Western Transportation Research Consortium


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Estimating Bridge Scour During Hydrological Disaster and Extreme Weather Events: Synthesis of Practice

WTRC Project 25-4 Final Report

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16. Abstract

Bridge scour is a leading cause of bridge failure in the United States, and detecting and measuring scour is critical during hydrological disasters and extreme weather events. However, turbulence, debris, and safety risks during such events often prevent the direct evaluation and measurement of bridge scour. The goal of the study was to investigate established and emerging tools and technologies used to estimate bridge scour in both normal and high-risk conditions. The Western Transportation Research Consortium pooled fund study (TPF-5(526)) conducted a synthesis research study that included a literature review of research and published guidance, as well a survey of state departments of transportation (DOTs) nationwide on their practices, challenges and future directions on this topic. The resulting synthesis of practice incorporates domestic and international literature, as well as survey responses from 30 state DOTs. Common themes across survey responses include reliance on field inspections and modeling tools and methods like Federal Highway Administration's Hydraulic Engineering Circular No. 18 (HEC-18) and the US Army Corps of Engineers Hydrologic Engineering Center's River Analysis System (HEC-RAS), limited real-time monitoring during flood events, and widespread interest in emerging tools like drones, sonar, and sensors. The synthesis report also presents gaps in findings and possible next steps that transportation agencies might take to address this topic.

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Abbreviations and Acronyms

AASHTO	American Association of State Highway and Transportation Officials
ADCP	acoustic Doppler current profiler
AI	artificial intelligence
ANFIS	adaptive neuro-fuzzy inference system
ANN	artificial neural network
CCTV	closed-circuit television
DOT	department of transportation
ELM	extreme learning machine
EMILY	emergency integrated lifesaving lanyard
FHWA	Federal Highway Administration
GEP	gene expression programming
GIS	geographic information system
GMDH	group method of data handling
GUI	graphical user interface
H&H	hydraulics and hydrology
HEC-RAS	US Army Corps of Engineers Hydrologic Engineering Center - River Analysis System
HEC-18	FHWA Hydraulic Engineering Circular No. 18 (Scour Manual)
HMS	hydrologic modeling system
IoT	internet of things
InSAR	interferometric synthetic aperture radar
LiDAR	light detection and ranging
LSPIV	large-scale particle image velocimetry
LSTM	long short-term memory (deep learning model)
MBES	multibeam echo sounder
MDOT	Michigan Department of Transportation
MEMS	micro-electro-mechanical systems
MSE	Mean square error
NBI	National Bridge Inventory
NWS	National Weather Service
POA	plan of action (for scour-critical bridges)
RAC	Research Advisory Committee
RQ-30	radar-based discharge/velocity gage

SBAS	small baseline subset (InSAR technique)
SHM	structural health monitoring
SMS	Surface-water Modeling System (software)
SNBI	Specifications for the National Bridge Inventory
SOP	standard operating procedure
SP&R	State Planning and Research (project designation)
SRICOS	scour rate in cohesive soils
SVM	support vector machine
TDR	time domain reflectometry
UAS	unmanned aerial system
USGS	United States Geological Survey
VTP	vibration-based turbulent pressure (sensor)
WTRC	Western Transportation Research Consortium

Executive Summary

Background

Bridge scour is a leading cause of bridge failure in the United States. While state departments of transportation (DOTs) have established methods for evaluating scour under normal flow conditions, assessing scour during hydrological disasters and extreme weather events remains a significant challenge. High-flow turbulence, debris, and safety risks often prevent direct measurements, so instead agencies rely on predictive models in these circumstances. Yet the accuracy of these models depends on reliable data input, which can be difficult to obtain during extreme conditions.

To address these challenges, the Western Transportation Research Consortium (WTRC) pooled fund study (TPF-5(526)), westerntrc.org), initiated a research effort on this topic proposed by WTRC member agency Colorado DOT. The goal of the study was to explore established and emerging tools and technologies for estimating bridge scour in both normal and high-risk conditions. Technologies such as drones, sonar, LiDAR, and embedded sensors offer new opportunities to gather data in hazardous environments and improve the inputs used in hydraulic modeling.

This synthesis of practice is a step in documenting how state DOTs currently monitor and estimate scour, understanding how effective these methods are, identifying challenges and gaps in knowledge and technologies, and outlining possible next steps for WTRC members. Working with guidance and oversight from a team of WTRC state DOT representatives, a consultant research team conducted a literature review of research and survey of state DOTs nationwide and summarized and synthesized the findings here.

Survey Findings

Survey responses from 30 state transportation agencies provide insight into the methods and technologies currently used to detect scour during normal flow conditions and during extreme hydrological events. Agencies also described the effectiveness of their approaches and the challenges they face with implementation.

The responses reveal a wide range of practices. Some states rely primarily on manual inspections and modeling, while others are piloting advanced tools like sonar, tilt sensors, and real-time monitoring systems. However, even the most advanced methods are often limited to a small number of high-risk sites, and few states report collecting flow or velocity data during flooding events.

State DOTs currently use a range of methods and technologies to measure or estimate scour during normal flow conditions. The most common tools and methods include hydraulic modeling (17 states reporting), field inspections (15), manual hydraulic measuring tools (12), and sonar (9).

States use a variety of methods to obtain scour-related data during extreme hydrological events such as flash floods. These include field inspections (12 states reporting), sonar (9), manual hydraulic measuring tools (7), and hydraulic modeling (5).

The methods and tools that states reported as being effective include streamgages (3 states reporting), modeling (2), sonar (2), soundings (2) and monitoring sensors (1).

The challenges most frequently reported include a limited number of streamgages in place (10 states reporting), safety concerns (4), the cost of implementing and maintaining advanced monitoring systems (4), and equipment damage (3).

Common themes across survey responses include reliance on field inspections and established scour analysis guidance and hydraulic modeling tools, including the Federal Highway Administration's Hydraulic Engineering Circular No. 18 (HEC-18) for scour calculations and the US Army Corps of Engineers Hydrologic Engineering Center's River Analysis System (HEC-RAS) platform for hydraulic and sediment transport modeling. States also reported limited real-time monitoring during flood events and widespread interest in emerging tools like drones, sonar, and sensors.

Colorado DOT Analysis

Early in the synthesis process, the complete survey responses were provided to the WTRC project subcommittee. Two Colorado DOT staff members performed an internal analysis on the results and compiled a spreadsheet tabulating states' responses in three tables:

- Technologies and methods currently used to measure or estimate bridge scour
- Technologies and methods to measure hydrological variables during disaster events
- Effectiveness; challenges and gaps

Findings from the Literature

A literature search of publicly available research includes domestic and international publications organized into the following topic areas:

- Overview Articles, Frameworks, and Critical Reviews.
- Vibration-Based Monitoring Techniques.
- Sonar Tools and Technologies.
- Remote Sensing: Radar, LiDAR, and InSAR.
- Embedded Sensors (Non-Vibration-Based).
- Emerging Technologies: AI and Machine Learning.
- Commercial Tools and Vendor Solutions.

