Technical Report M68

The Mouth of the Meramec River HSR MODEL
Mississippi River, River Miles 165.00 – 156.00

HYDRAULIC SEDIMENT RESPONSE MODEL INVESTIGATION

By
Bradley J. Krischel
Ashley N. Cox
Robert D. Davinroy, P.E.
Jasen L. Brown, P.E.
Timothy J. Lauth, P.E.
Jason J. Floyd
Adam M. Rockwell

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

Sponsored by and Prepared for:
U.S. ARMY CORPS OF ENGINEERS - ST. LOUIS DISTRICT
REGULATING WORKS PROJECT

In Cooperation With:
U.S. FISH & WILDLIFE SERVICE
ILLINOIS DEPARTMENT OF NATURAL RESOURCES
MISSOURI DEPARTMENT OF CONSERVATION
RIVER INDUSTRY ACTION COMMITTEE
KIRBY INLAND MARINE
AMEREN

Final Report – April, 2014*

***Amended June, 2015 (see Appendix E)**

INTRODUCTION

The U.S. Army Corps of Engineers, St. Louis District, conducted a study of the flow and sediment transport response near the mouth of the Meramec River reach of the Mississippi River between River Miles (RM) 165.00 and RM 156.00 near Oakville, MO. This study was funded by Regulating Works project. The objective of the model study was to produce a report that outlined the results of an analysis of various river engineering measures intended to reduce or eliminate the amount of maintenance dredging required between RM 162.00 and RM 160.00 of the Mississippi River.

The study was conducted between November, 2012 and April, 2014 using a physical hydraulic sediment response (HSR) model at the Applied River Engineering Center, St. Louis District in St. Louis, Missouri. The model study was performed by Bradley Krischel, Hydraulic Engineer, under direct supervision of Mr. Robert Davinroy, P.E., Chief of River Engineering Section for the St. Louis District. See Table 1 for other personnel involved in the study.

Table 1: Other Personnel Involved in the Study

Name	Position	District/Company
Leonard Hopkins, P.E.	Hydrologic and Hydraulic Branch Chief	St. Louis District
Rob Davinroy, P.E.	Chief of River Engineering Section	St. Louis District
Jasen Brown, P.E.	Hydraulic Engineer	St. Louis District
Timothy Lauth, P.E.	Hydraulic Engineer	St. Louis District
Ashley Cox	Hydraulic Engineer	St. Louis District
Edward Brauer, P.E.	Hydraulic Engineer	St. Louis District
Peter Russell, P.E.	Hydraulic Engineer	St. Louis District
Dave Gordon, P.E.	Chief of Hydraulic Design Section	St. Louis District
Michael Rodgers, P.E.	Project Manager for River Works Projects	St. Louis District
Adam Rockwell	Cartographic Technician	St. Louis District
Jason Floyd	Engineering Technician	St. Louis District
Brian Johnson	Chief of Environmental Planning Section	St. Louis District
Lance Engle	Dredging Project Manager	St. Louis District
Steele Beller	Real Estate	St. Louis District
Charles Wardle	AREC Co-op	St. Louis District
Butch Atwood	Mississippi River Fisheries Biologist	Illinois Dept. of Natural Resources
Matt Mangan	Biologist	U.S. Fish and Wildlife Service
Donovan Henry	Biologist	U.S. Fish and Wildlife Service
Danny Brown	Resource Staff Scientist	Missouri Dept. of Conservation
David Ostendorf	Resource Staff Scientist	Missouri Dept. of Conservation
Dave Knuth	Fisheries Management Biologist	Missouri Dept. of Conservation
Bernie Heroff	Port Captain	American River Transportation Co./ RIAC
Shannon Hughes	River Field Port Captain	Kirby Inland Marine
Bill Rogers	Manager, Coal Delivery	Ameren

TABLE OF CONTENTS

BACKGROUND

1. Study Purpose and Goals

The primary purpose of this study was to find a solution to reduce or eliminate the amount of dredging that occurs between RM 162.00 to RM 160.00, and produce a report that communicates the results of the Hydraulic Sediment Response (HSR) model study.

The goals of this study were to:

i. Investigate and provide analysis on the existing flow mechanics causing the sedimentation problems.

ii. Evaluate a variety of remedial measures utilizing an HSR model with the objectives of identifying the most effective and economical plan to reduce the dredging between RM 162.00 to RM 160.00. In order to determine the best alternative, 3 criteria were used to evaluate each alternative.

   a. The alternative should reduce or eliminate sedimentation from RM 162.00 – RM 160.00.
   b. The alternative should maintain the navigation channel requirements of at least 9 foot of depth and 300 foot of width.
   c. The alternative should not significantly impact environmental features within the reach.

iii. Communicate to other engineers, river industry personnel, and environmental agency personnel the results of the HSR model tests and the plans for improvements.

2. Study Reach

The study comprised a nine mile stretch of the Mississippi River, between RM 165.00 to RM 156.00 in Saint Louis County, Missouri and Monroe County, Illinois near Oakville and Kimmswick, Missouri. Plate 01 is a location and vicinity map of the study reach. Discussed below are a variety of features found within the reach.

The confluence of the Meramec River and the Mississippi River occurs upstream of Dike 160.60R and downstream of Dike 161.10R. The property along the RDB is a mix between industrial and timberland, and the property along the LDB is agricultural. The Columbia Dike and Levee System Number 3 is along the LDB in Monroe County, Illinois. Bee Tree County Park is located along the RDB near RM 162.00. Hoppies Marina is located along the RDB near RM 158.40. The following table lists property owners along the river's banklines.

Table 2: Property Owners along the Illinois and Missouri Banklines

State	RM	Owner
Illinois	162.5	EKR Inc
	162.4-161.5	Thomas and Judy Garleb
	161.5-160.5	Dale and Wilma Mehrtens
	160.3-159.7	Helen Rey
Missouri	160.5-162	Ameren UE
	160.1	David and Linda McNutt
	158.1	Lisa Tuano

There are a total of 66 river training structures including dikes, chevrons, and weirs as well as revetment along the RDB, shown in Plate 02. See Table 3 for the river training structures and the existing conditions.

Table 3: Study Reach River Structure History

River Training Structure	Description
Dike 164.90L	Stone dike constructed in 1929, 270’ in length
Dike 164.90R	Stone dike constructed in 1933, 1,160’ in length
Dike 164.85L	Stone dike constructed in 1949, 290’ in length
Dike 164.80L	Stone dike constructed in 1929, 250’ in length
Dike 164.75L	Stone dike constructed in 1946, 300’ in length
Dike 164.70L	Stone dike constructed in 1991, 350’ in length. Used 32,153 tons of stone
Dike 164.70R	Stone dike constructed in 1933, 520’ in length
Dike 164.50L	Stone dike constructed in 1928, 300’ in length
Dike 164.25L	Stone dike constructed in 1929, 225’ in length
Dike 164.10L	Stone dike constructed in 1928
Dike 164.00R	Stone dike constructed between 1942 and 1968, 440’ in length
Weir 164.00L	Stone weir constructed in 1996, 530’ in length
Dike 163.90L	Stone dike constructed before 1928, 85’ in length
Weir 163.80L	Stone weir constructed in 1996, 720’ in length
Weir 163.70L	Stone weir constructed in 1996, 560’ in length
Dike 163.70R	Stone dike constructed between 1942 and 1968, 250’ in length
Dike 163.60L	Stone dike constructed between 1927 and 1931, 250’ in length. Repaired in 2000 with 13,576 tons of stone
Weir 163.55L	Stone weir constructed in 1996, 640’ in length
Dike 163.50L	Stone dike constructed in 1933, 275’ in length
Weir 163.45L	Stone weir constructed in 1996, 525’ in length
Dike 163.30L	Stone dike constructed in 1927, 135’ in length
Weir 163.30L	Stone weir constructed in 1996, 750’ in length
Dike 163.00L	Stone dike constructed between 1927 and 1931, 380’ in length. Dike was removed in 2011 but hit sand. 1,695 tons of stone removed, 367’ elevation
Chevron 162.80L	Stone chevron constructed in 2011, 720’ in length
Dike 162.60L	Stone dike constructed between 1931 and 1936, 645’ in length

Chevron 162.60L	Stone chevron constructed in 2011, 720’ in length
Chevron 162.50L	Stone chevron constructed in 2011, 720’ in length. In 2011 7,129 tons of stone used in repair. In 2012 1,695 tons of stone used in repair
Chevron 162.40L	Stone chevron constructed in 2010, 720’ in length
Dike 162.30L	Stone dike constructed in 1934, 400’ in length
Dike 162.10L	Stone dike constructed in 2009, 650’ in length. 24,162 tons of stone used in construction
Dike 161.90L	Wooden dike constructed in 1934, covered in stone in 1987, 1,090’ in length. 10,275 tons of stone was used
Dike 161.50L	Stone dike constructed in 1934, 1,195’ in length
Dike 161.10L	Stone dike constructed in 2001, 1,290’ in length. 24,021 tons of stone used in construction
Dike 161.10R	Stone dike constructed between 1928 and 1942
Dike 160.90L	Stone dike constructed in 1937, 1,075’ in length. Dike extend in 1991, 14,693 tons of stone used
Dike 160.60L	Stone dike constructed between 1942 and 1968, 750’ in length
Dike 160.60R	Stone dike constructed before 1928
Dike 160.30L	Stone dike constructed in 1945, 470’ in length. In 2009 dike was shortened.
Chevron 160.30L	Stone chevron constructed in 2009, 730’ in length. Structure repaired in 2012, 7,836 tons of stone used, 386’ elevation
Dike 160.00L	Stone dike constructed between 1944 and 1945, 125’ in length. In 2009 dike was shortened
Chevron 160.00L	Stone chevron constructed in 2009, 730’ in length. 17,447 tons of stone added in 2009
Dike 159.90L	Stone dike constructed in 1945, 125’ in length. In 2009 dike was shortened 300’
Chevron 159.90L	Stone chevron constructed in 2009, 730’ in length. 71,446 tons of stone used in construction.
Dike 159.80R	Stone dike constructed in 1998, 375’ in length. Dikehead and roundout repaired. 33,459 tons of stone used in repair
Dike 159.70L	Stone dike constructed in 1945, 232’ in length. In 2009 dike shortened 350’
Dike 159.70R	Stone dike constructed in 1985, 810’ in length. Dikehead and roundout repaired. 20,989 tons of stone used in repair
Dike 159.50L	Stone dike constructed in 1945, 1,000’ in length
Dike 159.30R	Stone dike constructed in 1985, 890’ in length. Dikehead and roundout repaired.
Dike 159.20L	Stone dike constructed between 1942 and 1968, 425’ in length

Dike 159.10R	Listed as stone dike in dike shapefile, however it is not visible on low water aerial photographs and was not found on the site visit.
Dike 158.90L	Stone dike constructed between 1944 and 1945, 870’ in length
Dike 158.90R	Stone dike constructed in 1985, 850’ in length. Dikehead and roundout repaired.
Dike 158.60L	Stone dike constructed between 1942 and 1968, 550’ in length
Dike 158.30L	Listed as stone dike in dike shapefile, however it is not visible on low water aerial photographs and was not found on the site visit.
Dike 158.10L	Stone dike constructed in 1938, 400’ in length
Dike 158.10R	Stone dike constructed in 2009. Rootless dike 450’ in length, 385’ elevation, 23,326 tons of stone used in construction
Dike 158.00L	Wooden dike constructed before 1928, 1,730’ in length
Dike 157.80L	Stone dike constructed in 1938, 550’ in length
Dike 157.70R	Stone dike constructed in 2009. Rootless dike 450’ in length, 385’ elevation, 26,410 tons of stone used in construction
Dike 157.50L	Stone dike constructed in 1929, 675’ in length
Dike 157.40L	Stone dike constructed in 1932, 1,565’ in length
Dike 157.30R	Stone dike constructed in 2009. Rootless dike 380’ in length, 385’ elevation, 36,143 tons of stone used in construction
Dike 157.10L	Stone dike constructed in 1931, 1,910’ in length
Dike 156.70L	Stone dike constructed in 1931, 1,790’ in length
Dike 156.30L	Wooden pile dike constructed in 1931, rebuilt with stone 1,325’ in length
Dike 156.00L	Stone dike constructed in 1928, 1,660’ in length

A. Geomorphology

To understand the planform of the river near the confluence of the Meramec River and the Mississippi River, an investigation was conducted on the historical changes, both natural and manmade, that lead up to the present day condition.

From 1817 to 1866, both the LDB and the RDB expanded out from the center of the river as shown in Plate 03. The Mississippi River expanded considerably between RM

165.00 and RM 161.00. These changes occurred naturally, predating the use of river training structures in this river reach.

From 1866 to 1881, the river continued to undergo major changes, shown on Plate 04. The banklines still fluctuated from RM 165.00 to RM 156.00. In 1881, the RDB moved towards the center of the river for this entire reach of the river. The LDB moved away from the center of the river for this entire reach of the river. The creation of Beard Island can be seen in Plate 04. These changes occurred naturally, predating the use of river training structures in this river reach.

From 1881 to 1908, the river continued to transform, as seen on Plate 05. The RDB remained fairly constant and the LDB narrowed and moved towards the center of the river from RM 165.00 to RM 156.60. These changes occurred naturally, predating the use of river training structures in this river reach.

The river continued to transition from 1908 to 1928, shown on Plate 06. The Missouri bankline remained the same except between RM 165.0 and RM 164.00 and RM 161.5 and RM 160.6. The bankline in both banks moved towards the center of the river as shown in Plate 06. Between RM 164.00 and RM 161.0 the bankline moved towards the center of the river. The bankline moved away from the center of the river between RM 160.90 to RM 156.70, then the bankline moved back towards the center of the river for the remainder of the reach until RM 165.00. There were approximately 24 river training structures during this time frame.

From 1928 to 1956, the river still experienced changes to the planform, most likely due to the total of 44 river training structures at this time as shown in Plate 07. The Missouri and Illinois banklines remained constant from RM 165.00 to RM 162.00. The LDB shifted towards the center of the river from RM 162.00 to RM 156.00. The RDB remained similar to the 1928 bankline until RM 160.80 where it shifted towards the center of the river until RM 158.40, where it rejoined the 1928 bankline.

There were no significant changes to the banklines throughout the study reach from 1956 to 1968, as seen on Plate 08. This was due to the construction of the river training structures in previous years locking in the basic planform of the reach.

From 1968 to 1986, there were no major changes to the banklines throughout the study reach, but the bankline moved towards the center of the river from RM 165.00 to RM 161.50 on the LDB shown on Plate 09. There were approximately 44 river training structures during this time frame.

A majority of the existing revetment in the study reach was placed along the bankline between 1986 and 2003 as shown on Plate 10.

There were no significant measurable shifts or transformations of the planform from 2003 to 2011, shown on Plate 11. There were very minor changes to the banklines, due to sporadic round outs behind some downstream angled dikes. Additional revetment was placed during this time period.

B. Dredging/Problem Description

Dredging is a common practice used on the Mississippi River to maintain the river at the proper depth, width, and channel alignment for navigation. Just upstream of the confluence of the Meramec and Mississippi River, repetitive channel maintenance dredging has routinely occurred. Figure 1 shows the annual amount of material removed from 1994 to 2014 and Figure 2 shows the associated cost for the same time period. In the last 5 years, approximately 600,000 cubic yards of material has been removed between RM 162.00 and RM 160.00 at a cost of approximately $1.7M.

Figure 1: Study Reach Dredge Removal Data

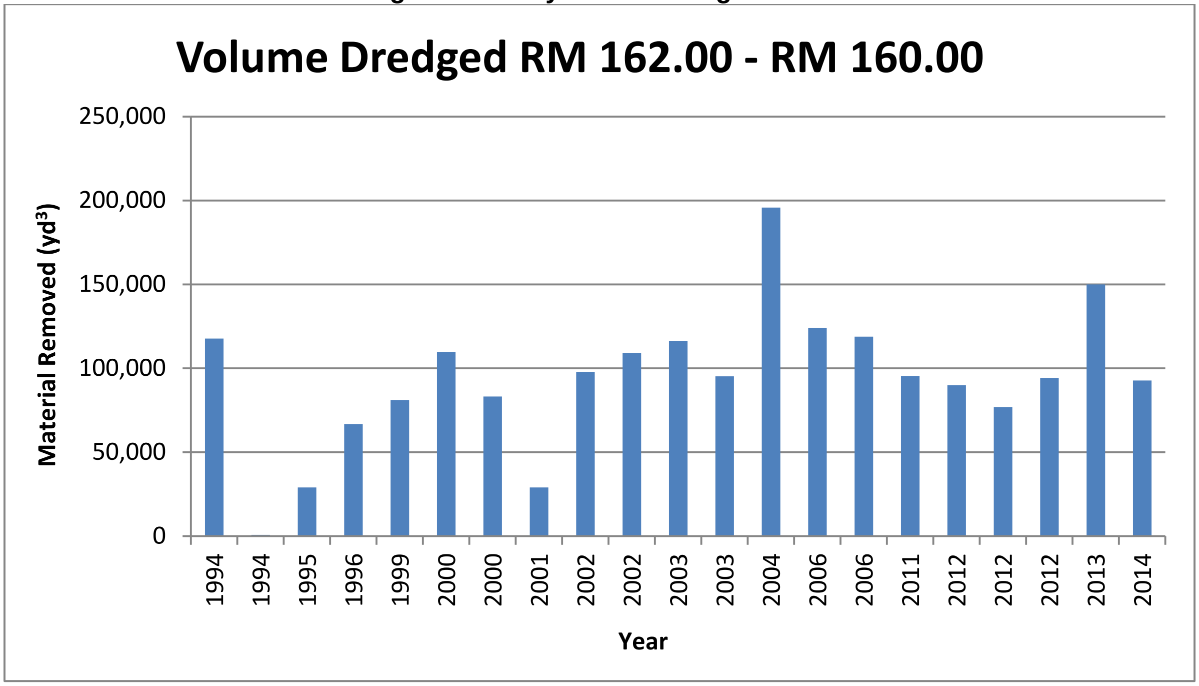
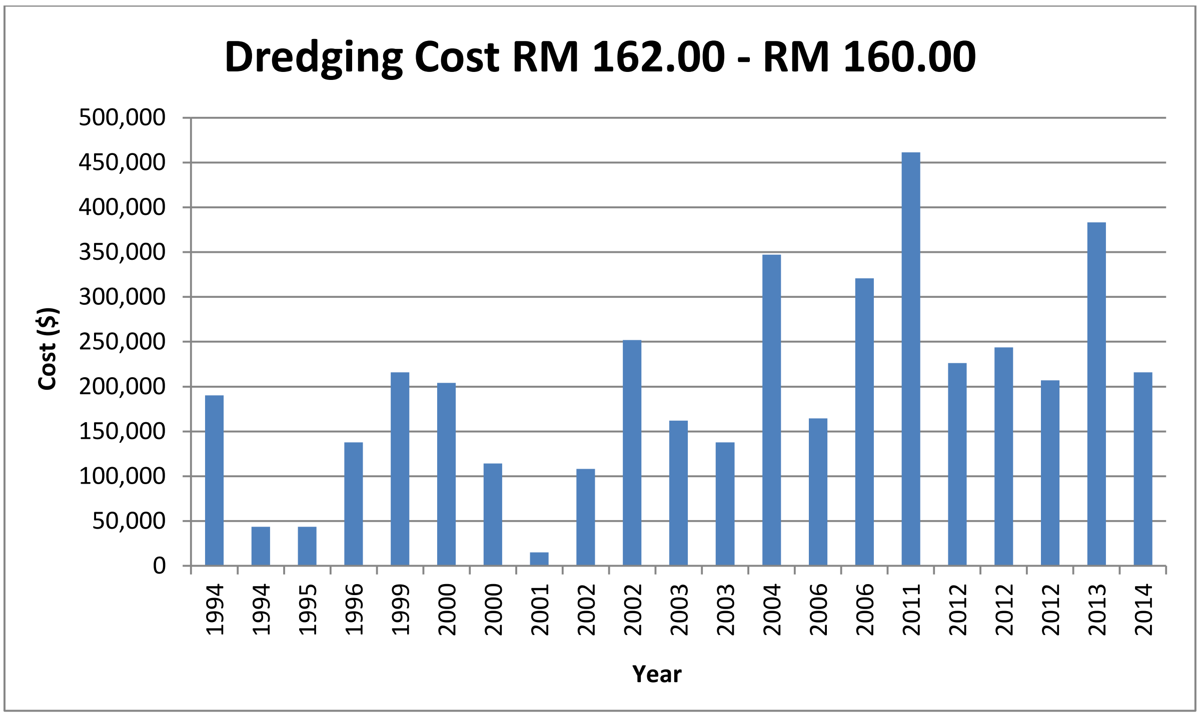


Figure 2: Study Reach Cost of Dredge Removal



C. Channel Characteristics and General Trends

i. Bathymetry

Range line and multi-beam hydrographic surveys of the Mississippi River from 2000 to 2013 within the HSR Model extents, are shown on Plates 12 -17. Plates 18 – 22 show pre-dredge conditions from 2005 – 2012. For this study, the bathymetric data was referenced to the Low Water Reference Plane (LWRP).

Recent surveys were used to determine general trends because they showed the most recent construction and the resultant river bed changes. The surveys showed that the bathymetric trends remained relatively constant from 2010 - 2013 after comparison of the above mentioned hydrographic surveys (due to recent dike construction):

Table 4: Study Reach Bathymetry Trends

River Miles	Description
162.80 - 158.30	The thalweg crossed to the RDB near RM 162.80 and continued until RM 158.30. There was scour along the tips of some dikes on the RDB with depths between -30 ft to -50 ft LWRP. There was some scour off the tips of dikes and around the chevrons along the LDB. There was deposition on the LDB along the dikes, and a point bar existed from Dike 161.90L to Dike 161.10L
158.30 - 157.40	The thalweg crossed to the LDB near RM 158.30 and stayed along the LDB until RM 157.40. There was scour off the tips of the dikes on both the LDB and the RDB, with depths ranging from -30 ft and -50 ft LWRP. There was a point bar and deposition along the RDB dike field.
157.40 - 156.00	The thalweg crossed to the RDB near RM 157.40 and continued through RM 156.00. There was some scour off the tips of the dikes on the LDB. There was significant scour along the RDB between RM 156.30 - 156.00 with depths of -30 ft to -50 ft LWRP. There was a point bar behind Dike 156.70L to Dike 156.00L and deposition along the LDB.

ii. Flow Mechanics

Just upstream of the confluence of the Meramec River and the Mississippi River is where a majority of the dredging occurs between RM 160.00 and RM 162.00. This increase in dredging could be attributed to the flow and deltaic deposition from the Meramec River.

iii. Site Data

On July 24, 2013, the authors of this report visited the Mouth of the Meramec reach to examine bank lines, structures, and any data that could not otherwise be gathered in the office. At the St. Louis gage, the river stage was 10.9 ft (390.84 ft in elevation). The river stage at Brickey's gage was 12.3 ft (370.08 ft in elevation). A majority of the structures were visible, due to the low water. The following observations were made:

- Dike 164.90L: Structure was visible.
- Dike 164.90R: Structure was visible, but appeared to be lower in elevation near the navigation channel.
- Dike 164.85L: Structure was visible.
- Dike 164.80L: Could not find structure, most likely part of the bankline (and not found on 2012 low water aerials).
- Dike 164.75L: Could not find structure, most likely part of the bankline (and not found on 2012 low water aerials).
- Dike 164.70L: Structure was not visible, but was built in 1991, so assuming it is degraded.
- Dike 164.70R: Structure was visible, but the structure was degraded/lower near the navigation channel.
- Dike 164.50L: Structure was visible.
- Dike 164.25L: Structure was visible.
- Dike 164.10L: Could not find structure, most likely part of the bankline (and not found on 2012 low water aerials).
- Dike 164.00R: Structure was visible.
- Dike 163.90L: Structure was visible.
- Dike 163.70R: Structure was visible.
- Dike 163.60L: Structure was visible.
- Dike 163.50L: Could not find structure, most likely part of the bankline (and not found on 2012 low water aerials).
- Dike 163.30L: Structure was visible.

- Revetment 163.90-163.25L: The revetment almost appeared to be off-bank and had a notch in it. There was water behind it in some locations, accretion and sparse vegetation in others.
- Chevron 162.8L: Structure was visible. There was a hole/degradation in the arch of the chevron more towards the navigation channel side. There was some minor bankline scour.
- Dike 162.60L: Structure was visible and there were some piles visible within the stone.
- Chevron 162.60L: Structure was visible.
- Chevron 162.40L: Structure was visible.
- Dike 162.30L: Structure was visible, but was very low. Piles were also visible within the stone.
- Dike 162.10L: Structure was visible.
- Dike 161.90L: There were some piles visible near the bankline. The stone structure was visible.
- Dike 161.50L: Structure was visible.
- Dike 161.10L: Structure was visible.
- Dike 161.10R: Could not find structure (and not found on 2012 low water aerials).
- Dike 160.90L: Structure was visible, but the entire structure was low and almost looked like it was notched next to the island.
- Dike 160.60L: Structure was visible, but appeared slightly low in elevation.
- Dike 160.60R: Could not find structure (and not found on 2012 low water aerials).
- Dike 160.30L: Structure was visible, but appeared low near the bankline.
- Chevron 160.30L: The arch of the chevron appeared lower in elevation than the legs.
- Dike 160.00L: Structure was not visible in the field, but can be found on 2012 low water aerials.
- Chevron 160.00L: The structure was visible, but was rough looking (not “topped off”).

- Dike 159.90L: Structure was visible.
- Chevron 159.9L: Structure was visible.
- Dike 159.80R: Structure was visible, but lower in elevation.
- Dike 159.70L: Structure was visible, but very low.
- Dike 159.50L: Structure was visible.
- Dike 159.30R: Structure was visible.
- Dike 159.20L: Structure was visible.
- Dike 159.10R: Could not find structure (and not found on 2012 low water aerials).
- Dike 158.90L: Structure was visible.
- Dike 158.90R: Structure was visible. Sloped down in elevation towards the navigation channel.
- Dike 158.60L: Structure was visible.
- Dike 158.30L: Could not find structure (and not found in 2012 low water aerials).
- Dike 158.10L: Structure was visible.
- Dike 158.10R: Structure was visible.
- Dike 157.80L: Structure was visible, but looked uneven and had low spots.
- Dike 157.70R: Structure was visible.
- Dike 157.50L: Structure was visible, but appeared to be lower in elevation than other structures.
- Dike 157.40L: Structure was visible. The end nearest the navigation channel appeared lower and possibly even had a hole/gap.
- Dike 157.30R: Structure was visible, but the middle appeared to be degraded.
- Dike 157.10L: Structure was visible. There appeared to be some piles under/in the rock.
- Dike 156.70L: Structure was visible.
- Dike 156.30L: Structure was visible. There appeared to be some piles under/in the rock.
- Dike 156.00L: Structure was visible.

HSR MODELING

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

1. Model Calibration and Replication

The HSR modeling methodology employed a calibration process designed to replicate the general conditions in the river at the time of the model study. Replication of the model was achieved during calibration and involved a three step process.

First, planform "fixed" boundary conditions of the study reach, i.e. banklines, islands, side channels, tributaries and other features were established according to the most recent available high resolution aerial photographs. Various other fixed boundaries were also introduced into the model including any channel improvement structures, underwater rock, clay and other non-mobile boundaries. These boundaries were based off of documentation (such as plans and specifications) provided by the Little Rock District.

Second, "loose" boundary conditions of the model were replicated. Bed material was introduced into the channel throughout the model to an approximate level plane. The combination of the fixed and loose boundaries served as the starting condition of the model.

Third, model tests were run using steady state discharge. Adjustment of the discharge, sediment volume, model slope, fixed boundaries, and entrance conditions were refined during these tests as part of calibration. The bed progressed from a static, flat, arbitrary bed into a fully-formed, dynamic, three dimensional mobile bed response. Repeated tests were simulated for the assurance of model stability and repeatability. When the general trends of the model bathymetry were similar to observed recent river bathymetry, and the tests were repeatable, the model was considered calibrated and alternative testing began.

One important parameter to note was that in calibration, non-erodible bed material (clay) was used in a localized area on the model riverbed to represent the bluffs and rock outcroppings of the Missouri bankline from RM 163.5 to RM 158.5. Because the non-erodible was required for calibration, the non-erodible remained in the model throughout the rest of the study (i.e. during alternative testing).

2. Scales and Bed Materials

The model employed a horizontal scale of 1 inch = 900 feet, or 1:10,800, and a vertical scale of 1 inch = 76 feet, or 1:912, for a 12 to 1 distortion ratio of linear scales. This distortion supplied the necessary forces required for the simulation of sediment transport conditions similar to those observed in the prototype. The bed material was granular plastic urea, Type II, with a specific gravity of 1.40.

3. Appurtenances

The HSR model planform insert was constructed according to the 2012 high-resolution aerial photography of the study reach. The insert was then mounted in a standard HSR model flume. The riverbanks of the model were routed into dense polystyrene foam and modified during calibration with clay and polymesh. Rotational jacks located within the hydraulic flume controlled the slope of the model. The measured slope of the insert and flume was approximately .012 inch/inch. River training structures in the model were made of galvanized steel mesh to generate appropriate scaled roughness.

4. Flow Control

Flow into the model was regulated by customized computer hardware and software interfaced with an electronic control valve and submersible pump. This interface was used to control the flow of water and sediment into the model. For all model tests, flow entering the model was held steady at 0.95 Gallons per Minute (GPM). This served as the average expected energy response of the river. Because of the constant variation experienced in the river, this steady state flow was used to replicate existing general conditions and empirically analyze the ultimate expected sediment response that could occur from future alternative actions.

5. Data Collection

Data from the HSR model was collected with a three dimensional (3D) laser scanner. The operation of this equipment is described below.

The river bed in the model was surveyed with a high definition, 3D laser scanner that collects a dense cloud of xyz data points. These xyz data points were then georeferenced to real world coordinates and triangulated to create a 3D surface. The surface was then color coded by elevation using standard color tables that were also used in color coding prototype surveys. This process allowed a direct comparison between HSR model bathymetry surveys and prototype bathymetry surveys.

6. Replication Test

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

Bathymetric trends were recorded from the model using a 3-D Laser Scanner. Calibration was achieved after numerous favorable bathymetric comparisons of the prototype surveys were made to several surveys of the model. The resultant bathymetry served as the bathymetry base test for the model and is shown on Plate 23.

Results of the HSR model base test bathymetry and a comparison to the 2010 through 2013 prototype surveys indicated the following trends:

Table 5: Study Reach and Prototype Bathymetry Trend Comparison

River Miles	Description
162.80 - 158.30	In both the prototype and the model, the thalweg crossed to the RDB near RM 162.80 and continued until RM 158.30. There was scour along some of the RD bankline and the tips of some dikes with depths between -30 ft to -40 ft LWRP. In the model there were longer scour holes near RM 160.5 to RM 158.5 than in the prototype. In both the prototype and the model there was some scour off the tips of dikes and around the chevrons along the LDB. There was more scour off the tip of Dike 161.10L in the model than in the prototype. In the prototype there was more diversity around the chevrons than in the model. There was deposition on the LDB along the dikes, and a point bar existed from Dike 161.90L to Dike 161.10L
158.30 - 157.40	The thalweg crossed to the LDB near RM 158.30 and stayed along the LDB until RM 157.40. There was scour off the tips of the dikes on both the LDB and the RDB, with depths ranging from -30 ft and -50 ft LWRP. There was a point bar and deposition along the RDB dike field.
157.40 - 156.00	The thalweg crossed to the RDB near RM 157.40 and continued through RM 156.00. There was some scour off the tips of the dikes on the LDB. There was significant scour along the RDB between RM 156.30 - 156.00 with depths of -30 ft to -50 ft LWRP. There was a point bar behind Dike 156.70L to Dike 156.00L and deposition along the LDB.

