Technical Report M58

# Grand Lake Towhead HSR MODEL
# Mississippi River Miles 26.0 – 10.5

# HYDRAULIC SEDIMENT RESPONSE MODEL INVESTIGATION

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# INTRODUCTION

The U.S. Army Corps of Engineers, St. Louis District, conducted a sedimentation improvement study of the Grand Lake Towhead reach of the Middle Mississippi River between River Miles (RM) 26.0 and 10.5 near Cairo, Illinois. This study was funded by the U.S. Army Corps of Engineers, St. Louis District. 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 dredging within the Grand Lake Towhead reach.

The study was conducted between December 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 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 | St. Louis District |
| Michael Rodgers, P.E. | Project Manager for River Works Projects | St. Louis District |
| Dave Gordon, P.E. | Chief of Hydraulic Design Section | St. Louis District |
| Jasen Brown, P.E. | Hydraulic Engineer | St. Louis District |
| Ashley Cox | Hydraulic Engineer | St. Louis District |
| June Jeffries, P.E. | Chief of Environmental Engineering Section | St. Louis District |
| Brian Johnson | Chief of Environmental Planning Section | St. Louis District |
| Brandon Schneider | Biologist | St. Louis District |
| Jennifer Brown | Regulatory Project Manager | St. Louis District |
| Lance Engle | Dredging Project Manager | St. Louis District |
| Jason Floyd | Engineering Technician | St. Louis District |
| Dana Fischer | AREC Co-op | St. Louis District |
| Jason Mewes | AREC Co-op | St. Louis District |
| Shannon Hughes | River Field Port Captain | Kirby Inland Marine |
| Brian Blaine | Captain | American River Transportation Co. |
| Bernie Heroff | Port Captain | American River Transportation Co. |
| Butch Atwood | Mississippi River Fisheries Biologist | Illinois Dept. of Natural Resources |
| David Ostendorf | Resource Staff Scientist | Missouri Dept. of Conservation |
| Matt Mangan | Biologist | U.S. Fish & Wildlife Service |

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## BACKGROUND

### 1. Problem Description

To maintain the navigation channel, from 1990 to 2010, between RM 26.0 and RM 10.5, approximately 7.5 million cubic yards was dredged at a cost of approximately $10.4M. To gain a better understanding of the dredging required within the Grand Lake Towhead reach, the dredging areas were split up into three extents (RM 26.0 – 20.0, RM 20.0 – 12.5, RM 12.5 – 10.5), which were chosen based on groups of frequent dredging locations. The dredging totals by year and percentage, broken down by the three extents, can be seen in Figure 1 and Figure 2 respectively.

**Figure 1:**

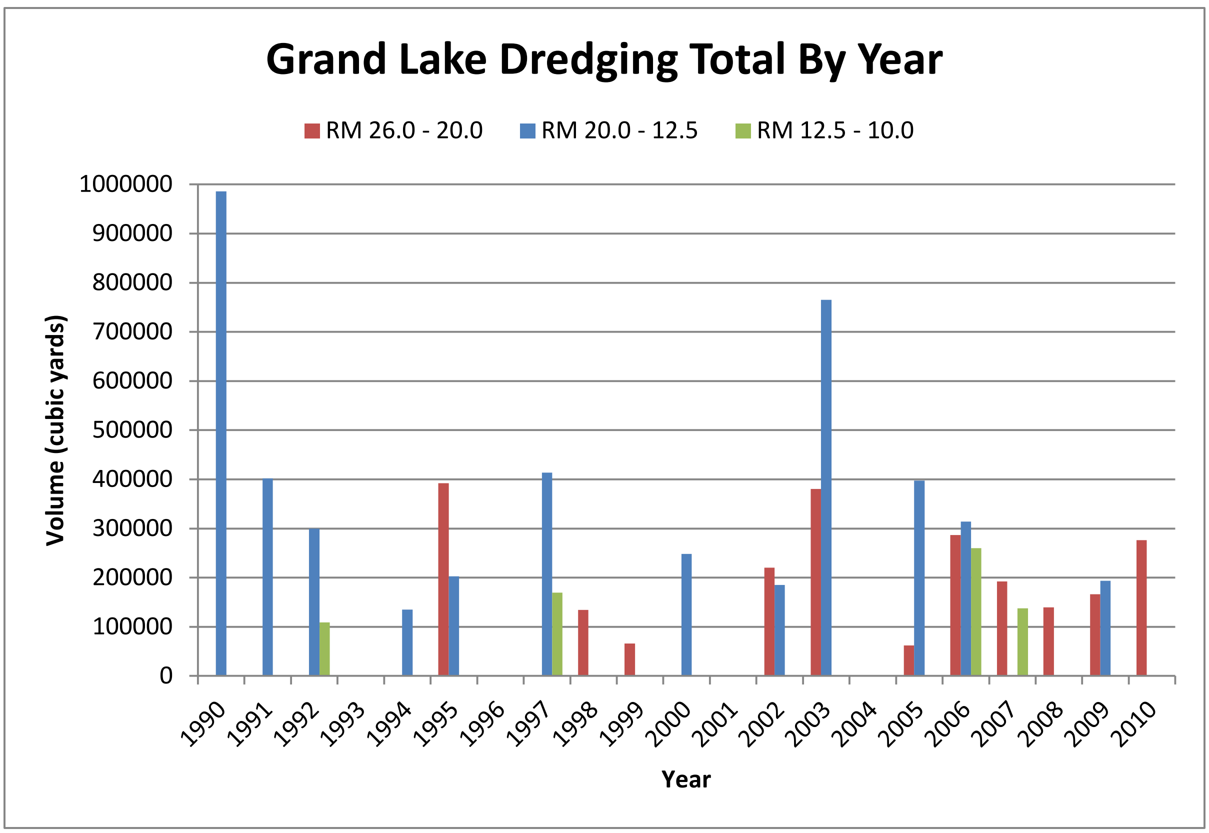
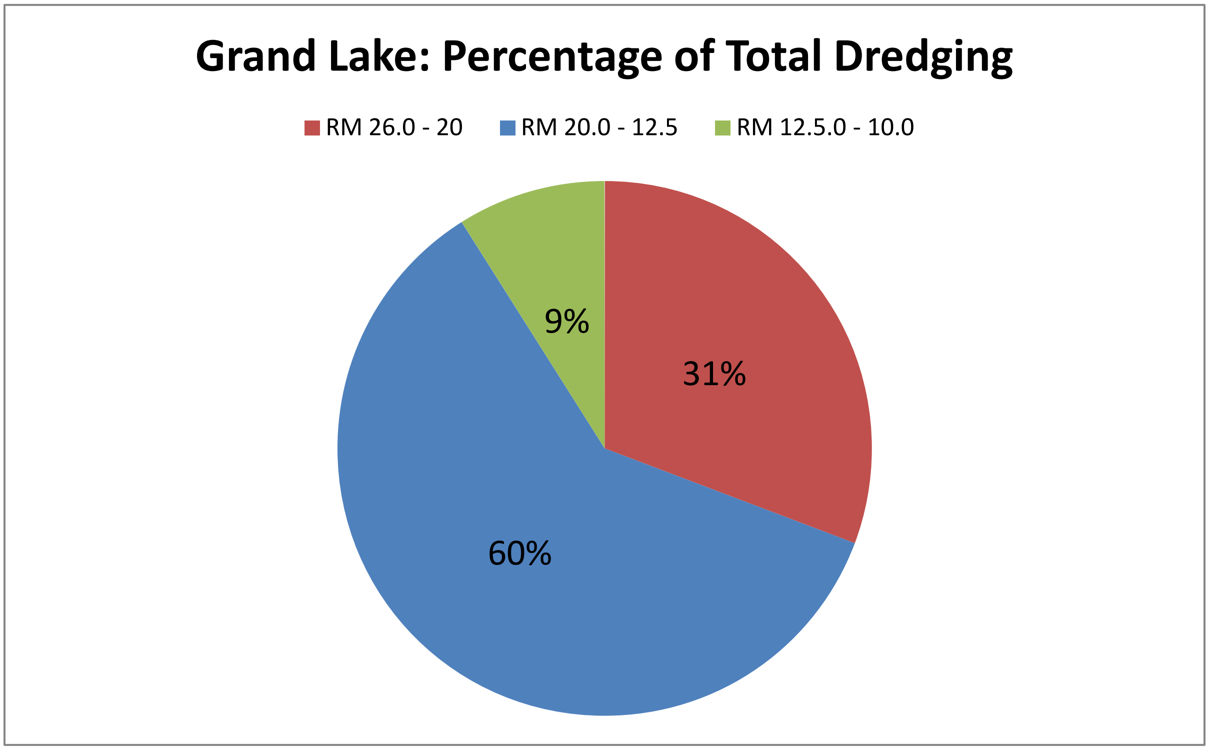