Gaps in Findings

Common gaps identified by survey respondents include:

- Lack of real-time monitoring at most bridges. Even when tools exist, they are often deployed only at select scour-critical sites.
- Limited gage coverage. Many states noted that existing USGS streamgages are insufficient to support accurate analysis across vast bridge networks.

- Inadequate velocity and flow depth data during disasters. Few states measure these parameters in real time, often relying instead on estimates or models, resulting in overestimation or underestimation of factors used in modeling, which may, in turn, affect decision-making.
- Limited personnel for post-flood forensic analysis. Some states noted that specialized post-event analyses require technical expertise that may reside with only a handful of personnel. This creates a risk of knowledge gaps if those individuals are unavailable or depart the agency, highlighting the need for cross-training and clear documentation of methods.

Next Steps

To improve scour assessment capabilities during extreme weather events, state DOTs might consider taking the following actions:

- Expand monitoring coverage to increase the number of instrumented sites, especially at scour-critical bridges, to improve emergency response and reduce risk.
- Pilot or adopt newer technologies that can survive turbulent conditions, which may be more practical than surface-mounted devices and safer than taking measurements in the field during or after an event.
- Invest in low-cost assessment tools for quick-reaction teams who do not need significant training in this area, such as maintenance staff, to respond to situations and determine whether a more thorough data collection process would be required to obtain critical parameters for more accurate modeling.
- Invest in training and the development of standard operating procedures (SOPs). Several states noted the need for internal training and SOPs for deploying and interpreting advanced tools.
- Collaborate with the United States Geological Survey (USGS), universities, and local agencies to expand access to hydraulic data and support cross-training efforts.
- Evaluate cost-benefit tradeoffs. While some technologies carry high upfront costs, they may reduce inspection burdens and improve safety during flood events.
- Track the progress of pilot projects from other states. Multiple DOTs are currently piloting new scour detection methods, including unmanned vessels, radar-based measurements, and drone-mounted sonar. Following the results of these projects can help other agencies decide whether to adopt similar technologies.
- Pursue or support future research on using emerging tools like sonar, sensors, and drones in challenging conditions and developing practical guidance for when and where to use these tools across large bridge networks.

1. Background and Report Organization

1.1. Background

Bridge scour is a leading cause of bridge failure in the United States. While state departments of transportation (DOTs) have established methods for evaluating scour under normal flow conditions, assessing scour during hydrological disasters and extreme weather events remains a significant challenge. High-flow turbulence, debris, and safety risks often prevent direct measurements, so instead agencies rely on predictive models in these circumstances. Yet the accuracy of these models depends on reliable data input, which can be difficult to obtain during extreme conditions.

To address these challenges, the Western Transportation Research Consortium (WTRC) pooled fund study (TPF-5(526)), westerntrc.org), initiated a research effort on this topic proposed by WTRC member agency Colorado DOT. The goal of the study was to explore established and emerging tools and technologies for estimating bridge scour in both normal and high-risk conditions. Technologies such as drones, sonar, LiDAR, and embedded sensors offer new opportunities to gather data in hazardous environments and improve the inputs used in hydraulic modeling.

This synthesis of practice is a step in documenting how state DOTs currently monitor and estimate scour, understanding how effective these methods are, identifying challenges and gaps in knowledge and technologies, and outlining possible next steps for WTRC members. Working with guidance and oversight from a team of WTRC state DOT representatives, a consultant research team conducted a literature review of research and survey of state DOTs nationwide and summarized and synthesized the findings here.

1.2. Report Organization

Survey of Findings

Chapter 2 presents detailed findings from the survey, organized into six sections that correspond to the six questions that were asked in the survey.

Each section begins with a short overview of responses for that question and includes a summary table that highlights the major themes and patterns.

Sections 2.1 and 2.2 provide a more detailed look at the specific tools and methods states reported using during normal-flow and extreme-flow conditions, grouped into four categories:

- Modeling.
- Field Inspections and Manual Tools and Methods.
- Sonar Tools and Technologies.
- Remote Visual and Real-Time Monitoring.

Each category includes a table showing narrative responses from select states to provide context and illustrate how states use the tools or methods in practice.

Section 2.3 summarizes states' responses concerning the methods and tools they find to be effective and the challenges they face.

Section 2.4 presents survey attachments and other documentation, including research reports, state-developed methods mentioned in the survey, and links to select tools and resources that were referenced in the survey. This section also includes information provided by states about research in progress or in planning, as well as methods and technologies states are interested in exploring.

Literature Search

Chapter 3 presents findings from a literature search of domestic and international publications and resources related to monitoring and estimating bridge scour, organized into the following categories:

- Overview Articles, Frameworks, and Critical Reviews.
- Vibration-Based Monitoring Techniques.
- Sonar Tools and Technologies.
- Remote Sensing: Radar, LiDAR, and InSAR.
- Embedded Sensors (Non-Vibration-Based).
- Emerging Technologies: AI and Machine Learning.
- Commercial Tools and Vendor Solutions.

Gaps, Additional Analysis, and Next Steps

Chapter 4 highlights gaps and identifies possible next steps.

Appendices

Complete survey questions are listed in Appendix A. Appendix B presents a tabulation of data by the consultant research team, and Appendix C provides an independent tabulation of data by Colorado DOT.

2. Survey of Practice

An online survey was distributed to all 51 state DOT research offices through the AASHTO Research Advisory Committee (RAC) mailing list. Thirty states responded:

- Alabama
- California
- Colorado
- Connecticut
- Delaware
- Idaho
- Indiana
- Kansas
- Kentucky
- Maine
- Michigan
- Minnesota
- Mississippi
- Missouri
- Montana
- Nebraska
- Nevada
- New Hampshire
- New Jersey
- New Mexico
- New York
- North Dakota
- Oregon
- South Carolina
- South Dakota
- Texas
- Utah
- Vermont
- Washington
- Wyoming

The survey sought to identify the methods and technologies states currently use to measure or estimate bridge scour in normal conditions and during hydrological disaster events. It inquired about the effectiveness and challenges of these methods and technologies and which agency department is primarily responsible for bridge scour assessment and management. Respondents were asked to share documentation of any research conducted on the topic of measuring or estimating bridge scour.

Survey questions are provided below and in Appendix A. The survey tabulation used to help construct this synthesis is provided in Appendix B and organized in three tabs:

- Tab 1: How states measure or estimate scour in normal-flow conditions.
- Tab 2: How states obtain data for scour analyses in extreme-flow conditions.
- Tab 3: Categorized groupings of effective methods and challenges.

The survey questions are as follows:

1. What methods and technologies does your agency now use or plan to use to measure or estimate bridge scour in normal flow conditions?
2. What methods and technologies does your agency employ/deploy to obtain required data such as surface velocity, flow rate, flow depth, etc. for scour analysis during hydrological disaster events such as flash flooding?
3. How effective have these techniques and technologies been? What challenges and gaps has your agency identified?
4. Please provide any research/technical reports or documentation on this topic that you can share.
5. Which department, division, or office in your agency has the primary responsibility for bridge scour assessment and management?
6. Who may we contact at your agency with follow-up questions?

