Prepared in cooperation with the Nebraska Department of Roads

Repeated Multibeam Echosounder Hydrographic Surveys of 15 Selected Bridge Crossings Along the Missouri River from Niobrara to Rulo, Nebraska, During the Flood of 2011

Scientific Investigations Report 2014–5062

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

Cover photograph. Nebraska City Bridge over the Missouri River on Nebraska and Iowa Highway 2 at Nebraska City, Nebraska, 2011 (photograph by U.S. Geological Survey).

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SALLY JEWELL, Secretary

U.S. Geological Survey
Suzette M. Kimball, Acting Director

U.S. Geological Survey, Reston, Virginia: 2014

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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
yard (yd)	0.9144	meter (m)
	Area	
acre	4,047	square meter (m^2)
acre	0.4047	hectare (ha)
acre	0.4047	square hectometer (hm^2)
acre	0.004047	square kilometer (km^2)
	Volume	
acre-foot (acre-ft)	1,233	cubic meter (m^3)
	Flow rate	
foot per second (ft/s)	0.3048	meter per second (m/s)
cubic foot per second (ft^3/s)	0.0283	cubic meter per second (m^3/s)
	Frequency	
hertz (Hz)	1	cycle per second
kilohertz (kHz)	1,000	cycles per second

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

°C=(°F-32)/1.8

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).

Altitude, as used in this report, refers to distance above the vertical datum.

Repeated Multibeam Echosounder Hydrographic surveys of 15 Selected Bridge Crossings Along the Missouri River from Niobrara to Rulo, Nebraska, During the Flood of 2011

By Benjamin J. Dietsch, Brenda K. Densmore, and Kellan R. Strauch

Abstract

In 2011, unprecedented flooding in the Missouri River prompted transportation agencies to increase the frequency of monitoring riverbed elevations near bridges that cross the Missouri River. Hydrographic surveys were completed in cooperation with the Nebraska Department of Roads, using a multibeam echosounder at 15 highway bridges spanning the Missouri River from Niobrara to Rulo, Nebraska during and after the extreme 2011 flood.

Evidence of bed elevation change near bridge piers was documented. The greatest amount of bed elevation change during the 2011 flood documented for this study occurred at the Burt County Missouri River Bridge at Decatur, Nebraska, where scour of about 45 feet, from before flooding, occurred between a bridge abutment and pier. Of the remaining sites, highway bridges where bed elevation change near piers appeared to have exceeded 10 feet include the Abraham Lincoln Memorial Bridge at Blair, Nebr., Bellevue Bridge at Bellevue, Nebr., and Nebraska City Bridge at Nebraska City, Nebr.

Hydrographic surveys at 14 of the 15 sites were completed in mid-July and again in early October or late-November 2011. Near three of the bridges, the bed elevation of locations surveyed in July increased by more than 10 feet, on average, by late October or early November 2011. Bed elevations increased between 1 and 10 feet, on average, near six bridges. Near the remaining four bridges, bed elevations decreased between 1 and 4 feet, on average, from July to late October or early November.

Introduction

A riverbed is constantly changing with the movement of sediment by flowing water as sediment is both removed and deposited. The removal of channel-bed sediment and bank material is known as scour and occurs as velocity and shear stress increase, typically with flood passage (Leopold and others, 1964). Scour results in lower channel-bed elevations. Channel scour during flood conditions can have severe effects on river structures. Localized scour and fill around bridge piers and abutments, as well as water intakes, levees, and other river-management structures, can potentially cause infrastructure destruction, damage, or instability. Scour is the most frequently cited reason for bridge failure in the United States (Landers and Mueller, 1996).

Federal, State, county, and local governments have responsibility for most of the Nation's bridge infrastructure that is critical to local communities, statewide transportation networks, and interstate commerce. These bridges are inspected regularly to ensure structural integrity, and to evaluate channel-bank and underwater conditions for scour vulnerability. Flooding in the Missouri River Basin in 2011 (U.S. Army Corps of Engineers, 2011; Holmes and others, 2013) caused hydraulic conditions that were expected to increase velocities and shear stress near structures in the Missouri River channel. The flooding prompted transportation agencies to increase the frequency of monitoring riverbed elevations near bridges crossing the Missouri River.

Swift water velocity, increased turbulence, large floating debris, and other hazards during flood conditions present challenges for some methods of measuring scour and inspecting infrastructure. Soundings collected from a bridge or by dive teams may not provide adequate information about the spatial extent of localized scour near bridges, may be impractical, unsafe, and of poor quality, and yield little insight on general scour for the entire riverbed. Previous studies have used hydrographic surveys collected using multibeam echosounders (MBES) near bridges to assess the condition of bridges for stability and integrity with respect to bridge scour (Huizinga, 2010, 2011; Huizinga and others, 2010). Hydrographic survey methods using MBES allow safe and efficient data collection to document bed scour, assess bridge stability, and provide a basis for evaluating scour-prediction techniques. The U.S. Geological Survey (USGS) in cooperation with the Nebraska Department of Roads completed hydrographic surveys using MBES at 15 selected highway bridges along the Missouri River in 2011 during and after the flood conditions. Bridges surveyed were located between Niobrara and Rulo, Nebraska.

The hydrographic data collected near the 15 highway bridges documented riverbed conditions and provided improved understanding of the channel form. Hydrographic surveys give a detailed snapshot of the riverbed, which improve understanding of current riverbed conditions, and when repeated, also improve understanding of rates of change and sediment movement. Similar benefits can be derived when new surveys are compared to historical and future surveys.

Purpose and Scope

This report documents the methodology, and describes and compares the results of the MBES hydrographic surveys completed during and after the 2011 flood near 15 Missouri River bridges located from Niobrara to Rulo, Nebr. The hydrographic surveys around bridge structures were used by the Nebraska Department of Roads as one tool to evaluate the structural integrity of the bridges and ensure public safety. In areas where multiple surveys were completed, the results indicate the changing river conditions throughout the flood. In addition, these hydrographic surveys provide baseline information on riverbed elevations for possible comparison to future surveys and to advance scientific understanding of the fluvial geomorphology of the river system.

Background and Study Area

The 2011 Missouri River flood was caused by above-normal snowpack in the Rocky Mountains, additional late-season heavy snowfall, and widespread, heavy rainfall across the upstream subbasins (Vining and others, 2013). The combined May-through-June 2011 runoff for the Missouri River Basin upstream from Sioux City, Iowa, was 34.3 million acre-feet, greater than the annual total runoff in 102 of 113 years of record (U.S. Army Corps of Engineers, 2011; Holmes and others, 2013). This unexpected quantity of water caused the U.S. Army Corps of Engineers to increased releases from reservoirs on the Missouri River. The Federal Emergency Management Agency (FEMA) officially issued flood declarations in several North Dakota counties along the Missouri River on May 28, 2011 (Federal Emergency Management Agency, 2011). The official end to the 2011 Missouri River flood was declared on October 17, 2011, when river stages from Montana to St. Louis, Missouri, were all below flood stage.

The study area described in this report includes selected channel reaches of the Missouri River under and near 15 bridges located from Niobrara to Rulo, Nebr. (fig. 1). The Chief Standing Bear Memorial Bridge (Nebraska Highway 14/South Dakota Highway 37) near Niobrara, Nebr., is located upstream from Lewis and Clark Lake behind Gavins Point Dam. The remaining 14 bridges are located downstream from Gavins Point Dam. The Chief Standing Bear Memorial Bridge, the Yankton Discovery Bridge (U.S. Highway 81) at Yankton, S. Dak. (fig. 2), and the Vermillion-Newcastle Bridge (Nebraska Highway 15/South Dakota Highway 19) near Vermillion, S. Dak. (fig. 3), are located along the reach of river designated as the Missouri National Recreation River, which, except near Gavins Point Dam, is an unchannelized reach of the river characterized by the presence of sandbars, islands, and meanders. The 12 bridges downstream from Sioux City, Iowa, to Rulo, Nebr., are on a reach of the Missouri River that has been channelized with dikes, revetments, and other structures to support navigation. These bridges include the following: Siouxland Veterans Memorial Bridge on U.S. Highway 77 at Sioux City, Iowa (fig. 4); Sergeant Floyd Memorial Bridge on Interstate 129/U.S. Highway 20/U.S. Highway 75 at Sioux City, Iowa (fig. 5); Burt County Missouri River Bridge on Nebraska Highway 51/Iowa Highwat 175 at Decatur, Nebr. (fig. 6); Abraham Lincoln Memorial Bridge on U.S. Highway 30 at Blair, Nebr. (fig. 7); Mormon Pioneer Memorial Bridge on Interstate 680 at Omaha, Nebr. (fig. 8); Grenville Dodge Memorial Bridge on Interstate 480 at Omaha, Nebr. (fig. 9); Interstate 80 Bridge at Omaha, Nebr. (fig. 10); South Omaha Veterans Memorial Bridge on U.S. Highway 275/Nebraska and Iowa Highway 92 at Omaha, Nebr. (fig. 11); Bellevue Bridge Nebraska and Iowa Highway 370 at Bellevue, Nebr.; Plattsmouth Bridge on U.S. Highway 34 at Plattsmouth, Nebr.; Nebraska City Bridge on Nebraska and Iowa Highway 2 at Nebraska City, Nebr. (fig. 12); Rulo Bridge on U.S. Highway 159 at Rulo, Nebr. (fig. 13). Levees confined the width of the channel near most of the 12 downstream bridges.

Methods of Study

Hydrographic surveys were completed using a high-resolution multibeam echosounder mapping system installed on a motorized surveying boat. At each bridge, the hydrographic surveys covered the main channel where depth was sufficient to safely and effectively operate the multibeam echosounder, typically greater than 4.5 feet. The same high-resolution multibeam echosounder mapping system and the same surveying methods were used for all surveys.

Description of Bathymetric Sounding Equipment

The high-resolution mapping system used during the hydrographic surveys of the bridges across the Missouri River consisted of the MBES, the inertial measurement unit (IMU) and navigation system, and data collection/navigation computer. The MBES used on the surveying vessel was the RESON SeaBat™ 7125 sonar system operating at a frequency of 400 kilohertz (kHz) in equi-distance mode (512 equally spaced depth readings were received for every sonar ping), surveying a 128-degree (°)-wide swath with a beam width of 0.5 to 1° along the direction of travel (RESON, Inc., 2008). The maximum depth measurement capability for model 7125 far exceeded the depths measured during this study (table 1).

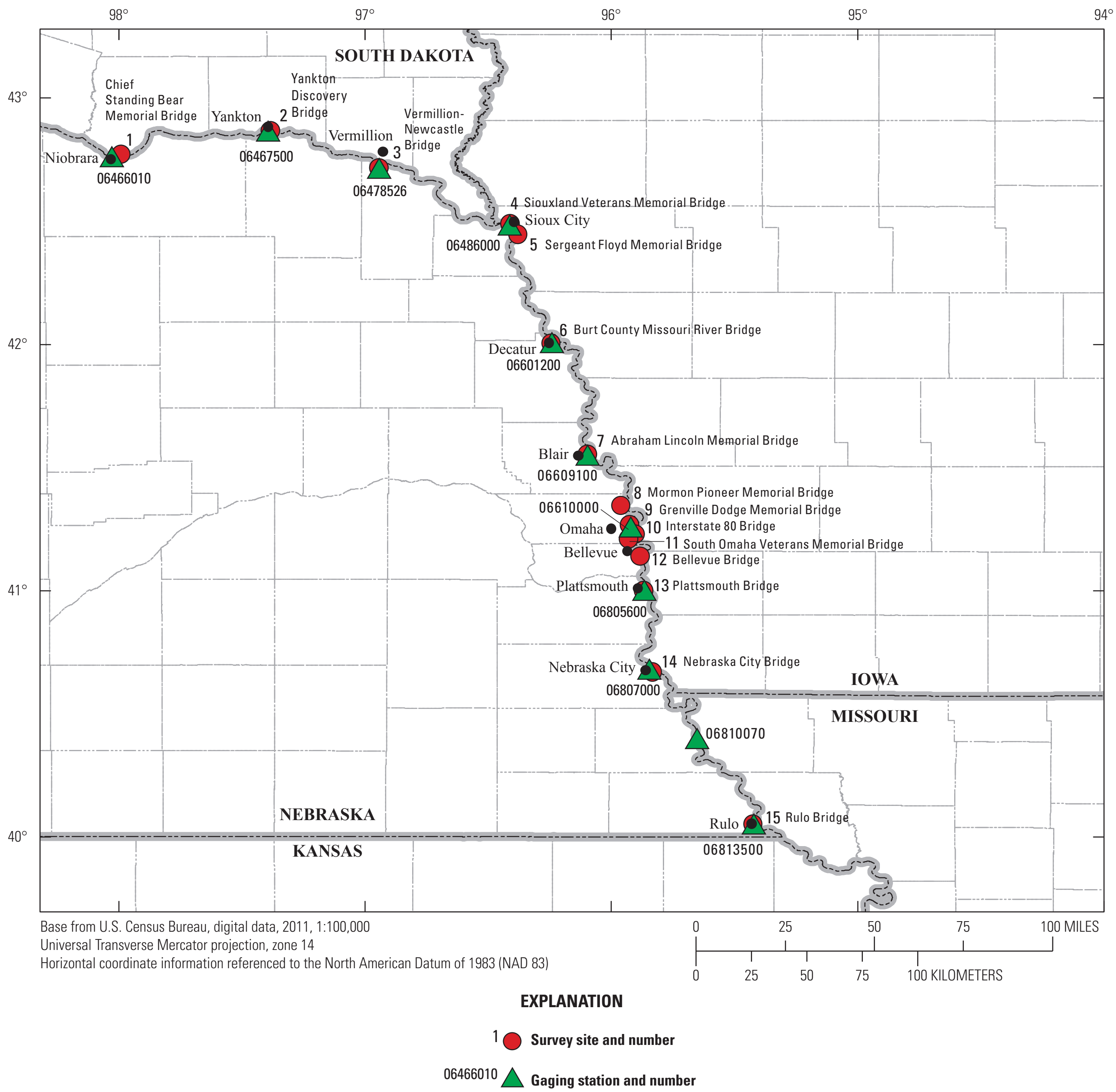


Figure 1. Location of bridges over Missouri River at reaches surveyed using multibeam echosounder, 2011.

Figure 2. Yankton Discovery Bridge over Missouri River on U.S. Highway 81 at Yankton, South Dakota, 2011.

Figure 3. Vermillion-Newcastle Bridge over Missouri River on Nebraska Highway 15/South Dakota Highway 19 near Vermillion, South Dakota, 2011.

Figure 4. Siouxland Veterans Memorial Bridge over Missouri River on U.S. Highway 77 at Sioux City, Iowa, 2011.

Figure 5. Sergeant Floyd Memorial Bridge over Missouri River on Interstate 129/U.S. Highway 20/U.S. Highway 75 at Sioux City, Iowa, 2011.

Figure 6. Burt County Missouri River Bridge over Missouri River on State Highway 51/Iowa Highway 175 at Decatur, Nebraska, 2011.

Figure 7. Abraham Lincoln Memorial Bridge over Missouri River on U.S. Highway 30 at Blair, Nebraska, 2011.

Figure 8. Mormon Pioneer Memorial Bridge over Missouri River on Interstate 680 at Omaha, Nebraska, 2011.

Figure 9 Grenville Dodge Memorial Bridge over Missouri River on Interstate 480 at Omaha, Nebraska, 2011.

Figure 10. Interstate 80 Bridge over Missouri River at Omaha, Nebraska, 2011.

Figure 11. South Omaha Veterans Memorial Bridge over Missouri River on U.S. Highway 275/Iowa and Nebraska Highway 92 at Omaha, Nebraska, 2011.

Figure 12. Nebraska City Bridge over Missouri River on Nebraska and Iowa Highway 2 at Nebraska City, Nebraska, 2011.

Figure 13. Rulo Bridge over Missouri River on U.S. Highway 159 at Rulo, Nebraska, 2011.

Table 1. RESON SeaBat™ 7125 specifications (RESON, Inc., 2008).

[kHz, kilohertz; ft, feet; °, degrees; Hz, hertz; CW, continuous wave; in, inches; µseconds, microseconds]

Frequency	400 kHz
Max Range	650 ft
Swath Coverage	128°
Beamwidth	0.5° x 1°
Number of Beams	256/512 Equi-angle or 512 Equi-distant
Max Update Rate	50 Hz
Waveform	Gated CW
Depth Resolution	0.2 in
Pulse Length	33 to 300 µseconds
Depth Rating	1,300 ft
System Control	7-P Processor unit
Mounting Angle	20 to -20 degrees

The projector and receiver arrays were mounted on a bracket attached to a pole on the starboard side of the survey vessel. The mounting bracket was configured to lock the projector and receiver into an offset-roll position oriented 20 degrees away from the vessel (on an axis parallel to the roll axis of the vessel), which permitted the sonar scans to be directed to the side of the vessel instead of straight down. The 20-degree offset-roll position was used for all scans and patch tests in this study. A sound velocity probe (RESON SVP-71) was attached to the mounting bracket near the projector and receiver (fig. 14) (RESON, Inc., 2008).

Hardware control and data flow to and from the SeaBat™ 7125 MBES was managed by the 7-P, a high-performance sonar signal processor (RESON, Inc., 2008). An Applanix Position Orientation Solution for Marine Vessels (POS MV™) WaveMaster IMU system provided attitude, heading, heave, position, and vessel velocity (Applanix Corporation, 2006). The POS MV™ was configured to use real-time kinematic (RTK) correction information and its Global Positioning System (GPS) azimuth measurement subsystem (GAMS) to

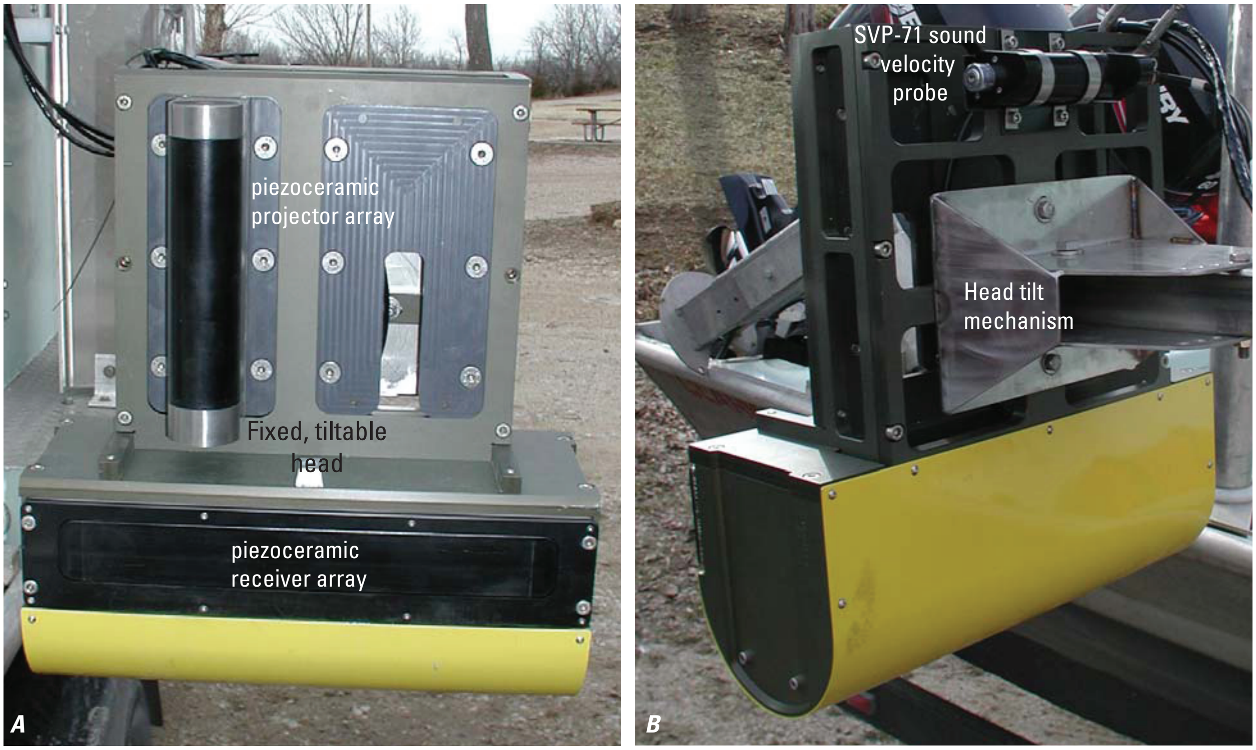


Figure 14. The RESON SeaBat™ 7125 multibeam echosounder components that are deployed into the water during data collection, as viewed from *A*, bottom view, and *B*, oblique view of upper side (Huizinga and others, 2010).

improve measurements of pitch, roll, heave, heading, position, and velocity during short GPS outages, which frequently occur near shorelines and under bridges.

Pitch, roll, heave, heading, position, velocity, and depth data were processed, stored, and displayed in real-time by using HYPACK® and HYSWEEP® software during surveying (HYPACK, Inc, 2007a and 2007b). Hydrographic data were post-processed using CARIS HIPS and SIPS software (CARIS, 2013).

The MBES system used to survey the Missouri River sites described in this report required calibration to determine offset values and timing adjustments. Patch tests were completed to determine the exact position of the projector and receiver relative to other MBES components and to correct minor timing inaccuracies caused by latency issues. Patch test procedures used for this study are described in the section of this report entitled “Quality Assurance and Quality Control”.

An identical set of hydrographic equipment was used to survey all 15 sites and for all survey rounds, as was described in this section of the report. Additional descriptions of the MBES equipment are in Huizinga and others (2010) and Huizinga (2010).

Hydrographic Surveys and Data Processing

In general, the surveys of each site used similar survey methods. Only minor changes were made to hardware and software settings. The MBES sensor configuration on the vessel did not change over the course of the study.

Field Procedures

An RTK base station was used at each survey site to provide Global Navigation Satellite System (GNSS) correction information to the survey vessel during data collection. If a known benchmark was not in close proximity to the survey area, a new benchmark was established. The GNSS data were internally logged in the base GNSS receiver and post-processed through the National Geodetic Survey’s Online Positioning Users Service (OPUS). During post-processing, corrections were made to survey data based on the results of OPUS processing, if necessary.

If the positioning data collected were assessed to be inadequate to accurately determine water-surface elevation, additional water-surface elevation data were collected. The additional water-surface elevation data were collected using a Trimble GPS unit that was separate from the units used by the vessel’s navigation system. The additional water-surface data were incorporated during post-processing for quality checks and to fill in missing values in the primary record collected by the MBES.

During the surveys, additional data were collected to calibrate offset values for the mounting position of the multibeam

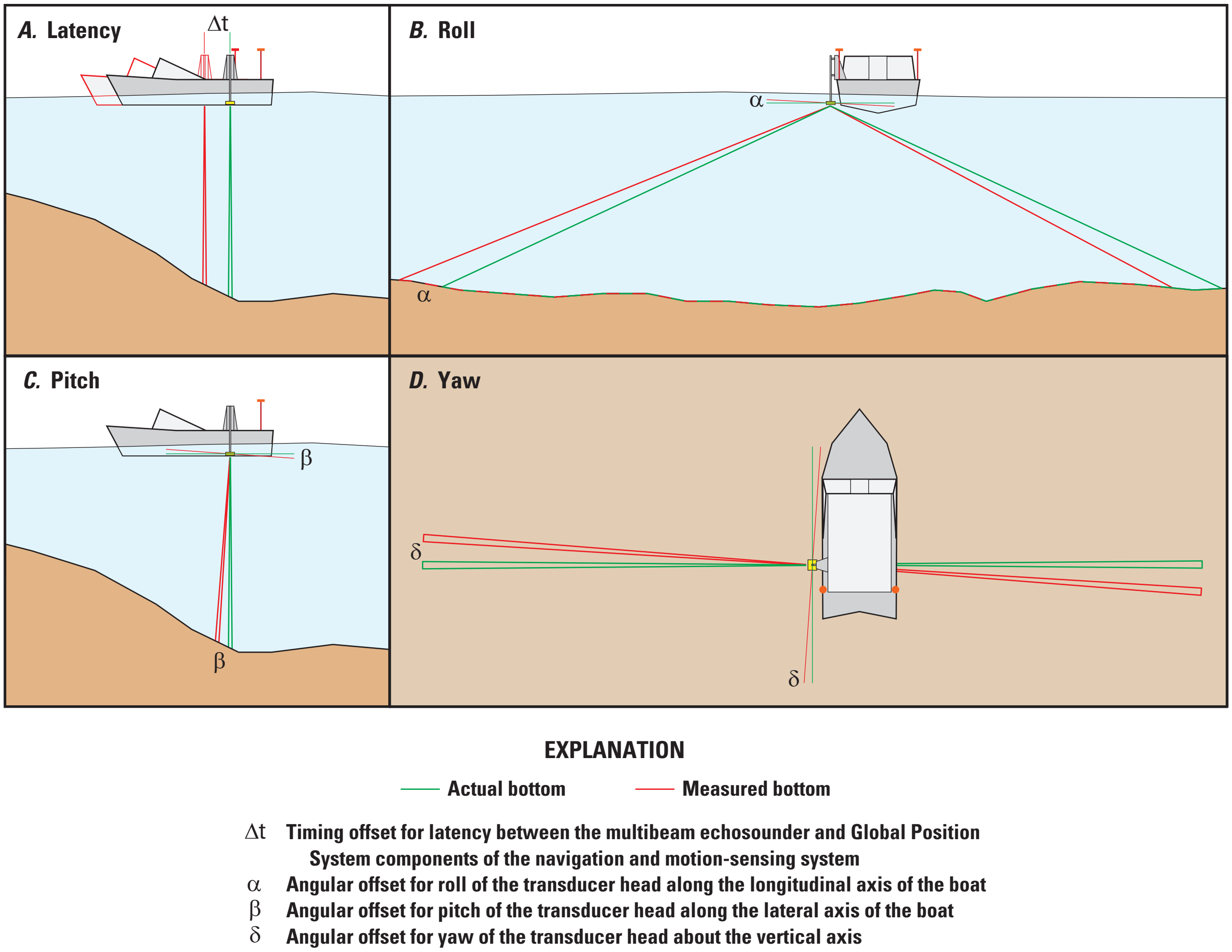


Figure 15. Effects of timing and angular offsets: *A*, timing offset for latency, and angular offsets for *B*, roll; *C*, pitch; and *D*, yaw on data from a multibeam echosounder (Huizinga, 2011).

unit. The calibration data are described in the ”Quality Assurance and Quality Control” section of this report.

Data-Processing Procedures

For this study, HYPACK® and HYSWEEP® software and CARIS HIPS, SIPS, and Bathy DataBASE: Base Editor software (CARIS, 2013) were used to process MBES data. Methods used for processing MBES are described in the user's manuals for the software.

Offset values and calibration values were determined and evaluated using techniques described in Densmore and others (2013). Calibration values were determined from processing data collected specifically for the calibration test. This test procedure is described in the ”Quality Assurance and Quality Control” section of this report.

Review of preliminary data indicated that most data points were collected with satisfactory water-surface elevation readings, but many were not. Therefore, for each survey, a time series of water-surface profiles was created by selecting representative upstream and downstream water-surface elevations from each survey dataset. The water-surface profiles were used to spatially interpolate the water surface for the time period of the survey. These water-surface profiles were used in CARIS HIPS and SIPS to assign water-surface elevations to each hydrographic data point.

After a water-surface profile was applied to the dataset, automated filters were applied to remove some of the erroneous data points from the hydrographic dataset. Each swath (width of a single passage or 128°, made up of many sonar pings, each containing 512 soundings) was evaluated manually to eliminate other data spikes not removed by automated filters.

The Combined Uncertainty and Bathymetry Estimator (CUBE) algorithm (Calder and Wells, 2007) was used to create a surface model based on the hydrographic dataset. The surface model was exported in a geospatial raster format — grids with 1.64-ft by 1.64-ft (0.5-m-by 0.5-m) cells. Each cell value represents an estimate of the most likely bed elevation associated with the area inside the cell.

For each bridge site, the surface model for the last survey was subtracted from the surface model for the first survey to determine the difference in bed elevation for the period of the study. Negative difference values indicate erosion; positive values indicate deposition. The mean of all difference values indicates the net erosion or deposition value for the area of survey overlap, that is, measured during both rounds of surveying.

Polygons were generated for each bridge site to define ‘bedload transport’ areas. These areas near the bridge were chosen to include parts of the channel where active bedform migration was ongoing during the flood. Bedload transport areas were delimited to exclude areas with stable elevations, such as concrete or rip rap, areas of local scour around bridge infrastructure, and near river banks. The purpose of delineating the bedload transport areas was to provide a sample of bed elevations near the bridge that was unlikely to be affected by local pier scour or by fixed-elevation points, and to use that sample to estimate general erosion or deposition across the riverbed.

Polygons were generated for each bridge pier that was surveyed with the MBES mapping system. The purpose of delineating the areas near piers was to provide a sample of the bed elevations that were likely to be affected by local pier scour. Flow patterns near the piers and localized slopes found in the bed elevations from the first round of surveying were used to estimate the spatial extent of polygons. The polygons were used to summarize the bed elevations near the piers.

Quality Assurance and Quality Control

Several methods were used for quality assurance and quality control (QA/QC) during collection and processing of data collected with the MBES system. During data collection, the multibeam operator adjusted the transducer power, gate settings, and signal filters to optimize hardware and recording settings to improve the quality of data collected. The operator also compared the data collected in overlapping sections to immediately identify problems with data acquisition.

Patch tests are lines collected on specifically selected areas, in certain directions, to determine or confirm orientation and timing offsets of the MBES with respect to the IMU. In addition, patch tests were used to determine or confirm the angular offsets of the MBES projector/receiver with respect to the IMU; these angular offsets are referred to as roll, pitch, and yaw (U.S. Army Corps of Engineers, 2001). Seven patch tests were completed during the study and consisted of tests for latency, roll, pitch, and yaw.

The latency test was used to determine a timing offset (Δt) between the MBES system and the inertial positioning or GPS component of the POS MV as shown in figure 15*A*. Latency offsets were determined by collecting data on the same line over a slope or feature in the same direction but at two different speeds. Latency tests performed for the surveys reported herein indicated that the latency was zero for the collected data (Δt=0), so no timing offset was applied.

A roll test was used to determine the angular offset of the MBES projector/receiver alignment with respect to the IMU orientation in the longitudinal direction of the vessel. This angle is shown in figure 15*B* as α. To determine the roll angle offset α, soundings were collected over a flat area on two separate lines that overlap when the vessel is driven in opposite directions to collect each line. Roll tests performed for the surveys reported herein indicated that the roll angle offset (α) was equal to -19.6°, which was close to the expected value of -20° (the off-nadir angle at which the projector/receiver was mounted).

The pitch test was used to determine the angular offset of the MBES transducer projector/receiver alignment with respect to the IMU orientation in the direction of travel of the vessel. The pitch offset angle is shown as angle β in figure 15*C*. To determine the pitch angle offset β, one line was surveyed twice over a slope or feature, with data being collected in opposite directions. Pitch tests performed for the surveys reported herein indicated that the pitch angle offset (β) was equal to -3° for the deployment used in this study.

The yaw test was used to determine the angular offset of the MBES transducer projector/receiver alignment with respect to the IMU orientation about the vertical axis. The yaw offset angle is shown as angle δ in figure 15*D*. To determine the yaw angle offset δ, two lines are collected parallel to each other, driven in the same direction over a slope or feature. The yaw tests performed for the surveys reported herein indicated that the yaw angle offset (δ) was equal to 3.5°.

Mean total vertical uncertainty was calculated for each survey. Standard deviation values of the elevations used to estimate the most likely bed elevations associated with the area inside each cell were exported from the CARIS grids. Standard deviation values were multiplied by 1.96 to provide an estimate of total vertical uncertainty within each grid cell to a 95-percent confidence level (International Hydrographic Organization, 2008). The mean total vertical uncertainty for each survey was computed as the mean value of vertical uncertainty for all of the grid cells in the survey.

Hydrographic Surveys of the Missouri River at Selected Bridges

Bridges that span the Missouri River and that enter Nebraska were surveyed at different times during the 2011 Missouri River flood. Four rounds of surveying occurred at different times during and after the flood at 14 of the 15 study sites on the Missouri River (table 2). At the Chief Standing Bear Memorial Bridge near Niobrara, Nebr., (site 1, fig. 1) two rounds of surveying were completed. For 13 of the 14 sites with 4 rounds of surveying, the first 2 rounds of surveying occurred when releases at Gavins Point Dam were at or near the peak flood release of 160,000 cubic feet per second (ft^3/s), the third round of surveying occurred when releases from Gavins Point Dam were near 90,000 ft^3/s, and the fourth round of surveying occurred after releases dropped to 40,000 ft^3/s (fig. 16, table 3). At one site, the Vermillion-Newcastle Bridge

Table 2. Bridge crossings surveyed along the Missouri River from Niobrara to Rulo, Nebraska, during the flood of 2011.

[River miles, miles above mouth near St. Louis, Missouri; NA, Not applicable]

Site number (fig. 1)	Bridge name	Route	City	River mile	Survey 1	Survey 2	Survey 3	Survey 4
1	Chief Standing Bear Memorial Bridge	Nebraska Highway 14, South Dakota Highway 37	Niobrara, Nebraska	841	7/25/2011	7/29/2011	NA	NA
2	Yankton Discovery Bridge	US Highway 81	Yankton, South Dakota	806	7/20/2011	7/29/2011	9/6/2011	10/31/2011
3	Vermillion-Newcastle Bridge	Nebraska Highway 15 and South Dakota Highway 19	Vermillion, South Dakota	775	6/23/2011	7/21/2011	8/4/2011	9/1/2011
4	Siouxland Veterans Memorial Bridge	US Highway 77	Sioux City, Iowa	732	7/24/2011	8/5/2011	9/2/2011	11/1/2011
5	Sergeant Floyd Memorial Bridge	Interstate 129, US Highway 20, US Highway 75	Sioux City, Iowa	728	7/24/2011	8/5/2011	9/2/2011	11/1/2011
6	Burt County Missouri River Bridge	Nebraska Highway 51 and Iowa Highway 175	Decatur, Nebraska	691	7/12/2011	7/28/2011	8/31/2011	11/2/2011
7	Abraham Lincoln Memorial Bridge	US Highway 30	Blair, Nebraska	648	7/25/2011	7/28/2011	9/6/2011	11/2/2011
8	Mormon Pioneer Memorial Bridge	Interstate 680	Omaha, Nebraska	626	7/13/2011	8/1/2011	9/7/2011	11/3/2011
9	Grenville Dodge Memorial Bridge	Interstate 480	Omaha, Nebraska	616	7/13/2011	8/3/2011	9/7/2011	11/3/2011
10	Interstate 80 Bridge	Interstate 80	Omaha, Nebraska	614	7/13/2011	8/3/2011	9/7/2011	11/3/2011
11	South Omaha Veterans Memorial Bridge	US Highway 275, Nebraska Highway 92, Iowa Highway 92	Omaha, Nebraska	612	7/14/2011	8/3/2011	9/7/2011	11/3/2011
12	Bellevue Bridge	Nebraska Highway 370, Iowa Highway 370	Bellevue, Nebraska	601	7/26/2011	7/30/2011	9/7/2011	11/9/2011
13	Plattsmouth Bridge	US Highway 34	Plattsmouth, Nebraska	590	7/18/2011	7/27/2011	9/8/2011	11/4/2011
14	Nebraska City Bridge	Nebraska Highway 2	Nebraska City, Nebraska	561	7/19/2011	8/2/2011	9/13/2011	10/19/2011
15	Rulo Bridge	US Highway 159	Rulo, Nebraska	498	7/26/2011	7/30/2011	9/14/2011	11/4/2011

near Vermillion, S.Dak. (site 3, fig. 1), three rounds of surveying occurred at or near the peak flood releases from Gavins Point Dam, and the fourth round of surveying occurred when releases from Gavins Point Dam were near 90,000 ft^3/s. At the Chief Standing Bear Memorial Bridge near Niobrara, Nebr., both surveys occurred during peak releases.

The benchmarks used to complete these hydrographic surveys are listed in table 4. Data collected by the base receiver each survey day were processed through NGS OPUS to establish high-quality coordinates at newly established benchmarks and to check the coordinates at existing benchmarks.

Mean total vertical uncertainties for each survey were summarized (table 5). The median value for mean vertical uncertainties of the 58 surveys was 0.85 ft (0.26 m). The survey with the greatest mean total vertical uncertainty was the first round of surveying at Chief Standing Bear Memorial Bridge near Niobrara, Nebr. (1.80 ft [0.55 m]). The survey with the least mean vertical uncertainty was the fourth round of surveying at the Grenville Dodge Memorial Bridge at Omaha, Nebr. (0.42 ft [0.13 m]). Forty-six of the 58 surveys (79 percent) had mean vertical uncertainties of 1.0 ft (0.30 m) or less.

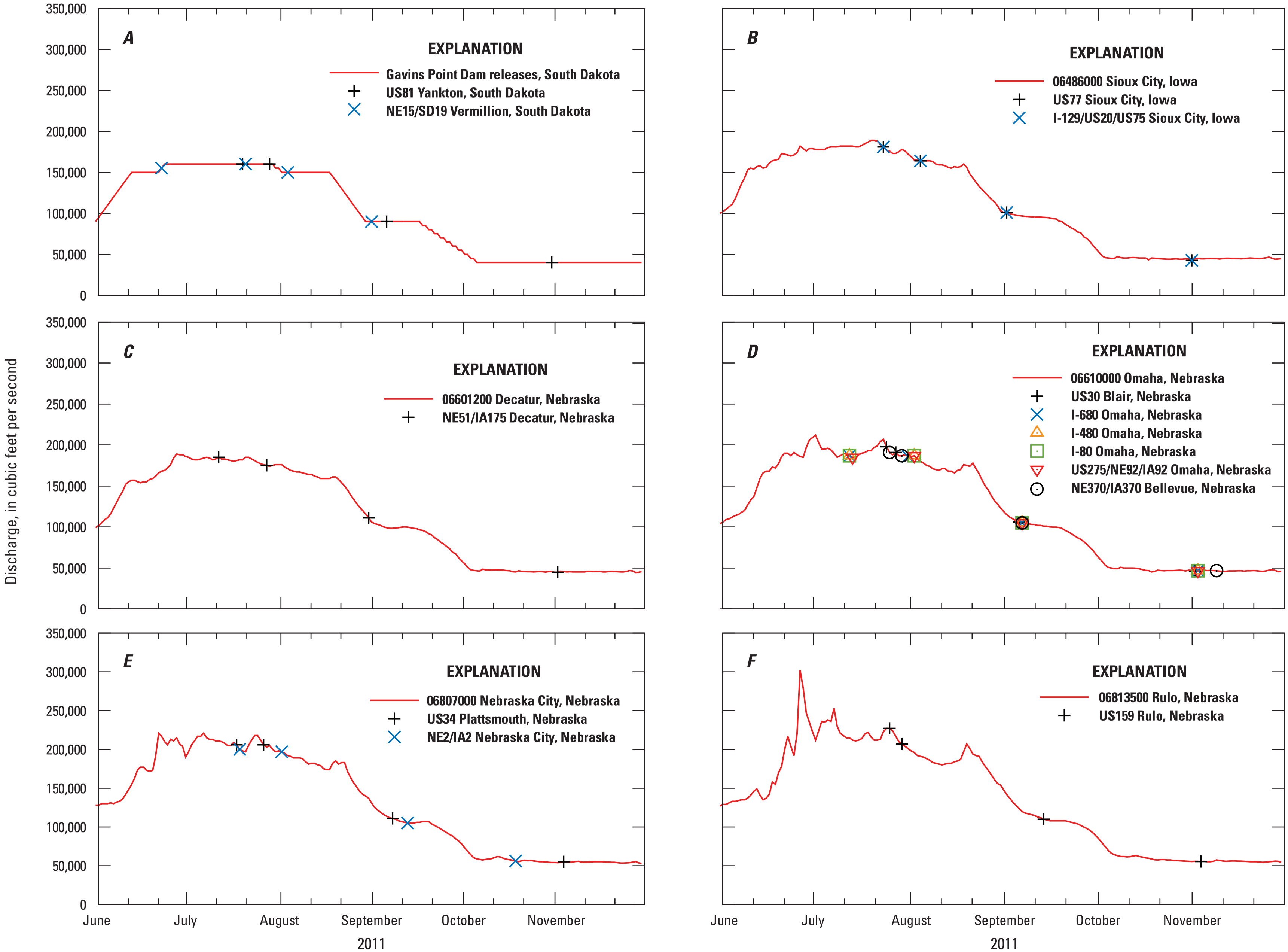


Figure 16. Discharge of the Missouri River at *A*, Gavins Point Dam; *B*, Sioux City, Iowa; *C*, Decatur, Nebraska; *D*, Omaha, Nebraska; *E*, Nebraska City, Nebraska; and *F*, Rulo, Nebraska, also indicated by highway route number of nearby bridge and the dates of hydrographic surveys during flooding of 2011.

Table 3. River discharge during hydrographic surveys during the 2011 flood event on the Missouri River.

[ft, feet; NAVD 88, North American Vertical Datum of 1988; USGS, U.S. Geological Survey; ft^3/s, cubic foot per second; --, no data]

Site number (fig. 1)	Route	Survey date	Water surface near bridge during survey (ft above NAVD 88)	USGS streamgage or source of discharge	Discharge (ft^3/s)
3	Nebraska State Highway 15 near Vermillion, SD	6/23/2011	1,131.93	Releases from Gavins Point Dam at Yankton, SD	155,000
6	Nebraska Highway 51 at Decatur, NE	7/12/2011	1,050.22	06601200 Missouri River at Decatur, NE	185,000
8	Interstate 680 at Omaha, NE	7/13/2011	991.60	06610000 Missouri River at Omaha, NE	187,000
9	Interstate 480 at Omaha, NE	7/13/2011	983.26	06610000 Missouri River at Omaha, NE	187,000
10	Interstate 80 at Omaha, NE	7/13/2011	981.82	06610000 Missouri River at Omaha, NE	187,000
11	US Highway 275 at Omaha, NE	7/14/2011	980.18	06610000 Missouri River at Omaha, NE	185,000
13	US Highway 34 at Plattsmouth, NE	7/18/2011	963.05	06807000 Missouri River at Nebraska City, NE	206,000
14	Nebraska Highway 2 at Nebraska City, NE	7/19/2011	927.99	06807000 Missouri River at Nebraska City, NE	200,000
2	US Highway 81 at Yankton, SD	7/20/2011	1,165.99	Releases from Gavins Point Dam at Yankton, SD	[1]160,000
3	Nebraska State Highway 15 near Vermillion, SD	7/21/2011	1,132.08	Releases from Gavins Point Dam at Yankton, SD	[1]160,000
4	US Highway 77 at Sioux City, IA	7/24/2011	1,091.76	06486000 Missouri River at Sioux City, IA	181,000
5	Interstate 129 at Sioux City, IA	7/24/2011	1,087.73	06486000 Missouri River at Sioux City, IA	181,000
1	Nebraska Highway 14 near Niobrara, NE	7/25/2011	1,224.36	Releases from Gavins Point Dam at Yankton, SD	[1]160,000
7	US Highway 30 at Blair, NE	7/25/2011	1,008.61	06610000 Missouri River at Omaha, NE	198,000
12	Nebraska Highway 370, at Bellevue, NE	7/26/2011	972.70	06610000 Missouri River at Omaha, NE	191,000
15	US Highway 159 at Rulo, NE	7/26/2011	862.59	06813500 Missouri River at Rulo, NE	227,000
13	US Highway 34 at Plattsmouth, NE	7/27/2011	962.56	06807000 Missouri River at Nebraska City, NE	206,000
6	Nebraska Highway 51 at Decatur, NE	7/28/2011	1,049.88	06601200 Missouri River at Decatur, NE	175,000
7	US Highway 30 at Blair, NE	7/28/2011	1,008.35	06610000 Missouri River at Omaha, NE	191,000
1	Nebraska Highway 14 near Niobrara, NE	7/29/2011	1,224.08	Releases from Gavins Point Dam at Yankton, SD	[1]160,000
2	US Highway 81 at Yankton, SD	7/29/2011	1,165.94	Releases from Gavins Point Dam at Yankton, SD	[1]160,000
12	Nebraska Highway 370, at Bellevue, NE	7/30/2011	972.08	06610000 Missouri River at Omaha, NE	187,000
15	US Highway 159 at Rulo, NE	7/30/2011	862.10	06813500 Missouri River at Rulo, NE	207,000
8	Interstate 680 at Omaha, NE	8/1/2011	991.45	06610000 Missouri River at Omaha, NE	186,000
14	Nebraska Highway 2 at Nebraska City, NE	8/2/2011	927.33	06807000 Missouri River at Nebraska City, NE	197,000
9	Interstate 480 at Omaha, NE	8/3/2011	983.68	06610000 Missouri River at Omaha, NE	187,000
10	Interstate 80 at Omaha, NE	8/3/2011	981.92	06610000 Missouri River at Omaha, NE	187,000
11	US Highway 275 at Omaha, NE	8/3/2011	980.21	06610000 Missouri River at Omaha, NE	187,000
3	Nebraska State Highway 15 near Vermillion, SD	8/4/2011	1,131.15	Releases from Gavins Point Dam at Yankton, SD	150,000
4	US Highway 77 at Sioux City, IA	8/5/2011	1,090.89	06486000 Missouri River at Sioux City, IA	164,000

Table 3. River discharge during hydrographic surveys during the 2011 flood event on the Missouri River.—Continued

[ft, feet; NAVD 88, North American Vertical Datum of 1988; USGS, U.S. Geological Survey; ft^3/s, cubic foot per second; --, no data]

Site number (fig. 1)	Route	Survey date	Water surface near bridge during survey (ft above NAVD 88)	USGS streamgage or source of discharge	Discharge (ft^3/s)
5	Interstate 129 at Sioux City, IA	8/5/2011	1,086.89	06486000 Missouri River at Sioux City, IA	164,000
6	Nebraska Highway 51 at Decatur, NE	8/31/2011	1,045.55	06601200 Missouri River at Decatur, NE	111,000
3	Nebraska State Highway 15 near Vermillion, SD	9/1/2011	1,127.52	Releases from Gavins Point Dam at Yankton, SD	90,000
4	US Highway 77 at Sioux City, IA	9/2/2011	1,083.13	06486000 Missouri River at Sioux City, IA	101,000
5	Interstate 129 at Sioux City, IA	9/2/2011	1,080.45	06486000 Missouri River at Sioux City, IA	101,000
2	US Highway 81 at Yankton, SD	9/6/2011	1,160.58	Releases from Gavins Point Dam at Yankton, SD	90,000
7	US Highway 30 at Blair, NE	9/6/2011	1,004.05	06610000 Missouri River at Omaha, NE	106,000
8	Interstate 680 at Omaha, NE	9/7/2011	985.35	06610000 Missouri River at Omaha, NE	105,000
9	Interstate 480 at Omaha, NE	9/7/2011	977.95	06610000 Missouri River at Omaha, NE	105,000
10	Interstate 80 at Omaha, NE	9/7/2011	976.92	06610000 Missouri River at Omaha, NE	105,000
11	US Highway 275 at Omaha, NE	9/7/2011	975.52	06610000 Missouri River at Omaha, NE	105,000
12	Nebraska Highway 370, at Bellevue, NE	9/7/2011	966.24	06610000 Missouri River at Omaha, NE	105,000
13	US Highway 34 at Plattsmouth, NE	9/8/2011	957.12	06807000 Missouri River at Nebraska City, NE	111,000
14	Nebraska Highway 2 at Nebraska City, NE	9/13/2011	924.23	06807000 Missouri River at Nebraska City, NE	105,000
15	US Highway 159 at Rulo, NE	9/14/2011	858.66	06813500 Missouri River at Rulo, NE	110,000
		Post flood event surveys			
14	Nebraska Highway 2 at Nebraska City, NE	10/19/2011	918.05	06807000 Missouri River at Nebraska City, NE	56,200
2	US Highway 81 at Yankton, SD	10/31/2011	1,154.90	Releases from Gavins Point Dam at Yankton, SD	40,000
4	US Highway 77 at Sioux City, IA	11/1/2011	1,070.40	06486000 Missouri River at Sioux City, IA	42,500
5	Interstate 129 at Sioux City, IA	11/1/2011	1,068.12	06486000 Missouri River at Sioux City, IA	42,500
6	Nebraska Highway 51 at Decatur, NE	11/2/2011	1,035.32	06601200 Missouri River at Decatur, NE	44,800
7	US Highway 30 at Blair, NE	11/2/2011	994.13	06610000 Missouri River at Omaha, NE	45,900
8	Interstate 680 at Omaha, NE	11/3/2011	975.11	06610000 Missouri River at Omaha, NE	46,500
9	Interstate 480 at Omaha, NE	11/3/2011	967.29	06610000 Missouri River at Omaha, NE	46,500
10	Interstate 80 at Omaha, NE	11/3/2011	966.52	06610000 Missouri River at Omaha, NE	46,500
11	US Highway 275 at Omaha, NE	11/3/2011	965.74	06610000 Missouri River at Omaha, NE	46,500
13	US Highway 34 at Plattsmouth, NE	11/4/2011	948.14	06807000 Missouri River at Nebraska City, NE	55,100
15	US Highway 159 at Rulo, NE	11/4/2011	850.87	06813500 Missouri River at Rulo, NE	55,500
12	Nebraska Highway 370, at Bellevue, NE	11/9/2011	956.14	06610000 Missouri River at Omaha, NE	46,600

[1]National Oceanic and Atmospheric Administration, 2012.

Table 4. Location of benchmarks used during the 2011 hydrographic surveys.

[All coordinate values are in feet, all horizontal coordinates shown in Universal Transverse Mercator, Zone 14, referenced to the North American Datum 1983; GRS80, Geodetic Reference System 1980; NAVD 88, North American Vertical Datum of 1988; Geoid09, model for transforming heights between ellipsoidal coordinates and NAVD 88 orthometric heights]

Date		Northing	Easting	Orthometric height (NAVD 88 determined from Geoid09)	Ellipsoid height (GRS80)
7/25/2011	Chief Standing Bear Memorial Bridge	1911422.28	15537141.95	1,324.63	1,239.99
7/20/2011	Yankton Discovery Bridge	2073161.01	15574877.48	1,173.39	1,089.55
6/23/2011	Vermillion-Newcastle Bridge	2191454.18	15522495.58	1,139.11	1,055.38
7/24/2011	Siouxland Veterans Memorial Bridge	2338511.83	15444227.52	1,099.96	1,014.41
7/24/2011	Sergeant Floyd Memorial Bridge	2347833.45	15428544.37	1,135.00	1,049.30
7/12/2011	Burt County Missouri River Bridge	2389095.86	15268716.26	1,058.85	971.46
7/25/2011	Abraham Lincoln Memorial Bridge	2434800.45	15105500.89	1,009.60	916.92
7/13/2011	Mormon Pioneer Memorial Bridge	2474950.74	15031281.93	1,027.99	936.36
7/14/2011	South Omaha Veterans Memorial Bridge	2485127.71	14982481.16	983.26	893.53
7/13/2011	Grenville Dodge Memorial Bridge	2485353.83	15002859.98	994.49	904.06
7/13/2011	Interstate 80 Bridge	2492509.70	14989308.70	987.34	897.31
7/26/2011	Bellevue Bridge	2498861.58	14956318.62	992.88	903.42
7/18/2011	Plattsmouth Bridge	2504525.18	14906455.65	1,043.34	953.39
7/19/2011	Nebraska City Bridge	2518918.06	14786328.84	1,010.49	914.37
7/26/2011	Rulo Bridge	2641147.22	14565704.68	886.29	785.35

Table 5. Mean total vertical uncertainty for Missouri River sites surveyed with multibeam echosounder during and after the flood of 2011.

Site number (fig. 1)	Bridge name	Route	City	River mile	Mean total vertical uncertainty (feet)			
					Survey 1	Survey 2	Survey 3	Survey 4
1	Chief Standing Bear Memorial Bridge	Nebraska Highway 14, South Dakota Highway 37	Niobrara, Nebraska	841	1.80	0.68	NA	NA
2	Yankton Discovery Bridge	US Highway 81	Yankton, South Dakota	806	0.65	0.70	0.68	0.59
3	Vermillion-Newcastle Bridge	Nebraska Highway 15 and South Dakota Highway 19	Vermillion, South Dakota	775	0.76	0.71	0.77	0.73
4	Siouxland Veterans Memorial Bridge	US Highway 77	Sioux City, Iowa	732	1.02	1.06	0.92	0.82
5	Sergeant Floyd Memorial Bridge	Interstate 129, US Highway 20, US Highway 75	Sioux City, Iowa	728	1.12	1.10	0.97	0.78
6	Burt County Missouri River Bridge	Nebraska Highway 51 and Iowa Highway 175	Decatur, Nebraska	691	1.01	0.94	0.93	0.75
7	Abraham Lincoln Memorial Bridge	US Highway 30	Blair, Nebraska	648	1.02	0.96	0.88	0.78
8	Mormon Pioneer Memorial Bridge	Interstate 680	Omaha, Nebraska	626	0.49	0.47	0.75	0.61
9	Grenville Dodge Memorial Bridge	Interstate 480	Omaha, Nebraska	616	0.56	0.57	0.48	0.42
10	Interstate 80 Bridge	Interstate 80	Omaha, Nebraska	614	1.00	0.60	0.50	0.44
11	South Omaha Veterans Memorial Bridge	US Highway 275, Nebraska Highway 92, Iowa Highway 92	Omaha, Nebraska	612	0.93	1.02	0.91	0.80
12	Bellevue Bridge	Nebraska Highway 370, Iowa Highway 370	Bellevue, Nebraska	601	0.66	1.19	1.19	1.09
13	Plattsmouth Bridge	US Highway 34	Plattsmouth, Nebraska	590	0.89	0.94	0.93	0.77
14	Nebraska City Bridge	US Highway 2	Nebraska City, Nebraska	561	0.95	0.96	0.93	0.77
15	Rulo Bridge	US Highway 159	Rulo, Nebraska	498	0.88	0.93	0.90	0.81

Chief Standing Bear Memorial Bridge (Nebraska Highway 14, South Dakota Highway 37) near Niobrara, Nebraska, at River Mile 841

The Chief Standing Bear Memorial Bridge crosses the Missouri River near Niobrara, Nebr., and links Nebraska Highway 14 to South Dakota Highway 37 (figs. 17–22). The bridge was closed during much of the 2011 Missouri River flooding because water flowed over the road on Highway 14. The bridge reach was surveyed twice during the 2011 flood: on July 25 and July 29, 2011 (table 2).

A large sandbar approximately 400 ft wide was observed in the middle of the channel during both survey events. The bed elevations surveyed in the bedload transport area during the July 25 survey ranged from 1,188 ft to 1,217 ft (fig. 18). The elevations observed during the July 25 survey were similar to the range of elevations surveyed during the July 29 survey (from 1,188 ft to 1,216 ft) (fig. 19). Eleven piers of the Chief Standing Bear Memorial Bridge were surveyed during both surveys. From the first survey to the second survey 4 days later, bed elevations near the piers did not change more than the amplitude of nearby bedforms.

The difference in bed elevation from July 25 to July 29 was computed for each grid cell sounded during both surveys (fig. 20). Changes in elevation from the July 25 survey to the July 29 survey were small in most areas (approximately -1 ft to +1 ft) and attributable to dune movement. A cross section of the hydrographic data collected at the upstream side of Chief Standing Bear Memorial Bridge shows little difference in bed elevation between July 25 and July 29 (fig. 21). The mean difference value of all re-sounded cells was -0.3 ft, providing no conclusive evidence of overall deposition or erosion in the survey area from July 25 to July 29.

In the bedload transport area, there was little change in the distribution of elevations at the site from July 25 to July 29 (fig. 22). The overall mean bed elevation of the bedload transport area decreased by 0.1 ft.

Base from U.S. Department of Agriculture National Aerial Imagery Program, 2010
Universal Transverse Mercator projection, Zone 14
Horizontal coordinate information referenced to the North American Datum of 1983 (NAD 83)

Figure 17. Location of hydrographic surveys of the Missouri River in the vicinity of the Chief Standing Bear Memorial Bridge near Niobrara, Nebraska, July 2011.

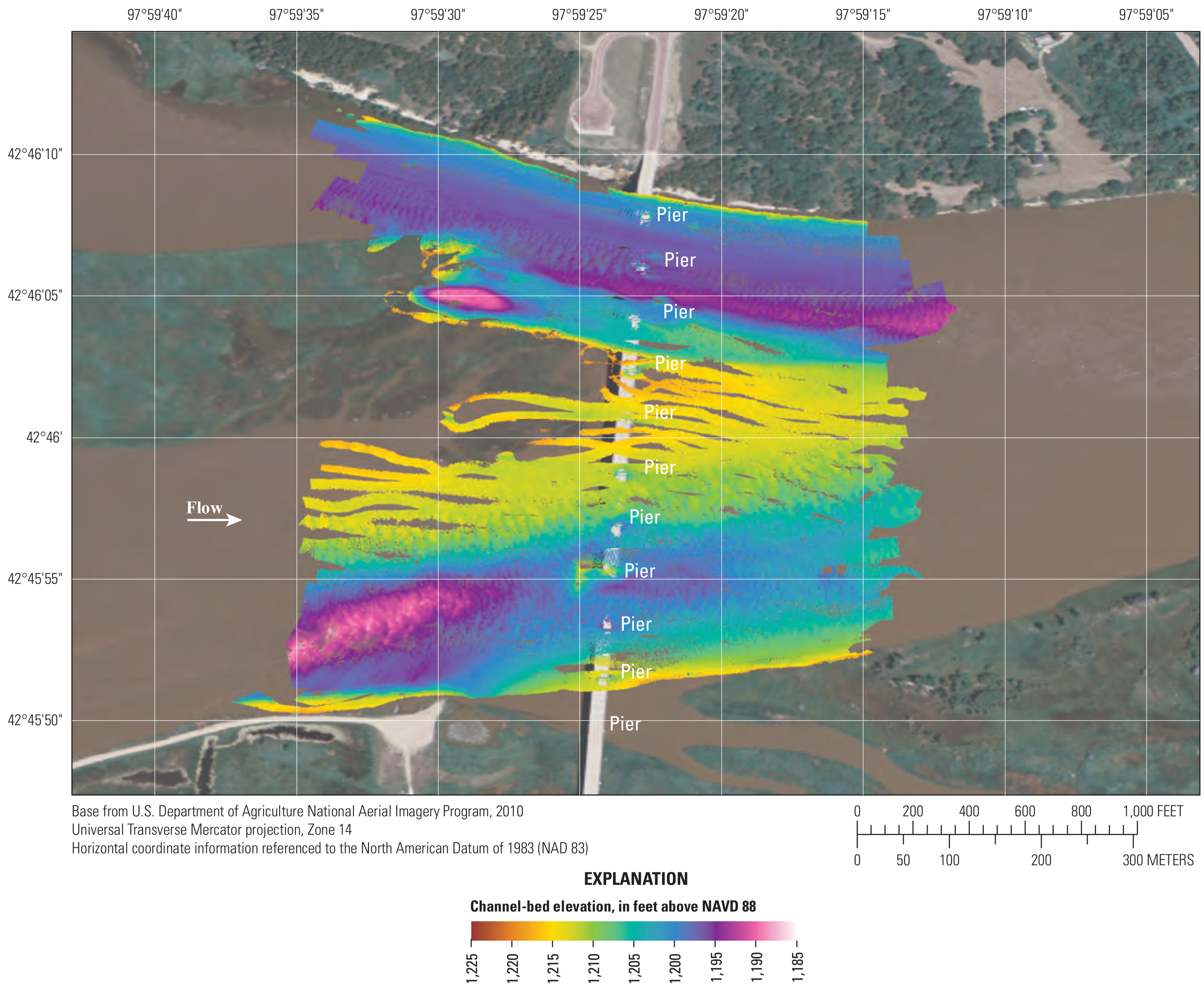


Figure 18. Channel-bed elevations of the Missouri River in the vicinity of the Chief Standing Bear Memorial Bridge near Niobrara, Nebraska, during flow of 160,000 cubic feet per second, July 25, 2011.

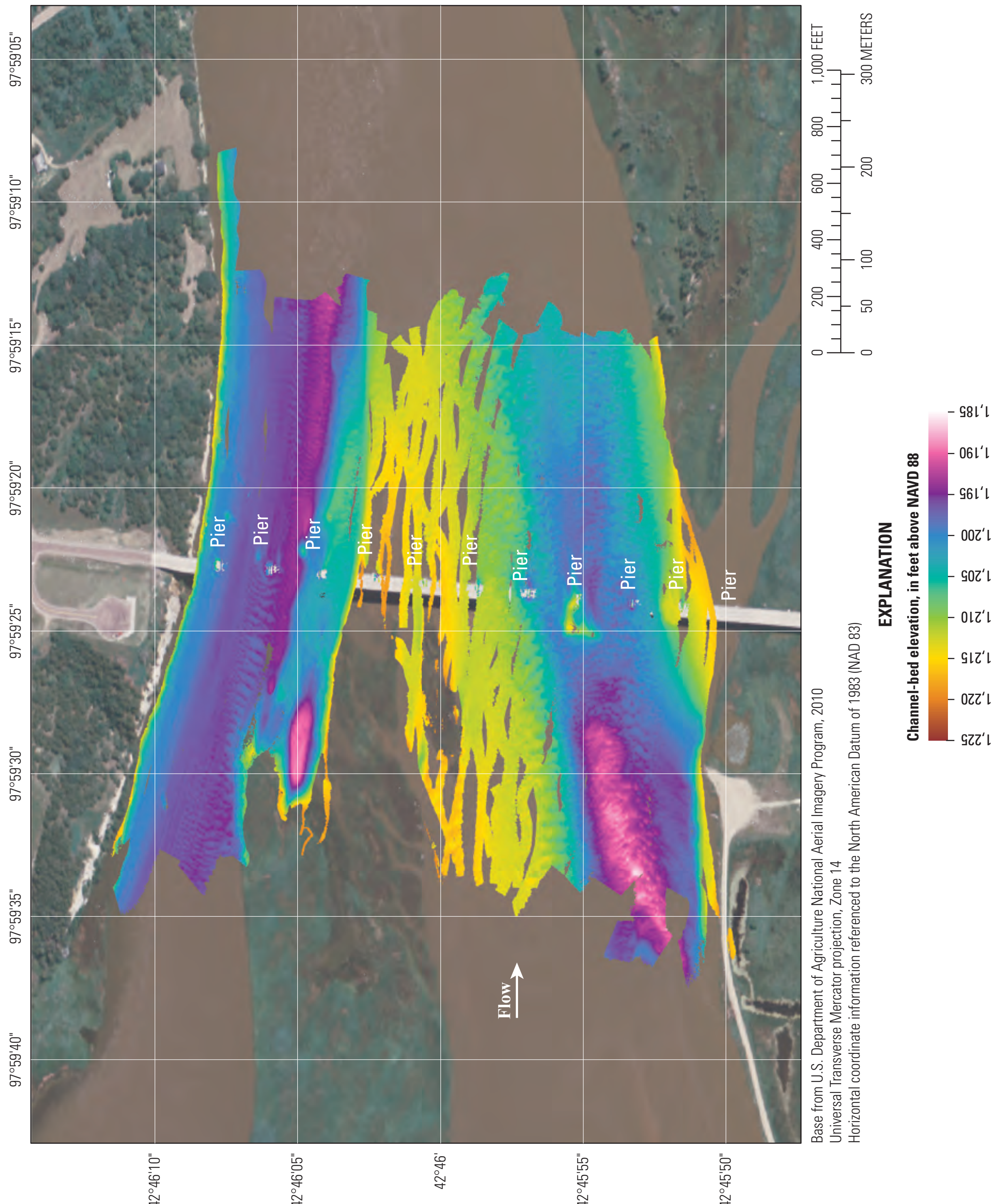


Figure 19. Channel-bed elevations of the Missouri River in the vicinity of the Chief Standing Bear Memorial Bridge near Niobrara, Nebraska, during flow of 160,000 cubic feet per second, July 29, 2011.

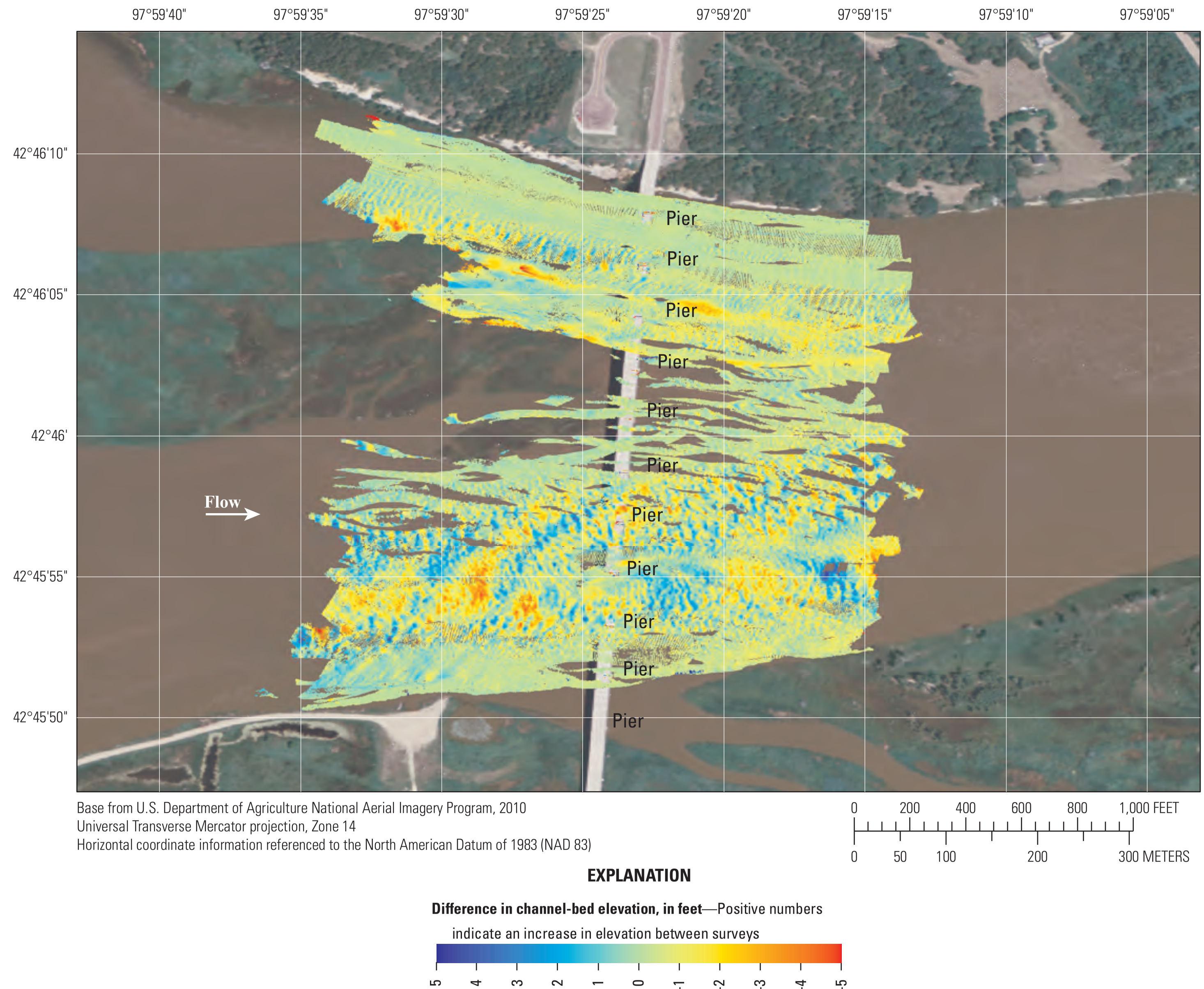


Figure 20. Difference in channel-bed elevation of the Missouri River in the vicinity of the Chief Standing Bear Memorial Bridge near Niobrara, Nebraska, between July 25 and July 29, 2011.

