Technical Report M63

Carondelet HSR MODEL
Mississippi River Miles 181.0 – 165.0

HYDRAULIC SEDIMENT RESPONSE MODEL INVESTIGATION

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INTRODUCTION

The U.S. Army Corps of Engineers, St. Louis District, conducted a study of the flow and sediment transport regime of the Carondelet reach of the Middle Mississippi River between River Miles (RM) 181.0 and RM 165.0 near Saint Louis, Missouri. This study was funded by the Regulating Works Project. The objective of the model study was to produce a report that outlined the results of an analysis of various river engineering measures intended to reduce or eliminate the need for repetitive maintenance dredging within the Carondelet reach.

The study was conducted between October 2011 and March 2013 using a physical Hydraulic Sediment Response (HSR) model at the Applied River Engineering Center in St. Louis, Missouri. The model study was performed by Mr. Bradley Krischel, Hydraulic Engineer, under direct supervision of Mr. Robert Davinroy, P.E., Chief of River Engineering Section for the St. Louis District. See Table 1 for other personnel involved in the study.

Table 1: Other Personnel Involved in the Study

Name	Position	District/Company
Leonard Hopkins, P.E.	Hydrologic and Hydraulic Branch Chief	USACE, St. Louis District
Michael Rodgers, P.E.	Project Manager for River Works Projects	USACE, St. Louis District
Dave Gordon, P.E.	Chief of Hydraulic Design Section	USACE, St. Louis District
Jasen Brown, P.E.	Hydraulic Engineer	USACE, St. Louis District
Ashley Cox	Hydraulic Engineer	USACE, St. Louis District
June Jeffries, P.E.	Chief of Environmental Engineering Section	USACE, St. Louis District
Brian Johnson	Chief of Environmental Planning Section	USACE, St. Louis District
Brandon Schneider	Biologist	USACE, St. Louis District
Jennifer Brown	Regulatory Project Manager	USACE, St. Louis District
Lance Engle	Dredging Project Manager	USACE, St. Louis District
Jason Floyd	Engineering Technician	USACE, St. Louis District
Dana Fischer	AREC Co-op	USACE, St. Louis District
Butch Atwood	Mississippi River Fisheries Biologist	Illinois Dept. of Natural Resources
Matt Mangan	Biologist	U.S. Fish & Wildlife Service
Dawn Lamm	Hydraulic Engineer	USACE, St. Louis District
Ed Henleben	Senior Operations Manager	Ingram Marine Group
Mike Canada	Manager, St. Louis Fleet Dispatch	Ingram Marine Group
Terry Hoover	Manager, Safety Training and Environmental	Ingram Marine Group
Jeff Vogrin	Barge Inspector	Ingram Marine Group
Gary Holt	AVP of Customer Service	Ingram Marine Group
Shannon Hughes	River Field Port Captain	Kirby Inland Marine
Sarah Markenson	Real Estate	USACE, St. Louis District
Dave Knuth	Biologist	Missouri Dept. of Conservation
Rian Christensen		U.S. Coast Guard
David Ostendorf	Resource Staff Scientist	Missouri Dept. of Conservation
Kat McCain	Biologist	USACE, St. Louis District

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BACKGROUND

1. Study Purpose and Goals

The purpose of the Carondelet HSR model study was to produce a report with an analysis of river engineering measures intended to reduce or eliminate the need for repetitive dredging within the Carondelet reach.

The goals of this study were to:

i. Investigate and provide analysis on the existing flow mechanics causing the repetitive dredging problems.

ii. Evaluate a variety of remedial measures utilizing an HSR model with the objective of identifying the most effective and economical plan to reduce or eliminate dredging within the study reach. In order to determine the best alternative, four criteria were used to evaluate each alternative.
   a. The alternative should reduce or eliminate dredging within the Carondelet reach.
   b. The alternative should maintain the navigation channel requirements of at least 9 foot of depth and 300 foot of width.
   c. The alternative should avoid and minimize impacts to fleeting areas within the reach.
   d. The alternative should avoid and minimize impacts to environmental areas.

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

2. Study Reach

The study comprised a 16.0 mile stretch of the Mississippi River, between RM 181.0 and RM 165.0 in Madison, St. Clair, and Monroe Counties in Illinois and St. Louis County and St. Louis City in Missouri. Plate 1 is a location and vicinity map of the study reach. Discussed below are a variety of features found within the reach.

At the time of this study, the reach had a total of 35 dikes and 12 bendway weirs. Also, the majority of the banklines in the reach were revetted. Plate 2 is a 2007 aerial photograph illustrating the planform and nomenclature of the study reach. The Carondelet reach of the Mississippi River is part of the St. Louis harbor, which is the third largest inland port of the United States and handles more than 110 million tons of freight each year. In terms of the river, fleeting is defined as the storing and moving of barges. Fleeting areas are numerous within the reach due to the St. Louis harbor's close location to the Illinois River, Missouri River, Kaskaskia River, and Interstates 70, 64, 55, and 44. Furthermore, Lock and Dam 27, which is just upstream of the St. Louis harbor, is the most downstream lock on the system, and the 3x5 barge configurations increase in size for navigation on the lower river. Plate 3 shows the numerous fleeting locations within the reach.

A. Geomorphology

To understand the existing planform of the river near St. Louis, Missouri, an investigation was conducted on the historical changes, both natural and manmade, that lead up to the present day condition.

Since 1817, the river has remained in approximately the same location. Two prominent locations within the Carondelet study reach where there were island formations in the past were at RM 175.0 and RM 170.0 – RM 167.0. The island at RM 175.0 was Arsenal Island, which was formed by the Cahokia Chute side channel. The island formations seen at RM 170.0 – RM 167.0 were part of the Carroll Island complex. Plate 5 is taken from the "Geomorphology of the Middle Mississippi River" report, which was produced by the St. Louis District (2005), and it shows the 1881 bankline in comparison to other years.

Plates 6 through 11 show the study reach through aerial photographs and sounding maps from 1928, 1942, 1956, 1977, 1983, and 1987, respectively. Between 1928 and 1987, there were mostly changes due to dike construction within the reach. The dikes that were constructed in this time period were all incremental steps to the current configuration of the river. One of two major changes between 1942 and 1987 was Cahokia Chute closing off from the main channel, which resulted in Arsenal Island joining with the Illinois bank. Determining the exact time and reason that Arsenal Island combined with the Illinois bank was difficult since aerial photos were only taken periodically, but it appeared to take place sometime between 1942 and 1977. The second major change that took place was the formation of Jefferson Barracks Chute, which began along the left descending bank (LDB) at RM 168.8 and formed sometime between 1928 and 1942. By 1956, dikes had been built across the upper part of Jefferson Barracks Chute, and by 1971 the dikes and chute had caused two major islands to form along the LDB. The first island stretched between RM 168.8 and RM 167.7, and the second island was located between RM 167.6 and RM 166.5. In 1996, a weir field consisting of 5 structures was constructed along the right descending bank (RDB) between RM 174.6 and RM 174.0.

A 2001 sedimentation study of the Jefferson Barracks reach of the Middle Mississippi River was completed using an HSR model. The recommended alternative of 9 dikes, which included both new and modified structures, was never constructed due to a contaminated soils issue within the construction location.

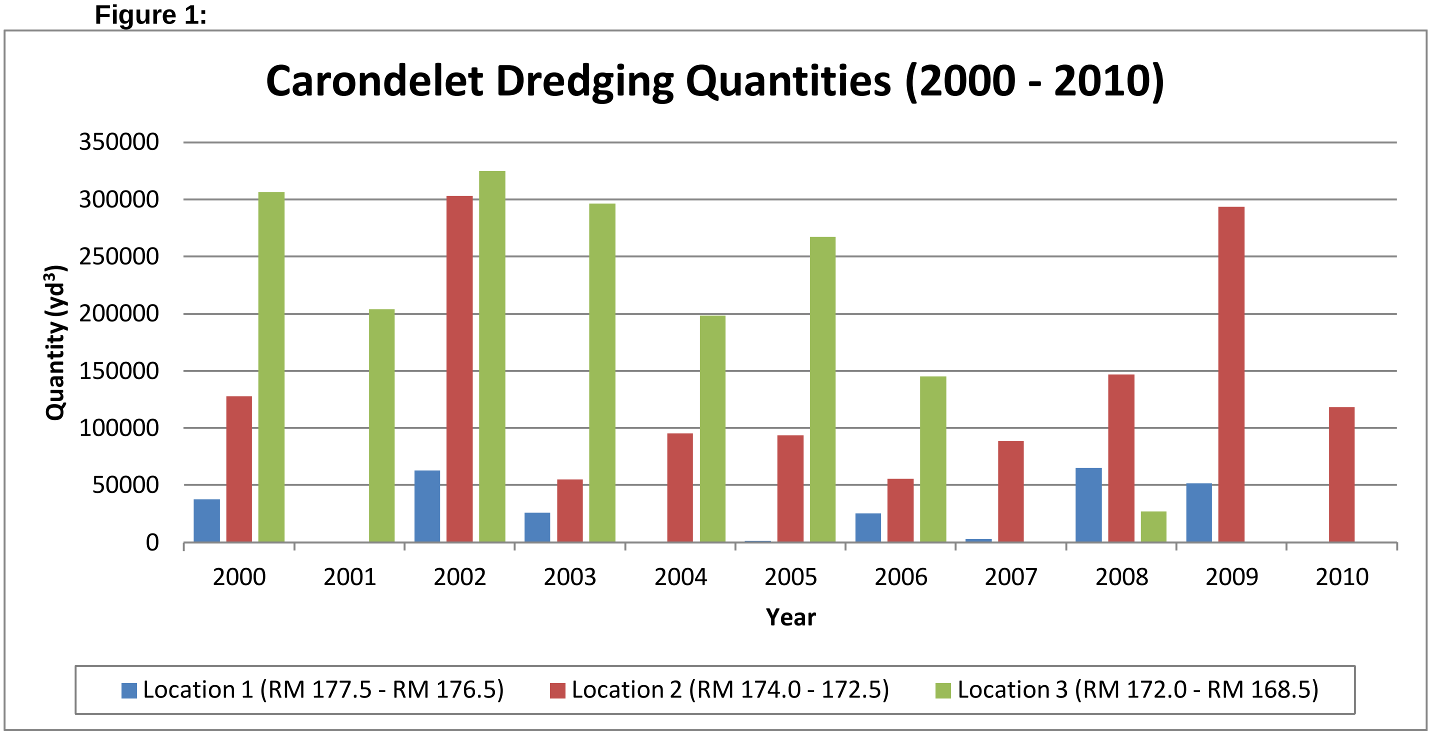
Two more weir fields were constructed within the study reach in 2002 and 2008. The 2002 weir field was constructed along the RDB between RM 172.7 and RM 172.3, and the 2008 weir field was constructed along the LDB between RM 179.9 and RM 179.6.

