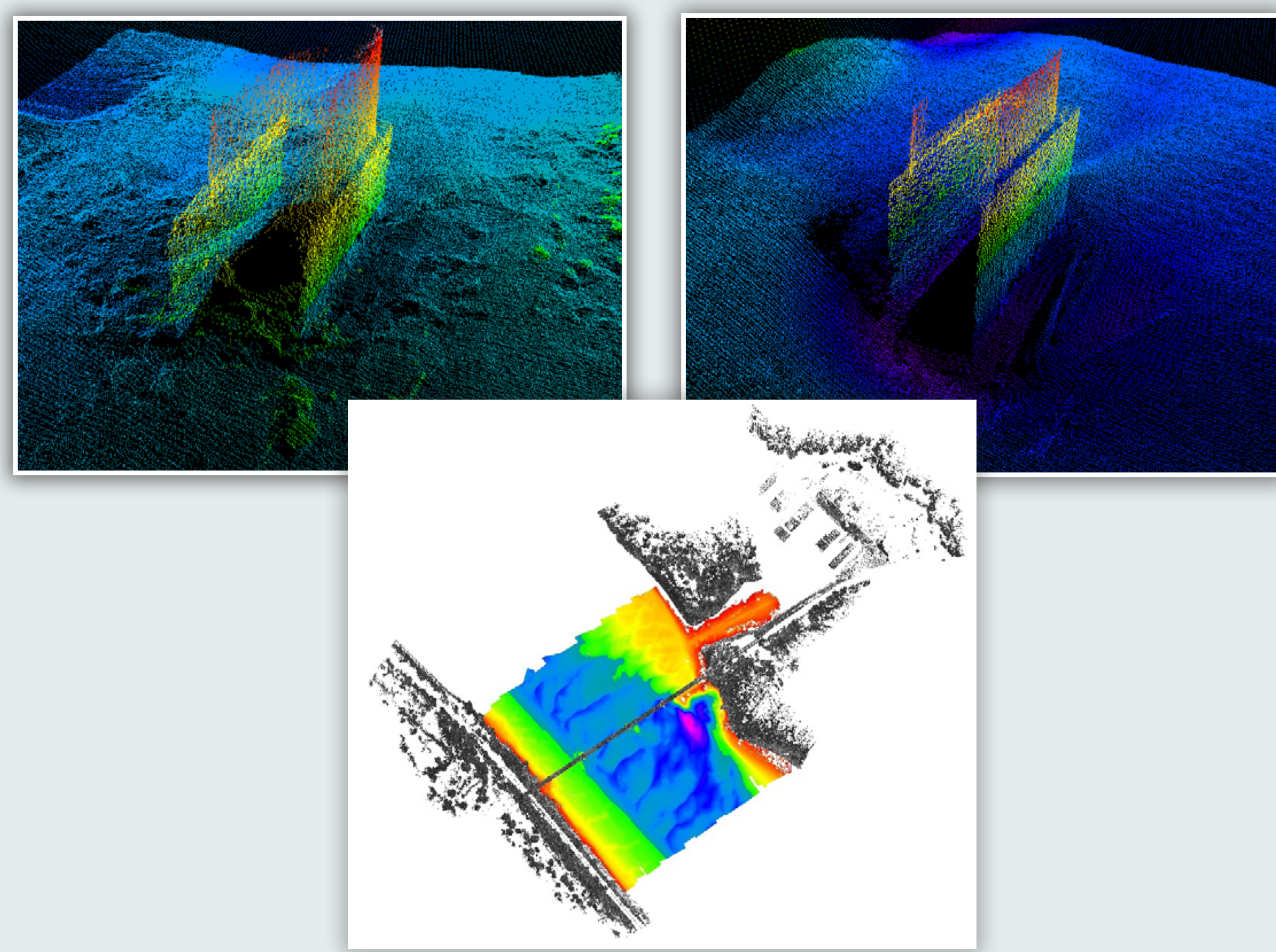
Prepared in cooperation with the Federal Highway Administration

Bridge Scour Countermeasure Assessments at Select Bridges in the United States, 2014–16



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Cover:
Banner:
Photograph showing topographical survey being conducted during the August 2016 site visit using total station scanners at the Two Medicine River near Browning, Montana (site ID 026).

Top left:
Bathymetric point cloud data obtained by Richard Huizinga during the July 2015 hydrographic survey at the Mississippi River at US-54 (site ID 003) near pier 2.