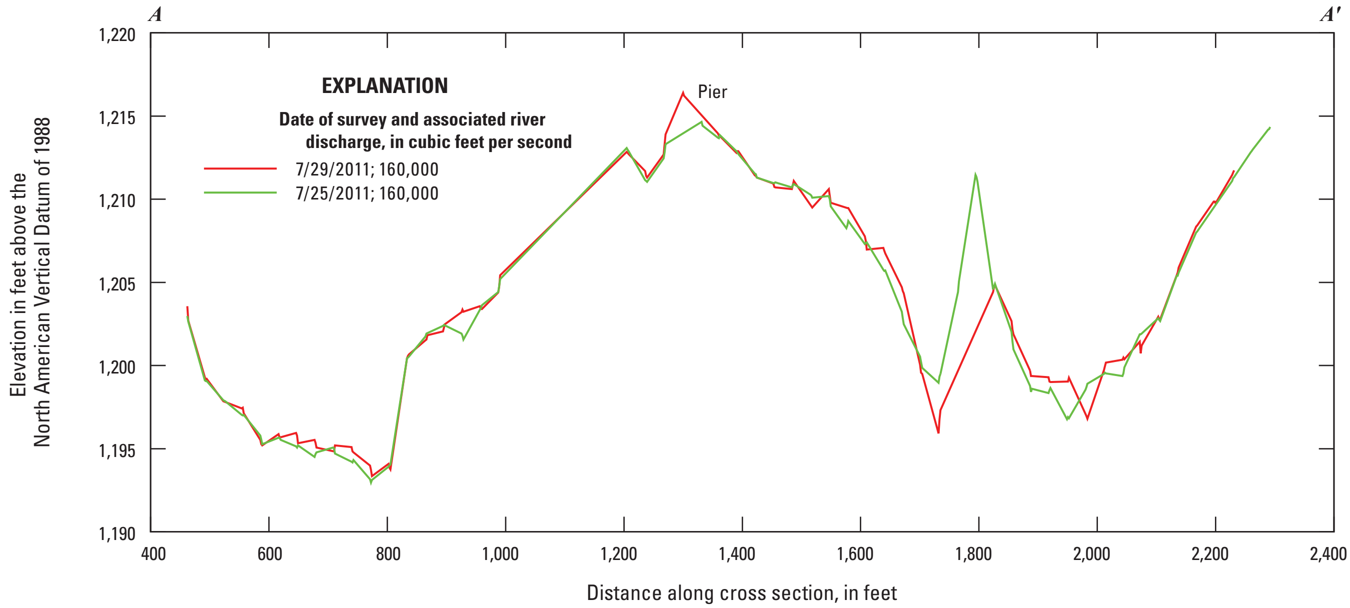


Figure 21. Hydrographic data collected by repeated surveys on the Missouri River along the upstream side of the Chief Standing Bear Memorial Bridge near Niobrara, Nebraska, July 2011.

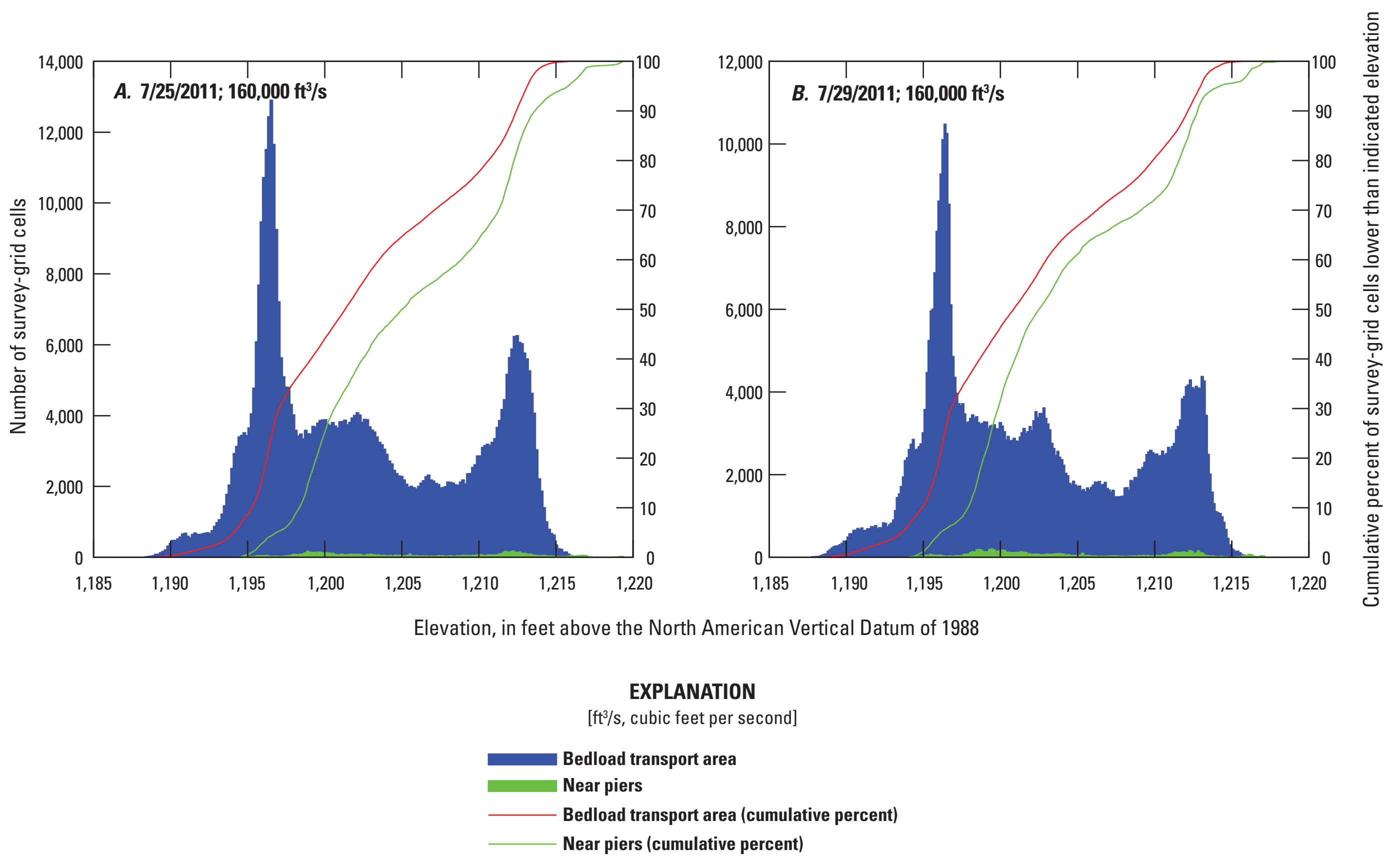


Figure 22. Frequency distribution of bed elevation, for hydrographic survey-grid cells (1.64 by 1.64 feet) sounded on the Missouri River in the vicinity of the Chief Standing Bear Memorial Bridge near Niobrara, Nebraska, *A*, July 25 and *B*, July 29, 2011.

Yankton Discovery Bridge (U.S. Highway 81) and Meridian Bridge at Yankton, South Dakota, at River Mile 806

The Yankton Discovery Bridge crosses over the Missouri River at Yankton, S.Dak., and also is known as the U.S. Highway 81 Bridge (figs. 23–30). The Yankton Discovery Bridge has five bridge piers located in the surveyed area. The Meridian Bridge (old U.S. Highway 81) is approximately 850 ft downstream from the Yankton Discovery Bridge and has four piers in the surveyed area. A reach that includes both bridges was surveyed four times during and after the 2011 flood: on July 20, July 29, September 6, and October 31, 2011 (table 2). The discharge released from Gavins Point Dam (about 5 miles upstream) was 160,000 ft^3/s during the July 20 and July 29 surveys. Releases from Gavins Point Dam had dropped to 90,000 ft^3/s by the September 6 survey. During the October 31 survey, 40,000 ft^3/s was flowing from Gavins Point Dam (table 3).

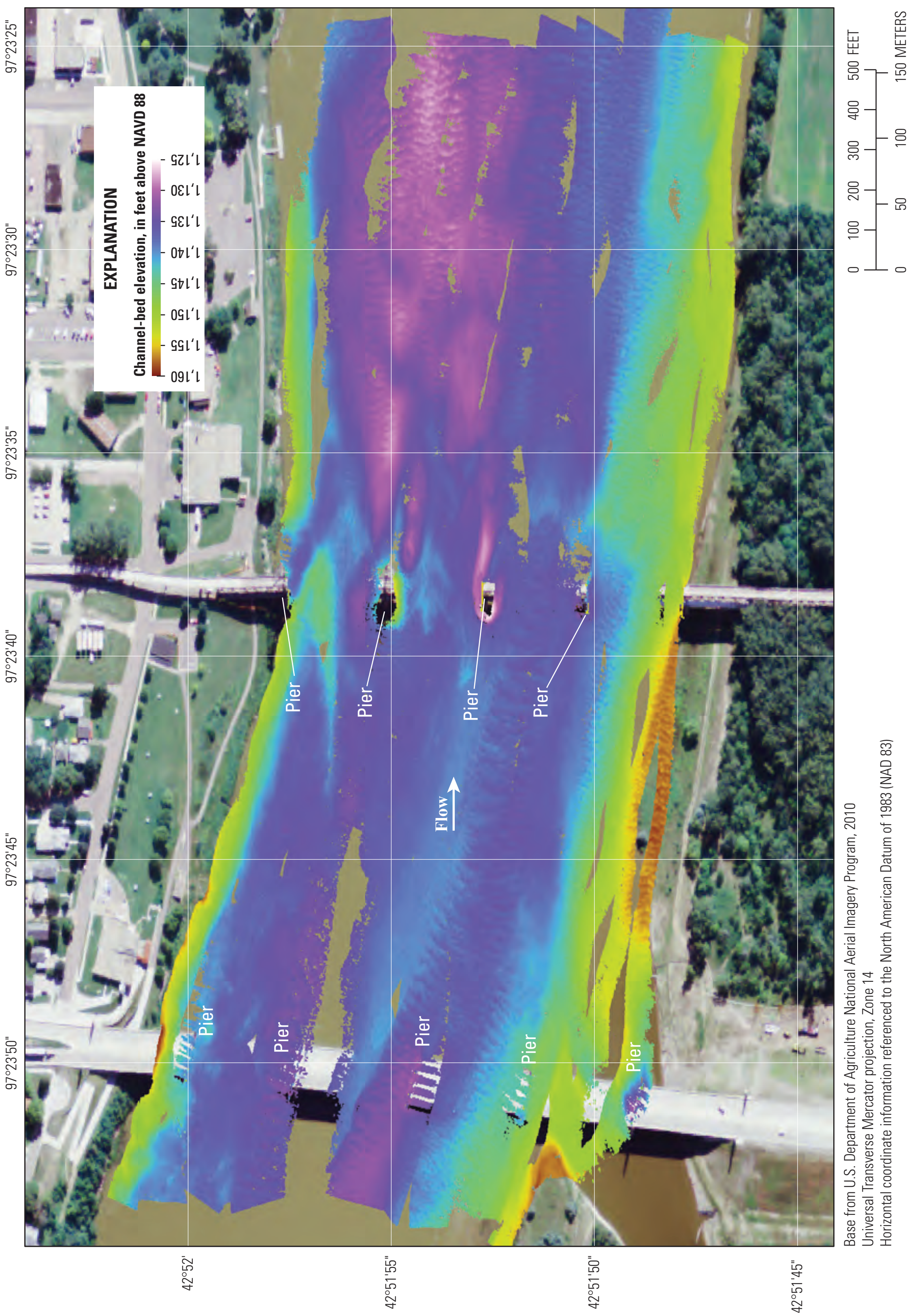
The bed elevations in the bedload transport area surveyed on July 20 ranged from 1,128 ft to 1,154 ft (fig. 24). There appeared to be little local scouring near the Yankton Discovery Bridge piers during the July 20 survey. The lowest bed elevation at the Yankton Discovery Bridge was surveyed in the center of the channel. In the area near the Meridian Bridge, the lowest area surveyed on July 20 occurred near the third pier of the bridge south from the north river bank. Bed elevations close to the pier were about 1,125 ft, whereas elevations near the bridge but not near the pier were typically 1,135 ft or greater. The data collected during the July 29 survey indicate that local scouring was not apparent near the piers of the Yankton Discovery Bridge (fig. 25). By July 29, the areal extent of the localized minimum elevation area (scour hole) near the third pier south from the north bank of the Meridian Bridge had increased. Bed elevation surveyed on September 6 (fig. 26) ranged from 1,130 ft to 1,148 ft for the entire site. Bed elevations on September 6 were not substantially different than previous elevations near the piers of the Yankton Discovery Bridge or at the piers of Meridian Bridge. There was no substantial change in elevation at the site from July 29 to September 6. Between September 6 and October 31 (fig. 27), the bed elevations had increased in many parts of the channel, particularly in the thalweg, by 5 ft or more.

The difference in bed elevation from July 20 to October 31 was computed for each cell sounded during both surveys (fig. 28). The mean difference value of all such cells was 1.2 ft, which exceeds the vertical uncertainty (table 5), indicating that net deposition likely occurred in the survey area between July 20 and October 31. A cross section of the hydrographic data collected at the upstream side of the Yankton Discovery Bridge shows that less than 5 feet of bed elevation change occurred near the cross section between July 20 and October 31.

In the bedload transport area, the frequency distribution indicated fewer cells with elevations less than 1,135 ft were present in July 20 than in October 31 (fig. 30). On July 20, the most frequently observed elevation in the bedload transport area was about 1,136 ft, whereas on October 31, the most frequently observed elevation was 1,138 ft. The mean elevation for the bedload transport area was about 1,135 ft on July 20 and about 1,137 ft on October 31.

Base from U.S. Department of Agriculture National Aerial Imagery Program, 2010
Universal Transverse Mercator projection, Zone 14
Horizontal coordinate information referenced to the North American Datum of 1983 (NAD 83)

Figure 23. Location of hydrographic surveys of the Missouri River in the vicinity of the Yankton Discovery Bridge at Yankton, South Dakota, July–October 2011.



Base from U.S. Department of Agriculture National Aerial Imagery Program, 2010
Universal Transverse Mercator projection, Zone 14
Horizontal coordinate information referenced to the North American Datum of 1983 (NAD 83)

Figure 24. Channel-bed elevations of the Missouri River in the vicinity of the Yankton Discovery Bridge at Yankton, South Dakota, during flow of 160,000 cubic feet per second, July 20, 2011.

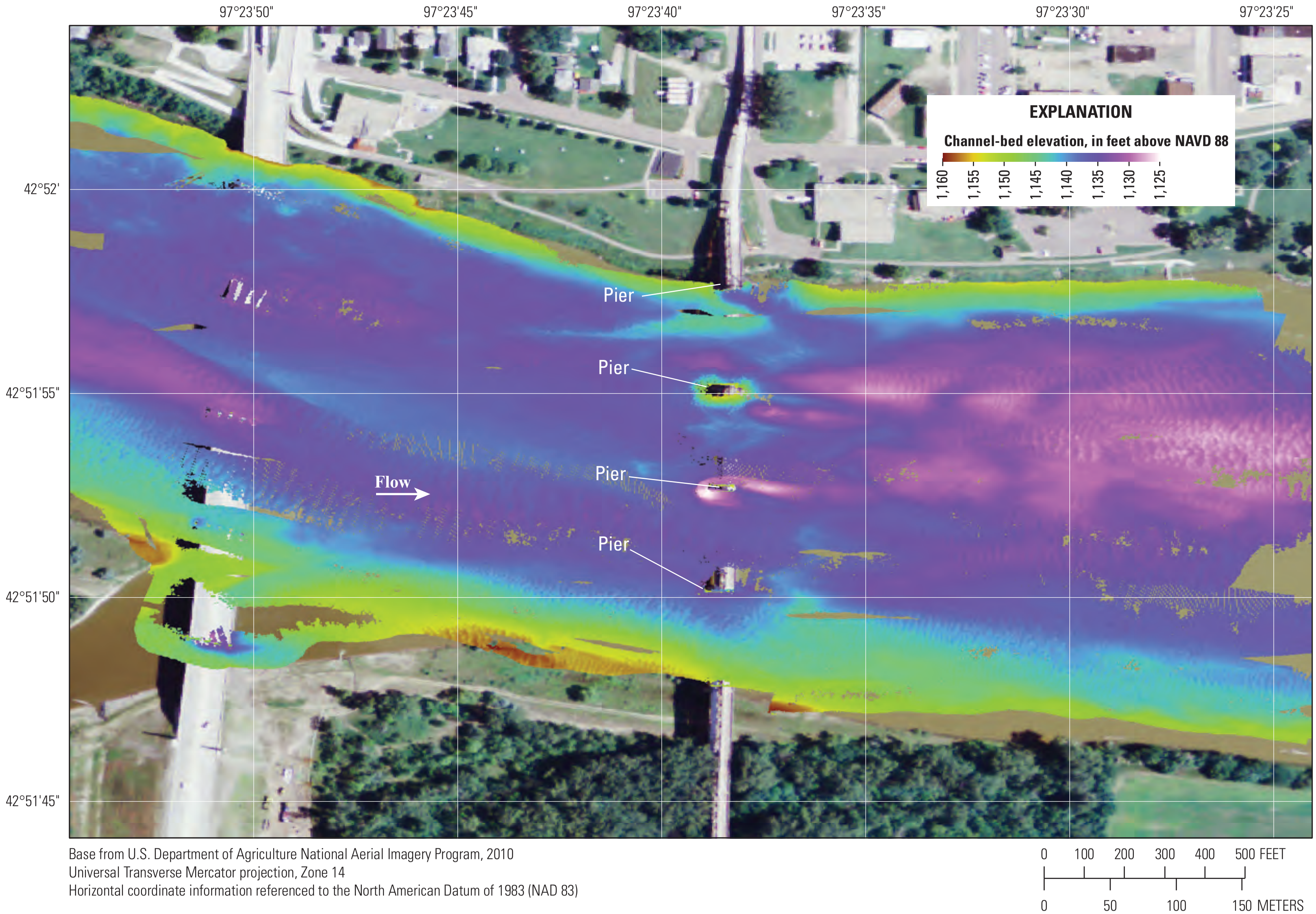


Figure 25. Channel-bed elevations of the Missouri River in the vicinity of the Yankton Discovery Bridge at Yankton, South Dakota, during flow of 160,000 cubic feet per second, July 29, 2011.

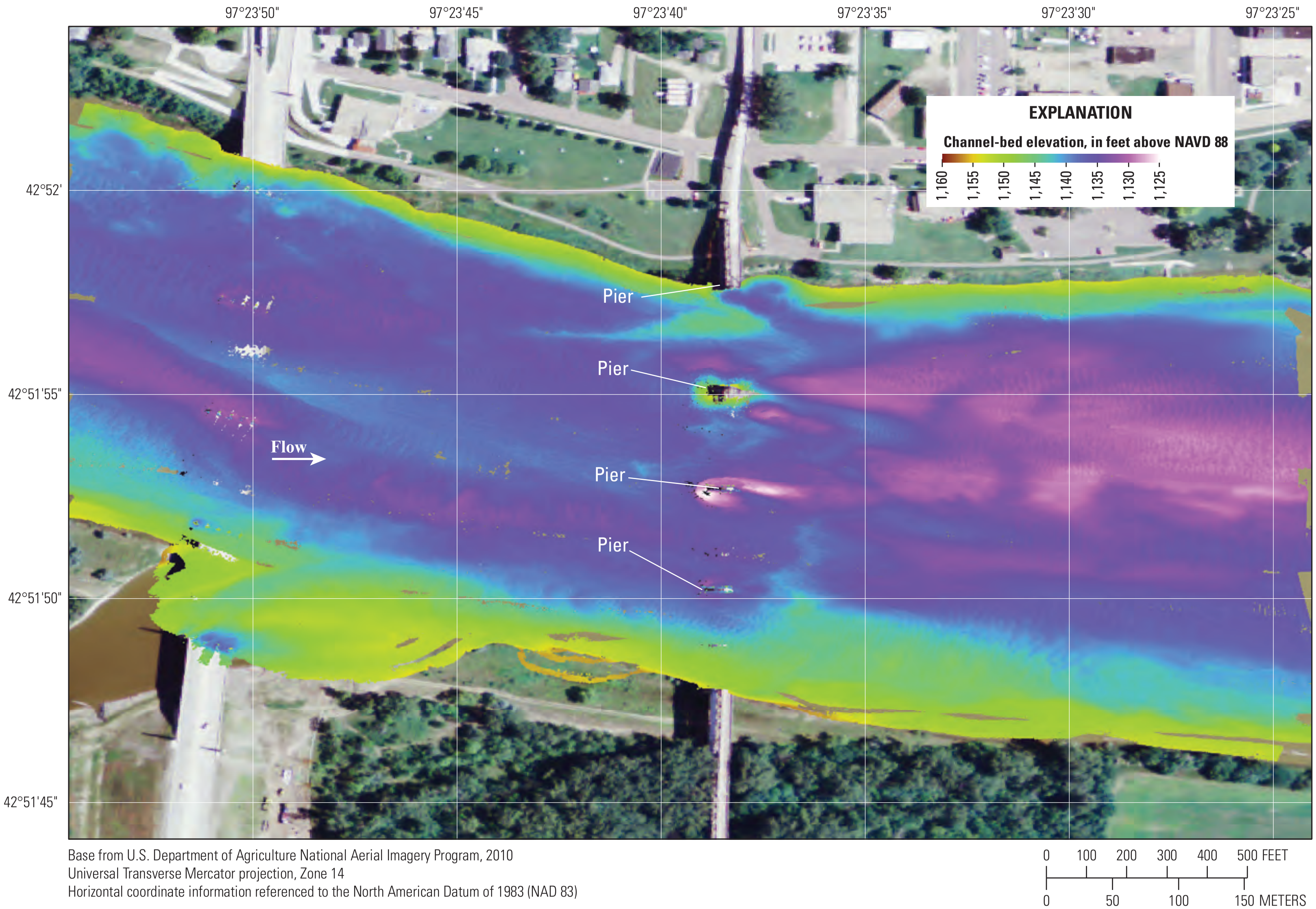


Figure 26. Channel-bed elevations of the Missouri River in the vicinity of the Yankton Discovery Bridge at Yankton, South Dakota, during flow of 90,000 cubic feet per second, September 6, 2011.

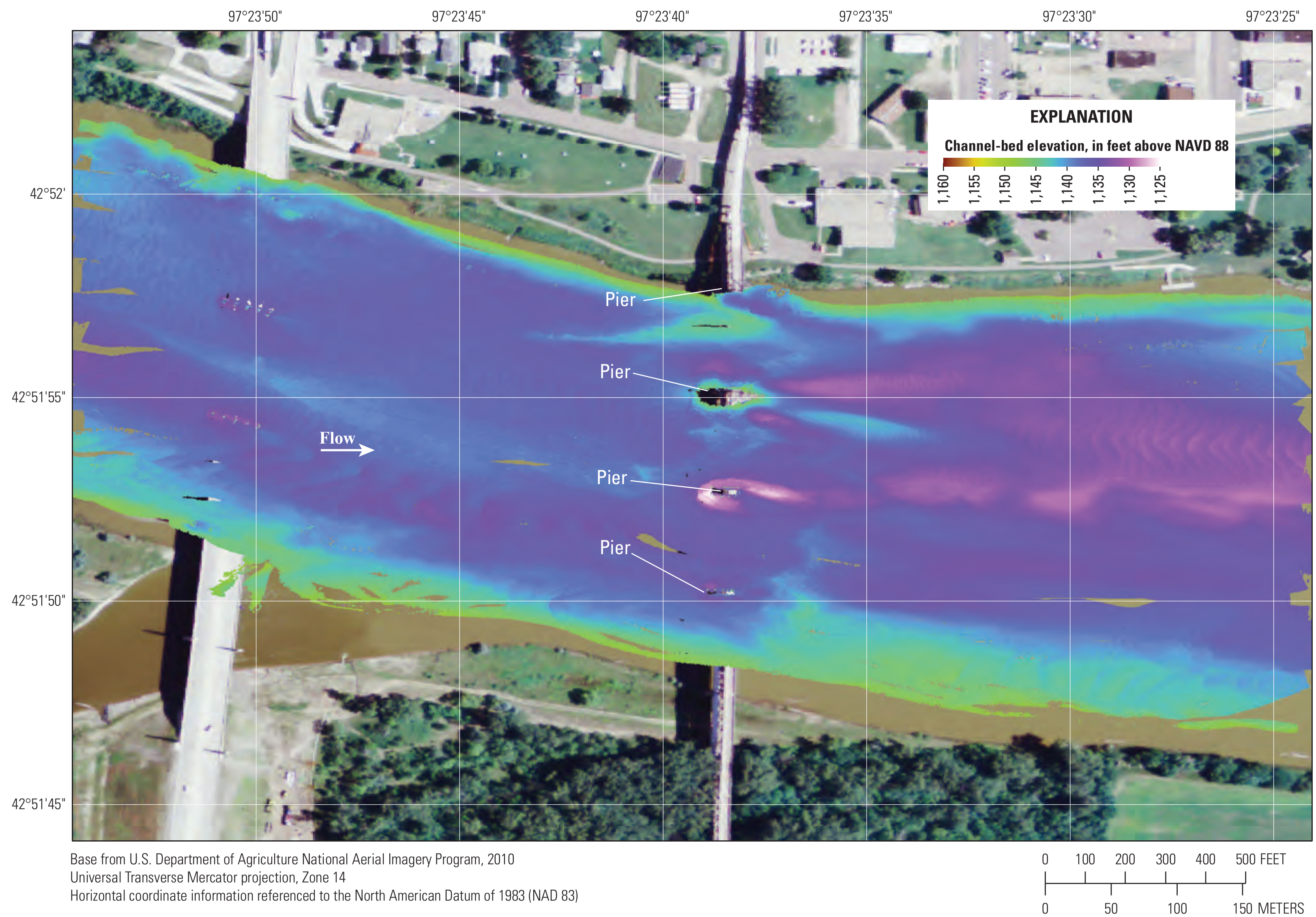


Figure 27. Channel-bed elevations of the Missouri River in the vicinity of the Yankton Discovery Bridge at Yankton, South Dakota, during flow of 40,000 cubic feet per second, October 31, 2011.

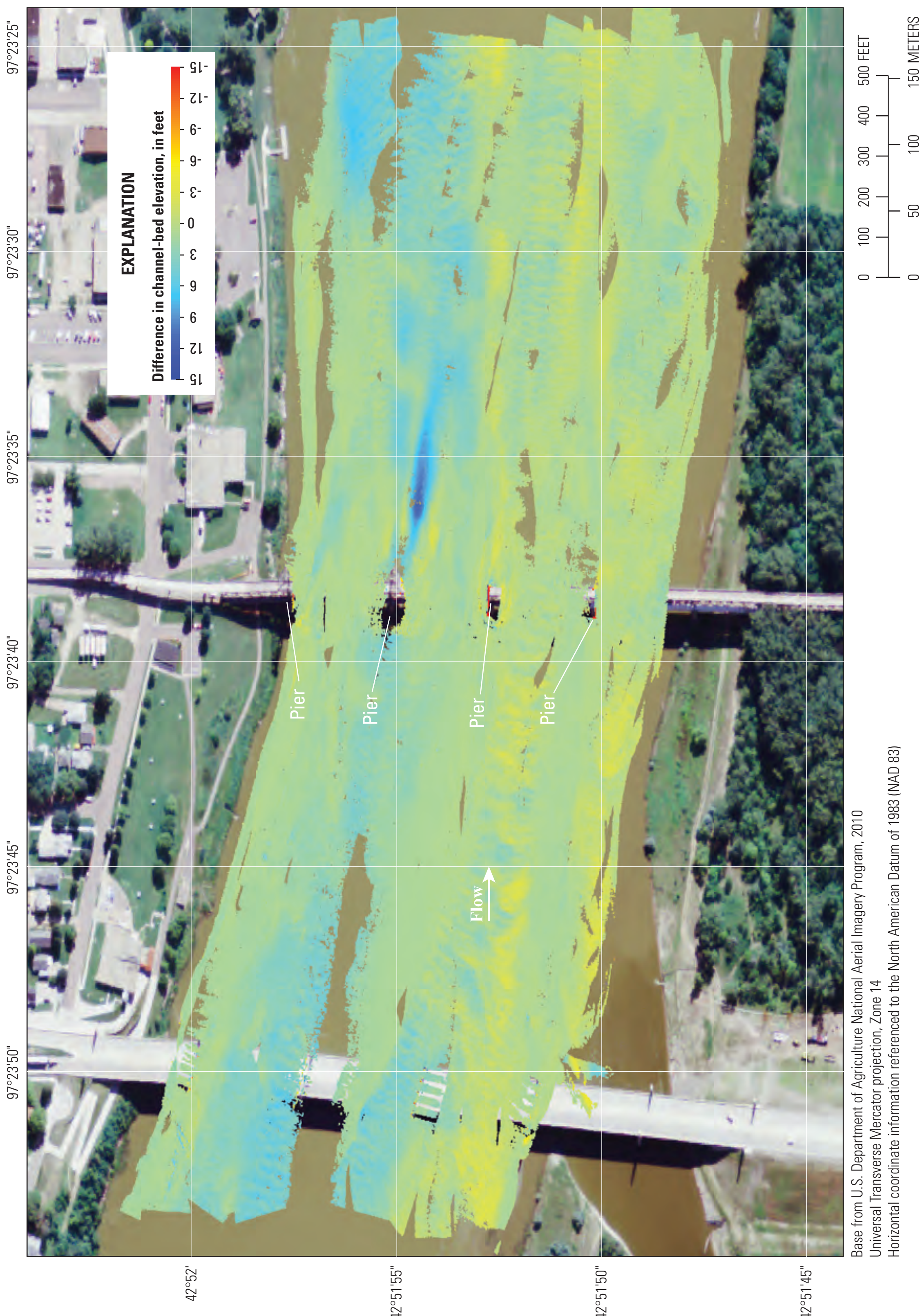


Figure 28. Difference in channel-bed elevation of the Missouri River in the vicinity of the Yankton Discovery Bridge at Yankton, South Dakota, between July 20 and October 31, 2011.

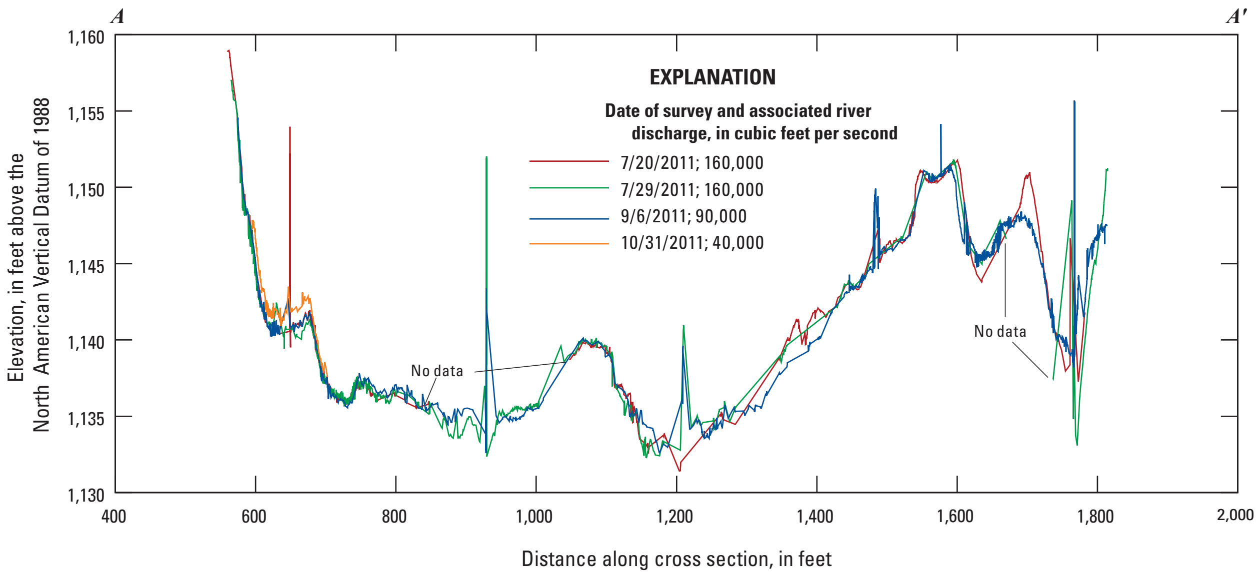


Figure 29. Hydrographic data collected by repeated surveys on the Missouri River along the upstream side of the Yankton Discovery Bridge at Yankton, South Dakota, July–October 2011.

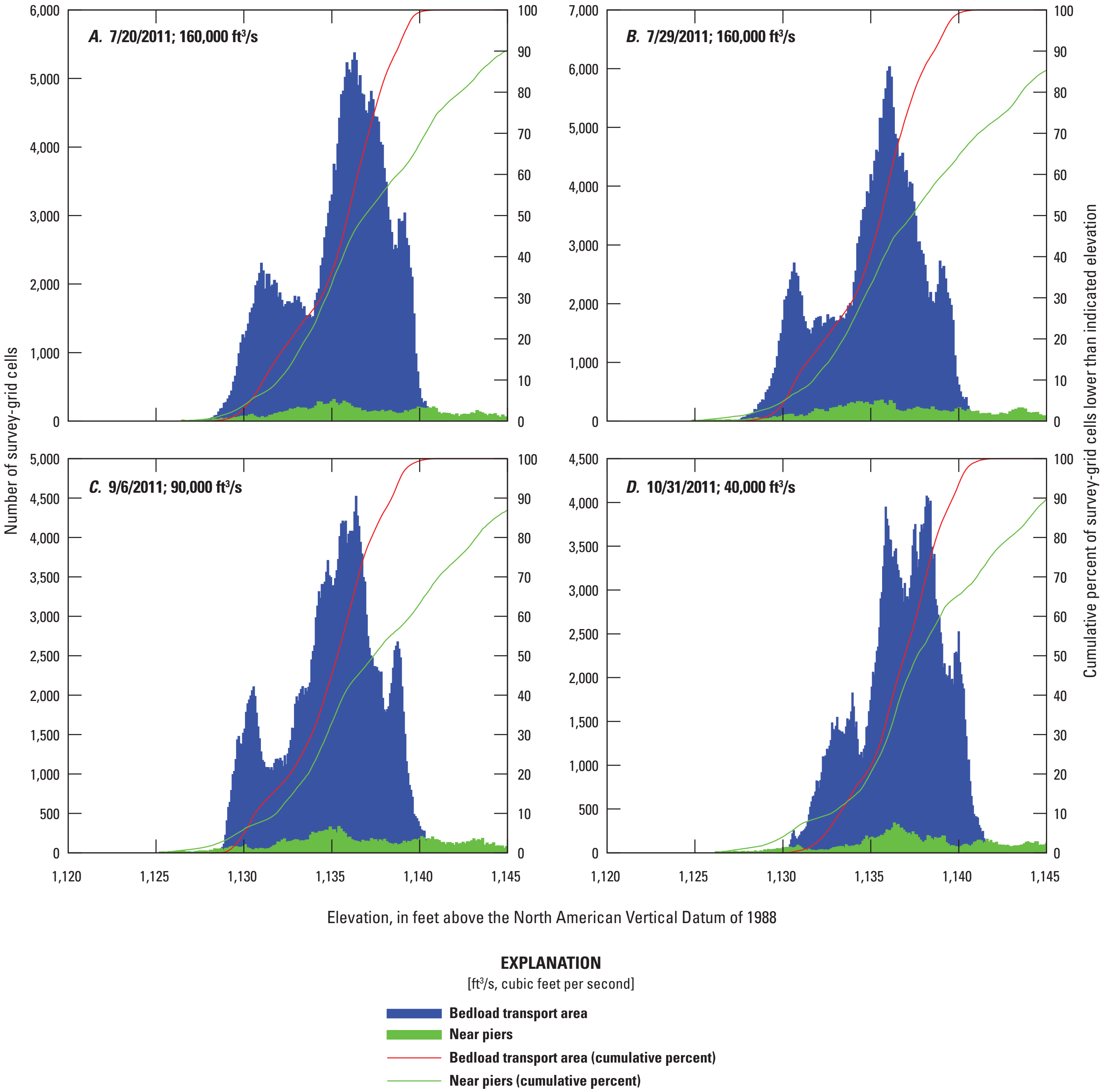


Figure 30. Frequency distribution of bed elevation, for hydrographic survey-grid cells (1.64 by 1.64 feet) sounded on the Missouri River in the vicinity of the Yankton Discovery Bridge at Yankton, South Dakota, *A*, July 20; *B*, July 29; *C*, September 6; and *D*, October 31, 2011.

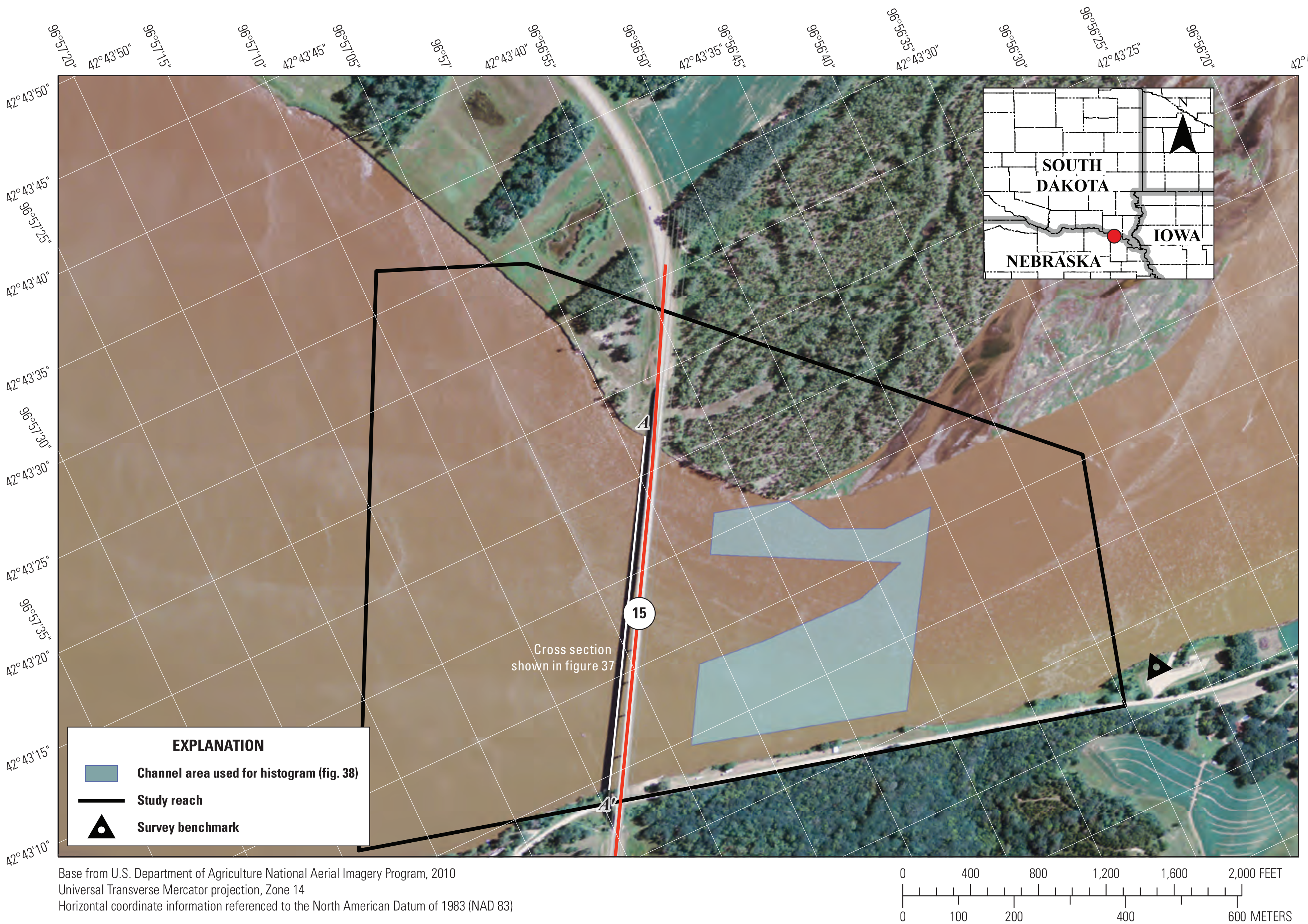
Vermillion-Newcastle Bridge (Nebraska Highway 15 and South Dakota Highway 19) near Vermillion, South Dakota, at River Mile 775

The Vermillion-Newcastle Bridge crosses the Missouri River near Vermillion, S.Dak., and joins Nebraska Highway 15 and South Dakota Highway 19 (figs. 31–38). There are 10 bridge piers located in the main channel. The Vermillion-Newcastle Bridge was surveyed four times during the 2011 flood (table 2). The discharge from Gavins Point Dam (about 36 miles upstream) was 155,000 ft^3/s during the June 23 survey and 160,000 ft^3/s during the July 21 survey (table 3). Releases from Gavins Point Dam were near 150,000 ft^3/s during the August 4 survey and at about 90,000 ft^3/s during the September 1 survey. The area surveyed on June 23 extended from about 250 ft downstream from the Vermillion-Newcastle Bridge to about 1,350 ft downstream from the bridge and did not include the area underneath the bridge because the survey was completed before the study began and was for purposes different from the objectives of the study. The June 23 data were used to compare changes in elevation within the bedload transport area.

The bed elevations surveyed in the bedload transport area on June 23 ranged from 1,092 ft to 1,117 ft (fig. 32). The July 21 survey (fig. 33) and subsequent surveys extended the investigated area to upstream from the bridge and included all 10 piers. The minimum channel-bed elevation in the survey area for each of the four surveys was located in the main channel thalweg and was about 1,090 ft. During the June 23 survey, a submerged sandbar was observed just upstream from the bridge outside of the June 23 survey area. The sandbar's location and migration were documented by the surveys of July 21 and August 4 (figs. 33 and 34). By September 1, the submerged sandbar extended from at least the upstream limits of the survey area to about 1,075 ft downstream from the bridge (fig. 35).

The difference in bed elevation from June 23 to September 1 was computed for each cell sounded during both surveys (fig. 36). The mean difference for all re-sounded cells was -0.3 ft, which is less than the vertical uncertainty for the survey between June 23 and September 1. A cross section of hydrographic data on the upstream side of the bridge shows that the thalweg near the South Dakota bank deepened by more than 5 feet from July 21 to September 1 (fig. 37).

In the bedload transport area, the mean of the September 1 bed elevations (1,108 ft) was not substantially different from the June 23 survey (1,109 ft); however, a general downward shift in elevations within the bedload transport area occurred over the course of the flood (fig. 38). The most frequently observed elevation in the June 23 survey was 1,114 ft; whereas, the most frequently observed elevation for the September 1 survey was 1,106 ft.



Base from U.S. Department of Agriculture National Aerial Imagery Program, 2010
Universal Transverse Mercator projection, Zone 14
Horizontal coordinate information referenced to the North American Datum of 1983 (NAD 83)

Figure 31. Location of hydrographic surveys of the Missouri River in the vicinity of the Vermillion-Newcastle Bridge near Vermillion, South Dakota, June–September 2011.

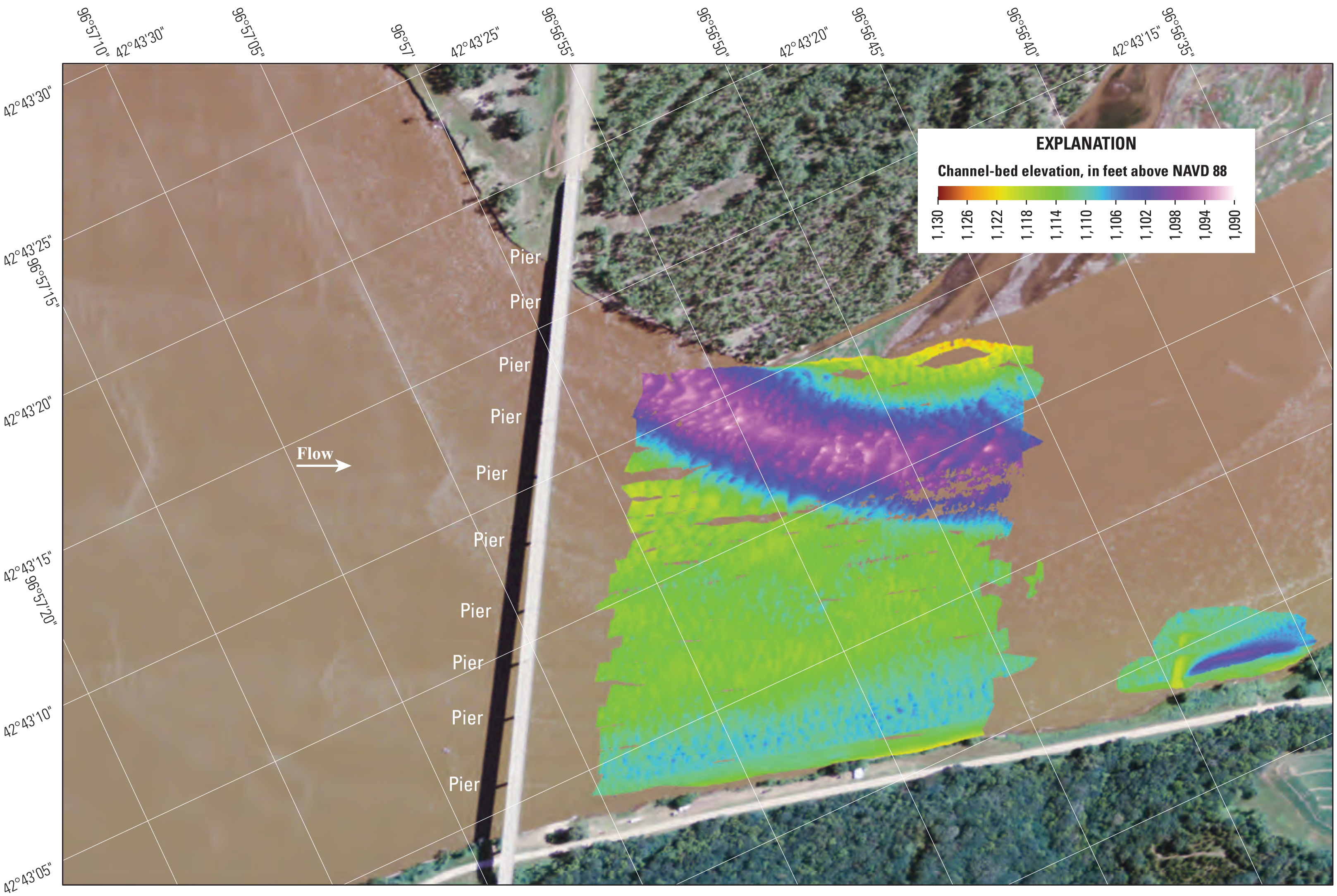


Figure 32. Channel-bed elevations of the Missouri River in the vicinity of the Vermillion-Newcastle Bridge near Vermillion, South Dakota, during flow of 155,000 cubic feet per second, June 23, 2011.

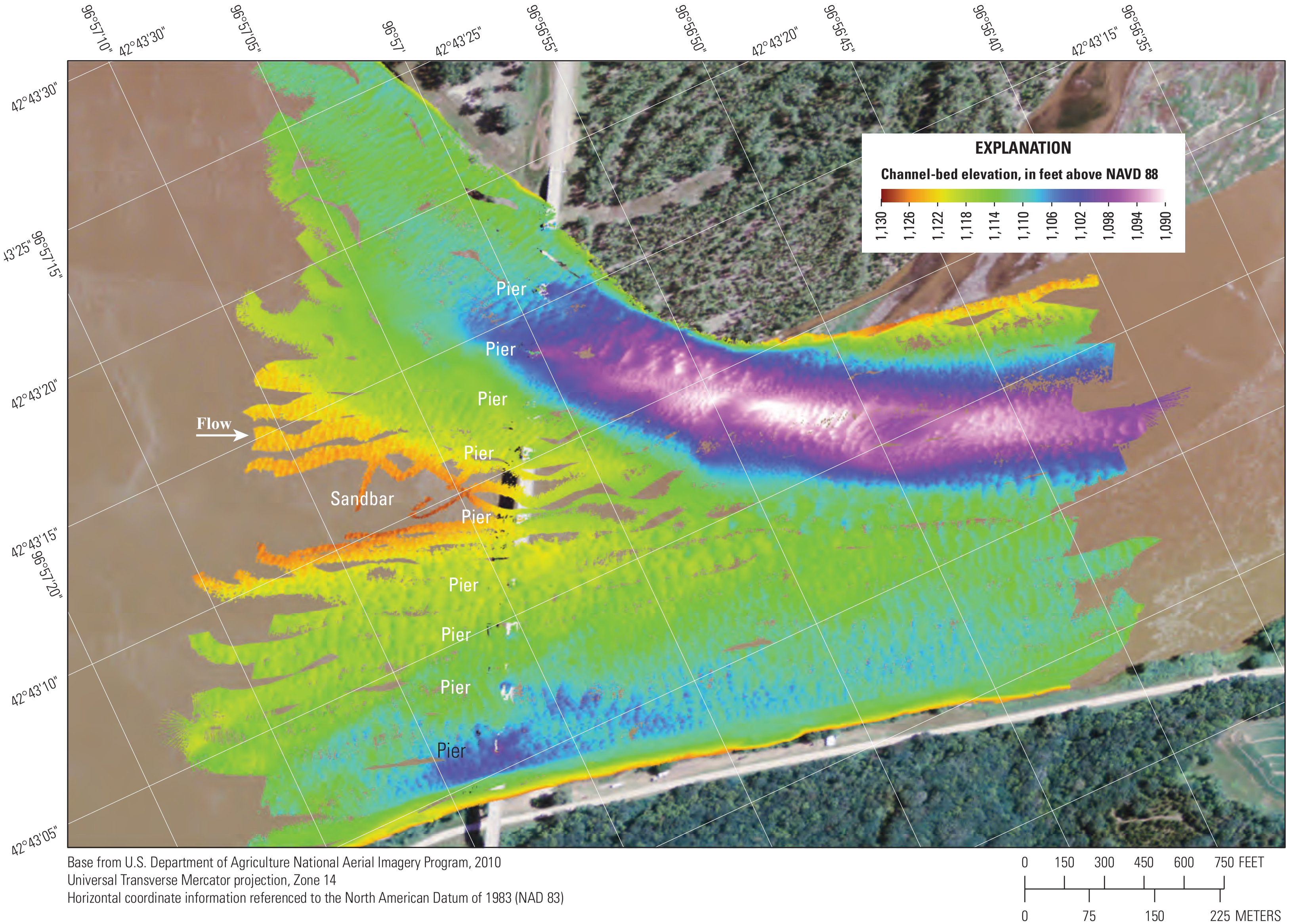
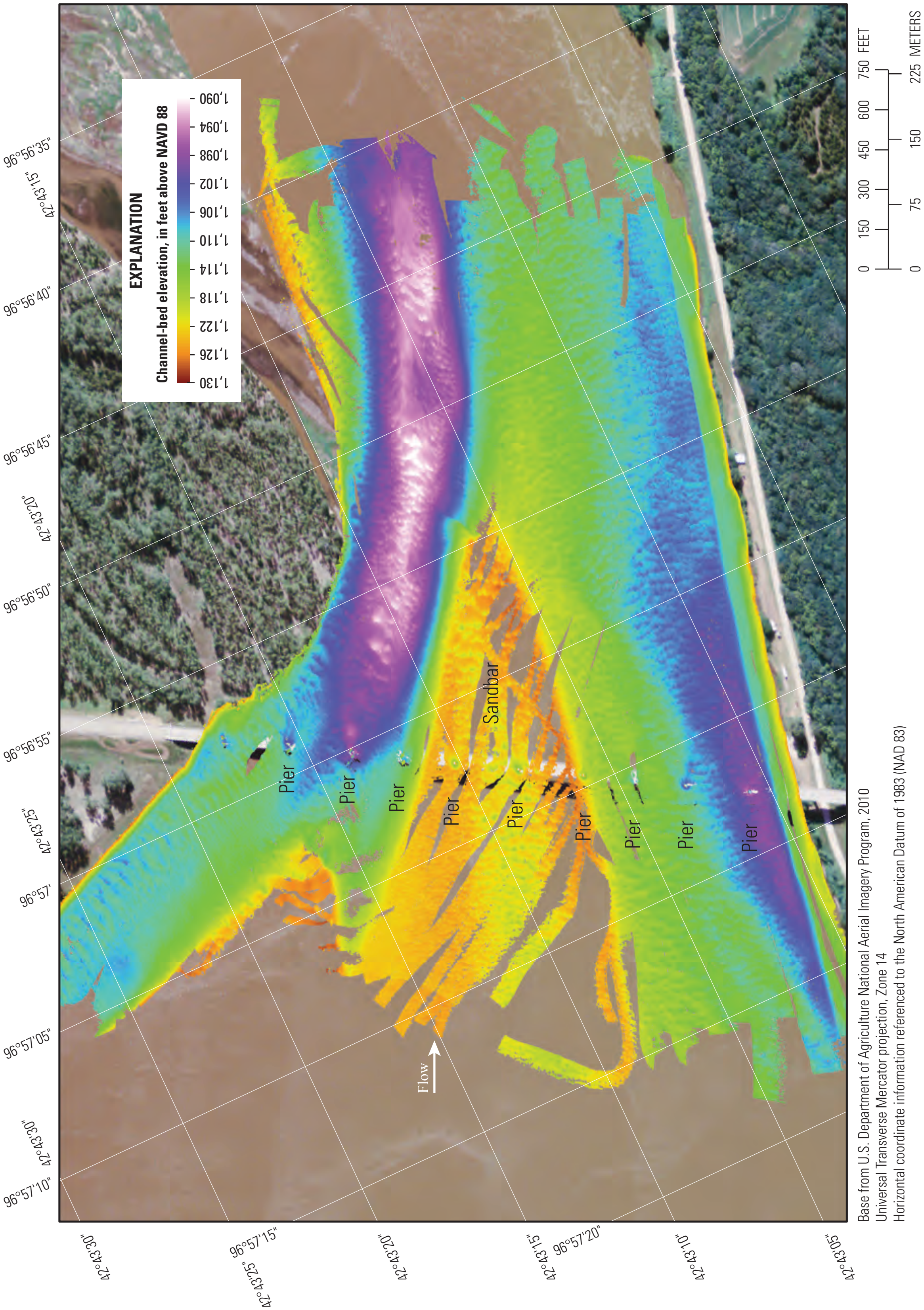


Figure 33. Channel-bed elevations of the Missouri River in the vicinity of the Vermillion-Newcastle Bridge near Vermillion, South Dakota, during flow of 160,000 cubic feet per second, July 21, 2011.



Base from U.S. Department of Agriculture National Aerial Imagery Program, 2010
Universal Transverse Mercator projection, Zone 14
Horizontal coordinate information referenced to the North American Datum of 1983 (NAD 83)

Figure 34. Channel-bed elevations of the Missouri River in the vicinity of the Vermillion-Newcastle Bridge near Vermillion, South Dakota, during flow of 150,000 cubic feet per second, August 4, 2011.

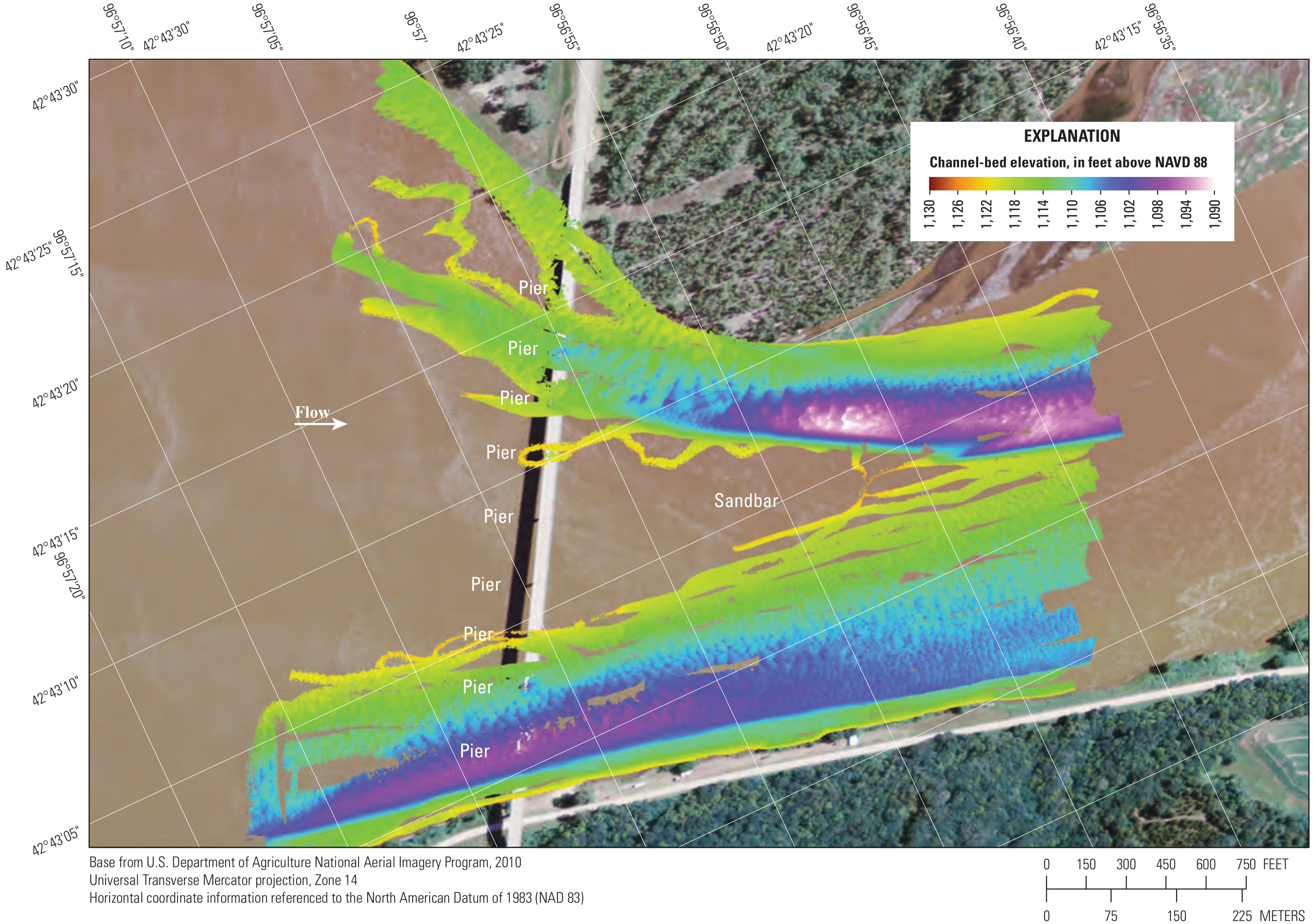
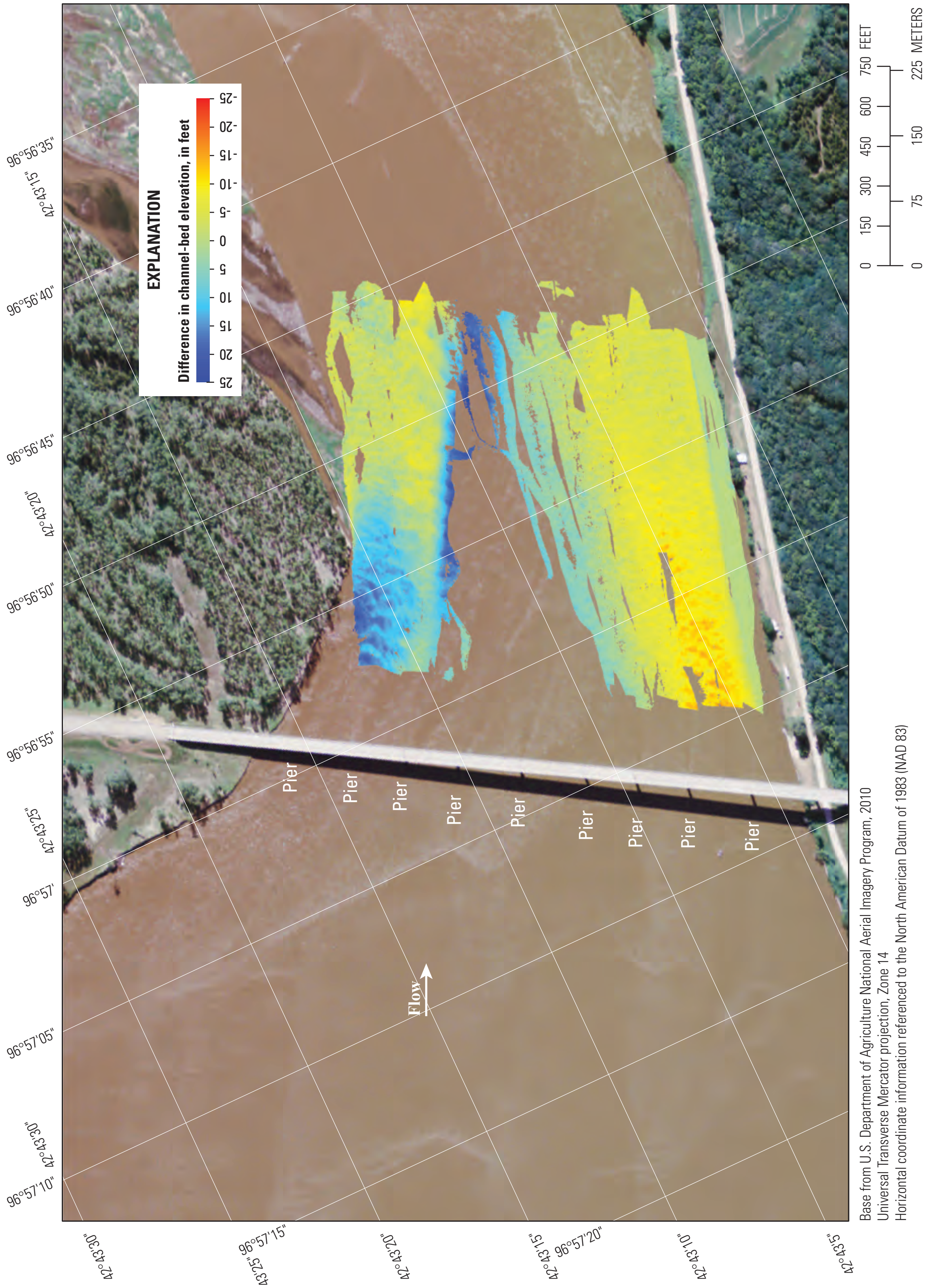


Figure 35. Channel-bed elevations of the Missouri River in the vicinity of the Vermillion-Newcastle Bridge near Vermillion, South Dakota, during flow of 90,000 cubic feet per second, September 1, 2011.



Base from U.S. Department of Agriculture National Aerial Imagery Program, 2010
Universal Transverse Mercator projection, Zone 14
Horizontal coordinate information referenced to the North American Datum of 1983 (NAD 83)

Figure 36. Difference in channel-bed elevation of the Missouri River in the vicinity of the Vermillion-Newcastle Bridge near Vermillion, South Dakota, between June 23 and September 1, 2011.

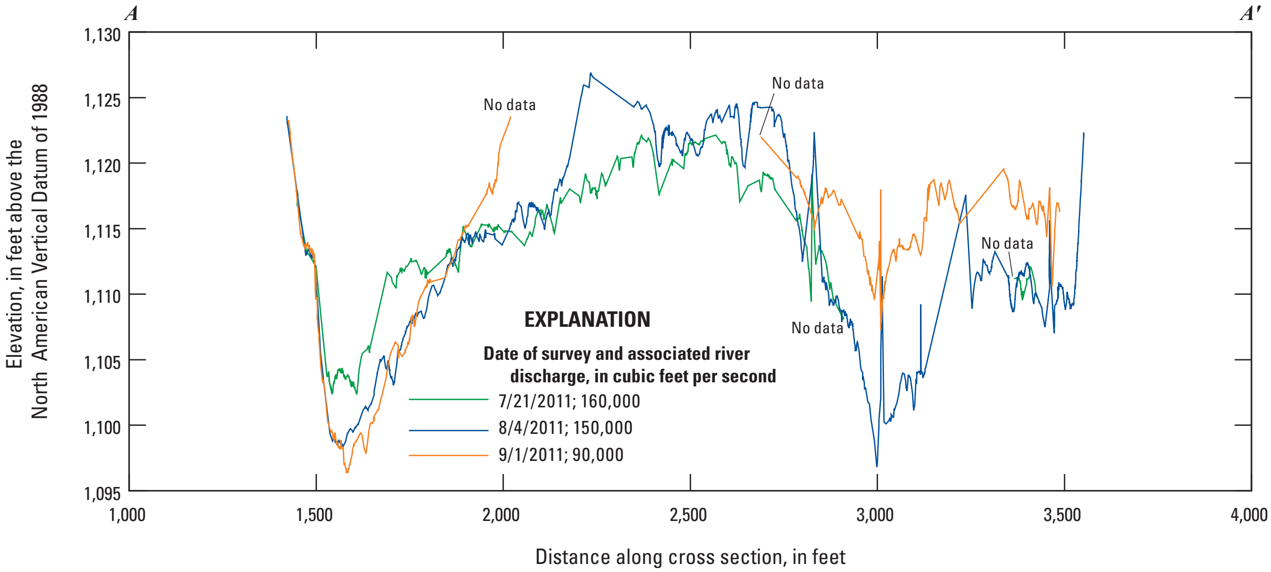


Figure 37. Hydrographic data collected by repeated surveys on the Missouri River along the upstream side of the Vermillion-Newcastle Bridge near Vermillion, South Dakota, July–September 2011.