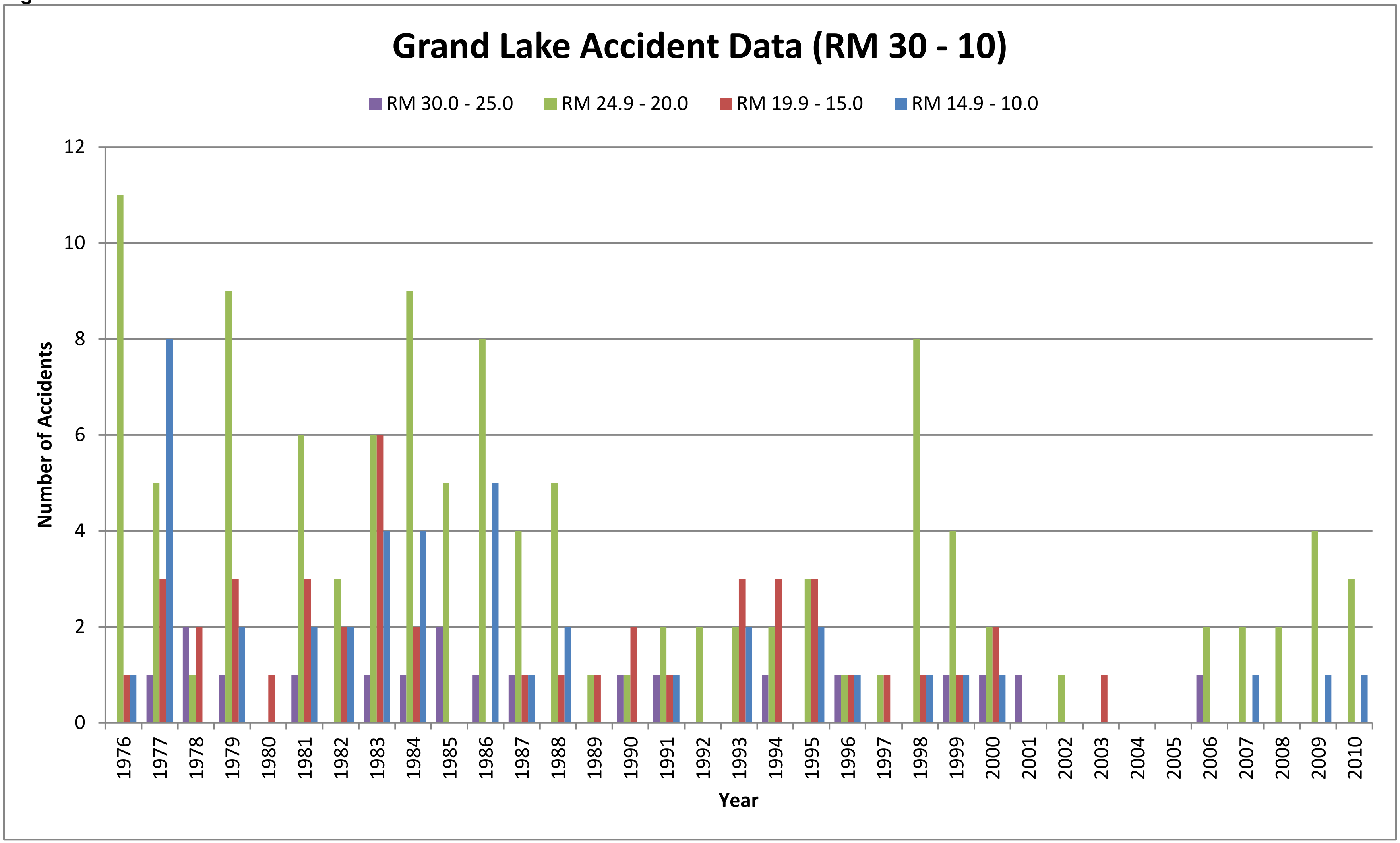
**Figure 2:**




As illustrated in Figures 1 and 2, the most problematic area within the model extents was within RM 20.0 – 12.5, which contains the Grand Lake Towhead reach. Between 1990 and 2010, the Grand Lake Towhead reach had approximately 4.5 million cubic yards dredged at a cost of approximately $5.4M. Plate 2 shows all of the dredging and disposal locations within the study reach between 1990 and 2010. To help alleviate the navigation concerns, the Army Corps of Engineers – St. Louis District has dredged within the reach. Dredging can be dangerous for fish due to instantaneous impacts on their environment, so eliminating the need for dredging will be beneficial for both the navigation industry as well as the environment.

The Grand Lake Towhead reach of the Middle Mississippi River, which has extents between RM 17.5 – 12.5, has been a problematic reach for the navigation industry for many years. The narrow channel, in combination with multiple bends, makes navigation extremely challenging and potentially dangerous. Figure 3 shows accident data, which includes groundings and collisions, provided by the United States Coast Guard.

**Figure 3:**



Grand Lake Accident Data (RM 30 - 10)
RM 30.0 - 25.0
RM 24.9 - 20.0
RM 19.9 - 15.0
RM 14.9 - 10.0
Number of Accidents
0
2
4
6
8
10
12
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
Year

## 2. Study Purpose and Goals

The U.S. Army Corps of Engineers, St. Louis District, had proposed a set of structures within the Grand Lake Towhead reach as part of a 2009 General Plan. Following the proposal, the St. Louis District coordinated with the Illinois Department of Natural Resources, U.S. Fish and Wildlife Service, River Industry Action Committee, and the Missouri Department of Conservation. There were questions raised by our partners about what impact the structures would have on the problem area, and if the structures would have any negative impact on environmental areas. In response, the St. Louis District decided to complete an HSR model study to obtain more information before moving forward with construction.

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, three criteria were used to evaluate each alternative.

    a. The alternative should reduce or eliminate dredging within the Grand Lake Towhead 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 not negatively impact environmental areas, and impacts on shallow water habitat should be closely monitored. More specifically, the alternative should not impact the bars at Browns Bar, Thompson Towhead, or Greenleaf Bend. In addition, Sister Chute should not be negatively affected.

iii. 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 15.5 mile stretch of the Mississippi River, between RM 26.0 and RM 10.5 in Alexander County in Illinois and Mississippi County in Missouri. Discussed below are a variety of features found within the reach. Plate 1 is a location and vicinity map of the study reach.

