Technical Report M 68

UPPER BROWN'S BAR HSR MODEL
MISSISSIPPI RIVER MILES 29.00 – 20.00
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 response in the Upper Browns Bar reach of the Mississippi River between River Miles (RM) 29.00 and 20.00 near Dogtooth Bend, located in Scott and Mississippi County in Missouri and Alexander County in Southern Illinois. This study was funded by the U.S. Army Corps of Engineers, St. Louis District's Regulating Works Project for the Middle Mississippi River. 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 repetitive channel maintenance dredging from RM 25.00 to RM 23.50.

The study was conducted between January, 2013 and August, 2014 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 Ivan H Nguyen, 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.	Chief of Hydrologic and Hydraulic Branch	St. Louis District
Ashley Cox	Hydraulic Engineer	St. Louis District
Bradley Krischel	Hydraulic Engineer	St. Louis District
James Wallace	Hydraulic Design	St. Louis District
Jasen Brown, P.E.	Hydraulic Engineer	St. Louis District
Edward Brauer, P.E.	Hydraulic Engineer	St. Louis District
Jason Floyd	Engineering Technician	St. Louis District
Adam Rockwell	Cartographic Technician	St. Louis District
Shawn Kempshall	River Surveyor	St. Louis District
Lance Engle	Dredge Project Manager	St. Louis District
Brian Johnson	Chief of Environmental Planning Section	St. Louis District
David Gordon, P.E.	Chief of Hydraulic Design	St. Louis District
Mike Rodgers, P.E.	Project Manager	St. Louis District
Dawn Lamm	Hydraulic Design	St. Louis District
Peter Russell, P.E.	Hydraulic Design	St. Louis District
Steele Beller	Realty Specialist	St. Louis District
Atwood Butch	Mississippi River Fishery Biologist	Illinois Department of Natural Resource (IDNR)
Matthew Mangan	Biologist	U.S. Fish and Wildlife (FWS)
Donovan Henry	Biologist	U.S. Fish and Wildlife (FWS)
Bernie Heroff	Port Captain	ARTCO
Ed Henleben	Senior Operations Manager	River Industry Action Committee (RIAC)
Dave Ostendorf	Fishery Biologists	Missouri Department of Conservation (MDC)

Mark Boone	Program Advisor	Missouri Department of Conservation (MDC)
Dave Knuth	Fisheries Management Biologist	Missouri Department of Conservation (MDC)
Ryan Christensen	Waterways Assistant Chief	U.S. Coast Guard
Shannon Hughes	Port Captain	Kirby Inland Marine
Terry Hoover	Safety Manager	Ingram Barge Company
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BACKGROUND

1. Problem Description

The minimum standards for ensuring the safe passage of all commercial vessels on the Middle Mississippi River are a 9 feet deep and 300 feet wide navigation channel, with additional width in bends as required. It is the responsibility of the U.S. Army Corps of Engineers to maintain these dimensions. From 2006 to 2010, approximately 600,000 cubic yards of material was dredged between RM 25.00 and RM 23.75 at a cost of $1.4M. To maintain the navigation channel in this reach, dredging has been required for adequate depth and width. Any reduction in dredging at this location while maintaining the navigation channel will increase the efficiency of waterways transportation.

A. Dredging

Dredging has occurred nearly every year between RM 25.00 and RM 23.75 (See Plate 2). During that time frame an average of 114,000 cubic yards was dredged near RM 24.50 at a cost of $275,000. See Figure 1 below for dredge material removed near RM 24.50.

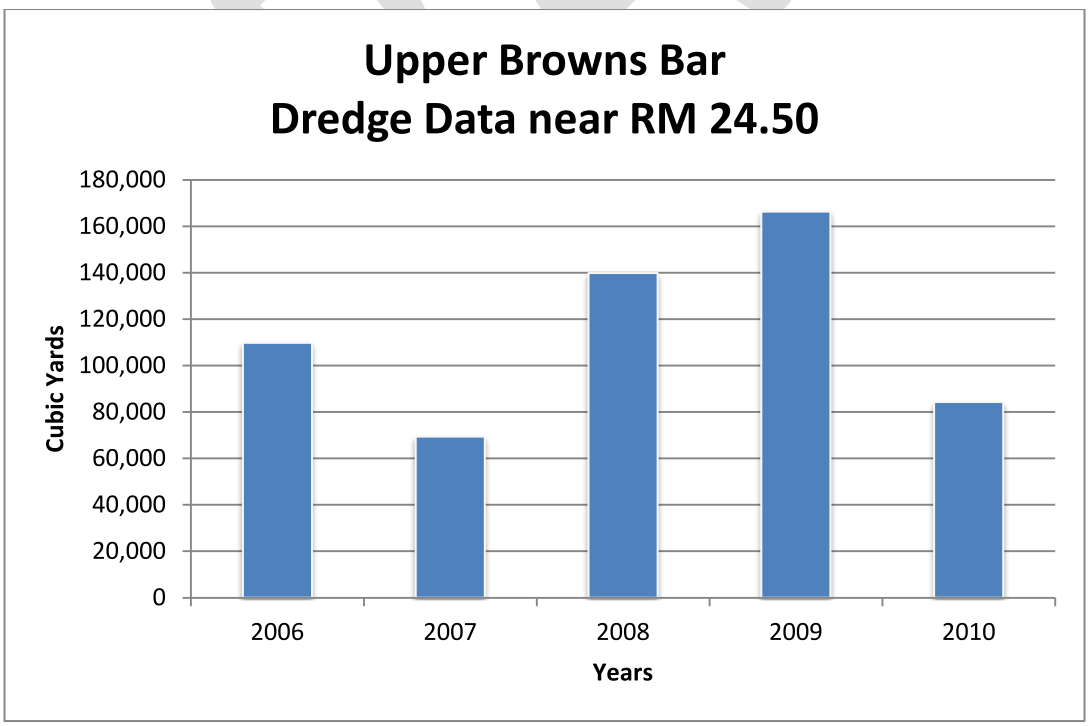

Figure 1: Dredge Data near RM 24.50

B. Existing Flow Mechanics

The Upper Browns Bar reach has a sharp 180 degree bend with shallow crossings in the channel, scour on the outside of the bend, and two shallow side channels. The main channel depths range from -10 feet to -50 feet LWRP. There are two closure structures in Brown's Chute with significant scour holes located just downstream. Figure 2 is a generalized schematic of the existing flow mechanics in the study reach.

Figure 2: Existing Flow Mechanics

Based on aerial photography and flow data analysis at Upper Brown's Bar, it was determined that Dike 24.50L was the controlling structure that diverts and maintains flow to the side channel. See Figure 3 for more details. Therefore, Dike 24.50L should not be modified, along with four other dikes upstream (Dike 25.00L, 25.20L, 25.30L, and 25.40L) because they may disrupt flow in this area. Figure 4 shows the area to avoid when making structural changes in order to maintain the current side channel conditions.

Figure 3: Looking Downstream at Upper Browns Chute (Side Channel Flow Patterns)

Figure 4: Area to avoid in order to maintaining current side channel conditions (2012 Aerial Photograph)

2. **Study Purpose and Goals**

The purpose of the Upper Brown's Bar model study was to perform a comprehensive analysis of river engineering measures that would reduce or eliminate repetitive dredging between River Miles 25.00 to 23.75 and produce a report that communicates the results of the HSR model study.

The goals of this study were to:

i. Investigate and provide analysis on the existing flow mechanics causing the sedimentation 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 sedimentation from RM 25.00 to RM 23.50. In order to determine the best alternative, 3 criteria were used to evaluate each alternative.
    a. The alternative should reduce or eliminate sedimentation between RM 25.00 and RM 23.50.
    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 significantly impact existing environmental features within the reach.
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 9 mile stretch of the Mississippi River, between RM 29.00 and RM 20.00 near Dogtooth Island which passes through Scott and Mississippi County in Missouri and Alexander County in Southern Illinois. Plate 1 is a location and vicinity map of the study reach. Discussed below are a variety of features found within the reach.

Plate 2 is a 2012 aerial photograph illustrating the planform and nomenclature of the Middle Mississippi River between RM 29.00 and RM 20.00. A majority of the property on both sides of the Mississippi River is used for agriculture. The Len Small Levee system is located on the left descending bank (LDB) side of the river.

The Thompson Bend Riparian Corridor Project is located in this reach along the right descending bank (RDB). During the 1993 flood the river tried to cut off approximately 16 miles of river near RM 21.80, but as a result of the tree screens placed in 1986, the river was unsuccessful and stayed within its existing planform. After the flood the bankline was built back up with revetment, two baffles were constructed on the floodplain in the area where the river had scoured and removed sediment, and the Corps worked with the private landowners to acquire perpetual easements to go back in and plant tree screens. Even though this was a huge project and required immense amounts of coordination, costs for this project were much less than those which would occur if a channel cut-off had developed.

There were a total of 50 river training structures as well as revetment within the study reach. See Table 2 for the river training structures' history and existing conditions. Revetment was in place on a majority of the RDB from RM 29.00 to 19.60. Part of Buffalo Island, as well as a majority of the LDB throughout the study reach was revetted.

Table 2: Study Reach River Structure History

River Training Structure	Length (feet)	Description
Dike 28.00L	420	Constructed prior to June 1958 hydrographic survey. Repaired October 1978. (Photograph 1, Plate 3)
Dike 27.60R	300	Constructed in 1942 and repaired in 1946. (Photograph 2, Plate 3)
Dike 27.50L	550	Constructed in 1928 and repaired in 1946. Extended October 1979. (Photograph 3, Plate 3)

Dike 27.30R	270	Constructed in 1933 and extended in 1938. Repaired in 1946. (Photograph 2, Plate 3)
Dike 27.20L	370	Constructed August 1979. (Photograph 4, Plate 3)
Dike 27.00R	915	Constructed in 1933 and extended in 1938. Repaired in 1946 and April 1989. (Photograph 1, Plate 4)
Dike 26.90R	1,320	Constructed in 1933. Extended in 1938 and again in October 1979. (Photograph 2, Plate 4)
Dike 26.80L	250	Constructed October 1979. (Photograph 3, Plate 4)
Dike 26.70R	2,400	Pile dike constructed in 1933. Extended in 1938 and October 1979. (Photograph 4, Plate 4)
Dike 26.40R	630	Constructed in 1933. Extended in 1938 and June 1979. (Photograph 1, Plate 5)
Dike 26.10R	1,280	Constructed in 1945. Repaired in October 1979 and extended April 1989. (Photograph 2, Plate 5)
Dike 25.50R	500	Constructed prior to September 1970 hydrographic survey and extended prior to the June 1983 hydrographic survey. Repaired in 1989.
Dike 25.40L	170	Constructed in 1939. (Photograph 4, Plate 5)
Dike 25.30L	350	Constructed in 1939. (Photograph 1, Plate 6)
Dike 25.30R	220	Constructed July 1979. (Photograph 2, Plate 6)
Dike 25.20L	380	Constructed in 1939. (Photograph 3, Plate 6)
Dike 25.00L	670	Constructed in 1939. Repaired May 1988. (Photograph 4, Plate 6)
Dike 24.90L	1,250	Constructed in 1932 and repaired in November 1979. Extended March 1989. (Photograph 1, Plate 7)
Dike 24.80R	920	Constructed prior to March 1977 hydrographic survey. Extended in August 1979 and April 1989. (Photograph 2 - 4, Plate 7)
Dike 24.70R	310	Constructed prior to September 1970 hydrographic survey. (Photograph 1, Plate 8)

Dike 24.60R	110	Constructed prior to 1942 hydrographic survey and extended August 1979.
Dike 24.50L	1,840	Constructed in 1929. Extended in 1933, 1939 and November 1979. (Photograph 2, Plate 8)
Dike 24.40L	1,270	Constructed prior to the April 1983 hydrographic survey. Extended July 1979. (Photograph 3, Plate 8)
Dike 24.30L	2,190	Constructed in 1934 and extended in 1939. (Photograph 4, Plate 8)
Weir 24.29R	920	Constructed in April 1990.
Weir 23.90R	530	Constructed in April 1990.
Dike 24.20L	950	Constructed October 1979. (Photograph 4, Plate 9)
Dike 23.80L	2,750	Constructed in 1929. Extended in 1931 and 1932. (Photograph 1 - 3, Plate 9)
Weir 23.70R	535	Constructed November 1990.
Weir 23.50R	1,070	Constructed December 1990.
Weir 23.40R	1,000	Constructed December 1990.
Weir 23.30R	770	Constructed November 1990.
Weir 23.20R	920	Constructed December 1990.
Weir 23.10R	815	Constructed November 1990.
Weir 23.00R	820	Constructed December 1991.
Weir 22.90R	890	Constructed December 1990.
Weir 22.80R	900	Constructed November 1990.
Weir 22.70R	900	Constructed December 1990.
Weir 22.45R	600	Constructed November 1990.
Dike 23.30R	450	Constructed in 1940 and repaired in October 1979.
Dike 22.30L	150	Constructed prior to 1942 hydrographic survey and repaired in May 1985. (Photograph 1 - 4, Plate 10)
Dike 22.20L	1,290	Dike constructed in 1932. (Photograph 1, Plate 11)
Dike 22.10L	380	Constructed April 2011. (Photograph 2, Plate 11)
Dike 21.90L	1,000	Constructed in 1933 and repaired in March 2001.