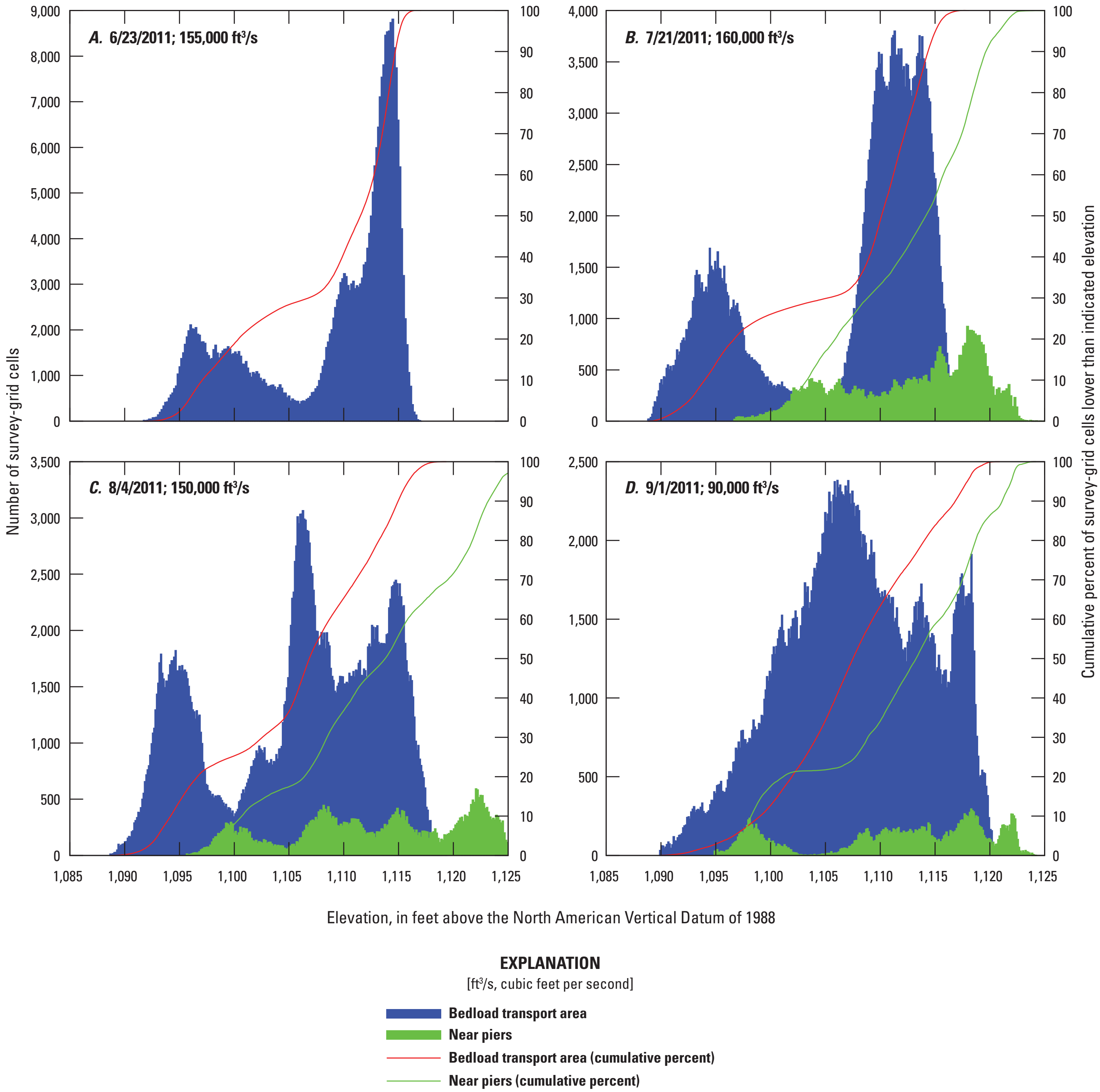


Figure 38. Frequency distribution of bed elevation, for hydrographic survey-grid cells (1.64 by 1.64 feet) sounded on the Missouri River in the vicinity of the Vermillion-Newcastle Bridge near Vermillion, South Dakota, *A*, June 23; *B*, July 21; *C*, August 4; and *D*, September 1, 2011.

Siouxland Veterans Memorial Bridge (U.S. Highway 77) at Sioux City, Iowa at River Mile 732

The Siouxland Veterans Memorial Bridge, also known as the U.S. Highway 77 Bridge, crosses the Missouri River at Sioux City, Iowa (figs. 39–46). The Siouxland Veterans Memorial Bridge was surveyed on four dates during and after the 2011 Missouri River flooding event (table 2). The USGS streamgaging station 06486000 Missouri River at Sioux City, Iowa, is located at this bridge. The discharges reported for streamgaging station 06486000 were 181,000 ft^3/s on July 24; 164,000 ft^3/s on August 5; 101,000 ft^3/s on September 2; and 42,500 ft^3/s on November 1 (table 3).

The bed elevations surveyed on July 24 ranged from 1,036 ft to 1,060 ft (fig. 40). For all four surveys, bed elevations were 1,050 ft or higher near the north pier and 1,040 ft or higher near the mid-channel pier. Bed elevations near the piers generally were within the range of bed elevations of dunes in other parts of the bedload transport area.

The difference in bed elevation from July 24 to November 1 was computed for each grid cell sounded during both surveys (fig. 44). The mean difference value of all re-sounded cells was 5.2 ft, indicating that net deposition occurred in the surveyed area between July 24 and November 1. Bed elevations at a cross section on the upstream side of the bridge do not indicate a clear pattern of change between July 24 and September 2, however bed elevations in center of the channel rose by 5 ft or more from September 2 to November 1 (fig. 45).

In the bedload transport area, the frequency distribution of elevations shifted upward between July 24 and November 1 (fig. 46), with the most pronounced shift occurring at the end of the flood (between the surveys of Sept. 2 and Nov. 1, 2011). The mean elevation for cells in the bedload transport area was 1,049 ft on July 24, whereas the mean elevation was 1,055 ft on November 1.

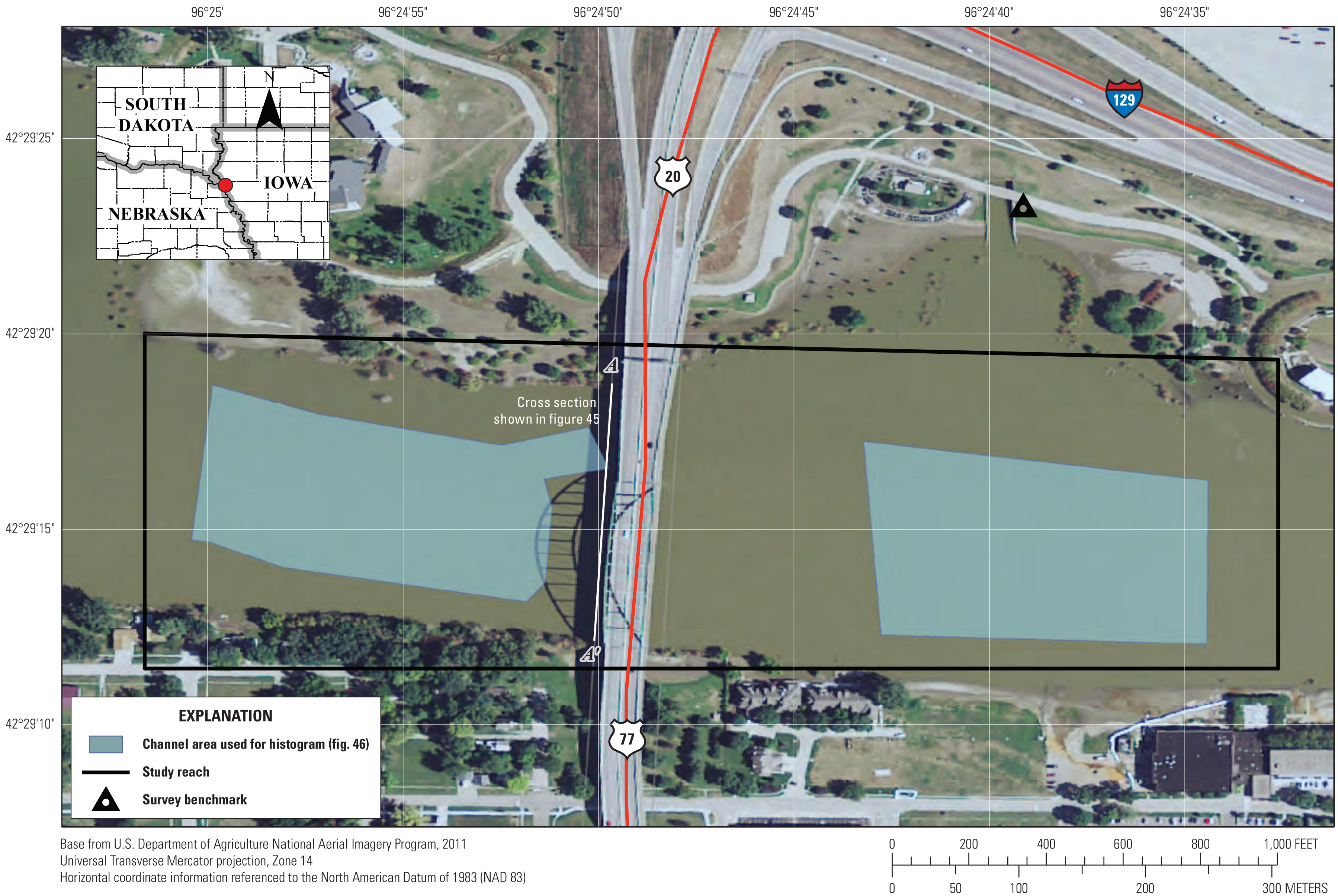


Figure 39. Location of hydrographic surveys of the Missouri River in the vicinity of the Siouxland Veterans Memorial Bridge at Sioux City, Iowa, July–November 2011.

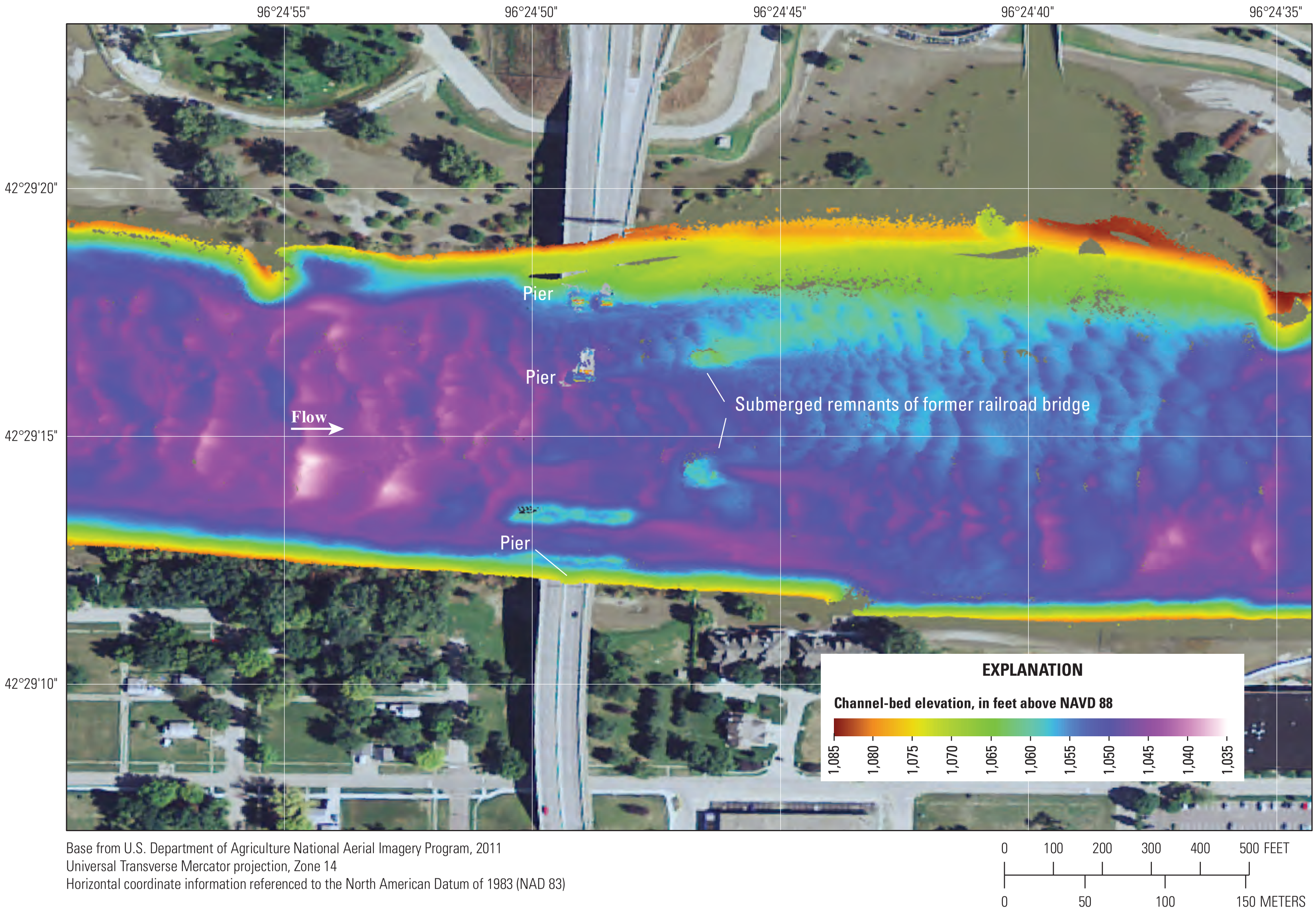
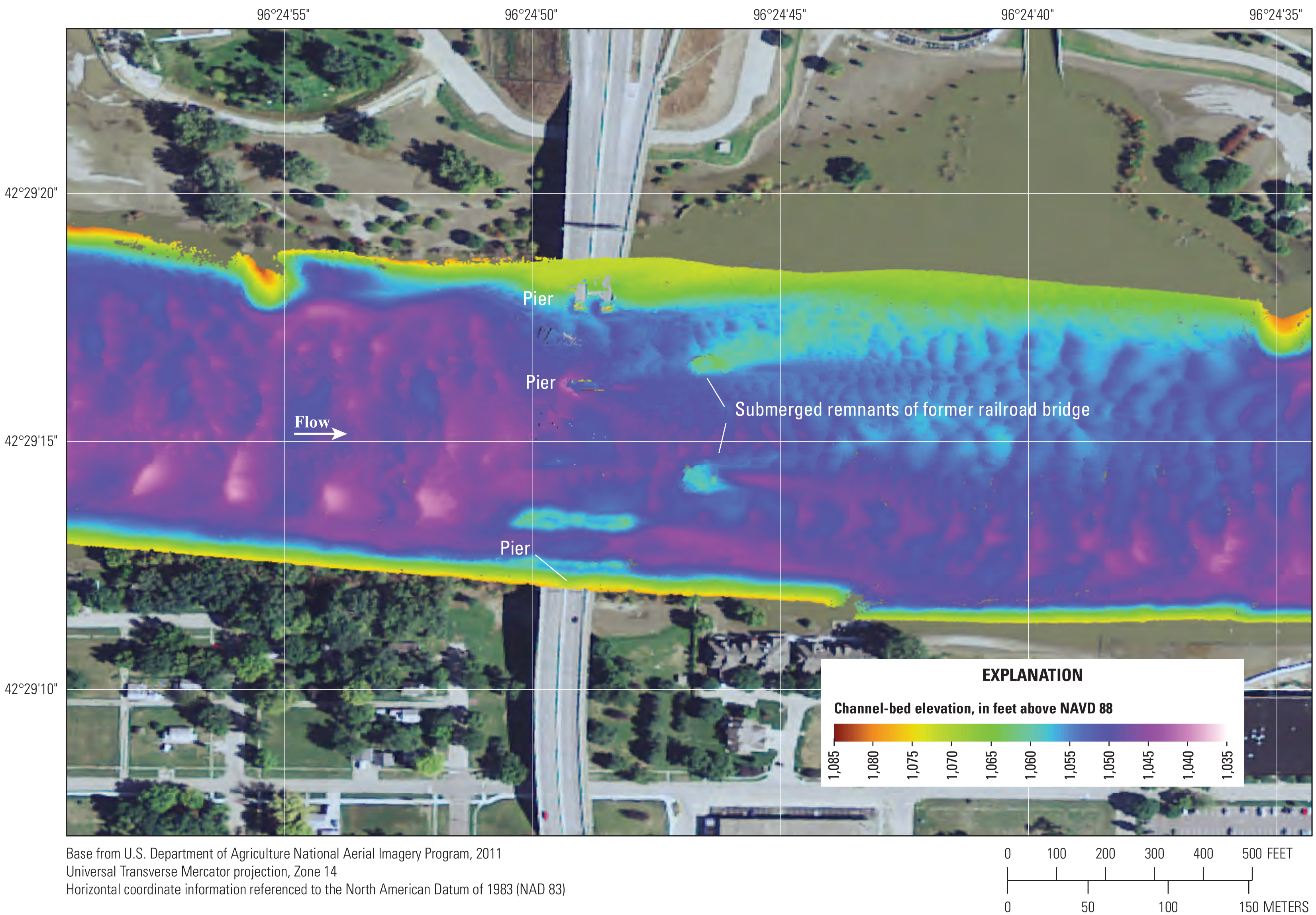


Figure 40. Channel-bed elevations of the Missouri River in the vicinity of the Siouxland Veterans Memorial Bridge at Sioux City, Iowa, during flow of 181,000 cubic feet per second, July 24, 2011.



Base from U.S. Department of Agriculture National Aerial Imagery Program, 2011
Universal Transverse Mercator projection, Zone 14
Horizontal coordinate information referenced to the North American Datum of 1983 (NAD 83)

Figure 41. Channel-bed elevations of the Missouri River in the vicinity of the Siouxland Veterans Memorial Bridge at Sioux City, Iowa, during flow of 164,000 cubic feet per second, August 5, 2011.

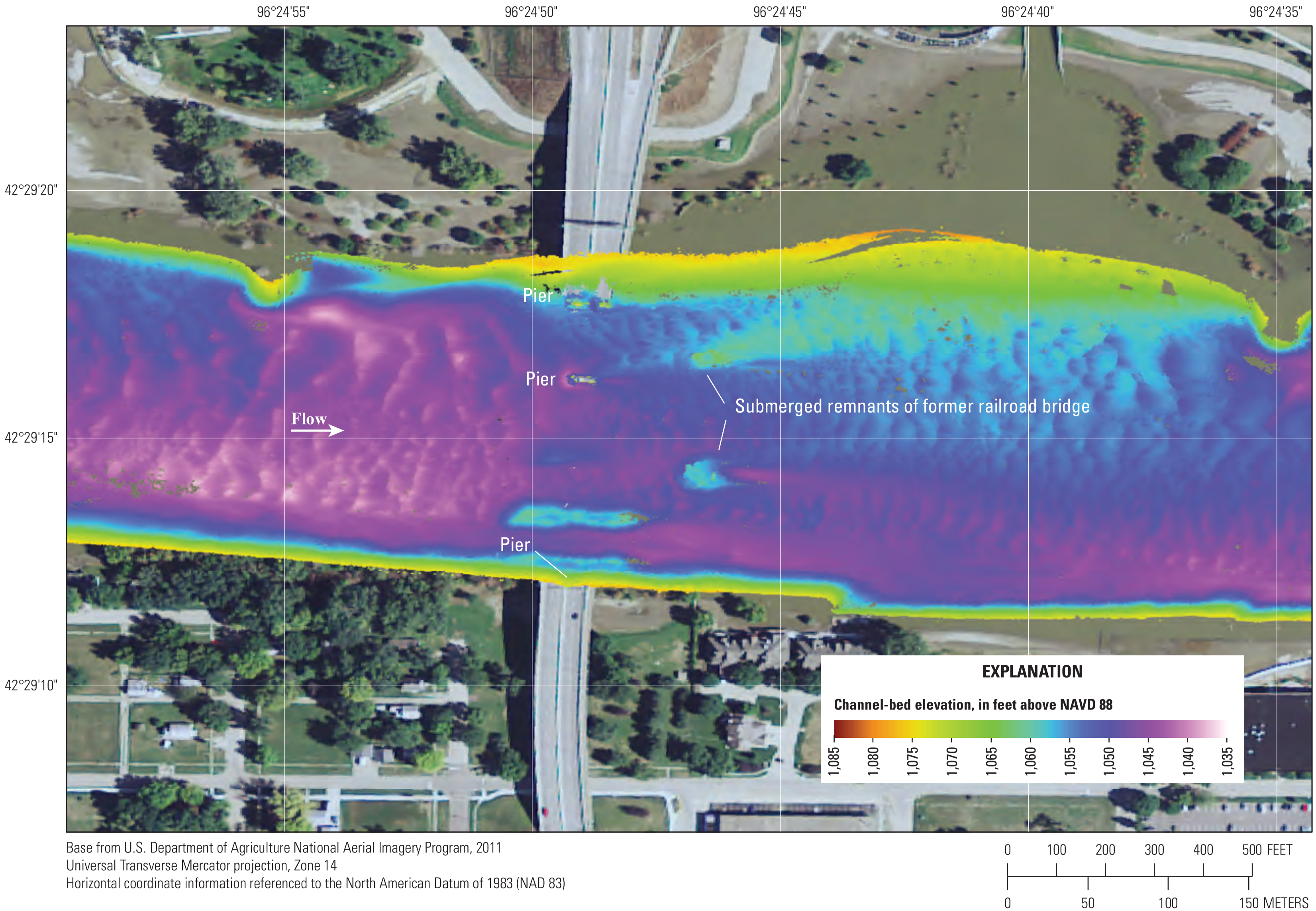
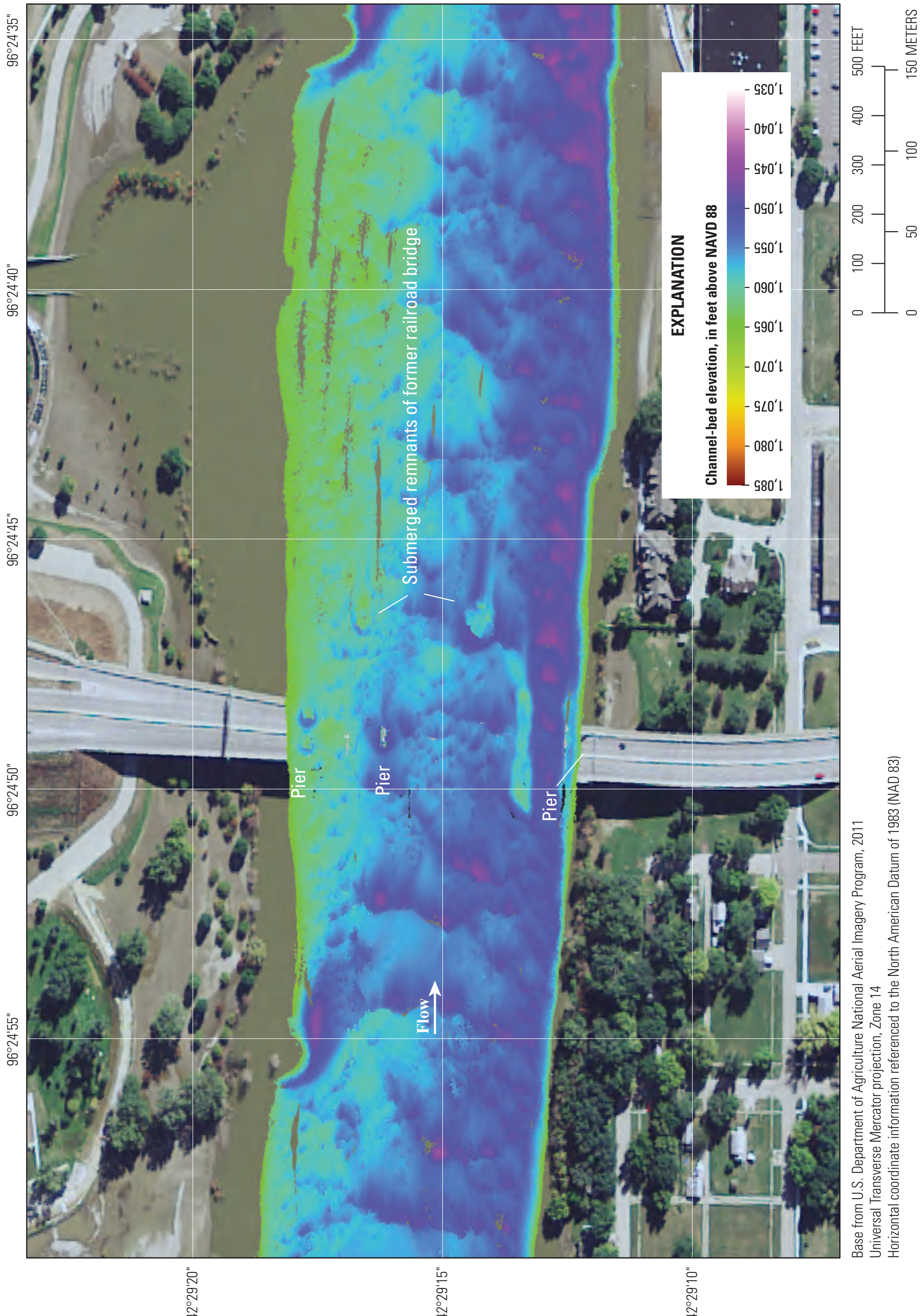
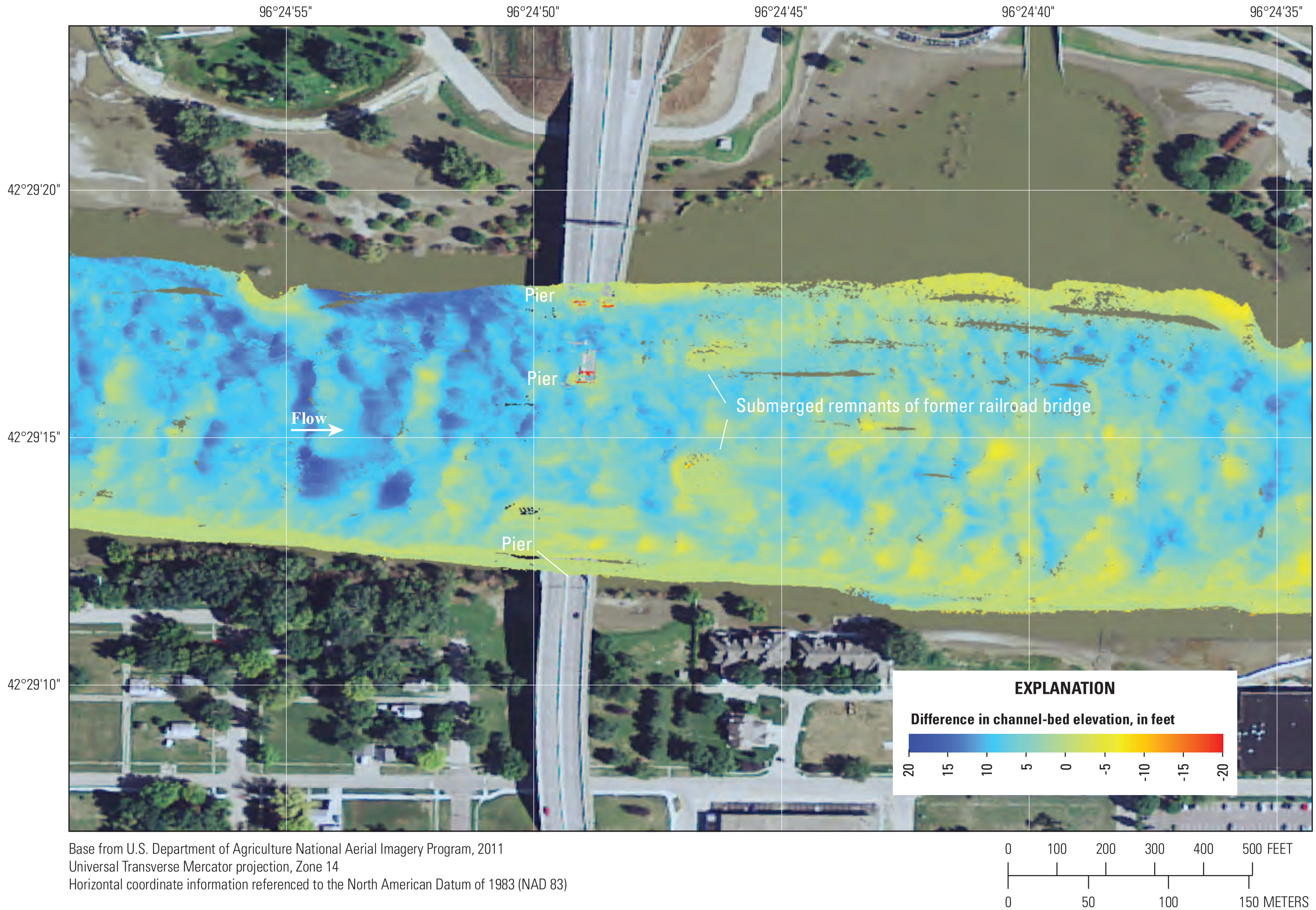


Figure 42. Channel-bed elevations of the Missouri River in the vicinity of the Siouxland Veterans Memorial Bridge at Sioux City, Iowa, during flow of 101,000 cubic feet per second, September 2, 2011.



Base from U.S. Department of Agriculture National Aerial Imagery Program, 2011
Universal Transverse Mercator projection, Zone 14
Horizontal coordinate information referenced to the North American Datum of 1983 (NAD 83)

Figure 43. Channel-bed elevations of the Missouri River in the vicinity of the Siouxland Veterans Memorial Bridge at Sioux City, Iowa, during flow of 42,500 cubic feet per second, November 1, 2011.



Base from U.S. Department of Agriculture National Aerial Imagery Program, 2011
Universal Transverse Mercator projection, Zone 14
Horizontal coordinate information referenced to the North American Datum of 1983 (NAD 83)

Figure 44. Difference in channel-bed elevation of the Missouri River in the vicinity of the Siouxland Veterans Memorial Bridge at Sioux City, Iowa, between July 24 and November 1, 2011.

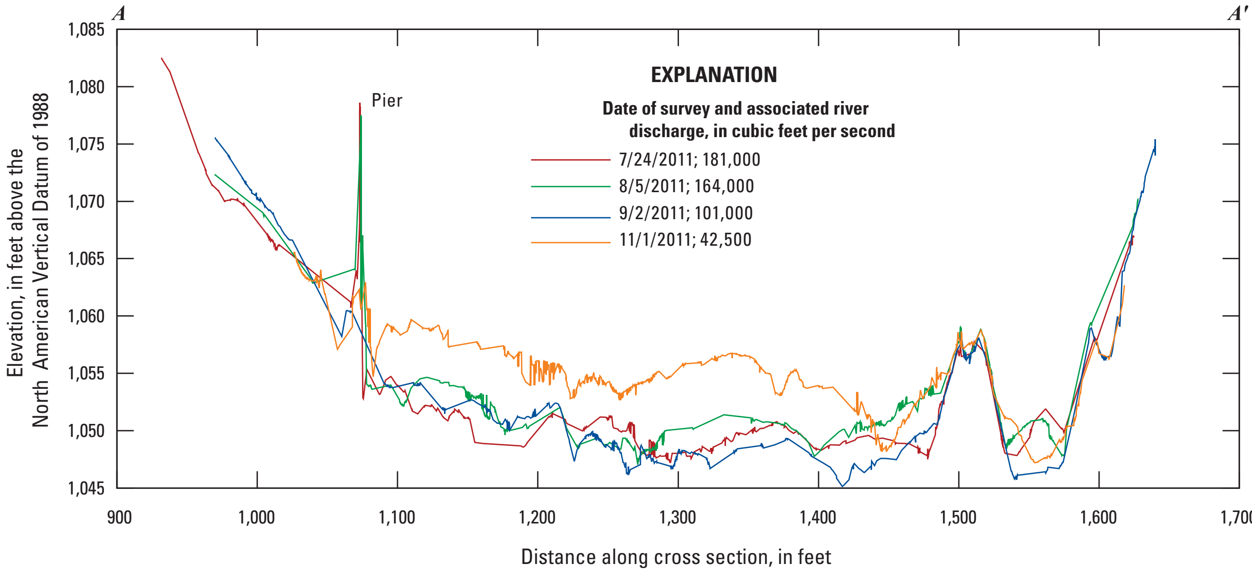


Figure 45. Hydrographic data collected by repeated surveys on the Missouri River along the upstream side of the Siouxland Veterans Memorial Bridge at Sioux City, Iowa, July–November 2011.

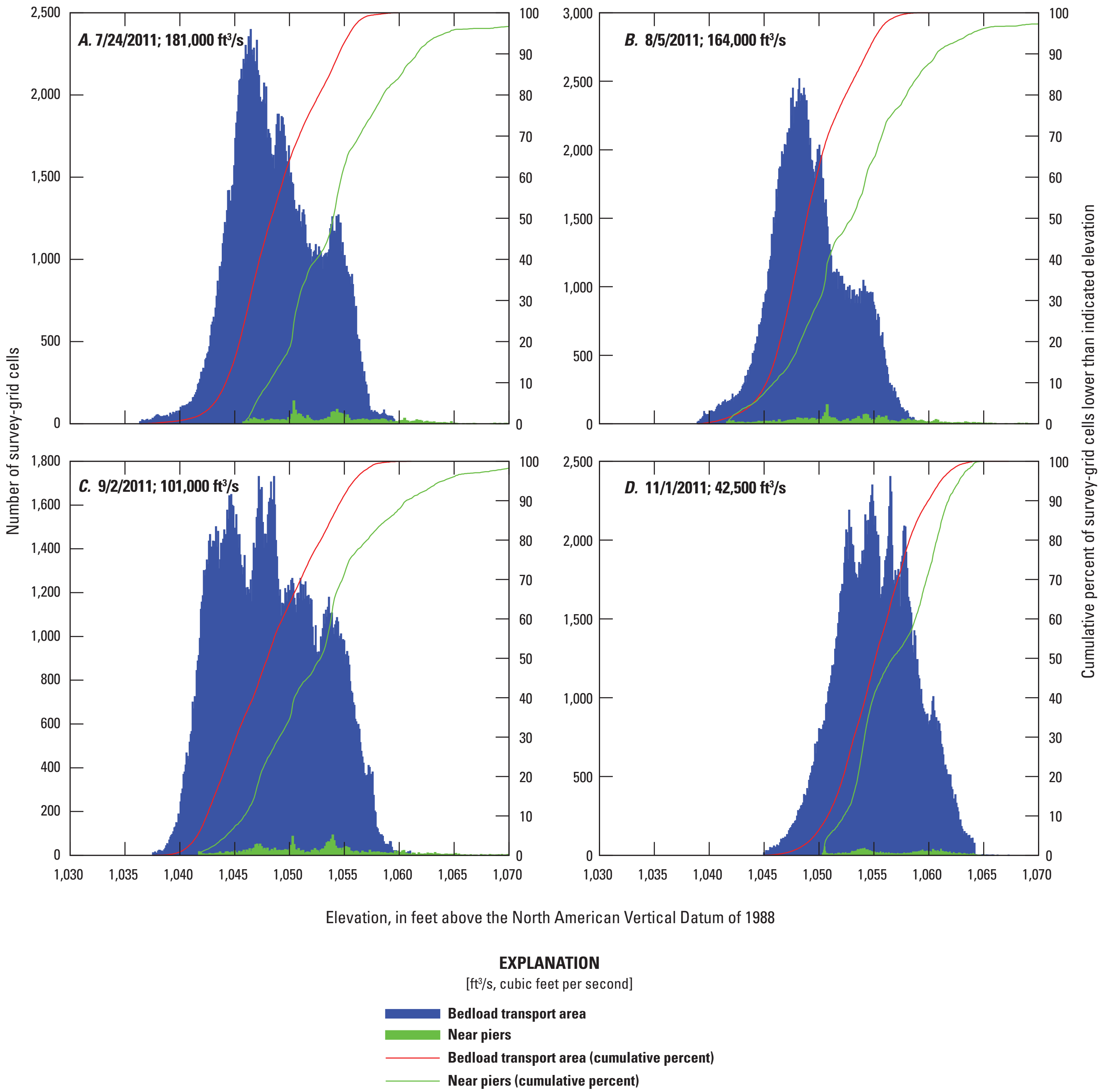


Figure 46. Frequency distribution of bed elevation, for hydrographic survey-grid cells (1.64 by 1.64 feet) sounded on the Missouri River in the vicinity of the Siouxland Veterans Memorial Bridge at Sioux City, Iowa, *A*, July 24; *B*, August 5; *C*, September 2; and *D*, November 1, 2011.

Sergeant Floyd Memorial Bridge (Interstate 129, U.S. Highway 20, U.S. Highway 75) at Sioux City, Iowa, at River Mile 728

The Sergeant Floyd Memorial Bridge, also known the Interstate 129 Bridge, crosses the Missouri River at Sioux City, Iowa (figs. 47–54). Four surveys were made at the Sergeant Floyd Memorial Bridge during 2011 (table 2). The discharges reported for USGS streamgaging station 06486000 (4 miles upstream) were 181,000 ft^3/s on July 24; 164,000 ft^3/s on August 5; 101,000 ft^3/s on September 2; and 42,500 ft^3/s on November 1 (table 3).

The bed elevations surveyed during the July 24 survey ranged from 1,042 ft to 1,062 ft (fig. 48). A map of the bed elevation for July 24 shows that the mid-channel bridge pier was located in the trough between two large bedforms. The minimum bed elevation surveyed near the pier on July 24 was about 1,035 ft. By August 5, dune amplitudes appeared to decrease (fig. 49). In addition, much of the large bedform had eroded, and the trough had filled in by as much as 10 ft. The minimum bed elevation surveyed near the mid-channel pier on August 5 was about 1,040 ft. For the remaining two surveys, bed elevations near the bridge pier remained near 1,040 ft (figs. 50 and 51).

The difference in bed elevation from July 24 to November 1 was computed for each grid cell sounded during both surveys (fig. 52). The mean difference value of all re-sounded cells was -2.3 ft, indicating that net erosion occurred in the surveyed area from July 24 to November 1. A cross section of the hydrographic data collected at the upstream side of the Sergeant Floyd Memorial Bridge is shown in figure 45.

In the bedload transport area, the mean bed elevation changed less than 1 ft from July 24 to November 1; however, there was a smaller range for the November 1 elevations than for those of July 24, as indicated by a narrower histogram for the later surveys than for the July 24 survey (fig. 54).

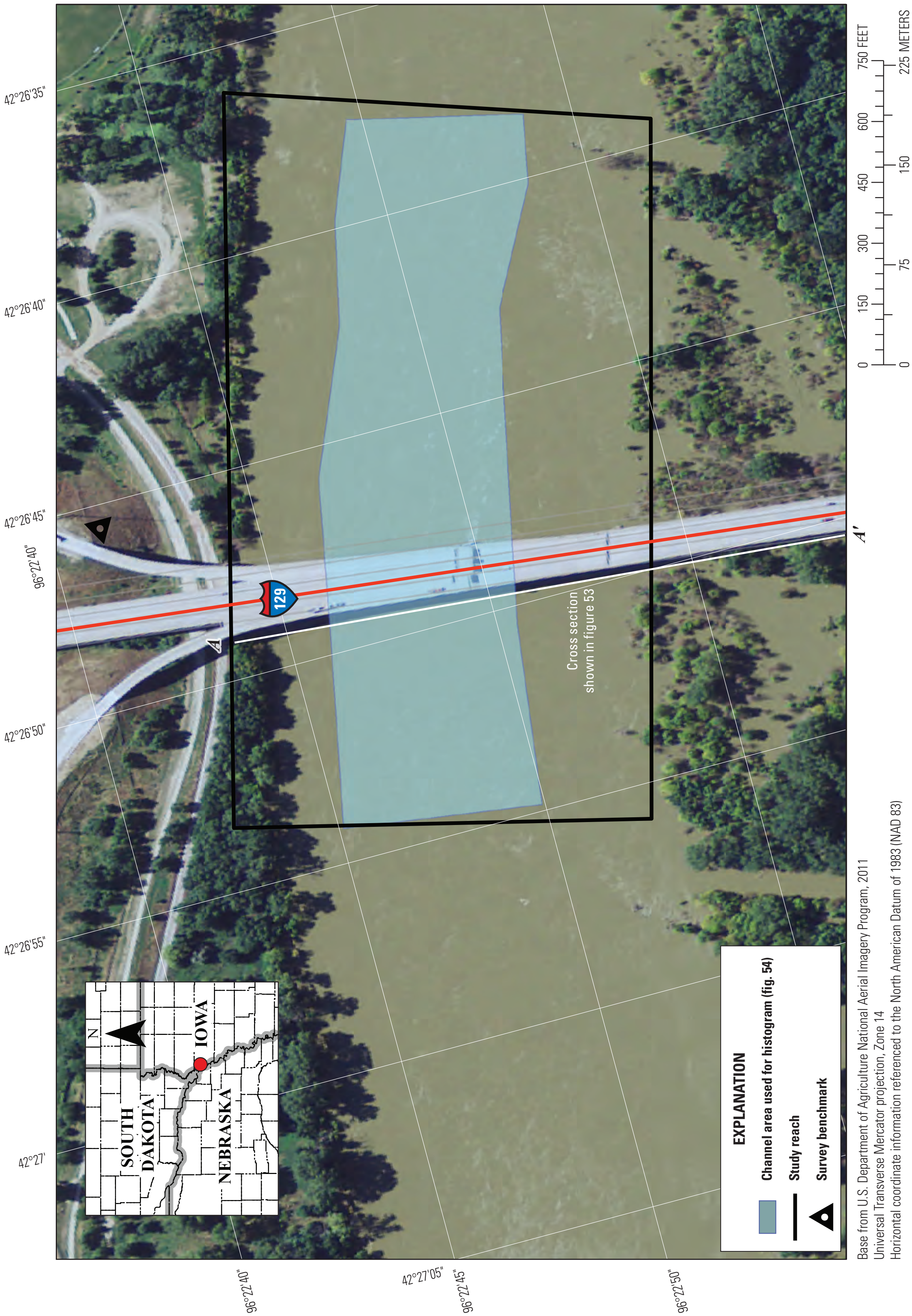


Figure 47. Location of hydrographic surveys of the Missouri River in the vicinity of the Sergeant Floyd Memorial Bridge at Sioux City, Iowa, July–November 2011.

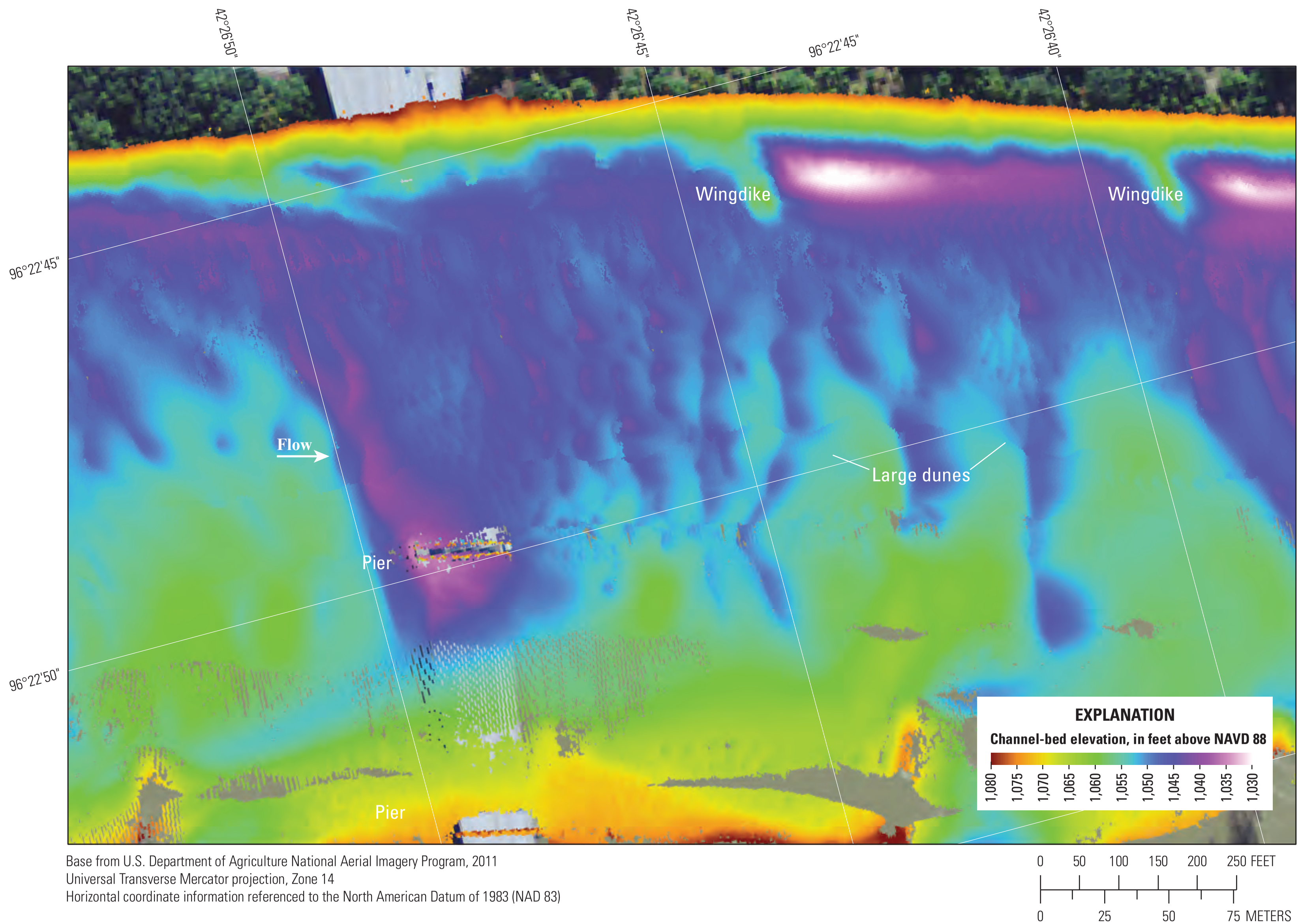


Figure 48. Channel-bed elevations of the Missouri River in the vicinity of the Sergeant Floyd Memorial Bridge at Sioux City, Iowa, during flow of 181,000 cubic feet per second, July 24, 2011.

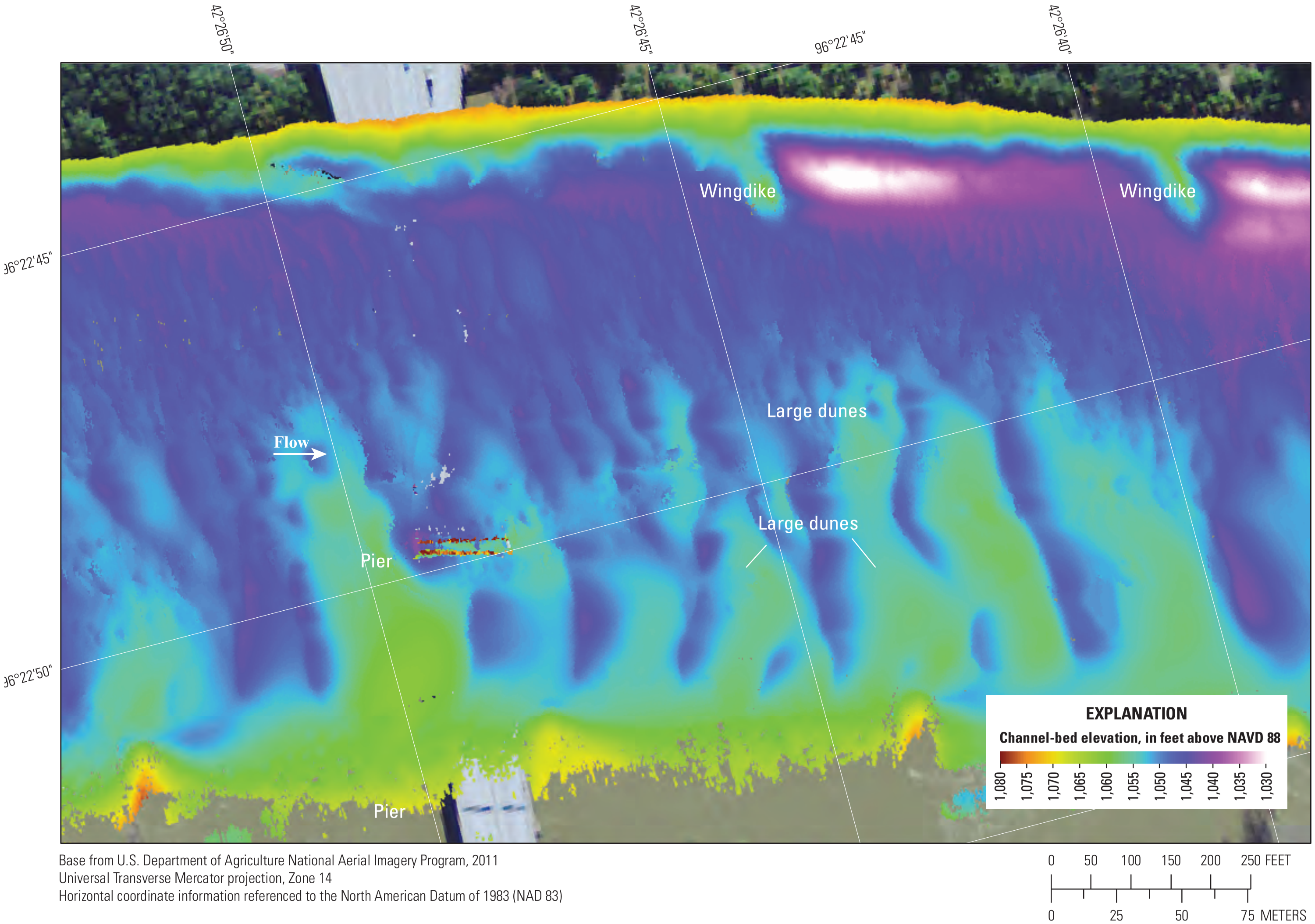
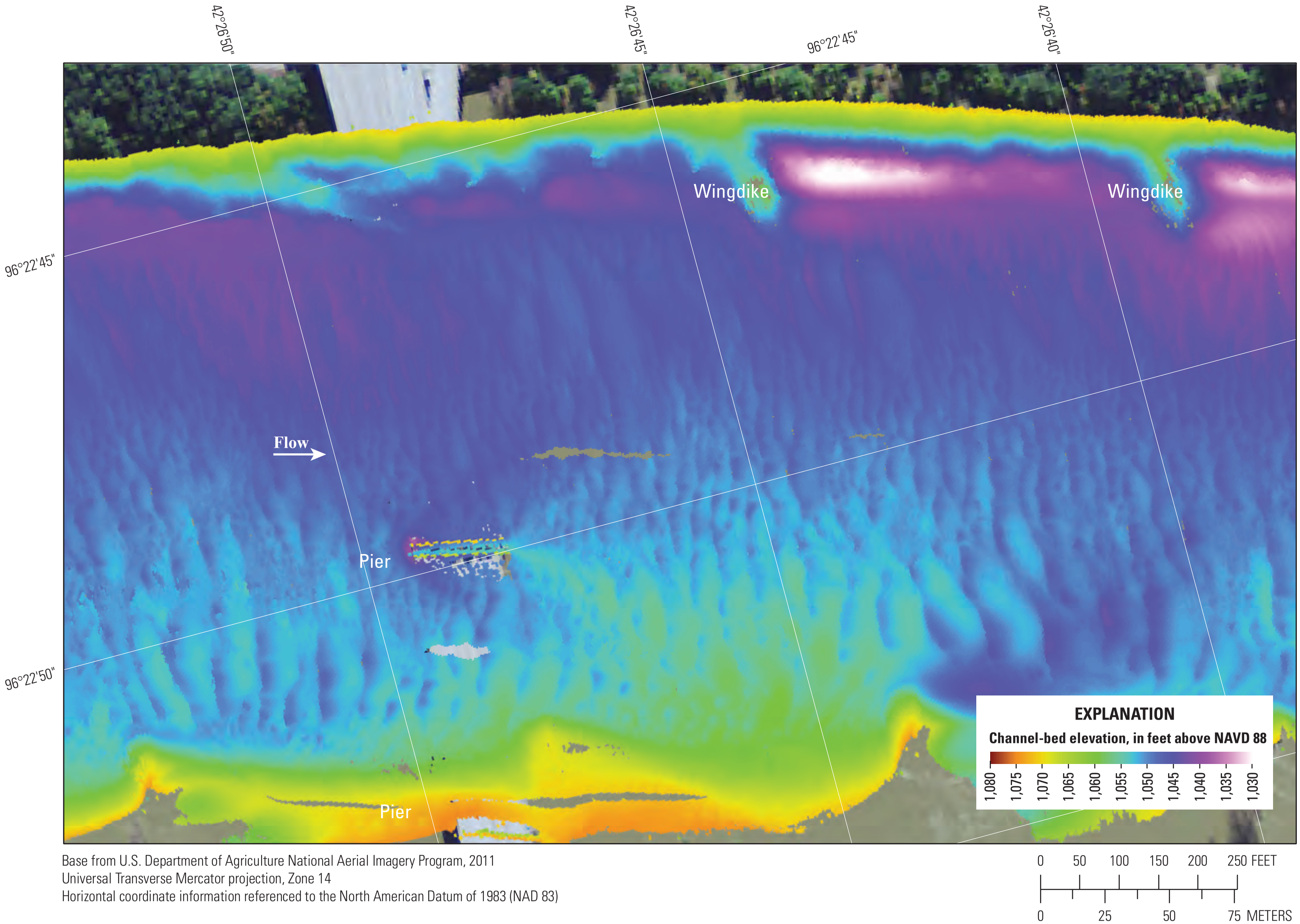


Figure 49. Channel-bed elevations of the Missouri River in the vicinity of the Sergeant Floyd Memorial Bridge at Sioux City, Iowa, during flow of 164,000 cubic feet per second, August 5, 2011.



Base from U.S. Department of Agriculture National Aerial Imagery Program, 2011
Universal Transverse Mercator projection, Zone 14
Horizontal coordinate information referenced to the North American Datum of 1983 (NAD 83)

Figure 50. Channel-bed elevations of the Missouri River in the vicinity of the Sergeant Floyd Memorial Bridge at Sioux City, Iowa, during flow of 101,000 cubic feet per second, September 2, 2011.

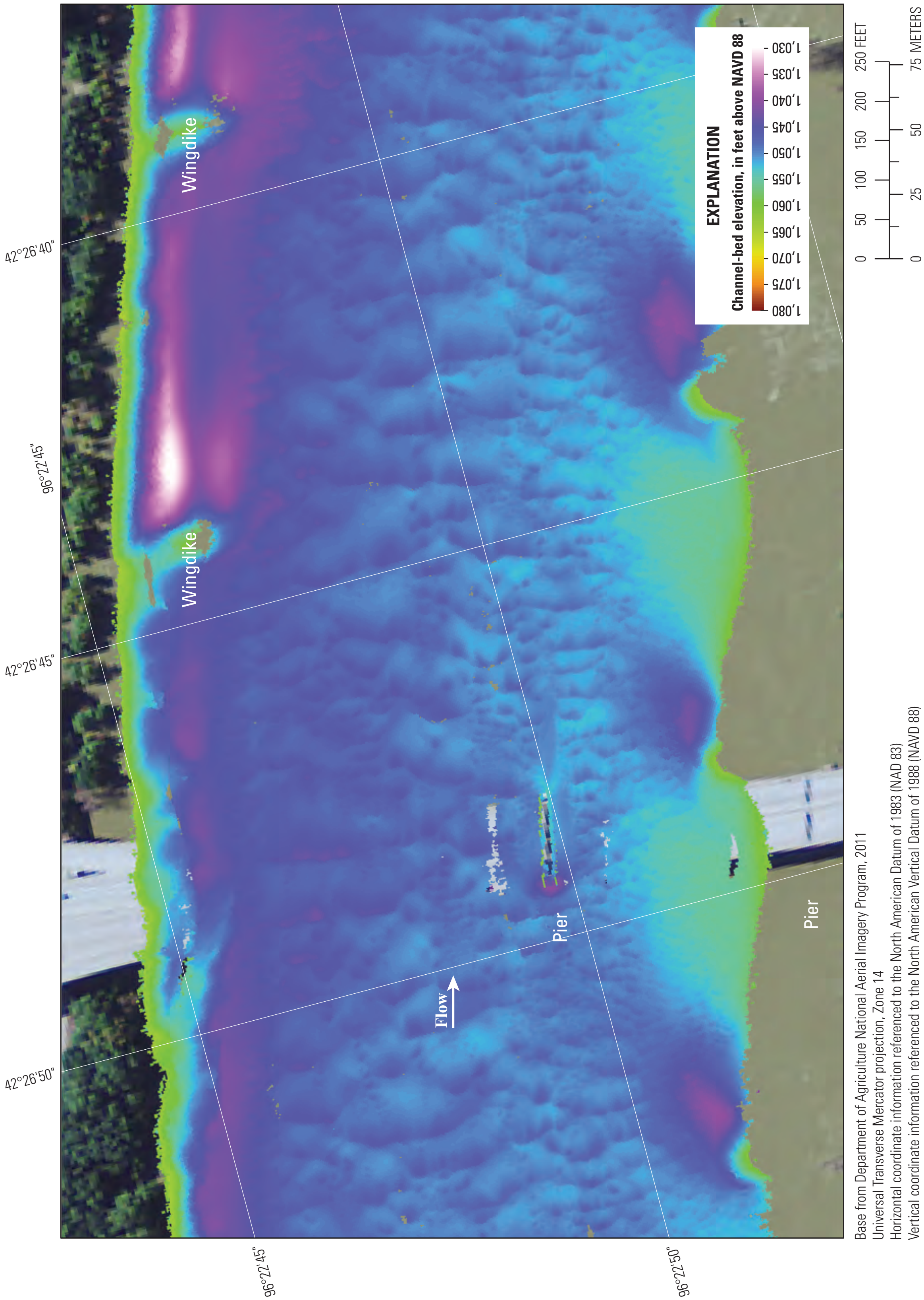
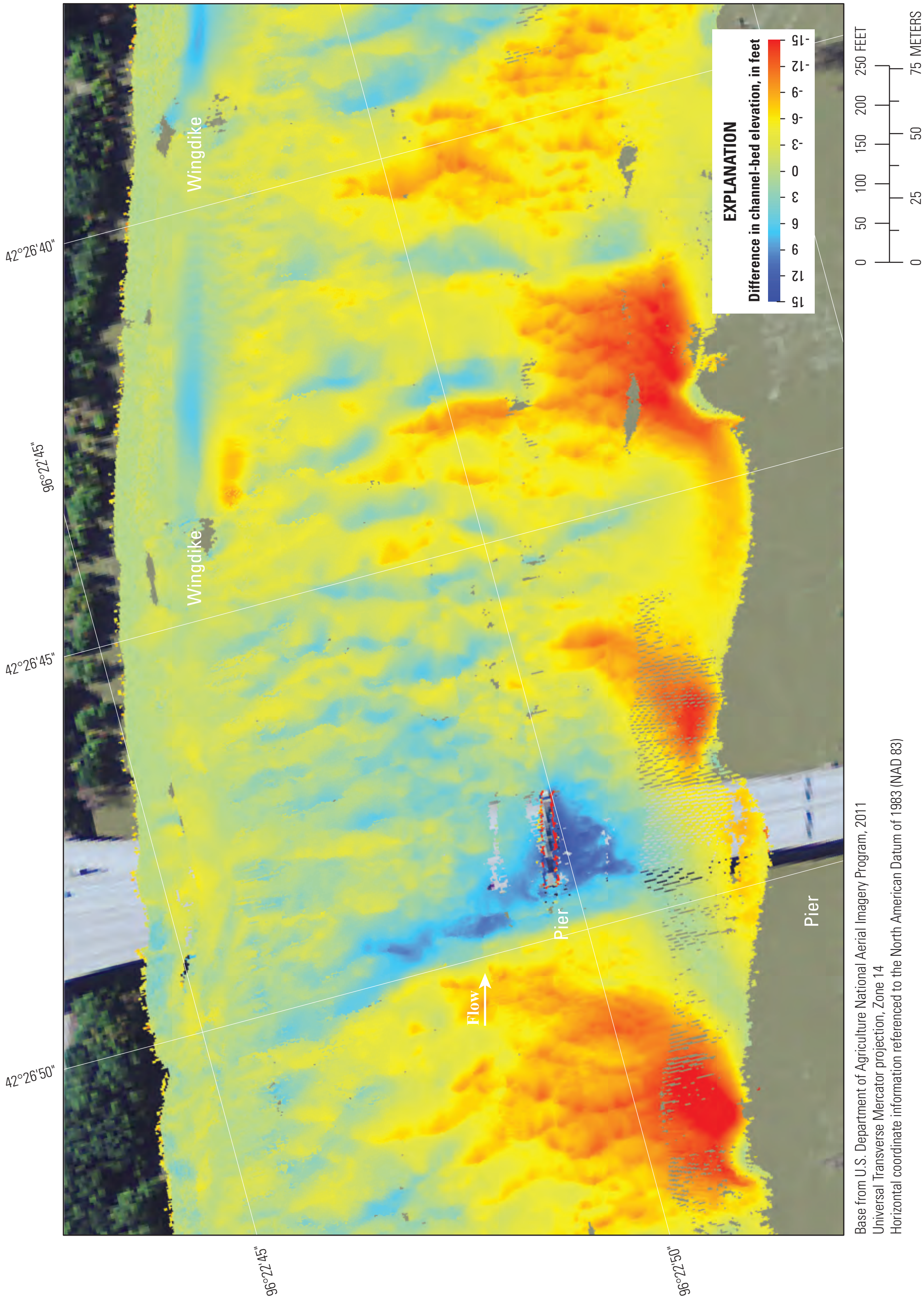


Figure 51. Channel-bed elevations of the Missouri River in the vicinity of the Sergeant Floyd Memorial Bridge at Sioux City, Iowa, during flow of 42,500 cubic feet per second, November 1, 2011.



Base from U.S. Department of Agriculture National Aerial Imagery Program, 2011
Universal Transverse Mercator projection, Zone 14
Horizontal coordinate information referenced to the North American Datum of 1983 (NAD 83)

Figure 52. Difference in channel-bed elevation of the Missouri River in the vicinity of the Sergeant Floyd Memorial Bridge at Sioux City, Iowa, between July 24 and November 1, 2011.

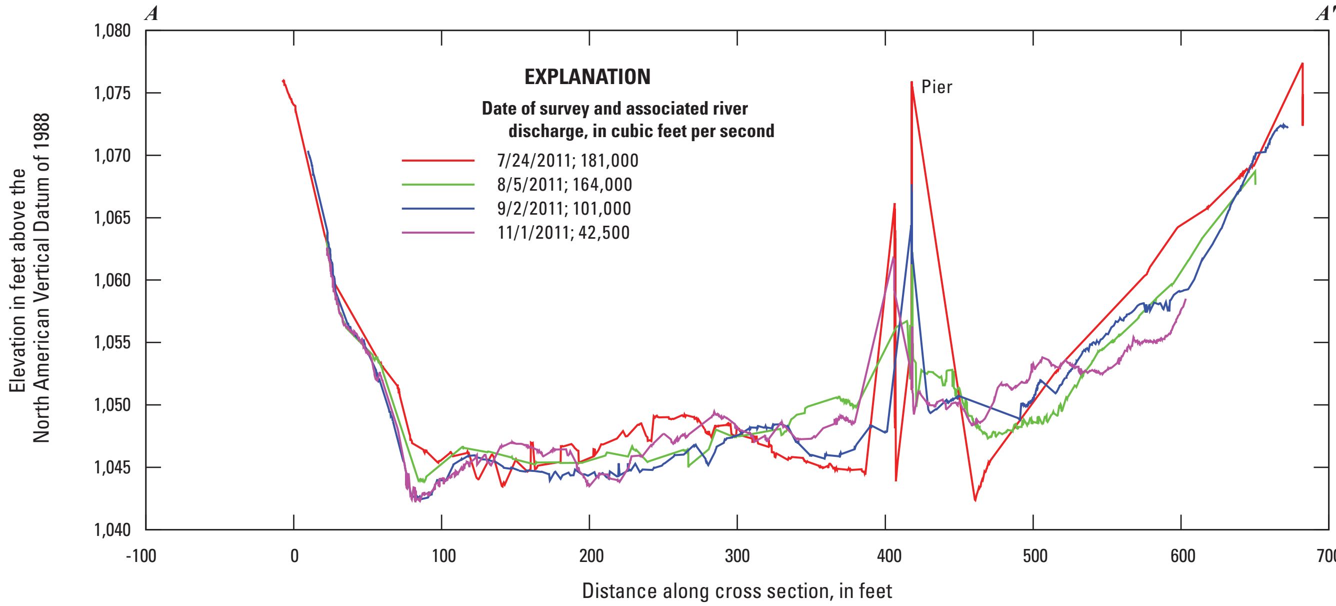


Figure 53. Hydrographic data collected by repeated surveys on the Missouri River along the upstream side of the Sergeant Floyd Memorial Bridge at Sioux City, Iowa, July–November 2011.

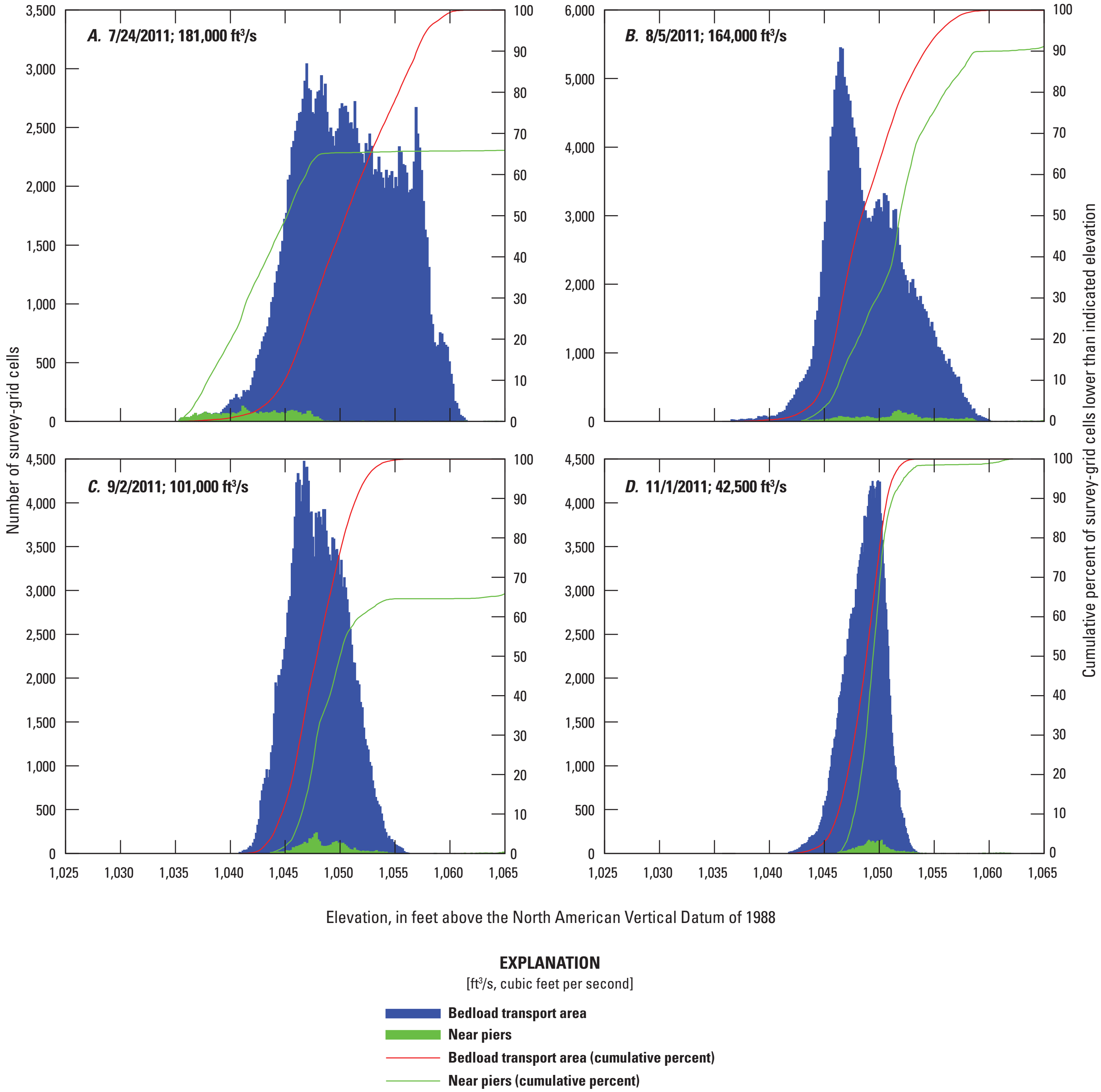


Figure 54. Frequency distribution of bed elevation, for hydrographic survey-grid cells (1.64 by-1.64 feet) sounded on the Missouri River in the vicinity of the Sergeant Floyd Memorial Bridge at Sioux City, Iowa, *A*, July 24; *B*, August 5; *C*, September 2; and *D*, November 1, 2011.

