Technical Report M60

ESTABLISHMENT CHUTE HYDRAULIC SEDIMENT RESPONSE MODEL STUDY
UPPER MISSISSIPPI RIVER MILES 134.0-128.0

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INTRODUCTION

The U.S. Army Corps of Engineers, St. Louis District initiated a study of the Middle Mississippi River between Miles 134.0 and 128.0, approximately twenty miles downstream of Herculaneum, Missouri. This study was funded by the Avoid and Minimize Program. The objective of the study was to evaluate environmental design alternatives for the development of side channel and island habitat, utilizing an existing dike field and island complex on the Mississippi River.

The study was conducted between January 2010 and September 2011 using a physical hydraulic sediment response (HSR) model at the Applied River Engineering Center, St. Louis District in St. Louis, Missouri. The model study was performed by Brad Krischel, Hydraulic Engineer, under direct supervision of Mr. Robert Davinroy, P.E., Chief of River Engineering Section for the St. Louis District. Other Corps of Engineers St. Louis District personnel included: Mr. Leonard Hopkins, P.E., Hydrologic and Hydraulic Branch Chief, Mr. Dave Gordon, P.E., Chief of Hydraulic Design Section, Ms. June Jeffries, P.E., Project Manager, Mr. Mike Rodgers, P.E., Project Manager, Mr. Jasen Brown, P.E., River Engineer, Brian Johnson, Chief of Environmental Planning, Donovan Henry, Environmental Branch, and Alan Edmondson, Regulatory Branch. Personnel from other agencies included: Bernie Heroff, American River Transportation Company, Matt Mangan, United States Fish and Wildlife Service, Shannon Hughes, Kirby Inland Marine, David Goin, Marquette Transportation, and Terry Rottler, family property owner.

TABLE OF CONTENTS

BACKGROUND

1. Problem Description

Over time, the Establishment Chute side channel of the Middle Mississippi River had silted in, which had caused there to be very shallow bathymetry. Surveys of the side channel indicated that the bed of Establishment Chute was relatively high and homogenous. As a result of the shallow elevations, there was little aquatic diversity within the side channel. Typically, side channels, both continuous and detached, serve as important backwater habitats for a variety of fish species. Alternating bars, deep scour holes, and other forms of diversity are desired within side channels, but this habitat does not exist within Establishment Chute.

2. Study Purpose and Goals

The purpose of this study was to produce a report that communicates the results of the HSR analysis of various river engineering measures used to develop diversity within Establishment Chute. The increased diversity within Establishment Chute would, in turn, create a more beneficial aquatic habitat.

The goals of this study were to:

i. Evaluate a variety of remedial measures utilizing an HSR model with the primary objective of identifying the most effective and economical plan to diversify aquatic habitat in Establishment Chute. The secondary objective was to create a secondary side channel between Establishment Island and the existing point bar. In order to determine the best alternative, three criteria were used to evaluate each alternative.

   a. The alternative should increase aquatic habitat within Establishment Chute by creating more bathymetric diversity.
   b. The alternative should maintain the navigation channel requirements of at least 9 ft of depth and 300 ft of width.

c. The alternative should not negatively impact the bar located between Establishment Island / Schmidts Island and the main channel.

ii. Communicate to other engineers, river industry personnel, and environmental agency personnel the results of the HSR model tests and the plans for improvements.

3. Study Reach

The study comprised a 6-mile stretch of the Middle Mississippi River, between RM 134.0 and RM 128.0, which is approximately 20 miles downstream of Herculaneum, Missouri. The study reach was located near Ste. Genevieve County on the Missouri side and Randolph County on the Illinois side. Plate 1 is a location and vicinity map of the study reach.

Plate 2 is a 2006 aerial photograph illustrating the planform and nomenclature of the Middle Mississippi River between RM 134.0 and RM 128.0. At the time of this study, the entire study reach had a total of 35 dikes, 13 bendway weirs, and 2 chevrons. Within the study reach, revetments were located between RM 134.0 and RM 132.7 on the right descending bank (RDB), RM 132.0 and RM 128.0 on the left descending bank (LDB), and RM 130.0 and RM 128.2 (RDB). Banklines along the side channel behind Establishment Island, as well as all banklines of both the main island and secondary islands, were not revetted.

A. Geomorphology

A historical look at the Establishment Chute reach of the Middle Mississippi revealed that the river channel within the study reach has changed over time. Plate 4 shows an overview of the changes that have taken place from 1817 to 2003. More specifically, the meander migration between RM 134.0 and RM 130.0 displays noteworthy changes. In 186 years, the river migrated approximately 4,000 ft across the floodplain in the Northeast direction between RM 134.0 and RM 130.0. By 1928, the planform of the river was stabilized through the use of revetment on the banklines. Plate 4 was taken from the “Geomorphology of the Middle Mississipi River” report, which was produced by the St. Louis District (2005).

