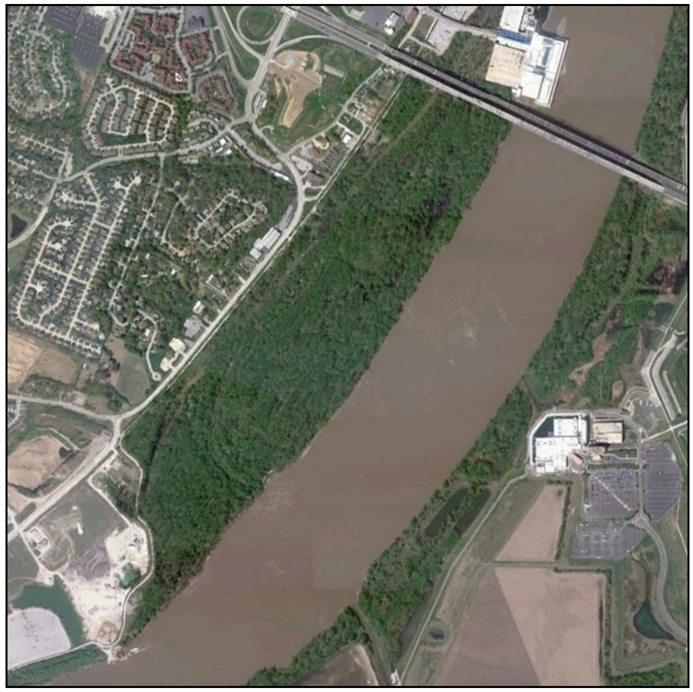
TECHNICAL REPORT M56

FINAL REPORT—SEPTEMBER 2011

US Army Corps of Engineers
St. Louis District

BANGERT ISLAND HYDRAULIC SEDIMENT RESPONSE MODEL STUDY



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U.S. ARMY CORPS OF ENGINEERS
ST. LOUIS DISTRICT
HYDROLOGIC AND HYDRAULICS BRANCH
APPLIED RIVER ENGINEERING CENTER
FOOT OF ARSENAL STREET
ST. LOUIS, MISSOURI 63118

Sponsored by and Prepared for: The Missouri River Recovery Program;
U. S. Army Corps of Engineers, Kansas City District;
City of St. Charles, MO

In Cooperation With:
Missouri Department of Conservation
Missouri Department of Natural Resources
U.S. Fish and Wildlife Service
Missouri Department of Transportation

APPLIED RIVER ENGINEERING CENTER

TECHNICAL
REPORT
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BANGERT ISLAND
HYDRAULIC SEDIMENT RESPONSE MODEL STUDY
MISSOURI RIVER MILES 34.3 to 28.1

APPLIED RIVER ENGINEERING CENTER

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Bangert Island HSR Model
Missouri River Miles 34.3 to 28.1

Hydraulic Sediment Response Model Investigation

By

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THE CITY OF ST. CHARLES, MISSOURI

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Final Report – September 2011

INTRODUCTION

The U.S. Army Corps of Engineers (USACE), St. Louis District (MVS), conducted a side channel viability study for Bangert Island on the Missouri River between River Miles (RM) 31.1 and 29.0 at St. Charles, MO. This study was funded jointly by the City of St. Charles, MO and through the Missouri River Recovery Program administered by the USACE, Kansas City District (NWK).

The Missouri Department of Conservation currently owns the Bangert Island property, which it manages as a public park with unfinished bike and hiking trails. Bangert Island was previously unattached from St. Charles County, but slowly reconnected to the County as the side channel filled with deposits between the 1930s and 1970s. Since 1980, the property has remained attached.

The main objective of this study was to determine what conditions maximize the chance for a reopened Bangert Island Side Channel to avoid closure due to deposition. These conditions were also evaluated as to their effect on the navigation channel, I-70 (Blanchette) Bridge, and Ameristar Casino.

The study was conducted between December, 2010 and September, 2011 using a Hydraulic Sediment Response (HSR) model at the Applied River Engineering Center, St. Louis District, in St. Louis, MO. The model study was performed by Mr. Timothy Lauth, Hydraulic Engineer, under direct supervision, of Mr. Robert Davinroy, P.E., Chief of the River Engineering Section for MVS. Other MVS involved include Mr. Jasen Brown, P.E., Hydraulic Engineer, Mrs. Laurie Farmer, Strategic Initiatives Coordinator, Mr. Jason Floyd, Engineering Technician, Mr. Bradley Krischel, Hydraulic Engineer, Mrs. Ashley Cox, Hydraulic Engineer, Ms. Emily Rivera, Engineering Co-op, and Ms. Dana Fischer, Engineering Co-op.

NWK personnel that were involved in project development, alignment development, and alternatives include: Mr. Michael Chapman, P.E., Chief of the River Engineering Section for NWK, Mr. Chance Bitner, P.E., Project Manager for the Missouri River Recovery Program, Mrs. Colleen Roberts, Hydraulic Engineer, and Ms. Heather Hill, Hydraulic Engineer. The City of St. Charles, Missouri was represented by Mr. Gary Elmestad, President, Gary Elmestad & Assoc., Mr. Kevin Riggs, P.E., President of Cole & Associates Inc., and Mrs. Sally Faith, Mayor of the City of St. Charles.

Multiple partners have been involved in the development of the overall project and provided input on the modeling efforts. The Missouri Department of Conservation was represented by Mr. Danny Brown, Management Biologist, Mr. Lynn Schrader, St. Louis

Regional Supervisor, Mr. Tim Ripperger, Deputy Director, and Mr. David Thorne, Policy Supervisor. The Missouri Department of Transportation was represented by Kurt Gribble, P.E., Structural Liaison Engineer. The U.S. Fish and Wildlife Service was represented by Ms. Jane Ledwin, Fish and Wildlife Biologist. The Missouri Department of Natural Resources was represented by Ms. Kelsey Thompson.

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BACKGROUND

1. Problem Description

Bangert Island at River Mile (RM) 31.1 to RM 29.0 on the Missouri River was once an island separated from the bluff at St. Charles by a side channel. However, closure structures were constructed in the 1930s and 1940s that likely led to deposition within the side channel. This deposition choked the original side channel entrance to the point of closure by 1980 and effectively reattached Bangert Island to the bluff. At the time of this study, only portions of the side channel conveyed water to drain Bangert Island and nearby St. Charles neighborhoods along the adjacent bluff.

The closure of the side channel led to the loss of environmental features in this reach of the Missouri River. The side channel provided flow diversity not available in the main river channel. This flow diversity allowed for off river habitat for various aquatic species. The island itself acted as a predator-free habitat for avian species. Before side channel closure, the Bangert Island area had considerably more sandbar areas that are attractive to various species; these have since been buried under plant life and woody debris.

NWK and the City of St. Charles believe that some of the environmental benefits mentioned would return upon the restoration of the side channel.

2. Study Purpose and Goals

The main objective of this study was to determine what conditions maximize the chance for a reopened Bangert Island Side Channel to avoid closure due to deposition. At the same time, these measures were to avoid negatively impacting navigation channel, the I-70 (Blanchette) Bridge, or Ameristar Casino.

The goals of this study were to:

i. Replicate the existing bathymetry and energy distribution of the study reach using a Hydraulic Sediment Response model.
ii. Replicate anticipated river bathymetry with the side channel installed with no structural changes. The side channel planform was provided by NWK.
iii. Using the model, investigate the channel modification means necessary to promote increased velocities and depths in the side channel.
iv. If a sustainable reopened side channel can be established, evaluate the alternatives based on the following criteria:
    a. Effect on flow and sedimentation changes in the main navigation channel.
    b. Effect on flow and sedimentation changes on the I-70 (Blanchette) Bridge structure immediately downstream of the side channel.
    c. Effect on flow and sedimentation changes on the Ameristar Casino.
v. Communicate to USACE – NWK, St. Charles representatives and staff, environmental agencies, other governmental agencies, and relevant interested parties the results of the study.

3. Study Reach

Over six miles of the Missouri River in the vicinity of St. Charles, MO was modeled. The reach extended from RM 34.3 to RM 28.1. The study reach was located in both St. Charles and St. Louis County. **Plate 1** is a location and vicinity map of the study reach.

An aerial photo of the reach with nomenclature is provided on **Plate 2**. The study reach began at RM 34.3, slightly upstream of Jane Dowing Island and Chute. The Rt. 364 (Page Avenue Extension) Bridge crossed the reach at RM 32.6 and constricted the navigation channel down to 500 ft. There was a quarry with a fleeting operation located on the Left Descending Bank (LDB) at RM 31.3. The entrance to the proposed side channel was on the LDB at RM 31.05. A tributary creek joined the channel at RM 30.7 on the Right Descending Bank (RDB). The proposed side channel reconnected to the main channel at RM 29.65. The I-70 (Blanchette) Bridge crossed over the channel at RM 29.6. The potential for additional scour at the bridge piers was a concern during the modeling process. The bridge piers constricted the navigation channel to 400 ft. The Ameristar Casino was located directly downstream of the I-70 Bridge along the LDB and slightly protruded into the channel. The flow patterns and additional scour around the Ameristar Casino were also a concern during the modeling process. A remnant channel of the previous side channel connected to the main channel at RM 29.0. There was a small dock located on the LDB at RM 28.9 and a larger fleeting operation from RM 28.2 to RM 27.8 along the RDB.

Bankline stability for the Missouri River was analyzed by reviewing aerial photography from 1958 to the present. The relative stability of the banklines historically suggests that the assumption of fixed boundaries in the HSR model was reasonable.

There were seventeen dike structures modeled along the LDB of the study reach. Fifteen dike structures were modeled along the RDB. The LDB had three areas of revetment that were specifically modeled as part of the study; the RDB had two areas. In total, 37 structures were initially modeled in the study reach.