Further detailed calculations on model cross sections were compared directly to the prototype and are shown in Appendix C. Results indicated that the model replication bed response was very similar to the prototype response and was within the natural variation observed in the river.

7. Design Alternative Tests

The testing process consisted of modeling alternative measures in the HSR model followed by analyses of the bathymetry and velocity results. The goal was identifying the most effective and economical plan to reduce the dredging between RM 162.00 to RM 160.00. Evaluation of each alternative was accomplished through a qualitative comparison to the model replication test bathymetry (deposition). Plates 24 – 39 show all alternatives that were considered in this model study.

Alternative 1:

Type of Structure	River Mile	LDB or RDB	Dimensions (Feet)	Structure Top Elevation (ft in LWRP)
Rootless Dike Extension	161.50	LDB	375	18.5
Rootless Dike Extension	161.10	LDB	185	18.5

Results: *Bathymetry (Plate 24) Analysis*

Reduced Dredging	Incorporated Features to Avoid and Minimize Environmental Impacts	Additional Comments
No	Yes	The alternative included 2 rootless dike extensions, which were intended to avoid and minimize environmental impacts. There was no significant change in main channel bathymetry or depth diversity within the existing side channel.

<u>Alternative 2:</u>

Type of Structure	River Mile	LDB or RDB	Dimensions (Feet)	Structure Top Elevation (ft in LWRP)
Rootless Dike	161.55	LDB	375	18.5
Rootless Dike	161.15	LDB	185	18.5

Results: *Bathymetry (Plate 25) Analysis*

Reduced Dredging	Incorporated Features to Avoid and Minimize Environmental Impacts	Additional Comments
No	Yes	The alternative included 2 rootless dikes, which were intended to avoid and minimize environmental impacts. There was no significant change in the main channel bathymetry or depth diversity within the existing side channel.

Alternative 3:

Type of Structure	River Mile	LDB or RDB	Dimensions (Feet)	Structure Top Elevation (ft in LWRP)
Rootless Dike				
Rootless Dike	161.70	LDB	355	18.5
Extension	161.50	LDB	350	18.5
Rootless Dike	161.10	LDB	225	18.5
Extension				

Results: *Bathymetry (Plate 26) Analysis*

Reduced Dredging	Incorporated Features to Avoid and Minimize Environmental Impacts	Additional Comments
Yes	Yes	Alternative 3 included 1 rootless dike and 2 rootless dike extensions, which were intended to avoid and minimize environmental impacts and produced elevations ranging on average between -10 ft to -12 ft LWRP within the dredging area. There were a few small locations within the dredging area that had elevations above -9 ft LWRP. There were no significant changes in depth diversity within the existing side channel.

Alternative 4:

Type of Structure	River Mile	LDB or RDB	Dimensions (Feet)	Structure Top Elevation (ft in LWRP)
Rootless Dike	161.70	LDB	375	18.5
Rootless Dike	161.45	LDB	650	18.5

Results: *Bathymetry (Plate 27) Analysis*

Reduced Dredging	Incorporated Features to Avoid and Minimize Environmental Impacts	Additional Comments
Yes	Yes	Alternative 4 included 2 rootless dikes, which were intended to avoid and minimize environmental impacts and produced elevations ranging on average between -8 ft to -12 ft LWRP within the dredging area. There were no significant changes in depth diversity within the existing side channel.

Alternative 5:

Type of Structure	River Mile	LDB or RDB	Dimensions (Feet)	Structure Top Elevation (ft in LWRP)
Rootless Dike	161.85	LDB	310	18.5
Rootless Dike	161.50	LDB	570	18.5

Results: *Bathymetry (Plate 28) Analysis*

Reduced Dredging	Incorporated Features to Avoid and Minimize Environmental Impacts	Additional Comments
No	Yes	Alternative 5 included 2 rootless dikes, which were intended to avoid and minimize environmental impacts and produced elevations ranging on average between -8 ft to -12 ft LWRP within the dredging area. A large area of the repetitive dredging location still showed elevations above -9 ft LWRP. There were no significant changes in depth diversity within the existing side channel.

Alternative 6:

Type of Structure	River Mile	LDB or RDB	Dimensions (Feet)	Structure Top Elevation (ft in LWRP)
Dike Extension	161.90	LDB	560	18.5
Dike Extension	161.50	LDB	590	18.5
Dike Extension	161.10	LDB	325	18.5

Results: *Bathymetry (Plate 29) Analysis*

Reduced Dredging	Incorporated Features to Avoid and Minimize Environmental Impacts	Additional Comments
Yes	No	Alternative 6 produced elevations ranging on average between -9 ft to -12 ft LWRP within the dredging area. There were no significant changes in depth diversity within the existing side channel.

Alternative 7:

Type of Structure	River Mile	LDB or RDB	Dimensions (Feet)	Structure Top Elevation (ft in LWRP)
Rootless Dike	161.70	LDB	575	18.5
Dike Extension	161.50	LDB	400	18.5

Results: *Bathymetry (Plate 30) Analysis*

Reduced Dredging	Incorporated Features to Avoid and Minimize Environmental Impacts	Additional Comments
No	Yes	Alternative 7 included 1 rootless dike, which was intended to avoid and minimize environmental impacts, and 1 traditional dike extension yielding elevations ranging on average between -8 ft to -12 ft LWRP within the dredging area. A large area of the repetitive dredging location still showed elevations above -9 ft LWRP. There were no significant changes in depth diversity within the existing side channel.

Alternative 8:

Type of Structure	River Mile	LDB or RDB	Dimensions (Feet)	Structure Top Elevation (ft in LWRP)
Rootless Dike	161.70	LDB	470	18.5
Dike Extension	161.45	LDB	625	18.5

Results: *Bathymetry (Plate 31) Analysis*

Reduced Dredging	Incorporated Features to Avoid and Minimize Environmental Impacts	Additional Comments
No	Yes	Alternative 8 included 2 rootless dikes, which were intended to avoid and minimize environmental impacts, and produced elevations ranging on average between -8 ft to -12 ft LWRP within the dredging area. A large area of the repetitive dredging location still showed elevations above -9 ft LWRP. There were no significant changes in depth diversity within the existing side channel.

Alternative 9:

Type of Structure	River Mile	LDB or RDB	Dimensions (Feet)	Structure Top Elevation (ft in LWRP)
Rootless Dike	161.70	LDB	620	18.5
Dike Extension	161.50	LDB	485	18.5

Results: *Bathymetry (Plate 32) Analysis*

Reduced Dredging	Incorporated Features to Avoid and Minimize Environmental Impacts	Additional Comments
No	Yes	Alternative 9 included 1 rootless dike, which was intended to avoid and minimize environmental impacts, and 1 traditional dike. The alternative produced elevations ranging on average between -8 ft to -12 ft LWRP within the dredging area. A large area of the repetitive dredging location still showed elevations above -9 ft LWRP. There were no significant changes in depth diversity within the existing side channel.

Alternative 10:

Type of Structure	River Mile	LDB or RDB	Dimensions (Feet)	Structure Top Elevation (ft in LWRP)
Dike Extension	161.90	LDB	550	18.5
Rootless Dike	161.70	LDB	530	18.5
Dike Extension	161.50	LDB	490	18.5
Dike Extension	161.10	LDB	310	18.5

Results: *Bathymetry (Plate 33) Analysis*

Reduced Dredging	Incorporated Features to Avoid and Minimize Environmental Impacts	Additional Comments
No	Yes	Alternative 10 included 1 rootless dike, intended to avoid and minimize environmental impacts, and 3 traditional dike extensions. The alternative produced elevations ranging between -8 ft to -12 ft LWRP within the dredging area. A large area of the repetitive dredging location still showed elevations above -9 ft LWRP. There were no significant changes in depth diversity within the existing side channel.

Alternative 11:

Type of Structure	River Mile	LDB or RDB	Dimensions (Feet)	Structure Top Elevation (ft in LWRP)
Dike Extension	161.90	LDB	565	18.5
Dike Extension	161.50	LDB	610	18.5
Dike Extension	161.10	LDB	315	18.5

Results: *Bathymetry (Plate 34) Analysis*

Reduced Dredging	Incorporated Features to Avoid and Minimize Environmental Impacts	Additional Comments
No	No	Alternative 11 included 3 traditional dike extensions and produced elevations ranging between -8 ft to -12 ft LWRP within the dredging area. A portion of the repetitive dredging location still showed elevations above -9 ft LWRP. There were no significant changes in depth diversity within the existing side channel.

Alternative 12:

Type of Structure	River Mile	LDB or RDB	Dimensions (Feet)	Structure Top Elevation (ft in LWRP)
Dike Extension	161.90	LDB	680	18.5
Dike Extension	161.50	LDB	765	18.5
Dike Extension	161.10	LDB	445	18.5
Rootless Dike	161.00	LDB	360	18.5

Results: *Bathymetry (Plate 35) Analysis*

Reduced Dredging	Incorporated Features to Avoid and Minimize Environmental Impacts	Additional Comments
No	Yes	Alternative 12 included 1 rootless dike, which was intended to avoid and minimize environmental impacts, and 3 traditional dike extensions. The alternative produced elevations ranging between -8 ft to -12 ft LWRP within the dredging area. A portion of the repetitive dredging location still showed elevations above -9 ft LWRP. There were no significant changes in depth diversity within the existing side channel.

Alternative 13:

Type of Structure	River Mile	LDB or RDB	Dimensions (Feet)	Structure Top Elevation (ft in LWRP)
Dike Extension	161.90	LDB	690	18.5
Rootless Dike	161.50	LDB	900	18.5
Dike Extension	161.10	LDB	445	18.5
Rootless Dike	161.00	LDB	260	18.5

Results: *Bathymetry (Plate 36) Analysis*

Reduced Dredging	Incorporated Features to Avoid and Minimize Environmental Impacts	Additional Comments
No	Yes	Alternative 13 included 2 rootless dikes, which were intended to avoid and minimize environmental impacts, as well as 2 traditional dike extensions. The alternative produced elevations ranging between -8 ft to -12 ft LWRP within the dredging area. A portion of the repetitive dredging location still showed elevations above -9 ft LWRP. There were no significant changes in depth diversity within the existing side channel.

Alternative 14:

Type of Structure	River Mile	LDB or RDB	Dimensions (Feet)	Structure Top Elevation (ft in LWRP)
Dike Extension	161.90	LDB	660	18.5
Dike Extension	161.50	LDB	565	18.5
Dike	161.50	RDB	330	18.5
Dike	161.20	RDB	350	18.5
Dike Extension	161.00	LDB	350	18.5

Results: *Bathymetry (Plate 37) Analysis*

Reduced Dredging	Incorporated Features to Avoid and Minimize Environmental Impacts	Additional Comments
Yes	No	Alternative 14 included 3 traditional dike extensions as well as 3 traditional dikes and produced elevations ranging on average between -10 ft to -12 ft LWRP within the dredging area. However, it should be noted that the structures along the RDB would impact Ameren, who is located along the RDB in that area. There were no significant changes in depth diversity within the existing side channel.

Alternative 15:

Type of Structure	River Mile	LDB or RDB	Dimensions (Feet)	Structure Top Elevation (ft in LWRP)
Dike Extension	161.90	LDB	620	18.5
Rootless Dike	161.70	LDB	475	18.5
Dike Extension	161.50	LDB	560	18.5
Dike	161.50	RDB	240	18.5
Dike	161.20	RDB	310	18.5
Dike Extension	161.00	LDB	260	18.5

Results: *Bathymetry (Plate 38) Analysis*

Reduced Dredging	Incorporated Features to Avoid and Minimize Environmental Impacts	Additional Comments
Yes	Yes	Alternative 15 included 3 traditional dike extensions, 2 traditional dikes, and 1 rootless dike. The rootless dike was intended to avoid and minimize environmental impacts. The alternative produced elevations ranging on average between -10 ft to -15 ft LWRP within the dredging area. However, it should be noted that the structures along the RDB would impact Ameren, who is located along the RDB near RM 161.50. There were no significant changes in depth diversity within the existing side channel.

Alternative 16:

Type of Structure	River Mile	LDB or RDB	Dimensions (Feet)	Structure Top Elevation (ft in LWRP)
Weir	162.30	RDB	520	-15.0
Weir	162.20	RDB	645	-15.0
Weir	162.15	RDB	720	-15.0
Weir	162.10	RDB	700	-15.0
Rootless Dike	161.70	LDB	615	18.5
Rootless Dike	161.50	LDB	500	18.5
Rootless Dike	161.10	LDB	325	18.5

Results: *Bathymetry (Plate 39) Analysis*

Reduced Dredging	Incorporated Features to Avoid and Minimize Environmental Impacts	Additional Comments
Yes	Yes	Alternative 16 included 4 weirs and 3 rootless dikes, which were intended to avoid and minimize environmental impacts. The alternative produced elevations ranging on average between -10 ft to -15 ft LWRP within the dredging area. The results of Alternative 16 were very comparable to the results of Alternative 15. However, Alternative 16 would not negatively impact Ameren, who is located along the LDB near RM 161.50. There were no significant changes in depth diversity within the existing side channel.

CONCLUSIONS

1. Evaluation and Summary of the Model Tests

Alternatives	Reduced Dredging	Incorporated Features to Avoid and Minimize Environmental Impacts	Positive Overall Impact on Study Reach
Alternative 1	No	Yes	No
Alternative 2	No	Yes	No
Alternative 3	Yes	Yes	Yes
Alternative 4	Yes	Yes	Yes
Alternative 5	No	Yes	No
Alternative 6	Yes	No	Yes
Alternative 7	No	Yes	No
Alternative 8	No	Yes	No
Alternative 9	No	Yes	No
Alternative 10	No	Yes	No
Alternative 11	No	No	No
Alternative 12	No	Yes	No
Alternative 13	No	Yes	No
Alternative 14	Yes	No	Yes
Alternative 15	Yes	Yes	Yes
Alternative 16	Yes	Yes	Yes

In order to determine the best alternative, certain criteria, based on the study purpose and goals, were used to evaluate each alternative. The first and most important consideration was that the alternative had to reduce or eliminate the amount of dredging necessary between RM 162.00 to RM 160.00. The second condition was that the design should incorporate measures intended to avoid and minimize negative impacts to the environment, so long as the primary goal of reducing the need for dredging is not compromised. Although there were a number of alternatives that showed improvements to the repetitive dredging location while maintaining the navigation channel requirements, the selected alternative provided the highest likelihood of achieving this goal. Although Alternatives 6 and 15 showed a significant reduction to dredging, they were not chosen. Alternative 6 did not incorporate any features to avoid and minimize environmental impacts, and therefore, was not chosen as a viable option. Alternative 15 included one rootless structure intended to avoid and minimize environmental impacts, but was not chosen because the recommended alternative showed a significant reduction in dredging while incorporating 3 rootless structures. Furthermore, Alternatives 14 and 15 included dikes 161.50 and 161.20, which Ameren personnel indicated may be problematic for their facility located along the RDB near RM 161.50.

2. Recommendations

Alternative 16, Plate 39, was recommended as the most desirable alternative because of its observed ability to significantly reduce elevations observed in the repetitive dredging area between RM 162.00 and RM 160.00. The alternative also incorporated rootless dike structures instead of traditional dikes in an effort to avoid and minimize the environmental impacts in the project area. The rootless Dike 161.50 was placed at an angle in an attempt to divert a small amount of additional flow towards the small side channel located along the LDB. Flow visualization observed in the HSR model showed a slight increase in the amount of flow entering the side channel, but no bathymetric changes were observed. Flow visualization was achieved by dropping floating particles on the water surface and visually inspecting their path through the river reach. Overall, this alternative enhanced navigation safety for industry by providing a deeper navigation channel while maintaining and potentially improving environmental features within the project area. Notes from the April 17, 2014 HSR model coordination meeting minutes can be found in Appendix D.

The recommended design included the following:

- RM 162.30R: Construct Weir (520 ft)
    - Structure top elevation = 354.0 ft (NGVD 1929)
- RM 162.20R: Construct Weir (645 ft)
    - Structure top elevation = 354.0 ft (NGVD 1929)

- RM 162.10R: Construct Weir (720 ft)
    - o Structure top elevation = 354.0 ft (NGVD 1929)

- RM 162.00R: Construct Weir (700 ft)
    - o Structure top elevation = 354.0 ft (NGVD 1929)

- RM 161.70L: Construct Rootless Dike (615 ft)
    - o Structure top elevation = 387.0 ft (NGVD 1929)

- RM 161.50L: Construct Rootless Dike Extension (500 ft)
    - o Structure top elevation = 387.0 ft (NGVD 1929)
    - o
- RM 161.10L: Construct Rootless Dike Extension (325 ft)
    - o Structure top elevation = 387.0 ft (NGVD 1929)

3. Interpretation of Model Test Results

In the interpretation and evaluation of the model test results, it should be remembered that these results are qualitative in nature. Any hydraulic model, whether physical or numerical, is subject to biases introduced as a result of the inherent complexities that exist in the prototype. Anomalies in actual hydrographic events, such as prolonged periods of high or low flows are not reflected in these results, nor are complex physical phenomena, such as the existence of underlying rock formations or other non-erodible variables. Water surfaces were not analyzed and flood flows were not simulated in this study.

This model study was intended to serve as a tool for the river engineer to guide in assessing the general trends that could be expected to occur in the Mississippi River from a variety of imposed design alternatives. Measures for the final design may be modified based upon engineering knowledge and experience, real estate and construction considerations, economic and environmental impacts, or any other special requirements.

FOR MORE INFORMATION

For more information about HSR modeling or the Applied River Engineering Center, please contact Robert Davinroy, P.E. or Brad Krischel 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) 865-6326 or (314) 865-6325
Fax: (314) 865-6352

E-mail: Robert.D.Davinroy@usace.army.mil
Bradley.J.Krischel@usace.army.mil

Or you can visit us on the World Wide Web at:
http://mvs-wc.mvs.usace.army.mil/arec/

APPENDIX A: Report Plates

1. Location and Vicinity Map
2. Nomenclature and Dike Locations
3. Geomorphology: 1817 vs 1866
4. Geomorphology: 1866 vs 1881
5. Geomorphology: 1881 vs 1908
6. Geomorphology: 1908 vs 1928
7. Geomorphology: 1928 vs 1956
8. Geomorphology: 1956 vs 1968
9. Geomorphology: 1968 vs 1986
10. Geomorphology: 1986 vs 2003
11. Geomorphology: 2003 vs 2011
12. 2000 Hydrographic Survey
13. 2001 Hydrographic Survey
14. 2005 Hydrographic Survey
15. 2007 Hydrographic Survey
16. 2010 Hydrographic Survey
17. 2013 Hydrographic Survey
18. 2005 Pre-Dredge Survey
19. 2006 Pre-Dredge Survey
20. 2008 Pre-Dredge Survey
21. 2011 Pre-Dredge Survey
22. 2012 Pre-Dredge Survey
23. Model Replication
24. Model Replication vs. Alternative 1
25. Model Replication vs. Alternative 2
26. Model Replication vs. Alternative 3
27. Model Replication vs. Alternative 4
28. Model Replication vs. Alternative 5
29. Model Replication vs. Alternative 6
30. Model Replication vs. Alternative 7

31. Model Replication vs. Alternative 8
32. Model Replication vs. Alternative 9
33. Model Replication vs. Alternative 10
34. Model Replication vs. Alternative 11
35. Model Replication vs. Alternative 12
36. Model Replication vs. Alternative 13
37. Model Replication vs. Alternative 14
38. Model Replication vs. Alternative 15
39. Model Replication vs. Alternative 16

B. HSR Model Theory

The principle behind the use of a hydraulic sediment response model is similitude, the linking of parameters between a model and prototype so that behavior in one can predict behavior in the other.

There are two different types of similitude; mathematical similitude and empirical similitude. Mathematical similitude is founded on the scale relationship between all linear dimensions (geometric similarity), a scale relationship between all components of velocity (kinematic), or both geometric and kinematic similarity with the ratio of all common point forces equal (dynamic similarity).

In contrast to mathematical similitude, empirical similitude is based on the belief that the laws of mathematical similitude can be relaxed as long as other more fundamental relationships are preserved between the model and the prototype. All physical models used in the past by USACE employed, to some degree, empirical similitude. Numerous definitions of what relationships must be preserved have been put forward concerning physical sediment models. These relationships often deal with the scalability of elements of sediment transport processes or surface or structure roughness. Hydraulic sediment response models depend on similitude in the morphologic response, i.e. the ability of the model to replicate known prototype parameters associated with the bed response in the river under study. Bed response includes thalweg location, scour and deposition within the channel and at various river structures, and the overall resultant bed configuration. These parameters are directly compared to what is observed from prototype surveys.

Detailed cross-sectional analysis of prototype and model surveys defining bed response and bed configuration have shown that HSR model variation from the prototype is often approximately that of the natural variation observed in the prototype. This correspondence allows hydraulic engineers to use the HSR model with confidence and introduce alternatives in the model to approximate the bed response that can be expected to occur in the prototype.

HSR models were developed from empirical large scale coal bed models utilized by the USACE Waterways Experiment Station (Environmental Research and Development Center). These models were used by MVS from 1940 to the mid 1990s. For a more thorough explanation of the HSR model development, please refer to the following link:

http://mvs-wc.mvs.usace.army.mil/arec/Documents/Publications/M53_Hydraulic_Sediment_Response_Modeling_Replication_Accuracy.pdf

C. Cross Section Comparison

To verify the predictive capabilities of the HSR model used for this study, cross sections were developed for the replication model condition and three prototype bathymetries, the 2010 and 2013 river surveys. The 2010 and 2013 surveys were chosen because they were the most recent surveys of the last 5 years that had full coverage of the model extents. From these cross sections, the cross-sectional areas and percent differences were calculated. The cross sections were modeled and area calculations were performed using Bentley's InRoads and MicroStation software. The cross sections were cut at 2,000 foot intervals along the sailing line for the same locations for all three surveys. The survey areas in close proximity to the model's entrance and exit conditions were not used, so only stations 100+00 through 360+00 were used. Furthermore, it should be noted that this is a limited data set, and a more detailed analysis was not completed due to constraints in time and funding. See Figures 1 and 2 on the following pages for graphical cross-sectional comparisons.

The initial comparison was between the replicated model scan and the 2010 bathymetry. The cross sections were generated with a vertical distortion of 15 feet horizontal for 1 foot vertical, which dictated using 15 as a correction factor for the area calculations. The results of the area calculations are presented in Table 6. The average percent difference between the cross-sectional areas, model to prototype, was 8.4%, with a low of 0.4% and a high of 23.1%.

The second comparison was between the replicated model scan and the 2013 bathymetry. The cross sections were generated with a vertical distortion of 15 feet horizontal for 1 foot vertical, which dictated using 15 as a correction factor for the area calculations. The results of the area calculations are presented in Table 7. The average percent difference between the cross-sectional areas, model to prototype, was 8.4%, with a low of 0.5% and a high of 14.2%.

Cross sections were generated in the same manner comparing the 2010 and 2013 bathymetries to get a measure of the natural variation of the channel. The average percent difference was 5.1%; the lowest percent difference was 0.8% and the highest was 13.2%. The natural variation of the channel compared well with the average percent difference of 8.4% between the model and prototype.

Figure 1:

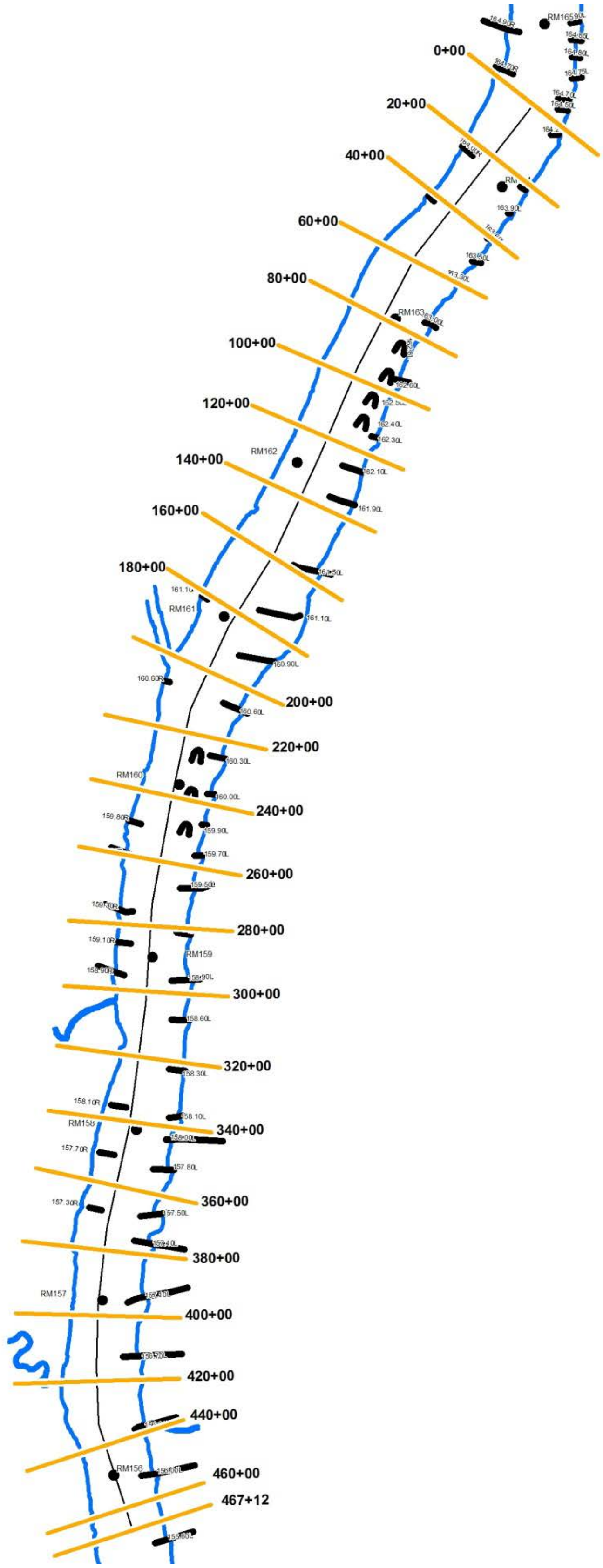

0+00
20+00
40+00
60+00
80+00
100+00
120+00
140+00
160+00
180+00
200+00
220+00
240+00
260+00
280+00
300+00
320+00
340+00
360+00
380+00
400+00
420+00
440+00
460+00
467+12
RM162
RM161
RM160
RM159
RM158
RM157
RM156

Figure 2:

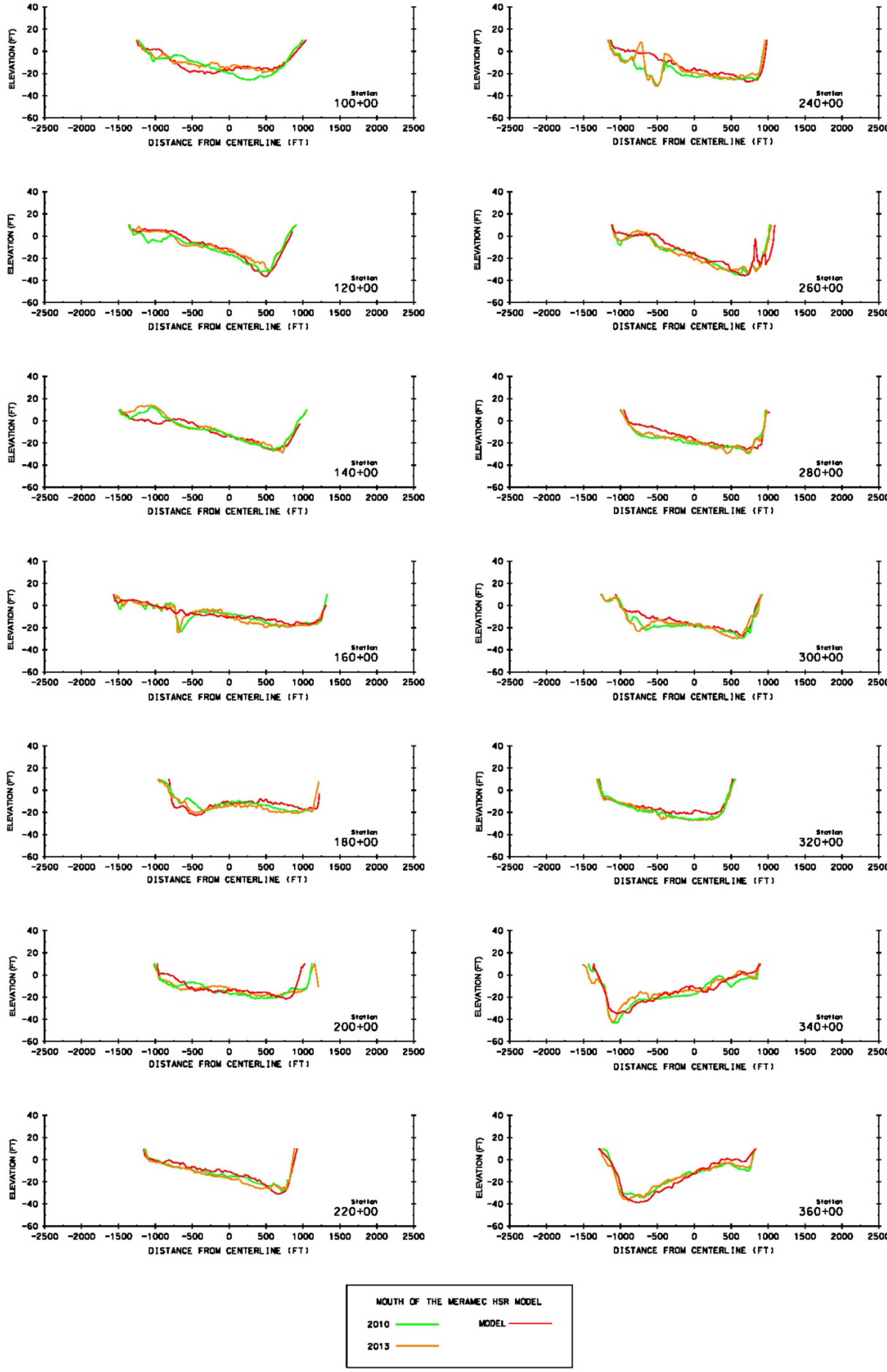

ELEVATION (FT)
DISTANCE FROM CENTERLINE (FT)
Station 100+00
Station 240+00
Station 120+00
Station 260+00
Station 140+00
Station 280+00
Station 160+00
Station 300+00
Station 180+00
Station 320+00
Station 200+00
Station 340+00
Station 220+00
Station 360+00
MOUTH OF THE MERAMEC HSR MODEL
2010
MODEL
2013