Top right:
Bathymetric point cloud data obtained by Richard Huizinga during the July 2015 hydrographic survey at the Mississippi River at US-54 (site ID 003) near pier 4.

Bottom:
Survey extent showing lidar and bathymetric point cloud data obtained by Richard Huizinga at the Mississippi River at US-54 (site ID 003).

Bridge Scour Countermeasure Assessments at Select Bridges in the United States, 2014–16

By Taylor J. Dudunake, Richard J. Huizinga, and Ryan L. Fosness

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

U.S. Department of the Interior
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Conversion Factors

Inch/Pound to International System of Units

Multiply	By	To obtain
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

Datums

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

Abbreviations

AEP	annual exceedance probability
DOT	Department of Transportation
FHWA	Federal Highway Administration
MBES	multibeam echo sounder
NBI	National Bridge Inventory
NWIS	National Water Information System
OFR	Open-File Report
RI	recurrence interval
RTK-GNSS	real-time kinematic-global navigation satellite system
SBES	singlebeam echosounder
T-LiDAR	terrestrial light detection and ranging technology
USGS	U.S. Geological Survey

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Abstract

In 2009, the Federal Highway Administration published Hydraulic Engineering Circular No. 23 (HEC-23) to provide specific design and implementation guidelines for bridge scour and stream instability countermeasures. However, the effectiveness of countermeasures implemented over the past decade following those guidelines has not been evaluated. Therefore, in 2013, the U.S. Geological Survey, in cooperation with the Federal Highway Administration, began a study to assess the current condition of bridge-scour countermeasures at selected sites to evaluate their effectiveness. Bridge-scour countermeasures were assessed during 2014-2016. Site assessments included reviewing countermeasure design plans, summarizing the peak and daily streamflow history, and assessments at each site. Each site survey included a photo log summary, field form, and topographic and bathymetric geospatial data and metadata. This report documents the study area and site-selection criteria, explains the survey methods used to evaluate the condition of countermeasures, and presents the complete documentation for each countermeasure assessment.

Introduction

On April 5, 1987, 10 people lost their lives as a result of the failure of a New York State Thruway bridge over Schoharie Creek (Lumia, 1998). The cause of the failure was erosion of the channel bed material, or scouring, under pier 3, which supported two of the five bridge spans (National Transportation Safety Board, 1988). According to the Federal Highway Administration (FHWA), scouring around bridge foundations is the most common cause of bridge failure (Federal Highway Administration, 2012). This risk can be mitigated by implementing effective bridge-scour countermeasures.

Bridge-scour countermeasures minimize risk to public transportation infrastructure by reducing sediment scour at bridges. Countermeasures can be defined as structures incorporated into a highway-stream crossing system that monitor, control, inhibit, change, delay, or minimize potential stream instability, bridge-scour, or both (Federal Highway Administration, 2009). In 2009, the FHWA published the Hydraulic Engineering Circular No. 23 (HEC-23) to provide specific design and implementation guidelines for bridge scour and stream instability countermeasures. However, the effectiveness of countermeasures implemented over the past decade following FHWA HEC-23 guidelines has not been evaluated (Federal Highway Administration, 2009). Therefore, in 2013, the U.S. Geological Survey (USGS), in cooperation with the FHWA, began a study to assess the current condition of bridge-scour countermeasures at 14 selected sites in four states. The FHWA will use these site-specific assessments to evaluate the effectiveness of bridge-scour countermeasures described in the HEC-23 design guidelines.

Purpose and Scope

This report summarizes countermeasure site assessments conducted in 2014 through 2016 at selected sites across the United States. Site assessments included reviewing countermeasure design plans, summarizing the peak and daily streamflow history, and a site survey to document the existing site and countermeasure. This report presents the complete documentation for each countermeasure assessment. This is the initial phase of a longer-term study that will apply similar objectives and methods to other sites across the United States.

This report documents the study area and site-selection criteria, explains the survey methods used to evaluate the condition of countermeasures, and presents site assessments summarizing the countermeasure condition.

Description of Study Area

The study area in this report includes 14 bridge sites in four States—Florida, Illinois, Missouri, and Montana (fig. 1). These sites represent various conditions with respect to river and bridge size, magnitude of flow, and type of countermeasures.