The location of Bangert Island presents multiple challenges for side channel rehabilitation including, but not limited to:

- The island is located on the inside of a bend.
- There are currently structures blocking the side channel entrance from the main channel.
- Present plans call for the new side channel to have a different alignment than the previous side channel.
- There are bridge piers in the vicinity of the proposed side channel exit

Bangert Island currently is operated by the Missouri Department of Conservation and the St. Charles County Parks Department as the Louis H. Bangert Memorial Wildlife Area. The Department of Conservation manages the park under a 30-year, renewable lease from the Kurtz family. The 160-acre park includes 2.6 miles of unfinished trails used by hikers and mountain bikers. The park is occasionally un-accessible due to flooding along the old Bangert Island side channel. The Katy Trail acts as a perimeter for much of the island, with a number of houses built on the eastern side of the trail.

4. Study Reach Channel Characteristics and General Trends

A. Bathymetry

Hydrographic surveys of the Missouri River between 1998 and 2009 used in the HSR Model extents are shown on **Plates 3-6**. The contours and resulting bathymetry were developed from interpolation of 250 ft interval range lines. The geometries of the replication test scan, prototype hydrographic surveys, and all alternative scans were referenced to the Construction Reference Plane (CRP). The CRP is an theoretical sloping plane based on the 75% exceedance discharge calculated from the daily mean stream flow data. The plane is used to facilitate the design of structure heights on the Missouri River. Referencing the surveys and scans to the CRP allowed for direct visual comparison between surveys and scans. For the area of interest around the proposed side channel, 0 ft CRP roughly corresponds to a Mean Sea Level (MSL) elevation of 425.5 ft. The following bathymetric trends were observed in the study reach:

River Miles	Description
34.3 – 32.8	There was a 90° bend in the river. After the initial bend, the flow was oriented towards the northeast. Depths along the thalweg reached 33 ft below CRP. A corresponding point bar formed along the RDB. The point bar reached a height of 3 ft above CRP. Through the bend, the point bar constricted the navigation channel to approximately 400 ft.
32.8 – 31.1	A crossing occurred between RM 32.3 - 31.1 with depths reaching approximately 34 ft below CRP. A divided flow transition began at approximately RM 32.3 and continued until the flow re-established itself along the RDB bank at RM 31.3. The length and complex geometry of this transition posed a potential modeling difficulty. A point bar developed at RM 31.2 due to a left bend in river. The elevation of this bar acted as an impediment to channeling additional energy to the proposed side channel.
31.1 – 28.9	The thalweg was located along the RDB. Depths along the thalweg reached -33 ft CRP. A corresponding point bar formed along the LDB. The point bar reached a height of 2 ft above CRP. The entrance of the proposed side channel would be built at RM 31.0 on the LDB. The exit of the channel would be built at RM 29.7.
28.9 – 28.1	A crossing occurred between RM 28.9 – 28.1, with depths of reaching approximately 34 ft below CRP.

B. Site Visit Data Collection

An initial site visit was conducted November 19, 2010. The full site visit description is included in **Appendix 3**. The major findings from the visit were: 1) sections of the old side channel remain active and convey drainage both from Bangert Island and creeks running from nearby neighborhoods of St. Charles, 2) no topography (such as depressions or rock formations) exist that would naturally favor the proposed side channel alignment, and 3) both the LDB of the Missouri River and Bangert Island appear to be formed from highly erodible material, suggesting that the side channel would require measures to “lock in” or sustain the proposed geometry.

A second trip was taken March 30, 2011 with the specific goal of collecting bed sediment samples to determine bed material. Samples were collected with a grab sampler operated with a tension pin. Multiple samples were taken at each sample location. Sample sites are shown on **Plate 7**. The collected samples all revealed relatively uniform sand that included smaller gravel particles. Two samples gathered included coal material assumed to have fallen from a barge.

HSR MODELING

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. A summary of the theory behind the replication process can be found in **Appendix 2**. 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 or geologic survey data as relevant.

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.

2. Scales and Bed Materials

The model was constructed to a horizontal scale of 1 inch = 300 ft, or 1:3600, and a vertical scale of 1 inch = 27 feet, or 1:324, for approximately an 11 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. The zero reference plane of the prototype was assumed to be CRP. The bed consisted of granular plastic urea, Type II, having 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 a 2009 aerial photography of the study reach. The model bank lines were routed into the polystyrene foam and modified with either polymesh or clay as necessary during calibration. The flume was equipped with rotational jacks to control the slope. The slope on this model was determined to be 0.006 ft / 100 ft. River training structures in the model were made of galvanized steel mesh to generate the appropriate scaled roughness. A picture of the HSR model can be seen on **Plate 8**.

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 flow rate. A flow rate of 3.96 gal / min was held constant for model replication and during all alternative testing. This served as the average expected energy response of the river. Because of the constant variation experienced by 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

In order to document results from the HSR model, accurate data needed to be collected and compared to river data.

A. Laser Scanner

The model bed was surveyed with a high definition, three-dimensional laser scanner that collects a dense cloud of xyz data points. These xyz data points were then geo-referenced 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. Detailed comparisons between the model and the prototype surveys can be found in Section 6A.

B. Laser Doppler Velocimeter (1D LDV)

The magnitude (speed) and direction of flow in the model was measured with the LDV. Use of the 1D LDV required two scans to be taken at each location for the replication test and each alternative. The data collected was then processed to produce velocity vector transects. Each velocity vector transect was normalized to the highest vector magnitude in the transect. The resulting normalized vectors were then sized and color coded using standard vector arrow sizes and color tables.

6. Replication Test

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

A. Bathymetry

Bathymetric trends were recorded from the model using a 3-D Laser Scanner. 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 bathymetry replication test for the model and is shown on **Plate 9**.

Results of the HSR model replication test bathymetry and a comparison to the 1989, 2007, 2008, and 2009 prototype surveys indicated the following:

Starting at RM 32.7, depths between -14 ft to -18 ft dominated the channel. The prototype surveys indicated more elevation variability on the RDB immediately south of the I-364 (page Ave. Extension) Bridge. Both the model and the prototype surveys had scour occurring off the tips of the structures at RM 32.25 and 31.9, although the model showed this as continuous scour. At RM 31.6, the LDB displayed a slightly higher elevation on the prototype surveys than the model. Both the model and prototype surveys displayed a transition of the thalweg to the RDB by RM 31.3. The dominance of the thalweg on the RDB began roughly 0.2 RM downstream on the model test as compared to the prototype surveys. The model maintained a lower elevation at the thalweg through the bend. The point bar that had developed on the LDB starting at RM 31.4 consistently showed a more gradual elevation transition in the prototype surveys than in the model. This same point bar displayed an extension of higher elevation out into the channel at RM 29.6 in the prototype surveys. The LDB point bar from RM 29.4 to RM 28.7 showed more deposition on the prototype surveys than the model. Overall, the general trends of the model were very similar to the general trends of the prototype.

Further detailed calculations on model cross sections were compared directly to the prototype and are shown in **Appendix 4**. 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.

B. Velocity

Velocity measurements were taken with the 1-dimensional Laser Doppler Velocimeter (1D LDV) for the base test and all alternatives. Measurements were taken after the model bathymetry was determined to have reached an equilibrium energy response. Two locations were scanned with the 1D LDV; one location captured the vicinity around and in the entrance of the proposed side channel, the other captured the exit. The two locations were chosen to capture changes in energy distribution at the side channel entrance and effects of the energy distribution change on downstream structures.

Initial use of the LDV was found to return incorrect values for velocity measurements taken in the side channel. It was hypothesized that the shallow depth in the side channel was the cause, which necessitated the use of an additional tailgate to raise the water level. The water surface elevation without the secondary gate was ~0 ft CRP; with the secondary gate, the water surface elevation was ~+10 ft CRP. To determine the effects of the additional gate on the energy distribution, velocity measurements were taken of the replication test with and without the additional gate. The normalized velocity distributions taken for the replication test of the model without the second gate can be seen on **Plates 10 and 11** and the distributions taken with the second gate can be seen on **Plates 12 and 13**. A qualitative comparison of the distributions suggested a highly similar response, leading to the second gate being used for all subsequent LDV measurements.

The normalized velocity measurements at the upstream measurement location demonstrate the end of the transition of the main flow path from the LDB to the RDB. At the same time, the development of the point bar along the LDB demonstrates the change from high to low velocities caused by an increased bed elevation. The downstream measurement location shows the same change from high to low velocities caused by an increased bed elevation. The downstream has the addition of the Ameristar Casino protruding into the flow, but with the velocities low on the point bar, little effect is registered. The normalized velocity in the vicinity of the Ameristar Casino was approximately 20% - 30% of the maximum velocity.

7. Design Alternative Tests

The testing process consisted of modeling alternative measures in the HSR model followed by analyses of the bathymetry and velocity results. The goal was to increase the side channel velocity and positively alter the bathymetry and/or velocity in the side channel without negatively impacting the navigation channel, the I-70 (Blanchette) Bridge, and Ameristar Casino. Evaluation of each alternative was accomplished through a qualitative comparison to the model replication test bathymetry, model replication test velocity (LDV) data, and visual observation of the model.

The design elevation for the side channel bed was -5 ft CRP. The design elevation for river training structures was +12 ft CRP.

Alternative 1: *Definition (Plate 14)*

Alternative Actions	River Mile	LDB or RDB	Length (Feet)	Existing Structure Top Elevation (ft in MSL)
Open Side Channel	31.1	LDB	7350	-

Results: *Bathymetry (Plate 15) and Velocity (Plates 16 and 17)*

Deposition / Erosion in the Side Channel (CRP)	Deposition / Erosion in the Navigation Channel, at Blanchette Bridge, or at Ameristar Casino	Additional Comments
Insignificant (± 3 ft)	None	The side channel entrance normalized velocities were 0% - 30% of the maximum main channel velocity. Normalized velocities at the exit were 0% - 30% of the maximum main channel velocity. Velocity in the vicinity of the Ameristar Casino is approximately 40% - 50% of the maximum velocity.