Burt County Missouri River Bridge (Nebraska Highway 51 and Iowa Highway 175) at Decatur, Nebraska, at River Mile 691

The Burt County Missouri River Bridge crosses the Missouri River at Decatur, Nebr. (figs. 55–64). The Burt County Missouri River Bridge was closed on June 27, 2011, because of erosion near the Iowa-side bridge abutment. Riprap was added along the Iowa-side abutment over the course of the 2011 flooding. The study reach was surveyed using the multibeam echosounder on four dates during the 2011 Missouri River flooding (table 2). The USGS streamgaging station 06601200 Missouri River at Decatur, Nebr., is located at this bridge. The discharges reported for station 06601200 were 185,000 ft^3/s on July 12; 175,000 ft^3/s on July 28; 111,000 ft^3/s on August 31; and 44,800 ft^3/s on November 2 (table 3).

Hydrographic data collected at near the Burt County Missouri River Bridge were mapped (figs. 56–59). Substantial flow through an old channel on the Iowa side of the river observed during the June and July surveys was likely a major contributor to scouring between the abutment and bridge pier. During two of the surveys, July 12 and July 28 (figs. 56 and 57), MBES surveys were completed near the Iowa-side abutment. Bed elevations surveyed during the July 12 survey were about 1,006 ft near the first pier from the Iowa-side abutment (fig. 56) and over a flooded access road, which was at an elevation of about 1,045 ft before flooding. By July 28, bed elevations had been scoured to 998 ft (fig. 57). Elevations at this location from previous surveys (Nebraska Department of Roads, written commun., 2011) and elevations observed for this survey adjacent to the scour hole were about 1,045 ft, indicating that more than 45 ft of scour had occurred since the beginning of the flood. Figure 61 is a three-dimensional depiction of the scour hole near the Iowa-side abutment, with the deepest parts shown in red. Scour also was evident near the mid-channel pier (fig. 62). Bed elevations at a cross section of hydrographic data collected at the upstream side of the bridge indicate that scour occurred between July 12 to July 28 near the Iowa-side abutment and in the main channel (fig. 63). Minimum bed elevations near the mid-channel pier were about 994 ft on July 12, 955 ft on July 28, and 996 ft on August 31 (figs. 56, 57, and 58, respectively). By November 2, minimum bed elevations near the mid-channel pier were about 1,000 ft (fig. 59). The bridge reopened on November 2, 2011, after the scour hole near the Iowa side was filled and the roadway embankment was stabilized.

The difference in bed elevation from July 12 to November 2 was computed for each grid cell sounded during both surveys (fig. 60). The mean difference for all re-sounded cells was 4.2 ft, indicating that net deposition likely occurred in the surveyed area from July 12 to November 2.

In the bedload transport area, the frequency distribution of bed elevations shifted upward between July 12 and November 2 (fig. 64). The mean elevation for cells in the bedload transport area was about 1,009 ft on July 12, whereas the mean elevation was about 1,016 ft on November 2.

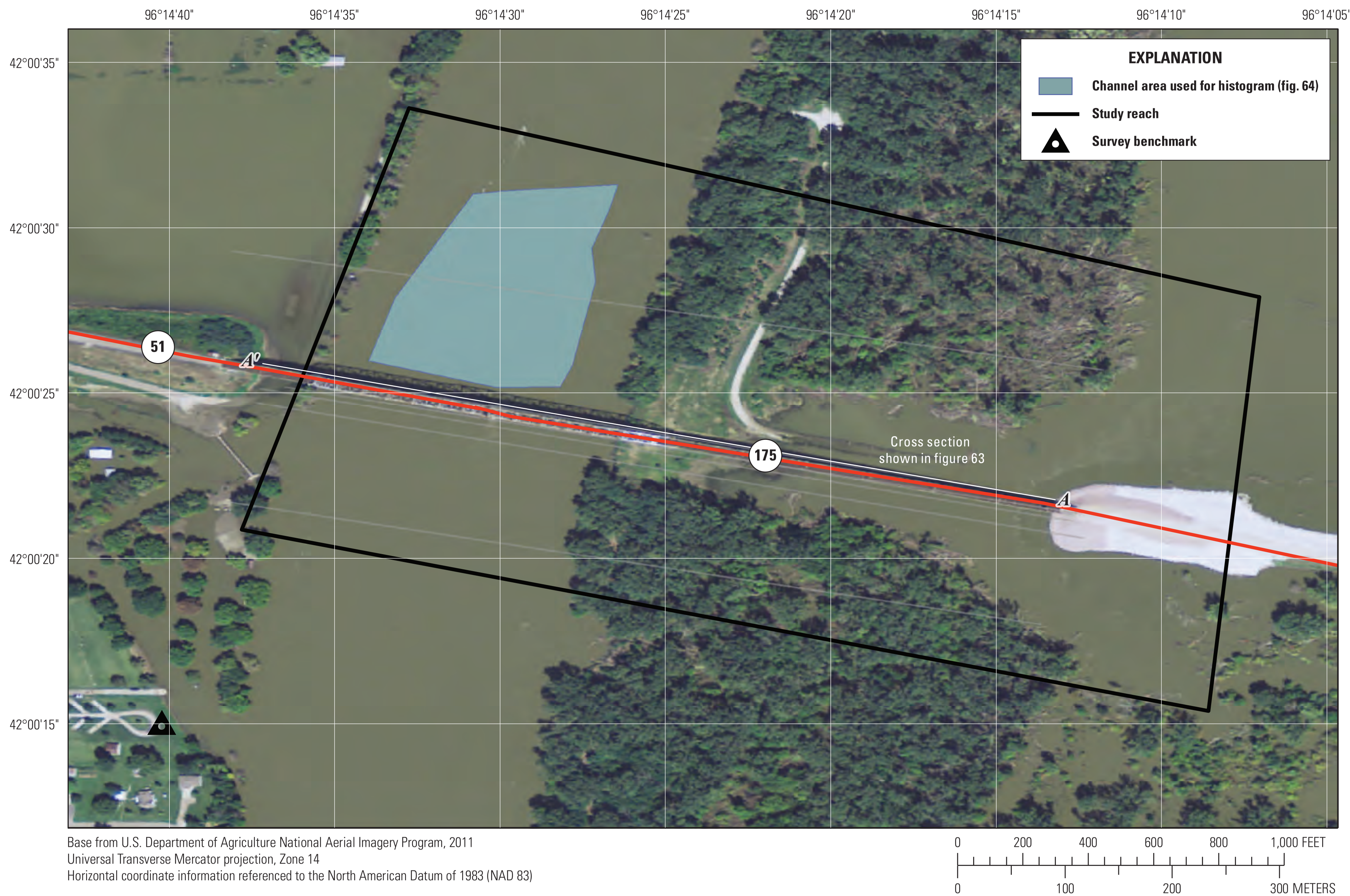
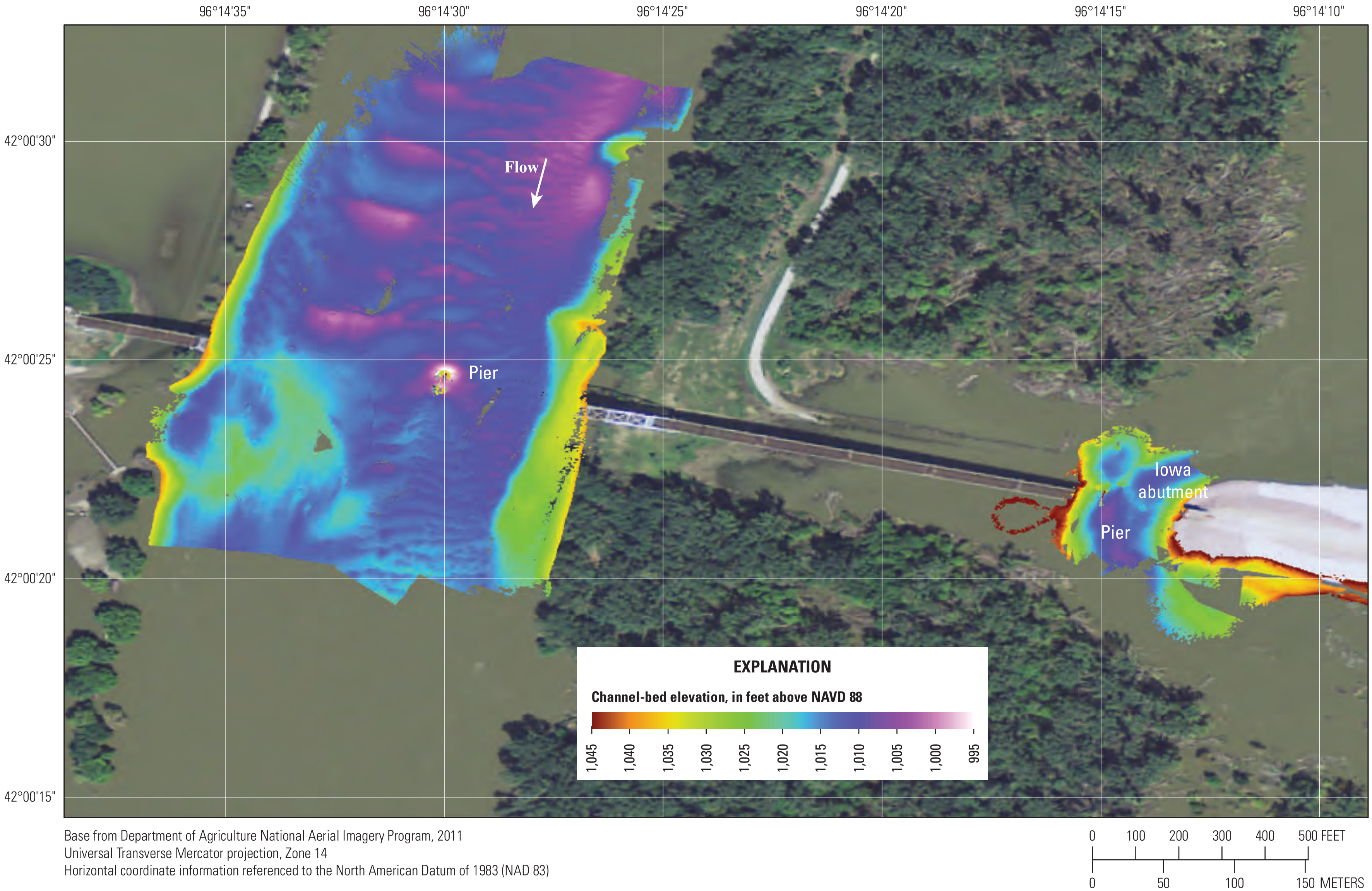
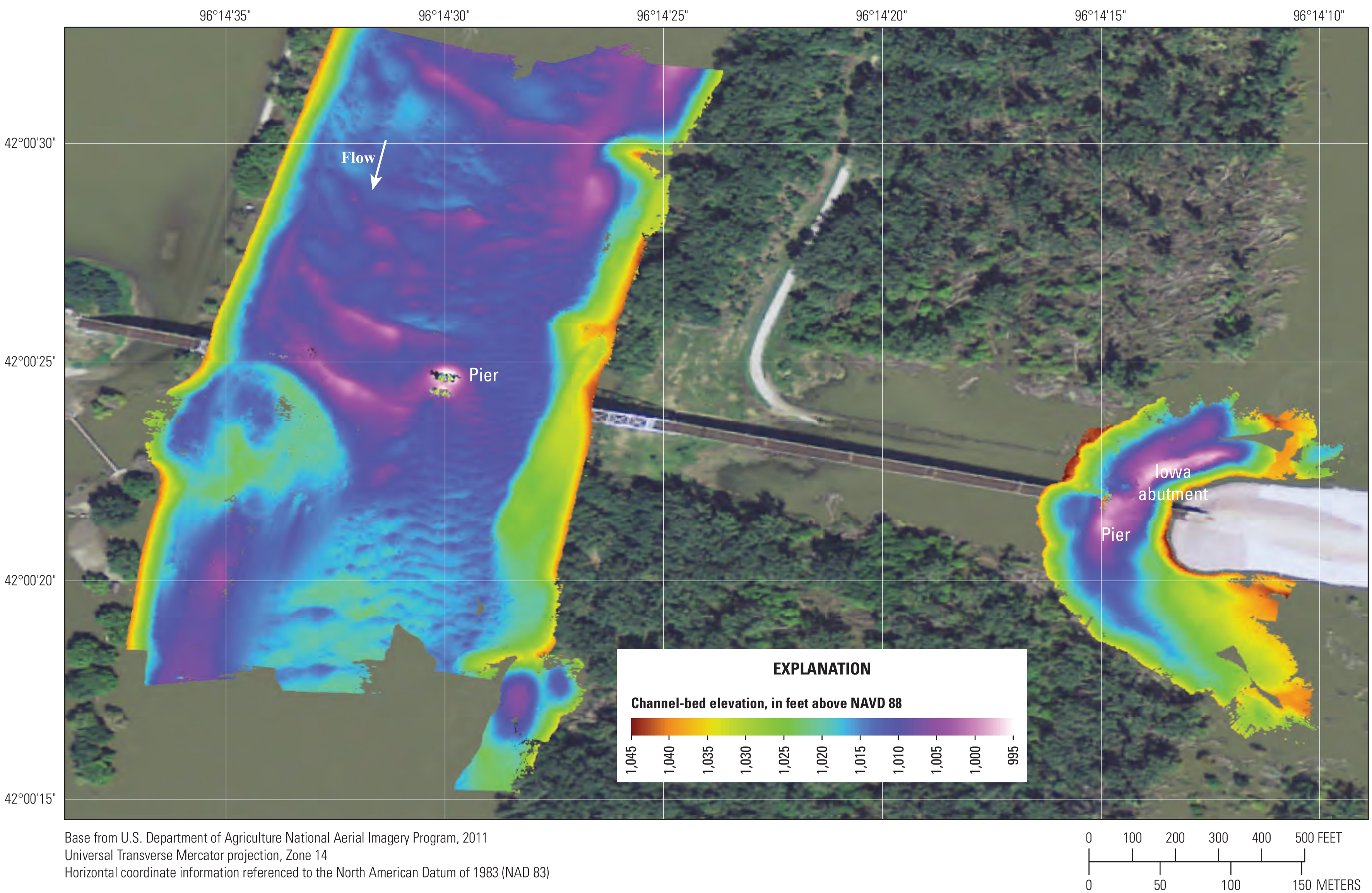


Figure 55. Location of hydrographic surveys of the Missouri River in the vicinity of the Burt County Missouri River Bridge at Decatur, Nebraska, July–November 2011.



Base from Department of Agriculture National Aerial Imagery Program, 2011
Universal Transverse Mercator projection, Zone 14
Horizontal coordinate information referenced to the North American Datum of 1983 (NAD 83)

Figure 56. Channel-bed elevations of the Missouri River in the vicinity of the Burt County Missouri River Bridge at Decatur, Nebraska, during flow of 185,000 cubic feet per second, July 12, 2011.



Base from U.S. Department of Agriculture National Aerial Imagery Program, 2011
Universal Transverse Mercator projection, Zone 14
Horizontal coordinate information referenced to the North American Datum of 1983 (NAD 83)

Figure 57. Cannel-bed elevations of the Missouri River in the vicinity of the Burt County Missouri River Bridge at Decatur, Nebraska, during flow of 175,000 cubic feet per second, July 28, 2011.

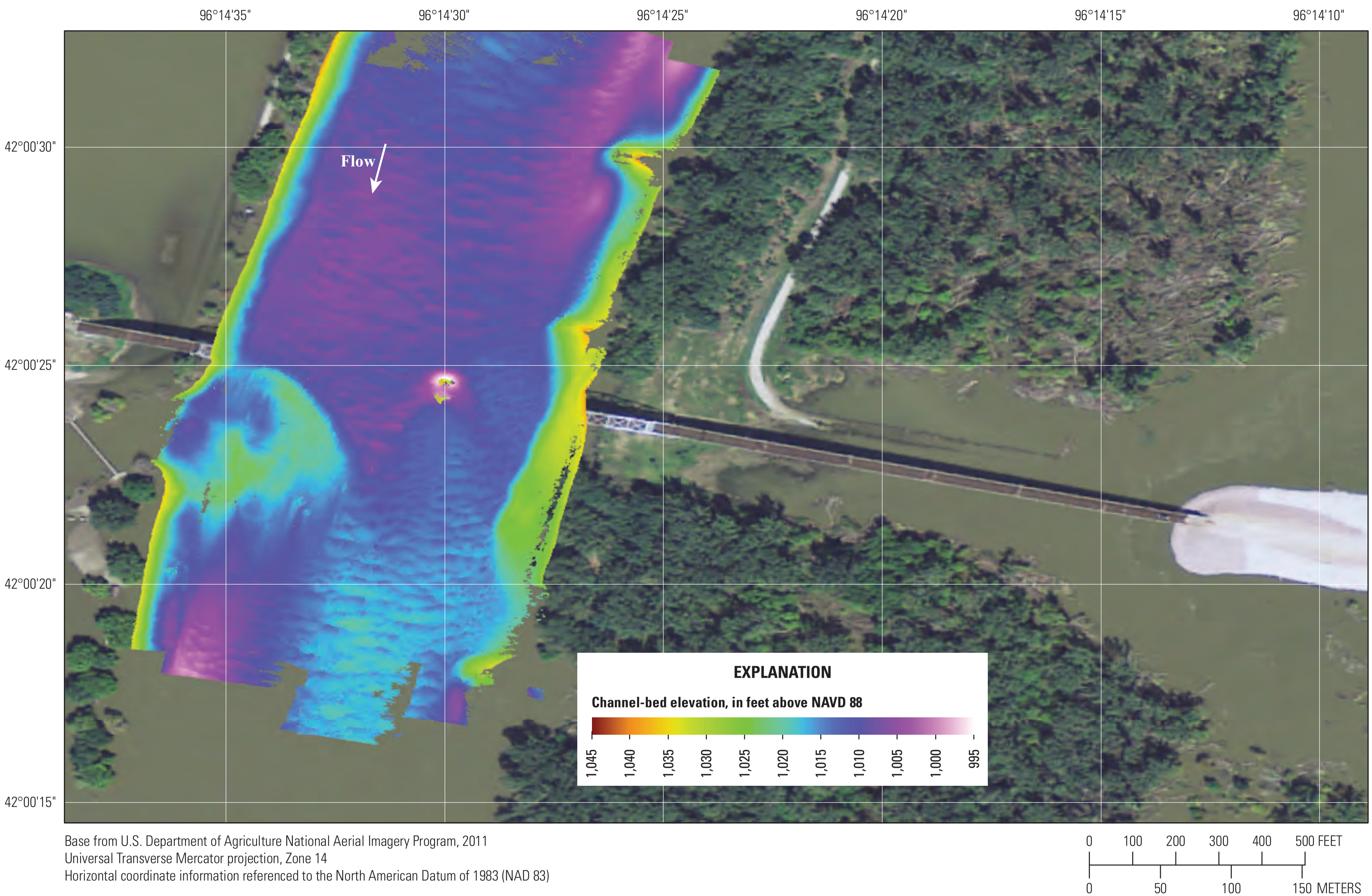


Figure 58. Channel-bed elevations of the Missouri River in the vicinity of the Burt County Missouri River Bridge at Decatur, Nebraska, during flow of 111,000 cubic feet per second, August 31, 2011.

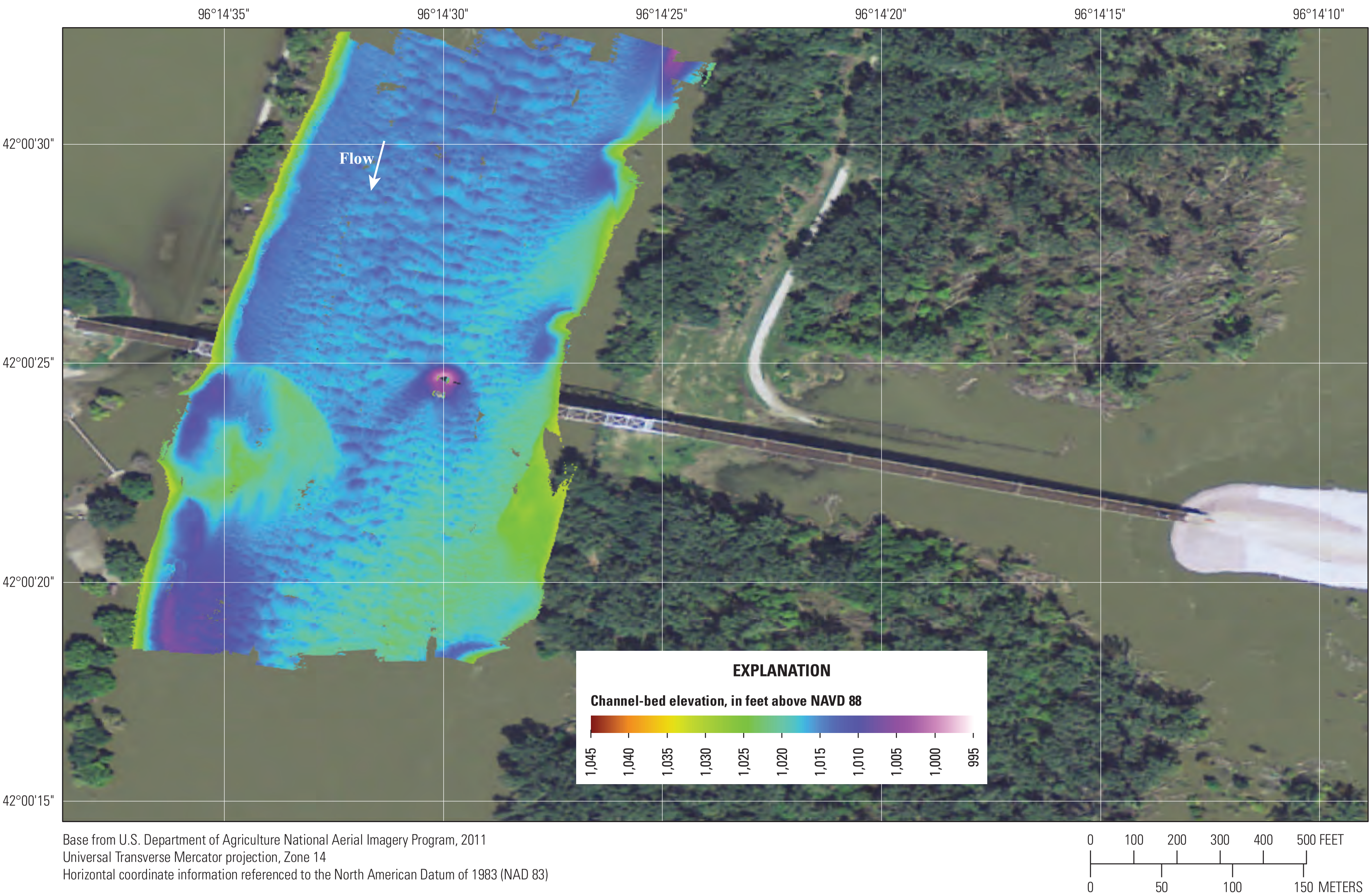


Figure 59. Channel-bed elevations of the Missouri River in the vicinity of the Burt County Missouri River Bridge at Decatur, Nebraska, during flow of 44,800 cubic feet per second, November 2, 2011.

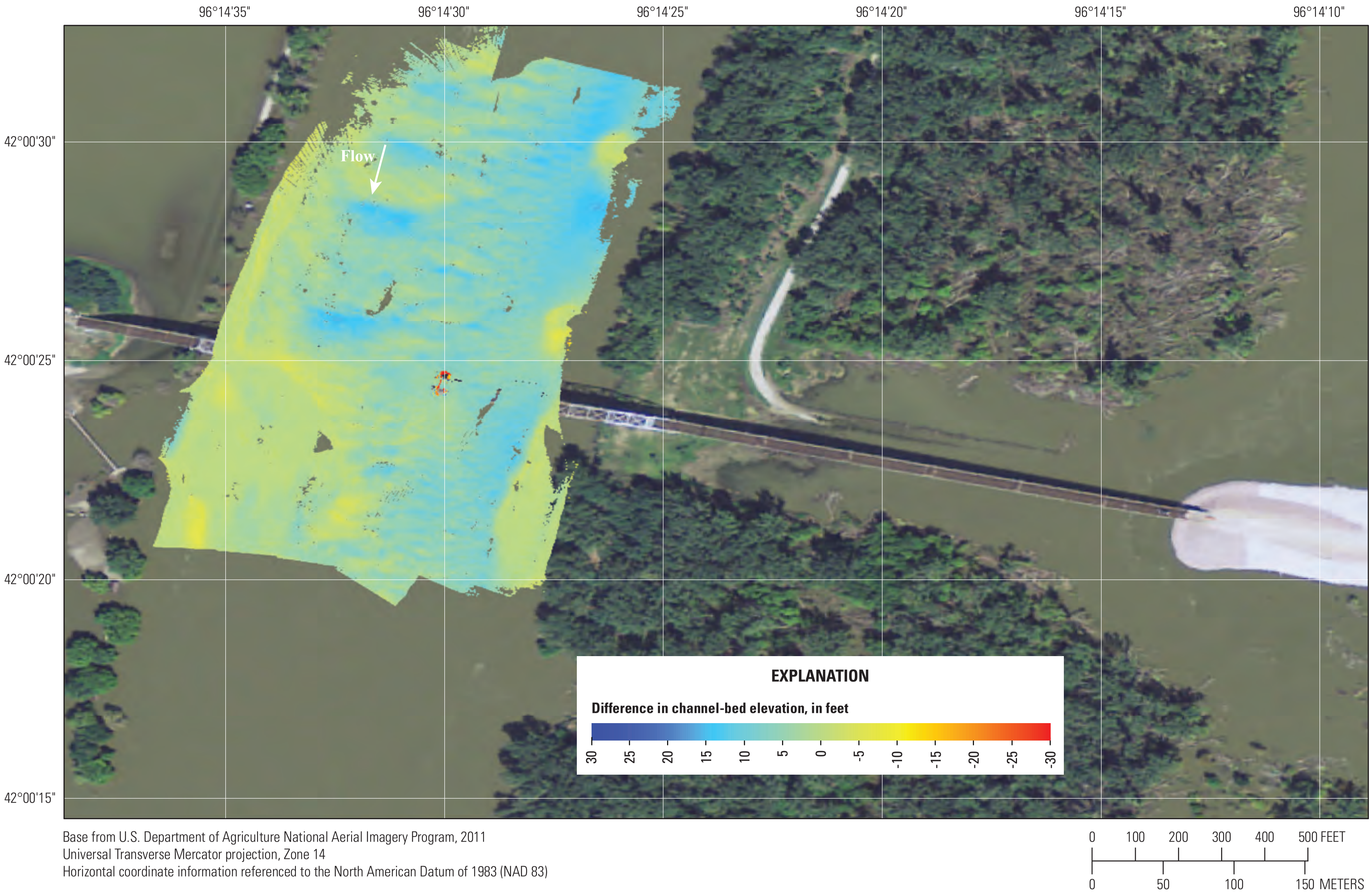


Figure 60. Difference in channel-bed elevation of the Missouri River in the vicinity of the Burt County Missouri River Bridge at Decatur, Nebraska, between July 12 and November 2, 2011.

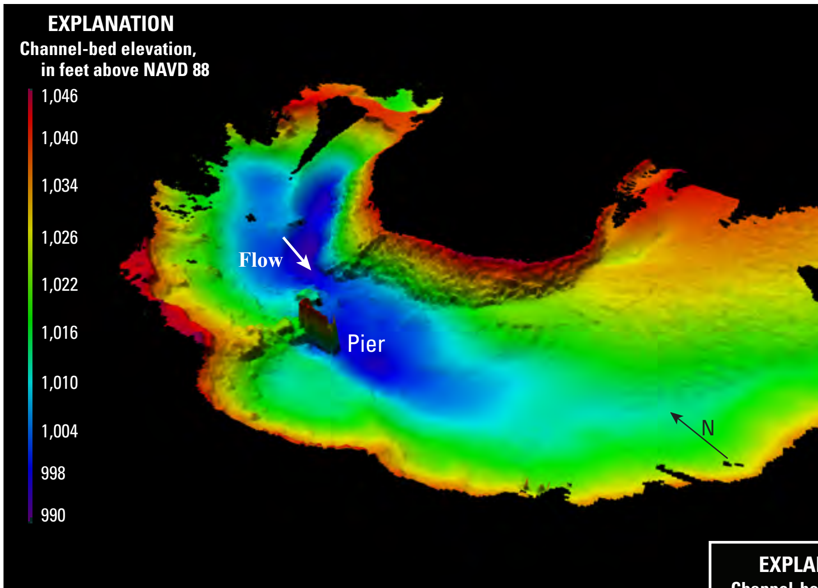


Figure 61. Three-dimensional view of the channel bed of the Missouri River and Burt County Missouri River Bridge pier near the Iowa-side abutment of the bridge at Decatur, Nebraska, July 28, 2011.

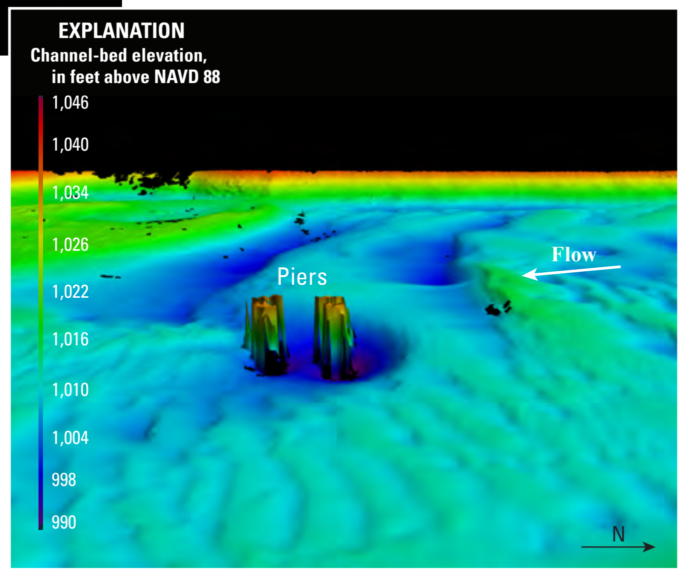


Figure 62. Three-dimensional view of the channel bed of the Missouri River and mid-channel pier of the Burt County Missouri River Bridge at Decatur, Nebraska, July 28, 2011.

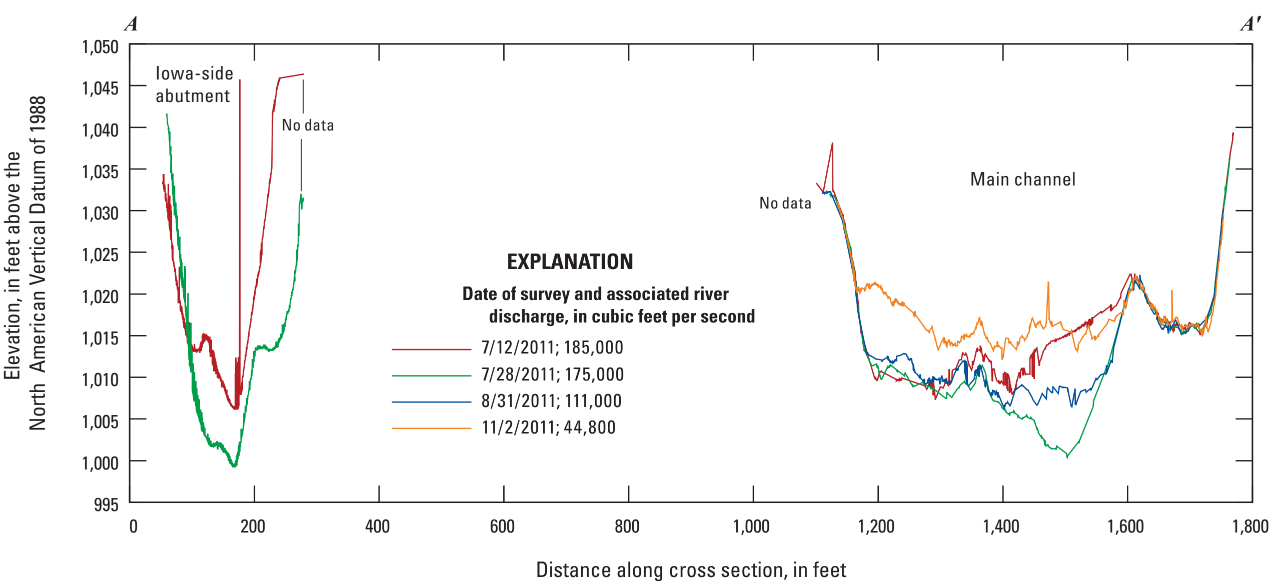


Figure 63. Hydrographic data collected by repeated surveys on the Missouri River along the upstream side of the Burt County Missouri River Bridge at Decatur, Nebraska, July–November 2011.

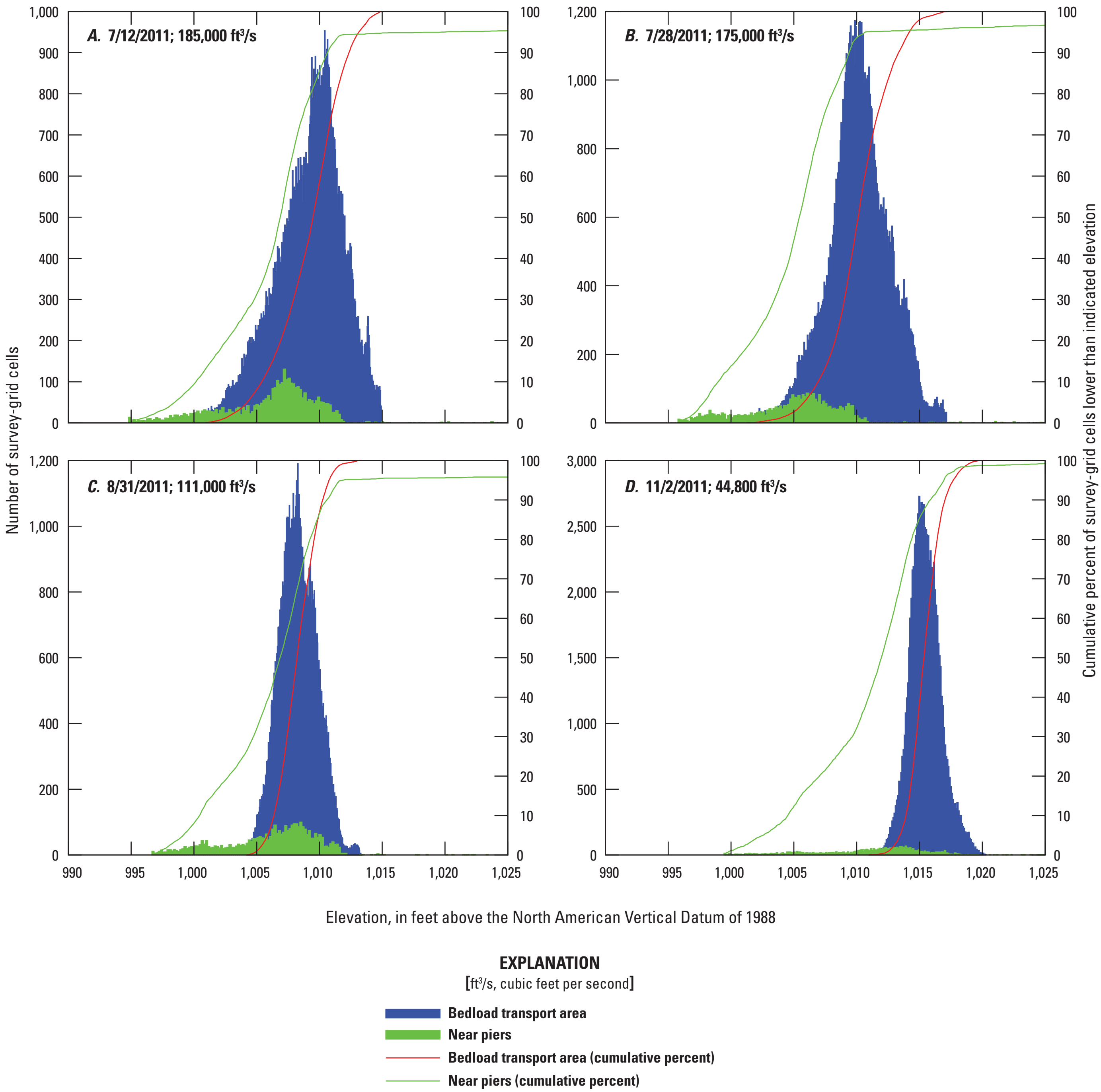


Figure 64. Frequency distribution of bed elevation, for hydrographic survey-grid cells (1.64-by-1.64 feet) sounded on the Burt County Missouri River Bridge at Decatur, Nebraska, *A*, July 12; *B*, July 28; *C*, August 31; and *D*, November 2, 2011.

Abraham Lincoln Memorial Bridge (U.S. Highway 30) at Blair, Nebraska, at River Mile 648

The Abraham Lincoln Memorial Bridge crosses the Missouri River at Blair, Nebr., and carries traffic for U.S. Highway 30 (figs. 65–72). The area near the bridge was surveyed using the MBES four times in 2011: July 25 (198,000 ft^3/s at USGS streamgaging station 06610000 Missouri River at Omaha, Nebr.), July 28 (191,000 ft^3/s), September 6 (106,000 ft^3/s), and November 2 (45,900 ft^3/s) (tables 2–3).

Minimum channel-bed elevations near the mid-channel pier were about 941 ft during the July 25 survey (fig. 66) and 942 ft during the July 28 survey and about 5–10 feet lower than the thalweg (fig. 67). By September 6, minimum bed elevations near the pier were about 955 ft (fig. 68). On November 2, minimum bed elevations near the pier were about 958 ft (fig. 69).

The difference in bed elevation from July 25 to November 2 was computed for each grid cell sounded during both surveys (fig. 70). The mean difference for all re-sounded cells was 12.7 ft, indicating that net deposition occurred in the surveyed area from July 25 to November 2. At a cross section on the upstream side of the Abraham Lincoln Memorial Bridge, bed elevations rose by 10 ft or more across much of the width of the channel near the bridge from July 25 to November 2 (fig. 71).

In the bedload transport area, the frequency distribution of bed elevations sounded during the survey shifted upward between July 25 and November 2 (fig. 72). The mean elevation for cells in the bedload transport area was about 954 ft on July 25, whereas the mean elevation was about 975 ft on November 2.

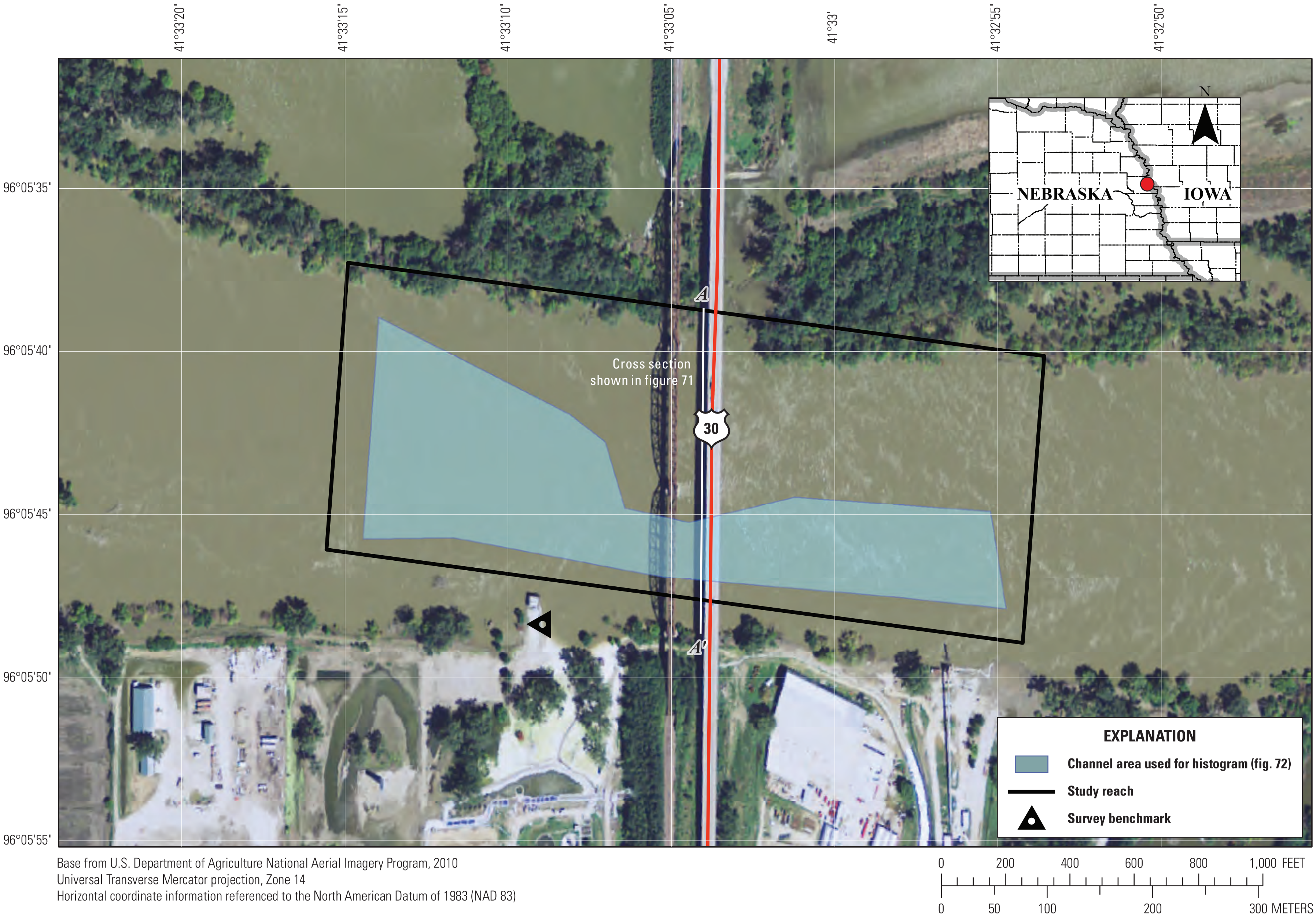
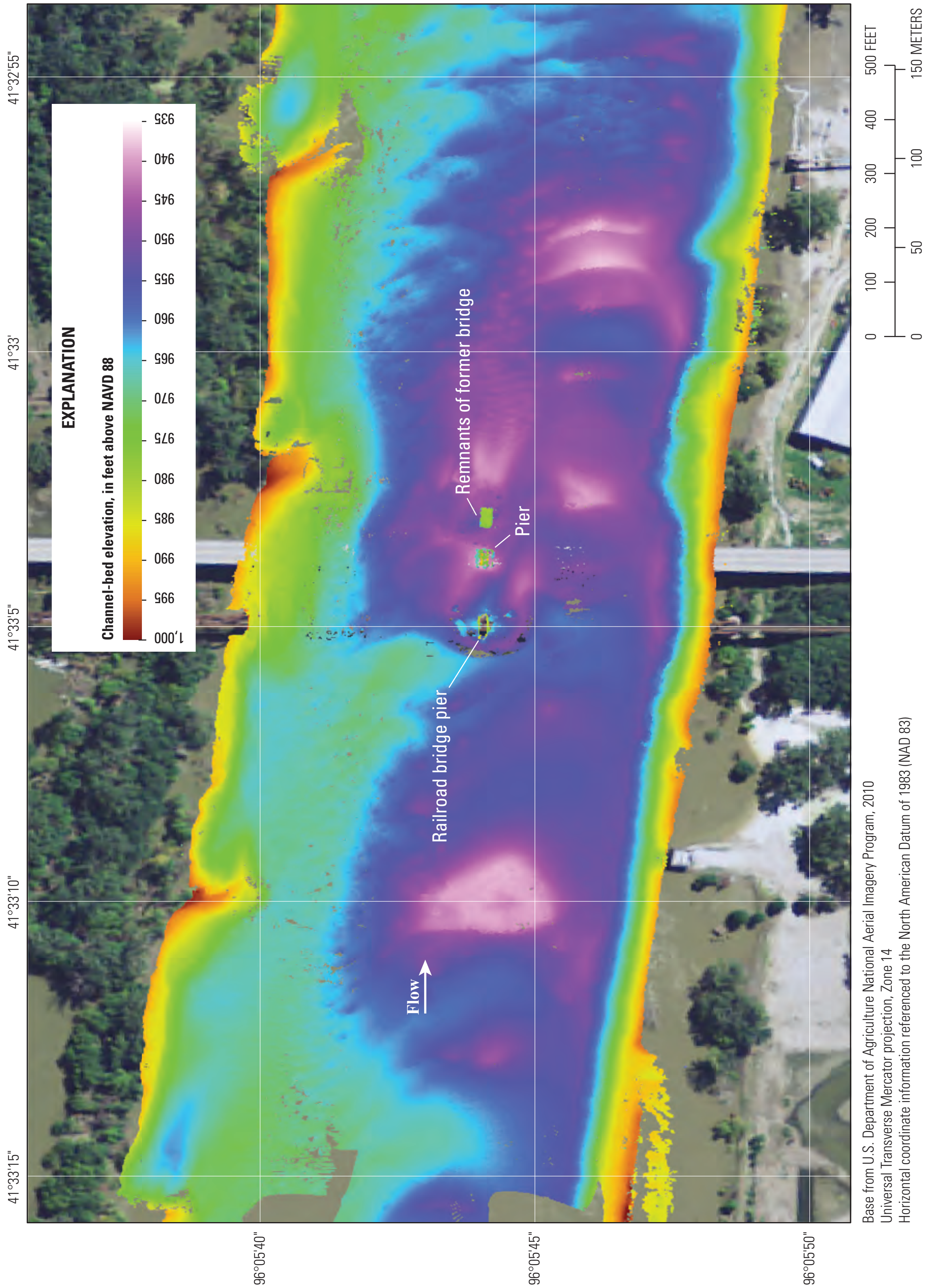
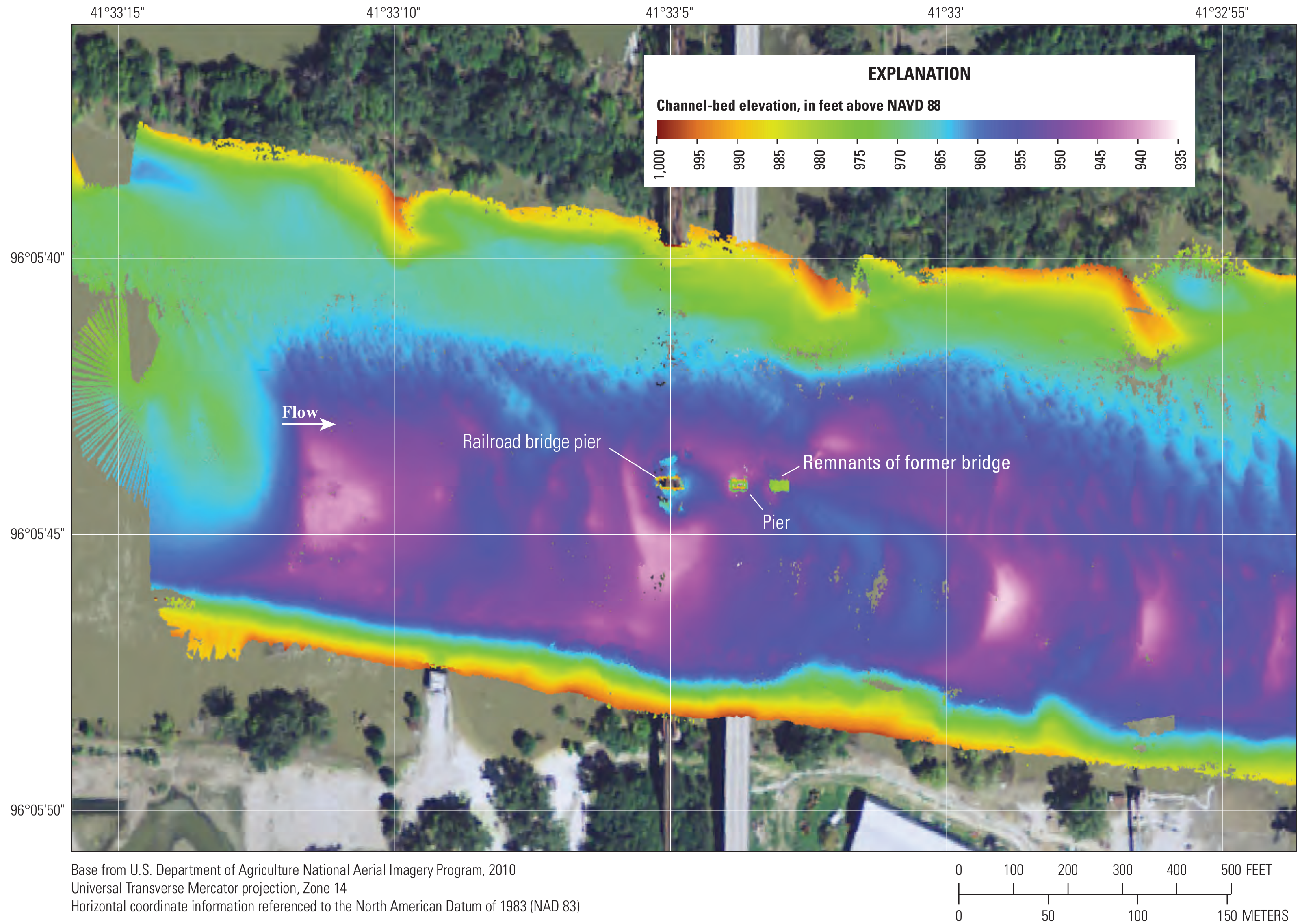


Figure 65. Location of hydrographic surveys of the Missouri River in the vicinity of the Abraham Lincoln Memorial Bridge at Blair, Nebraska, July–November 2011.



Base from U.S. Department of Agriculture National Aerial Imagery Program, 2010
Universal Transverse Mercator projection, Zone 14
Horizontal coordinate information referenced to the North American Datum of 1983 (NAD 83)

Figure 66. Channel-bed elevations of the Missouri River in the vicinity of the Abraham Lincoln Memorial Bridge at Blair Nebraska, during flow of 198,000 cubic feet per second, July 25, 2011.



Base from U.S. Department of Agriculture National Aerial Imagery Program, 2010
Universal Transverse Mercator projection, Zone 14
Horizontal coordinate information referenced to the North American Datum of 1983 (NAD 83)

Figure 67. Channel-bed elevations of the Missouri River in the vicinity of the Abraham Lincoln Memorial Bridge at Blair Nebraska, during flow of 191,000 cubic feet per second, July 28, 2011.

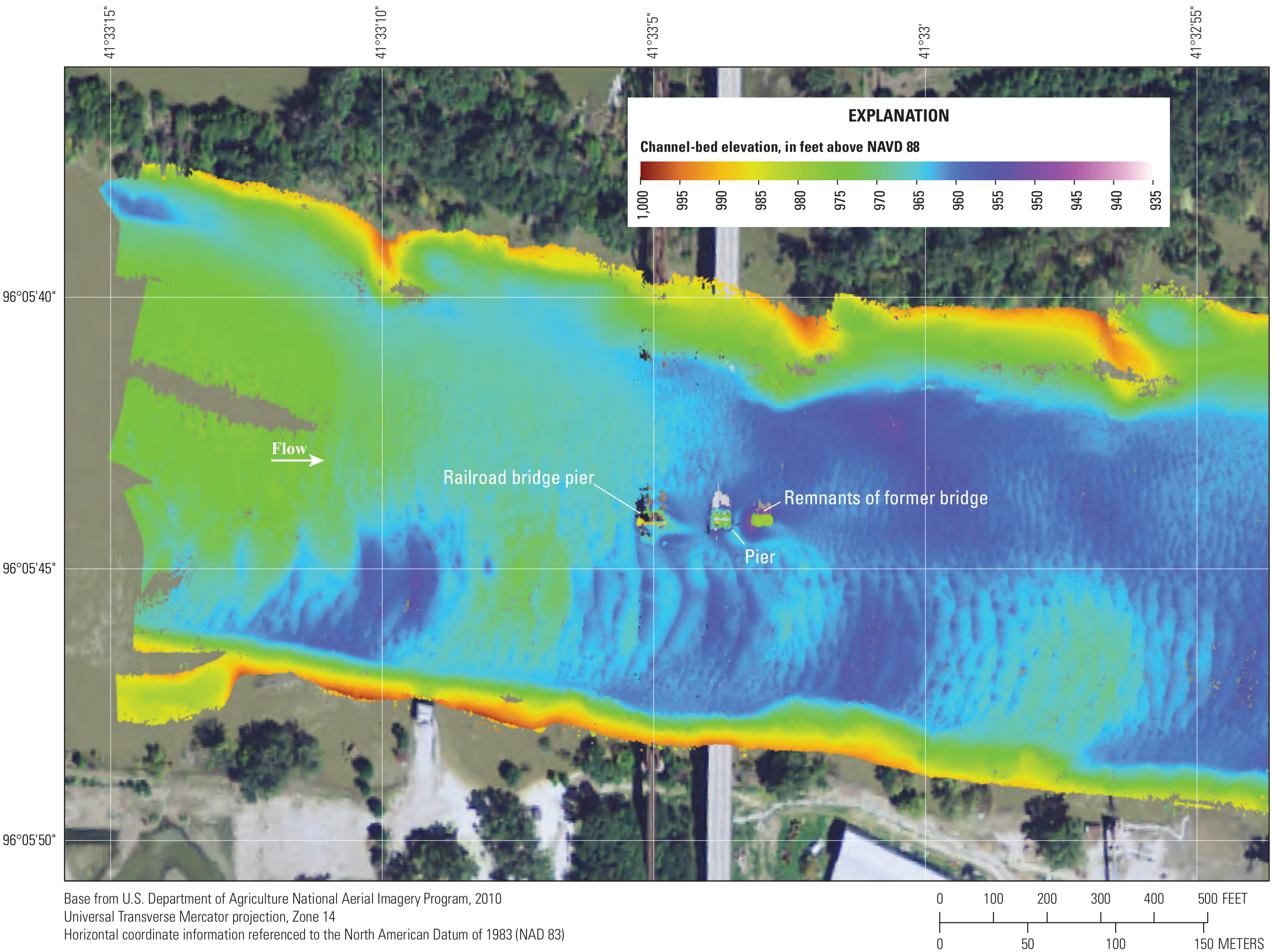
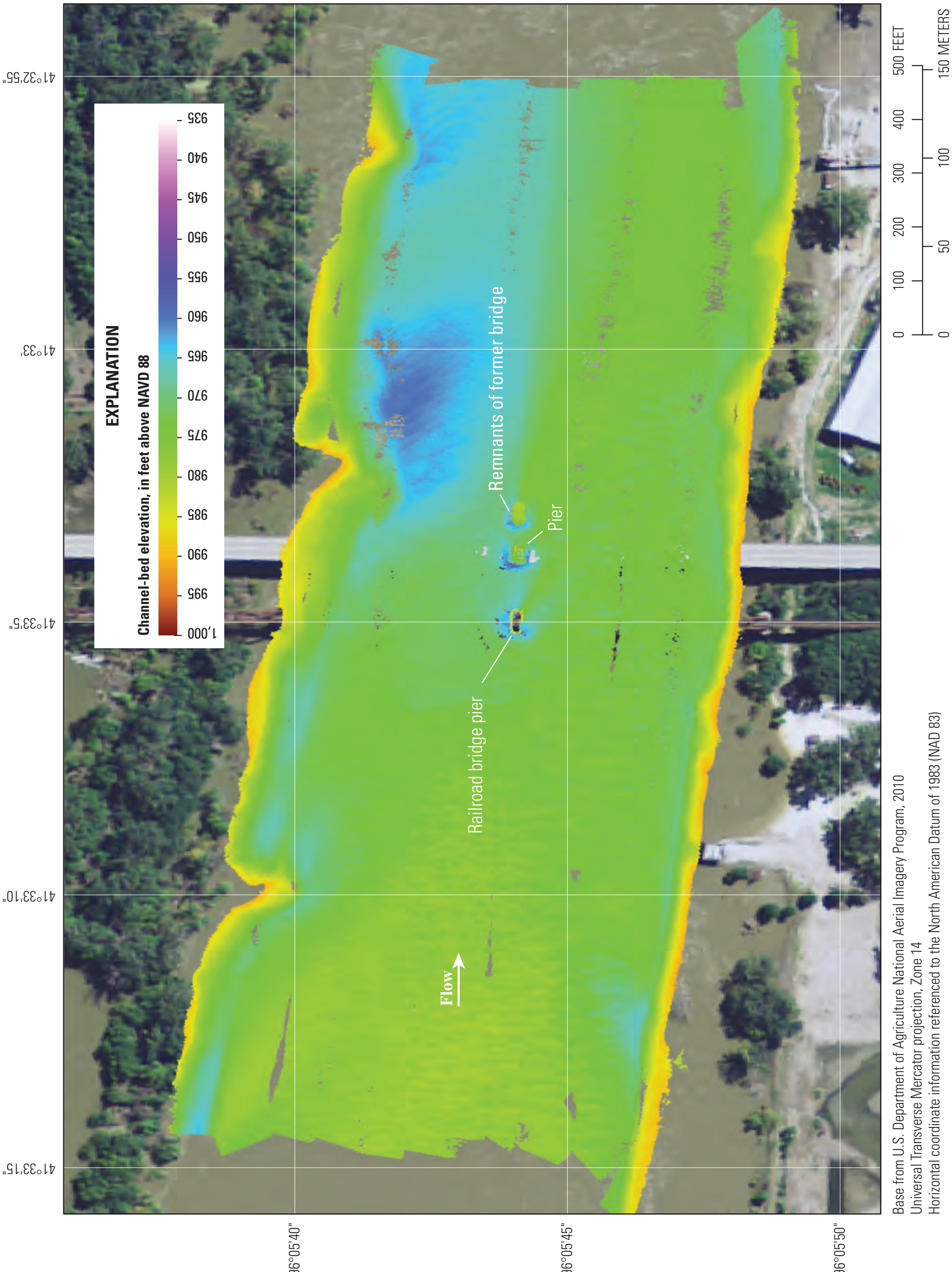
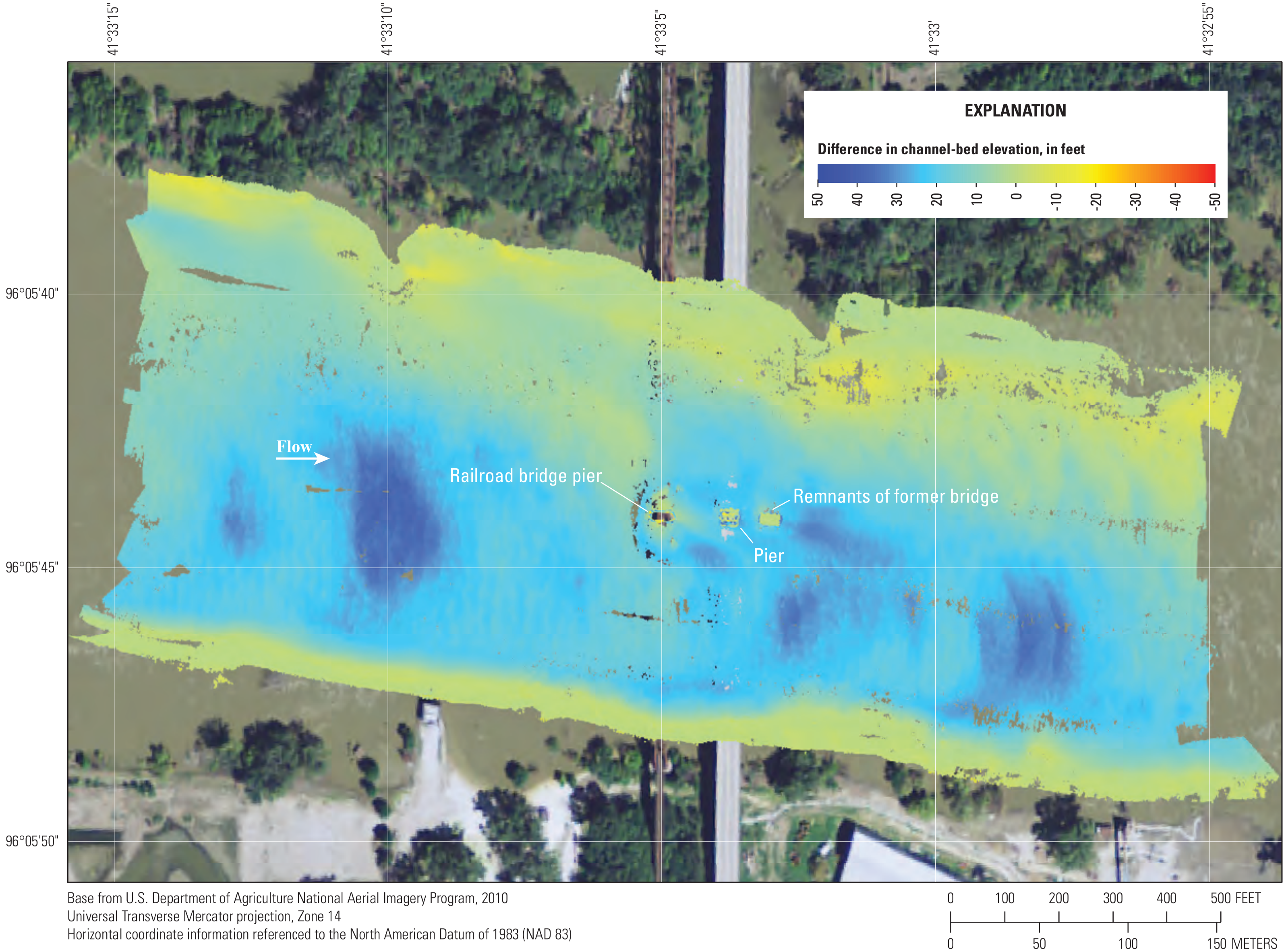


Figure 68. Channel-bed elevations of the Missouri River in the vicinity of the Abraham Lincoln Memorial Bridge at Blair, Nebraska, during flow of 106,000 cubic feet per second, September 6, 2011.



Base from U.S. Department of Agriculture National Aerial Imagery Program, 2010
Universal Transverse Mercator projection, Zone 14
Horizontal coordinate information referenced to the North American Datum of 1983 (NAD 83)

Figure 69. Channel-bed elevations of the Missouri River in the vicinity of the Abraham Lincoln Memorial Bridge at Blair, Nebraska, during flow of 45,900 cubic feet per second, November 2, 2011.



Base from U.S. Department of Agriculture National Aerial Imagery Program, 2010
Universal Transverse Mercator projection, Zone 14
Horizontal coordinate information referenced to the North American Datum of 1983 (NAD 83)

Figure 70. Difference in channel-bed elevation of the Missouri River in the vicinity of the Abraham Lincoln Memorial Bridge at Blair, Nebraska, between July 25 and November 2, 2011.

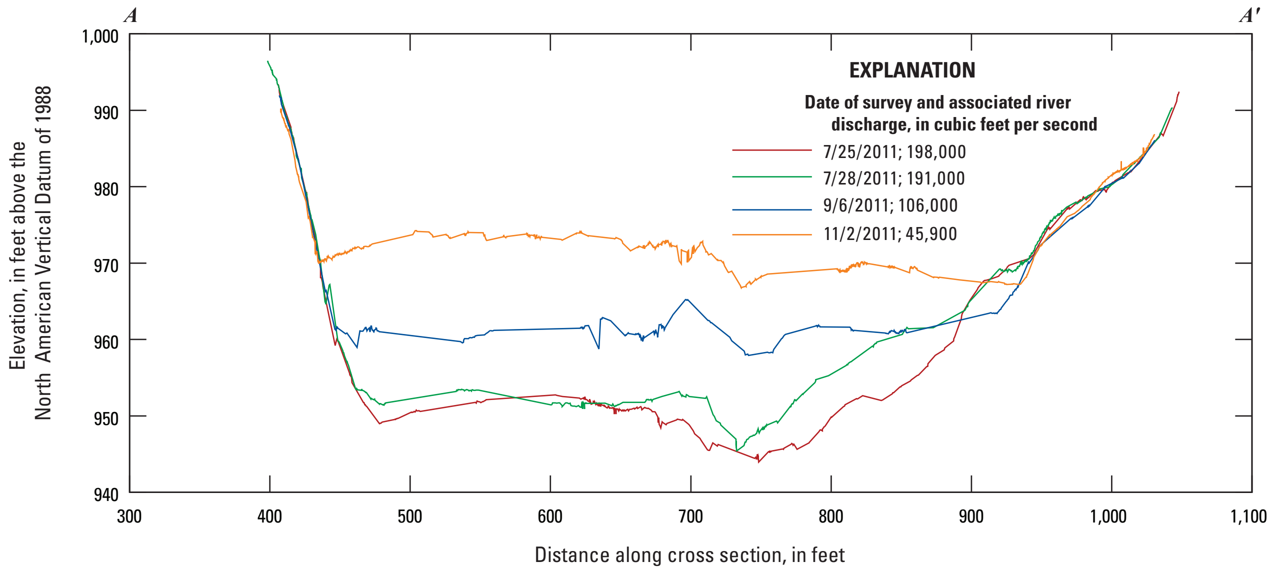


Figure 71. Hydrographic data collected by repeated surveys on the Missouri River along the upstream side of the Abraham Lincoln Memorial Bridge at Blair, Nebraska, July–November 2011.

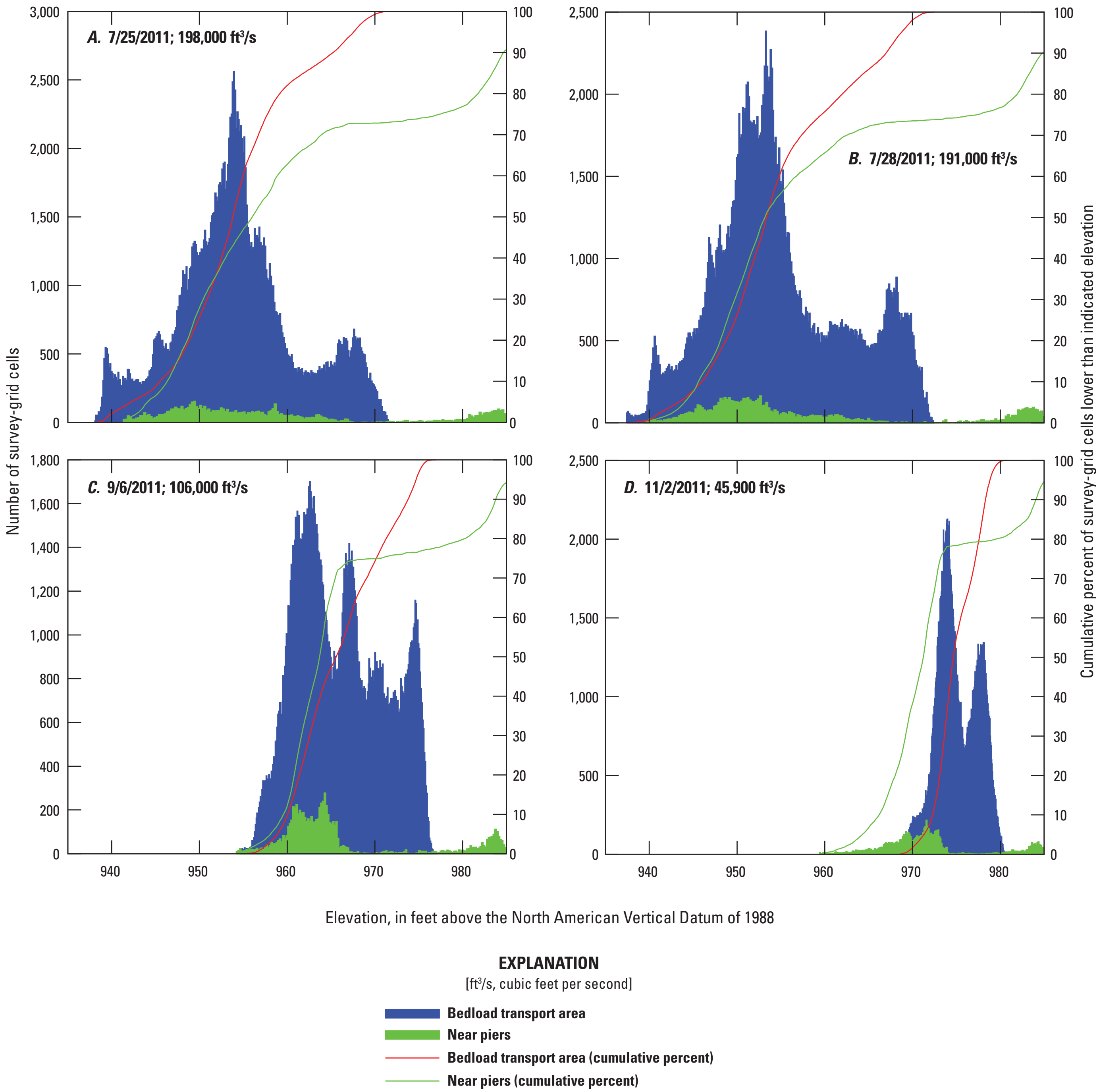


Figure 72. Frequency distribution of bed elevation, for hydrographic survey-grid cells (1.64-by-1.64 feet) sounded on the Missouri River in the vicinity of the Abraham Lincoln Memorial Bridge at Blair, Nebraska, *A*, July 25; *B*, July 28; *C*, September 6; and *D*, November 2, 2011.