Note: Lack of mention does not imply lack of use: Some states may use additional methods or technologies that were not cited in their survey responses. This synthesis of practice reports only on what states explicitly stated in the survey.

In various places throughout the survey, several states reported using state-developed estimation methods, which are presented in Table 2.1 with links to the documentation.

Table 2.1. State-Developed Estimation Methods Mentioned in Survey Responses

State	Method or Model
Michigan	Utilizing MDOT's Bridge High Flow Event Monitoring Site
Michigan	Bridge High-Flow Event Monitoring Website
Nevada	Scour Plan of Action
New York	NYSDOT Hydraulic Vulnerability Model
South Carolina	SCDOT/USGS Real Time Scour Program
Texas	TxDOT Scour Analysis Guide
Texas	SRICOS Method (Texas A&M)

Also throughout the survey, some states mentioned specific tools and resources they use to monitor or estimate scour in normal-flow and extreme-flow conditions. Table 2.2 provides links to select tools and resources mentioned by various survey respondents.

Table 2.2. Links to Select Tools, Models, Methods, and Technologies Mentioned in the Survey

State Mentioning	Tool, Model, Method, or Technology	Type
Connecticut	BridgeWatch	Software
Delaware	USGS StreamStats	Web Application
Michigan	University of Michigan's Digital Water Lab	Real-Time Monitoring Tool
Mississippi	USGS WaterAlert	Web-Based Tool
Mississippi	USGS Pier-Scour Envelope Equation	Report
Montana	Blue View Sonar	Product
North Dakota	Iowa Flood Center	Information System
South Carolina	NCHRP Synthesis 573 Practices for Integrated Flood Prediction and Response Systems	Synthesis Report

2.1. Methods and Technologies Used to Measure or Estimate Scour in Normal Flow Conditions

States reported a variety of approaches to monitor or estimate scour in normal flow conditions. Commonly cited methods include hydraulic modeling, field inspections, manual measurements, and sonar. Idaho reported that scour does not occur during normal flow conditions. Responses to Question 1 are summarized in the following tables and presented in Tab 1 of the tabulation provided in Appendix B.

Table 2.3. Methods and Technologies Used to Measure or Estimate Bridge Scour in Normal Flow Conditions

Method	Number of States Using	States
Hydraulic Modeling	19	AL, CO, DE, IN, KS, KY, ME, MN, MS, MT, NJ, NM, NY, SC, TX, UT, VT, WA, WY
Field Inspections	17	CO, CT, DE, KS, KY, MN, MS, MT, NV, NH, NM, NY, ND, OR, TX, VT, WY
Manual Tools and Methods	12	CA, CO, DE, MN, MO, MT, NE, NY, OR, SC, SD, TX
Sonar	9	CA, CO, MI, MN, MO, MT, SC, SD, TX
Real-Time Monitoring	4	CO, CT, MN, MS
Remote Visual Monitoring	2	KY, MS

2.1.1. Modeling

To estimate bridge scour during normal flow conditions, 17 states use hydraulic modeling tools and methods. Commonly cited tools include HEC-18, HEC-RAS, FHWA Hydraulic Toolbox, and SRH-2D. These models rely on inputs like site geometry, historical flow data, and soil conditions, although their accuracy may be limited during turbulent or high-flow events.

Table 2.4. Hydraulic Modeling Tools and Methods

Modeling Tool/Method	States Reporting Use	Which States?
HEC-18	15	AL, CO, DE, IN, KS, ME, MN, MS, NJ, NM, NY, SC, UT, VT, WY
SRH-2D	6	CO, MN, MS, MT, NM, UT
HEC-RAS	5	DE, IN, KS, MN, MT
HEC-RAS 2D	3	CO, KS, MN
SMS	3	MT, NM, UT
FHWA Hydraulic Toolbox	3	DE, IN, UT
USGS pier-scour envelope equation	2	MS, SC
Not specified	1	WA
NCHRP 24-20	1	KS
HEC-20	1	DE
USGS Rapid Estimation Method	1	MT
USGS StreamStats	1	DE

Table 2.5. Data Sources for Modeling in Normal Flow Conditions

Method	Number of States Reporting	Which States?
Historical/structural data, past models	3	DE, NJ, NY
As-built pile tip elevations	2	DE, NY
USGS depth soundings @ stream gages	1	MS
FEMA post-flood data	1	DE
USGS post-flood data	1	DE
Estimated flows from drainage areas	1	ME
Historical soundings	1	MS
Soil gradations from the field	1	NM
Channel diagrams and site conditions	1	VT
Channel survey	1	ND
Cross-section measurements	1	MI

Table 2.6. Select State Responses: Modeling Tools, Methods, and Data Sources

State	Response
Colorado	Colorado uses 2D hydraulic modeling software that provides the necessary information and parameters to estimate bridge scour using HEC methodology and guidance. Bridges selected for evaluation vary based on regional priority, current projects and emergency response.
Delaware	Delaware primarily estimates scour using conventional hydraulic and field inspection techniques. HEC-18 is used for channel hydraulics and contraction/local scour calculations; the FHWA Hydraulic Toolbox is used for pier and abutment scour estimates; and USGS StreamStats is used to supplement watershed characteristics and flow estimates at sites without a streamgage. Delaware also collects as-built pile tip elevations and maintains scour assessment records internally for ongoing risk tracking.
Kansas	Kansas uses HEC-RAS 1D for hydraulic modeling and HEC-18 to estimate pier and contraction scour. It utilizes the NCHRP 24-20 approach to estimate abutment scour. Additionally, Kansas utilizes its bridge inspection teams' evaluations of site conditions.