Plate 3 is a 2007 aerial photograph illustrating the planform and nomenclature of the Middle Mississippi River between RM 26.0 and RM 10.5. At the time of this study, the reach had a total of 81 dikes and 22 bendway weirs. Alos, the majority of the reach was revetted.

A historical look at the Grand Lake reach of the Middle Mississippi River revealed that the river planform has changed over time. Plate 4 shows an overview of the changes that have taken place from 1817-2003. More specifically, the meander migration of Dogtooth Bend (RM 25.0 – 20.0) and Greenleaf Bend (RM 16.0 – 13.0) showed noteworthy changes. Since 1817, the river migrated approximately 5,500 feet across the floodplain in the Eastern direction between RM 22.0 and RM 20.0. Also, the river migrated approximately 4,000 feet in the Southern direction between RM 14.0 and RM 12.0. In 1817, the river was much wider (between 5,000 and 10,000 feet) in locations of bends. Mostly, the wide river was due to the numerous islands and side channels found within the reach. By 1928, the planform of the river had become stabilized through the use of revetment on the banklines. Plate 4 is taken from the "Geomorphology of the Middle Mississippi River" report, which was produced by the St. Louis District (2005).

Plates 5 through 10 show the study reach through aerial photographs and sounding maps from 1928, 1942, 1956, 1977, 1983, and 1987, respectively. In 1928, there were three islands along the right descending bank (RDB) between RM 25.0 and

RM 23.0, one of which was Sliding Towhead. These islands were created due to the connection of multiple side channels. Along the LDB in the same location, a few dikes had been put in place. Further downstream at RM 19.0, another two islands existed. One was located along the RDB and formed by another small side channel. The other island was Thompson Towhead, which separated the main channel and a side channel, which was approximately 1,000 feet wide. Three dike structures can be seen on the RDB between RM 14.5 and RM 13.5.

The 1942 map (Plate 6) of the study area shows that two of the three islands along the RDB between RM 25.0 and RM 23.0 still existed, but the island that was farthest downstream no longer existed. Four more islands existed along the LDB as well. The largest of these four islands was named Browns Bar. These islands were likely formed due to the dike structures that were present in the 1928 aerial photographs. Approximately 15 new dike structures had been constructed on the LDB and RDB between RM 25.0 and RM 20.5 between 1928 and 1942. Between RM 24.0 and RM 22.0, the main channel appeared to have shifted from the inside of the bend to the outside of the bend. This 2,000 foot shift was probably due to the newly formed islands, which were created from the dike structures located on the inside of the bend. Thompson Towhead still existed downstream, but 10 new dike structures had been constructed along the RDB between RM 19.0 and RM 16.0, all of which connected to either the side channel or main channel side of Thompson Towhead. Along the RDB between RM 15.0 and RM 12.0, 4 new dike structures had been constructed. Lastly, 8 new dikes had been constructed along the LDB between RM 12.0 and RM 10.5.

The 1956 map (Plate 7) was limited mostly to the main channel due to the fact that it was a hydrographic survey. The study reach appeared to have almost identical structures in place as observed in the 1942 planform, but the island structures and bankline locations appeared to have changed a significant amount in some locations. The dike structures that had been constructed off of the main channel side of Thompson Towhead had begun to create higher elevations between the dikes. Further downstream, the dike structures that had been put in place along the

RDB between RM 15.0 and RM 12.0 had begun to form Sister Chute, which resembled the side channel that can be observed in that location today.

1977 aerial photographs (Plate 8) showed a planform that greatly resembled what is in place today. Browns Bar at RM 23.0 had a large amount of vegetation, which showed that it was very well established. The side channel behind Thompson Towhead still had water in it, but it was not quite connected back to the main channel during normal flow conditions. A closure structure at the entrance and exit had turned the area into a location for excess water to drain. Along the LDB between RM 14.0 and RM 13.0, 5 dikes had been constructed. On the opposing bank of those dikes was Sister Chute, which had formed into a side channel by two established islands.

1983 and 1987 aerial photographs (Plates 9 and 10) of the study reach showed a similar planform to the 2007 aerial photographs (Plate 2). In the 1983 and 1987 photographs, large point bars had begun to form off of Brown's Bar (RM 23.0) and Thompson Towhead (RM 17.0). The point bars at both locations had narrowed the channel to approximately 750 feet. In 1990, a set of 13 weirs were constructed along the RDB between RM 24.2 and RM 22.4 to assist in keeping the channel navigable at Brown's Bar. A similar solution was used downstream at Thompson Towhead. A set of 9 weirs were constructed in 1995 along the LDB between RM 17.3 and RM 16.7. Revetment played a role in creating a river channel that did not meander, but construction dates for revetment in specific areas are not well documented.

All of the above information provided further understanding as to what characteristics the river had shown over the past 186 years. This included changes that are both natural and man-made. 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 islands, side channels, sand bars, and other features.

## A. 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 - 14. The plates show range line and multi-beam surveys from 2000 to 2010. For this study, 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 river training structures built in 2005 were the last navigation items constructed at the time of the study, so the surveys following should be relatively consistent. It should be noted that a set of structures between RM 22.5 and RM 21.0 were scheduled to be constructed in 2011 (see Plate 15), but because they had not been built at the time of the study, there was no survey information accessible to reflect the bathymetry changes. The following bathymetric trends remained relatively constant from 2005 to 2010 after comparison of the above mentioned hydrographic surveys:

**Table 2: Study Reach Bathymetry Trends**

| River Miles | Description |
|---|---|
| 26.0 – 25.5 | The thalweg was located on the LDB with depths between -20 ft and -30 ft LWRP. |
| 25.5 – 24.5 | A crossing was observed between RM 25.5 – 24.5. The first bend within the model extents begins at RM 25.0. |
| 24.5 – 19.5 | The thalweg was located on the RDB with depths between -15 ft and -40 ft LWRP. A large bar was located near RM 24.5 to RM 23.0 on the LDB. The first river bend continues through this section and ends at RM 20.0. |
| 19.5 – 18.5 | A crossing was observed between RM 19.5 – 18.5. |
| 18.5 – 12.5 | The thalweg was located on the LDB with depths between -10 ft and -40 ft LWRP. A large bar was located near RM 17.5 to RM 16.5 on |

| | |
|---|---|
| | the RDB. Another large bar was located near RM 14.3 and RM 12.5 on the RDB. The second river bend within the model extents occured in this section of the river between RM 18.0 and RM 12.5. This was a long bend, which straightened out between RM 16.0 and RM 15.0. This planform allowed a lot of sediment to fall out in this area. Hence, the large amount of repetitive dredging within this reach. This section of the river has a narrow navigable channel. |
| 12.5 – 11.0 | A crossing was observed between RM 12.5 and RM 11.0. |
| 11.0 – 10.0 | The thalweg was located on the RDB with depths between -10 ft and -25 ft LWRP. |

### ii. Site Data

On August 2, 2011, engineers from the St. Louis District conducted a site visit to the Grand Lake Towhead reach. This site visit was used to analyze general flow trends, inspect the condition of the banklines, and analyze the current condition of river training structures within the reach. Gage information, pictures, and descriptions from the trip can be seen in Appendix B.

# HSR MODELING

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

## 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 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 = 800 feet, or 1:9,600, and a vertical scale of 1 inch = 37 feet, or 1:444, for a 21.5 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 and aluminum oxide gravel in small places as the non-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 2007 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.

## 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 1.95 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 testing was taking place.