		(Photograph 1 - 4, Plate 12)
Chevron 21.80L	770	Constructed April 2011. (Photograph 3 & 4, Plate 11)
Dike 21.70R	480	Constructed 1997.
Dike 21.40L	340	Constructed March 2011. (Photograph 1, Plate 13)
Dike 21.10L	520	Constructed October 1979 and repaired June 2005. (Photograph 2, Plate 13)
Dike 20.50L	1,000	Constructed prior to 1942 hydrographic survey and extended in October 1979. (Photograph 3, Plate 13)

A. Geomorphology

To understand the planform of the river near Upper Brown's Bar, an investigation was conducted on the historical changes, both natural and manmade, that lead up to the present day condition. Plate 14 shows geomorphic planform changes from RM 29.00 to RM 20.00, encompassing the years between 1817 and 2011. Based on this planform comparison, the present position of Browns Bar developed sometime between 1908 and 1928.

From 1817 to 1881, the LDB of the river near RM 26.00 shifted eastward approximately 2,800 feet in some locations. The channel significantly widened from RM 27.00 to RM 25.00. The river shifted southwards at the bend, and southeast from RM 20.00 to RM 18.00. In 1881 there were nine islands, compared to seven in 1817 (see Plate 15). The Missouri bankline was constant from RM 29.00 to RM 25.00. These changes occurred naturally, predating the use of river training structures in this reach.

The river continued to undergo major changes from 1881 to 1908, shown on Plate 16. The Illinois bankline shifted westward from RM 28.00 to RM 25.00, while the Missouri Bankline remained unchanged in that reach. The bend near RM 23.00 to RM 20.00 shifted southward, in some locations nearly 6,000 feet. The changes in the reach drastically reduced the number of islands from nine in 1881 to two in 1908. The channel widened by approximately 2,500 feet between RM 20.00 and 17.00.

From 1908 to 1928 the river continued to transform, as seen on Plate 17. The RDB shifted eastward, cutting off the existing island and side channel. The LDB slightly widened approximately 1,200 feet from RM 27.50 to RM 23.00. The Missouri bankline at the bend gradually moved south and westward approximately 3,000 feet from RM 22.00 to RM 20.50. The Illinois bankline at the bend shifted south and westward approximately 3,000 feet from RM 22.00 to RM 18.50. There were only two islands in 1908 and six islands in 1928. These changes occurred because the side channel along the Missouri bankline, between RM 29.00 and RM 24.00, was closed off thus shifting the bankline eastward.

The river continued to transition from 1928 to 1956, as shown on Plate 18. The Missouri bankline shifted eastward yet again, cutting off another island and side channel from RM 27.00 to RM 23.50. The Illinois bankline shifted westward at the beginning of the study reach from RM 28.50 to RM 26.50. There were six islands in 1928 and there were five islands in 1956. There were approximately 22 river training structures built during this time frame.

From 1956 to 1968, the river experienced small changes to the planform as a result of the previously constructed structures. The Missouri and Illinois banklines remained constant throughout the study reach. There were five islands in 1956 and only two islands in 1968, as seen on Plate 19. This was due to four small islands accreting and consolidating to become Brown's Bar. There was one river training structure constructed during this time.

There were minimal changes to the banklines throughout the study reach from 1968 to 1986, as seen on Plate 20. There were two islands in 1968 and six islands in 1986. This was most likely due to river training structures degrading over time. There were six river training structures constructed during this time.

From 1986 to 2003, there were no major changes to the banklines throughout the study reach, as shown on Plate 21. The RDB near RM 26.50 shifted eastward, cutting off a side channel and island. There were six islands 1986 and six islands in 2003. There were thirteen river training structures constructed during this time frame (all weirs).

There were no significant measurable shifts or transformations of the planform from 2003 to 2011, see Plate 22. There were minor changes to the banklines, due to sporadic round outs behind some downstream angled dikes. Brown's Bar had shifted, as well as increased and decreased in size throughout the years, but in 2011 it consisted of 2 vegetated islands and surrounding sandbars. There were three river training structures constructed between 2003 and 2011. Plate 23-29 show aerial maps from 1928 to 1986 overlayed on top of a 2012 aerial photograph.

A side channel analysis based on historical and recent aerial photographs and hydrographic surveys was lead by Tom Keevin and conducted by Erin Guntren (MVS personnel) in FY 2012. Their analysis looked at the area changes of side channels based on aerial photographs and the volume changes based on cross sections taken from hydrographic surveys. They also determined choke points (the highest elevation controlling water flow or connectivity through a side channel). There was no significant choke point found for Brown's Chute. Based on typical monthly river stages and the choke point, connectivity was determined. During a typical hydrographic year, Brown's Chute is connected year round. Based on cross sections from side channel hydrographic surveys conducted in all seasons since 1956, both area and volume of the chute have fluctuated. The side channel increased in area and volume from 1956 to 1986. From 1986 to 1993 the side channel decreased in area and volume. Again the side channel increased in area and volume from 1993 to 2001. Once again the side channel increased in area and volume from 2001 to 2011. Buffalo Chute has a choke point at +11.9 feet LWRP, which allows the channel to be connected for approximately 9 months out of the year. There is minimal diversity in Buffalo Chute, with only one minor plunge pool located downstream of a closure structure.

B. Channel Characteristics and General Trends

i. Bathymetry

Range line and multi-beam hydrographic surveys of the Mississippi River from 2005 to 2010 within the HSR Model extents, are shown on Plates 30 – 34. Plates 35 – 38 show pre-dredge conditions from 2008 – 2011. (Pre-dredge surveys from prior to 2008 show similar trends, so only the most recent surveys were included in the report.) For this study, all 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
29.00 – 27.00	The thalweg was located along the RDB with depths ranging from -10 feet to -30 feet LWRP. There was a shallow bar along the LDB that encroached out around RM 27.50. The thalweg crossed from the RDB to the LDB at RM 27.00. There was some scour observed off the tips of dikes 27.60R, 27.50L and 27.20L.
27.00 – 24.50	The thalweg remained along the LDB with depths ranging from -15 feet to -40 feet LWRP. A bar developed along the RDB near Buffalo Island. Behind Buffalo Island was a shallow side channel with two closure structures at the downstream end. The depths in the side channel were approximately +10 feet LWRP. Along the LDB was the entrance to Brown's Chute where two scour holes occurred immediately downstream of Dike 24.50L and Dike 24.40L. Dike 24.50L also diverted flow to the side channel.

24.50 – 22.50	The thalweg crossed from the LDB to the RDB near RM 24.60. The thalweg remained along the RDB throughout this reach. There were depths ranging from -15 feet to -50 feet LWRP. Brown’s Chute was large and wide but lacked diversity. There were two significant plunge pools located downstream from each closure structure.
22.50 – 20.00	There was a large shallow bar developed along Brown’s Bar between RM 21.90 and RM 20.50. The thalweg remained along the RDB with depths ranging from -30 feet to -20 feet LWRP. Scour occurred at the tip of Dikes 22.10L and 21.90L.

ii. Site Data

On April 18, 2012 and August 1, 2013, the authors of this report visited the Upper Brown’s Bar reach to examine banklines, structures, and any data that could not otherwise be gathered in the office. On April 18, 2012, the river stage was 20.50 feet LWRP (322.33 feet in elevation) at the Commerce gage. On August 1, 2013, the river stage was 15.0 feet LWRP (315.00 feet in elevation) at the Thebes gage. Pictures from the site visit can be seen on Plates 3 – 13. The following observations were made:

- Dike 20.50L: Fairly good condition, slightly degrade on the RDB side.
- Dike 21.10L: Good condition. Couldn’t identify the side structures
- Chevron 21.80L: Was slightly degraded at the upper of the chevron.
- Dike 21.90L: It had an additional notch not shown in ARCGIS File.
- Dike 22.20L: Logs were on the surface where the dike should have been but couldn’t see the actual structure.
- Dike 22.30L: The structure was slightly degraded on the part of the dike extending from Browns Bar.
- Dike 23.80L: Degraded in the main channel, on top of sandbar.
- Dike 23.80L: The dike had a low spot in the middle of the side channel. In the middle of that low spot, there was a rock pile structure (See Plate 9, Photograph 3). On the sandbar in the main channel, the structure looked good.
- Dike 24.20L: Was slightly degraded in a few locations.

- Dike 24.30L: The structure was seen on the low water aerial, but at the current stage (15.0 feet at Thebes= 315 feet Elev.) it wasn't visible.
- Dike 24.40L: There was about 20 feet of water behind the structure. The trail dike was not visible in the field or on the low water 2012 aerial. There were visible signs on the water surface that suggested a degraded structure was under the water, but the depth finder on the boat read approximately 20 feet of the depth where the structure should have been.
- Dike 24.50L: The trail dike wasn't visible, but the rest of the dike was in good condition. The RDB side of the dike was slightly degraded.
- Dike 24.60LR: The structure was not visible in the field, but was on the low water 2012 aerial photograph.
- Dike 24.70R: Not visible.
- Dike 24.80R: Towards the center of Buffalo Chute, the dike was underwater.
- Dike 24.90L: The dike and trail were in good condition. The trail has a lower elevation than the rest of the structure.

C. Real Estate

The following table shows all the property owners located along both the Illinois and Missouri sides of the study reach.

Table 4: Property Owners along the Illinois and Missouri Banklines

State	River Mile	Owner
Missouri	26.00 - 23.50	Westrich Farms LLC & Pringle Tyronza
	23.50 – 20.00	Hillhouse River Farms LLC
Illinois	32.00 – 28.00	Bumgard Island Land & Timber
	28.00 – 27.50	Lynn Willis
	27.50 – 27.00	Bonnie Sue Willis
	27.00 – 26.50	Lois Foris
	26.50 – 25.50	Mildred Gallagher
	25.50 – 25.25	Jackson Greenway Sams
	25.25 – 25.00	JGF
	25.00 – 24.75	Hunlet Safety Inc.
	24.75 – 24.50	Martha Farms Inc.
	24.50 – 24.00	Carl Wilis & Sons Inc
	24.00 – 20.00	Laurie Coldwell LLC.

HSR MODELING

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. These boundaries were based off of documentation (such as plans and specifications) as well as hydrographic surveys.

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, and 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.

