate length is 490 Ft.

Dike height is +19 to +12 Ft. LWRP
Approximate length is 500 Ft.

Dike height is +12 to +10 Ft. LWRP
Approximate length is 300 Ft.

Photographs taken on July 24, 2002 at a Red Rock gage reading of +13.60 feet LWRP

U.S. ARMY ENGINEER DISTRICT, ST. LOUIS
CORPS OF ENGINEERS
ST. LOUIS, MO

PREPARED BY: J. HUNN
DRAWN BY: D. LAMM
CHECKED BY: R. DAVINROY

BIOLOGICAL OPINION MICRO MODEL STUDY
MISSISSIPPI RIVER MILES 93.0 TO 86.0

REACH 1 DIKE INFORMATION

DESIGN FILE: REACH 1.PUB | PLOT DATE: 01 OCT 02

PLATE NO. 5