### A. Bathymetry

Bathymetric trends were recorded from the model using a three-dimensional 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 15.

Results of the HSR model replication test bathymetry and a comparison to the 2005 through 2010 prototype surveys indicated the following trends:

**Table 4: Study Reach and Prototype Bathymetry Trend Comparison**

| River Miles | Description |
|---|---|
| 26.0 – 25.5 | The model and the prototype surveys showed the thalweg on the LDB. |
| 25.5 – 24.5 | In both the model and the prototype, the crossing was observed starting at RM 25.5 but ended at RM 24.5 in the prototype and RM 24.0 in the model. Also, the model crossing was deeper in the prototype than in the model. The bar at the inside of the bend developed near RM 24.5 in the prototype and extended to RM 23.0. In the model, the bar formed near RM 23.5 and only extended to RM 22.9. The bar in the prototype surveys was typically higher in elevation than in the model replication test. |
| 24.5 – 19.5 | The model and the prototype surveys both showed the thalweg on the RDB from RM 24.5 to RM 19.5. |
| 19.5 – 18.5 | In the prototype a crossing was observed between RM 19.5 – 18.5, while the model showed a split flow condition between RM 19.5 – 18.0. The LDB side of the split flow crossed to the LDB at RM 19.0 while the RDB side of the split flow crossed to the LDB at RM 18.0. |
| 18.5 – 12.5 | The thalweg was located on the LDB in the model and prototype. A large bar was located near RM 17.5 to RM 16.5 on the RDB in both the prototype and the model, but the bar in the prototype surveys was typically higher in elevation than in the model base test. Along the RDB between RM 16.0 and RM 14.5, the model showed higher elevations than the prototype surveys, but the area was a repetitive dredging area. Another large bar was located near RM 14.3 and RM 12.5 on the RDB in both the prototype and the model, but again, the |

| | |
|---|---|
| | bar in the prototype surveys was typically higher in elevation than in the model base test. |
| 12.5 – 10.0 | In the prototype survey, a crossing was observed between RM 12.5 and RM 11.0, but the thalweg remained along the LDB in the model. However, this crossing was close to the exit of the model, so exit conditions could have limited the crossing from taking place. |

Further detailed calculations on model cross sections were compared directly to the prototype and are shown in Appendix D. 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.

During the time of the model study, there was construction planned within the study reach. The structures to be constructed in FY11 (Plate 16) were put in the model after replication was achieved because there was no survey information available at the time of the study. The FY11 structures were in place during all alternative testing since the structures would be constructed by the time the selected Grand Lake Towhead model alternative was built.

## 6. 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 alter the model bed response in a manner intended to reduce dredging within the Grand Lake Towhead reach. 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:***

| Type of Structure | River Mile | LDB or RDB | Dimensions (Feet) | Structure Top Elevation (ft in LWRP) |
|---|---|---|---|---|
| Chevron | 16.3 | RDB | 300 x 300 | 15 |
| Rootless Dike | 16.0 | RDB | 300 | 15 |
| Chevron | 15.8 | RDB | 300 x 300 | 15 |
| Dike Extension | 15.5 | RDB | 150 | 15 |
| Dike Extension | 15.1 | RDB | 250 | 15 |
| Dike Extension | 14.9 | RDB | 110 | 15 |
| Dike Extension | 14.7 | RDB | 250 | 15 |

**Results:** *Bathymetry (Plate 17)*

| Reduced Dredging | Positive Impact or No Change in Environmental Areas | Additional Comments |
|---|---|---|
| No | Yes | This alternative was the General Plan proposed in 2009. There was no significant change in bathymetry. There was still a large amount of sediment along the RDB. Furthermore, the navigation channel along the LDB did not show any increased depth. |

***Alternative 2:***

| Type of Structure | River Mile | LDB or RDB | Dimensions (Feet) | Structure Top Elevation (ft in LWRP) |
|---|---|---|---|---|
| Chevron | 16.3 | RDB | 300 x 300 | 15 |
| Rootless Dike | 16.0 | RDB | 300 | 15 |
| Chevron | 15.8 | RDB | 300 x 300 | 15 |
| Dike Extension | 15.5 | RDB | 150 | 15 |
| Dike Extension | 15.1 | RDB | 250 | 15 |
| Dike Extension | 14.9 | RDB | 110 | 15 |
| Dike Extension | 14.7 | RDB | 250 | 15 |

**Results:** *Bathymetry (Plate 18)*

| Reduced Dredging | Positive Impact or No Change in Environmental Areas | Additional Comments |
|---|---|---|
| No | Yes | This alternative was a variation of the General Plan proposed in 2009 (Alternative 1). This alternative was different from Alternative 1 in that the Chevron at RM 16.3 was moved farther away from the RDB. There was no significant change in bathymetry. There was still a large amount of sediment along the RDB. Furthermore, the navigation channel along the LDB did not show any increased depth. |

***Alternative 3:***

| Type of Structure | River Mile | LDB or RDB | Dimensions (Feet) | Structure Top Elevation (ft in LWRP) |
|---|---|---|---|---|
| Chevron | 16.3 | RDB | 300 x 300 | 15 |
| Rootless Dike | 16.0 | RDB | 300 | 15 |
| Chevron | 15.8 | RDB | 300 x 300 | 15 |
| Dike Extension | 15.5 | RDB | 150 | 15 |
| Dike Extension | 15.1 | RDB | 250 | 15 |
| Dike Extension | 14.9 | RDB | 110 | 15 |
| Dike Extension | 14.7 | RDB | 250 | 15 |

**Results:** *Bathymetry (Plate 19)*

| Reduced Dredging | Positive Impact or No Change in Environmental Areas | Additional Comments |
|---|---|---|
| No | Yes | This alternative was a variation of the General Plan proposed in 2009 (Alternative 1). This alternative was different from Alternative 1 in that the Chevron at RM 16.3 and the Rootless Dike were moved farther away from the RDB. There was no significant change in bathymetry. There was still a large amount of sediment along the RDB. A ridge with elevations between 0 ft and +5 ft had developed on the RDB side of the most upstream chevron. The rootless dike extension of Dike No. 16.0R displayed a small amount of scour between the existing structure and the extension. Again, the navigation channel along the LDB did not show any increased depth. |

***Alternative 4:***

| Type of Structure | River Mile | LDB or RDB | Dimensions (Feet) | Structure Top Elevation (ft in LWRP) |
|---|---|---|---|---|
| Chevron | 16.3 | RDB | 300 x 300 | 15 |
| Rootless Dike | 16.0 | RDB | 300 | 15 |
| Chevron | 15.8 | RDB | 300 x 300 | 15 |
| Dike Extension | 15.5 | RDB | 150 | 15 |
| Dike Extension | 15.1 | RDB | 250 | 15 |
| Dike Extension | 14.9 | RDB | 110 | 15 |
| Dike Extension | 14.7 | RDB | 250 | 15 |

**Results:** *Bathymetry (Plate 20)*

| Reduced Dredging | Positive Impact or No Change in Environmental Areas | Additional Comments |
|---|---|---|
| No | Yes | This alternative was a variation of the General Plan proposed in 2009 (Alternative 1). This alternative was different from Alternative 1 in that the Chevron at RM 16.3, the Rootless Dike, and the Chevron at RM 15.8 were moved farther away from the RDB. There was no significant change in bathymetry. There was still a large amount of sediment along the RDB. The rootless dike extension of Dike No. 16.0R displayed a small amount of scour between the existing structure and the extension. Furthermore, the navigation channel along the LDB did not show any increased depth. |