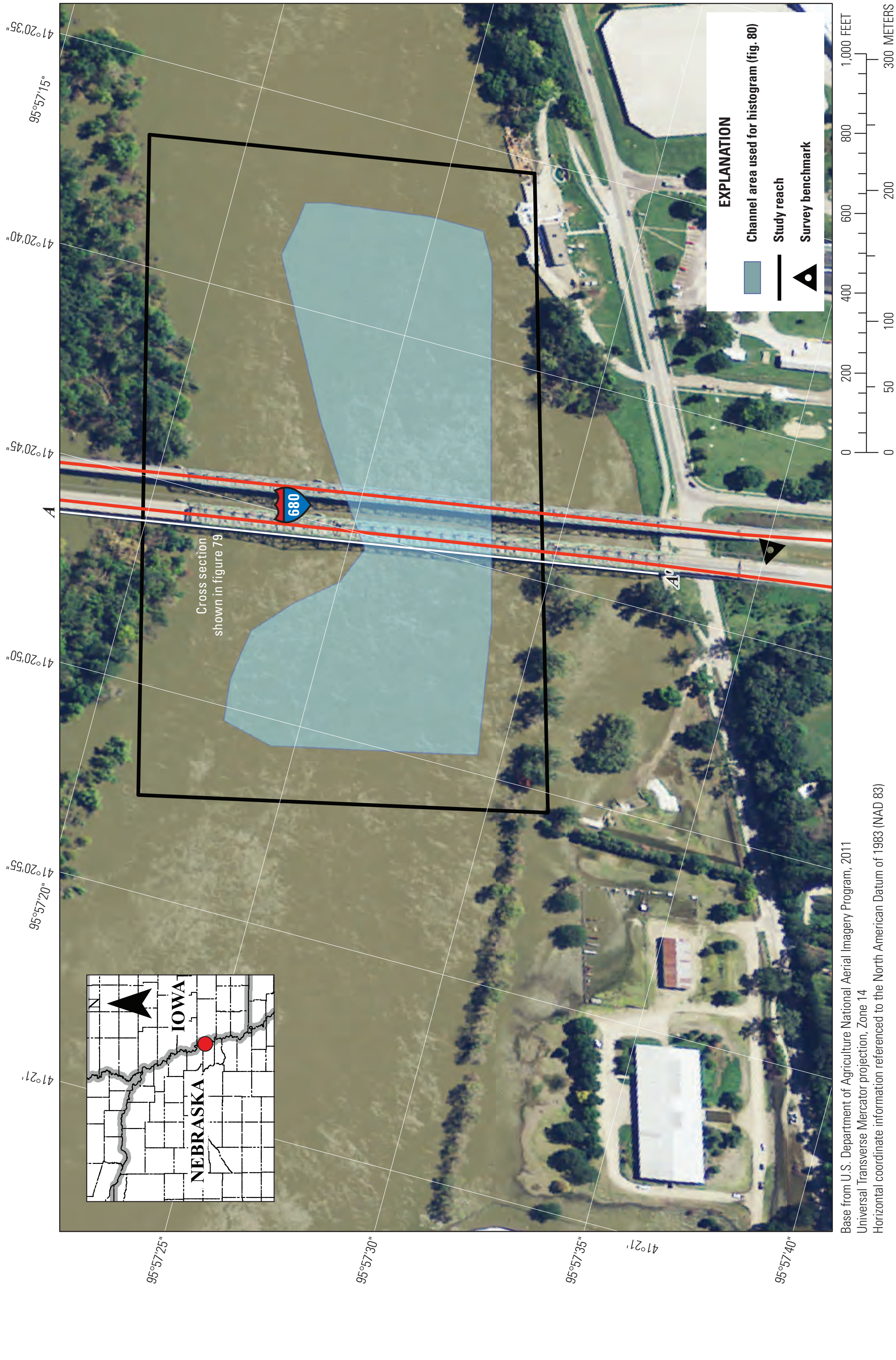
Mormon Pioneer Memorial Bridge (Interstate 680) at Omaha, Nebraska, at River Mile 626

The Mormon Pioneer Memorial Bridge, also known as the Interstate 680 Bridge, crosses the Missouri River at Omaha, Nebr. (figs. 73–80). For most of the 2011 flood, the Mormon Pioneer Memorial Bridge was closed because of flooding across the approach on the Iowa side. The Mormon Pioneer Memorial Bridge was surveyed on four dates during the 2011 Missouri River flooding event (table 2). The USGS streamgaging station 06610000 Missouri River at Omaha, Nebr., is located about 10 miles downstream from this bridge. The discharges reported for streamgaging station 06610000 were 187,000 ft^3/s on July 13; 186,000 ft^3/s on August 1; 105,000 ft^3/s on September 7; and 46,500 ft^3/s on November 3 (table 3).

The bed elevations surveyed on July 13 ranged from 942 ft to 967 ft (fig. 74). For all four surveys, bed elevations near the mid-channel bridge piers did not change greatly and were not lower than the thalweg; bed elevations near the piers were about 960 ft during all four surveys and generally were within the range of bed elevations of dunes in other parts of the bedload transport area.

The difference in bed elevation from July 13 to November 3 was computed for each grid cell sounded during both surveys (fig. 78). The mean difference for all re-sounded cells was 1.0 ft, indicating that net deposition likely occurred in the surveyed area from July 13 to November 3. A cross section on the upstream side of the Mormon Pioneer Memorial Bridge shows little change in the deepest part of the channel from July 13 through September 7, however, bed elevations rose by nearly 5 ft in the main channel between September 7 and November 3 (fig. 79).

In the bedload transport area, the most frequently observed elevation for each survey (between 960 and 961 ft) did not change more than the vertical uncertainty between July 13 and November 3. The mean elevation for grid cells in the transport area was 957 ft on July 13 and 959 ft on November 3.



Base from U.S. Department of Agriculture National Aerial Imagery Program, 2011
Universal Transverse Mercator projection, Zone 14
Horizontal coordinate information referenced to the North American Datum of 1983 (NAD 83)

Figure 73. Location of hydrographic surveys of the Missouri River in the vicinity of the Mormon Pioneer Memorial Bridge at Omaha, Nebraska, July–November 2011.

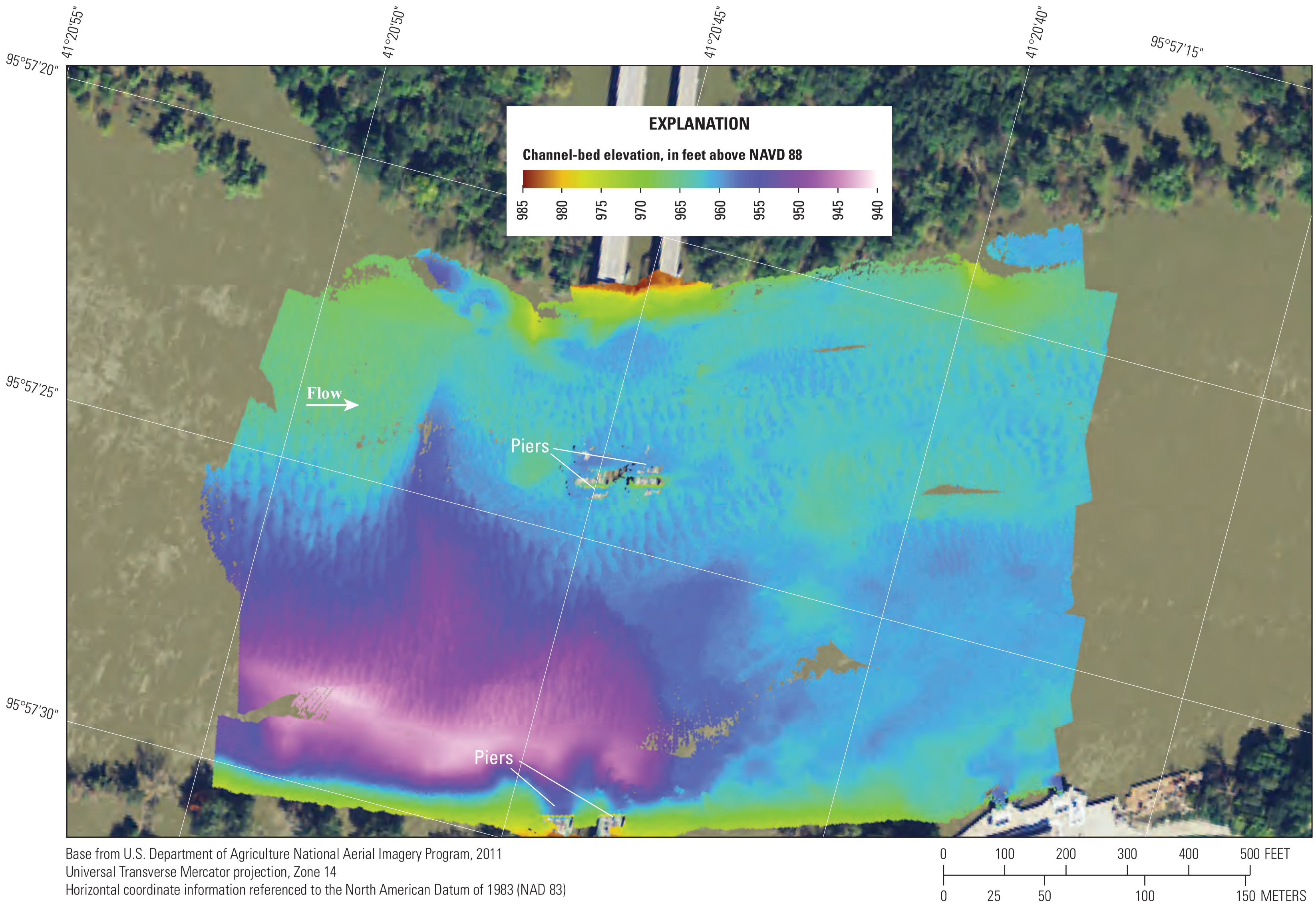
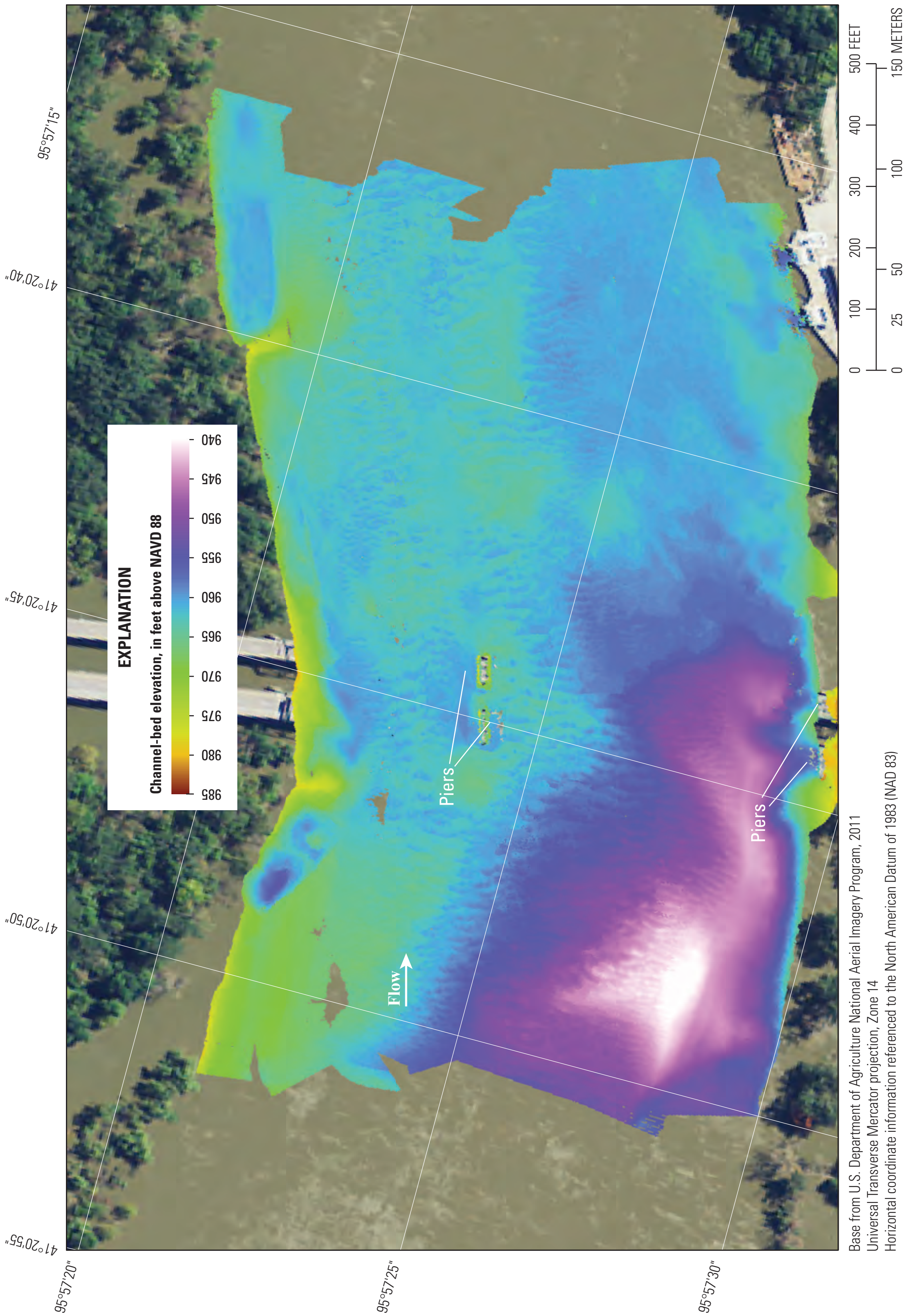


Figure 74. Channel-bed elevations of the Missouri River in the vicinity of the Mormon Pioneer Memorial Bridge at Omaha, Nebraska, during flow of 187,000 cubic feet per second, July 13, 2011.



Base from U.S. Department of Agriculture National Aerial Imagery Program, 2011
Universal Transverse Mercator projection, Zone 14
Horizontal coordinate information referenced to the North American Datum of 1983 (NAD 83)

Figure 75. Channel-bed elevations of the Missouri River in the vicinity of the Mormon Pioneer Memorial Bridge at Omaha, Nebraska, during flow of 186,000 cubic feet per second, August 1, 2011.

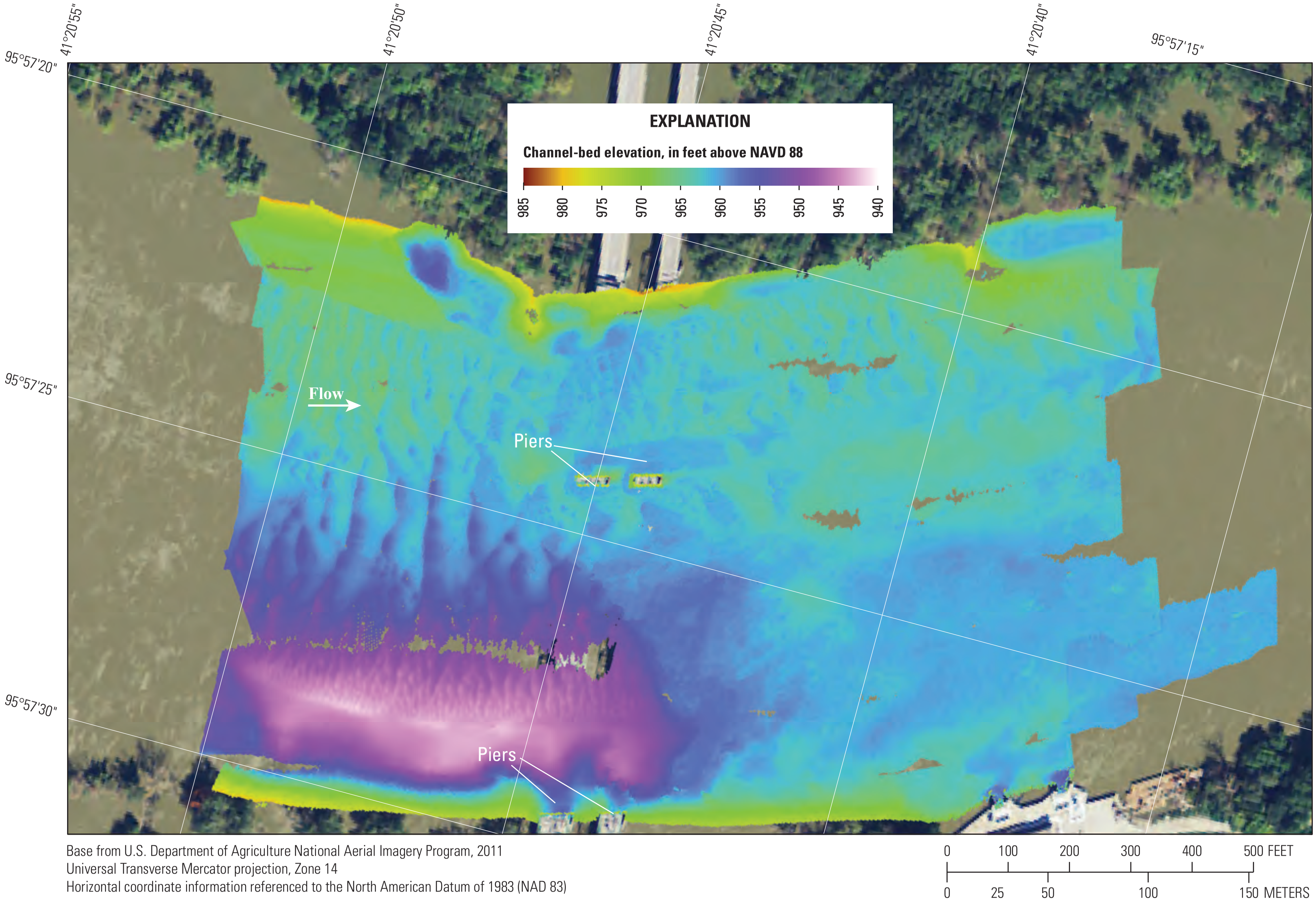
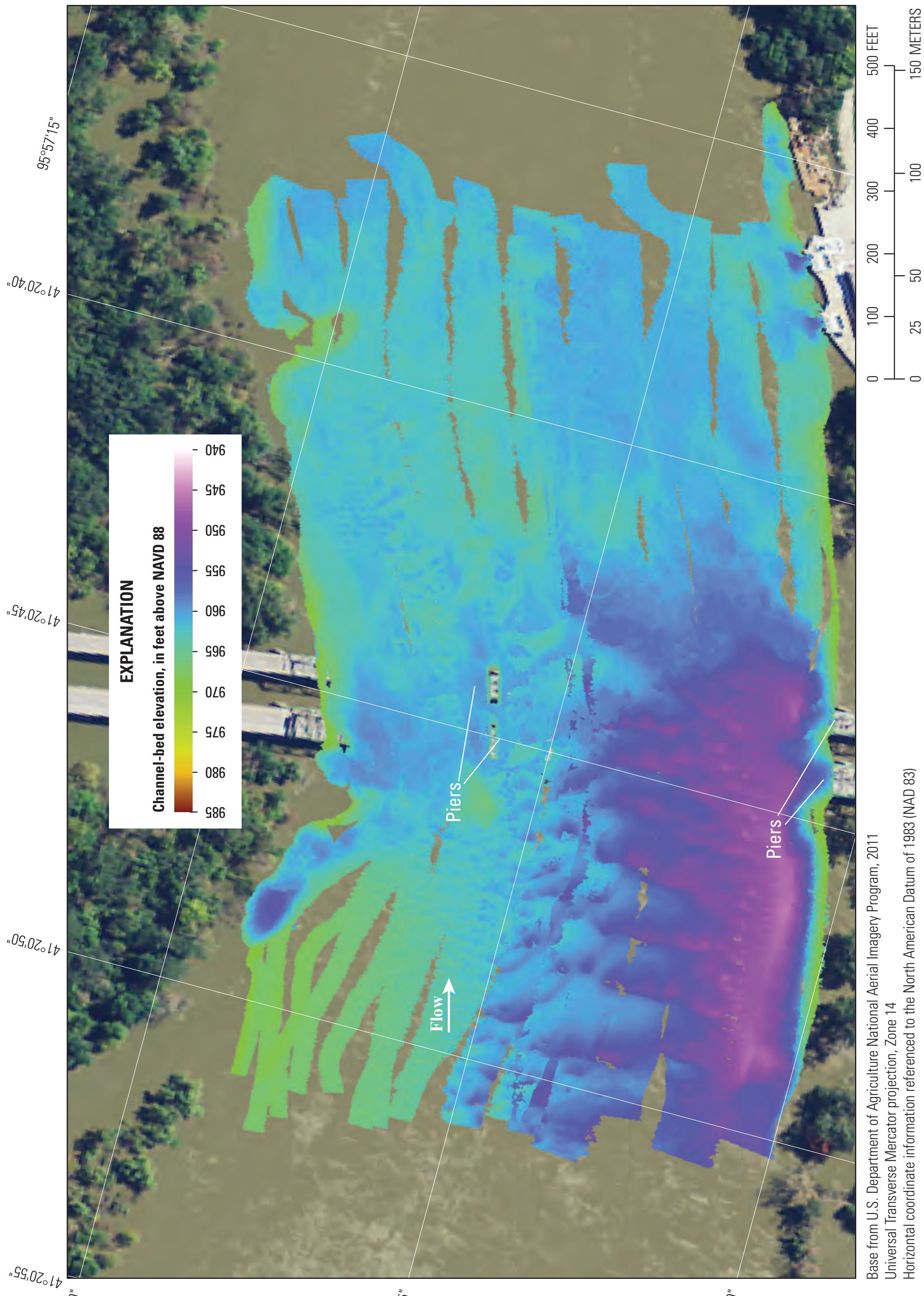


Figure 76. Channel-bed elevations of the Missouri River in the vicinity of the Mormon Pioneer Memorial Bridge at Omaha, Nebraska, during flow of 105,000 cubic feet per second, September 7, 2011.



Base from U.S. Department of Agriculture National Aerial Imagery Program, 2011
Universal Transverse Mercator projection, Zone 14
Horizontal coordinate information referenced to the North American Datum of 1983 (NAD 83)

Figure 77. Channel-bed elevations of the Missouri River in the vicinity of the Mormon Pioneer Memorial Bridge at Omaha, Nebraska, during flow of 46,500 cubic feet per second, November 3, 2011.

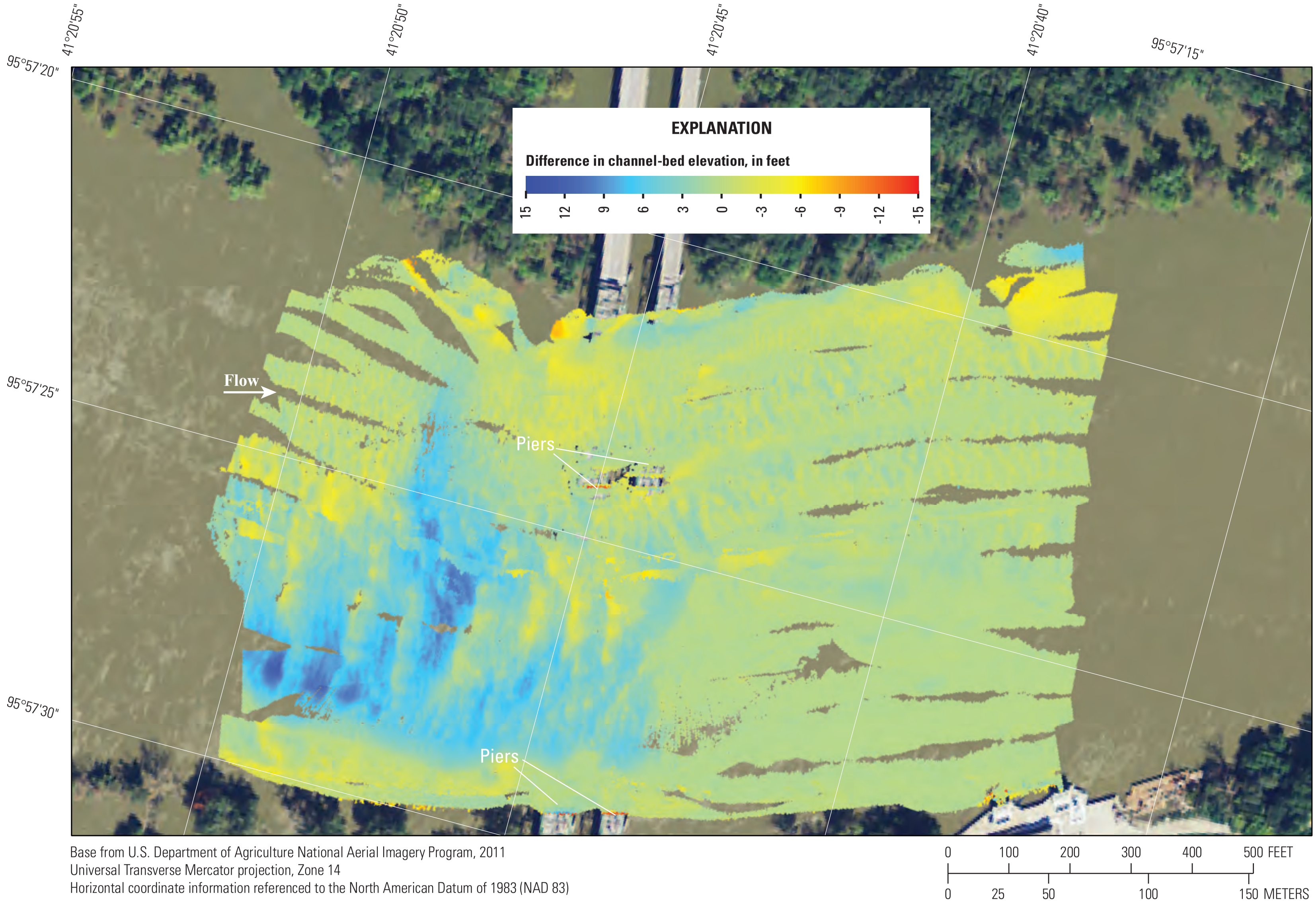


Figure 78. Difference in channel-bed elevation of the Missouri River in the vicinity of the Mormon Pioneer Memorial Bridge at Omaha, Nebraska, between July 13 and November 3, 2011.

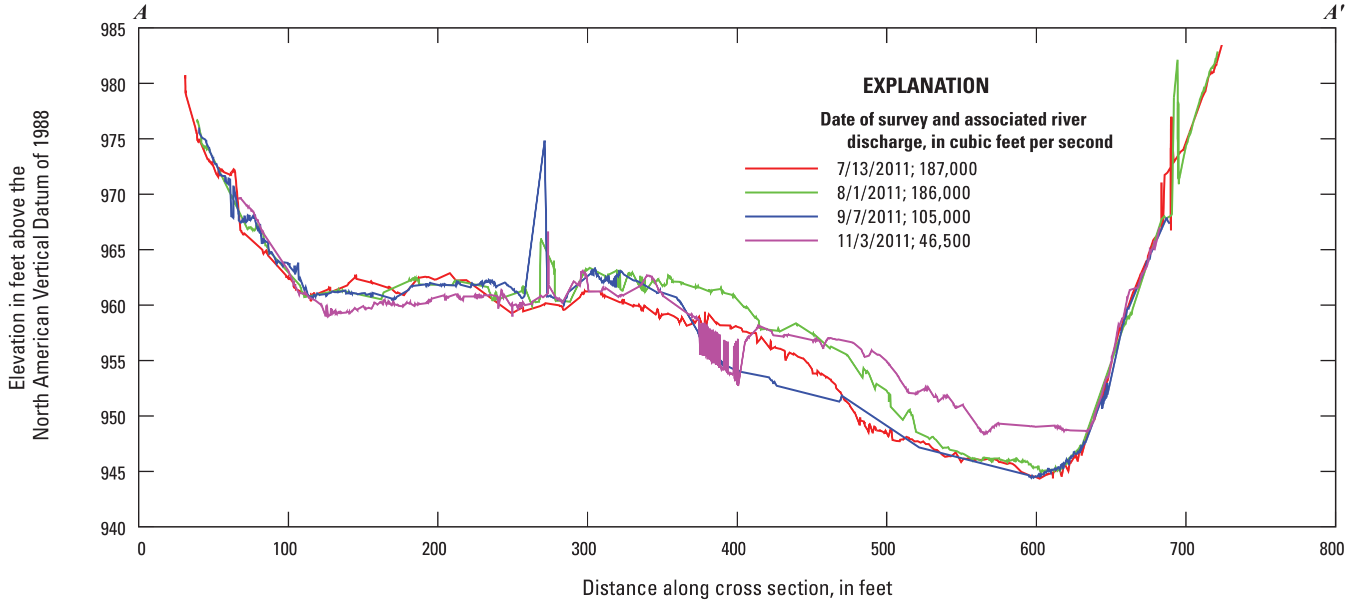


Figure 79. Hydrographic data collected by repeated surveys on the Missouri River along the upstream side of the Mormon Pioneer Memorial Bridge at Omaha, Nebraska, July–November 2011.

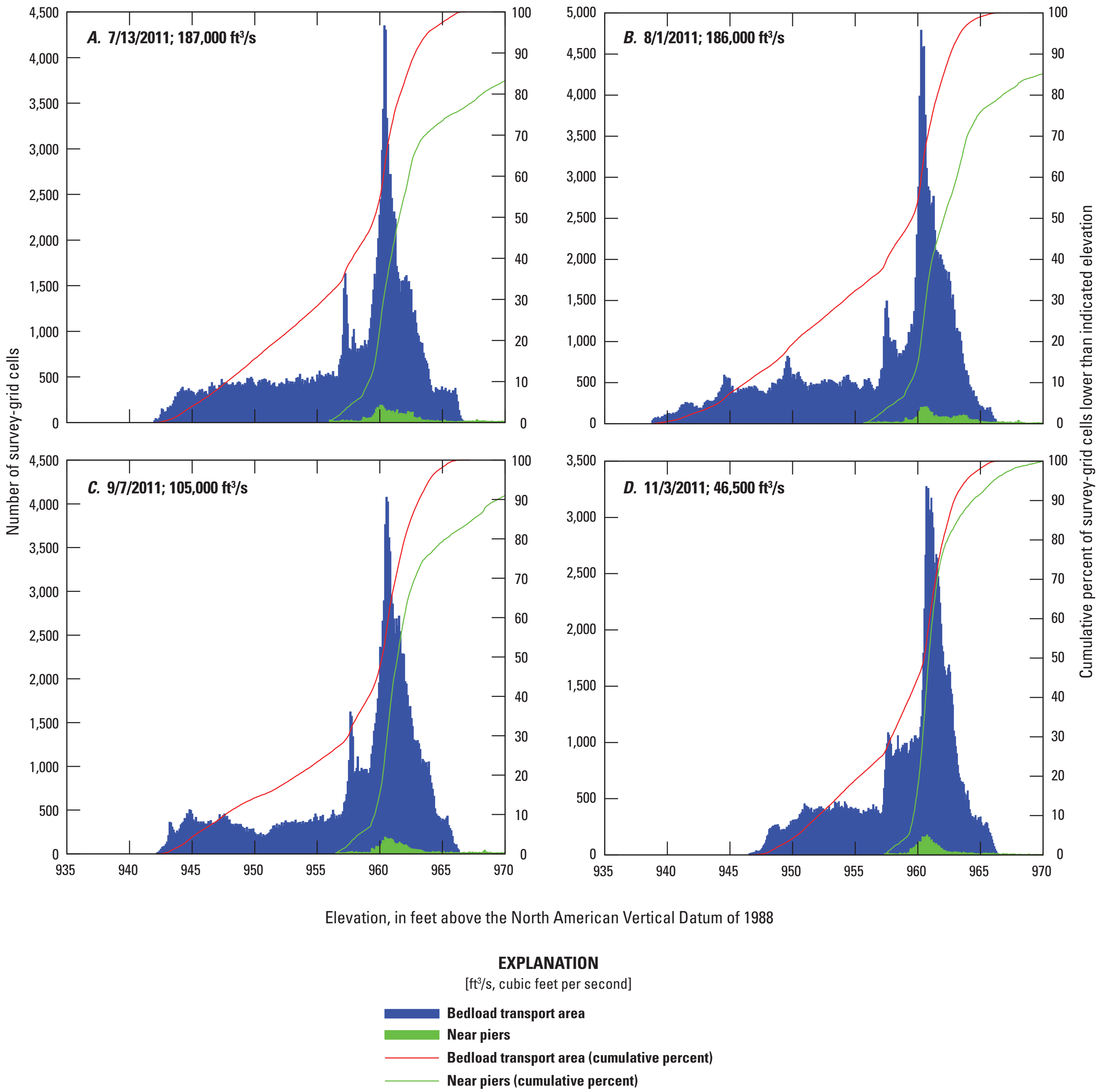


Figure 80. Frequency distribution of bed elevation, for hydrographic survey-grid cells (1.64-by-1.64 feet) sounded on the Missouri River in the vicinity of the Mormon Pioneer Memorial Bridge at Omaha, Nebraska, *A*, July 13; *B*, August 1; *C*, September 7; and *D*, November 3, 2011.

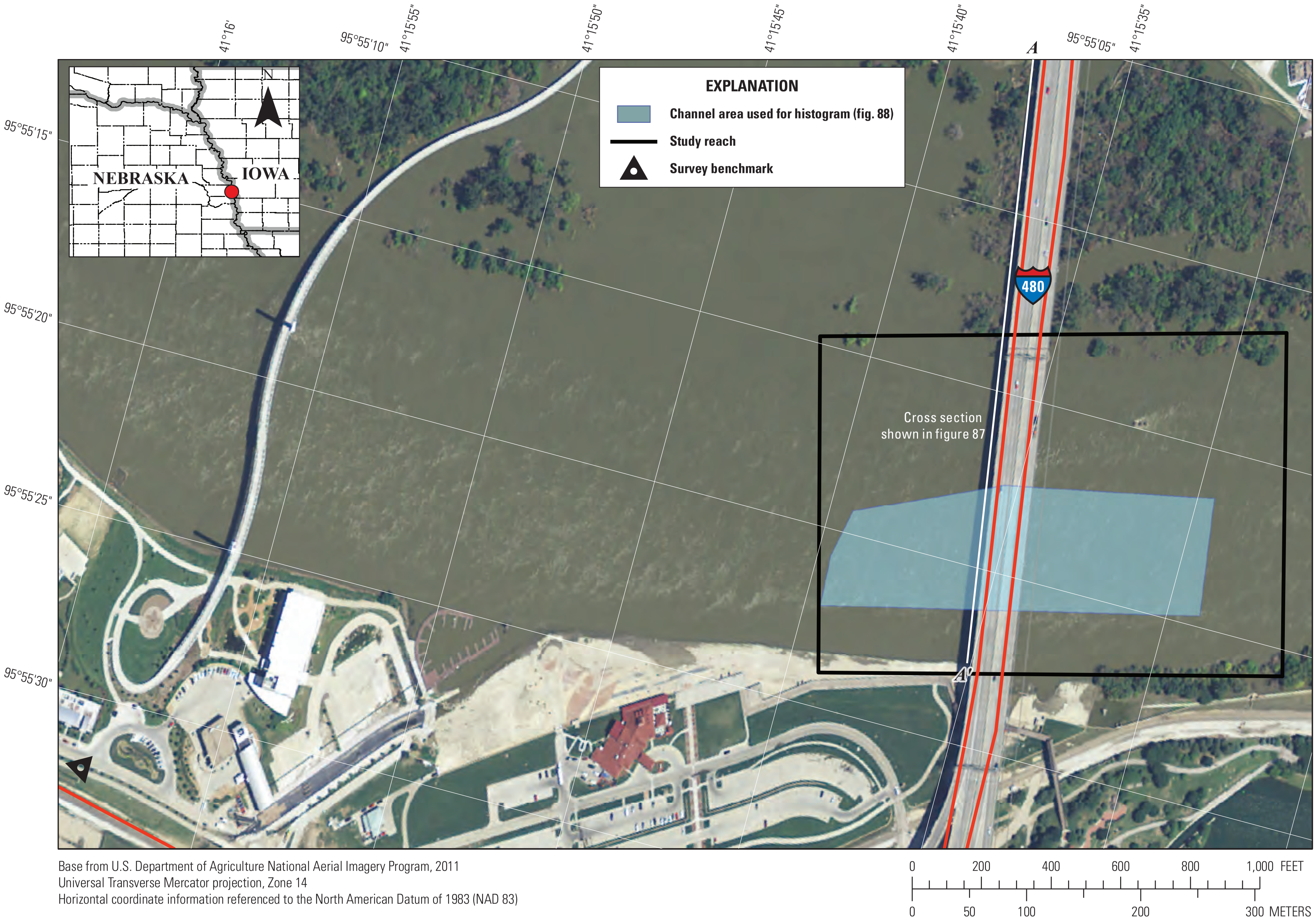
Grenville Dodge Memorial Bridge (Interstate 480) at Omaha, Nebraska, at River Mile 616

The Grenville Dodge Memorial Bridge, also known as the Interstate 480 Bridge, crosses the Missouri River at downtown Omaha, Nebr. (figs. 81–88). The Grenville Dodge Memorial Bridge was surveyed on four dates during the 2011 flood (table 2). The USGS streamgaging station 06610000 is located at the bridge. The discharges for the dates of MBES surveys were 187,000 ft^3/s on July 13; 187,000 ft^3/s on August 3; 105,000 ft^3/s on September 7; and 46,500 ft^3/s on November 3 (table 3).

The bed elevations surveyed on July 13 ranged from 940 ft to 956 ft (fig. 82). The minimum bed elevation near the main-channel east bridge piers was about 948 ft during the July 13 survey. Between the July 13 and August 3 surveys, large dunes moved through the site, and the bed elevations near the east or mid-channel pier (local minimum of 944 ft) corresponded to a trough between dunes (fig. 83). The minimum bed elevation near this pier during the September 7 survey was about 948 ft (fig. 84). Elevations along the eastern part of the channel near the bridge decreased by as much as 11 ft from July 13 to November 3 as the large dunes dissipated.

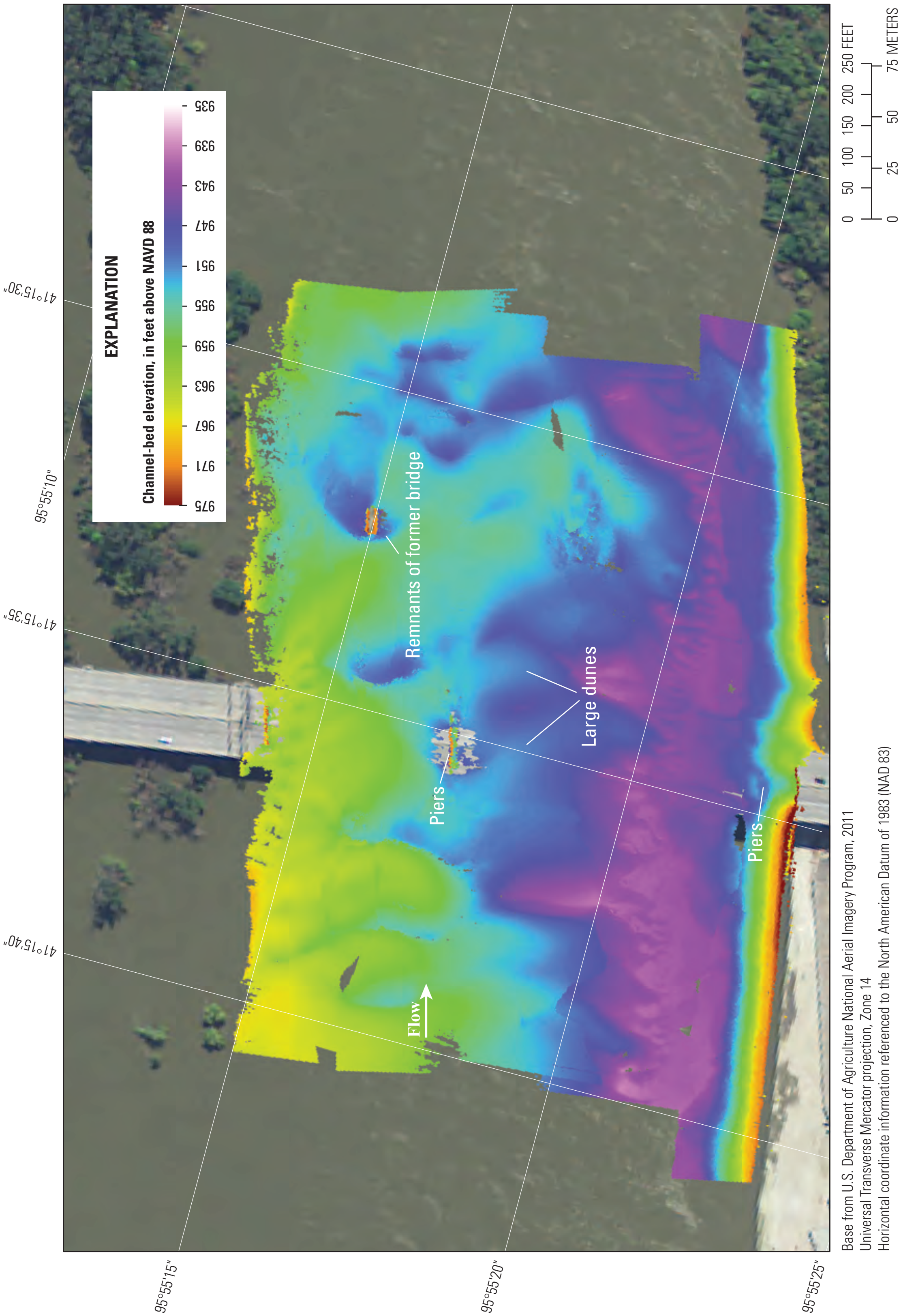
The difference in bed elevation from July 13 to November 3 was computed for each grid cell sounded during both surveys (fig. 86). The mean difference for all re-sounded cells was -3.6 ft, indicating that net erosion occurred in the surveyed area from July 13 to November 3. A cross section on the upstream side of the Grenville Dodge Memorial Bridge shows that bed elevations decreased by 5 ft or more in the left part of the channel from July 13 to November 3 (fig. 87).

In the bedload transport area, the most frequently observed elevation shifted upward from 941 to 943 between July 13 and November 3; however, the proportion of observed elevations higher than 945 ft became smaller in later surveys (fig. 88). The mean elevation for grid cells in the bedload transport area was 948 ft on July 13, whereas the mean elevation was 945 ft on November 3.



Base from U.S. Department of Agriculture National Aerial Imagery Program, 2011
Universal Transverse Mercator projection, Zone 14
Horizontal coordinate information referenced to the North American Datum of 1983 (NAD 83)

Figure 81. Location of hydrographic surveys of the Missouri River in the vicinity of the Grenville Dodge Memorial Bridge at Omaha, Nebraska, July–November 2011.



Base from U.S. Department of Agriculture National Aerial Imagery Program, 2011
Universal Transverse Mercator projection, Zone 14
Horizontal coordinate information referenced to the North American Datum of 1983 (NAD 83)

Figure 82. Channel-bed elevations of the Missouri River in the vicinity of the Grenville Dodge Memorial Bridge at Omaha, Nebraska, during flow of 187,000 cubic feet per second, July 13, 2011.

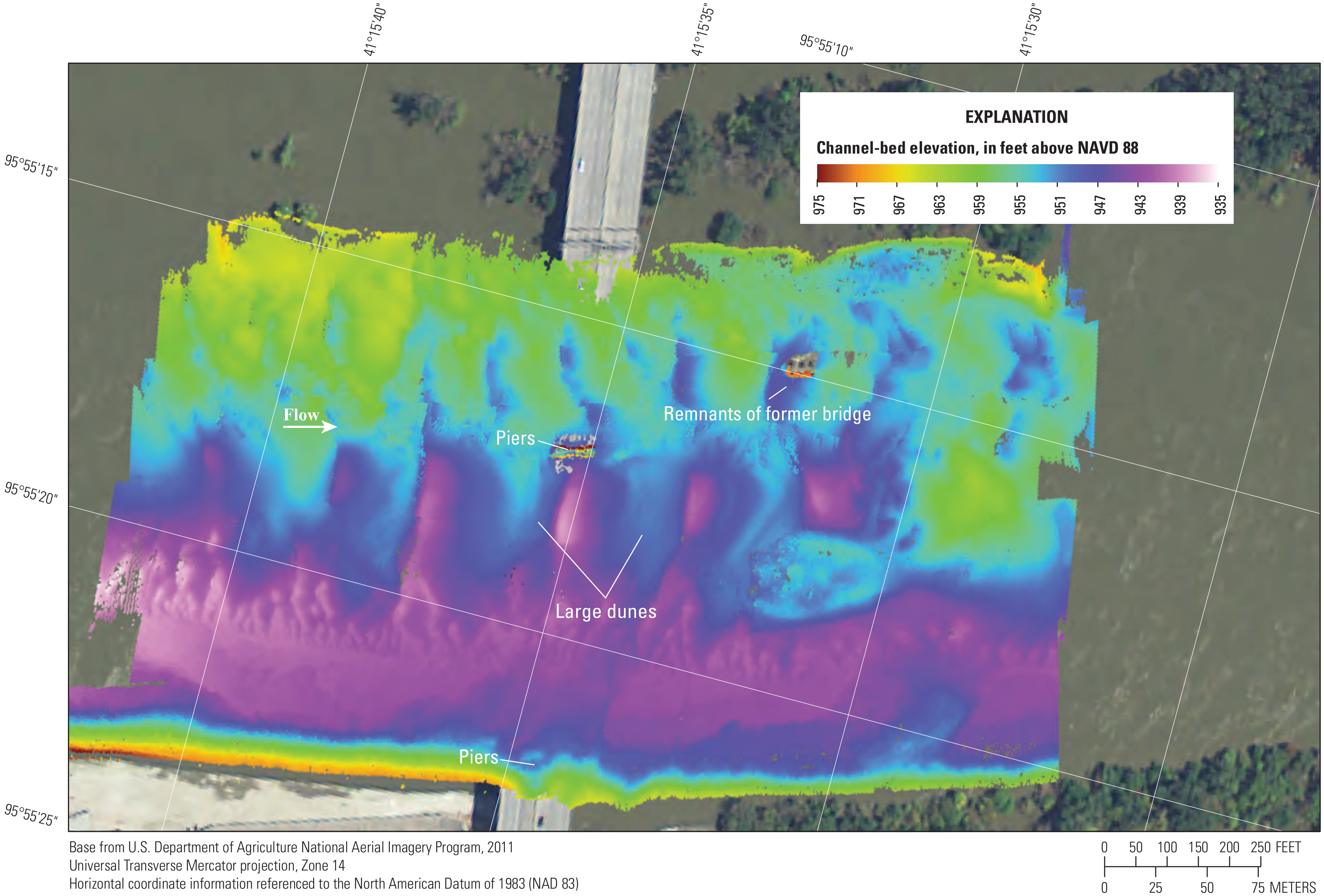
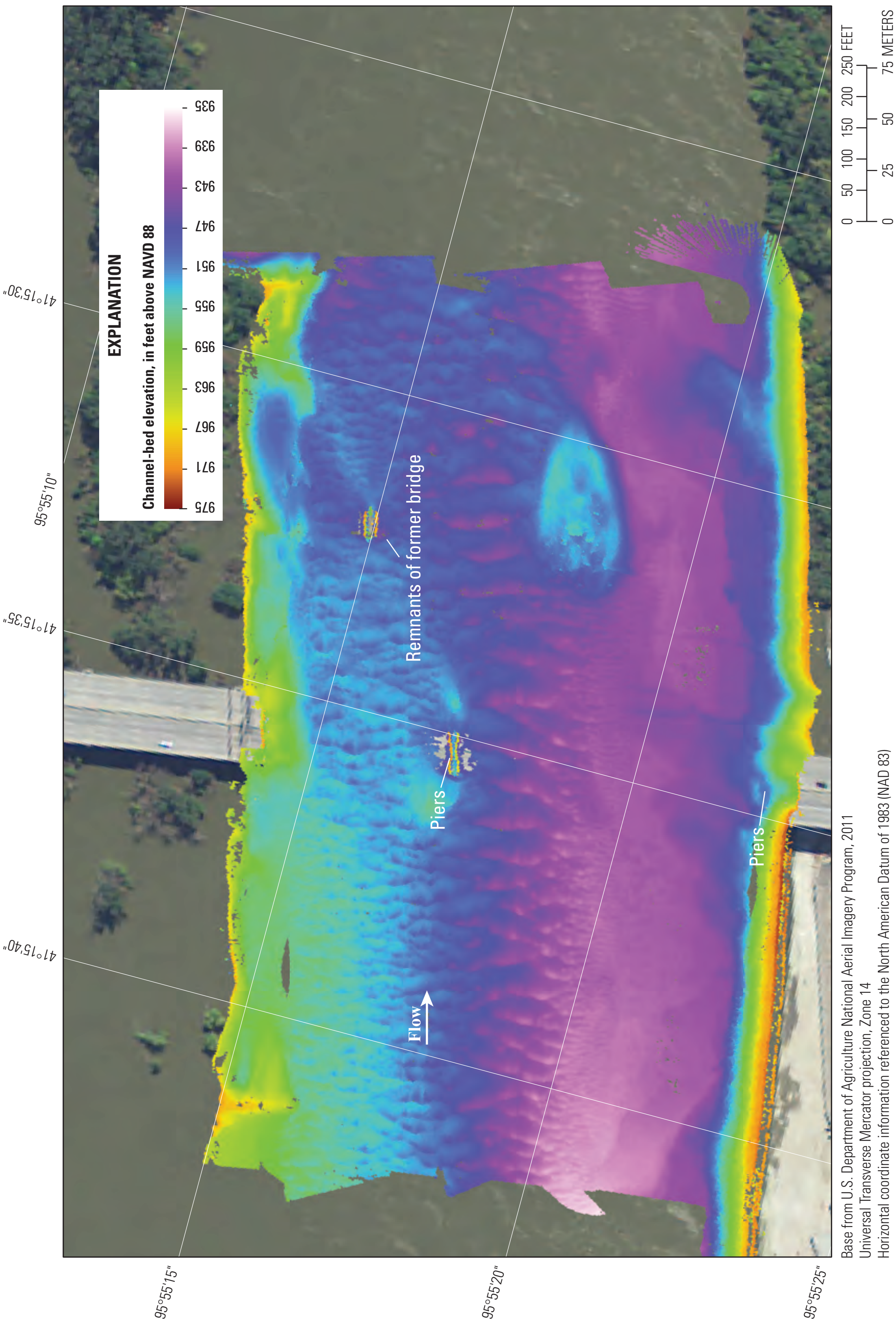


Figure 83. Channel-bed elevations of the Missouri River in the vicinity of the Grenville Dodge Memorial Bridge at Omaha, Nebraska, during flow of 187,000 cubic feet per second, August 3, 2011.



Base from U.S. Department of Agriculture National Aerial Imagery Program, 2011
Universal Transverse Mercator projection, Zone 14
Horizontal coordinate information referenced to the North American Datum of 1983 (NAD 83)

Figure 84. Channel-bed elevations of the Missouri River in the vicinity of the Grenville Dodge Memorial Bridge at Omaha, Nebraska, during flow of 105,000 cubic feet per second, September 7, 2011.

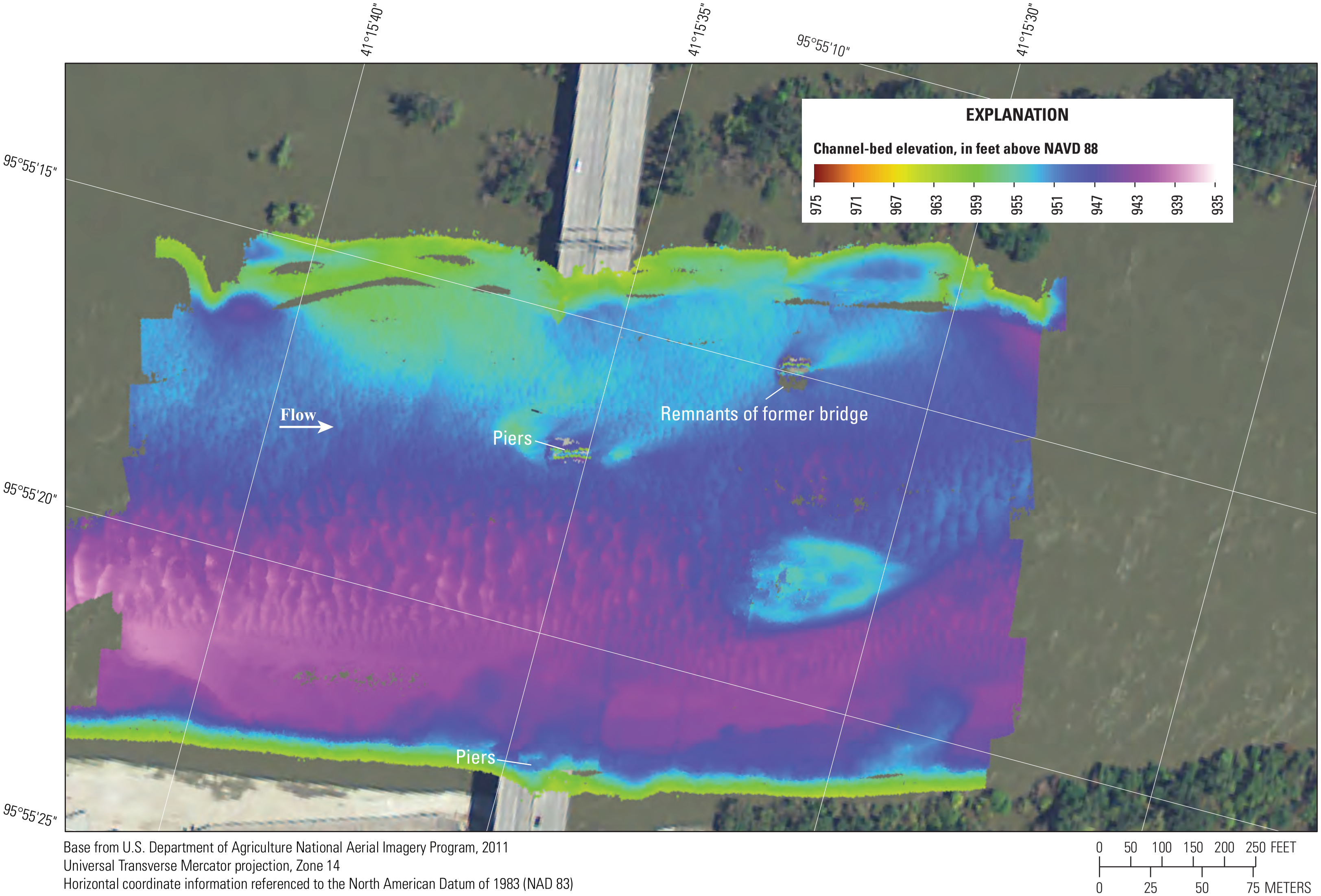
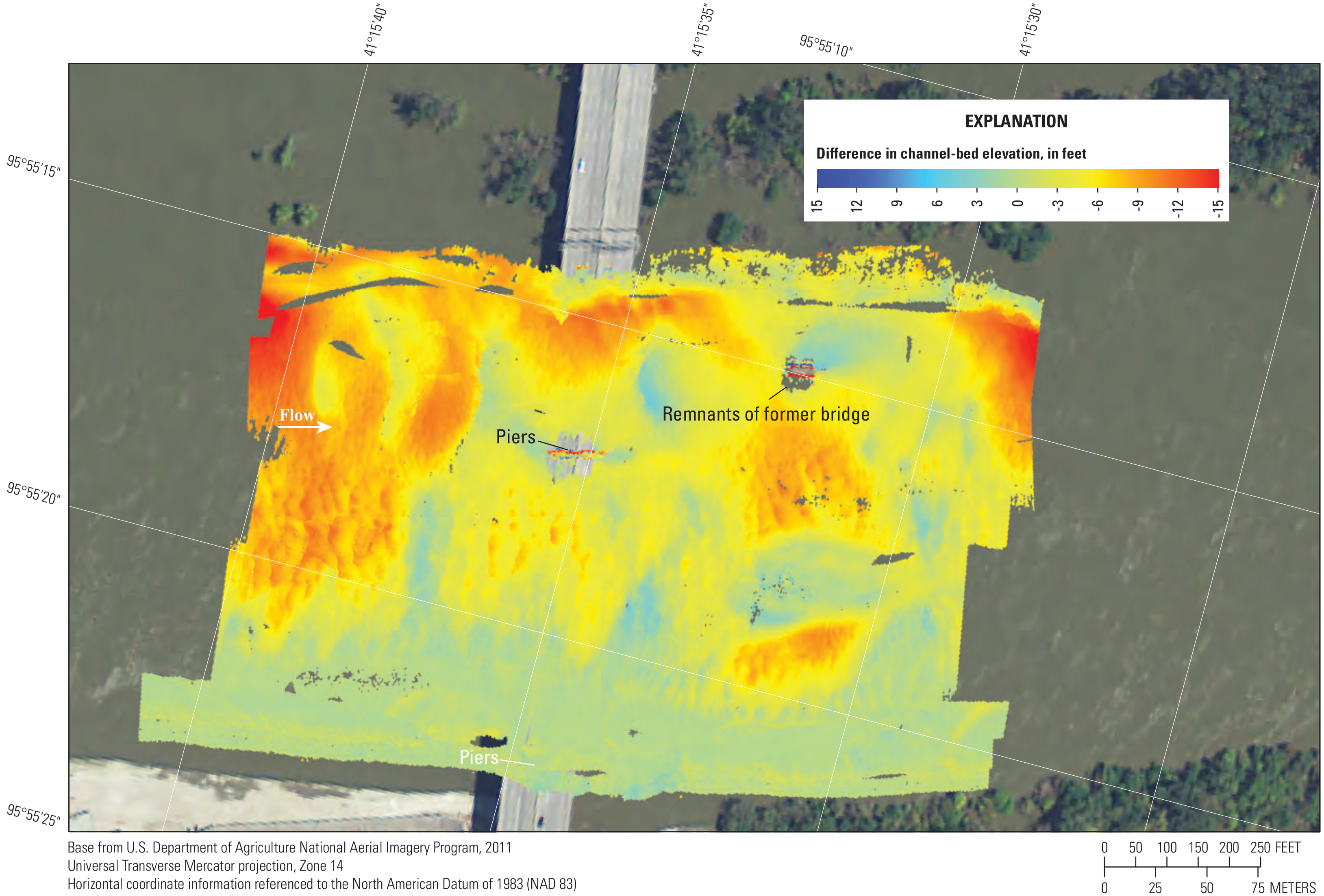


Figure 85. Channel-bed elevations of the Missouri River in the vicinity of the Grenville Dodge Memorial Bridge at Omaha, Nebraska, during flow of 46,500 cubic feet per second, November 3, 2011.



Base from U.S. Department of Agriculture National Aerial Imagery Program, 2011
Universal Transverse Mercator projection, Zone 14
Horizontal coordinate information referenced to the North American Datum of 1983 (NAD 83)

Figure 86. Difference in channel-bed elevation of the Missouri River in the vicinity of the Grenville Dodge Memorial Bridge at Omaha, Nebraska, between July 13 and November 3, 2011.

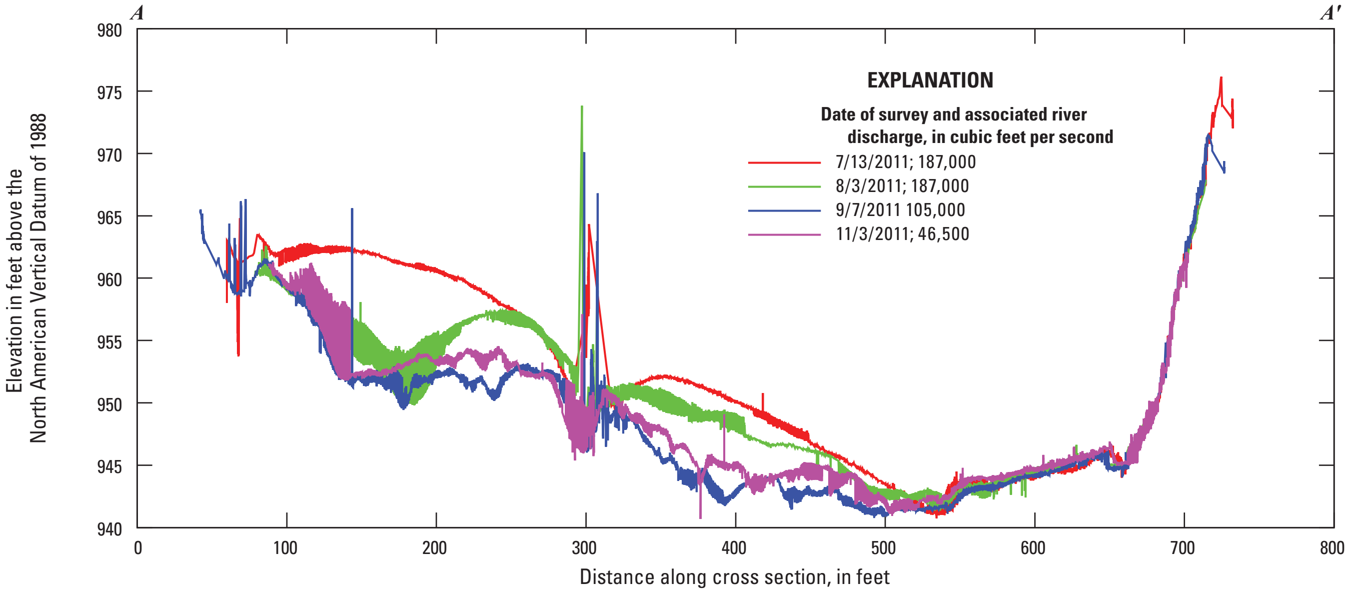


Figure 87. Hydrographic data collected by repeated surveys on the Missouri River along the upstream side of the Grenville Dodge Memorial Bridge at Omaha, Nebraska, July–November 2011.

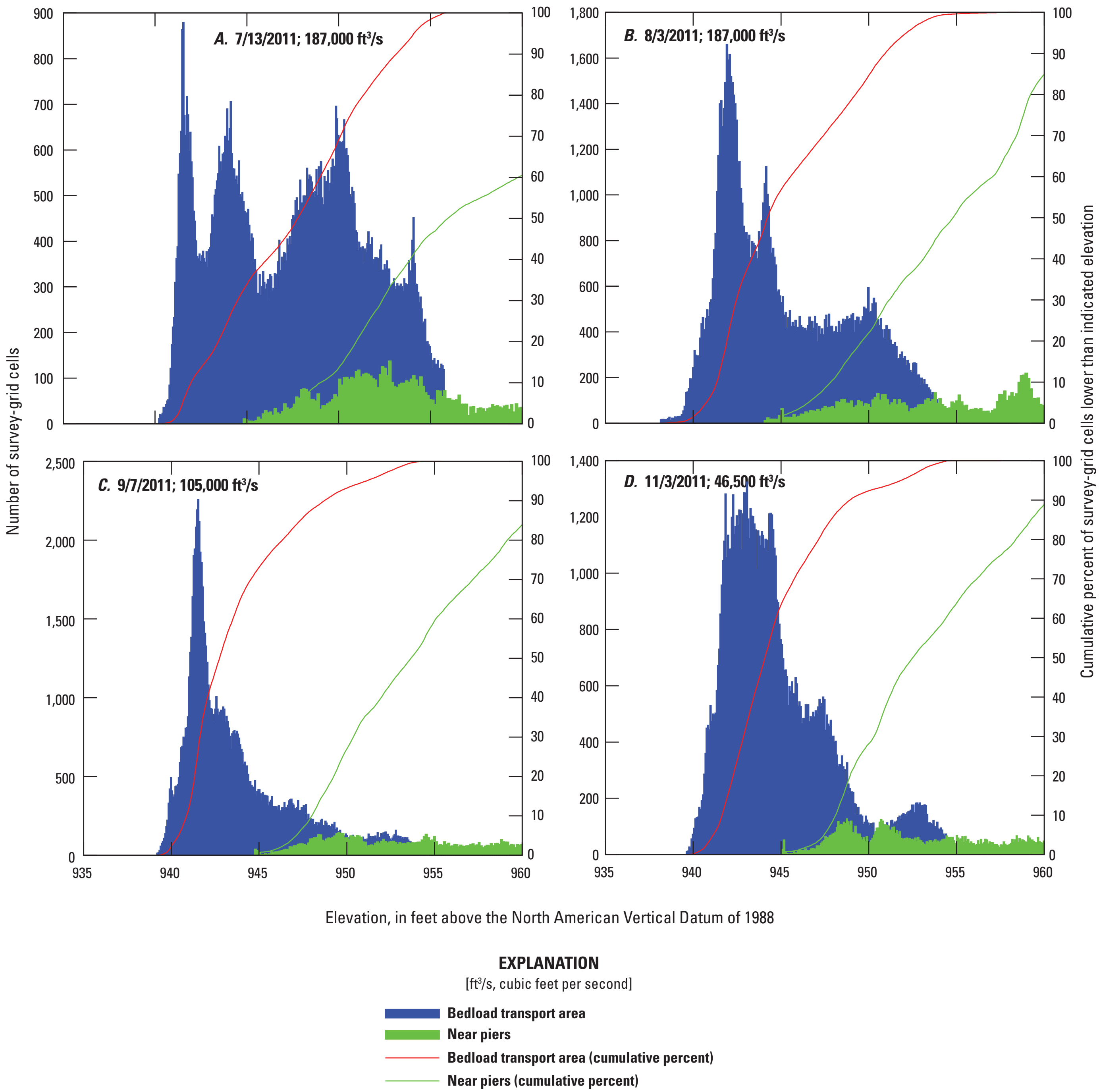


Figure 88. Frequency distribution of bed elevation, for hydrographic survey-grid cells (1.64-by-1.64 feet) sounded on the Missouri River in the vicinity of the Grenville Dodge Memorial Bridge at Omaha, Nebraska, *A*, July 13; *B*, August 3; *C*, September 7; and *D*, November 3, 2011.