Alternative 2: *Definition (Plate 18)*

Alternative Actions	River Mile	LDB or RDB	Dimensions (Feet)	Existing Structure Top Elevation (ft in MSL)
Remove Portion of Existing Revetment	31.3	LDB	1500	NA
Open Side Channel	31.1	LDB	7350	-
Remove Existing Dike	31.05	LDB	390	429
Remove Existing Dike	31.0	LDB	675	434

Results: *Bathymetry (Plate 19) and Velocity (Plates 20 and 21)*

Deposition / Erosion in the Side Channel (CRP)	Deposition / Erosion in the Navigation Channel, at Blanchette Bridge, or at Ameristar Casino	Additional Comments
Insignificant (± 3 ft)	None	The side channel entrance normalized velocities were 0% - 30% of the maximum main channel velocity. Normalized velocities at the exit were 0% - 30% of the maximum main channel velocity. Velocity in the vicinity of the Ameristar Casino is approximately 30% - 40% of the maximum velocity.

Alternative 3: *Definition (Plate 22)*

Alternative Actions	River Mile	LDB or RDB	Length (Feet)	Existing Structure Top Elevation (ft in MSL)
Remove Portion of Existing Dike	31.5	LDB	300	441
Remove Portion of Existing Revetment	31.3	LDB	1500	NA
Remove Portion of Existing Dike	31.3	LDB	50	442
Open Side Channel	31.1	LDB	7350	-
Remove Existing Dike	31.05	LDB	390	429
Remove Existing Dike	31	LDB	675	434

Results: *Bathymetry (Plate 23) and Velocity (Plates 24 and 25)*

Deposition / Erosion in the Side Channel (CRP)	Deposition / Erosion in the Navigation Channel, at Blanchette Bridge, or at Ameristar Casino	Additional Comments
Insignificant (± 3 ft); minor point bar erosion at entrance (< -4 ft)	None	The side channel entrance normalized velocities were 10% - 30% of the maximum main channel velocity. Normalized velocities at the exit were 10% - 40% of the maximum main channel velocity. Velocity in the vicinity of the Ameristar Casino is approximately 30% - 40% of the maximum velocity.

Alternative 4: *Definition (Plate 26)*

Alternative Actions	River Mile	LDB or RDB	Length (Feet)	Existing Structure Top Elevation (ft in MSL)
Remove Portion of Existing Dike	31.5	LDB	300	441
Remove Portion of Existing Revetment	31.3	LDB	1500	NA
Remove Portion of Existing Dike	31.3	LDB	50	442
Open Side Channel	31.1	LDB	7350	-
Construct New Dike	31.1	LDB	375	-
Remove Existing Dike	31.05	LDB	390	429
Remove Existing Dike	31.0	LDB	675	434

Results: *Bathymetry (Plate 27) and Velocity (Plates 28 and 29)*

Deposition / Erosion in the Side Channel (CRP)	Deposition / Erosion in the Navigation Channel, at Blanchette Bridge, or at Ameristar Casino	Additional Comments
Insignificant (± 3 ft)	Deepening of the channel immediately upstream of the bridge.	The side channel entrance normalized velocities were 10% - 50% of the maximum main channel velocity. Normalized velocities at the exit were 10% - 40% of the maximum main channel velocity. Velocity in the vicinity of the Ameristar Casino is approximately 30-40% of the maximum velocity.

Alternative 5: *Definition (Plate 30)*

Alternative Actions	River Mile	LDB or RDB	Length (Feet)	Existing Structure Top Elevation (ft in MSL)
Remove Portion of Existing Dike	31.5	LDB	300	441
Remove Portion of Existing Revetment	31.3	LDB	1500	NA
Remove Portion of Existing Dike	31.3	LDB	50	442
Open Side Channel	31.1	LDB	7350	-
Construct New Dike	31.1	LDB	585	-
Remove Existing Dike	31.05	LDB	390	429
Remove Existing Dike	31.0	LDB	675	434

Results: *Bathymetry (Plate 31) and Velocity (Plates 32 and 33)*

Deposition / Erosion in the Side Channel (CRP)	Deposition / Erosion in the Navigation Channel, at Blanchette Bridge, or at Ameristar Casino	Additional Comments
Insignificant (± 3 ft); minor point bar erosion at entrance (< -4 ft)	None	The side channel entrance normalized velocities were 0% - 50% of the maximum main channel velocity. Normalized velocities at the exit were 0% - 40% of the maximum main channel velocity. Velocity in the vicinity of the Ameristar Casino is approximately 40-50% of the maximum velocity.

Alternative 6: *Definition (Plate 34)*

Alternative Actions	River Mile	LDB or RDB	Length (Feet)	Existing Structure Top Elevation (ft in MSL)
Remove Portion of Existing Dike	31.5	LDB	300	441
Remove Portion of Existing Revetment	31.3	LDB	1500	NA
Remove Portion of Existing Dike	31.3	LDB	50	442
Construct New Dike	31.2	LDB	990	-
Open Side Channel	31.1	LDB	7350	-
Remove Existing Dike	31.05	LDB	390	429
Remove Existing Dike	31.0	LDB	675	434

Results: *Bathymetry (Plate 35) and Velocity (Plates 36 and 37)*

Deposition / Erosion in the Side Channel (CRP)	Deposition / Erosion in the Navigation Channel, at Blanchette Bridge, or at Ameristar Casino	Additional Comments
Insignificant (± 3 ft); minor point bar erosion at entrance (< -4 ft)	None	The side channel entrance normalized velocities were 10% - 50% of the maximum main channel velocity. Normalized velocities at the exit were 0% - 50% of the maximum main channel velocity. Velocity in the vicinity of the Ameristar Casino is approximately 50-60% of the maximum velocity.

Alternative 7: *Definition (Plate 38)*

Alternative Actions	River Mile	LDB or RDB	Length (Feet)	Existing Structure Top Elevation (ft in MSL)
Remove Portion of Existing Dike	31.5	LDB	300	441
Remove Portion of Existing Revetment	31.3	LDB	1500	NA
Remove Portion of Existing Dike	31.3	LDB	50	442
Construct New Dike	31.3	LDB	1700	-
Open Side Channel	31.1	LDB	7350	-
Remove Existing Dike	31.05	LDB	390	429
Remove Existing Dike	31.0	LDB	675	434

Results: *Bathymetry (Plate 39) and Velocity (Plates 40 and 41)*

Deposition / Erosion in the Side Channel (CRP)	Deposition / Erosion in the Navigation Channel, at Blanchette Bridge, or at Ameristar Casino	Additional Comments
Insignificant (± 3 ft); Deposition (< +4 ft) along RDB of side channel at entrance; Point bar erosion (< -8 ft) outside the entrance; point bar expansion at entrance (approximately 300 ft width)	Deposition downstream of the side channel entrance (approximately 200 ft width).	The side channel entrance normalized velocities were 10% - 60% of the maximum main channel velocity. Normalized velocities at the exit were 10% - 50% of the maximum main channel velocity. Velocity in the vicinity of the Ameristar Casino is approximately 40-50% of the maximum velocity.

Alternative 8: *Definition (Plate 42)*

Alternative Actions	River Mile	LDB or RDB	Length (Feet)	Existing Structure Top Elevation (ft in MSL)
Remove Portion of Existing Dike	31.5	LDB	300	441
Construct New J-Dike	31.5	LDB	705	-
Remove Portion of Existing Revetment	31.3	LDB	1500	NA
Remove Portion of Existing Dike	31.3	LDB	50	442
Construct New Dike	31.15	LDB	225	-
Construct New Dike	31.15	LDB	300	-
Open Side Channel	31.1	LDB	7350	-
Remove Existing Dike	31.05	LDB	390	429
Remove Existing Dike	31.0	LDB	675	434

Results: *Bathymetry (Plate 43) and Velocity (Plates 44 and 45)*

Deposition / Erosion in the Side Channel (CRP)	Deposition / Erosion in the Navigation Channel, at Blanchette Bridge, or at Ameristar Casino	Additional Comments
Insignificant (± 3 ft); point bar erosion at entrance (< -8 ft); point bar expansion at entrance (approximately 450 ft width)	Deepening of the channel immediately upstream and at the bridge (< 4 ft additional depth between 2 piers nearest to RDB). Deposition downstream of the side channel entrance (approximately 200 ft width).	The side channel entrance normalized velocities were 0% - 50% of the maximum main channel velocity. Normalized velocities at the exit were 10% - 40% of the maximum main channel velocity. Velocity in the vicinity of the Ameristar Casino is approximately 40-50% of the maximum velocity.

Alternative 9: *Definition (Plate 46)*

Alternative Actions	River Mile	LDB or RDB	Length (Feet)	Existing Structure Top Elevation (ft in MSL)
Remove Portion of Existing Dike	31.5	LDB	300	441
Construct New Dike	31.4	LDB	950	-
Remove Portion of Existing Revetment	31.3	LDB	1500	NA
Remove Portion of Existing Dike	31.3	LDB	50	442
Open Side Channel	31.1	LDB	7350	-
Construct New Dike	31.1	LDB	100	-
Construct New Dike	31.1	LDB	405	-
Remove Existing Dike	31.05	LDB	390	429
Remove Existing Dike	31.0	LDB	675	434

Results: *Bathymetry (Plate 47) and Velocity (Plates 48 and 49)*

Deposition / Erosion in the Side Channel (CRP)	Deposition / Erosion in the Navigation Channel, at Blanchette Bridge, or at Ameristar Casino	Additional Comments
Insignificant (± 3 ft); point bar erosion at entrance (< -6 ft); point bar expansion at entrance (approximately 450 ft width)	Deposition downstream of the side channel entrance (approximately 200 ft width).	The side channel entrance normalized velocities were 0% - 60% of the maximum main channel velocity. Normalized velocities at the exit were 10% - 40% of the maximum main channel velocity. Velocity in the vicinity of the Ameristar Casino is approximately 30-40% of the maximum velocity.