***Alternative 5:***

| Type of Structure | River Mile | LDB or RDB | Dimensions (Feet) | Structure Top Elevation (ft in LWRP) |
|---|---|---|---|---|
| Remove Dike | 16.7 | RDB | 1,100 | TO GRADE |
| Dike Extension | 16.0 | RDB | 300 | 15 |
| Chevron | 15.8 | RDB | 300 x 300 | 15 |
| Chevron | 15.6 | RDB | 300 x 300 | 15 |

**Results:** *Bathymetry (Plate 21)*

| Reduced Dredging | Positive Impact or No Change in Environmental Areas | Additional Comments |
|---|---|---|
| No | Yes | There was no significant change in bathymetry. There was still a large amount of sediment along the RDB. The point bar at RM 17.0 was degraded compared to the replication test. Furthermore, the navigation channel along the LDB did not show any increased depth. |

***Alternative 6:***

| Type of Structure | River Mile | LDB or RDB | Dimensions (Feet) | Structure Top Elevation (ft in LWRP) |
|---|---|---|---|---|
| Weir | 16.4 | LDB | 625 | -15 |

**Results:** *Bathymetry (Plate 22)*

| Reduced Dredging | Positive Impact or No Change in Environmental Areas | Additional Comments |
|---|---|---|
| No | Yes | There was no significant change in bathymetry. There was still a large amount of sediment along the RDB. Furthermore, the navigation channel along the LDB did not show any increased depth. |

***Alternative 7:***

| Type of Structure | River Mile | LDB or RDB | Dimensions (Feet) | Structure Top Elevation (ft in LWRP) |
|---|---|---|---|---|
| Weir | 16.6 | LDB | 625 | -15 |
| Weir | 16.5 | LDB | 590 | -15 |

**Results:** *Bathymetry (Plate 23)*

| Reduced Dredging | Positive Impact or No Change in Environmental Areas | Additional Comments |
|---|---|---|
| No | Yes | There was no significant change in bathymetry. There was still a large amount of sediment along the RDB. Furthermore, the navigation channel along the LDB did not show any increased depth. |

***Alternative 8:***

| Type of Structure | River Mile | LDB or RDB | Dimensions (Feet) | Structure Top Elevation (ft in LWRP) |
|---|---|---|---|---|
| Weir | 16.6 | LDB | 625 | -15 |
| Weir | 16.5 | LDB | 625 | -15 |

**Results:** *Bathymetry (Plate 24)*

| Reduced Dredging | Positive Impact or No Change in Environmental Areas | Additional Comments |
|---|---|---|
| No | Yes | There was no significant change in bathymetry. There was still a large amount of sediment along the RDB. This was the first time an alternative showed a -15 ft to -20 ft LWRP channel throughout the problem area between RM 16.0 and RM 15.0. |

***Alternative 9:***

| Type of Structure | River Mile | LDB or RDB | Dimensions (Feet) | Structure Top Elevation (ft in LWRP) |
|---|---|---|---|---|
| Weir | 16.6 | LDB | 625 | -15 |
| Weir | 16.5 | LDB | 575 | -15 |
| Weir | 16.4 | LDB | 500 | -15 |

**Results:** *Bathymetry (Plate 25)*

| Reduced Dredging | Positive Impact or No Change in Environmental Areas | Additional Comments |
|---|---|---|
| No | Yes | There was no significant change in bathymetry. There was still a large amount of sediment along the RDB. Furthermore, the navigation channel along the LDB did not show any increased depth. |

***Alternative 10:***

| Type of Structure | River Mile | LDB or RDB | Dimensions (Feet) | Structure Top Elevation (ft in LWRP) |
|---|---|---|---|---|
| Weir | 16.7 | LDB | 450 | -15 |

**Results:** *Bathymetry (Plate 26)*

| Reduced Dredging | Positive Impact or No Change in Environmental Areas | Additional Comments |
|---|---|---|
| No | Yes | This alternative attempted to change the bathymetry between RM 15.0 and RM 16.0 by adjusting the length and angle of weir 16.7L. The existing weir was removed and a new weir was placed as shown on Plate 26. There was no significant change in bathymetry. |

***Alternative 11:***

| Type of Structure | River Mile | LDB or RDB | Dimensions (Feet) | Structure Top Elevation (ft in LWRP) |
|---|---|---|---|---|
| Weir | 16.8 | LDB | 450 | -15 |
| Weir | 16.7 | LDB | 450 | -15 |

**Results:** *Bathymetry (Plate 27)*

| Reduced Dredging | Positive Impact or No Change in Environmental Areas | Additional Comments |
|---|---|---|
| No | Yes | This alternative attempted to change the bathymetry between RM 15.0 and RM 16.0 by adjusting the length and angle of Weir 16.8L and Weir 16.7L. The existing weirs were removed and the new weirs were placed as shown on Plate 27. There was no significant change in bathymetry. |

***Alternative 12:***

| Type of Structure | River Mile | LDB or RDB | Dimensions (Feet) | Structure Top Elevation (ft in LWRP) |
|---|---|---|---|---|
| Chevron | 19.4 | RDB | 300 x 300 | 15 |
| Dike Extension | 18.1 | RDB | 165 | 15 |
| Dike Extension | 17.8 | RDB | 230 | 15 |

**Results:** *Bathymetry (Plate 28)*

| Reduced Dredging | Positive Impact or No Change in Environmental Areas | Additional Comments |
|---|---|---|
| No | Yes | The chevron placed at RM 19.4R created a deeper crossing to the LDB. The dike extensions at RM 18.1 and RM 17.8 were used to help keep the crossing aligned near the LDB. The goal was to align the thalweg along the LDB to create a different approach into the weir field, which in turn, would create a deeper channel between RM 16.0 and RM 15.0. However, the problem area remained unchanged. |

***Alternative 13:***

| Type of Structure | River Mile | LDB or RDB | Dimensions (Feet) | Structure Top Elevation (ft in LWRP) |
|---|---|---|---|---|
| Chevron | 19.4 | RDB | 300 x 300 | 15 |
| Chevron | 19.1 | RDB | 300 x 300 | 15 |
| Dike Extension | 17.8 | RDB | 675 | 15 |

**Results:** *Bathymetry (Plate 29)*

| Reduced Dredging | Positive Impact or No Change in Environmental Areas | Additional Comments |
|---|---|---|
| No | Yes | The two chevrons placed at RM 19.4R and RM 19.1R respectively, created a deeper crossing to the LDB. The dike extension at RM 17.8 was used to help keep the crossing aligned near the LDB. The goal was to align the thalweg along the LDB to create a different approach into the weir field, which in turn, would create a deeper channel between RM 16.0 and RM 15.0. This area showed elevations between -15 ft and -20 ft LWRP along the LDB. |

***Alternative 14:***

| Type of Structure | River Mile | LDB or RDB | Dimensions (Feet) | Structure Top Elevation (ft in LWRP) |
|---|---|---|---|---|
| Chevron | 19.4 | RDB | 300 x 300 | 15 |
| Chevron | 19.1 | RDB | 300 x 300 | 15 |
| Chevron | 18.7 | RDB | 300 x 300 | 15 |
| Dike Extension | 17.8 | RDB | 675 | 15 |

**Results:** *Bathymetry (Plate 30)*

| Reduced Dredging | Positive Impact or No Change in Environmental Areas | Additional Comments |
|---|---|---|
| No | Yes | The three chevrons placed at RM 19.4R, RM 19.1R, and RM 18.7R respectively, created a deeper crossing to the LDB. The dike extension at RM 17.8 was used to help keep the crossing aligned near the LDB. The goal was to align the thalweg along the LDB to create a different approach into the weir field, which in turn, would create a deeper channel between RM 16.0 and RM 15.0. This area showed elevations between -15 ft and -20 ft LWRP along the LDB. |