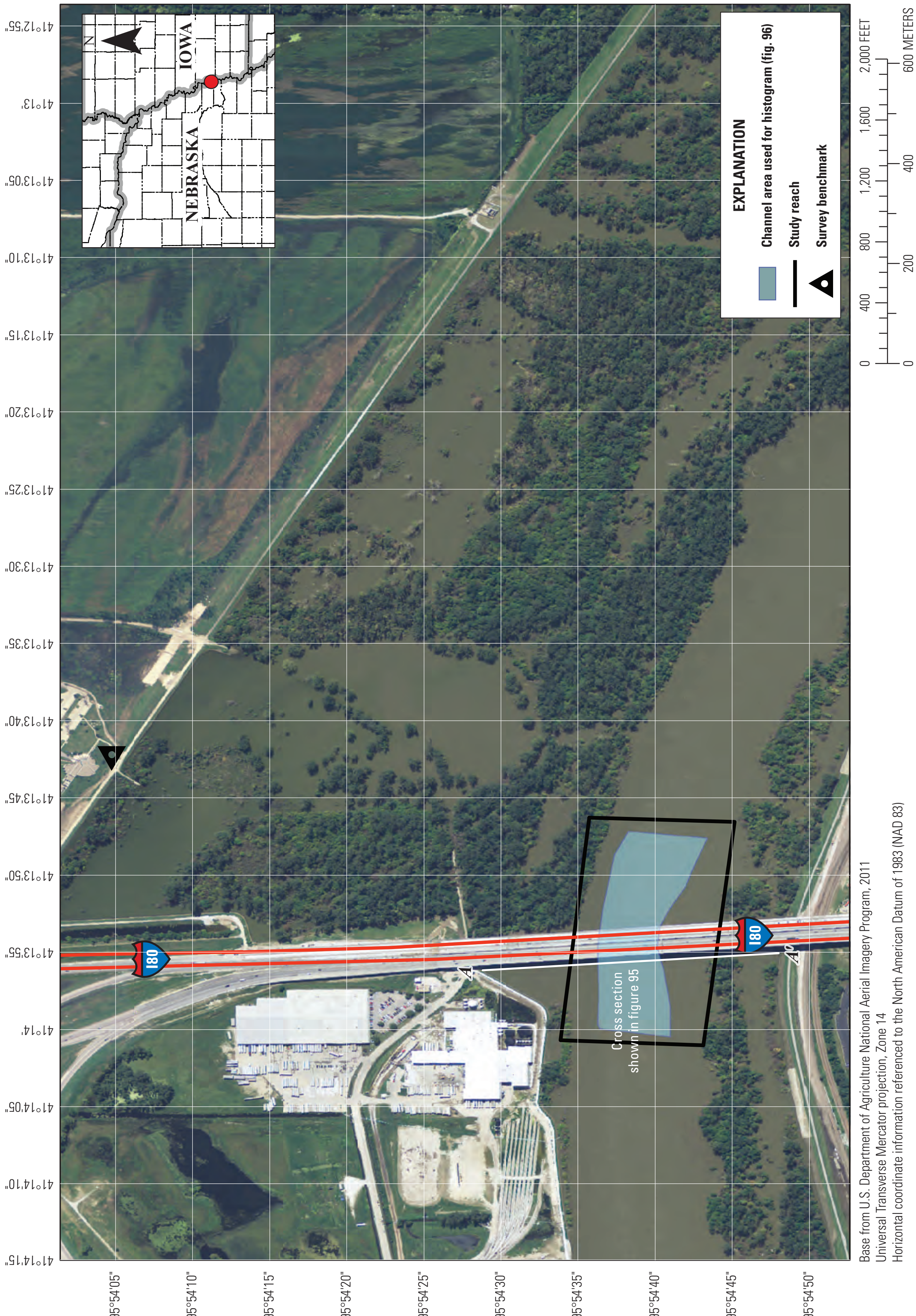
Interstate 80 Bridge at Omaha, Nebraska, at River Mile 614

The Interstate 80 Bridge crosses the Missouri River at Omaha, Nebr. (figs. 89–96). The study reach near the Interstate 80 Bridge was surveyed on four dates during the 2011 Missouri River flood, and discharges from USGS streamgaging station 06610000 (about 2 miles upstream) were 187,000 ft^3/s on July 13; 187,000 ft^3/s on August 3; 105,000 ft^3/s on September 7; and 46,500 ft^3/s on November 3 (tables 2–3).

The bed elevations in the bedload transport area surveyed on July 13 ranged from 928 ft to 953 ft (fig. 90). Two sets of bridge piers were located within the area surveyed at this site: the bridge piers near the left (east) bank and the bridge piers near the middle of the channel. During the July 13 survey, the minimum bed elevation near the mid-channel piers was about 936 ft. Between July 13 and August 3, the minimum bed elevation near the mid-channel piers did not change substantially (fig. 91). During the September 7 survey, the minimum bed elevation near the mid-channel piers was about 932 ft (fig. 92).

The difference in bed elevation from July 13 to November 3 was computed for each grid cell sounded during both surveys (fig. 94). The mean difference value of all re-sounded cells was -2.6 ft, indicating that net erosion likely occurred in the surveyed area from July 13 to November 3. A cross section of hydrographic survey data on the upstream side of the Interstate 80 Bridge show that, from July 13 to September 7, 6 ft or more of deepening occurred across much of the channel, but from September 7 to November 3 bed elevations appear to increase across the middle of the channel (fig. 95).

In the bedload transport area, the histogram of bed elevations narrowed, and the percentage of observed elevations greater than 935 ft and less than 945 ft increased from about 63 percent to about 94 percent from July 13 to November 3 (fig. 96). The mean elevation for grid cells in the bedload transport area was 942 ft on July 13; whereas, the mean elevation was 940 ft on November 3.



Base from U.S. Department of Agriculture National Aerial Imagery Program, 2011
Universal Transverse Mercator projection, Zone 14
Horizontal coordinate information referenced to the North American Datum of 1983 (NAD 83)

Figure 89. Location of hydrographic surveys of the Missouri River and surveyed benchmarks in the vicinity of Interstate 80 Bridge at Omaha, Nebraska, July–November 2011.

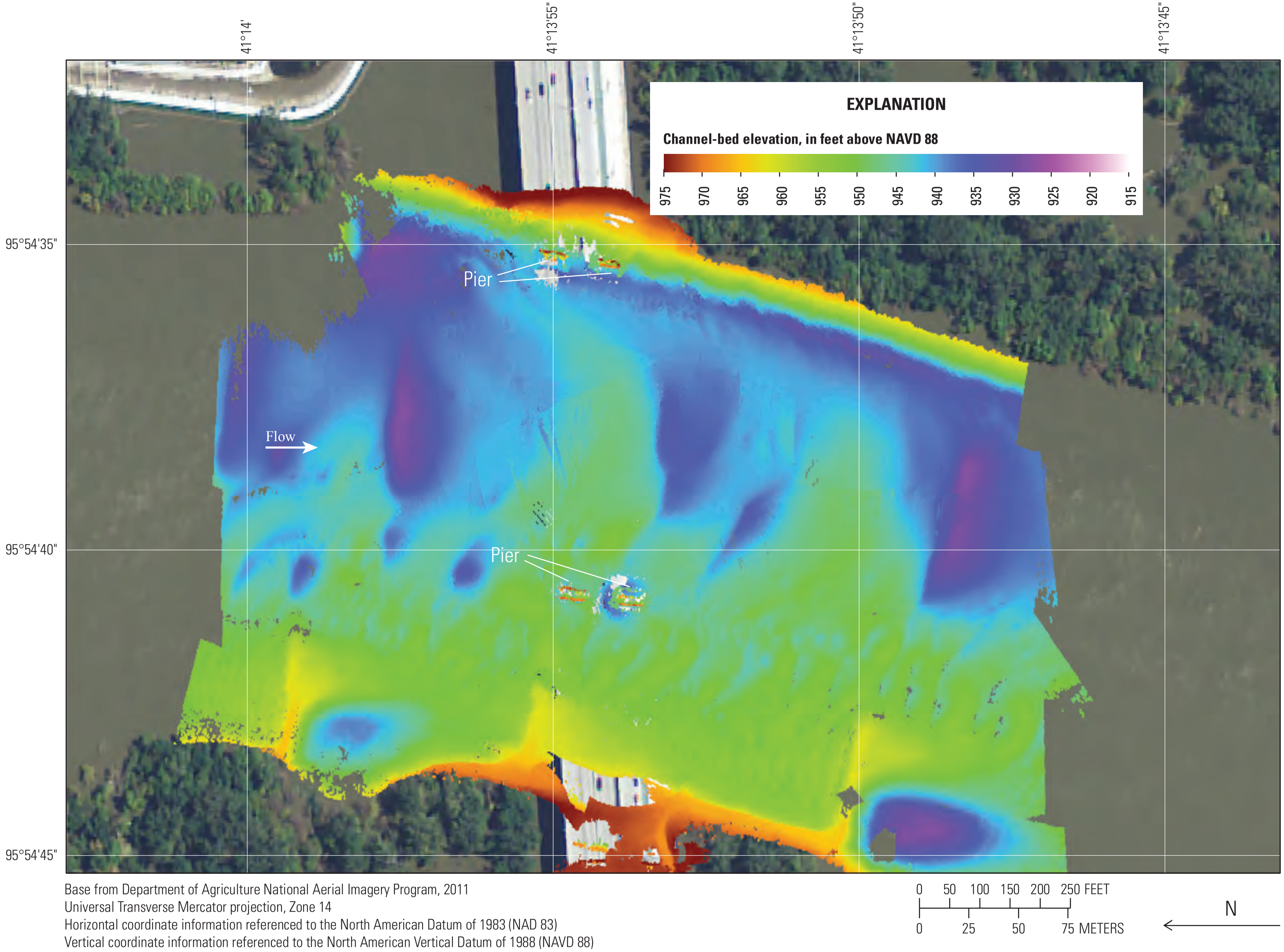
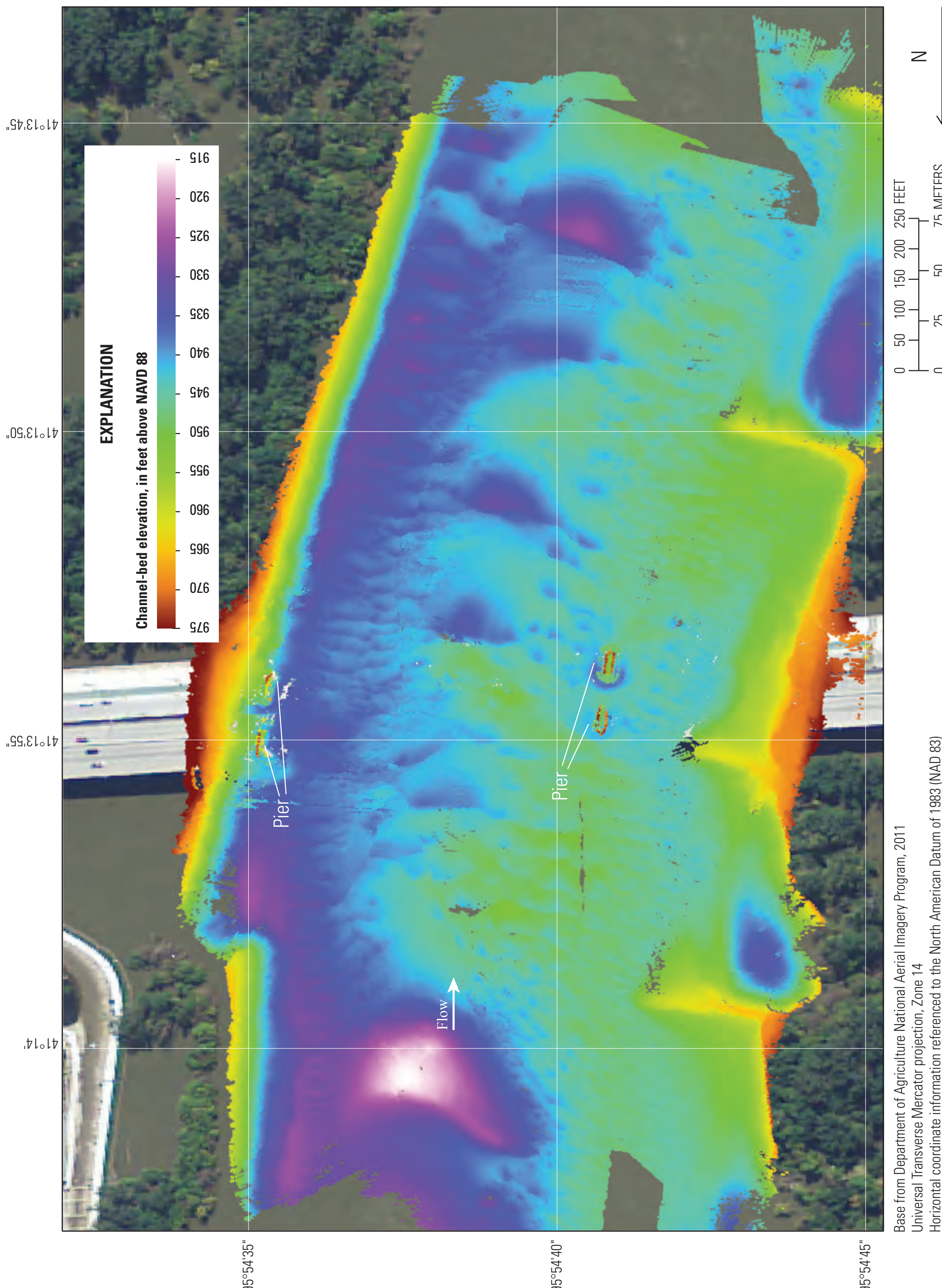


Figure 90. Channel-bed elevations of the Missouri River in the vicinity of the Interstate 80 Bridge at Omaha, Nebraska, during flow of 187,000 cubic feet per second, July 13, 2011.



Base from Department of Agriculture National Aerial Imagery Program, 2011
Universal Transverse Mercator projection, Zone 14
Horizontal coordinate information referenced to the North American Datum of 1983 (NAD 83)
Vertical coordinate information referenced to the North American Vertical Datum of 1988 (NAVD 88)

Figure 91. Channel-bed elevations of the Missouri River in the vicinity of the Interstate 80 Bridge at Omaha, Nebraska, during flow of 187,000 cubic feet per second, August 3, 2011.

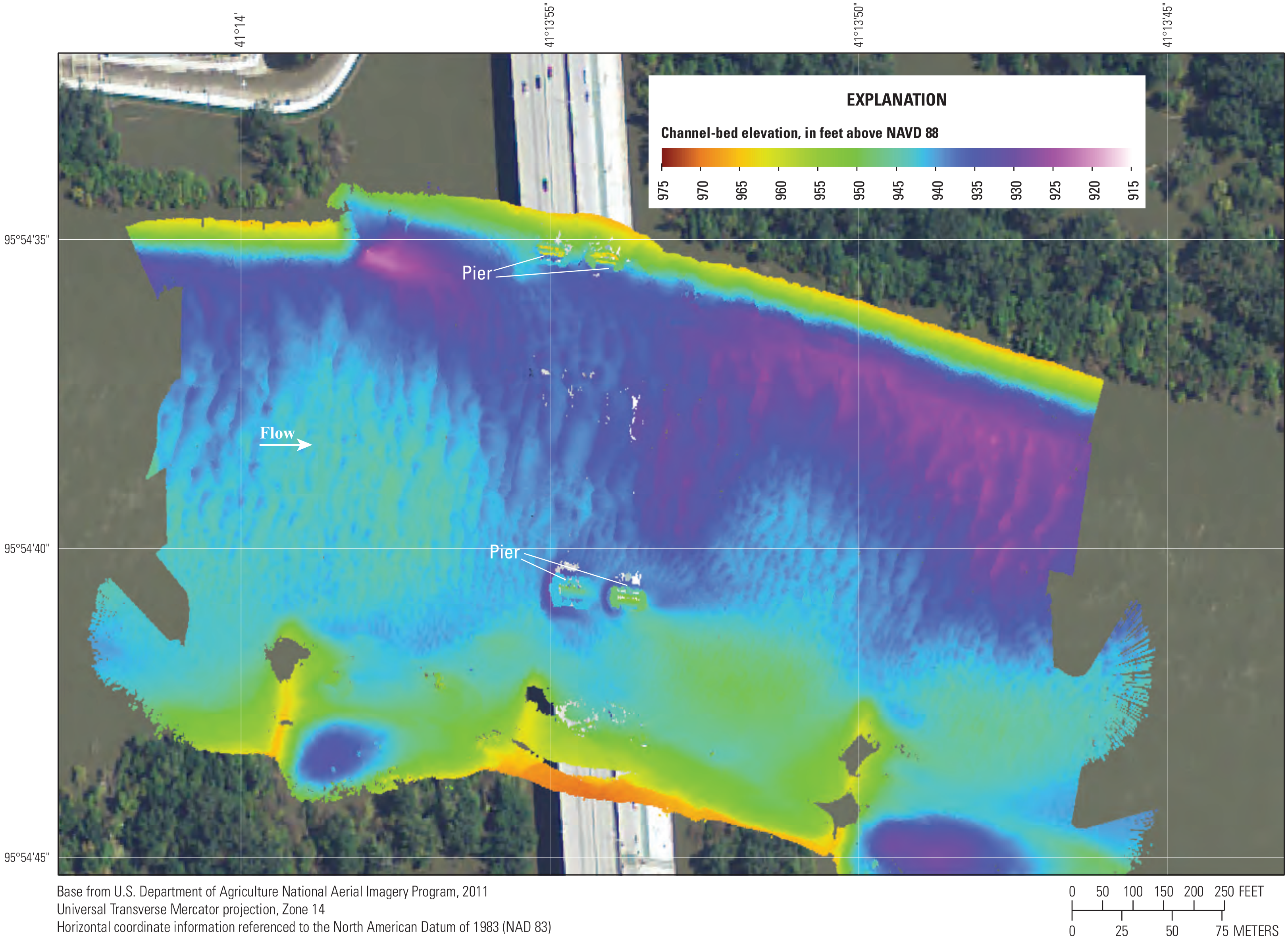


Figure 92. Channel-bed elevations of the Missouri River in the vicinity of the Interstate 80 Bridge at Omaha, Nebraska, during flow of 105,000 cubic feet per second, September 7, 2011.

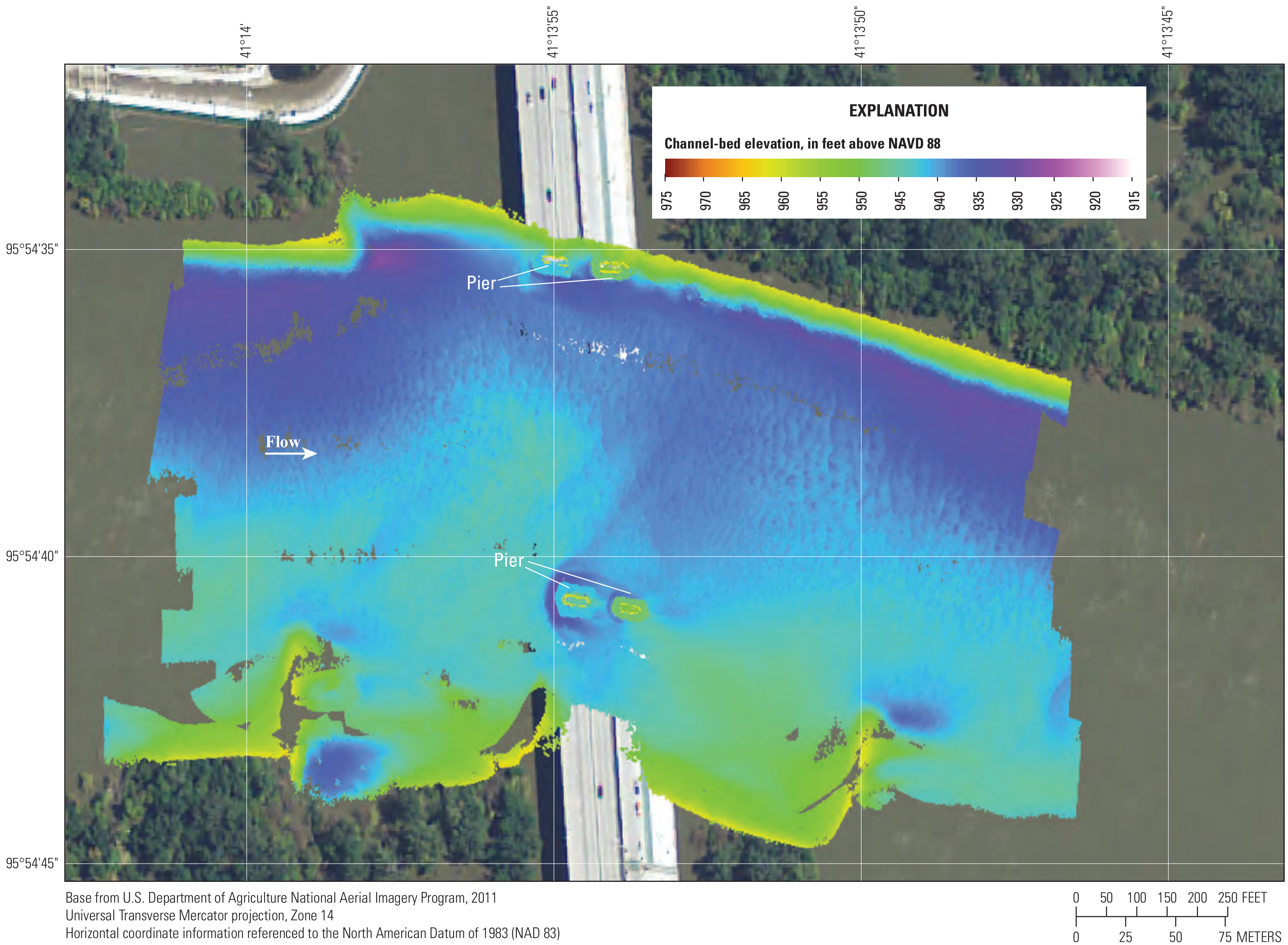
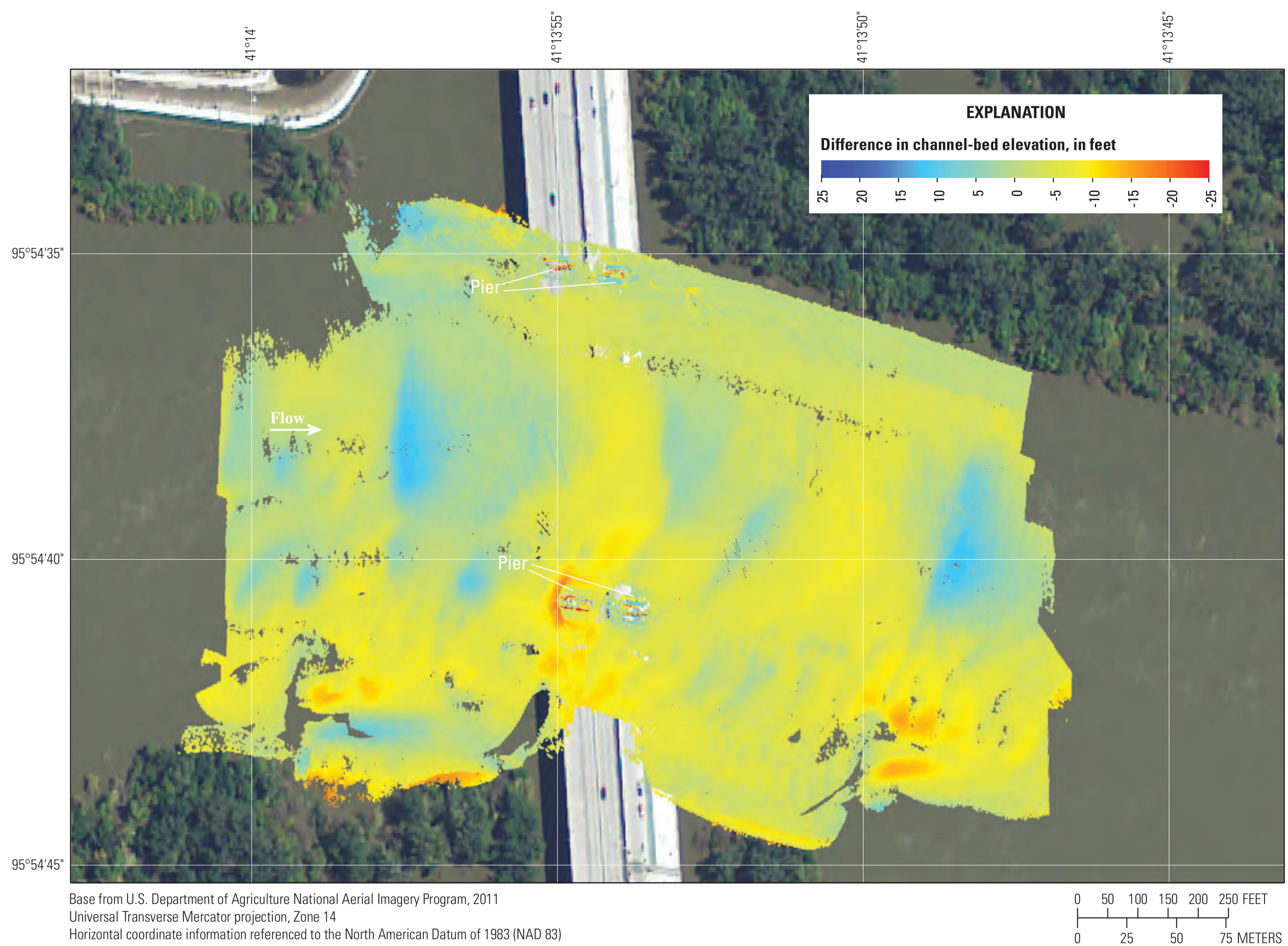


Figure 93. Channel-bed elevations of the Missouri River in the vicinity of the Interstate 80 Bridge at Omaha, Nebraska, during flow of 46,500 cubic feet per second, November 3, 2011.



Base from U.S. Department of Agriculture National Aerial Imagery Program, 2011
Universal Transverse Mercator projection, Zone 14
Horizontal coordinate information referenced to the North American Datum of 1983 (NAD 83)

Figure 94. Difference in channel-bed elevation of the Missouri River in the vicinity of the Interstate 80 Bridge at Omaha, Nebraska, between July 13 and November 3, 2011.

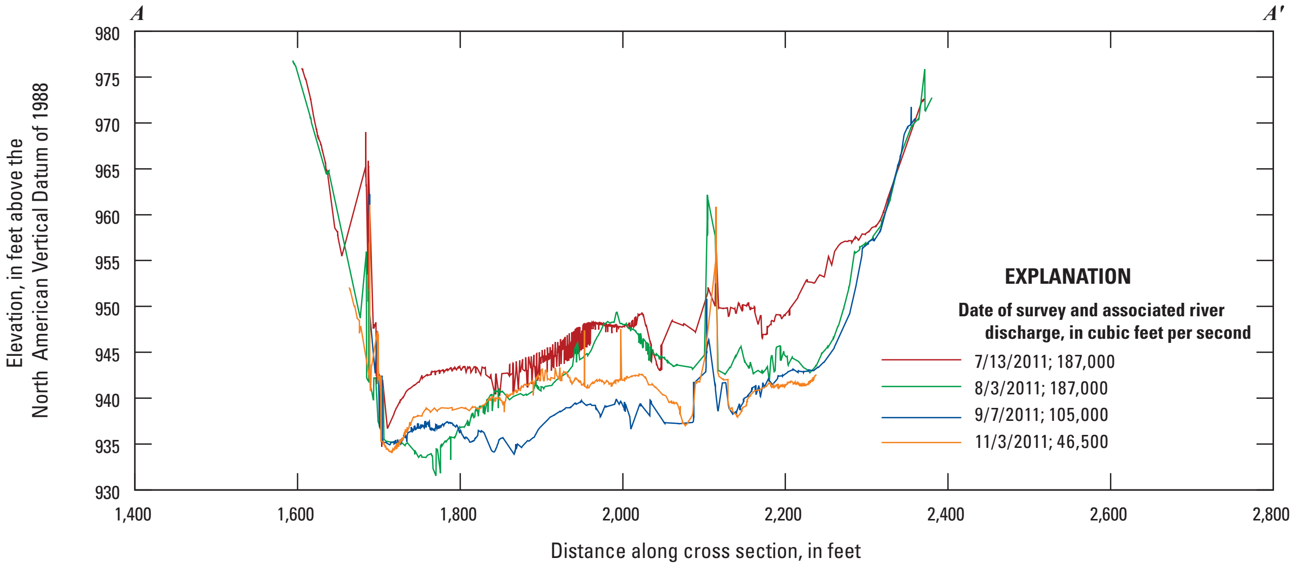


Figure 95. Hydrographic data collected by repeated surveys on the Missouri River along the upstream side of the Interstate 80 Bridge at Omaha, Nebraska, July–November 2011.

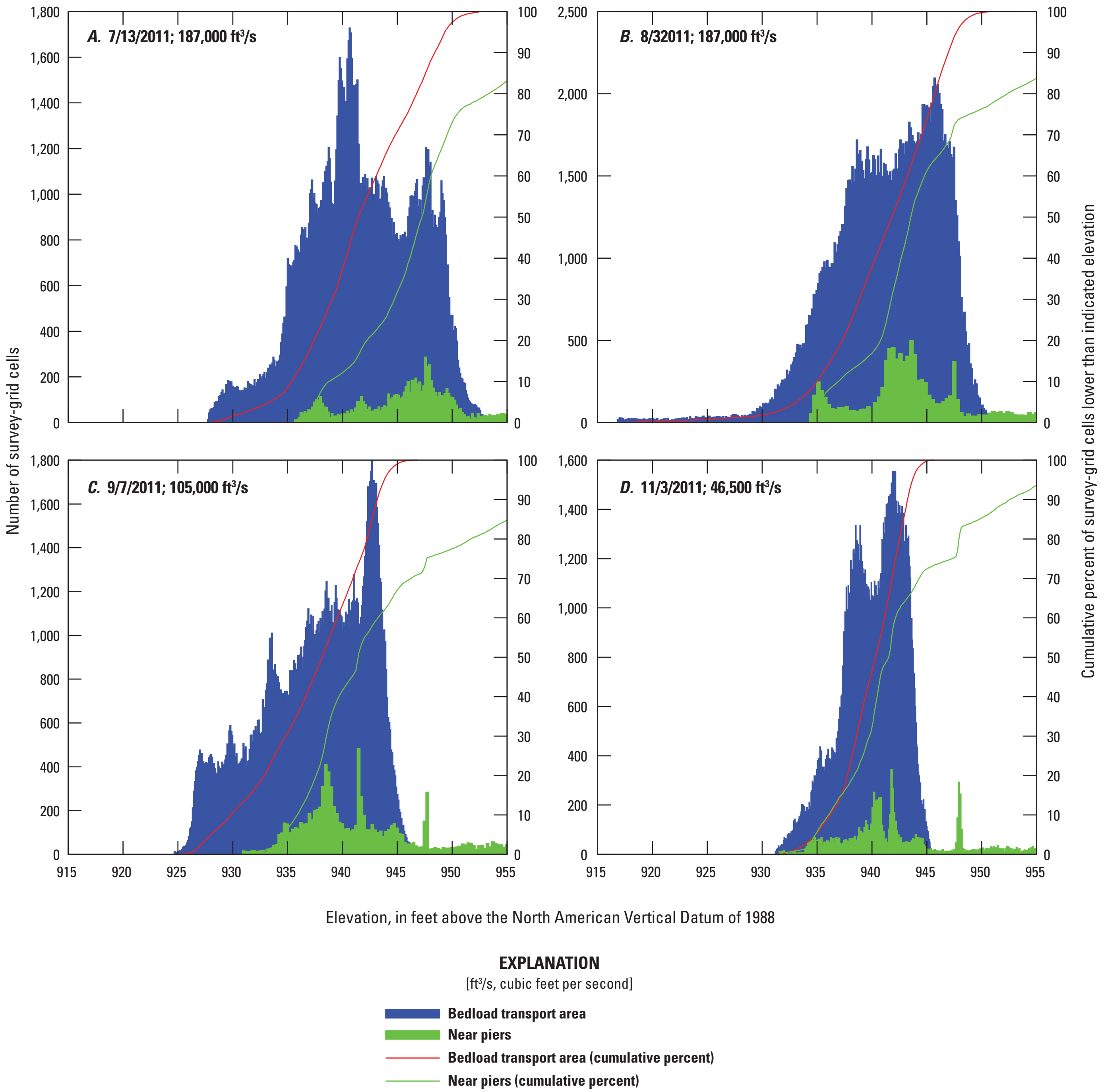


Figure 96. Frequency distribution of bed elevation, for hydrographic survey-grid cells (1.64-by-1.64 feet) sounded on the Missouri River in the vicinity of the Interstate 80 Bridge at Omaha, Nebraska, *A*, July 13; *B*, August 3; *C*, September 7; and *D*, November 3, 2011.

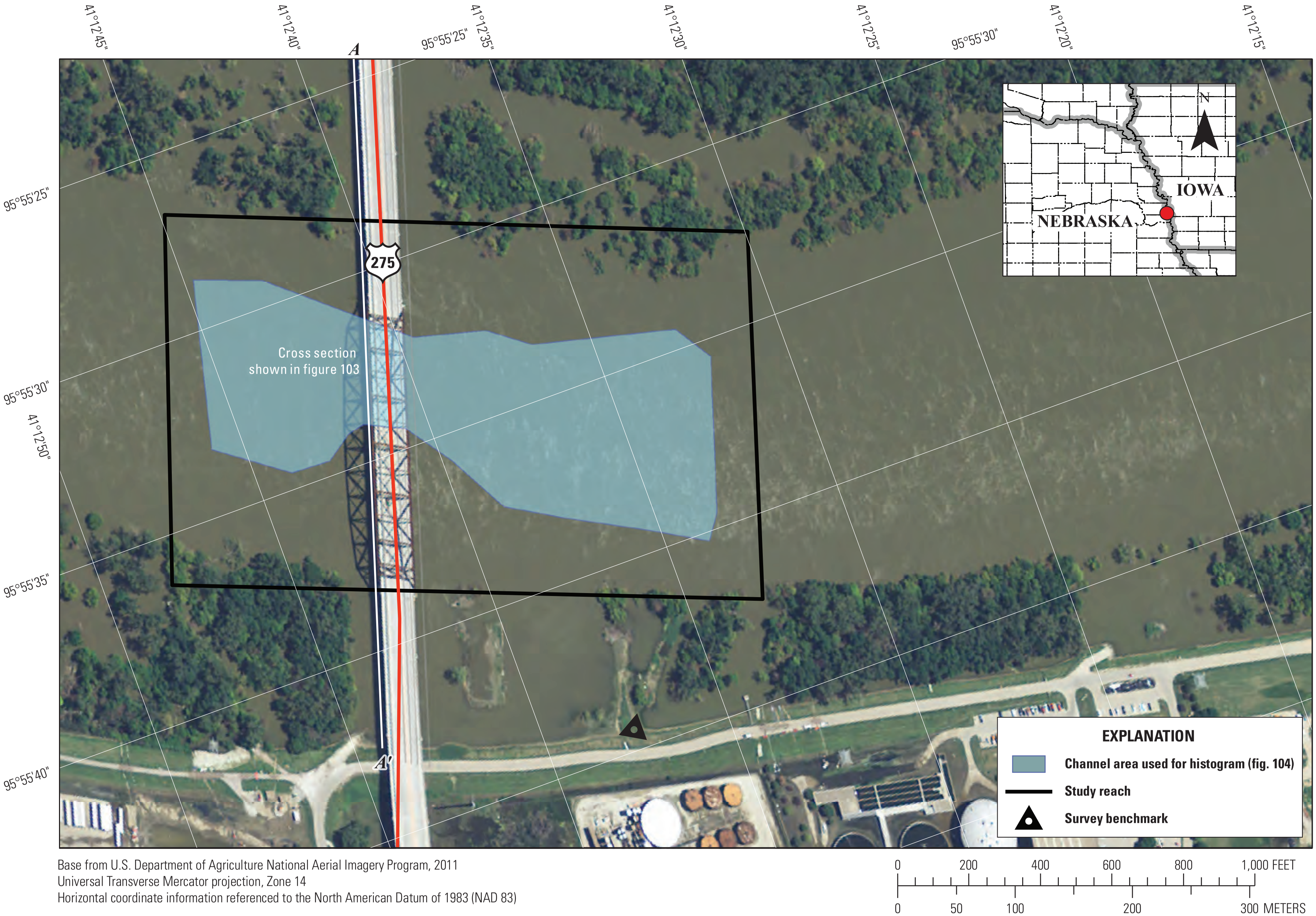
South Omaha Veterans Memorial Bridge (U.S. Highway 275, Nebraska Highway 92, Iowa Highway 92) at Omaha, Nebraska, at River Mile 612

The South Omaha Veterans Memorial Bridge crosses the Missouri River at Omaha, Nebr. (figs. 97–104). The South Omaha Veterans Memorial Bridge was surveyed four times during the 2011 Missouri River flooding event (table 2), and discharges reported for USGS streamgaging station 06610000 (about 4 miles upstream) were 185,000 ft^3/s on July 14; 187,000 ft^3/s on August 3; 105,000 ft^3/s on September 7; and 46,500 ft^3/s on November 3 (table 3).

The bed elevations surveyed in the bedload transport area on July 14 ranged from 927 ft to 959 ft (fig. 98). For all four surveys, bed elevations did not indicate substantial local scouring near the two bridge piers in the survey area; however, a large hole under the bridge was present downstream from a wing dike on the east bank. The minimum bed elevation in the hole beneath the bridge was about 939 ft for all four of the surveys. Bed elevation patterns characteristic of scouring were observed near the submerged remnants of the former South Omaha Bridge. The minimum bed elevation near the buried upstream remnant of the former bridge piers was about 950 ft on July 14. The minimum bed elevation near the downstream pier remnant was about 929 ft on July 14, which was about 5 ft lower than the thalweg on the west side of the channel and about 18 ft lower than the minimum bed elevations in the area unlikely to be affected by scour processes 100 ft or more upstream from the pier remnants. Between July 14 and September 7, the minimum bed elevation near the upstream remnant of the former bridge piers changed from 950 ft to 930 ft, confirming that local scour processes were taking place near the former piers. Between September 7 and November 3, about 8 ft of deposition occurred on the upstream side of the upstream remnant of the former bridge piers.

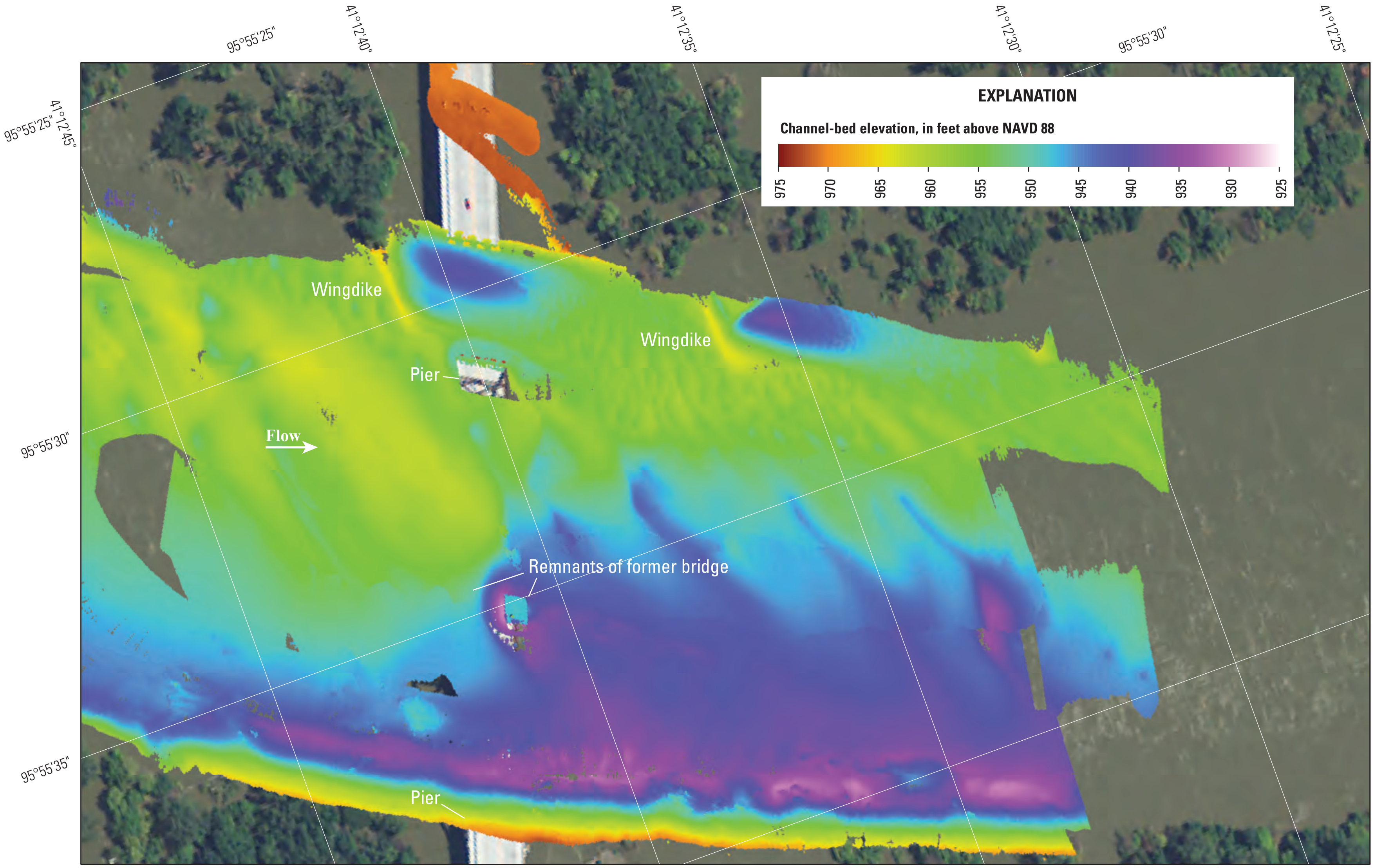
The difference in bed elevation from July 17 to November 3 was computed for each grid cell sounded during both surveys (fig. 102). Areas upstream from the bridge underwent net erosion of more than 10 ft during this time period; whereas deposition occurred in an area downstream from the bridge in the center of the channel. The mean difference for all re-sounded grid cells was -3.1 ft, indicating that net erosion likely occurred in the surveyed area from July 17 to November 3. A cross section of hydrographic survey data on the upstream side of the South Omaha Veterans Memorial Bridge is shown in figure 103.

In the bedload transport area, the frequency distribution of elevations shifted downward from July 14 to November 3 (fig. 104). The mean elevation for cells in the bedload transport area was 950 ft on July 14, whereas the mean elevation was 946 ft on November 3. Bed elevations between 940 ft and 950 ft constituted 34 percent of elevations observed on July 14. By November 3, the histogram had narrowed and 82 percent of elevations observed in the bedload transport area were between 940 ft and 950 ft.



Base from U.S. Department of Agriculture National Aerial Imagery Program, 2011
Universal Transverse Mercator projection, Zone 14
Horizontal coordinate information referenced to the North American Datum of 1983 (NAD 83)

Figure 97. Location of hydrographic surveys of the Missouri River in the vicinity of the South Omaha Veterans Memorial Bridge at Omaha, Nebraska, July–November 2011.



Base from U.S. Department of Agriculture National Aerial Imagery Program, 2011
Universal Transverse Mercator projection, Zone 14
Horizontal coordinate information referenced to the North American Datum of 1983 (NAD 83)

0 50 100 150 200 250 FEET
0 25 50 75 METERS

Figure 98. Channel-bed elevations of the Missouri River in the vicinity of the South Omaha Veterans Memorial Bridge at Omaha, Nebraska, during flow of 185,000 cubic feet per second, July 14, 2011.

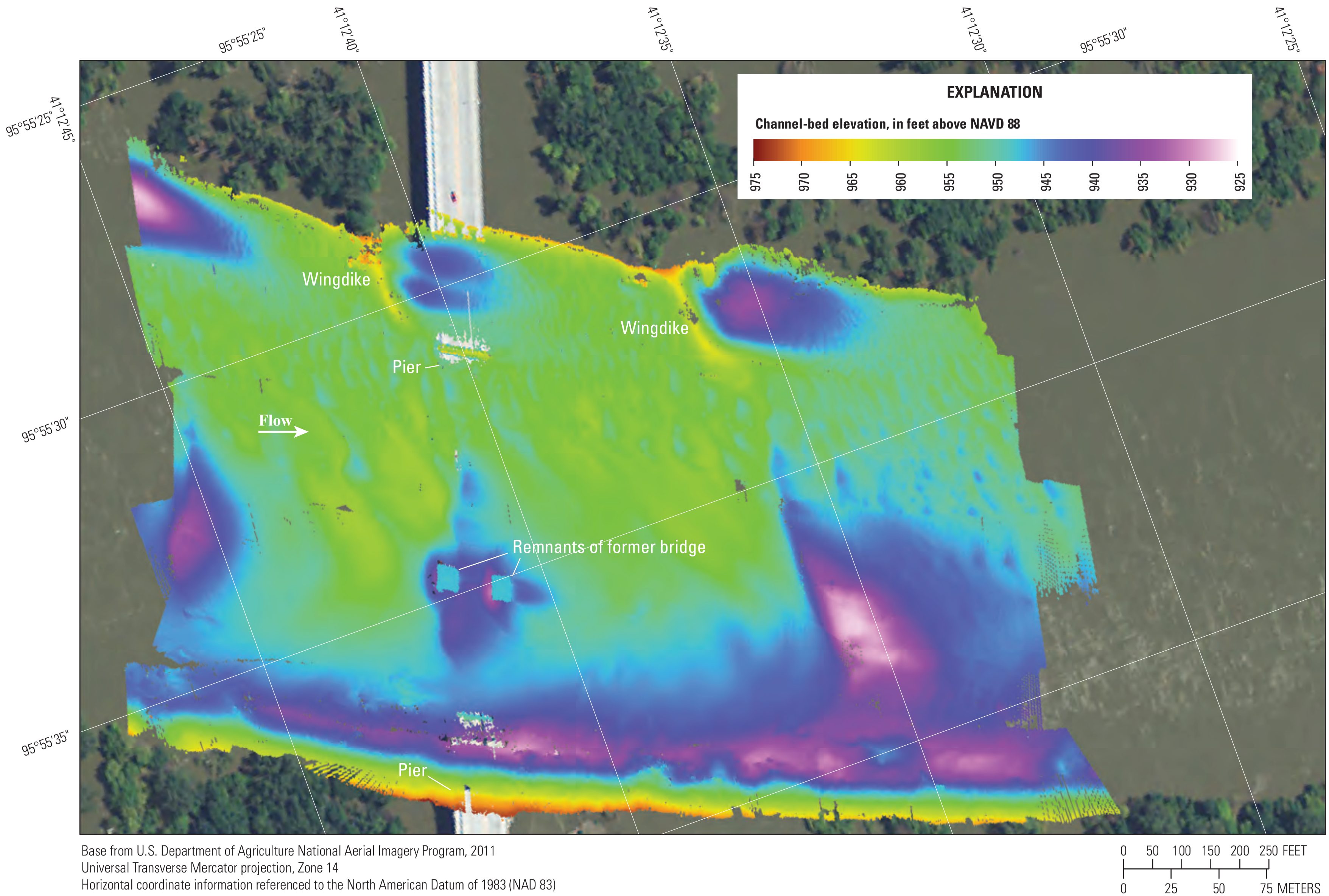


Figure 99. Channel-bed elevations of the Missouri River in the vicinity of the South Omaha Veterans Memorial Bridge at Omaha, Nebraska, during flow of 187,000 cubic feet per second, August 3, 2011.

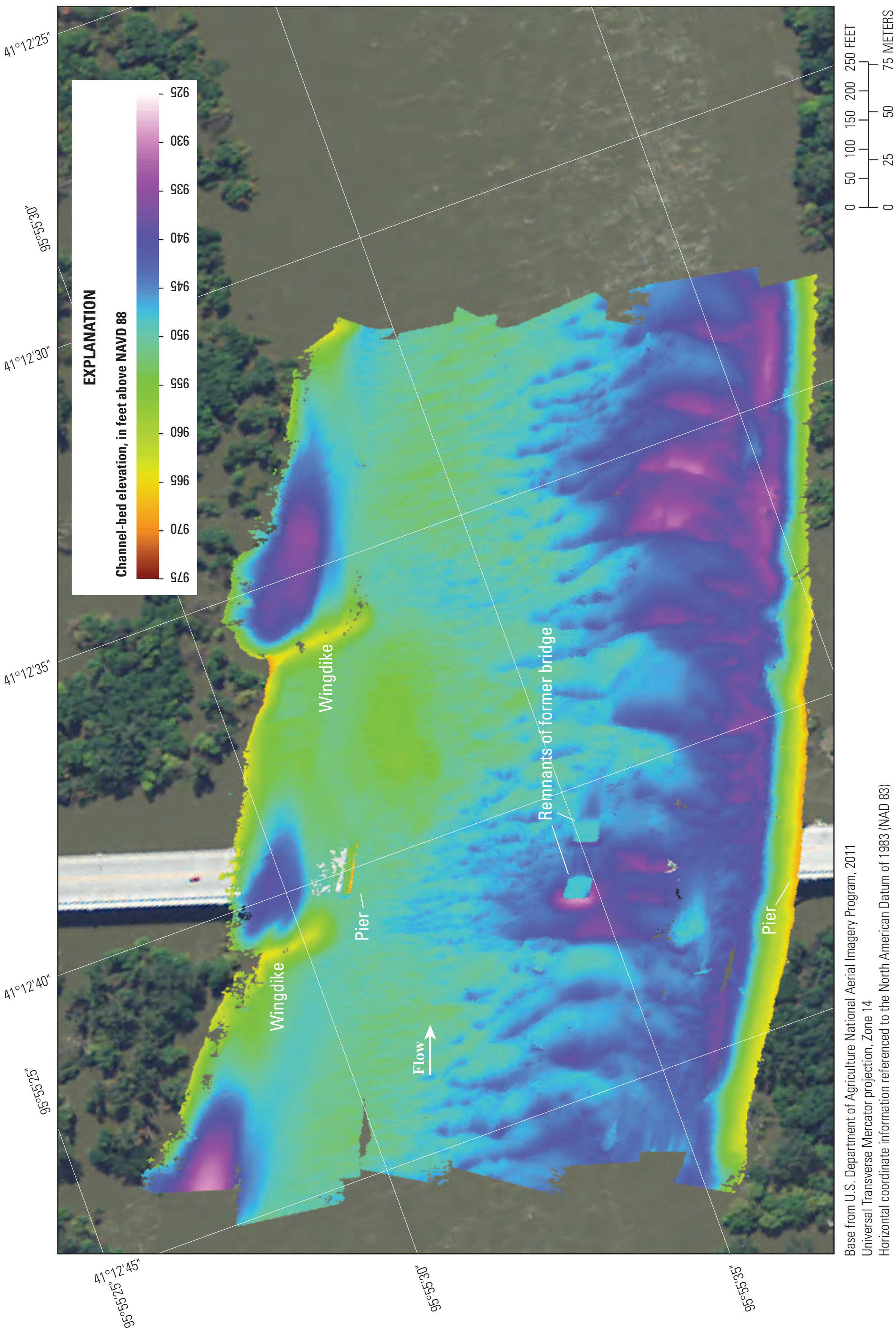


Figure 100. Channel-bed elevations of the Missouri River in the vicinity of the South Omaha Veterans Memorial Bridge at Omaha, Nebraska, during flow of 105,000 cubic feet per second, September 7, 2011.

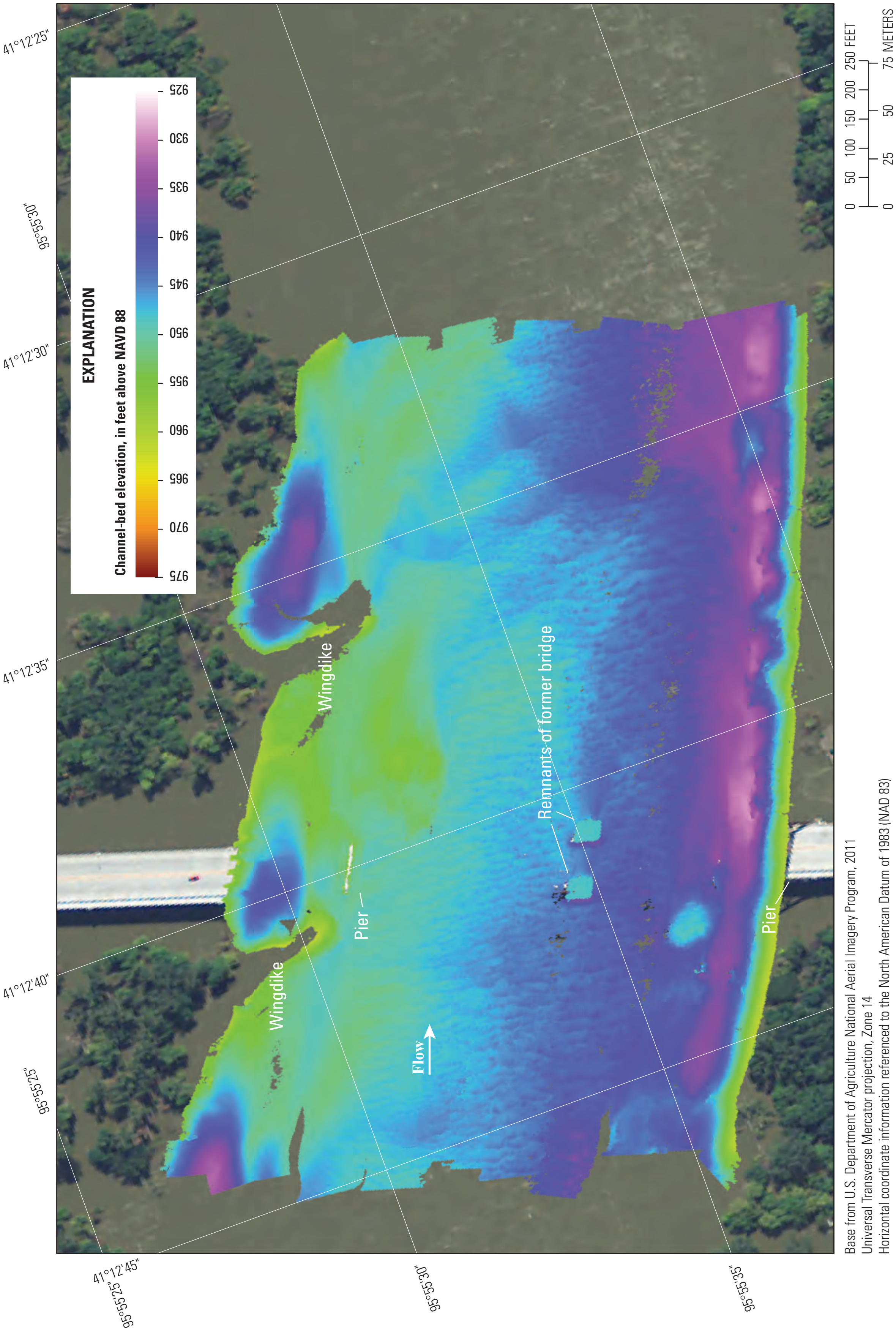


Figure 101. Channel-bed elevations of the Missouri River in the vicinity of the South Omaha Veterans Memorial Bridge at Omaha, Nebraska, during flow of 46,500 cubic feet per second, November 3, 2011.

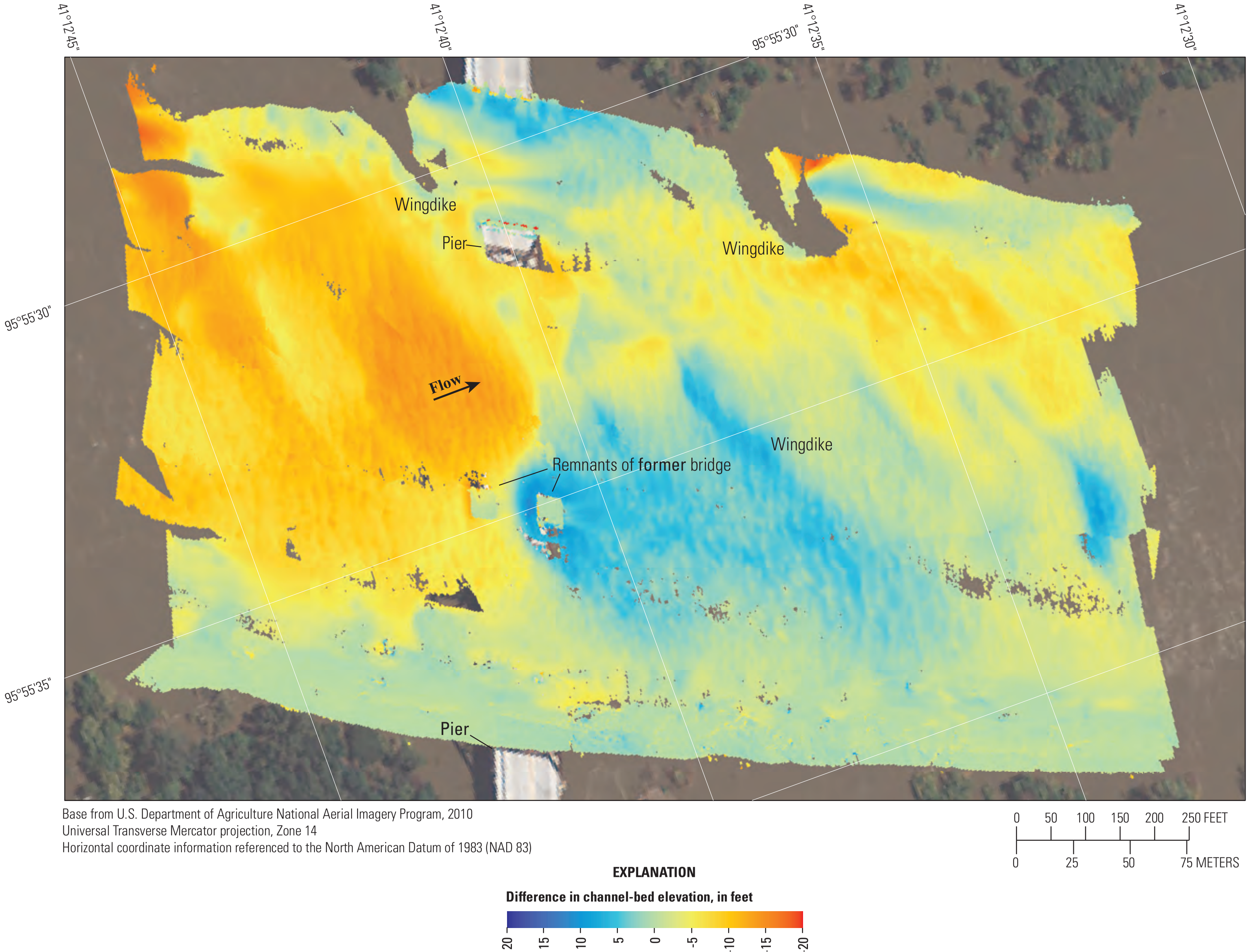


Figure 102. Difference in channel-bed elevation of the Missouri River in the vicinity of the South Omaha Veterans Memorial Bridge at Omaha, Nebraska, between July 14 and November 3, 2011.

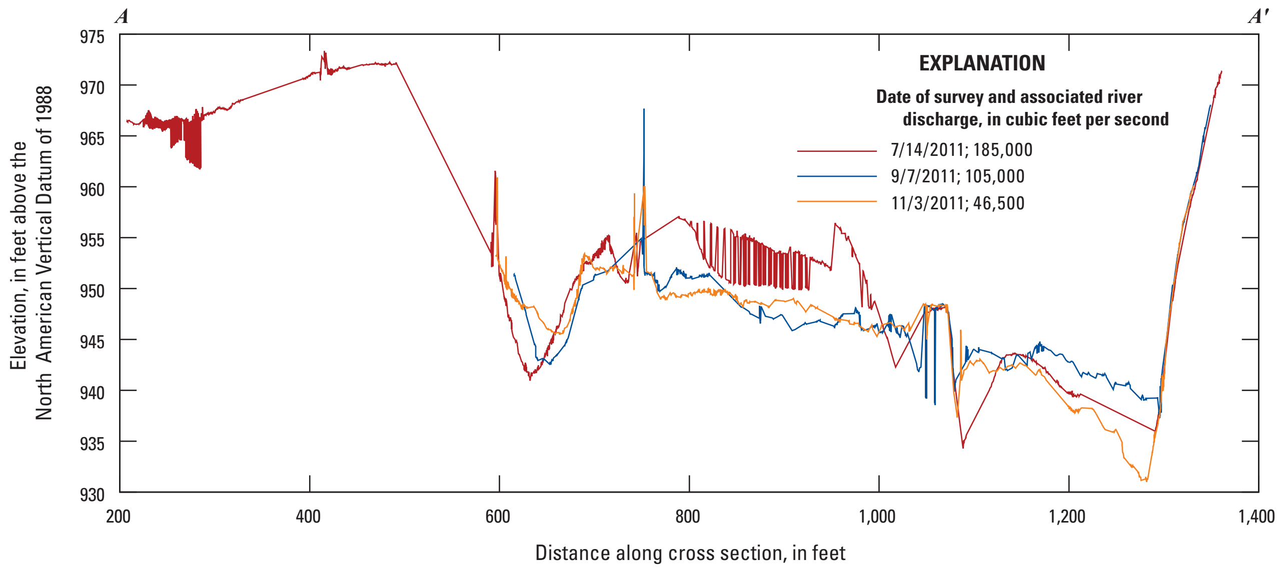


Figure 103. Hydrographic data collected by repeated surveys on the Missouri River along the upstream side of the South Omaha Veterans Memorial Bridge at Omaha, Nebraska, July–November 2011.

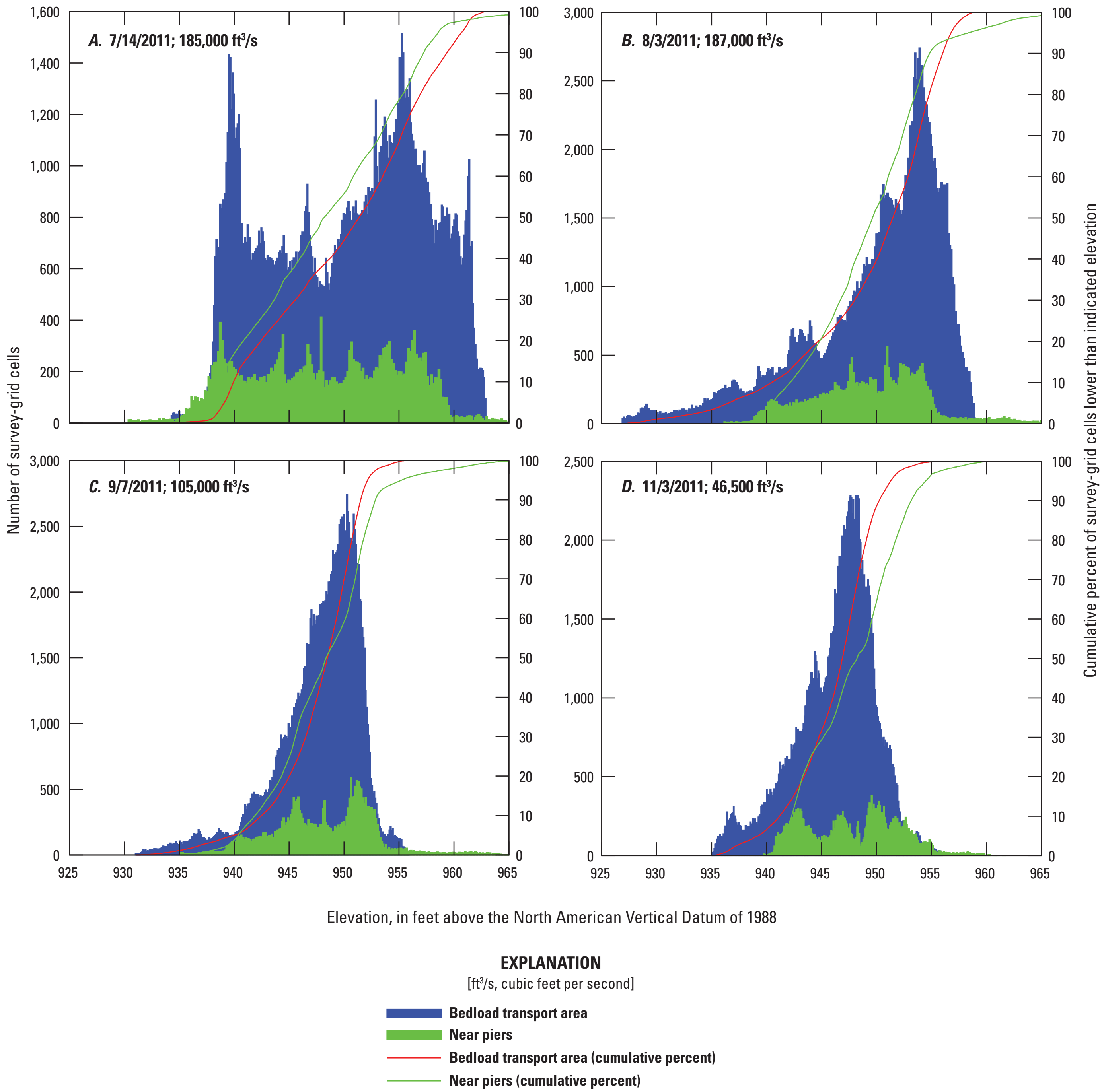


Figure 104. Frequency distribution of bed elevation, for hydrographic survey-grid cells (1.64-by-1.64 feet) sounded on the Missouri River in the vicinity of the South Omaha Veterans Memorial Bridge at Omaha, Nebraska, *A*, July 14; *B*, August 3; *C*, September 7; and *D*, November 3, 2011.

Bellevue Bridge (Nebraska Highway 370, Iowa Highway 370) at Bellevue, Nebraska, at River Mile 601

The Bellevue Bridge crosses the Missouri River at Bellevue, Nebr. (figs. 105–112). The Bellevue Bridge was surveyed four times during the 2011 Missouri River flooding (table 2). The discharges reported for USGS streamgaging station 06610000 (about 14 miles upstream) were 191,000 ft^3/s on July 26; 187,000 ft^3/s on July 30; 105,000 ft^3/s on September 7; and 46,600 ft^3/s on November 9 (table 3).

The bed elevations surveyed on July 26 ranged generally from 913 to 940 ft, and the minimum bed elevation near the mid-channel pier was about 908 ft (fig. 106). During the July 30 and September 7 surveys, minimum bed elevations near the mid-channel pier were about 910 ft (figs. 107 and 108). Between September 7 and November 9, deposition of 20 ft or more occurred in parts of the channel, and the minimum bed elevation observed near the mid-channel pier was 928 ft (fig. 109).

The difference in bed elevation from July 26 to November 9 was computed for each grid cell sounded during both surveys (fig. 110). The mean difference for all re-sounded cells was 16.3 ft, indicating that net deposition occurred in the surveyed area from July 26 to November 9. A cross section of hydrographic survey data on the upstream side of the Bellevue Bridge shows that more than 20ft of shoaling occurred across the width of the channel from July 26 to November 9 (fig. 111).