Plates 5, 6, and 7 showed the study reach through aerial photographs and sounding maps from 1928, 1942, and 1956, respectively. In 1928 (Plate 5), there were two islands located on the Illinois side of the study reach: Fort Chartres Island and Turkey Island. On the Missouri side of the study reach, there were a total of four islands. These islands were created from the connection of multiple side channels. The side channels seen in the 1928 photographs are narrow compared to the current side channel. The common trend with all of the side channels was that each started at a location on the Mississippi River, connected with Establishment Creek, and then connected to the river channel at approximately RM 128.7. Originally, Establishment Island was formed from the connection of a small side channel that started at RM 133.5 and another side channel that started at RM 132.0.

The 1942 map (Plate 6) of the study area shows that three islands existed on the Missouri side of the study reach, between RM 133.5 and RM 128.7. Again, the islands were formed from the connection of multiple narrow side channels. Also visible on the 1942 map was the addition of nine dikes (Dikes 133.0, 132.93, 132.9, 132.5, 131.9, 131.3, 130.6, 130.3, and 130.2). Revetment was added on Establishment Island at the entrance of the side channel, which began at RM 132.7.

The 1956 map (Plate 7) was limited mostly to the main channel due to the fact that it was a sounding map. The nine dikes that were in place in 1942 remained, but there was a significant difference in the islands along the RDB. The island that the dikes were built across in 1942 had split into four separate islands by 1956 due to the reaction between the side channel, main channel, and dikes. Also, the side channel had become much wider, and had started to resemble the side channel that is observed in that location today.

1977 aerial photographs (Plate 8) showed that many of today's dike structures were constructed prior to 1977. The original Establishment Island no longer existed due to the closure of the entrance of the side channel located at RM 133.7 and the closure of the side channel split, which was located at RM 132.0. The closure of the side channel split created a disconnect between the side channel and Establishment Creek. By 1977, the four small islands that were visible on the 1956 sounding map had combined into one island, which is what is known as Establishment Island today. Differences between the 1977 and 2006 aerial photos can be seen on Plates 8 and 2 respectively.

1982 and 1987 aerial photographs (Plates 9 and 10) of the project area showed a channel configuration very similar to that shown in the 2006 aerial photographs (Plate 2). Establishment Island and the smaller island, as well as the side channel width and connectivity to the main channel, are similar to what can be seen on the 2006 aerial photograph. It should be noted that weir structures were constructed in 1994 and 1998, but since weirs are submerged structures, they cannot be seen on the aerial photographs. One consistent trend in all of the historical photographs from 1928 to 2006 was that the LDB of the main channel remained in the same approximate location.

B. Study Reach Channel Characteristics and General Trends

i. Bathymetry

Hydrographic surveys of the Mississippi River, within the HSR Model extents, are shown on Plates 11-16. The plates show range line and multi-beam surveys from 1956 to 2009. For this study, the bathymetric data was referenced to the Low Water Reference Plane (LWRP).

Recent surveys were used to determine general trends because they showed the most recent construction and the resultant river bed changes. The following bathymetric trends remained relatively constant from 2005 to 2009:

Main Channel

- The main channel thalweg entered the study reach along the RDB near RM 133.0 with depths up to -30 ft LWRP.
- Scour holes of various sizes existed off of the tip and downstream of the dikes on the RDB between RM 132.5R and RM 131.9R. Scour holes with depths up to -65 ft LWRP existed off of the tips of Dike 132.6R and Dike 132.5R. Furthermore, a plunge pool with depths up to -40 ft LWRP existed downstream of Dike 132.5R, which was located at the entrance of Establishment Chute. Scour hole depths up to -50 ft LWRP existed off the tip of Dike 132.3R. Downstream and off of the tip of Dike 132.1R, scour holes with depths up to -40 ft LWRP existed. A scour hole existed off the tip of Dike 131.9R and had depths up to -30 ft LWRP.
- The thalweg crossed to the LDB between RM 132.3 and RM 131.8.
- A large, dominant point bar on the inside of the bend between RM 131.7 and RM 130.0 of the main channel existed and had depths up to and above +10 ft LWRP.
- A small amount of scour, which had depths ranging between 0 ft and -10 ft LWRP, was noted off of the smaller island in the main channel between RM 131.0 and RM 130.8.
- The thalweg remained along the LDB from RM 131.8 to RM 130.6, with depths ranging between -30 ft to -65 ft LWRP.
- Scour holes, with depths ranging between -30 ft to -65 ft, were observed downstream and off of the tip and downstream of dikes and weirs on the LDB between RM 131.0 and RM 129.9.
- The thalweg of the main channel crossed back over to the RDB between RM 130.6 and RM 129.5.