***Alternative 15:***

| Type of Structure | River Mile | LDB or RDB | Dimensions (Feet) | Structure Top Elevation (ft in LWRP) |
|---|---|---|---|---|
| Dike Extension | 19.3 | RDB | 450 | 15 |

**Results:** *Bathymetry (Plate 31)*

| Reduced Dredging | Positive Impact or No Change in Environmental Areas | Additional Comments |
|---|---|---|
| No | Yes | This alternative was used to test a dike extension instead of a chevron as in Alternative 12 (Plate 28) to create a different alignment into the weir field at RM 17.0. There was no significant change in bathymetry. |

***Alternative 16:***

| Type of Structure | River Mile | LDB or RDB | Dimensions (Feet) | Structure Top Elevation (ft in LWRP) |
|---|---|---|---|---|
| Dike Extension | 19.3 | RDB | 450 | 15 |
| Dike Extension | 19.0 | RDB | 350 | 15 |

**Results:** *Bathymetry (Plate 32)*

| Reduced Dredging | Positive Impact or No Change in Environmental Areas | Additional Comments |
|---|---|---|
| No | Yes | This alternative was used to test two dike extensions instead of chevrons as in Alternative 13 (Plate 29) to create a different alignment into the weir field at RM 17.0. There was no significant change in bathymetry. |

***<u>Alternative 17:</u>***

| Type of Structure | River Mile | LDB or RDB | Dimensions (Feet) | Structure Top Elevation (ft in LWRP) |
|---|---|---|---|---|
| Chevron | 19.4 | RDB | 300 x 300 | 15 |
| Chevron | 19.1 | RDB | 300 x 300 | 15 |
| Chevron | 18.7 | RDB | 300 x 300 | 15 |
| Dike Extension | 18.1 | RDB | 650 | 15 |
| Dike Extension | 17.8 | RDB | 675 | 15 |
| Chevron | 16.3 | RDB | 300 x 300 | 15 |
| Chevron | 15.8 | RDB | 300 x 300 | 15 |

**Results:** *Bathymetry (Plate 33)*

| Reduced Dredging | Positive Impact or No Change in Environmental Areas | Additional Comments |
|---|---|---|
| No | Yes | The three chevrons placed at RM 19.4R, RM 19.1R, and RM 18.7R respectively, created a deeper crossing to the LDB. The dike extension at RM 17.8 was used to help keep the crossing aligned near the LDB. The chevrons at RM 16.3 and 15.8 were used to constrict the channel. The goal was to align the thalweg along the LDB to create a different approach into the weir field, which in turn, would create a deeper channel between RM 16.0 and RM 15.0. This area showed elevations between -15 ft and -20 ft LWRP along the LDB. There was point bar formation at RM 15.0, which had elevations between -5 ft and -10 ft LWRP, that constricted the navigation channel to 430 ft. |

***Alternative 18:***

| Type of Structure | River Mile | LDB or RDB | Dimensions (Feet) | Structure Top Elevation (ft in LWRP) |
|---|---|---|---|---|
| Chevron | 19.4 | RDB | 300 x 300 | 15 |
| Chevron | 19.1 | RDB | 300 x 300 | 15 |
| Chevron | 18.7 | RDB | 300 x 300 | 15 |
| Trail Dike | 16.7 | RDB | 1,750 | 15 |
| Dike | 16.5 | LDB | 275 | 15 |
| Rootless Dike Extension | 16.0 | RDB | 300 | 15 |
| Dike | 15.9 | LDB | 240 | 15 |
| Dike Extension | 15.5 | RDB | 150 | 15 |
| Dike | 15.5 | LDB | 270 | 15 |

**Results:** *Bathymetry (Plate 34)*

| Reduced Dredging | Positive Impact or No Change in Environmental Areas | Additional Comments |
|---|---|---|
| No | Yes | The three chevrons placed at RM 19.4R, RM 19.1R, and RM 18.7R respectively, created a deeper crossing to the LDB. The goal was to align the thalweg along the LDB to create a different approach into the weir field, which in turn, would create a deeper channel between RM 16.0 and RM 15.0. The dike structures placed between RM 17.0 and RM 15.0 constricted the channel, while slightly shifting the navigation channel away from the LDB. This alternative had a negative effect on the bathymetry between RM 16.0 and 15.0. |

***Alternative 19:***

| Type of Structure | River Mile | LDB or RDB | Dimensions (Feet) | Structure Top Elevation (ft in LWRP) |
|---|---|---|---|---|
| Chevron | 19.4 | RDB | 300 x 300 | 15 |
| Chevron | 19.1 | RDB | 300 x 300 | 15 |
| Chevron | 18.7 | RDB | 300 x 300 | 15 |
| Dike Extension | 17.8 | RDB | 430 | 15 |
| Trail Dike | 16.7 | RDB | 1,750 | 15 |
| Rootless Dike Extension | 16.0 | RDB | 300 | 15 |
| Dike | 15.9 | LDB | 260 | 15 |
| Dike | 15.5 | LDB | 275 | 15 |

**Results:** *Bathymetry (Plate 35)*

| Reduced Dredging | Positive Impact or No Change in Environmental Areas | Additional Comments |
|---|---|---|
| No | Yes | The three chevrons placed at RM 19.4R, RM 19.1R, and RM 18.7R respectively, created a deeper crossing to the LDB. The goal was to align the thalweg along the LDB to create a different approach into the weir field, which in turn, would create a deeper channel between RM 16.0 and RM 15.0. The dike structures placed between RM 17.0 and RM 15.0 constricted the channel, while slightly shifting the navigation channel away from the LDB. This alternative had a negative effect on the bathymetry. |

***Alternative 20:***

| Type of Structure | River Mile | LDB or RDB | Dimensions (Feet) | Structure Top Elevation (ft in LWRP) |
|---|---|---|---|---|
| Chevron | 19.4 | RDB | 300 x 300 | 15 |
| Chevron | 19.1 | RDB | 300 x 300 | 15 |
| Chevron | 18.7 | RDB | 300 x 300 | 15 |
| Non-Erodable | 17.3 – 16.7 | LDB | 550 | -15 |

**Results:** *Bathymetry (Plate 36)*

| Reduced Dredging | Positive Impact or No Change in Environmental Areas | Additional Comments |
|---|---|---|
| No | Yes | The three chevrons placed at RM 19.4R, RM 19.1R, and RM 18.7R respectively, created a deeper crossing to the LDB. The goal was to align the thalweg along the LDB to create a different approach into the weir field, which in turn, would create a deeper channel between RM 16.0 and RM 15.0. In addition, non-erodable material was placed over the weir field to an elevation of -15 ft LWRP. However, there was no significant change in bathymetry downstream of the weir field. |

***Alternative 21:***

| Type of Structure | River Mile | LDB or RDB | Dimensions (Feet) | Structure Top Elevation (ft in LWRP) |
|---|---|---|---|---|
| Chevron | 19.4 | RDB | 300 x 300 | 15 |
| Chevron | 19.1 | RDB | 300 x 300 | 15 |
| Chevron | 18.7 | RDB | 300 x 300 | 15 |
| Trail Dike | 16.7 | RDB | 1,750 | 15 |
| Dike | 16.1 | LDB | 340 | 15 |
| Dike | 16.0 | RDB | 300 | 15 |
| Dike | 15.9 | LDB | 270 | 15 |
| Dike | 15.8 | RDB | 650 | 15 |
| Dike | 15.7 | LDB | 320 | 15 |
| Dike | 15.7 | RDB | 735 | 15 |
| Dike | 15.5 | LDB | 280 | 15 |
| Dike Extension | 15.5 | RDB | 340 | 15 |
| Dike | 15.3 | LDB | 215 | 15 |
| Dike | 15.3 | RDB | 675 | 15 |

