Technical Report M41

CLIFF CAVE-KIMMSWICK HYDRAULIC SEDIMENT RESPONSE MODEL STUDY UPPER MISSISSIPPI RIVER MILES 168.0-156.6

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INTRODUCTION

The U.S. Army Corps of Engineers, St. Louis District initiated a study of the Middle Mississippi River between Miles 168.0 and 156.6 near Kimmswick, Missouri. The purpose of the study was to evaluate environmental design alternatives for the development of side channel and island habitat, utilizing an existing dike field on the Mississippi River.

Mr. Edward J. Brauer, hydraulic engineer, and Mr. Edward H. Riiff, engineering technician, under direct supervision of, Mr. David C. Gordon, P.E. Hydraulic Engineer and Mr. Robert D. Davinroy, Chief of River Engineering, conducted the study between April 2006 and September 2006. Other personnel also involved with the study included: Mr. Leonard Hopkins, Project Manager for the Biological Opinion Program, Mr. Brian Johnson and Mr. Ken Cook from the Environmental Branch of the Planning, Programs, and Project Management Division, Mr. Lance Engle, Dredging Project Manager. Personnel from other agencies involved in the study included: Mr. Butch Atwood from the Illinois Department of Natural Resources, and Ms. Joyce Collins, Mr. Robert Cail, Mr. Dick Steinbach from the U.S. Fish and Wildlife Service, Ms. Elisa Royce from the American Land Conservancy and Mr. Danny Brown from the Missouri Department of Conservation.

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BACKGROUND

Hydraulic Sediment Response (HSR) modeling methodology was used to evaluate sediment transport conditions as well as the impact of various structural alternatives along the Cliff Cave-Kimmswick Reach of the Middle Mississippi River. This study was funded as part of the Biological Opinion Program of the U. S. Army Corps of Engineers, St. Louis District.

The primary goal of this study was to diversify aquatic habitat by modifying present dike structures, developing new side channels and bar formations while maintaining the integrity of the navigation channel.

1. Study Reach

The study reach was located approximately 15 miles south of St. Louis, Missouri. The study comprised a 12-mile stretch of the Middle Mississippi River, between Miles 168.0 and 156.6. Plate 1 is a location and vicinity map of the study reach. The study area was located in St. Louis and Jefferson Counties in Missouri, and Monroe County in Illinois. The reach was in the southern portion of the greater St. Louis Harbor, which is an important fleeting area for a large number of terminal facilities located in the St. Louis area.

Plate 2 is a 2006 aerial photograph illustrating the planform and nomenclature of the Middle Mississippi River between Miles 168.0 and 156.6. The right descending bank (RDB) consists of limestone bluffs. The bluffs are approximately 300 feet tall and act as a natural revetment to the channel. Major tributaries in the study reach are; Carr Creek which is located on the left descending bank (LDB) near Mile 165.6, the Meramec River, located on the RDB near Mile 160.6 and Rock Creek on the RDB around Mile 159.0. Adjacent to the left LDB is a large floodplain. The floodplain consists of sand, silts and clays with an occasional sedimentary rock outcrop.

Dike Name	Length (ft)	Elevation (Blue Book) in LWRP	Dike Name	Length (ft)	Elevation (Blue Book) in LWRP
167.70L	470	18	161.90L	Not Visible	23
167.50L	730	17	161.50L	700	22
167.40L	260	17	161.10L	1000	22
167.10L	340	17	160.90L	890	17
166.60L	820	15	160.60L	570	22
166.40R	300	18	160.30L	680	17
166.20R	370	16	160.00L	500	17
166.20L	450	19	159.90L	400	17
166.10R	330	23	159.80R	320	9
165.90R	480	16	159.70R	290	16
165.90L	100	19	159.70L	500	17
165.70R	280	18	159.50L	430	17
165.50R	420	16	159.30R	300	17
165.30R	230	16	159.20L	390	17
165.10R	350	16	158.90R	260	18
164.90R	300	16	158.90L	600	17
164.90L	190	21	158.60L	500	17
164.80L	Not Visible	23	158.10L	320	18
164.70R	360	16	158.00L	140	23
164.50L	170	Not Listed	157.80L	550	18
164.25L	180	17	157.50L	610	18
164.00R	430	23	157.40L	635	Not Listed
163.70R	150	22	157.30R	Not Visible	17
163.00L	250	21	157.10L	580	17
162.60L	330	16	156.70L	560	17
162.30L	300	17			

Table 1: Dike Information

2. Problem Description

The limestone bluffs along the RDB and dike structures along both the LDB and RDB contract this reach of the Middle Mississippi River to form a uniformly deep and narrow channel. Figure 1 shows the limestone bluffs along the bankline in the study reach. The contracted channel is excellent for navigation purposes. However, more aquatic habitat diversity is desired throughout the reach. Fish species thrive in slow, shallow channels, deep pools and around bar formations. This type of habitat may be developed from the alteration of existing dikes, i.e. notching, increasing or decreasing length and height, or by adding new dikes, or by a combination of either/or.

Figure 1: Limestone Bluffs

3. History

A. Planform Changes

A historical look at the Cliff Cave-Kimmswick reach of the Middle Mississippi revealed that the channel alignment remained roughly in the same location in the 189 years between 1817 and 2006. The planform in 1817 (Plate 3), extracted from 1817-1821 Government Land Office Surveys, had an average width of about 4200 feet. Three islands were located within the Cliff Cave-Kimmswick reach for a cumulative island area of 1.47 square miles. Over the next sixty years the reach saw a transition into a wider braided canaliform. The average planform width in 1880 (Plate 4), extracted from 1880 Mississippi River Commission surveys, was around 5000 feet. The number of islands increased to 15 with a cumulative area of 3.03 square miles. This increase in island area included scattered sand bars within the channel, Chelsey Island, Beards Island, and a large vegetated island on the RDB between Miles 166.0 and 164.5. In an effort to curtail erosion and maintain a navigation channel wood pile dikes and side channel closure structures were constructed in the 1880's. By 1928 the present channel alignment had taken shape (Plate 5). In the 50 years between 1880 and 1930 flow in the side channels around Beards Island, Chelsey Island and the large vegetated island on the RDB between Miles 166.0 and 164.5 had been eliminated as the result of closure structures. The islands became part of the bankline.

B. Dredging

Dredging occurred in the Cliff Cave-Kimmswick reach of the Middle Mississippi River 58 times between 1989 and 2005 for a volume of approximately 7,580,000 cubic yards of material. The consistent dredge locations are located (Plate 6):

- at the beginning of the study reach at Miles 168.0-165.5.
- at Miles 161.5-160
- at the end of the study reach at Miles 158.5-157.

4. Field Observations

Personnel from the Applied River Engineering Center inspected the study reach by foot, shallow draft boat and helicopter. These reconnaissance missions allowed the site to be photographed and studied. The site visit is described below with the water surface elevation referenced to LWRP at the St. Louis, Missouri gage.

+2.85 feet LWRP (December 27, 2005)

Field observations were recorded and photographs were taken of the riverside floodplain of the LDB. The photographs can be found in Figures 2 and 3.

The purpose of this field visit was to determine the feasibility and potential locations for the excavation of new side channels. The riverside floodplain contains both farmland and riparian area. Evidence of historic channels was found in the form of ridges and deep holes. Due to time constraints excavated side channel alternatives were not modeled in this study.

Figure 2: Riverside Floodplain, Mile 158.6 L

Figure 3: Riverside Floodplain, Mile 157.3 L

+12.81 feet LWRP (May 19, 2006)

Field observations were recorded and sediment samples were taken on the RDB at river mile 162.6 to help explain anomalous behavior in the model. It was discovered, through the use of sediment samples and hydrographic surveys that a rock shelf exists along the RDB between approximately river miles 163.0 and roughly mile 161.5L.

It was also discovered that a fleeting area exists on the LDB Downstream of Dike 161.5L. Photos of these fleeting areas can be found in Figures 4 and 5. It was learned through coordination with the Regulatory Branch of the Corps of Engineers that fleeting rights are granted for three spots between Miles 161.9 and 160.6. An emphasis was placed on avoiding the fleeting areas if at all possible.

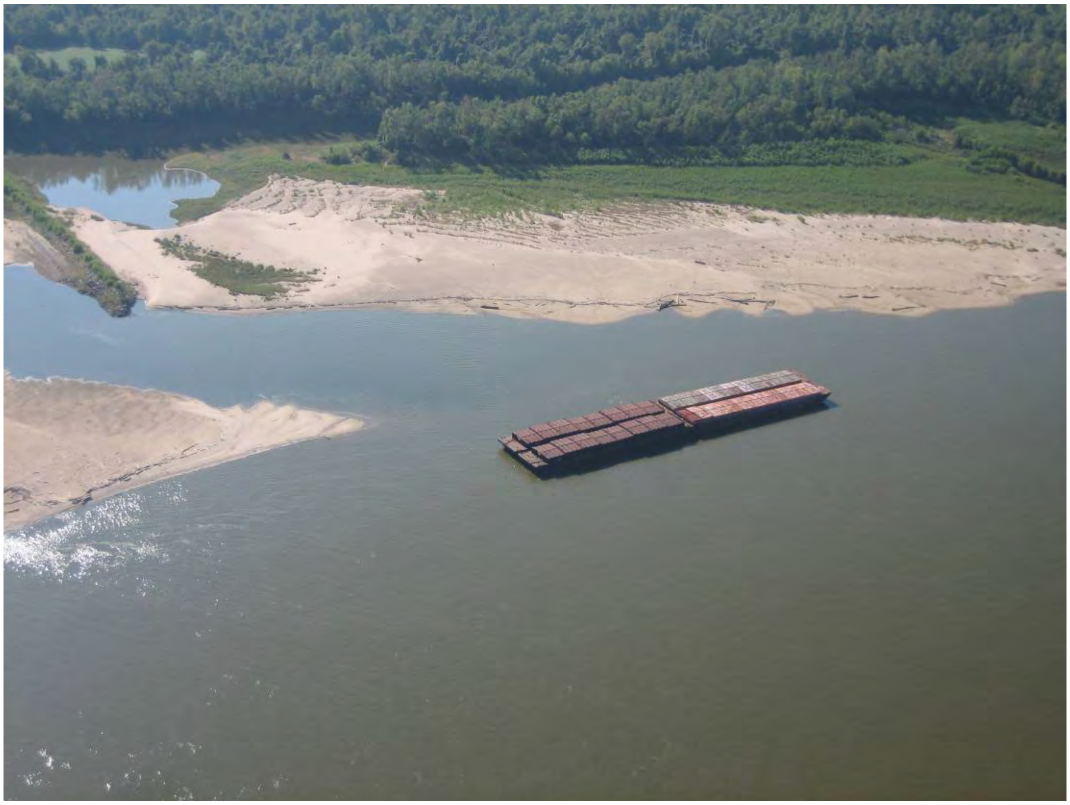


Figure 4: Fleeting off of Dike 161.5L

Figure 5: Fleeting at Mile 161.7L

+3.92 feet LWRP (June 27, 2006)

A recurring trend seen in the Middle Mississippi River in the summer of 2006 was the growth of vegetation on sand bars. Due to the drought conditions that had existed since the end of 2002, the vegetation was more prominent than in years past. A photograph of the sandbar on the LDB at RM 158.6 in December 27, 2005 is shown in Figure 6. The same sandbar is shown in Figure 7 on June 27, 2006. During high water the roughness of mature vegetation on a sandbar causes sediment to accrete. This accretion causes the elevation of the sandbar to rise, therefore decreasing amount of time the sandbar is submerged. The cycle then starts over and through the repetition of high water and low water the sandbar could possibly become permanently vegetated and become part of the bankline.

Figure 6: Sandbar December 27, 2005

Figure 7: Vegetation on Sandbar June 27, 2006

+1.5 feet LWRP (September 14, 2006)

Photographs were taken of some of the structures in the reach from a helicopter flying approximately 700 feet above the surface. Emphasis was placed on the site of potential alternatives along the LDB. Photographs taken of some of the structures impacted by the tested alternatives are shown in Figures 8-12.

Figure 8: Dike 163.00L

Figure 9: Dike 162.6L

Figure 10: Dike 162.3L

Figure 11: Dike 161.9L

Figure 12: Dike 160.3L

5. Study Purpose and Goals

The purpose of this study was to design structural modifications to the existing dike fields to enhance the aquatic habitat diversity and flow dynamics within the reach. The study was performed to address two separate sediment transport goals. The first goal was to create island and side channel aquatic habitat within the dike field. The second goal was to maintain current depths in the navigation channel to assure the need for additional dredging would not arise.

HSR MODEL DESCRIPTION

1. Scales and Bed Materials

In order to investigate the sediment transport conditions described previously, a physical HSR model was designed and constructed. Plate 7 is a photograph of the HSR model used in this study. The zero reference plane of the prototype was assumed to be LWRP (low water reference plane) condition. The model employed a horizontal scale of 1 inch = 800 feet, or 1:9600, and a vertical scale of 1 inch = 70 feet, or 1:840, for a 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 of the prototype. The bed material was granular plastic urea, Type II, with a specific gravity of 1.40.

2. Appurtenances

The HSR model insert was constructed according to the 2004 high-resolution aerial photograph of the study reach. The insert was then mounted in a standard HSR hydraulic flume. The riverbanks of the model were constructed from dense polystyrene foam, and modified during calibration. Rotational jacks located within the hydraulic flume controlled the slope of the model. The measured slope of the insert and flume was approximately 0.008 inch/inch. River training structures in the model were made of galvanized steel mesh for proper scaling of roughness.

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 automatically 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 digitizer.

HSR MODEL TESTS

1. Model Calibration

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

A. HSR Model Operation

In all model tests, a steady state flow was simulated in the Middle Mississippi 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 2.05 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 channel forming flow and sediment transport potential at bankfull stage.

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 8 through 14 are plan view hydrographic survey maps of the Mississippi River from 1959, 1970, 1983, 1996, 1998, 2001, and 2005 respectively.

The bathymetry of the most recent prototype surveys (2001 and 2005) were very similar to each other and were used to calibrate the HSR model. Depths below –15 feet LWRP were maintained in the thalweg throughout most of the study reach, with some areas experiencing depths below –20 feet and –30 feet LWRP.

The exceptions were:

- the crossing between Miles 167.1 and 166.4 (depths between -8 feet and -15 feet LWRP).
- the crossing between Miles 158.2 and 157.5 (depths between -8 feet and -15 feet LWRP).

The thalweg location in the two prototype surveys were as follows:

- Mile 168.0-165.5: along the RDB, with depths below –8 feet LWRP.
- Mile 165.5-163.0: along the LDB, with depths below –16 feet LWRP.
- Mile 163.0-158.5: along the RDB, with depths below –16 feet LWRP.
- Mile 158.5-156.6: along the LDB, with depths below -8 feet LWRP.

Other notable trends found in the two prototype surveys were:

- Scour holes of deeper than 50 feet LWRP off of the following dikes:

Dike	Width* (ft)	Length* (ft)	Dike	Width* (ft)	Length* (ft)
166.20L	300	400	159.80R	200	400
164.90L	200	600	159.30R	100	300
164.50L	200	400	159.90R	200	600
161.1R	200	600			

Table 2: Scour Hole Locations

*Widths and Lengths are approximate

- A scour hole measuring 200 feet wide by 700 feet long off of the end of weir 163.30L
- Scour off of the RDB at Mile 158.5
- A large sandbar upstream of Atwood Chute between Miles 162.6 and 161.1
- A large sandbar at Mile 162.8
- An increase of 600 feet in channel width downstream of the Meramec River from approximately 1000 feet of channel width upstream of the Meramec River to 1600 feet of channel width downstream of the Meramec River.

2. Base Test

Model calibration was achieved once it was determined through qualitative comparisons that the prototype surveys were similar to several surveys of the model. The resultant bathymetry of this calibrated bed response served as the base test of the HSR model (Plate 15). This base test survey served as the comparative bathymetry for all design alternative tests.

Results of the HSR model base test and a comparison to the 2001 and 2005 hydrographic surveys indicated the following similar trends:

- - The thalweg crossed from the RDB to the LDB at Mile 166.4 and continued along the LDB at Mile 165.5 where it remained until Mile 163.0. A scour hole with depths greater than -30 feet LWRP developed off the tip of Dike 164.5L.
- A large bar with depths less than -4 feet LWRP developed on the RDB in the dike field between Mile 165.3 and 163.0.
- The thalweg crossed back to the RDB at Mile 163.0 with depths between -14 and -20 feet LWRP. A large scour hole along the RDB between mile 162.3 and 161.0 was prevented in the river by a rock shelf at a depth of -30 feet LWRP extending approximately 700 feet from the bankline. This scour was prevented in the model by adding a non erodeable material in this location. A large scour hole with depths greater than -30 feet LWRP developed off of the tip of Dike 161.10R.
- A large bar with depths less than -4 feet LWRP developed on the LDB in the dike field between Mile 162.6 and 159.7.
- The thalweg remained along the RDB between Mile 163.0 and 158.5 with scour holes having depths greater than -30 feet LWRP developing along the RDB at mile 160.0, off of Dikes 159.8R and 159.7R, off of Dike 158.9R and on the RDB at Mile 158.6.
- The thalweg crossed back to the LDB between Miles 158.6 and 158.0. For the remainder of the study reach the thalweg was aligned along the LDB. The depths at the crossing were as shallow as -10 feet LWRP.

- A bar of depths less than -6 feet formed along the RDB between miles 158.1 and 157.0
- The overall width of the –10 feet LWRP contour, or navigation width, was very similar in the model as compared to the hydrographic surveys, with an average channel width of 1300 feet noted through most of the reach.
- One difference observed in the model was the width of the channel between Mile 161.5 and 160.0. This area has been repeatedly dredged over the past 15 years.

Overall, the trends of the model base test were very similar to the hydrographic surveys and were thus used with confidence for design alternative analysis.

3. Design Alternative Tests

All design alternatives studied in the HSR model utilized the existing dike configurations in the prototype surveys. Since Dikes 166.9L and 166.3L were constructed during the time of this study they were added after the base test was established and prior to testing alternatives. Modifications to the dikes included uprooting, notching and extending. Some design alternatives included the addition of blunt nosed chevrons. Twenty one design alternative plans were model tested to examine methods of modifying the sediment transport response trends that would create aquatic habitat diversity within this reach of the Middle Mississippi River. The effectiveness of each design was evaluated by comparing the resultant bed configuration to that of the base test. Impacts or changes induced by each alternative were evaluated by observing the sediment response of the model.

A team participation meeting was held at the Applied River Engineering Center (AREC) in St. Louis, Missouri prior to the testing of alternatives to outline objectives and concerns in the study reach. Personnel from the St. Louis District Corps of Engineers, Missouri Department of Conservation, Illinois Department of Natural Resources, U.S. Fish and Wildlife Service and the River Industry Action Committee were present at this meeting. It was brought to the team's attention that the bar on the RDB between Miles 165.0-164.0 contained unique Pallid Sturgeon habitat. It was recommended that, if at all possible, no structures detrimental to this habitat be used in the final design. At this meeting the team decided on two areas of emphasis. These two areas were along the LDB downstream of dike 163.0L and on the LDB downstream of Dike 160.9L.

During the alternative testing process the effect of potential upstream alternatives on possible downstream alternatives was studied. These studies showed the upstream alternatives had no impact on the downstream alternatives. This allows upstream alternatives and downstream alternatives to be used in conjunction with each other.

A second team participation meeting was held at AREC following the testing of Alternatives to conduct a qualitative evaluation of the ramifications to the main channel and the side channels. Personnel from the St. Louis District Corps of Engineers, Missouri Department of Conservation, Illinois Department of Natural Resources, U.S. Fish and Wildlife Service and the River Industry Action Committee carefully examined and discussed each alternative.

Alternatives tested are described in the below tables and shown on Plates 16-36. Alternatives were labeled as successful if they showed the creation of some form of side channel and bar formation with no negative impact to the navigation channel.

Alternative Number	Structure	Type of Structure	Dimension/Height (ft)	Alternative Successful	Comments
			Upstream Alternatives		
1	163.00L	Existing Dike - Notched	-200	No	Notching dikes had very little impact. Not enough water was diverted to create a sustainable side channel
	162.60L	Existing Dike - Notched	-200		
	162.30L	Existing Dike - Notched	-200		
2	163.00L	Existing Dike - Extended, Notched	200, -400 / +15 LWRP	No	In an attempt to increase flow into the side channel Dike 163.0L was notched and extended. Not enough water was diverted to create a sustainable side channel
	162.60L	Existing Dike - Extended, Notched	200, -400 / +15 LWRP		
	162.30L	Existing Dike - Extended, Notched	200, -400 / +15 LWRP		
	161.90L	Existing Dike - Extended, Notched	200, -400 / +15 LWRP		
3	163.00L	Existing Dike-Removed	-	No	A chevron was added to try to divert flow thus helping create a sustainable side channel. Not enough water was diverted and therefore a side channel was not created.
	163.00L	Chevron	250 x 250 / +15 LWRP		
	162.60L	Existing Dike - Notched	-200		
	162.30L	Existing Dike - Notched	-200		
4	163.00L	Existing Dike-Removed	-	Yes	Chevron 163.0L was moved off the bank and a second chevron was added dowstream. A shallow side channel developed.
	163.00L	Chevron	350 x 350 / +15 LWRP		
	162.70L	Chevron	350 x 350 / +15 LWRP		
	162.60L	Existing Dike - Notched	-200		
	162.30L	Existing Dike - Notched	-200		
5	163.00L	Existing Dike - Removed	-	No	A small side channel developed but too much water was diverted from the navigation channel and created a possible future dredging issue.
	162.80L	Chevron	350 x 350 / +15 LWRP		
	162.60L	Existing Dike - Removed	-		
	162.40L	Chevron	350 x 350 / +15 LWRP		
	162.30L	Existing Dike - Notched	-200		
6	162.80L	Chevron	350 x 350 / +15 LWRP	No	Dike 163.0L was replaced in an effort to sustain depth in the navigation channel. The crossing was still too shallow. A side channel was formed.
	162.60L	Existing Dike - Removed	-		
	162.40L	Chevron	300 x 300 / +15 LWRP		
	162.30L	Existing Dike - Notched	-200		
	161.90L	Existing Dike - Notched	-400		
7	162.80L	Chevron	350 x 350 / +15 LWRP	No	A third chevron was added to help streamline flow thus creating a continuous side channel. This alternative had an extremely negative impact on the navigation channel. A continuous side channel was not created.
	162.60L	Existing Dike - Removed	-		
	162.40L	Chevron	350 x 350 / +15 LWRP		
	162.30L	Existing Dike - Removed	-		
	162.10L	Chevron	350 x 350 / +15 LWRP		
	161.90L	Existing Dike - Notched	-500		
8	164.00R	Existing Dike - Extended	200 / +15 LWRP	No	Dikes 163.7R and 164.0R were extended in an effort to maintain depth in the navigation channel while diverting enough flow for a sustainable side channel. A shallow side channel was created around a series of small bars but negatively effected the navigation channel adjacent to the structures.
	163.70R	Existing Dike - Extended	200 / +15 LWRP		
	162.80L	Chevron	350 x 350 / +15 LWRP		
	162.60L	Existing Dike - Removed	-		
	162.40L	Chevron	350 x 350 / +15 LWRP		
	162.30L	Existing Dike - Removed	-		
	162.10L	Chevron	350 x 350 / +15 LWRP		
	161.90L	Existing Dike - Notched	-400		
9	163.70R	Existing Dike - Extended	200 / +15 LWRP	Not Completely	Dike 163.3R was created to help divert more flow into the side channel while maintaining depth in the navigation channel. A shallow side cahnnel was created. The bar created by the chevrons is too wide into the navigation channel.
	163.30R	Dike	1150 / +15 LWRP		
	163.00L	Existing Dike - Removed	-		
	162.80L	Chevron	350 x 350 / +15 LWRP		
	162.60L	Existing Dike - Extended, Notched	250, -400 / +15 LWRP		
	162.40L	Chevron	350 x 350 / +15 LWRP		
	162.30L	Existing Dike - Extended, Notched	250, -400 / +15 LWRP		
	162.10L	Chevron	350 x 350 / +15 LWRP		
	161.90L	Existing Dike - Extended, Notched	700, -400 / +15 LWRP		