In the bedload transport area, the frequency distribution of elevations shifted slightly downward between July 26 and July 30, but moved upward between September 7 and November 9 (fig. 112). The mean elevations for cells in the bedload transport area on July 26, July 30, and September 7 were 926 ft, 925 ft, and 926 ft, respectively. On November 9, the mean elevation was 944 ft.

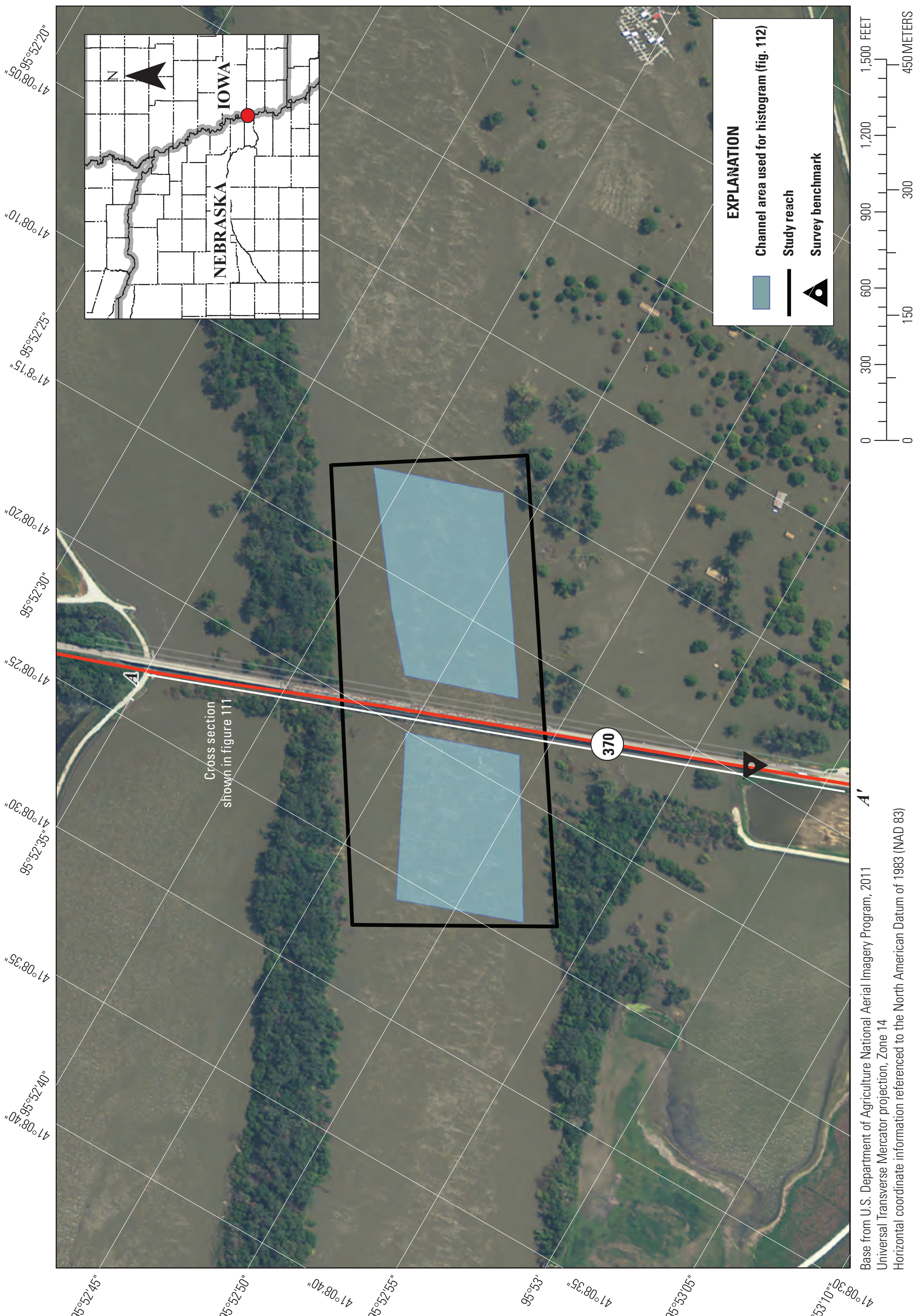
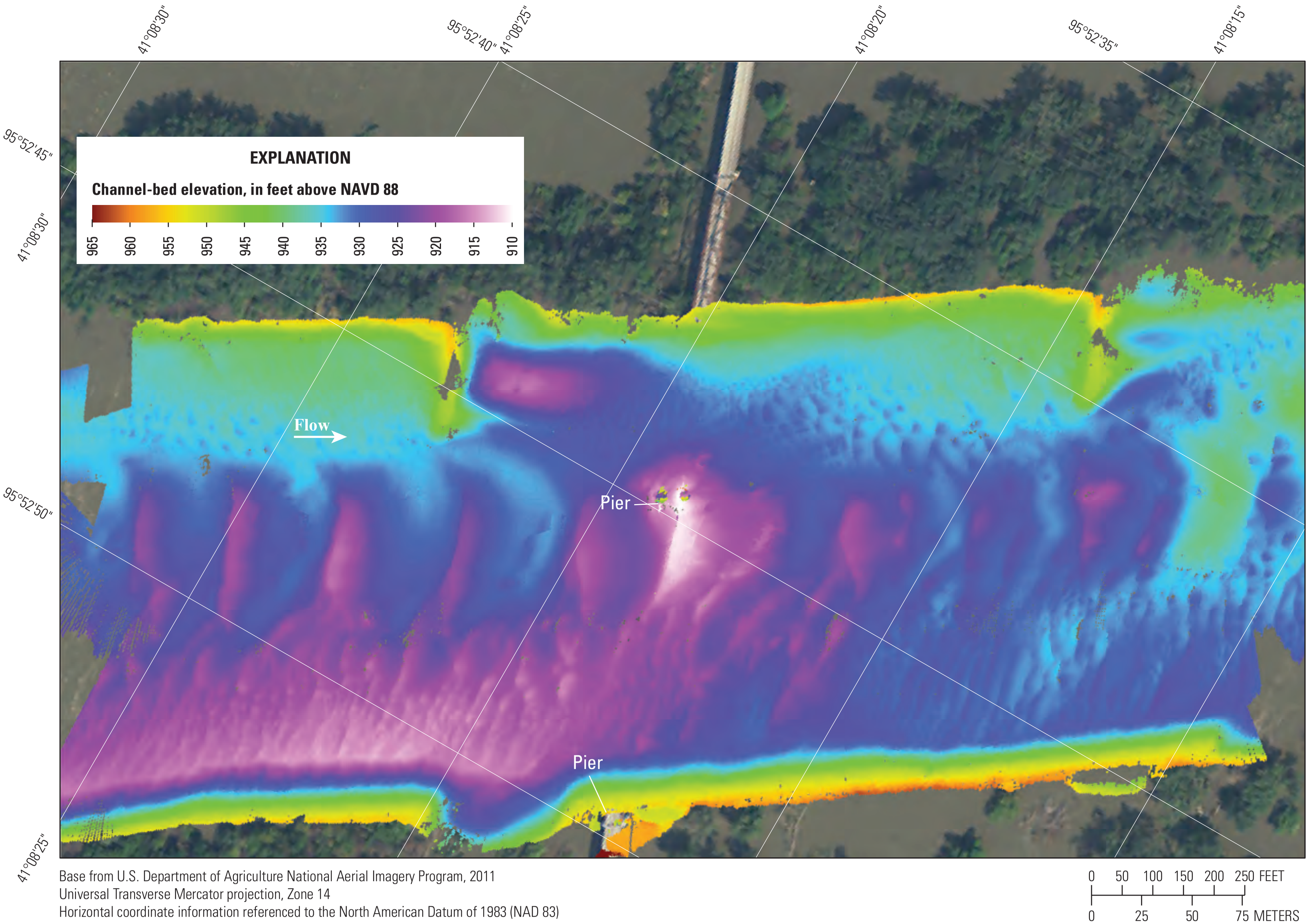
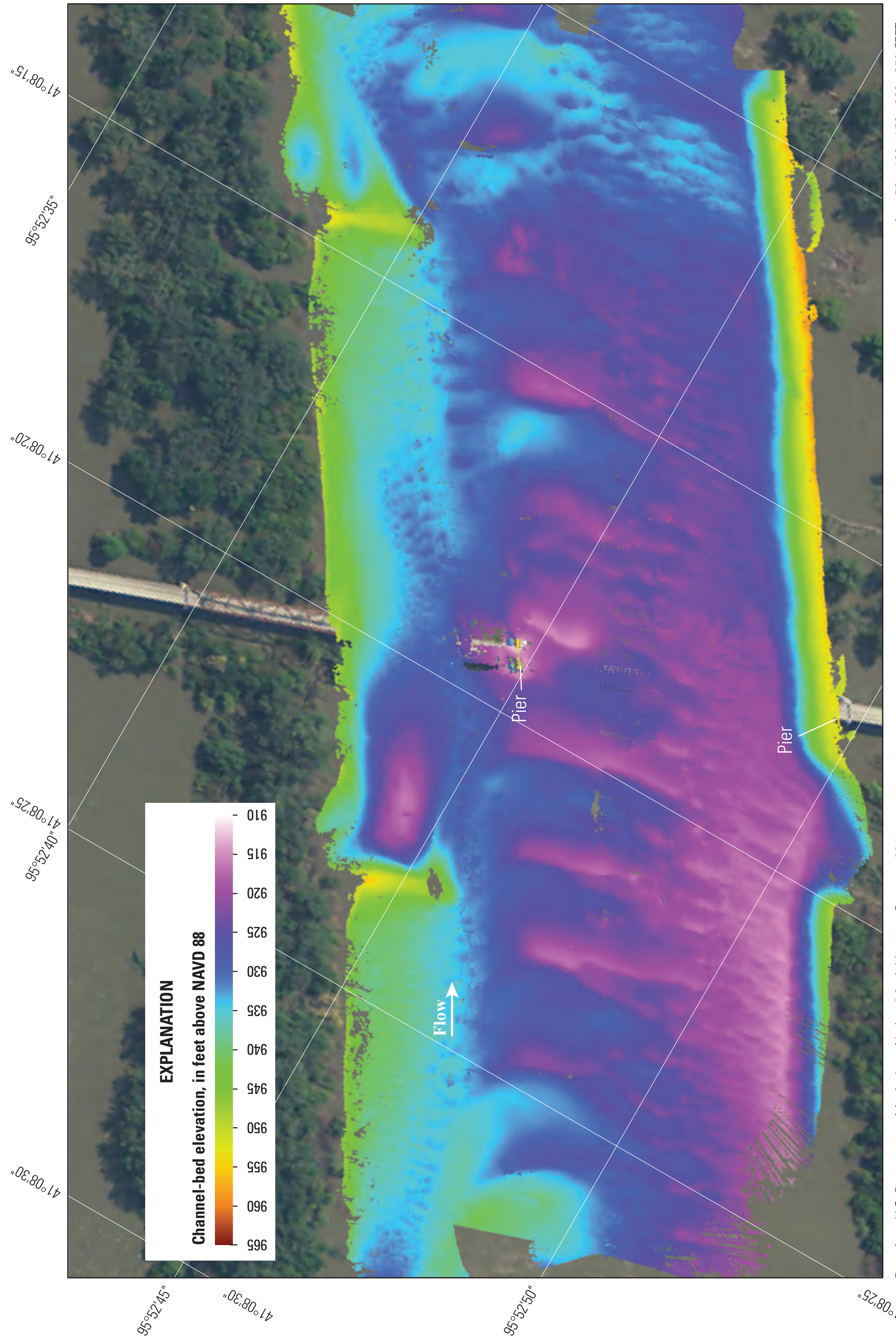


Figure 105. Location of hydrographic surveys of the Missouri River in the vicinity of the Bellevue Bridge at Bellevue, Nebraska, July–November 2011.



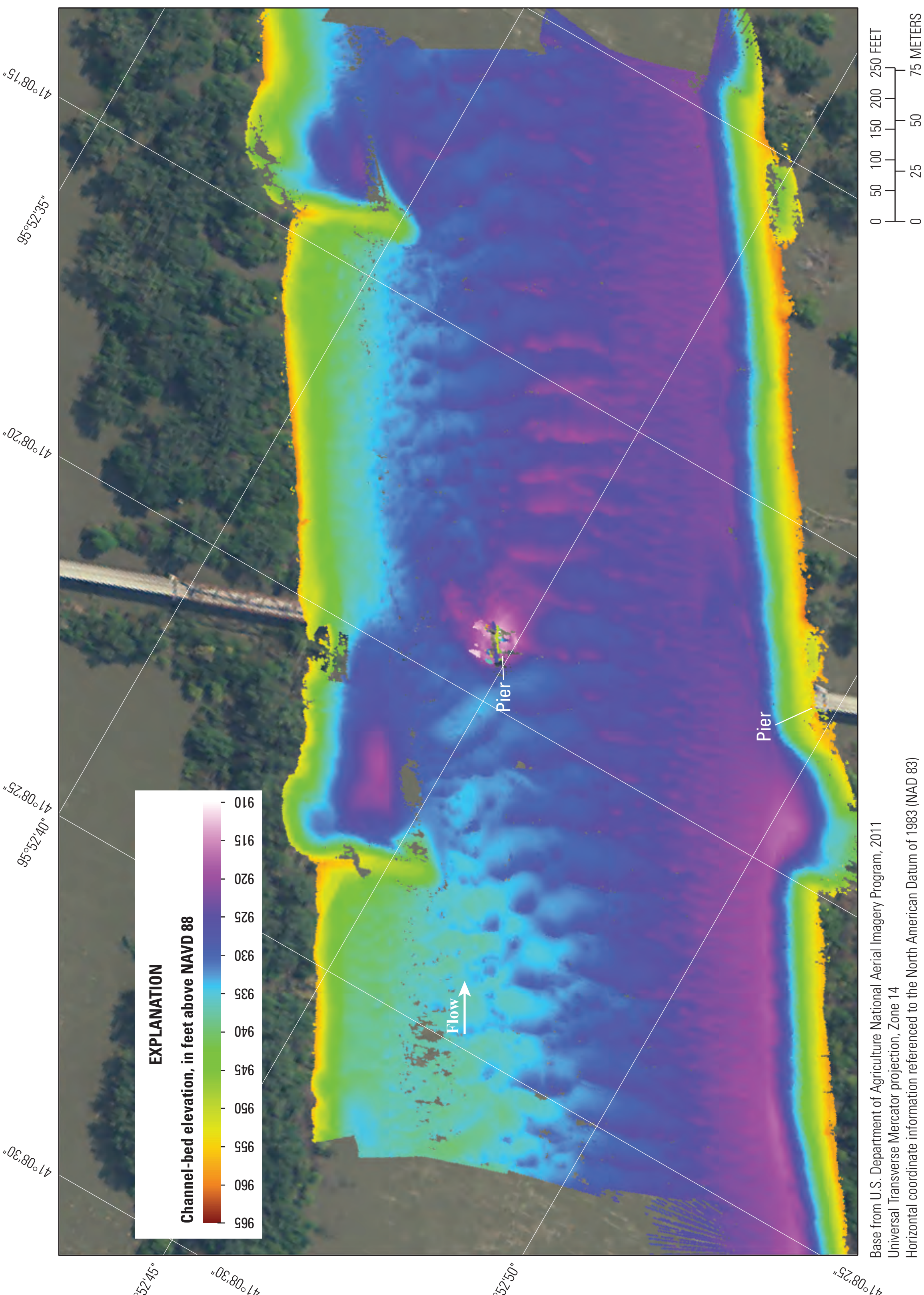
Base from U.S. Department of Agriculture National Aerial Imagery Program, 2011
Universal Transverse Mercator projection, Zone 14
Horizontal coordinate information referenced to the North American Datum of 1983 (NAD 83)

Figure 106. Channel-bed elevations of the Missouri River in the vicinity of the Bellevue Bridge at Bellevue, Nebraska, during flow of 191,000 cubic feet per second, July 26, 2011.



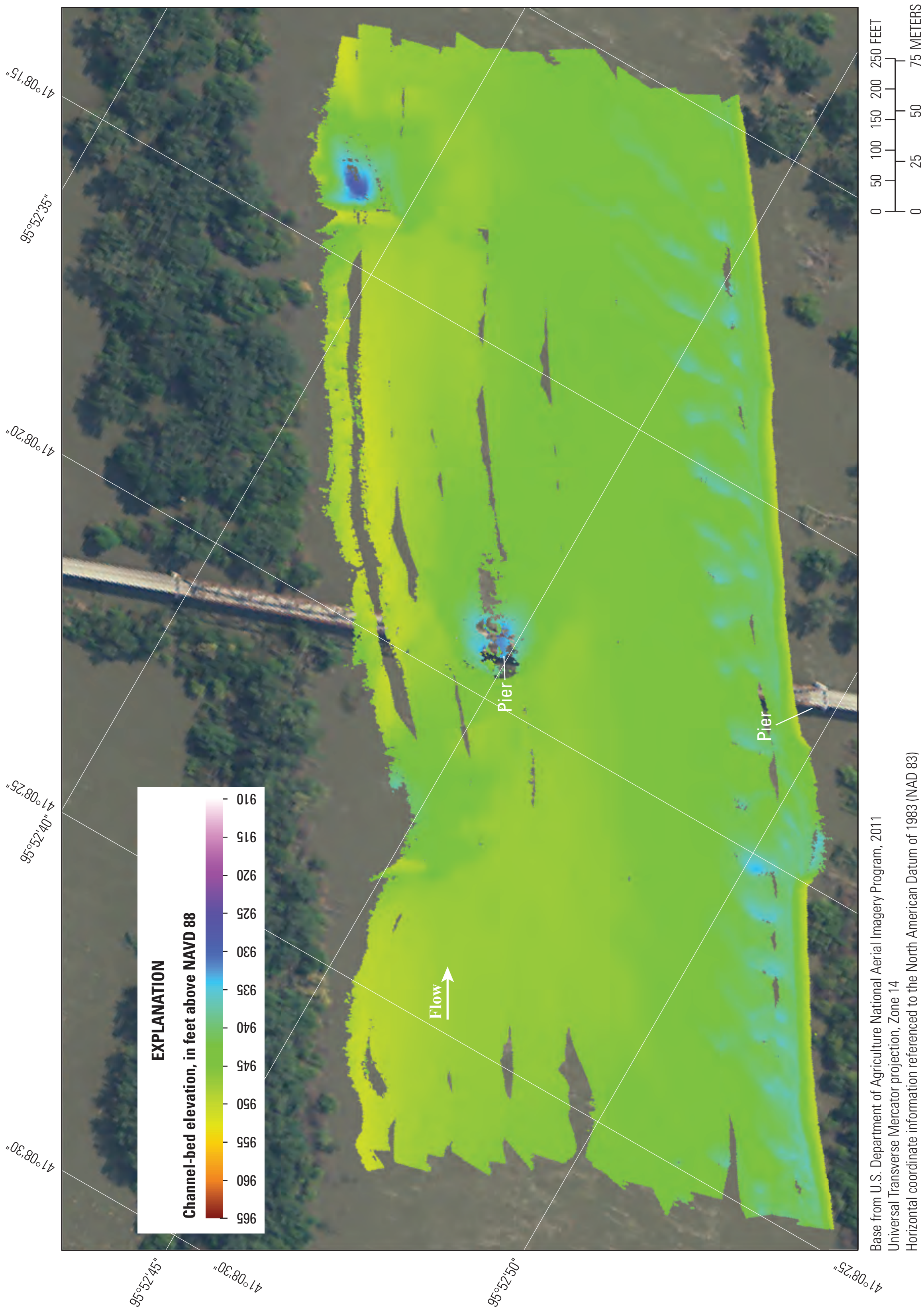
Base from U.S. Department of Agriculture National Aerial Imagery Program, 2011
Universal Transverse Mercator projection, Zone 14
Horizontal coordinate information referenced to the North American Datum of 1983 (NAD 83)

Figure 107. Channel-bed elevations of the Missouri River in the vicinity of the Bellevue Bridge at Bellevue, Nebraska, during flow of 187,000 cubic feet per second, July 30, 2011.



Base from U.S. Department of Agriculture National Aerial Imagery Program, 2011
Universal Transverse Mercator projection, Zone 14
Horizontal coordinate information referenced to the North American Datum of 1983 (NAD 83)

Figure 108. Channel-bed elevations of the Missouri River in the vicinity of the Bellevue Bridge at Bellevue, Nebraska, during flow of 105,000 cubic feet per second, September 7, 2011.



Base from U.S. Department of Agriculture National Aerial Imagery Program, 2011
Universal Transverse Mercator projection, Zone 14
Horizontal coordinate information referenced to the North American Datum of 1983 (NAD 83)

Figure 109. Channel-bed elevations of the Missouri River in the vicinity of the Bellevue Bridge at Bellevue, Nebraska, during flow of 46,600 cubic feet per second, November 9, 2011.

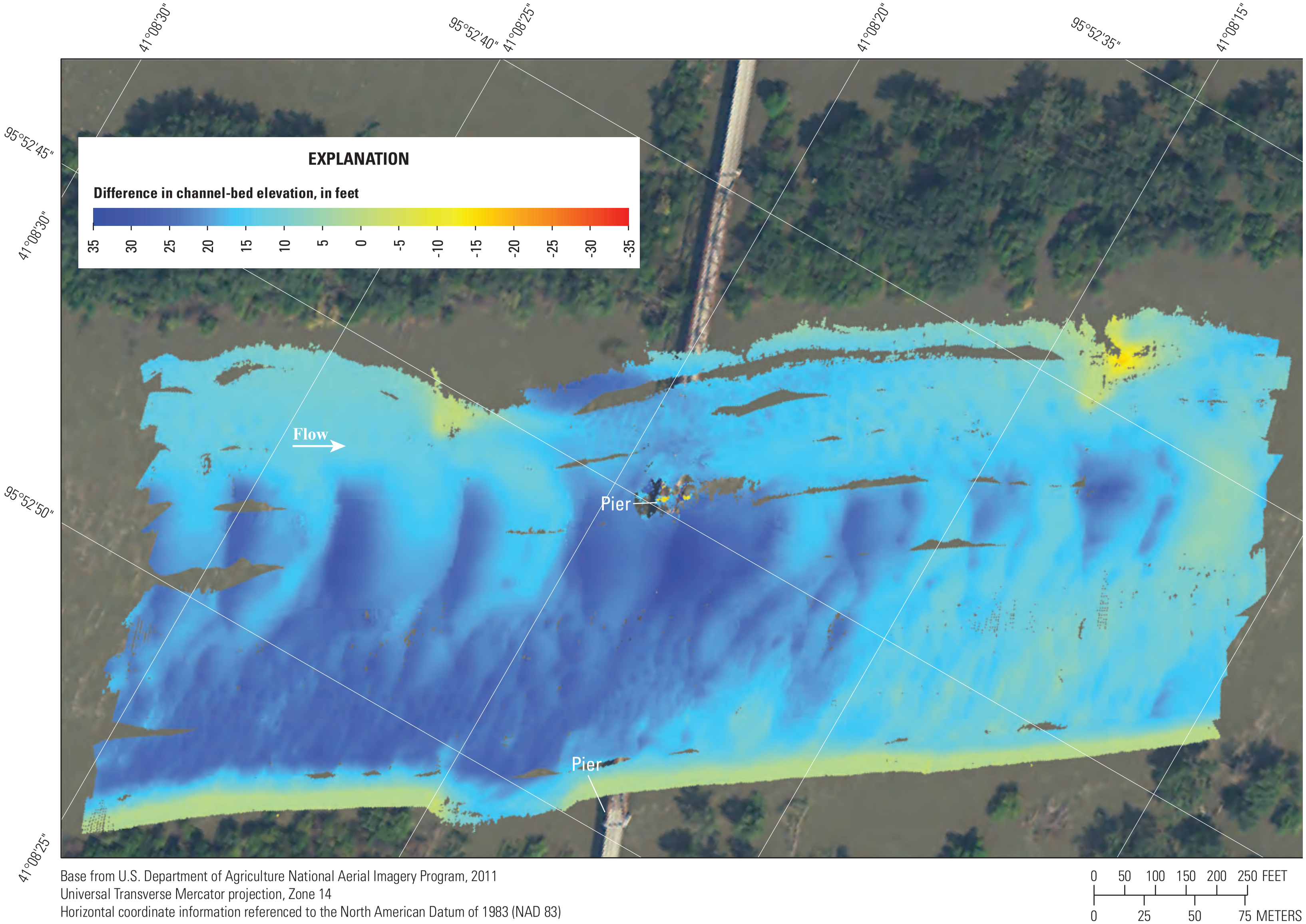


Figure 110. Difference in channel-bed elevation of the Missouri River in the vicinity of the Bellevue Bridge at Bellevue, Nebraska, between July 26 and November 9, 2011.

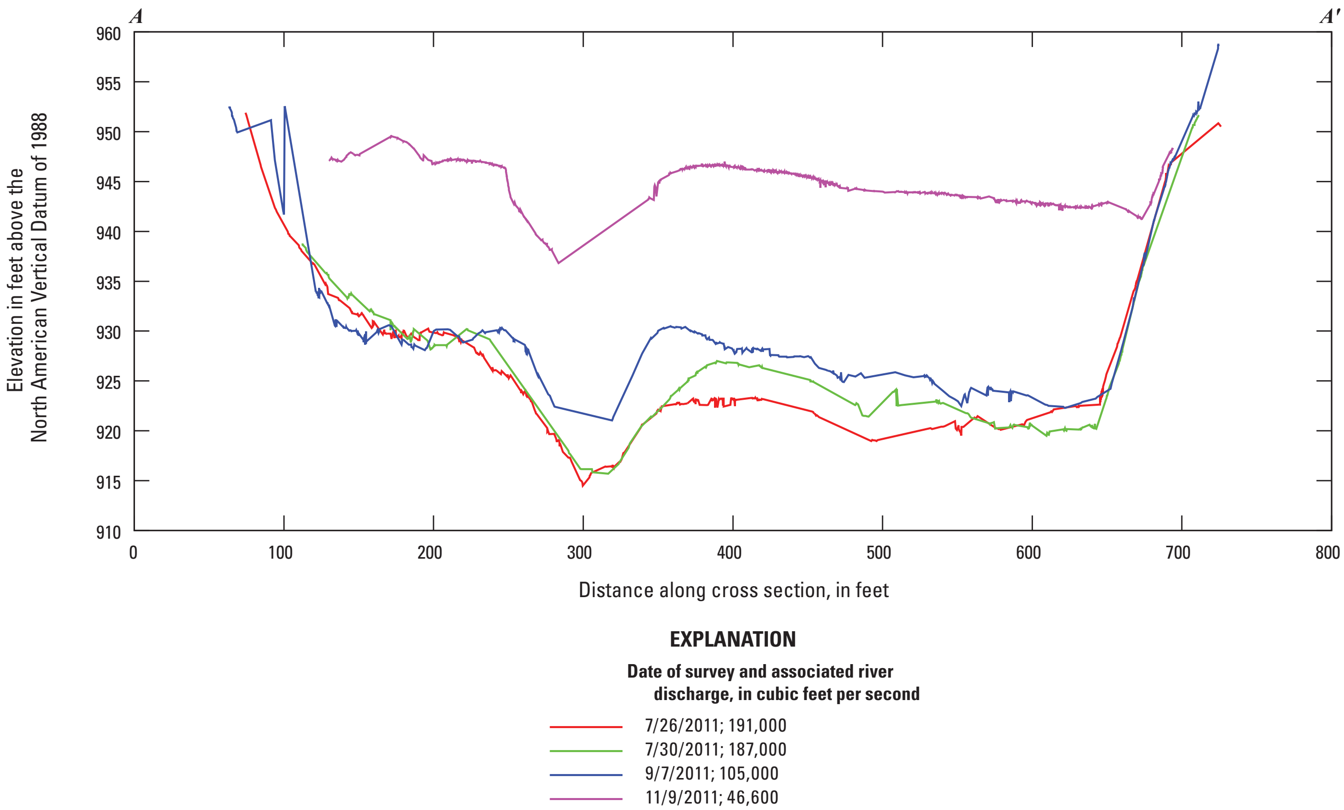


Figure 111. Hydrographic data collected by repeated surveys on the Missouri River along the upstream side of the Bellevue Bridge at Bellevue, Nebraska, July–November 2011.

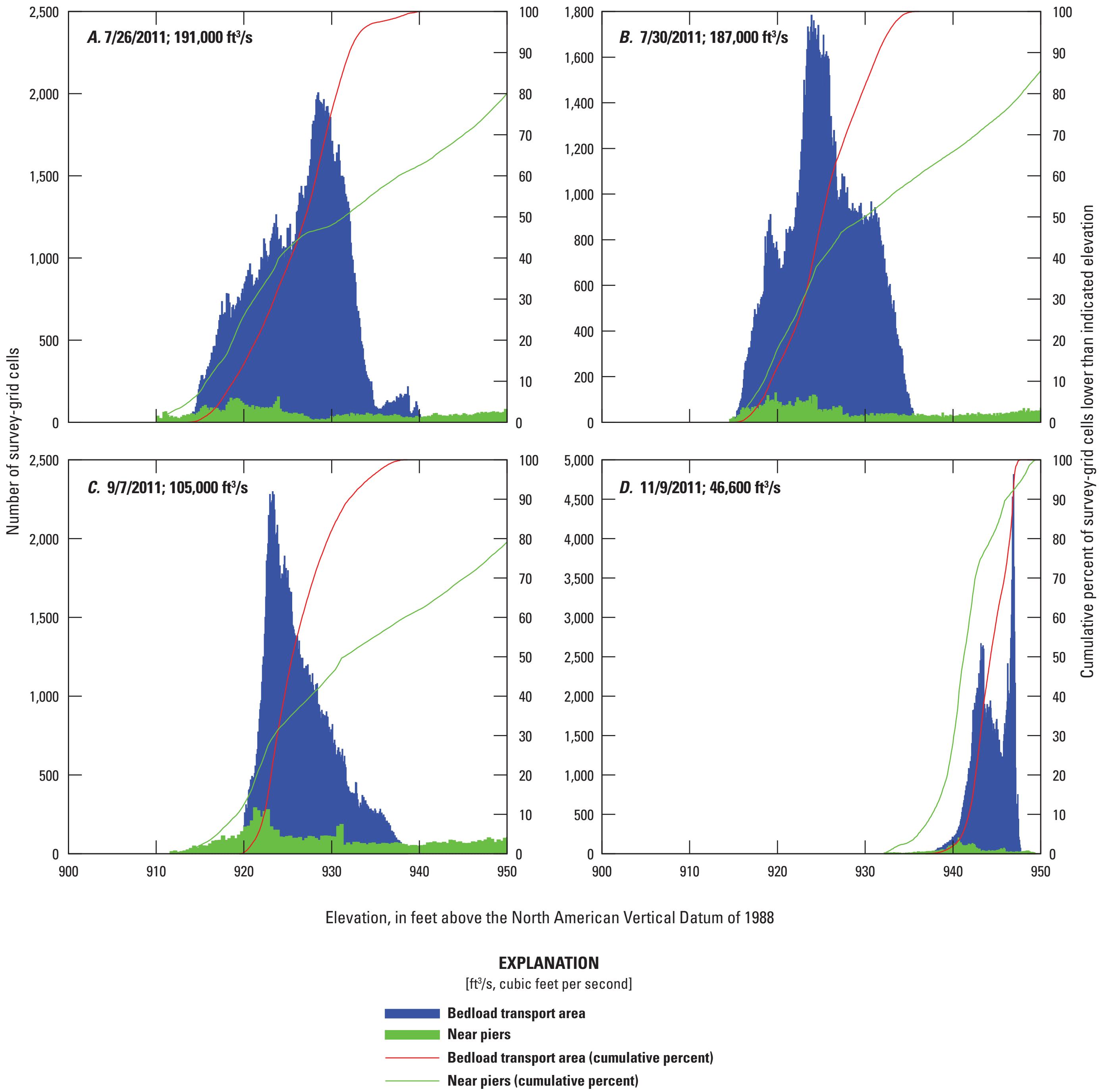


Figure 112. Frequency distribution of bed elevation, for hydrographic survey-grid cells (1.64-by-1.64 feet) sounded on the Missouri River in the vicinity of the Bellevue Bridge at Bellevue, Nebraska, *A*, July 26; *B*, July 30; *C*, September 7; and *D*, November 9, 2011.

Plattsmouth Bridge (U.S. Highway 34) near Plattsmouth, Nebraska, at River Mile 590

The Plattsmouth Bridge, also known the U.S. Highway 34 Bridge, crosses the Missouri River at Plattsmouth, Nebr. (figs. 113–120). The USGS streamgaging station 06807000 Missouri River at Nebraska City, Nebr., is located approximately 29 miles downstream from this bridge. The river discharges for the dates of surveys (table 2) were reported for station 06807000 as 206,000 ft^3/s on July 18; 206,000 ft^3/s on July 27; 111,000 ft^3/s on September 8; and 55,100 ft^3/s on November 4 (table 3).

The bed elevations surveyed on July 18 ranged from 908 to 931 ft (fig. 114). Minimum bed elevations on July 18 were 910 ft near the mid-channel bridge pier of the Plattsmouth Bridge and 911 ft in the thalweg upstream from the Plattsmouth Bridge (fig. 114). On July 27, the minimum bed elevation near the mid-channel pier was 908 ft, and 909 ft in the thalweg upstream from the Plattsmouth Bridge (fig. 115). On September 8, the minimum bed elevation was 908 ft near the mid-channel pier of the Plattsmouth Bridge bridge and 912 ft in the thalweg upstream from the Plattsmouth Bridge (fig. 116). By November 4, deposition had increased the minimum bed elevation to 917 ft near the mid-channel pier and to 928 ft in the thalweg upstream (fig. 117).

The difference in bed elevation from July 18 to November 4 was computed for each grid cell sounded during both surveys (fig. 118). The bed elevation increased by more than 10 ft in about 65 percent of the survey area. In a large area upstream from the highway bridge, the difference value ranged from 20–25 ft. The mean difference for all re-sounded cells was 11.9 ft, indicating that net deposition occurred in the surveyed area from July 18 to November 4. Hydrographic survey data indicates that, from July 18 to November 4, bed elevations increased by 10 ft or more across width of the channel near the upstream side of the Plattsmouth Bridge (fig. 119).

In the bedload transport area, the frequency distribution of elevations shifted upward between July 18 and November 4, with most change occurring from September 8 to November 4 (fig. 120). The mean bed elevation for grid cells in the bedload transport area was 920 ft on July 18, 918 ft on July 27, 923 ft on September 8, and 934 ft on November 4.

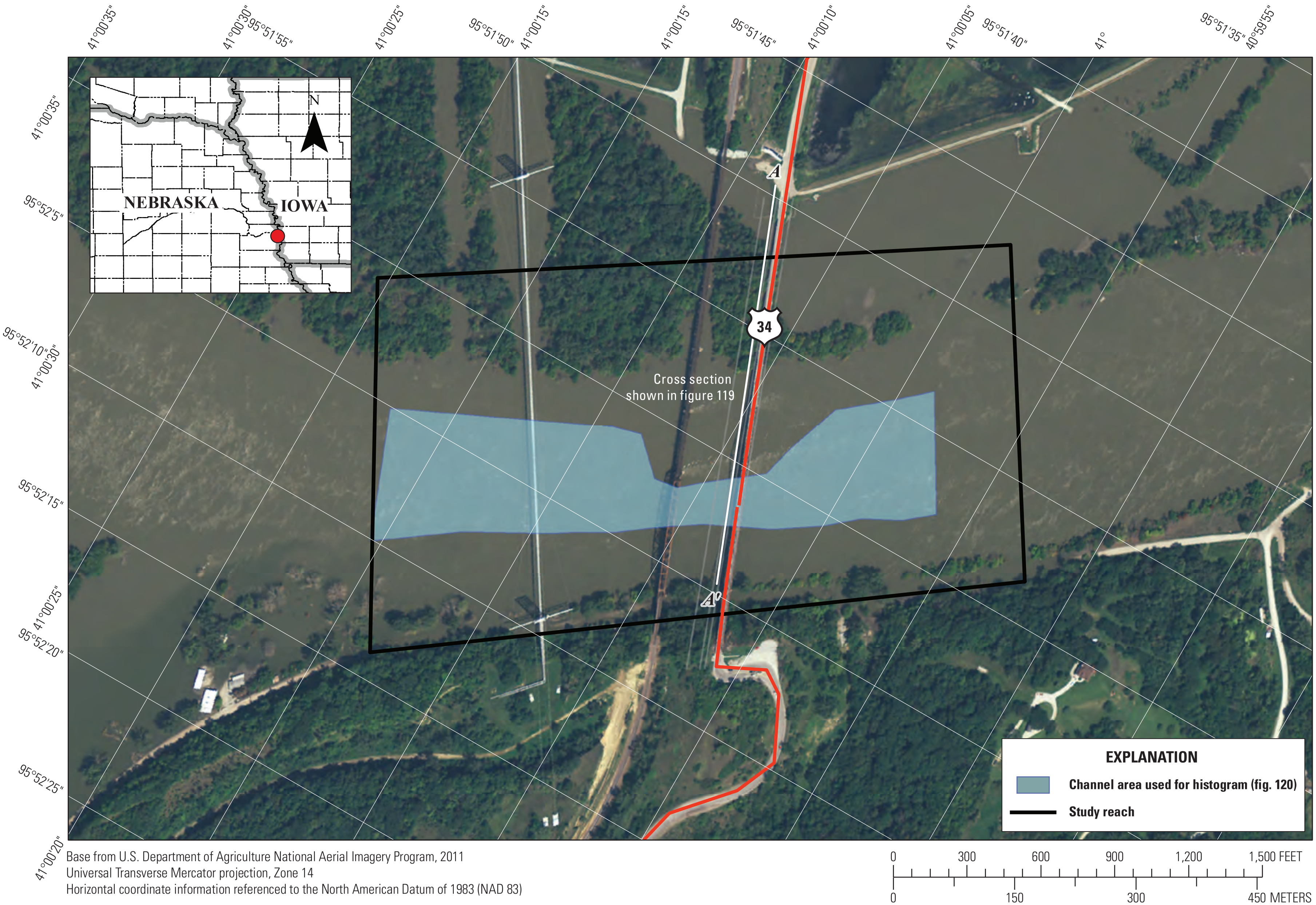
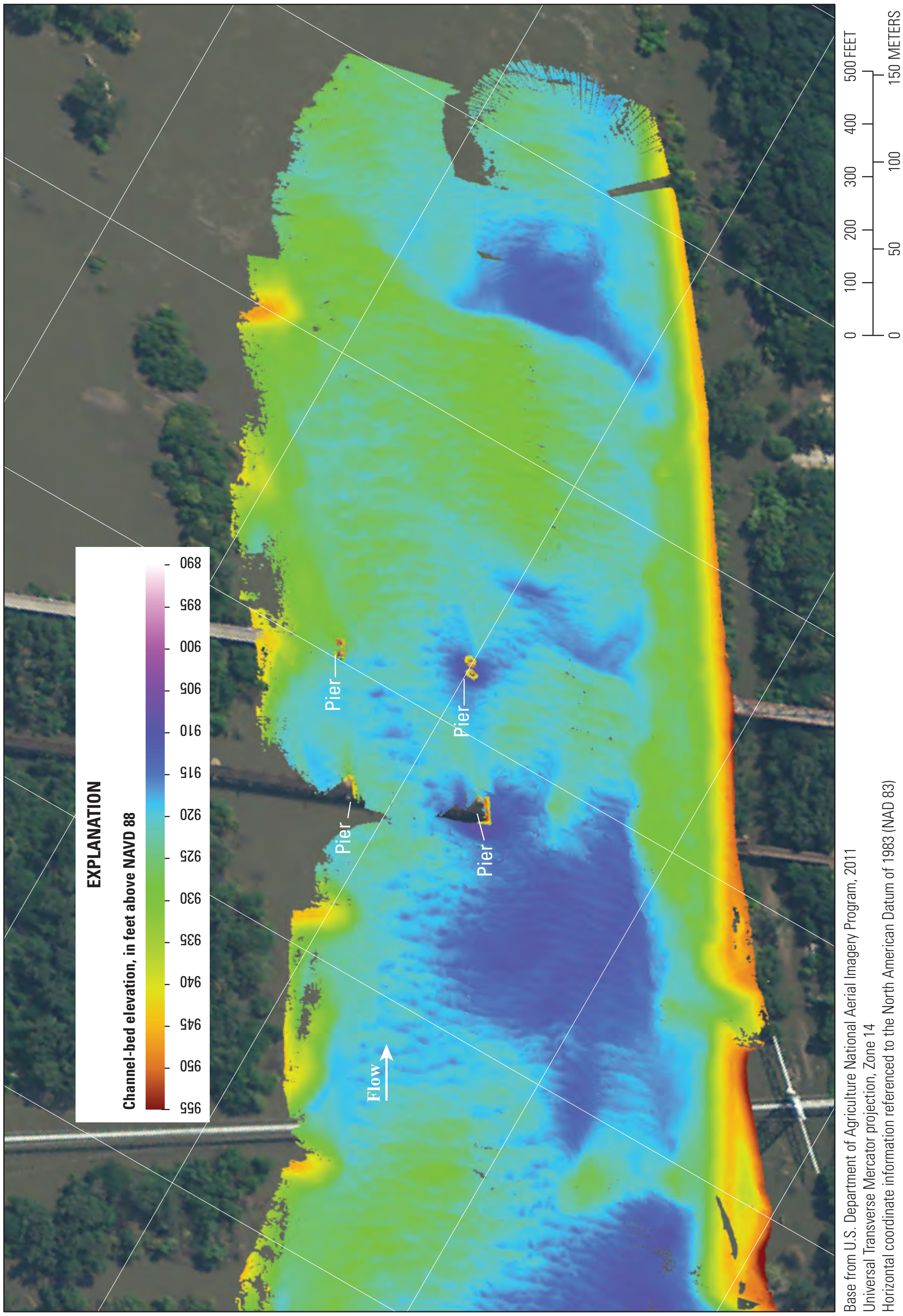
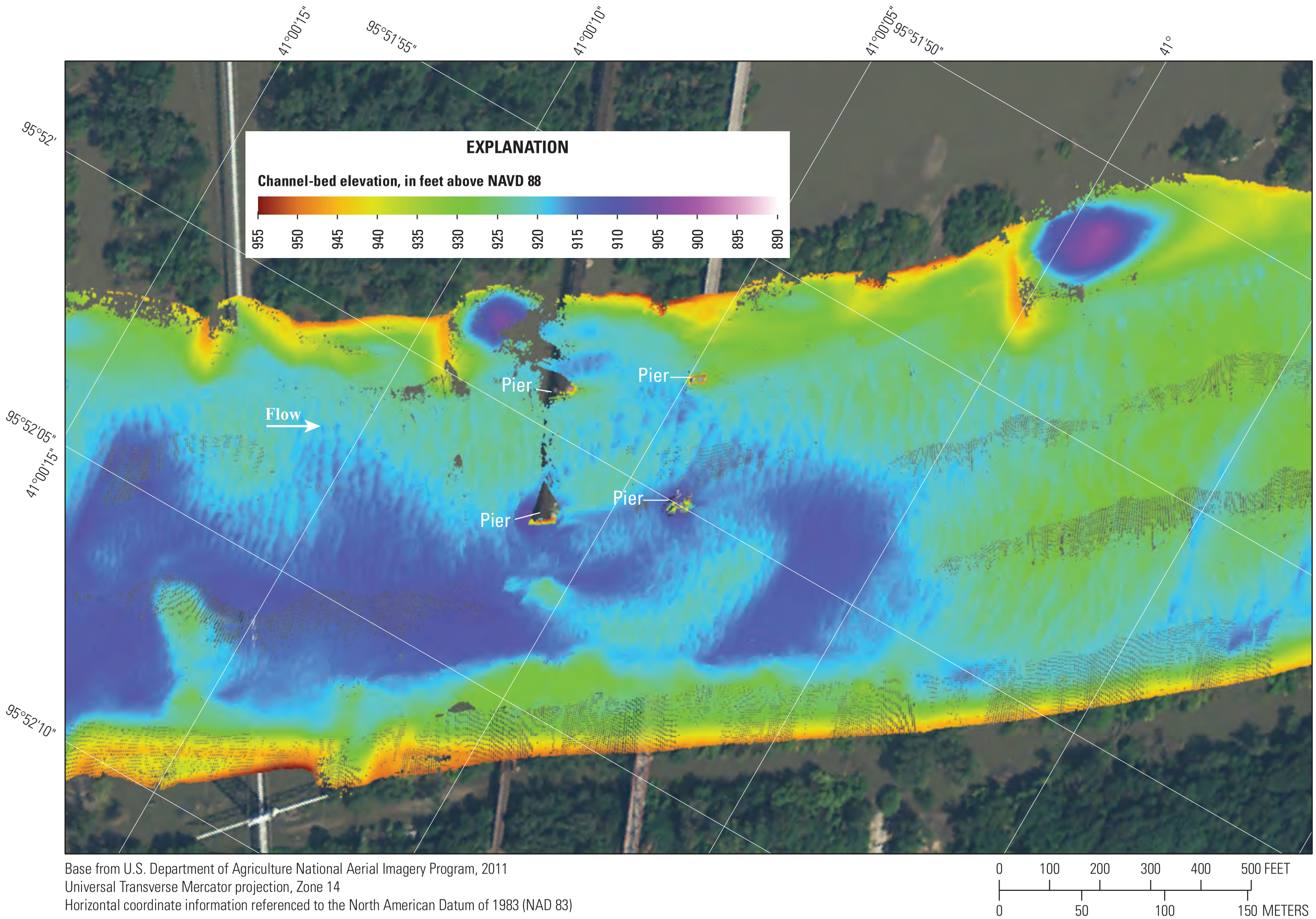


Figure 113. Location of hydrographic surveys of the Missouri River in the vicinity of the Plattsmouth Bridge at Plattsmouth, Nebraska, July–November 2011.



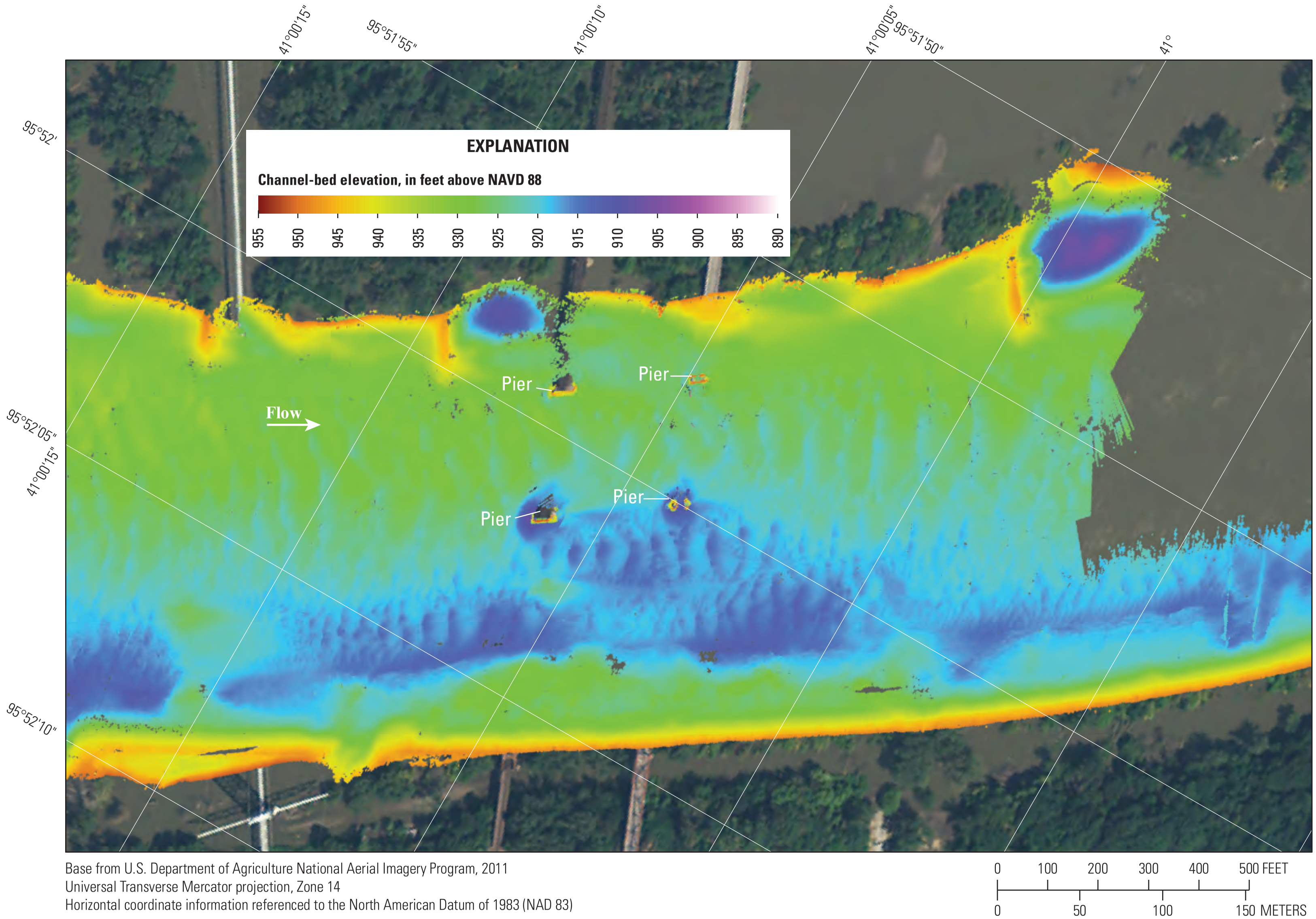
Base from U.S. Department of Agriculture National Aerial Imagery Program, 2011
Universal Transverse Mercator projection, Zone 14
Horizontal coordinate information referenced to the North American Datum of 1983 (NAD 83)

Figure 114. Channel-bed elevations of the Missouri River in the vicinity of the Plattsmouth Bridge at Plattsmouth, Nebraska, during flow of 206,000 cubic feet per second, July 18, 2011.



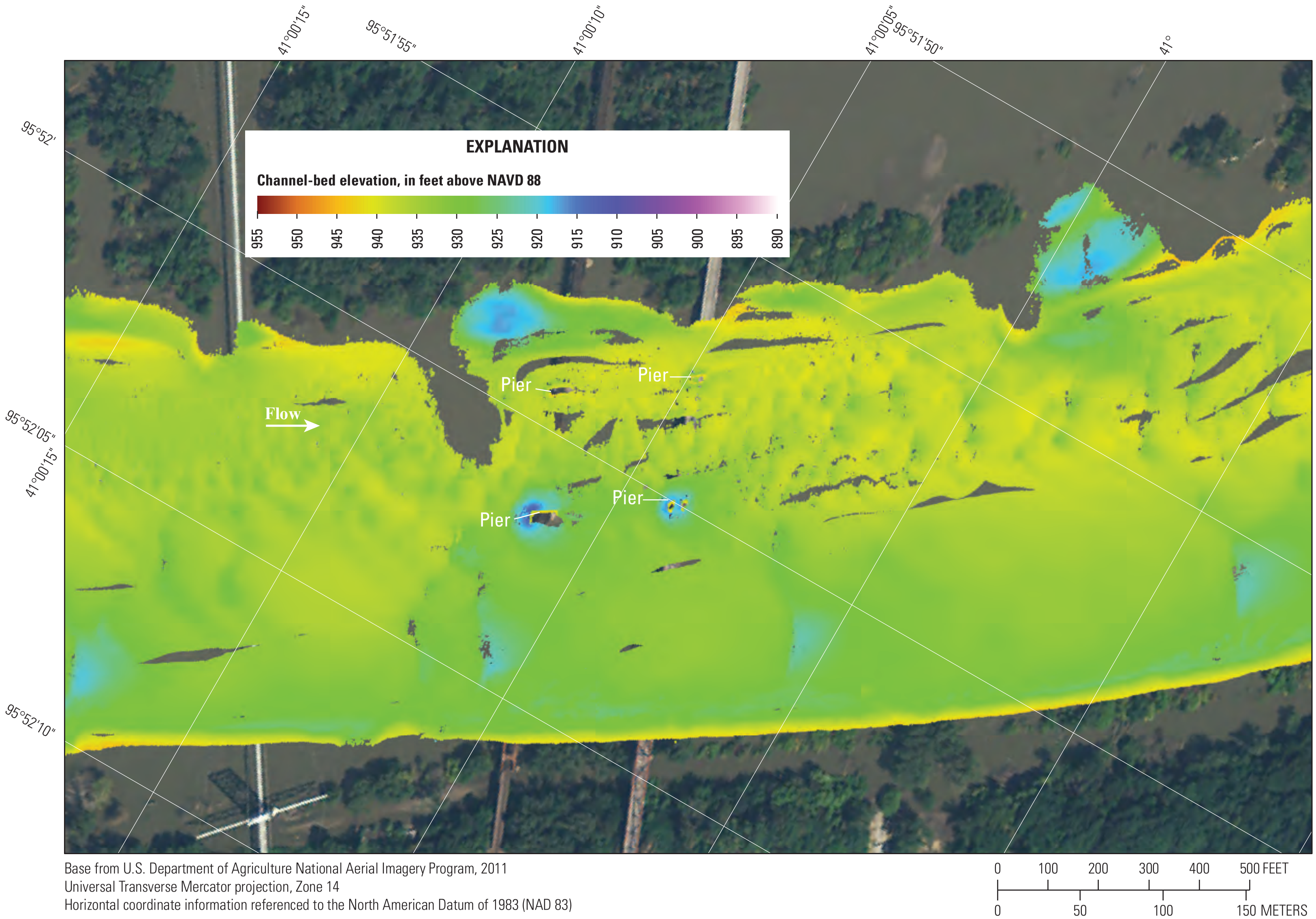
Base from U.S. Department of Agriculture National Aerial Imagery Program, 2011
Universal Transverse Mercator projection, Zone 14
Horizontal coordinate information referenced to the North American Datum of 1983 (NAD 83)

Figure 115. Channel-bed elevations of the Missouri River in the vicinity of the Plattsmouth Bridge at Plattsmouth, Nebraska, during flow of 206,000 cubic feet per second, July 27, 2011.



Base from U.S. Department of Agriculture National Aerial Imagery Program, 2011
Universal Transverse Mercator projection, Zone 14
Horizontal coordinate information referenced to the North American Datum of 1983 (NAD 83)

Figure 116. Channel-bed elevations of the Missouri River in the vicinity of the Plattsmouth Bridge at Plattsmouth, Nebraska, during flow of 111,000 cubic feet per second, September 8, 2011.



Base from U.S. Department of Agriculture National Aerial Imagery Program, 2011
Universal Transverse Mercator projection, Zone 14
Horizontal coordinate information referenced to the North American Datum of 1983 (NAD 83)

Figure 117. Channel-bed elevations of the Missouri River in the vicinity of the Plattsmouth Bridge at Plattsmouth, Nebraska, during flow of 55,100 cubic feet per second, November 4, 2011.

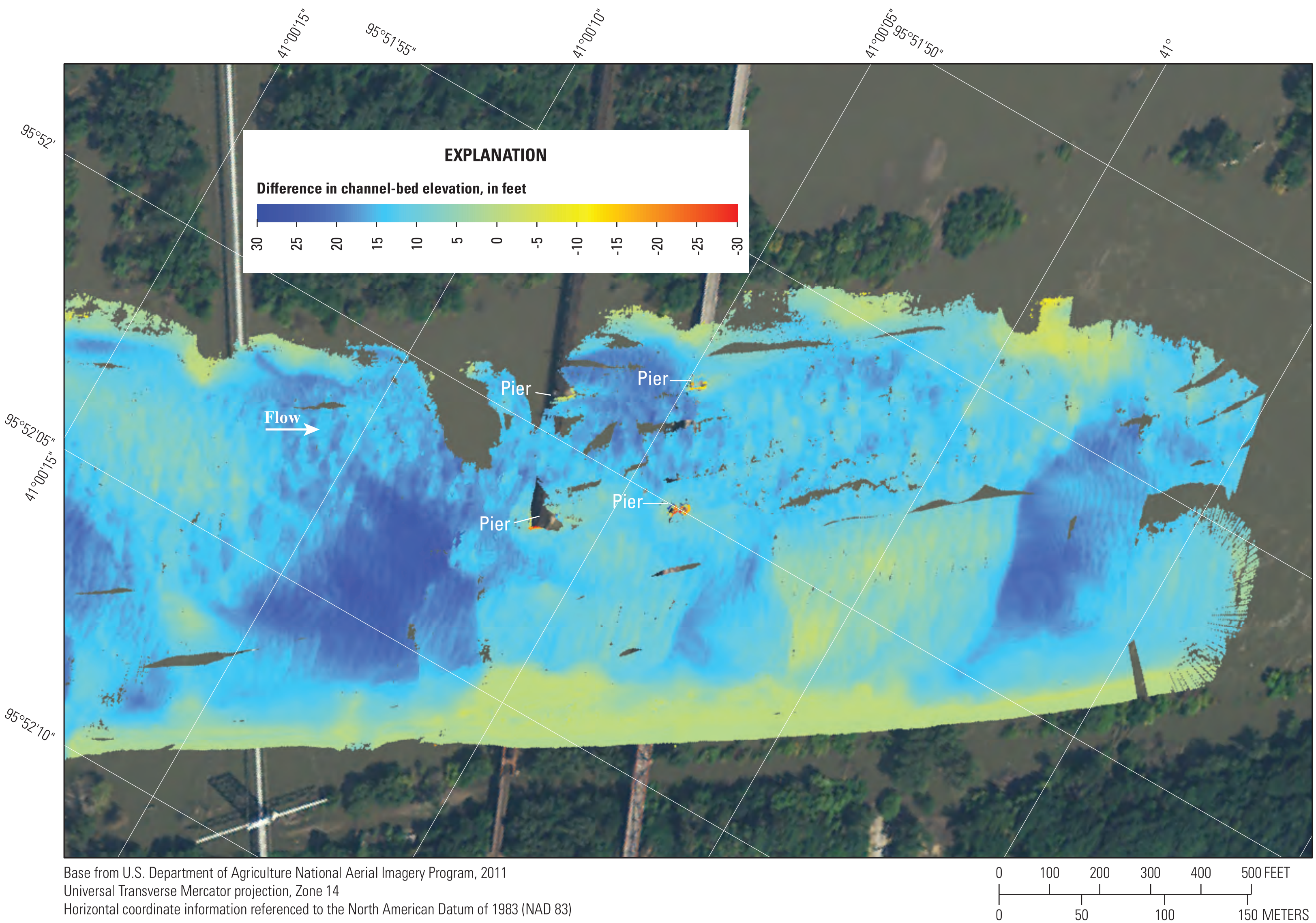


Figure 118. Difference in channel-bed elevation of the Missouri River in the vicinity of the Plattsmouth Bridge at Plattsmouth, Nebraska, between July 18 and November 4, 2011.

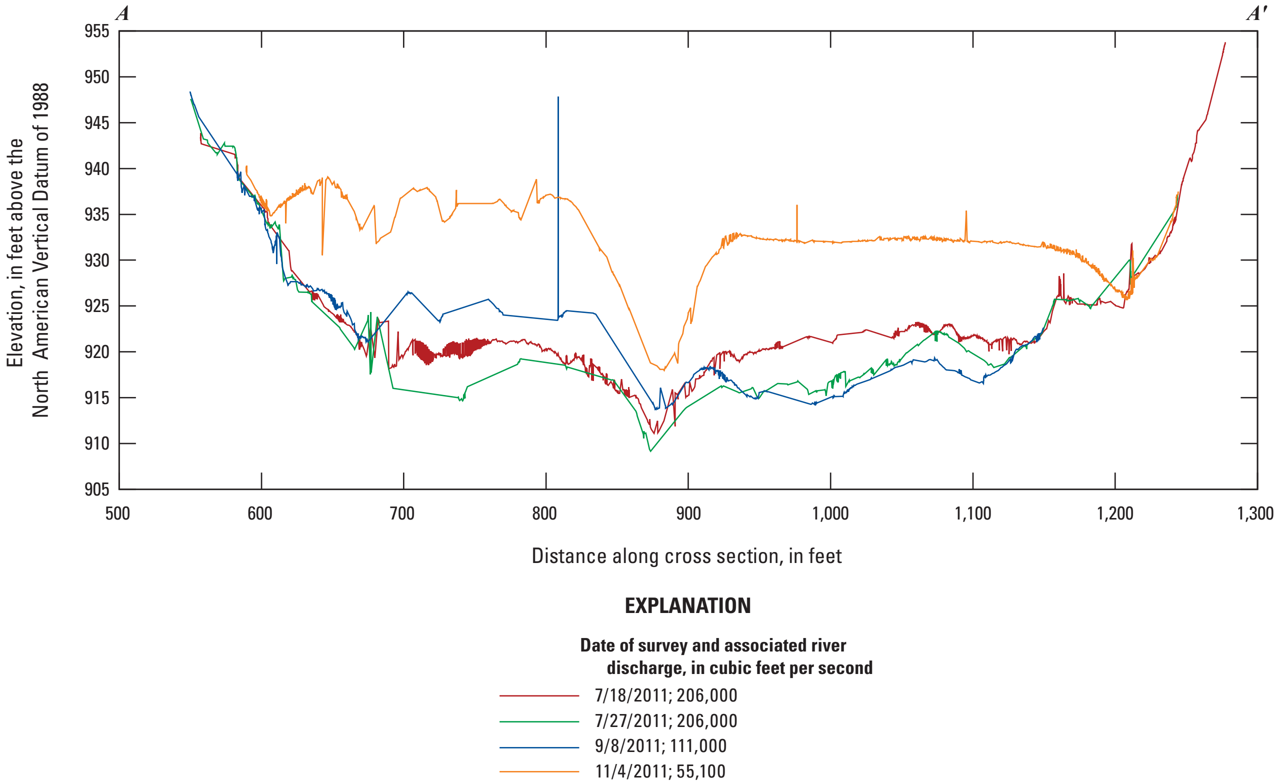


Figure 119. Hydrographic data collected by repeated surveys on the Missouri River along the upstream side of the Plattsmouth Bridge at Plattsmouth, Nebraska, July–November 2011.

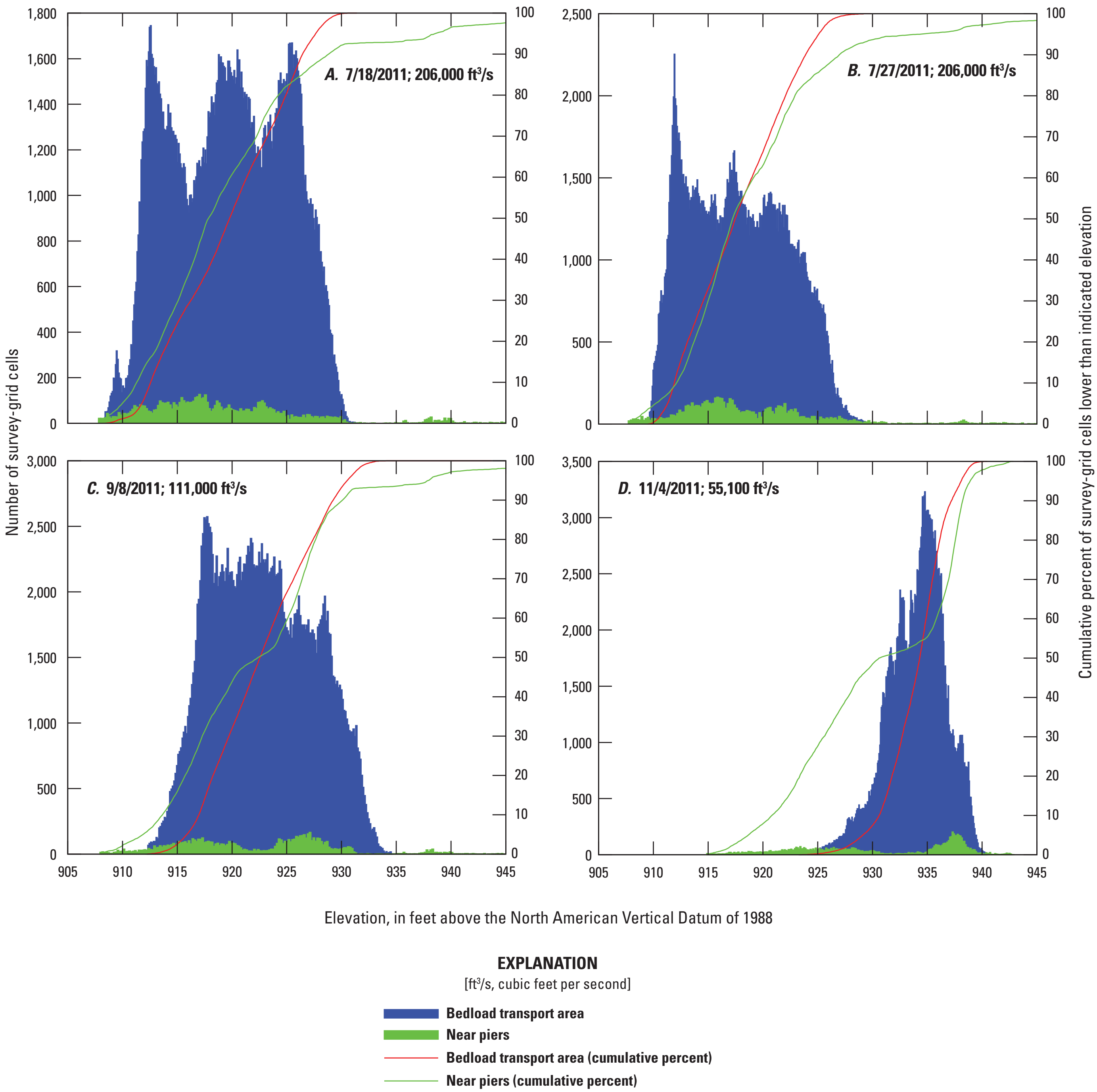


Figure 120. Frequency distribution of bed elevation, for hydrographic survey-grid cells (1.64-by-1.64 feet) sounded on the Missouri River in the vicinity of the Plattsmouth Bridge at Plattsmouth, Nebraska, *A*, July 18; *B*, July 27; *C*, September 8; and *D*, November 4, 2011.

