Technical Report M29

SEDIMENTATION STUDY OF THE MIDDLE MISSISSIPPI RIVER AT BUFFALO ISLAND RIVER MILES 28.0 TO 22.0

HYDRAULIC MICRO MODEL INVESTIGATION

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INTRODUCTION

The U.S. Army Corps of Engineers, St. Louis District initiated a side channel study of the Middle Mississippi River between Miles 28.0 and 21.0 at the Buffalo Island side channel. The purpose of the study was to evaluate environmental design alternatives for the preservation of side channel and island habitat through the modification of existing river structures or new construction.

Mr. Jasen L. Brown, Hydraulic Engineer, and Mr. Edward H. Riff, Engineering Technician, under direct supervision of Mr. Michael T. Rodgers, Hydraulic Engineer, and Mrs. Dawn M. Lamm, Hydraulic Engineer and Mr. Robert D. Davinroy, District Potamologist, conducted the study between April 2003 and October 2003. Other personnel also involved with the study included: Mr. Leonard Hopkins from the River Engineering Unit of the Hydrologic and Hydraulics Branch; Mr. Brian Johnson and Mr. Thixton Miller from the Environmental Branch of the Planning, Programs, and Project Management Division. Personnel from other agencies involved in the study included: Mr. Butch Atwood from the Illinois Department of Natural Resources, Mr. Mike Thomas from the U.S. Fish and Wildlife Service, and Mr. David Ostendorf and Mr. Mark Boone from the Missouri Department of Conservation.

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BACKGROUND

Micro modeling methodology was used to evaluate sediment transport conditions as well as the impact of various structural measures along the Buffalo Island side channel reach of the Mississippi River. This study was funded as part of the Avoid and Minimize Program of the Middle Mississippi River.

The primary goal of this study was to preserve and diversify the present aquatic conditions in Buffalo Chute. Adding new structures and making structural modifications to existing structures, while maintaining the integrity of the navigation channel, was the focus of this study.

1. Study Reach

The study reach was located approximately fifteen miles south of Cape Girardeau, Missouri. The study comprised a 7-mile stretch of the Middle Mississippi River, between Miles 28.0 and 22.0. Plate 1 is a location and vicinity map of the study reach. The study area was located in Scott and Mississippi County in Missouri, and Alexander County in Illinois. Plate 2 is a 2002 aerial photograph illustrating the planform and nomenclature of the Middle Mississippi River between Miles 28.0 and 22.0.

At the time of this study, the Buffalo Island study area included three dike fields and one weir field, containing a total of forty-two structures (Plate 2). All dike and weir structures were of stone construction.

Dike Field 1 was located along the left descending bank (LDB) and contained 4 dikes. The dikes were located at Miles 28.0L, 27.5L, 27.2L, and 26.8L. Structure lengths ranged from 250 feet to 500 feet. Dike Field 2 was located along the right descending bank (RDB) and contained 9 dikes. The dikes were located at Miles 27.6R, 27.3R, 27.0R, 26.9R, 26.7R, 26.4R, 26.1R, 25.5R, and 25.3R.

Structure lengths ranged from 400 feet to 1100 feet. Dike Field 3 was located along the LDB and contained 10 dikes. The dikes were located at Miles 25.4L, 25.3L, 25.2L, 25.0L, 24.9L, 24.5L, 24.4L, 24.3L, 23.8L, and 22.3L. Structure lengths ranged from 400 feet to 3300 feet.

Weir Field 1 was located along the RDB and contained 13 weirs as shown on Plate 2. The weirs were located at Miles 24.2R, 23.9R, 23.7R, 23.5R, 23.4R, 23.3R, 23.2R, 23.1R, 23.0R, 22.9R, 22.8R, 22.7R, and 22.45R. Structure lengths varied from 550 feet to 1000 feet.

The following table summarizes the location, elevation, and length of existing rock structures located within the study reach:

Weirs		
River Mile	Elevation (feet LWRP)	Length (feet)
24.2R	-15	920
23.9R	-15	530
23.7R	-15	535
23.5R	-16	1070
23.4R	-15	1000
23.3R	-15	770
23.2R	-15	920
23.1R	-16	815
23.0R	-15	820
22.9R	-15	890
22.8R	-15	900
22.7R	-15	900
22.4R	-15	600

Dikes		
River Mile	Elevation (feet above MSL)	Length (feet)
28.0L		500
27.6R	309	250
27.5L	308	600
27.3R	308	650
27.2L	308	400
27.0R	305	475
26.9R	Sloped	450
26.8R	306	600
26.7R	306	1700
26.4R	305	650
26.1R	305	1550
25.5R	Sloped	425
25.4L	306	125
25.3R	306	1130
25.3L	304	400

Dikes		
River Mile	Elevation (feet above MSL)	Length (feet)
25.2L	304	250
25.0L	307	500
24.8L	305	150
24.7R	303	307
24.6L	303	250
24.5L	303	550
24.4L	303	750
24.3L	306	300
24.2L	305	1200
23.8R	304	3350
22.3L	305	1175
22.2L	305	670
21.9L	306	600
21.1L	302	650
20.5L	307	800

2. Problem Description

The captured planform of the Mississippi River consisted of the thalweg being located along the LDB between Miles 26.5 and 24.9. Along this area the channel has been relatively deep and narrow. As a result, a depositional zone has developed along the opposite right descending bank (RDB), which has included the entire Buffalo Island side channel. This side channel, between Miles 26.1R and 24.7R, has been relatively shallow, which has continued to pose a threat to local fish species and other aquatic life. While Buffalo Chute has provided a slow-flowing habitat, a desire to increase energy and depth for the development of breeding and over-wintering habitat was desired by team members. To achieve this, the alteration or modification of dikes affecting the chute was the primary objective of this study.