Table 6: Cross Section Comparison – Model Replication Scan vs 2010 Bathymetry

Cross Section Station	Area Without Correction		Corrected Area		Percent Difference
	Model Replication (ft^2)	2010 Survey (ft^2)	True Model Replication (ft^2)	True 2010 Survey (ft^2)	
100+00	708409	731961	47227	48797	3.3%
120+00	633834	705879	42256	47059	10.8%
140+00	708881	659511	47259	43967	7.2%
160+00	761328	804235	50755	53616	5.5%
180+00	728107	722223	48540	48148	0.8%
200+00	653930	741097	43595	49406	12.5%
220+00	664823	687964	44322	45864	3.4%
240+00	712714	899127	47514	59942	23.1%
260+00	776207	819807	51747	54654	5.5%
280+00	712118	806451	47475	53763	12.4%
300+00	704782	818806	46985	54587	15.0%
320+00	685697	763048	45713	50870	10.7%
340+00	821820	883687	54788	58912	7.3%
360+00	781568	778247	52105	51883	0.4%
				Average	8.4%

Table 7: Cross Section Comparison – Model Replication vs 2013 Bathymetry

Cross Section Station	Area Without Correction		Corrected Area		Percent Difference
	Model Replication (ft^2)	2013 Survey (ft^2)	True Model Replication (ft^2)	True 2013 Survey (ft^2)	
100+00	708409	664445	47227	44296	6.4%
120+00	633834	618574	42256	41238	2.4%
140+00	708881	622913	47259	41528	12.9%
160+00	761328	812599	50755	54173	6.5%
180+00	728107	786545	48540	52436	7.7%
200+00	653930	729313	43595	48621	10.9%
220+00	664823	739399	44322	49293	10.6%
240+00	712714	817724	47514	54515	13.7%
260+00	776207	836981	51747	55799	7.5%
280+00	712118	793609	47475	52907	10.8%
300+00	704782	812644	46985	54176	14.2%
320+00	685697	779329	45713	51955	12.8%
340+00	821820	815103	54788	54340	0.8%
360+00	781568	785424	52105	52362	0.5%
				Average	8.4%

Table 8: Cross Section Comparison – 2010 Bathymetry vs 2013 Bathymetry

Cross Section Station	Area Without Correction		Corrected Area		Percent Difference
	2010 Survey (ft^2)	2013 Survey (ft^2)	True 2010 Survey (ft^2)	True 2013 Survey (ft^2)	
100+00	731961	664445	48797	44296	9.7%
120+00	705879	618574	47059	41238	13.2%
140+00	659511	622913	43967	41528	5.7%
160+00	804235	812599	53616	54173	1.0%
180+00	722223	786545	48148	52436	8.5%
200+00	741097	729313	49406	48621	1.6%
220+00	687964	739399	45864	49293	7.2%
240+00	899127	817724	59942	54515	9.5%
260+00	819807	836981	54654	55799	2.1%
280+00	806451	793609	53763	52907	1.6%
300+00	818806	812644	54587	54176	0.8%
320+00	763048	779329	50870	51955	2.1%
340+00	883687	815103	58912	54340	8.1%
360+00	778247	785424	51883	52362	0.9%
				Average	5.1%

D: April 17, 2014 Mouth of the Meramec HSR Model Coordination Meeting Minutes

Agencies and Personnel Attending:

United States Army Corps of Engineers, St. Louis District (USACE-MVS)

Rob Davinroy	Lance Engle	Jasen Brown	Eddie Brauer
Brian Johnson	Brad Krischel	Dawn Lamm	Tim Lauth
Matt Collins	Ivan Nguyen	Mike Rodgers	

United States Fish and Wildlife Service (USFWS)

Matt Mangan*	Donovan Henry*

Missouri Department of Conservation (MDC)

John West	Molly Sobotka	Danny Brown*	Dave Knuth*
David Ostendorf*			

Illinois Department of Natural Resources (IDNR)
Butch Atwood

River Industry Action Committee (RIAC)
Shannon Hughes (Specifically Kirby Inland Marine)

Ameren MO
Bill Rogers*

*communication through email

Narrative:

The U.S. Army Corps of Engineers, St. Louis District conducted an HSR model study of the mouth of the Meramec reach on the Middle Mississippi River between River Mile (RM) 165.00 and RM 156.00. The study was funded by the Regulating Works Project for the Middle Mississippi River. In this reach, repetitive channel maintenance dredging has previously been required near RM 161.3. The objective of the study was to evaluate a variety of remedial measures with a goal of identifying the most effective and economical plan to reduce or eliminate repetitive dredging while improving the existing natural habitat. The recommended alternative (Alternative 16 – Plate 39) was to construct four weirs and three rootless dikes. This alternative was the most desirable because of its observed ability to reduce elevations observed in the repetitive dredging area between RM 162.00 and RM 160.00. Furthermore, rootless dikes were used instead of traditional dikes in an effort to provide more environmental diversity in the project area.

USACE-MVS, IDNR, and RIAC were represented at the final HSR meeting and all in attendance supported the recommended alternative of four weirs and three rootless dikes. Some members of MDC were present at the meeting, but they did not give a response to the proposed alternative at the meeting since some of the normal personnel involved would be reviewing the recommended alternative through email at a later date. USFWS, MDC, and Ameren MO all had some members coordinate via email, which were noted with asterisks in the attendance above. A couple of notable comments received via email can be found below.

Matt Mangan of USFWS thought Alternatives 3, 4, and 6 achieved similar results as Alternative 16 while requiring less construction. Therefore, USFWS recommended a less aggressive, phased approach to minimize impacts to the environment. The USACE – St. Louis District agree that alternatives 3, 4, and 6 did achieve favorable results, the results of the alternative 16 were more favorable. During the HSR meetings there was no mention of Pallid Sturgeon, Least Tern, or any other form of habitat impact, so our plan is to move forward with alternative 16. Furthermore, the St. Louis District will evaluate the use of phased construction for the project.

Bill Rogers communicated on behalf of Ameren MO that Ameren had no issues with the proposed design since the model showed there would be no additional siltation at the intake structure of the Ameren plant located along the RDB near RM 161.5.

Brad Krischel, P.E.
Applied River Engineering Center
USACE, St. Louis District
(314) 865-6325

E: Mouth of the Meramec HSR Model Report: Revisions

As part of the U.S. Army Corps of Engineers – St. Louis District's Regulating Works Project Mosenthein / Ivory Landing Phase 5 Environmental Assessment (EA) and District Quality Control (DQC) process, slight changes and adjustments were required to the Mouth of the Meramec HSR report. Below is a list of the sections and respective description of the edits that were made to the document.

(06/03/15)

A. Geomorphology
   - Minor grammatical changes and rewording.

B. Dredging/Problem Description
   - Expanded the dredging quantities, costs, and graphs to include the previous 20 years of data. The analysis only includes the repetitive dredging location of River Mile (RM) 162.00 to RM 160.00.
   - Minor grammatical changes and rewording.

Conclusions – 1. Evaluation and Summary of the Model Tests
   - Reworded to better convey the design testing philosophy and why the recommended alternative was chosen.

Conclusions – 2. Recommendations
   - Added a sentence about observed flow visualization in the model.

(06/10/15)

7. Design Alternative Tests
   - The original table heading, "Increased Environmental Diversity", specifically addressed if the alternative design increased depth diversity within the existing side channel of the HSR model. Although none of the alternatives created additional depth diversity in the side channel, continuous flow was observed throughout the testing process. Many of the alternatives tested in the model study incorporated river training structures such as rootless dikes, rootless dike extensions, and angled dikes, which were designed instead of traditional dikes, to avoid and minimize environmental impacts of cutting off flow to the existing side channel. This avoiding and minimizing of impacts was not addressed in the original HSR Report since this is normal business practice in modeling alternatives. Therefore, to clarify this, the evaluation criteria in the alternative table were revised to explain if each alternative "incorporated features to avoid and minimize environmental impacts" within

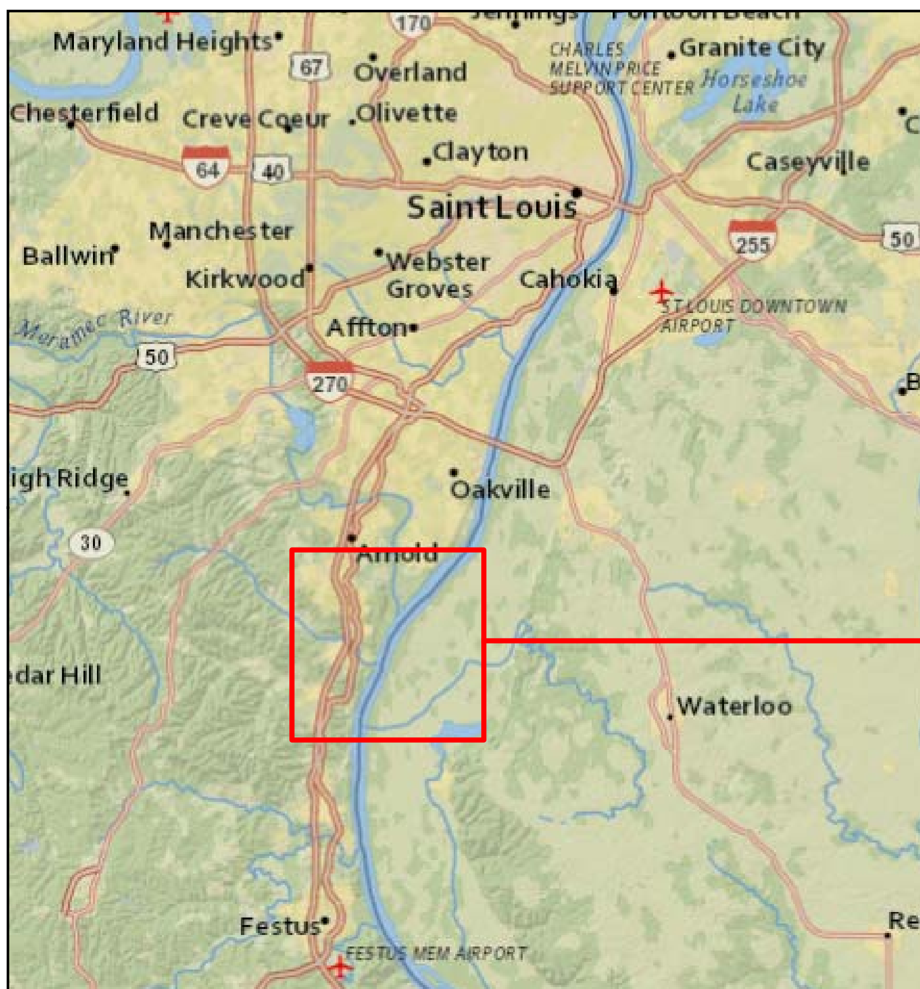
the entire study reach instead of solely focusing on the depth diversity within the side channel.

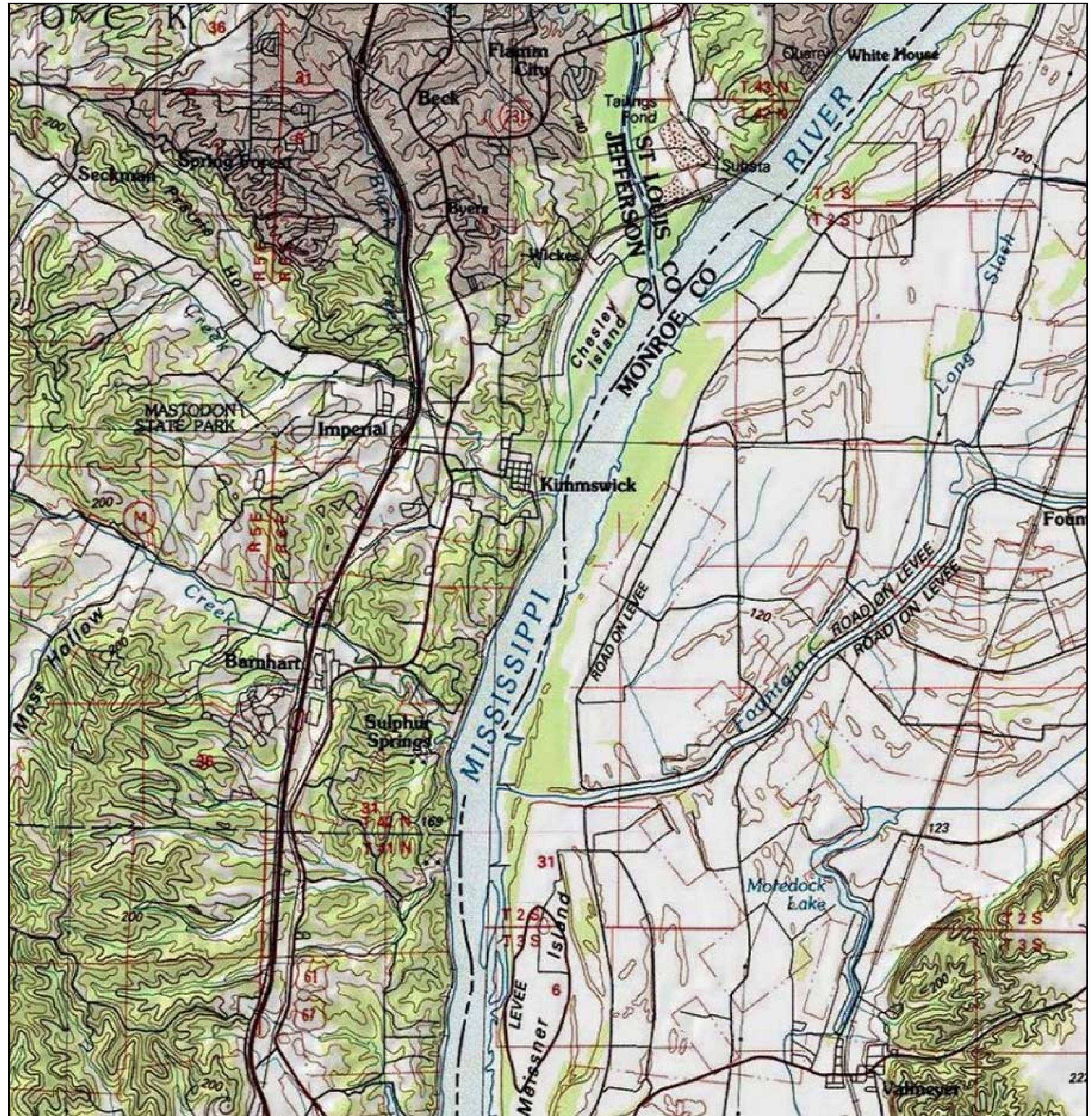
Conclusions – 1. Evaluation and Summary of the Model Tests

- Updated the alternative testing summary table to reflect the revisions made in Section 7: Design Alternative Tests.
- Clarified why Alternative 6 and 15 were not chosen as viable solutions based on their ability to avoid and minimize environmental impacts.

Conclusions – 2. Recommendations

- Updated sentence to reflect the change from “Increased Environmental Diversity” to “Incorporated Features to Avoid and Minimize Environmental Impacts” in the previous sections.





US Army Corps of Engineers
St. Louis District

APPLIED RIVER ENGINEERING CENTER

N W E S

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

Mississippi River Basin
St. Louis District
Mouth of the Meramec
HSR Model

DESIGNED BY: B Krischel
DRAWN BY: B Krischel
REVIEWED BY: T Lauth, P.E.
CHECKED BY: R Davinroy, P.E.
SUBMITTED: B Krischel
APPROVED: Rob Davinroy, P.E.
FILE NAME: L:\Mouth of the Meramec\Plates
PLOT DATE: 04/11/2013

Mouth of the Meramec Location & Vicinity Map

PLATE NUMBER
1

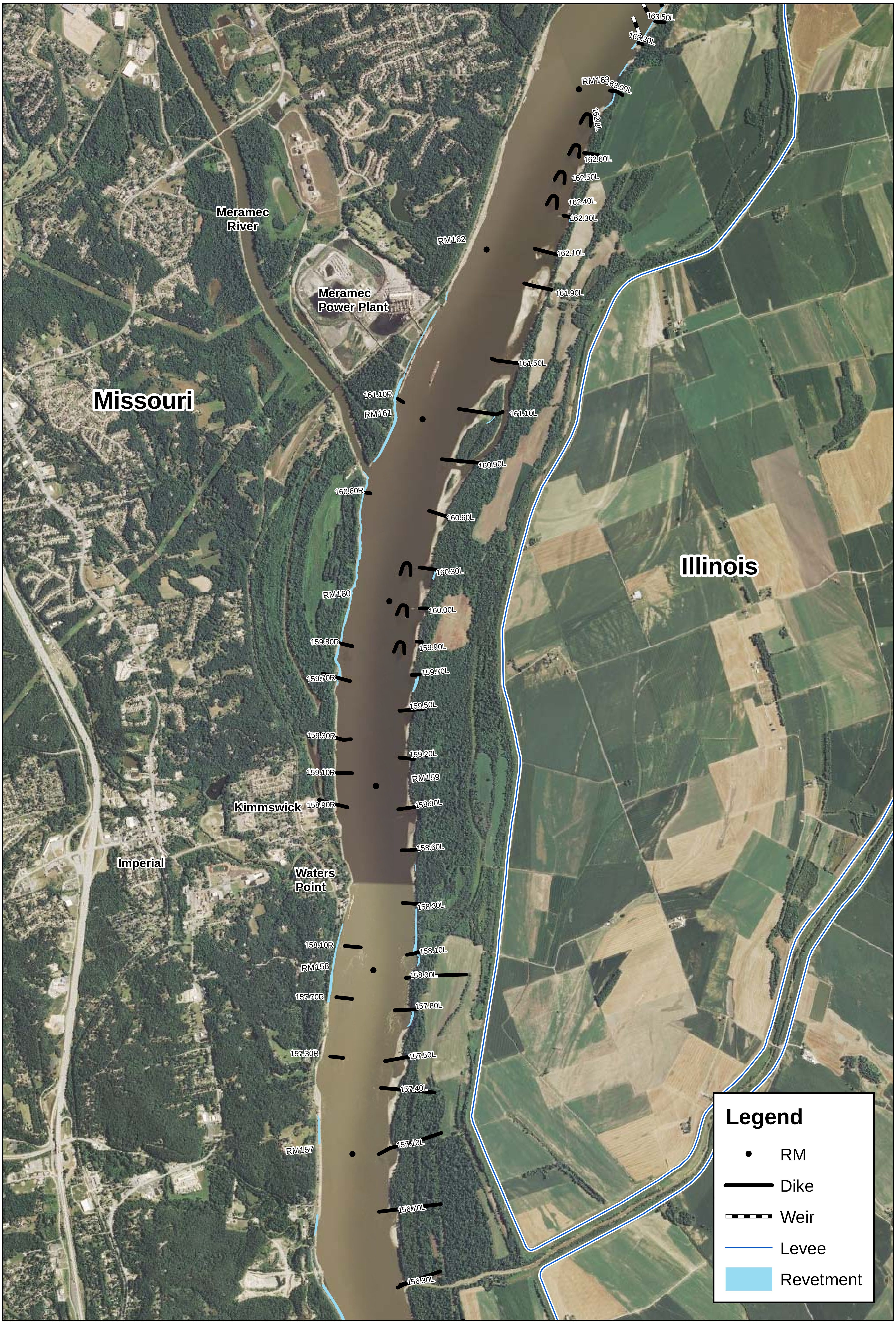


PLATE NUMBER 02

0 700 1,400 2,800 4,200
Feet

Location and Vicinity Map
2012 Aerial Photograph

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

Mississippi River Basin
St. Louis District
Mouth of the Meramec
HSR Model

DESIGNED BY: B Krischel	SURVEY DATE:	
DRAWN BY: B Krischel	REVIEWED BY: T Lauth, P.E.	CHECKED BY: R Davinroy, P.E.
SUBMITTED: B Krischel	APPROVED: Rob Davinroy, P.E.	
FILE NAME: L:\Mouth of the Meramec\Plates	PLOT DATE: 04/11/2014	

N E S W

APPLIED RIVER ENGINEERING CENTER

US Army Corps of Engineers
St. Louis District

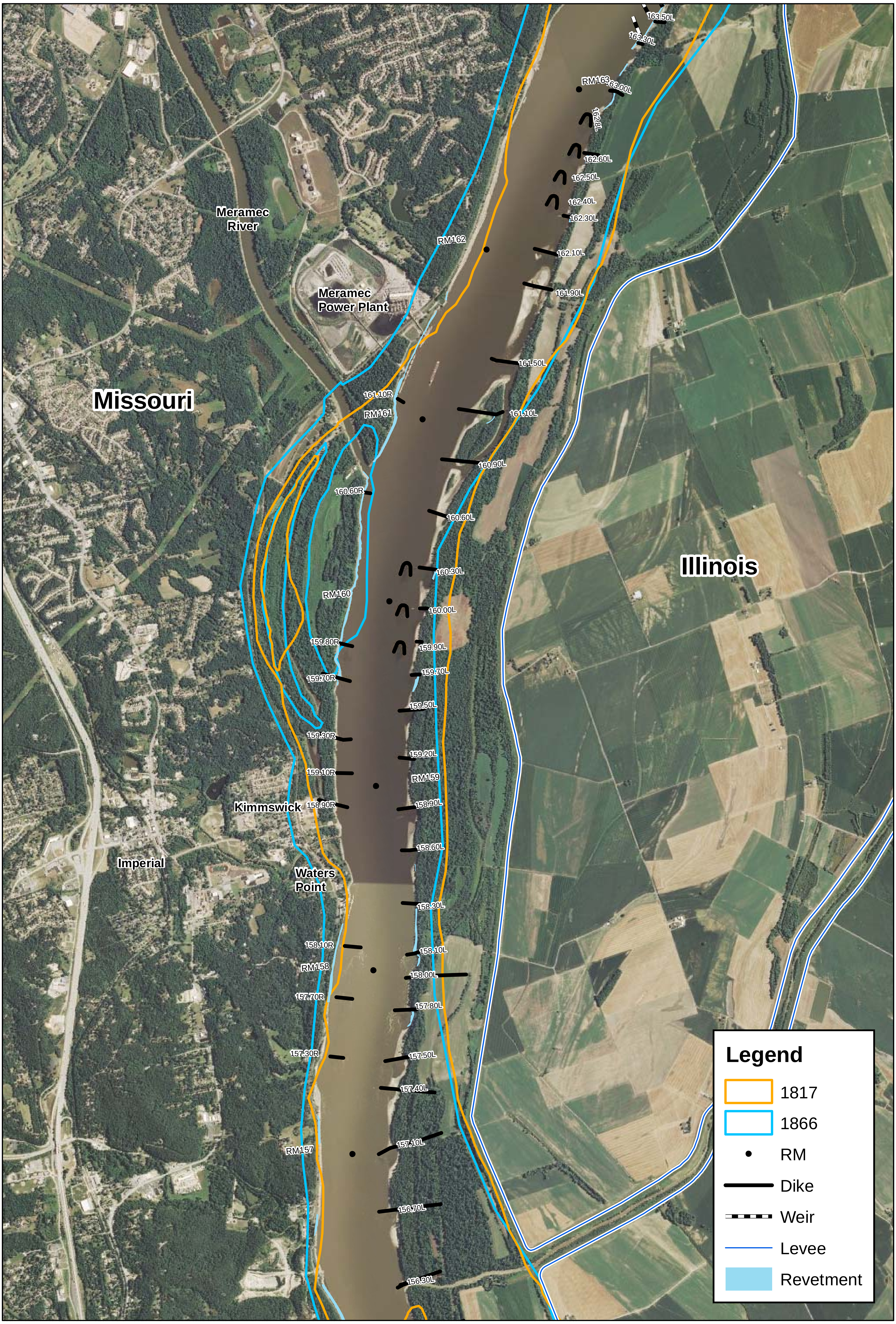


PLATE NUMBER 03

0 700 1,400 2,800 4,200
Feet

Geomorphology: 1817 vs 1866
2012 Aerial Photograph

U.S. ARMY ENGINEER DIVISION CORPS OF ENGINEERS ST. LOUIS, MISSOURI	DESIGNED BY: B Krischel	SURVEY DATE:	
	DRAWN BY: B Krischel	REVIEWED BY: T Lauth, P.E.	CHECKED BY: R Davinroy, P.E.
Mississippi River Basin St. Louis District Mouth of the Meramec HSR Model	SUBMITTED: B Krischel	APPROVED: Rob Davinroy, P.E.	
	FILE NAME: L:\Mouth of the Meramec\Plates	PLOT DATE: 04/11/2014	

N E S W

APPLIED RIVER ENGINEERING CENTER

US Army Corps of Engineers
St. Louis District

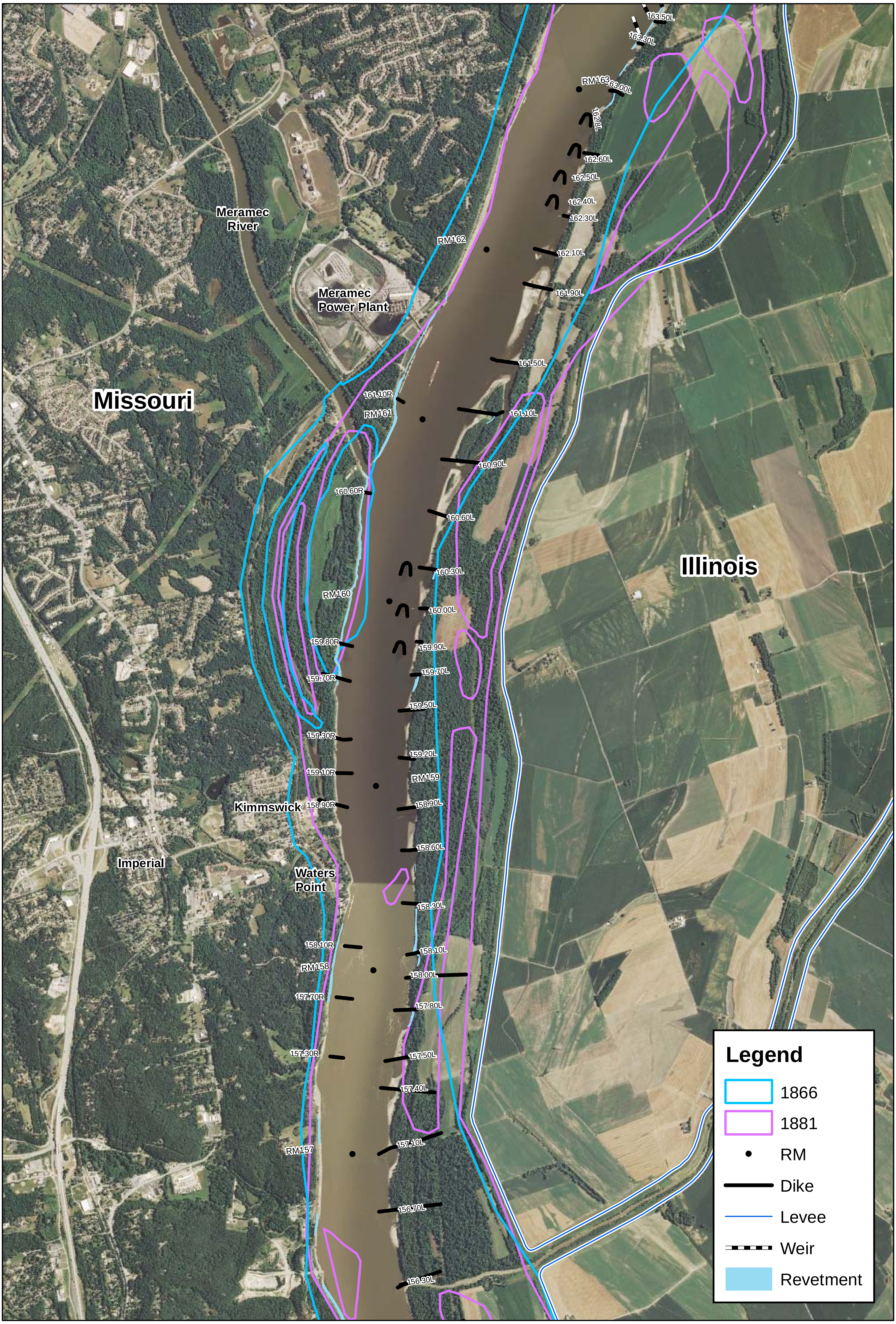


PLATE NUMBER 04

0 700 1,400 2,800 4,200
Feet

Geomorphology: 1866 vs 1881
2012 Aerial Photograph

U.S. ARMY ENGINEER DIVISION CORPS OF ENGINEERS ST. LOUIS, MISSOURI	DESIGNED BY: B Krischel	SURVEY DATE:	
	DRAWN BY: B Krischel	REVIEWED BY: T Lauth, P.E.	CHECKED BY: R Davinroy, P.E.
Mississippi River Basin St. Louis District Mouth of the Meramec HSR Model	SUBMITTED: B Krischel	APPROVED: Rob Davinroy, P.E.	
	FILE NAME: L:\Mouth of the Meramec\Plates		PLOT DATE: 04/11/2014

