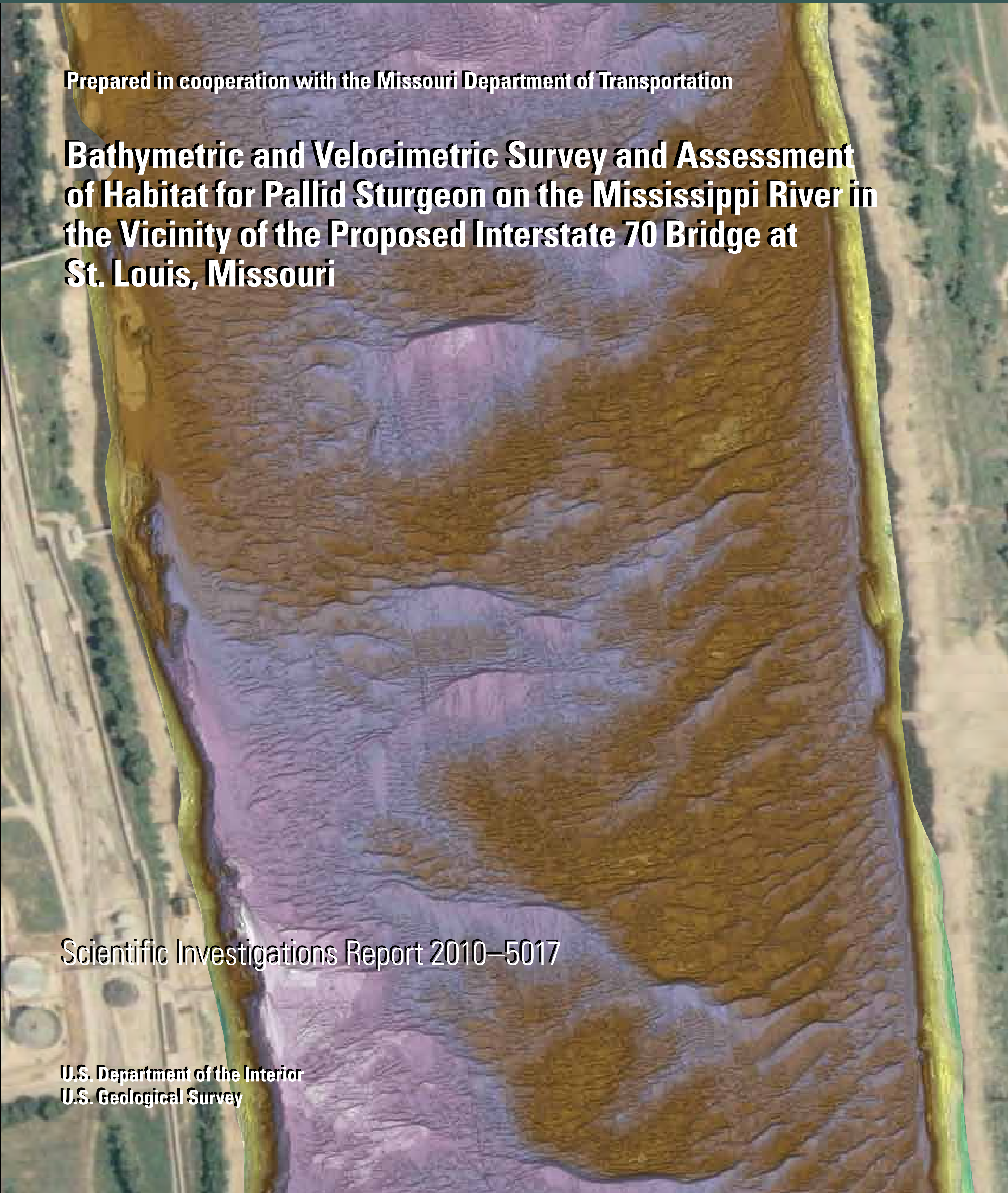

Prepared in cooperation with the Missouri Department of Transportation

Bathymetric and Velocimetric Survey and Assessment of Habitat for Pallid Sturgeon on the Mississippi River in the Vicinity of the Proposed Interstate 70 Bridge at St. Louis, Missouri

Scientific Investigations Report 2010–5017

U.S. Department of the Interior
U.S. Geological Survey

Cover: Bathymetry of the Mississippi River channel in the vicinity of the proposed Interstate 70 bridge at St. Louis, Missouri.

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U.S. Department of the Interior
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Conversion Factors and Datums

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Flow rate	
foot per second (ft/s)	0.3048	meter per second (m/s)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

In this report, the words “left” and “right” generally refer to directions that would be reported by an observer facing downstream.

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Bathymetric and Velocimetric Survey and Assessment of Habitat for Pallid Sturgeon on the Mississippi River in the Vicinity of the Proposed Interstate 70 Bridge at St. Louis, Missouri

By Richard J. Huizinga, Caroline M. Elliott, and Robert B. Jacobson

Abstract

A bathymetric and velocimetry survey was conducted on the Mississippi River in the vicinity of a proposed new bridge for Interstate 70 at St. Louis, Missouri. A multibeam echo sounder mapping system and an acoustic Doppler current profiler were used to obtain channel-bed elevations and vertically averaged and near-bed velocities for a 3,545-foot (1,080-meter) long reach of the Mississippi River approximately 1,935 feet (590 meters) wide from the Illinois to Missouri banks. Data from the 2009 survey were used to determine the conditions of the benthic habitat in the vicinity of the proposed Interstate 70 bridge.

The channel-bed elevations ranged from approximately 346 feet (105.46 meters) to 370 feet (112.78 meters) above the North American Vertical Datum of 1988 in a majority of the channel except for the channel banks. Large dune features up to 12.5 feet (3.81 meters) high were present in the middle of the channel, and numerous smaller dunes and many ripples as smaller features were superimposed on the larger dunes. However, it is uncertain if the large dune features present in mid-channel are long-term features or an artifact of the seasonal flooding on the Mississippi River. A substantial scour depression was present on the right descending bank (Missouri side) near the downstream end of the study area, as well as other smaller scour holes near the instream barge mooring structures on the Missouri bank.

The vertically averaged velocities acquired with the acoustic Doppler current profiler ranged from approximately 2 feet per second (0.61 meters per second) along the channel margins to approximately 7.0 feet per second (2.13 meters per second) in the main channel, with an average velocity of 5.5 feet per second (1.68 meters per second) in mid-channel. The orientation of the vertically averaged velocity vectors showed flow crossing from the Illinois bank to the Missouri bank from upstream to downstream in the study area, which was confirmed by the orientation of the large dune features in mid-channel and a shift in the channel thalweg from the Illinois bank to the Missouri bank. The near-bottom velocities acquired with the acoustic Doppler current profiler ranged from 0.3 to 7.0 feet per second (0.09 to 2.13 meters per second), and the effects of the large dune features were apparent in the more random scattering of the velocity vectors, the low velocities downstream from the dunes, and higher velocities near the crests of the dunes.

Despite the considerable physical complexity of this site because of the arrangement of large sand dunes in the middle of the channel, existing studies do not document persistent use of these deep, fast, main-channel habitats by pallid sturgeon. Narrow channel-margin areas on both banks having relatively low velocity, high depth slope, and high velocity gradients are similar to adult migration habitats as documented on the Missouri River downstream from Kansas City, Missouri. Although the reach generally lacks features associated with sturgeon habitat selection on the Middle Mississippi River, the barge mooring areas on the right descending bank have topographic complexity and contain large woody debris and small patches of probable gravel-cobble substrate that may have positive habitat value for sturgeon or other species. Furthermore, telemetry studies have documented sturgeon migrating upstream and downstream through this reach as adults, and they probably drift downstream through this reach as free-embryo larvae. Successful upstream migration may depend on availability of areas with hydraulic complexity and relatively low velocities, as presently exist on the margins of the site. Additionally, complexity at the channel margin may provide areas where larvae settle out from drifting in the main current or may act to slow bulk drift rates. Construction of bridge piers close to the banks will likely alter hydraulics and sediment transport on the channel margins and may result in substantial changes to potential migration habitat near the piers and banks. Changes to habitat because of construction could be assessed with post-construction replication of the surveys presented in this report.

Introduction

Built on the banks of the Mississippi River, St. Louis, Missouri, has been a hub of commerce and trade for over two centuries. However, transportation of people and goods across the formidable boundary created by the Mississippi River has always required substantial effort. Early crossings were made by boat, but the commercial advantages of more permanent solutions were sought. The first bridge to span the Mississippi River in St. Louis was the Eads Bridge, built in 1874 (Mound City on the Mississippi, 2010), and since that time many other bridges have been built to accommodate vehicle and train traffic across the river (Wikipedia, 2010). The existing Poplar Street Bridge was finished in 1968 and currently (2010) carries traffic from three interstate highways as well as local downtown traffic across the river. In an effort to relieve traffic congestion on the Poplar Street Bridge, the Departments of Transportation for Missouri (MoDOT) and Illinois (IDOT) have proposed to construct a new bridge across the Mississippi River, diverting traffic from Interstate 70 (I-70) to this proposed bridge.

However, fish and other aquatic wildlife make their home in the Mississippi River. Bridge piers inserted into the flow will have an effect on velocities in the river and may potentially change the habitat for various forms of aquatic wildlife. Of particular concern are pallid sturgeon (*Scaphirhynchus albus*), a Federally listed endangered species. Alterations to their habitat can be detrimental to their survival and may be inconsistent with protections afforded under the Endangered Species Act. Therefore, the U.S. Geological Survey (USGS), in cooperation with the Missouri Department of Transportation (MoDOT), conducted a bathymetric and velocimetric survey to measure the current (2009) benthic habitat conditions in the vicinity of the proposed I-70 bridge and to assess the quality of potential pallid sturgeon habitat.

Purpose and Scope

The purpose of this report is to document equipment and methods used and results obtained from a bathymetric and velocimetric survey of part of the Mississippi River in the vicinity of a proposed bridge for I-70 at St. Louis, Missouri. The results obtained from the bathymetric and velocimetric survey of the channel were used to assess the area for potential pallid sturgeon habitat.

Description of Proposed Interstate 70 Bridge Project

The Poplar Street Bridge (fig. 1) was finished in 1968 and currently conveys traffic from three interstate highways across the Mississippi River. On the Missouri side, Interstate 55 (I-55) from the south, Interstate 64 (I-64) from the west, and I-70 from the northwest all converge at this one bridge to cross the river on the south side of downtown St. Louis. The volume of traffic combined with rapid convergence and divergence of the interstate highways on either side of the river results in frequent traffic congestion and crashes (Federal Highway Administration, 2001).

To improve traffic flow and efficiency in this area, a new bridge is proposed across the Mississippi River approximately 2 miles [mi; 3.22 kilometers (km)] upstream from the existing Poplar Street Bridge (New Mississippi River Bridge, 2010; fig. 1), which will divert traffic from I-70 north of downtown St. Louis. The overall proposed project includes the new bridge and several connector highways, as well as improvements to sections of existing highways and interchanges (fig. 1).

Description of Study Area

The study area for this report is a part of the Mississippi River at St. Louis, Missouri (fig. 2), which is the site of the proposed new bridge for I-70. The study area is approximately 3,545 feet [ft; 1,080 meters (m)] long and extends approximately 1,445 ft (440 m) upstream and 2,100 ft (640 m) downstream from the proposed centerline of the new I-70 bridge, from the Illinois to the Missouri banks of the river, or approximately 1,935 ft (590 m) wide (fig. 2). The upstream and downstream boundaries of the study area are assumed to be beyond the localized effects on flow that might be caused by the proposed I-70 bridge piers.

Based on bed-sediment core samples obtained in the study area, the predominant bed-sediment material is medium to coarse sand (Bree McMurray, Missouri Department of Transportation, written commun., 2009), which is the common bed sediment found in this part of the Mississippi River (Meade, 1995; Keown and others, 1981, 1986). The right descending bank (the Missouri bank) is covered with revetment in the form of large rock cobbles and broken concrete debris. There is a short rock dike or outcrop at the upstream end of the study area on the left descending bank (the Illinois bank; fig. 2), and there appear to be a few isolated areas of revetment in the form of rock cobbles, primarily near the downstream end of the study area. There are several docks and instream barge mooring structures (hereinafter referred to as “mooring dolphins”) for industries located on the right descending bank, and there is a single barge mooring area on the left descending bank near the middle of the study area (fig. 2).

Bathymetric and Velocimetric Survey

The bathymetry of the Mississippi River in the study area was determined using a high-resolution multibeam mapping system. Velocities were determined using an acoustic Doppler current profiler (ADCP).

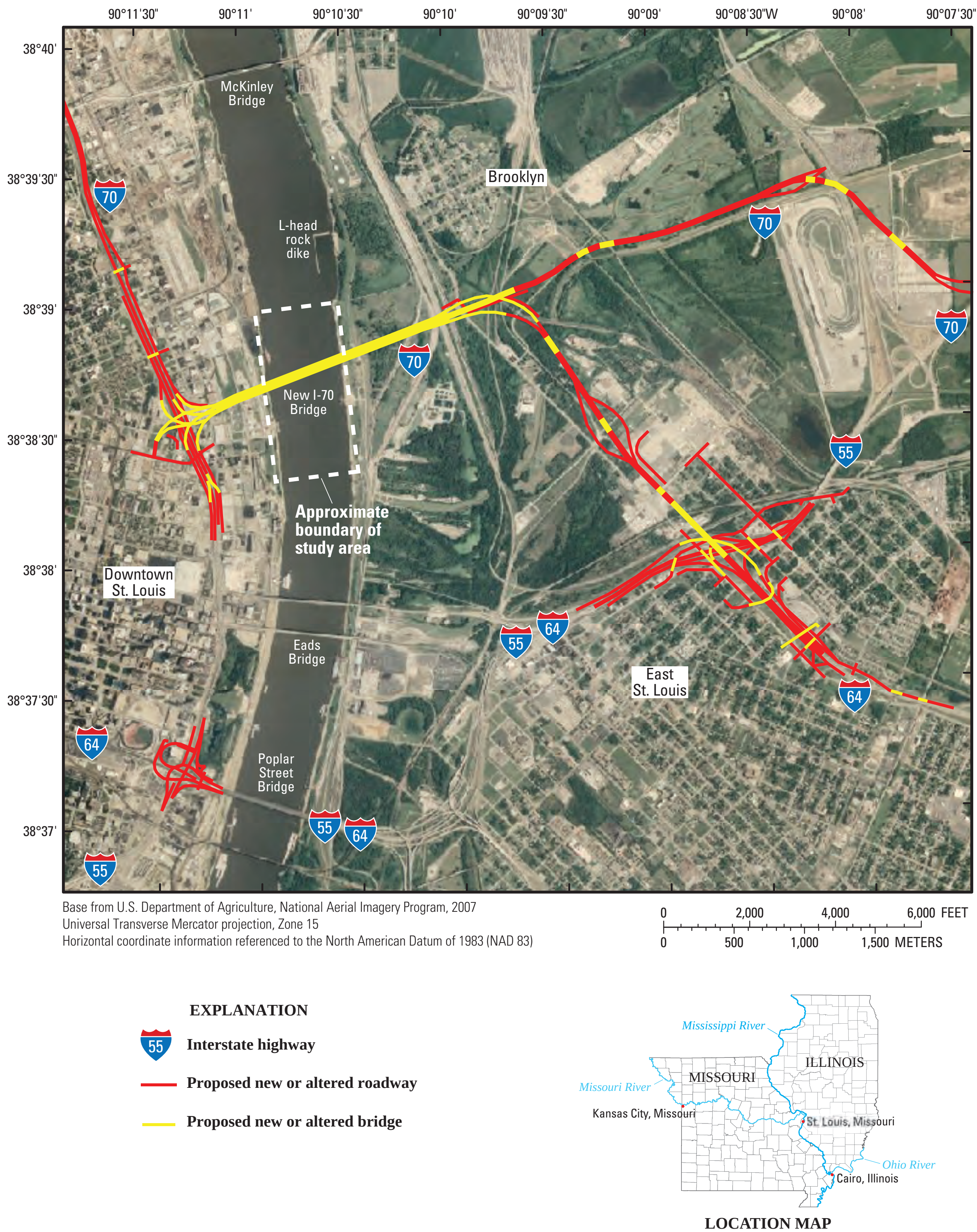

Figure 1. Overall project concept for the new Mississippi River bridge for Interstate 70 at St. Louis, Missouri (from New Mississippi River Bridge, 2010).