2. Scales and Bed Materials

The model employed a horizontal scale of 1 inch = 800 feet, or 1:9600, and a vertical scale of 1 inch = 60 feet, or 1:720, for a 13.3 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 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 2012 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 polymesh. 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 0.012 inch/inch. River training structures in the model were made of galvanized steel mesh to generate appropriate scaled roughness. A picture of the HSR model can be seen on Plate 38.

4. Flow Control

Flow into the model was regulated by customized computer hardware and software interfaced with an electronic control valve and submersible pump. This interface was used to control the flow of water and sediment into the model. For all model tests, flow entering the model was held steady at 1.16 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 replication for the model and is shown on Plate 39.

Results of the HSR model replication and a comparison to the 2005 through 2013 prototype surveys indicated the following trends:

Table 5: Study Reach and Prototype Bathymetry Trend Comparison

River Miles	Description
29.00 – 27.00	The model and the prototype surveys showed scour occurred off the tips of dikes located along the LDB with depths as low as -20 feet LWRP. The thalweg was located along the RDB with depths

	between -30 feet and -10 feet LWRP. There was a shallow sandbar located along the LDB.
27.00 – 24.50	The thalweg crossed from the RDB to the LDB at RM 27.00. The thalweg remained on the LDB through this stretch with depths ranging from -15 feet to -40 feet LWRP. Scour occurred along the LDB between RM 26.00 and RM 25.20 but was slightly exaggerated in the replication test. A bar developed along the RDB near Buffalo Island. There was a shallow side channel behind Buffalo Island with depths of +10 feet LWRP on both the model and prototype (based on field observations).
24.50 – 22.50	The thalweg crossed from the LDB to the RDB near RM 24.50. The thalweg remained along the RDB throughout this reach. The depths were ranged from -15 feet to -50 feet LWRP and below around the weir field and continued to the end of study reach. Deposition occurred at the crossing in the replication test where the representative dredge box cut was located (near RM 24.50). However, in the prototype survey the crossing's depths were around -10 feet LWRP. The reason for this was because the prototype survey was a post-dredge survey. Two plunge pools were located immediately downstream of two closure structures inside Upper Brown's Chute.

Further detailed calculations on model cross sections were compared directly to the prototype and are shown in Appendix 3. 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 results. The goal was to identify the most effective and economical plan to reduce or eliminate sedimentation from RM 25.00 to 23.50. Evaluation of each alternative was accomplished through a qualitative comparison to the model replication test bathymetry (deposition).

Alternative 1:

Type of Structure	River Mile	LDB / RDB	Dimensions (Feet)	Structure Top Elevation (feet in LWRP)
Dike Extension	24.50	LDB	225	+18.5
Dike Extension	24.30	LDB	280	+18.5
Dike Extension	24.20	LDB	100	+18.5
Dike Extension	23.80	LDB	500	+18.5

Alternative 1 Result: Bathymetry Analysis (Plate 40)

Reduced Deposition at RM 24.50	Eliminate Deposition at RM 24.50	Additional Comments
Yes	No	Degradation occurred at the crossing between RM 24.50 and RM 23.80. There were no significant bathymetry changes to Upper Brown's Bar and Chute.

Alternative 2:

Type of Structure	River Mile	LDB / RDB	Dimensions (Feet)	Structure Top Elevation (feet in LWRP)
Offset Dike Extension	24.50	LDB	225	+18.5
Offset Dike Extension	24.30	LDB	280	+18.5
Offset Dike Extension	24.20	LDB	180	+18.5
Dike Extension	23.80	LDB	500	+18.5

Alternative 2 Result: Bathymetry Analysis (Plate 41)

Reduced Deposition at RM 24.50	Eliminate Deposition at RM 24.50	Additional Comments
Yes	No	Degradation occurred at the crossing between RM 24.60 and RM 23.90. There were no significant bathymetry changes to Upper Brown's Bar and Chute.

Alternative 3:

Type of Structure	River Mile	LDB / RDB	Dimensions (Feet)	Structure Top Elevation (feet in LWRP)
Offset Dike Extension	24.50	LDB	225	+18.5
Offset Dike Extension	24.30	LDB	280	+18.5
Offset Dike Extension	24.20	LDB	200	+18.5
Dike Extension	23.80	LDB	500	+18.5
Dike Extension	25.30	RDB	240	+18.5
Dike Extension	24.80	RDB	240	+18.5
Dike Extension	24.60	RDB	240	+18.5

Alternative 3 Result: Bathymetry Analysis (Plate 42)

Reduced Deposition at RM 24.50	Eliminate Deposition at RM 24.50	Additional Comments
Yes	No	Degradation occurred at the crossing between RM 24.60 and RM 23.90. There were no significant bathymetry changes to Upper Brown's Bar and Chute.

Alternative 4:

Type of Structure	River Mile	LDB / RDB	Dimensions (Feet)	Structure Top Elevation (feet in LWRP)
Offset Dike Extension	24.50	LDB	225	+18.5
Offset Dike Extension	24.30	LDB	280	+18.5
Offset Dike Extension	24.20	LDB	200	+18.5
Dike Extension	23.80	LDB	500	+18.5
Dike Extension	25.30	RDB	240	+18.5
Dike Extension	24.80	RDB	240	+18.5
Dike Extension	24.60	RDB	240	+18.5

Alternative 4 Result: Bathymetry Analysis (Plate 43)

Reduced Deposition at RM 24.50	Eliminate Deposition at RM 24.50	Additional Comments
Yes	No	The channel deepened (from -2 feet to -7 feet LWRP) at the crossing between RM 24.60 and RM 23.80. There were no significant bathymetry changes to Upper Brown's Bar and Chute.

Alternative 5:

Type of Structure	River Mile	LDB / RDB	Dimensions (Feet)	Structure Top Elevation (feet in LWRP)
Dike Extension	24.50	LDB	225	+18.5
Dike Extension	24.30	LDB	280	+18.5
Dike Extension	24.20	LDB	200	+18.5
Dike Extension	23.80	LDB	500	+18.5
Dike Extension	25.30	RDB	240	+18.5
Offset Dike Extension	24.80	RDB	240	+18.5
Dike Extension	24.60	RDB	240	+18.5

Alternative 5 Result: Bathymetry Analysis (Plate 44)

Reduced Deposition at RM 24.50	Eliminate Deposition at RM 24.50	Additional Comments
Yes	No	The channel deepened (from -2 feet to -9 feet LWRP) at the crossing between RM 24.50 and RM 23.80. There were no significant bathymetry changes to Upper Brown's Bar and Chute.

Alternative 6:

Type of Structure	River Mile	LDB / RDB	Dimensions (Feet)	Structure Top Elevation (feet in LWRP)
Weir	25.70	LDB	800	-15.0
Weir	25.60	LDB	900	-15.0
Weir	25.50	LDB	900	-15.0
Weir	25.40	LDB	1000	-15.0
Weir	25.30	LDB	1050	-15.0
Dike Extension	24.30	LDB	280	+18.5
Dike Extension	25.30	RDB	300	+18.5
Dike Extension	24.80	RDB	250	+18.5
Dike Extension	24.60	RDB	150	+18.5

Alternative 6 Result: Bathymetry Analysis (Plate 45)

Reduced Deposition at RM 24.50	Eliminate Deposition at RM 24.50	Additional Comments
No	No	The depositional area at the crossing remained the same. There were no significant bathymetry changes to Upper Brown's Bar and Chute.

Alternative 7:

Type of Structure	River Mile	LDB / RDB	Dimensions (Feet)	Structure Top Elevation (feet in LWRP)
Weir	25.80	LDB	800	-15.0
Weir	25.70	LDB	800	-15.0
Weir	25.60	LDB	900	-15.0
Weir	25.50	LDB	900	-15.0
Weir	25.40	LDB	1000	-15.0
Weir	25.30	LDB	1050	-15.0
Dike Extension	24.30	LDB	280	+18.5
Dike Extension	25.30	RDB	300	+18.5
Dike Extension	24.80	RDB	250	+18.5
Dike Extension	24.60	RDB	150	+18.5

Alternative 7 Result: Bathymetry Analysis (Plate 46)

Reduced Deposition at RM 24.50	Eliminate Deposition at RM 24.50	Additional Comments
Yes	No	The channel deepened (from -2 feet to -7 feet LWRP) at the crossing between RM 24.60 and RM 23.80. There were no significant bathymetry changes to Upper Browns Bar and Chute.

Alternative 8:

Type of Structure	River Mile	LDB / RDB	Dimensions (Feet)	Structure Top Elevation (feet in LWRP)
Weir	25.80	LDB	800	-15.0
Weir	25.70	LDB	800	-15.0
Weir	25.60	LDB	900	-15.0
Weir	25.50	LDB	900	-15.0
Weir	25.40	LDB	1000	-15.0
Weir	25.30	LDB	1050	-15.0
Dike Extension	24.50	LDB	280	+18.5
Dike Extension	24.30	LDB	225	+18.5
Dike Extension	24.20	LDB	275	+18.5
Dike Extension	23.80	LDB	500	+18.5
Dike Extension	25.30	RDB	300	+18.5
Dike Extension	24.80	RDB	250	+18.5
Dike Extension	24.60	RDB	150	+18.5

Alternative 8 Result: Bathymetry Analysis (Plate 47)

Reduced Deposition at RM 24.50	Eliminate Deposition at RM 24.50	Additional Comments
Yes	No	The channel deepened (from -2 feet to -9 feet LWRP) at the crossing between RM 24.60 and RM 23.80. There were no significant bathymetry changes to Upper Browns Bar and Chute.

Alternative 9:

Type of Structure	River Mile	LDB / RDB	Dimensions (Feet)	Structure Top Elevation (feet in LWRP)
Weir	25.80	LDB	550	-15.0
Weir	25.70	LDB	600	-15.0
Weir	25.60	LDB	600	-15.0
Weir	25.50	LDB	650	-15.0
Weir	25.40	LDB	750	-15.0
Weir	25.30	LDB	800	-15.0

Alternative 9 Result: Bathymetry Analysis (Plate 48)

Reduced Deposition at RM 24.50	Eliminate Deposition at RM 24.50	Additional Comments
Yes	No	Degradation occurred at the crossing. There were no significant bathymetry changes to Upper Brown's Bar and Chute.

Alternative 10:

Type of Structure	River Mile	LDB / RDB	Dimensions (Feet)	Structure Top Elevation (feet in LWRP)
Weir	25.85	LDB	500	-15.0
Weir	25.75	LDB	600	-15.0
Weir	25.65	LDB	700	-15.0
Weir	25.50	LDB	700	-15.0
Weir	25.35	LDB	800	-15.0
Weir	25.15	LDB	850	-15.0
Weir	24.90	LDB	700	-15.0

Alternative 10 Result: Bathymetry Analysis (Plate 49)

Reduced Deposition at RM 24.50	Eliminate Deposition at RM 24.50	Additional Comments
Yes	No	The channel deepened (from -2 feet to -7 feet LWRP) at the crossing between RM 24.60 and RM 23.80. There were no significant bathymetry changes to Upper Brown's Bar and Chute.

Alternative 11:

Type of Structure	River Mile	LDB / RDB	Dimensions (Feet)	Structure Top Elevation (feet in LWRP)
Weir	25.85	LDB	520	-15.0
Weir	25.75	LDB	600	-15.0
Weir	25.65	LDB	650	-15.0
Weir	25.50	LDB	650	-15.0
Weir	25.35	LDB	1,000	-15.0
Weir	25.15	LDB	1,000	-15.0
Weir	24.90	LDB	1,000	-15.0
Dike Extension	24.30	LDB	225	+18.5
Dike Extension	24.20	LDB	330	+18.5
Dike Extension	23.80	LDB	500	+18.5
Dike Extension	25.50	RDB	350	+18.5
Dike Extension	25.30	RDB	320	+18.5
Dike Extension	24.80	RDB	300	+18.5

Alternative 11 Result: Bathymetry Analysis (Plate 50)

Reduced Deposition at RM 24.50	Eliminate Deposition at RM 24.50	Additional Comments
Yes	No	The channel deepened (from -2 feet to -9 feet LWRP) at the crossing between RM 24.60 and RM 23.80. There were no significant bathymetry changes to Upper Brown's Bar and Chute.