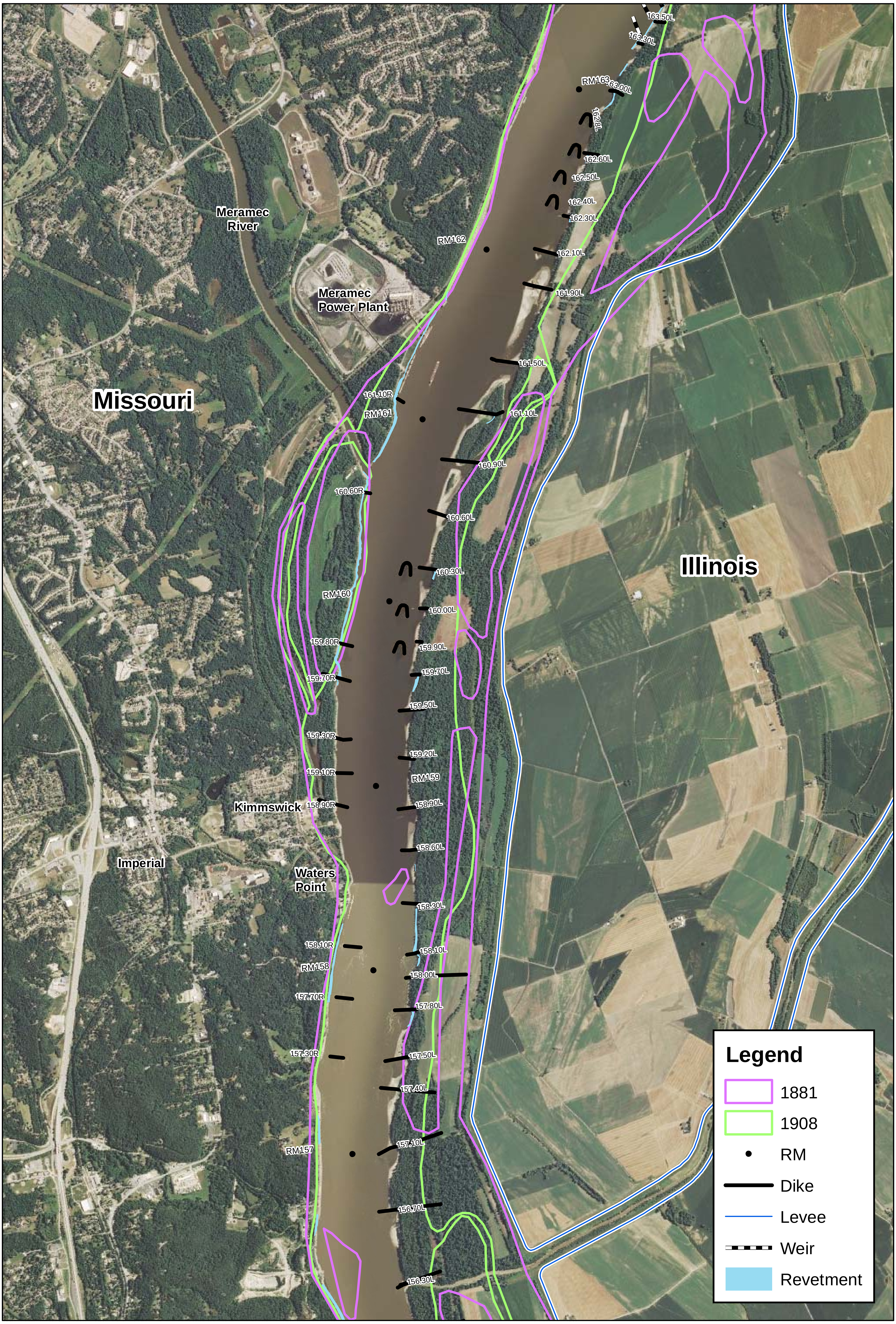


PLATE NUMBER 05

0 700 1,400 2,800 4,200
Feet

Geomorphology: 1881 vs 1908
2012 Aerial Photograph

U.S. ARMY ENGINEER DIVISION CORPS OF ENGINEERS ST. LOUIS, MISSOURI	DESIGNED BY: B Krischel	SURVEY DATE:
	DRAWN BY: B Krischel · REVIEWED BY: T Lauth, P.E.	CHECKED BY: R Davinroy, P.E.
Mississippi River Basin St. Louis District Mouth of the Meramec HSR Model	SUBMITTED: B Krischel	APPROVED: Rob Davinroy, P.E.
	FILE NAME: L:\Mouth of the Meramec\Plates	PLOT DATE: 04/11/2014

N E S W

APPLIED RIVER ENGINEERING CENTER

US Army Corps of Engineers St. Louis District

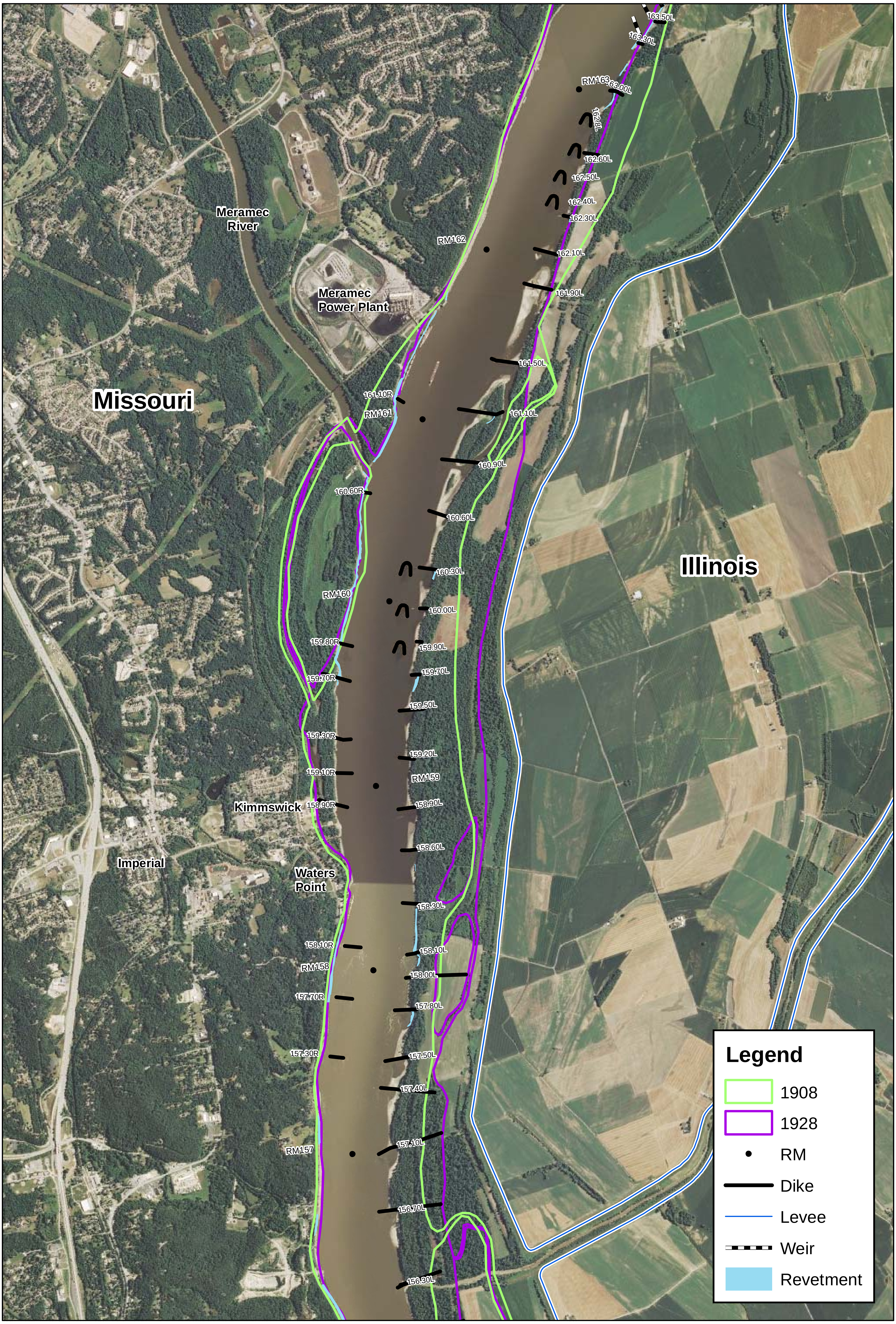


PLATE NUMBER
06

0 700 1,400 2,800 4,200
Feet

Geomorphology: 1908 vs 1928
2012 Aerial Photograph

U.S. ARMY ENGINEER DIVISION CORPS OF ENGINEERS ST. LOUIS, MISSOURI	DESIGNED BY: B Krischel		SURVEY DATE:
	DRAWN BY: B Krischel	REVIEWED BY: T Lauth, P.E.	CHECKED BY: R Davinroy, P.E.
Mississippi River Basin St. Louis District Mouth of the Meramec HSR Model	SUBMITTED: B Krischel	APPROVED: Rob Davinroy, P.E.	
	FILE NAME: L:\Mouth of the Meramec\Plates		PLOT DATE: 04/11/2014

N
E
S
W

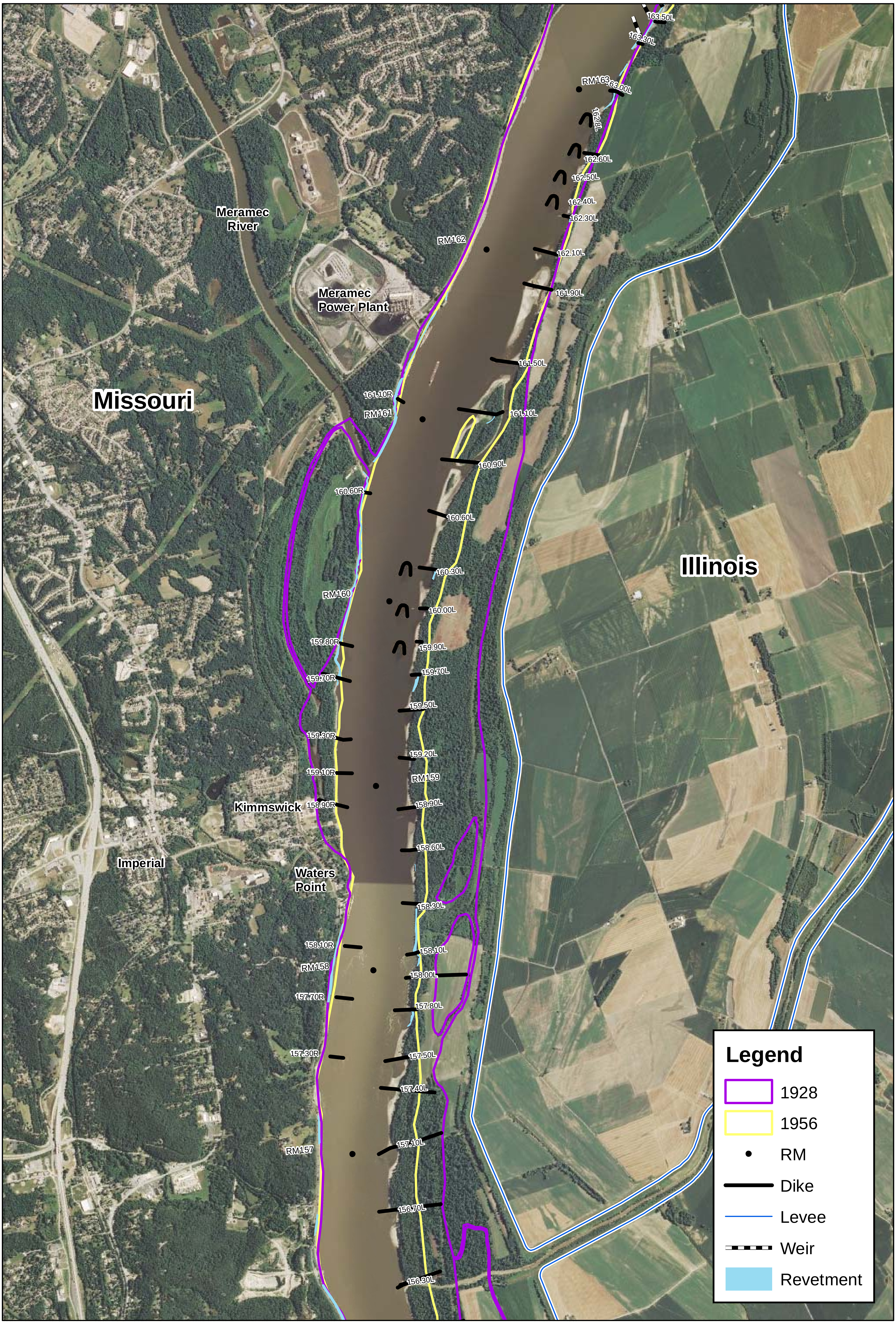


PLATE NUMBER 07

0 700 1,400 2,800 4,200
Feet

Geomorphology: 1928 vs 1956
2012 Aerial Photograph

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

Mississippi River Basin
St. Louis District
Mouth of the Meramec
HSR Model

DESIGNED BY: B Krischel		SURVEY DATE:
DRAWN BY: B Krischel	REVIEWED BY: T Lauth, P.E.	CHECKED BY: R Davinroy, P.E.
SUBMITTED: B Krischel	APPROVED: Rob Davinroy, P.E.	
FILE NAME: L:\Mouth of the Meramec\Plates		PLOT DATE: 04/11/2014

N E S W

APPLIED RIVER ENGINEERING CENTER

US Army Corps of Engineers
St. Louis District

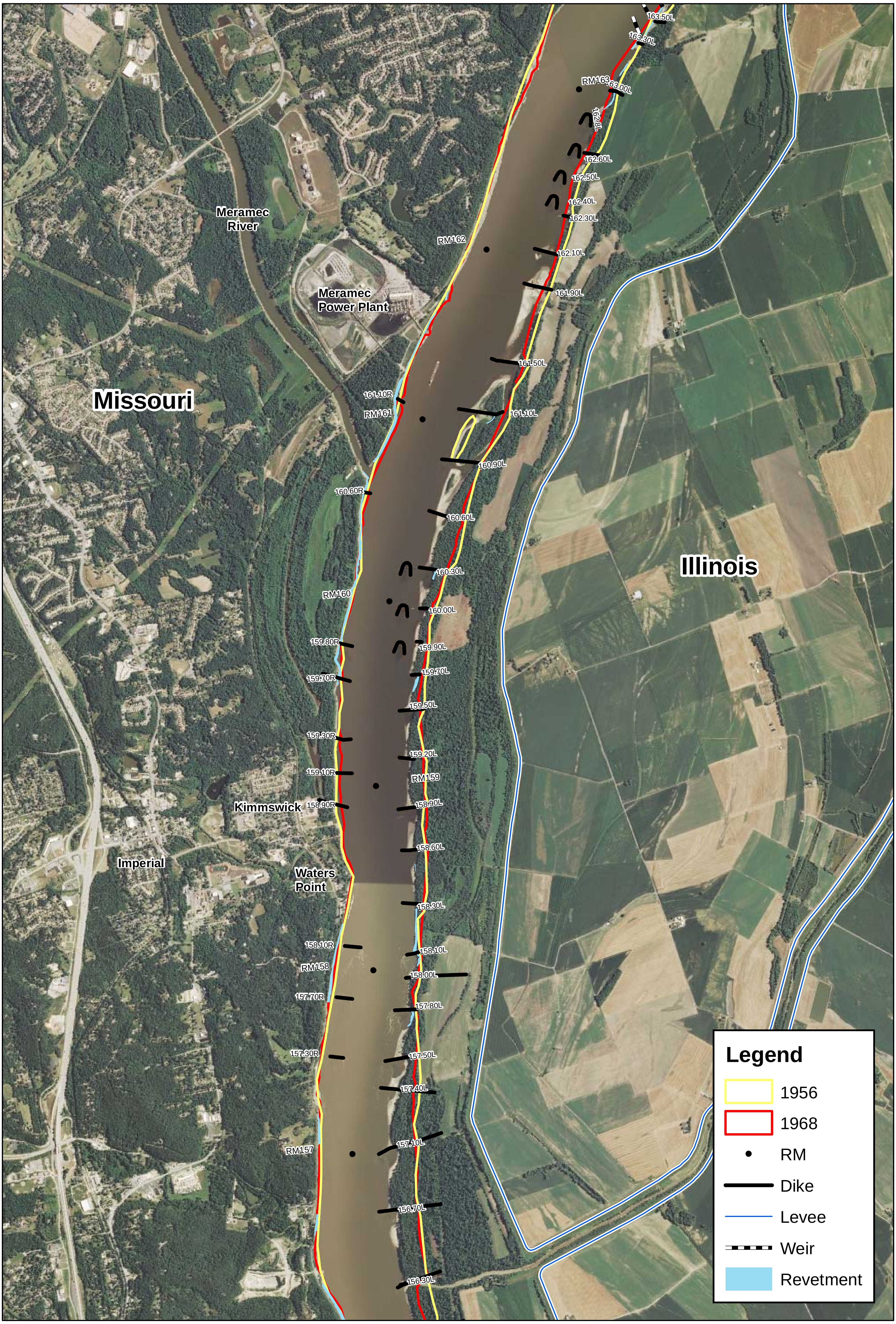


PLATE NUMBER
08

0 700 1,400 2,800 4,200
Feet

Geomorphology: 1956 vs 1968
2012 Aerial Photograph

U.S. ARMY ENGINEER DIVISION CORPS OF ENGINEERS ST. LOUIS, MISSOURI	DESIGNED BY: B Krischel	SURVEY DATE:	
	DRAWN BY: B Krischel	REVIEWED BY: T Lauth, P.E.	CHECKED BY: R Davinroy, P.E.
Mississippi River Basin St. Louis District Mouth of the Meramec HSR Model	SUBMITTED: B Krischel	APPROVED: Rob Davinroy, P.E.	
	FILE NAME: L:\Mouth of the Meramec\Plates	PLOT DATE: 04/11/2014	

N E S W

APPLIED RIVER ENGINEERING CENTER

US Army Corps of Engineers®
St. Louis District

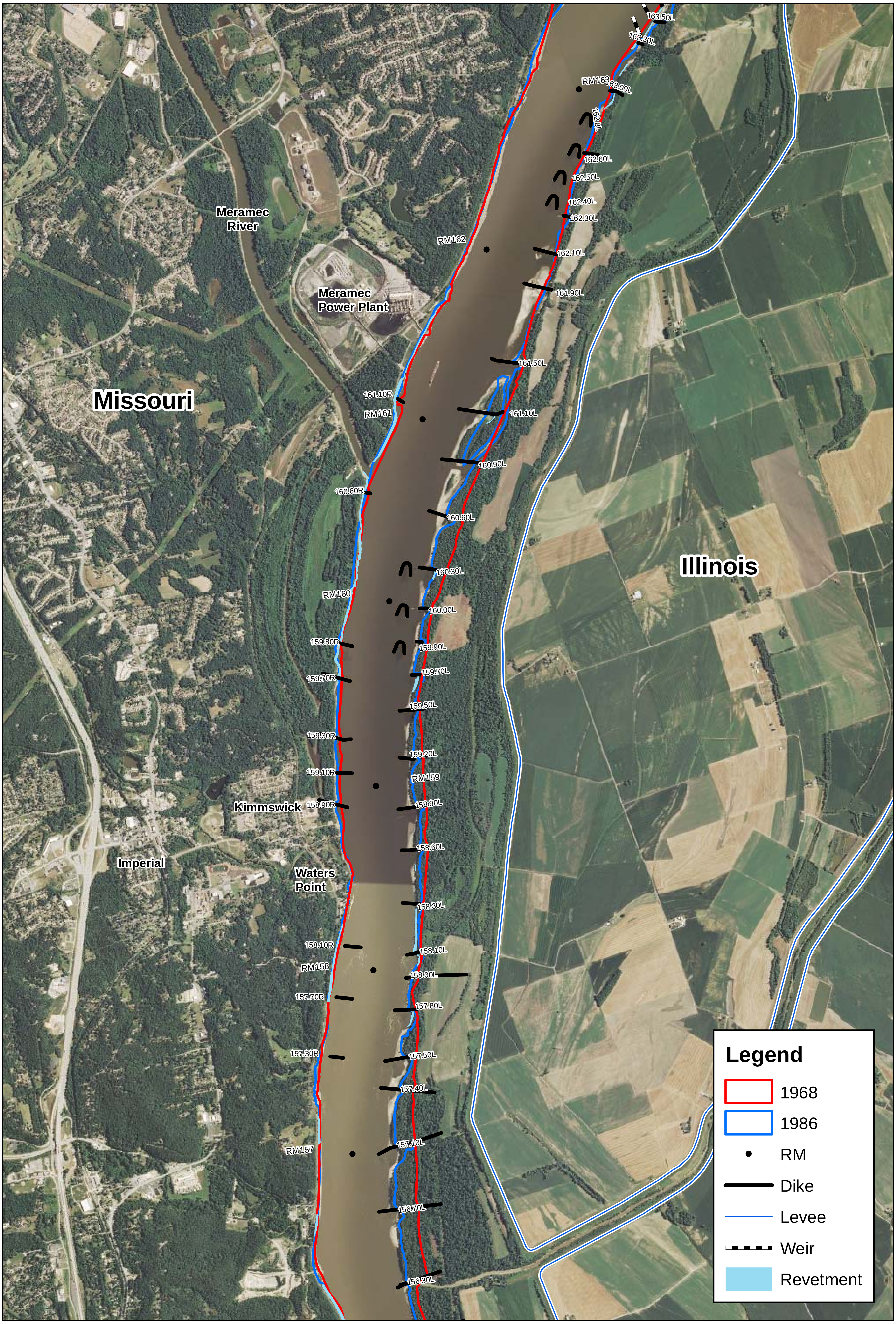


PLATE NUMBER 09

0 700 1,400 2,800 4,200
Feet

Geomorphology: 1968 vs 1986
2012 Aerial Photograph

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

Mississippi River Basin
St. Louis District
Mouth of the Meramec
HSR Model

DESIGNED BY: B Krischel		SURVEY DATE:
DRAWN BY: B Krischel	REVIEWED BY: T Lauth, P.E.	CHECKED BY: R Davinroy, P.E.
SUBMITTED: B Krischel	APPROVED: Rob Davinroy, P.E.	
FILE NAME: L:\Mouth of the Meramec\Plates		PLOT DATE: 04/11/2014

APPLIED RIVER ENGINEERING CENTER

US Army Corps of Engineers
St. Louis District

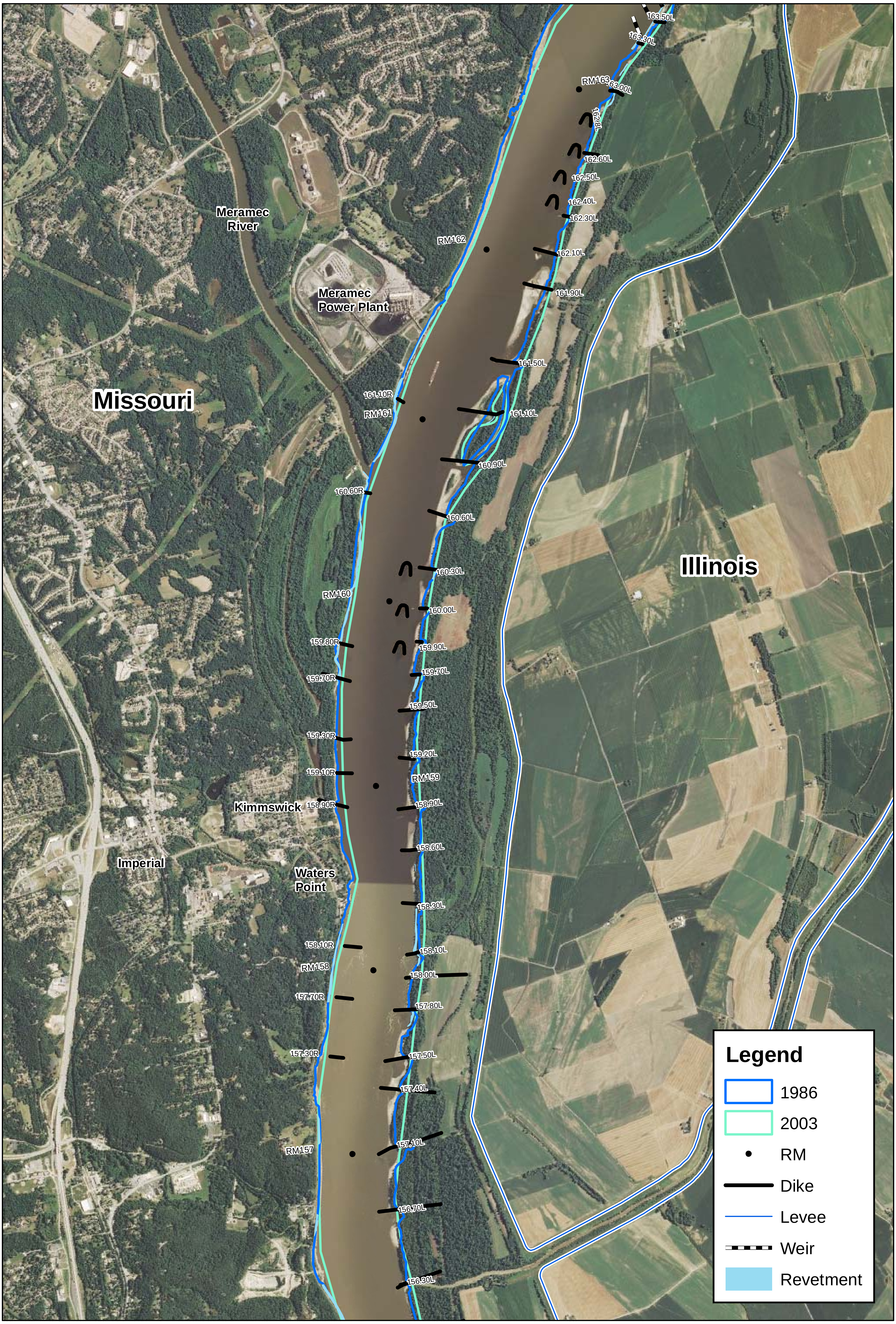


PLATE NUMBER 10

0 700 1,400 2,800 4,200
Feet

Geomorphology: 1986 vs 2003
2012 Aerial Photograph

U.S. ARMY ENGINEER DIVISION CORPS OF ENGINEERS ST. LOUIS, MISSOURI	DESIGNED BY: B Krischel		SURVEY DATE:
	DRAWN BY: B Krischel	REVIEWED BY: T Lauth, P.E.	CHECKED BY: R Davinroy, P.E.
Mississippi River Basin St. Louis District Mouth of the Meramec HSR Model	SUBMITTED: B Krischel	APPROVED: Rob Davinroy, P.E.	
	FILE NAME: L:\Mouth of the Meramec\Plates		PLOT DATE: 04/11/2014

N E S W

APPLIED RIVER ENGINEERING CENTER

US Army Corps of Engineers St. Louis District

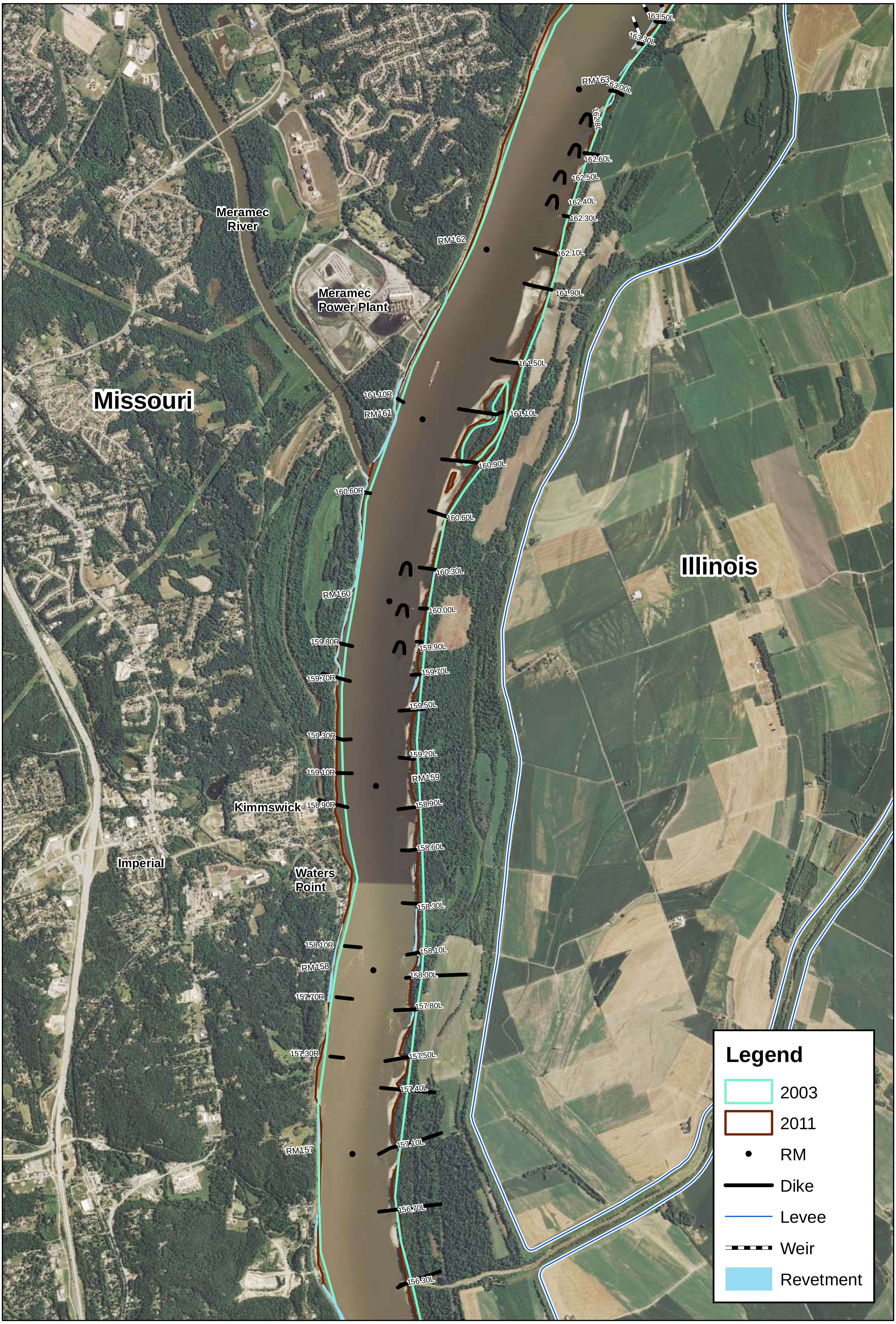


PLATE NUMBER 11

0 700 1,400 2,800 4,200
Feet

Geomorphology: 2003 vs 2011
2012 Aerial Photograph

U.S. ARMY ENGINEER DIVISION CORPS OF ENGINEERS ST. LOUIS, MISSOURI	DESIGNED BY: B Krischel		SURVEY DATE:
	DRAWN BY: B Krischel	REVIEWED BY: T Lauth, P.E.	CHECKED BY: R Davinroy, P.E.
Mississippi River Basin St. Louis District Mouth of the Meramec HSR Model	SUBMITTED: B Krischel	APPROVED: Rob Davinroy, P.E.	
	FILE NAME: L:\Mouth of the Meramec\Plates		PLOT DATE: 04/11/2014