10	164.00R	Existing Dike - Extended	250 / +15 LWRP	Yes	A side channel with deep pools developed. The effect on the navigation was minimal.
	163.70R	Existing Dike - Extended	250 / +15 LWRP		
	163.30R	Dike	800 / +15 LWRP		
	163.00L	Existing Dike - Trimmed	-200		
	162.80L	Chevron	350 x 350 / +15 LWRP		
	162.60L	Existing Dike - Trimmed	-200		
	162.50L	Chevron	350 x 350 / +15 LWRP		
	162.30L	Existing Dike - Notched	-200		
11	164.00R	Existing Dike - Extended	300/ +15 LWRP	Not Completely	A deep side channel developed. The crossing in the navigation channel was too shallow and may create a dredging issue.
	163.70R	Existing Dike - Extended	200/ +15 LWRP		
	163.30R	Dike	800 / +15 LWRP		
	162.80L	Chevron	350 x 350 / +15 LWRP		
	162.60L	Existing Dike - Trimmed	-200		
	162.60L	Chevron	350 x 350 / +15 LWRP		
	162.40L	Chevron	350 x 350 / +15 LWRP		
	162.30L	Existing Dike - Trimmed	-200		
	162.20L	Chevron	350 x 350 / +15 LWRP		
12	164.00R	Existing Dike - Extended	200 / +15 LWRP	Not Completely	A deep side channel developed. The crossing in the navigation channel was too shallow and may create a dredging issue.
	163.70R	Existing Dike - Extended	200 / +15 LWRP		
	163.30R	Dike	600 / +15 LWRP		
	163.00R	Dike	600 / +15 LWRP		
	163.00L	Existing Dike - Trimmed	-200		
	162.80L	Chevron	350 x 350 / +15 LWRP		
	162.60L	Existing Dike - Trimmed	-200		
	162.60L	Chevron	350 x 350 / +15 LWRP		
	162.40L	Chevron	350 x 350 / +15 LWRP		
	162.30L	Existing Dike - Trimmed	-200		
	162.20L	Chevron	350 x 350 / +15 LWRP		
13	163.00L	Existing Dike - Trimmed	-250	Yes	A deep side channel developed. This alternative had little impact to the navigation channel.
	163.00L	Chevron	350 x 350 / +15 LWRP		
	162.80L	Chevron	350 x 350 / +15 LWRP		
	162.60L	Existing Dike - Trimmed	-250		
	162.60L	Chevron	350 x 350 / +15 LWRP		
	162.50L	Chevron	350 x 350 / +15 LWRP		
	162.40L	Chevron	350 x 350 / +15 LWRP		
	162.30L	Existing Dike - Trimmed	-150		
	162.10L	Dike	600 / +15 LWRP		
14	163.00L	Existing Dike - Trimmed	-200	Yes	A shallow side channel developed. This alternative had little impact on the navigation channel.
	162.80L	Chevron	350 x 350 / +15 LWRP		
	162.60L	Existing Dike - Trimmed	-200		
	162.60L	Chevron	350 x 350 / +15 LWRP		
	162.50L	Chevron	350 x 350 / +15 LWRP		
	162.40L	Chevron	350 x 350 / +15 LWRP		
	162.30L	Existing Dike - Trimmed	-150		
	162.10L	Dike	650 / +15 LWRP		
15	163.00L	Dike-Remove	-	Yes	A varying side channel with varying depth developed. This alternative had little impact on the navigation channel.
	162.80L	Chevron	350 x 350 / +15 LWRP		
	162.60L	Existing Dike - Trimmed	-200		
	162.60L	Chevron	350 x 350 / +15 LWRP		
	162.50L	Chevron	350 x 350 / +15 LWRP		
	162.40L	Chevron	350 x 350 / +15 LWRP		
	162.30L	Existing Dike - Trimmed	-150		
	162.10L	Dike	650 / +15 LWRP		

Downstream Alternatives					
16	160.90R	Dike	500 / +15 LWRP	Not Completely	Three chevrons were added into the dike field downstream of Dike 160.3L in an effort to create a side channel and bar. A shallow side channel was created but the bar extends into the navigation channel.
	160.30L	Existing Dike - Notched	-250		
	160.30L	Chevron	350 x 350 / +15 LWRP		
	160.00L	Existing Dike - Notched	-250		
	160.00L	Chevron	350 x 350 / +15 LWRP		
	159.90L	Existing Dike - Removed	-		
	159.90L	Chevron	350 x 350 / +15 LWRP		
17	160.90R	Dike	500 / +15 LWRP	Not Completely	A deep side channel was created by three staggered chevrons. The bar creeps into the navigation channel leaving a channel as narrow as 670 feet.
	160.30L	Existing Dike - Removed	-		
	160.30L	Chevron	350 x 350 / +15 LWRP		
	160.00L	Existing Dike - Trimmed	-400		
	160.00L	Chevron	350 x 350 / +15 LWRP		
	159.90L	Existing Dike - Trimmed	-300		
	159.90L	Chevron	350 x 350 / +15 LWRP		
	159.70L	Existing Dike - Notched	-350		
18	160.30L	Existing Dike - Removed	-	Yes	A shallow side channel developed. The navigation channel has a minimum width of 900 feet through the adjacent reach.
	160.30L	Chevron	350 x 350 / +15 LWRP		
	160.00L	Existing Dike - Trimmed	-400		
	160.00L	Chevron	350 x 350 / +15 LWRP		
	159.90L	Existing Dike - Trimmed	-300		
	159.90L	Chevron	350 x 350 / +15 LWRP		
	159.70L	Existing Dike - Notched	-400		
19	160.30L	Chevron	350 x 350 / +15 LWRP	Yes	A shallow side channel with deep pools was created around a shallow bar. The navigation channel has a minimum width of 900 feet through the adjacent reach.
	160.30L	Existing Dike - Trimmed	-250		
	160.00L	Chevron	350 x 350 / +15 LWRP		
	160.00L	Existing Dike - Trimmed	-350		
	159.90L	Chevron	350 x 350 / +15 LWRP		
	159.90L	Existing Dike - Trimmed	-300		
	159.70L	Existing Dike - Trimmed	-350		
20	160.30L	Chevron	350 x 350 / +15 LWRP	Yes	A shallow side channel with a deep pool was created around a shallow bar. The navigation channel has a minimum width of 900 feet through the adjacent reach.
	160.30L	Existing Dike - Trimmed	-250		
	160.00L	Chevron	350 x 350 / +15 LWRP		
	160.00L	Existing Dike - Trimmed	-250		
	159.95L	Chevron	350 x 350 / +15 LWRP		
	159.90L	Existing Dike - Extended, Notched	250, -400 / +15 LWRP		
21	163.30L	Existing Dike - Trimmed	-200	Not Completely	A shallow side channel with deep pools developed. The bar creeps into the navigation channel creating a possible dredging issue.
	163.30L	Chevron	350 x 350 / +15 LWRP		
	160.00L	Existing Dike - Trimmed	-350		
	160.00L	Chevron	350 x 350 / +15 LWRP		
	159.95L	Chevron	350 x 350 / +15 LWRP		
	159.90L	Existing Dike - Extended, Notched	250,-4 00 / +15 LWRP		
	159.70L	Existing Dike - Trimmed	-200		

CONCLUSIONS

1. Evaluation and Summary of the Model Tests

Several alternative design tests were conducted in the HSR model. Each alternative was evaluated using the following two objectives along with an effort to reduce the need for dredging in the reach:

1. The creation of some form of side channel and bar formation
2. No negative impact to the navigation channel

Alternative Number	Creation of some form of side channel and bar formation	No negative impact to the navigation channel
1		X
2		X
3		X
4	X	X
5	X	
6	X	
7	X	
8	X	
9	X	
10	X	X
11	X	
12	X	
13	X	X
14	X	X
15	X	X
16	X	
17	X	
18	X	X
19	X	X
20	X	X
21	X	

Table 3: Summary of Alternatives

Alternatives 4-21 (Plates 19-36 respectively) were successful in creating some form of side channel. Eleven alternatives had no negative impact to the navigation channel. Alternatives 4, 10,13,14,15,18,19,20 (Plates 19,25,28,29,30,33,34,35 respectively) created some from of side channel with no negative impact on navigation. These 8 alternatives were analyzed to determine the most effective alternative using the least amount of material. The combination of Alternatives 14 and 19 was chosen as the most economically beneficial. This combination creates side channels in two areas of the study reach and has no negative effect on the navigation channel.

2. Recommendations

The combination of Alternatives 14 and 19 is the recommended plan to diversify aquatic habitat in the Cliff Cave-Kimmswick reach. The addition of Chevrons creates two bars surrounded by side channels. The partial removal rather than the entire removal of existing structures creates scour holes adding diversity to the side channels. Eliminating one of the two recommended alternatives will not have a detrimental effect on the effectiveness of the chosen alternative, therefore the two alternatives can be constructed over two phases in any order. In the recommended alternative 7 chevrons were added, 7 dikes partially removed, and 1 dike added. The structures are configured as follows:

- Alternative 14 (Shown blown up over the 2006 aerial photograph in Plate 37):
    - Trim existing dike 163.00L 200 feet from the tip.
    - Install chevron 162.8L at +15 LWRP with dimensions of 350 feet by 350 feet.
    - Trim existing dike 162.6L 200 feet from the tip.
    - Install chevron 162.6L at +15 LWRP with dimensions of 350 feet by 350 feet.
    - Install chevron 162.5L at +15 LWRP with dimensions of 350 feet by 350 feet.
    - Install chevron 162.4L at +15 LWRP with dimensions of 350 feet by 350 feet.
    - Trim existing dike 162.3L 150 feet from the tip.
    - Install dike 162.1L at +15 LWRP with a length of 650 feet

- It is recommended all material removed by trimming existing dikes be used as material for new structures.

- Alternative 19 (Shown blown up over 2006 aerial photograph in Plate 38):
    - Install chevron 160.3L at +15 LWRP with dimensions of 350 feet by 350 feet.
    - Trim existing dike 160.3L 250 feet from the tip.
    - Install chevron 160.00L at +15 LWRP with dimensions of 350 feet by 350 feet.
    - Trim existing dike 160.0L 350 feet.
    - Install chevron 159.9L at +15 LWRP with dimensions of 350 feet by 350 feet.
    - Trim existing dike 159.9L 300 feet from the tip.
    - Trim existing dike 159.7L 350 feet from the tip.
    - It is recommended all material removed by trimming existing dikes be used as material for new structures.

3. 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 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.

FOR MORE INFORMATION

For more information about HSR modeling or the Applied River Engineering Center, please contact Robert Davinroy, David Gordon, P.E. or Edward Brauer at:

Applied River Engineering Center
U.S. Army Corps of Engineers - St. Louis District
Hydrologic and Hydraulics Branch
Foot of Arsenal Street
St. Louis, Missouri 63118

Phone: (314) 263-4714, (314) 263-4230 or (314) 263-8094
Fax: (314) 263-4166

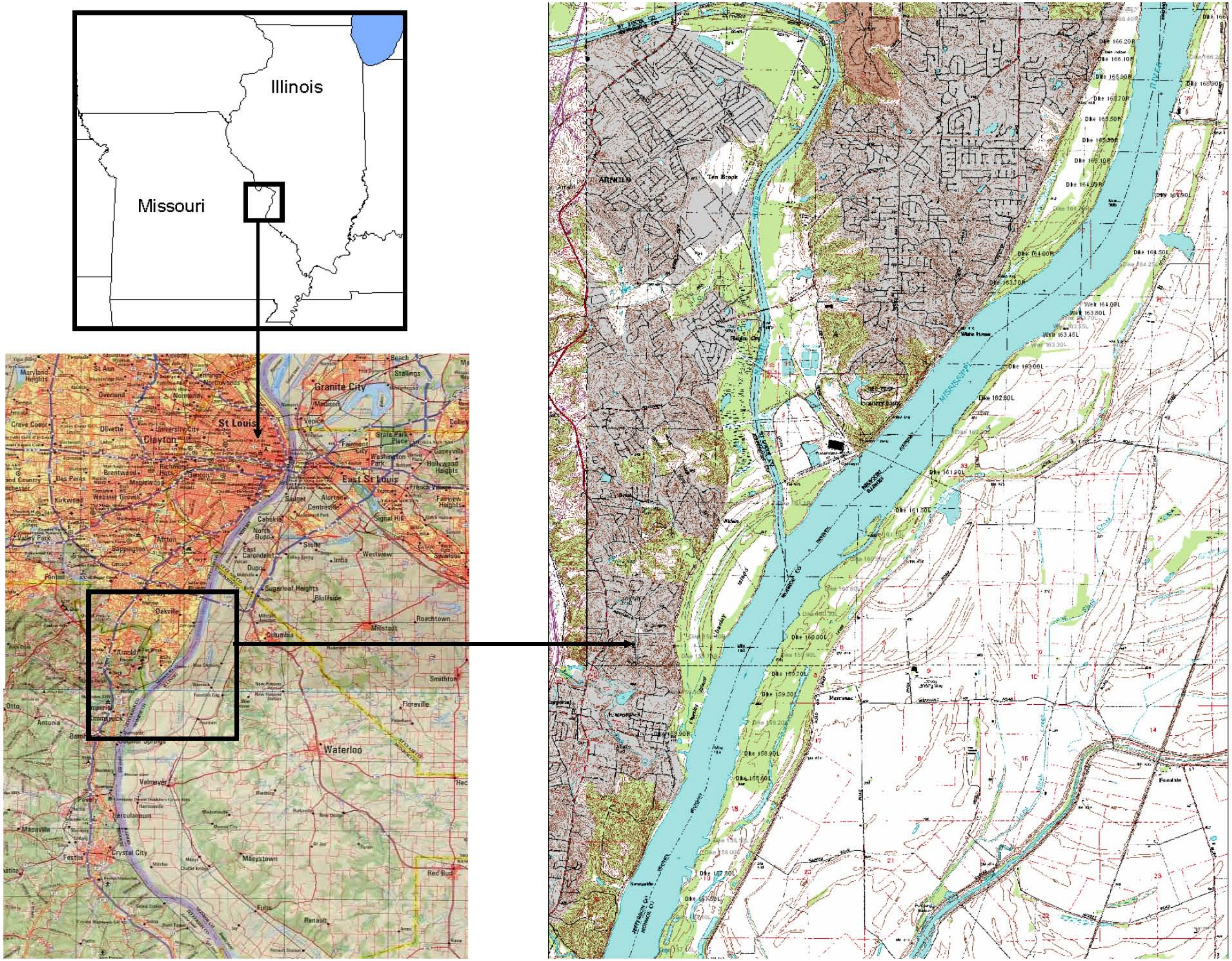
E-mail:
Robert.D.Davinroy@mvs02.usace.army.mil
David.C.Gordon@mvs02.usace.army.mil
Edward.J.Brauer@mvs02.usace.army.mil

Or you can visit us on the World Wide Web at:
http://www.mvs.usace.army.mil/eng-con/expertise/arec/welcome_page_2.html

APPENDIX OF PLATES

Plate number 1 through 36 follow:

28. Alternative 13
29. Alternative 14
30. Alternative 15
31. Alternative 16
32. Alternative 17
33. Alternative 18
34. Alternative 19
35. Alternative 20
36. Alternative 21
37. Alternative 14 over 2006 Aerial Photograph
38. Alternative 19 over 2006 Aerial Photograph



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U.S. ARMY CORPS OF ENGINEERS ST. LOUIS, DISTRICT	PLOT DATE September 21, 2006
	REVIEWED BY: D. Gordon
UPPER MISSISSIPPI RIVER Cliff Cave-Kimmswick River Miles 168.0-156.6	DRAWN BY E. Brauer
	FILE NAME:

LOCATION AND VICINITY MAP – USGS QUAD SHEET
Cliff Cave-Kimmswick
(River Miles 168.0-156.6)

PLATE NUMBER

1

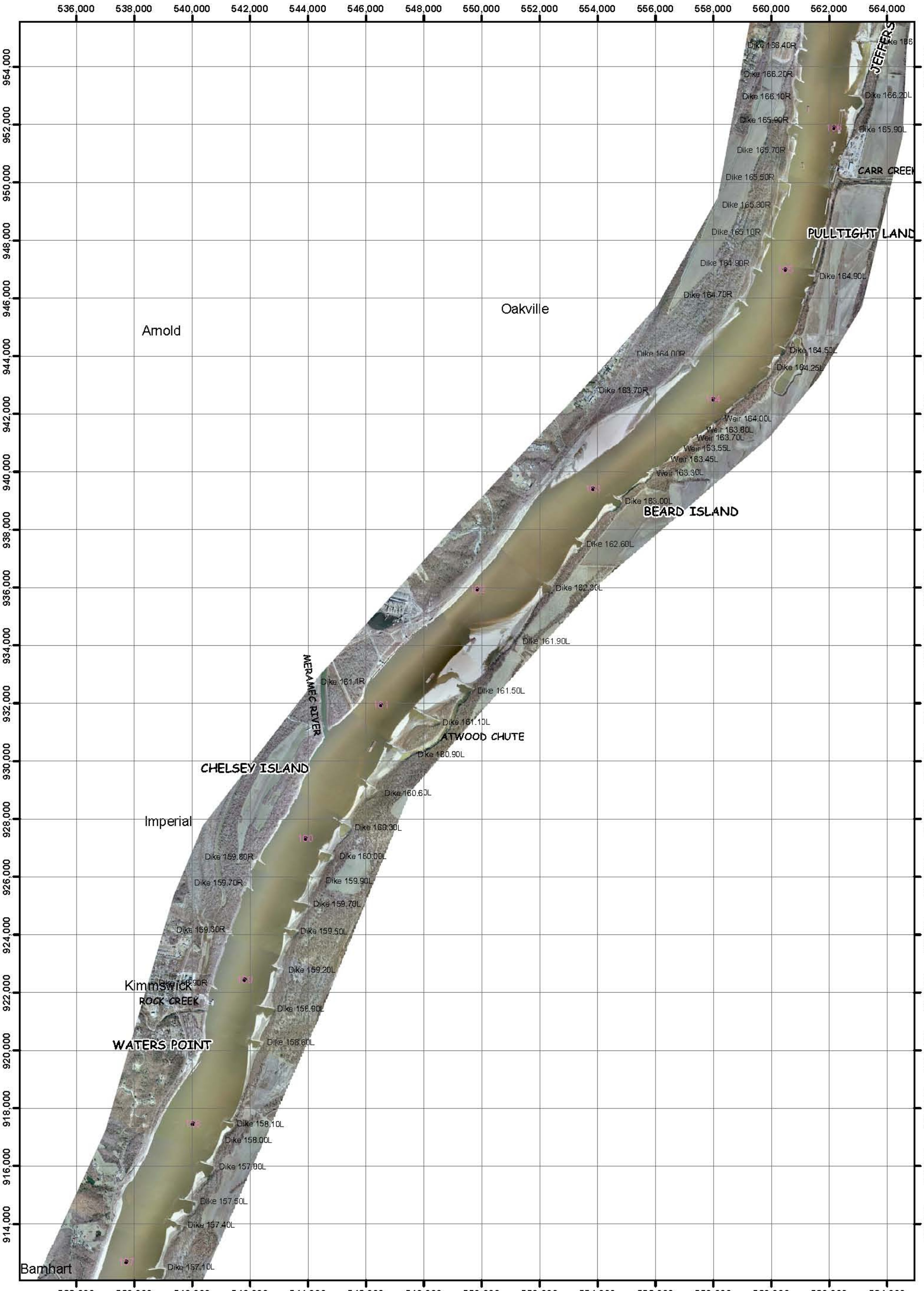

PLATE NUMBER 2

0 500 1,000 2,000 3,000 Feet

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2006 Aerial Photograph

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UPPER MISSISSIPPI RIVER BASIN
Cliff Cave HSR Model
River Miles 168.0-156.6

PLOT DATE: SEPTEMBER 22, 2006

DRAWN BY: E. BRAUER | CHECKED BY: D. GORDON

REVIEWED BY: R. DAVINROY

FILE NAME: L:\Cliff Cave-Kimmswick Reaches\ARC\Cliff Cave.mxd

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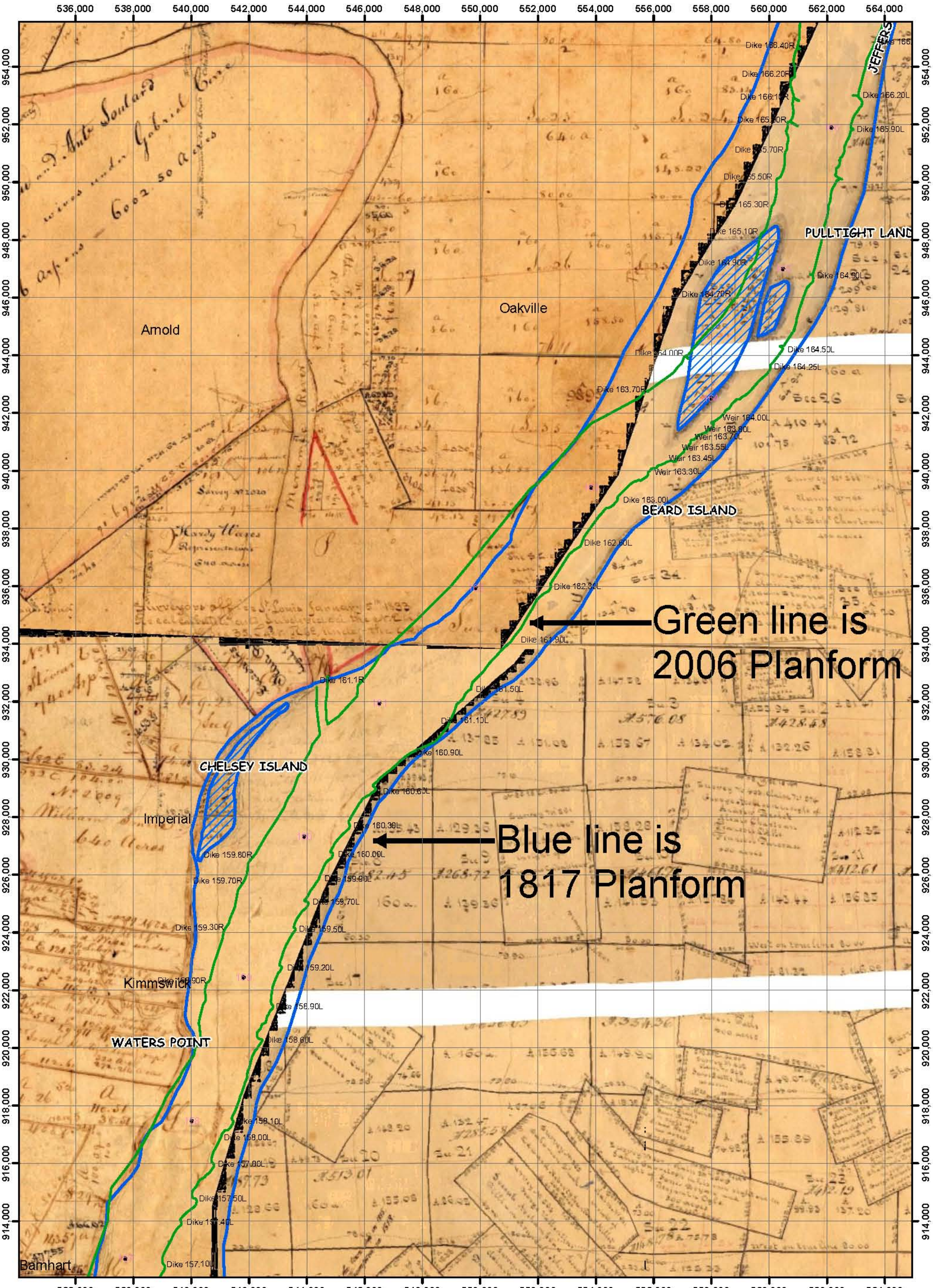

PLATE NUMBER 3

0 500 1,000 2,000 3,000 Feet

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1817 Planform

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River Miles 168.0-156.6

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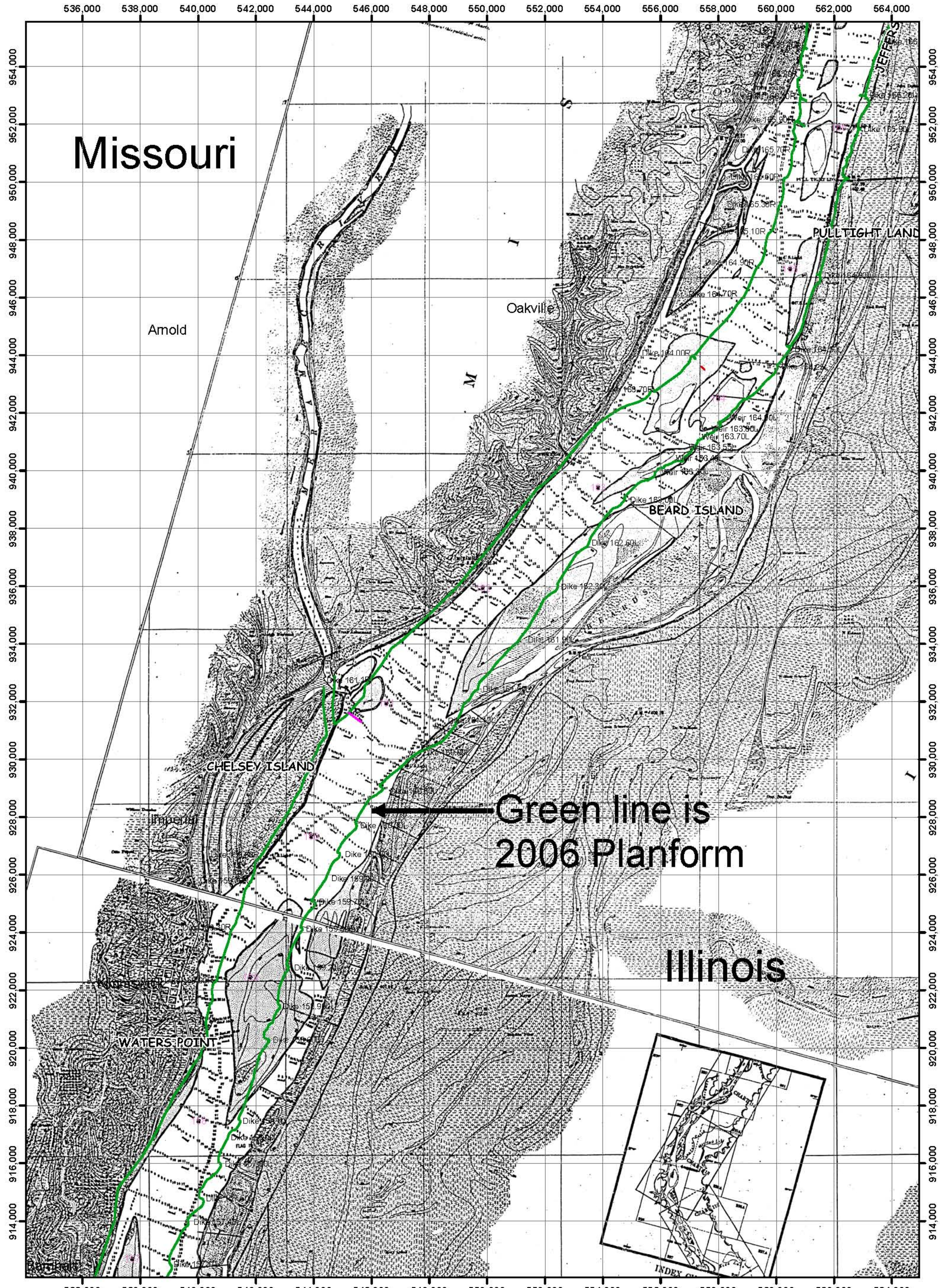