Side Channel

- Depths in Establishment Chute (RM 132.5R to RM 130.3R) ranged from -2 ft to above +10 ft LWRP, except for three scour locations. A scour hole with depths up to -16 ft LWRP was observed at the bend in the entrance of the side channel (approximately RM 132.5). Another scour hole was observed downstream of remnant pile Dike 131.9R and had depths up to -20 ft LWRP. Finally, a large plunge pool with depths up to -50 ft LWRP existed downstream of Dike 131.0R.

Between 1979 and 2010, dredging occurred in the Establishment Chute reach of the Middle Mississippi River 20 times between RM 134.0 and RM 128.0 for a total volume of approximately 3,504,000 cubic yards of material. The consistent dredge locations are located (Plate 17):

- At Miles 132.3 – 131.3
- At Miles 130.2 – 129.3

Table 1 shows the dredging events that occurred between 1979 and 2010:

Table 1. Dredging Quantities

Dredging Year	Number of Times	Quantity (yd^3)
1979-1980	2	368,500
1986-1987	1	201,400
1989-1990	3	392,600
1991-1992	2	174,700
1994-1995	1	124,100
1995-1996	1	81,800
1999-2000	1	125,300
2000-2001	2	323,800
2001-2002	2	392,700
2002-2003	2	401,500
2003-2004	2	311,200
2004-2005	1	397,100
2005-2006	1	209,500

ii. Site Data

Personnel from the Applied River Engineering Center (AREC) inspected the study reach on two occasions. The first trip took place on August 24, 2010, and the gage at Brickey's Landing (RM 136.0) was +15.2 ft. This trip was used to verify structure locations and heights and analyze the condition of the bankline. Higher river stages allowed boat access to the entire length of Establishment Chute but also caused many of the structures in the study reach to be underwater. The shore lines had abundant vegetation, mostly in the form of willows varying in height. All unrevetted banklines along all islands and side channels were experiencing some form of erosion, but the predominant erosion rate observed was low. Some moderate erosion was observed along the existing chute directly below Dikes 131.9R and 131.3R and along the upper end of the smaller island between RM 131.0 and RM 130.7 (RDB). Pictures from the August site visit can be seen on Plate 3.

On September 8, 2010 personnel from AREC inspected the study reach for a second time. The Brickey's Landing gage (RM 136.0) was at a stage of +18.4 ft. This trip was used to verify river conditions stated by our partners during an August 28, 2010 model meeting, and also to observe the condition of structures and bankline after a long duration of high water events. This site visit showed similar trends and conditions as the August 24, 2010 inspection.

One of the most important observations made on these site visits was the condition of structures. Modeling the correct condition of existing structures within the study reach was critical to the modeling process. One of the structures with significant degradation was Dike 131.3R. The original structure crossed the side channel (325 ft) and also extended 1,000 ft off of Establishment Island into the main channel. After years of degradation, Dike 131.3R displayed little to no hydraulic effect. The only evidence of this structure within the side channel and main channel was a small round-out area on the bank downstream of where the dike was located. Since the structure showed little hydraulic effect, it was not included in the HSR model.

Dike 130.6R showed similar characteristics to Dike 131.3R. The original structure crossed the side channel (500 ft) and also extended 500 ft off of the smaller island. Remnant piles of Dike 130.6R were visible on 2006 aerial photographs taken at low water conditions. However, on the site visit there was no evidence of a round-out downstream of the dike location, and therefore, was determined that the remnant piles had no hydraulic effect. For these reasons, Dike 130.6R was not modeled.

Another remnant pile dike that existed in the side channel was Dike 130.3R, which originally crossed the entire side channel and had a length of 420 ft. There was no evidence of the dike on either of the site visits due to higher river stages. However, remnant piles can be seen on the RDB of the side channel on 2006 aerial photographs taken at low water conditions. Since the structure showed no hydraulic effect, it was not included in the HSR model.

A structure that was not in our records, but was found on the 2008 multibeam survey of the study reach, was a section of remnant revetment located along the RDB between RM 132.7 and RM 132.6. This revetment can be seen labeled on 1928 aerial photographs (Plate 5). At the time of construction, the revetment was placed on the bank, but due to degradation and failure of the protection, the bankline has moved Southwest past the revetment and can be seen immediately downstream of Weir 132.7R on Plate 2.

HSR MODELING

A discussion of HSR modeling theory is included in Appendix B.

1. Model Calibration and Replication

HSR modeling methodology employs a calibration process designed to replicate the general conditions in the river at the time of the model study. Calibration of the model was achieved utilizing a three step process.

First, planform "fixed" boundary conditions of the study reach, i.e. banklines, islands, side channels, tributaries and other features were established according to the most recent available high resolution aerial photographs. Various other fixed boundaries were also introduced into the model including any channel improvement structures, underwater rock, and other non-mobile boundaries. These boundaries were based off of historical survey data and aerial photography.

