Prepared in cooperation with the Federal Highway Administration

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

Open-File Report 2017–1048
Version 1.1, October 2017

U.S. Department of the Interior
U.S. Geological Survey
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).
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U.S. Department of the Interior
U.S. Geological Survey
Conversion Factors

Inch/Pound to International System of Units

<table>
<thead>
<tr>
<th>Multiply</th>
<th>By</th>
<th>To obtain</th>
</tr>
</thead>
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<tr>
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<td>0.02832</td>
<td>cubic meter per second (m³/s)</td>
</tr>
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</table>

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
NWI      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 Campellton, 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; ft³/s, cubic feet per second; AEP, annual exceedance probability; USACE, U.S. Army Corps of Engineers; FL, Florida; MO, Missouri; IL, Illinois; MT, Montana]

<table>
<thead>
<tr>
<th>Site No.</th>
<th>NBI structure No.</th>
<th>Site name</th>
<th>Latitude (dms)</th>
<th>Longitude (dms)</th>
<th>Survey Category</th>
<th>Representative streamgage</th>
<th>Year countermeasure installed</th>
<th>Peak-flow post-countermeasure (ft³/s)</th>
<th>Year of peak flow post-countermeasure</th>
<th>Peak-flow, post-countermeasure, AEP (percent)</th>
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<tbody>
<tr>
<td>001</td>
<td>500086, 500087</td>
<td>Apalachicola River at I-10 (SR 8), near Chattahoochee, FL</td>
<td>30 37 59.67</td>
<td>-84 54 10.95</td>
<td>1/2</td>
<td>02358000</td>
<td>2000</td>
<td>159,000</td>
<td>2005</td>
<td>10</td>
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<tr>
<td>002</td>
<td>530910</td>
<td>Spring Creek at US-231, near Cambellton, FL</td>
<td>30 59 07.12</td>
<td>-85 24 25.80</td>
<td>5</td>
<td>02358789</td>
<td>2011</td>
<td>10,000</td>
<td>2013</td>
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<tr>
<td>003</td>
<td>K0932</td>
<td>Mississippi River at US-54, (K0932) at Louisiana, MO</td>
<td>39 27 24.78</td>
<td>-91 02 50.83</td>
<td>1/2</td>
<td>USACE MILO</td>
<td>1992</td>
<td>456,000</td>
<td>2008</td>
<td>0.5–1</td>
</tr>
<tr>
<td>004</td>
<td>1936</td>
<td>Mississippi River at I-155 (A1700), near Caruthersville, MO</td>
<td>36 07 06.22</td>
<td>-89 36 54.27</td>
<td>1/2</td>
<td>USACE MS117</td>
<td>1973</td>
<td>2,040,000</td>
<td>2011</td>
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<td>007</td>
<td>33175 (097-0003/0004)</td>
<td>Wabash River at I-64 (097-0003/0004), near Grayville, IL</td>
<td>38 13 42.00</td>
<td>-87 59 06.00</td>
<td>1/2</td>
<td>03377500</td>
<td>2009</td>
<td>270,000</td>
<td>2011</td>
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<td>008</td>
<td>A0906</td>
<td>Thompson River at MO-6 (A0906), near Trenton, MO</td>
<td>40 04 09.74</td>
<td>-93 38 16.27</td>
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<td>2006</td>
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<td>Site No.</td>
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<td>Site name</td>
<td>Latitude (dms)</td>
<td>Longitude (dms)</td>
<td>Survey Category</td>
<td>Representative streamgage</td>
<td>Year counter-measure installed</td>
<td>Peak-flow post-counter-measure (ft³/s)</td>
<td>Year of peak flow post-counter-measure</td>
<td>Peak-flow, post-counter-measure, AEP (percent)</td>
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<tr>
<td>---------</td>
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</tr>
<tr>
<td>009</td>
<td>A4584</td>
<td>Fox River at US-61 (A4584), near Wayland, MO</td>
<td>40 21 47.62</td>
<td>-91 34 25.78</td>
<td>5/6</td>
<td>05495000</td>
<td>2009</td>
<td>26,600</td>
<td>2011</td>
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<tr>
<td>017</td>
<td>L32210001+0.0801</td>
<td>Clark Fork River at Turah Road, near Bonner, MT</td>
<td>46 49 34.04</td>
<td>-113 48 52.07</td>
<td>8</td>
<td>12334550</td>
<td>2006</td>
<td>13,400</td>
<td>2011</td>
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<td>019</td>
<td>I00090292+0.42512</td>
<td>Gallatin River at I-90, near Manhattan, MT</td>
<td>45 49 25.11</td>
<td>-111 16 19.70</td>
<td>8</td>
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<td>022</td>
<td>S00205014+0.5181</td>
<td>Gallatin River at S-205, near Manhattan, MT</td>
<td>45 49 30.11</td>
<td>-111 16 18.00</td>
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<td>9,360</td>
<td>2011</td>
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<td>023</td>
<td>P00081024+0.962</td>
<td>Judith River at MT-81, near Lewistown, MT</td>
<td>47 16 25.33</td>
<td>-109 43 12.11</td>
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<td>06114700</td>
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<td>024</td>
<td>S003000000+0.2001</td>
<td>Musselshell River at S-300, at Ryegate, MT</td>
<td>46 17 38.04</td>
<td>-109 15 28.23</td>
<td>9</td>
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<td>9,190</td>
<td>2011</td>
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<td>025</td>
<td>I00094137+0.4601</td>
<td>Tongue River at I-94, at Miles City, MT</td>
<td>46 23 05.00</td>
<td>-105 50 43.54</td>
<td>8</td>
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<td>15,300</td>
<td>2011</td>
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<td>026</td>
<td>P00003101+0.8001</td>
<td>Two Medicine River at US-89, near Browning, MT</td>
<td>48 28 22.74</td>
<td>-112 48 05.61</td>
<td>9</td>
<td>06091700</td>
<td>2008</td>
<td>7,940</td>
<td>2011</td>
<td>20</td>
</tr>
</tbody>
</table>

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]

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

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.

Acknowledgments

The authors express their appreciation to the Departments of Transportation in Florida, Illinois, Missouri, and Montana for providing necessary data for each of these sites. Finally, we thank our USGS colleagues Pete Cinotto, Chad Wagner, Kathryn Lee, Justin Boldt, Tom Suro, Steve Holnbeck, Sean Lawlor, Ben Dietsch, Justin Krahulik, Brenda Densmore, Rich Akins, Ben Rivers, and Ben Sleeper for their assistance with fieldwork, logistical support, and overall management of this project.
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