All of the above information provided further understanding of the geomorphic changes that have taken place over the past 194 years. This included changes that were both natural and anthropogenic. Specifically, the analysis showed how features within the study reach had been established and why they will likely remain in place. Most importantly, the use of revetment provided a means of restricting the channel from migrating, which in turn, created a well-established channel with stable features.

B. Dredging

The U.S. Army Corps of Engineers – St Louis District is responsible for maintaining a navigation channel 9 feet deep and 300 feet wide, with additional width as required in bends, on 300 miles of the Mississippi River from Saverton, Missouri to Cairo, Illinois. If a bathymetric survey shows elevations that do not provide the nine foot depth within the navigation channel, dredging is typically required. Some areas of the river require the Corps to dredge repeatedly. Between 2000 and 2011, the Carondelet reach had experienced approximately 6 million cubic yards dredged at a cost of approximately $13.2M. Over the entire 300 miles of Mississippi River within the St. Louis District the Carondelet reach is the most heavily dredged location. Plate 4 shows all of the dredging and disposal locations within the study reach between 2000 and 2011. Dredging, which includes sediment removal and disposal, can have a detrimental effect on fish habitat. In addition, navigation traffic can be shut down or delayed while dredging is taking place. Therefore, eliminating the need for dredging will be beneficial for the navigation industry, the environment, and taxpayers alike. The dredging totals by year for the Carondelet reach broken down by three extents can be seen in Figure 1. The repetitive dredging at Location 2, specifically RM 173.4, will be the focus of this model study.

Figure 1:



C. Channel Characteristics and General Trends

Range line and multi-beam hydrographic surveys of the Mississippi River from 2005 to 2010 within the HSR Model extents, are shown on Plates 12 – 14. Plates 15 and 16 show pre-dredge conditions from 2010 – 2011. 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 – 2010 after comparison of the above mentioned hydrographic surveys:

Table 3: Study Reach Bathymetry Trends

River Miles	Description
178.0-177.0	A crossing from the RDB to the LDB was observed between RM 178.0 and RM 177.0.
177.0-176.5	The thalweg was located along the LDB with depths between -20 ft and -40 ft LWRP.
176.5-175.5	A crossing from the LDB to the RDB was observed between RM 176.5 and RM 175.5.
175.5-166.0	The thalweg was located along the RDB with depths between -20 ft and -40 ft LWRP.
175.3-173.5	A large bar formation existed along the LDB between RM 175.3 and RM 173.4 and had elevations between 0 ft and +10 ft LWRP.
173.5-173.0	A shallow area with depths between -14 ft and -10 ft LWRP existed in the center of the channel between RM 173.5 and RM 173.0.

172.7-172.2	Scour holes with elevations of -30 ft to -40 ft LWRP existed off of the tips and downstream of the weirs between RM 172.75 and RM 172.2.
171.0-166.0	Bar formations existed between the structures along the LDB between RM 171.0 and RM 166.0 and had elevations between -6 ft and +10 ft LWRP. In addition, scour holes with depths between -50 ft and -20 ft LWRP existed off of the tips of the structures along the LDB.
166.5-165.7	A crossing from the RDB to the LDB was observed between RM 166.5 and RM 165.7.

HSR MODELING

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

1. Model Calibration and Replication

The HSR modeling methodology employed a calibration process designed to replicate the general conditions in the river at the time of the model study. Replication of the model was achieved during calibration and involved 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, clay and other non-mobile boundaries.

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 calibrated and alternative testing began.

One important parameter to note was that in calibration, non-erodible bed material of higher specific gravity was used in a localized area on the model riverbed to represent clay, rock, and other non-erodible materials found in the prototype river bed. Because the non-erodible was required for calibration, the non-erodible remained in the model throughout the rest of the study (i.e. during alternative testing).

2. Scales and Bed Materials

The model employed a horizontal scale of 1 inch = 700 feet, or 1:8400, and a vertical scale of 1 inch = 75 feet, or 1:900, for a 9.33 to 1 distortion ratio of geometric linear scales. This distortion supplied the necessary forces required for the simulation of sediment transport conditions similar to those observed in the prototype. The bed material was granular plastic urea, Type II, with a specific gravity of 1.40.

3. Appurtenances

The HSR model planform insert was constructed according to the 2007 high-resolution aerial photography of the study reach. The insert was then mounted in a standard HSR model flume. The riverbanks of the model were routed into dense polystyrene foam and modified during calibration with clay and steel mesh. Leveler feet located on the bottom of the hydraulic flume controlled the slope of the model. The measured slope of the insert and flume was approximately 0.04 inch/inch. River training structures in the model were made of galvanized steel mesh to generate appropriate scaled roughness.

4. Flow Control

Flow into the model was regulated by a control valve and submersible pump. This interface was used to control the flow of water and sediment into the model. For all model tests, flow entering the model was held steady at 1.8 Gallons per Minute (GPM). This served as the average expected energy response of the river. Because of the constant variation experienced in the river, this steady 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. 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 were 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 directly 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.

Replication 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 replicated test for the model and is shown on Plate 17.

Results of the HSR model replication bathymetry and a comparison to the 2007 through 2010 prototype surveys indicated the following trends:

Table 4: Study Reach and Prototype Bathymetry Trend Comparison

River Miles	Description
178.0-177.0	A crossing from the RDB to the LDB was observed between RM 178.0 and RM 177.0.
177.0-176.5	The thalweg was located along the LDB with depths between -20 ft and -30 ft LWRP.
176.5-175.5	A crossing from the LDB to the RDB was observed between RM 176.5 and RM 175.5.

175.5-166.0	The thalweg was located along the RDB with depths between -20 ft and -40 ft LWRP.
175.3-173.5	A large bar formation existed along the LDB between RM 175.3 and RM 173.5 and had elevations between 0 ft and +10 ft LWRP.
173.5-173.0	A shallow area with depths between -16 ft and -10 ft LWRP existed in the center of the channel between RM 173.5 and RM 173.0.
172.7-172.2	Scour holes with elevations of -30 ft to -40 ft LWRP existed off of the tips and downstream of the weirs between RM 172.75 and RM 172.2.
171.0-166.0	Bar formations existed between the structures along the LDB between RM 171.0 and RM 166.0 and had elevations between -6 ft and +10 ft LWRP. In addition, scour holes with depths between -40 ft and -20 ft LWRP existed off of the tips of the structures along the LDB.
166.5-165.7	A crossing from the RDB to the LDB was observed between RM 166.5 and RM 165.7.

Further detailed calculations on model cross sections were compared directly to the prototype and are shown in Appendix C. Results indicated that the model replication bed response was very similar to the prototype response and was within the natural variation observed in the river.

7. Design Alternative Tests

The testing process consisted of modeling alternative measures in the HSR model followed by analyses of the bathymetry and velocity results. The goal was to reduce or eliminate dredging within the Carondelet reach, maintain the navigation channel, minimize impacts to fleeting areas, and maintain environmental areas. Evaluation of each alternative was accomplished through a qualitative comparison to the model replication test bathymetry between RM 174.0 and 173.4.

Alternative 1:

Type of Structure	River Mile	LDB or RDB	Dimensions (Feet)	Structure Top Elevation (ft in LWRP)
Chevron	173.4	LDB	350x350	15
Chevron	173.2	LDB	350x350	15

Results: *Bathymetry (Plate 18)*

Reduce or Eliminate Dredging Area (RM 174.0 – 172.5)	Maintain Existing Navigation Channel	Structure Placed Within Existing Fleeting Area	Maintain Existing Bars at	
			RM 174.0	RM 171.0 – RM 168.5
No	No	No	Yes	Yes

***Additional comments**:* When compared to the model replication, this alternative produced higher bed elevations within the navigation channel between RM 171.5 and RM 171.0.