Alternative 12:

Type of Structure	River Mile	LDB / RDB	Dimensions (Feet)	Structure Top Elevation (feet in LWRP)
Weir	25.85	LDB	575	-15.0
Weir	25.75	LDB	650	-15.0
Weir	25.65	LDB	750	-15.0
Weir	25.50	LDB	750	-15.0
Weir	25.35	LDB	1,000	-15.0
Weir	25.15	LDB	1,000	-15.0
Weir	24.90	LDB	1,000	-15.0
Dike Extension	24.30	LDB	280	+18.5
Dike Extension	24.20	LDB	330	+18.5
Dike Extension	23.80	LDB	500	+18.5
Dike Extension	25.50	RDB	350	+18.5
Dike Extension	25.30	RDB	320	+18.5
Dike Extension	24.80	RDB	300	+18.5
Dike Extension	24.70	RDB	280	+18.5
Construct Dike	24.25	RDB	250	+18.5

Alternative 12 Result: Bathymetry Analysis (Plate 51)

Reduced Deposition at RM 24.50	Eliminate Deposition at RM 24.50	Additional Comments
No	Yes	The channel deepened (from -2 feet to -10 feet LWRP) at the crossing between RM 24.60 and RM 23.80 with widths ranging between 1,000 feet and 1,400 feet. A scour hole occurred between Dike 24.20L and Dike 23.80L. There were no significant bathymetry changes to Upper Brown's Bar and Chute.

Alternative 13:

Type of Structure	River Mile	LDB / RDB	Dimensions (Feet)	Structure Top Elevation (feet in LWRP)
Weir	25.85	LDB	575	-15.0
Weir	25.75	LDB	650	-15.0
Weir	25.65	LDB	750	-15.0
Weir	25.50	LDB	750	-15.0
Weir	25.35	LDB	1,000	-15.0
Weir	25.15	LDB	1,000	-15.0
Weir	24.90	LDB	1,000	-15.0
Dike Extension	24.90	LDB	225	+18.5
Dike Extension	24.50	LDB	290	+18.5
Dike Extension	24.40	LDB	425	+18.5
Dike Extension	24.30	LDB	625	+18.5
Dike Extension	24.20	LDB	430	+18.5
Dike Extension	23.80	LDB	550	+18.5
Dike Extension	25.50	RDB	230	+18.5
Dike Extension	25.30	RDB	340	+18.5
Dike Extension	24.80	RDB	230	+18.5
Dike Extension	24.70	RDB	150	+18.5

Alternative 13 Result: Bathymetry Analysis (Plate 52)

Reduced Deposition at RM 24.50	Eliminate Deposition at RM 24.50	Additional Comments
Yes	Yes	The channel deepened (from -2 feet to -18 feet LWRP) at the crossing between RM 24.60 and RM 23.80. However, the navigation channel was constricted to 1,000 feet. There were no significant bathymetry changes to Upper Brown's Bar and Chute.

Alternative 14:

Type of Structure	River Mile	LDB / RDB	Dimensions (Feet)	Structure Top Elevation (feet in LWRP)
Weir	25.85	LDB	700	-15.0
Weir	25.75	LDB	800	-15.0
Weir	25.65	LDB	900	-15.0
Weir	25.50	LDB	900	-15.0
Weir	25.35	LDB	1,000	-15.0
Weir	25.15	LDB	1,000	-15.0
Weir	24.90	LDB	1,000	-15.0
L-Dike Extension	24.90	LDB	475	+18.5
L-Dike Extension	24.50	LDB	580	+18.5
L-Dike Extension	24.40	LDB	730	+18.5
Dike Extension	24.30	LDB	625	+18.5
Dike Extension	24.20	LDB	430	+18.5
Dike Extension	23.80	LDB	550	+18.5
Dike Extension	25.50	RDB	230	+18.5
Dike Extension	25.30	RDB	340	+18.5
Dike Extension	24.80	RDB	230	+18.5
Dike Extension	24.70	RDB	150	+18.5
Construct Dike	24.90	LDB	225	+18.5

Alternative 14 Result: Bathymetry Analysis (Plate 53)

Reduced Deposition at RM 24.50	Eliminate Deposition at RM 24.50	Additional Comments
Yes	Yes	The channel deepened (from -2 feet to -17 feet LWRP) at the crossing between RM 24.60 and RM 23.80. There were no significant bathymetry changes to Upper Brown's Bar and Chute.

Alternative 15:

Type of Structure	River Mile	LDB / RDB	Dimensions (Feet)	Structure Top Elevation (feet in LWRP)
Weir	25.85	LDB	400	-15.0
Weir	25.75	LDB	550	-15.0
Weir	25.65	LDB	650	-15.0
Weir	25.50	LDB	700	-15.0
Weir	25.35	LDB	750	-15.0
Weir	25.15	LDB	850	-15.0
Weir	24.90	LDB	750	-15.0
Dike Extension	24.30	LDB	115	+18.5
Dike Extension	24.20	LDB	220	+18.5
Dike Extension	23.80	LDB	350	+18.5
Dike Extension	25.50	RDB	245	+18.5
Dike Extension	25.30	RDB	400	+18.5
Dike Extension	24.80	RDB	330	+18.5
Dike Extension	24.70	RDB	330	+18.5
Dike Extension	24.25	RDB	400	+18.5
Dike Extension	23.95	RDB	300	+18.5

Alternative 15 Result: Bathymetry Analysis (Plate 54)

Reduced Deposition at RM 24.50	Eliminate Deposition at RM 24.50	Additional Comments
Yes	No	The channel deepened (from -2 feet to -9 feet LWRP) at the crossing between RM 24.60 and RM 23.80. There were no significant bathymetry changes to Upper Brown’s Bar and Chute.

Alternative 16:

Type of Structure	River Mile	LDB or RDB	Dimensions (Feet)	Structure Top Elevation (feet in LWRP)
Weir	25.85	LDB	500	-15.0
Weir	25.75	LDB	600	-15.0
Weir	25.65	LDB	750	-15.0
Weir	25.50	LDB	750	-15.0
Weir	25.35	LDB	900	-15.0
Weir	25.15	LDB	900	-15.0
Weir	24.90	LDB	950	-15.0
L-Dike Extension	24.90	LDB	475	+18.5
L-Dike Extension	24.50	LDB	580	+18.5
L-Dike Extension	24.40	LDB	730	+18.5
Dike Extension	24.30	LDB	480	+18.5
Dike Extension	24.20	LDB	220	+18.5
Dike Extension	23.80	LDB	390	+18.5
Dike Extension	25.50	RDB	230	+18.5
Dike Extension	25.30	RDB	390	+18.5
Dike Extension	24.80	RDB	320	+18.5
Dike Extension	24.70	RDB	300	+18.5

Alternative 16 Result: Bathymetry Analysis (Plate 55)

Reduced Deposition at RM 24.50	Eliminate Deposition at RM 24.50	Additional Comments
Yes	No	The channel deepened (from -2 feet to -9 feet LWRP) at the crossing between RM 24.60 and RM 23.80. There were no significant bathymetry changes to Upper Brown's Bar and Chute.

Alternative 17:

Type of Structure	River Mile	LDB / RDB	Dimensions (Feet)	Structure Top Elevation (feet in LWRP)
Weir	25.85	LDB	600	-15.0
Weir	25.75	LDB	800	-15.0
Weir	25.65	LDB	900	-15.0
Weir	25.50	LDB	900	-15.0
Weir	25.35	LDB	1,000	-15.0
Weir	25.15	LDB	1,000	-15.0
Weir	24.90	LDB	1,000	-15.0
L-Dike Extension	24.90	LDB	475	+18.5
L-Dike Extension	24.50	LDB	580	+18.5
L-Dike Extension	24.40	LDB	730	+18.5
Dike Extension	24.30	LDB	480	+18.5
Dike Extension	24.20	LDB	220	+18.5
Dike Extension	23.80	LDB	390	+18.5
Dike Extension	25.50	RDB	230	+18.5
Dike Extension	25.30	RDB	390	+18.5
Dike Extension	24.80	RDB	180	+18.5
Dike Extension	24.70	RDB	150	+18.5

Alternative 17 Result: Bathymetry Analysis (Plate 56)

Reduced Deposition at RM 24.50	Eliminate Deposition at RM 24.50	Additional Comments
Yes	No	The channel deepened (from -2 feet to -10 feet LWRP) at the crossing between RM 24.60 and RM 23.80. However, the navigation channel was constricted to 1,100 feet at RM 25.00. There were no significant bathymetry changes to Upper Brown's Bar and Chute.

<u>Alternative 18:</u>

Type of Structure	River Mile	LDB / RDB	Dimensions (Feet)	Structure Top Elevation (feet in LWRP)
Weir	25.75	LDB	700	-15.0
Weir	25.65	LDB	800	-15.0
Weir	25.50	LDB	900	-15.0
Weir	25.30	LDB	900	-15.0
Weir	25.00	LDB	1,000	-15.0
Weir	24.90	LDB	1,000	-15.0

Alternative 18 Result: Bathymetry Analysis (Plate 57)

Reduced Deposition at RM 24.50	Eliminate Deposition at RM 24.50	Additional Comments
No	No	There were no significant bathymetry changes to the main channel or Upper Brown's Bar and Chute.

Alternative 19:

Type of Structure	River Mile	LDB / RDB	Dimensions (Feet)	Structure Top Elevation (feet in LWRP)
Weir	25.40	LDB	800	-15.0
Weir	25.30	LDB	800	-15.0
Weir	25.00	LDB	800	-15.0
Weir	24.90	LDB	800	-15.0

Alternative 19 Result: Bathymetry Analysis (Plate 58)

Reduced Deposition at RM 24.50	Eliminate Deposition at RM 24.50	Additional Comments
No	No	The crossing remained the same. There were no significant bathymetry changes to Upper Brown's Bar and Chute.

Alternative 20:

Type of Structure	River Mile	LDB / RDB	Dimensions (Feet)	Structure Top Elevation (feet in LWRP)
Weir	25.80	LDB	600	-15.0
Weir	25.60	LDB	600	-15.0
Weir	25.40	LDB	600	-15.0
Weir	25.20	LDB	600	-15.0
Weir	25.00	LDB	600	-15.0
Dike Extension	25.50	RDB	350	+18.5
Dike Extension	25.30	RDB	400	+18.5
Dike Extension	24.80	RDB	375	+18.5
Dike Extension	24.70	RDB	450	+18.5

Alternative 20 Result: Bathymetry Analysis (Plate 59)

Reduced Deposition at RM 24.50	Eliminate Deposition at RM 24.50	Additional Comments
No	No	The crossing remained the same. There were no significant bathymetry changes to Upper Brown's Bar and Chute.

Alternative 21:

Type of Structure	River Mile	LDB / RDB	Dimensions (Feet)	Structure Top Elevation (feet in LWRP)
Weir	25.80	LDB	600	-15.0
Weir	25.60	LDB	600	-15.0
Weir	25.40	LDB	600	-15.0
Weir	25.20	LDB	600	-15.0
Weir	25.00	LDB	600	-15.0
Dike Extension	25.50	RDB	350	+18.5
Dike Extension	25.30	RDB	400	+18.5
Dike Extension	24.80	RDB	375	+18.5
Dike Extension	24.70	RDB	450	+18.5
Construct Dike	24.25	RDB	375	+18.5

Alternative 21 Result: Bathymetry Analysis (Plate 60)

Reduced Deposition at RM 24.50	Eliminate Deposition at RM 24.50	Additional Comments
No	No	The crossing remained the same. There were no significant bathymetry changes to Upper Brown's Bar and Chute.