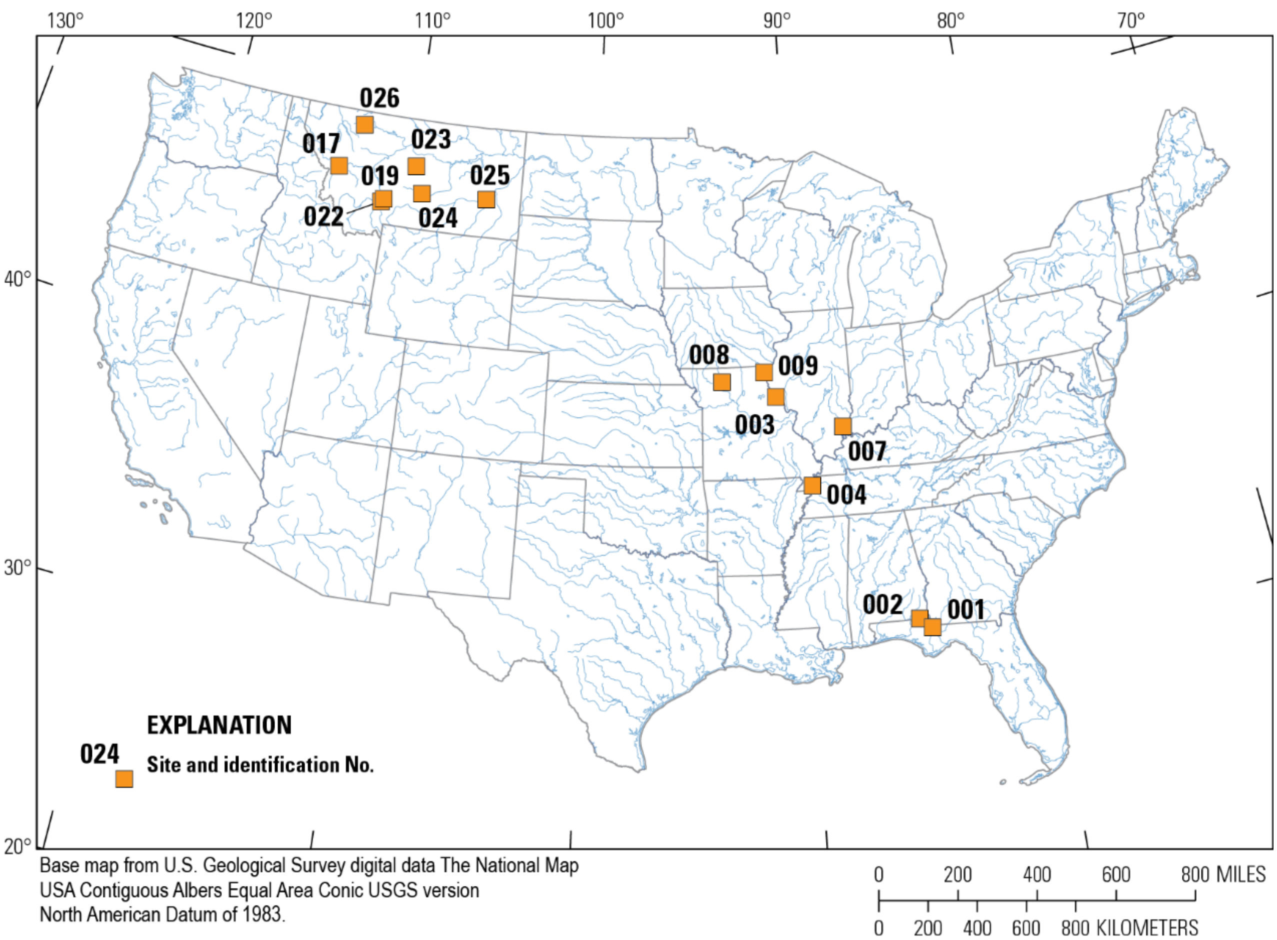

Figure 1. Map showing sites of the assessment of scour-related countermeasures at representative bridges throughout the United States, 2014–16.

Methods

To date, there has been no comprehensive evaluation of the effectiveness of the long-term performance of bridge-scour countermeasures provided by FHWA (2012). This study focused on collecting data to assess the current condition of different bridge-scour countermeasure types, mainly armoring structures (riprap, articulated blocks, concrete armor units, and gabion mattresses). Photographs, field forms, topographic surveys, and bathymetric surveys were collected at the selected sites. The following sections outline the methods used to complete these tasks.