3. History

1880

A historical examination of the Buffalo Island reach of the Middle Mississippi River revealed that the channel contained a different alignment 120 years ago. According to the 1880 topographic and hydrographic map (Plate 3), the main channel was wider and contained several bars, including a large middle island (Blacke Island) between Miles 25.9 to 25.2. The bars and island probably consisted of fine sands, silts and clays. The thalweg was located along the LDB between Mile 28.2 to 27, migrated to the RDB at Mile 26.9 and remained along the RDB until it crossed back to the LDB at Mile 24.9. The thalweg crossed back to the RDB at Mile 23.9 and remained in that position to the end of the reach. At the time of this survey no structures were located in this reach of the river. River miles were marked on this map as a general reference and do not represent modern day mileage.

Buffalo Chute (Mile 26.9R to 24.5R) appeared relatively shallow, with a few isolated pockets of water noted along the chute. Buffalo Chute contained four meanders along the upstream portion of the channel. The lower portion was relatively straight.

1908

Plate 4 is a 1908 historical topography and hydrographic survey map. Buffalo Island's side channel size and location changed slightly since 1880. The survey indicated that the upper entrance to the chute was eroded away as a result of the migration of the main channel. Conversely, the first meander in the chute was eliminated. The notable changes in the main channel were channel migration between Miles 28.0 and 27.0 toward the RDB and additional shoaling and deposition. Large sand bars were observed in the center of the channel at Miles 27.8, 27.2 and 26.3 as well as on the outside of the bend between Mile 25.5 and 23.5. Blacke Island also became part of the floodplain on the LDB. The thalweg was located on the RDB from Mile 28.5 to Mile 26.0 where it then crossed to the LDB. The thalweg remained along the LDB until Mile 24.9, where it then crossed back over toward the RDB at Mile 24.0.

1929

Plate 5 is a 1929 aerial photograph of the Buffalo Island reach. Changes indicated by the aerial photo included a new island developed at Mile 26.0. Also, another new island named Sliding Towhead had developed between Miles 24.0 and 25.0 along the RDB. The lower end of this island was formerly the lower end of Buffalo Chute in 1908. Several dike locations were marked on the photo located along the RDB.

1956

The 1956 hydrographic survey is shown on Plate 6. Several pile dikes were placed across the upstream portion of Buffalo Chute, including Dikes 27.6R, 27.3R, 27R, 26.9R, 26.4R, and 26.1R. The downstream portion of Buffalo Chute was markedly wider than observed in 1929. The main channel between Miles 26.0 and 25.0 was also firmly located along the left descending bank. In addition, the sliding towhead island had become the RDB of the main channel.

1970

The 1970 hydrographic survey is shown on Plate 7. This was the first survey available after several timber pile structures were converted to stone in 1964. Floods, ice and floating drift extensively damaged timber pile structures and in many cases the life span of the structures were short-lived. The location of the thalweg of the main channel in this survey was similar to the 1956 survey. The main difference observed on this map as compared with all previous maps is the marked increase in width and decrease in length of Buffalo Chute. The five most upstream dikes had converted the Buffalo Chute into terrestrial habitat, thereby shortening the upper chute by almost one mile.

1977

The 1977 hydrographic survey is shown on Plate 8. The bathymetry of this survey was similar to the 1970 survey. The main change in bathymetry was additional shoaling along the inside of Dogtooth Bend, which caused the channel to become more constricted and deeper through the bend. The trends along Buffalo Chute remained generally the same as in 1970.

1983

The 1983 hydrographic survey is shown on Plate 9. The bathymetry of this survey was similar to the 1977 survey. Additional dikes were placed on the LDB at Miles 28.0 L, 27.2 L, 26.8 L and 25.0 L to increase bank stability through this reach. The effects of the new dike placement were minimal to the overall channel and the thalweg location remained the same. Browns Chute appeared generally the same as in 1977.

MICROMODEL SETUP

1. Scales and Bed Materials

In order to investigate the sediment transport issues and habitat development described previously, a physical hydraulic micro model was designed and constructed. Plate 10 is a photograph of the hydraulic micro model used in this study. The model employed a horizontal scale of 1 inch = 500 feet, or 1:6000, and a vertical scale of 1 inch = 50 feet, or 1:600, for a 10 to 1 distortion ratio of linear scales. This distortion supplied the necessary forces required for the simulation of sediment transport conditions similar to those of the prototype. The bed material was granular plastic urea, Type II, with a specific gravity of 1.40.

2. Appurtenances

The micro model insert was constructed according to the year 2000 high-resolution aerial photography of the study reach as shown on Plate 11. The insert was then mounted in a standard micro model hydraulic flume. The riverbanks of the model were constructed from pliable brass sheet metal. Rotational jacks located within the hydraulic flume controlled the slope of the model. The measured slope of the insert and flume was approximately .0057 inch/inch. River training structures in the model were made of galvanized steel mesh.

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. Discharge was monitored by a magnetic flow meter interfaced with the customized computer software. Water stages were manually checked with a mechanical three- dimensional point digitizer. Resultant bed configurations were measured and recorded with a three-dimensional laser scanner.

MICROMODEL TESTS

1. Model Calibration

The calibration of the micro model involved the adjustment of water discharge, sediment volume, model slope, entrance conditions, and exit conditions of the model. These parameters were refined until the measured bed response of the model was similar to that of the prototype.