Alternative 22:

Type of Structure	River Mile	LDB / RDB	Dimensions (Feet)	Structure Top Elevation (feet in LWRP)
Weir	25.80	LDB	600	-15.0
Weir	25.60	LDB	600	-15.0
Weir	25.40	LDB	600	-15.0
Weir	25.20	LDB	600	-15.0
Weir	25.00	LDB	600	-15.0
Offset Dike Extension	24.30	LDB	220	+18.5
Dike Extension	24.20	LDB	180	+18.5
Dike Extension	23.80	LDB	220	+18.5
Dike Extension	25.50	RDB	350	+18.5
Dike Extension	25.30	RDB	400	+18.5
Dike Extension	24.80	RDB	375	+18.5
Dike Extension	24.70	RDB	450	+18.5
Construct Dike	24.25	RDB	375	+18.5

Alternative 22 Result: Bathymetry Analysis (Plate 61)

Reduced Deposition at RM 24.50	Eliminate Deposition at RM 24.50	Additional Comments
Yes	No	The channel deepened (from -2 feet to -7 feet LWRP) at the crossing between RM 24.60 and RM 23.80. There were no significant bathymetry changes to Upper Brown's Bar and Chute.

Alternative 23:

Type of Structure	River Mile	LDB / RDB	Dimensions (Feet)	Structure Top Elevation (feet in LWRP)
Weir	25.80	LDB	600	-15.0
Weir	25.60	LDB	600	-15.0
Weir	25.40	LDB	600	-15.0
Weir	25.20	LDB	600	-15.0
Weir	25.00	LDB	600	-15.0
L-Dike Extension	24.30	LDB	580	+18.5
L-Dike Extension	24.20	LDB	520	+18.5
L-Dike Extension	23.80	LDB	840	+18.5
Dike Extension	25.50	RDB	350	+18.5
Dike Extension	25.30	RDB	400	+18.5
Dike Extension	24.80	RDB	375	+18.5
Dike Extension	24.70	RDB	450	+18.5
Construct Dike	24.25	RDB	375	+18.5

Alternative 23 Result: Bathymetry Analysis (Plate 62)

Reduced Deposition at RM 24.50	Eliminate Deposition at RM 24.50	Additional Comments
Yes	No	The channel deepened (from -2 feet to -7 feet LWRP) at the crossing between RM 24.60 and RM 23.80. There were no significant bathymetry changes to Upper Brown's Bar and Chute.

Alternative 24:

Type of Structure	River Mile	LDB / RDB	Dimensions (Feet)	Structure Top Elevation (feet in LWRP)
Weir	25.80	LDB	600	-15.0
Weir	25.60	LDB	600	-15.0
Weir	25.40	LDB	600	-15.0
Weir	25.20	LDB	600	-15.0
Weir	25.00	LDB	600	-15.0
L-Dike Extension	24.30	LDB	580	+18.5
L-Dike Extension	24.20	LDB	520	+18.5
L-Dike Extension	23.80	LDB	840	+18.5
Dike Extension	24.80	RDB	375	+18.5
Dike Extension	24.70	RDB	450	+18.5

Alternative 24 Result: Bathymetry Analysis (Plate 63)

Reduced Deposition at RM 24.50	Eliminate Deposition at RM 24.50	Additional Comments
Yes	No	The channel deepened (from -2 feet to -7 feet LWRP) at the crossing between RM 24.60 and RM 23.80. There were no significant bathymetry changes to Upper Brown's Bar and Chute.

Alternative 25:

Type of Structure	River Mile	LDB / RDB	Dimensions (Feet)	Structure Top Elevation (feet in LWRP)
Weir	25.80	LDB	600	-15.0
Weir	25.60	LDB	600	-15.0
Weir	25.40	LDB	600	-15.0
Weir	25.20	LDB	600	-15.0
Weir	25.00	LDB	600	-15.0
L-Dike Extension	24.30	LDB	580	+18.5
L-Dike Extension	24.20	LDB	520	+18.5
L-Dike Extension	23.80	LDB	840	+18.5
Dike Extension	24.80	RDB	375	+18.5
Dike Extension	24.70	RDB	450	+18.5
Closure Structure	22.35	LDB	1,200	+18.5

Alternative 25 Result: Bathymetry Analysis (Plate 64)

Reduced Deposition at RM 24.50	Eliminate Deposition at RM 24.50	Additional Comments
Yes	No	The channel deepened (from -2 feet to -7 feet LWRP) at the crossing between RM 24.60 and RM 23.80. There were no significant bathymetry changes to Upper Brown's Bar and Chute. However, the closure structure in Browns Chute caused the scour downstream from Dike 22.30L to go away.

Alternative 26:

Type of Structure	River Mile	LDB / RDB	Dimensions (Feet)	Structure Top Elevation (feet in LWRP)
Weir	25.80	LDB	600	-15.0
Weir	25.60	LDB	600	-15.0
Weir	25.40	LDB	600	-15.0
Weir	25.20	LDB	600	-15.0
Weir	25.00	LDB	600	-15.0
L-Dike Extension	24.40	LDB	500	+18.5
L-Dike Extension	24.30	LDB	580	+18.5
L-Dike Extension	24.20	LDB	520	+18.5
L-Dike Extension	23.80	LDB	840	+18.5
Dike Extension	24.80	RDB	375	+18.5
Dike Extension	24.70	RDB	450	+18.5
Closure Structure	22.35	LDB	1,200	+18.5

Alternative 26 Result: Bathymetry Analysis (Plate 65)

Reduced Deposition at RM 24.50	Eliminate Deposition at RM 24.50	Additional Comments
Yes	Yes	The channel deepened (from -2 feet to -12 feet LWRP) at the crossing between RM 24.60 and RM 23.80. By avoiding the area near Dike 24.50L (See Figure 4 in Existing Flow Mechanics), the flow coming in to Browns Chute was not disturbed. Thus, maintaining any existing environmental habitats. There were no significant bathymetry changes to Upper Brown's Bar and Chute.

Alternative 27:

Type of Structure	River Mile	LDB / RDB	Dimensions (Feet)	Structure Top Elevation (feet in LWRP)
Weir	25.75	LDB	520	-15.0
Weir	25.60	LDB	650	-15.0
Weir	25.45	LDB	600	-15.0
Weir	25.30	LDB	600	-15.0
Weir	25.15	LDB	600	-15.0
Weir	25.00	LDB	600	-15.0
L-Dike Extension	24.40	LDB	500	+18.5
L-Dike Extension	24.30	LDB	925	+18.5
L-Dike Extension	24.20	LDB	675	+18.5
L-Dike Extension	23.80	LDB	840	+18.5
Dike Extension	24.80	RDB	375	+18.5
Dike Extension	24.70	RDB	450	+18.5
Construct Dike	24.25	LDB	320	+18.5

Alternative 27 Result: Bathymetry Analysis (Plate 66)

Reduced Deposition at RM 24.50	Eliminate Deposition at RM 24.50	Additional Comments
Yes	No	The channel deepened (from -2 feet to -8 feet LWRP) at the crossing between RM 24.60 and RM 23.80. The weirs field between RM 25.80 and RM 25.00 maintained depths as low as -30 feet LWRP. There were no significant bathymetry changes to Upper Brown's Bar and Chute.

Alternative 28:

Type of Structure	River Mile	LDB / RDB	Dimensions (Feet)	Structure Top Elevation (feet in LWRP)
Weir	25.75	LDB	520	-15
Weir	25.60	LDB	650	-15
Weir	25.45	LDB	600	-15
Weir	25.30	LDB	600	-15
Weir	25.15	LDB	600	-15
Weir	25.00	LDB	600	-15
L-Dike Extension	24.40	LDB	500	+18.5
L-Dike Extension	24.30	LDB	925	+18.5
L-Dike Extension	24.20	LDB	675	+18.5
L-Dike Extension	23.80	LDB	840	+18.5
Dike Extension	24.80	RDB	300	+18.5
Dike Extension	24.70	RDB	300	+18.5
Construct Dike	24.25	LDB	320	+18.5
Construct Dike	23.95	LDB	150	+18.5

Alternative 28 Result: Bathymetry Analysis (Plate 67)

Reduced Deposition at RM 24.50	Eliminate Deposition at RM 24.50	Additional Comments
Yes	No	The channel deepened (from -2 feet to -8 feet LWRP) at the crossing between RM 24.60 and RM 23.80. The weirs field between RM 25.80 and RM 25.00 maintained depths as low as -30 feet LWRP. There were no significant bathymetry changes to Upper Brown's Bar and Chute.

Alternative 29:

Type of Structure	River Mile	LDB / RDB	Dimensions (Feet)	Structure Top Elevation (feet in LWRP)
Weir	25.75	LDB	520	-15.0
Weir	25.60	LDB	650	-15.0
Weir	25.45	LDB	600	-15.0
Weir	25.30	LDB	600	-15.0
Weir	25.15	LDB	600	-15.0
Weir	25.00	LDB	600	-15.0
L-Dike Extension	24.40	LDB	500	+18.5
L-Dike Extension	24.30	LDB	925	+18.5
L-Dike Extension	24.20	LDB	675	+18.5
L-Dike Extension	23.80	LDB	840	+18.5
Dike Extension	25.50	RDB	300	+18.5
Dike Extension	25.30	RDB	300	+18.5
Dike Extension	24.80	RDB	300	+18.5
Dike Extension	24.50	RDB	300	+18.5
Construct Dike	24.25	LDB	320	+18.5
Construct Dike	23.95	LDB	150	+18.5

Alternative 29 Result: Bathymetry Analysis (Plate 68)

Reduced Deposition at RM 24.50	Eliminate Deposition at RM 24.50	Additional Comments
Yes	No	The channel deepened (from -2 feet to -8 feet LWRP) at the crossing between RM 24.60 and RM 23.80. The weirs field between RM 25.80 and RM 25.00 maintained depths as low as -30 feet LWRP. There were no significant bathymetry changes to Upper Brown's Bar and Chute.

Alternative 30:

Type of Structure	River Mile	LDB / RDB	Dimensions (Feet)	Structure Top Elevation (feet in LWRP)
Weir	25.75	LDB	520	-15.0
Weir	25.60	LDB	650	-15.0
Weir	25.45	LDB	600	-15.0
Weir	25.30	LDB	600	-15.0
Weir	25.15	LDB	600	-15.0
L-Dike Extension	24.40	LDB	500	+18.5
L-Dike Extension	24.30	LDB	925	+18.5
L-Dike Extension	24.20	LDB	675	+18.5
L-Dike Extension	23.80	LDB	840	+18.5
Dike Extension	25.50	RDB	300	+18.5
Dike Extension	25.30	RDB	300	+18.5
Construct Dike	24.77	RDB	130	+18.5
Construct Dike	24.75	RDB	230	+18.5
Construct Dike	24.73	RDB	130	+18.5
Construct Dike	24.25	RDB	320	+18.5
Construct Rootless Dike	24.70	RDB	200	+18.5
Notch Closure	24.80	RDB	200	-10.0
Remove Closure	24.70	RDB	1,200	Existing Bed Elevation

Alternative 30 Result: Bathymetry Analysis (Plate 69)

Reduced Deposition at RM 24.50	Eliminate Deposition at RM 24.50	Additional Comments
Yes	Yes	The channel deepened (from -2 feet to -12 feet LWRP) at the crossing between RM 24.60 and RM 23.80. The weirs field between RM 25.80 and RM 25.00 maintained depths as low as -30 feet LWRP. By avoiding the area near Dike 24.50L (See Figure 4 in Existing Flow Mechanics), the flow coming through Browns Chute was not disturbed. Thus maintaining any existing environmental habitats. The alternative also enhanced environmental features by introducing additional flow through Buffalo Chute. There were no significant bathymetry changes to Upper Brown's Bar and Chute.