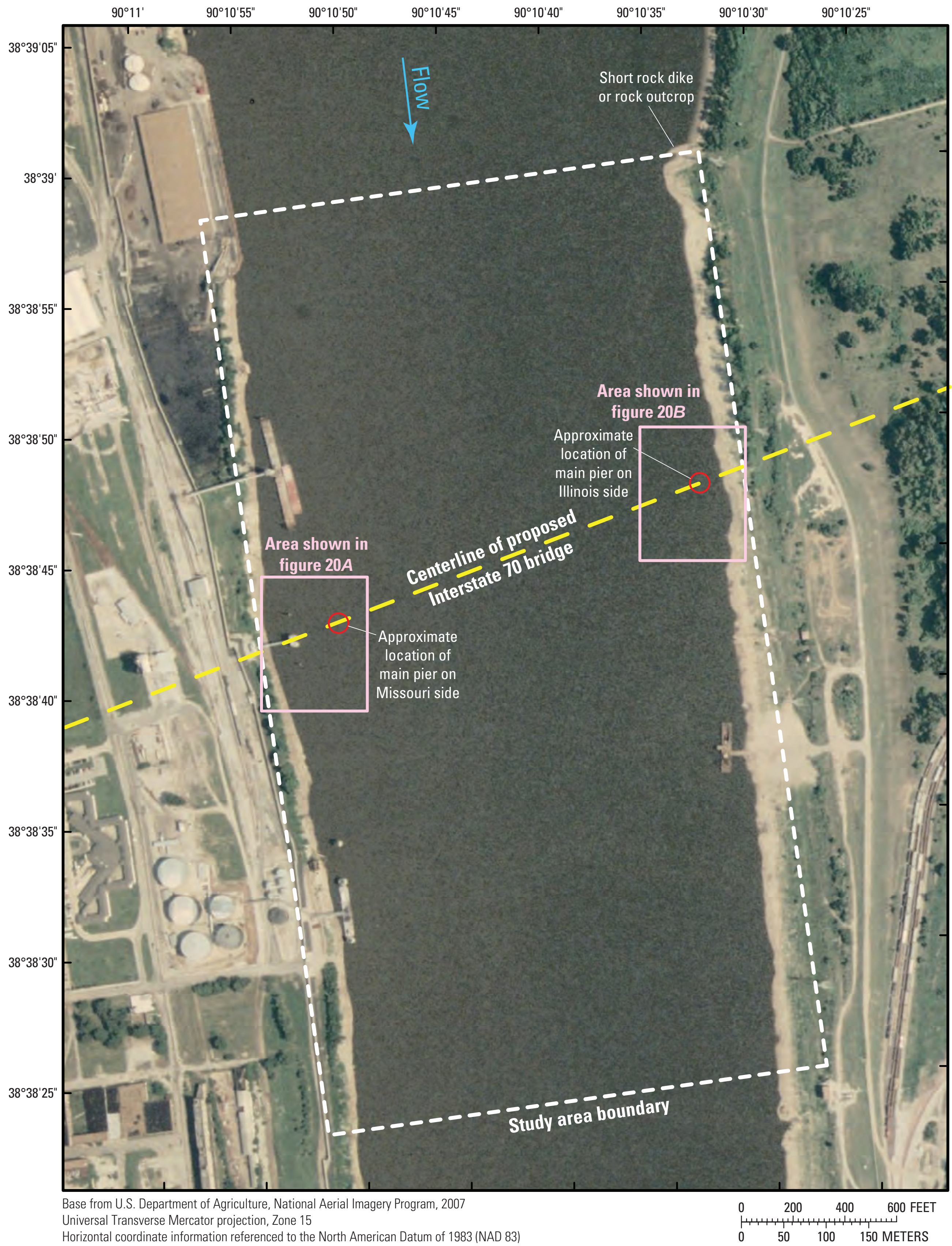

Figure 2. The study area on the Mississippi River at St. Louis, Missouri.

Description of Equipment

A multibeam mapping system is an integration of several individual components: the multibeam echo sounder (MBES) itself, a navigation and motion-sensing system, and a data collection and processing computer. The navigation system accurately locates the multibeam echo sounder in three-dimensional space, while the motion-sensing system measures the heave, pitch, roll and heading of the vessel (and, thereby, the MBES) to accurately position the data received by the MBES. The data from the MBES and navigation and motion-sensing components are processed and integrated into a cohesive dataset for cleanup and visualization by the data collection and processing computer. The various components of the multibeam mapping system used for this study are discussed below, followed by a description of the ADCP system used to obtain the velocity data.

RESON SeaBat™ 7125 Multibeam Echo Sounder

The RESON SeaBat™ 7125 MBES consists of projector and receiver arrays of piezoceramics (fig. 3*A*) operating at a frequency of 400 kilohertz (kHz) attached to a fixed, tiltable head mounted on a retracting pole on the port side of the USGS Missouri Water Science Center (MoWSC) survey boat (figs. 3 and 4). A sound-velocity probe (SVP-71) also is attached to the head to accurately measure the speed of sound in water near the projector and receiver arrays, which is critical to the accurate determination of depth (Hughes-Clarke and others, 1996; RESON, Inc., 2008; fig. 3*B*).

The projector and receiver arrays can operate in depths from 3 to 656 ft (1 to 200 m). The projector array emits one sound wave that the receiver array forms into 512 equidistant beams with a spacing of less than 0.25 degrees (°) distributed across the ship track and 1° wide along the track (fig. 5). This beam geometry can generate up to a 128° swath that can cover up to 4.1 times the water depth across track (fig. 5) with up to 512 depth readings with each sounding.

Settings for and data from the MBES are processed through the RESON 7K Controller software (RESON, Inc., 2008) on the 7-P Sonar Processing Unit computer (hereinafter referred to as “the 7-P”). Settings such as sonar depth range, projector power, maximum ping rate, pulse length, receiver gain, spreading coefficients, and sound absorption losses are displayed and adjusted through the 7K Controller software, and the depth soundings being received by the MBES are shown on the computer display. Various diagnostic tools and displays are available in the 7K Controller software as well.

Applanix POS MV™

The Applanix Position Orientation Solution for Marine Vessels (POS MV™) WaveMaster system utilizes dual Trimble Zephyr Global Positioning System (GPS) antennae

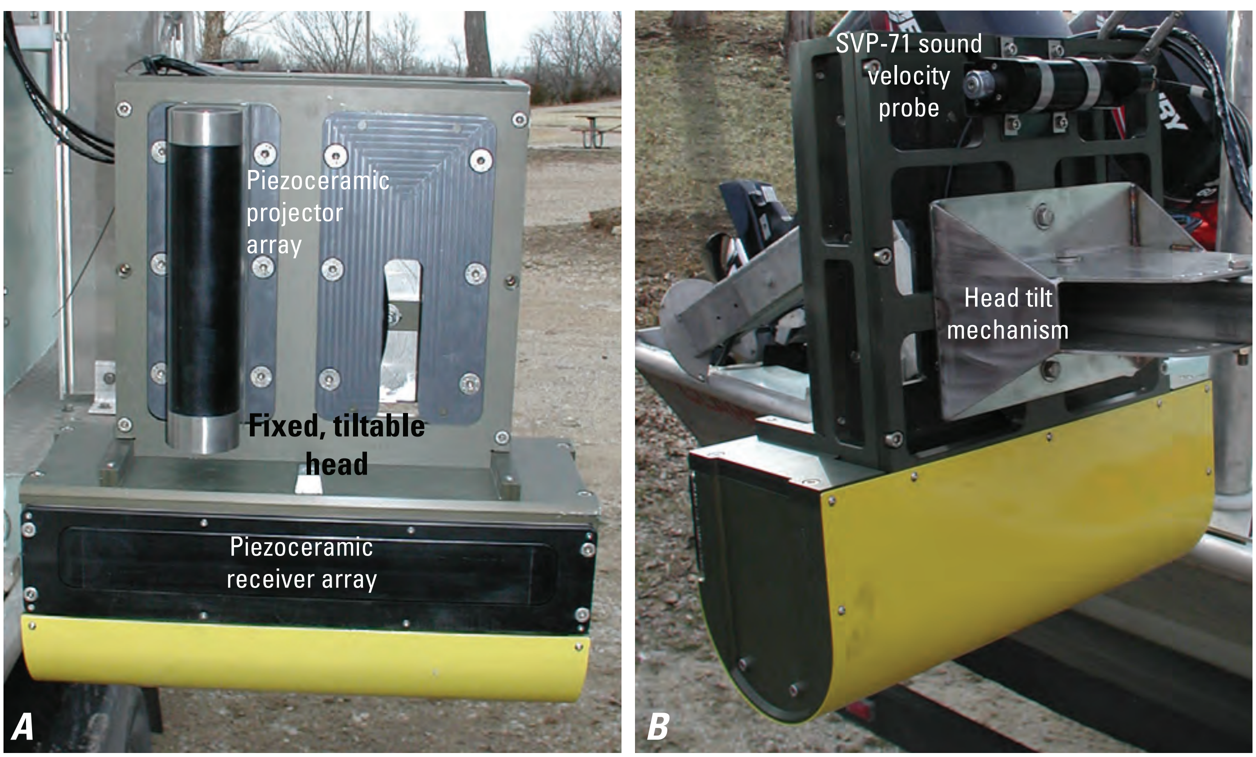

Figure 3. The RESON SeaBat™ 7125 multibeam echo sounder system as viewed from (*A*) the bottom, and (*B*) the top.

Figure 4. The RESON SeaBat™ 7125 multibeam echo sounder system on the port side of the U.S. Geological Survey Missouri Water Science Center survey boat.

combined with an inertial motion unit (IMU) for navigation and vessel motion sensing. The dual GPS antennae provide stand-alone GPS position accuracy for the navigation of the boat of approximately +/- 32.8 ft (10 m); however, the navigation solution was improved to +/- 0.79 inches [in.; 2 centimeters (cm)] in the absence of structures that might block signal from the GPS constellation of satellites through utilization of a radio link to an additional, fixed GPS base station on the Missouri bank, which provided a real-time kinetic (RTK) navigation and tide solution (Applanix Corporation, 2006).

The IMU records vessel motion (pitch, roll, yaw, and heave) with an accuracy of 0.03° for pitch, roll, and yaw, and

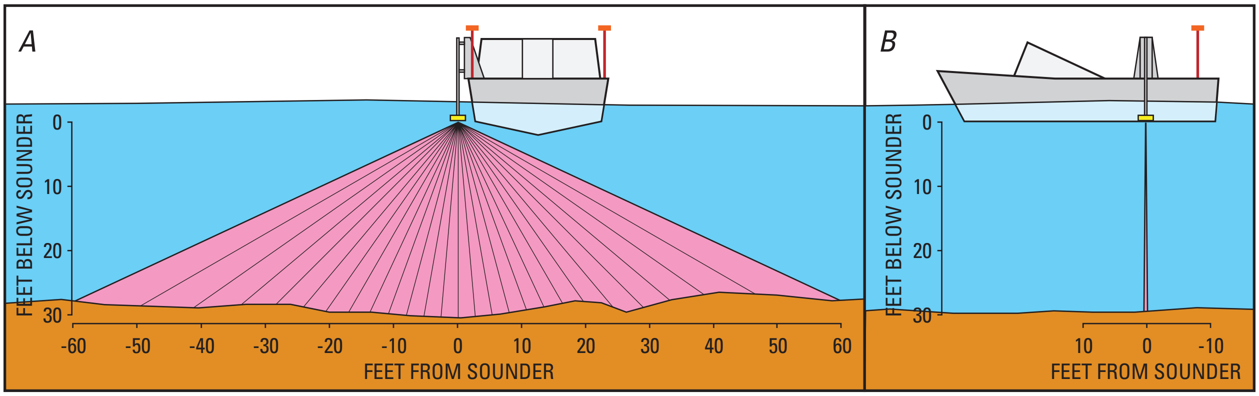

Figure 5. Approximate beam geometry of RESON SeaBat™ 7125 multibeam echo sounder (*A*) across ship track and (*B*) along ship track.

5 percent of heave amplitude, or 1.96 in. (5 cm), whichever is greater (Applanix Corporation, 2006). The IMU is used to measure the vessel motion, so that data received from the MBES can be correctly positioned in three-dimensional space as the vessel rotates and moves on the water surface. The IMU also provides an inertial position solution that is reliable through RTK outages for periods of less than about 1 minute.

Settings for and data from the Applanix POS MV™ are processed through the MV-POSView Controller software (Applanix Corporation, 2006) on the 7-P computer. Offsets for the GPS antennae and IMU relative to the vessel center of rotation are entered to accurately translate the motion of the vessel into true roll, pitch, yaw, and heave. Vessel speed and elevation also are obtained. Various navigation and motion-sensing diagnostic tools are available in the MV-POSView Controller software.

Field Computer and HYPACK®/HYSWEEP® Data Acquisition Software

A laptop field computer onboard the MoWSC survey boat runs the HYPACK®/HYSWEEP® data acquisition software (HYPACK, Inc, 2007a, 2007b; hereinafter referred to as “the HYPACK® computer”), which is used to prepare for the bathymetric survey, collect and process the survey data, and create various output products from the survey. A map or other background image of the survey area can be imported and used to plan the location of survey lines. The bathymetric sounding data and the navigation and position solution collected and processed by the 7-P computer are transmitted by high-speed Local Area Network (LAN) Ethernet connection to the HYPACK® computer. During the survey, the navigation and position solution from the POS MV™ are used in conjunction with the survey lines to keep the survey boat on a proper heading by means of a helms display for the boat captain. Continual screen refreshing provides a low-resolution near real-time map of the survey as it progresses, which permits the immediate reacquisition of data in areas that might be missed during the survey.