<u>Alternative 10:</u> *Definition (Plate 50)*

Alternative Actions	River Mile	LDB or RDB	Length (Feet)	Existing Structure Top Elevation (ft in MSL)
Extend Existing Dike	32.15	RDB	100	
Extend and Raise Existing Dike	32.0	RDB	110	
Extend and Raise Existing Dike	31.8	RDB	150	
Construct New Dike	31.65	RDB	420	-
Construct New Dike	31.55	LDB	1270	-
Remove Portion of Existing Dike	31.5	LDB	300	441
Remove Portion of Existing Revetment	31.3	LDB	1500	NA
Remove Portion of Existing Dike	31.3	LDB	50	442
Construct New Dike	31.15	LDB	400	-
Open Side Channel	31.1	LDB	7350	-
Construct New Dike	31.1	LDB	140	-
Remove Existing Dike	31.05	LDB	390	429
Remove Existing Dike	31.0	LDB	675	434

Results: *Bathymetry (Plate 51) and Velocity (Plates 52 and 53)*

Deposition / Erosion in the Side Channel (CRP)	Deposition / Erosion in the Navigation Channel, at Blanchette Bridge, or at Ameristar Casino	Additional Comments
Insignificant (± 3 ft); minor point bar erosion at entrance (< -4 ft); point bar loss at entrance	Deepening of the channel immediately upstream of the bridge. Deposition downstream of the side channel entrance (approximately 200 ft width).	The side channel entrance normalized velocities were 10% - 40% of the maximum main channel velocity. Normalized velocities at the exit were 10% - 40% of the maximum main channel velocity. Velocity in the vicinity of the Ameristar Casino is approximately 40-50% of the maximum velocity.

Alternative 11: *Definition (Plate 54)*

Alternative Actions	River Mile	LDB or RDB	Length (Feet)	Existing Structure Top Elevation (ft in MSL)
Extend Existing Dike	32.15	RDB	100	438
Extend and Raise Existing Dike	32.0	RDB	110	435
Extend and Raise Existing Dike	31.8	RDB	150	430
Construct New Dike	31.65	RDB	420	-
Construct New Dike	31.55	LDB	1270	-
Remove Portion of Existing Dike	31.5	LDB	300	441
Remove Portion of Existing Revetment	31.3	LDB	1500	NA
Remove Portion of Existing Dike	31.3	LDB	50	442
Open Side Channel	31.1	LDB	7350	-
Remove Existing Dike	31.05	LDB	390	429
Remove Existing Dike	31.0	LDB	675	434

Results: *Bathymetry (Plate 55) and Velocity (Plates 56 and 57)*

Deposition / Erosion in the Side Channel (CRP)	Deposition / Erosion in the Navigation Channel, at Blanchette Bridge, or at Ameristar Casino	Additional Comments
Insignificant (± 3 ft); point bar loss at entrance (approximately 200 ft width)	Deepening of the channel immediately upstream of the bridge. Erosion downstream of the side channel entrance (approximately 200 ft width).	Proposed structures along RDB force channel against LDB for RM 32.0 – RM 31.0 instead of transition zone. The side channel entrance normalized velocities were 10% - 40% of the maximum main channel velocity. Normalized velocities at the exit were 10% - 40% of the maximum main channel velocity. Velocity in the vicinity of the Ameristar Casino is approximately 40-50% of the maximum velocity.

Alternative 12: *Definition (Plate 58)*

Alternative Actions	River Mile	LDB or RDB	Length (Feet)	Existing Structure Top Elevation (ft in MSL)
Extend and Raise Existing Dike	32.0	RDB	290	435
Extend and Raise Existing Dike	31.8	RDB	300	430
Construct New Dike	31.65	RDB	650	-
Construct New Dike	31.55	LDB	1270	-
Remove Portion of Existing Dike	31.5	LDB	300	441
Construct New Dike	31.5	RDB	650	-
Remove Portion of Existing Revetment	31.3	LDB	1500	NA
Remove Portion of Existing Dike	31.3	LDB	50	442
Construct New Dike	31.3	RDB	650	-
Open Side Channel	31.1	LDB	7350	-
Remove Existing Dike	31.05	LDB	390	429
Remove Existing Dike	31.0	LDB	675	434

Results: *Bathymetry (Plate 59) and Velocity (Plates 60 and 61)*

Deposition / Erosion in the Side Channel (CRP)	Deposition / Erosion in the Navigation Channel, at Blanchette Bridge, or at Ameristar Casino	Additional Comments
Insignificant (± 3 ft); point bar loss at entrance (approximately 300 ft width)	Deepening of the channel immediately upstream of the bridge. Erosion downstream of the side channel entrance (approximately 350 ft width).	Proposed structures along RDB force channel against LDB for RM 32.0 – RM 31.0 instead of transition zone. The side channel entrance normalized velocities were 10% - 60% of the maximum main channel velocity. Normalized velocities at the exit were 10% - 50% of the maximum main channel velocity. Velocity in the vicinity of the Ameristar Casino is approximately 40-50% of the maximum velocity.

Alternative 13: *Definition (Plate 62)*

Alternative Actions	River Mile	LDB or RDB	Length (Feet)	Existing Structure Top Elevation (ft in MSL)
Extend and Raise Existing Dike	32.0	RDB	290	435
Extend and Raise Existing Dike	31.8	RDB	300	430
Construct New Dike	31.65	RDB	650	-
Construct New Dike	31.55	LDB	1270	-
Remove Portion of Existing Dike	31.5	LDB	300	441
Construct New Dike	31.5	RDB	650	-
Remove Portion of Existing Revetment	31.3	LDB	1500	NA
Remove Portion of Existing Dike	31.3	LDB	50	442
Construct New Dike	31.3	RDB	650	-
Open Side Channel	31.1	LDB	7350	-
Construct New Dike	31.1	LDB	660	-
Remove Existing Dike	31.05	LDB	390	429
Remove Existing Dike	31.0	LDB	675	434

Results: *Bathymetry (Plate 63) and Velocity (Plates 64 and 65)*

Deposition / Erosion in the Side Channel (CRP)	Deposition / Erosion in the Navigation Channel, at Blanchette Bridge, or at Ameristar Casino	Additional Comments
Insignificant (± 3 ft); point bar deposition at entrance (< +5 ft) at entrance; point bar loss at entrance (approximately 200 ft width)	Deepening of the channel immediately upstream of the bridge. Erosion downstream of the side channel entrance (approximately 200 ft width).	Proposed structures along RDB force channel against LDB for RM 32.0 – RM 31.0 instead of transition zone. The side channel entrance normalized velocities were 10% - 50% of the maximum main channel velocity. Normalized velocities at the exit were 10% - 40% of the maximum main channel velocity. Velocity in the vicinity of the Ameristar Casino is approximately 30-40% of the maximum velocity.

Alternative 14: *Definition (Plate 66)*

Alternative Actions	River Mile	LDB or RDB	Length (Feet)	Existing Structure Top Elevation (ft in MSL)
Extend and Raise Existing Dike	32.0	RDB	290	435
Extend and Raise Existing Dike	31.8	RDB	300	430
Construct New Dike	31.65	RDB	650	-
Construct New Dike	31.55	LDB	1270	-
Remove Portion of Existing Dike	31.5	LDB	300	441
Construct New Dike	31.5	RDB	650	-
Remove Portion of Existing Revetment	31.3	LDB	1500	NA
Remove Portion of Existing Dike	31.3	LDB	50	442
Construct New Dike	31.3	RDB	650	-
Construct New Chevron	31.2	LDB	270	-
Open Side Channel	31.1	LDB	7350	-
Construct New Chevron	31.1	LDB	270	-
Remove Existing Dike	31.05	LDB	390	429
Construct New Dike	31.05	LDB	220	-
Remove Existing Dike	31.0	LDB	675	434

Results: *Bathymetry (Plate 67) and Velocity (Plates 68 and 69)*

Deposition / Erosion in the Side Channel (CRP)	Deposition / Erosion in the Navigation Channel, at Blanchette Bridge, or at Ameristar Casino	Additional Comments
Insignificant (± 3 ft); minor point bar erosion at entrance (< -4 ft); point bar loss at entrance (approximately 300 ft width)	Deepening of the channel immediately upstream and at the bridge (~5 ft additional depth between 2 piers nearest to RDB). Erosion downstream of the side channel entrance (approximately 150 ft width).	Proposed structures along RDB force channel against LDB for RM 32.0 – RM 31.0 instead of transition zone. The side channel entrance normalized velocities were primarily 0% - 50% of the maximum main channel velocity. Normalized velocities at the exit were 10% - 50% of the maximum main channel velocity. Velocity in the vicinity of the Ameristar Casino is approximately 40-50% of the maximum velocity.