Alternative 2:

Type of Structure	River Mile	LDB or RDB	Dimensions (Feet)	Structure Top Elevation (ft in LWRP)
Rootless Dike	173.5	LDB	650	15
Dike	173.2	LDB	625	15

Results: *Bathymetry (Plate 19)*

Reduce or Eliminate Dredging Area (RM 174.0 – 172.5)	Maintain Existing Navigation Channel	Structure Placed Within Existing Fleeting Area	Maintain Existing Bars at	
			RM 174.0	RM 171.0 – RM 168.5
Yes	No	Yes	Yes	Yes

***Additional comments**:* When compared to the model replication, this alternative produced higher bed elevations within the navigation channel between RM 171.5 and RM 171.0.

Alternative 3:

Type of Structure	River Mile	LDB or RDB	Dimensions (Feet)	Structure Top Elevation (ft in LWRP)
Rootless Dike	173.6	LDB	800	15
Chevron	173.4	LDB	350x350	15

Results: *Bathymetry (Plate 20)*

Reduce or Eliminate Dredging Area (RM 174.0 – 172.5)	Maintain Existing Navigation Channel	Structure Placed Within Existing Fleeting Area	Maintain Existing Bars at	
			RM 174.0	RM 171.0 – RM 168.5
Yes	Yes	Yes	Yes	Yes

***Additional comments**:* Increased depths were observed within the repetitive dredging location, but the 800-ft rootless dike was placed within an existing fleeting location.

Alternative 4:

Type of Structure	River Mile	LDB or RDB	Dimensions (Feet)	Structure Top Elevation (ft in LWRP)
Notch	175.3	LDB	400	0
Notch	174.5	LDB	375	0
Dike	173.5	LDB	900	15

Results: *Bathymetry (Plate 21)*

Reduce or Eliminate Dredging Area (RM 174.0 – 172.5)	Maintain Existing Navigation Channel	Structure Placed Within Existing Fleeting Area	Maintain Existing Bars at	
			RM 174.0	RM 171.0 – RM 168.5
Yes	Yes	Yes	Yes	Yes

Additional comments: Increased depths were observed within the repetitive dredging location, but the 800-ft rootless dike was placed within an existing fleeting location.

Alternative 5:

Type of Structure	River Mile	LDB or RDB	Dimensions (Feet)	Structure Top Elevation (ft in LWRP)
Dike	173.4	LDB	925	15
Dike	173.2	RDB	175	15
Dike	173.0	RDB	175	15

Results: *Bathymetry (Plate 22)*

Reduce or Eliminate Dredging Area (RM 174.0 – 172.5)	Maintain Existing Navigation Channel	Structure Placed Within Existing Fleeting Area	Maintain Existing Bars at	
			RM 174.0	RM 171.0 – RM 168.5
No	No	Yes	Yes	Yes

***Additional comments**:* The repetitive dredging location still showed depths that would require dredging, and higher bed elevations were observed within the navigation channel between RM 171.5 and RM 171.0. Furthermore, the two 175-ft dikes proposed for the alternative were placed within an existing fleeting location.

Alternative 6:

Type of Structure	River Mile	LDB or RDB	Dimensions (Feet)	Structure Top Elevation (ft in LWRP)
Weir	173.8	RDB	875	-15

Results: *Bathymetry (Plate 23)*

Reduce or Eliminate Dredging Area (RM 174.0 – 172.5)	Maintain Existing Navigation Channel	Structure Placed Within Existing Fleeting Area	Maintain Existing Bars at	
			RM 174.0	RM 171.0 – RM 168.5
No	Yes	No	Yes	Yes

***Additional comments**:* The repetitive dredging location still showed depths that would require dredging. Within the navigation channel between RM 171.5 and RM 171.0 similar bed elevations were observed when compared to the model replication.

Alternative 7:

Type of Structure	River Mile	LDB or RDB	Dimensions (Feet)	Structure Top Elevation (ft in LWRP)
Weir	173.8	RDB	875	-15
Weir	173.7	RDB	875	-15

Results: *Bathymetry (Plate 24)*

Reduce or Eliminate Dredging Area (RM 174.0 – 172.5)	Maintain Existing Navigation Channel	Structure Placed Within Existing Fleeting Area	Maintain Existing Bars at	
			RM 174.0	RM 171.0 – RM 168.5
No	Yes	No	Yes	Yes

***Additional comments**:* The repetitive dredging location still showed depths that would require dredging. Within the navigation channel between RM 171.5 and RM 171.0, decreased bed elevations were observed when compared to the model replication.

Alternative 8:

Type of Structure	River Mile	LDB or RDB	Dimensions (Feet)	Structure Top Elevation (ft in LWRP)
Dike	175.5	LDB	650	15

Results: *Bathymetry (Plate 25)*

Reduce or Eliminate Dredging Area (RM 174.0 – 172.5)	Maintain Existing Navigation Channel	Structure Placed Within Existing Fleeting Area	Maintain Existing Bars at	
			RM 174.0	RM 171.0 – RM 168.5
No	Yes	Yes	Yes	Yes

Additional comments*:* The purpose of this alternative was to determine if placing a structure 2.5 miles upstream of the problem location would cause a change in flow patterns downstream that would alleviate the repetitive dredging problem. The repetitive dredging location still showed depths that would require dredging. Furthermore, the 650-ft dike was placed within an existing fleeting location.

Alternative 9:

Type of Structure	River Mile	LDB or RDB	Dimensions (Feet)	Structure Top Elevation (ft in LWRP)
L-Dike	173.5	LDB	2200	15
Weir	173.4	LDB	600	-15

Results: *Bathymetry (Plate 26)*

Reduce or Eliminate Dredging Area (RM 174.0 – 172.5)	Maintain Existing Navigation Channel	Structure Placed Within Existing Fleeting Area	Maintain Existing Bars at	
			RM 174.0	RM 171.0 – RM 168.5
Yes	Yes	Yes	Yes	Yes

***Additional comments**:* This alternative used a weir structure in the middle of the channel near the repetitive dredging location. The weir tied into the L-dike shown. Increased depths were observed with this alternative, but the dike structure would impact fleeting locations.

Alternative 10:

Type of Structure	River Mile	LDB or RDB	Dimensions (Feet)	Structure Top Elevation (ft in LWRP)
Chevron	173.4	LDB	350 x 350	15

Results: *Bathymetry (Plate 27)*

Reduce or Eliminate Dredging Area (RM 174.0 – 172.5)	Maintain Existing Navigation Channel	Structure Placed Within Existing Fleeting Area	Maintain Existing Bars at	
			RM 174.0	RM 171.0 – RM 168.5
No	Yes	Yes	Yes	Yes

Additional comments: This alternative did not reduce or eliminate the repetitive dredging area, and the chevron was placed within an existing fleeting area.

Alternative 11:

Type of Structure	River Mile	LDB or RDB	Dimensions (Feet)	Structure Top Elevation (ft in LWRP)
Dike	173.2	LDB	775	15

Results: *Bathymetry (Plate 28)*

Reduce or Eliminate Dredging Area (RM 174.0 – 172.5)	Maintain Existing Navigation Channel	Structure Placed Within Existing Fleeting Area	Maintain Existing Bars at	
			RM 174.0	RM 171.0 – RM 168.5
Yes	Yes	No	Yes	Yes

***Additional comments**:* Increased depths were observed within the repetitive dredging location.

Alternative 12:

Type of Structure	River Mile	LDB or RDB	Dimensions (Feet)	Structure Top Elevation (ft in LWRP)
Dike	173.5	RDB	175	15
Chevron	173.5	LDB	350 x 350	15
Dike	173.3	RDB	250	15
Chevron	173.3	LDB	350 x 350	15

Results: *Bathymetry (Plate 29)*

Reduce or Eliminate Dredging Area (RM 174.0 – 172.5)	Maintain Existing Navigation Channel	Structure Placed Within Existing Fleeting Area	Maintain Existing Bars at	
			RM 174.0	RM 171.0 – RM 168.5
Yes	Yes	Yes	Yes	Yes

***Additional comments**:* Increased depths were observed within the repetitive dredging location, but one of the proposed chevrons and one of the proposed dikes were placed within an existing fleeting location.

Alternative 13:

Type of Structure	River Mile	LDB or RDB	Dimensions (Feet)	Structure Top Elevation (ft in LWRP)
Chevron	173.5	LDB	350 x 350	15
Chevron	173.3	LDB	350 x 350	15

Results: *Bathymetry (Plate 30)*

Reduce or Eliminate Dredging Area (RM 174.0 – 172.5)	Maintain Existing Navigation Channel	Structure Placed Within Existing Fleeting Area	Maintain Existing Bars at	
			RM 174.0	RM 171.0 – RM 168.5
Yes	Yes	Yes	Yes	Yes

***Additional comments**:* Increased depths were observed within the repetitive dredging location, but one of the proposed chevrons was placed within an existing fleeting location.

Alternative 14:

Type of Structure	River Mile	LDB or RDB	Dimensions (Feet)	Structure Top Elevation (ft in LWRP)
Weir	173.0	RDB	750	-15
Weir	172.9	RDB	675	-15
Chevron	171.5	LDB	350 x 350	15

Results: *Bathymetry (Plate 31)*

Reduce or Eliminate Dredging Area (RM 174.0 – 172.5)	Maintain Existing Navigation Channel	Structure Placed Within Existing Fleeting Area	Maintain Existing Bars at	
			RM 174.0	RM 171.0 – RM 168.5
No	No	Yes	Yes	Yes

***Additional comments**:* This alternative did not improve the repetitive dredging location. Furthermore, the chevron placed at RM 171.5 would impact an existing fleeting area. The structure at RM 171.5 was tested to determine if the crossing between RM 172.0 and RM 171.0 could be improved.