Upon completion of the survey, the acquired depth data can be processed using the HYPACK®/HYSWEEP® software to remove data spikes and other spurious points in the multibeam swath trace. There are a variety of tools and filters in HYPACK®/HYSWEEP® that can be utilized to identify and selectively remove potential erroneous data points. After cleanup, the data are georeferenced using the navigation and position solution data from the POS MV™, and can be visualized in HYPACK®/HYSWEEP® as a Triangulated Irregular Network (TIN) surface or a point cloud. The data can be output to an ASCII XYZ file with no data reduction or filtered and reduced based on a desired data resolution.

In addition to the depth readings, the intensity of the signal return is recorded with each sounding. When a series of these signal-intensity returns are combined and displayed along a survey line, a two-dimensional image of the channel bed along either side of the vessel is formed, called a “side-scan” image. Sidescan imagery can be georeferenced using the navigation and position solution from the POS MV™ and used in conjunction with the bathymetry data to locate and identify features and conditions on the channel bed.

Acoustic Doppler Current Profiler

Information about the velocity of the river at various points throughout the study reach was obtained by means of an acoustic Doppler current profiler, or “ADCP” (fig. 6). A Teledyne RD Instruments Rio Grande ADCP operating at 600 kHz was used to obtain velocities at 0.5-m increments, or “bins,” throughout the water column. The Rio Grande ADCP operates in depths from 2.3 to 245 ft (0.7 to 75 m), and determines the velocity of the water by measuring the Doppler shift of an acoustic signal reflected from various particles suspended in

Figure 6. The Teledyne RD Instruments Rio Grande acoustic Doppler current profiler and differential Global Positioning System antenna on the starboard side of the U.S. Geological Survey Missouri Water Science Center survey boat.

the water (Mueller and Wagner, 2009). By measuring the Doppler shift in four different beam directions, the velocity of the water in each bin can be determined in three dimensions.

Although the POS MV™ provides a relatively precise location of the boat for the bathymetric survey, the location of the ADCP in space was determined by means of a single differential GPS (DGPS) antenna mounted on a pole above the ADCP (fig. 6) because of problems with interfacing the ADCP and POS MV™ data in HYPACK® (Joe Burnett, HYPACK, Inc., oral commun., 2009). Nevertheless, the DGPS navigation solution provides a position accuracy of +/- 1.64 ft (0.5 m) to the ADCP.

Description of Survey Methods

The survey was conducted on July 7, 2009. The Mississippi River was flowing at approximately 295,000 cubic feet per second [ft^3/s; 8,350 cubic meters per second (m^3/s)] during the survey, based on data from the USGS streamgage (station 07010000, Mississippi River at St. Louis, Missouri; U.S. Geological Survey, 2010) located on the Eads Bridge downstream from the study area (fig. 1). First, the bathymetric data were obtained with the MBES, and then the velocity data were obtained with the ADCP.

The GPS base station used for the RTK navigation and tide solution during the survey was set up on the Missouri bank, near the proposed location of the main pier on the Missouri side (figs. 2 and 7). Before the survey began, the MBES indicated depths ranging from 40 to 50 ft (12 to 15 m) in the middle of the channel. In order to ensure complete coverage of the channel bed and minimize sonic "shadows," the survey was planned such that there would be 200 percent coverage of the channel bed. Sonic "shadows" occur when a tall feature is present in the water column, preventing soundings immediately behind the object (fig. 8). Knowing that the beam geometry of the MBES provides a swath width that is approximately 4.1 times the depth across track (fig. 5) and using the MBES transducer head as the tracking point, survey lines were spaced 82 ft (25 m) apart to provide approximately 200 percent coverage of the channel bed, and coverage on both sides of any feature that might create a sonic "shadow" (fig. 8). Substantial overlap was achieved for all of the surveyed lines, except for lines 1 and 21 along the Missouri and Illinois channel banks and areas near moored barges on the banks. Furthermore, it was possible to remove the outermost beams from the swath without compromising coverage. The outer beams are most susceptible to small errors in boat position and attitude or the effects of refraction (Hughes-Clarke and others, 1996).

Channel-bed coverage along the survey line is dependent upon the speed of the vessel relative to the channel bottom (hereinafter referred to as "absolute boat speed") and the ping rate of the MBES. In the riverine environment, the survey boat has to have enough forward velocity to overcome the current and make headway on upstream passes, whereas on downstream passes, the survey boat has to have enough forward velocity to maintain steerage. Therefore, the survey boat always has greater speed relative to the channel bed when traveling downstream than when traveling upstream in the riverine environment. On the day of the survey, the Mississippi River was flowing at a velocity of about 3 to 3.5 knots or approximately 5 to 6 feet per second [ft/s; 1.52 to 1.83 meters per second (m/s)]. Consequently, when traveling downstream, the absolute boat speed was approximately 6 knots (10.1 ft/s or 3.08 m/s), whereas when traveling upstream, the absolute boat speed was approximately 3 knots (5.1 ft/s or 1.55 m/s). In order to provide equivalent coverage in the upstream and downstream directions, the ping rate of the MBES was altered relative to the absolute boat speed. For downstream passes with an absolute boat speed of 6 knots, the ping rate was set to 20 pings per second, which provided one ping approximately every 0.5 ft (0.15 m). For upstream passes with an absolute boat speed of 3 knots, the ping rate was set to 10 pings per second, which again provided one ping approximately every 0.5 ft (0.15 m). For passes near the channel banks, where the current was not as strong, the ping rate was set relative to the absolute boat speed to maintain the approximate 0.5 ft per ping coverage; for example, with an absolute boat speed of 4 to 5 knots, the ping rate was set to 15 pings per second.

As mentioned in the Description of Equipment section, the speed of sound in water is critical to the accurate measurement of distances using a MBES (Hughes-Clarke and others, 1996), and is dependent upon several factors, the primary of which are temperature, salinity, and pressure. In a lake or ocean setting, routine sound-velocity profile casts are taken during a survey to determine the presence of thermoclines and accurately measure the speed of sound throughout the water column. However, in the riverine environment, it is assumed that flow mixing is occurring, such that the speed of sound as measured at the water surface is the same throughout the water column. Nevertheless, pockets of warm or cool water were present near the water surface on the day of the survey. When one of these pockets was encountered, it had the effect of changing the speed of sound as measured by the SVP-71 on the MBES transducer head (fig. 3*B*), which invariably altered the measured depth to the channel bed for the duration of several pings of the MBES.

Two techniques were used to mitigate the effects of these temperature changes. First, an "ambient" speed of sound in water was determined during several survey lines, and this value (4,905 ft/s or 1,495 m/s) was used to override the value being measured and updated by the SVP-71, which resulted in fewer incorrectly refracted swaths. Second, for the survey lines in the middle of the channel, the swath was limited to 45° from nadir or 90° total, removing the outer 19° of the swath on either side. As mentioned in the Description of Equipment section, these outer beams are most susceptible to the effects of refraction (Hughes-Clarke and others, 1996). The outer beams were not removed from survey lines near the channel banks to limit gaps in channel-bed coverage in these shallow areas, and warm and cool water pockets generally were not encountered in these areas.

After completion of the bathymetric survey with the MBES, the velocity data were obtained with the ADCP along 22 transects across the channel within the study area. Unlike the bathymetry data obtained along predefined longitudinal survey lines (fig. 7), the velocity data were obtained along unplanned transects that were a simple lateral traverse of the river at approximately right angles to the average flow direction with a slight downstream trend. In this way, velocity data were obtained in a zig-zag pattern across the study area. Each lateral traverse of the river was considered a separate transect. The average distance between transects was about 155 ft (47.2 m).

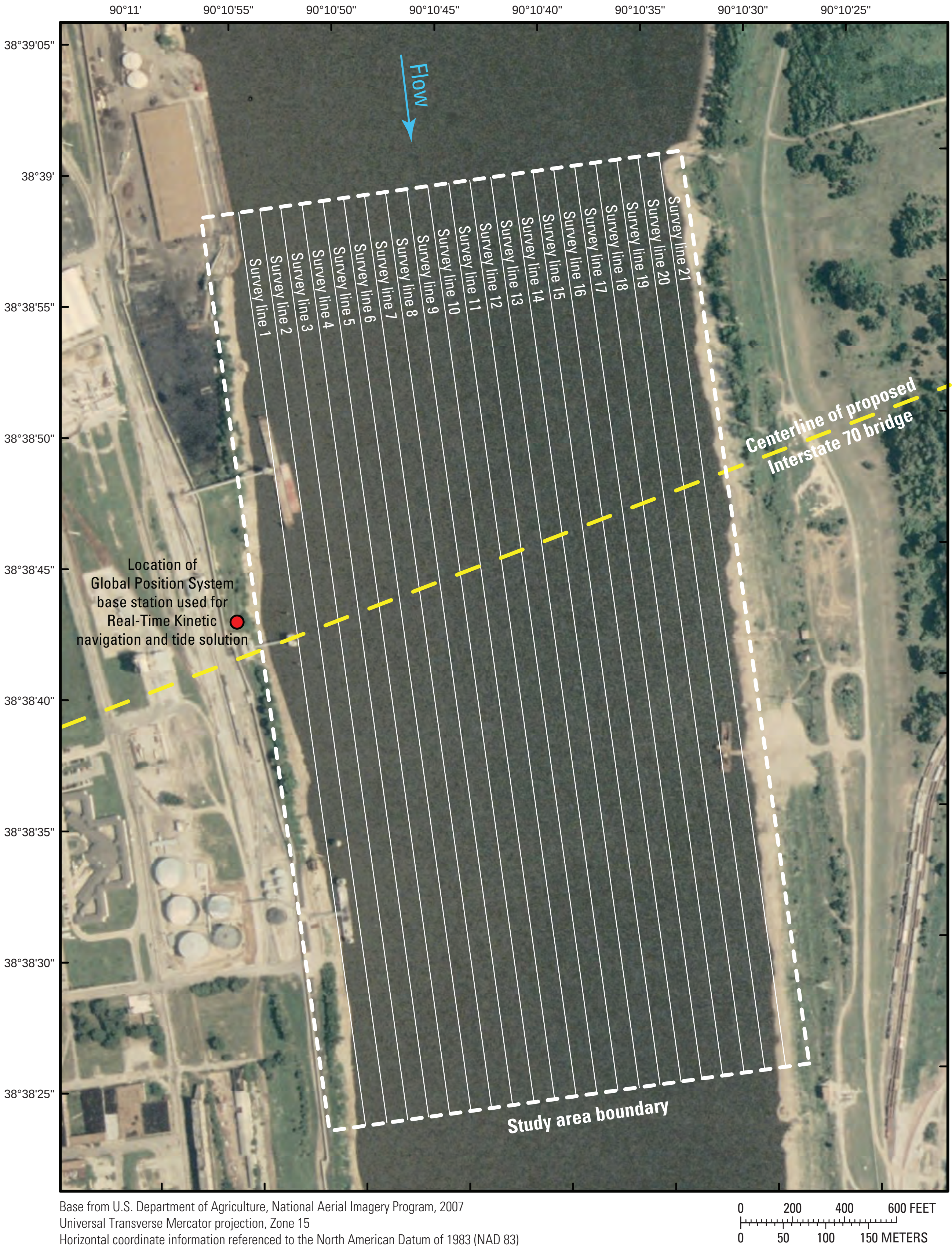

Figure 7. Survey setup and planned survey lines used to obtain bathymetric data in the study area on the Mississippi River at St. Louis, Missouri.

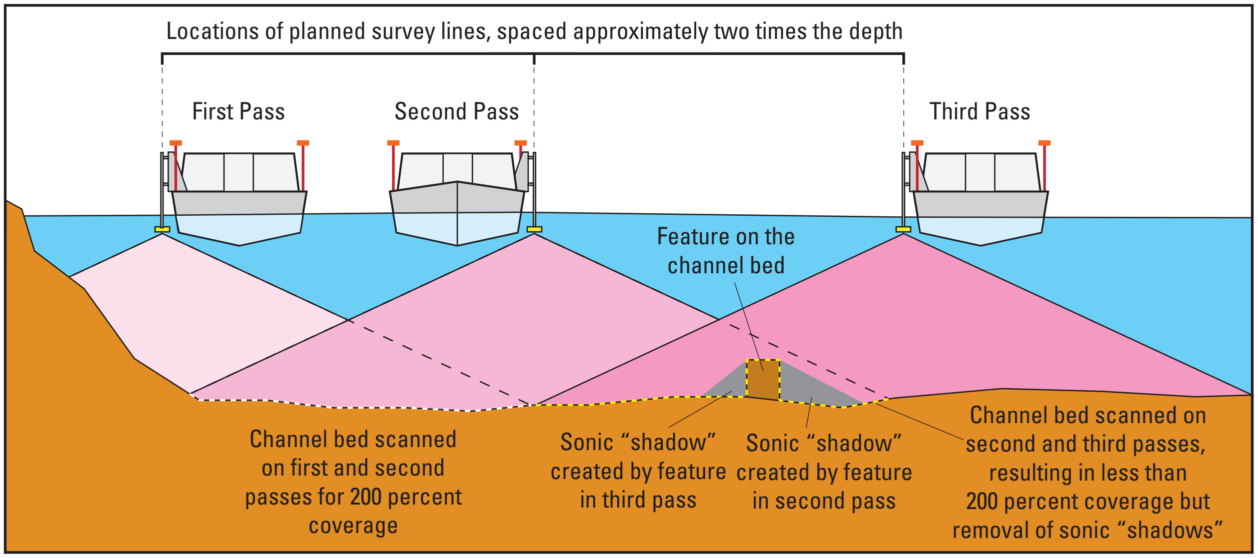

Figure 8. Method of survey line spacing used to ensure complete coverage of the channel bed and minimize sonic "shadows."

Survey Quality-Assurance/Quality-Control Measures

A quality-assurance plan has been established for discharge measurements using ADCPs (Oberg and others, 2005), including several instrument diagnostic checks and calibrations. These standard operating procedures were followed when acquiring the velocity profile data for this survey. For a detailed discussion of these procedures, see Oberg and others (2005).

For the MBES mapping system, the principal quality-assurance assessments for this survey were performed in real time during the survey. The MBES operator was constantly assessing the quality of the data during collection, making visual observations of across-track swaths (such as convex, concave, or skewed bed returns in flat, smooth bottoms), noting data quality flags and alarms from the MBES and POS MV™, and noting comparisons between adjacent overlapping swaths. However, in addition to the real-time quality-assurance assessments during the survey, there are several tests that were performed to ensure the quality of the data acquired by the MBES mapping system. For this survey, a beam angle check and a suite of patch tests were performed to ensure quality data were acquired from the MBES mapping system.