A. Micro Model Operation

In all model tests, a steady state flow was simulated in the model river channel. This served as the average design energy response of the river. Because of the constant variation experienced in the prototype, this steady state flow was used to theoretically analyze the ultimate expected sediment response. The flow was held steady at a constant flow rate of 3.00 GPM during model calibration and for all design alternative tests. The most important factor during the modeling process is the establishment of an equilibrium condition of sediment transport. The high steady flow in the model simulated an average energy condition representative of the river's ultimate channel forming flow and sediment transport potential.

B. Prototype Data and Observations

To determine the general bathymetric characteristics and sediment response trends that existed in the prototype, several present and historic hydrographic surveys were examined. Plates 6,7,8, and 9 are plan view hydrographic survey maps of the Mississippi River from 1956, 1970, 1977, and 1983 respectively. Plates 11, 12, 13, and 14 are hydrographic surveys taken in 1996, 1998, 2000, and 2001. All of the surveys displayed the same general location of the channel thalweg. Two crossings were consistently observed at Mile 27.0 and Mile 24.0. All of these surveys showed that the thalweg of the main channel crossed from one bank to another twice in this reach. It should be noted, however, that the crossover located approximately at Mile 23.0, seemed to cross more sharply than natural. This may have been due to repetitive maintenance dredging in this area.

The bathymetry of the most recent prototype surveys (1996, 1998, 2000, and 2001) were very similar to each other and were used to calibrate the micro model. Significant shoaling was present between Miles 28.0 and 27.0 and occured along the LDB. After Mile 26.5, the thalweg crossed to the LDB while shoaling occured along the RDB. The mouth of Buffalo Chute was located at Mile 26.0. The thalweg continued to favor the LDB until it encountered Dike 25.4L where significant scour was observed. From Mile 25.0 to 24.0 the channel width increased approximately 50 percent, causing velocities to decrease and sediment to drop out of suspension. Plate 15 shows areas of repetitive dredging. The exit of Buffalo Chute was located at Mile 24.5 in this area of shoaling. The river then encountered the RDB and the Bendway Weirs of Dogtooth Bend and constricted significantly at Mile 23.0, the narrowest length of channel in this study. This constriction caused a deepening of the channel as the flow favored the RDB around the bend. After Mile 23.0, continuing to Mile 22.0, the channel width increased and less scour occurred along the RDB.

2. Base Test

Model calibration was achieved once favorable qualitative comparisons of the prototype surveys were made to several surveys of the model. The resultant bathymetry of this bed response served as the base test of the micro model. Plate 16 shows the resultant bed configuration of the micro model base test. The base test was developed once bed stability was reached and a similar bed response was achieved as compared with prototype surveys. This survey then served as the comparative bathymetry for all design alternative tests.

Results of the micro model base test bathymetry and a comparison to the 1995 through 1998 prototype surveys indicated the following trends:

- Near Mile 28.0, the main channel was located along the RDB in the prototype as well as the model. A bar developed along the LDB in both the prototype and model as well. The model was generally deeper than the prototype off the end of the LDB dikes

- Between Miles 28.0 and 26.0, the channel in the prototype crossed from the RDB to the LDB, and that same trend was also present in the model.

- The large depositional bar in the vicinity of Buffalo Island was observed in both the prototype and the model.

- Between Miles 25.0 and 23.5, the main channel crossed from the LDB to the RDB in both the prototype and model. This area showed significant deposition in both the model and prototype, although the model was approximately 5 to 10 feet shallower than the prototype. However, depths in the main channel in the prototype have been artificially maintained from historical dredge cuts (Plate 15).

- From Mile 24.0 to Mile 22.7, the thalweg followed the RDB through the bend in the river, resulting in significant scour around the Dogtooth weir field located in the same stretch of river. The model scour patterns were very similar to what was observed in the prototype.

- The bathymetry through Brown's Chute in the model and the prototype were very similar, with scour observed just below Dike 23.8 L and just below Dike 22.3 L.

3. Design Alternatives

Testing began immediately after model calibration was achieved. An important factor in testing was to alter only the aspects of the model pertinent to the individual alternative being tested. Model discharge and entrance conditions were not to be altered in any way. Some fine-tuning of the model, however, was necessary near areas where dike structure changes were being made but were kept to a minimum in order to ensure validity of testing results. Structures in the model were added with care taken to ensure proper scale, as well as proper alignment and elevation.

The aforementioned laser scanner was used to survey and capture any changes in bathymetry caused by the implementation of alternatives.

Flow visualization was used to evaluate general changes in surface flow patterns between the base test and design alternatives. This is located on the accompanying CD of this report.

All design alternatives studied in the micro model utilized the existing dike configurations along with new structures. This was due to environmental concerns and the cost required in either removing or relocating the dikes. Some new structures were intended to represent rock dikes, while others were intended to represent dikes comprised of a conglomeration of wooden elements. Ten design alternative plans were model tested to examine methods of modifying the sediment transport response trends that would enhance side channel or island habitat. The effectiveness of each design was evaluated by comparing the resultant bed configuration to that of the base condition. Impacts or changes induced by each alternative were evaluated by observing the sediment response of the model. A qualitative evaluation of the ramifications to the main channel and Buffalo Chute was made during team participation meetings at the Applied River Engineering Center in St. Louis, Missouri. Personnel from the St. Louis District Corps of Engineers, Missouri Department of Conservation, Illinois

Department of Natural Resources, and the U.S. Fish and Wildlife Service carefully examined and discussed each alternative.

Alternative 1: In an attempt to create additional flow and more energy into the Buffalo Island side channel, several changes were implemented. An existing dike was angled upstream at the entrance of the channel. Two woody structures were added in the upstream portion of Buffalo Chute. The closure structure in the downstream end of the channel was notched on the island side. Two dikes were added along the RDB near the exit of Buffalo Chute. The closure structure at the exit of Buffalo Chute was lowered on the island side. Finally, a blunt nosed chevron was added near the main channel towards the downstream end of Buffalo Island.