<u>Alternative 15:</u>

Type of Structure	River Mile	LDB or RDB	Dimensions (Feet)	Structure Top Elevation (ft in LWRP)
Chevron	173.5	LDB	350 x 350	15
Dike	172.0	LDB	625	15
Chevron	171.5	LDB	350 x 350	15

Results: *Bathymetry (Plate 32)*

Reduce or Eliminate Dredging Area (RM 174.0 – 172.5)	Maintain Existing Navigation Channel	Structure Placed Within Existing Fleeting Area	Maintain Existing Bars at	
			RM 174.0	RM 171.0 – RM 168.5
No	Yes	Yes	Yes	Yes

***Additional comments**:* This alternative did not improve the repetitive dredging location, and it would have impacts on multiple existing fleeting locations. The structures at RM 172.0 and RM 171.5 were tested to determine if the crossing between RM 172.0 and RM 171.0 could be improved.

Alternative 16:

Type of Structure	River Mile	LDB or RDB	Dimensions (Feet)	Structure Top Elevation (ft in LWRP)
Dike	173.6	LDB	1200	15
Dike	173.4	LDB	825	15
Chevron	171.5	LDB	350 x 350	15

Results: *Bathymetry (Plate 33)*

Reduce or Eliminate Dredging Area (RM 174.0 – 172.5)	Maintain Existing Navigation Channel	Structure Placed Within Existing Fleeting Area	Maintain Existing Bars at	
			RM 174.0	RM 171.0 – RM 168.5
Yes	Yes	Yes	Yes	Yes

***Additional comments**:* This alternative improved the repetitive dredging location, but would impact fleeting locations. The structure at RM 171.5 was tested to determine if the crossing between RM 172.0 and RM 171.0 could be improved.

Alternative 17:

Type of Structure	River Mile	LDB or RDB	Dimensions (Feet)	Structure Top Elevation (ft in LWRP)
Dike	173.5	RDB	175	15
Chevron	173.5	LDB	350 x 350	15
Dike	173.3	RDB	250	15
Chevron	173.3	LDB	350 x 350	15
Dike	171.6	LDB	450	15
Chevron	171.3	LDB	350 x 350	15

Results: *Bathymetry (Plate 34)*

Reduce or Eliminate Dredging Area (RM 174.0 – 172.5)	Maintain Existing Navigation Channel	Structure Placed Within Existing Fleeting Area	Maintain Existing Bars at	
			RM 174.0	RM 171.0 – RM 168.5
Yes	Yes	Yes	Yes	Yes

Additional comments*:* This alternative improved the repetitive dredging location, but would impact fleeting locations. The structures at RM 171.6 and RM 171.3 were tested to determine if the crossing between RM 172.0 and RM 171.0 could be improved. The crossing improved, but again, the structures would impact an existing fleeting location.

Alternative 18:

Type of Structure	River Mile	LDB or RDB	Dimensions (Feet)	Structure Top Elevation (ft in LWRP)
Dike	173.5	RDB	175	15
Dike	173.3	RDB	250	15
Chevron	173.3	LDB	350 x 350	15
Dike	171.6	LDB	450	15
Chevron	171.3	LDB	350 x 350	15

Results: *Bathymetry (Plate 35)*

Reduce or Eliminate Dredging Area (RM 174.0 – 172.5)	Maintain Existing Navigation Channel	Structure Placed Within Existing Fleeting Area	Maintain Existing Bars at	
			RM 174.0	RM 171.0 – RM 168.5
Yes	Yes	Yes	Yes	Yes

***Additional comments**:* This alternative improved the repetitive dredging location, but would impact fleeting locations. The structures at RM 171.6 and RM 171.3 were tested to determine if the crossing between RM 172.0 and RM 171.0 could be improved. The crossing improved, but again, the structures would impact an existing fleeting location.

Alternative 19:

Type of Structure	River Mile	LDB or RDB	Dimensions (Feet)	Structure Top Elevation (ft in LWRP)
Chevron	173.4	LDB	350 x 350	15
Dike	171.6	LDB	450	15
Chevron	171.3	LDB	350 x 350	15

Results: *Bathymetry (Plate 36)*

Reduce or Eliminate Dredging Area (RM 174.0 – 172.5)	Maintain Existing Navigation Channel	Structure Placed Within Existing Fleeting Area	Maintain Existing Bars at	
			RM 174.0	**RM 171.0 – RM 168.5**
No	Yes	Yes	Yes	Yes

***Additional comments**:* This alternative improved the repetitive dredging location, but would impact fleeting locations. The structures at RM 171.6 and RM 171.3 were tested to determine if the crossing between RM 172.0 and RM 171.0 could be improved. The crossing improved, but dredging may still be required. In addition, the structures at RM 171.6 and 171.3 were within existing fleeting locations.

Alternative 20:

Type of Structure	River Mile	LDB or RDB	Dimensions (Feet)	Structure Top Elevation (ft in LWRP)
Weir	173.8	RDB	750	-15
Weir	173.7	RDB	750	-15
Weir	173.5	RDB	750	-15
Weir	173.3	RDB	750	-15
Weir	173.2	RDB	750	-15
Weir	173.0	RDB	750	-15
Dike	171.6	LDB	450	15
Chevron	171.3	LDB	350 x 350	15

Results: *Bathymetry (Plate 37)*

Reduce or Eliminate Dredging Area (RM 174.0 – 172.5)	Maintain Existing Navigation Channel	Structure Placed Within Existing Fleeting Area	Maintain Existing Bars at	
			RM 174.0	RM 171.0 – RM 168.5
No	Yes	Yes	Yes	Yes

Additional comments: This alternative did not improve the repetitive dredging location. The structures at RM 171.6 and RM 171.3 were tested to determine if the crossing between RM 172.0 and RM 171.0 could be improved. The crossing improved, but the structures at RM 171.6 and 171.3 were within existing fleeting locations.

Alternative 21:

Type of Structure	River Mile	LDB or RDB	Dimensions (Feet)	Structure Top Elevation (ft in LWRP)
Remove Weir	174.65	RDB	510	Existing bed
Remove Weir	174.5	RDB	630	Existing bed
Remove Weir	174.35	RDB	670	Existing bed
Remove Weir	174.2	RDB	820	Existing bed
Remove Weir	174.0	RDB	750	Existing bed

Results: *Bathymetry (Plate 38)*

Reduce or Eliminate Dredging Area (RM 174.0 – 172.5)	Maintain Existing Navigation Channel	Structure Placed Within Existing Fleeting Area	Maintain Existing Bars at	
			RM 174.0	RM 171.0 – RM 168.5
No	No	No	Yes	Yes

Additional comments*:* This alternative consisted of removing a weir field, which did not improve the repetitive dredging location. Furthermore, the crossing between RM 172.0 and RM 171.0 deteriorated.

Alternative 22:

Type of Structure	River Mile	LDB or RDB	Dimensions (Feet)	Structure Top Elevation (ft in LWRP)
Remove Dike	175.3	LDB	2300	Existing bed
Remove Dike	175.3	LDB	1500	Existing bed
Remove Dike	175.3	LDB	1500	Existing bed

Results: *Bathymetry (Plate 39)*

Reduce or Eliminate Dredging Area (RM 174.0 – 172.5)	Maintain Existing Navigation Channel	Structure Placed Within Existing Fleeting Area	Maintain Existing Bars at	
			RM 174.0	RM 171.0 – RM 168.5
Yes	No	No	Yes	Yes

***Additional comments**:* This alternative improved the repetitive dredging location. A point bar, which extended into the navigation channel, was created as a result of the removal of the structures.

Alternative 23:

Type of Structure	River Mile	LDB or RDB	Dimensions (Feet)	Structure Top Elevation (ft in LWRP)
Remove Dike	175.3	LDB	2300	Existing bed
Remove Dike	175.3	LDB	1500	Existing bed
Remove Dike	175.3	LDB	1500	Existing bed
Remove Dike	174.5	LDB	900	Existing bed

Results: *Bathymetry (Plate 40)*

Reduce or Eliminate Dredging Area (RM 174.0 – 172.5)	Maintain Existing Navigation Channel	Structure Placed Within Existing Fleeting Area	Maintain Existing Bars at	
			RM 174.0	RM 171.0 – RM 168.5
No	No	No	Yes	Yes

Additional comments*:* This alternative improved the repetitive dredging location. A point bar, which extended into the navigation channel, was created as a result of the removal of the structures. Furthermore, the existing bar at RM 174.0 had a decrease in elevations greater than 0 ft LWRP.

Alternative 24:

Type of Structure	River Mile	LDB or RDB	Dimensions (Feet)	Structure Top Elevation (ft in LWRP)
Dike	176.6	LDB	225	15
Dike	176.4	LDB	225	15

Results: *Bathymetry (Plate 41)*

Reduce or Eliminate Dredging Area (RM 174.0 – 172.5)	Maintain Existing Navigation Channel	Structure Placed Within Existing Fleeting Area	Maintain Existing Bars at	
			RM 174.0	RM 171.0 – RM 168.5
No	No	Yes	Yes	Yes

***Additional comments**:* This alternative did not improve the repetitive dredging location, and the existing navigation channel saw increased depths off of the tips of the dikes at RM 176.6 and RM 176.4.