Alternative 15: *Definition (Plate 70)*

Alternative Actions	River Mile	LDB or RDB	Length (Feet)	Existing Structure Top Elevation (ft in MSL)
Extend and Raise Existing Dike	32.0	RDB	290	435
Extend and Raise Existing Dike	31.8	RDB	300	430
Construct New Dike	31.65	RDB	650	-
Construct New Dike	31.55	LDB	1270	-
Remove Portion of Existing Dike	31.5	LDB	300	441
Construct New Dike	31.5	RDB	650	-
Remove Portion of Existing Revetment	31.3	LDB	1500	NA
Remove Portion of Existing Dike	31.3	LDB	50	442
Construct New Dike	31.3	RDB	650	-
Construct New Dike	31.15	LDB	50	-
Construct New Dike	31.15	LDB	210	-
Open Side Channel	31.1	LDB	7350	-
Remove Existing Dike	31.05	LDB	390	429
Remove Existing Dike	31.0	LDB	675	434

Results: *Bathymetry (Plate 71) and Velocity (Plates 72 and 73)*

Deposition / Erosion in the Side Channel (CRP)	Deposition / Erosion in the Navigation Channel, at Blanchette Bridge, or at Ameristar Casino	Additional Comments
Insignificant (± 3 ft); point bar loss at entrance (approximately 400 ft width)	Deepening of the channel upstream of the bridge. Erosion downstream of the side channel entrance (approximately 200 ft width).	Proposed structures along RDB force channel against LDB for RM 32.0 – RM 31.0 instead of a transition zone. The side channel entrance normalized velocities were primarily 0% - 50% of the maximum main channel velocity. Normalized velocities at the exit were 10% - 50% of the maximum main channel velocity. Velocity in the vicinity of the Ameristar Casino is approximately 40-50% of the maximum velocity.

Alternative 16: *Definition (Plate 74)*

Alternative Actions	River Mile	LDB or RDB	Length (Feet)	Existing Structure Top Elevation (ft in MSL)
Construct New Dike	32.15	LDB	350	-
Construct New Dike	31.95	LDB	350	-
Construct New Dike	31.8	LDB	350	-
Construct New Dike	31.7	LDB	350	-
Remove Portion of Existing Dike	31.5	LDB	300	441
Remove Portion of Existing Revetment	31.3	LDB	1500	NA
Remove Portion of Existing Dike	31.3	LDB	50	442
Open Side Channel	31.1	LDB	7350	-
Construct New Dike	31.1	LDB	320	-
Remove Existing Dike	31.05	LDB	390	429
Remove Existing Dike	31.0	LDB	675	434

Results: *Bathymetry (Plate 75) and Velocity (Plates 76 and 77)*

Deposition / Erosion in the Side Channel (CRP)	Deposition / Erosion in the Navigation Channel, at Blanchette Bridge, or at Ameristar Casino	Additional Comments
Insignificant (± 3 ft)	-	Deposition along LDB from RM 32.2 – 31.65. The side channel entrance normalized velocities were primarily 0% - 30% of the maximum main channel velocity. Normalized velocities at the exit were 0% - 40% of the maximum main channel velocity. Velocity in the vicinity of the Ameristar Casino is approximately 30-40% of the maximum velocity.

Alternative 17: *Definition (Plate 78)*

Alternative Actions	River Mile	LDB or RDB	Length (Feet)	Existing Structure Top Elevation (ft in MSL)
Construct New Dike	31.7	LDB	180	-
Construct New Dike	31.65	RDB	330	-
Construct New Dike	31.55	RDB	460	-
Construct New Dike	31.55	LDB	1270	-
Remove Portion of Existing Dike	31.5	LDB	300	441
Construct New Dike	31.4	RDB	580	-
Remove Portion of Existing Revetment	31.3	LDB	1500	NA
Remove Portion of Existing Dike	31.3	LDB	50	442
Construct New Dike	31.25	RDB	650	-
Open Side Channel	31.1	LDB	7350	-
Construct New Dike	31.1	RDB	690	-
Construct New Dike	31.1	LDB	240	-
Remove Existing Dike	31.05	LDB	390	429
Remove Existing Dike	31.0	LDB	675	434
Remove Existing Dike	30.9	LDB	1125	429

Results: *Bathymetry (Plate 79) and Velocity (Plates 80 and 81)*

Deposition / Erosion in the Side Channel (CRP)	Deposition / Erosion in the Navigation Channel, at Blanchette Bridge, or at Ameristar Casino	Additional Comments
Insignificant (± 3 ft); point bar loss at entrance (approximately 350 ft width)	Erosion downstream of the side channel entrance (up to 600 ft width). Deepening of the channel immediately upstream of the bridge.	Proposed structures along RDB force channel against LDB for RM 31.7 – RM 30.5. The side channel entrance normalized velocities were primarily 0% - 50% of the maximum main channel velocity. Normalized velocities at the exit were 10% - 50% of the maximum main channel velocity. Velocity in the vicinity of the Ameristar Casino is approximately 40-50% of the maximum velocity.

__Alternative 18:__ *Definition (Plate 82)*

Alternative Actions	River Mile	LDB or RDB	Length (Feet)	Existing Structure Top Elevation (ft in MSL)
Remove Portion of Existing Dike	31.5	LDB	300	441
Remove Portion of Existing Revetment	31.3	LDB	1500	NA
Remove Portion of Existing Dike	31.3	LDB	50	442
Expand Side Channel Entrance 450 ft Upstream	31.2	LDB	200	-
Open Side Channel	31.1	LDB	7350	-
Remove Existing Dike	31.05	LDB	390	429
Remove Existing Dike	31.0	LDB	675	434

Results: *Bathymetry (Plate 83) and Velocity (Plates 84 and 85)*

Deposition / Erosion in the Side Channel (CRP)	Deposition / Erosion in the Navigation Channel, at Blanchette Bridge, or at Ameristar Casino	Additional Comments
Insignificant (± 3 ft); minor point bar erosion at entrance (< -4 ft)	Deposition downstream of side channel entrance (approximately +4 ft for 300 ft width)	The side channel entrance normalized velocities were primarily 0% - 40% of the maximum main channel velocity. Normalized velocities at the exit were 10% - 30% of the maximum main channel velocity. Velocity in the vicinity of the Ameristar Casino is approximately 30-40% of the maximum velocity.

<u>Alternative 19:</u> *Definition (Plate 86)*

Alternative Actions	River Mile	LDB or RDB	Length (Feet)	Existing Structure Top Elevation (ft in MSL)
Remove Portion of Existing Dike	31.5	LDB	300	441
Remove Portion of Existing Revetment	31.3	LDB	1500	NA
Remove Portion of Existing Dike	31.3	LDB	50	442
Expand Side Channel Entrance 450 ft Upstream	31.2	LDB	200	-
Open Side Channel	31.1	LDB	7350	-
Construct New Dike	31.1	LDB	280	-
Remove Existing Dike	31.05	LDB	390	429
Remove Existing Dike	31.0	LDB	675	434

Results: *Bathymetry (Plate 87) and Velocity (Plates 88 and 89)*

Deposition / Erosion in the Side Channel (CRP)	Deposition / Erosion in the Navigation Channel, at Blanchette Bridge, or at Ameristar Casino	Additional Comments
Insignificant (± 3 ft); minor point bar erosion at entrance (< -4 ft)	Deposition downstream of side channel entrance (approximately +4 ft for 250 ft width)	The side channel entrance normalized velocities were primarily 0% - 60% of the maximum main channel velocity. Normalized velocities at the exit were 10% - 50% of the maximum main channel velocity. Velocity in the vicinity of the Ameristar Casino is approximately 40-50% of the maximum velocity.

Alternative 20: *Definition (Plate 90)*

Alternative Actions	River Mile	LDB or RDB	Length (Feet)	Existing Structure Top Elevation (ft in MSL)
Remove Portion of Existing Dike	31.5	LDB	300	441
Remove Portion of Existing Revetment	31.3	LDB	1500	NA
Remove Portion of Existing Dike	31.3	LDB	50	442
Expand Side Channel Entrance 450 ft Upstream	31.2	LDB	200	-
Open Side Channel	31.1	LDB	7350	-
Construct New Dike	31.1	LDB	375	-
Remove Existing Dike	31.05	LDB	390	429
Remove Existing Dike	31.0	LDB	675	434

Results: *Bathymetry (Plate 91) and Velocity (Plates 92 and 93)*

Deposition / Erosion in the Side Channel (CRP)	Deposition / Erosion in the Navigation Channel, at Blanchette Bridge, or at Ameristar Casino	Additional Comments
Insignificant (± 3 ft); minor point bar erosion at entrance (< -4 ft)	Minor deposition in navigation channel at and immediately downstream of side channel entrance (approximately +2 ft for 150 ft width)	The side channel entrance normalized velocities were primarily 10% - 50% of the maximum main channel velocity. Normalized velocities at the exit were 10% - 50% of the maximum main channel velocity. Velocity in the vicinity of the Ameristar Casino is approximately 40-50% of the maximum velocity.

Alternative 21: *Definition (Plate 94)*

Alternative Actions	River Mile	LDB or RDB	Length (Feet)	Existing Structure Top Elevation (ft in MSL)
Remove Portion of Existing Revetment	31.3	LDB	1500	NA
Remove Portion of Existing Dike	31.3	LDB	50	442
Open Side Channel	31.1	LDB	7350	-
Construct New Dike	31.1	LDB	375	-
Remove Existing Dike	31.05	LDB	390	429
Remove Existing Dike	31.0	LDB	675	434

Results: *Bathymetry (Plate 95) and Velocity (Plates 96 and 97)*

Deposition / Erosion in the Side Channel (CRP)	Deposition / Erosion in the Navigation Channel, at Blanchette Bridge, or at Ameristar Casino	Additional Comments
Insignificant (± 3 ft); minor point bar erosion at entrance (< -4 ft); minor point bar loss at entrance (approximately 100 ft width)	Minor deposition in navigation channel at and immediately downstream of side channel entrance (approximately +2 ft for 200 ft width)	The side channel entrance normalized velocities were primarily 0% - 40% of the maximum main channel velocity. Normalized velocities at the exit were 10% - 40% of the maximum main channel velocity. Velocity in the vicinity of the Ameristar Casino is approximately 40-50% of the maximum velocity.