Second, "loose" boundary conditions of the model were replicated. Bed material was introduced into the channel throughout the model to an approximate level plane. The combination of the fixed and loose boundaries served as the starting condition of the model.

Third, model tests were run using steady state discharge. Adjustment of the discharge, sediment volume, model slope, fixed boundaries, and entrance conditions were refined during these tests as part of calibration. The bed progressed from a static, flat, arbitrary bed into a fully-formed, dynamic three-dimensional mobile bed response. Repeated tests were simulated for the assurance of model stability and repeatability. When the general trends of the model bathymetry were similar to observed recent river bathymetry, and the tests were repeatable, the model was considered replicated and alternative testing began.

One important parameter to note was that in calibration, non-erodible bed material of higher specific gravity was used in some localized areas on the model riverbed to better replicate likely areas of non-erodible material observed in the prototype. Because the non-erodible was required for calibration, the non-erodible remained in the model throughout the rest of the study (ie during alternative testing).

2. Scales and Bed Materials

The model was constructed to a horizontal scale of 1 inch = 400 feet, or 1:4,800, and a vertical scale of 1 inch = 50 feet, or 1:600, for a 8 to 1 distortion ratio of linear scales. This distortion supplied the necessary forces required for the simulation of sediment transport conditions similar to those observed in the prototype. The zero reference plane of the prototype assumed to be Low Water Reference Plane (LWRP) condition. The bed consisted of granular plastic urea, Type II, with a specific gravity of 1.40, as the erodible bed sediment.

3. Appurtenances

The HSR model insert was initially constructed by gluing a GIS aerial photo overlay to a dense polystyrene base. The HSR model insert was cut to the channel boundaries based on the permanent tree line evident in 2009 aerial photography of the study reach. The model bank lines were routed into the polystyrene foam and modified with either polymesh or clay as necessary during calibration. The slope on this model was determined to be 0.01 inch/inch. The HSR model was kept level for all testing. River training structures in the model were made of galvanized steel mesh to generate the appropriate scaled roughness. A picture of the HSR model can be seen on Plate 18.

4. Flow Control

Flow into the model was regulated by a control valve. A sediment re-circulating system, submersible pump, and constant head tank were responsible for maintaining flow and sediment load in the model. A magnetic flow meter was used to determine the flow rate. A flow rate of 3.5 gal / min was held constant for model replication and during all alternatives testing. This serves as the average expected energy response of the river. Because of the constant variation experienced by the river, this stead state flow was used to replicate existing general conditions and empirically analyze the ultimate expected sediment response that could occur from future alternative actions.

5. Data Collection

Data from the HSR model was collected with a three dimensional (3D) laser scanner and a laser doppler velocimeter (LDV). The operation of this equipment is described below.

A. 3D Laser Scanner

The river bed in the model was surveyed with a high definition, 3D laser scanner that collects a dense cloud of xyz data points. These xyz data points were then georeferenced to real world coordinates and triangulated to create a 3D surface. The surface was then color coded by elevation using standard color tables that are also used in color coding prototype surveys. This process allowed a direct comparison between HSR model bathymetry surveys and prototype bathymetry surveys.

6. Replication Test

Once the model adequately replicated general prototype trends, the resultant bathymetry served as a benchmark for the comparison of all future model alternative tests. In this manner, the actions of any alternative, such as new channel improvement structures, realignments etc., were compared to the replicated condition. General trends were evaluated for any major differences positive or negative between the alternative test and the replication test by comparing the surveys of the two and also carefully observing the model while the actual testing was taking place.

A. Bathymetry

Bathymetric trends were recorded from the model using a 3-D Laser Scanner. Calibration was achieved after numerous favorable bathymetric comparisons of the prototype surveys were made to several surveys of the model. The resultant bathymetry served as the bathymetry replication test for the model and is shown on Plate 19.

Results of the HSR model replication test bathymetry indicated the following trends:

Main Channel

- The thalweg entered the study reach along the RDB near RM 133.0 with depths up to approximately -30 ft LWRP.
- Scour holes of various sizes developed off of the tip of the dikes on the RDB between RM 132.5R and RM 131.9R. Scour hole depths up to -40 ft LWRP were observed off of the tip of Dikes 132.5R, 132.3R, and 132.1R. A scour hole with depths up to -30 ft LWRP existed off the tip of Dike 131.9R.
- The thalweg crossed to the LDB between RM 131.9 and RM 131.5. A dredging problem has existed within this crossing (see Table 1). The model displayed depths as shallow as -4 ft LWRP. This area has been artificially maintained by historical dredge cuts. The rest of the thalweg had depths ranging from -10 ft to -30 ft LWRP.
- The thalweg remained along the LDB between RM 131.5 and RM 130.3 with depths ranging between -30 ft and -55 ft LWRP.
- A bar on the inside of the bend of the main channel existed and had depths up to and above +10 ft LWRP, similar to what was observed in the prototype.
- The thalweg crossed back to the RDB between RM 130.3 and RM 129.4. A dredging problem has existed within this crossing (see Table 1).