N E S W

APPLIED RIVER ENGINEERING CENTER

US Army Corps of Engineers St. Louis District®

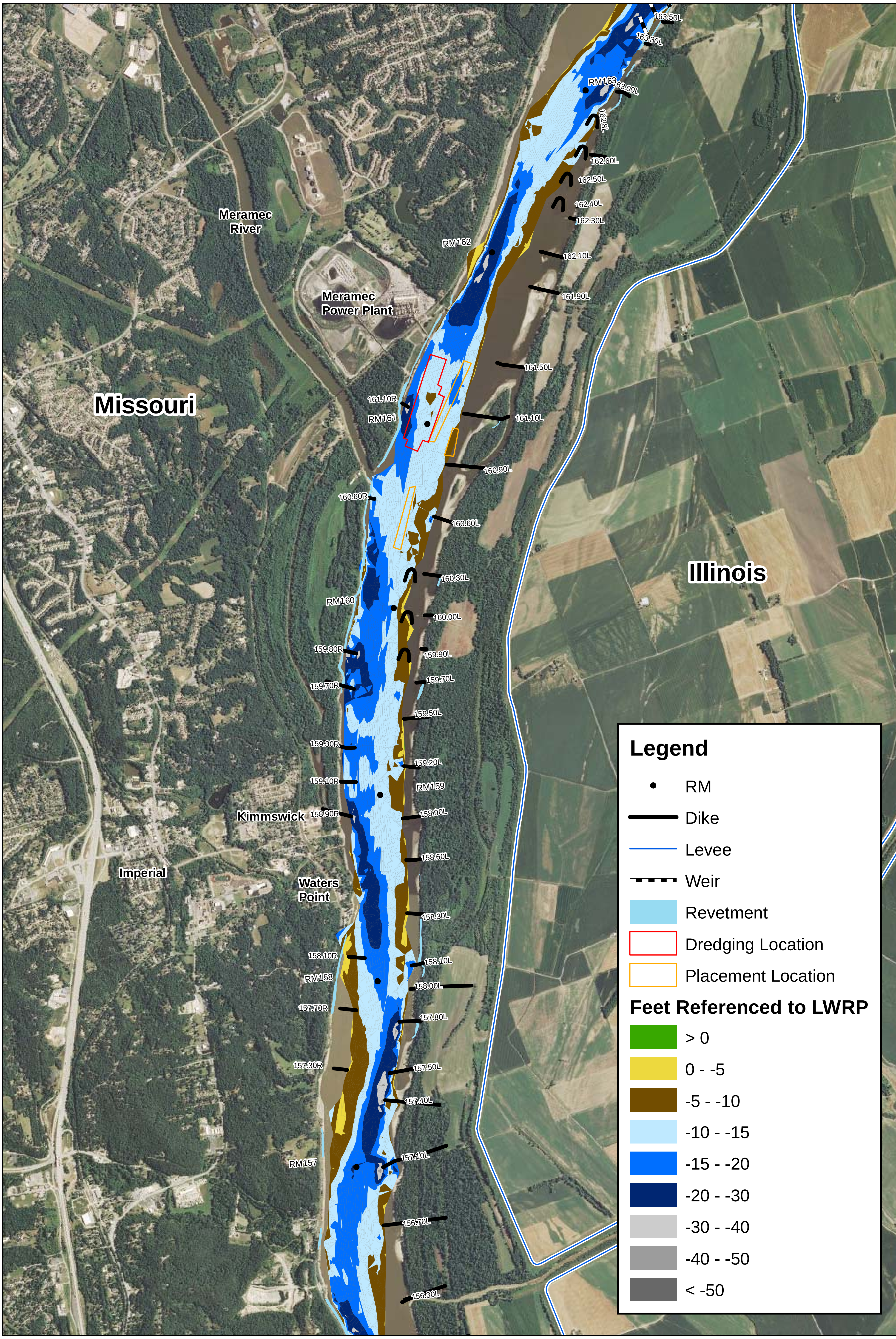


PLATE NUMBER 12

0 700 1,400 2,800 4,200
Feet

2000 Hydrographic Survey
2012 Aerial Photograph

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

DESIGNED BY: B Krischel	SURVEY DATE: 2000	
DRAWN BY: B Krischel	REVIEWED BY: T Lauth, P.E.	CHECKED BY: R Davinroy, P.E.
SUBMITTED: B Krischel	APPROVED: Rob Davinroy, P.E.	
FILE NAME: L:\Mouth of the Meramec\Plates		PLOT DATE: 04/11/2014

Mississippi River Basin
St. Louis District
Mouth of the Meramec
HSR Model

APPLIED RIVER ENGINEERING CENTER

US Army Corps of Engineers
St. Louis District

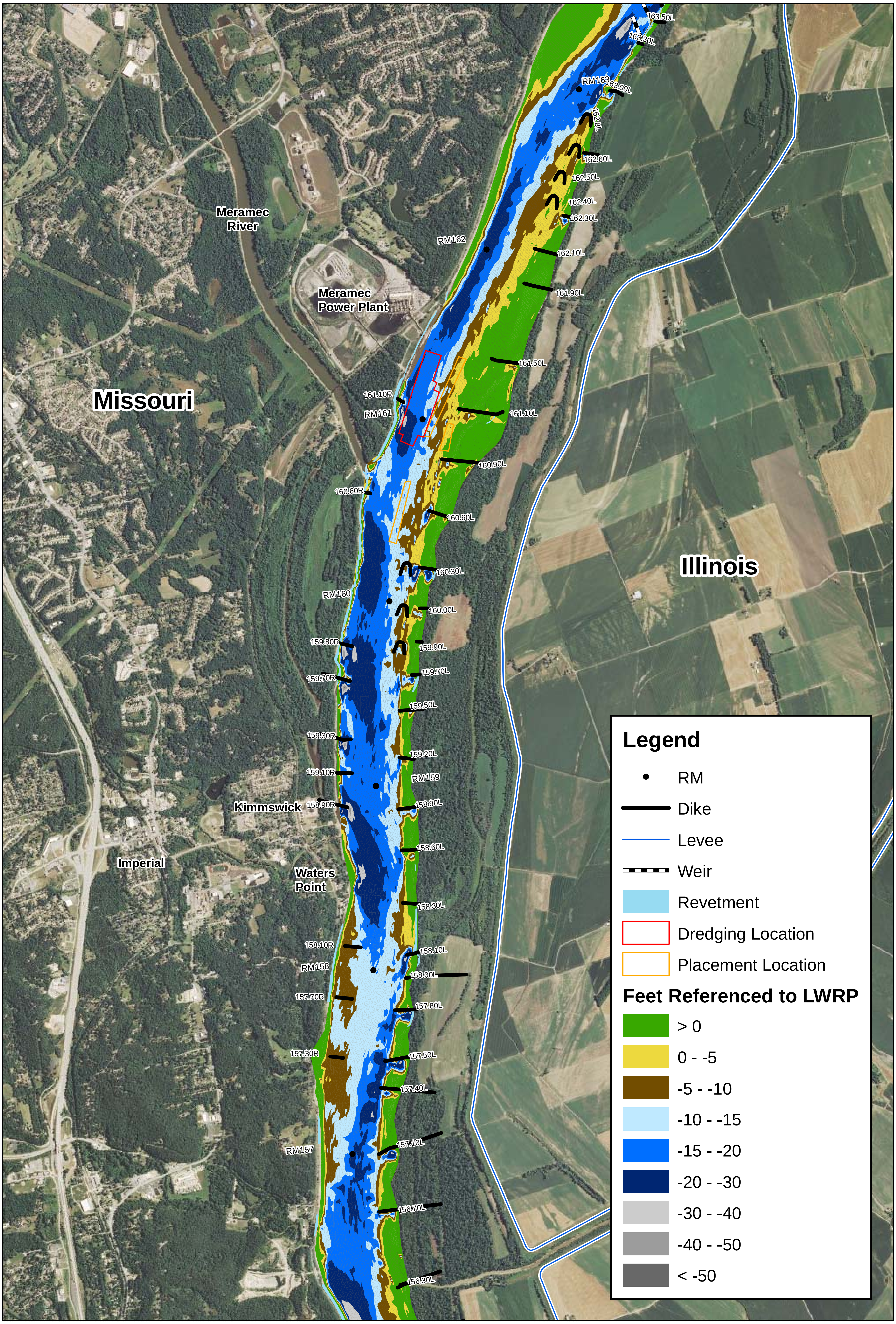


PLATE NUMBER 13

0 700 1,400 2,800 4,200
Feet

2001 Hydrographic Survey
2012 Aerial Photograph

U.S. ARMY ENGINEER DIVISION CORPS OF ENGINEERS ST. LOUIS, MISSOURI	DESIGNED BY: B Krischel	SURVEY DATE: 2001	
	DRAWN BY: B Krischel	REVIEWED BY: T Lauth, P.E.	CHECKED BY: R Davinroy, P.E.
Mississippi River Basin St. Louis District Mouth of the Meramec HSR Model	SUBMITTED: B Krischel	APPROVED: Rob Davinroy, P.E.	
	FILE NAME: L:\Mouth of the Meramec\Plates	PLOT DATE: 04/11/2014	

N E S W

APPLIED RIVER ENGINEERING CENTER

US Army Corps of Engineers
St. Louis District

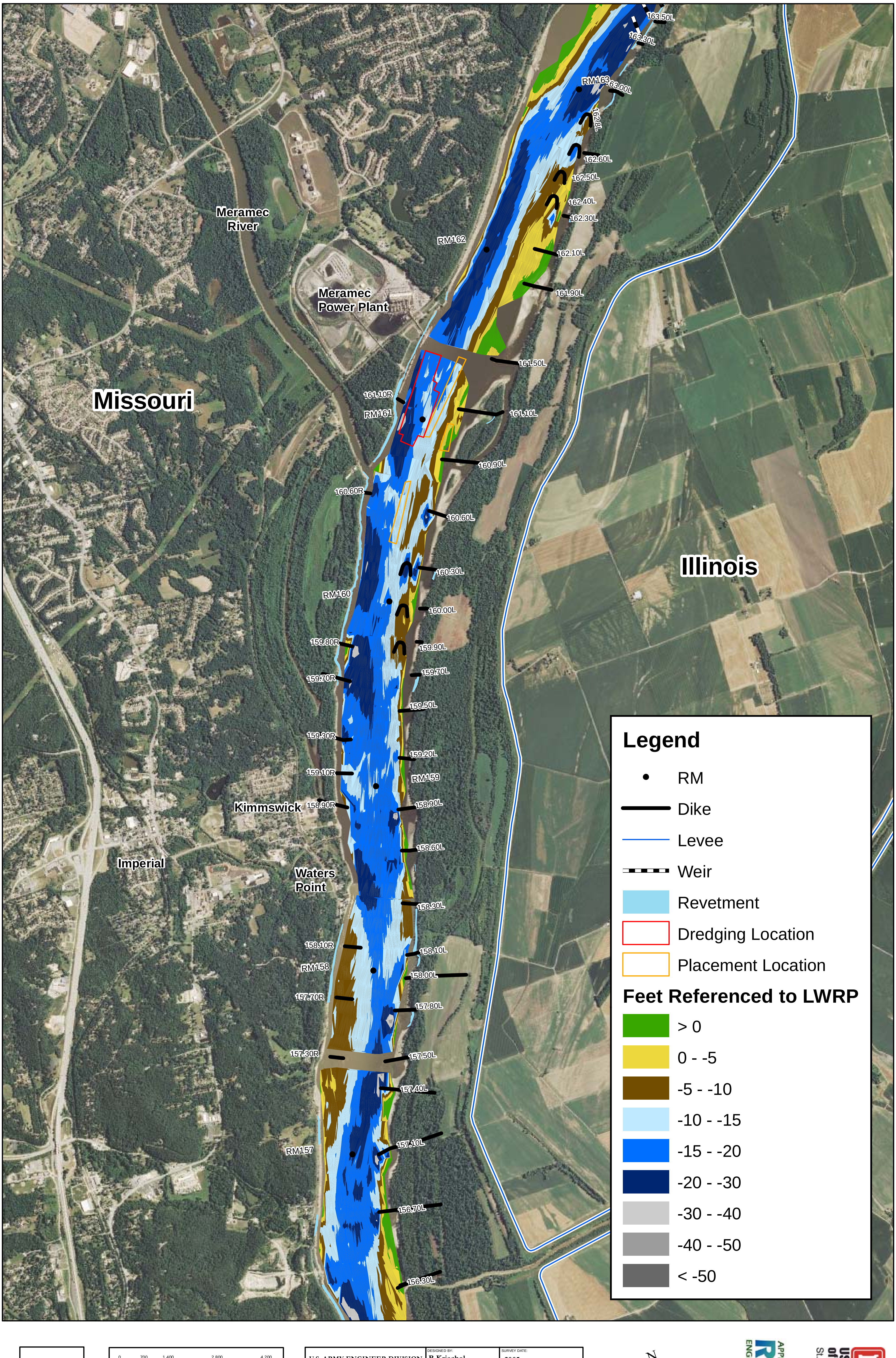


PLATE NUMBER
14

0 700 1,400 2,800 4,200
Feet

2005 Hydrographic Survey
2012 Aerial Photograph

U.S. ARMY ENGINEER DIVISION CORPS OF ENGINEERS ST. LOUIS, MISSOURI	DESIGNED BY: B Krischel	SURVEY DATE: 2005	
	DRAWN BY: B Krischel	REVIEWED BY: T Lauth, P.E.	CHECKED BY: R Davinroy, P.E.
Mississippi River Basin St. Louis District Mouth of the Meramec HSR Model	SUBMITTED: B Krischel	APPROVED: Rob Davinroy, P.E.	
	FILE NAME: L:\Mouth of the Meramec\Plates	PLOT DATE: 04/11/2014	

N E S W

APPLIED RIVER ENGINEERING CENTER

US Army Corps of Engineers
St. Louis District

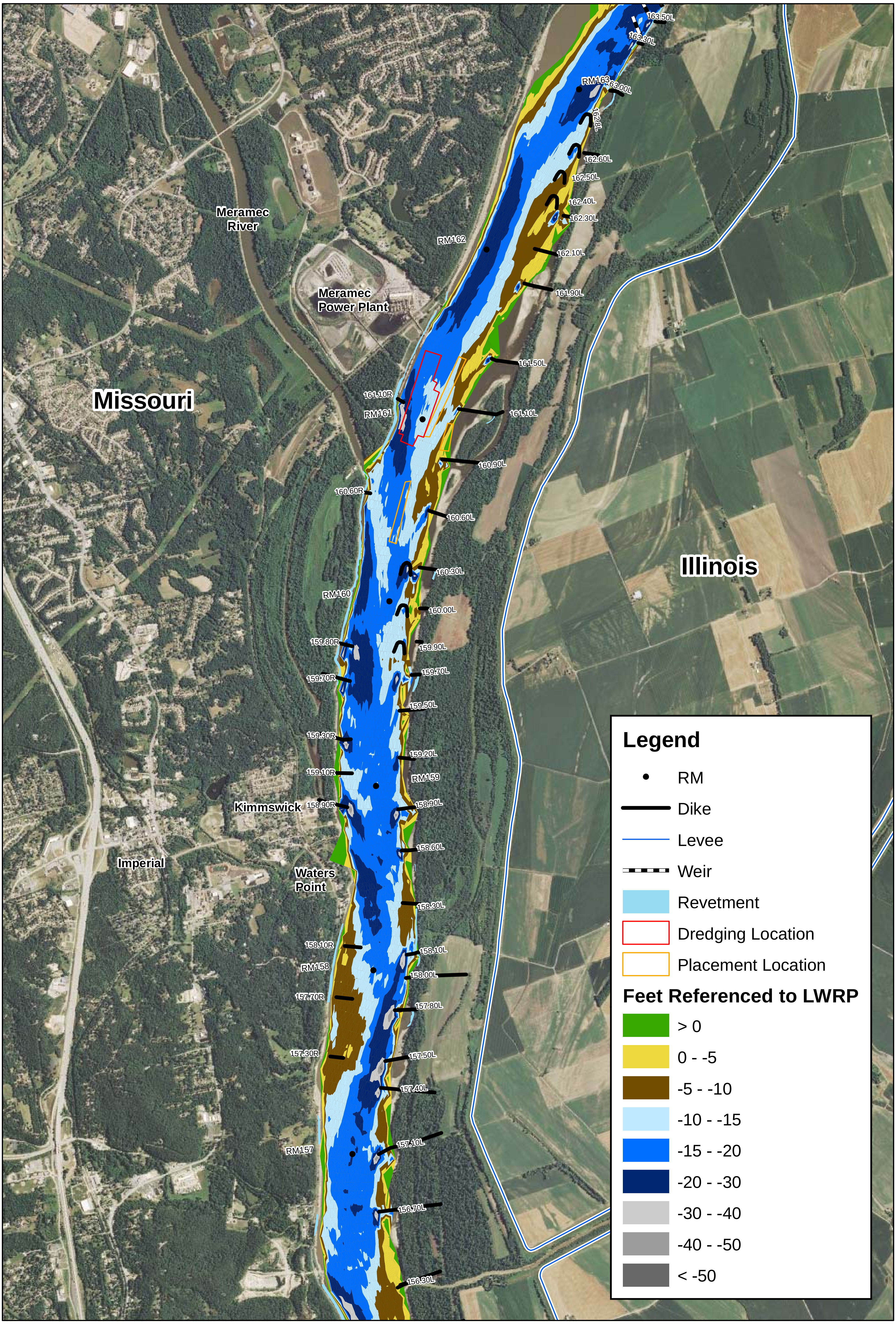


PLATE NUMBER 15

0 700 1,400 2,800 4,200
Feet

2007 Hydrographic Survey
2012 Aerial Photograph

U.S. ARMY ENGINEER DIVISION CORPS OF ENGINEERS ST. LOUIS, MISSOURI	DESIGNED BY: B Krischel		SURVEY DATE: 2007
	DRAWN BY: B Krischel	REVIEWED BY: T Lauth, P.E.	CHECKED BY: R Davinroy, P.E.
Mississippi River Basin St. Louis District Mouth of the Meramec HSR Model	SUBMITTED: B Krischel	APPROVED: Rob Davinroy, P.E.	
	FILE NAME: L:\Mouth of the Meramec\Plates		PLOT DATE: 04/11/2014

N E S W

APPLIED RIVER ENGINEERING CENTER

US Army Corps of Engineers St. Louis District

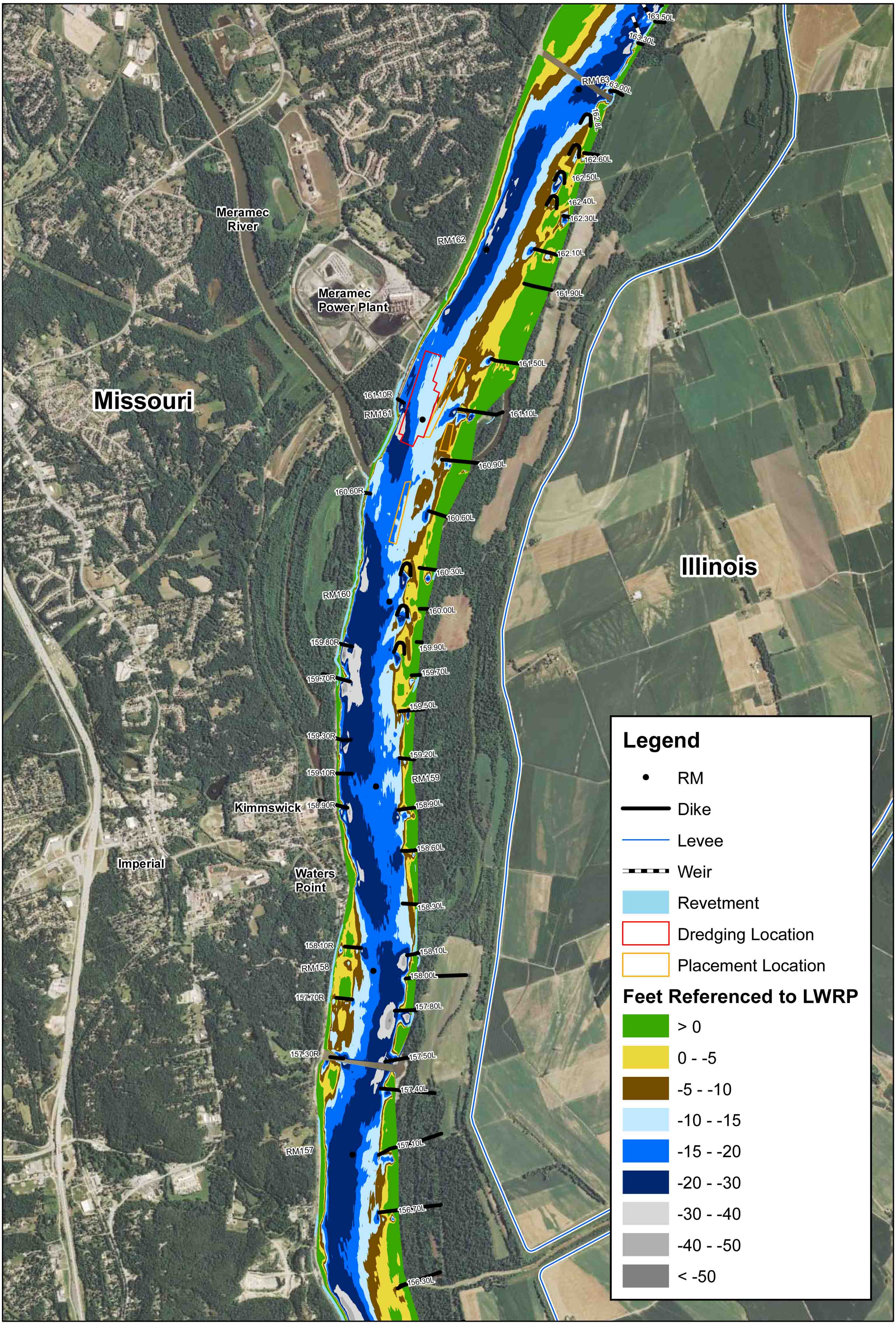


PLATE NUMBER 16

0 700 1,400 2,800 4,200
Feet

2010 Hydrographic Survey
2012 Aerial Photograph

U.S. ARMY ENGINEER DIVISION CORPS OF ENGINEERS ST. LOUIS, MISSOURI	DESIGNED BY: B Krischel		SURVEY DATE: 2010
	DRAWN BY: B Krischel	REVIEWED BY: T Lauth, P.E.	CHECKED BY: R Davinroy, P.E.
Mississippi River Basin St. Louis District Mouth of the Meramec HSR Model	SUBMITTED: B Krischel	APPROVED: Rob Davinroy, P.E.	
	FILE NAME: L:\Mouth of the Meramec\Plates		PLOT DATE: 04/11/2014

APPLIED RIVER ENGINEERING CENTER

US Army Corps of Engineers St. Louis District

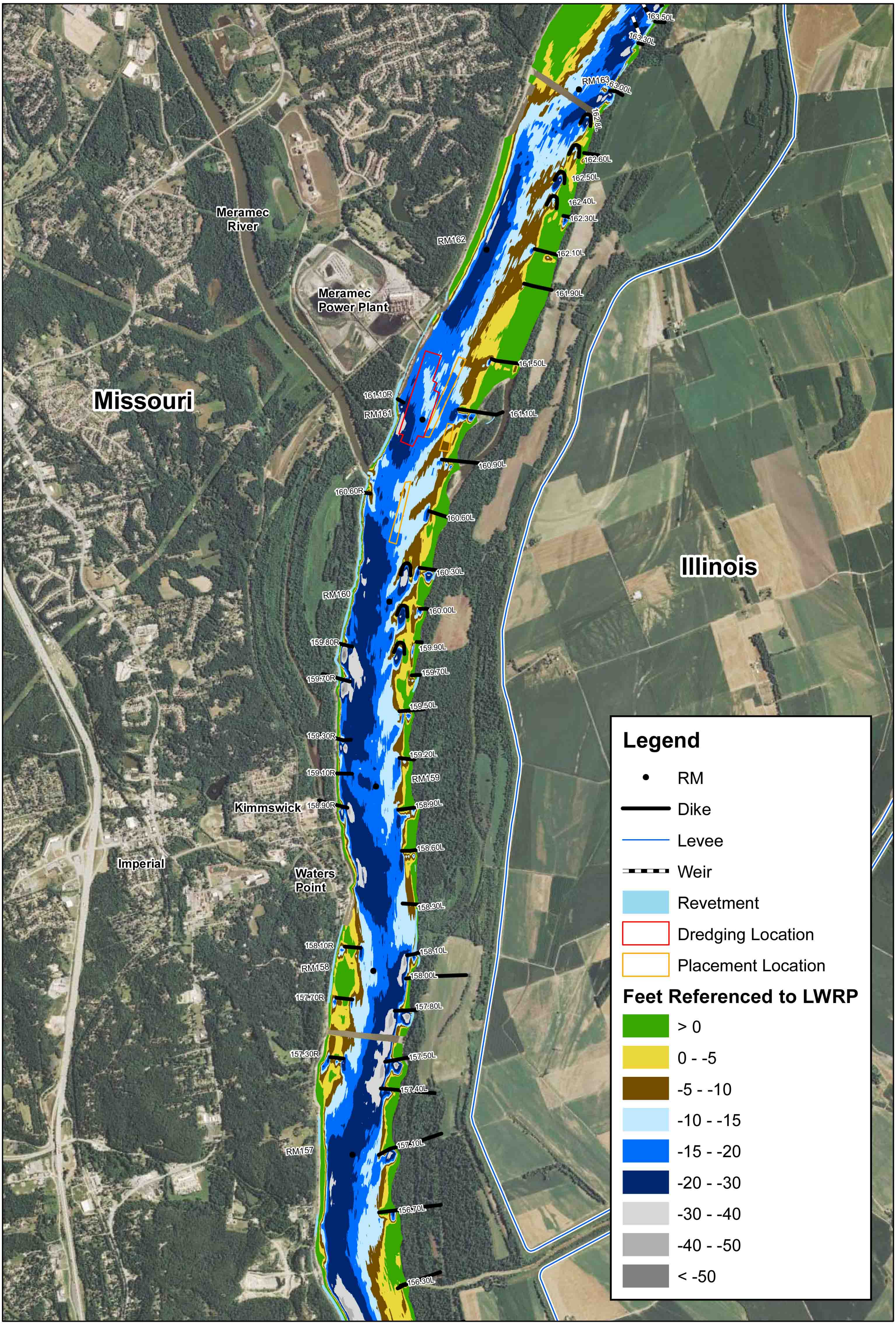


PLATE NUMBER 17

0 700 1,400 2,800 4,200
Feet

2013 Hydrographic Survey
2012 Aerial Photograph

U.S. ARMY ENGINEER DIVISION CORPS OF ENGINEERS ST. LOUIS, MISSOURI	DESIGNED BY: B Krischel	SURVEY DATE: 2013	
	DRAWN BY: B Krischel	REVIEWED BY: T Lauth, P.E.	CHECKED BY: R Davinroy, P.E.
Mississippi River Basin St. Louis District Mouth of the Meramec HSR Model	SUBMITTED: B Krischel	APPROVED: Rob Davinroy, P.E.	
	FILE NAME: L:\Mouth of the Meramec\Plates	PLOT DATE: 04/11/2014	

APPLIED RIVER ENGINEERING CENTER

US Army Corps of Engineers St. Louis District

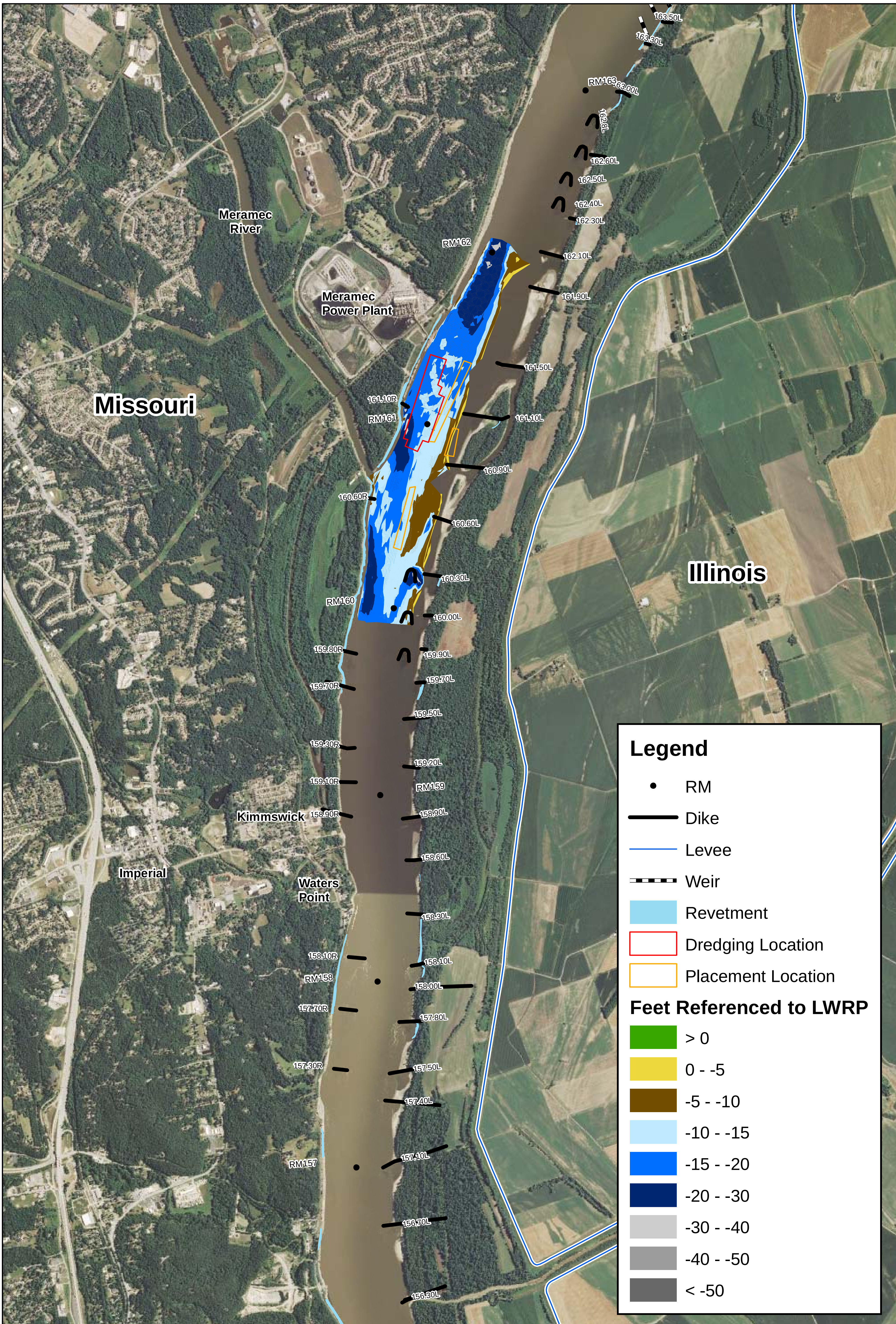


PLATE NUMBER 18

0 700 1,400 2,800 4,200 Feet

2005 Pre-Dredge Survey
2012 Aerial Photograph

U.S. ARMY ENGINEER DIVISION CORPS OF ENGINEERS ST. LOUIS, MISSOURI	DESIGNED BY: B Krischel		SURVEY DATE: September 10, 2005
	DRAWN BY: B Krischel	REVIEWED BY: T Lauth, P.E.	CHECKED BY: R Davinroy, P.E.
Mississippi River Basin St. Louis District Mouth of the Meramec HSR Model	SUBMITTED: B Krischel		APPROVED: Rob Davinroy, P.E.
	FILE NAME: L:\Mouth of the Meramec\Plates		PLOT DATE: 04/11/2014