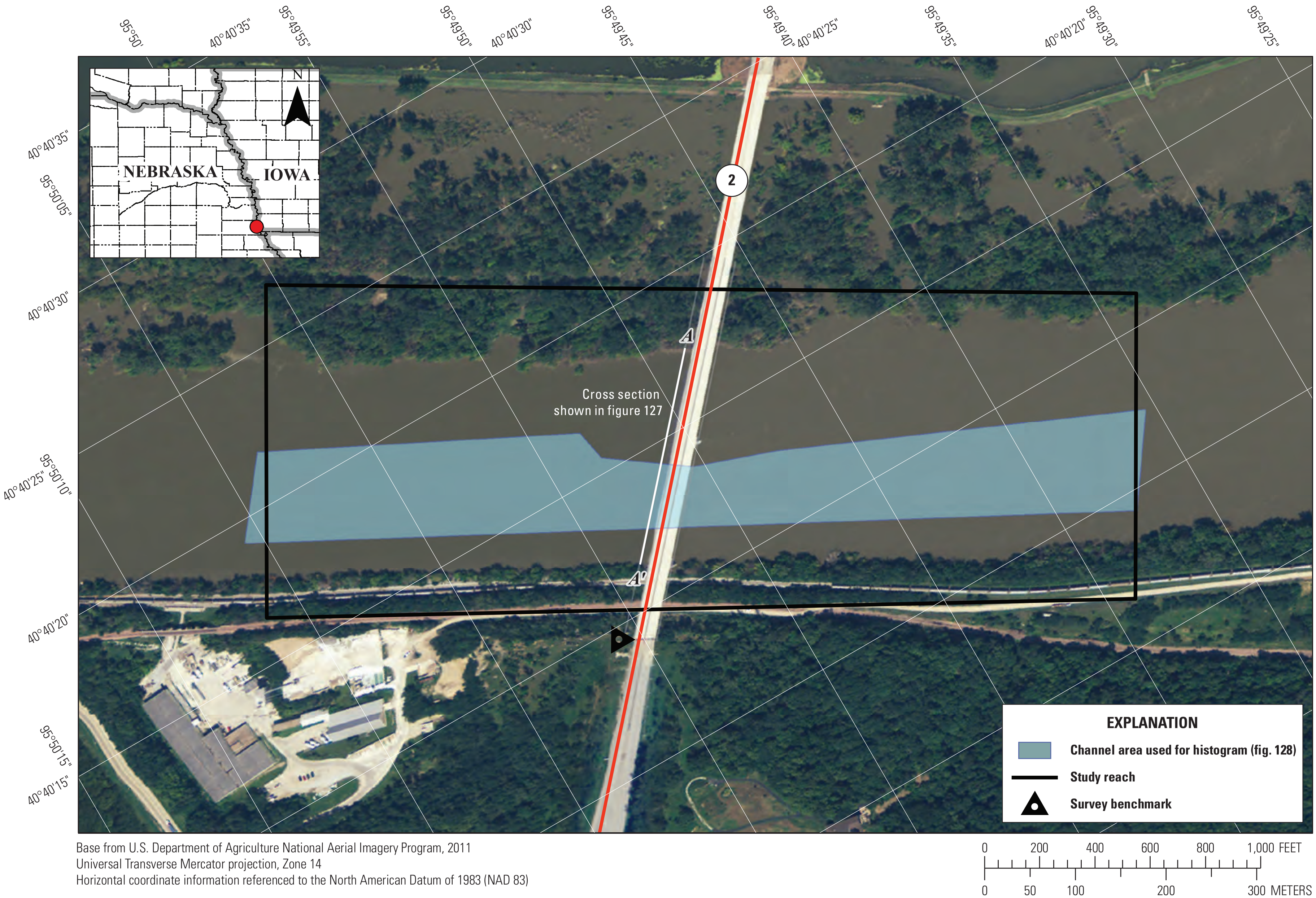
Nebraska City Bridge (Nebraska and Iowa Highway 2) at Nebraska City, Nebraska, at River Mile 561

The Nebraska City Bridge crosses the Missouri River at Nebraska City, Nebr. (figs. 121–128). For much of the 2011 Missouri River flooding, the bridge was closed because the Iowa-side approach of Iowa Highway 2 was submerged. The Nebraska City Bridge was surveyed on four dates during the 2011 Missouri River flooding (table 2). The USGS streamgaging station 06807000 Missouri River at Nebraska City, Nebr., is located at this bridge. The discharges reported for station 06807000 were 200,000 ft^3/s on July 19; 197,000 ft^3/s on August 2; 105,000 ft^3/s on September 13; and 56,200 ft^3/s on October 19 (table 3).

Bed elevations surveyed on July 19 ranged from 878 to 897 ft (fig. 122). Bed elevations adjacent to the mid-channel pier were about 20 ft or more lower than minimums upstream from the pier and in the thalweg. Upstream from the bridge in an area unlikely to be affected by local scour, minimum bed elevations on July 19 were about 888 ft; whereas, the minimum bed elevation near the pier was 868 ft (fig. 122). During the August 2 and September 13 surveys, bed elevations near the mid-channel pier were about 874 ft, whereas the minimum bed elevations upstream from the pier were about 888 ft (figs. 123 and 124). The minimum bed elevation near the mid-channel pier was about 882 ft on October 19 (fig. 125).

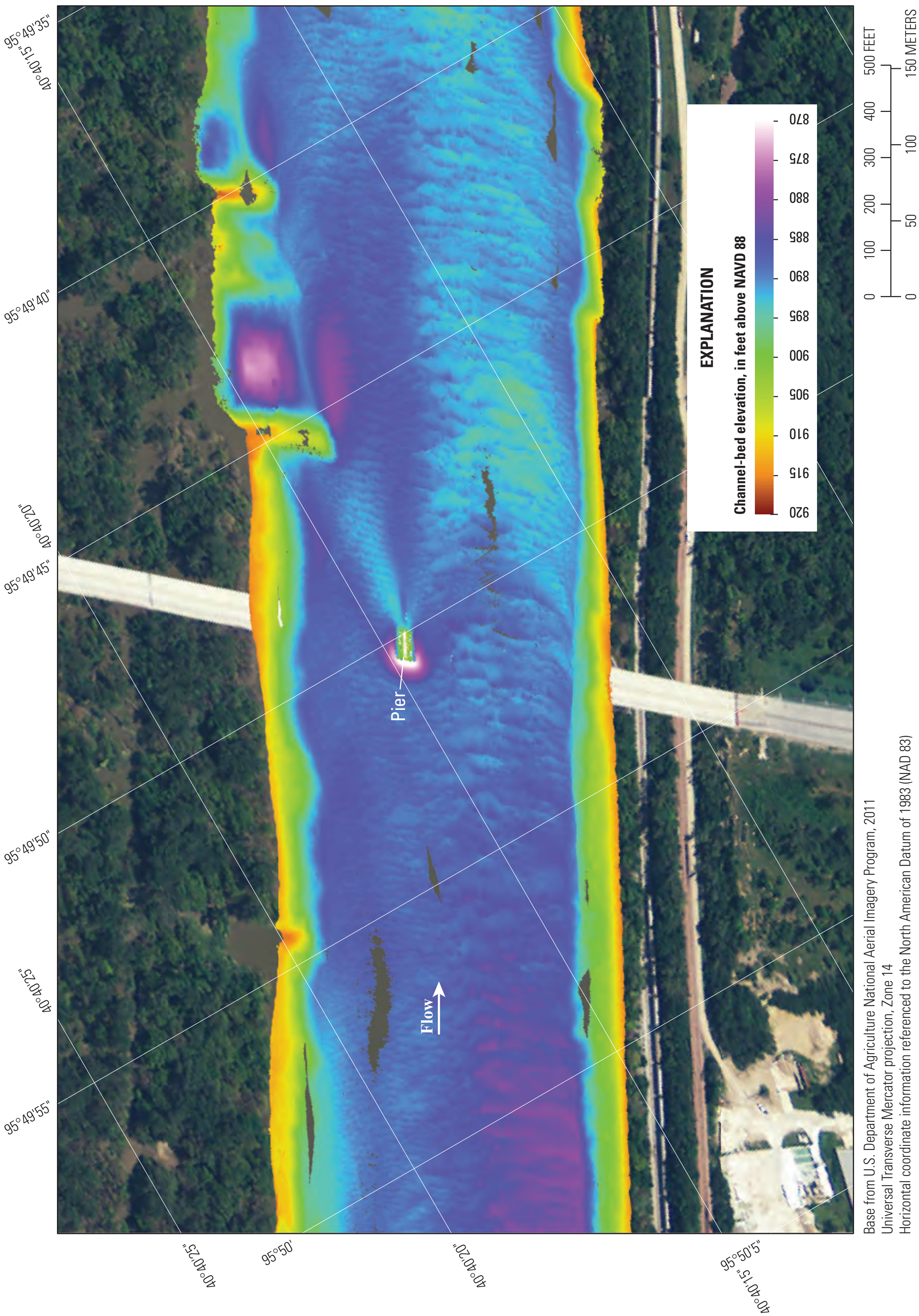
The difference in bed elevation from July 19 to October 19 was computed for each grid cell sounded during both surveys (fig. 126). For most of the surveyed area, bed elevations increased by as much as 10 ft from July 19 to October 19. Near the Nebraska bank, bed elevations decreased by 0 to 2 ft. The mean difference for all re-sounded cells was 4.6 ft, indicating that net deposition likely occurred in the surveyed area from July 19 to October 19. A cross section of hydrographic survey data on the upstream side of the Nebraska City Bridge shows that bed elevations increased by more than 5 ft across most of the width of the channel from July 19 to October 19 (fig. 127).

In the bedload transport area, the frequency distribution of elevations shifted upward between July 19 and October 19 (fig. 128). For grid cells in the bedload transport area, the mean elevation was 889 ft on July 19 and August 2, 890 ft on September 13, and 894 ft on October 19.



Base from U.S. Department of Agriculture National Aerial Imagery Program, 2011
Universal Transverse Mercator projection, Zone 14
Horizontal coordinate information referenced to the North American Datum of 1983 (NAD 83)

Figure 121. Location of hydrographic surveys of the Missouri River in the vicinity of the Nebraska City Bridge, at Nebraska City, Nebraska, July–October 2011.



Base from U.S. Department of Agriculture National Aerial Imagery Program, 2011
Universal Transverse Mercator projection, Zone 14
Horizontal coordinate information referenced to the North American Datum of 1983 (NAD 83)

Figure 122. Channel-bed elevations of the Missouri River in the vicinity of the Nebraska City Bridge, at Nebraska City, Nebraska, during flow of 200,000 cubic feet per second, July 19, 2011.

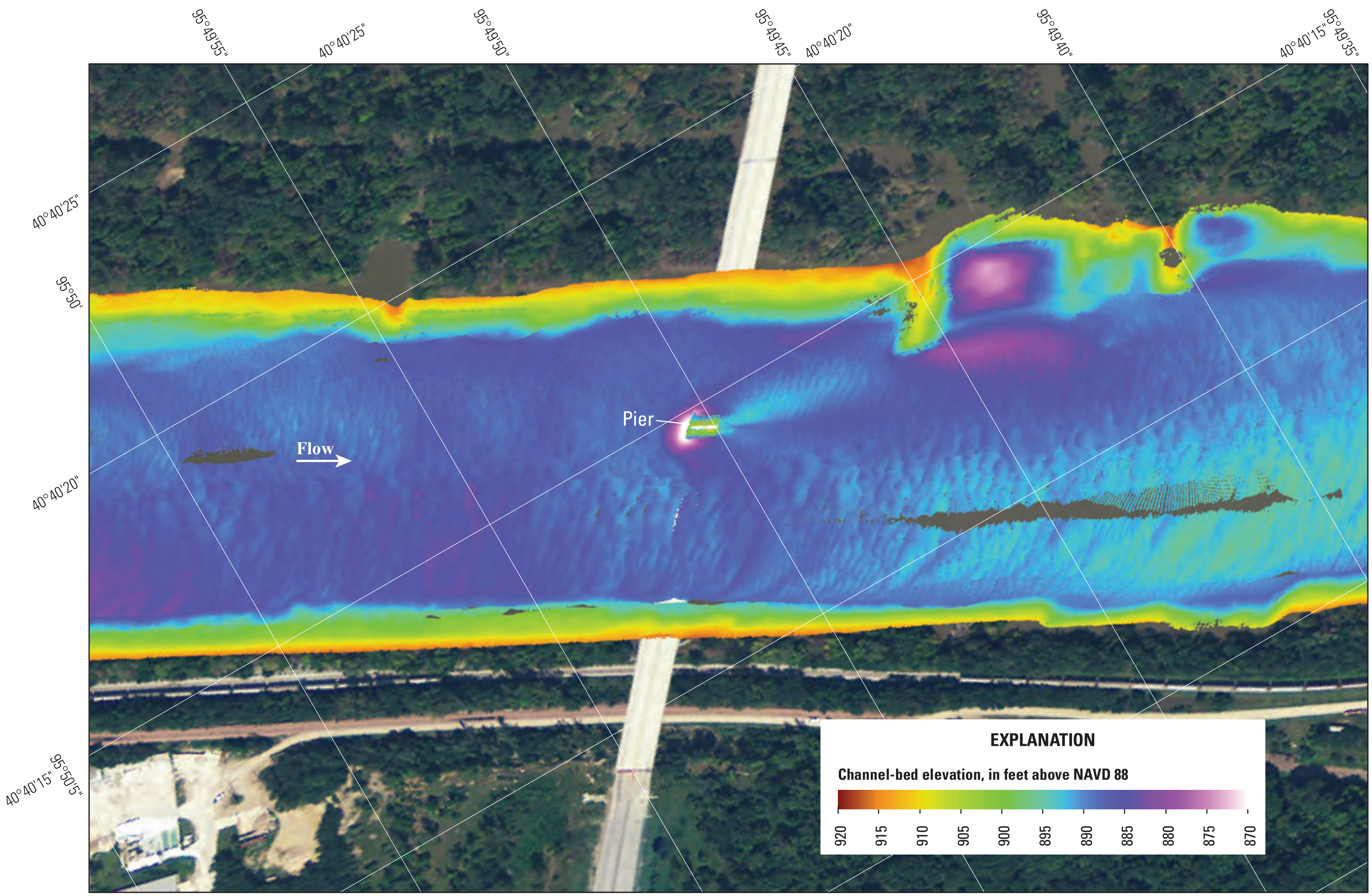
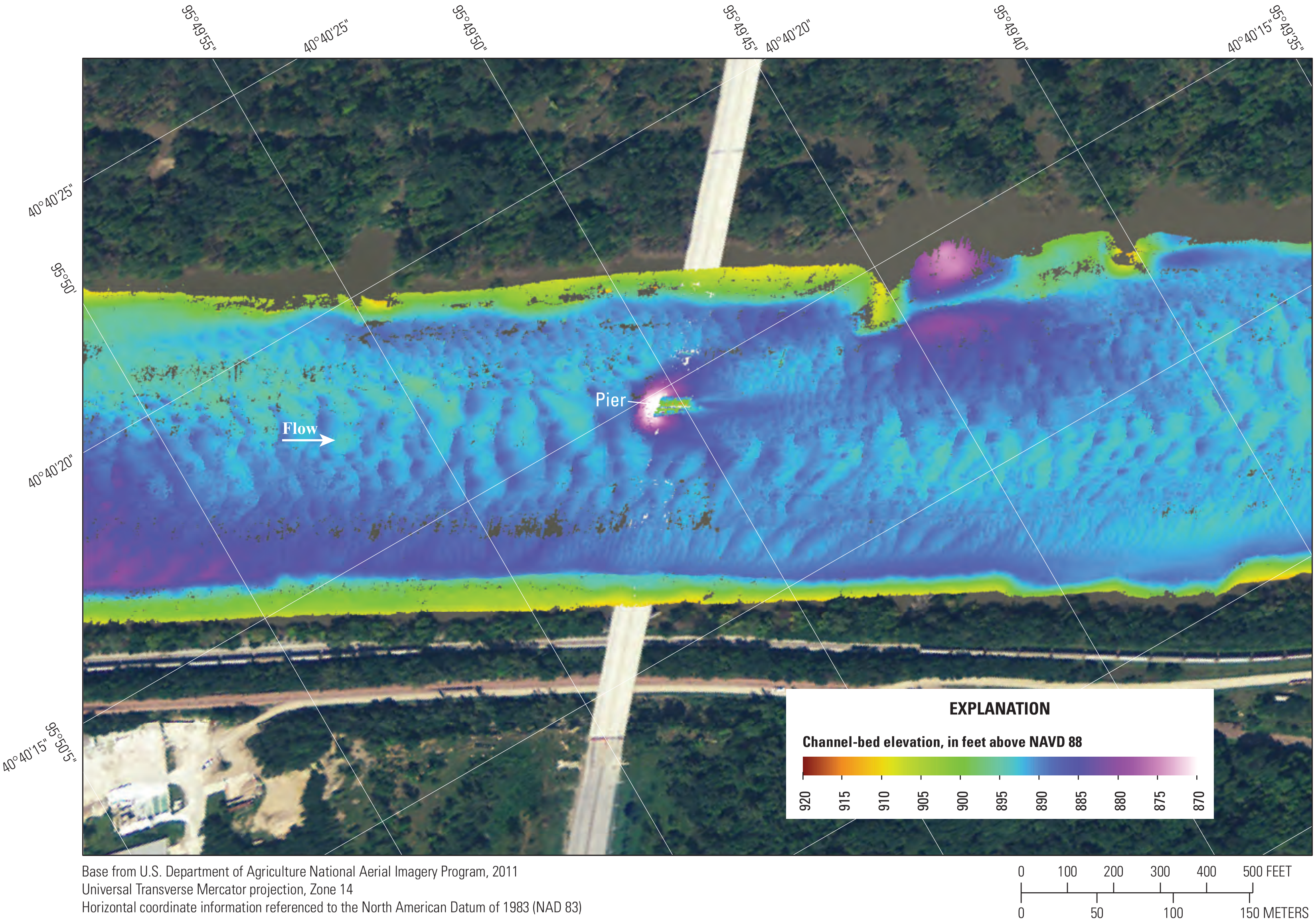


Figure 123. Channel-bed elevations of the Missouri River in the vicinity of the Nebraska City Bridge, at Nebraska City, Nebraska, during flow of 197,000 cubic feet per second, August 2, 2011.



Base from U.S. Department of Agriculture National Aerial Imagery Program, 2011
Universal Transverse Mercator projection, Zone 14
Horizontal coordinate information referenced to the North American Datum of 1983 (NAD 83)

Figure 124. Channel-bed elevations of the Missouri River in the vicinity of the Nebraska City Bridge, at Nebraska City, Nebraska, during flow of 105,000 cubic feet per second, September 13, 2011.

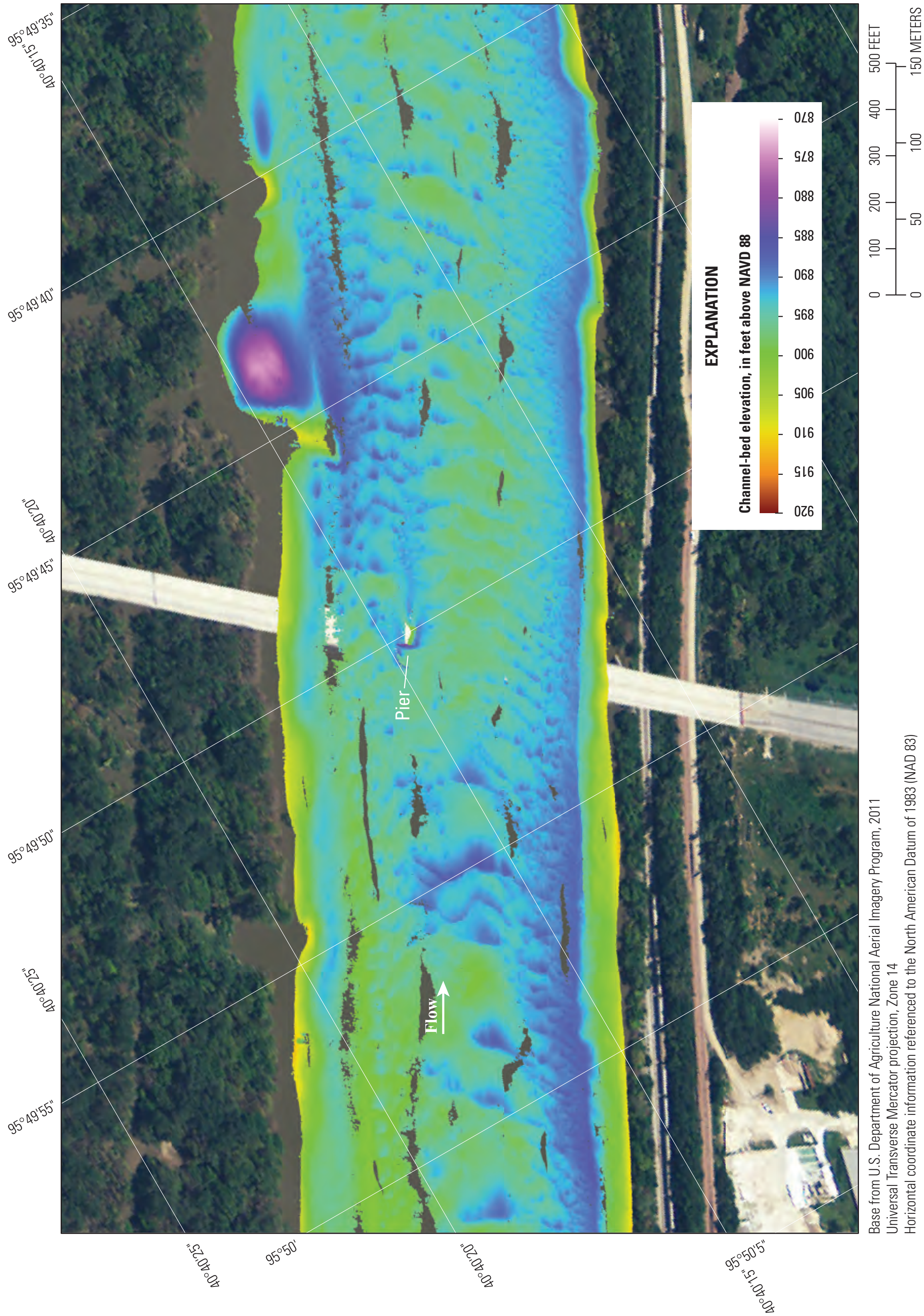


Figure 125. Channel-bed elevations of the Missouri River in the vicinity of the Nebraska City Bridge, at Nebraska City, Nebraska, during flow of 56,200 cubic feet per second, October 19, 2011.

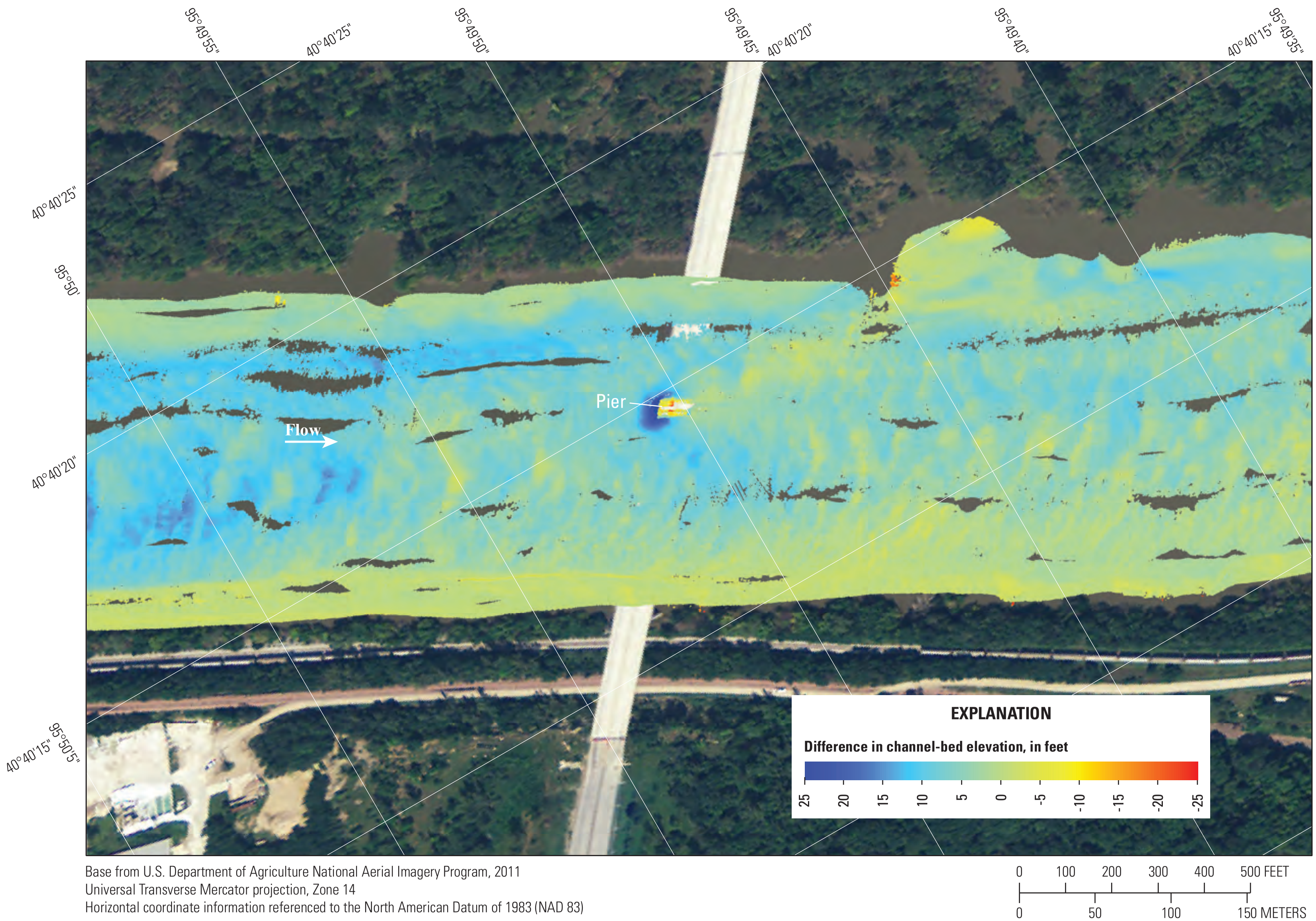


Figure 126. Difference in channel-bed elevation of the Missouri River in the vicinity of the Nebraska City Bridge, at Nebraska City, Nebraska, between July 19 and October 19, 2011.

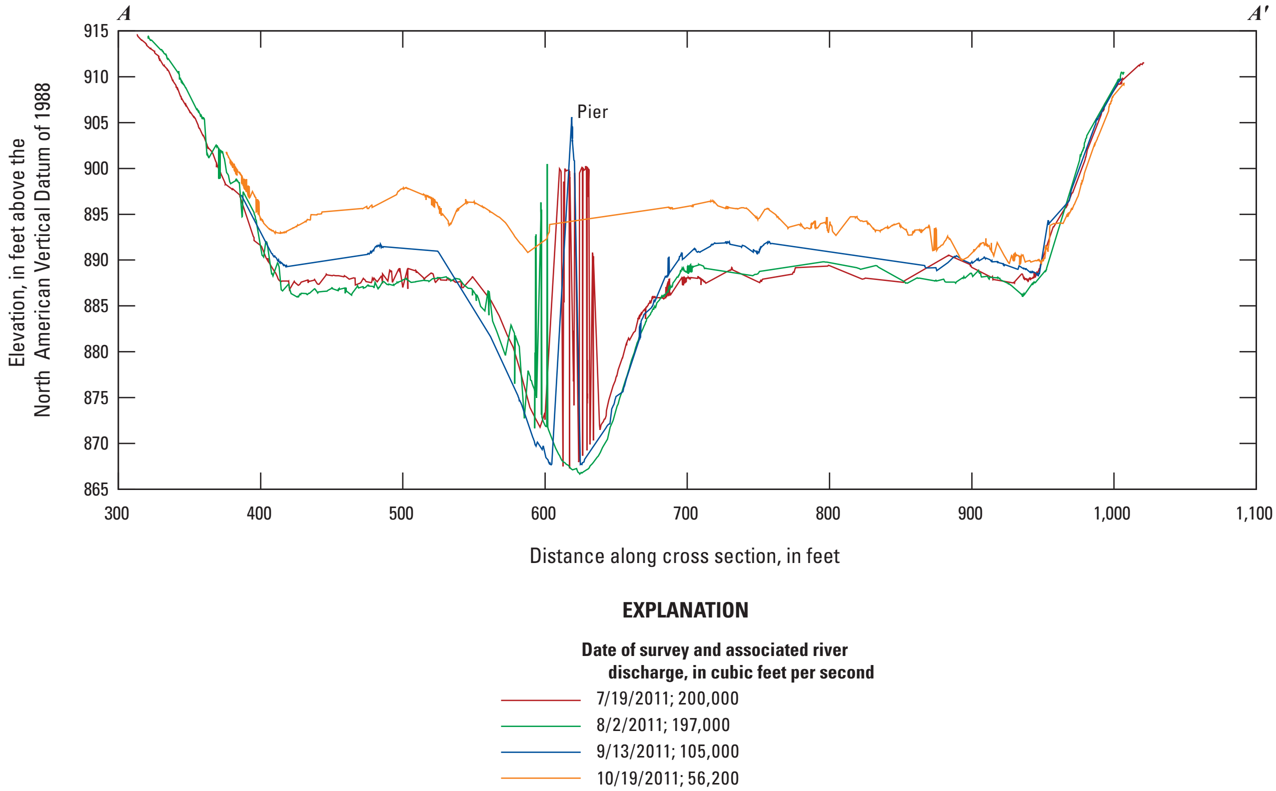


Figure 127. Hydrographic data collected by repeated surveys on the Missouri River along the upstream side of the Nebraska City Bridge, at Nebraska City, Nebraska, July–October 2011.

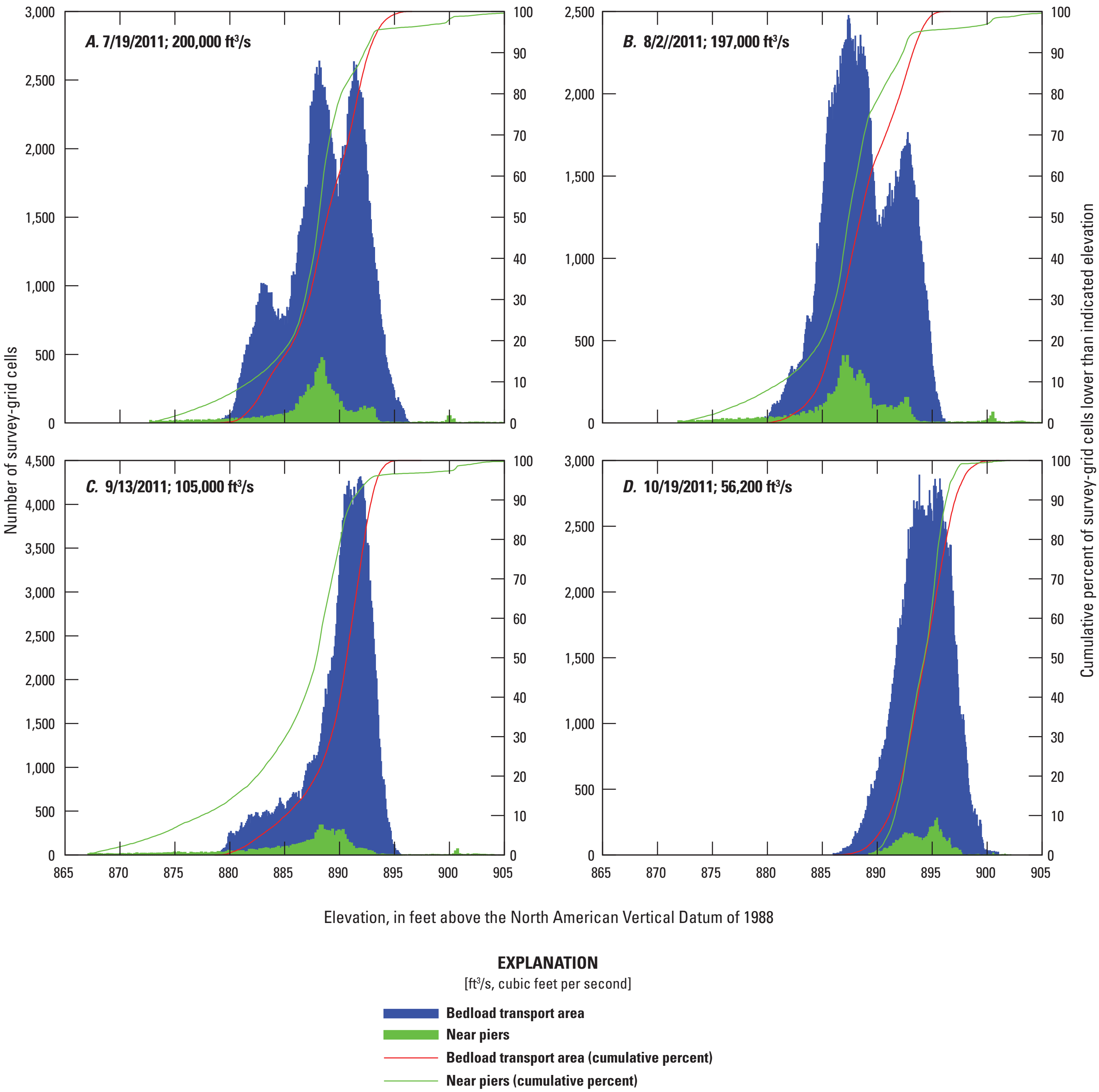


Figure 128. Frequency distribution of bed elevation, for hydrographic survey-grid cells (1.64-by-1.64 feet) sounded on the Missouri River in the vicinity of the Nebraska City Bridge, at Nebraska City, Nebraska, *A*, July 19; *B*, August 2; *C*, September 13; and *D*, October 19, 2011.

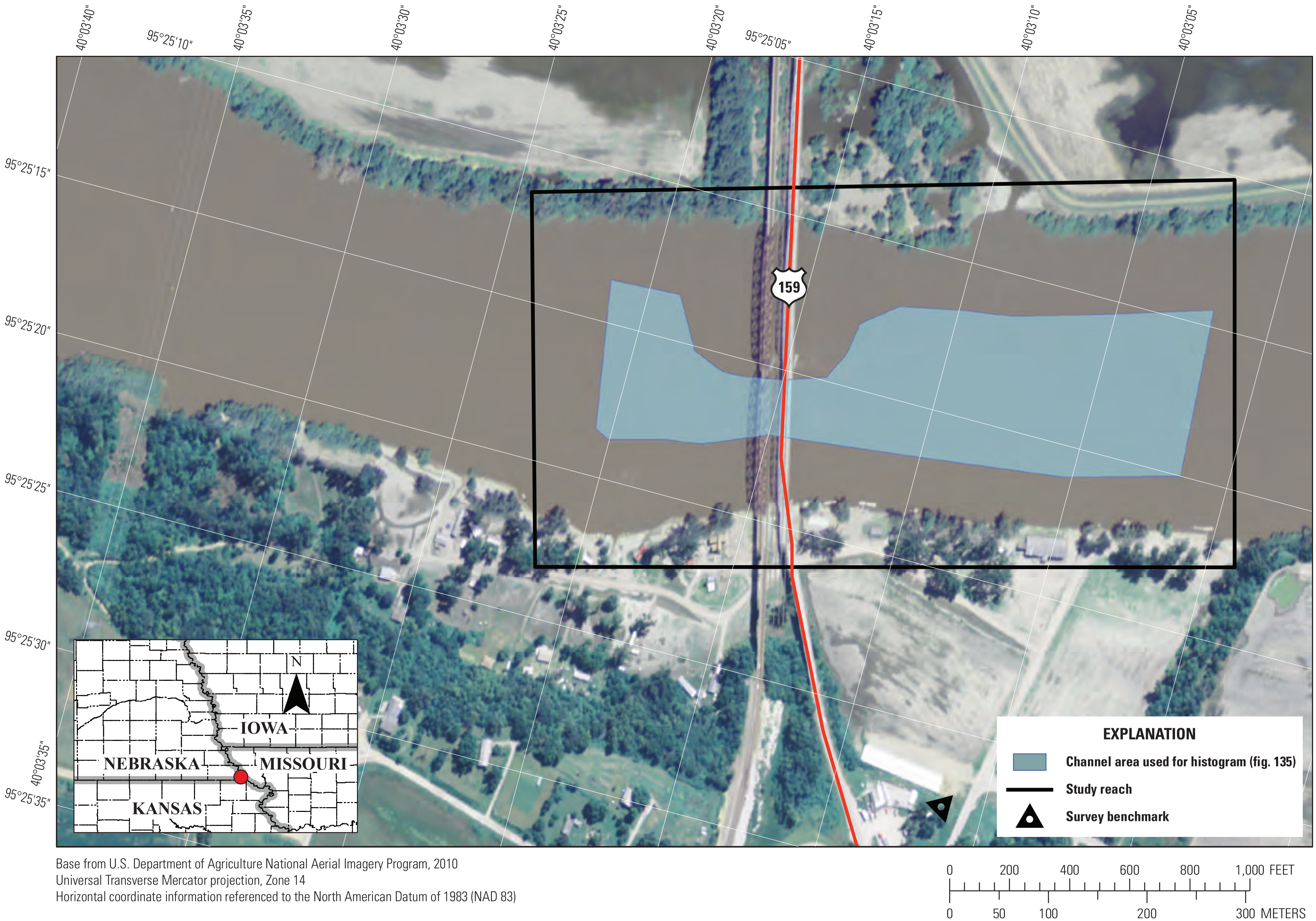
Rulo Bridge (U.S. Highway 159) at Rulo, Nebraska, at River Mile 498

The Rulo Bridge crosses the Missouri River at Rulo, Nebr. on route U.S. Highway 159 (figs. 129–135). Four surveys were made at the Rulo Bridge during 2011(table 2). The discharges reported for USGS streamgaging station 06813500 Missouri River at Rulo, Nebraska, located at the Rulo Bridge were 227,000 ft^3/s on July 26; 207,000 ft^3/s on July 30; 110,000 ft^3/s on September 14; and 55,500 ft^3/s on November 4 (table 3).

The bed elevations surveyed during the July 26 survey ranged from 819 ft to 837 ft (fig. 130). The minimum bed elevation surveyed near the mid-channel pier was about 823 ft on July 26 and about 824 on July 30 (figs. 130 and 131). The bed elevation of the thalweg along the west bank was about 815 ft on July 26 and on July 30 (figs. 130 and 131). By September 14, the minimum bed elevation near the pier was about 827 ft, and the bed elevation of the thalweg along the west bank was about 822 ft (fig. 132). On November 4, the minimum bed elevation near the pier was about 823 ft, and the bed elevation of the thalweg along the west bank was about 822 ft (fig. 133).

The difference in bed elevation from July 26 to November 4 was computed for each cell occupied during both surveys (fig. 134). The mean difference value of all reoccupied cells was 1.1 ft, indicating that net deposition likely occurred in the surveyed area from July 26 to November 4.

In the bedload transport area, mean elevation for cells was similar for all four surveys: 829 ft on July 26 and July 30; 830 ft on September 14 and November 4. The range of elevations in the bedload transport area decreased during the same period (fig. 135). In the bedload transport area, 86 percent of elevations fell between 825 ft and 835 ft on July 26, whereas more than 99 percent of elevations fell in the same range on November 4.



Base from U.S. Department of Agriculture National Aerial Imagery Program, 2010
Universal Transverse Mercator projection, Zone 14
Horizontal coordinate information referenced to the North American Datum of 1983 (NAD 83)

Figure 129. Location of hydrographic surveys of the Missouri River in the vicinity of the Rulo Bridge at Rulo, Nebraska, July–November 2011.

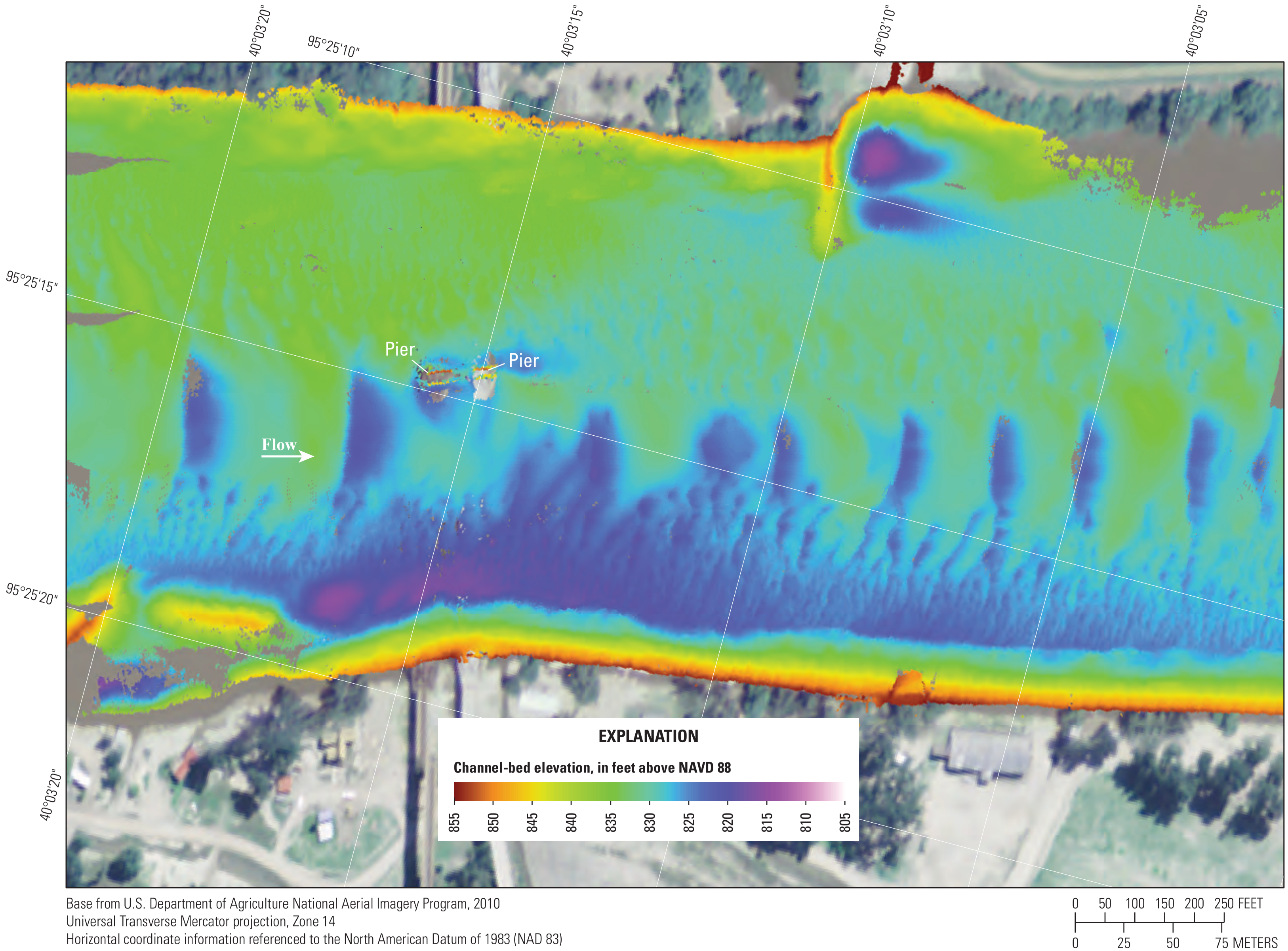


Figure 130. Channel-bed elevations of the Missouri River in the vicinity of the Rulo Bridge at Rulo, Nebraska, during flow of 227,000 cubic feet per second, July 26, 2011.

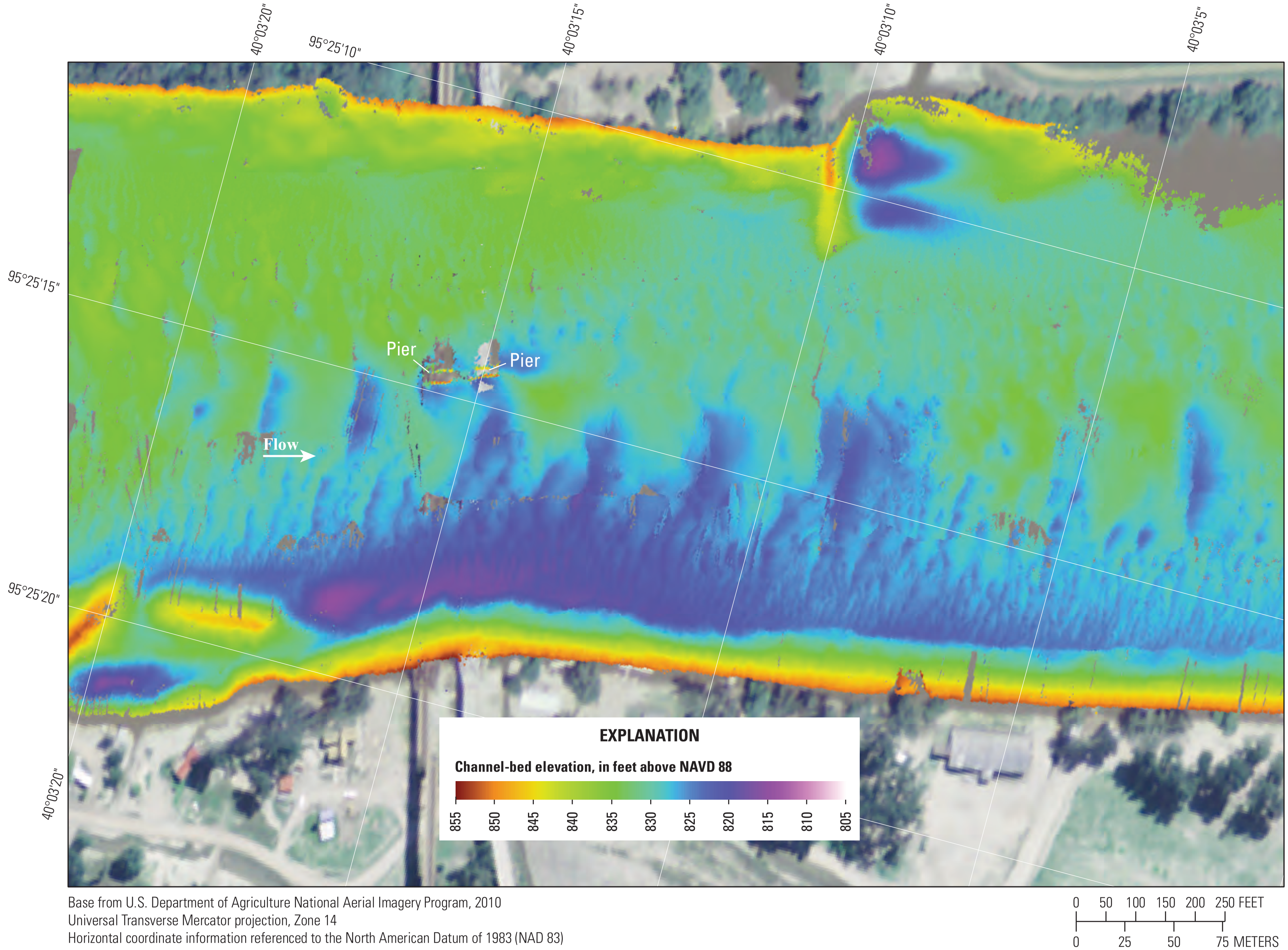
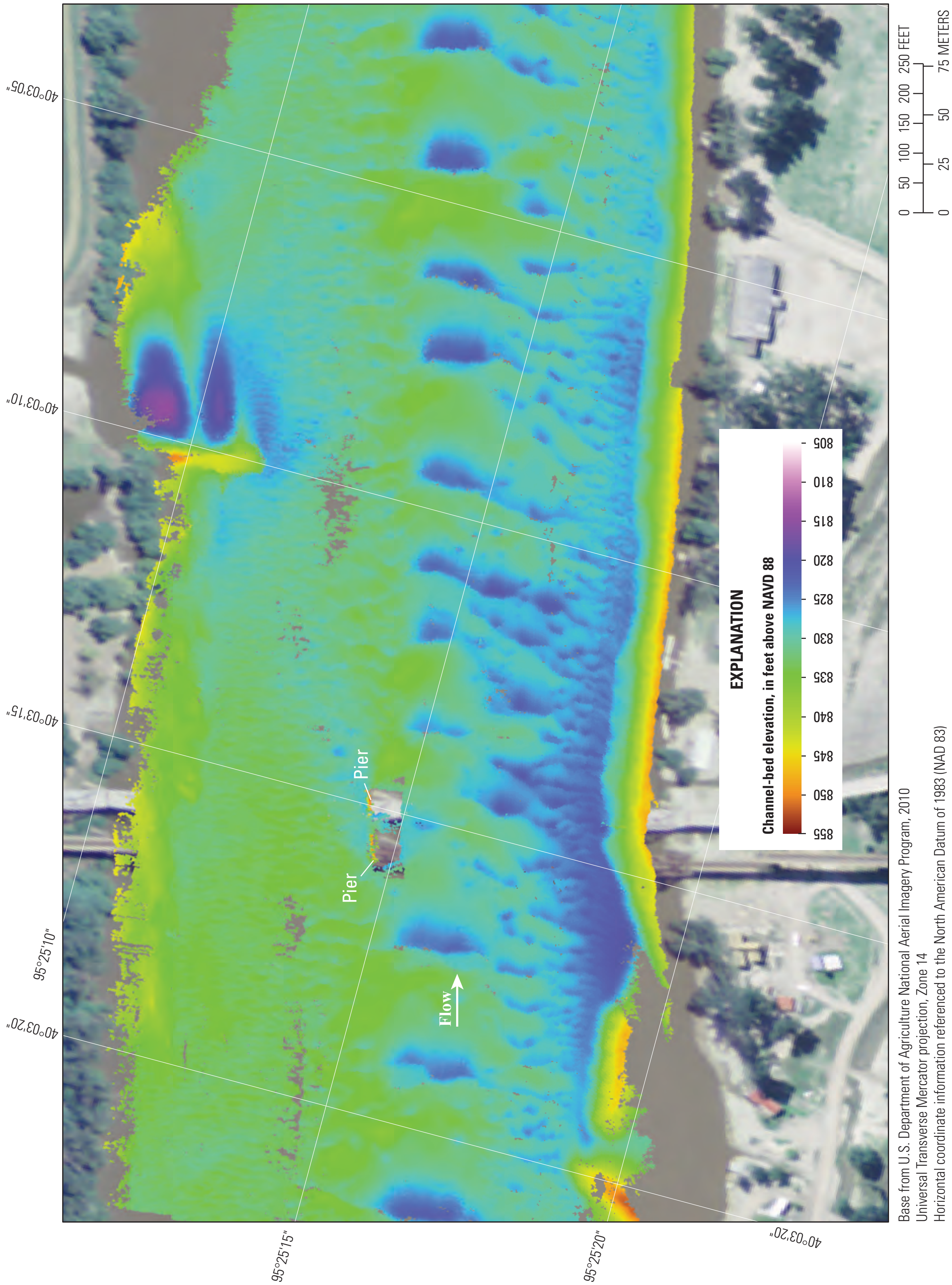
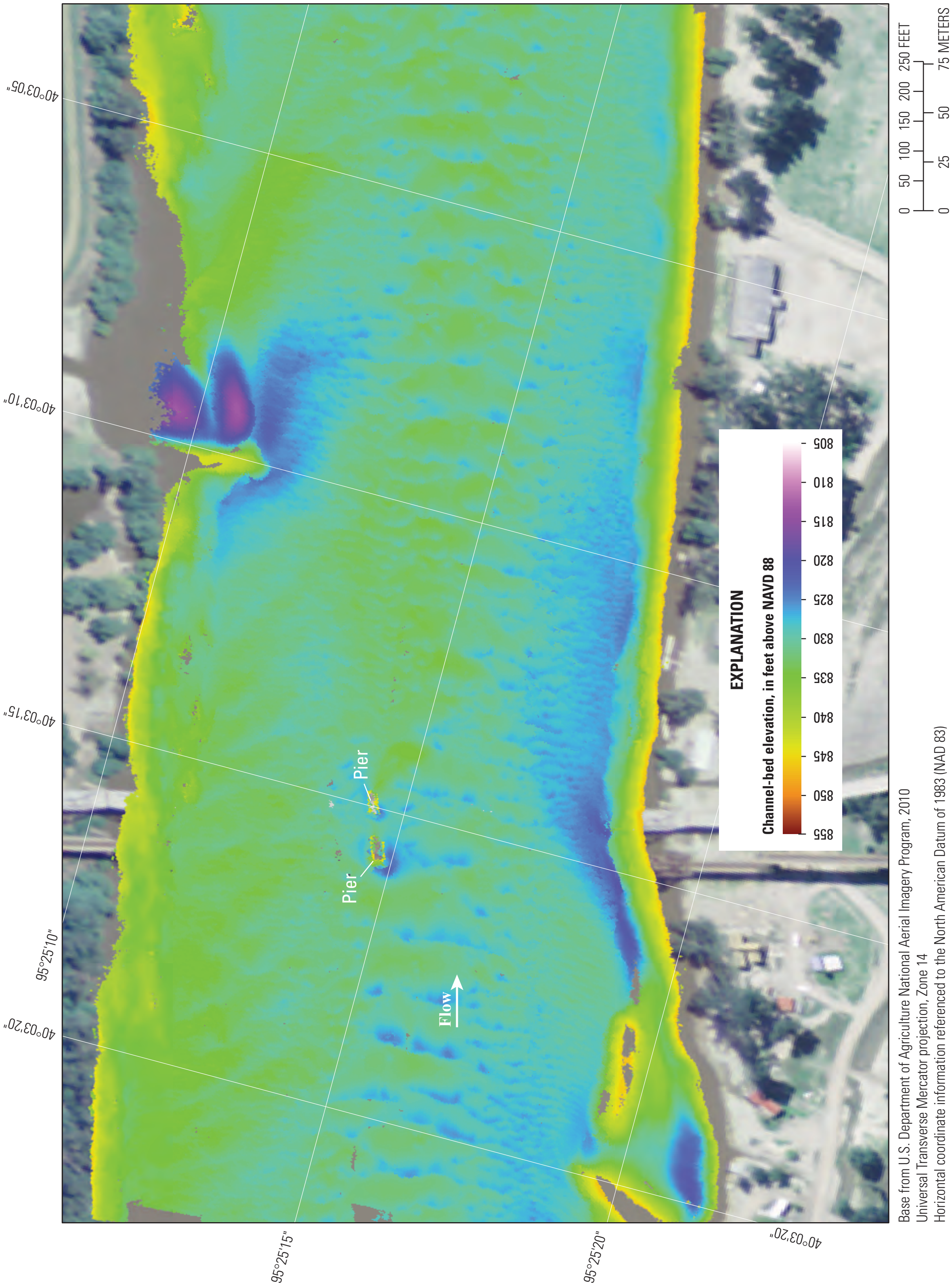


Figure 131. Channel-bed elevations of the Missouri River in the vicinity of the Rulo Bridge at Rulo, Nebraska, during flow of 207,000 cubic feet per second, July 30, 2011.



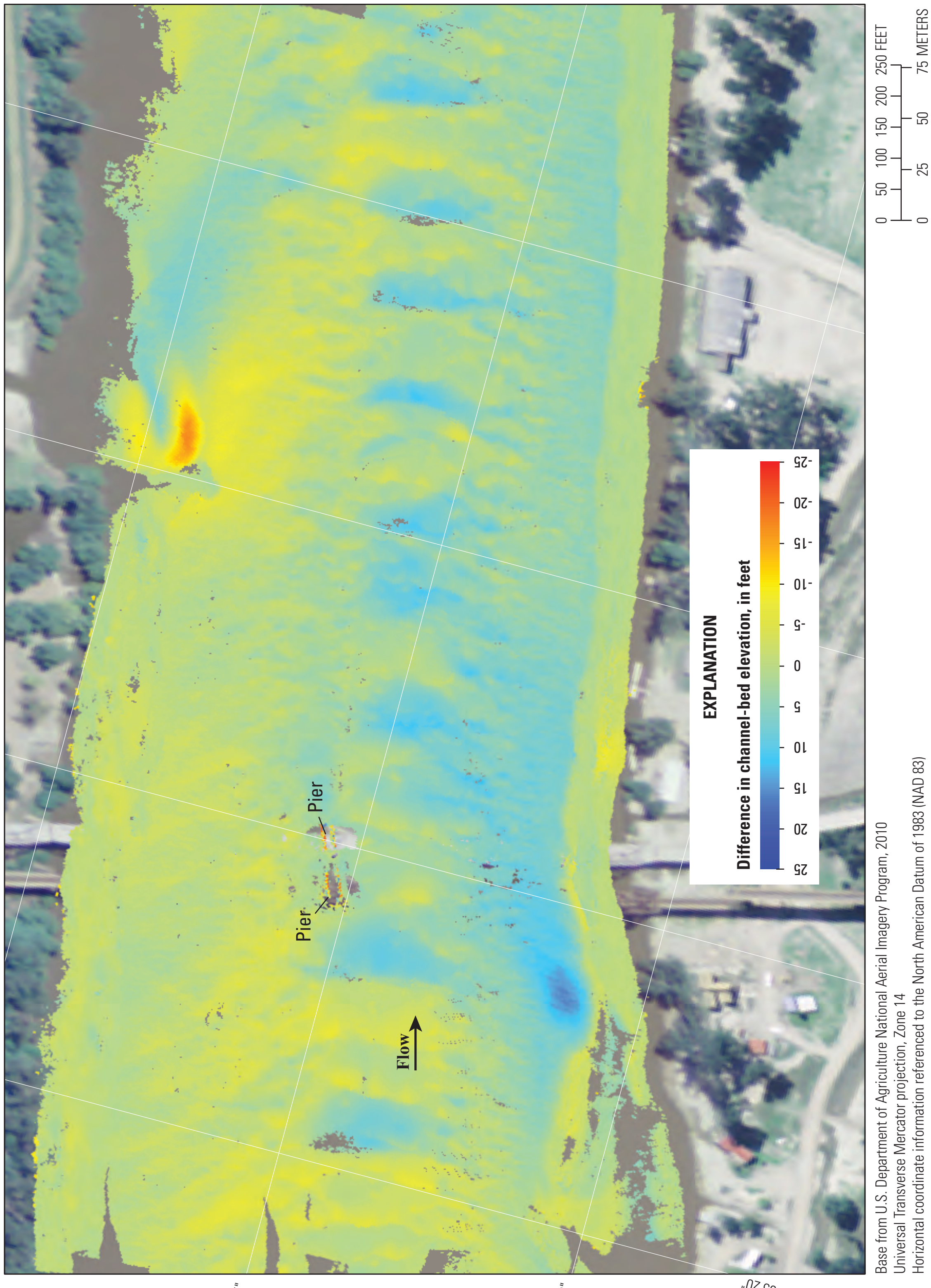
Base from U.S. Department of Agriculture National Aerial Imagery Program, 2010
Universal Transverse Mercator projection, Zone 14
Horizontal coordinate information referenced to the North American Datum of 1983 (NAD 83)

Figure 132. Channel-bed elevations of the Missouri River in the vicinity of the Rulo Bridge at Rulo, Nebraska, during flow of 110,000 cubic feet per second, September 14, 2011.



Base from U.S. Department of Agriculture National Aerial Imagery Program, 2010
Universal Transverse Mercator projection, Zone 14
Horizontal coordinate information referenced to the North American Datum of 1983 (NAD 83)

Figure 133. Channel-bed elevations of the Missouri River in the vicinity of the Rulo Bridge at Rulo, Nebraska, during flow of 55,500 cubic feet per second, November 4, 2011.



Base from U.S. Department of Agriculture National Aerial Imagery Program, 2010
Universal Transverse Mercator projection, Zone 14
Horizontal coordinate information referenced to the North American Datum of 1983 (NAD 83)

Figure 134. Difference in channel-bed elevation of the Missouri River in the vicinity of the Rulo Bridge at Rulo, Nebraska, between July 26 and November 4, 2011.

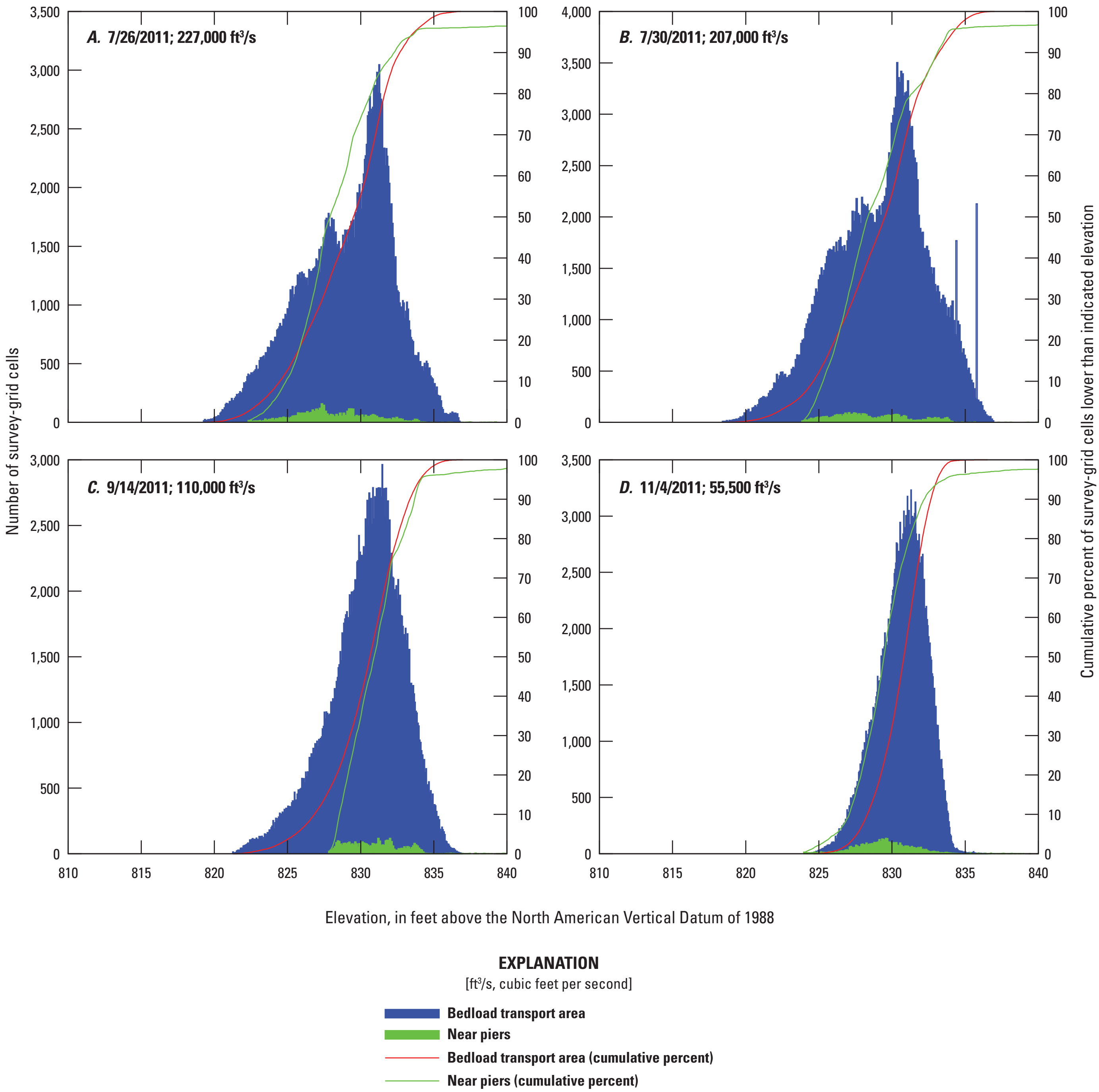


Figure 135. Frequency distribution of bed elevation, for hydrographic survey-grid cells (1.64-by-1.64 feet) sounded on the Missouri River in the vicinity of the the Rulo Bridge, at Rulo, Nebraska, *A*, July 26; *B*, July 30; *C*, September 14; and *D*, November 4, 2011.

Summary

Extreme flooding in the Missouri River Basin in 2011 caused unprecedented conditions that were expected to result in scour near structures in the Missouri River channel. The flooding prompted transportation agencies to increase the frequency of monitoring riverbed elevations near bridges that cross the Missouri River. In cooperation with the Nebraska Department of Roads, the U.S. Geological Survey completed hydrographic surveys using a multibeam echosounder at 15 highway bridges along the Missouri River from Niobrara to Rulo, Nebraska during and after the 2011 flood. This report documents the methodology, and describes and compares the results of the hydrographic surveys.

A high-resolution multibeam echosounder mapping system using real-time kinetic global positioning data was used for the hydrographic surveys. Four rounds of surveying occurred at different times during and after the flood at 14 of the 15 study sites on the Missouri River. One site, at the Chief Standing Bear Memorial Bridge, was surveyed twice. For most of the sites, the first two rounds of surveying occurred when releases at Gavins Point Dam were at or near the peak flood release of 160,000 cubic feet per second (ft^3/s), a third round of surveying occurred when releases from Gavins Point Dam were near 90,000 ft^3/s, and a fourth round of surveying occurred after releases dropped to 40,000 ft^3/s.

Mean total vertical uncertainty was calculated for each survey. The mean total vertical uncertainty ranged from 0.42 to 1.80 feet. Forty-six of the 58 surveys (79 percent) had mean vertical uncertainties of 1.0 foot or less.

Near three of the bridges, the bed elevation of locations surveyed in July increased by more than 10 feet, on average, by late October or early November 2011. Bed elevations increased between 1 and 10 feet, on average, near 6 bridges. Near the remaining four bridges, bed elevations decreased between 1 and 4 feet, on average, from July to late October or early November. Highway bridges where bed elevation change near piers appeared to have exceeded 10 feet include the Abraham Lincoln Memorial Bridge at Blair, Nebr., the Bellevue Bridge at Bellevue, Nebr., and the Nebraska City Bridge at Nebraska City, Nebr .

At the Chief Standing Bear Memorial Bridge, changes in elevation from the July 25 survey to the July 29 survey were small in most areas and attributable to dune movement. At Yankton, South Dakota, local scouring was not readily apparent near the piers of the Yankton Discovery Bridge on July 29; however, bed elevation increased 10–15 feet from July 20 to October 31, 2011, at the northernmost bridge pier of the Meridian Bridge immediately downstream. Sandbar movement through the survey area at Vermillion-Newcastle Bridge was documented; however, the mean of bed elevations at the bedload transport area was not substantially different from June 23 to September 1, 2011. For all four rounds of surveying at Siouxland Veterans Memorial (U.S. Highway 77) Bridge at Sioux City, Iowa, bed elevations near the two bridge piers in the survey area did not indicate more than minor local scouring; bed elevations near the piers generally fell within the range of bed elevations of dunes in other parts of the bedload transport area. Bed elevations near the piers of Sergeant Floyd Memorial (Interstate 129) Bridge in Sioux City, Iowa, were affected by bedform movement, varying as much as 10 feet between rounds of surveying. Substantial flows measured by field crews through an old channel on the Iowa side of the Missouri River at the Burt County Missouri River Bridge at Decatur, Nebr., likely contributed to scour depths of 45 feet between the abutment and bridge pier. At the Memorial (U.S. Highway 30) Bridge at Blair, Nebr., bed elevations at the mid-channel pier were 5–10 feet lower than the deepest part of the main channel during the flooding event, and an average of more than 12 feet of deposition occurred over the survey area after flows decreased. All four surveys at the Mormon Pioneer Memorial Bridge at Omaha, Nebr., indicated that no more than minor bed elevation changes occurred near the mid-channel bridge piers; bed elevations near these piers generally were within the range of bed elevations of dunes in other parts of the bedload transport area. At the Grenville Dodge Memorial (Interstate 480) Bridge at Omaha, minimum bed elevations near the mid-channel piers were affected by dune movement, and varied by about 4 feet between survey rounds. Minimum bed elevation near the mid-channel piers of the Interstate 80 Bridge at Omaha did not change more than 4 feet for the three rounds of surveying during the flood. At the South Omaha Veterans Memorial Bridge large scour holes were present downstream from wing dikes on the east bank; however, bed elevations near the two bridge piers in the survey area did not indicate substantial local scouring. Also at the South Omaha study site, about 18 feet of change in bed elevation was observed near the submerged remnants of the former South Omaha Bridge. At the Bellevue Bridge at Bellevue, Nebr., deposition of 20 feet or more occurred in parts of the channel between September 7 and November 9. Bed elevations near the mid-channel bridge pier of the Plattsmouth Bridge at Plattsmouth, Nebr., were about 1 to 4 feet lower than the deepest part of the channel during the first two rounds of surveying, and more than 9 feet of deposition occurred near the mid-channel pier after flooding subsided. Bed elevations adjacent to the mid-channel pier of the Nebraska City (Nebraska and Iowa Highway 2) Bridge at Nebraska City, Nebr., were about 20 feet lower than the lowest parts of the channel upstream from the bridge on July 19, however about 14 feet of deposition occurred at the pier by October. At the Rulo Bridge at Rulo, Nebr., the minimum bed elevation surveyed near the mid-channel pier did not change substantially between surveys.

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