Site Selection

The FWHA and the USGS selected bridges for this study from a combination of the National Bridge Inventory (NBI) and State Departments of Transportation databases using the following criteria:

1. The site had bridge-scour countermeasures in place that were designed according to HEC-23 guidelines.
2. The site was near an existing streamgage with a daily and peak streamflow record.
3. The site had experienced a significant streamflow event since the countermeasure was installed.

Criterion 1. Although the study objective was to assess the quality and overall effectiveness of countermeasures designed to FHWA HEC-23 guidelines, some exceptions were made for sites with installed countermeasures designed to earlier versions of FHWA guidelines. Site 004, Mississippi River at I-155 near Caruthersville, Missouri, is one example of this exception. The site's countermeasure remained structurally sound around main channel piers even though it experienced several substantial floods. Extensive details provided in the bridge-scour countermeasure plans made it a sufficient candidate for this study.

Criterion 2. Daily and peak streamflow data were evaluated at a nearby streamgage to review the flood history after countermeasures were installed. Historical streamflow observations and flood frequency statistics were obtained from the USGS National Water Information System (U.S. Geological Survey, 2016a), the USGS StreamStats Web application (U.S. Geological Survey, 2016b), and the U.S. Army Corps of Engineers (U.S. Army Corps of Engineers, 2014).

Criterion 3. Peak flow statistics were reviewed using StreamStats to determine the exceedance probability of each flood event after countermeasure installation. Peak flow statistics were estimated using PeakFQ or Flood Insurance Survey data when StreamStats was unavailable (Veilleux and others, 2014). The flood history was particularly important when assessing the effectiveness of designed countermeasures. Sites that experienced streamflows exceeding the 4-percent AEP (25-year recurrence interval) since the countermeasure had been installed were included in this study. As defined by the American Society of Civil Engineers, the recurrence interval (RI) is the average interval of time within which the given flood will be equaled or exceeded once (American Society of Civil Engineers, 1953). In some cases, countermeasures that experienced peak flows lower than the 4-percent AEP were considered if the bridges were located in mountainous regions. For example, sites on a high-gradient stream that experienced streamflows less than the 4-percent AEP were determined to have a stream power and complexity of hydraulics that caused scouring comparable to that of a 4-percent AEP event. The site was selected when the bankfull discharge (typically 1–2-year RI) produced scouring comparable to the 4-percent AEP event given a specific set of basin characteristics (Holnbeck and McCarthy, 2009). Most of the selected sites in Montana met the bankfull discharge criteria.

The 14 sites selected for countermeasure assessments represented hydraulically and geographically diverse environments (table 1) and were categorized 1–9 based on specific site characteristics including depth and turbidity of water, riparian vegetation, and surveying methods used to acquire data (table 2).

Scour Countermeasure Assessments

Site surveys included: (1) collecting detailed site photographs, (2) completing field forms summarizing site characteristics, and (3) collecting bathymetric and topographic data based on the survey category described in table 1. The USGS and the FHWA selected the Apalachicola River at I-10, near Chattahoochee, Florida, and Spring Creek at US-231, near Cambellton, Florida (sites 001 and 002, respectively) as locations to develop site survey methods.

The field team collected detailed photographs of the bridge structure, surrounding floodplain, and visible countermeasures. Photographs were documented in an annotated photo log for each site. Field forms derived from Cinotto and White (2000) were completed to describe the surrounding floodplain, channel characteristics, bridge substructure, and the countermeasures. These photographic and textual descriptions may assist in future modeling efforts and survey site analyses.

Survey sites requiring a manned boat to survey across large bodies of water were categorized as 1 and 2 sites (table 2). At the time of survey, depths at these sites generally exceeded 15 ft, suitable for using a multibeam echosounder (MBES) to acquire bathymetric data. Category 1 survey sites had clear water at the time of survey; allowing a gridded camera to be used to collect underwater images around the countermeasure if needed. Category 2 survey sites generally had turbid water that was unsuitable for underwater images. Sidescan technology was used at category 2 sites; providing high resolution images around the countermeasures.

The MBES provides high-resolution bathymetry data around submerged countermeasures. Coupled with real-time kinematic global navigation satellite systems (RTK-GNSS), the MBES is more advantageous than a single-beam echosounder (SBES), acoustic Doppler current profilers (ADCP), or other sounding methods because it provides greater coverage of the streambed to capture the bathymetry of the waterbody (Weakland and others, 2011).