<u>Alternative 31:</u>

Type of Structure	River Mile	LDB / RDB	Dimensions (Feet)	Structure Top Elevation (feet in LWRP)
L-Dike Extension	24.40	LDB	500	+18.5
L-Dike Extension	24.30	LDB	925	+18.5
L-Dike Extension	24.20	LDB	675	+18.5
L-Dike Extension	23.80	LDB	840	+18.5
Dike Extension	25.50	RDB	300	+18.5
Dike Extension	25.30	RDB	300	+18.5
Construct Dike	24.25	LDB	320	+18.5

Alternative 31 Result: Bathymetry Analysis (Plate 70)

Reduced Deposition at RM 24.50	Eliminate Deposition at RM 24.50	Additional Comments
Yes	No	The channel deepened (from -2 feet to -8 feet LWRP) at the crossing between RM 24.60 and RM 23.80. There were no significant bathymetry changes to Upper Brown's Bar and Chute.

Alternative 32:

Type of Structure	River Mile	LDB / RDB	Dimensions (Feet)	Structure Top Elevation (feet in LWRP)
Weir	25.75	LDB	520	-15.0
Weir	25.60	LDB	650	-15.0
Weir	25.45	LDB	600	-15.0
Weir	25.30	LDB	600	-15.0
Weir	25.15	LDB	600	-15.0
L-Dike Extension	24.90	LDB	475	+18.5
L-Dike Extension	24.50	LDB	925	+18.5
L-Dike Extension	24.40	LDB	675	+18.5
Dike Extension	24.30	LDB	450	+18.5
Dike Extension	24.20	LDB	220	+18.5
Dike Extension	23.80	LDB	350	+18.5
Dike Extension	25.50	RDB	230	+18.5
Dike Extension	25.30	RDB	350	+18.5
Dike Extension	24.80	RDB	150	+18.5
Dike Extension	24.70	RDB	150	+18.5
Construct Dike	24.30	RDB	240	+18.5

Alternative 32 Result: Bathymetry Analysis (Plate 71)

Reduced Deposition at RM 24.50	Eliminate Deposition at RM 24.50	Additional Comments
No	Yes	The channel deepened (from -2 feet to -12 feet LWRP) at the crossing between RM 24.60 and RM 23.80. The weirs field between RM 25.80 and RM 25.00 maintained depths as low as -25 feet LWRP. There were no significant bathymetry changes to Upper Brown's Bar and Chute.

Alternative 33:

Type of Structure	River Mile	LDB or RDB	Dimensions (Feet)	Structure Top Elevation (feet in LWRP)
Weir	25.90	LDB	700	-15.0
Weir	25.70	LDB	800	-15.0
Weir	25.60	LDB	925	-15.0
Weir	25.40	LDB	1,000	-15.0
Weir	25.30	LDB	1,000	-15.0
Weir	24.90	LDB	950	-15.0
L-Dike Extension	24.90	LDB	475	+18.5
L-Dike Extension	24.50	LDB	925	+18.5
L-Dike Extension	24.40	LDB	675	+18.5
Dike Extension	24.30	LDB	450	+18.5
Dike Extension	24.20	LDB	220	+18.5
Dike Extension	23.80	LDB	350	+18.5
Dike Extension	25.50	RDB	350	+18.5
Dike Extension	25.30	RDB	150	+18.5
Dike Extension	24.80	RDB	150	+18.5
Dike Extension	24.70	RDB	150	+18.5
Construct Dike	23.90	RDB	240	+18.5
Construct Closure	23.80	LDB	1,600	+18.5
Construct Closure	22.30	LDB	1,400	+18.5

Alternative 33 Result: Bathymetry Analysis (Plate 72)

Reduced Deposition at RM 24.50	Eliminate Deposition at RM 24.50	Additional Comments
Yes	Yes	The channel deepened (from -2 feet to -12 feet LWRP) at the crossing between RM 24.60 and RM 23.80. The weirs field between RM 25.80 and RM 25.00 maintained depths as low as -25 feet LWRP. There were no significant bathymetry changes to Upper Brown's Bar and Chute.

Alternative 34:

Type of Structure	River Mile	LDB / RDB	Dimensions (Feet)	Structure Top Elevation (feet in LWRP)
Weir	25.70	LDB	600	-15.0
Weir	25.60	LDB	650	-15.0
Weir	25.40	LDB	700	-15.0
Weir	25.20	LDB	900	-15.0
Weir	24.90	LDB	900	-15.0
L-Dike Extension	24.40	LDB	500	+18.5
L-Dike Extension	24.30	LDB	925	+18.5
Rootless Dike Extension	25.30	RDB	200	+18.5
Rootless Dike Extension	24.80	RDB	200	+18.5
Rootless Dike Extension	24.70	RDB	200	+18.5
Construct Dike	24.25	RDB	240	+18.5
Construct Dike	24.25	RDB	240	+18.5
Notch Closure	24.80	RDB	200	-10.0
Remove Closure	24.70	RDB	1200	Existing Bed Elevation

Alternative 34 Result: Bathymetry Analysis (Plate 73)

Reduced Deposition at RM 24.50	Eliminate Deposition at RM 24.50	Additional Comments
Yes	No	The channel deepened (from -2 feet to -8 feet LWRP) at the crossing between RM 24.60 and RM 23.80. The weir field between RM 25.80 and RM 25.00 maintained depths as low as -25 feet LWRP. More connectivity occurred along Buffalo Chute due to a notch. There were no significant bathymetry changes to Upper Brown's Bar and Chute.

Alternative 35:

Type of Structure	River Mile	LDB / RDB	Dimensions (Feet)	Structure Top Elevation (feet in LWRP)
Weir	25.70	LDB	600	-15.0
Weir	25.60	LDB	650	-15.0
Weir	25.40	LDB	700	-15.0
Weir	25.20	LDB	900	-15.0
Weir	24.90	LDB	900	-15.0
L-Dike Extension	24.40	LDB	500	+18.5
L-Dike Extension	24.30	LDB	925	+18.5
L-Dike Extension	24.20	LDB	675	+18.5
L-Dike Extension	23.80	LDB	1,000	+18.5
Rootless Dike Extension	25.30	RDB	200	+18.5
Rootless Dike Extension	24.80	RDB	200	+18.5
Rootless Dike Extension	24.70	RDB	200	+18.5
Construct Dike	24.25	RDB	240	+18.5
Construct Dike	24.25	RDB	240	+18.5
Notch Closure	24.80	RDB	200	-10.0
Remove Closure	24.70	RDB	1200	Existing Bed Elevation

Alternative 35 Result: Bathymetry Analysis (Plate 74)

Reduced Deposition at RM 24.50	Eliminate Deposition at RM 24.50	Additional Comments
Yes	Yes	The channel deepened (from -2 feet to -12 feet LWRP) at the crossing between RM 24.60 and RM 23.80. The weir field between RM 25.80 and RM 25.00 maintained depths as low as -25 feet LWRP. More connectivity occurred along Buffalo Chute due to a notch, which enhanced environmental features. There were no significant bathymetry changes to Upper Brown's Bar and Chute.

Alternative 36:

Type of Structure	River Mile	LDB / RDB	Dimensions (Feet)	Structure Top Elevation (feet in LWRP)
Weir	25.70	LDB	600	-15.0
Weir	25.60	LDB	650	-15.0
Weir	25.40	LDB	700	-15.0
Weir	25.20	LDB	900	-15.0
Weir	24.90	LDB	900	-15.0
L-Dike Extension	24.40	LDB	500	+18.5
L-Dike Extension	24.30	LDB	925	+18.5
L-Dike Extension	24.20	LDB	675	+18.5
Rootless Dike Extension	25.30	RDB	200	+18.5
Rootless Dike Extension	24.80	RDB	200	+18.5
Rootless Dike Extension	24.70	RDB	200	+18.5
Construct Dike	24.25	RDB	240	+18.5
Construct Dike	24.25	RDB	240	+18.5
Notch Closure	24.80	RDB	200	-10.0
Remove Closure	24.70	RDB	1200	Existing Bed Elevation

Alternative 36 Result: Bathymetry Analysis (Plate 75)

Reduced Deposition at RM 24.50	Eliminate Deposition at RM 24.50	Additional Comments
Yes	Yes	The channel deepened (from -2 feet to -12 feet LWRP) at the crossing between RM 24.60 and RM 23.80. The weir field between RM 25.80 and RM 25.00 maintained depths as low as -25 feet LWRP. By avoiding the area near Dike 24.50L (See Figure 4 in Existing Flow Mechanics), the flow coming in to Browns Chute was not disturbed. Thus maintaining any existing environmental habitats. The alternative also added more connectivity to Buffalo Chute which enhanced environmental features. There were no significant bathymetry changes to Upper Brown's Bar and Chute.

Alternative 37:

Type of Structure	River Mile	LDB / RDB	Dimensions (Feet)	Structure Top Elevation (feet in LWRP)
Weir	25.70	LDB	600	-15.0
Weir	25.60	LDB	650	-15.0
Weir	25.40	LDB	700	-15.0
Weir	25.20	LDB	900	-15.0
L-Dike Extension	24.40	LDB	500	+18.5
L-Dike Extension	24.30	LDB	925	+18.5
L-Dike Extension	24.20	LDB	675	+18.5
Rootless Dike Extension	25.50	RDB	300	+18.5
Rootless Dike Extension	24.80	RDB	300	+18.5
Rootless Dike Extension	24.70	RDB	300	+18.5
Construct Dike	24.75	RDB	320	+18.5
Construct Dike	24.25	RDB	320	+18.5
Notch Closure	24.80	RDB	200	-15.0
Remove Closure	24.70	RDB	1200	-15.0

Alternative 37 Result: Bathymetry Analysis (Plate 76)

Reduced Deposition at RM 24.50	Eliminate Deposition at RM 24.50	Additional Comments
No	Yes	The channel deepened (from -2 feet to -12 feet LWRP) at the crossing between RM 24.60 and RM 23.80. The weir field between RM 25.80 and RM 25.00 maintained depths as low as -25 feet LWRP. By avoiding the area near Dike 24.50L (See Figure 4 in Existing Flow Mechanics), the flow coming in to Browns Chute was not disturbed. Thus maintaining any existing environmental habitats. The alternative also added more connectivity to Buffalo Chute which enhanced environmental features. There were no significant bathymetry changes to Upper Brown's Bar and Chute.

Alternative 38:

Type of Structure	River Mile	LDB / RDB	Dimensions (Feet)	Structure Top Elevation (feet in LWRP)
Weir	25.70	LDB	600	-15.0
Weir	25.60	LDB	650	-15.0
Weir	25.40	LDB	700	-15.0
Weir	25.20	LDB	900	-15.0
L-Dike Extension	24.40	LDB	500	+18.5
L-Dike Extension	24.30	LDB	925	+18.5
L-Dike Extension	24.20	LDB	675	+18.5
Offset Rootless Dike Extension	25.50	RDB	300	+18.5
Offset Rootless Dike Extension	24.80	RDB	300	+18.5
Offset Rootless Dike Extension	24.70	RDB	300	+18.5
Construct Dike	24.75	RDB	320	+18.5
Construct Dike	24.25	RDB	320	+18.5
Notch Closure	24.80	RDB	200	-15.0
Remove Closure	24.70	RDB	1200	-15.0

Alternative 38 Result: Bathymetry Analysis (Plate 77)

Reduced Deposition at RM 24.50	Eliminate Deposition at RM 24.50	Additional Comments
No	Yes	The channel deepened (from -2 feet to -12 feet LWRP) at the crossing between RM 24.60 and RM 23.80. The weir field between RM 25.80 and RM 25.00 maintained depths as low as -25 feet LWRP. By avoiding the area near Dike 24.50L (See Figure 4 in Existing Flow Mechanics), the flow coming in to Browns Chute was not disturbed. Thus maintaining any existing environmental habitats. The alternative also added more connectivity to Buffalo Chute which enhanced environmental features. There were no significant bathymetry changes to Upper Brown's Bar and Chute.