N E S W

APPLIED RIVER ENGINEERING CENTER

US Army Corps of Engineers St. Louis District

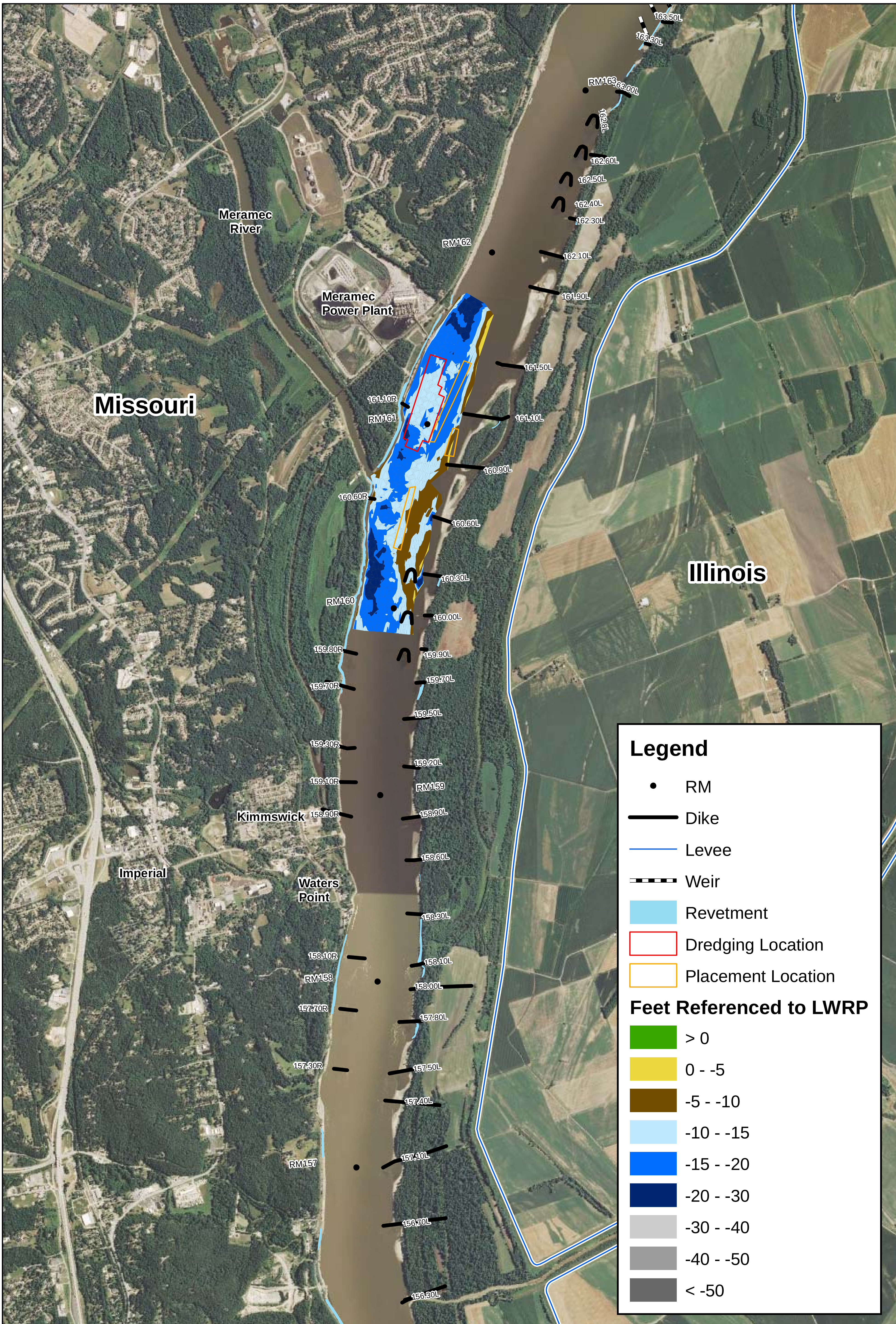


PLATE NUMBER 19

0 700 1,400 2,800 4,200
Feet

2006 Pre-Dredge Survey
2012 Aerial Photograph

U.S. ARMY ENGINEER DIVISION CORPS OF ENGINEERS ST. LOUIS, MISSOURI	DESIGNED BY: B Krischel	SURVEY DATE: September 14, 2006
	DRAWN BY: B Krischel REVIEWED BY: T Lauth, P.E.	CHECKED BY: R Davinroy, P.E.
Mississippi River Basin St. Louis District Mouth of the Meramec HSR Model	SUBMITTED: B Krischel	APPROVED: Rob Davinroy, P.E.
	FILE NAME: L:\Mouth of the Meramec\Plates	PLOT DATE: 04/11/2014

N
E
S
W

APPLIED RIVER ENGINEERING CENTER

US Army Corps of Engineers
St. Louis District

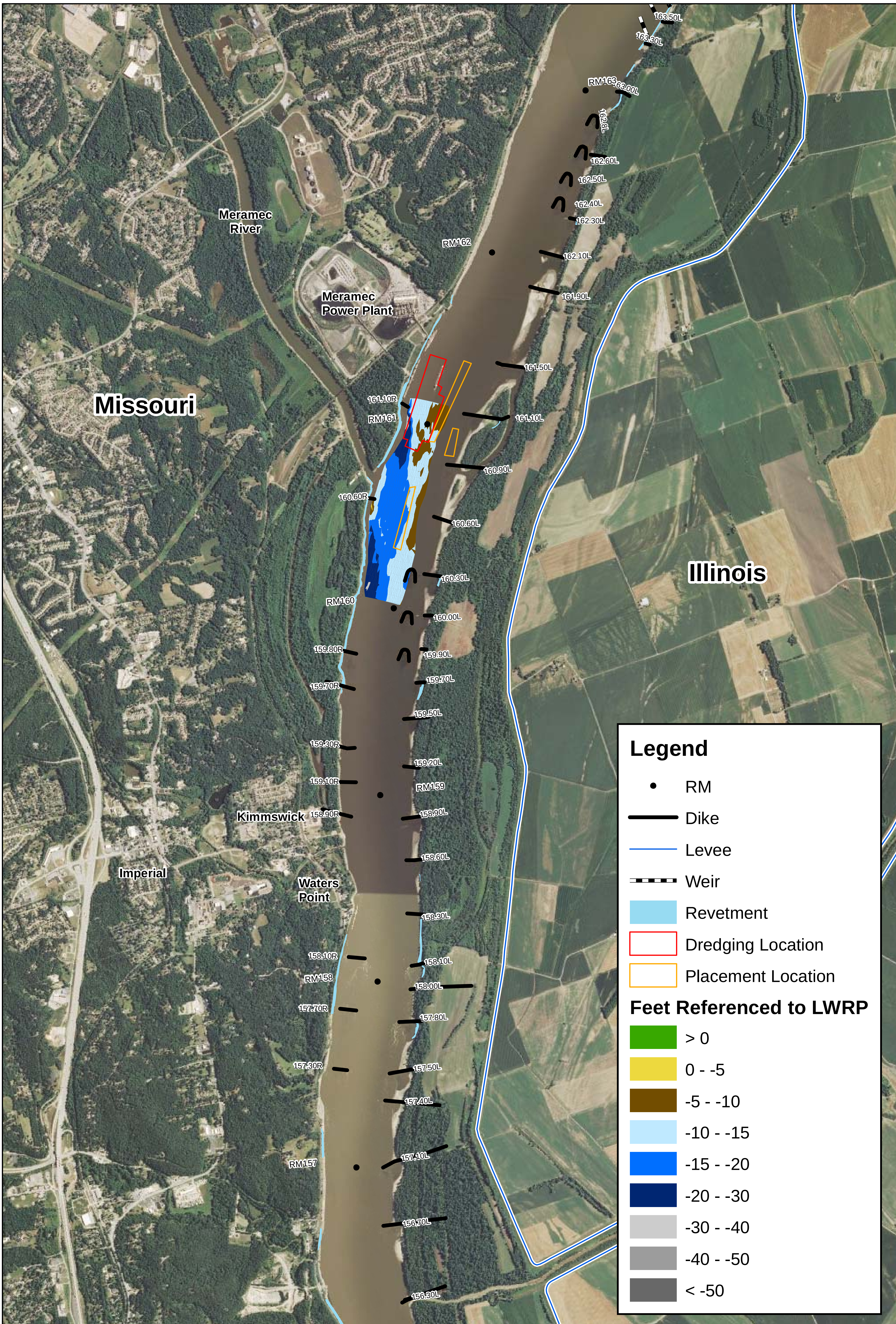


PLATE NUMBER 20

0 700 1,400 2,800 4,200
Feet

2008 Pre-Dredge Survey
2012 Aerial Photograph

U.S. ARMY ENGINEER DIVISION CORPS OF ENGINEERS ST. LOUIS, MISSOURI	DESIGNED BY: B Krischel		SURVEY DATE: 2008
	DRAWN BY: B Krischel	REVIEWED BY: T Lauth, P.E.	CHECKED BY: R Davinroy, P.E.
Mississippi River Basin St. Louis District Mouth of the Meramec HSR Model	SUBMITTED: B Krischel	APPROVED: Rob Davinroy, P.E.	
	FILE NAME: L:\Mouth of the Meramec\Plates		PLOT DATE: 04/11/2014

APPLIED RIVER ENGINEERING CENTER

US Army Corps of Engineers St. Louis District

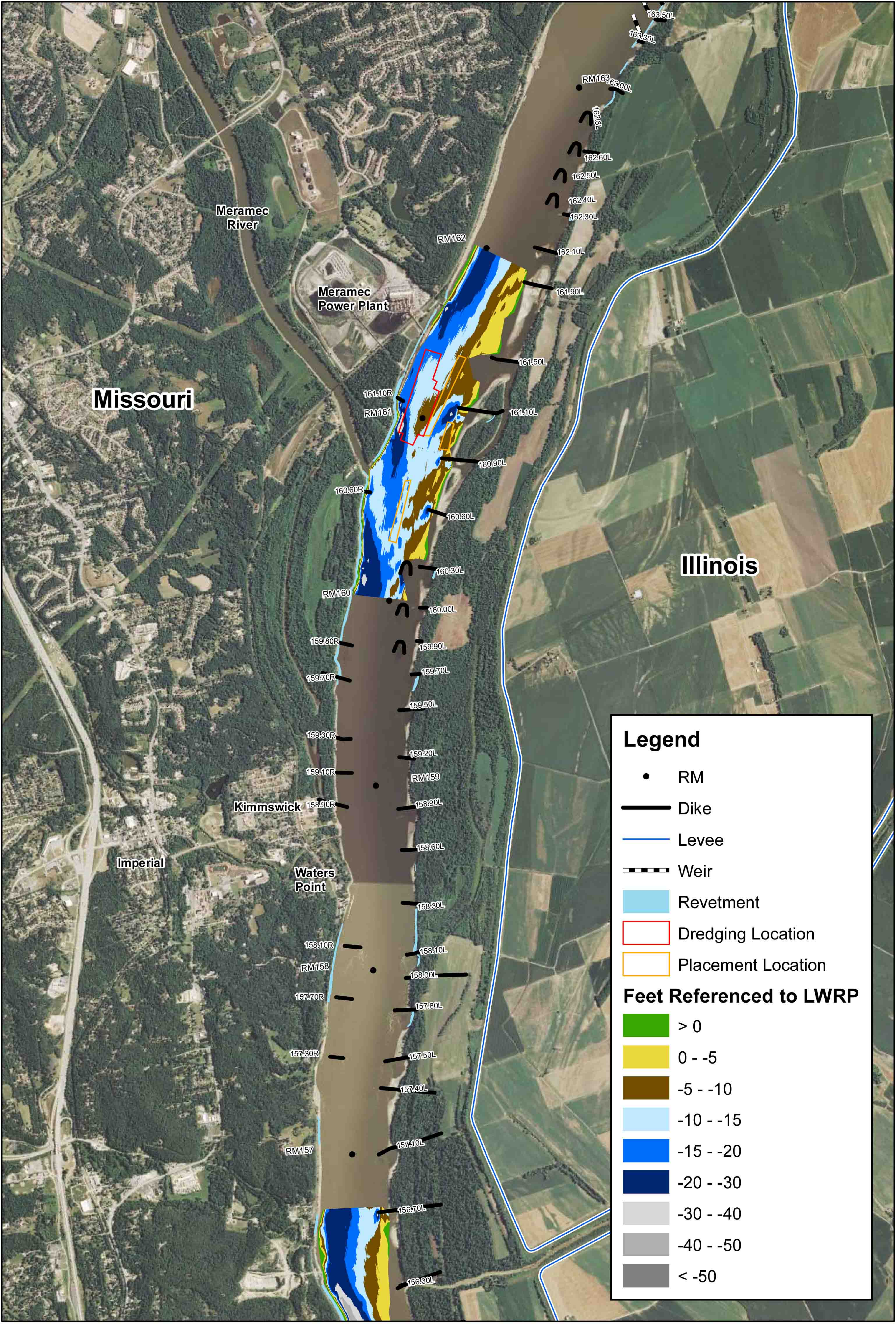


PLATE NUMBER 21

0 700 1,400 2,800 4,200
Feet

2011 Pre-Dredge Survey
2012 Aerial Photograph

U.S. ARMY ENGINEER DIVISION CORPS OF ENGINEERS ST. LOUIS, MISSOURI	DESIGNED BY: B Krischel	SURVEY DATE: 2011
	DRAWN BY: B Krischel; REVIEWED BY: T Lauth, P.E.	CHECKED BY: R Davinroy, P.E.
Mississippi River Basin St. Louis District Mouth of the Meramec HSR Model	SUBMITTED: B Krischel	APPROVED: Rob Davinroy, P.E.
	FILE NAME: L:\Mouth of the Meramec\Plates	PLOT DATE: 04/11/2014

N E S W

APPLIED RIVER ENGINEERING CENTER

US Army Corps of Engineers St. Louis District

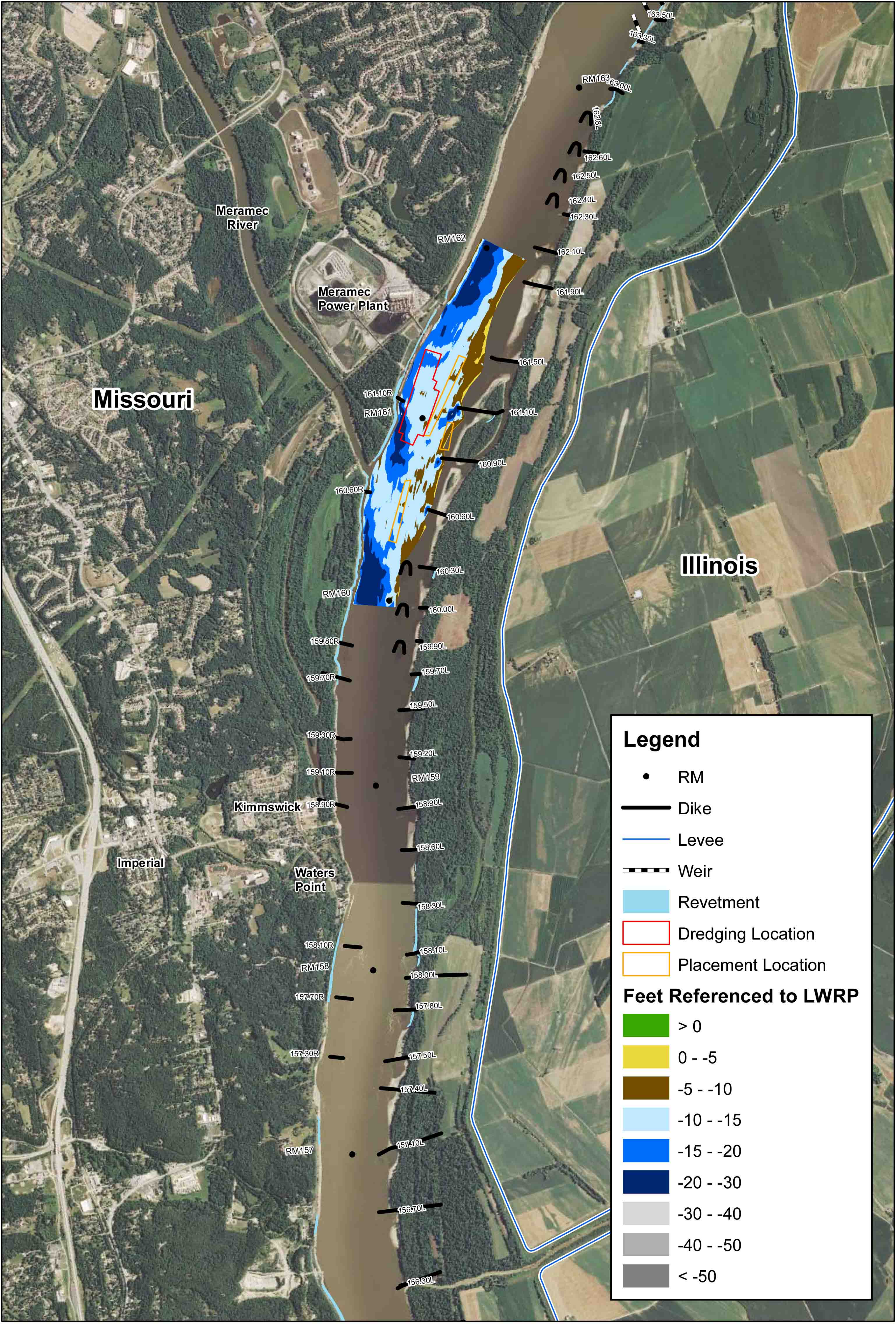


PLATE NUMBER 22

0 700 1,400 2,800 4,200
Feet

2012 Pre-Dredge Survey
2012 Aerial Photograph

U.S. ARMY ENGINEER DIVISION CORPS OF ENGINEERS ST. LOUIS, MISSOURI	DESIGNED BY: B Krischel		SURVEY DATE: June 04, 2012
	DRAWN BY: B Krischel	REVIEWED BY: T Lauth, P.E.	CHECKED BY: R Davinroy, P.E.
Mississippi River Basin St. Louis District Mouth of the Meramec HSR Model	SUBMITTED: B Krischel	APPROVED: Rob Davinroy, P.E.	
	FILE NAME: L:\Mouth of the Meramec\Plates		PLOT DATE: 04/11/2014

N E S W

APPLIED RIVER ENGINEERING CENTER

US Army Corps of Engineers
St. Louis District

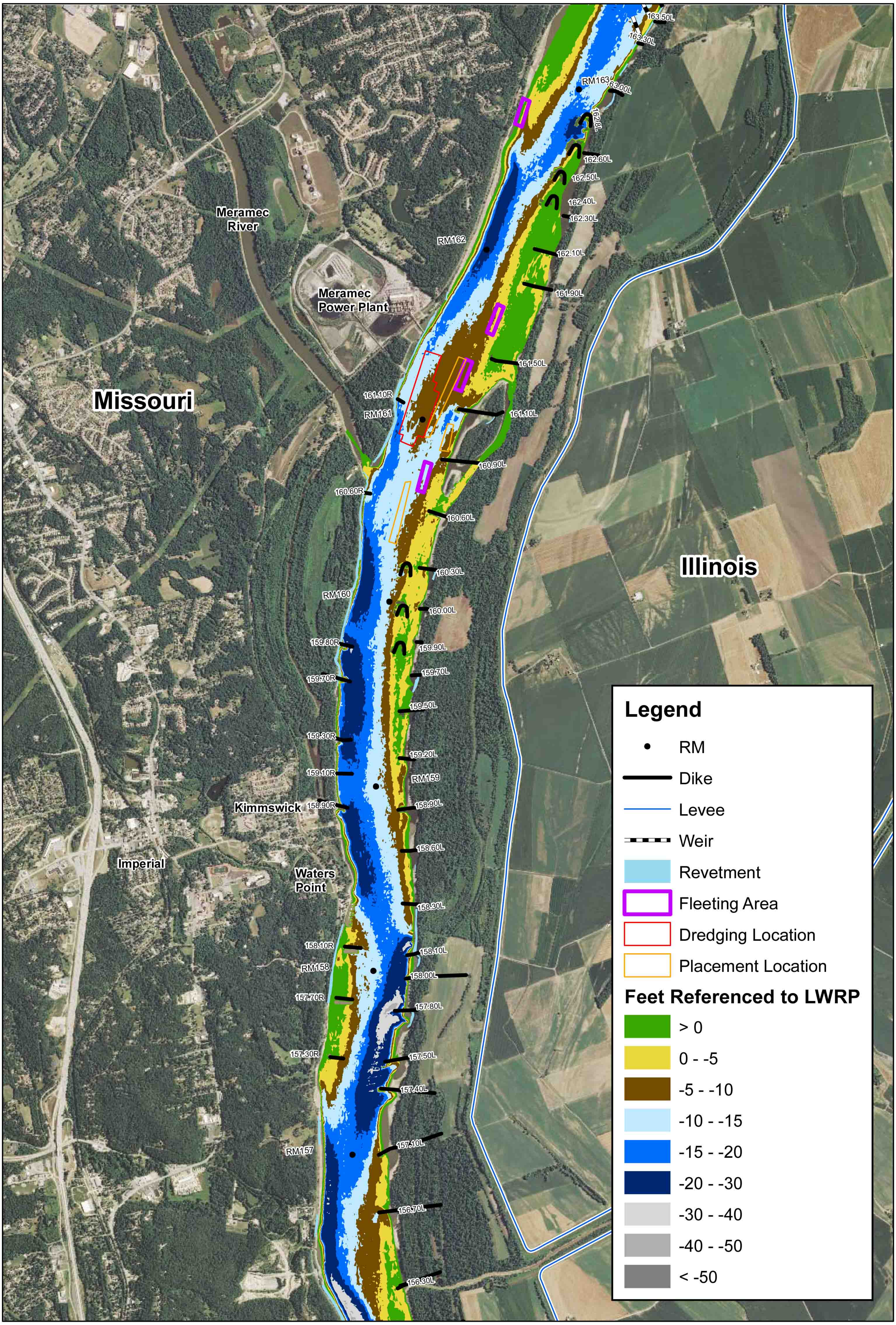


PLATE NUMBER 23

0 700 1,400 2,800 4,200
Feet

Model Replication
2012 Aerial Photograph

U.S. ARMY ENGINEER DIVISION CORPS OF ENGINEERS ST. LOUIS, MISSOURI	DESIGNED BY: B Krischel	SURVEY DATE: February 28, 2014
	DRAWN BY: B Krischel; REVIEWED BY: T Lauth, P.E.	CHECKED BY: R Davinroy, P.E.
Mississippi River Basin St. Louis District Mouth of the Meramec HSR Model	SUBMITTED: B Krischel	APPROVED: Rob Davinroy, P.E.
	FILE NAME: L:\Mouth of the Meramec\Plates	PLOT DATE: 04/11/2014

APPLIED RIVER ENGINEERING CENTER

US Army Corps of Engineers
St. Louis District

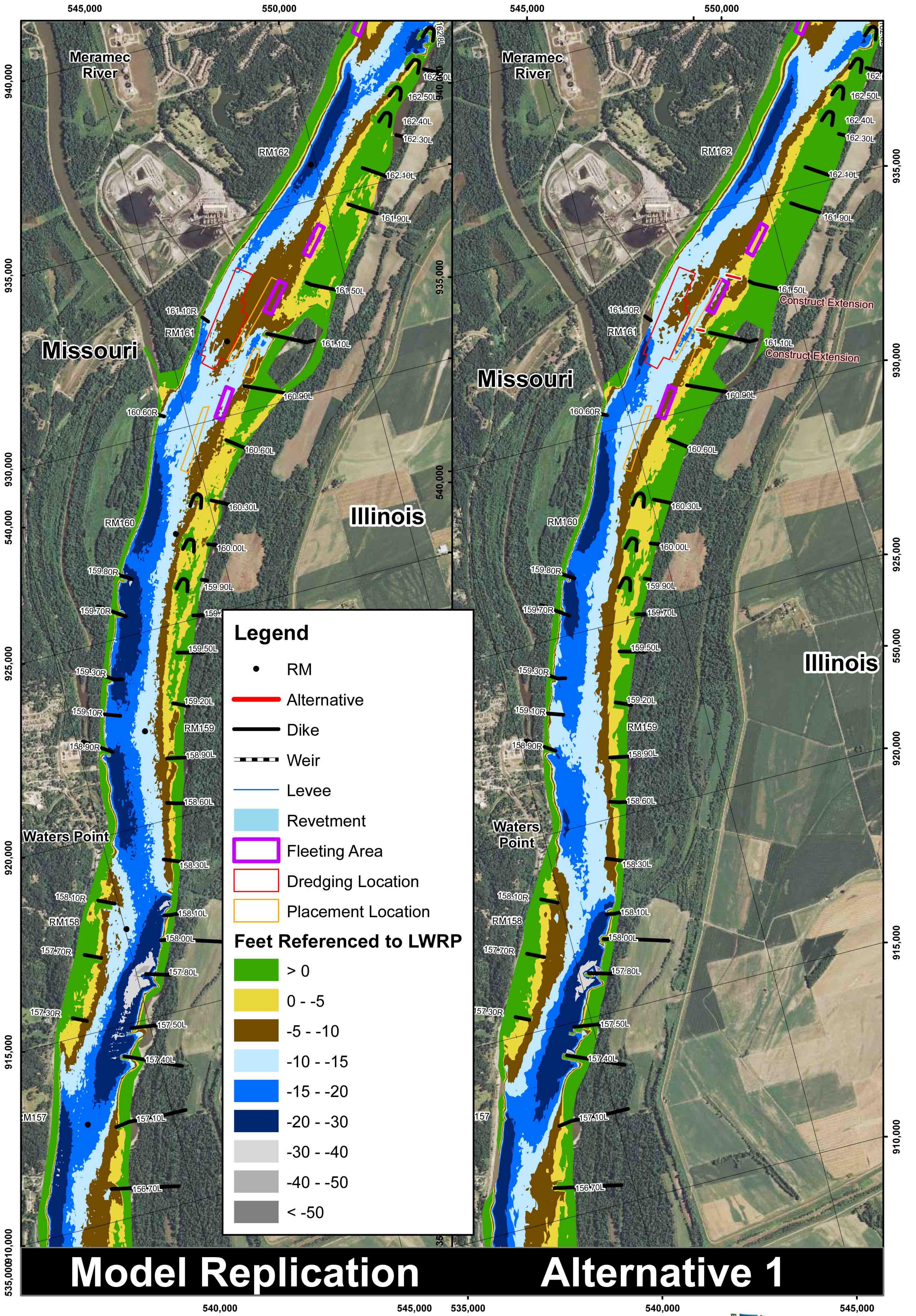


PLATE NUMBER 24

0 650 1,300 2,600 3,900 Feet

Model Replication vs Alternative 1

2012 Aerial Photograph

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

Mississippi River Basin
St. Louis District
Mouth of Meramec
HSR Model

DESIGNED BY: B Krischel		SURVEY DATE: 02/10/14
DRAWN BY: B Krischel	REVIEWED BY: T Lauth, P.E.	CHECKED BY: R Davinroy, P.E.
SUBMITTED: B Krischel		APPROVED: Rob Davinroy, P.E.
FILE NAME: L:\Mouth of the Meramec\Plates		PLOT DATE: 04/11/2014

N E S W

APPLIED RIVER ENGINEERING CENTER

US Army Corps of Engineers St. Louis District

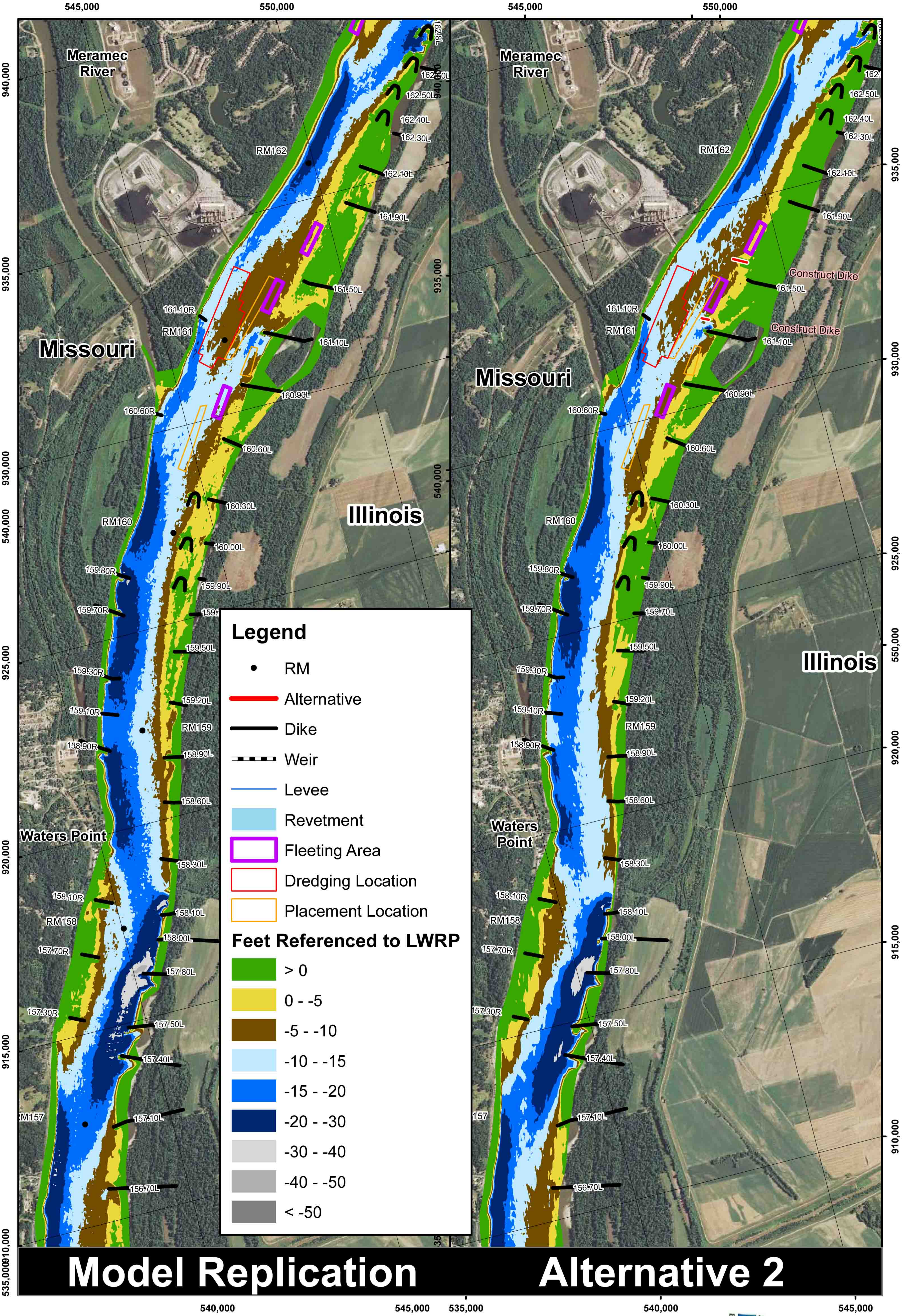


PLATE NUMBER 25

Model Replication vs Alternative 2

2012 Aerial Photograph

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

Mississippi River Basin
St. Louis District
Mouth of Meramec
HSR Model

DESIGNED BY: B Krischel	SURVEY DATE: 02/18/14	
DRAWN BY: B Krischel	REVIEWED BY: T Lauth, P.E.	CHECKED BY: R Davinroy, P.E.
SUBMITTED: B Krischel	APPROVED: Rob Davinroy, P.E.	
FILE NAME: L:\Mouth of the Meramec\Plates	PLOT DATE: 04/11/2014	