State	Response
Mississippi	Mississippi employs SRH-2D modeling using HEC-18 methods. It also uses the USGS pier-scour envelope equation for Mississippi streams, along with historical soundings from the state's ground-to-grade (GTG) data and USGS depth soundings during flooding, mostly at streamgages. SRH-2D has been an improvement in modeling the flow vectors and quantity through the bridge openings, and in turn has improved the scour parameters used in the HEC-18 methods. The GTG data, the USGS historical soundings, and the USGS pier-scour envelope equation provide a comparison with the HEC-18 calculated scour to help determine if calculations are reasonable when evaluating existing bridges.
Nevada	Nevada follows the procedures laid out in its Scour Plan of Action, which is currently being updated. Follow-up underwater inspections are conducted after an event triggers an inspection. The updated Scour Plan of Action will include a program it will use for future inspections and planning. The program will have updated flow gage triggers and will use rainfall, snowfall, and snow melt to help predict whether a scour evaluation is needed.
New Jersey	New Jersey uses HEC-18 methods and compares the scour depths to historical data from previous storms and the inspection report results for each individual scour-critical bridge. New Jersey reported that HEC-18 formulas sometimes overestimate scour depth, so it is important to compare the results to current conditions and historical data.
New Mexico	New Mexico typically uses SMS/SRH-2D for modeling and to generate the input to HEC-18. The HEC-18 calculations are in coordination with soil gradations from the field when appropriate. The state has limited means to measure scour after the fact. It is typically done by field observation, which can be misleading as many of New Mexico's channels are live beds and fill in after the scour.
New York	New York follows guidelines from HEC 18 to design for scour at new bridges and follows guidance outlines in the NYSDOT Hydraulic Vulnerability Manual to estimate scour at existing bridges.
Texas	Texas utilizes both traditional and innovative scour analysis techniques to estimate future scour for bridge design purposes. Each method is summarized in TxDOT's Scour Analysis Guide. Notably, TxDOT uses the SRICOS method developed by Texas A&M to predict scour in cohesive channel beds. Texas is currently working on research with Texas A&M to develop SRICOS amplification factors to account for pressure scour conditions.
Utah	Utah uses HEC-18 methodologies and the FHWA Hydraulic Toolbox with inputs derived from a hydraulic model. The current Design Manual of Instruction requires the use of SMS with SRH-2D for bridge modeling to estimate scour at bridges. Within the SMS interface is the FHWA Hydraulic Toolbox, which is used to calculate scour depths. HEC-RAS has been used but is a deviation from manual design criteria.
Vermont	Since 2011, Vermont has used the methodologies found in HEC-18 to estimate scour and design structures to be resilient during the 100-year event.

State	Response
Washington	Washington collects bathymetry data for hydraulic modeling. Additionally, it uses geotechnical data from drilling or geophysics, when available, to evaluate erodibility of non-alluvial materials, when pertinent.

2.1.2. Field Inspections and Manual Measuring Tools and Methods

Twenty-two states reported using field inspections to evaluate scour during normal flow conditions. These methods include visual inspections, diver surveys, and manual tools such as weighted tapes, sounding rods, and velocity meters.

Table 2.7. Field Inspections and Manual Tools and Methods

Method	Number of States Reporting	States
Routine inspections	10	CO, CT, DE, KS, NH, NY, ND, OR, TX, WY
Weighted Tape/Dropline	7	CA, MO, NE, NY, SC, SD, TX
Underwater inspection	6	MN, MS, MT, NV, NY, OR,
Visual inspection of site conditions	4	MN, MT, NM, VT
Wading & probing	3	CA, DE, MT
Range pole	2	MO, NE
Survey/level rod	2	CO, MN
Sounding rods	2	DE, OR
Velocity meter	2	CO, MN
Scour probe rods (probes)	1	KY
Ultrasonic hammer for exposed piles	1	KY
Sounding weight & crane	1	MN
Diver inspection (consultant or in house)	1	NH

Table 2.8. Select State Responses: Field Inspection and Manual Tools and Methods

State	Response
California	To measure scour during normal flow conditions, California primarily uses a weighted tape at the upstream face of the bridge. This method may be supplemented with wading, probing, and measurements when flow conditions are amenable.
Colorado	Colorado observes scour during routine inspections, although results vary since conditions in the field are dynamic and make it difficult to observe all aspects of scour across the channel's bathymetry.

State	Response
Connecticut	The Connecticut Hydraulics and Drainage section or a consultant performs scour analyses. Channel measurements are obtained during routine and special bridge inspections.
Kentucky	At bridge locations that have scour with piles exposed, Kentucky uses an ultrasonic hammer that allows the agency to calculate the length of piling in place if no plans are available. This tool helps to determine the length of piling exposed and the severity of a scour issue.
Minnesota	Minnesota conducts visual and underwater inspections for larger rivers. For smaller streams, the agency conducts direct measurements using level rods.
Nebraska	Nebraska currently uses a weighted tape deployed from the bridge deck. When the scour is underneath a bridge, the state has used a range pole with 1-foot red-and-white demarcations.
New Hampshire	New Hampshire contracts with consultant divers for scour-critical bridges and those with significant scour issues. Scour-critical bridges are inspected specifically for scour on a five-year cycle, or more frequently if needed.
New Mexico	New Mexico reported that most bridges in the state are over ephemeral channels that can be inspected in dry conditions. Two bridges over perennial channels recently underwent underwater inspections that showed significant scour. The new geometry was analyzed to estimate how vulnerable the bridges were to further scour, a joint determination involving the Drainage Design Bureau, Bridge Bureau, and Geotechnical Bureau.
New York	New York performs dropline readings at bridge fascia and along bridge foundations to document existing scour and compare it to past or as-built readings. This is done through the general inspection process and during post-flood inspection investigations for bridges where the water depth is less than three feet. For water depths greater than three feet, scour is documented through the diving inspection process.
North Dakota	North Dakota conducts a channel survey during routine bridge inspections every four years.
Texas	For span-style bridges over water, Texas conducts scour measurements every two years using a weighted tape to measure the distance from the bridge deck to the channel bed at regular intervals across the length of the bridge. The measured scour depth is assessed for scour criticality according to the Scour Vulnerability Assessment (SVA) method, which is explained in TxDOT's Scour Evaluation Guide. This methodology is intentionally conservative and largely conducted by district offices. If the conservative SVA method identifies a high scour risk, the bridge is then evaluated in more detail by TxDOT's central geotechnical branch.

2.1.3. Sonar

Nine states use sonar-based tools to monitor scour under normal conditions. Technologies range from multibeam and sidescan sonar to pole-mounted and handheld devices. Several states are piloting or investing in remotely operated survey systems.

Table 2.9. Sonar Tools and Technologies

Method	Number of States Reporting	States
Multibeam echo sounder (MBES)	4	CA, MN, MT, SC
Sonar monitoring, not otherwise specified	3	CO, MN, SC
Simple depth finder (fathometer/fish finder/transducer)	3	MN, SC, SD
Acoustic Doppler current profiler (ADCP)	2	CA, MN
Sidescan sonar	2	MN, SC
Sonar contractors (3D bathymetric)	1	TX
Single-beam sonar	1	MN
Blue View Sonar	1	MT
Pole-mounted sonar with GPS	1	CA (not currently used)
Handheld sonar device	1	MI
Boat-mounted depth finder	1	MO
Remote controlled sonar device (EMILY)	1	MI