PLATE NUMBER 4

0 500 1,000 2,000 3,000 Feet

THE INFORMATION DEPICTED ON THIS MAP REPRESENTS THE RESULTS OF SURVEYS MADE ON THE DATES INDICATED AND CAN ONLY BE CONSIDERED AS INDICATING THE GENERAL CONDITIONS EXISTING AT THAT TIME

1880 Planform

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UPPER MISSISSIPPI RIVER BASIN
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River Miles 168.0-156.6

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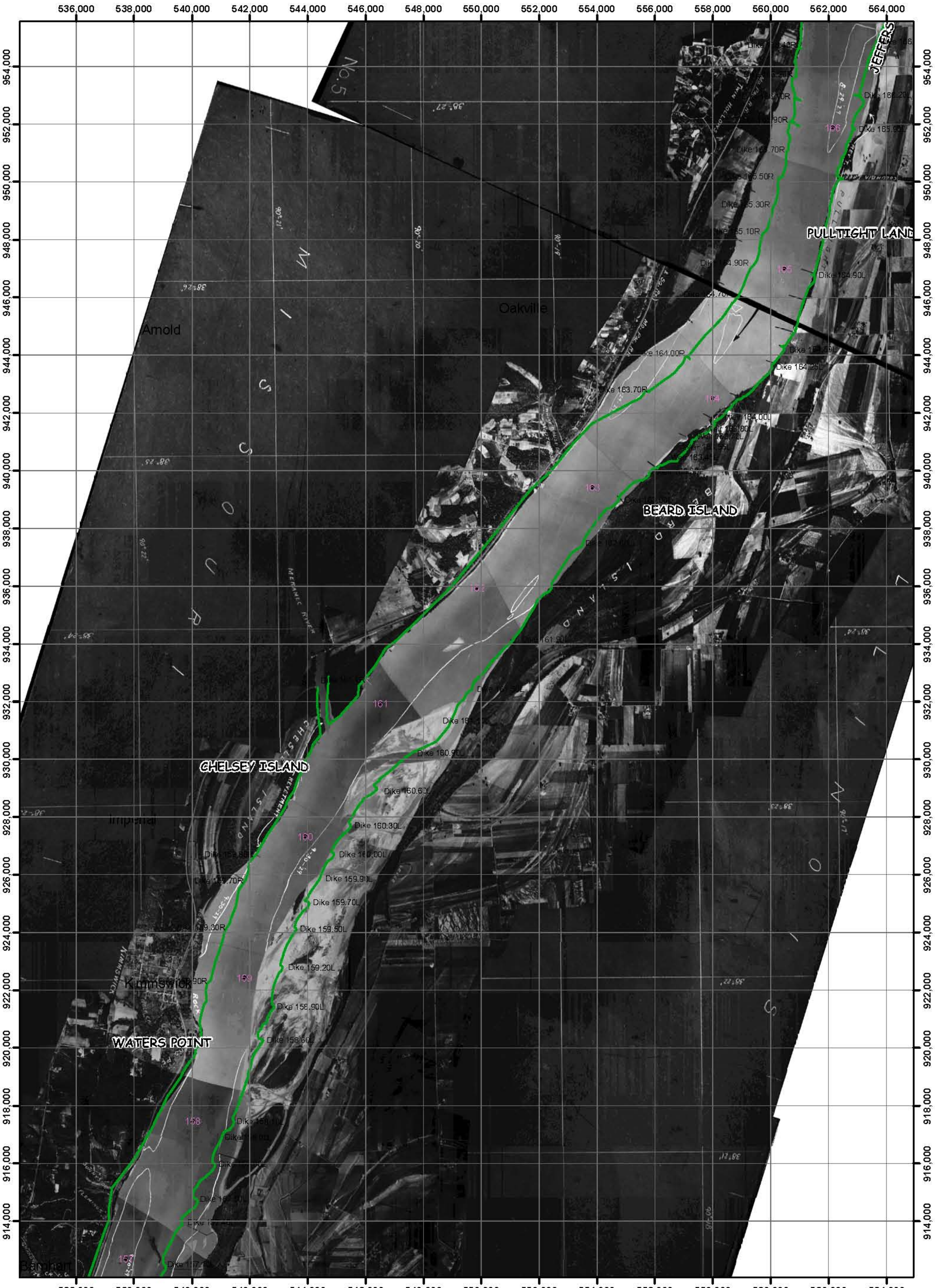

0 500 1,000 2,000 3,000 Feet

THE INFORMATION DEPICTED ON THIS MAP REPRESENTS THE RESULTS OF SURVEYS MADE ON THE DATES INDICATED AND CAN ONLY BE CONSIDERED AS INDICATING THE GENERAL CONDITIONS EXISTING AT THAT TIME

1928 Aerials

PLATE NUMBER 5

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UPPER MISSISSIPPI RIVER BASIN
Cliff Cave HSR Model
River Miles 168.0-156.6

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REVIEWED BY: R. DAVINROY	
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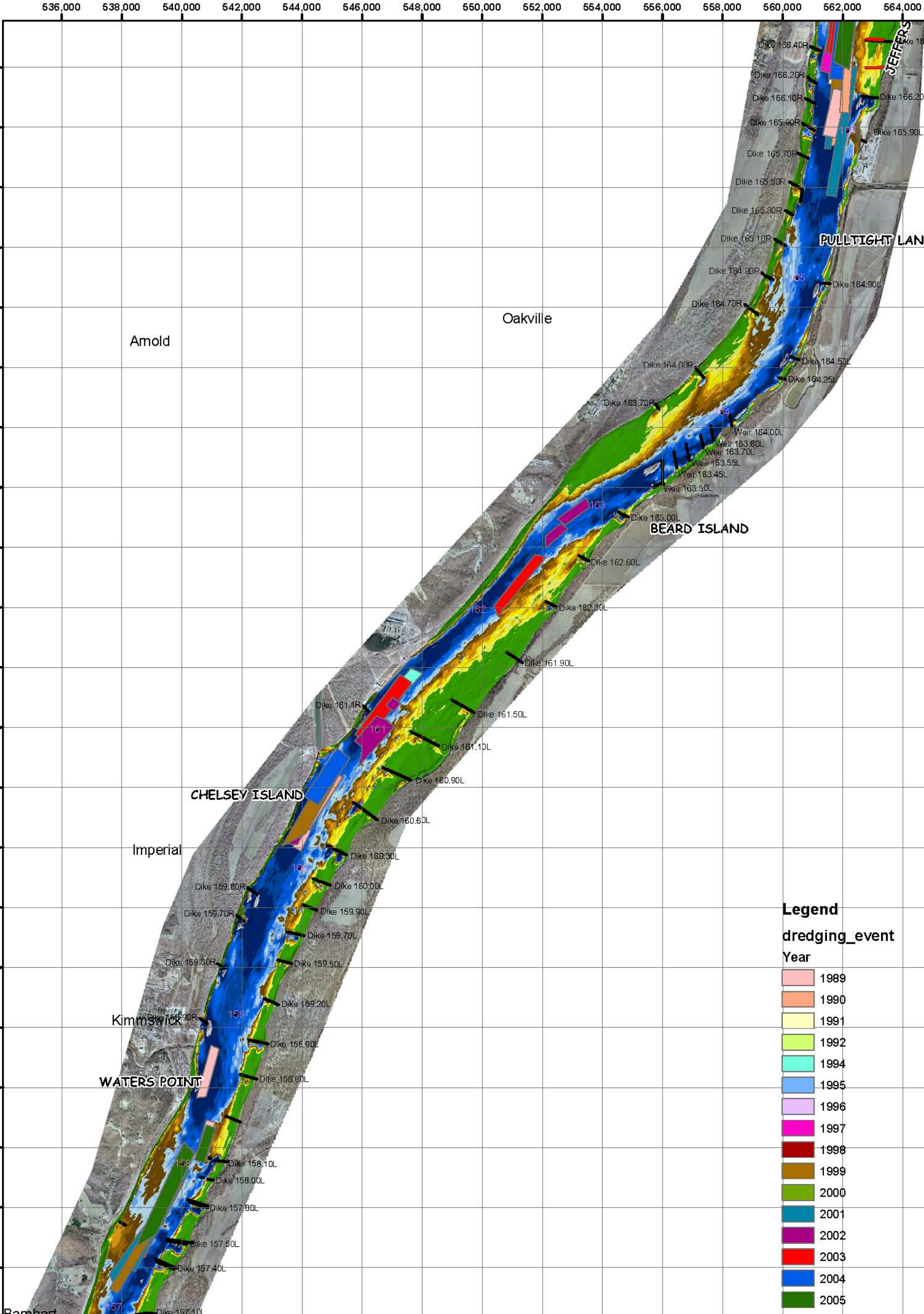

PLATE NUMBER 6

0 500 1,000 2,000 3,000 Feet

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Dredging Events

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UPPER MISSISSIPPI RIVER BASIN
Cliff Cave HSR Model
River Miles 168.0-156.6

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PLATE NUMBER 7

HYDRAULEC SEDIMENT RESPONSE MODEL CLIFF CAVE (River Miles 168.0-156.6)

U.S. ARMY CORPS OF ENGINEERS ST. LOUIS, DISTRICT	PHOTOGRAPH DATE: September 23, 2006
	REVIEWED BY: David Gordon
UPPER MISSISSIPPI RIVER BASIN Cliff Cave HSR Model River Miles 168.0-156.6	PREPARED BY: E. BRAUER
	FILE NAME: HSR Model Photograph

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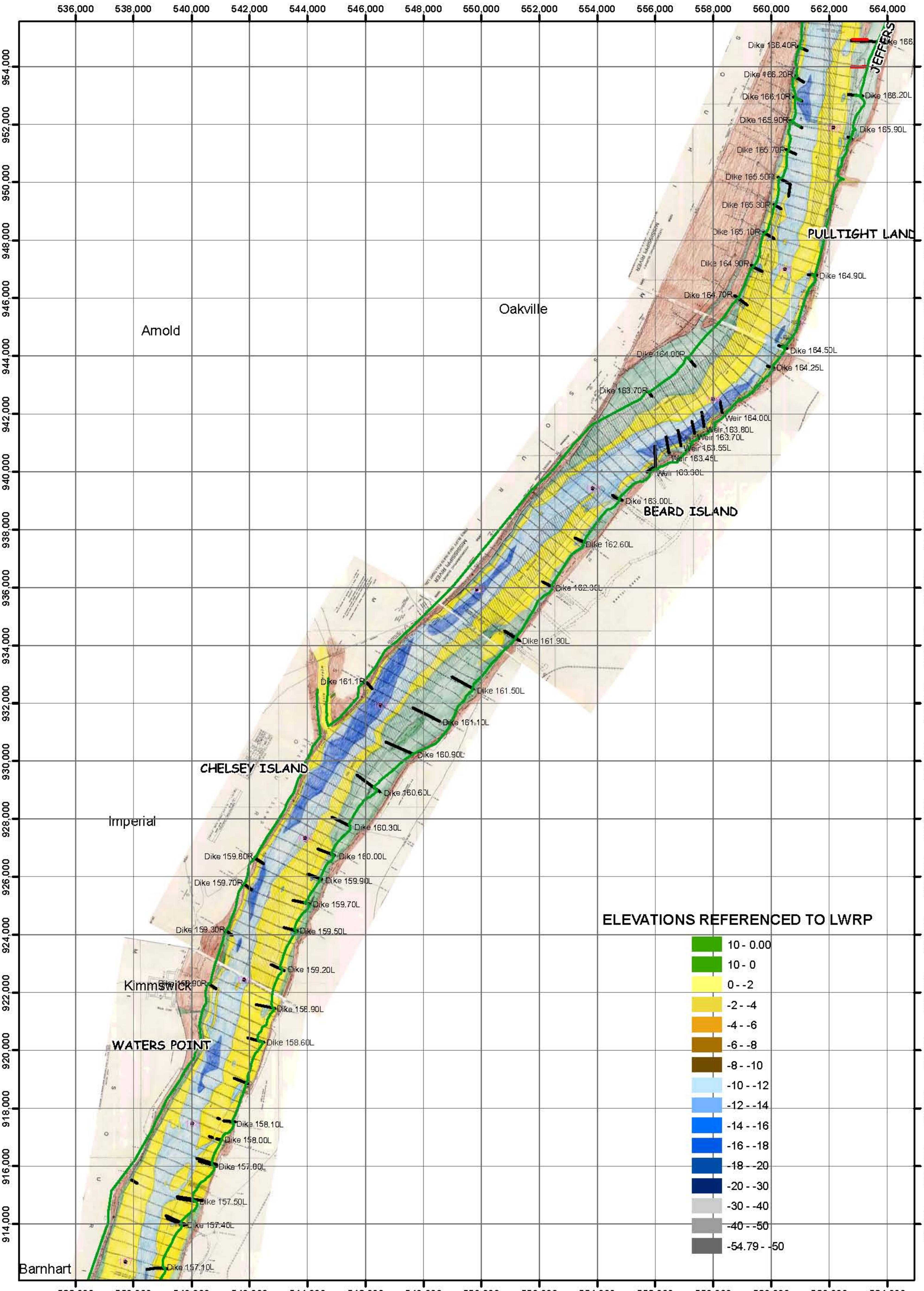

PLATE NUMBER 8

0 500 1,000 2,000 3,000 Feet

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1959 Hydrographic Survey

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UPPER MISSISSIPPI RIVER BASIN
Cliff Cave HSR Model
River Miles 168.0-156.6

PLOT DATE: SEPTEMBER 22, 2006	
DRAWN BY: E. BRAUER	CHECKED BY: D. GORDON
REVIEWED BY: R. DAVINROY	
FILE NAME: Lt\Cliff Cave-Kimmswick Reaches\ ARC\Cliff Cave.mxd	

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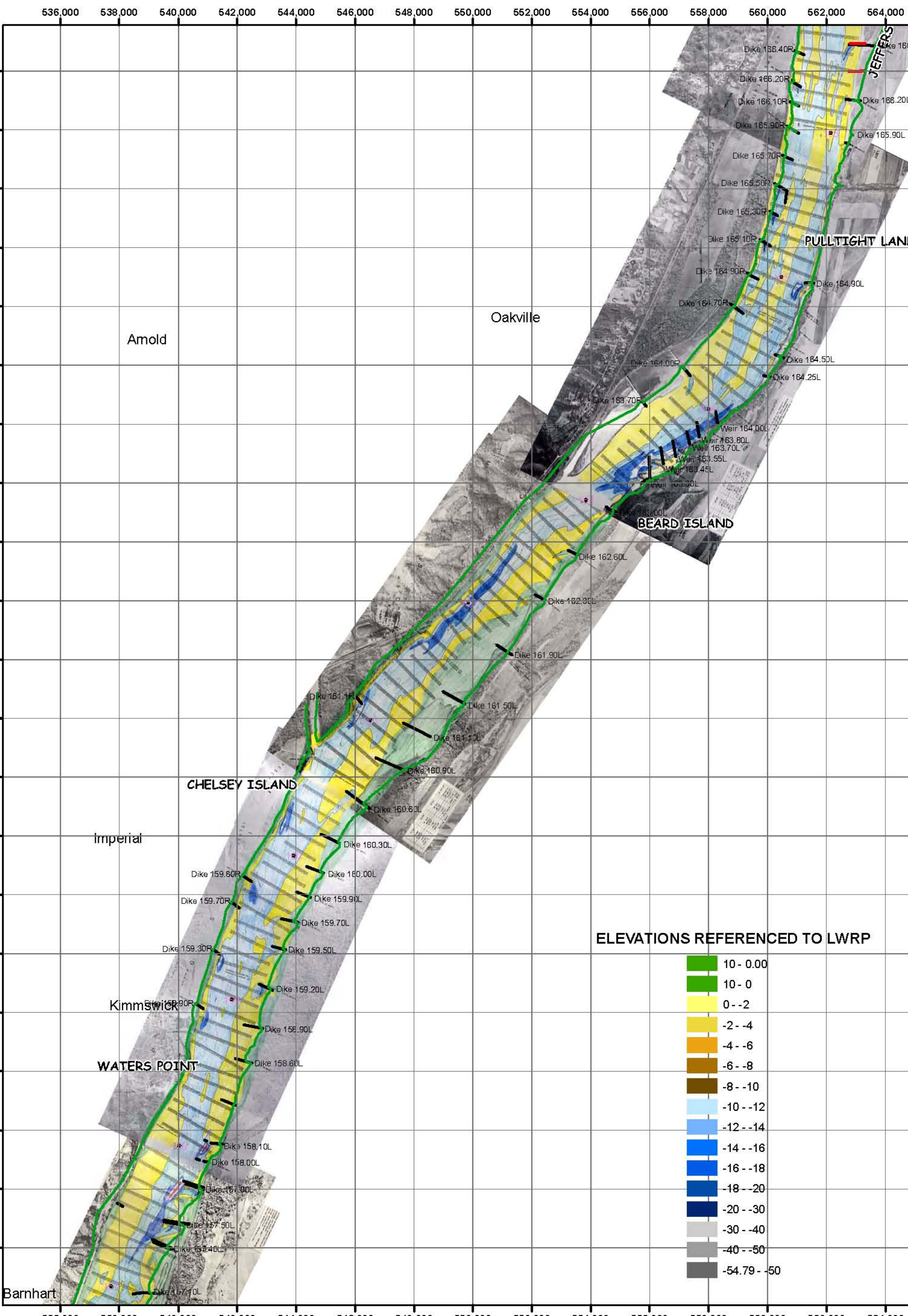

PLATE NUMBER
9

0 500 1,000 2,000 3,000 Feet

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1971 Hydrographic Survey

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River Miles 168.0-156.6

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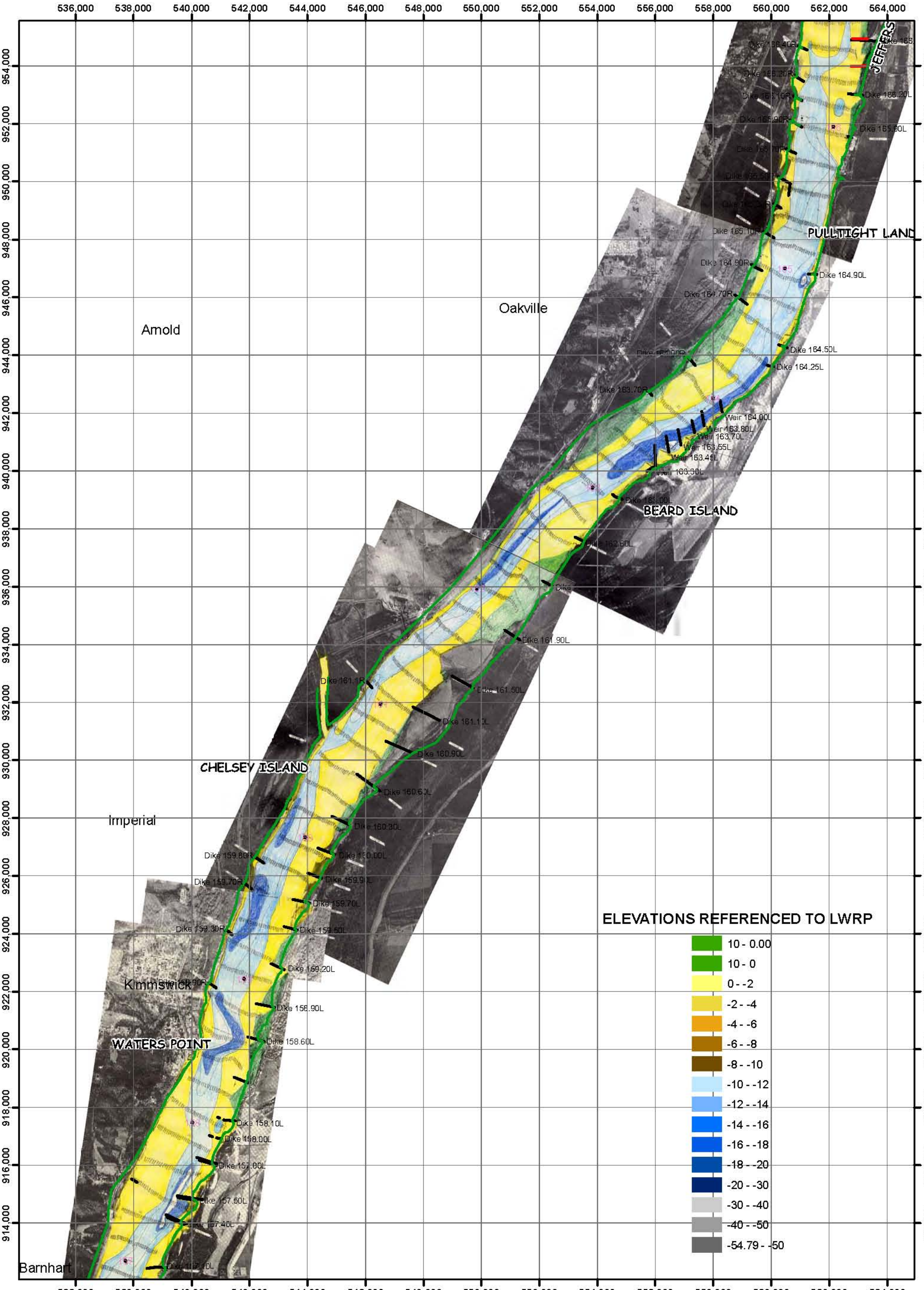

PLATE NUMBER 10

0 500 1,000 2,000 3,000 Feet

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1983 Hydrographic Survey

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River Miles 168.0-156.6

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REVIEWED BY: R. DAVINROY	
FILE NAME: Lr\Cliff Cave-Kimmswick Reaches\ARC\Cliff Cave.mxd	