Alternative 25:

Type of Structure	River Mile	LDB or RDB	Dimensions (Feet)	Structure Top Elevation (ft in LWRP)
L-Dike	173.8	LDB	1500	15

Results: *Bathymetry (Plate 42)*

Reduce or Eliminate Dredging Area (RM 174.0 – 172.5)	Maintain Existing Navigation Channel	Structure Placed Within Existing Fleeting Area	Maintain Existing Bars at	
			RM 174.0	RM 171.0 – RM 168.5
Yes	Yes	Yes	Yes	Yes

***Additional comments**:* This alternative improved the repetitive dredging location, but the L-Dike would impact two existing fleeting locations.

Alternative 26:

Type of Structure	River Mile	LDB or RDB	Dimensions (Feet)	Structure Top Elevation (ft in LWRP)
L-Dike	173.7	LDB	700	15
Dike	173.5	LDB	325	15
Dike	173.4	LDB	325	15

Results: *Bathymetry (Plate 42)*

Reduce or Eliminate Dredging Area (RM 174.0 – 172.5)	Maintain Existing Navigation Channel	Structure Placed Within Existing Fleeting Area	Maintain Existing Bars at	
			RM 174.0	RM 171.0 – RM 168.5
Yes	Yes	Yes	Yes	Yes

***Additional comments**:* This alternative improved the repetitive dredging location, but the proposed structures would impact existing fleeting areas.

Alternative 27:

Type of Structure	River Mile	LDB or RDB	Dimensions (Feet)	Structure Top Elevation (ft in LWRP)
L-Dike	173.7	LDB	850	15
Dike	173.5	LDB	300	15
Dike	173.4	LDB	300	15

Results: *Bathymetry (Plate 42)*

Reduce or Eliminate Dredging Area (RM 174.0 – 172.5)	Maintain Existing Navigation Channel	Structure Placed Within Existing Fleeting Area	Maintain Existing Bars at	
			RM 174.0	RM 171.0 – RM 168.5
Yes	Yes	Yes	Yes	Yes

***Additional comments**:* This alternative improved the repetitive dredging location, but the proposed structures would impact existing fleeting areas.

Alternative 28:

Type of Structure	River Mile	LDB or RDB	Dimensions (Feet)	Structure Top Elevation (ft in LWRP)
L-Dike	173.7	LDB	850	15
Dike	173.5	LDB	325	15

Results: *Bathymetry (Plate 42)*

Reduce or Eliminate Dredging Area (RM 174.0 – 172.5)	Maintain Existing Navigation Channel	Structure Placed Within Existing Fleeting Area	Maintain Existing Bars at	
			RM 174.0	RM 171.0 – RM 168.5
Yes	Yes	Yes	Yes	Yes

Additional comments*:* This alternative improved the repetitive dredging location, but the proposed structures would impact existing fleeting areas.

Alternative 29:

Type of Structure	River Mile	LDB or RDB	Dimensions (Feet)	Structure Top Elevation (ft in LWRP)
Dike	173.9	LDB	1800	1 ft above existing elevation
Dike	173.75	LDB	1800	1 ft above existing elevation
Dike	173.6	LDB	1700	1 ft above existing elevation
Dike	173.45	LDB	1600	1 ft above existing elevation

Results: *Bathymetry (Plate 42)*

Reduce or Eliminate Dredging Area (RM 174.0 – 172.5)	Maintain Existing Navigation Channel	Structure Placed Within Existing Fleeting Area	Maintain Existing Bars at	
			RM 174.0	RM 171.0 – RM 168.5
Yes	Yes	Yes	Yes	Yes

***Additional comments**:* The purpose of this alternative was to determine if structures built to an elevation that followed the natural contour of the existing bar would yield similar effects as structures built to a +15 LWRP elevation. The alternative improved the repetitive dredging location, but the proposed structures would impact existing fleeting areas.

Alternative 30:

Type of Structure	River Mile	LDB or RDB	Dimensions (Feet)	Structure Top Elevation (ft in LWRP)
Dike	173.7	LDB	250	15
Dike	173.6	LDB	250	15
Dike	173.5	LDB	250	15
Dike	173.4	LDB	250	15

Results: *Bathymetry (Plate 42)*

Reduce or Eliminate Dredging Area (RM 174.0 – 172.5)	Maintain Existing Navigation Channel	Structure Placed Within Existing Fleeting Area	Maintain Existing Bars at	
			RM 174.0	RM 171.0 – RM 168.5
Yes	Yes	Yes	Yes	Yes

***Additional comments**:* The alternative improved the repetitive dredging location, but the proposed structures would impact existing fleeting areas.

Alternative 31:

Type of Structure	River Mile	LDB or RDB	Dimensions (Feet)	Structure Top Elevation (ft in LWRP)
Dike	173.4	LDB	550	15

Results: *Bathymetry (Plate 42)*

Reduce or Eliminate Dredging Area (RM 174.0 – 172.5)	Maintain Existing Navigation Channel	Structure Placed Within Existing Fleeting Area	Maintain Existing Bars at	
			RM 174.0	RM 171.0 – RM 168.5
Yes	Yes	No	Yes	Yes

***Additional comments**:* The alternative improved the repetitive dredging location, and the structure was strategically placed between two existing fleeting locations.

CONCLUSIONS

1. Evaluation and Summary of the Model Tests

Alternatives	Reduce or Eliminate Dredging Area (RM 174.0 – 172.5)	Maintain Existing Navigation Channel	Structure Placed Within Existing Fleeting Area	Maintain Existing Bars at	
				RM 174.0	RM 171.0 – RM 168.5
Alternative 1	No	No	No	Yes	Yes
Alternative 2	Yes	No	Yes	Yes	Yes
Alternative 3	Yes	Yes	Yes	Yes	Yes
Alternative 4	Yes	Yes	Yes	Yes	Yes
Alternative 5	No	No	Yes	Yes	Yes
Alternative 6	No	Yes	No	Yes	Yes
Alternative 7	No	Yes	No	Yes	Yes
Alternative 8	No	Yes	Yes	Yes	Yes
Alternative 9	Yes	Yes	Yes	Yes	Yes
Alternative 10	No	Yes	Yes	Yes	Yes
Alternative 11	Yes	Yes	No	Yes	Yes
Alternative 12	Yes	Yes	Yes	Yes	Yes
Alternative 13	Yes	Yes	Yes	Yes	Yes
Alternative 14	No	No	Yes	Yes	Yes
Alternative 15	No	Yes	Yes	Yes	Yes
Alternative 16	Yes	Yes	Yes	Yes	Yes
Alternative 17	Yes	Yes	Yes	Yes	Yes
Alternative 18	Yes	Yes	Yes	Yes	Yes
Alternative 19	No	Yes	Yes	Yes	Yes
Alternative 20	No	Yes	Yes	Yes	Yes
Alternative 21	No	No	No	Yes	Yes
Alternative 22	Yes	No	No	Yes	Yes
Alternative 23	No	No	No	Yes	Yes
Alternative 24	No	No	Yes	Yes	Yes
Alternative 25	Yes	Yes	Yes	Yes	Yes
Alternative 26	Yes	Yes	Yes	Yes	Yes
Alternative 27	Yes	Yes	Yes	Yes	Yes
Alternative 28	Yes	Yes	Yes	Yes	Yes
Alternative 29	Yes	Yes	Yes	Yes	Yes
Alternative 30	Yes	Yes	Yes	Yes	Yes
Alternative 31	Yes	Yes	No	Yes	Yes

In order to determine the best alternative, certain criteria, based on the study purpose and goals, were used to evaluate each alternative. The first and most important consideration was that the alternative had to reduce or eliminate the need for repetitive maintenance dredging within the Carondelet reach. The second condition was that the alternative had to maintain the navigation channel requirements of at least 9 feet of depth and 300 foot of width. Third, the alternative should avoid and minimize impacts to fleeting areas within the reach. Finally, the alternative should avoid and minimize impacts to environmental areas. There were a number of alternatives that showed minimal improvements to the repetitive dredging location while maintaining the navigation channel requirements, although most involved placing structures within existing fleeting locations.

2. Recommendations

Alternative 31, Plate 48, was recommended as the most desirable alternative because of its observed ability to reduce or eliminate the need for repetitive maintenance dredging within the Carondelet reach. In addition, this alternative maintained the navigation channel requirements of at least 9 foot of depth and 300 foot of width and the structure was not placed directly within an existing fleeting location. The structure was within the immediate vicinity of two existing fleeting locations, but spokesmen from Ingram Barge Company stated that they were okay with the proposed alternative being placed between the two existing fleeting locations. Finally, the alternative did not impact the existing bars near RM 174.0 or between RM 171.0 and RM 168.5. Overall, this alternative enhanced navigation by providing a channel that would not require repetitive maintenance dredging, which impacts the navigation industry, environmental habitat, and tax payers.

The recommended design included the following:

- RM 173.4L: Construct Dike
    - Structure top elevation = +15 ft (LWRP)

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. Water surfaces were not analyzed and 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.

4. Additional Testing

In addition to testing alternatives to address the repetitive dredging issue at RM 173.4, the Carondelet HSR model was used to verify results of a past HSR model study, which investigated a side channel study near Jefferson Barracks, Missouri. Appendix D provides information on Jefferson Barracks HSR model study from 2001 and how the results from that model study were implemented into the Carondelet HSR model.