Table 2.10. Select State Responses: Sonar

State	Response
California	In the past, California has successfully collected cross-section data using a pole-mounted sonar with GPS but currently does not employ this approach. For cases of significant scour concern, and when the water depth or velocities exceed the limitations of safe wading and probing, California surveys the scour and surrounding bathymetry using a multibeam echosounder (MBES) that is mounted on an inflatable boat. California is currently in the process of acquiring, via a research project, a remote-controlled drone mounted with MBES, which is expected to work in mild flows. California can also deploy an acoustic Doppler current profiler (ADCP) from an inflatable boat to measure flow velocity magnitude, direction and discharges, although this is not a routine practice.
Michigan	Michigan reports that its EMILY boat has provided reliable data while scanning for scour and footing exposure, although a learning curve exists while becoming familiar with its setup and use. While the EMILY boat is a safe alternative during higher flows, the data output can be blurry in turbulent water. Additionally, the EMILY boat requires 8 to 10 feet of water—attempting to scan shallow channels of 4 to 8 feet of water results in unclear data output.
Minnesota	Minnesota uses mobile and static MBES, single-beam sonar mounted on a boogie board or Z-boat, ADCP, and a combination of a simple depth finder and side-imaging.
Nebraska	Recently, Nebraska's Bridge Hydraulic Section was awarded a set budget to order bathymetric survey equipment to measure scour around bridge structures and take bathymetric surveys to supplement LiDAR surveys for hydraulic designs. The state is trying two approaches: The first is fish finder sonar equipment (Deeper Pro) that will attach to a rod and reel. Multiple casts will be taken to obtain the necessary survey coverage, which will then be used to analyze the terrain file for scour or for hydraulic design. The second approach is higher-grade bathymetric equipment that will be mounted onto a remote-controlled boat.
South Carolina	The SCDOT/USGS Real Time Scour Program has sonar sensors at nine sites. In-house and consultant bridge inspectors use weighted tapes, fathometers, fish finders, multibeam sonar, and sidescan sonar to monitor scour in normal flow conditions.

2.1.4. Remote Visual and Real-Time Monitoring

A small number of states reported using drones, tilt sensors, float-outs, and other real-time scour instrumentation, typically at scour-critical bridges. These technologies can improve data collection during unsafe conditions, but implementation is often limited by cost, access, or environmental challenges.

Table 2.11. Remote Visual and Real-Time Monitoring

Method	Number of States Reporting	States
Drones	2	KY, MS
Tilt sensors	2	MS, MN
Real-time scour instrumentation	1	MS
"More advanced scour monitoring devices"	1	CT
Float-outs	1	MN
Buried tether switch	1	MN

Table 2.12. Select State Responses: Remote Visual and Real-Time Monitoring

State	Response
Colorado	For scour-critical bridges, Colorado utilizes active tilt sensors or sonar monitoring on a limited basis to monitor real-time scour in the field. Although the monitoring sensors deployed on the most vulnerable bridges have proven effective, limitations such as low flows, ice buildup, and debris can cause the monitoring sensor data to be skewed or unavailable. Colorado notes that ultimately, it has a mostly static scour snapshot for most bridges on the DOT system.
Kentucky	Kentucky uses drones to access bridges that are scour critical to determine the extent of scour. Personnel then produce a sketch and upload it to the agency's Bridge Management System, using the length, width, and depth of scour to determine the ratings for Item 113 and the scour vulnerability rating that complies with the Specifications for the National Bridge Inventory (SNBI). Drones are also used in instances where the scour involves a steep drop-off, and personnel cannot safely access the substructure. In such cases, drones are used to visualize the scour issue and support the estimation of the length of pile exposed or the length of undermining.

State	Response
Mississippi	In addition to using sonar for underwater bridge inspections, Mississippi utilizes drones with imagery and LiDAR for surveys to get more current topography and help define the bathymetry for scour calculations for new and existing bridges. This survey data is used with publicly available LiDAR. USGS has helped Mississippi with real-time scour instrumentation at some bridges. A threshold can be assigned with USGS WaterAlert to notify the agency when a bridge needs to be assessed for potential closure to the public. Challenges with these methods include issues with large amounts of drift that can destroy sensor wiring along the pier. USGS WaterAlert can also be used in places where there is no scour instrumentation, but which may have a predetermined stage or discharge that could serve as a threshold that triggers notification alerts when exceeded.

2.2. Methods and Technologies for Obtaining Scour Analysis Data During Hydrological Disasters

States reported a wide range of tools and methods used to assess scour during flooding and other extreme hydrological events. While 13 states reported they do not take direct measurements during flooding events, others use modeling tools, sonar, and post-event inspections for scour analysis. Although many states rely on streamgage data for modeling and inferring flow conditions, most agree that the limited number of gages is a major challenge. Responses to this question are summarized in the following tables and presented in Tab 2 of the tabulation provided in Appendix B.

Table 2.13. Methods and Technologies Used to Obtain Hydrological Data for Scour Analysis During Extreme Hydrological Events

Method	Number of States Using	States
Field Inspections	12	CO, DE, KS, KY, MI, MO, NE, NH, NM, NY, TX, UT,
Sonar	9	CA, KS, KY, MN, MS, MO, MT, OR, TX
Manual Hydraulic Measuring Tools	7	CA, CO, IN, MN, MS, NE, OR
Real-Time Monitoring	6	CT, MI, MS, NH, TX, WA
Hydraulic Modeling Tools and Methods	5	IN, MT, NJ, NM, WY
Remote Visual Monitoring	5	CA, CO, KY, MS, WA

2.2.1. Modeling

Five states reported using hydraulic modeling to estimate scour during extreme events, most often supported by streamgage and weather data.

Table 2.14. Hydraulic Modeling Tools and Methods

Modeling Tool/Method	Number of States Reporting	Which States?
Not specified	3	MT, NM, WY
HEC-RAS	2	IN, NJ
HEC-WMS/HMS	1	NM
NRCS method	1	NJ
Simplified Peak method	1	NM
Unit Hydrograph method	1	NM

Table 2.15. Hydraulic Data Sources

Method	Number of States Reporting	Which States?
USGS stream gages	16	CT, DE, IN, ME, MI, MN, NE, NV, NM, NY, ND, SC, TX, UT, VT, WA
National weather data/Weather radar data	2	NM, TX
DOT stream gage	1	MI
Precipitation data	1	CT
NOAA California Nevada River Forecast Center	1	NV
Data sharing with local municipal governments	1	UT
FEMA flow data	1	NJ
NOAA precipitation data	1	VT
Coordinated discharges	1	IN
Rapid deployment gages	1	SC
Historical data/past models	1	IN