**Results:** *Bathymetry (Plate 37)*

| Reduced Dredging | Positive Impact or No Change in Environmental Areas | Additional Comments |
|---|---|---|
| No | Yes | The three chevrons placed at RM 19.4R, RM 19.1R, and RM 18.7R respectively, created a deeper crossing to the LDB. The goal was to align the thalweg along the LDB to create a different approach into the weir field, which in turn, would create a deeper channel between RM 16.0 and RM 15.0. The dike structures placed between RM 17.0 and RM 15.0 constricted the channel, while slightly shifting the navigation channel away from the LDB. This alternative did not have a negative effect on the bathymetry between RM 16.0 and 15.0. Instead, the thalweg was shifted more to the middle of the channel in the problem location, but had similar depths that were seen in the base test. |

***Alternative 22:***

| Type of Structure | River Mile | LDB or RDB | Dimensions (Feet) | Structure Top Elevation (ft in LWRP) |
|---|---|---|---|---|
| Curvilinear Dike | 18.0 – 16.5 | LDB | 8,750 | 15 |
| Chevron | 15.8 | RDB | 300 x 300 | 15 |
| Chevron | 15.6 | RDB | 300 x 300 | 15 |

**Results:** *Bathymetry (Plate 38)*

| Reduced Dredging | Positive Impact or No Change in Environmental Areas | Additional Comments |
|---|---|---|
| No | Yes | The large curvilinear dike in this alternative was used to see how changing the bankline through the weir field would affect the bathymetry between RM 16.0 and RM 15.0. In addition, the two chevrons at RM 15.8 and 15.6 were used to constrict the channel. The point bar at RM 17.0 was reduced, but the bathymetry between RM 16.0 and 15.0 showed no significant change. |

***Alternative 23:***

| Type of Structure | River Mile | LDB or RDB | Area Dimensions (Square Feet) | Structure Top Elevation (ft in LWRP) |
|---|---|---|---|---|
| Removal of Bankline | 18.6 – 17.6 | RDB | 1,600,000 | To grade |

**Results:** *Bathymetry (Plate 39)*

| Reduced Dredging | Positive Impact or No Change in Environmental Areas | Additional Comments |
|---|---|---|
| No | Yes | The bathymetry at RM 19.0 to RM 18.0 showed higher elevations. This was most likely due to the fact that the channel was widened, so the existing dikes were no longer having as much of an effect. |

# CONCLUSIONS

## 1. Evaluation and Summary of the Model Tests

| Alternatives | Reduced Dredging | Positive Impact or No Change in Environmental Areas | Positive Overall Impact on Study Reach |
|---|---|---|---|
| Alternative 1 | No | Yes | No |
| Alternative 2 | No | Yes | No |
| Alternative 3 | No | Yes | No |
| Alternative 4 | No | Yes | No |
| Alternative 5 | No | Yes | No |
| Alternative 6 | No | Yes | No |
| Alternative 7 | No | Yes | No |
| Alternative 8 | No | Yes | No |
| Alternative 9 | No | Yes | No |
| Alternative 10 | No | Yes | No |
| Alternative 11 | No | Yes | No |
| Alternative 12 | No | Yes | No |
| Alternative 13 | No | Yes | No |
| Alternative 14 | No | Yes | No |
| Alternative 15 | No | Yes | No |
| Alternative 16 | No | Yes | No |
| Alternative 17 | No | Yes | No |
| Alternative 18 | No | Yes | No |
| Alternative 19 | No | Yes | No |
| Alternative 20 | No | Yes | No |
| Alternative 21 | No | Yes | No |
| Alternative 22 | No | Yes | No |
| Alternative 23 | No | Yes | No |

## 2. Recommendations

After reviewing the model results and using engineering judgment, no alternative was recommended for this model study. An internal review of the Grand Lake Towhead HSR model study at the Applied River Engineering Center determined that thorough testing of alternatives was completed, but no alternative showed significant change to warrant the cost of construction. Even major, costly alternatives such as dramatically changing the outside curvature of the bend or excavating the inside bank showed no positive improvement to the navigation channel between RM 16.0 to RM 15.0. In addition, working sessions were conducted with experienced river engineers by examining additional measures that are not documented in this report. It was concluded that the uniqueness of the hydraulic sediment transport response occurring in the reach between RM 18.0 and 13.0, made a viable, economic solution problematic. As a result, the preferred recommendation is to continue periodic dredging throughout the Grand Lake Towhead reach.

## 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 White 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

## A. Report Plates

1. Location and Vicinity Map
2. Dredging Locations – 1:35,000
3. 2007 Aerial Photograph – 1:35,000
4. Geomorphology (1817 – 2003)
5. 1928 Aerial Photograph – 1:35,000
6. 1942 Planform Map – 1:35,000
7. 1956 Planform Map – 1:35,000
8. 1977 Aerial Photographs – 1:35,000
9. 1983 Aerial Photographs – 1:35,000
10. 1987 Aerial Photographs – 1:35,000
11. 2000 Hydrographic Survey – 1:35,000
12. 2005 Hydrographic Survey – 1:35,000
13. 2007 Hydrographic Survey – 1:35,000
14. 2010 Hydrographic Survey – 1:35,000
15. Replication Test – 1:35,000
16. Fiscal Year 2011 Construction – 1:15,000
17. Alternative 1 – 1:35,000
18. Alternative 2 – 1:35,000
19. Alternative 3 – 1:35,000
20. Alternative 4 – 1:35,000
21. Alternative 5 – 1:35,000
22. Alternative 6 – 1:35,000
23. Alternative 7 – 1:35,000
24. Alternative 8 – 1:35,000
25. Alternative 9 – 1:35,000
26. Alternative 10 – 1:35,000
27. Alternative 11 – 1:35,000
28. Alternative 12 – 1:35,000
29. Alternative 13 – 1:35,000
30. Alternative 14 – 1:35,000

31. Alternative 15 – 1:35,000
32. Alternative 16 – 1:35,000
33. Alternative 17 – 1:35,000
34. Alternative 18 – 1:35,000
35. Alternative 19 – 1:35,000
36. Alternative 20 – 1:35,000
37. Alternative 21 – 1:35,000
38. Alternative 22 – 1:35,000
39. Alternative 23 – 1:35,000

# Appendix B:  Grand Lake Towhead Site Visit

Date: August 2, 2011

| GAGE SITE | RM | GAGE ZERO (ELEV) | FLOOD LEVEL (FT ABOVE LWRP) | LWRP (ELEV) | GAGE (FT ABOVE LWRP) ON 08/02/11 @ 12 PM |
|---|---|---|---|---|---|
| Thebes | 43.7 | 300.0 | 33.0 | 304.8 | 29.5 |
| Price Landing | 28.2 | 299.8 | 24.0 | 293.1 | 20.5 |
| Birds Point | 2.0 | 274.5 | 38.0 | 277.9 | 25.3 |

**1 –** Looking upstream at the exit of Sister Chute, which enters the main channel of the Mississippi River along the RDB at RM 12.0.