FOR MORE INFORMATION

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Appendix A: Report Plates

30. Alternative 13 – 1:28,000
31. Alternative 14 – 1:28,000
32. Alternative 15 – 1:28,000
33. Alternative 16 – 1:28,000
34. Alternative 17 – 1:28,000
35. Alternative 18 – 1:28,000
36. Alternative 19 – 1:28,000
37. Alternative 20 – 1:28,000
38. Alternative 21 – 1:28,000
39. Alternative 22 – 1:28,000
40. Alternative 23 – 1:28,000
41. Alternative 24 – 1:28,000
42. Alternative 25 – 1:28,000
43. Alternative 26 – 1:28,000
44. Alternative 27 – 1:28,000
45. Alternative 28 – 1:28,000
46. Alternative 29 – 1:28,000
47. Alternative 30 – 1:28,000
48. Alternative 31 – 1:28,000
49. Jefferson Barracks HSR Model Study Recommended Alternative
50. Jefferson Barracks Dike Test Alternative 1 – 1:28,000
51. Jefferson Barracks Dike Test Alternative 2 – 1:28,000
52. Jefferson Barracks Dike Test Alternative 3 – 1:28,000
53. Jefferson Barracks Dike Test Alternative 4 – 1:28,000
54. Jefferson Barracks Dike Test Alternative 5 – 1:28,000
55. Jefferson Barracks Dike Test Alternative 6 – 1:28,000
56. Jefferson Barracks Dike Test Alternative 7 – 1:28,000
57. Jefferson Barracks Dike Test Alternative 8 – 1:28,000
58. Jefferson Barracks Dike Test Alternative 9 – 1:28,000

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

Appendix C: Cross Section Comparison

To verify the predictive capabilities of the HSR model used for this study, cross sections were developed for the replication model condition and two prototype bathymetries, the 2007 and 2010 river surveys. The 2007 and 2010 surveys were chosen because they were the most recent surveys of the last 10 years that had full coverage of the model extents. From these cross sections, the cross-sectional areas and percent differences were calculated. Due to the numerous fleeting areas within the reach, the prototype surveys rarely contained bank to bank bathymetry. Because of this limitation, cross sections were trimmed to where the two prototype surveys and model survey were present. The cross sections were modeled and area calculations were performed using Bentley's InRoads and MicroStation software. The cross sections were cut at 2,000 feet. intervals along the sailing line for the same locations for all three surveys. The survey areas in close proximity to the model's entrance and exit conditions were not used. Furthermore, it should be noted that this is a limited data set, and a more detailed analysis was not completed due to constraints in time and funding. See Figure 2 on the next page for graphical cross-sectional comparisons.

The initial comparison was calculated between the replicated model scan and the 2007 bathymetry. The cross sections were generated with a vertical distortion of 15 feet horizontal for 1 foot vertical, which dictated using 15 as a correction factor for the area calculations. The results of the area calculations are presented on the next page in Table 4. The average percent difference between the cross-sectional areas, model to prototype, was 9.4%, with a low of 0.0% and a high of 28.5%.

The second comparison was between the replicated model scan and the 2010 bathymetry. The cross sections were generated with a vertical distortion of 15 feet horizontal for 1 foot vertical, which dictated using 15 as a correction factor for the area calculations. The results of the area calculations are presented in Table 5. The average percent difference between the cross-sectional areas, model to prototype, was 12.4%, with a low of 0.1% and a high of 28.5%.

Cross sections were generated in the same manner comparing the 2007 and 2010 bathymetries to get a measure of the natural variation of the channel. The average percent difference was 8.2%; the lowest percent difference was 0.2% and the highest was 22.1%. The natural variation of the channel compared well with the average percent difference of 10.9% between the model and prototype.

Figure 2:

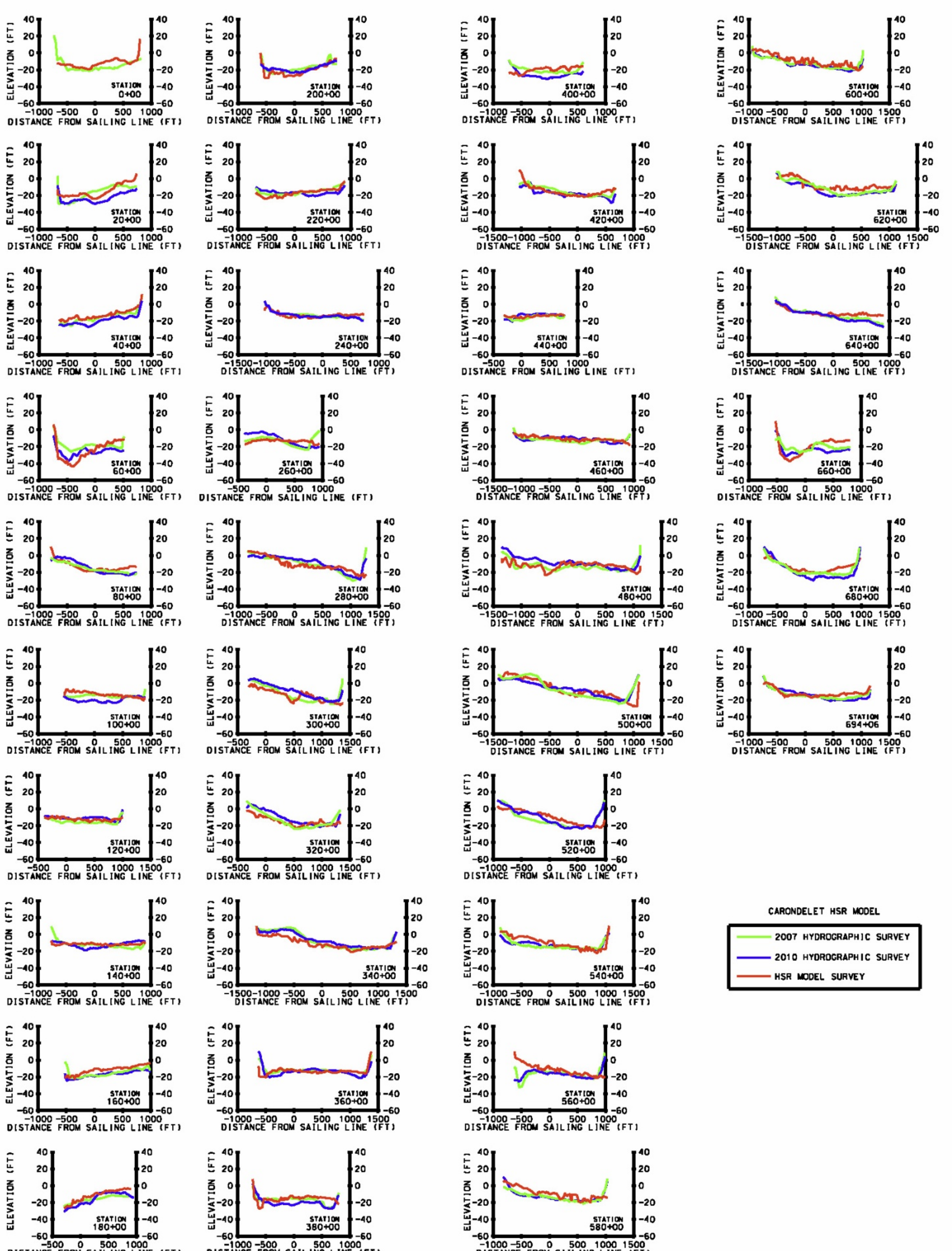
ELEVATION (FT)
DISTANCE FROM SAILING LINE (FT)
STATION 0+00
STATION 20+00
STATION 40+00
STATION 60+00
STATION 80+00
STATION 100+00
STATION 120+00
STATION 140+00
STATION 160+00
STATION 180+00
STATION 200+00
STATION 220+00
STATION 240+00
STATION 260+00
STATION 280+00
STATION 300+00
STATION 320+00
STATION 340+00
STATION 360+00
STATION 380+00
STATION 400+00
STATION 420+00
STATION 440+00
STATION 460+00
STATION 480+00
STATION 500+00
STATION 520+00
STATION 540+00
STATION 560+00
STATION 580+00
STATION 600+00
STATION 620+00
STATION 640+00
STATION 660+00
STATION 680+00
STATION 694+06
CARONDELET HSR MODEL
2007 HYDROGRAPHIC SURVEY
2010 HYDROGRAPHIC SURVEY
HSR MODEL SURVEY

Table 4: Cross Section Comparison Model Replication Scan and 2007 Bathymetry

Cross Section Station	Area Without Correction		Corrected Area		Percent Difference
	Model Replication (ft^2)	2007 Survey (ft^2)	True Model Replication (ft^2)	True 2007 Survey (ft^2)	
20+00	532240	571153	35483	38077	7.1%
40+00	506156	559557	33744	37304	10.0%
60+00	665685	547672	44379	36511	19.5%
80+00	537379	574419	35825	38295	6.7%
100+00	507237	553542	33816	36903	8.7%
120+00	466291	525634	31086	35042	12.0%
140+00	541803	565193	36120	37680	4.2%
160+00	488839	577739	32589	38516	16.7%
180+00	384438	463209	25629	30881	18.6%
200+00	626389	564425	41759	37628	10.4%
220+00	637967	609618	42531	40641	4.5%
240+00	605897	606103	40393	40407	0.0%
260+00	471016	472044	31401	31470	0.2%
280+00	656800	653236	43787	43549	0.5%
300+00	620143	586742	41343	39116	5.5%
320+00	626480	591934	41765	39462	5.7%
340+00	772324	650205	51488	43347	17.2%
360+00	708349	688265	47223	45884	2.9%
380+00	592704	626126	39514	41742	5.5%
400+00	592530	604555	39502	40304	2.0%
420+00	646743	646940	43116	43129	0.0%
440+00	391293	416297	26086	27753	6.2%
460+00	644975	688915	42998	45928	6.6%
480+00	644397	858632	42960	57242	28.5%
500+00	629979	645320	41999	43021	2.4%
520+00	580030	644157	38669	42944	10.5%
540+00	577671	666758	38511	44451	14.3%
560+00	528273	650678	35218	43379	20.8%
580+00	530534	644354	35369	42957	19.4%
600+00	564215	660994	37614	44066	15.8%
620+00	563616	675333	37574	45022	18.0%
640+00	593998	654626	39600	43642	9.7%
660+00	604831	609289	40322	40619	0.7%
680+00	612778	676089	40852	45073	9.8%
694+06	625693	685423	41713	45695	9.1%
				Average	9.4%