Side Channel

- Depths in the Establishment Chute (River Mile 132.5R to RM 130.3R) ranged from 0 ft to +10 ft LWRP except for a plunge pool, which existed downstream of Dike 131.0R and had depths up to -40 ft LWRP.

The main differences between the model replication test and prototype surveys are listed below. It should be noted that the model was considered replicated between RM 132.7 and RM 129.5, so the differences outside of that area are not mentioned.

- Generally, the bar on the LDB between RM 133.0 and RM 131.5 had a greater width than that of the prototype bar.
- Within the model, scour hole and plunge pool formations off the tips and downstream of most of the dikes were not as defined within the reach with the exception of the plunge pool located downstream of Dike 131.0R.
- The model replication test elevations within Establishment Chute between RM 132.4 and RM 131.0 only varied between 0 ft to +10 ft LWRP, while the prototype varied between -6 ft to +10 ft LWRP.
- The depth of the channel along the LDB, between RM 131.5 and RM 130.0, was about 15 feet deeper and 150 feet wider than what was observed in the prototype.
- The model showed similar scour trends in the main channel between RM 130.6 and RM 130.3 but displayed shallower depths.

In general, the overall bathymetric trends established in the HSR model replication test were similar to those trends observed in the prototype. The thalweg remained in the same general location in both the model replication test and the prototype, and the depths of Establishment Chute were very similar to the prototype.

6. Design Alternative Tests

The testing process consisted of modeling alternative measures in the HSR model followed by analyses of the bathymetry results. The goal was to alter the model bed response in a manner intended to create more diversity within Establishment Chute while maintaining the existing navigation channel. Evaluation of each alternative was accomplished through a qualitative comparison to the model replication test bathymetry. The environmental impacts of alternatives were analyzed by looking at bathymetry changes in specified environmental areas.

Alternative 1:

Alternative 1 (Plate 20) consisted of placing a 450 ft wide, shallow notch in Dike 132.5R.

Results indicated that the point bar had elevations between 0 ft and +12 ft LWRP. A very small amount of scour developed along the small island with depths between -4 ft and 0 ft LWRP. Establishment Chute had depths that ranged from -4 ft to +10 ft LWRP. The notch in Dike 132.5R allowed for more scour, with depths up to -40 ft LWRP, to develop between Dike 132.3R and Establishment Island.

Alternative 2:

Alternative 2 (Plate 21) consisted of removing Dike 132.5R (450 ft) to grade.

Results indicated that the point bar had elevations between 0 ft and +12 ft LWRP. A very small amount of scour developed along the small island with depths between -4 ft and 0 ft LWRP. Establishment Chute had depths that ranged from -4 ft to +10 ft LWRP. The removal of Dike 132.5R allowed for more scour, with depths up to -40 ft LWRP, to develop between Dike 132.3R and Establishment Island.

Alternative 3:

Alternative 3 (Plate 22) consisted of placing six alternating dikes (each 100 ft long and set to an elevation of +18 ft LWRP) within Establishment Chute side channel between RM 131.7 and RM 131.5.

Results indicated that the point bar, for the most part, no longer had elevations above +10 ft LWRP. Instead, most of the point bar had elevations between +5 ft and +10 ft LWRP. An area of scour developed along the small island with depths between -18 ft and 0 ft LWRP. Establishment Chute had depths that ranged from 0 ft to +10 ft LWRP except the area where the three alternative structures were placed, which had depths between -4 ft to 0 ft LWRP.

Alternative 4:

Alternative 4 (Plate 23) consisted of placing six alternating dikes (each 100 ft long and set to an elevation of +18 ft LWRP) within Establishment Chute side channel between RM 131.7 and RM 131.5. Also, a 225 ft shallow notch was placed in Dike 132.3R.

Results indicated that the point bar, for the most part, no longer had elevations above +10 ft LWRP. Instead, most of the point bar had elevations between +5 ft and +10 ft LWRP. An area of scour developed along the lower part of Establishment Island and continued along the small island with depths between -16 ft and 0 ft LWRP. Establishment Chute had depths that ranged from 0 ft to +10 ft LWRP except the area where the three alternative structures were placed, which had depths between -4 ft to 0 ft LWRP.

Alternative 5:

Alternative 5 (Plate 24) consisted of restoring Dike 131.9R and Dike 131.3R to their as-built conditions of crossing the entire channel. Each were built to an elevation of +18 ft LWRP.