Table 2.16. Select State Responses: Modeling

State	Response
Indiana	Indiana estimates velocity from HEC-RAS distribution to determine scour countermeasures. It estimates flow rate from various sources, including past models, coordinated discharges, and streamgage data.
Kansas	Kansas noted that HEC-18 scour equations are not intended for use with real-time hydraulic parameters, are not calibrated to specific site conditions, and could result in incorrect assessments of actual conditions.
Maine	Maine obtains stream flow data from nearby gages but reported overconservative estimates of scour.
Michigan	Michigan uses USGS stream gages and state-owned stage gages developed by the University of Michigan's Digital Water Lab. However, the state does not have enough gages to accurately monitor all scour-critical bridges, and the high cost of installing and maintaining USGS gages was the reason for a recent University of Michigan research project.
New Jersey	New Jersey uses HEC-RAS to estimate velocity and flow depth. It uses FEMA flow data or the NRCS method to estimate flow rate. While these results have been effective, New Jersey has realized that designing for the 100-year storm is no longer sufficient and has changed the requirement to 200-year storms instead. New Jersey shared two helpful scour models.
New Mexico	During post-event analyses, New Mexico determines the flow rate using whatever data is available. In rare cases, a nearby streamgage data provides data, but if there is no streamgage, the agency uses a combination of field observations of maximum water surface during the flood and an analysis of weather radar data during the event, which is converted to flow rates using HEC-WMS/HMS, the Simplified Peak Method, or the Unit Hydrograph Method. New Mexico has no method to measure velocity during an extreme hydrological event. Velocity calculations are performed in a 2D model using the estimated flood flow rate, then compared to the observed flow depth as indicated by highwater marks or debris. New Mexico reported that predictive models work well—the state has not had any problems with bridges designed and built in the last 10 to 20 years. An important challenge for post-flood analysis is ensuring that more than one person internally knows how to do the forensic radar analyses to determine the amount of rainfall produced during the event.
South Carolina	While the data South Carolina collects from gages are usable, the main challenge is collecting data from sites far from gages, collecting velocity data, having personnel on-site to take manual measurements during an event, being able to cover multiple sites during widespread floods, and the safety of personnel.
Vermont	If available, Vermont uses adjacent USGS streamgages to estimate flows. Otherwise, observed precipitation data published by NOAA is used to determine the bridge watershed's average rainfall precipitation, which is then used to estimate flow. Vermont reported that while streamgages are effective, it does not have enough of them—or other flow monitoring systems.

State	Response
Wyoming	Wyoming uses hydrologic modeling to collect the variables needed to determine scour, but only at pre-determined flow rates. While these techniques and technologies have been effective, one challenge is determining the "scourability of rock" and how it may limit scour.

2.2.2. Field Inspections and Manual Tools and Methods

Thirteen states do not take direct measurements during flooding, citing turbulent conditions and safety risks. Some states rely on manual tools and/or visual observations, such as highwater marks or scour placards, to assess conditions during or shortly after an event.

Table 2.17. Field Inspections and Manual Tools and Methods

Method	Number of States Reporting	States
No direct measurements taken during flood events	13	CO, CT, DE, ID, KY, MO, MT, NM, NY, SC, SD, VT, WA
Field crews do visual inspection/measurements during event	6	DE, KS, MO, NM, TX, UT
High water marks	4	NE
Weighted Tape	3	CA, CO, SC
Conduct special inspections on scour critical/susceptible bridges post-event	2	KY, UT
Underwater observation/inspection	2	KS, KY
Standard discharge measuring equipment	2	IN, MS
Stage gage painted on bridge abutments	1	MI
Scour placards	1	NH
Scour analysis by scour countermeasure contractors	1	KY
Take a current cross-section	1	NE
Handheld velocity meters	1	MN

Table 2.18. Select State Responses: Field Inspections and Manual Tools and Methods

State	Response
California	During flood events, California commonly measures water surface elevations using a weighted tape and relates it to the most recent channel cross-section to estimate depth and flow rates via normal depth assumptions.
Colorado	Colorado currently has no method for measuring or determining hydraulic parameters during flooding events. The state has tried using drop weights over bridge decks to obtain scour depths during flooding, but at high water velocities, the weight would wrap around the bridge piers or get cut off from the ropes. Colorado can also obtain high watermarks based on the water levels at the piers.
Delaware	During active flood events, Delaware generally deploys field crews for observations, photos, and anecdotal evidence to identify scour-prone locations for follow-up investigations. Due to safety reasons, direct measurements are not generally taken during an event.
Kansas	To obtain scour information during or after a flood event, Kansas uses on-site measurements and observations of conditions underwater at the foundation locations as soon as conditions allow.
Kentucky	Kentucky does not have tools to determine surface velocity, flow rate or flow depth during a hydrological disaster event or flash flooding. In such events, due to the large number of bridges that need quick inspections to determine their structural integrity, Kentucky conducts special inspections on all scour-critical or scour-susceptible bridges and any structures that are emailed or called in by personnel or the public. These inspections are conducted once water levels are safe for field personnel. Each structure is coded according to federal guidelines, and bridges are closed or placed under rehabilitation when needed. Kentucky noted that its main challenge is having more effective scour countermeasures available to state bridge crews beyond riprap. Kentucky provided attachments of the scour assessment it utilizes and the new scour assessment the agency is currently working on.
Minnesota	Minnesota reported that aside from visual inspections, the agency has no practical way of measuring flash flood-induced scour. Districts have successfully employed sonar and manual measurements, producing various types of data, including single cross-sections, full bathymetric scans, and flow rates. Minnesota provided attachments of a bridge scour tech transfer workshop presentation and an underwater monitoring webinar.
Missouri	Although measurements are not generally taken during flood events due to safety concerns, Missouri has previously attempted to use a boat-mounted depth finder or remote depth finder deployed on a tethered float. However, the effectiveness of these methods is limited due to difficult or dangerous conditions and low confidence in depth-finder measurements taken in turbulent water with a high sediment load.

State	Response
New Hampshire	To determine whether a bridge closure is necessary during a hydrological event, New Hampshire monitors flow depths and elevations using scour placards with a red mark indicating the closure elevation has been reached. The bridge remains closed until it can be evaluated.
New York	During flash flood events, the only data New York collects at a scour critical bridge is water elevation/depth, measured by markings of water depth along the wingwall and abutments. Surface velocities and flow rates are not collected at the bridge site during storm events, although this data is collected if there is a USGS gaging station close by upstream or downstream from the bridge. These techniques have been effective in protecting public safety during a storm event. The challenge is that before a bridge can be reopened after a flood event, it must be inspected for scour, and the conditions must be safe before divers and inspection teams can physically inspect it.
Texas	Texas monitors USGS gages and national weather data before, during, and after emergency flood events. Regional maintenance offices stage crews as needed to provide eyes on the ground and close roads to traffic before they become impassable. However, on-site observations are limited during peak flooding due to personnel safety concerns.
Utah	Utah uses USGS stream gages where available to collect flow rates after high-flow events. As events are happening, Utah uses video and photo documentation, data sharing among local municipal governments, and site visits by maintenance personnel to identify issues, focusing on scour-critical bridges. However, the current process is not fully effective in identifying scour issues since Utah does not have real-time monitoring during an event or a notification system in place for flood events.

2.2.3. Sonar

Several states deploy sonar tools during or shortly after flooding events when conditions allow. Sonar technologies include Acoustic Doppler Current Profiler (ADCP), multibeam sonar, depth finders, and sonar mounted on trucks, poles, or floating devices.