Table 5: Cross Section Comparison Model Replication Scan and 2010 Bathymetry

Cross Section Station	Area Without Correction		Corrected Area		Percent Difference
	Model Replication (ft^2)	2010 Survey (ft^2)	True Model Replication (ft^2)	True 2010 Survey (ft^2)	
20+00	532240	707429	35483	47162	28.3%
40+00	506156	649984	33744	43332	24.9%
60+00	665685	683563	44379	45571	2.7%
80+00	537379	552315	35825	36821	2.7%
100+00	507237	648901	33816	43260	24.5%
120+00	466291	442063	31086	29471	5.3%
140+00	541803	557184	36120	37146	2.8%
160+00	488839	614892	32589	40993	22.8%
180+00	384438	458628	25629	30575	17.6%
200+00	626389	579271	41759	38618	7.8%
220+00	637967	637066	42531	42471	0.1%
240+00	605897	618020	40393	41201	2.0%
260+00	471016	434908	31401	28994	8.0%
280+00	656800	602824	43787	40188	8.6%
300+00	620143	496380	41343	33092	22.2%
320+00	626480	528097	41765	35206	17.0%
340+00	772324	627409	51488	41827	20.7%
360+00	708349	725964	47223	48398	2.5%
380+00	592704	697096	39514	46473	16.2%
400+00	592530	712084	39502	47472	18.3%
420+00	646743	708753	43116	47250	9.1%
440+00	391293	383118	26086	25541	2.1%
460+00	644975	664336	42998	44289	3.0%
480+00	644397	690806	42960	46054	7.0%
500+00	629979	625180	41999	41679	0.8%
520+00	580030	594597	38669	39640	2.5%
540+00	577671	662457	38511	44164	13.7%
560+00	528273	660060	35218	44004	22.2%
580+00	530534	643349	35369	42890	19.2%
600+00	564215	678677	37614	45245	18.4%
620+00	563616	750945	37574	50063	28.5%
640+00	593998	686328	39600	45755	14.4%
660+00	604831	676233	40322	45082	11.1%
680+00	612778	737978	40852	49199	18.5%
694+06	625693	684170	41713	45611	8.9%
				Average	12.4%

Table 5: Cross Section Comparison 2007 Bathymetry and 2010 Bathymetry

Cross Section Station	Area Without Correction		Corrected Area		Percent Difference
	2007 Survey (ft^2)	2010 Survey (ft^2)	True 2007 Survey (ft^2)	True 2010 Survey (ft^2)	
20+00	571153	707429	38077	47162	21.3%
40+00	559557	649984	37304	43332	15.0%
60+00	547672	683563	36511	45571	22.1%
80+00	574419	552315	38295	36821	3.9%
100+00	553542	648901	36903	43260	15.9%
120+00	525634	442063	35042	29471	17.3%
140+00	565193	557184	37680	37146	1.4%
160+00	577739	614892	38516	40993	6.2%
180+00	463209	458628	30881	30575	1.0%
200+00	564425	579271	37628	38618	2.6%
220+00	609618	637066	40641	42471	4.4%
240+00	606103	618020	40407	41201	1.9%
260+00	472044	434908	31470	28994	8.2%
280+00	653236	602824	43549	40188	8.0%
300+00	586742	496380	39116	33092	16.7%
320+00	591934	528097	39462	35206	11.4%
340+00	650205	627409	43347	41827	3.6%
360+00	688265	725964	45884	48398	5.3%
380+00	626126	697096	41742	46473	10.7%
400+00	604555	712084	40304	47472	16.3%
420+00	646940	708753	43129	47250	9.1%
440+00	416297	383118	27753	25541	8.3%
460+00	688915	664336	45928	44289	3.6%
480+00	858632	690806	57242	46054	21.7%
500+00	645320	625180	43021	41679	3.2%
520+00	644157	594597	42944	39640	8.0%
540+00	666758	662457	44451	44164	0.6%
560+00	650678	660060	43379	44004	1.4%
580+00	644354	643349	42957	42890	0.2%
600+00	660994	678677	44066	45245	2.6%
620+00	675333	750945	45022	50063	10.6%
640+00	654626	686328	43642	45755	4.7%
660+00	609289	676233	40619	45082	10.4%
680+00	676089	737978	45073	49199	8.8%
694+06	685423	684170	45695	45611	0.2%
				Average	8.2%

Appendix D: Jefferson Barracks Dike Testing

In addition to testing alternatives to address the repetitive dredging issue at RM 173.4, the Carondelet HSR model was used to verify results of a past HSR model study, which investigated a side channel study near Jefferson Barracks, Missouri. The Jefferson Barracks HSR model study was never constructed due to a contaminated soils issue. That issue has been resolved, so the U.S. Army Corps of Engineers – St. Louis District made the decision to revisit the Jefferson Barracks recommended alternative to ensure it would yield similar results once the Carondelet recommended alternative was in place. This appendix will describe the Jefferson Barracks HSR Model (2001), and then detail how the results from that model were implemented into the Carondelet HSR model (2013).

1. Jefferson Barracks HSR Model Study (2001)

A. Study Purpose and Goals

Between June 2000 and February 2001, Mrs. Dawn Lamm conducted a side channel study of the Middle Mississippi River between RM 176.0 and RM 166.0 near Jefferson Barracks, Missouri. The purpose of the Jefferson Barracks HSR model study was to design structural modifications to the existing JB dike field in order to enhance physical diversity and flow dynamics within the reach. The study was performed to address two separate sediment transport goals. The first was to create island and side channel aquatic habitat within the existing dike field. The second goal was to increase depths in the adjacent navigation channel to reduce repetitive maintenance dredging.

B. Problem Description

The area of concern in the study reach began along the LDB at RM 172.0 and extended downstream to RM 168.0. There were two problems associated with that area. The first involved a lack of aquatic diversity within the existing dike field. The high elevations of the existing sandbar meant that the area was dry a majority of the time. Although the dikes had been notched in the past, there was still a lack of depth diversity and side channel formation throughout the dike field. The second problem involved recurring deposition in the adjacent navigation channel between RM 172.0 and RM 170.5. Repetitive maintenance dredging had been required in this reach to maintain adequate depths in the navigation channel.

C. Design Alternative Tests

All design alternatives studied in the original HSR model utilized the existing dike configurations. This was due to environmental concerns and the cost required in either removing or relocating the dikes. Fifteen design alternative plans were tested to examine methods of modifying the sediment transport response trends that would create both side channel and island habitat while also reducing dredging within the navigation channel. 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. A qualitative evaluation of the ramifications to the main channel and side channel was made during team participation meetings at the Applied River Engineering Center in St. Louis, Missouri. Personnel from the St. Louis U.S. Army Corps of Engineers, Missouri Department of Conservation, Illinois Department of Natural Resources, and the U.S. Fish and Wildlife Service carefully examined and discussed each alternative.

After evaluating each alternative, the Corps along with their stakeholders selected Alternative 14 (Plate 49) as the recommended alternative. The color table seen on Plate 49 differs from the rest of the Carondelet plates due to a difference in the way model surveys were processed in 2001. The recommended alternative consisted of the following:

- *Dike 170.9L, +17 feet LWRP, 400-foot wide notch from the bankline without an invert.*
- *Added a 700-foot long angled rootless dike at an elevation of +17 feet LWRP with the midpoint of the structure located at RM 170.7.*
- *Dikes 170.4L and 170.0L, +17 feet LWRP, 300-foot wide notch from the bankline without an invert.*
- *Added a 600-foot long angled rootless dike at an elevation of +17 feet LWRP with the midpoint of the structure located at RM 169.85L.*
- *Added a 1500-foot long angled dike at an elevation of +17 feet LWRP with the midpoint of the structure located at RM 169.75L. The beginning of the dike was located where Dike 169.45L originates. The structure had a 300-foot wide notch beginning 600 feet from the bank without an invert.*
- *Dike 169.45L, +17 feet LWRP, 300-foot wide notch beginning 700 feet from the bank without an invert.*
- *Dike 168.5L was not altered.*
- *An initial side channel was artificially dredged to an elevation of -10 feet LWRP with the material placed within the intended island area.*
- *The scour hole that formed just upstream and downstream of the notch in Dike 170.0L was armored during the test.*

D. Summary and Recommendations

The test results indicated that the design was effective in sustaining the dredged side channel complex. The notches in the dikes along the bankline directed some flows that maintained a distinct side channel. During the test a large scour hole formed at Dike 170.0L. To eliminate the additional material that entered the side channel from the scour hole, the area was armored to an elevation of -10 feet LWRP. However, the influx of bed load from the main channel decreased the depths in some of the dredged areas. The downstream end of the side channel experienced some deposition although elevations of +5 feet LWRP were still maintained. The design slightly increased depths in the navigation channel adjacent to and upstream of Dike 170.9L. Depths in the thalweg adjacent to the dike field also increased slightly. It was also noted that if the recommended alternative is eventually constructed in the river, revetment of the bankline should also be carried out along the LDB, between RM 171.0 and RM 168.8L. This measure will ensure protection of adjacent private floodplain lands and preserve flow energy necessary for the formation of the side channel.