Beam Angle Check

A beam angle check is used to determine the accuracy of the depth readings obtained by the outer beams of the MBES (U.S. Army Corps of Engineers, 2004). A reference surface is created from a small survey of a flat area in a lake and is compared to check lines across the surface. To create the reference surface, five parallel survey lines are run that are spaced at a distance equal to the water depth. The beams outside of 30° from nadir are removed because these beams are most susceptible to effects of refraction. A second set of five parallel lines are run perpendicular to the first set, and the beams outside of 30° from nadir are removed. A sound velocity profile cast is made in the area, and the corrections are applied to the data. The data are minimally processed to remove data spikes, and the reference surface is created using a cell resolution of 1 ft by 1 ft (0.3 m by 0.3 m) with the elevation of each cell being the average of all of the individual elevations in the cell from the survey lines. The check lines are two perpendicular survey lines across the center of the reference surface using the full swath width of the MBES. In this way, the data quality from the outer beams can be assessed as compared to a reference surface.

The HYPACK®/HYSWEEP® software has a program that will perform a statistical assessment of the quality of the outer beams compared to a reference surface. On July 6, 2009, a reference surface was created for a portion of Little Prairie Lake near Rolla, Missouri, and check lines were run across the reference surface. The results of the beam angle check are shown in table 1 and are within the recommended standards utilized by the U.S. Army Corps of Engineers for hydrographic surveys (U.S. Army Corps of Engineers, 2004).

Patch Tests

Patch tests are a series of dynamic calibration tests that are run to check for subtle variations in the orientation and timing of the MBES with respect to the POS MV™ and real world coordinates. The patch tests are used to determine timing offsets caused by latency between the MBES and the POS

Table 1. Results of beam angle check from two check lines over a reference surface at Little Prairie Lake, Missouri, on July 6, 2009.

[ft, feet; <, less than: --, no data]

Beam angle limit (degrees)	Maximum outlier (ft)	Mean difference (ft)	Standard deviation (ft)	95 percent confidence (ft)
20	0.52	0	0.10	0.16
25	.33	0	.07	.16
30	.43	-.03	.07	.13
35	.62	-.03	.07	.13
40	.89	-.03	.07	.13
45	.98	-.03	.07	.13
50	.46	-.07	.07	.13
55	.52	-.03	.10	.16
60	.52	-.03	.13	.23
65	.62	-.07	.13	.26
70	.39	-.13	.03	.07
Performance standards[1]	1.00	<.20	--	<.50
Within standards	Yes	Yes	--	Yes

[1] Performance standard check values are from U.S. Army Corps of Engineers, 2004, table 3-1.

MV™, and angular offsets to roll, pitch, and yaw caused by the alignment of the transducer head.

A latency test measures the timing offset, Δt, between the MBES system and the GPS component of the POS MV™ (fig. 9*A*). In a latency test, a line that is perpendicular to a slope or distinct feature on the channel bed is surveyed twice in the same direction but at slow and fast speeds. Latency errors will appear as a horizontal offset in the slope or feature between the two surveyed lines. For this survey, there was no measured latency offset (Δt = 0), which is consistent with latency test results for this boat and configuration used in other surveys.

A roll test measures the angular offset, α, of the transducer head along the longitudinal axis of the boat, which leads to horizontal and vertical position errors of a measured channel-bed point (fig. 9*B*). In a roll test, a line over a relatively flat channel bed is surveyed twice in opposite directions at the same speed. A roll error will cause the flat bed to appear sloped in opposing directions across the reciprocal lines. For this survey, the measured roll offset, α, equals 0.65°, which is consistent with roll offset values determined for this boat during other surveys.

A pitch test measures the angular offset, β, of the transducer head in a bow or aft direction along the lateral

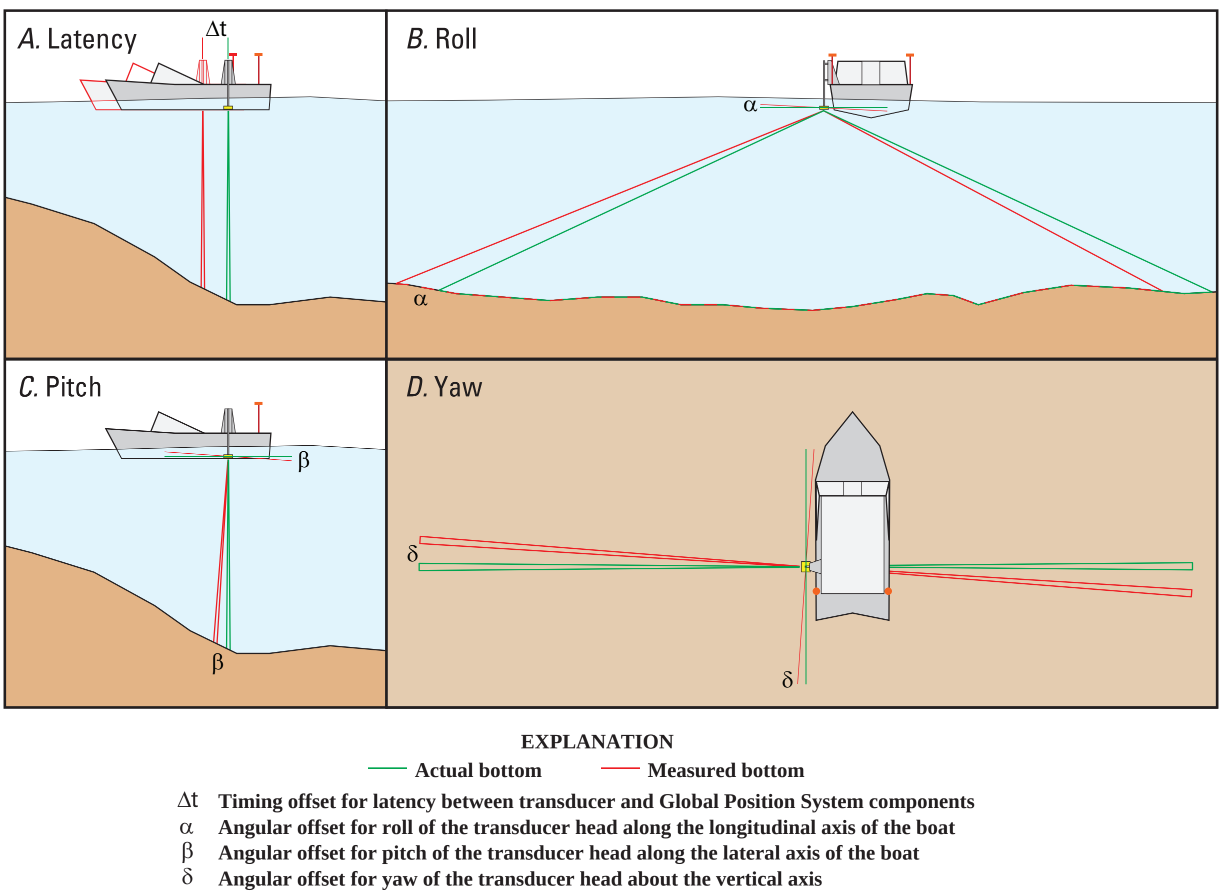

Figure 9. Effects of timing and angular offsets for (*A*) latency, (*B*) roll, (*C*) pitch, and (*D*) yaw on data from a multibeam echo sounder.

axis of the boat, which leads to horizontal position errors of a measured channel-bed point (fig. 9*C*). In a pitch test, a line that is perpendicular to a slope or distinct feature on the channel bed is surveyed twice in opposite directions at the same speed. A pitch error will appear as a horizontal offset in the slope or feature between the reciprocal lines. For this survey, the measured pitch offset, β, equals -2.40°, which is consistent with pitch offset values determined for this boat during other surveys.

A yaw test measures the angular offset, δ, of the transducer head in terms of its rotation about the vertical axis, which results in horizontal position errors of a measured channel-bed point for points in the outer beams (fig. 9*D*). In a yaw test, two lines perpendicular to a slope or distinct feature on the channel bed are surveyed in the same direction at the same speed. A yaw error will appear as a horizontal offset in the slope or feature in the area between the surveyed lines. For this survey, the measured yaw offset, δ, equals 1.10°, which is consistent with yaw offset values determined for this boat during other surveys.

Results of Bathymetric and Velocimetric Survey

The bathymetric data were processed to apply the patch test corrections and remove data spikes and other spurious points in the multibeam swaths. The bathymetry data were then output to an averaged ASCII XYZ grid at a resolution of 1 m. Velocity data were processed through the WinRiver II software (Teledyne RD Instruments, 2007) and were output as data points with a two-dimensional XY planar position and an averaged velocity magnitude and direction.

The XYZ bathymetry data were used to generate a TIN of the channel bed (fig. 10). The channel-bed elevations ranged from approximately 346 ft (105.46 m) to 370 ft (112.78 m) above NAVD 88 for a majority of the channel except for the channel banks. The vertical accuracy of the bed elevations is +/- 0.03 ft (0.01 m). There were several large dune features up to 12.5 ft (3.81 m) high in the middle of the channel, and numerous smaller dunes and many ripples were superimposed on the larger dunes. A substantial scour depression existed on the Missouri bank near the downstream end of the study area, approximately 700 ft downstream from the proposed pier location, and other smaller scour holes existed near the mooring dolphins on the Missouri bank.

It is uncertain if the large dune features present in mid-channel were long-term features or an artifact of seasonal flooding on the Mississippi River. Comparisons can be made from MBES scans of the Mississippi River channel bed in the vicinity of the Jefferson Barracks Bridge on Interstate 255 on the south side of St. Louis made by the MoWSC survey boat and MBES that occurred on October 2–3, 2008, May 12–13, 2009, and July 8, 2009, as part of another study (Rydlund, 2009; fig. 11). The October 2008 scan occurred during moderate- to low-flow conditions after the end of the 2008 flood season, and no large dunes were present. The May 2009 scan occurred during moderate high-flow conditions in the middle of the 2009 flood season, and only a few poorly formed large dunes were present at that time. However, numerous, well-formed large dunes were present during the scan on July 8, 2009, which was the day after the scan at the proposed I-70 bridge site and occurred towards the end of the 2009 flood season. It is presumed that the large dune features present at the proposed I-70 bridge site were an artifact of the 2009 flood season that may have disappeared later in the fall of 2009 and were not a long-term feature at the site.

The velocity profile data acquired with the ADCP were averaged at a given location to provide a vertically averaged velocity for points throughout the study area (fig. 12). The vertically averaged velocities ranged from approximately 2 ft/s (0.61 m/s) along the Illinois and Missouri banks to an average of approximately 5.5 ft/s (1.68 m/s) in mid-channel. There were several low velocity areas, such as near the Illinois bank, as well as local velocity spikes as high as 7.0 ft/s (2.13 m/s; fig. 12).

The orientation of the vertically averaged velocity vectors shows that flow was crossing from the Illinois bank to the Missouri bank from upstream to downstream in the study area (fig. 12). The large dune features and the channel thalweg also appeared to cross from Illinois to Missouri (fig. 10). The study area is located on a gradual bend in the river (fig. 1), and flow crossing from Illinois to Missouri in this reach means flow was crossing from the outside of the channel bend to the inside, which is not a natural phenomenon. A large L-head rock dike protrudes from the Illinois bank upstream from the study area (fig. 1), and this dike appears to be the primary cause of the flow crossing. The short rock dike or outcrop at the upstream end of the study area (fig. 2) likely contributes to the flow crossing as well. The location at which the thalweg meets the Missouri bank is the location of the large scour depression in the downstream part of the study area (fig. 10).

Velocities near the channel bottom also were extracted from the velocity profile data acquired with the ADCP for points throughout the study area (fig. 13). The near-bottom velocities ranged from 0.3 to 7.0 ft/s (0.09 to 2.13 m/s), and the effects of the large dune features were apparent in the random scattering of the velocity vectors, low velocities downstream from the dunes, and higher velocities near the crests of the dunes.

Assessment of Habitat for Pallid Sturgeon

The proposed I-70 Mississippi River bridge site is located near the upstream end of the Middle Mississippi River, which is the reach of the Mississippi River between its confluence with the Missouri River near St. Louis, Missouri, and the Ohio River near Cairo, Illinois (fig. 1). Habitat assessment at the proposed I-70 bridge site is based on available information

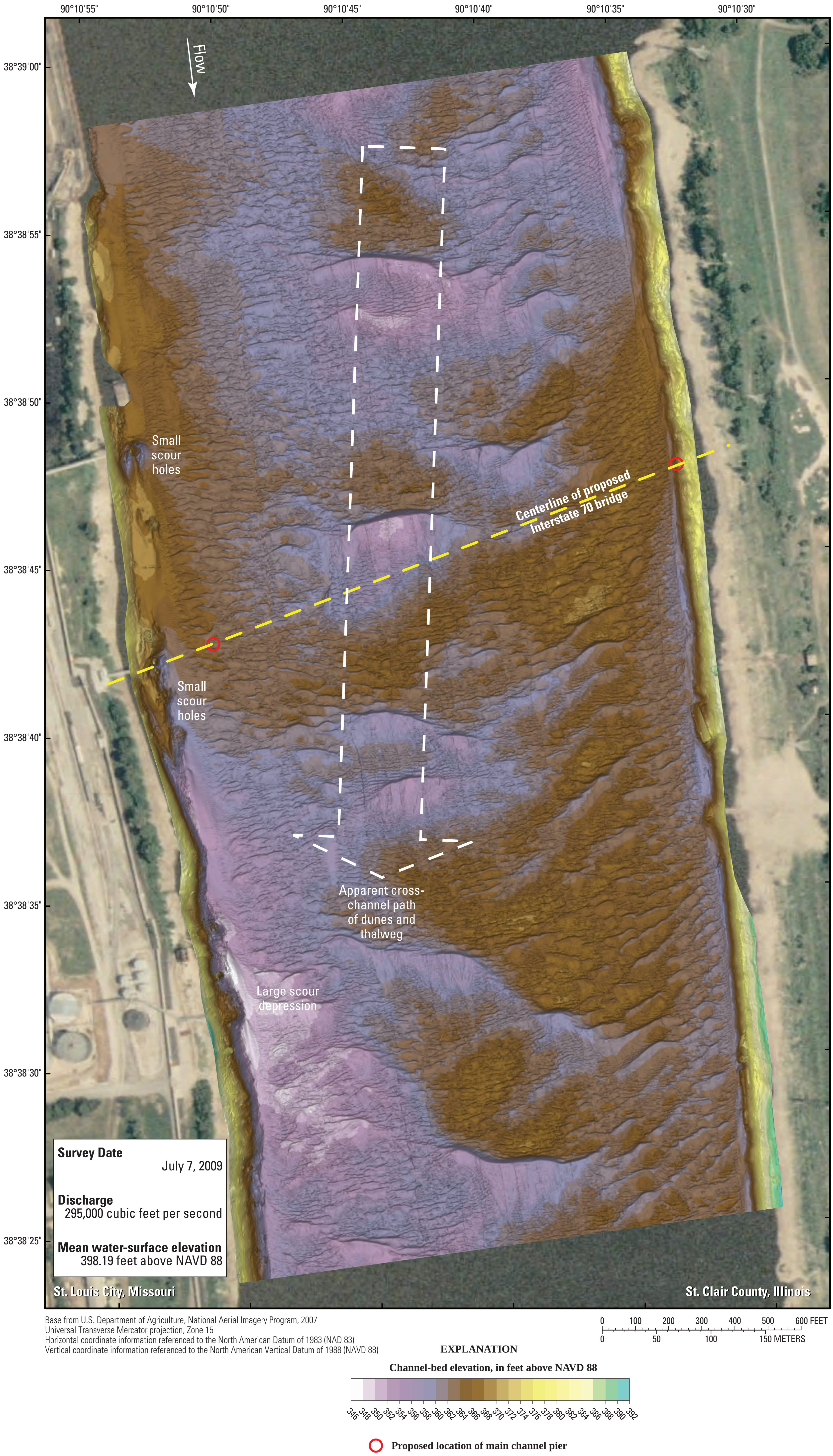

Figure 10. Bathymetry of the Mississippi River channel in the vicinity of the proposed Interstate 70 bridge at St. Louis, Missouri.