Alternative 22: *Definition (Plate 98)*

Alternative Actions	River Mile	LDB or RDB	Length (Feet)	Existing Structure Top Elevation (ft in MSL)
Remove Portion of Existing Revetment	31.3	LDB	1500	NA
Open Side Channel	31.1	LDB	7350	-
Construct New Dike	31.1	LDB	375	-
Remove Existing Dike	31.05	LDB	390	429
Remove Existing Dike	31.0	LDB	675	434

Results: *Bathymetry (Plate 99) and Velocity (Plates 100 and 101)*

Deposition / Erosion in the Side Channel (CRP)	Deposition / Erosion in the Navigation Channel, at Blanchette Bridge, or at Ameristar Casino	Additional Comments
Insignificant (± 3 ft); minor point bar loss at entrance (approximately 100 ft width)	None	The side channel entrance normalized velocities were primarily 0% - 30% of the maximum main channel velocity. Normalized velocities at the exit were 10% - 40% of the maximum main channel velocity. Velocity in the vicinity of the Ameristar Casino is approximately 40-50% of the maximum velocity.

Alternative 23: *Definition (Plate 102)*

Alternative Actions	River Mile	LDB or RDB	Length (Feet)	Existing Structure Top Elevation (ft in MSL)
Remove Portion of Existing Revetment	31.3	LDB	3000	NA
Remove Portion of Existing Dike	31.3	LDB	50	442
Open Side Channel	31.1	LDB	7350	-
Construct New Dike	31.1	LDB	375	-
Remove Existing Dike	31.05	LDB	390	429
Remove Existing Dike	31.0	LDB	675	434
Remove Existing Dike	30.9	LDB	1125	429
Open Secondary Entrance	30.75	LDB	1050	-

Results: *Bathymetry (Plate 103) and Velocity (Plates 104 and 105)*

Deposition / Erosion in the Side Channel (CRP)	Deposition / Erosion in the Navigation Channel, at Blanchette Bridge, or at Ameristar Casino	Additional Comments
Insignificant (± 3 ft); minor point bar erosion at entrance (< -4 ft)	Minor deposition in navigation channel at and immediately downstream of side channel entrance (approximately +4 ft)	The side channel entrance normalized velocities were primarily 0% - 30% of the maximum main channel velocity. Normalized velocities at the exit were 10% - 40% of the maximum main channel velocity. Velocity in the vicinity of the Ameristar Casino is approximately 40-50% of the maximum velocity.

Alternative 24: *Definition (Plate 106)*

Alternative Actions	River Mile	LDB or RDB	Length (Feet)	Existing Structure Top Elevation (ft in MSL)
Remove Portion of Existing Dike	31.5	LDB	300	441
Remove Portion of Existing Revetment	31.3	LDB	1500	NA
Remove Portion of Existing Dike	31.3	LDB	50	442
Open Side Channel	31.1	LDB	7350	-
Construct New Dike	31.1	LDB	375	-
Remove Existing Dike	31.05	LDB	390	429
Remove Existing Dike	31.0	LDB	675	434
Construct New Dike	29.65	LDB	465	-

Results: *Bathymetry (Plate 107) and Velocity (Plate 108)*

Deposition / Erosion in the Side Channel (CRP)	Deposition / Erosion in the Navigation Channel, at Blanchette Bridge, or at Ameristar Casino	Additional Comments
Insignificant (± 3 ft); minor point bar erosion at entrance (< -4 ft)	Minor deposition in navigation channel at and immediately downstream of side channel entrance (approximately +4 ft)	Normalized velocities at the exit were 10% - 40% of the maximum main channel velocity. Velocity in the vicinity of the Ameristar Casino is approximately 30-40% of the maximum velocity.

CONCLUSIONS

1. Evaluation and Summary of the Model Tests (Condition Analyses Combined)

Alternative	Deposition / Erosion in the Side Channel	Deposition / Erosion in the Navigation Channel, at Blanchette Bridge, or at Ameristar Casino	Velocity Measurements (Side Channel Entrance / Exit / Ameristar Casino, % of Main Channel Flow)
Alternative 1	-	-	0% - 30% / 0% - 30% / 40% - 50%
Alternative 2	-	-	0% - 30% / 0% - 30% / 30% - 40%
Alternative 3	Entrance erosion	-	10% - 30% / 10% - 40% / 30% - 40%
Alternative 4	-	Erosion upstream of Bridge	10% - 50% / 10% - 40% / 30% - 40%
Alternative 5	Entrance erosion	-	0% - 50% / 0% - 40% / 40% - 50%
Alternative 6	Entrance erosion	-	10% - 50% / 0% - 50% / 50% - 60%
Alternative 7	Entrance erosion; Point bar expansion	Deposition downstream of entrance	10% - 60% / 10% - 50% / 40% - 50%
Alternative 8	Entrance erosion; Point bar expansion	Deposition downstream of entrance; Erosion upstream of Bridge	0% - 50% / 10% - 40% / 40% - 50%
Alternative 9	Entrance erosion; Point bar expansion	Deposition downstream of entrance	0% - 60% / 10% - 40% / 30% - 40%
Alternative 10	Entrance erosion; Point bar loss	Deposition downstream of entrance; Erosion upstream of Bridge	10% - 40% / 10% - 40% / 40% - 50%
Alternative 11	Point bar loss	Erosion downstream of entrance; Erosion upstream of Bridge	10% - 40% / 10% - 40% / 40% - 50%
Alternative 12	Point bar loss	Erosion downstream of entrance; Erosion upstream of Bridge	10% - 60% / 10% - 50% / 40% - 50%
Alternative 13	Entrance deposition; Point bar loss	Erosion downstream of entrance; Erosion upstream of Bridge	10% - 50% / 10% - 40% / 30% - 40%
Alternative 14	Entrance erosion; Point bar loss	Erosion downstream of entrance; Erosion upstream of Bridge	0% - 50% / 10% - 50% / 40% - 50%
Alternative 15	Point bar loss	Erosion downstream of entrance; Erosion upstream of Bridge	0% - 50% / 10% - 50% / 40% - 50%
Alternative 16	-	-	0% - 30% / 0% - 40% / 30% - 40%
Alternative 17	Point bar loss	Erosion downstream of entrance; Erosion upstream of Bridge	0% - 50% / 10% - 50% / 40% - 50%
Alternative 18	Entrance erosion	Deposition downstream of entrance	0% - 40% / 10% - 30% / 30% - 40%
Alternative 19	Point bar loss	Deposition downstream of entrance	0% - 60% / 10% - 50% / 40% - 50%
Alternative 20	Entrance erosion	Deposition downstream of entrance	10% - 50% / 10% - 50% / 40% - 50%
Alternative 21	Entrance erosion; Point bar loss	Deposition at and downstream of entrance	0% - 40% / 10% - 40% / 40% - 50%
Alternative 22	Entrance erosion	-	0% - 30% / 10% - 40% / 40% - 50%
Alternative 23	Entrance erosion	Deposition at and downstream of entrance	0% - 30% / 10% - 40% / 40% - 50%
Alternative 24	Entrance erosion	Deposition at and downstream of entrance	- / 10% - 40% / 30% - 40%

In order to determine the best alternative, certain criteria, based on the study purpose and goals, were used to evaluate each alternative. The first condition was that the alternative could not lead to deposition in the vicinity of the side channel entrance. The second condition was that there was to be no encroachment of the point bar into the main navigation channel. The third condition was constructability, based on cost and required changes to the side channel. The final condition was the degree and uniformity of velocity changes within the entire side channel. Some of the Alternatives that met the criterion but were not chosen were alternatives 5, 6, and 19.

2. Recommendations

Alternative 4, Plates 26-29, was recommended as the most desirable alternative because it increased the normalized velocities within the side channel without having detrimental effects on the navigation channel, the I-70 (Blanchette) Bridge, or Ameristar Casino. This alternative was chosen over the three alternatives mentioned above because it demonstrated more consistent increases in side channel normalized velocity. Increasing the normalized velocity in the side channel qualitatively increases the fine sediment transport capacity, lowering the risk of sedimentation compared to simply opening the side channel (as seen in Alternative 1). According to the bathymetry, this alternative did not demonstrate the propensity for near-entrance deposition exhibited by other alternatives. This comparatively lowers the risk of sedimentation due to bedload movement. The addition of an additional side entrance (Alternative 23) or downstream diversion structure (Alternative 24) did not improve the performance of this alternative.

There is no means to guarantee that a reopened side channel at Bangert Island would not require dredging at some future date. It is, however, the recommendation of the authors that the suggested alternative provides the best attempt at keeping the side channel open.

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 Missouri River and Bangert Island side channel 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 ADDITIONAL INFORMATION

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Appendix 1: Plates

Appendix 2: HSR 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/reports/Hydraulic%20Sediment%20Response%20Modeling,%20Replication%20Accuracy,%20TPM53.pdf

Appendix 3: November 18, 2010 Site Visit

AREC staff consisting of Timothy Lauth, Jasen Brown, P.E., and Jason Floyd visited the site of the proposed Bangert Island side channel on Friday, November 19, 2010 from roughly 9 AM to 12 PM. The weather was mostly cloudy, with temperatures in the high 40s to mid 50s.

Bangert Island is part of the Cowmire Creek watershed. The majority of Bangert Island is a 160-acre wildlife area, owned by the Missouri Department of Conservation after a donation from the Kurtz family. A 2.6 mile-long section of the Katy Trail is located within the remnant side channel complex. The trail winds as a figure 8 near the majority of the circumference of the island. This trail is open to both biking and hiking; in the time that the site visit team was on the island, 7-8 bikers and approximately 10-15 hikers passed us.

The site visit started at the Bangert Island park entrance along the Katy Trail. From there, the site visit team crossed onto the island using the trail foot bridge, taking note of the confluence of the old side channel and a drainage tributary that passes under the Old South River Road Bridge (Figure 1). The old side channel from this point northward had well established bank lines to where it crossed under the I-70 Bridge. Past the confluence, the site visit team followed the old side channel southwest for some distance. The old side channel is still active from runoff and the water table for large sections southwest of the previously mentioned confluence (Figure 2). Sections of the St. Charles bankline form the back portion of homeowners' property lines; for these properties, the bankline is low but seemingly stable. Occasional gravel bars were also evident in the old side channel (Figure 3).