Results indicated that the point bar had elevations between 0 ft and +10 ft LWRP. An area of scour developed at the upstream tip and along the small island with depths between -8 ft and 0 ft LWRP. Establishment Chute had depths that ranged from -4 ft to +10 ft LWRP. An area of 500 ft upstream and 400 ft downstream of Dike 131.3R had elevations between -4 ft and 0 ft LWRP.

Alternative 6:

Alternative 6 (Plate 25) consisted of placing a 150 ft shallow notch in Dike 131.0R. This notch was placed directly in the middle of the dike section that stretched between the tip of Establishment Island and the RDB of Establishment Chute.

Results indicated that the point bar, for the most part, no longer had elevations above +10 ft LWRP. Instead, most of the point bar had elevations between +5 ft and +10 ft LWRP. An area of scour developed along the lower part of Establishment Island and continued along the small island with depths between -18 ft and 0 ft LWRP. Establishment Chute had depths that ranged from 0 ft to +5 ft LWRP except the area just upstream of the notch in Dike 131.0R where depths between -8 ft and 0 ft LWRP were observed.

Alternative 7:

Alternative 7 (Plate 26) consisted of placing a 100 ft shallow notch in Dike 131.0R. This notch was placed in the directly in the middle of the dike section that stretched between the tip of Establishment Island and the side channel side of the small island.

Results indicated that the point bar, for the most part, no longer had elevations above +10 ft LWRP. Instead, most of the point bar had elevations between +5 ft and +10 ft LWRP. The lower part of the point bar, which was close to the main channel between RM 131.0R and RM 130.8R, had elevations of +10 ft LWRP and above. An area of scour developed along the lower part of Establishment Island and continued along the small island with depths between -12 ft and 0 ft LWRP. Establishment Chute had depths that ranged from -4 ft to +5 ft LWRP.

Alternative 8:

Alternative 8 (Plate 27) was a combination of Alternative 6 (Plate 25) and Alternative 7 (Plate 26). A 150 ft shallow notch was placed directly in the middle of the section of Dike 131.0R that stretched between the tip of Establishment Island and the RDB of Establishment Chute. Also, a 100 ft shallow notch was placed directly in the middle of the section of Dike 131.0R that stretched between the tip of Establishment Island and the side channel side of the small island.

Results indicated that the point bar, for the most part, no longer had elevations above +10 ft LWRP. Instead, most of the point bar had elevations between +5 ft and +10 ft LWRP. An area of scour developed along the lower part of Establishment Island and continued along the small island with depths between -12 ft and 0 ft LWRP. Establishment Chute had depths that ranged from -4 ft to +10 ft LWRP.

Alternative 9:

Alternative 9 (Plate 28) consisted of placing a 150 ft notch directly in the middle of the section of Dike 131.0R that stretched between the tip of Establishment Island and the RDB of Establishment Chute. Also, a 100 ft notch was placed directly in the middle of the section of Dike 131.0R that stretched between the tip of Establishment Island and the side channel side of the small island. Furthermore, a 100 ft wide, shallow notch was placed in Dike 131.9R.

Results indicated that the point bar had elevations between 0 ft and above +10 ft LWRP. An area of scour developed along the lower part of the small island with depths between -8 ft and 0 ft LWRP. Establishment Chute had depths that ranged from -4 ft to +10 ft LWRP. Also, a scour hole, which had depths between -12 ft to -4 ft LWRP, developed just upstream of the western-most notch in Dike 131.0R.

Alternative 10:

Alternative 10 (Plate 29) consisted of creating a 100 ft wide, shallow notch in Dike 131.9R.

Results indicated that some diversity developed between the point bar and the islands with depths mostly between 0 ft to +10 ft LWRP. An isolated bar could not be created because no continuous side channel was created. Establishment Chute displayed little change from the replication test, with observed depths from -4 ft to +10 ft LWRP. A large portion of sediment deposited at the upper portion of Establishment Chute between RM 132.5 and RM 132.1.

Alternative 11:

Alternative 11 (Plate 30) was an extension of Alternative 10 (Plate 29). A 100 ft wide, shallow notch was placed in Dike 131.9R, and a small dike (175 ft long and set to an elevation of +18 ft LWRP) was placed extending off of Establishment Island towards the point bar at RM 131.3. In addition, two chevrons (each 150 ft by 150 ft and set to an elevation of +18 ft LWRP) were placed at the lower end of the point bar between RM 130.8 and RM 130.6.

Results indicated that the point bar had elevations between 0 ft and above +10 ft LWRP. An area of scour developed at the upstream tip of the small island with depths between -6 ft and 0 ft LWRP. Also, scour developed along the lower part of the small island with depths between -8 ft and 0 ft LWRP. Establishment Chute had depths that ranged from -4 ft to +10 ft LWRP. A small amount of scour developed around the immediate downstream locations of the chevrons located on the point bar, but depths only ranged between -4 ft and 0 ft LWRP.