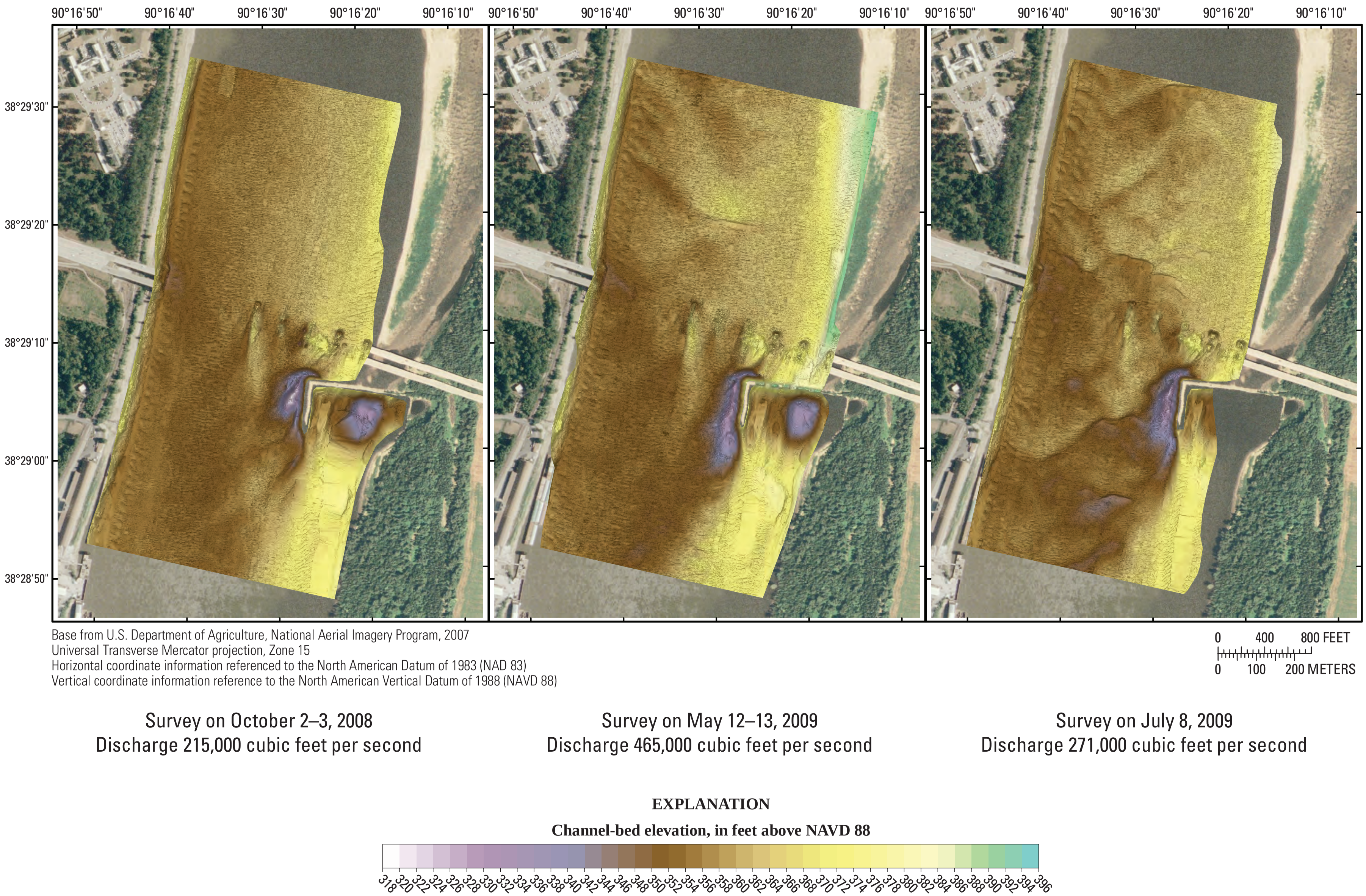

Figure 11. Bathymetry of the Mississippi River channel in the vicinity of the Jefferson Barracks Bridge on Interstate 255 at St. Louis, Missouri, from three surveys with a multibeam echo sounder.

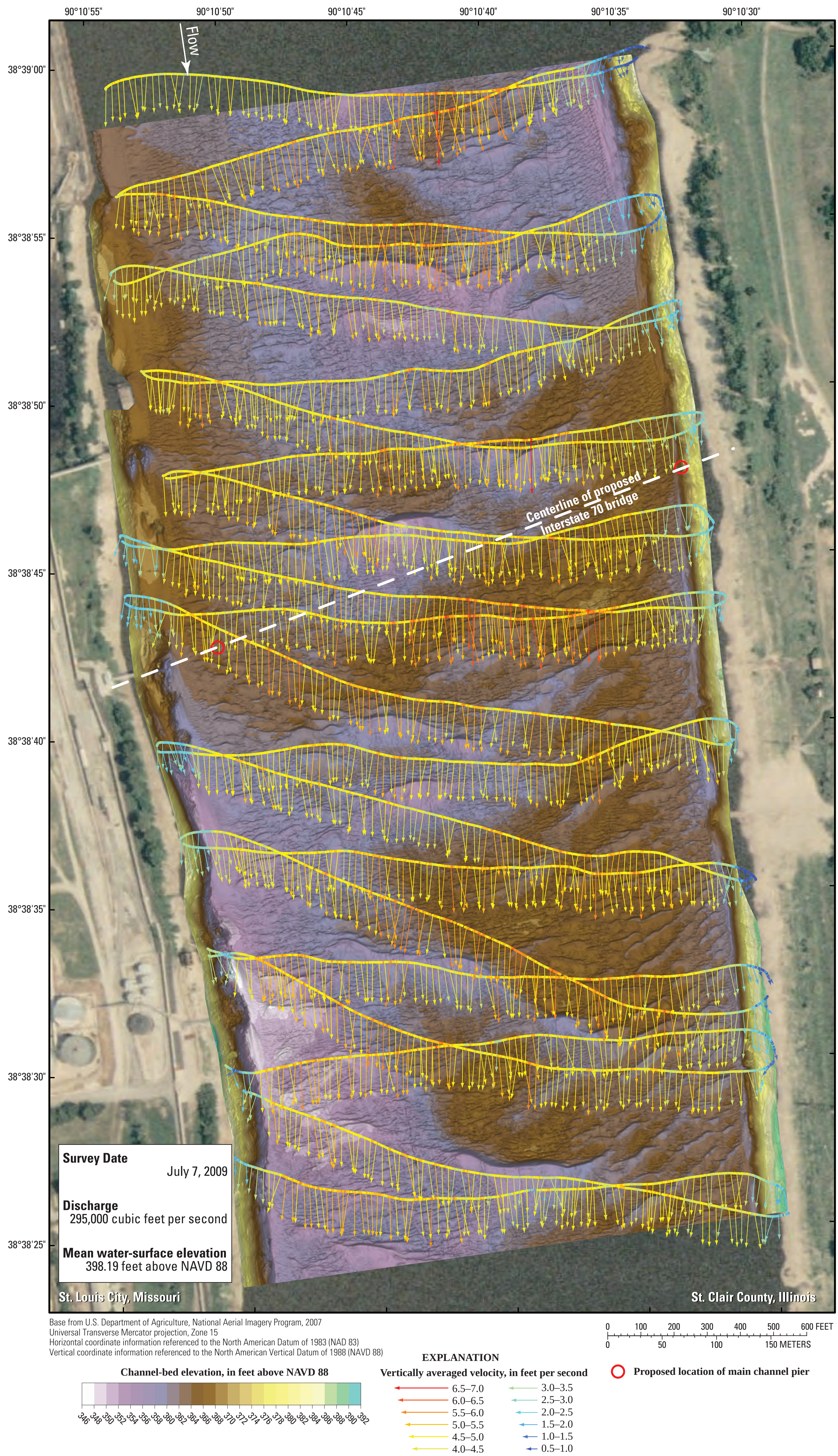

Figure 12. Bathymetry and vertically averaged velocities of the Mississippi River channel in the vicinity of the proposed Interstate 70 bridge at St. Louis, Missouri.

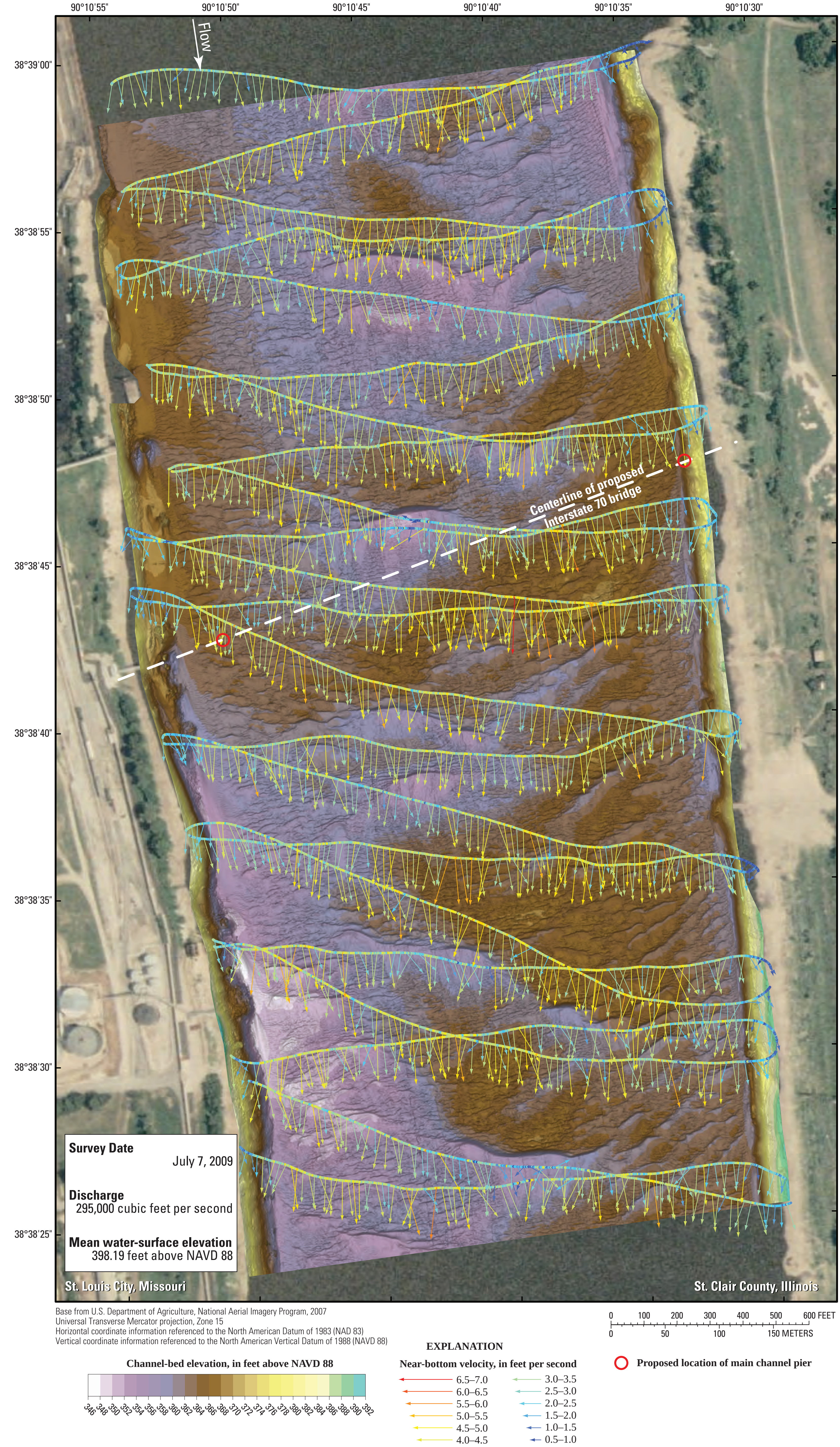

Figure 13. Bathymetry and near-bottom velocities of the Mississippi River channel in the vicinity of the proposed Interstate 70 bridge at St. Louis, Missouri.

on pallid sturgeon (*Scaphirhynchus albus*) habitat selection from telemetry and habitat measurements on the Middle Mississippi River (Garvey and others, 2009) and the Missouri River downstream from Kansas City, Missouri, (fig. 1; DeLonay and others, 2007; Reuter and others 2008, Delonay and others, 2009; Reuter and others, 2009). Quantitative studies of habitat selection by pallid sturgeon and the closely related shovelnose sturgeon (*Scaphirhynchus platorynchus*) on the Missouri River provide the framework for this habitat assessment.

Sturgeon Habitat Use

Telemetry on the Middle Mississippi River has shown that adult pallid sturgeon use areas around wing dikes for foraging and residence (Garvey and others, 2009). Although wing dike habitat is preferred, adult pallid sturgeon have occupied all Mississippi River habitats except tributary mouths. Velocity measurements made from near-bottom flow velocities with ADCP equipment found pallid sturgeon using areas with sandy bottoms and an average flow velocity of 2.95 ft/s (0.9 m/s; Garvey and others, 2009). Pallid sturgeon migration of large distances in the spring has been documented upstream and downstream in the Middle Mississippi River, and these movements are believed to be associated with reproduction. However, little is known about pallid sturgeon spawning habitat on the Middle Mississippi River (Garvey and others, 2009).