After walking the old side channel for a distance, the site visit team cut towards the trail and followed it. Walking the trail (which cuts through portions of the proposed channel), the site visit team saw no topography that favored a side channel placement. At a point closest to the Missouri River bankline, the site visit team left the trail to look at the bankline and find the proposed channel entrance. Just downstream of the proposed entrance, the bank consisted largely of highly erodible silty sands that exhibited multiple minor benches from multiple sustained water levels. There were several dike structures along the bankline; some pile dike structures (Figure 4) and other rock structures. Large scalloping of the bankline was present, and was likely the result of the hydraulic forces imparted by the aforementioned structures (Figure 5). The site visit team continued up the bankline to the point of the proposed side channel entrance, where there was an older T-shaped rock dike (Figure 96, Figure 7, Figure 8, and Figure 9) which upon further investigation was observed to be part of a larger trail dike structure. The rock dike appears to be largely constructed out of shale which exhibits large amounts of cracking from freeze-thaw cycles. There was no sign of the original side channel entrance. Just upstream of the proposed side channel entrance, the quarry adjacent to the island property maintains an unloading site for barges, which may be impacted by changing flow conditions.

From the side channel entrance, the site visit team walked back to the proposed exit via the Katy Trail. The proposed exit was reached by using the lower Ameristar access bridge to cross the old side channel. The proposed exit of the side channel has similar soil conditions to much of the upstream bankline (Figure 10, Figure 11). The piers of the I-70 Bridge and the rear of the Ameristar Casino both need to be considered for any potential flow changes.

Figure 1 Confluence of old side channel and drainage tributary

Figure 2 Old side channel southwest of confluence

Figure 3 Old side channel southwest of confluence with gravel bar

Figure 4 Pile dike on the Missouri

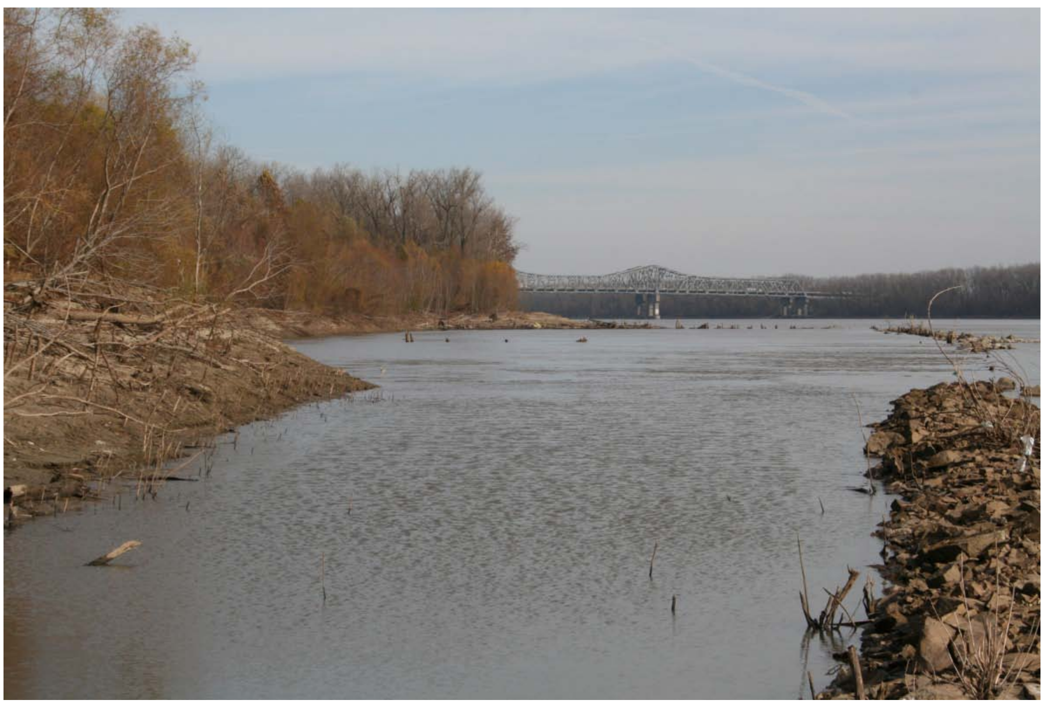

Figure 5 Large-scale bankline scalloping

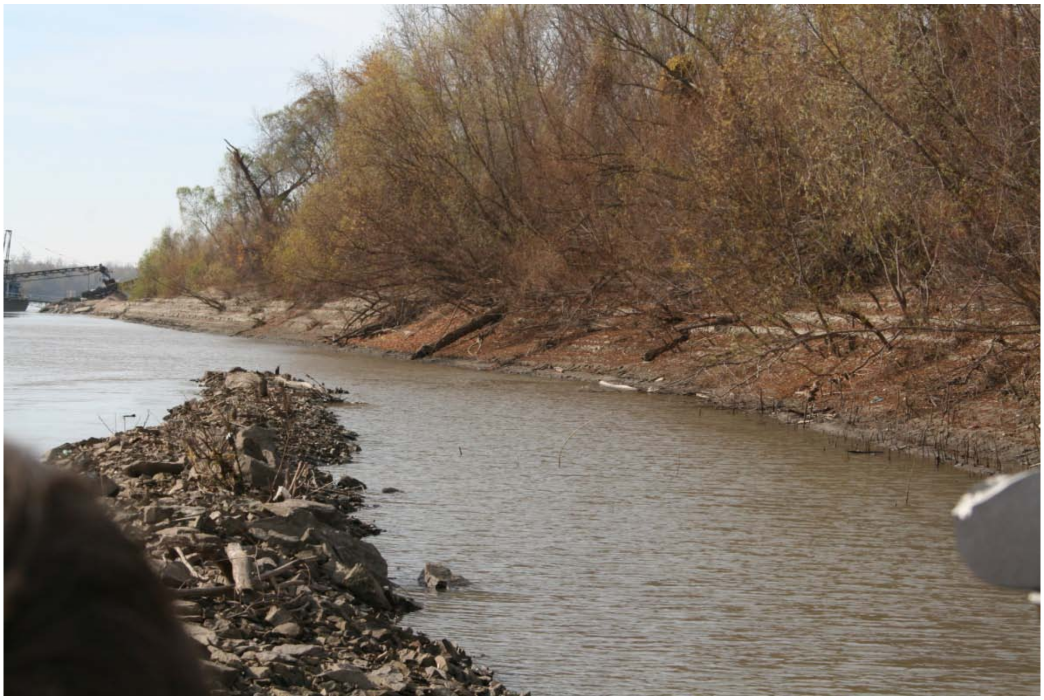

Figure 6 Upstream view of Missouri River bankline at proposed side channel entrance