Alternative 12:

Alternative 12 (Plate 31) consisted of creating a 100 ft wide, shallow notch in Dike 131.9R. A small dike (175 ft long and set to an elevation of +18 ft LWRP) was placed extending off of Establishment Island towards the point bar at RM 131.3. Another three structures (each 250 ft long and set to an elevation of +18 ft LWRP) were placed between the small island and the point bar between RM 131.0 and RM 130.5.

Results indicated that the point bar no longer had elevations above +10 ft LWRP. Instead, most of the point bar had elevations between +5 ft and +10 ft LWRP. Furthermore, a continuous side channel with depths between -35 ft to +5 ft LWRP developed between the point bar and the two islands. The continuous side channel totally isolated the bar and connected back with the main channel at RM 130.2. Within the continuous side channel, a large amount of scour developed off the three structures located along the small island, which was where the readings of -35 ft to -10 ft LWRP readings were observed. Establishment Chute had depths that ranged from -4 ft to +5 ft LWRP, except for one large area of scour with depths up to -12 ft LWRP at RM 132.1.

Alternative 13:

Alternative 13 (Plate 32) consisted of 12 dike structures (each 300 ft long and set to an elevation of +18 ft LWRP) placed along the inside of the point bar adjacent to Establishment Island, between RM 131.5 and RM 130.5. An additional dike (800 ft long and set to an elevation of +18 ft LWRP) was placed between Establishment Island and the lower unnamed island.

Results indicated that, in comparison to the prototype, there was little change from the most upstream end of the point bar to approximately RM 130.5, with depths between +5 ft to +10 ft LWRP. Downstream of this point, depths were between 0 ft to +5 ft LWRP between the small, unnamed island and the point bar. Establishment Chute had depths that ranged from -6 ft to +5 ft LWRP.

Alternative 14:

Alternative 14 (Plate 33) consisted of placing a 100 ft wide, shallow notch in Dike 131.9R to allow more flow across the point bar. Also, 12 dike structures (each 300 ft long and set to an elevation of +18 ft LWRP) were placed along the inside of the point bar adjacent to Establishment Island, between RM 131.5 and RM 130.5. An additional dike (800 ft long and set to an elevation of +18 ft LWRP) was placed between Establishment Island and the lower unnamed island.

Results indicated that, in comparison to the prototype, there was little change from the most upstream end of the point bar to approximately RM 130.5, with depths between +5 ft to +10 ft LWRP. Downstream of this point, depths were between 0 ft to +5 ft LWRP due to the concentration of energy caused by the structures. Establishment Chute had depths that ranged from -6 ft to +10 ft LWRP.

The alternative allowed for a slightly more defined shallow water channel between Establishment Island and the point bar, while the rest of the study reach remained unchanged.

Alternative 15:

Alternative 15 (Plate 34) was an extension of Alternative 2. The alternative consisted of placing a 100 ft wide, shallow notch in Dike 131.9R to allow more flow across the point bar. Also, 12 dike structures (each 300 ft long and set to an elevation of +18 ft LWRP) were placed along the inside of the point bar adjacent to Establishment Island, between RM 131.5 and RM 130.5. An additional dike (800 ft long and set to an elevation of +18 ft LWRP) was placed between Establishment Island and the lower unnamed island. A dike structure (1,500 ft long and set to an elevation of +18 ft LWRP) was placed along the smaller island and angled downstream pointing towards the tip of Dike 130.2R.

Results indicated that a continuous side channel with depths between -10 ft to +5 ft LWRP developed between the point bar and the two islands. The continuous side channel totally isolated the bar and connected back with the main channel at RM 130.2. Within the continuous side channel, a large amount of scour developed off the 800 ft and 1,500 ft dike structures, which was where all of the -10 ft LWRP readings were observed. Establishment Chute had depths that ranged mostly between -10 ft to +5 ft LWRP.

Alternative 16:

Alternative 16 (Plate 35) consisted of placing a 1,400 upstream L-dike at the tip of Establishment Island. This structure was used to capture flow and direct it into the side channel. Also, 200 ft of Dike 132.5R was removed in order to allow the captured flow into the side channel. Next, 325 ft of Dike 131.0R, between Establishment Island and the RDB of Establishment Chute, was removed.

Results indicated that Establishment Chute had depths between -30 ft to -10 ft LWRP. The navigation channel looked narrow within the crossing between RM 132.0 and RM 131.5, but this area was also narrower in the replication test than in the prototype.

CONCLUSIONS

1. <u>Evaluation and Summary of the Model Tests</u>

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 increase diversity of aquatic habitat within Establishment Chute. The second consideration was to create a design that would not negatively affect the navigation channel. Finally, the bar located between Establishment Island / Schmidts Island and the navigation channel should not be negatively impacted.