On the Missouri River downstream from Kansas City, Missouri, sturgeon research from 2005–09 has focused on telemetry of adult shovelnose and pallid sturgeon coupled with hydroacoustic habitat mapping (DeLonay and others, 2007; Reuter and others, 2008; DeLonay and others, 2009; Reuter and others, 2009). Research has placed an emphasis on migration habitat during the spawning season by adult male and female shovelnose and pallid sturgeon (DeLonay and others, 2007; Reuter and others, 2009) and spawning habitat for gravid (egg bearing) female pallid sturgeon (DeLonay and others, 2009). Less information is available about sturgeon habitat use on the Middle Mississippi and Missouri Rivers for sturgeon outside the adult reproductive life stage (such as larval, juvenile, and overwintering habitat).

On the engineered Missouri River, Reuter and others (2008, 2009) analyzed 153 reach-scale [approximately 1.55 mi (2.5-km) length] habitat maps of depth, depth-averaged velocity, and substrate, and the derived values of depth slope, velocity gradient, and Froude number (a dimensionless value relating velocity to the square root of depth times the gravitational constant) of randomized and targeted sturgeon telemetry locations for habitat selection [for full methods and results see Reuter and others (2008, 2009)]. Adult sturgeon were shown to use nearly the full range of available habitat on the Missouri River, although at the reach scale, sturgeon were shown to select regions within the mapped reaches with relatively high velocity gradient, high depth slope, low Froude number, and low depth-averaged velocity. For comparison with the Middle Mississippi River and the proposed I-70 bridge site, a subset of this dataset for the lower 370 mi (595 km) of the Missouri River (59 mapped sites) was used in this habitat assessment (fig. 14). Ivlev's selectivity coefficients (Manly and others, 2002; Reuter and others, 2009) were calculated for habitat variables as well (fig. 14). Habitat use was compared to all habitats available to indicate the strength of habitat selection. The data indicate that selection is significant for relatively shallow water, steep slopes, low velocities, relatively high velocity gradient (shear), and relatively low Froude number. Selectivity coefficients near zero indicate habitat is used in proportion to its availability. Positive selectivity coefficients indicate habitat selection and negative coefficients indicate avoidance.

Telemetry and multibeam habitat mapping of adult pallid sturgeon locations on the Missouri River in 2008 and 2009 indicated that spawning is associated with upstream migration movement, and that sturgeon are likely to spawn at the upstream most point, or "apex," of migration movement (DeLonay and others, 2009). Spawning on the Missouri River has been documented in patches on outside revetted bends in habitats that are relatively deep, fast, and turbulent (DeLonay and others, 2009).

Comparison of Missouri River and Mississippi River Datasets

The Missouri River and the Middle Mississippi River are large sand-bedded rivers but differ in depth, velocity, and discharge. The Missouri River sturgeon-selection dataset represents a wide range of spring and summer discharges on the Missouri River downstream from Kansas City, Missouri, ranging from average daily discharges of 38,000 to 106,000 ft^3/s (1,080 to 3,000 m^3/s). The proposed I-70 bridge site was mapped once at an average discharge of 295,000 ft^3/s (8,350 m^3/s) according to the U.S. Geological Survey streamflow-gaging station at St. Louis, Missouri (U.S. Geological Survey, 2010), which represents a relatively high flow for the Middle Mississippi River (16 percent daily flow exceedance; U.S. Geological Survey, 2003). The Missouri River habitat survey dataset [59 compiled hydroacoustic single-beam maps, see Reuter and others (2008) for methods] was compared to the depths and velocities derived from the July 7, 2009, survey of the Mississippi River I-70 bridge site. The maps derived for average velocity and depth from ADCP data for the proposed I-70 bridge site were gridded with a 32.8-ft (10-m) spacing appropriate to the scale of data collection (fig. 12). Comparison of the depth, velocity, and derived variables of depth slope, velocity gradient, and Froude number shows the Mississippi River on the survey date to be considerably deeper and faster than any data from the lower 370 mi (595 km) of the Missouri River (fig. 15). Froude number is higher on the Missouri River. Depth-slope values are higher for the proposed I-70 bridge site and velocity gradients are fairly comparable to those found on the Missouri River (fig. 15).

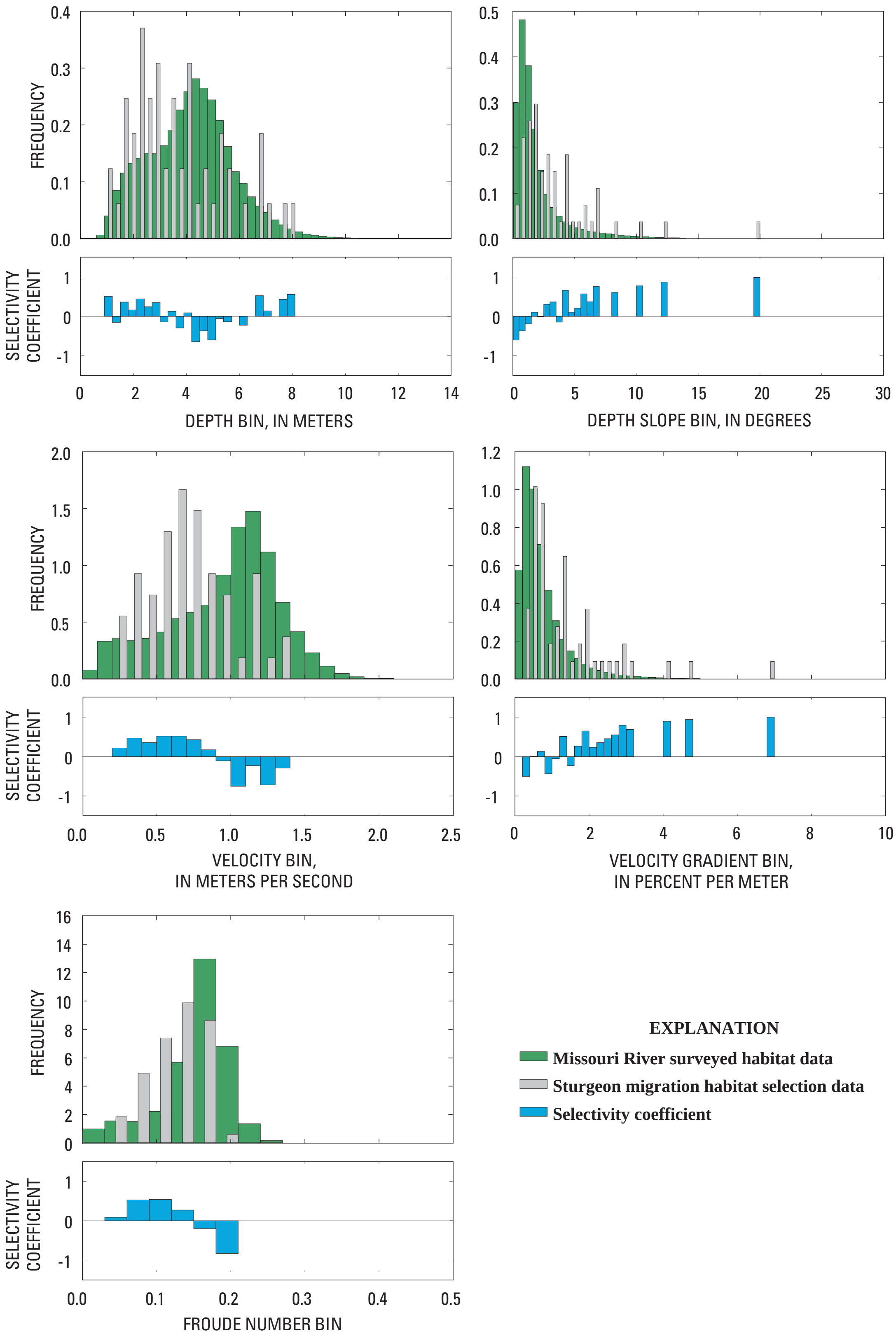

Figure 14. Sturgeon habitat availability and use for the lower 370 miles of the Missouri River (from Reuter and others, 2009).

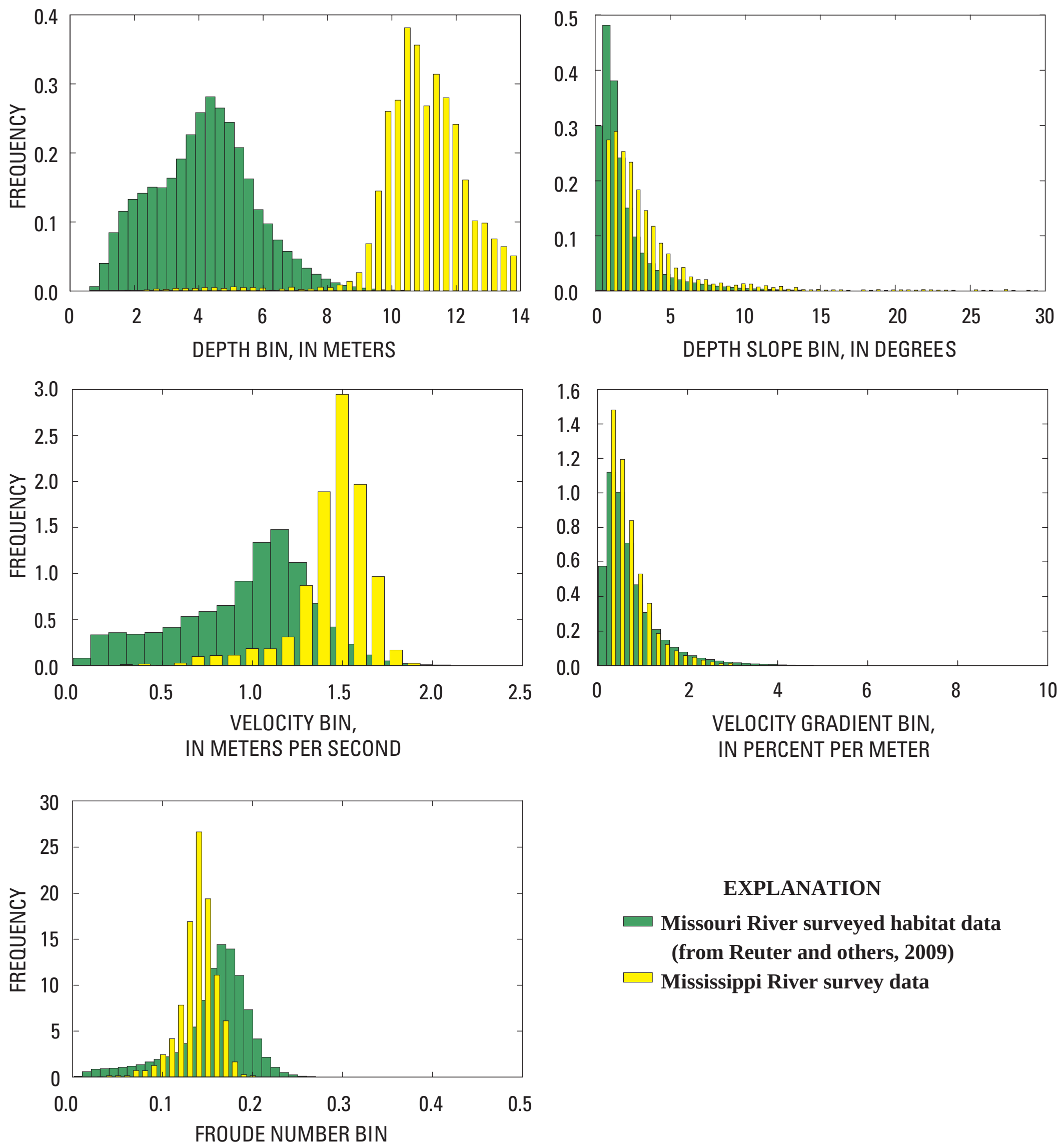

Figure 15. Habitat assessment values derived from hydroacoustic mapping on the lower 370 miles of the Missouri River and on the Mississippi River in the vicinity of the proposed Interstate 70 bridge at St. Louis, Missouri.

Values and selectivity coefficients for habitat variables derived from sturgeon habitat selection on the Missouri River downstream from Kansas City, Missouri, were compared to the values derived from ADCP-based depth and velocity grids and their habitat derivatives for the proposed I-70 bridge site (fig. 16). These comparisons show that sturgeon may be expected to use areas with lower depths and velocities than most of the channel at the proposed I-70 bridge site. Based on depth slope and Froude number criteria from the Missouri River, sturgeon would be predicted to select large areas of the main channel. Based on velocity gradient criteria from the Missouri River, sturgeon would be predicted to select regions of higher velocity gradient on the margins of the Mississippi River channel (Reuter and others, 2009).

To illustrate regions of high habitat selection probability in the channel, ranges of depth, velocity, depth slope, velocity gradient, and Froude number with selectivity coefficients greater than zero were mapped (figs. 17 and 18). Predicted selection based on depth and velocity occurs on the outer edges of the Mississippi River channel in the study area (fig. 17). These areas are likely to exhibit more connectivity than shown in these map as gaps in the ADCP dataset occur on the edges and around structures in the river channel (fig. 12). The depths and velocities that occur in the main channel of the proposed I-70 bridge site are higher than those mapped in the Missouri River habitat reaches downstream from Kansas City, Missouri (fig. 15); it is unknown to what extent these regions are used by sturgeon on the Mississippi River. Spatial

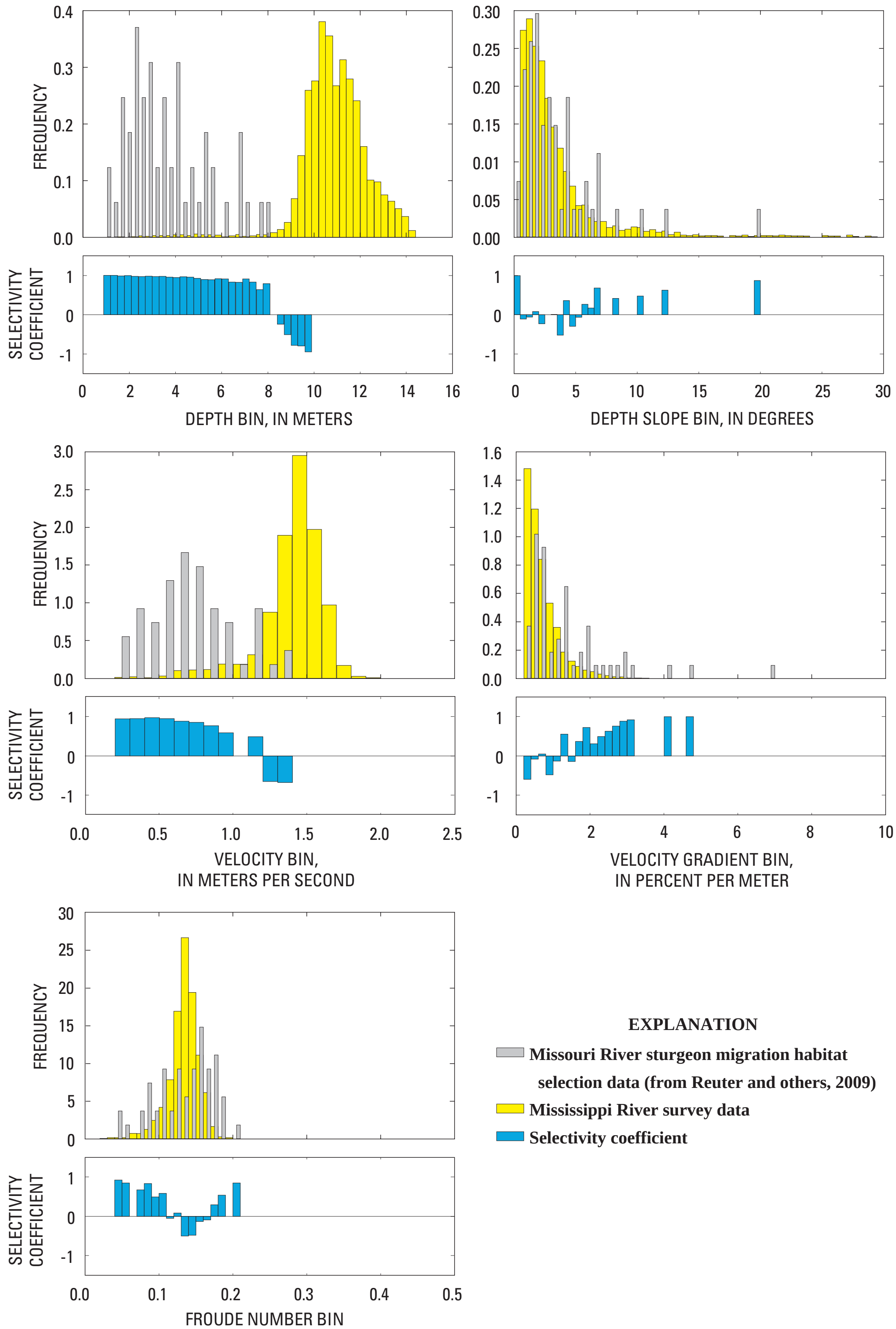

Figure 16. Sturgeon habitat use from the lower 370 miles of the Missouri River and habitat availability on the Mississippi River in the vicinity of the proposed Interstate 70 bridge at St. Louis, Missouri.