Alternative 39:

Type of Structure	River Mile	LDB / RDB	Dimensions (Feet)	Structure Top Elevation (feet in LWRP)
Weir	25.70	LDB	600	-15.0
Weir	25.60	LDB	650	-15.0
Weir	25.40	LDB	700	-15.0
Weir	25.20	LDB	900	-15.0
L-Dike Extension	24.40	LDB	600	+18.5
L-Dike Extension	24.30	LDB	1,025	+18.5
L-Dike Extension	24.20	LDB	775	+18.5
Rootless Dike Extension	25.50	RDB	300	+18.5
Rootless Dike Extension	24.80	RDB	300	+18.5
Rootless Dike Extension	24.70	RDB	200	+18.5
Construct Dike	24.75	RDB	320	+18.5
Construct Dike	24.25	RDB	320	+18.5
Notch Closure	24.80	RDB	200	-15.0
Remove Closure	24.70	RDB	1200	-15.0

Alternative 39 Result: Bathymetry Analysis (Plate 78)

Reduced Deposition at RM 24.50	Eliminate Deposition at RM 24.50	Additional Comments
No	Yes	The channel deepened (from -2 feet to -12 feet LWRP) at the crossing between RM 24.60 and RM 23.80. The weirs field between RM 25.80 and RM 25.00 maintained depths as low as -25 feet LWRP. By avoiding the area near Dike 24.50L (See Figure 4 in Existing Flow Mechanics), the flow coming in to Browns Chute was not disturbed. Thus maintaining any existing environmental habitats. The alternative also added more connectivity to Buffalo Chute which enhanced environmental features. There were no significant bathymetry changes to Upper Brown's Bar and Chute.

CONCLUSIONS

1. Evaluation and Summary of the Model Tests

Alternatives	Reduced Deposition Between RM 24.50 and RM 23.75	Eliminate Deposition Between RM 24.50 and RM 23.75	Maintain / Enhance Environmental Features
Alternative 1	Yes	-	-
Alternative 2	Yes	-	-
Alternative 3	Yes	-	-
Alternative 4	Yes	-	-
Alternative 5	Yes	-	-
Alternative 6	-	-	-
Alternative 7	Yes	-	-
Alternative 8	Yes	-	-
Alternative 9	Yes	-	-
Alternative 10	Yes	-	-
Alternative 11	Yes	-	-
Alternative 12	Yes	Yes	-
Alternative 13	Yes	Yes	-
Alternative 14	Yes	Yes	-
Alternative 15	Yes	-	-
Alternative 16	Yes	-	-
Alternative 17	Yes	-	-
Alternative 18	-	-	-
Alternative 19	-	-	-
Alternative 20	-	-	-
Alternative 21	-	-	-
Alternative 22	Yes	-	-
Alternative 23	Yes	-	-
Alternative 24	Yes	-	-

Alternative 25	Yes	-	
Alternative 26	Yes	Yes	Yes
Alternative 27	Yes	-	-
Alternative 28	Yes	-	-
Alternative 29	Yes	-	-
Alternative 30	Yes	Yes	Yes
Alternative 31	Yes	-	-
Alternative 32	Yes	Yes	-
Alternative 33	Yes	Yes	-
Alternative 34	Yes	-	-
Alternative 35	Yes	Yes	Yes
Alternative 36	Yes	Yes	Yes
Alternative 37	Yes	Yes	Yes
Alternative 38	Yes	Yes	Yes
Alternative 39	Yes	Yes	Yes

NOTE: “-” denotes alternative did not satisfy the condition

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 sedimentation between RM 25.00 and RM 23.75. The second condition was that the alternative had to maintain the navigation channel requirements of at least 9 foot of depth and 300 foot of width. Although there were a number of alternatives that showed improvements to sedimentation between RM 25.00 and RM 23.50 while maintaining the navigation channel requirements, they were not recommended. These alternatives were not recommended primarily because they had negative impacts to the environmental features in the reach, specifically Upper Browns Chute. Some of the alternatives that met the criterion but were not chosen were alternatives 12, 13 and 14.

Flow visualization was used to make flow patterns visible in the model to get qualitative information such as flow and direction. The analysis was done only to the recommended alternative to verify the results and to provide a visual understanding of the design. See Section 5 in the Appendix

(Please note that there is a DVD available with this report to view the video. Furthermore, Youtube hyperlinks will be provided in the online version of the report. To access the Youtube videos simply click on the still image of the video, and it will direct you to the associated Youtube video.)

2. Recommendations

Alternative 39, Plate 78, was recommended as the most desirable alternative because of its observed ability to eliminate the dredging between RM 25.00 and RM 23.50. The weirs directed more flow and energy toward the middle of the channel where sediment deposition occurred. The weirs, in combination with dike extensions, eliminated much of the deposition between RM 25.00 and RM 23.50. The notched closure structure 24.80R allowed more flow and connectivity in Buffalo Chute.

Overall, this alternative eliminated the deposition between RM 25.00 and RM 23.50 while maintaining and enhancing the environmental features of the reach. The side channels showed no significant bathymetry changes.

The recommended design included the following:

- Construct Weir at RM 25.70 (L)
    - Construct Weir 600 feet long
    - Top elevation of the Weir will be -15 feet LWRP
- Construct Weir at RM 25.60 (L)
    - Construct Weir 690 feet long
    - Top elevation of the Weir will be -15.0 feet LWRP
- Construct Weir at RM 25.40 (L)
    - Construct Weir 740 feet long
    - Top elevation of the Weir will be -15.0 feet LWRP
- Construct Weir at RM 25.20 (L)

- Construct Weir 900 feet long
- Top elevation of the Weir will be -15.0 feet LWRP

- Construct Rootless Dike Extension at RM 25.30 (R)
  - Construct Rootless Dike Extension 130 feet long and 150 feet away from existing structure
  - Top elevation of the rootless dike extension will be +18.5 feet LWRP
- Construct Rootless Dike at RM 24.80 (R)
  - Construct Rootless Dike Extension 130 feet long and 115 feet away from existing structure
  - Top elevation of the rootless dike extension will be +18.5 feet LWRP
- Construct Rootless Dike at RM 24.70 (R)
  - Construct Rootless Dike Extension 145 feet long and 150 feet away from existing structure
  - Top elevation of the rootless dike extension will be +18.5 feet LWRP
- Construct Dike at RM 24.75 (R)
  - Construct Dike 225 feet long
  - Top elevation of Dike will be +18.5 feet LWRP
- Construct Dike at RM 24.25 (R)
  - Construct Dike 225 feet long
  - Top elevation of Dike will be +18.5 feet LWRP
- Notch Closure Structure at RM 24.80 (R)
  - Notch 200 foot section from the Missouri bankline
  - Top elevation of the Notch will be -10.0 feet LWRP
- Remove Closure Structure at RM 24.70 (R)
  - Remove 1,200 foot section between Buffalo Island and Dike 24.70R
  - Top elevation will be existing bed elevation.
- Construct L-Dike Extension at RM 24.40 (L)
  - Construct L-Dike Extension 500 feet long
  - Top elevation of L-Dike Extension will be +18.5 feet LWRP
- Construct L-Dike Extension at RM 24.30 (L)
  - Construct L-Dike Extension 925 feet long

  - Top elevation of L-Dike Extension will be +18.5 feet LWRP
- Construct L-Dike Extension at RM 24.20 (L)
  - Construct L-Dike Extension 675 feet long
  - Top elevation of L-Dike Extension will be +18.5 feet LWRP

3. <u>Interpretation of Model Test Results</u>

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.

FOR MORE INFORMATION

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APPENDIX 3: 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 three prototype bathymetries, the 2007, 2010 and 2013 river surveys. At 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 2000 feet intervals along the sailing line for the same locations for all four surveys. See Plate 79.

The initial comparison was 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. See Plate 79. The results of the area calculations are presented on the next page in Table 6. The average difference between the cross-sectional areas, model to prototype, was 8.6%. Tables 7 and 8 show the comparison between the replicated model scan to the 2010 and 2013 bathymetry. The average differences between the cross-sectional areas were 8.2% and 7.9% respectively. The average difference in cross-section between the replicated model scan and three prototype bathymetric surveys was 8.2%. See Table 12.

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. Table 9 shows the average percent difference was 7.6%. Table 10 shows the cross sectional comparison between the 2010 and 2013 bathymetries. The average difference was 7.7%. Table 11 shows the cross sectional comparison between the 2007 and 2013 bathymetries. The average difference was 8.6%. The average variation in cross sectional area was 7.8%. The natural variation of the channel compared within 1% to the replication model. See Table 13.

Table 6: Cross Section Comparison Model Replication Scan and 2007 Bathymetry

Cross Section Station	Area Without Correction		Corrected Area		Percent Difference
	Model Replication (feet²)	2007 Survey (feet²)	True Model Replication (feet²)	True 2007 Survey (feet²)	
20+00	613,900	572,205	40,927	38,147	7.0%
40+00	602,868	557,732	40,191	37,182	7.8%
60+00	589,353	591,963	39,290	39,464	0.4%
80+00	639,376	577,495	42,625	38,500	10.2%
100+00	658,989	777,381	43,933	51,825	16.5%
120+00	661,040	642,071	44,069	42,805	2.9%
140+00	639,584	600,487	42,639	40,032	6.3%
160+00	683,660	618,172	45,577	41,211	10.1%
180+00	576,558	554,608	38,437	36,974	3.9%
200+00	595,534	569,981	39,702	37,999	4.4%
220+00	676,166	673,627	45,078	44,908	0.4%
240+00	646,667	659,707	43,111	43,980	2.0%
260+00	487,302	543,692	32,487	36,246	10.9%
280+00	473,374	491,654	31,558	32,777	3.8%
300+00	478,026	392,804	31,868	26,187	19.6%
320+00	547,550	584,729	36,503	38,982	6.6%
340+00	472,956	548,704	31,530	36,580	14.8%
360+00	503,624	495,706	33,575	33,047	1.6%
380+00	499,286	461,755	33,286	30,784	7.8%
400+00	533,244	455,793	35,550	30,386	15.7%
420+00	675,161	505,444	45,011	33,696	28.8%
				Average	**8.6%**

Table 7: Cross Section Comparison Model Replication Scan and 2010 Bathymetry

Cross Section Station	Area Without Correction		Corrected Area		Percent Difference
	Model Replication (feet²)	2010 Survey (feet²)	True Model Replication (feet²)	True 2010 Survey (feet²)	
20+00	613,900	617,199	40,927	41,147	0.5%
40+00	602,868	671,192	40,191	44,746	10.7%
60+00	589,353	625,800	39,290	41,720	6.0%
80+00	639,376	572,179	42,625	38,145	11.1%
100+00	658,989	717,049	43,933	47,803	8.4%
120+00	661,040	682,302	44,069	45,487	3.2%
140+00	639,584	649,393	42,639	43,293	1.5%
160+00	683,660	671,609	45,577	44,774	1.8%
180+00	576,558	549,877	38,437	36,658	4.7%
200+00	595,534	630,302	39,702	42,020	5.7%
220+00	676,166	786,099	45,078	52,407	15.0%
240+00	646,667	667,599	43,111	44,507	3.2%
260+00	487,302	496,671	32,487	33,111	1.9%
280+00	473,374	442,166	31,558	29,478	6.8%
300+00	478,026	422,188	31,868	28,146	12.4%
320+00	547,550	629,493	36,503	41,966	13.9%
340+00	472,956	533,296	31,530	35,553	12.0%
360+00	503,624	568,231	33,575	37,882	12.1%
380+00	499,286	472,092	33,286	31,473	5.6%
400+00	533,244	437,220	35,550	29,148	19.8%
420+00	675,161	572,110	45,011	38,141	16.5%
				Average	**8.2%**