APPLIED RIVER ENGINEERING CENTER

US Army Corps of Engineers
St. Louis District

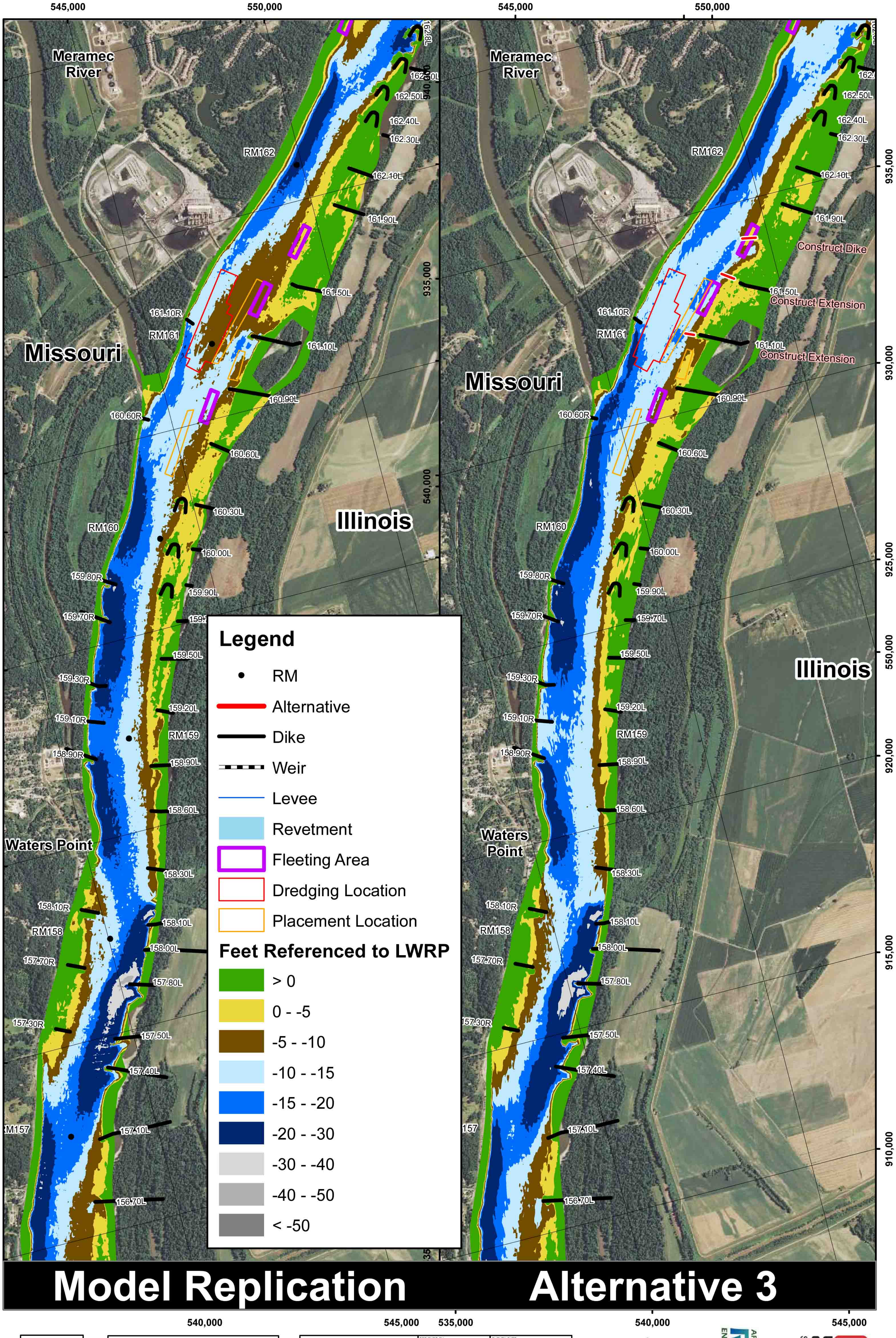


PLATE NUMBER 26

0 650 1,300 2,600 3,900 Feet

Model Replication vs Alternative 3

2012 Aerial Photograph

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

Mississippi River Basin St. Louis District Mouth of Meramec HSR Model

DESIGNED BY: B Krischel	SURVEY DATE: 02/18/14	
DRAWN BY: B Krischel	REVIEWED BY: T Lauth, P.E.	CHECKED BY: R Davinroy, P.E.
SUBMITTED: B Krischel	APPROVED: Rob Davinroy, P.E.	
FILE NAME: L:\Mouth of the Meramec\Plates	PLOT DATE: 04/11/2014	

APPLIED RIVER ENGINEERING CENTER

US Army Corps of Engineers® St. Louis District

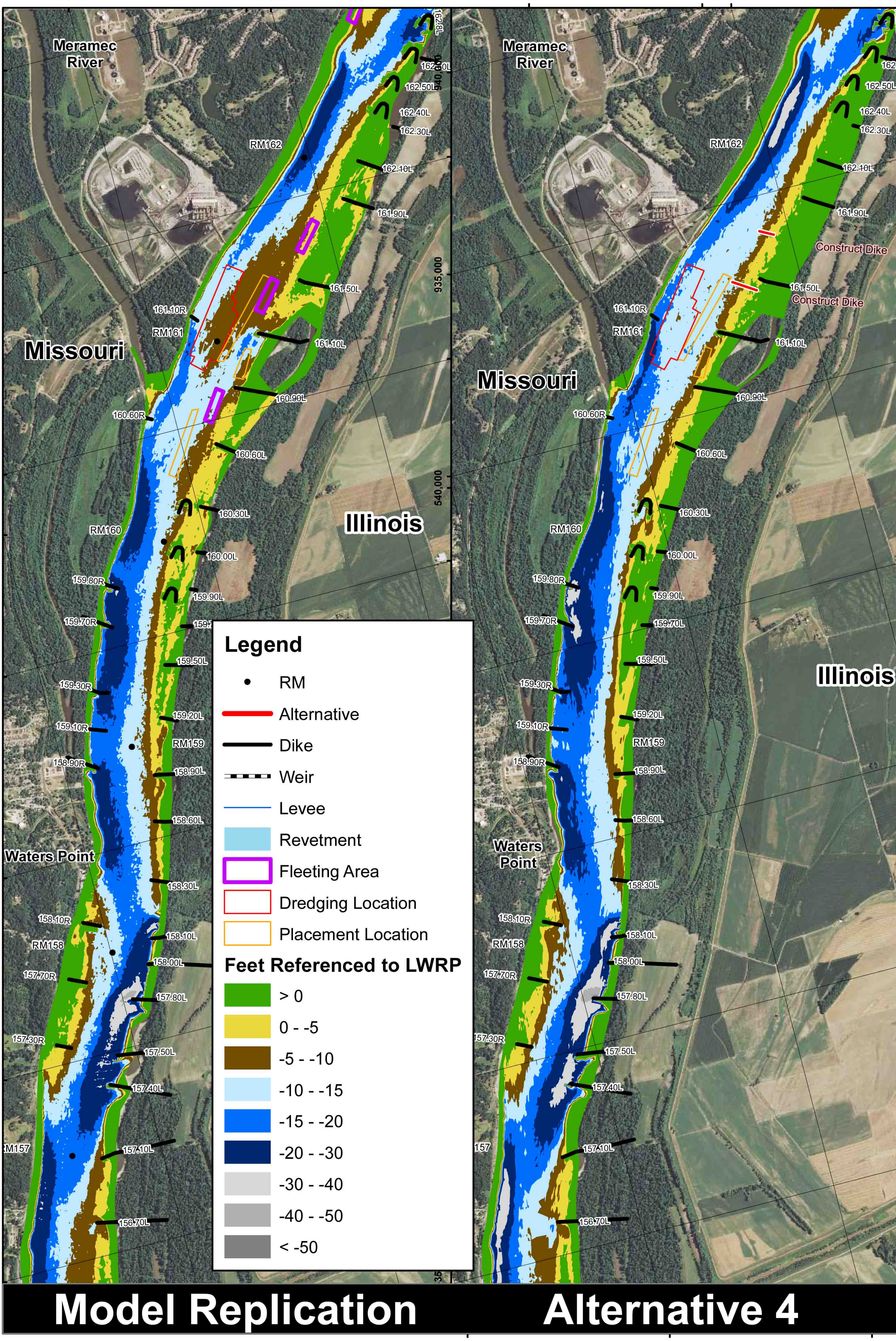


PLATE NUMBER 27

0 650 1,300 2,600 3,900
Feet

Model Replication vs Alternative 4
2012 Aerial Photograph

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

Mississippi River Basin
St. Louis District
Mouth of Meramec
HSR Model

DESIGNED BY: B Krischel		SURVEY DATE: 02/24/14
DRAWN BY: B Krischel	REVIEWED BY: T Lauth, P.E.	CHECKED BY: R Davinroy, P.E.
SUBMITTED: B Krischel		APPROVED: Rob Davinroy, P.E.
FILE NAME: L:\Mouth of the Meramec\Plates		PLOT DATE: 04/22/2014

N E S W

APPLIED RIVER ENGINEERING CENTER

US Army Corps of Engineers®
St. Louis District

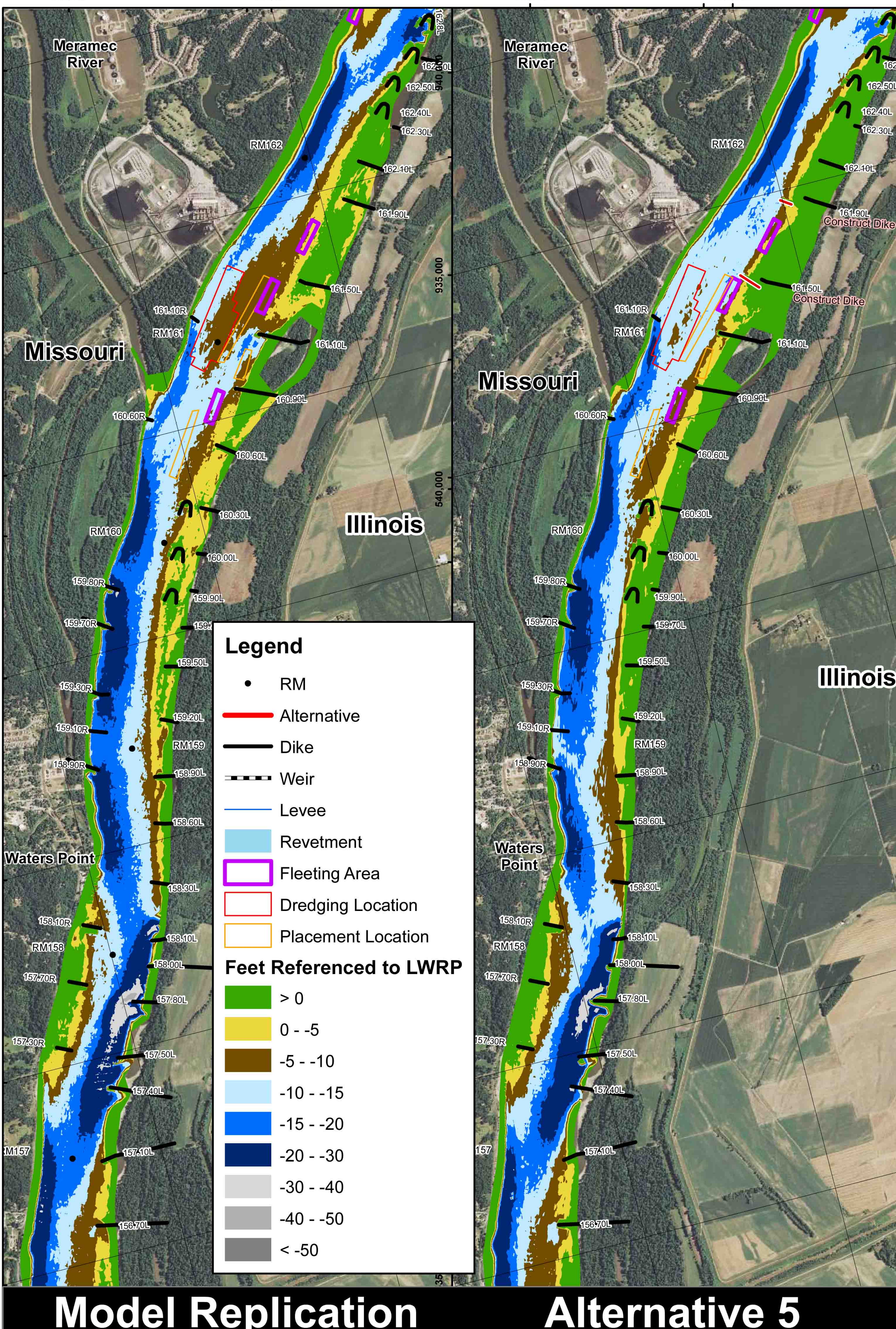


PLATE NUMBER 28

Model Replication vs Alternative 5

2012 Aerial Photograph

U.S. ARMY ENGINEER DIVISION CORPS OF ENGINEERS ST. LOUIS, MISSOURI	DESIGNED BY: B Krischel	SURVEY DATE: 03/05/14
	DRAWN BY: B Krischel; REVIEWED BY: T Lauth, P.E.	CHECKED BY: R Davinroy, P.E.
Mississippi River Basin St. Louis District Mouth of Meramec HSR Model	SUBMITTED: B Krischel	APPROVED: Rob Davinroy, P.E.
	FILE NAME: L:\Mouth of the Meramec\Plates	PLOT DATE: 04/22/2014

APPLIED RIVER ENGINEERING CENTER

US Army Corps of Engineers St. Louis District

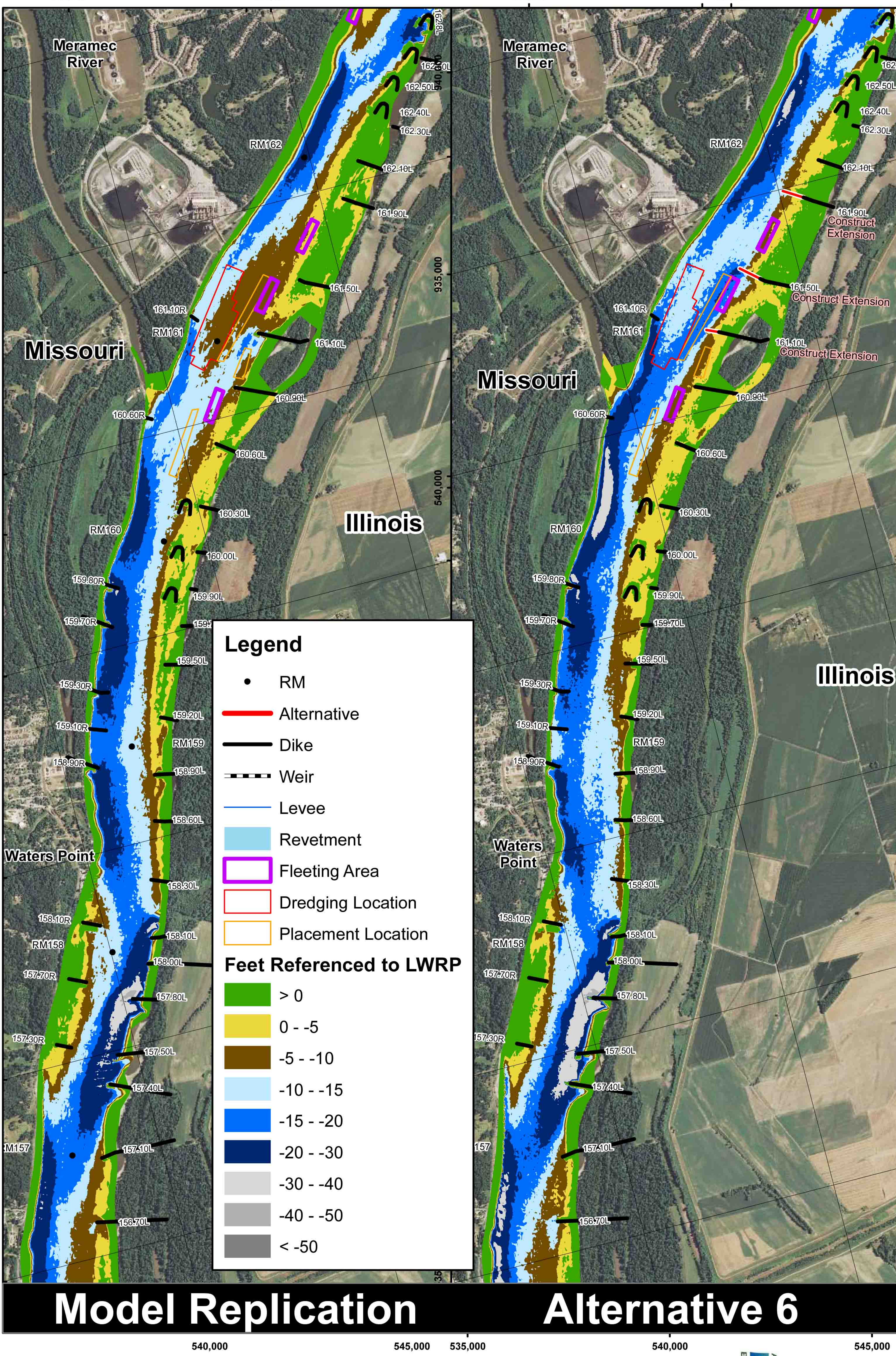


PLATE NUMBER 29

0 650 1,300 2,600 3,900 Feet

Model Replication vs Alternative 6

2012 Aerial Photograph

U.S. ARMY ENGINEER DIVISION CORPS OF ENGINEERS ST. LOUIS, MISSOURI	DESIGNED BY: B Krischel	SURVEY DATE: 03/13/14
	DRAWN BY: B Krischel / REVIEWED BY: T Lauth, P.E.	CHECKED BY: R Davinroy, P.E.
Mississippi River Basin St. Louis District Mouth of Meramec HSR Model	SUBMITTED: B Krischel	APPROVED: Rob Davinroy, P.E.
	FILE NAME: L:\Mouth of the Meramec\Plates	PLOT DATE: 04/22/2014

N E S W

APPLIED RIVER ENGINEERING CENTER

US Army Corps of Engineers St. Louis District

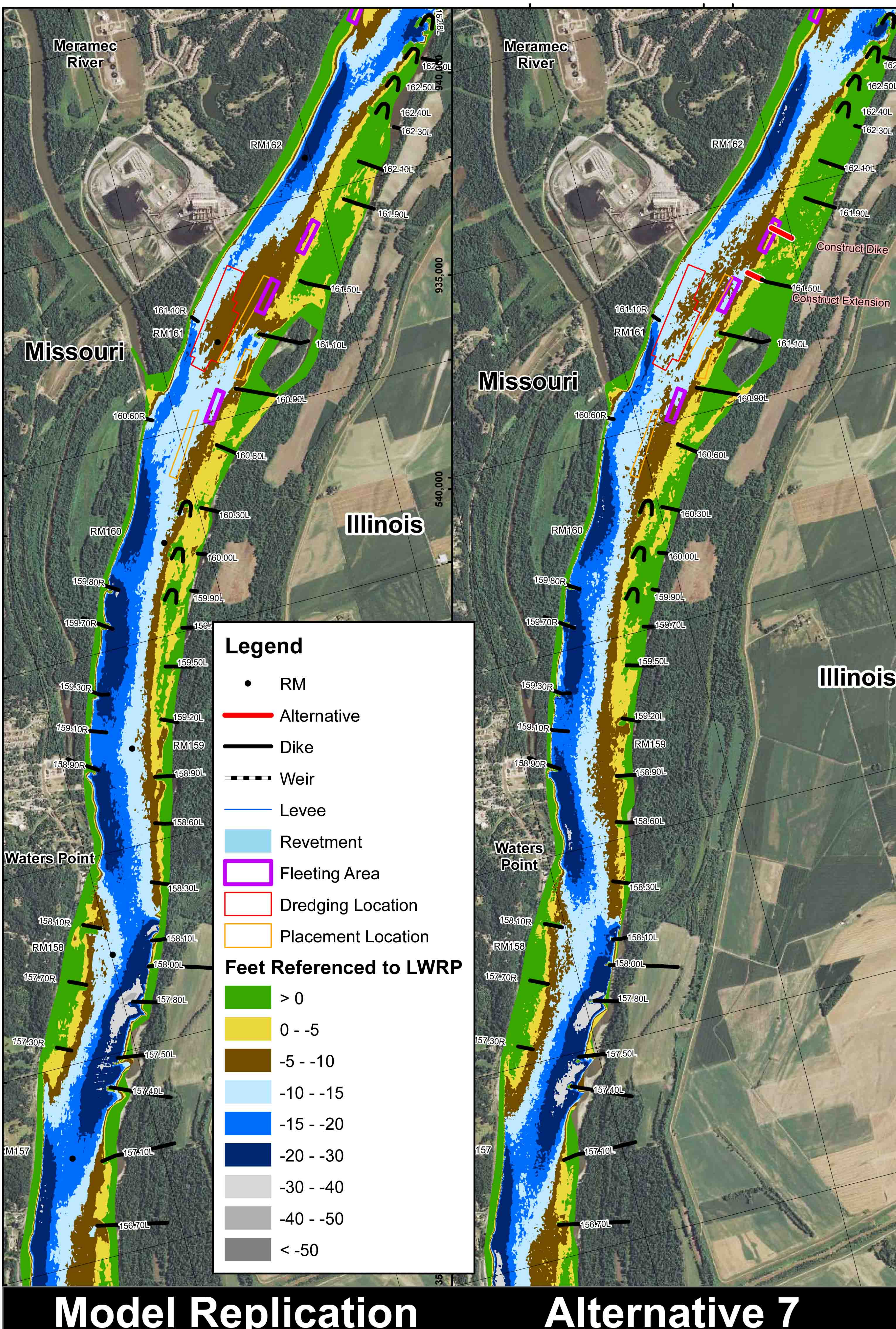


PLATE NUMBER 30

0 650 1,300 2,600 3,900 Feet

Model Replication vs Alternative 7

2012 Aerial Photograph

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

Mississippi River Basin
St. Louis District
Mouth of Meramec
HSR Model

DESIGNED BY: B Krischel	SURVEY DATE: 03/26/14	
DRAWN BY: B Krischel	REVIEWED BY: T Lauth, P.E.	CHECKED BY: R Davinroy, P.E.
SUBMITTED: B Krischel	APPROVED: Rob Davinroy, P.E.	
FILE NAME: L:\Mouth of the Meramec\Plates	PLOT DATE: 04/22/2014	

APPLIED RIVER ENGINEERING CENTER

US Army Corps of Engineers St. Louis District

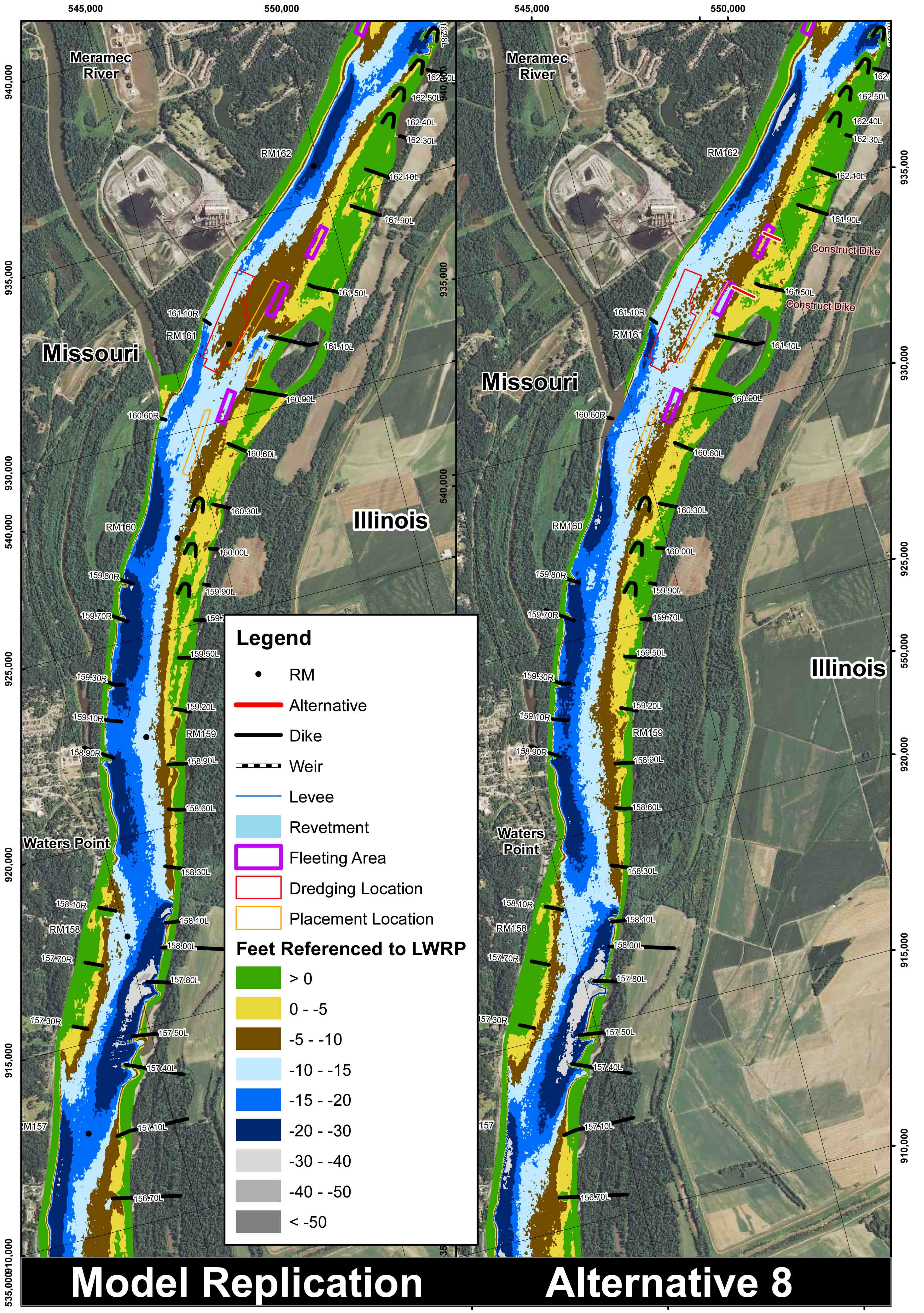


PLATE NUMBER 31

0 650 1,300 2,600 3,900 Feet

Model Replication vs Alternative 8

2012 Aerial Photograph

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

Mississippi River Basin
St. Louis District
Mouth of Meramec
HSR Model

DESIGNED BY: B Krischel		SURVEY DATE: 03/28/14
DRAWN BY: B Krischel	REVIEWED BY: T Lauth, P.E.	CHECKED BY: R Davinroy, P.E.
SUBMITTED: B Krischel		APPROVED: Rob Davinroy, P.E.
FILE NAME: L:\Mouth of the Meramec\Plates		PLOT DATE: 04/22/2014

N E S W

APPLIED RIVER ENGINEERING CENTER

US Army Corps of Engineers St. Louis District

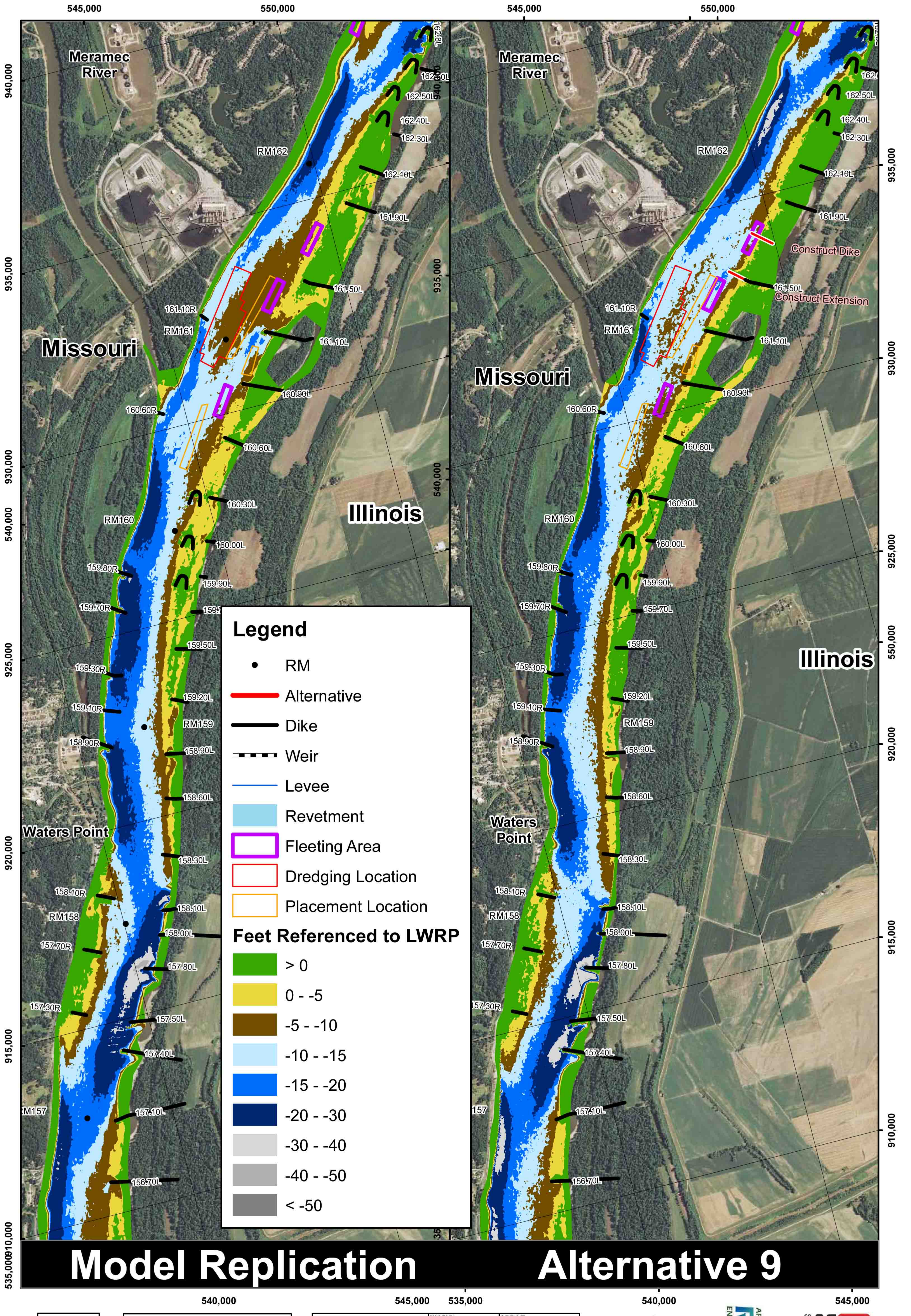


PLATE NUMBER 32

0 650 1,300 2,600 3,900 Feet

Model Replication vs Alternative 9

2012 Aerial Photograph

U.S. ARMY ENGINEER DIVISION CORPS OF ENGINEERS ST. LOUIS, MISSOURI	DESIGNED BY: B Krischel		SURVEY DATE: 04/01/14
	DRAWN BY: B Krischel	REVIEWED BY: T Lauth, P.E.	CHECKED BY: R Davinroy, P.E.
Mississippi River Basin St. Louis District Mouth of Meramec HSR Model	SUBMITTED: B Krischel		APPROVED: Rob Davinroy, P.E.
	FILE NAME: L:\Mouth of the Meramec\Plates		PLOT DATE: 04/22/2014