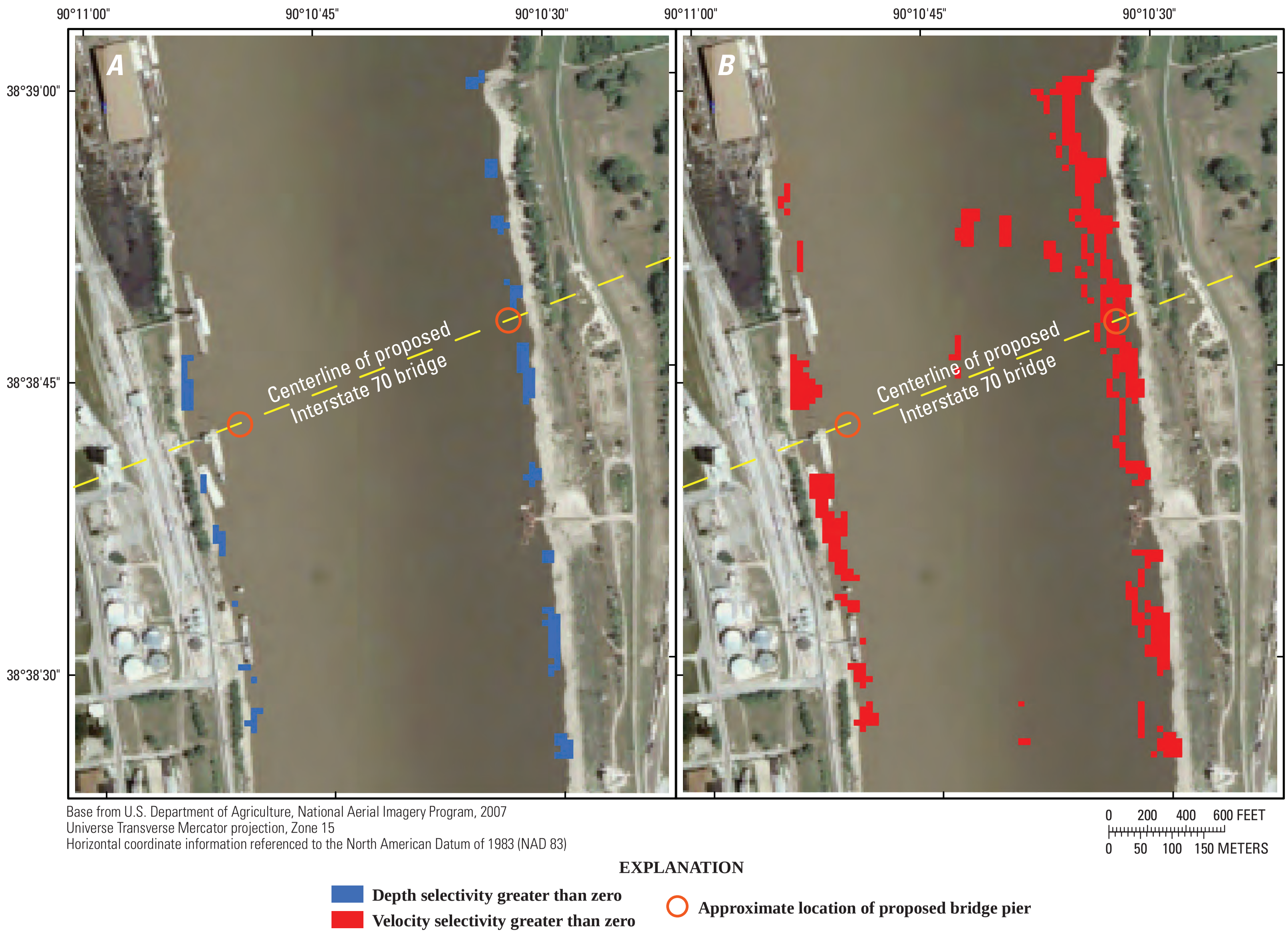

Figure 17. Regions where habitat assessment selectivity values are greater than zero (indicating predicted habitat selection) for (*A*) depth, and (*B*) velocity on the Mississippi River in the vicinity of the proposed Interstate 70 bridge at St. Louis, Missouri.

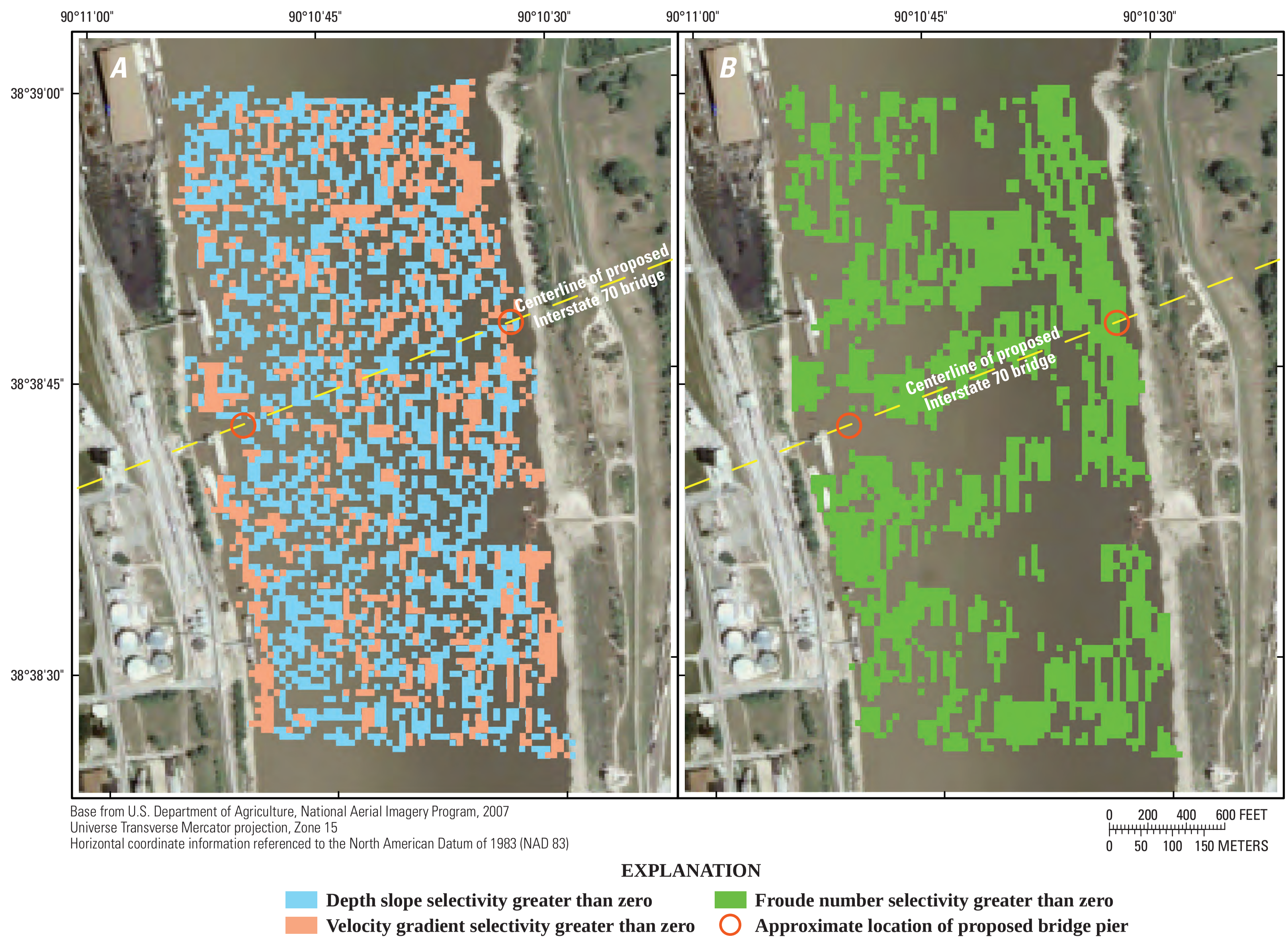

Figure 18. Regions where habitat assessment selectivity values are greater than zero (indicating predicted habitat selection) for (*A*) depth slope and velocity gradient, and (*B*) Froude number on the Mississippi River in the vicinity of the proposed Interstate 70 bridge at St. Louis, Missouri.

patterns in depth slope, velocity gradient, and Froude number on the Mississippi River in the study area are more complex than those on the Missouri River. The patterns appear to relate to the topographic complexity caused by large dunes in the Mississippi River channel (figs. 10 and 18). The values of depth slope, velocity gradient, and Froude number that occur in relation to the dune structures in the main Mississippi River channel in the study area are similar to habitat variable values that occur on channel edges in the Missouri River where sturgeon migration pathways have been documented (Reuter and others, 2009). Very large mid-channel dunes with 12.5 ft (3.81 m; fig. 10) of relief mapped at the proposed I-70 bridge site have not been observed in the habitat studies on the Missouri River, and the extent of their use by migrating adult sturgeon is unknown.

The velocities that Garvey and others (2009) found in areas most often used by pallid sturgeon on the Middle Mississippi River were around 2.95 ft/s (0.9 m/s). The areas for which the velocities were near this value (2.62 to 3.28 ft/s or 0.8 to 1.0 m/s) are on the channel margins on the Mississippi River grid derived from ADCP mapping (fig. 19).

Sidescan Sonar

An additional derived map from the multibeam data that is useful for habitat assessment is sidescan imagery mosaiced to the 0.79-in (2-cm) pixel scale. Sidescan imagery was reprocessed from multibeam data in HYPACK® at the 0.79-in (2-cm) scale to show the regions near the locations of the proposed I-70 bridge piers. On the right descending bank (the Missouri bank), large woody debris can be seen near the mooring dolphins in the high-resolution sidescan imagery (fig. 20*A*). Woody debris is frequently associated with general

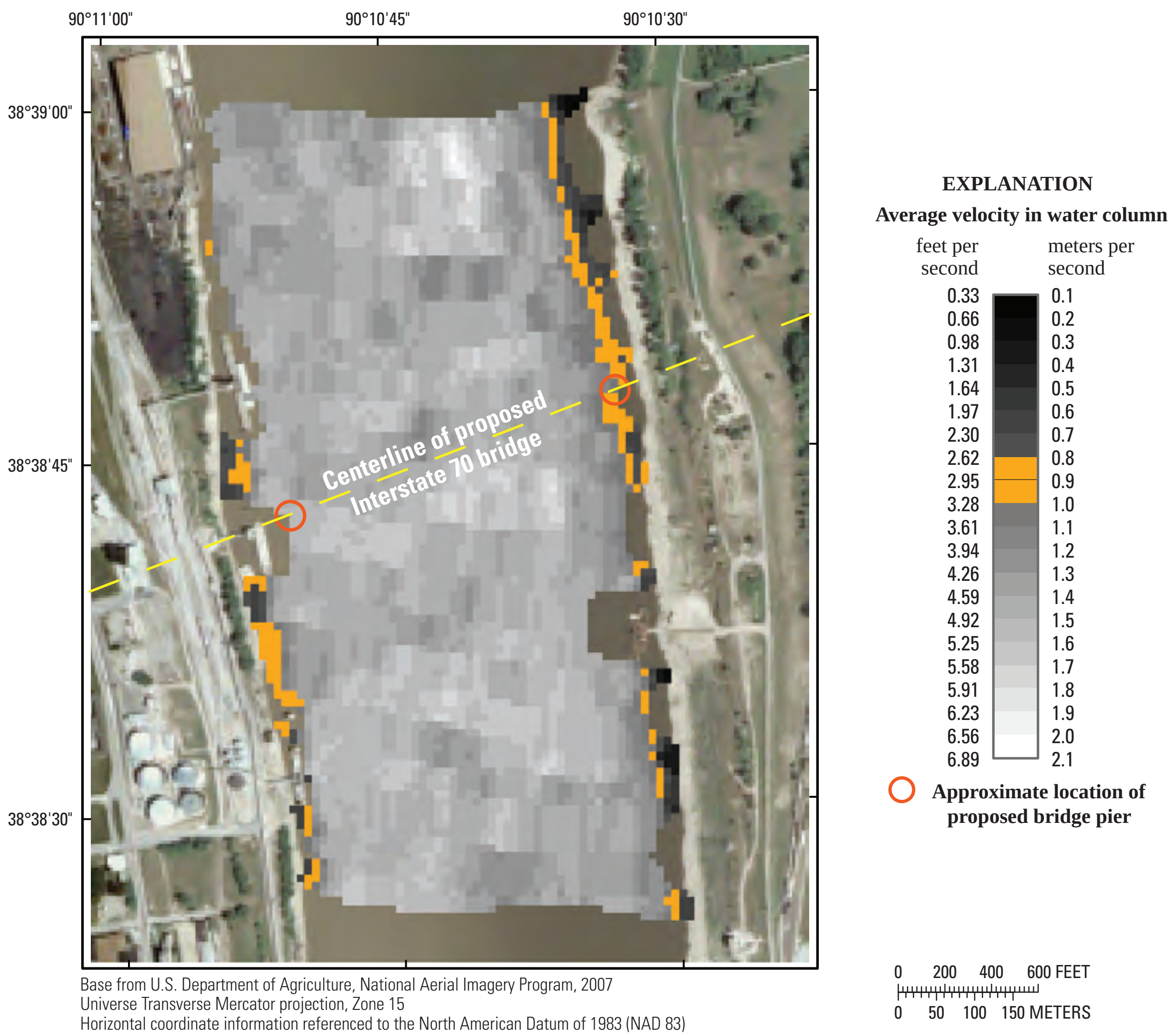

Figure 19. Regions with average water column velocities between 2.62 and 3.28 feet per second (0.8 and 1.0 meters per second) on the Mississippi River in the vicinity of the proposed Interstate 70 bridge at St. Louis, Missouri.