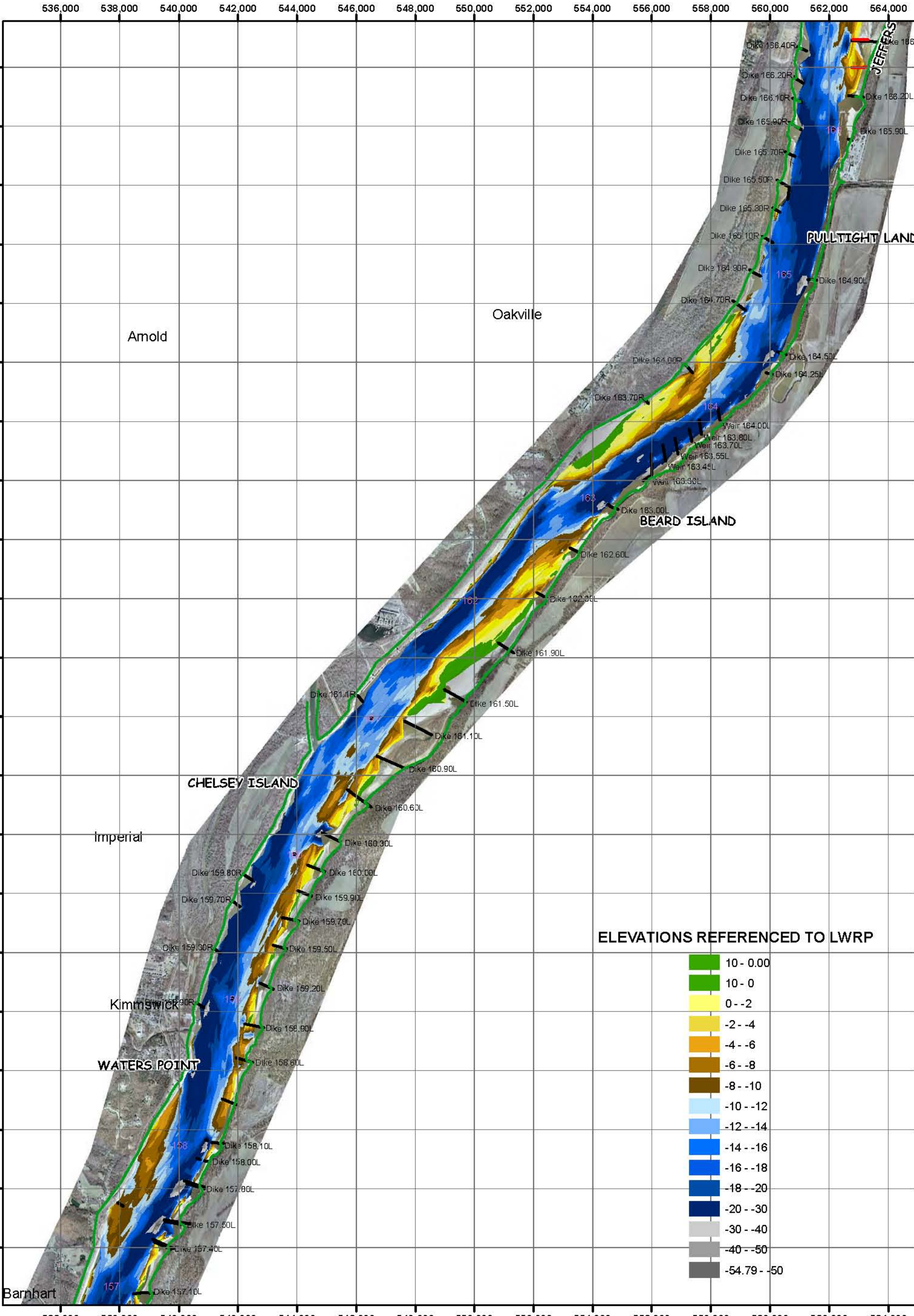

PLATE NUMBER 11

0 500 1,000 2,000 3,000 Feet

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1996 Hydrographic Survey

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River Miles 168.0-156.6

PLOT DATE: SEPTEMBER 22, 2006

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REVIEWED BY: R. DAVINROY

FILE NAME: Lr\Cliff Cave-Kimmswick Reaches\ARC\Cliff Cave.mxd

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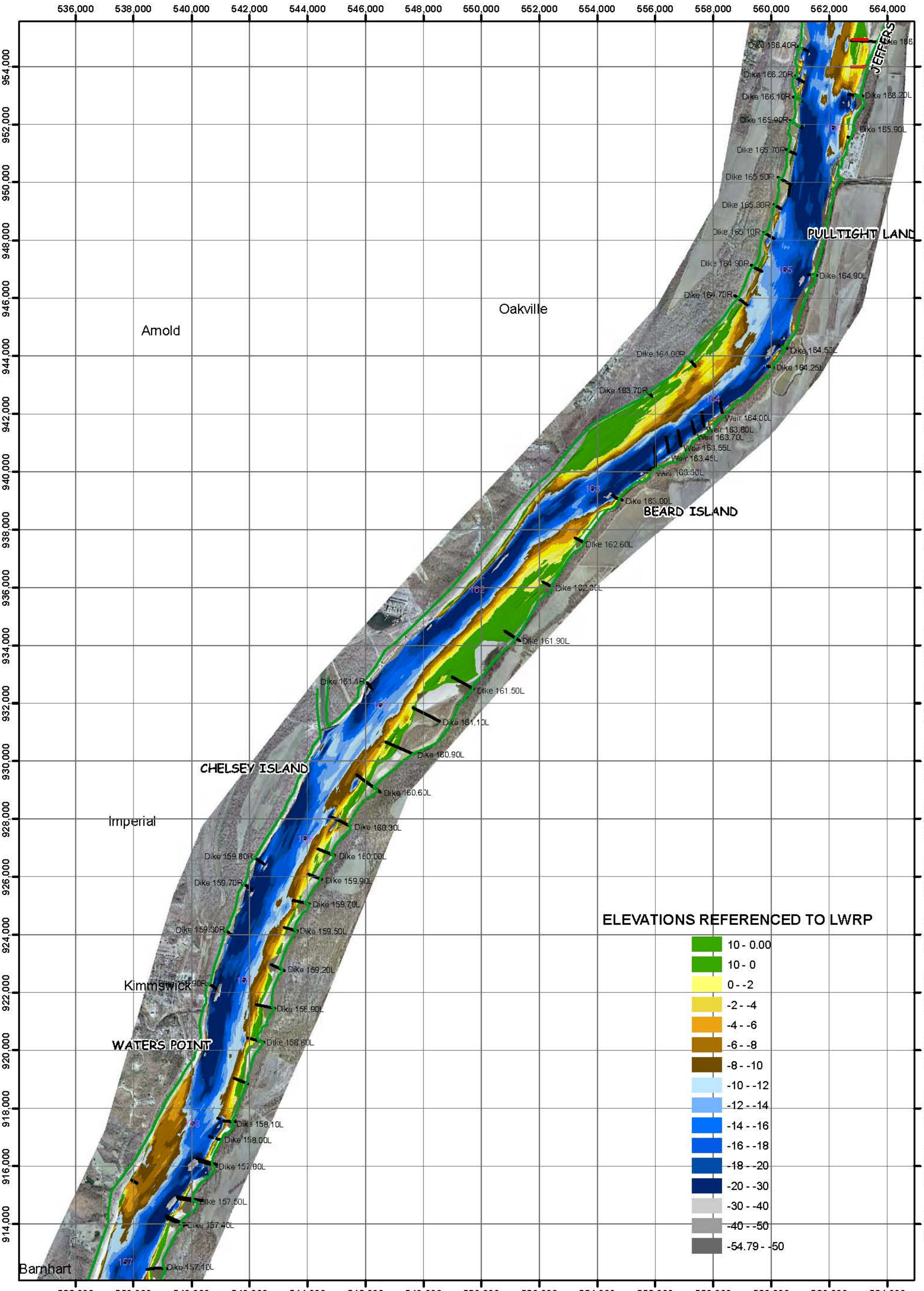

PLATE NUMBER 12

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1998 Hydrographic Survey

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Cliff Cave HSR Model
River Miles 168.0-156.6

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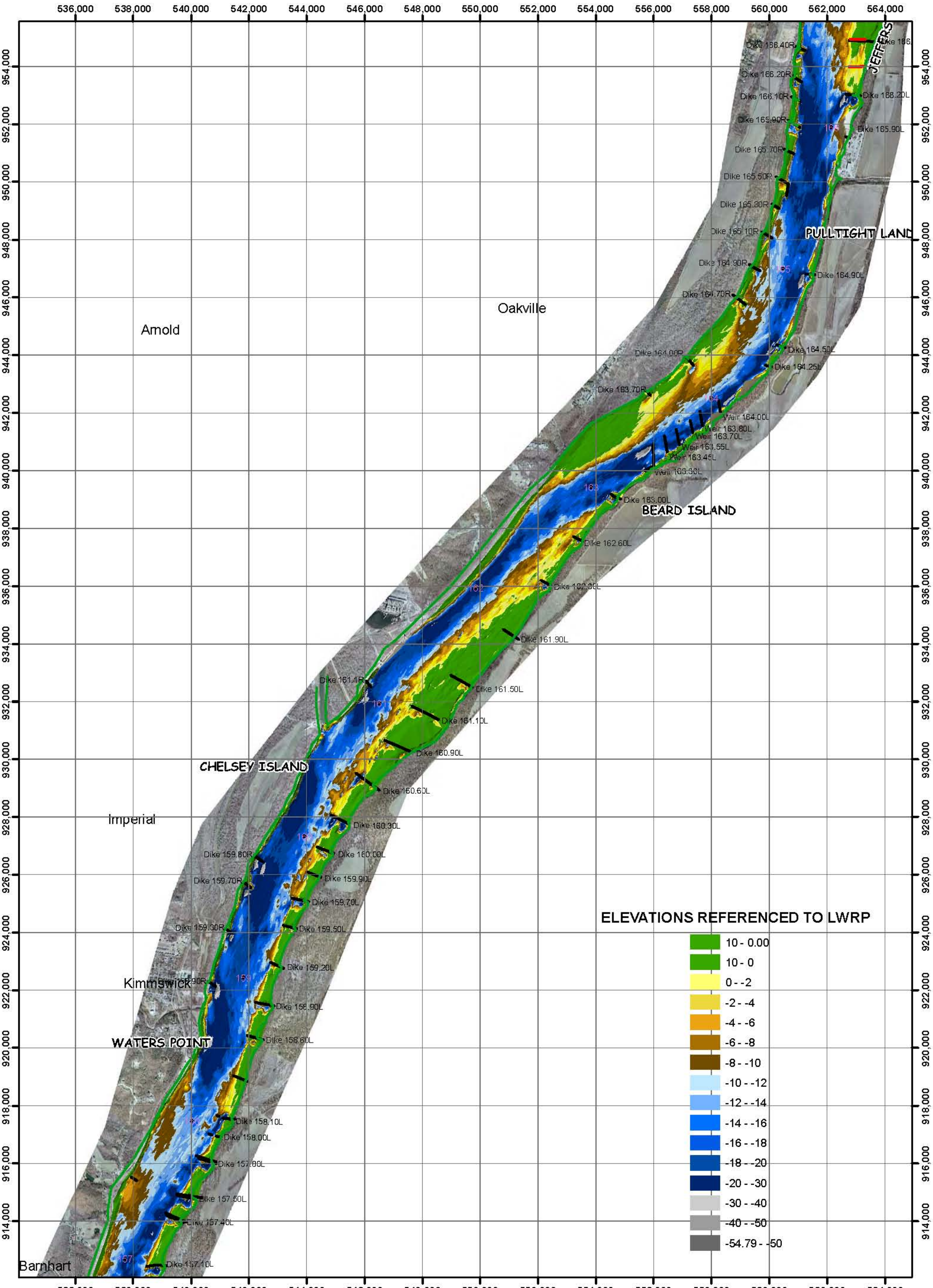

PLATE NUMBER 13

0 500 1,000 2,000 3,000 Feet

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2001 Hydrographic Survey

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UPPER MISSISSIPPI RIVER BASIN
Cliff Cave HSR Model
River Miles 168.0-156.6

PLOT DATE: SEPTEMBER 22, 2006
DRAWN BY: E. BRAUER
CHECKED BY: D. GORDON
REVIEWED BY: R. DAVINROY
FILE NAME: Lt\Cliff Cave-Kimmswick Reaches\ARC\Cliff Cave.mxd

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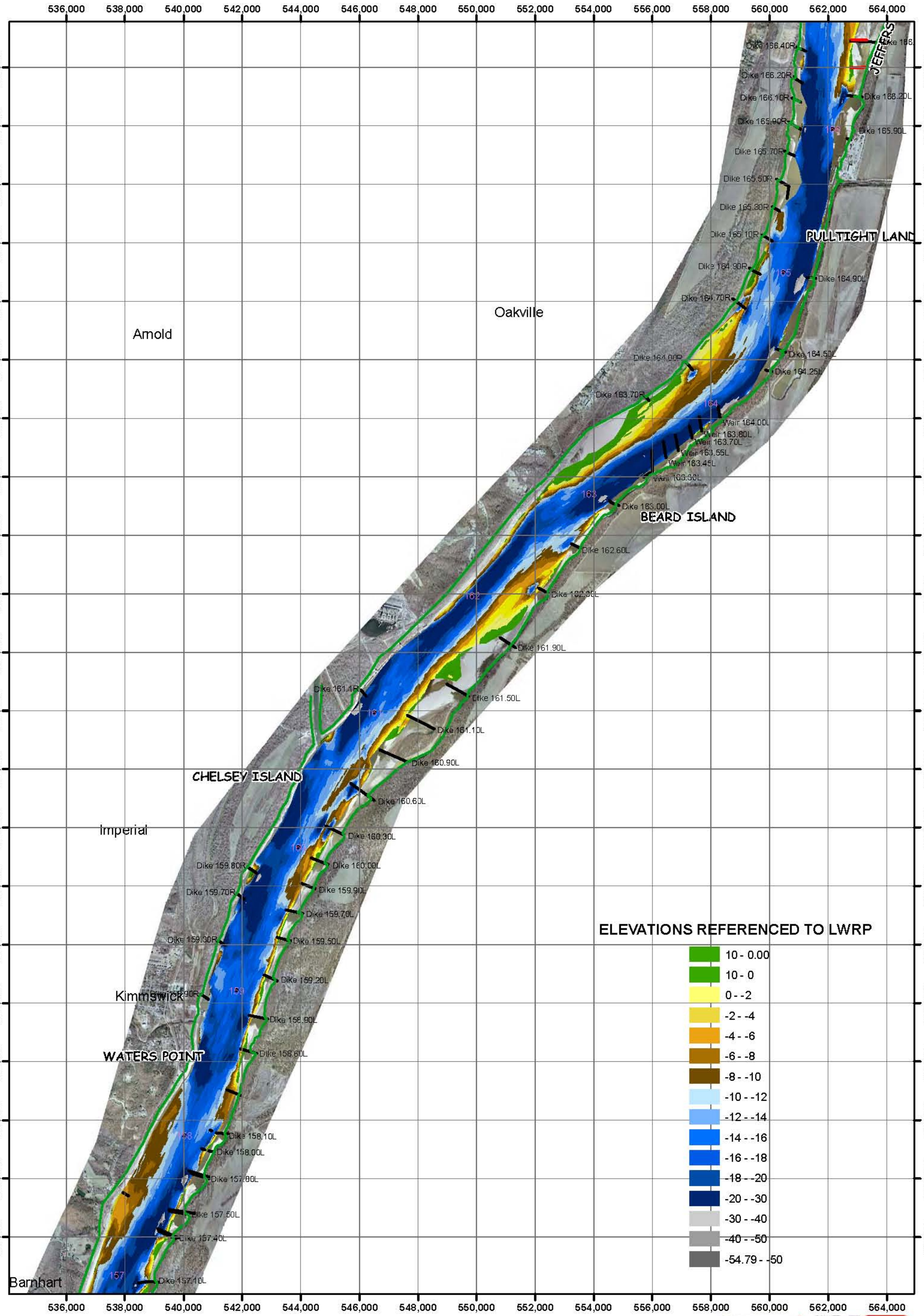

PLATE NUMBER 14

0 500 1,000 2,000 3,000 Feet

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2005 Hydrographic Survey

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UPPER MISSISSIPPI RIVER BASIN
Cliff Cave HSR Model
River Miles 168.0-156.6

PLOT DATE:	
SEPTEMBER 22, 2006	
DRAWN BY: E. BRAUER	CHECKED BY: D. GORDON
REVIEWED BY R. DAVINROY	
FILE NAME: Lr\Cliff Cave-Kimmswick Reaches\ARC\Cliff Cave.mxd	

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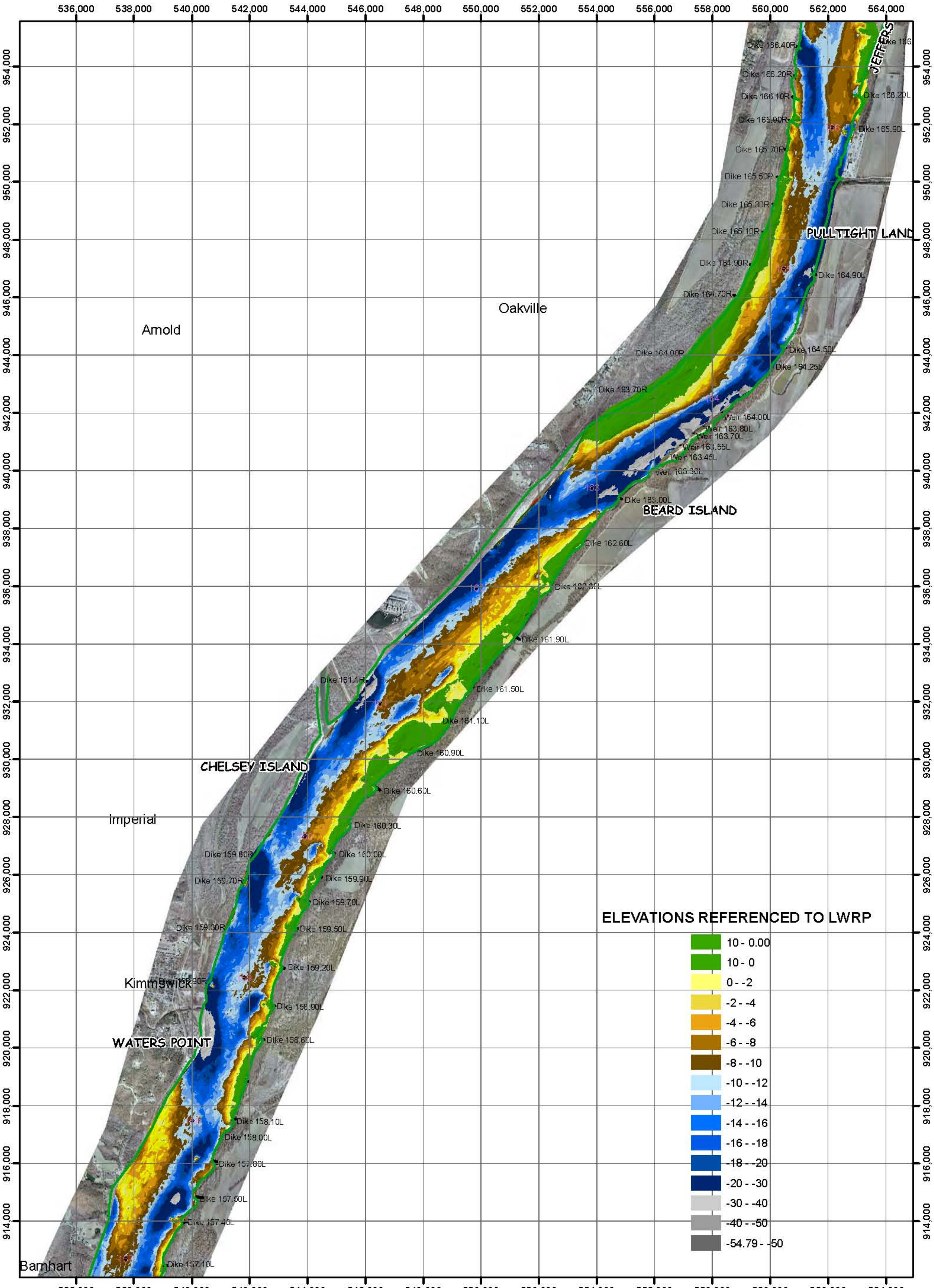

PLATE NUMBER
15

0 500 1,000 2,000 3,000 Feet

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Base Test

U.S. ARMY ENGINEER DIVISION CORPS OF ENGINEERS ST. LOUIS, MISSOURI	PLOT DATE: SEPTEMBER 22, 2006	
	DRAWN BY: E. BRAUER	CHECKED BY: D. GORDON
UPPER MISSISSIPPI RIVER BASIN Cliff Cave HSR Model River Miles 168.0-156.6	REVIEWED BY R. DAVINROY	
	FILE NAME L:\Cliff Cave-Kimmswick Reaches\ ARC\Cliff Cave.mxd	

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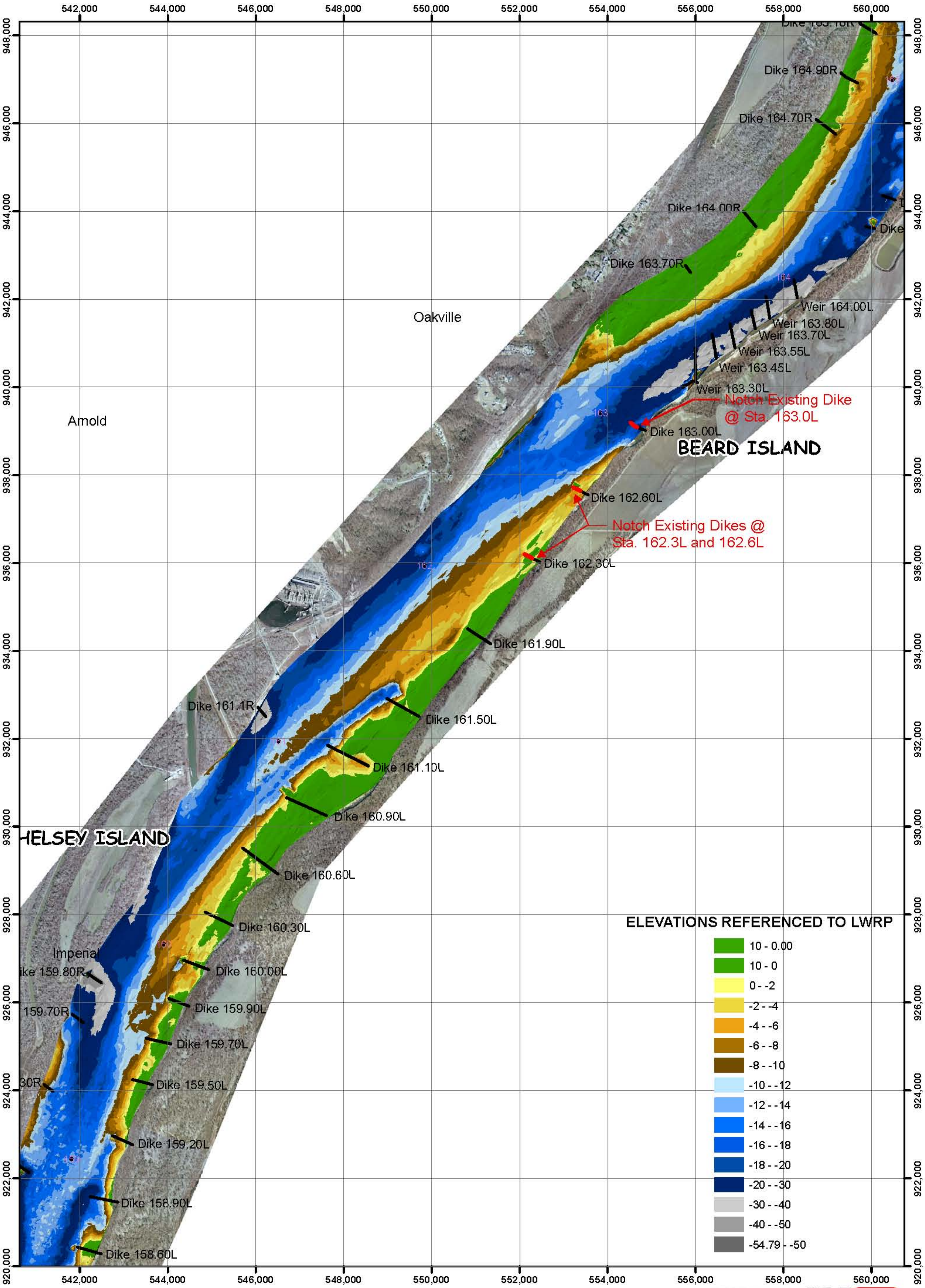

PLATE NUMBER 16

0 500 1,000 2,000 3,000 Feet

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ALTERNATIVE 1

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UPPER MISSISSIPPI RIVER BASIN
Cliff Cave HSR Model
River Miles 168.0-156.6

PLOT DATE: SEPTEMBER 22, 2006
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CHECKED BY: D. GORDON
REVIEWED BY: R. DAVINROY
FILE NAME: L:\Cliff Cave-Kimmswick Reaches\ARC\Cliff Cave.mxd

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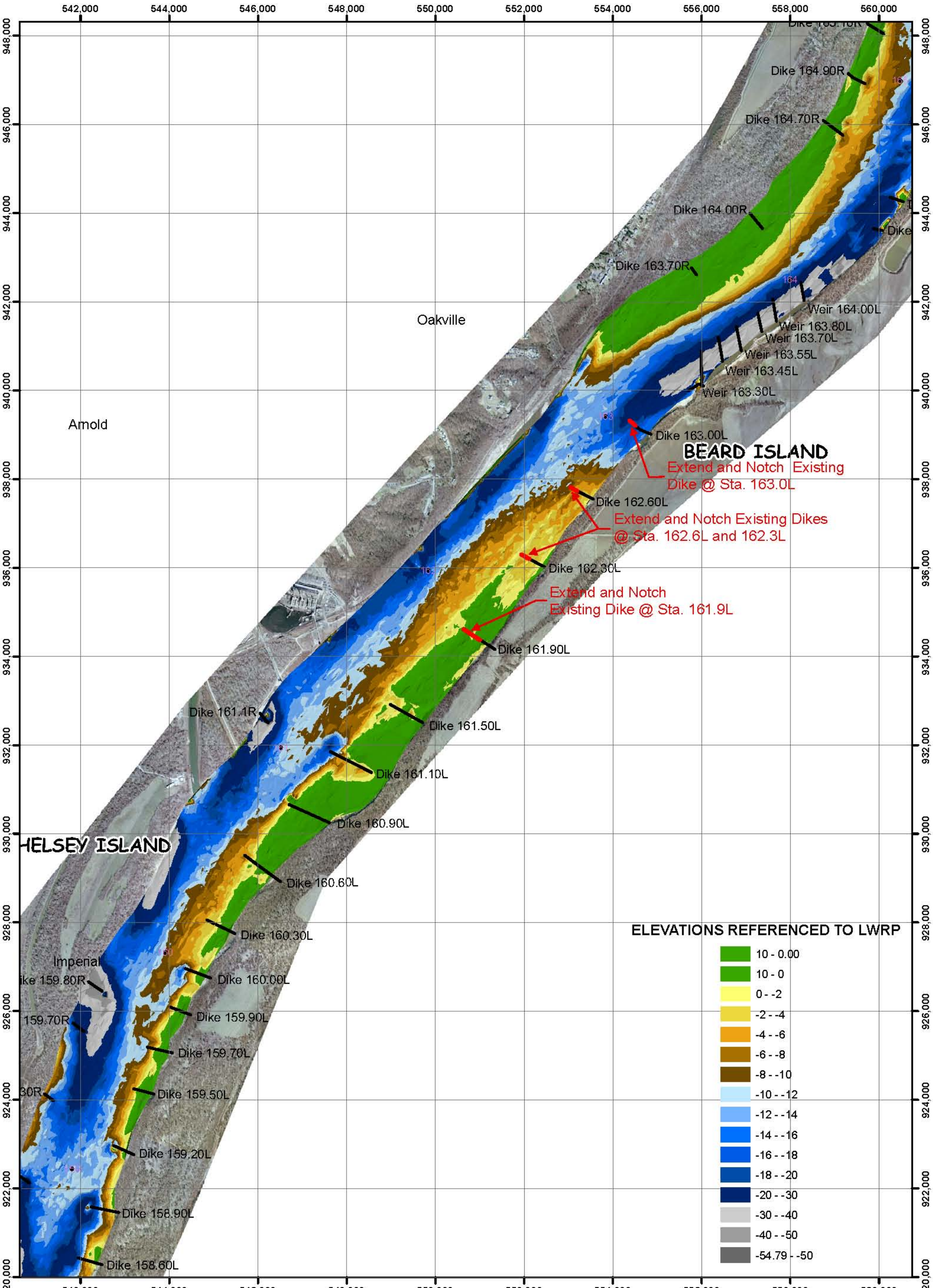