- Dike 26.1 R: Angled upstream 20 degrees while attaching to bank at the original position. Dike elevation remains at +15 feet LWRP. Overall dike length remains the same.
- Mile 25.6: 150-foot woody structure placed on island side of side channel at +15 LWRP.
- Mile 25.4: 150-foot woody structure placed on island side of side channel at +15 LWRP.
- Dike 24.8 R: 200-foot section removed from the dike extending from island bank out.
- Mile 24.75: 225-foot Dike added extending from RDB at +15 LWRP.
- Mile 24.76: 150-foot Dike added extending from RDB at +15 LWRP.
- Mile 24.75: Closure structure lowered to +4.5 LWRP for 500 feet extending downstream from the downstream end of Buffalo Island.
- Mile 24.8: Blunt nosed chevron added at 250 ft toward the channel from Buffalo Island.

Plate 17 is a plan view map of the resultant bed configuration of Alternative 1. The test results indicated that this design was effective in creating additional depth at the downstream end of Buffalo Chute. In the base test, a significant depositional area was present at the exit of Buffalo Chute. That depositional area was not present in Alternative 1. Dike 26.1 R, angled upstream, resulted in no significant change in bathymetry as opposed to the base test. At Mile 25.6 in Buffalo Chute, additional depth was observed when compared to the base test. Again, this was an area of problematic deposition in the base test and prototype. The chevron added at Mile 24.8 in the main channel showed no significant change in bathymetry.

Flow visualization showed increased flow into Buffalo Chute past Dike 26.1 (R). Woody structures served to focus the increased flow into a smaller width with increased velocity toward then along the RDB. The chevron added near the downstream end of the island at Mile 25 helped capture a small percentage of flow from the main channel and direct it toward the exit of Buffalo Chute. The notch in Dike 24.8 (R) combined with the additional dikes added at Mile 25.0 directed flow toward the lowered portion of the stone closure structure at the exit of Buffalo Chute. The combination of new structures and modified structures allowed for increased flow out of Buffalo Chute as compared to the base test.

Alternative 2: In an attempt to create higher energy flows through the Buffalo Island side channel, several changes were implemented. An existing dike was angled downstream at the entrance of the channel. Two woody structures were added in the upstream portion of Buffalo Chute. The closure structure in the downstream end of the channel was notched on the island side. Two dikes were added along the RDB near the exit of Buffalo Chute. The closure structure at the exit of Buffalo Chute was lowered on the island side. Finally, a blunt nosed chevron was added near the main channel towards the downstream end of Buffalo Island.

- Dike 26.1 R: Angled downstream 20 degrees while attaching to bank at the original position. Dike elevation remains at +15 feet LWRP. Overall dike length remains the same.

- Mile 25.6: 150-foot woody structure placed on island side of side channel at +15 LWRP.
- Mile 25.4: 150-foot woody structure placed on island side of side channel at +15 LWRP.
- Dike 24.8 R: 200-foot section removed from the dike extending from island bank out.
- Mile 24.75: 225-foot Dike added extending from RDB at +15 LWRP.
- Mile 24.76: 150-foot Dike added extending from RDB at +15 LWRP.
- Mile 24.75: Closure structure lowered to +4.5 LWRP for 500 feet extending downstream from the downstream end of Buffalo Island.
- Mile 24.8: Blunt nosed chevron added at 250 ft toward the channel from Buffalo Island.

Plate 18 is a plan view map of the resultant bed configuration of Alternative 2. The test results indicated that this design was effective in creating additional depth and diversity in Buffalo Chute. Dike 26.1 R, angled downstream, increase deposition at the entrance of Buffalo Chute when compared to the base test. Further into Buffalo Chute, where there once was a depositional problem at Mile 25.6, increased depth was observed. This area of additional depth continued past the notched Dike 24.8 (R), the two dike structures added at Mile 24.75, and through Buffalo Chute to the lowered 250-foot section of closure structure located at the exit of the channel. The chevron added near the downstream end of the island showed small amounts of scour at the upstream end of the structure, with no other significant departure in bathymetry from the base condition.

Flow visualization showed increased velocity through a decreased channel width at the entrance to Buffalo Chute past Dike 26.1 (R) which was angled downstream. Woody structures served to focus the flow into a smaller width with increased velocity toward then along the RDB at Mile 25.5 when compared to the base test. The chevron added near the downstream end of the island at Mile 25.0 helped capture a small percentage of flow from the main channel and direct it toward the exit of Buffalo Chute. The notch in Dike 24.8 (R) combined with the additional dikes added at Mile 25.0 directed flow toward the lowered portion of the stone closure structure at the exit of Buffalo Chute. The combination of these new structures and modified structures allowed for increased flow out of Buffalo Chute as compared to the base test.

Alternative 3: In an attempt to create additional flow and more energy into the Buffalo Island side channel, several changes were implemented at once. Two woody structures were added in the upstream portion of Buffalo Chute. The closure structure in the downstream end of the channel was notched on the island side. Two dikes were added on the RDB near the exit of Buffalo Chute. The closure structure at the exit of Buffalo Chute was lowered on the island side. Finally, a blunt nosed chevron was added near the main channel towards the downstream end of Buffalo Island.