Motion-compensated terrestrial light detection and ranging technology (T-LiDAR) captured high-resolution topography data for areas above the water surface and below the estimated peak flow stage. T-LiDAR technology uses rapidly moving laser pulses transmitted from the instrument. The pulses are reflected off the subject(s) and back to the instrument, which calculates the distance of the returned pulse based on the incoming velocity (Kimbrow and Lee, 2013). T-LiDAR data was generally collected around the super-structure, surrounding floodplain, bridge abutments, and piers that might be visible from the boat. Where vegetation was abundant in the area above water, RTK-GNSS topographical survey methods were used. The RTK-GNSS surveys followed the techniques and methods described in Rydlund and Densmore (2012).

Gridded camera systems were used to collect photographs at gridded locations around the piers and other submerged countermeasures. Visual samples were used to qualitatively assess the effects of aggradation, degradation, embeddedness, and the current condition of the countermeasure. This method excelled in deep-water conditions where SBES systems could not provide sufficient data resolution and MBES was not available. However, the camera systems were only useful in clear water conditions.

Table 1. Description of approved sites, assessment category, and post-countermeasure hydrologic summary with collected data throughout the United States, 2014–16.

[NBI, National Bridge Inventory; dms, degrees minutes seconds; ft^3/s, cubic feet per second; AEP, annual exceedance probability; USACE, U.S. Army Corps of Engineers; FL, Florida; MO, Missouri; IL, Illinois; MT, Montana]

Site No.	NBI structure No.	Site name	Latitude (dms)	Longitude (dms)	Survey Category	Representative streamgage	Year countermeasure installed	Peak-flow post-countermeasure (ft^3/s)	Year of peak flow post-countermeasure	Peak-flow, post-countermeasure, AEP (percent)
001	500086, 500087	Apalachicola River at I-10 (SR 8), near Chattahoochee, FL[1]	30 37 59.67	-84 54 10.95	1/2	02358000	2000	159,000	2005	10
002	530910	Spring Creek at US-231, near Cambellton, FL[1]	30 59 07.12	-85 24 25.80	5	02358789	2011	10,000	2013	
003	K0932	Mississippi River at US-54, (K0932) at Louisiana, MO	39 27 24.78	-91 02 50.83	1/2	USACE MILO	1992	456,000	2008	0.5–1
004	1936	Mississippi River at I-155 (A1700), near Caruthersville, MO	36 07 06.22	-89 36 54.27	1/2	USACE MS117	1973	2,040,000[2]	2011	1
007	33175 (097-0003/0004)	Wabash River at I-64 (097-0003/0004), near Grayville, IL	38 13 42.00	-87 59 06.00	1/2	03377500	2009	270,000	2011	4
008	A0906	Thompson River at MO-6 (A0906), near Trenton, MO	40 04 09.74	-93 38 16.27	3/4	06899500	2006	78,200	2014	2

Site No.	NBI structure No.	Site name	Latitude (dms)	Longitude (dms)	Survey Category	Represent-ative streamgage	Year counter-measure installed	Peak-flow post-counter-measure (ft^3/s)	Year of peak flow post-counter-measure	Peak-flow, post-counter-measure, AEP (percent)
009	A4584	Fox River at US-61 (A4584), near Wayland, MO	40 21 47.62	-91 34 25.78	5/6	05495000	2009	26,600	2011	1
017	L32210001+0.0801	Clark Fork River at Turah Road, near Bonner, MT	46 49 34.04	-113 48 52.07	8	12334550	2006	13,400	2011	10
019	I00090292+0.4251,2	Gallatin River at I-90, near Manhattan, MT	45 49 25.11	-111 16 19.70	8	06043500	2006	9,360	2011	4
022	S00205014+0.5181	Gallatin River at S-205, near Manhattan, MT	45 49 30.11	-111 16 18.00	8	06043500	2006	9,360	2011	4
023	P00081024+0.962	Judith River at MT-81, near Lewistown, MT	47 16 25.33	-109 43 12.11	9	06114700	2006	11,690	2011	0.5
024	S00300000+0.2001	Musselshell River at S-300, at Ryegate, MT	46 17 38.04	-109 15 28.23	9	06123030	2006	9,190	2011	1
025	I00094137+0.4601	Tongue River at I-94, at Miles City, MT	46 23 05.00	-105 50 43.54	8	06308500	2001	15,300	2011	2
026	P00003101+0.8001	Two Medicine River at US-89, near Browning, MT	48 28 22.74	-112 48 05.61	9	06091700	2008	7,940	2011	20

[1]Sites used to develop common survey methods among all personnel, data are limited.