PLATE NUMBER 17

0 500 1,000 2,000 3,000 Feet

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ALTERNATIVE 2

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Cliff Cave HSR Model
River Miles 168.0-156.6

PLOT DATE: SEPTEMBER 22, 2006
DRAWN BY: E. BRAUER
CHECKED BY: D. GORDON
REVIEWED BY: R. DAVINROY
FILE NAME: L:\Cliff Cave-Kimmswick Reaches\ARC\Cliff Cave.mxd

APPLIED RIVER ENGINEERING CENTER

US Army Corps of Engineers
St. Louis District

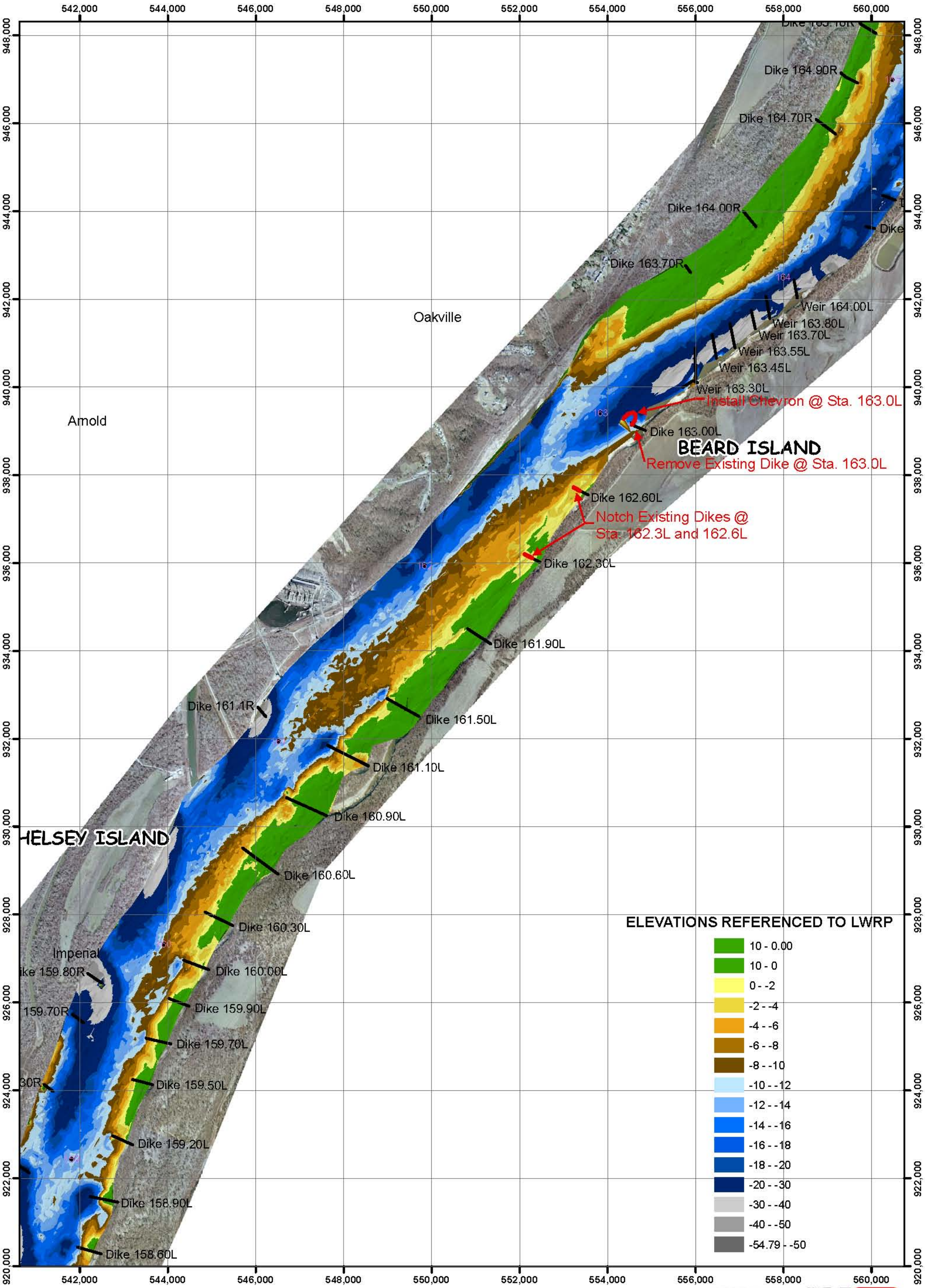

PLATE NUMBER 18

0 500 1,000 2,000 3,000 Feet

THE INFORMATION DEPICTED ON THIS MAP REPRESENTS THE RESULTS OF SURVEYS MADE ON THE DATES INDICATED AND CAN ONLY BE CONSIDERED AS INDICATING THE GENERAL CONDITIONS EXISTING AT THAT TIME

ALTERNATIVE 3

U.S. ARMY ENGINEER DIVISION
CORPS OF ENGINEERS
ST. LOUIS, MISSOURI

UPPER MISSISSIPPI RIVER BASIN
Cliff Cave HSR Model
River Miles 168.0-156.6

PLOT DATE: SEPTEMBER 22, 2006
DRAWN BY: E. BRAUER
CHECKED BY: D. GORDON
REVIEWED BY: R. DAVINROY
FILE NAME: L:\Cliff Cave-Kimmswick Reaches\ARC\Cliff Cave.mxd

N S W E

APPLIED RIVER ENGINEERING CENTER

US Army Corps of Engineers
St. Louis District

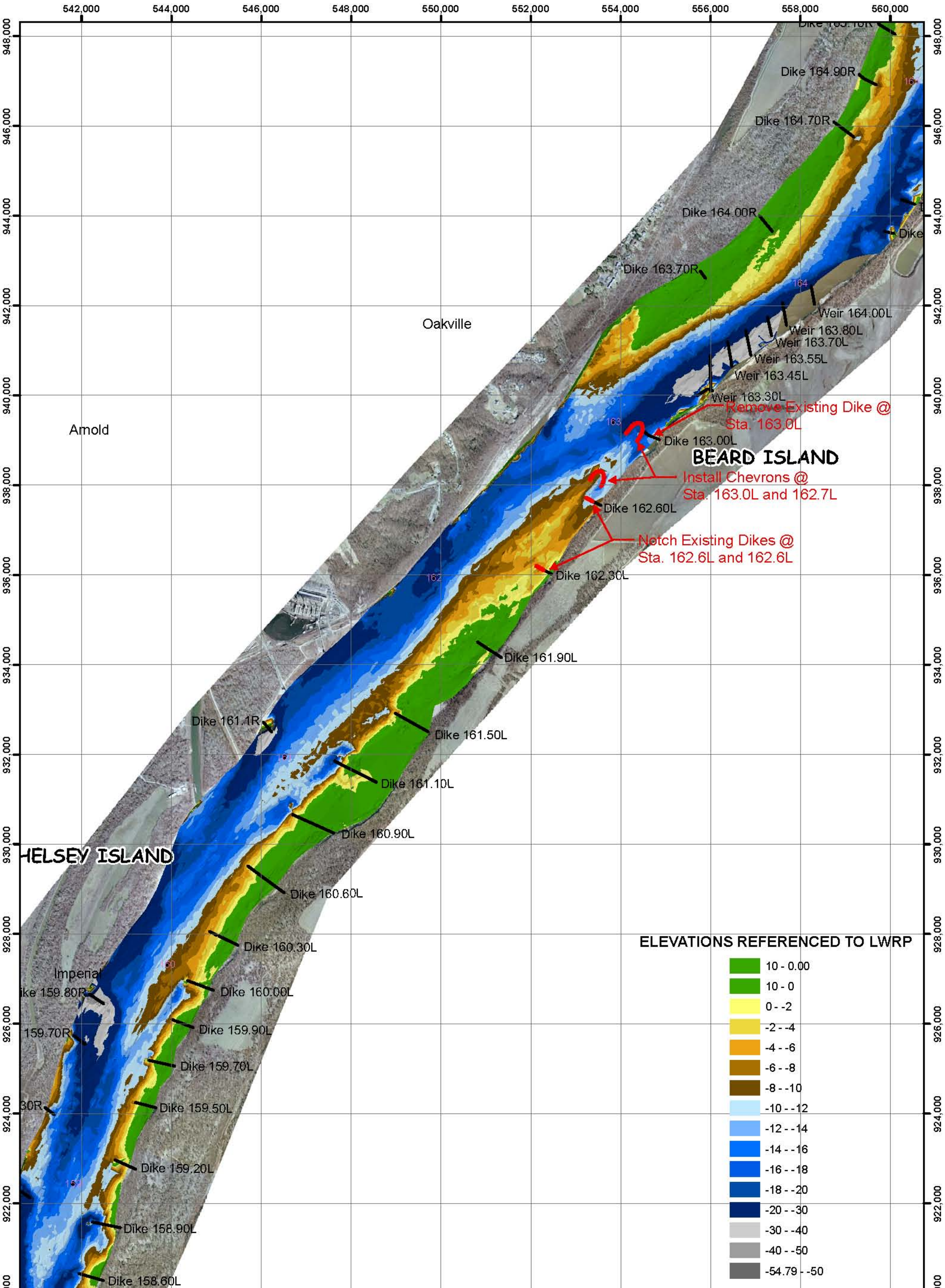

PLATE NUMBER 19

0 500 1,000 2,000 3,000 Feet

THE INFORMATION DEPICTED ON THIS MAP REPRESENTS THE RESULTS OF SURVEYS MADE ON THE DATES INDICATED AND CAN ONLY BE CONSIDERED AS INDICATING THE GENERAL CONDITIONS EXISTING AT THAT TIME

ALTERNATIVE 4

U.S. ARMY ENGINEER DIVISION
CORPS OF ENGINEERS
ST. LOUIS, MISSOURI

UPPER MISSISSIPPI RIVER BASIN
Cliff Cave HSR Model
River Miles 168.0-156.6

PLOT DATE: SEPTEMBER 22, 2006
DRAWN BY: E. BRAUER
CHECKED BY: D. GORDON
REVIEWED BY: R. DAVINROY
FILE NAME: L:\Cliff Cave-Kimmswick Reaches\ARC\Cliff Cave.mxd

N S E W

APPLIED RIVER ENGINEERING CENTER

US Army Corps of Engineers
St. Louis District

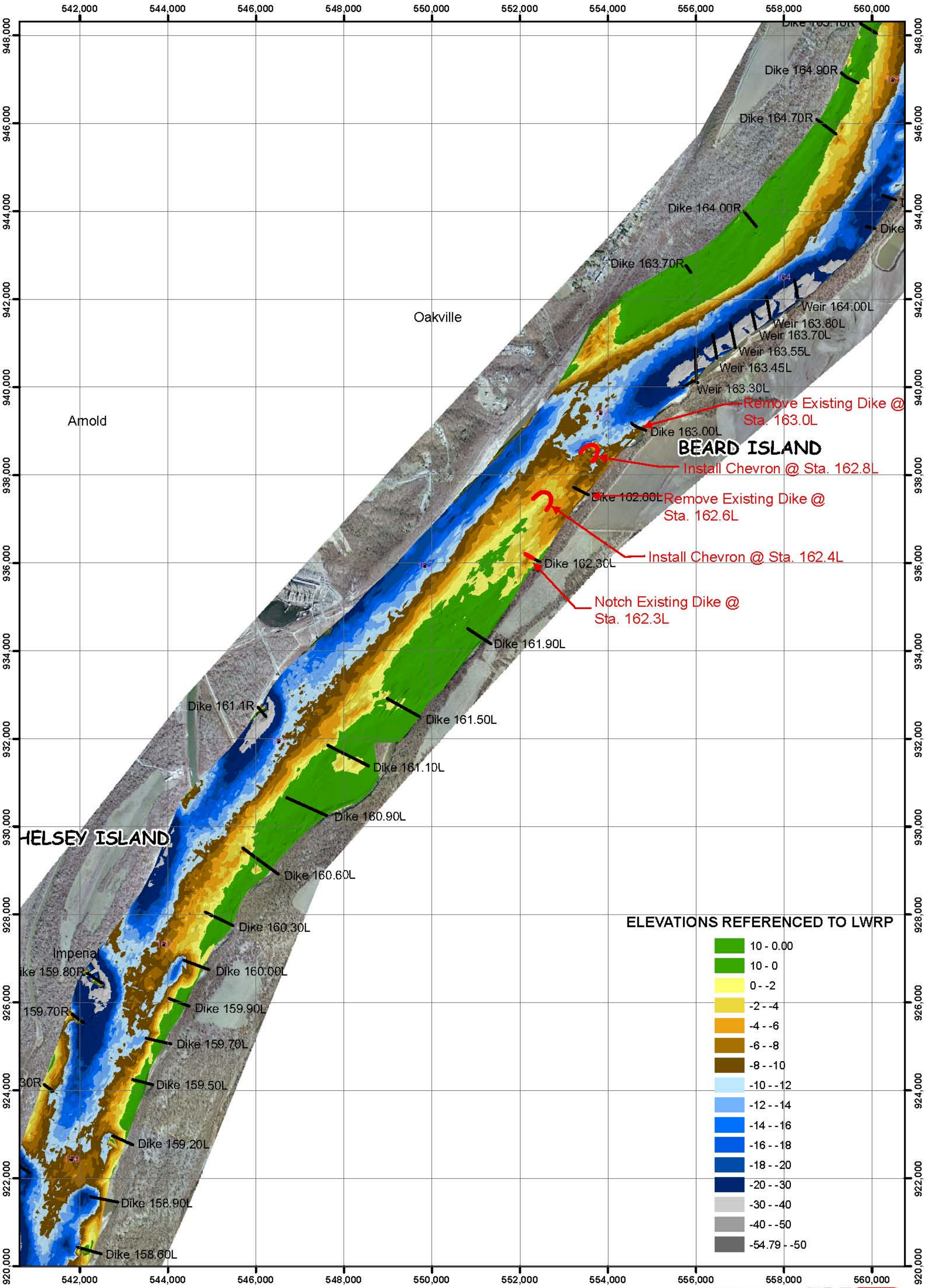

PLATE NUMBER 20

0 500 1,000 2,000 3,000 Feet

THE INFORMATION DEPICTED ON THIS MAP REPRESENTS THE RESULTS OF SURVEYS MADE ON THE DATES INDICATED AND CAN ONLY BE CONSIDERED AS INDICATING THE GENERAL CONDITIONS EXISTING AT THAT TIME

ALTERNATIVE 5

U.S. ARMY ENGINEER DIVISION
CORPS OF ENGINEERS
ST. LOUIS, MISSOURI

UPPER MISSISSIPPI RIVER BASIN
Cliff Cave HSR Model
River Miles 168.0-156.6

PLOT DATE: SEPTEMBER 22, 2006
DRAWN BY: E. BRAUER
CHECKED BY: D. GORDON
REVIEWED BY: R. DAVINROY
FILE NAME: L:\Cliff Cave-Kimmswick Reaches\ARC\Cliff Cave.mxd

APPLIED RIVER ENGINEERING CENTER

US Army Corps of Engineers
St. Louis District

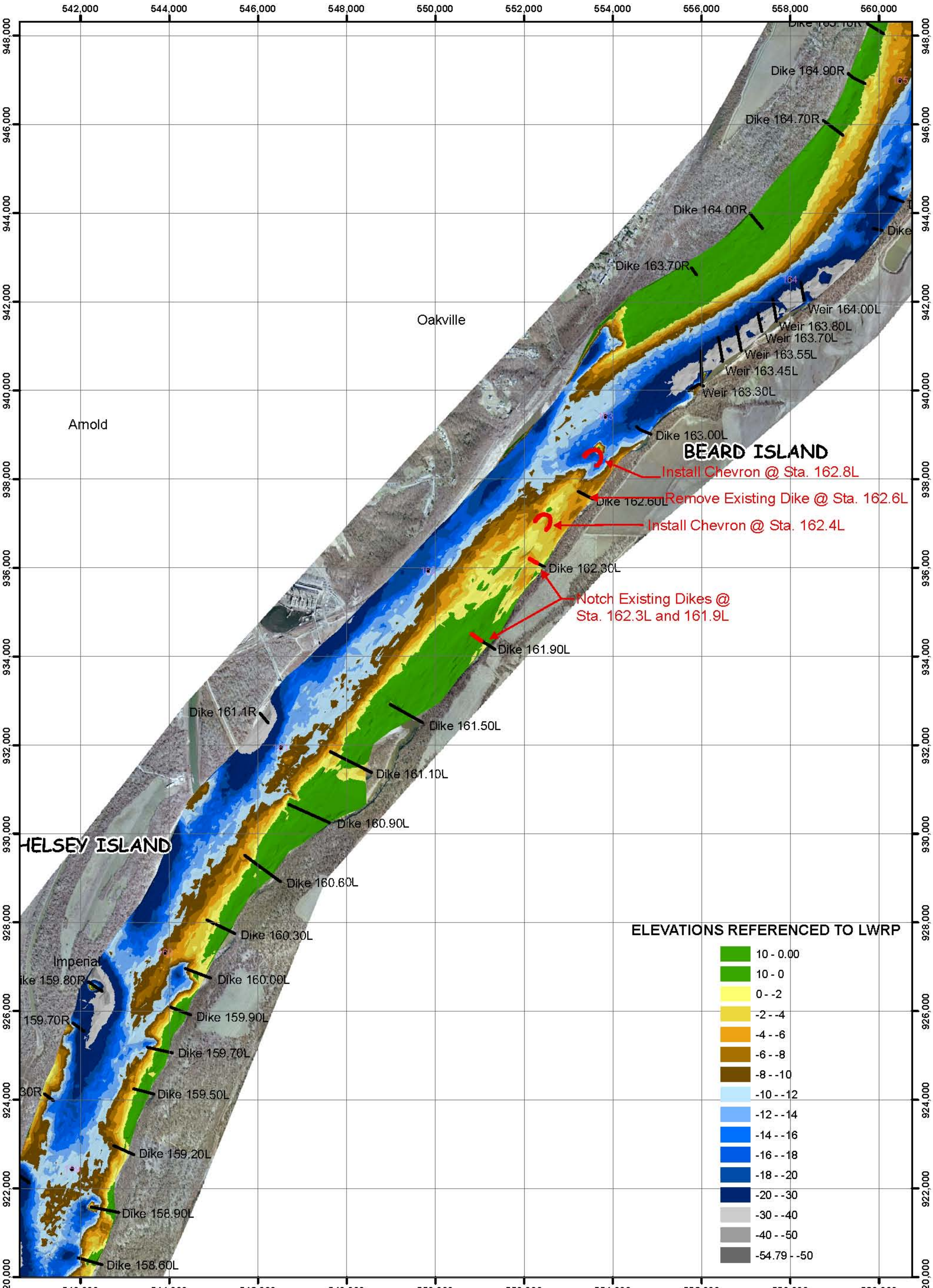

PLATE NUMBER 21

0 500 1,000 2,000 3,000 Feet

THE INFORMATION DEPICTED ON THIS MAP REPRESENTS THE RESULTS OF SURVEYS MADE ON THE DATES INDICATED AND CAN ONLY BE CONSIDERED AS INDICATING THE GENERAL CONDITIONS EXISTING AT THAT TIME

ALTERNATIVE 6

U.S. ARMY ENGINEER DIVISION
CORPS OF ENGINEERS
ST. LOUIS, MISSOURI

UPPER MISSISSIPPI RIVER BASIN
Cliff Cave HSR Model
River Miles 168.0-156.6

PLOT DATE: SEPTEMBER 22, 2006
DRAWN BY: E. BRAUER
CHECKED BY: D. GORDON
REVIEWED BY: R. DAVINROY
FILE NAME: L:\Cliff Cave-Kimmswick Reaches\ARC\Cliff Cave.mxd

US Army Corps of Engineers
St. Louis District
APPLIED RIVER ENGINEERING CENTER

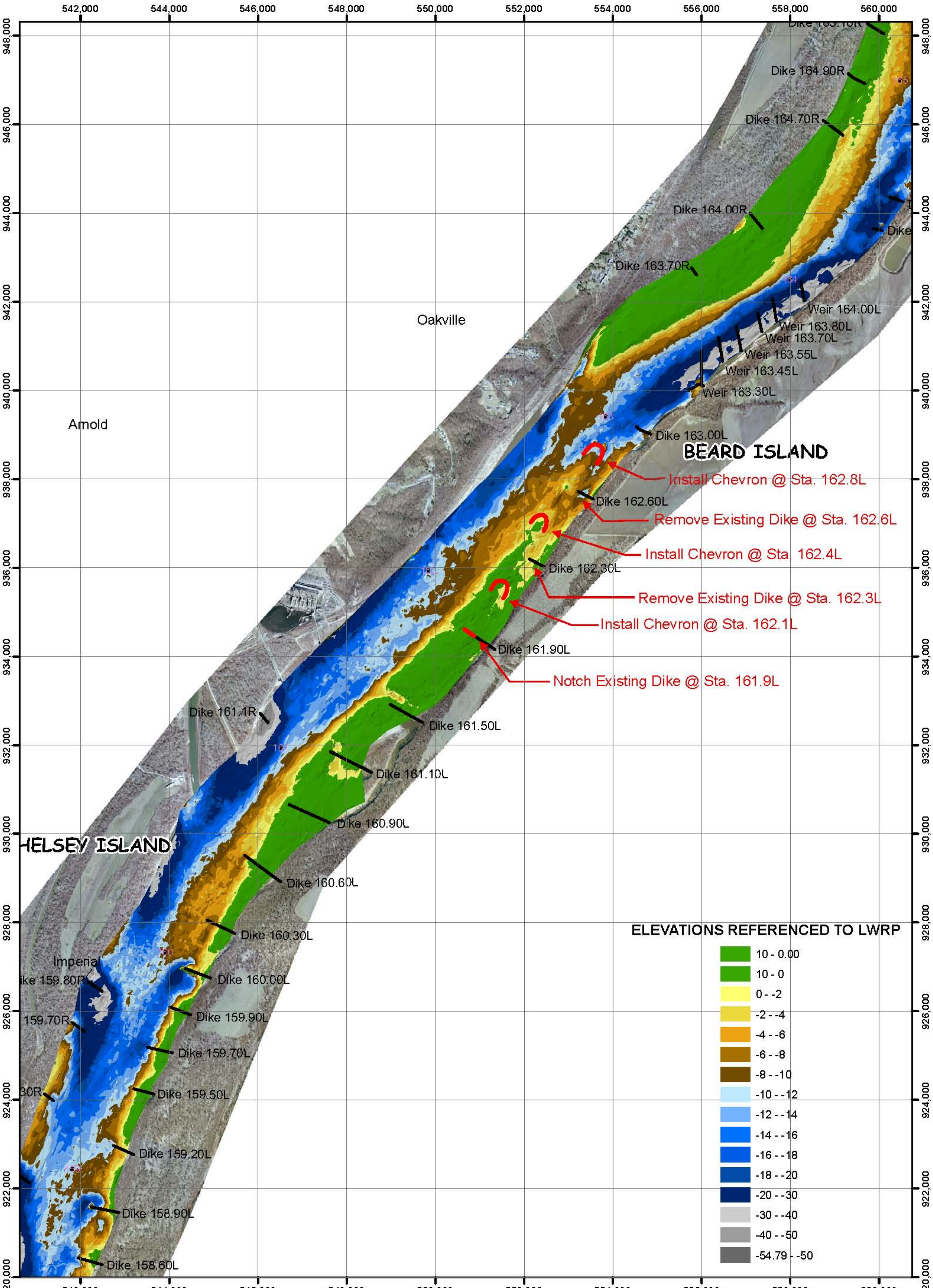

PLATE NUMBER 22

0 500 1,000 2,000 3,000 Feet

THE INFORMATION DEPICTED ON THIS MAP REPRESENTS THE RESULTS OF SURVEYS MADE ON THE DATES INDICATED AND CAN ONLY BE CONSIDERED AS INDICATING THE GENERAL CONDITIONS EXISTING AT THAT TIME