- Mile 25.6: 150-foot woody structure placed on island side of side channel at +15 LWRP. Mile 25.4: 150-foot woody structure placed on island side of side channel at +15 LWRP.
- Dike 24.8 R: 200-foot section removed from the dike extending from island bank out.
- Mile 24.75: 225-foot Dike added extending from RDB at +15 LWRP.
- Mile 24.76: 150-foot Dike added extending from RDB at +15 LWRP.
- Mile 24.75: Closure structure lowered to +4.5 LWRP for 500 feet extending downstream from the downstream end of Buffalo Island.
- Mile 24.8: Blunt nosed chevron added at 250 ft toward the channel from Buffalo Island.

Plate 19 is a plan view map of the resultant bed configuration of Alternative 3. The test results indicated that the bathymetry at the entrance to Buffalo Chute was similar to that of the base test. The bathymetry downstream of the entrance condition, including those around the new chevron, was similar to what was observed in Alternatives 1 and 2.

Flow visualization showed entrance flow velocity and direction similar to the base condition. At Mile 25.5 the flow slows down significantly in front of the woody structures placed on the LDB of Buffalo Chute. The notch in Dike 24.8 (R) combined with the additional dikes added at Mile 25 performed as described in tests 1 and 2. The chevron added near the downstream end of the island at Mile 25.0 performed similar to tests 1 and 2.

Alternative 4: In an attempt to predict the impact of proposed weir construction between Miles 25.4 and 24.9, four weirs were placed in this area at nearly equal lengths from each other, each angled upstream.

- Mile 25.3: A 775-foot weir was placed off the end of Dike 25.3 (L), angled approximately 20 degrees upstream, at –15 ft LWRP.
- Mile 25.2: A 700-foot weir was placed off the end of Dike 25.2 (L), angled approximately 20 degrees upstream, at -15 feet LWRP.
- Mile 25.0: A 700-foot weir was placed off the end of Dike 25.0 (L), angled approximately 20 degrees upstream, at -15 feet LWRP.
- Mile 24.9: An 800-foot weir was placed off the end of Dike 24.9 (L), angled approximately 20 degrees upstream, at -15 feet LWRP.

Plate 20 is a plan view map of the resultant bed configuration of Alternative 4. Bathymetry at and below Mile 26.0 showed less depth than was observed in the base test, most notably within the channel. An area of increased depth was observed between Miles 25.0 and 24.0 within the navigation channel. Conditions above Mile 26.0 and below Mile 24.0 were similar to the conditions observed in the base test.

Flow visualization for this alternative showed conditions similar to the base test, with the exception of the flow over the new weir structure located furthest downstream. Some flow over this area was disrupted by the underwater weir structure and directed toward the RDB then around the end of the weir before continuing downstream. Flow directly in front of the exit of Buffalo Chute was observed to be similar to that of the base test. Side channel flows were also similar to those observed in the base test. Note the reappearance of the depositional area at the exit of Buffalo Chute, which is similar to the exit condition of the base test.

Alternative 5: In an attempt to enhance the results of Alternative 4 towards a more positive impact on the exit condition of the Buffalo Island side channel, the two upstream weirs were lengthened, while the two downstream weirs remain unchanged from Alternative 4.

- Mile 26.2: A 450-foot weir was placed extending from the LDB, angled approximately 20 degrees upstream, at –15 ft LWRP.
- Mile 26.0: A 450-foot weir was placed extending from the LDB, angled approximately 20 degrees upstream, at -15 feet LWRP.
- Mile 25.9: A 500-foot weir was placed extending from the LDB, angled approximately 20 degrees upstream, at -15 feet LWRP.
- Mile 25.8: A 600-foot weir was placed extending from the LDB, angled approximately 20 degrees upstream, at -15 feet LWRP.
- Mile 25.7: A 750-foot weir was placed extending from the LDB, angled approximately 20 degrees upstream, at -15 feet LWRP.
- Mile 25.6: An 850-foot weir was placed extending from the LDB, angled approximately 20 degrees upstream, at -15 feet LWRP.
- Mile 25.3: A 775-foot weir was placed off the end of Dike 25.3 (L), angled approximately 20 degrees upstream, at –15 ft LWRP.
- Mile 25.2: A 700-foot weir was placed off the end of Dike 25.2 (L), angled approximately 20 degrees upstream, at -15 feet LWRP.
- Mile 25.0: A 700-foot weir was placed off the end of Dike 25.0 (L), angled approximately 20 degrees upstream, at -15 feet LWRP.
- Mile 24.9: An 800-foot weir was placed off the end of Dike 24.9 (L), angled approximately 20 degrees upstream, at -15 feet LWRP.

Plate 21 is a plan view map of the resultant bed configuration of Alternative 5. From Mile 28.0 thru Mile 26.0 the channel bathymetry was similar to the base test. Between Miles 26.0 and 25.0, multiple areas of deposition disrupted the navigable channel. This was a significant departure from the condition present in the base test. Less scour was observed along the LDB when compared to the base test. Downstream of Mile 24.0, the model bathymetry was similar to that observed in the base test.

Flow visualization for this alternative showed similar flow trends to the base test from Mile 28.0 to Mile 26.0. Increased width of flow was observed between Miles 26.0 and 25.0. Downstream of Mile 25.0, the flow patterns were similar to those observed in Alternative 4. Side channel flows were similar to those observed in the base test.

Alternative 6: In this alternative only woody structures were added to the base condition to evaluate what effect these woody structures alone would have on the flow patterns and bathymetry of Buffalo Chute located on the RDB of Buffalo Chute at Miles 25.45 and 25.55 were added to the base condition. Each structure was approximately 150 feet long.

- Mile 25.6: 150-foot woody structure placed on RDB of side channel at +15 LWRP.
- Mile 25.4: 150-foot woody structure placed on RDB of side channel at +15 LWRP.
- Mile 24.75: Closure structure lowered to +4.5 LWRP for 500 feet extending downstream from the downstream end of Buffalo Island.
- Dike 24.8 R: 200-foot section removed from the dike extending from island bank out.