Table 8: Cross Section Comparison Model Replication Scan and 2013 Bathymetry

Cross Section Station	Area Without Correction		Corrected Area		Percent Difference
	Model Replication (feet²)	2010 Survey (feet²)	True Model Replication (feet²)	True 2010 Survey (feet²)	
20+00	613,900	632,561	40,927	42,171	3.0%
40+00	602,868	646,956	40,191	43,130	7.1%
60+00	589,353	599,706	39,290	39,980	1.7%
80+00	639,376	631,980	42,625	42,132	1.2%
100+00	658,989	809,853	43,933	53,990	20.5%
120+00	661,040	704,963	44,069	46,998	6.4%
140+00	639,584	697,396	42,639	46,493	8.6%
160+00	683,660	619,359	45,577	41,291	9.9%
180+00	576,558	520,831	38,437	34,722	10.2%
200+00	595,534	640,660	39,702	42,711	7.3%
220+00	676,166	740,318	45,078	49,355	9.1%
240+00	646,667	705,187	43,111	47,012	8.7%
260+00	487,302	511,410	32,487	34,094	4.8%
280+00	473,374	488,770	31,558	32,585	3.2%
300+00	478,026	430,171	31,868	28,678	10.5%
320+00	547,550	575,291	36,503	38,353	4.9%
340+00	472,956	499,189	31,530	33,279	5.4%
360+00	503,624	447,766	33,575	29,851	11.7%
380+00	499,286	409,021	33,286	27,268	19.9%
400+00	533,244	501,629	35,550	33,442	6.1%
420+00	675,161	638,136	45,011	42,542	5.6%
				Average	**7.9%**

Table 9: Cross Section Comparison between 2007 and 2010 Bathymetry

Cross Section Station	Area Without Correction		Corrected Area		Percent Difference
	2007 Survey (feet²)	2010 Survey (feet²)	True 2007 Survey (feet²)	True 2010 Survey (feet²)	
20+00	572,205	617,199	38,147	41,147	7.6%
40+00	557,732	671,192	37,182	44,746	18.5%
60+00	591,963	625,800	39,464	41,720	5.6%
80+00	577,495	572,179	38,500	38,145	0.9%
100+00	777,381	717,049	51,825	47,803	8.1%
120+00	642,071	682,302	42,805	45,487	6.1%
140+00	600,487	649,393	40,032	43,293	7.8%
160+00	618,172	671,609	41,211	44,774	8.3%
180+00	554,608	549,877	36,974	36,658	0.9%
200+00	569,981	630,302	37,999	42,020	10.1%
220+00	673,627	786,099	44,908	52,407	15.4%
240+00	659,707	667,599	43,980	44,507	1.2%
260+00	543,692	496,671	36,246	33,111	9.0%
280+00	491,654	442,166	32,777	29,478	10.6%
300+00	392,804	422,188	26,187	28,146	7.2%
320+00	584,729	629,493	38,982	41,966	7.4%
340+00	548,704	533,296	36,580	35,553	2.8%
360+00	495,706	568,231	33,047	37,882	13.6%
380+00	461,755	472,092	30,784	31,473	2.2%
400+00	455,793	437,220	30,386	29,148	4.2%
420+00	505,444	572,110	33,696	38,141	12.4%
				Average	**7.6%**

Table 10: Cross Section Comparison between 2010 and 2013 Bathymetry

Cross Section Station	Area Without Correction		Corrected Area		Percent Difference
	2010 Survey (feet²)	2013 Survey (feet²)	True 2010 Survey (feet²)	True 2013 Survey (feet²)	
20+00	617199	632,561	41,147	42,171	2.5%
40+00	671192	646,956	44,746	43,130	3.7%
60+00	625800	599,706	41,720	39,980	4.3%
80+00	572179	631,980	38,145	42,132	9.9%
100+00	717049	809,853	47,803	53,990	12.2%
120+00	682302	704,963	45,487	46,998	3.3%
140+00	649393	697,396	43,293	46,493	7.1%
160+00	671609	619,359	44,774	41,291	8.1%
180+00	549877	520,831	36,658	34,722	5.4%
200+00	630302	640,660	42,020	42,711	1.6%
220+00	786099	740,318	52,407	49,355	6.0%
240+00	667599	705,187	44,507	47,012	5.5%
260+00	496671	511,410	33,111	34,094	2.9%
280+00	442166	488,770	29,478	32,585	10.0%
300+00	422188	430,171	28,146	28,678	1.9%
320+00	629493	575,291	41,966	38,353	9.0%
340+00	533296	499,189	35,553	33,279	6.6%
360+00	568231	447,766	37,882	29,851	23.7%
380+00	472092	409,021	31,473	27,268	14.3%
400+00	437220	501,629	29,148	33,442	13.7%
420+00	572110	638,136	38,141	42,542	10.9%
				Average	**7.7%**

Table 11: Cross Section Comparison between 2007 and 2013 Bathymetry

Cross Section Station	Area Without Correction		Corrected Area		Percent Difference
	2007 Survey (feet²)	2013 Survey (feet²)	True 2007 Survey (feet²)	True 2013 Survey (feet²)	
20+00	572,205	632,561	38,147	42,171	10.0%
40+00	557,732	646,956	37,182	43,130	14.8%
60+00	591,963	599,706	39,464	39,980	1.3%
80+00	577,495	631,980	38,500	42,132	9.0%
100+00	777,381	809,853	51,825	53,990	4.1%
120+00	642,071	704,963	42,805	46,998	9.3%
140+00	600,487	697,396	40,032	46,493	14.9%
160+00	618,172	619,359	41,211	41,291	0.2%
180+00	554,608	520,831	36,974	34,722	6.3%
200+00	569,981	640,660	37,999	42,711	11.7%
220+00	673,627	740,318	44,908	49,355	9.4%
240+00	659,707	705,187	43,980	47,012	6.7%
260+00	543,692	511,410	36,246	34,094	6.1%
280+00	491,654	488,770	32,777	32,585	0.6%
300+00	392,804	430,171	26,187	28,678	9.1%
320+00	584,729	575,291	38,982	38,353	1.6%
340+00	548,704	499,189	36,580	33,279	9.5%
360+00	495,706	447,766	33,047	29,851	10.2%
380+00	461,755	409,021	30,784	27,268	12.1%
400+00	455,793	501,629	30,386	33,442	9.6%
420+00	505,444	638,136	33,696	42,542	23.2%
				Average	**8.6%**

Table 12: Average Percent Difference between Model Replication and Prototype Surveys

Model Replication & 2007 Survey	Model Replication & 2010 Survey	Model Replication & 2012 Survey	Average Percent Difference
8.60	8.20	7.90	8.20

Table 13: Average Percent Difference between Prototype Surveys

2007 Survey & 2010 Survey	2007 Survey & 2012 Survey	2010 Survey & 2012 Survey	Average Percent Difference
7.20	7.70	8.60	7.80

APPENDIX 4: HSR MODELING 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.wes.army.mil/Welcome.html

APPENDIX 5: FLOW VISUALIZATION RESULTS

Flow visualization is a tool used to monitor the flow patterns in an HSR model. The preferred method at the Applied River Engineering Center is to dye the water and seed the water surface with dry white sediment (Poly-Urea grit) at the model entrance. The dry sediment floats on the top of the water surface and provides a visual representation of surface flow patterns in the model. A high definition video camera is used to record approximately 60 seconds of the sediment floating through the study area. The recording is processed with software that reduces the recording to approximately 20% of the original speed. The video speed reduction allows viewers to more easily track the flow patterns.

The first condition recorded was the replication test, or existing conditions as seen in Figure 5. The flow crossed over to the LDB at RM 26.0. As seen in the snapshot of the existing conditions, the resultant flow was concentrated along the LDB. Immediately downstream the flow began to disperse across the channel (sediment deposition occurred) and crossed over to the RDB at RM 24.0. No sediment movement was observed in Buffalo and Upper Browns Chutes. All structures are highlighted in pink for increased visibility.

Figure 5: Replication vs. Alternative 37 Flow Visualization

The next condition recorded was the post construction condition with the recommended alternative in place. Alternative 37 (recommended alternative) included dikes, weirs, rootless dike, L-dike extensions, and dike notching and removal that would eliminate dredging in addition to enhancing environmental diversity at Buffalo Island.

Again, the flow crossed over to the LDB at RM 26.0. As seen in the snapshot of the post construction conditions, the flow was more concentrated toward the middle of the channel. As a result, a more dependable and deeper channel was developed for industry use. When compared to the existing conditions, there was an increase in energy and sediment transport at the crossing where sediment deposition had occurred in the replication test.

Figure 6 showed Upper Brown’s Chute during replication and after construction. As seen in the snapshot, the side channel experienced similar flow patterns. No significant trends were observed.

Figure 6: Alternative 37 Upper Browns Bar Flow Visualization

Figure 7 showed Buffalo Chute after construction. As seen in the snapshot, more flow was able to pass through the chute where the notch was located. No bed changes were observed in Buffalo Chute.

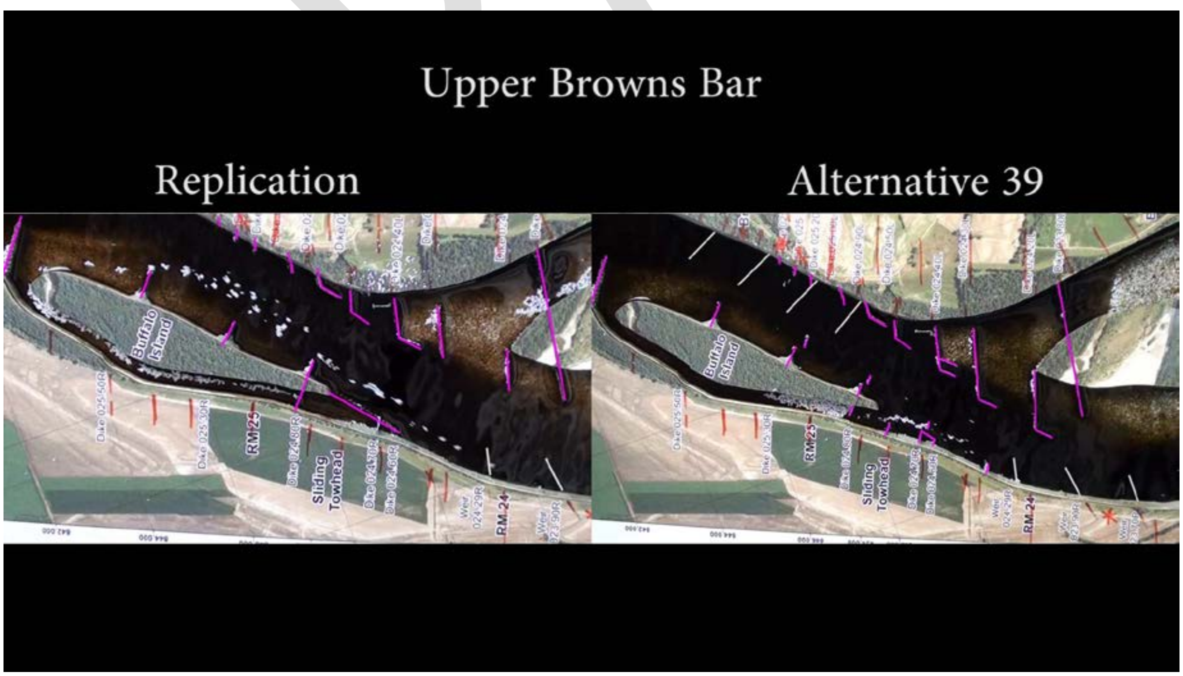

Figure 7: Alternative 37 Buffalo Island Flow Visualization