ALTERNATIVE 7

U.S. ARMY ENGINEER DIVISION
CORPS OF ENGINEERS
ST. LOUIS, MISSOURI

UPPER MISSISSIPPI RIVER BASIN
Cliff Cave HSR Model
River Miles 168.0-156.6

PLOT DATE: SEPTEMBER 22, 2006
DRAWN BY: E. BRAUER
CHECKED BY: D. GORDON
REVIEWED BY: R. DAVINROY
FILE NAME: L:\Cliff Cave-Kimmswick Reaches\ARC\Cliff Cave.mxd

N S E W

APPLIED RIVER ENGINEERING CENTER

US Army Corps of Engineers
St. Louis District

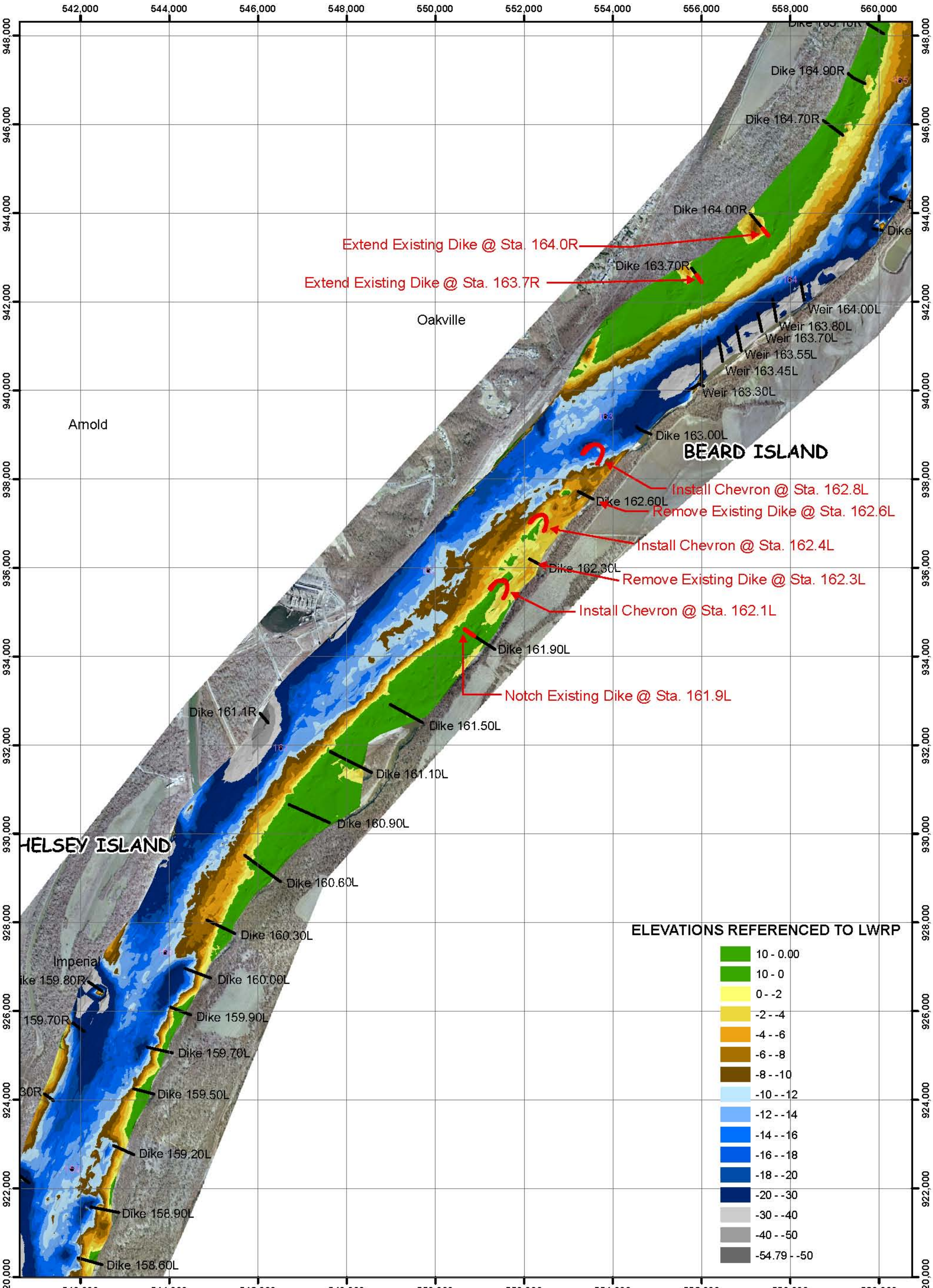

PLATE NUMBER 23

0 500 1,000 2,000 3,000 Feet

THE INFORMATION DEPICTED ON THIS MAP REPRESENTS THE RESULTS OF SURVEYS MADE ON THE DATES INDICATED AND CAN ONLY BE CONSIDERED AS INDICATING THE GENERAL CONDITIONS EXISTING AT THAT TIME

ALTERNATIVE 8

U.S. ARMY ENGINEER DIVISION
CORPS OF ENGINEERS
ST. LOUIS, MISSOURI

UPPER MISSISSIPPI RIVER BASIN
Cliff Cave HSR Model
River Miles 168.0-156.6

PLOT DATE: SEPTEMBER 22, 2006
DRAWN BY: E. BRAUER | CHECKED BY: D. GORDON
REVIEWED BY: R. DAVINROY

APPLIED RIVER ENGINEERING CENTER
US Army Corps of Engineers
St. Louis District

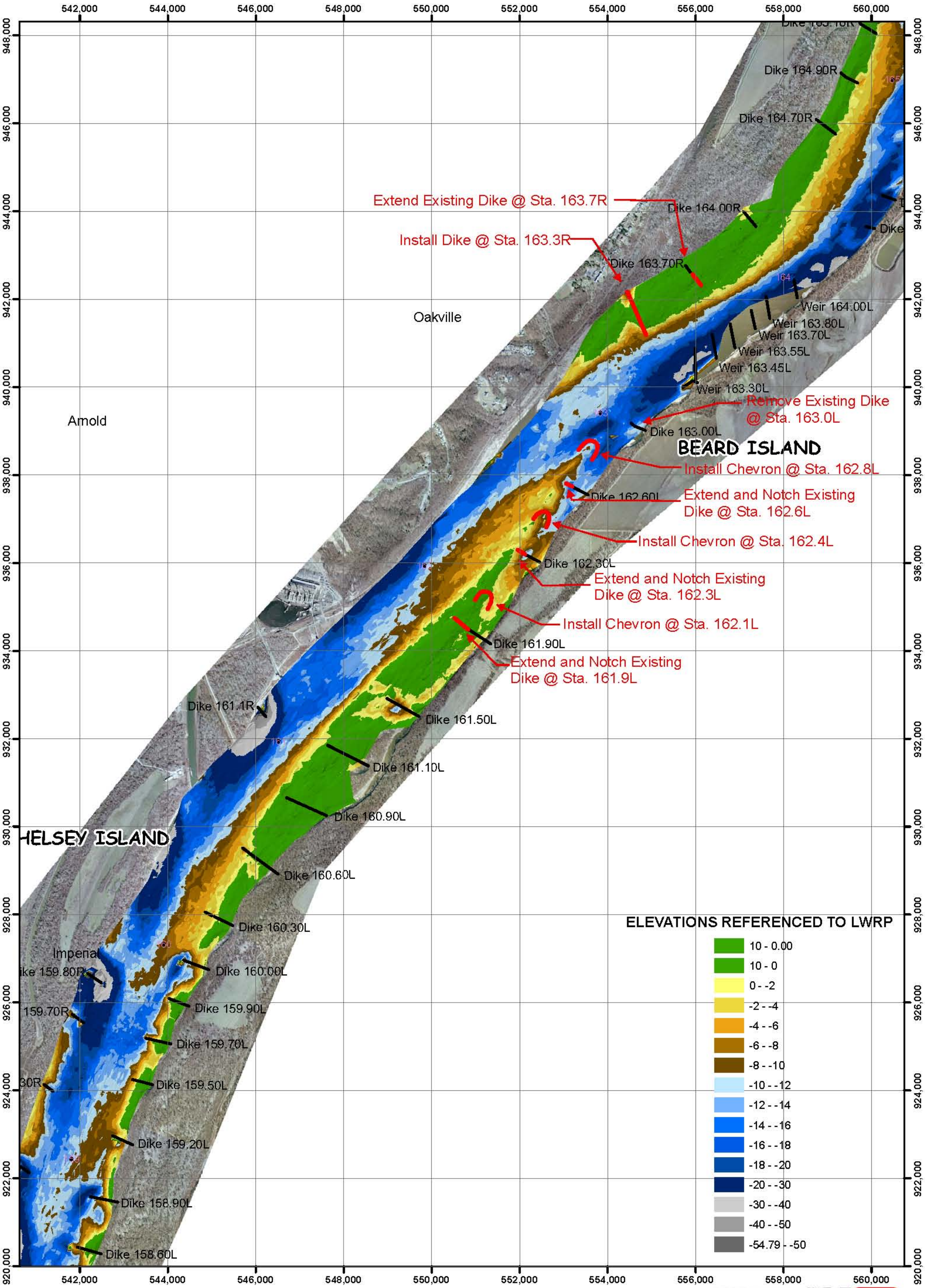

PLATE NUMBER 24

0 500 1,000 2,000 3,000 Feet

THE INFORMATION DEPICTED ON THIS MAP REPRESENTS THE RESULTS OF SURVEYS MADE ON THE DATES INDICATED AND CAN ONLY BE CONSIDERED AS INDICATING THE GENERAL CONDITIONS EXISTING AT THAT TIME

ALTERNATIVE 9

U.S. ARMY ENGINEER DIVISION
CORPS OF ENGINEERS
ST. LOUIS, MISSOURI

UPPER MISSISSIPPI RIVER BASIN
Cliff Cave HSR Model
River Miles 168.0-156.6

PLOT DATE: SEPTEMBER 22, 2006	
DRAWN BY: E. BRAUER	CHECKED BY: D. GORDON
REVIEWED BY R. DAVINROY	
FILE NAME:	

APPLIED RIVER ENGINEERING CENTER

US Army Corps of Engineers
St. Louis District

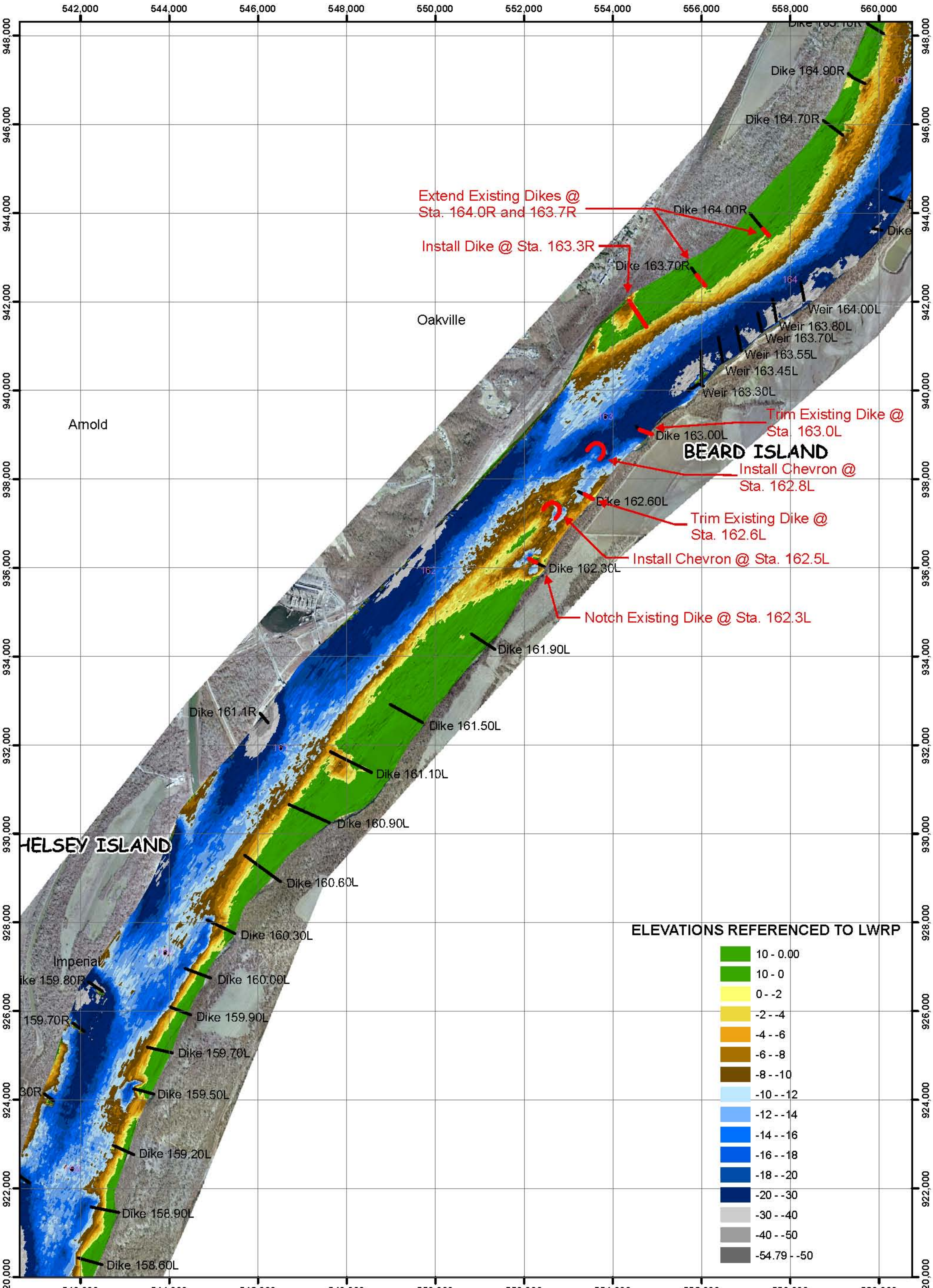

PLATE NUMBER 25

0 500 1,000 2,000 3,000 Feet

THE INFORMATION DEPICTED ON THIS MAP REPRESENTS THE RESULTS OF SURVEYS MADE ON THE DATES INDICATED AND CAN ONLY BE CONSIDERED AS INDICATING THE GENERAL CONDITIONS EXISTING AT THAT TIME

ALTERNATIVE 10

U.S. ARMY ENGINEER DIVISION
CORPS OF ENGINEERS
ST. LOUIS, MISSOURI

UPPER MISSISSIPPI RIVER BASIN
Cliff Cave HSR Model
River Miles 168.0-156.6

PLOT DATE: SEPTEMBER 22, 2006
DRAWN BY: E. BRAUER
CHECKED BY: D. GORDON
REVIEWED BY: R. DAVINROY
FILE NAME: L:\Cliff Cave-Kimmswick Reaches\ARC\Cliff Cave.mxd

N W E S

APPLIED RIVER ENGINEERING CENTER

US Army Corps of Engineers
St. Louis District

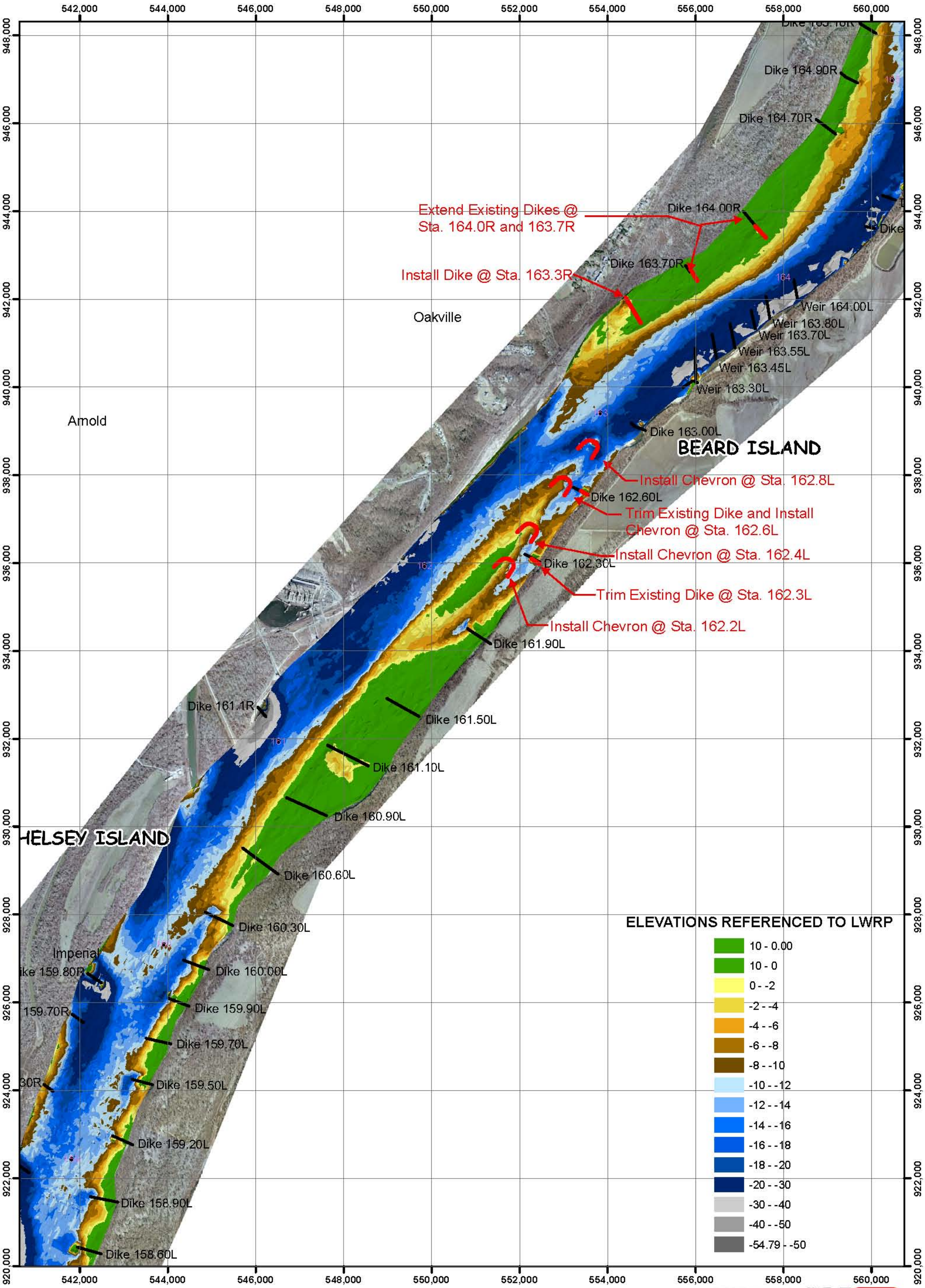

PLATE NUMBER 26

0 500 1,000 2,000 3,000 Feet

THE INFORMATION DEPICTED ON THIS MAP REPRESENTS THE RESULTS OF SURVEYS MADE ON THE DATES INDICATED AND CAN ONLY BE CONSIDERED AS INDICATING THE GENERAL CONDITIONS EXISTING AT THAT TIME

ALTERNATIVE 11

U.S. ARMY ENGINEER DIVISION
CORPS OF ENGINEERS
ST. LOUIS, MISSOURI

UPPER MISSISSIPPI RIVER BASIN
Cliff Cave HSR Model
River Miles 168.0-156.6

PLOT DATE: SEPTEMBER 22, 2006
DRAWN BY: E. BRAUER
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REVIEWED BY: R. DAVINROY

N W E S

APPLIED RIVER ENGINEERING CENTER

US Army Corps of Engineers
St. Louis District

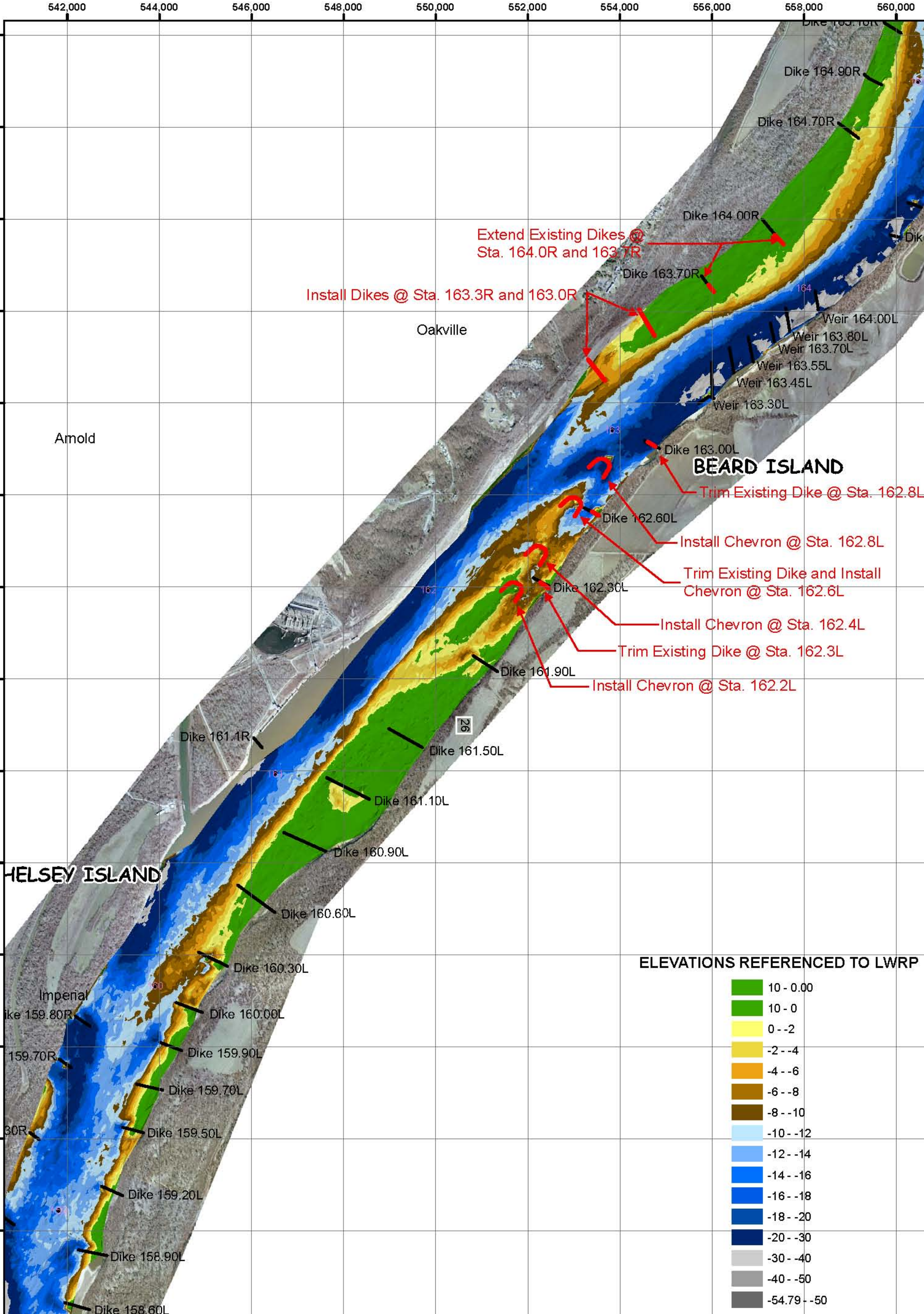

PLATE NUMBER 27

0 500 1,000 2,000 3,000 Feet

THE INFORMATION DEPICTED ON THIS MAP REPRESENTS THE RESULTS OF SURVEYS MADE ON THE DATES INDICATED AND CAN ONLY BE CONSIDERED AS INDICATING THE GENERAL CONDITIONS EXISTING AT THAT TIME

ALTERNATIVE 12

U.S. ARMY ENGINEER DIVISION
CORPS OF ENGINEERS
ST. LOUIS, MISSOURI

UPPER MISSISSIPPI RIVER BASIN
Cliff Cave HSR Model
River Miles 168.0-156.6

PLOT DATE: SEPTEMBER 22, 2006
DRAWN BY: E. BRAUER
CHECKED BY: D. GORDON
REVIEWED BY: R. DAVINROY
FILE NAME: L:\Cliff Cave-Kimmswick Reaches\ARC\Cliff Cave.mxd