Plate 22 is a plan view map of the resultant bed configuration of Alternative 6. Additional depth downstream of Mile 25.6 was observed in this alternative when compared to the base test. Other than the increased depth in Buffalo Chute, the model bathymetry was observed to be similar to that of the base test.

Flow visualization of this alternative showed the flow patterns above Mile 25.6 to be similar to the base test. At Mile 25.6 in Buffalo Chute flow was diverted away from the RDB of Buffalo Chute by the addition of woody structures along the RDB. Approximately 500 ft. downstream flow did focus along the RDB before rounding the slight bend in Buffalo Chute. Flow then continued down the center of Buffalo Chute until it reached Buffalo Chute exit, where an area of very low velocity was present behind the existing closure structure. Because of this backwater area, flow was directed out of Buffalo Chute over the lowered section of the closure structure as in Alternative's 1, 2, and 3. In all other areas flow patterns were similar to that of the base test.

Alternative 7: In this alternative the exit condition of the base test was altered slightly by extending a dike from the bank to the end of the section of closure structure that remained at it's original height. Also, a dike near the exit of the channel was notched, and part of the closure structure at the exit of the channel was lowered.

- Mile 24.75: Closure structure lowered to +4.5 LWRP for 500 feet extending downstream from the downstream end of Buffalo Island.
- Dike 24.8 R: 200-foot section removed from the dike extending from island bank out.
- Mile 24.75: Dike added extending from RDB to the end of the section of closure structure remaining at its original height. Top of Dike is level at +15 LWRP.

Plate 23 is a plan view map of the resultant bed configuration of Alternative 7. The bathymetry upstream and downstream of Buffalo Chute was similar to that of the base test. The bathymetry in the main channel adjacent to Buffalo Island was similar to the base test. The bathymetry of Buffalo Chute was similar to the bathymetry found in Alternatives 1, 2, 3, and 6.

Flow visualization for this alternative showed flow conditions in the model to be similar to the base test in all areas except the exit of Buffalo Chute. Flow conditions at the exit of Buffalo Chute differed from that of the base test in that flow sediment would hit the dike added at Mile 24.75 (R) and accumulate in that region until flow was redirected out of Buffalo Chute toward the main channel. This alternative caused the flow to turn at nearly a right angle before exiting Buffalo Chute.

Alternative 8: In this alternative the only departures from the base condition was the lowering of a section of the closure structure at the exit of Buffalo Chute, along with notching an existing dike in Buffalo Chute.

- Mile 24.75: Closure structure lowered to +4.5 LWRP for 1100 feet extending downstream from the downstream end of Buffalo Island.
- Dike 24.8 R: 200-foot section removed from the dike extending from island bank out.

Plate 24 is a plan view map of the resultant bed configuration of Alternative 8. The bathymetry upstream and downstream of Buffalo Chute and in the main channel adjacent to Buffalo Island was similar to the base test. The bathymetry of Buffalo Chute was similar to the bathymetry found in Alternatives 1, 2, 3, and 6.

Flow Visualization for this alternative showed similar results to the base condition upstream, downstream, adjacent, into, and through Buffalo Chute. The exit of Buffalo Chute showed flow exiting Buffalo Chute unobstructed before encountering the remaining structures at Mile 24.65 and taking an abrupt turn to exit into the main channel.

Alternative 9: In this alternative, departures from the base condition included the lowering of a section of the closure structure at the exit of Buffalo Chute, notching an existing dike in Buffalo Chute, the addition of a blunt nosed chevron, and the addition of 2 woody structures in Buffalo Chute.

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- Mile 24.75: Closure structure lowered to +4.5 LWRP for 500 feet extending downstream from the downstream end of Buffalo Island.
- Dike 24.8 R: 200-foot section removed from the dike extending from island bank out.
- Mile 24.75: Blunt nosed chevron added at +15 LWRP, approximately 900 feet from the RDB.

Plate 25 is a plan view map of the resultant bed configuration of Alternative 9. The bathymetry upstream and downstream of Buffalo Chute was similar to that of the base test. The bathymetry in the main channel adjacent to Buffalo Island showed results similar to those of the base test, except for a small scour hole developing behind the chevron added at Mile 24.75. The bathymetry of Buffalo Chute was similar to the bathymetry found in Alternatives 1, 2, 3, and 6.

Flow Visualization for this alternative showed similar results to the base condition upstream and downstream of Buffalo Chute. It should be noted that the video of Alternative 9 included on the accompanying CD focused on the portion of testing intended to show flow conditions into Buffalo Chute, and did not represent main channel flow patterns. Flow into Buffalo Chute was similar to the base test. Upstream of the woody structures, flow was focused along the RDB. At Mile 25.6, flow was redirected away from the RDB toward the center of Buffalo Chute by the addition of a woody structure extending 150 ft. into Buffalo Chute. The flow then followed a line nearly in the center of Buffalo Chute before exiting with flow conditions similar to those in Alternative 3. The chevron added near the exit of Buffalo Chute also performed similar to Alternative 3.

Alternative 10: In this alternative, eight structures on the LDB in the main channel were removed. In their place, four weir structures extending from the LDB and angled upstream were added.

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- Dike 25.4 L: Removed.
- Dike 25.3 L: Removed.
- Dike 25.2 L: Removed.
- Dike 25.0 L: Removed.
- Dike 24.9 L: Removed.
- Dike 24.5 L: Removed.
- Dike 24.4 L: Removed.
- Dike 24.3 L: Removed.
- Mile 26.1: 1100 foot weir at –15 LWRP and angled 35 degrees upstream was added.
- Mile 25.8: 1100 foot weir at –15 LWRP and angled 35 degrees upstream was added.
- Mile 25.4: 1100 foot weir at –15 LWRP and angled 35 degrees upstream was added.