[2]Streamflow determined through direct measurement.

Table 2. References for various data-collection techniques of category 1–9 sites.

[GNSS, global navigation satellite system; MBES, multibeam echo sounder; SBES, single beam echosounder; T-LiDAR, terrestrial light detection and ranging technology]

Category	Data collection technique	Reference
1/2	MBES	Wood and others, 2012; Huizinga, 2015; Fosness, 2013
	Gridded camera	Explained in report
	T-LiDAR	Kimbrow and Lee, 2013; Kimbrow, 2014; Brenner and others, 2016
3/4	SBES	Snyder and others, 2016
	Gridded camera	Explained in report
	T-LiDAR	Kimbrow and Lee, 2013; Kimbrow, 2014; Brenner and others, 2016
	Total station/RTK-GNSS	Rydlund and Densmore, 2012; Wood and others, 2012
5/6	Total station	Wood and others, 2012
	T-LiDAR	Kimbrow and Lee, 2013; Kimbrow, 2014; Brenner and others, 2016
7	T-LiDAR	Kimbrow and Lee, 2013; Kimbrow, 2014; Brenner and others, 2016
8	RTK-GNSS	Rydlund and Densmore, 2012
	Basic bathymetric survey	Mueller and Wagner, 2003
9	RTK-GNSS	Rydlund and Densmore, 2012
All	Basic countermeasure assessment field forms	Cinotto and White, 2000

Category 3 and 4 survey sites (table 2) had water conditions that were shallower than category 1 and 2 survey sites, roughly 5 –14 ft deep. At these sites, bathymetric data were collected with SBES or ADCP mounted to boogie-boards, small boats, and (or) by wading. T-LiDAR and RTK-GNSS were used to obtain topographic data as applicable. Sidescan technology and (or) gridded cameras also were used in similar situations as conditions allowed. Category 3 survey sites had clear water at the time of survey, while category 4 survey sites were turbid.

At category 5 and 6 survey sites (table 2), the water depth was less than 4 ft and a boat could not be used, so wading techniques were used instead. Surveyors used RTK-GNSS and total station to obtain bathymetric data. As with the category 3 and 4 survey sites, T-LiDAR, RTK-GNSS, or total station scanner systems were used to acquire topographic data. Category 5 survey sites had no vegetation that disturbed data collection, whereas obstructing vegetation existed at category 6 survey sites.

If the stream channel was dry, the site was classified as category 7 (table 2). This allowed for the use of T-LiDAR to obtain all data. Category 8 survey sites (table 2) were similar to category 3 and 4 survey sites, but were generally shallower than 4 ft deep. Additionally, category 8 survey sites did not require detailed structural, bathymetric, or topographic surveys using T-LiDAR or MBES. Category 9 survey sites (table 2) were less than 4 ft deep; did not require a bathymetric survey; and, similar to category 8 survey sites, did not require detailed structural, bathymetric, or topographic surveys using T-LiDAR or MBES. Base-level assessment data included photo documentation with cross-section bathymetry data and RTK-GNSS topography data (Mueller and Wagner, 2003).

Scour Countermeasure Assessment Data

Countermeasure assessment results from 14 bridges were processed and compiled for sites in Florida, Illinois, Missouri, and Montana (table 3). Results for each bridge included a compressed file containing three documents: countermeasure plans, detailed photograph log, and completed field forms. Geospatial data includes all topography and bathymetry data collected and associated metadata. A complete summary of geospatial data is available in Dudunake (2017).

Table 3. Surveyed sites, survey dates, and links to survey data for the assessment of scour-related countermeasures at representative bridges throughout the United States, 2014–16. (See https://doi.org/10.3133/ofr20171048.)

Summary

With the completion of bathymetric and topographical data collection, the FHWA will investigate the value of their countermeasure design guidelines by simulating conditions using computer modeling analyses and the acquired survey data. Additional bridge sites meeting the site selection criteria will be identified, and similar data collection will be conducted by the USGS followed by computer model analysis by the FHWA to provide the most complete dataset available. Final project reports will be written after all necessary documentation, summaries, and data have been collected. With the use these surveys and scour modeling, engineers will be able to design better bridge-scour countermeasures to withstand changing stream environments.

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