N S E W

APPLIED RIVER ENGINEERING CENTER

US Army Corps of Engineers
St. Louis District

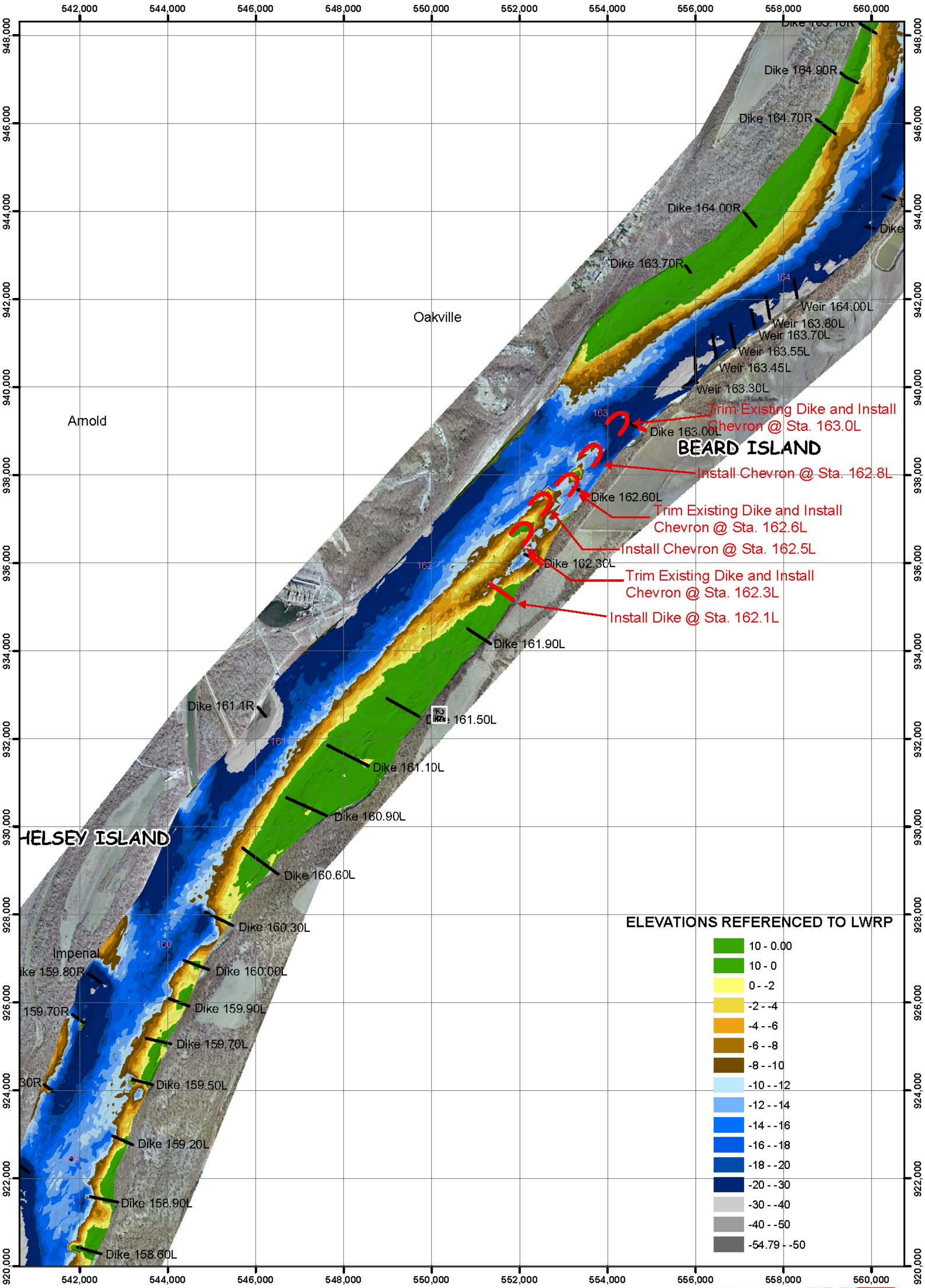

PLATE NUMBER 28

0 500 1,000 2,000 3,000 Feet

THE INFORMATION DEPICTED ON THIS MAP REPRESENTS THE RESULTS OF SURVEYS MADE ON THE DATES INDICATED AND CAN ONLY BE CONSIDERED AS INDICATING THE GENERAL CONDITIONS EXISTING AT THAT TIME

ALTERNATIVE 13

U.S. ARMY ENGINEER DIVISION
CORPS OF ENGINEERS
ST. LOUIS, MISSOURI

UPPER MISSISSIPPI RIVER BASIN
Cliff Cave HSR Model
River Miles 168.0-156.6

PLOT DATE: SEPTEMBER 22, 2006
DRAWN BY: E. BRAUER
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REVIEWED BY: R. DAVINROY
FILE NAME: L:\Cliff Cave-Kimmswick Reaches\ARC\Cliff Cave.mxd

APPLIED RIVER ENGINEERING CENTER

US Army Corps of Engineers
St. Louis District

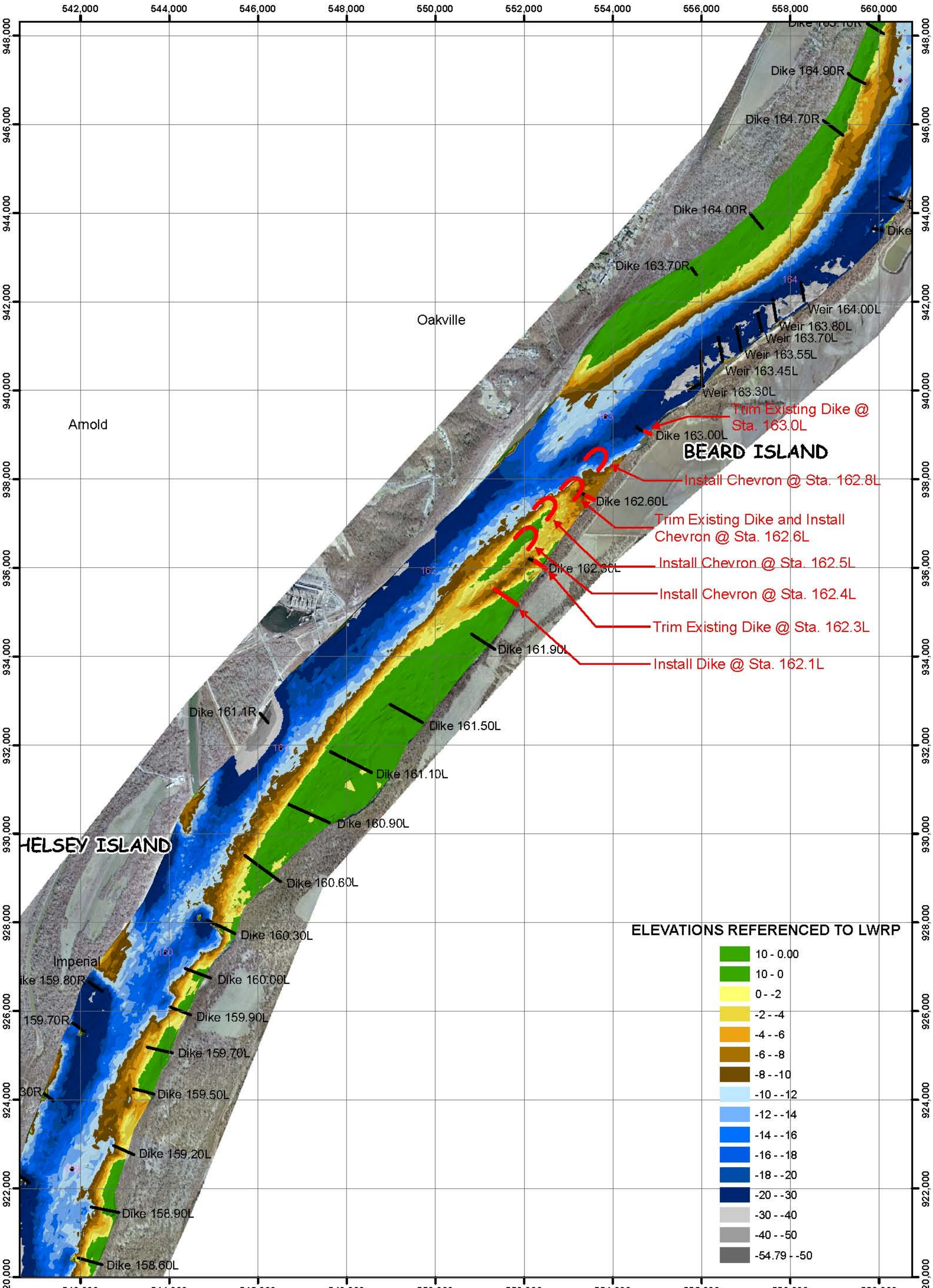

PLATE NUMBER 29

0 500 1,000 2,000 3,000 Feet

THE INFORMATION DEPICTED ON THIS MAP REPRESENTS THE RESULTS OF SURVEYS MADE ON THE DATES INDICATED AND CAN ONLY BE CONSIDERED AS INDICATING THE GENERAL CONDITIONS EXISTING AT THAT TIME

ALTERNATIVE 14

U.S. ARMY ENGINEER DIVISION
CORPS OF ENGINEERS
ST. LOUIS, MISSOURI

UPPER MISSISSIPPI RIVER BASIN
Cliff Cave HSR Model
River Miles 168.0-156.6

PLOT DATE: SEPTEMBER 22, 2006
DRAWN BY: E. BRAUER
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APPLIED RIVER ENGINEERING CENTER

US Army Corps of Engineers
St. Louis District

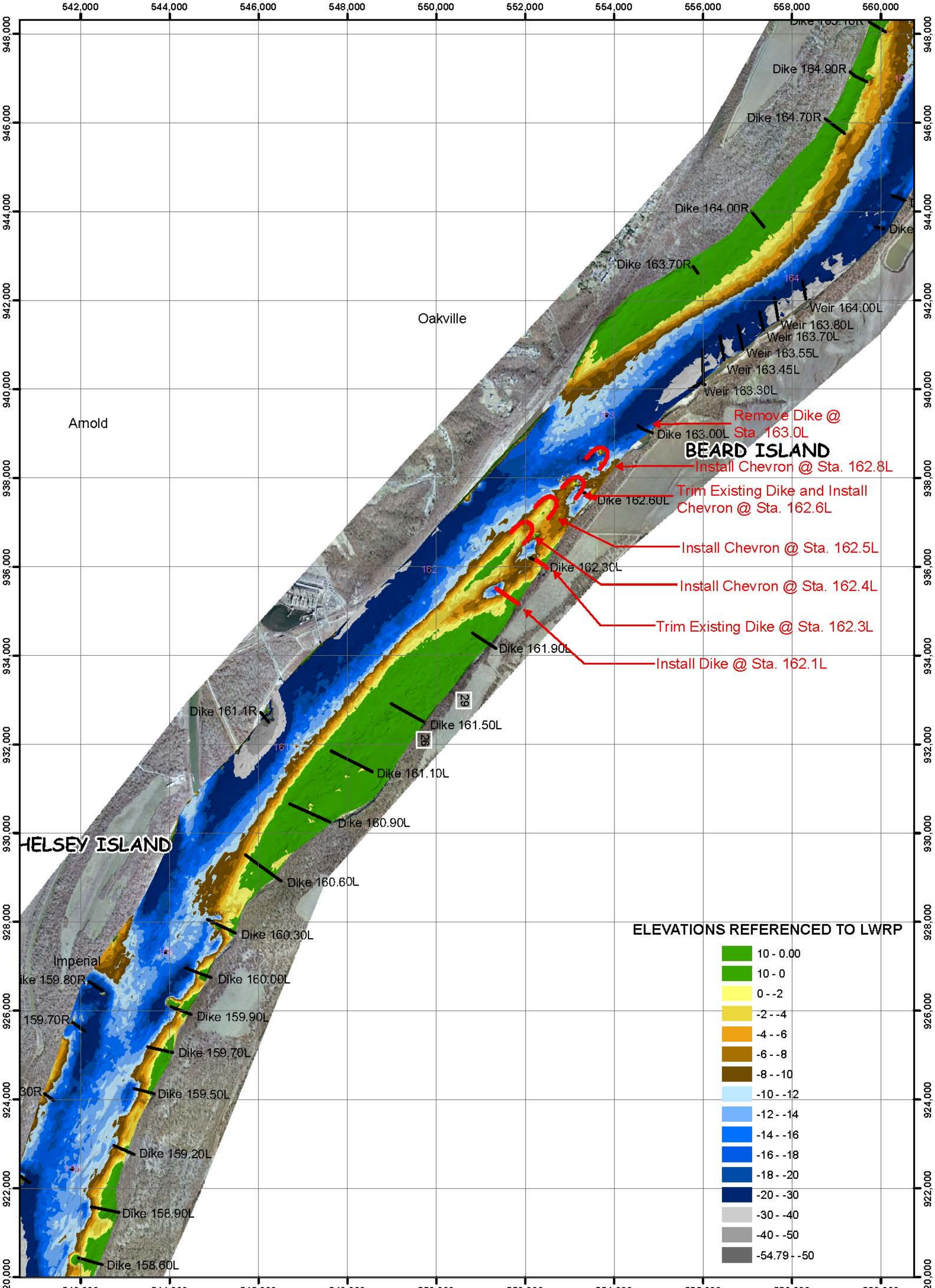

PLATE NUMBER 30

0 500 1,000 2,000 3,000 Feet

THE INFORMATION DEPICTED ON THIS MAP REPRESENTS THE RESULTS OF SURVEYS MADE ON THE DATES INDICATED AND CAN ONLY BE CONSIDERED AS INDICATING THE GENERAL CONDITIONS EXISTING AT THAT TIME

ALTERNATIVE 15

U.S. ARMY ENGINEER DIVISION
CORPS OF ENGINEERS
ST. LOUIS, MISSOURI

UPPER MISSISSIPPI RIVER BASIN
Cliff Cave HSR Model
River Miles 168.0-156.6

PLOT DATE: SEPTEMBER 22, 2006
DRAWN BY: E. BRAUER
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APPLIED RIVER ENGINEERING CENTER

US Army Corps of Engineers
St. Louis District

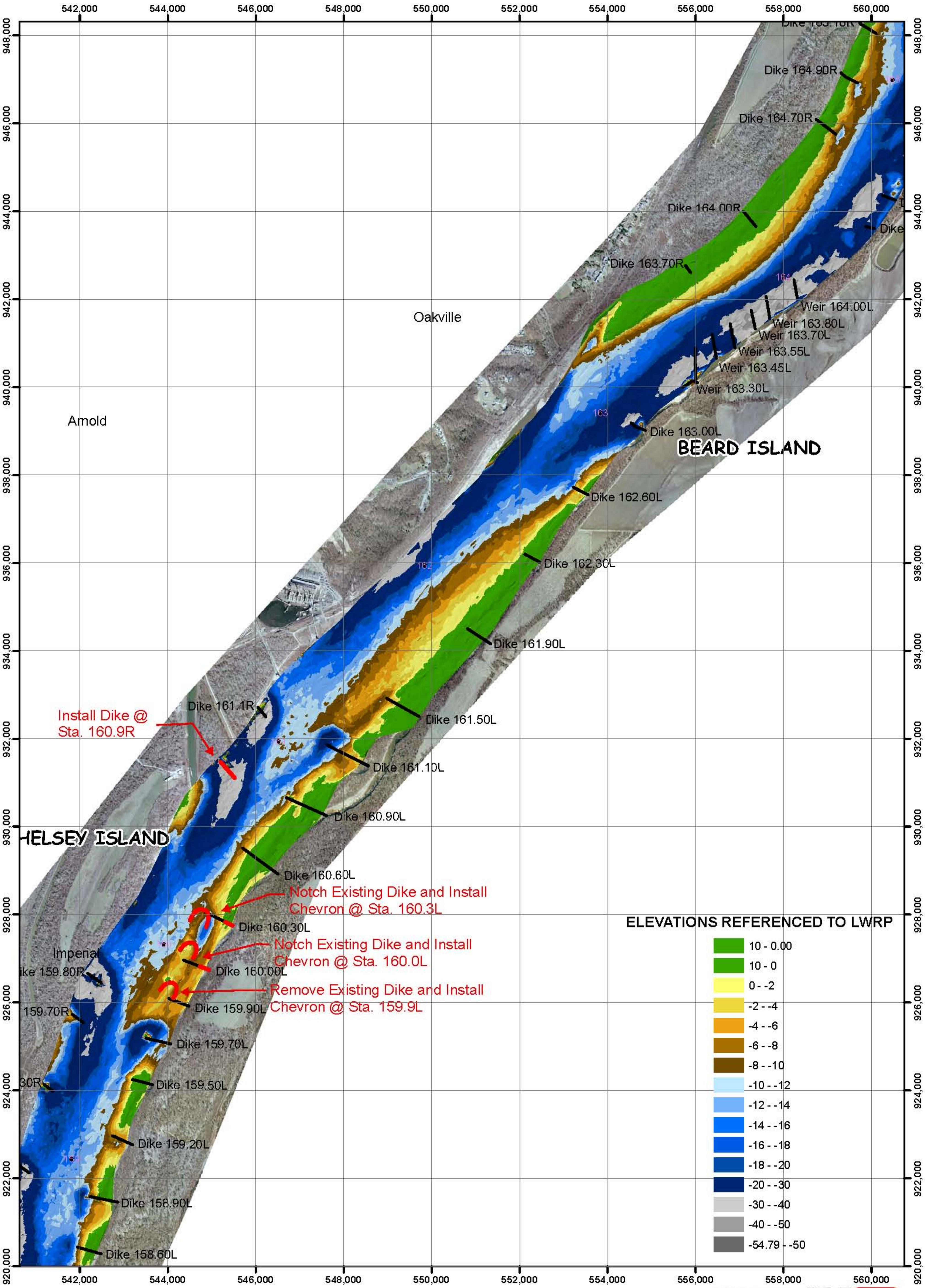

PLATE NUMBER 31

0 500 1,000 2,000 3,000 Feet

THE INFORMATION DEPICTED ON THIS MAP REPRESENTS THE RESULTS OF SURVEYS MADE ON THE DATES INDICATED AND CAN ONLY BE CONSIDERED AS INDICATING THE GENERAL CONDITIONS EXISTING AT THAT TIME

ALTERNATIVE 16

U.S. ARMY ENGINEER DIVISION
CORPS OF ENGINEERS
ST. LOUIS, MISSOURI

UPPER MISSISSIPPI RIVER BASIN
Cliff Cave HSR Model
River Miles 168.0-156.6

PLOT DATE: SEPTEMBER 22, 2006
DRAWN BY: E. BRAUER
CHECKED BY: D. GORDON
REVIEWED BY: R. DAVINROY
FILE NAME: L:\Cliff Cave-Kimmswick Reaches\ARC\Cliff Cave.mxd

APPLIED RIVER ENGINEERING CENTER

US Army Corps of Engineers
St. Louis District

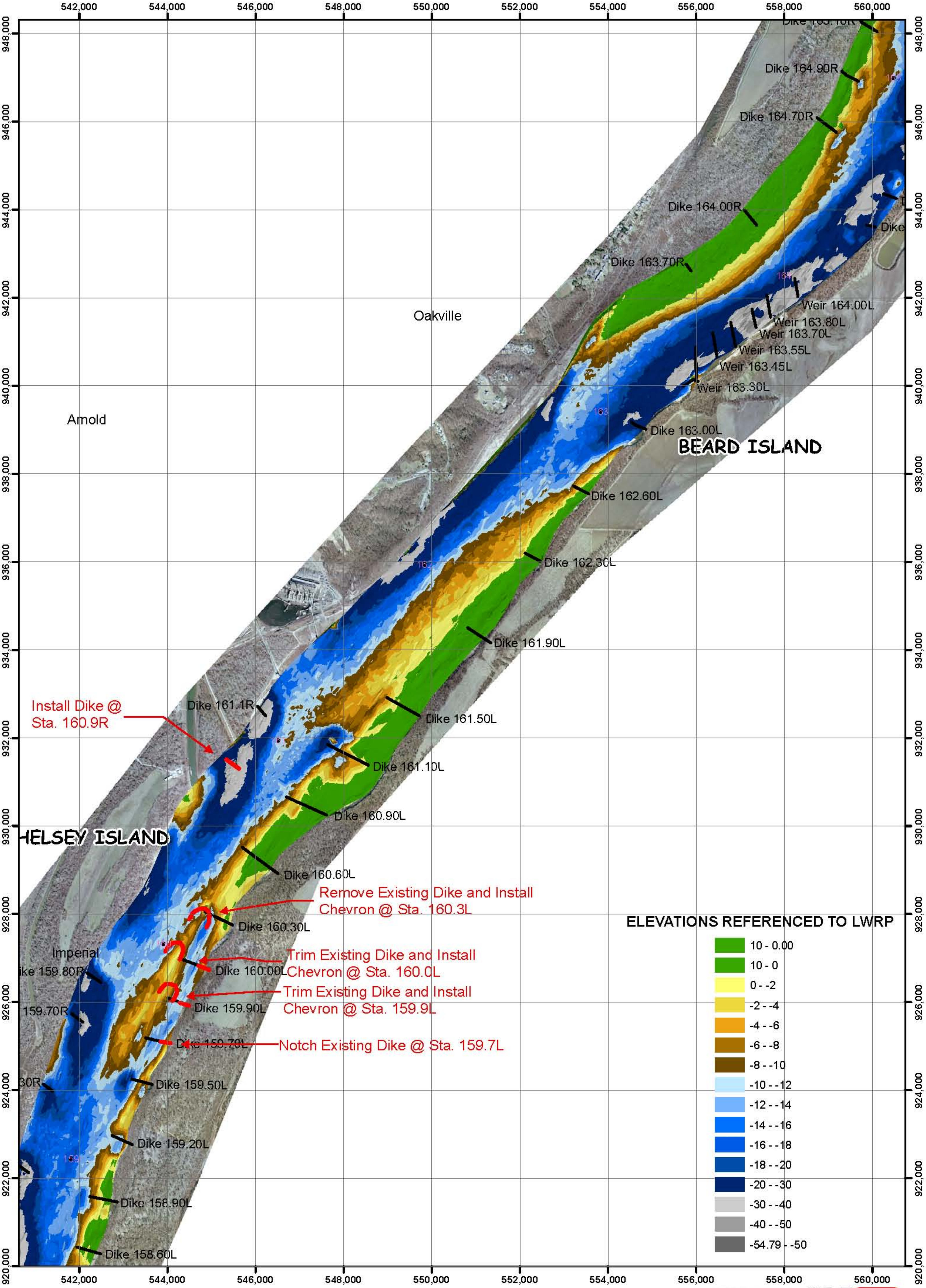

PLATE NUMBER 32

0 500 1,000 2,000 3,000 Feet

THE INFORMATION DEPICTED ON THIS MAP REPRESENTS THE RESULTS OF SURVEYS MADE ON THE DATES INDICATED AND CAN ONLY BE CONSIDERED AS INDICATING THE GENERAL CONDITIONS EXISTING AT THAT TIME

ALTERNATIVE 17

U.S. ARMY ENGINEER DIVISION
CORPS OF ENGINEERS
ST. LOUIS, MISSOURI

UPPER MISSISSIPPI RIVER BASIN
Cliff Cave HSR Model
River Miles 168.0-156.6

PLOT DATE: SEPTEMBER 22, 2006	
DRAWN BY: E. BRAUER	CHECKED BY: D. GORDON
REVIEWED BY: R. DAVINROY	
FILE NAME: L:\Cliff Cave-Kimmswick Reaches\ARC\Cliff Cave.mxd	

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APPLIED RIVER ENGINEERING CENTER