- Mile 25.0: 1300 foot weir at –15 LWRP and angled 35 degrees upstream was added.

Plate 26 is a plan view map of the resultant bed configuration of Alternative 10. The bathymetry of this alternative showed increased channel width at Mile 27.0 continuing through Mile 25.5. Average navigable channel width in this reach was 1100 feet. Below Mile 25.0 a significant drop in channel width was observed. When compared to the base test, the repetitive dredging area near Mile 24.3 was improved but not alleviated by this alternative. The depositional area on the inside of Dogtooth Bend at Mile 24.0 was greatly reduced, thus effectively removing a large portion of Brown's Bar.   Also, the scour on the downstream side of Dike 23.8 L and Dike 22.3 L in Brown's Chute was significantly increased when compared to the base test. At Mile 23.5, less scour was observed along the RDB than was present in the base test. Below Mile 23.5, the bathymetry was similar to that of the base test.

Buffalo Chute showed increased depth when compared to the base test between Miles 25.5 and 24.7. Upstream of Mile 25.5, the Buffalo Chute bathymetry was similar to that of the base test.

Flow visualization for this alternative showed the main channel flow to follow a broader path adjacent to Buffalo Island. The main channel flow was spread out over approximately two-thirds of the river width, as opposed to one-third of the river width in the base test. Also, the channel crossing at Mile 24.5 present in the base test did not occur, as the flow remained focused along the LDB until Mile 23.5 in Dogtooth Bend. Flow in Buffalo Chute was similar in direction to that of the base test, but showed increased velocity.

Alternative 11: In this alternative, eight structures on the LDB within the navigation channel were removed.

- Dike 25.4 L: Removed.
- Dike 25.3 L: Removed.
- Dike 25.2 L: Removed.
- Dike 25.0 L: Removed.
- Dike 24.9 L: Removed.
- Dike 24.5 L: Removed.
- Dike 24.4 L: Removed.

Plate 27 is a plan view map of the resultant bed configuration of Alternative 11. The bathymetry of this alternative showed increased channel width at Mile 28.0 continuing through Mile 26.0. Average channel width in this reach was 1500 feet. Below Mile 26.0 a significant reduction in channel width was observed. Scour deeper than –20 feet LWRP was observed along the LDB between Miles 25.5 and 24.5. Scour on the downstream side of Dike 23.8 L and Dike 22.3 L in Brown's Chute was significantly increased when compared to the base test. Between Miles 24.0 and 23.6 no navigable channel was observed, with a large depositional area along the RDB. Significant deepening occurred along the LDB and Brown's Bar near Mile 24.0 when compared to the base test. Less scour was present on the RDB at Mile 23.6 than was present in the base test. Between Miles 23.4 and 23.2 there was larger and deeper scour than the base test. Below Mile 23.0, the bathymetry was similar to that of the base test.

Buffalo Chute showed increased depth when compared to the base test on the upstream end between the entrance and Mile 25.0. Increased scour was observed on the downstream side of Dike 24.8 R when compared to the base test. There was increased deposition on the main channel side of the Buffalo Chute exit.

Flow visualization for this alternative showed that the main channel flow was focused on the LDB from Mile 26.5 to Mile 23.5 in Dogtooth Bend. Also, the main channel flow was focused in a narrow path along the bank, utilizing only one-third of the river width between Mile 26.5 to Mile 24.5. Between Mile 24.5 and Mile 23.5 the main flow spreads out along with a decrease in velocity. Flow through Buffalo Chute was similar to that of the base test.

CONCLUSIONS

1. Summary and Recommendations

Eleven alternative design tests were conducted in this particular study. Each alternative was tested with the intention of increasing depth and/or velocity and/or diversity in Buffalo Chute. These changes were to be implemented without negatively influencing the integrity of the navigation channel.

- Alternative 1, with Dike 26.1 (R) angled upstream, was successful in drawing in additional flow from the main channel toward the entrance of Buffalo Chute. Also, Alternative 1 showed that additional depth in Buffalo Chute could be expected at and downstream of Mile 25.5 if implemented. Woody structures added in Buffalo Chute helped to alleviate the issue of shoaling present at Mile 25.5 by effectively reducing channel width in the area. The configuration of structures both modified in and added to the exit condition worked well to focus the majority of the flow in a continuous, nearly unobstructed path out of Buffalo Chute. The chevron added at Mile 24.8 increased flow past the exit of Buffalo Chute, which helped cause a low pressure condition drawing flow out more efficiently than the base condition. The placement of the chevron effectively reduced the main channel width at Mile 24.8 to 1000 feet in this alternative. This restricted width could pose a risk to navigation in this stretch.

- Alternative 2, with Dike 26.1 (R) angled downstream, did not significantly alter the flowrate into Buffalo Chute. Alternative 2 showed that additional depth in Buffalo Chute could be expected at and downstream of Mile 25.5 if implemented. Woody structures added in Buffalo Chute helped to alleviate the issue of shoaling present at Mile 25.5 by effectively reducing channel width in the area. The configuration of structures both modified in and added to the exit condition worked well to focus the majority of the flow in a continuous, nearly unobstructed path out of Buffalo Chute. The chevron added at Mile 24.8 increased flow past the exit of Buffalo Chute. The placement of the chevron effectively reduced the main channel width at Mile 24.8 to 1000 feet in this alternative. This restricted width could pose a risk to navigation in this stretch.