E. Constructability of the Jefferson Barracks HSR Results

In October of 2005 the United States Environmental Protection Agency (U.S. EPA) collected sediment samples from the Mississippi River between the Chain of Rocks area to the Jefferson Barracks Chute. This sediment sampling was necessary to document a contaminant spill at Solutia Inc. near RM 178.0. Due to the investigation of contaminated soils, construction of the Jefferson Barracks recommended alternative was postponed until the EPA's study was complete. In 2011, the U.S. Army Corps of Engineers received notification that construction in the Jefferson Barracks area was safe, and at that time the Carondelet HSR model study was already underway.

2. Implementing Jefferson Barracks HSR (2001) Results into the Carondelet HSR Model (2013)

Since the Carondelet HSR model extents included the Jefferson Barracks dike field, the U.S. Army Corps of Engineers decided that the Jefferson Barracks recommended alternative should be revisited. The Carondelet recommended alternative included placing a 550-foot rootless dike at RM 173.4L. The addition of this new structure had a potential of changing bathymetry downstream, which in turn, could change how effective the Jefferson Barracks recommended alternative between RM 171.0 and RM 169.0 would be. For this reason, all testing to solve the Carondelet repetitive dredging issue had to be completed before implementing the Jefferson Barracks recommended alternative.

After the Carondelet recommended alternative was approved by our stakeholders, Dawn Lamm began testing the Jefferson Barracks recommended alternative in the Carondelet model. As a starting point, the exact recommended alternative was placed in the model to see if it reacted the same as in 2001. The results from this initial test can be seen on Plate 50. The model reacted comparably to the Jefferson Barracks HSR model study, but the Carondelet model had less depth diversity. Multiple variations of this alternative were tested in an attempt to yield depths similar to those in the original Jefferson Barracks HSR model study results.

Placing a structure upstream of the Jefferson Barracks dike field had a significant impact on the amount of depth diversity created within the dike field. Plate 56 shows a good example of this. However, adding a structure upstream of the Jefferson Barracks dike field would impact an additional fleeting area. Furthermore, adding a structure upstream of the dike field deteriorated the navigation channel at RM 171.5 – RM 170.5.

3. Conclusions

It is not recommended to construct Alternative 14 (Plate 49) of the Jefferson Barracks HSR Model Study (2001) due to many factors. When the alternative was placed in the Carondelet model, it did not create as much depth diversity as compared to the Jefferson Barracks model study of 2001.

Next, when trying to modify Alternative 14 by adding, removing, and modifying structures one of two things were observed during tests. First, there was significant depth diversity created within the Jefferson dike field, but the crossing at RM 171.5 – RM 170.5 was negatively impacted. Second, a structure placed upstream of the Jefferson Barracks dike field caused diversity within the dike field. However, placing a structure upstream of the dike field impacted a fleeting area. Since the Carondelet recommended alternative would already be impacting two fleeting locations, it is not recommended to place a structure immediately upstream of the Jefferson Barracks dike field.

Appendix E: CARONDELET FINAL MEETING NOTES (03/14/13)

The U.S. Army Corps of Engineers, St. Louis District conducted an HSR model study of the Carondelet reach on the Middle Mississippi River near St. Louis, Missouri. The study was funded by the Regulating Works Project for the Middle Mississippi River. In this reach, repetitive channel maintenance dredging has previously been required near RM 173.4. Throughout the Carondelet reach there are numerous fleeting locations (Plate 3), so all alternatives were to be designed in a way to minimize impacts to those established fleeting locations as well as established environmental locations. The objective of the study was to evaluate a variety of remedial measures with the goal of identifying the most effective and economical plan to reduce or eliminate repetitive maintenance dredging near RM 173.4. The recommended alternative (Plate 48) was to construct a rootless dike along the left descending bank just upstream of the repetitive dredging location. This alternative showed that the dredging would be reduced, and the placement of the structure will minimize impacts to fleeting areas.

After giving the general overview of the model and briefly going through the different alternatives that were tested, the floor was opened for questions. The main concerns were regarding the impacts that the structure would have on Ingram Barge Company's existing fleeting locations located along the LDB near RM 173.4. First, Ingram employees voiced their concerns with siltation downstream of the proposed dike structure because from what they have seen, many other dike fields tend to have siltation downstream of dike structures. Throughout testing of the model there always seemed to be adequate depths similar to the bathymetry shown on the Alternative 31 plate. The fact that there isn't as much deposition downstream of this particular dike structures is likely due to a couple of factors. First of all, the dike is a rootless structure, which means the dike is not tied into the bankline. By making the structure rootless, water is able to flow around both sides of the dike, and in turn, is likely to help keep sediment from depositing downstream. Furthermore, the proposed dike is placed in an area upstream of the problem location where the river is approximately 2,500 feet wide and just 1,000 feet downstream, the river narrows to 2,000 feet. Typically, a constriction of the river channel yields greater bathymetric depths, so the combination of the proposed rootless structure and the constricted river channel are contributing factors in keeping significant sedimentation from occurring downstream of the proposed structure.

The proposed structure was placed between two existing fleeting locations, and Ingram representatives agreed that the proposed structure was located in a way to minimize the impacts to their current fleeting operations. The structure was placed 250 feet downstream of Ingram's fleeting location at RM 173.4. The reason for this placement was to be of lesser impact to the fleeting location at RM 173.1. Ingram representatives found this to be a viable option if they were able to move their fleeting location at RM 173.4 upstream in order to distance themselves from the proposed dike structure. Ingram reported that moving the fleeting location at RM 173.4 upstream might be covered by their current permit, and they anticipated that there is adequate depth for them to do so.

There was one alternative that both the environmental and navigation partners thought would be worth testing again. This alternative included placing a 400 ft notch in Dike 175.3L, a 355 ft notch in Dike 174.5L, and a 900 ft dike at RM 173.4L. This alternative addressed the repetitive dredging location while also maintaining a diverse habitat near the bankline between RM 175.3 and RM 174.5. The partners proposed testing this alternative again, but instead of placing the 900-ft Dike that tied into the bankline place the 550-ft rootless dike from the proposed alternative. The environmental partners liked that there would be more bathymetric diversity between the bar and the bankline. The navigation partners thought that having a small "side channel" would allow more flow along the bankline, which would potentially help with keeping sediment from depositing downstream of the rootless dike (as described in the previous paragraph). This alternative will be tested, and the results will be disseminated to both our environmental and navigation partners once it is complete.
(Note: This alternative proved unsuccessful, and therefore was not included as an alternative in the report. The rootless dike diverted too much energy away from the navigation channel, so sedimentation occurred within the navigation channel crossing.)

Finally, there was some discussion about a previous HSR model study completed by Dawn Lamm, which focused on the dike field located along the LDB between RM 170.9L and RM 168.5L at Jefferson Barracks. This model study was completed in November of 2001, but the recommended alternative was never constructed due to a potential contaminated soils issue. Recently, it was determined that no contaminated soils would be impacted by constructing the proposed alternative. Since the Jefferson Barracks reach is within the Carondelet HSR model study limits, the St. Louis District decided to retest the proposed alternative for the Jefferson Barracks HSR model study. This testing is ongoing, and once complete, the final results will be presented to both our navigation and environmental partners.

Brad Krischel
Applied River Engineering Center
USACE, St. Louis District
(314)-865-6325

HSR Model Meetings

March 14, 2013 at 1:00 PM

Name	Company	Signature
Atwood, Butch	IDNR	[signature]
Brown, Danny	MDC	[signature]
Brown, Jasen	USACE	
Cail, Robert	USFWS	[signature]
Canada, Mike	Ingram Marine Group	[signature]
Frerker, Charles	USACE	[signature]
Henleben, Ed	Ingram Marine Group	
Heroff, Bernie	ARTCO	
Herzog, Dave	MDC	
Hoerner, Lynn	USACE	
Holt, Gary	Ingram Marine Group	[signature]
Hoover, Terry	Ingram Marine Group	[signature]
Hughes, Shannon	Kirby Inland Marine	[signature]
Johnson, Brian	USACE	
Knuth, Dave	MDC	[signature]
Lamm, Dawn	USACE	[signature]
Mangan, Matt	USFWS	
McMullen, Joe	MDC	[signature]
Moore, Adrienne	Ingram Marine Group	[signature]
Ostendorf, David	MDC	[signature]
Rodgers, Mike	USACE	[signature]
Runyon, Kip	USACE	
Schneider, Brandon	USACE	[signature]
Vogrin, Jeff	Ingram Marine Group	[signature]
[illegible]	USACE	
Zach Ryals	USACE	[signature]
Tim Lauth	USACE	[signature]

Note: Matt Mangan did not sign the attendance sheet, but he was in attendance