US Army Corps of Engineers
St. Louis District

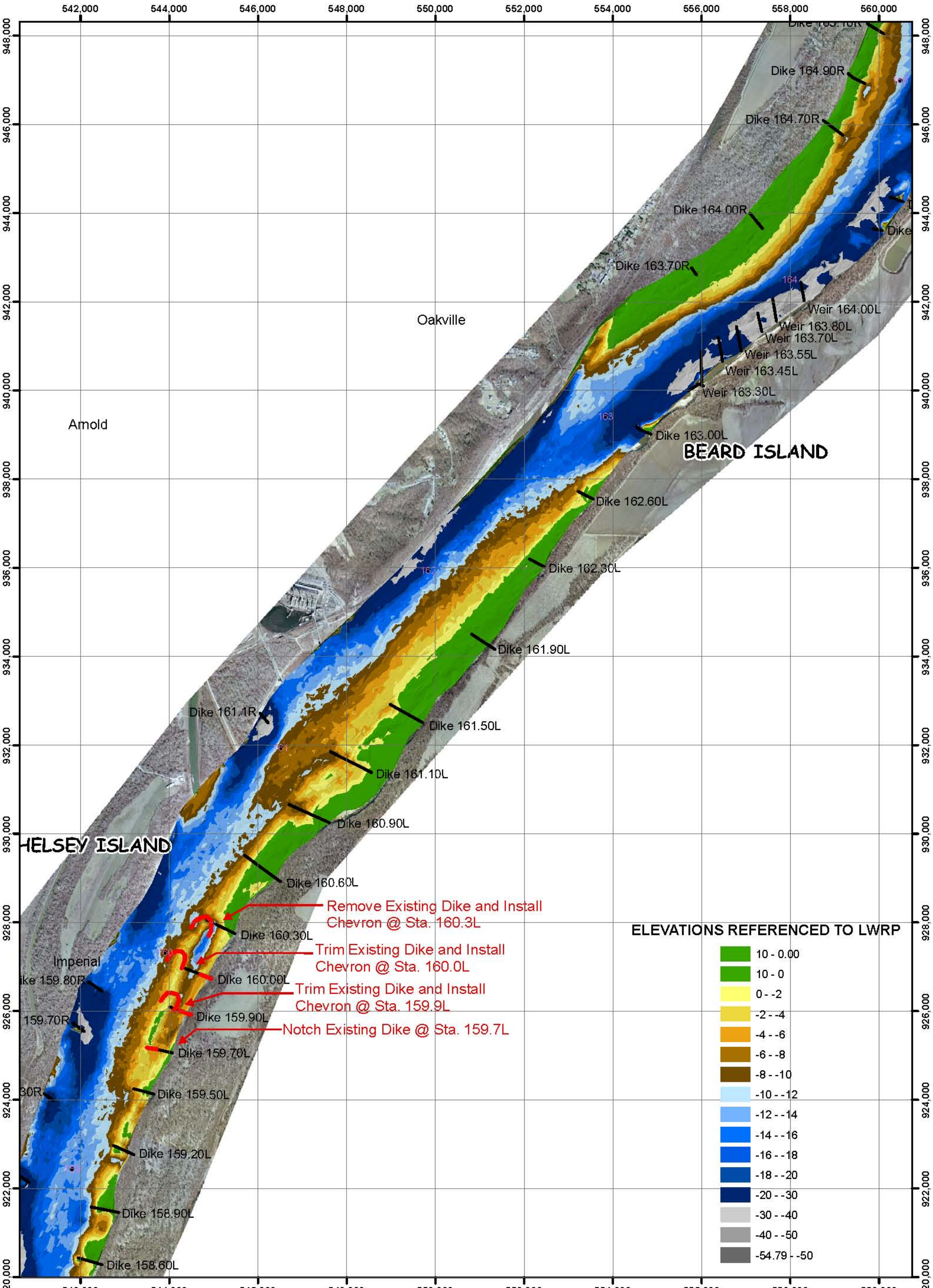

PLATE NUMBER 33

0 500 1,000 2,000 3,000 Feet

THE INFORMATION DEPICTED ON THIS MAP REPRESENTS THE RESULTS OF SURVEYS MADE ON THE DATES INDICATED AND CAN ONLY BE CONSIDERED AS INDICATING THE GENERAL CONDITIONS EXISTING AT THAT TIME

ALTERNATIVE 18

U.S. ARMY ENGINEER DIVISION
CORPS OF ENGINEERS
ST. LOUIS, MISSOURI

UPPER MISSISSIPPI RIVER BASIN
Cliff Cave HSR Model
River Miles 168.0-156.6

PLOT DATE: SEPTEMBER 22, 2006
DRAWN BY: E. BRAUER
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N S E W

APPLIED RIVER ENGINEERING CENTER

US Army Corps of Engineers
St. Louis District

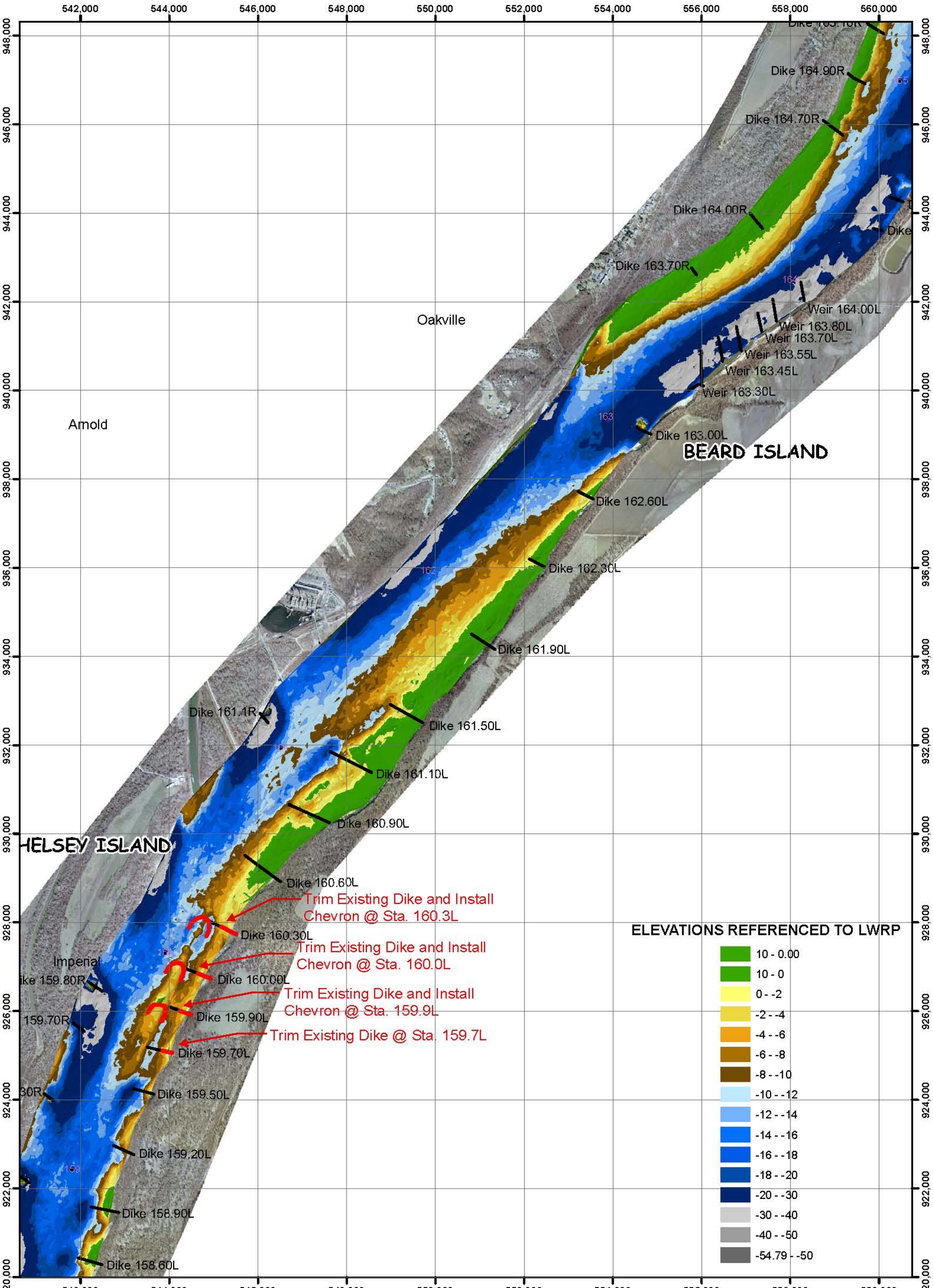

PLATE NUMBER 34

THE INFORMATION DEPICTED ON THIS MAP REPRESENTS THE RESULTS OF SURVEYS MADE ON THE DATES INDICATED AND CAN ONLY BE CONSIDERED AS INDICATING THE GENERAL CONDITIONS EXISTING AT THAT TIME

ALTERNATIVE 19

U.S. ARMY ENGINEER DIVISION
CORPS OF ENGINEERS
ST. LOUIS, MISSOURI

UPPER MISSISSIPPI RIVER BASIN
Cliff Cave HSR Model
River Miles 168.0-156.6

PLOT DATE: SEPTEMBER 22, 2006
DRAWN BY: E. BRAUER
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APPLIED RIVER ENGINEERING CENTER

US Army Corps of Engineers
St. Louis District

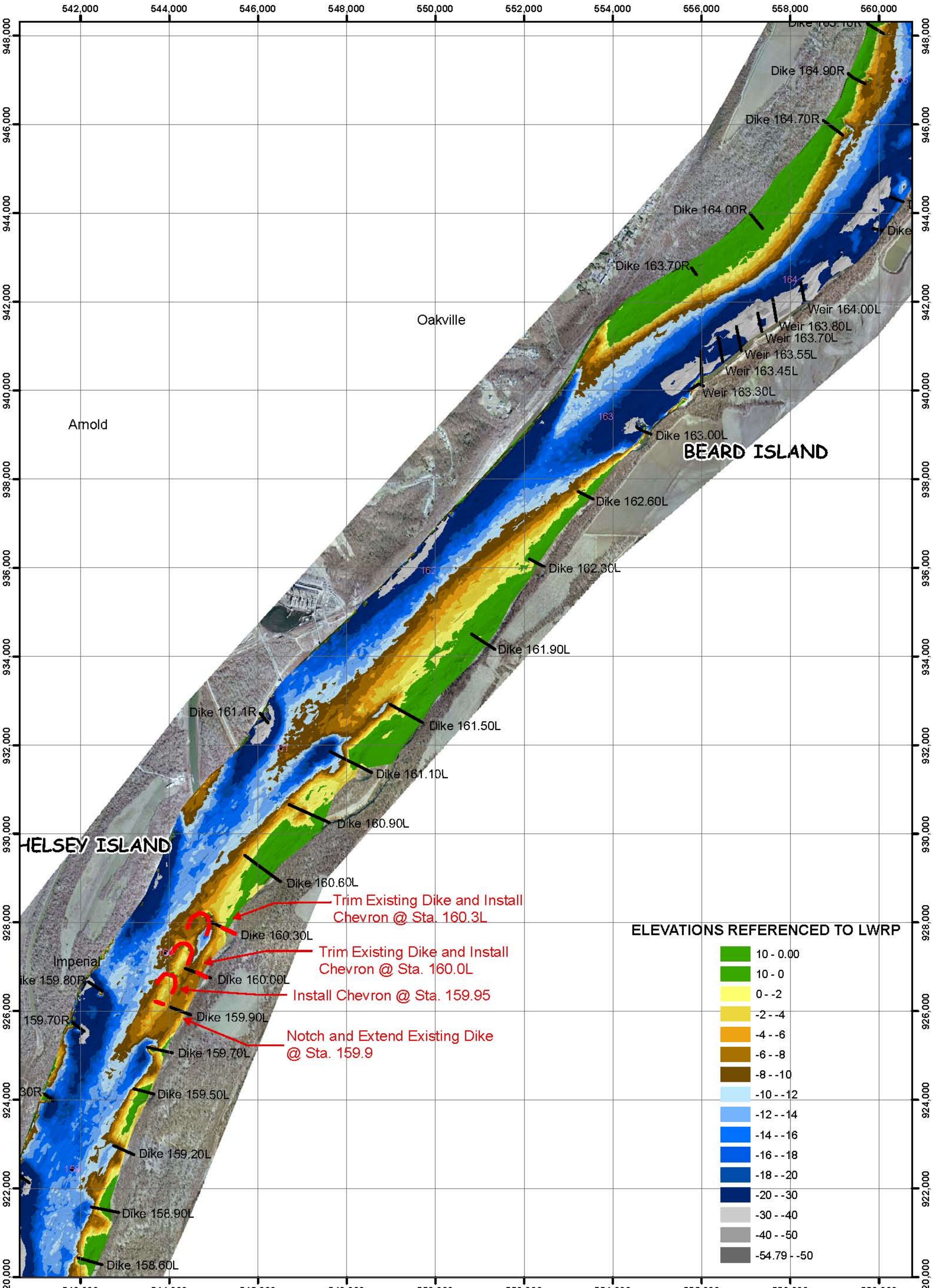

PLATE NUMBER 35

0 500 1,000 2,000 3,000 Feet

THE INFORMATION DEPICTED ON THIS MAP REPRESENTS THE RESULTS OF SURVEYS MADE ON THE DATES INDICATED AND CAN ONLY BE CONSIDERED AS INDICATING THE GENERAL CONDITIONS EXISTING AT THAT TIME

ALTERNATIVE 20

U.S. ARMY ENGINEER DIVISION
CORPS OF ENGINEERS
ST. LOUIS, MISSOURI

UPPER MISSISSIPPI RIVER BASIN
Cliff Cave HSR Model
River Miles 168.0-156.6

PLOT DATE: SEPTEMBER 22, 2006
DRAWN BY: E. BRAUER
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APPLIED RIVER ENGINEERING CENTER

US Army Corps of Engineers
St. Louis District

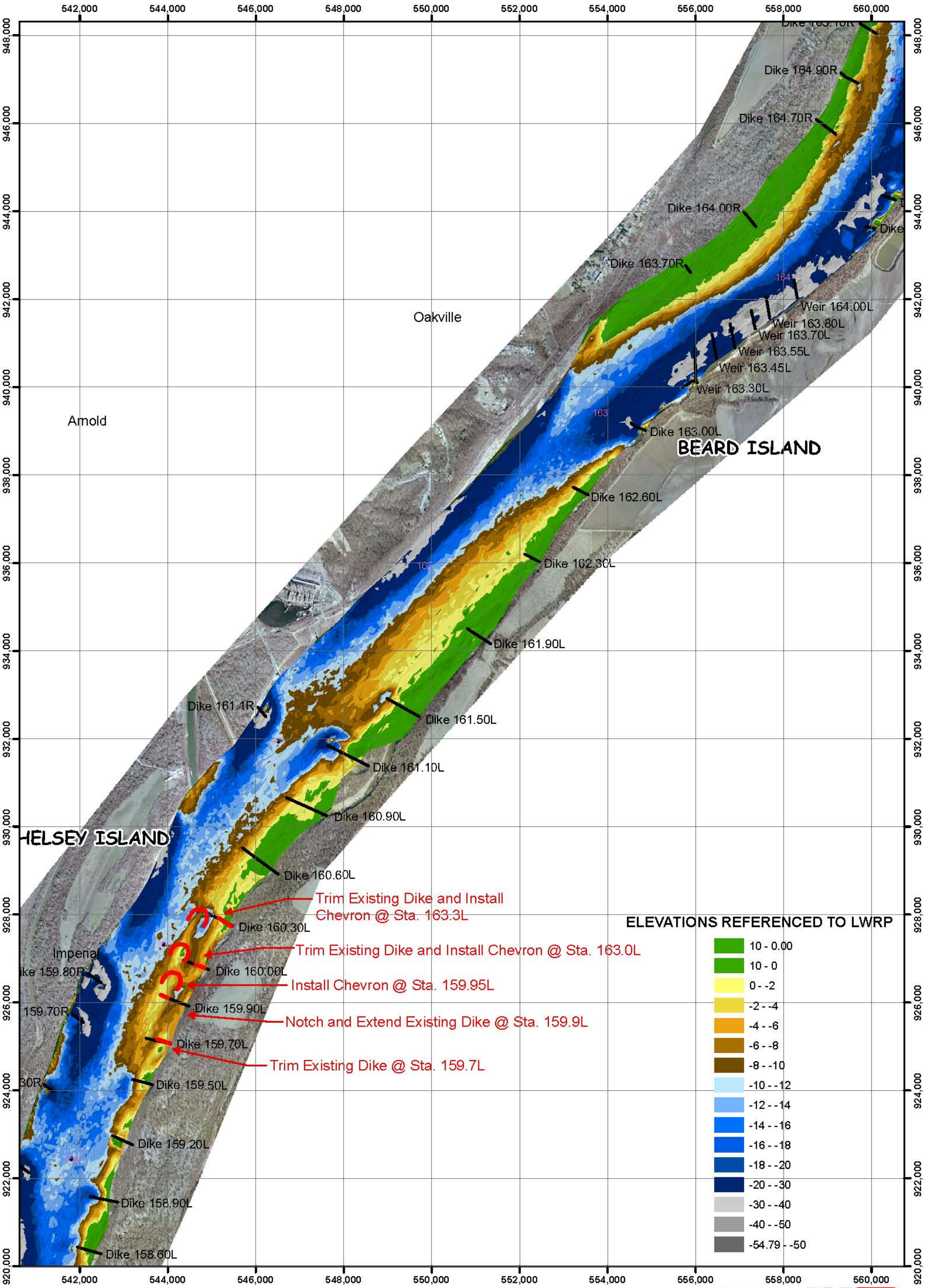

PLATE NUMBER 36

0 500 1,000 2,000 3,000 Feet

THE INFORMATION DEPICTED ON THIS MAP REPRESENTS THE RESULTS OF SURVEYS MADE ON THE DATES INDICATED AND CAN ONLY BE CONSIDERED AS INDICATING THE GENERAL CONDITIONS EXISTING AT THAT TIME

ALTERNATIVE 21

U.S. ARMY ENGINEER DIVISION
CORPS OF ENGINEERS
ST. LOUIS, MISSOURI

UPPER MISSISSIPPI RIVER BASIN
Cliff Cave HSR Model
River Miles 168.0-156.6

PLOT DATE: SEPTEMBER 22, 2006	
DRAWN BY: E. BRAUER	CHECKED BY: D. GORDON
REVIEWED BY: R. DAVINROY	
FILE NAME: L:\Cliff Cave-Kimmswick Reaches\ARC\Cliff Cave.mxd	

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APPLIED RIVER ENGINEERING CENTER

US Army Corps of Engineers
St. Louis District

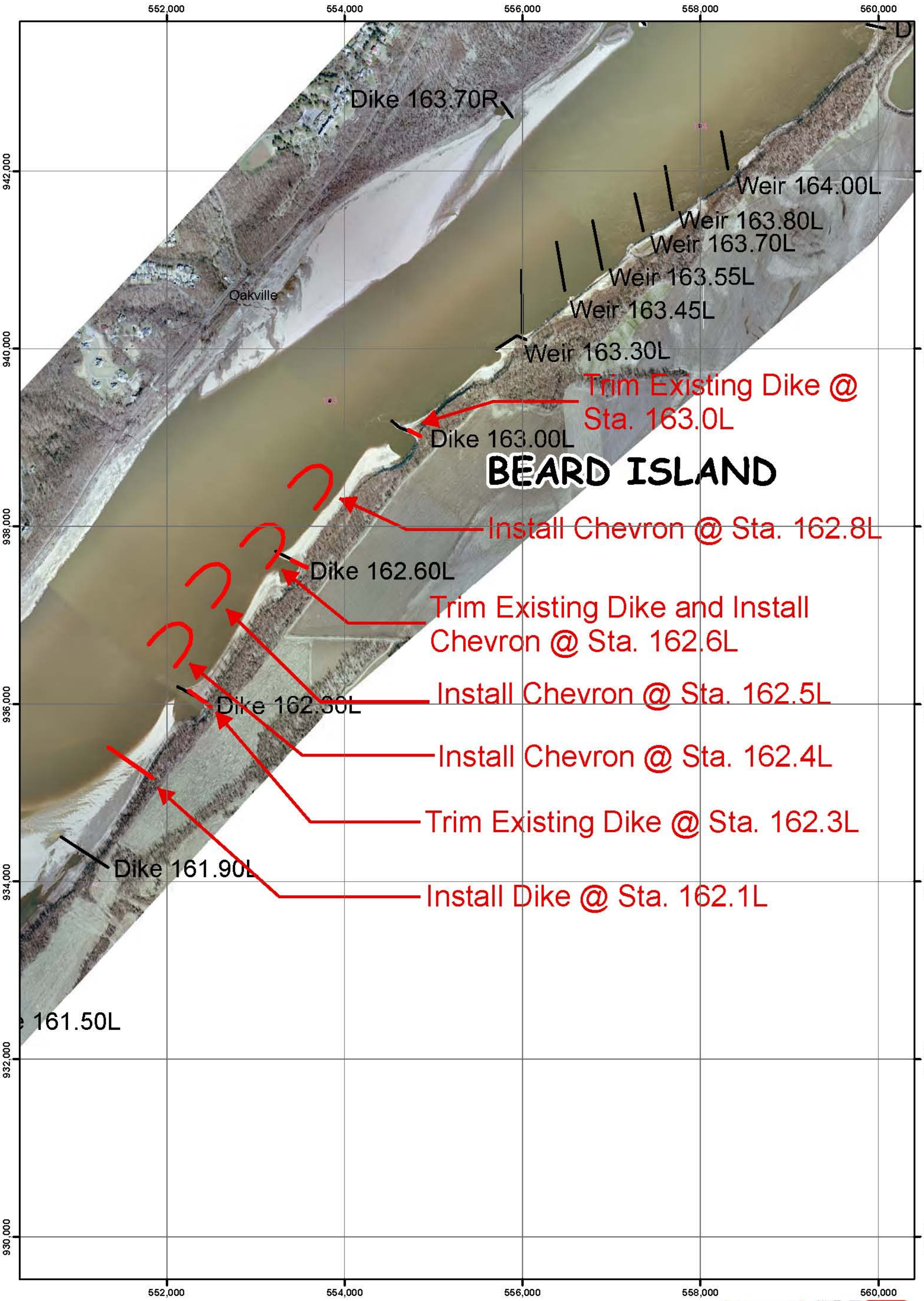

PLATE NUMBER 37

0 250 500 1,000 1,500 Feet

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Alternative 14

U.S. ARMY ENGINEER DIVISION
CORPS OF ENGINEERS
ST. LOUIS, MISSOURI

UPPER MISSISSIPPI RIVER BASIN
Cliff Cave HSR Model
River Miles 168.0-156.6

PLOT DATE: SEPTEMBER 22, 2006
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N W E S

APPLIED RIVER ENGINEERING CENTER

US Army Corps of Engineers
St. Louis District

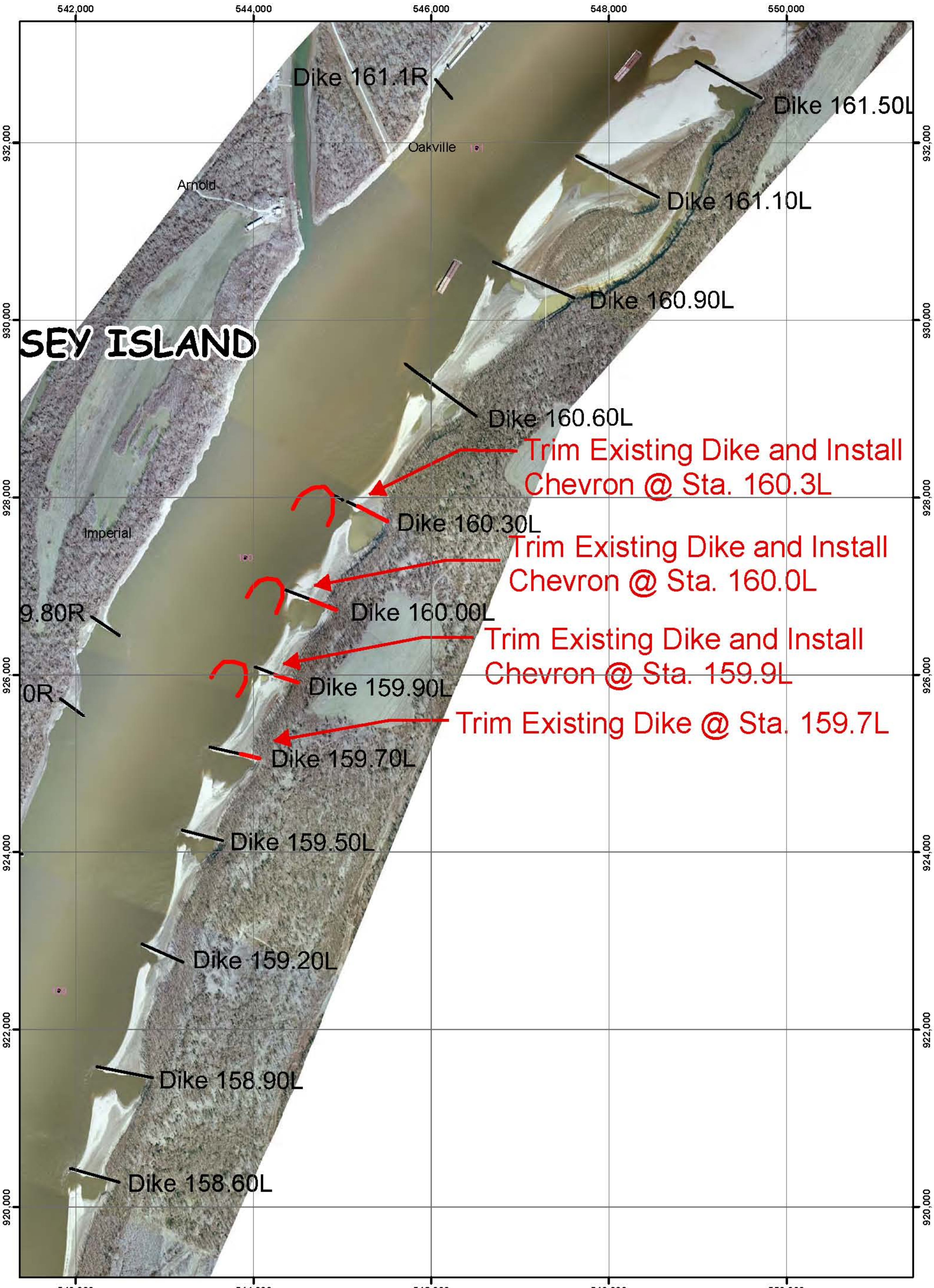

PLATE NUMBER 38

0 250 500 1,000 1,500 Feet

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Alternative 19

U.S. ARMY ENGINEER DIVISION
CORPS OF ENGINEERS
ST. LOUIS, MISSOURI

UPPER MISSISSIPPI RIVER BASIN
Cliff Cave HSR Model
River Miles 168.0-156.6

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US Army Corps of Engineers
St. Louis District
APPLIED RIVER ENGINEERING CENTER