- Alternative 3, with no alterations to Dike 26.1 (R), also did not significantly alter the flow rate into Buffalo Chute. Alternative 3 showed that additional depth in Buffalo Chute could be expected at and downstream of Mile 25.5 if implemented. Laser scans indicated that woody structures added in Buffalo Chute helped to alleviate the issue of shoaling present at Mile 25.5 of Buffalo Chute. Flow visualization in front of the woody structures indicated that possible shoaling problems could still be a problem. The configuration of structures both modified in and added to the exit condition worked well to focus the majority of the flow in a continuous, nearly unobstructed path out of Buffalo Chute. The chevron added at Mile 24.8 increased flow past the exit of Buffalo Chute. The placement of the chevron effectively reduced the main channel width at Mile 24.8 to 1000 feet in this alternative. This restricted width could pose a risk to navigation in this stretch.

- Alternative 4 was successful in creating additional depth at the exit of Buffalo Chute, which is a favorable condition for increased depth and flow into Buffalo Chute. At Mile 25.3, a depositional area formed and would be a navigation problem. Also, the severe turn of the thalweg from the LDB to the RDB at Mile 25.2 would potentially be hazardous to river navigation. Alternative 4 did, however, help alleviate a repetitive dredging problem present between Miles 24.5 and 24.0.

- Alternative 5 was not successful in creating additional depth at the exit of Buffalo Chute. At Mile 25.3, a depositional area formed that would be a navigation problem. Alternative 5 did not significantly alleviate a repetitive dredging problem present between Miles 24.5 and 24.0.

- Alternative 6 was successful in effectively reducing the channel width and shoaling problems near Mile 25.0. The exit of Buffalo Chute in this alternative showed deposition upstream of the exit structure at Mile 24.7, thus constricting Buffalo Chute width exiting into the main channel flow.

- Alternative 7 resulted in the flow exiting Buffalo Chute being forced to make an abrupt 90-degree turn to exit Buffalo Chute. Some accretion was observed upstream of the Dike 24.7 (R), which was modified to extend to the closure structure.

- Alternative 8 showed some similarity to Alternative 7, with the only difference being a wider exit condition resulting in decreased exit velocities. Even with the decreased exit velocities, no additional deposition was observed. No other changes were made for alternative 8.

- Alternative 9 was similar to Alternative 6 with one exception, a chevron dike added at Mile 24.5. This chevron dike was successful in creating additional depth at the exit of Buffalo Chute.

- Alternative 10 involved the removal of eight stone dike structures on the LDB adjacent to Buffalo Island, and replacing them with four weir structures. The four structures were equally spaced and of nearly equal length, all angled upstream. The effect of these weir structures on the river was a wider flow with less scour along the LDB adjacent to Buffalo Island. The weirs did not alleviate the dredging problem just downstream of the exit of Buffalo Chute. Much of Brown's Bar was reduced in elevation due to more flow enabled along the LDB.

- Alternative 11 involved only the removal of the eight stone dike structures along the LDB adjacent to Buffalo Island. This alternative resulted in the thalweg developing directly against the LDB, which caused the development of an abrupt crossing at Mile 24.0. Much of Brown's Bar was reduced in elevation.

All alternatives involving the modification of the closure structures near the downstream end of Buffalo Chute were successful in creating additional depth in Buffalo Chute, most notably Alternative 3. Notching Dike 24.8 R and lowering an upstream section of the longitudinal closure structure at the exit of Buffalo Chute, which were effectively acting as grade control structures, caused a significant head-cut through Buffalo Chute. If implemented, the rock removed from these two structures could then be used to construct an L dike extending 225 feet from the RDB near Mile 24.75 to help direct the flow toward the exit of Buffalo Chute. This side channel deepening helped to create additional depth and diversity desired in Buffalo Chute. Also, the addition of woody structures acting as dikes near Mile 25.5 of Buffalo Chute helped to reduce channel width and alleviate the depositional problem existing in this area. Due to the location of a levee structure and privately owned land along the RDB in Buffalo Chute, it is recommended that these woody structures be located along the LDB as in Alternatives 6 and 9. It should be noted however, that these woody structures could be compromised during high flow events and could result in additional maintenance requirements. Rock structures would also be suitable if woody structures prove impractical.

It is recommended that if any of the alternatives are implemented in the river, a phased construction approach should be followed. In addition, a close monitoring program of navigation channel conditions both before and after construction should be incorporated.

2. Interpretation of Model Test Results

In the interpretation and evaluation of the results of the tests conducted, it should be remembered that the results of these model tests were 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 unknown non-erodible variables. Flood flows were not simulated in this study.

This model study was intended to serve as a tool for the river engineer to guide in assessing the general trends that could be expected to occur in the actual 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.

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APPENDIX OF PLATES

Plate number 1 through 27 follow:

1. Location and Vicinity Map of the Study Reach
2. 2002 Aerial Photo and Location of Dike Fields
3. 1880 Hydrographic Survey
4. 1908 Hydrographic Survey
5. 1929 Aerial Photograph
6. 1956 Hydrographic Survey
7. 1970 Hydrographic Survey
8. 1977 Hydrographic Survey
9. 1983 Hydrographic Survey
10. Micro-Model Setup
11. 1996 Hydrographic Survey
12. 1998 Hydrographic Sweep Survey
13. 2000 Hydrographic Survey
14. 2001 Hydrographic Survey
15. Repetitive Dredging River Miles 25.0 to 24.0
16. Micro-Model Base Test
17. Alternative 1
18. Alternative 2
19. Alternative 3
20. Alternative 4
21. Alternative 5
22. Alternative 6
23. Alternative 7
24. Alternative 8
25. Alternative 9
26. Alternative 10
27. Alternative 11