N E S W

APPLIED RIVER ENGINEERING CENTER

US Army Corps of Engineers® St. Louis District

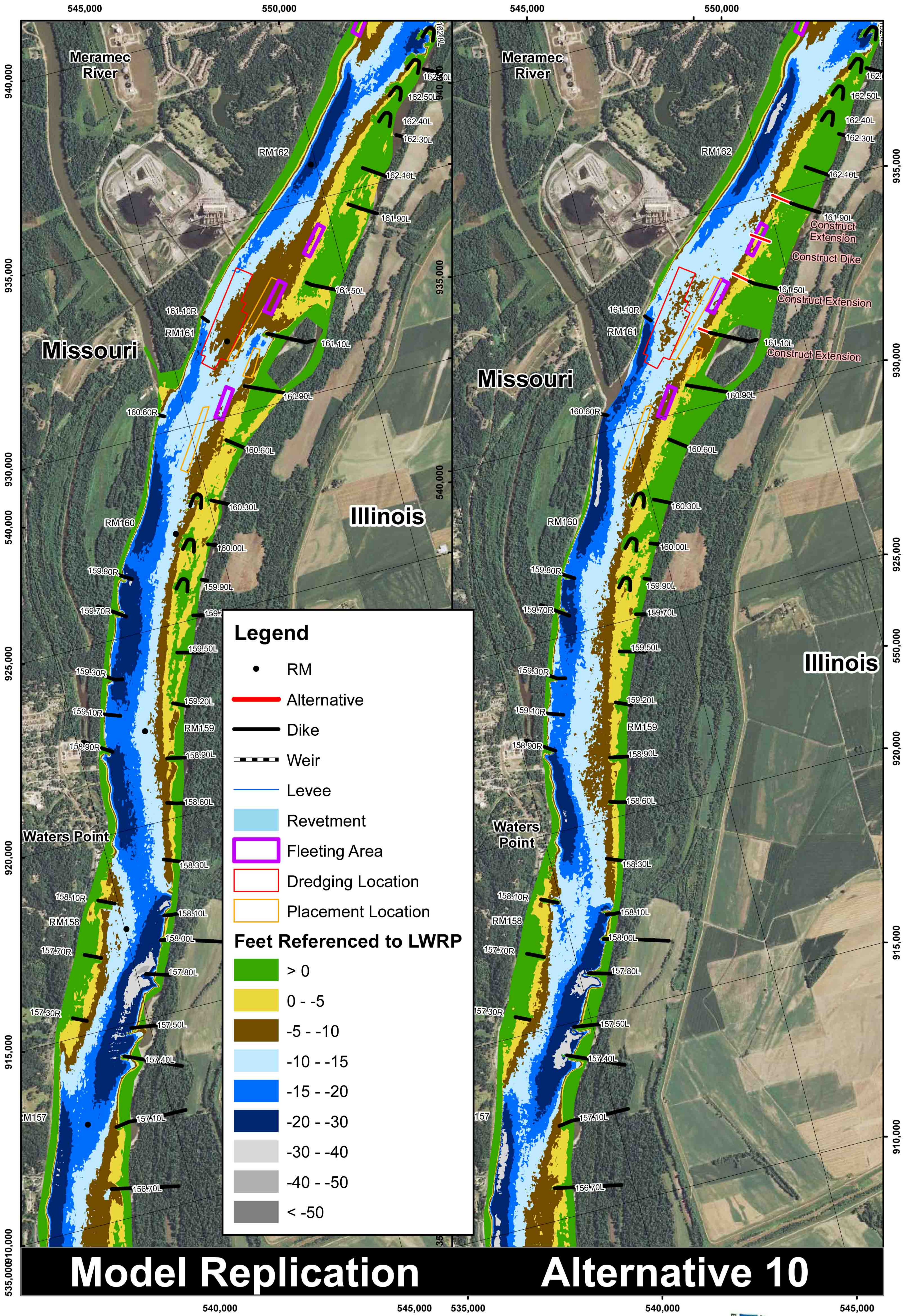


PLATE NUMBER 33

0 650 1,300 2,600 3,900 Feet

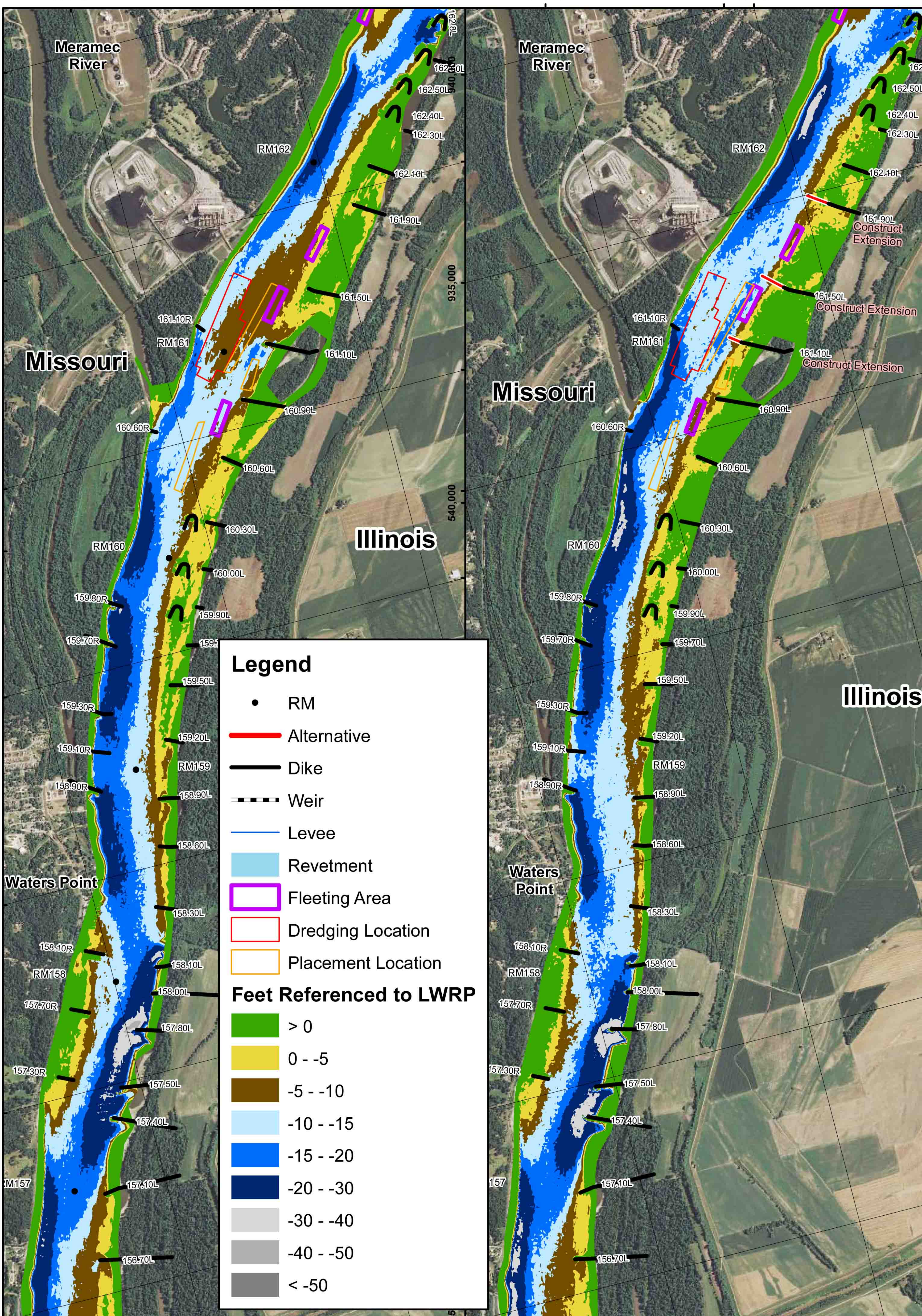
Model Replication vs Alternative 10

2012 Aerial Photograph

U.S. ARMY ENGINEER DIVISION CORPS OF ENGINEERS ST. LOUIS, MISSOURI	DESIGNED BY: B Krischel	SURVEY DATE: 04/01/14
	DRAWN BY: B Krischel; REVIEWED BY: T Lauth, P.E.	CHECKED BY: R Davinroy, P.E.
Mississippi River Basin St. Louis District Mouth of Meramec HSR Model	SUBMITTED: B Krischel	APPROVED: Rob Davinroy, P.E.
	FILE NAME: L:\Mouth of the Meramec\Plates	PLOT DATE: 04/22/2014

APPLIED RIVER ENGINEERING CENTER

US Army Corps of Engineers St. Louis District



Model Replication

Alternative 11

PLATE NUMBER 34

0 650 1,300 2,600 3,900
Feet

Model Replication vs Alternative 11

2012 Aerial Photograph

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

Mississippi River Basin
St. Louis District
Mouth of Meramec
HSR Model

DESIGNED BY: B Krischel	SURVEY DATE: 04/02/14	
DRAWN BY: B Krischel	REVIEWED BY: T Lauth, P.E.	CHECKED BY: R Davinroy, P.E.
SUBMITTED: B Krischel	APPROVED: Rob Davinroy, P.E.	
FILE NAME: L:\Mouth of the Meramec\Plates	PLOT DATE: 04/22/2014	

N E S W

APPLIED RIVER ENGINEERING CENTER

US Army Corps of Engineers
St. Louis District

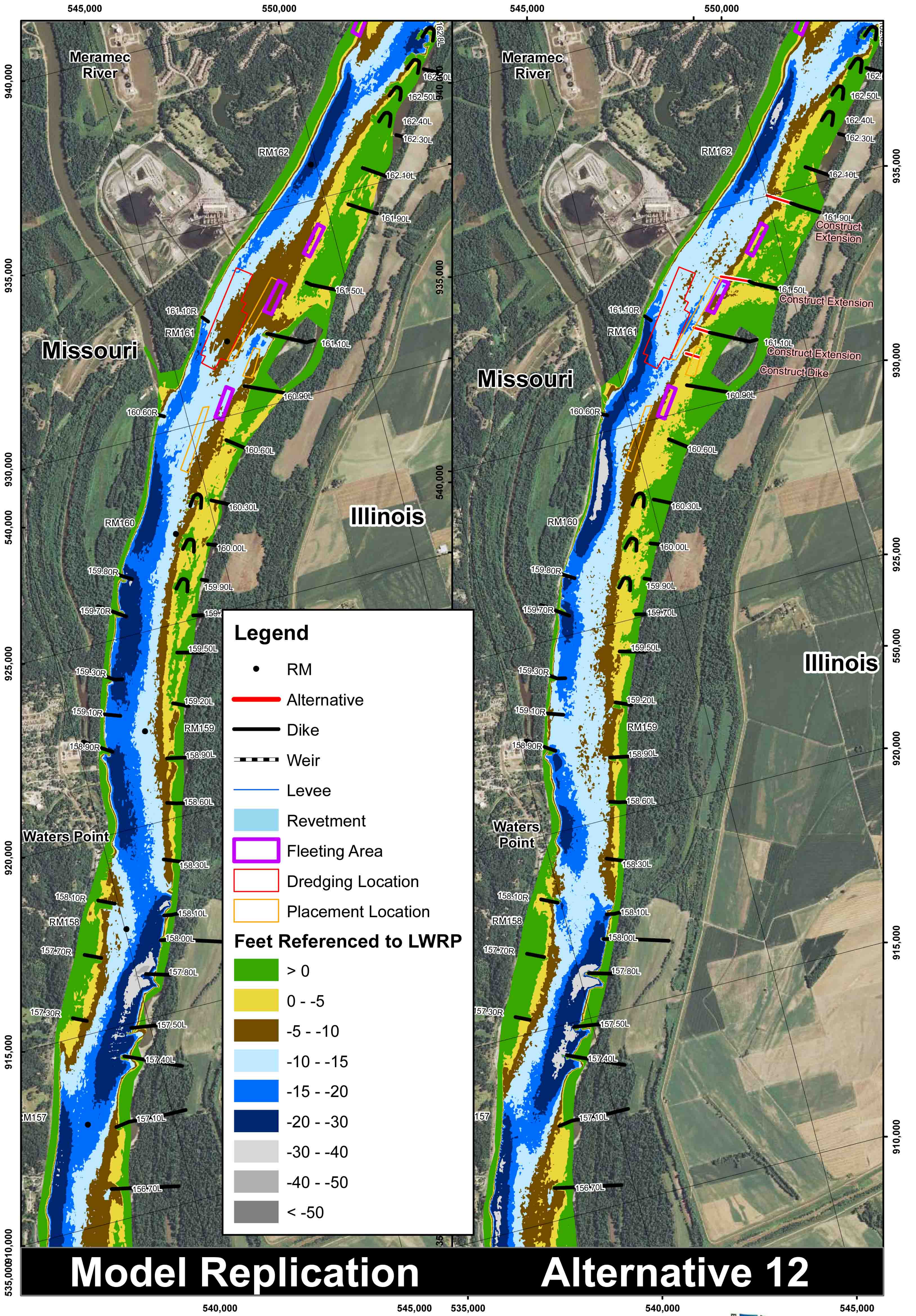


PLATE NUMBER 35

Model Replication vs Alternative 12

2012 Aerial Photograph

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

Mississippi River Basin
St. Louis District
Mouth of Meramec
HSR Model

DESIGNED BY: B Krischel		SURVEY DATE: 04/04/14
DRAWN BY: B Krischel	REVIEWED BY: T Lauth, P.E.	CHECKED BY: R Davinroy, P.E.
SUBMITTED: B Krischel		APPROVED: Rob Davinroy, P.E.
FILE NAME: L:\Mouth of the Meramec\Plates		PLOT DATE: 04/22/2014

APPLIED RIVER ENGINEERING CENTER

US Army Corps of Engineers
St. Louis District

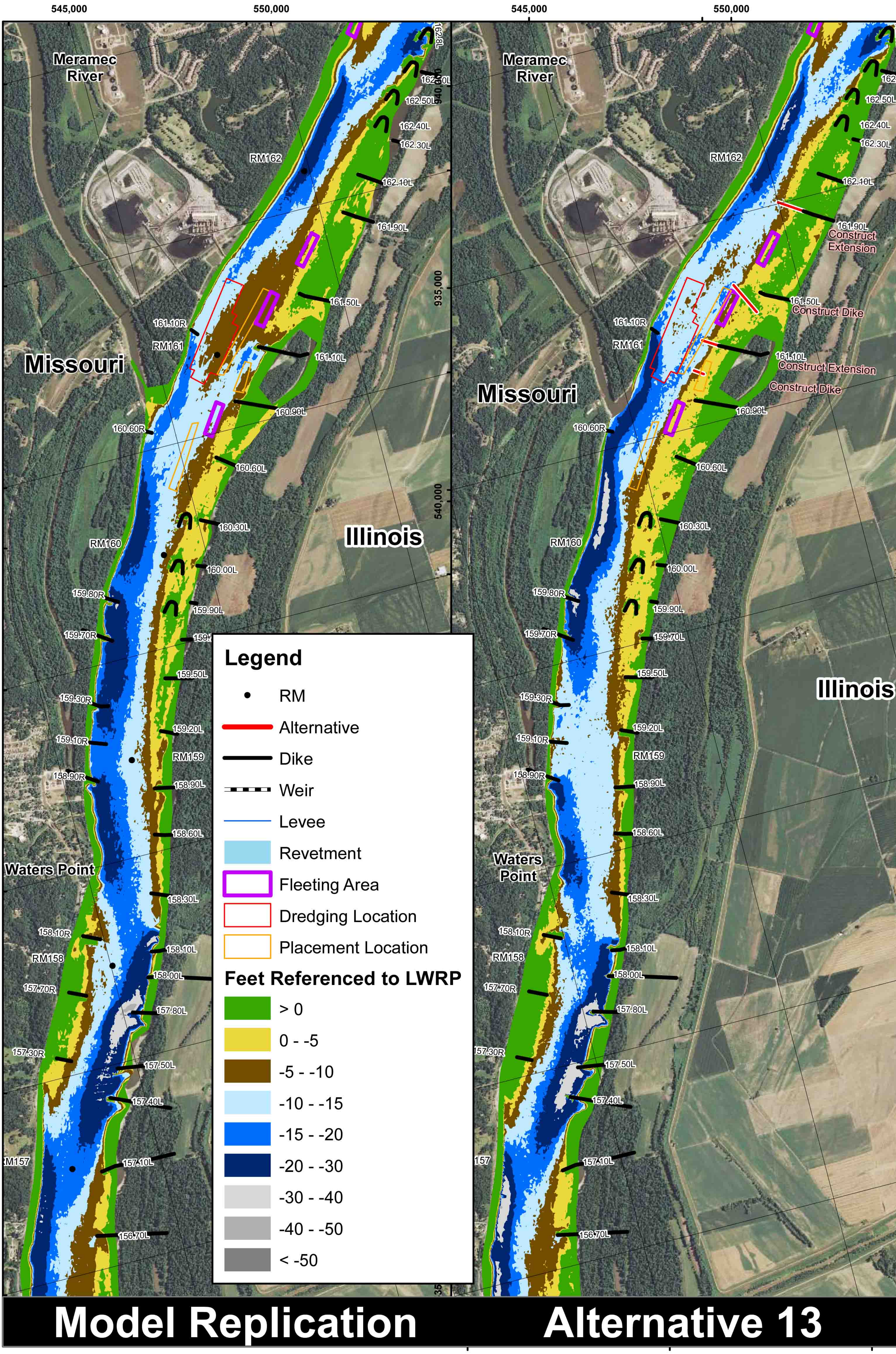


PLATE NUMBER 36

Model Replication vs Alternative 13

2012 Aerial Photograph

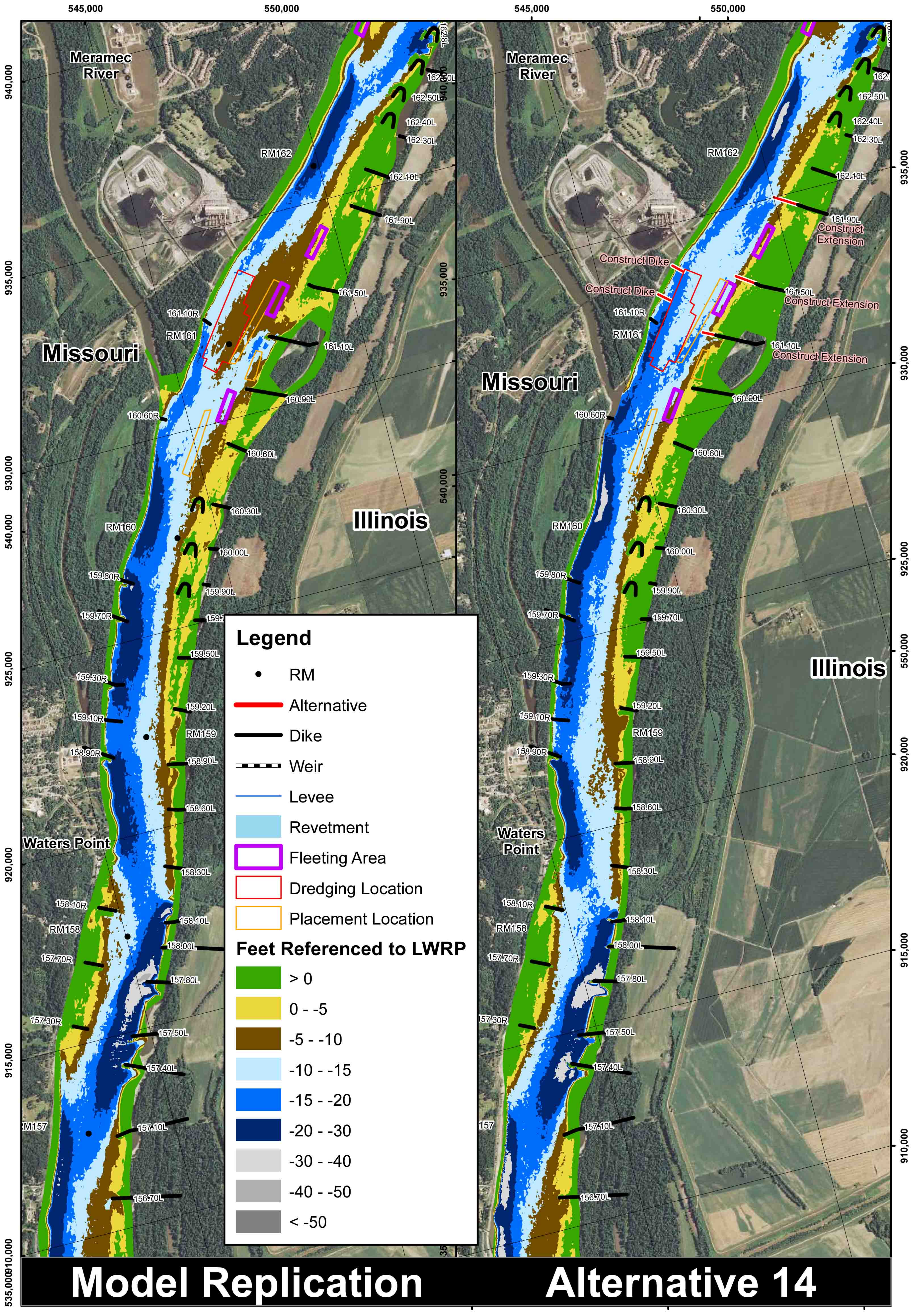
U.S. ARMY ENGINEER DIVISION
CORPS OF ENGINEERS
ST. LOUIS, MISSOURI

Mississippi River Basin
St. Louis District
Mouth of Meramec
HSR Model

DESIGNED BY: B Krischel	SURVEY DATE: 04/07/14	
DRAWN BY: B Krischel	REVIEWED BY: T Lauth, P.E.	CHECKED BY: R Davinroy, P.E.
SUBMITTED: B Krischel	APPROVED: Rob Davinroy, P.E.	
FILE NAME: L:\Mouth of the Meramec\Plates	PLOT DATE: 04/22/2014	

APPLIED RIVER ENGINEERING CENTER

US Army Corps of Engineers St. Louis District



Model Replication

Alternative 14

PLATE NUMBER 37

0 650 1,300 2,600 3,900 Feet

Model Replication vs Alternative 14

2012 Aerial Photograph

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

Mississippi River Basin
St. Louis District
Mouth of Meramec
HSR Model

DESIGNED BY: B Krischel	SURVEY DATE: 04/08/14	
DRAWN BY: B Krischel	REVIEWED BY: T Lauth, P.E.	CHECKED BY: R Davinroy, P.E.
SUBMITTED: B Krischel	APPROVED: Rob Davinroy, P.E.	
FILE NAME: L:\Mouth of the Meramec\Plates	PLOT DATE: 04/22/2014	

APPLIED RIVER ENGINEERING CENTER

US Army Corps of Engineers
St. Louis District

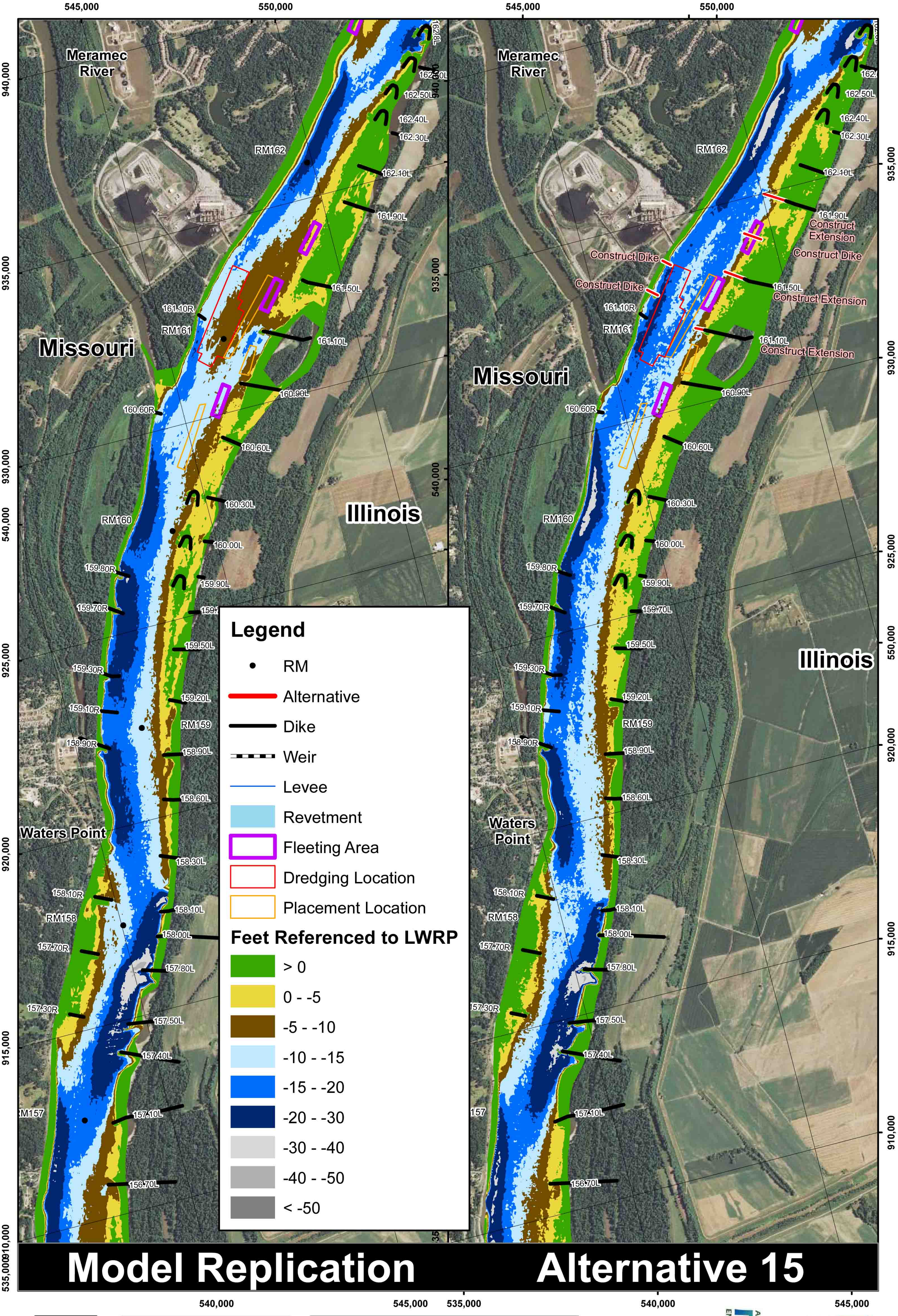


PLATE NUMBER 38

0 650 1,300 2,600 3,900 Feet

Model Replication vs Alternative 15

2012 Aerial Photograph

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

Mississippi River Basin
St. Louis District
Mouth of Meramec
HSR Model

DESIGNED BY: B Krischel		SURVEY DATE: 04/08/14
DRAWN BY: B Krischel	REVIEWED BY: T Lauth, P.E.	CHECKED BY: R Davinroy, P.E.
SUBMITTED: B Krischel	APPROVED: Rob Davinroy, P.E.	
FILE NAME: L:\Mouth of the Meramec\Plates		PLOT DATE: 04/22/2014

APPLIED RIVER ENGINEERING CENTER

US Army Corps of Engineers
St. Louis District

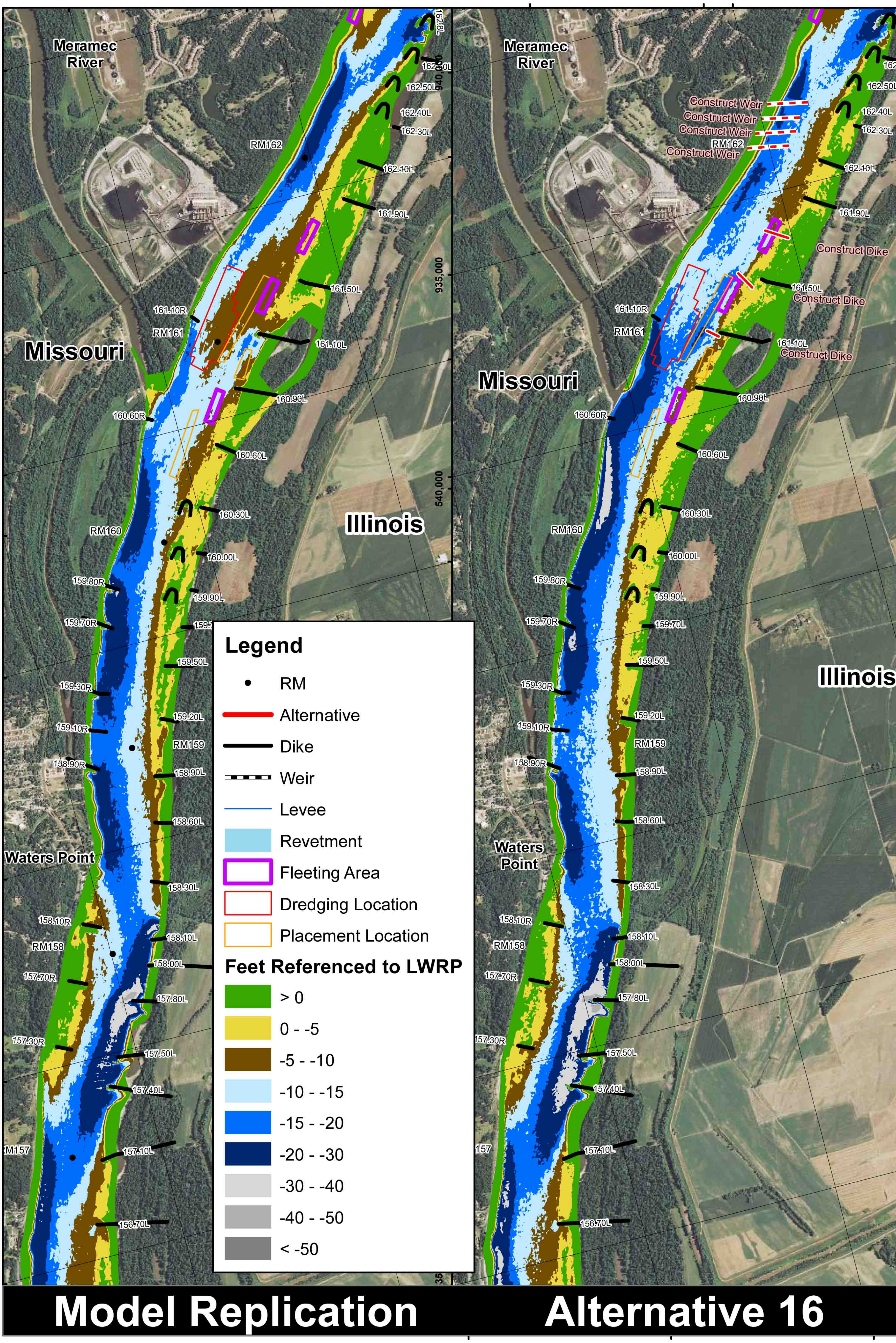


PLATE NUMBER 39

0 650 1,300 2,600 3,900 Feet

Model Replication vs Alternative 16

2012 Aerial Photograph

U.S. ARMY ENGINEER DIVISION CORPS OF ENGINEERS ST. LOUIS, MISSOURI	DESIGNED BY: B Krischel		SURVEY DATE: 04/10/14
	DRAWN BY: B Krischel	REVIEWED BY: T Lauth, P.E.	CHECKED BY: R Davinroy, P.E.
Mississippi River Basin St. Louis District Mouth of Meramec HSR Model	SUBMITTED: B Krischel		APPROVED: Rob Davinroy, P.E.
	FILE NAME: L:\Mouth of the Meramec\Plates		PLOT DATE: 04/22/2014

APPLIED RIVER ENGINEERING CENTER

US Army Corps of Engineers St. Louis District