2. <u>Recommendations</u>

Alternative 16, Plate 35, was recommended as the most desirable alternative because of its observed ability to create depth diversity within Establishment Chute. The alternative showed a narrow navigation channel within the crossing between RM 132.0 and RM 131.5, but this area was also narrower in the replication test than in the prototype. The alternative requires little changes to be made to the existing structures at the entrance to Establishment Chute, so the navigation channel should be minimally affected.

The recommended design included the following:

- RM 132.4R: Construct a 1,400 ft upstream L-dike.
  - Structure top elevation = 372 ft (+18 ft LWRP)

- RM 132.5R: Remove approximately 200 ft of the existing dike. The dike should be removed starting from the RDB and continue until it meets the upstream L-dike.

- RM 131.0R: Remove approximately 325 ft of the existing closure structure within Establishment Chute. The portion of the dike to be removed is from the RDB of Establishment Chute to the tip of Establishment Island.

3. Interpretation of Model Test Results

In the interpretation and evaluation of the model test results, it should be remembered that these results are 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 Mississippi 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 A

Report Plates

1. Location and Vicinity Map of the Study Reach
2. 2006 Aerial Photograph – 1:18,000
3. September Site Visit Pictures
4. Geomorphology (1817 - 2003)
5. 1928 Planform Map – 1:18,000
6. 1942 Planform Map – 1:18,000
7. 1956 Planform Map – 1:18,000
8. 1977 Aerial Photograph – 1:18,000
9. 1982 Aerial Photograph – 1:18,000
10. 1987 Aerial Photograph – 1:18,000
11. 1956 Hydrographic Survey – 1:18,000
12. 1977 Hydrographic Survey – 1:18,000
13. 1982 Hydrographic Survey – 1:18,000
14. 2005 Hydrographic Survey – 1:18,000
15. 2007 Hydrographic Survey – 1:18,000
16. 2008 / 2009 Combined Hydrographic Survey – 1:18,000
17. Historic Dredge Locations – 1:18,000
18. Establishment HSR Model
19. Replication Test – 1:18,000
20. Alternative 1 – 1:18,000
21. Alternative 2 – 1:18,000
22. Alternative 3 – 1:18,000
23. Alternative 4 – 1:18,000
24. Alternative 5 – 1:18,000
25. Alternative 6 – 1:18,000
26. Alternative 7 – 1:18,000
27. Alternative 8 – 1:18,000
28. Alternative 9 – 1:18,000

29. Alternative 10 – 1:18,000
30. Alternative 11 – 1:18,000
31. Alternative 12 – 1:18,000
32. Alternative 13 – 1:18,000
33. Alternative 14 – 1:18,000
34. Alternative 15 – 1:18,000
35. Alternative 16 – 1:18,000

Appendix B: HSR Model Theory

The principle behind the use of a hydraulic sediment response model is similitude, the linking of parameters between a model and prototype so that behavior in one can predict behavior in the other.

There are two different types of similitude; mathematical similitude and empirical similitude. Mathematical similitude is founded on the scale relationship between all linear dimensions (geometric similarity), a scale relationship between all components of velocity (kinematic), or both geometric and kinematic similarity with the ratio of all common point forces equal (dynamic similarity).

In contrast to mathematical similitude, empirical similitude is based on the belief that the laws of mathematical similitude can be relaxed as long as other more fundamental relationships are preserved between the model and the prototype. All physical models used in the past by USACE employed, to some degree, empirical similitude. Numerous definitions of what relationships must be preserved have been put forward concerning physical sediment models. These relationships often deal with the scalability of elements of sediment transport processes or surface or structure roughness. Hydraulic sediment response models depend on similitude in the morphologic response, i.e. the ability of the model to replicate known prototype parameters associated with the bed response in the river under study. Bed response includes thalweg location, scour and deposition within the channel and at various river structures, and the overall resultant bed configuration. These parameters are directly compared to what is observed from prototype surveys.

Detailed cross-sectional analysis of prototype and model surveys defining bed response and bed configuration have shown that HSR model variation from the prototype is often approximately that of the natural variation observed in the prototype. This correspondence allows hydraulic engineers to use the HSR model with confidence and introduce alternatives in the model to approximate the bed response that can be expected to occur in the prototype.

HSR models were developed from empirical large scale coal bed models utilized by the USACE Waterways Experiment Station (Environmental Research and Development Center). These models were used by MVS from 1940 to the mid 1990s. For a more thorough explanation of the HSR model development, please refer to the following link:

http://www.mvs.usace.army.mil/arec/Documents/hsr_models/Hydraulic_Sediment_Response_Modeling_Replication_Accuracy_TPM53.pdf