**2 –** Hand-placed revetment along the RDB just downstream of the Sister Chute exit.

**3 –** Confluence of the Cache and Mississippi Rivers. The Cache River enters the Mississippi River along the LDB at RM 13.0.

**4 –** Top of revetment along the LDB just downstream of Dike No. 13.1L.

**5 –** Main channel side of Islands No. 29 (left) and 29 (right), which are along the RDB. Between the two islands (center of picture) is a secondary entrance (RM 13.5) to Sister Chute.

**6 –** Surface effects from Dike No. 13.6L.

**7 –** Entrance to Sister Chute located along the RDB at RM 14.4.

**8 –** Small vegetated island located between Dikes 14.7R and 14.9R.

**9 –** Tow navigating downstream at RM 16.0

**10 –** Tow navigating upstream at RM 21.5.

**11 –** Surface effects from Chevron No. 21.8L.

**12 –** Looking upstream at Browns Bar, which is located along the LDB between RM 24.0 and 22.7.

**13 –** Looking downstream at Browns Chute. The entrance to Browns Chute begins at approximately RM 24.5.

## Appendix C: 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 D: 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 2005 and 2010 river surveys. From these cross sections, the cross-sectional areas and percent differences were calculated. 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 ft. 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 rejected.

The initial comparison was between the replicated model scan and the 2005 bathymetry. The cross sections were generated with a vertical distortion of 15 ft horizontal for 1 ft 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 2. The average percent difference between the cross-sectional areas, model to prototype, was 16.3%, with a low of 1.1% and a high of 47.66%.

Cross sections were generated in the same manner comparing the 2005 and 2010 bathymetries to get a measure of the natural variation of the channel. The average percent difference was 14.0%; the lowest percent difference was 0.1% and the highest was 32.8%. The natural variation of the channel compared well with the average percent difference of 16.3% between the model and the prototype.

**Table 2: Cross Section Comparison Model Replication Scan and 2005 Bathymetry**

| Cross Section Station | Area Without Correction | | Corrected Area | | Percent Difference |
|---|---|---|---|---|---|
| | Model Replication ($ft^2$) | 2005 Survey ($ft^2$) | True Model Replication ($ft^2$) | True 2005 Survey ($ft^2$) | |
| 360+00 | 583775 | 542851 | 38918 | 36190 | 7.3% |
| 380+00 | 571380 | 549400 | 38092 | 36627 | 3.9% |
| 400+00 | 585219 | 527596 | 39015 | 35173 | 10.4% |
| 420+00 | 692454 | 555251 | 46164 | 37017 | 22.0% |
| 440+00 | 656025 | 459881 | 43735 | 30659 | 35.2% |
| 460+00 | 677924 | 688442 | 45195 | 45896 | 1.5% |
| 480+00 | 591927 | 598573 | 39462 | 39905 | 1.1% |
| 500+00 | 615466 | 540406 | 41031 | 36027 | 13.0% |
| 520+00 | 689243 | 735408 | 45950 | 49027 | 6.5% |
| 540+00 | 710178 | 566268 | 47345 | 37751 | 22.5% |
| 560+00 | 721400 | 572130 | 48093 | 38142 | 23.1% |
| 580+00 | 623804 | 464690 | 41587 | 30979 | 29.2% |
| 600+00 | 767939 | 472354 | 51196 | 31490 | 47.7% |
| 620+00 | 740523 | 467581 | 49368 | 31172 | 45.2% |
| 640+00 | 663813 | 577919 | 44254 | 38528 | 13.8% |
| 660+00 | 506956 | 577095 | 33797 | 38473 | 12.9% |
| 680+00 | 540398 | 546936 | 36027 | 36462 | 1.2% |
| 700+00 | 438284 | 534980 | 29219 | 35665 | 19.9% |
| 720+00 | 418410 | 588339 | 27894 | 39223 | 33.8% |
| 740+00 | 355032 | 498703 | 23669 | 33247 | 33.7% |
| 760+00 | 424772 | 446813 | 28318 | 29788 | 5.1% |
| 780+00 | 502929 | 557787 | 33529 | 37186 | 10.3% |
| 800+00 | 667952 | 577840 | 44530 | 38523 | 14.5% |
| 820+00 | 544067 | 530978 | 36271 | 35399 | 2.4% |
| 840+00 | 506738 | 449590 | 33783 | 29973 | 12.0% |
| 860+00 | 538292 | 462478 | 35886 | 30832 | 15.2% |
| 880+00 | 558135 | 603630 | 37209 | 40242 | 7.8% |
| 900+00 | 602171 | 631919 | 40145 | 42128 | 4.8% |
| Total | 16495206 | 15325838 | 1099680 | 1021723 | |
| | | | | Average | 16.3% |

**Table 3: Cross Section Comparison Between 2005 Bathymetry and 2010 Bathymetry**

| Cross Section Station | Area Without Correction | | Corrected Area | | Percent Difference |
|---|---|---|---|---|---|
| | 2005 Survey ($ft^2$) | 2010 Survey ($ft^2$) | True 2005 Survey ($ft^2$) | True 2010 Survey ($ft^2$) | |
| 360+00 | 542851 | 592525 | 36190 | 39502 | 8.8% |
| 380+00 | 549400 | 605655 | 36627 | 40377 | 9.7% |
| 400+00 | 527596 | 591091 | 35173 | 39406 | 11.4% |
| 420+00 | 555251 | 595767 | 37017 | 39718 | 7.0% |
| 440+00 | 459881 | 472375 | 30659 | 31492 | 2.7% |
| 460+00 | 688442 | 621649 | 45896 | 41443 | 10.2% |
| 480+00 | 598573 | 678579 | 39905 | 45239 | 12.5% |
| 500+00 | 540406 | 645019 | 36027 | 43001 | 17.6% |
| 520+00 | 735408 | 687255 | 49027 | 45817 | 6.8% |
| 540+00 | 566268 | 593690 | 37751 | 39579 | 4.7% |
| 560+00 | 572130 | 572632 | 38142 | 38175 | 0.1% |
| 580+00 | 464690 | 474855 | 30979 | 31657 | 2.2% |
| 600+00 | 472354 | 504952 | 31490 | 33663 | 6.7% |
| 620+00 | 467581 | 613863 | 31172 | 40924 | 27.1% |
| 640+00 | 577919 | 620488 | 38528 | 41366 | 7.1% |
| 660+00 | 577095 | 723131 | 38473 | 48209 | 22.5% |
| 680+00 | 546936 | 703445 | 36462 | 46896 | 25.0% |
| 700+00 | 534980 | 685349 | 35665 | 45690 | 24.6% |
| 720+00 | 588339 | 818831 | 39223 | 54589 | 32.8% |
| 740+00 | 498703 | 641908 | 33247 | 42794 | 25.1% |
| 760+00 | 446813 | 544508 | 29788 | 36301 | 19.7% |
| 780+00 | 557787 | 646695 | 37186 | 43113 | 14.8% |
| 800+00 | 577840 | 684318 | 38523 | 45621 | 16.9% |
| 820+00 | 530978 | 600017 | 35399 | 40001 | 12.2% |
| 840+00 | 449590 | 533723 | 29973 | 35582 | 17.1% |
| 860+00 | 462478 | 568976 | 30832 | 37932 | 20.7% |
| 880+00 | 603630 | 681277 | 40242 | 45418 | 12.1% |
| 900+00 | 631919 | 720000 | 42128 | 48000 | 13.0% |
| Total | 15325838 | 17422573 | 1021723 | 1161505 | |
| | | | | Average | 14.0% |