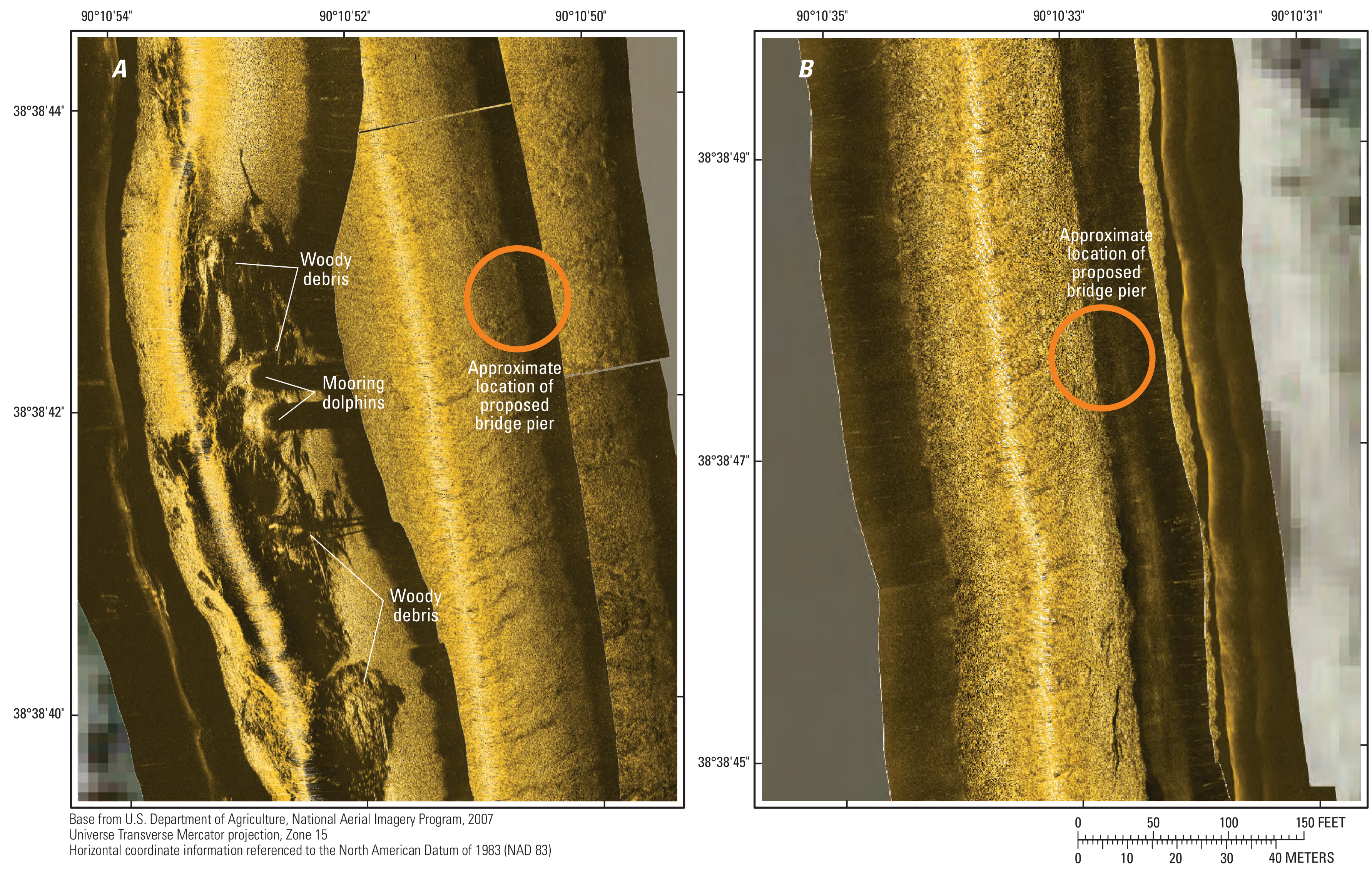

Figure 20. Sidescan sonar imagery of the Mississippi River channel on the (*A*) right descending bank (Missouri bank), and (*B*) left descending bank (Illinois bank) in the vicinity of the bridge piers of the proposed Interstate 70 bridge at St. Louis, Missouri.

fish habitat and appears to mainly occur in channel margin areas at the Mississippi River site. There may be small patches of coarse gravel associated with this region near the banks as well.

Most of the remainder of the channel away from the banks shows up as sand on the sidescan imagery, which is consistent with sand bedforms in the main channel seen in the multibeam bathymetry (fig. 10). On the left descending bank (the Illinois bank), the sidescan imagery shows sand dunes towards the main channel and what appears to be coarse gravel or cobbles near the bank (fig. 20*B*).

Habitat Evaluation

Although the Mississippi River at this site shows considerable physical complexity because of the arrangement of large sand dunes in the middle of the channel, existing studies do not document persistent use of these deep, fast, main-channel habitats by pallid sturgeon (Garvey and others, 2009; Reuter and others, 2009). Narrow channel-marginal areas on both banks having relatively low velocity, high depth slope, and high velocity gradients are similar to adult migration habitats as documented on the Missouri River downstream from Kansas City, Missouri. Except for topographic complexity associated with barge mooring areas on the right descending bank, the reach generally lacks features associated with sturgeon habitat selection (usually topographic features associated with wing dikes) on the Middle Mississippi River (Garvey and others, 2009). However, the barge mooring area on the right bank near the location of the proposed pier contains large woody debris and small patches of probable gravel-cobble substrate that may have positive habitat value for sturgeon or other species.

Although predicted adult sturgeon habitat is limited at this site, sturgeon are known to migrate upstream through this reach as adults, and they probably drift downstream through this reach as free-embryo larvae (DeLonay and others, 2009; Garvey and others, 2009). Telemetry studies have demonstrated multiple instances of pallid sturgeon moving through this reach on their way to the Missouri River, 12 miles upstream, or to apices of migration in the Chain of Rocks reach, 6.5 miles upstream (Garvey and others, 2009). Two adult pallid sturgeons tagged in the Missouri River have been documented moving downstream through the study area and into the Middle Mississippi River (Aaron DeLonay, U.S. Geological Survey, oral commun., 2009). Successful upstream migration may depend on availability of relatively small areas with hydraulic complexity and relatively low velocities as currently exist on the margins of the site. Complexity at the channel margin may provide areas where larvae settle out from drifting in the main current or may act to slow bulk drift rates. Construction of bridge piers close to the banks will likely alter hydraulics and sediment transport on the channel margins and may result in substantial changes to migration habitat between the piers and the bank. Changes to habitat because of construction could be assessed with post-construction replication of the surveys presented in this report.

Summary

A bathymetric and velocimetry survey was conducted of the Mississippi River in the vicinity of a proposed new bridge for Interstate 70 (I-70) at St. Louis, Missouri. A multibeam echo sounder (MBES) mapping system and an acoustic Doppler current profiler (ADCP) were used to obtain channel-bed elevations and vertically averaged and near-bed velocities for part of the Mississippi River approximately 1,935 feet [ft; 590 meters (m)] wide from the Illinois to Missouri banks, and approximately 3,545 ft (1,080 m) long. Information from the 2009 survey was used to determine the conditions of the benthic habitat in the vicinity of the proposed I-70 bridge.

The channel-bed elevations ranged from approximately 346 ft (105.46 m) to 370 ft (112.78 m) above the North American Vertical Datum of 1988 (NAVD 88) in a majority of the channel except for the channel banks. There were several large dune features up to 12.5 ft (3.81 m) high in the middle of the channel, and numerous smaller dunes and many ripples as smaller features were superimposed on the larger dunes. However, it is uncertain if the large dune features present in mid-channel were long-term features or an artifact of seasonal flooding on the Mississippi River. A substantial scour depression existed on the right descending bank (the Missouri bank) near the downstream end of the study area, approximately 700 ft downstream from the proposed pier location, and other smaller scour holes existed near the instream barge mooring structures on the Missouri bank.

The vertically averaged velocities acquired with the ADCP ranged from approximately 2 feet per second [ft/s; 0.61 meters per second (m/s)] along the Illinois and Missouri banks to approximately 7.0 ft/s (2.13 m/s) at locations in the main channel, with an average value of 5.5 ft/s (1.68 m/s) in mid-channel. The orientation of the vertically averaged velocity vectors shows that flow was crossing from the Illinois bank to the Missouri bank from upstream to downstream in the study area, which was confirmed by the orientation of the large dune features in mid-channel and that the thalweg also crossed from the Illinois bank to the Missouri bank. The location at which the thalweg meets the Missouri bank was the location of the large scour depression in the downstream part of the study area. The near-bottom velocities acquired with the ADCP ranged from 0.3 to 7.0 ft/s (0.09 to 2.13 m/s), and the effects of the large dune features were apparent in the random scattering of the velocity vectors, low velocities downstream from the dunes, and higher velocities near the crests of the dunes.

The Mississippi River at this site shows considerable physical complexity because of the arrangement of large sand dunes in the middle of the channel; however, existing studies do not document persistent use of these deep, fast, main-channel habitats by pallid sturgeon. Narrow channel-marginal areas on both banks having relatively low velocity, high depth slope, and high velocity gradients are similar to adult migration habitats as documented on the Missouri River downstream from Kansas City, Missouri. The reach generally lacks features associated with sturgeon habitat selection on the Middle Mississippi River; however, the barge mooring areas on the right descending bank have topographic complexity and contain large woody debris and small patches of probable gravel-cobble substrate that may have positive habitat value for sturgeon or other species.

Although predicted adult sturgeon habitat is limited at this site, telemetry studies have shown sturgeon migrate upstream and downstream through this reach as adults, and they probably drift downstream through this reach as free-embryo larvae. Successful upstream migration may depend on availability of relatively small areas with hydraulic complexity and relatively low velocities as presently exist on the margins of the site. Complexity at the channel margin may provide areas where larvae settle out from drifting in the main current or may act to slow bulk drift rates. Construction of bridge piers close to the banks will likely alter hydraulics and sediment transport on the channel margins and may result in substantial changes to migration habitat near the piers and banks. Changes to habitat because of construction could be assessed with post-construction replication of the surveys presented in this report.

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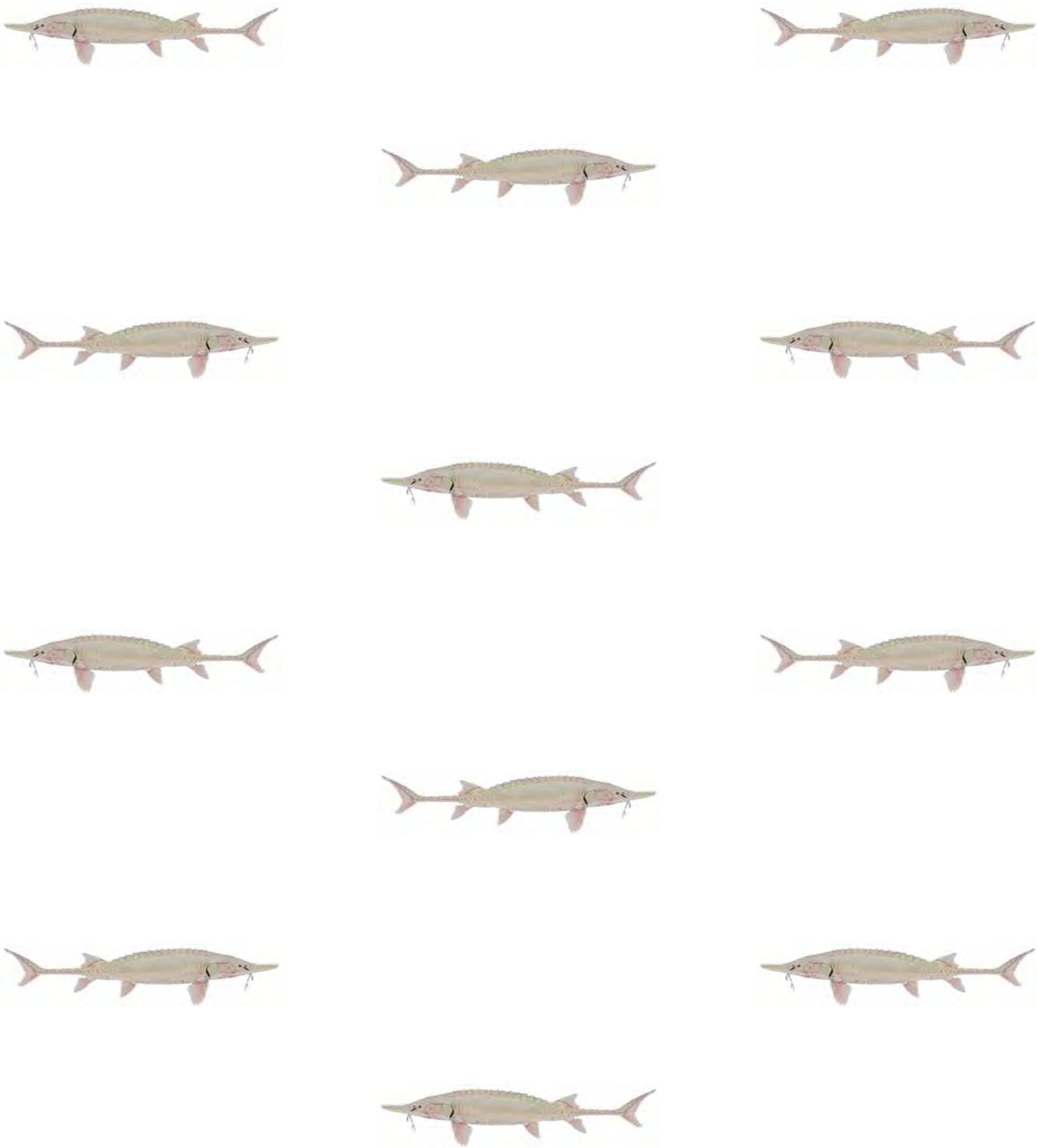

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