Table 2.19. Sonar

Method	Number of States Reporting	States
ADCP (in-house/contracted)	3	CA, MN, MS
Sonar monitoring (NOS)	2	KY, OR
Simple depth finders (fathometers/fish finders)	2	KY, TX
Boat-mounted depth finder	2	MO, OR
MBES	1	CA
Sidescan sonar	1	KS
Pole-mounted sonar	1	CA
Sonar mounted on a snooper truck	1	MT
Remote depth finder on tethered float	1	MO

Table 2.20. Select State Responses: Sonar

State	Response
California	California reported that pole-mounted sonar provided erratic data due to high turbulence and sediment in the flow. When conditions are safe, it tries to acquire MBES data to measure scour during or shortly after flood events. Although ADCP has been used to estimate flow velocities, this is less common. When California has been able to deploy its inflatable boat, the collection of sonar data has been useful, although the data is usually noisy and sometimes limited in where data can be collected due to difficult site conditions, such as debris on piers. California has been able to use this technique with a single-beam sonar and MBES. The biggest challenges with using the inflatable boat are the ability to deploy it in a timely manner due to travel time across the state and finding a safe location to deploy it.
Minnesota	Minnesota reported challenges with boat access at some locations, and in some cases, bridge decks are too high to deploy measuring equipment.
Mississippi	In the past, Mississippi has had USGS use ADCP and standard discharge measuring equipment to measure velocity, depth, and area. More recently, USGS has used real-time scour instrumentation at a scour-critical bridge until riprap could be placed around the pier. However, during the past few years, USGS has had fewer personnel to do this work. Mississippi attached documentation of various sites, including a few slides of a scour instrumentation installation that includes survey, ADCP, and recorded scour data.
Montana	For the most part, Montana relies on modeling, rather than measurements, to estimate scour during flooding events. However, several years ago, the state deployed sonar from a bridge deck on a snooper truck during a flood to determine whether to close the bridge and was able to verify that the observed scour was less than the calculated scour.
Oregon	The only direct measurements Oregon performs during an extreme event are depth via sounding, either manually over the rail of the bridge or via boat, using the depth gauge. A pilot study is currently underway to evaluate live scour monitoring using sonar on four structures, but these also primarily measure depth. Oregon reports that while soundings are an effective way to get consistent data with limited resources and training, challenges include large structures, high velocities, and pier geometry, each of which presents its own issues, such as drift due to wind or flow velocity and access to the nose of the pier.
Texas	As floodwaters recede after an event, Texas has historically assessed scour criticality by tying a fish finder to a water ski, which is lowered onto the water surface from various points along the length of a bridge to estimate water depth and assess any new channel degradation resulting from the flooding. In its survey response, Texas included an article that describes how TxDOT came to use the fish finder with a water ski.

2.2.4. Remote Visual and Real-Time Monitoring

Some states are piloting or deploying remote visual and real-time monitoring tools and devices, although implementing and scaling newer technologies like large-scale particle image velocimetry (LSPIV) and LiDAR present a variety of challenges, most importantly cost considerations.

Table 2.21. Remote Visual Monitoring

Method	Number of States Reporting	States
LiDAR	2	KY, MS
LSPIV (from aerial drone, not yet employed)	1	CA
Drones	1	CO
Stream cameras - real time	1	WA

Table 2.22. Real-Time Monitoring

Method	Number of States Reporting	States
Real-time streamgage data	5	AL, CO, DE, CT, ND
Real-time scour instrumentation	3	CT, MS, NH
Tilt sensors	1	WA
BridgeWatch (online monitoring software app)	1	CT
High flow event monitoring website	1	MI
RQ-30 gages	1	TX

Table 2.23. Select State Responses: Remote Visual and Real-Time Monitoring

State	Response
Alabama	Alabama utilizes nearby USGS streamgages to monitor certain structures during an extreme hydrological event. If a nearby flow gage reaches a predetermined threshold, local inspectors are deployed to assess and monitor the structure. However, locations with flow gages are limited.
California	California has developed a technique to use large-scale particle image velocimetry (LSPIV) to capture surface velocities and discharge measurements from an aerial drone. However, this technique has not yet been employed during an actual flood event.
Connecticut	Connecticut uses the online monitoring software application BridgeWatch, which links to USGS streamgages, two scour monitoring devices, and precipitation data and alerts personnel when extreme events are expected to occur at bridges. The scour monitoring devices show water and channel elevations, which can be related to other hydraulic variables determined with models, but these hydraulic variables are not measured in the field during hydrological events. Connecticut reports that while streamgages are effective for identifying extreme events at bridges, the network is not widespread enough to be effective for a significant number of bridges. For structures not within close proximity to a streamgage, the state relies purely on precipitation data to determine whether an event is happening.
Michigan	Michigan utilizes its bridge high-flow event monitoring website to monitor bridges for scour.
Minnesota	In Minnesota, USGS is experimenting with cameras instead of gages at flash flood locations, although this technique has not yet been implemented.
Missouri	Missouri is currently conducting research into the possibility of obtaining hydraulic parameters like velocity, depth, and elevation using drones.
Montana	Montana conducted a study with USGS on using LSPIV to measure surface velocities, but the results were inconclusive.
New Hampshire	New Hampshire has utilized remote real-time scour sensors in the past, but these typically get destroyed by plowing operations in winter months.
North Dakota	During flood events, North Dakota obtains flow rate and flow depth via USGS gages. When a flood warning is issued, PoAs are triggered using a GIS map overlay to identify and flag vulnerable bridges. Once the flood event ends, field inspections are conducted at the triggered locations. While this method is moderately effective, the number of gages is limited. North Dakota is planning to install gages at all scour-critical bridges that currently lack USGS gaging. Funding is in place, and the state is about to issue an RFP for this work.

State	Response
Texas	Texas has recently invested more than $10 million to develop a statewide flood assessment system. As part of this effort, 80 RQ-30 gages, which use radar to measure water surface elevation and velocity, have been installed. The assessment system includes data assimilation that refines the National Water Model estimates based on the RQ-30 measurements. The graphical user interface shows where roads are inundated and where bridges are in danger of overtopping. This approach accounts for the height of a bridge over the bare-earth terrain, and it defines bridge geometry in an automated fashion using a query from the National Bridge Inventory. Roadway geometry is taken from Open Street Map, and high-performance computing is utilized to create a continuous roadway elevation model by clipping best-available statewide LiDAR within the roadway boundaries. This system is still a research product, and user acceptance testing is commencing soon. Texas envisions this as an internal map service geared towards emergency managers.
Washington	During a flood event, Washington does not typically collect data other than at sites that have a USGS gage. Since many small streams do not have gages, judgment calls are made based on the data of surrounding rivers. Washington does have some locations with stream cameras that monitor the conditions in real time. On scour-critical bridges, tilt meters have been used to help determine if a bridge needs to be closed.

2.3. Effectiveness and Challenges of Methods and Technologies

States were asked about the effectiveness of their scour assessment methods and to describe any challenges associated with their tools and methods. States reported a range of tools that have proven effective and reliable, including streamgages, modeling tools, sonar, and sensor-based monitoring. Common challenges include limited gage coverage, access constraints, equipment damage or failure, and the difficulties associated with obtaining accurate data during extreme conditions. Responses to Question 3 are summarized in the following tables and presented in Tab 3 of Appendix B.