Figure 7 Missouri River bankline at proposed side channel entrance 1

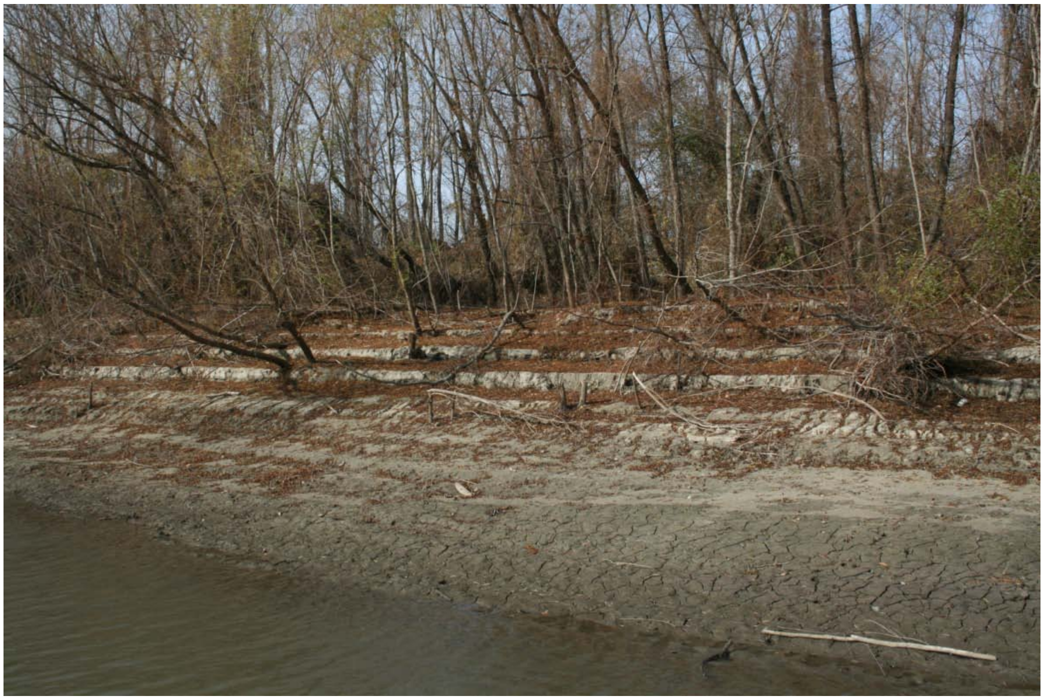

Figure 8 Missouri River bankline at proposed side channel entrance 2

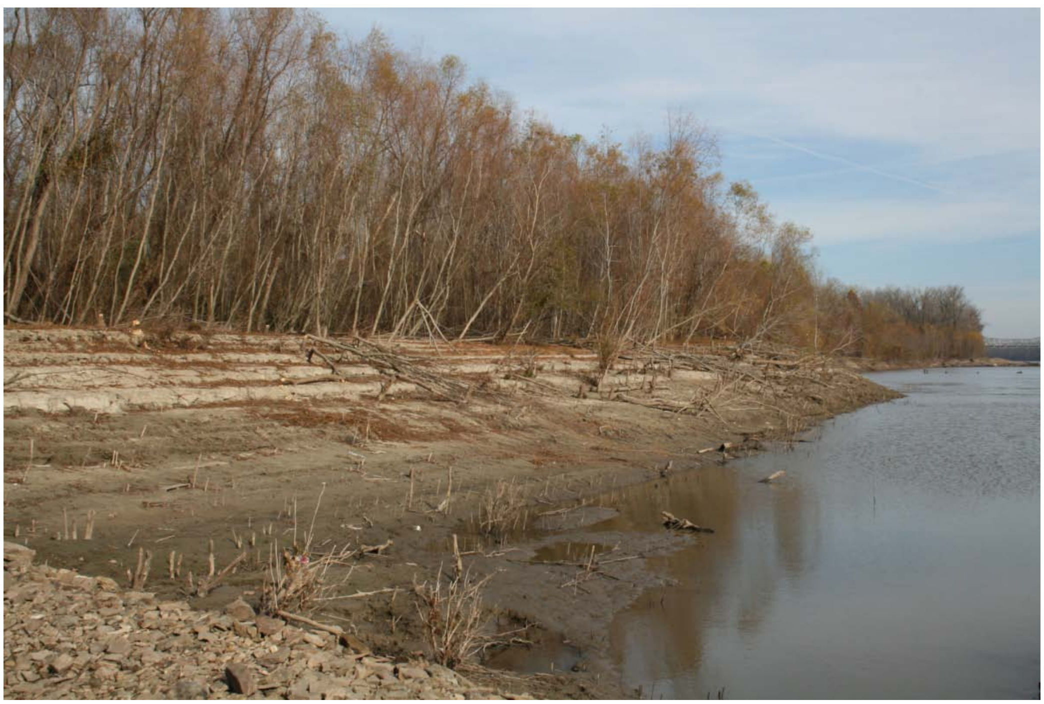

Figure 9 Downstream view of Missouri River bankline at proposed side channel entrance

Figure 10 Upstream view of Missouri River bankline at proposed side channel exit

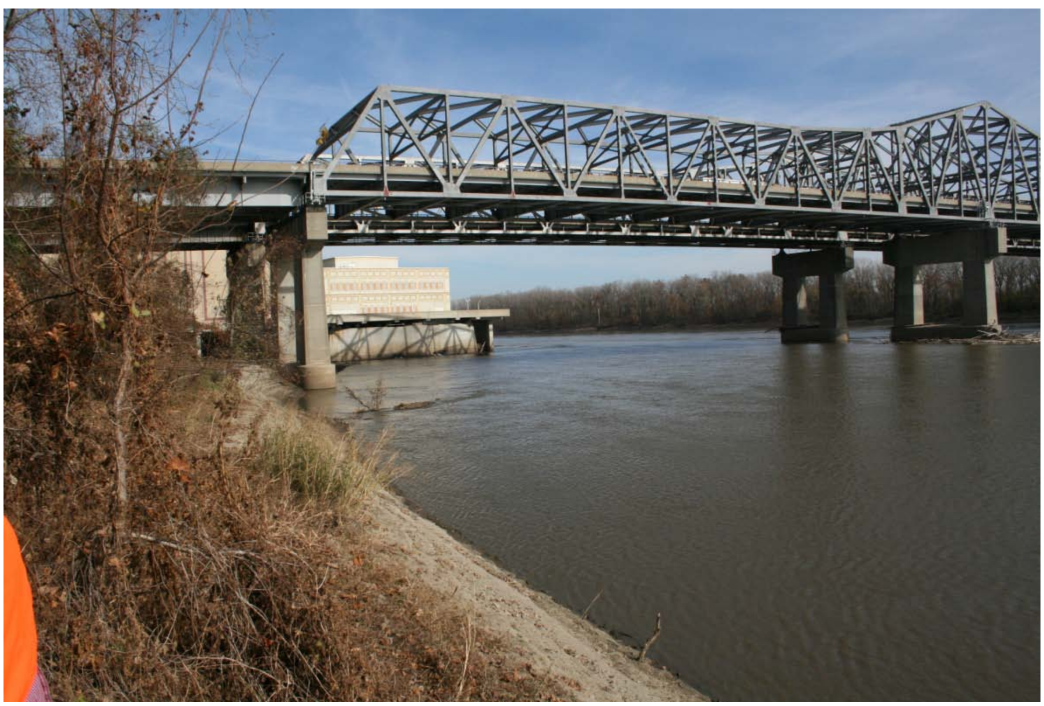

Figure 11 Downstream view of Missouri River bankline at proposed side channel exit

Appendix 4: Cross Section Comparison

To verify the predictive capabilities of the HSR model used for this study, cross sections were developed for the replication model condition and two prototype bathymetries, the 2007 and 1998 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 1000 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. Cross sections 70 and 110 were rejected because of the entrance of a chute and cross section placement directly on top of a parallel dike, respectively.

The initial comparison was between the replicated model scan and the 2007 bathymetry. Because the survey extents of the 2007 bathymetry were truncated in locations due to dike structures or point bar formations, the decision was made to trim the model scan to the limits of the 2007 bathymetry in cases where dikes or point bars were evident in the 2007 bathymetry. The cross sections were generated with a vertical distortion of 8 ft horizontal for 1 ft vertical, which dictated using 8 as a correction factor for the area calculations. The results of the area calculations are presented in Table 1. The average percent difference between the cross-sectional areas, model to prototype, was 9.7%, with a low of 0.6% and a high of 19.6%.

Cross sections were generated in the same manner comparing the 2007 and 1998 bathymetries to get a measure of the natural variation of the channel. As in the previous calculations, the surveys were trimmed to the limits of the 2007 bathymetry in cases where dikes or point bars were evident in the 2007 bathymetry. The average percent difference was 9.0%; the lowest percent difference was 0.3% and the highest was 32.0%. The relative agreement between the prototype-to-prototype and model-to-prototype cross-sectional area average percent differences demonstrates that the model was successful in replicating prototype bed activity.

Table 1 Cross Section Comparison between Replication Model Scan and 2007 Bathymetry

Cross Section	Area Without Correction		Corrected Area		Percent Difference	Percent Difference With Select Sections Removed
	Replication (ft^2)	2007 Survey (ft^2)	True Replication (ft^2)	True 2007 Survey (ft^2)		
30	260093	291086	32512	36386	11.2%	
40	288908	338187	36114	42273	15.7%	
50	287009	284713	35876	35589	0.8%	
60	232928	253873	29116	31734	8.6%	8.6%
70	220163	254486	27520	31811	14.5%	
80	240276	252314	30035	31539	4.9%	4.9%
90	230733	235488	28842	29436	2.0%	2.0%
100	237914	227904	29739	28488	4.3%	4.3%
110	228946	204050	28618	25506	11.5%	
120	242337	228305	30292	28538	6.0%	6.0%
130	283642	233926	35455	29241	19.2%	19.2%
140	253720	234821	31715	29353	7.7%	7.7%
150	254735	234139	31842	29267	8.4%	8.4%
160	229786	231271	28723	28909	0.6%	0.6%
170	240231	252989	30029	31624	5.2%	5.2%
180	263168	247553	32896	30944	6.1%	6.1%
190	289463	237879	36183	29735	19.6%	19.6%
200	291788	247355	36474	30919	16.5%	16.5%
210	295235	264379	36904	33047	11.0%	11.0%
220	282055	260944	35257	32618	7.8%	7.8%
230	311415	275593	38927	34449	12.2%	12.2%
240	273023	264535	34128	33067	3.2%	3.2%
250	280316	238721	35039	29840	16.0%	16.0%
260	296312	244501	37039	30563	19.2%	19.2%
270	294449	252348	36806	31544	15.4%	15.4%
280	318925	301453	39866	37682	5.6%	
Total	6927570	6592811	865946	824101		
				Average	9.7%	9.7%

Table 2 Cross Section Comparison between 2007 Bathymetry and 1998 Bathymetry

Cross Section	Area Without Correction		Corrected Area		Percent Difference	Percent Difference With Select Sections Removed
	2007 Survey (ft^2)	1998 Survey (ft^2)	True 2007 Survey (ft^2)	True 1998 Survey (ft^2)		
30	291086	158609	36386	19826	58.9%	
40	338187	136559	42273	17070	84.9%	
50	284713	143726	35589	17966	65.8%	
60	253873	183795	31734	22974	32.0%	32.0%
70	254486	247211	31811	30901	2.9%	
80	252314	209713	31539	26214	18.4%	18.4%
90	235488	210203	29436	26275	11.3%	11.3%
100	227904	221648	28488	27706	2.8%	2.8%
110	204050	224174	25506	28022	9.4%	
120	228305	217411	28538	27176	4.9%	4.9%
130	233926	233220	29241	29152	0.3%	0.3%
140	234821	228887	29353	28611	2.6%	2.6%
150	234139	247486	29267	30936	5.5%	5.5%
160	231271	232568	28909	29071	0.6%	0.6%
170	252989	225480	31624	28185	11.5%	11.5%
180	247553	232707	30944	29088	6.2%	6.2%
190	237879	244994	29735	30624	2.9%	2.9%
200	247355	229430	30919	28679	7.5%	7.5%
210	264379	226743	33047	28343	15.3%	15.3%
220	260944	216058	32618	27007	18.8%	18.8%
230	275593	243458	34449	30432	12.4%	12.4%
240	264535	256423	33067	32053	3.1%	3.1%
250	238721	252214	29840	31527	5.5%	5.5%
260	244501	273118	30563	34140	11.1%	11.1%
270	252348	269197	31544	33650	6.5%	6.5%
280	301453	287766	37682	35971	4.6%	
Total	6592811	5852798	824101	731600		
				Average	15.6%	9.0%