Table 2.24. Effectiveness of Methods and Technologies

Method	Number of States Reporting	States
Methods Stated in Q1/Q2	6	KY, NJ, NY, ND, VT, WY
Streamgages	3	CT, NE, SC
Modeling	2	MS, NM
Soundings	2	MS, OR
Sonar	2	CO, MI
Monitoring Sensors	1	CO
Sonar + Manual	1	MN

Table 2.25. Select State Responses: Effective Methods and Technologies

State	Response
Colorado	Active tilt sensors and sonar monitoring have been deployed on a limited basis but are proving to be effective in monitoring the most vulnerable bridges on the DOT system. The monitoring sensors that have been deployed on the most vulnerable bridges are proving to be effective.
Connecticut	Streamgages are very effective for identifying extreme events at bridges.
Kentucky	Methods used are effective overall. Kentucky has coded each structure according to federal guidelines and closes structures or puts them under rehabilitation when needed.
Michigan	The EMILY boat has provided reliable data while scanning for scour and footing exposure. The research projects with the University of Michigan have proved extremely effective, reliable, and cost effective.
Minnesota	Districts have successfully employed most of the sonar and manual measurements, producing various types of data including single cross-sections, full bathymetric scans, and flow rates. While streamgage data, ADCP, and handheld velocity meters are employed during flooding events, Minnesota has not had much success with using these during flash flooding.
Mississippi	SRH-2D flow modeling enables better modeling of the flow vectors and quantity through bridge openings and has in turn improved scour parameters used in HEC-18. Mississippi's ground-to-grade data and USGS historical soundings, along with the USGS pier-scour envelope equation, help in having a comparison with HEC-18 calculations to determine if calculations are reasonable.
Nebraska	Stream gages and site visits have been somewhat effective in determining the storm's discharge and corresponding frequency.
New Jersey	While New Jersey's methods have been very effective, it has realized that designing for 100-year storms is not sufficient, so it changed its requirements to 200-year storms.
New Mexico	New Mexico has not had any problems with predictive methods for bridges built in the past 10 to 20 years, so overall, methods seem to be working well.
New York	Collecting water elevation and depth data via markings of water depth along the wingwall and abutment and collecting surface velocities from nearby gages, when possible, have been very effective in protecting public safety during a storm event.
Oregon	Oregon reported that soundings are an effective way to get consistent data with limited resources and training.
Washington	Washington reported that the state has a lot of streams that are underlain by thin alluvium that overlies other geo-materials. Many streams are underlain by glacial deposits, including glacial till. There is also a lot of weathered and weak rock. These materials are difficult to characterize for scour purposes, as most of the existing guidance assumes alluvial material (sand). Long-term degradation is not well defined, and more guidance is necessary to determine best practices for mechanisms such as headcut migration and long-term abrasion scour of cohesive or rock-like materials.

Table 2.26. Challenges

Challenge	Number of States Reporting	States
Limited Gages/Data	10	AL, CT, DE, MI, NM, ND, SC, UT, VT, WA
Accuracy (Fixed Instrumentation, Field Observation, Modeling, Sensors, Sonar)	9	CA, CO, DE, KS, ME, MN, MO, NJ, NM
Miscellaneous	7	CA, KY, MI, MN, MS, MT, WY
Access	5	DE, MN, MO, NY, OR
Cost/Resources	4	CT, KS, MI, MN,
Difficult Conditions/Safety	4	CA, SC, SD, TX
Instrument Damage/Failure	3	MN, MS, NH
Coverage	2	SC, TX

Table 2.27. Select State Responses: Challenges

State	Response
California	When California can deploy inflatable boats, MBES and single-beam sonar data are useful but usually noisy and sometimes limited in where it can be used due to debris on piers. The greatest challenge with inflatable boats is deploying them in a timely manner due to travel time and safety issues on-site. For all techniques, data collecting challenges are fast water, sediment, turbulence, and floating objects.
Colorado	The effectiveness of monitoring sensors is limited by the conditions found at the structure, such as low flows, ice buildup, and debris, which can cause the monitoring sensor data to be skewed or unavailable. Ultimately, Colorado has a mostly static scour snapshot for the majority of bridges on the DOT system.
Connecticut	Connecticut reported that streamgages are not widespread enough to be effective for a significant number of bridges. Determining when extreme events occur at bridges far from a gage relies entirely on precipitation data.
Delaware	Delaware reported the following challenges: • Limited direct data during peak flood events hinders real-time understanding. • USGS gauge coverage is limited across most of the state. • Sediment transport assumptions in models are sometimes oversimplified and vary by site. • Access restrictions during and after events delay scour verification. • Resource constraints prevent widespread real-time monitoring at most bridges.
Indiana	Indiana cited bridge inspection and monitoring on Plan of Action bridges when a triggering event occurs as its biggest challenge. The state is presently working with FHWA to develop a better plan for inspection when these events occur.
Kansas	Kansas cited cost, maintenance and long-term reliability as the biggest obstacles to using semi-permanent devices and technologies at scour locations. Kansas noted that during extreme conditions, obtaining hydraulic parameters to apply to the HEC-18 scour equations are not intended for use in real-time evaluation; are not calibrated to specific site conditions; and could result in incorrect assessment of actual conditions.
Kentucky	Kentucky's main struggle is the need for more effective scour countermeasures available to state bridge crews that are not just riprap countermeasures.
Maine	Maine's primary challenge is overconservative estimates of scour.
Michigan	Michigan's challenges with the EMILY boat include a learning curve and the loss of data clarity in turbulent water. Additionally, EMILY requires 8 to 10 feet of water, so scanning shallower channels results in unclear data output. Other challenges include not enough gages throughout the state to accurately monitor all scour critical bridges and the high cost of installing and maintaining the USGS gages, which was the reason for a recent University of Michigan research project.

State	Response
Minnesota	Minnesota is phasing out fixed instrumentation for various reasons, citing drawbacks such as: • Effects of turbulence and sediment. • Damage due to barges, debris, and ice loads. • Power supply interruptions, including solar panel issues and batteries running out. • Software system bugs resulting in false alarms or issues with receiving alerts. • Recurring costs for data processing and maintenance. • Changes in workforce and knowledge transfer. Minnesota has not had much success with measuring scour during flash flooding, noting there is no practical way to measure flash flood-induced scour except visual inspection. Additionally, boat access during flooding events is challenging at some locations, and some bridge decks are too high to deploy measuring equipment.
Mississippi	Mississippi noted that USGS has lost personnel over the years, and other uncertainties could lead to personnel challenges. While real-time scour instrumentation has worked well with WaterAlert, it did have issues at times with large amounts of drifts destroying sensor wiring along the pier.
Missouri	Missouri's primary challenges are difficult or dangerous access to flooded areas and low confidence in depth-finder measurements in turbulent water with high sediment loads.
Montana	Cohesive soils are a current gap for Montana.
New Hampshire	New Hampshire reported that its remote sensors typically get destroyed by plowing ops or fail during winter months.
New Jersey	New Jersey reported that HEC-18 formulas sometimes overestimate scour, so it is important to compare the results to existing and historic conditions.
New Mexico	New Mexico cited a lack of data to evaluate after disaster events and noted that since many channels are live-bed and fill in after the scour, field observations can be misleading. It noted that for post-flood analysis, the state needs to internally ensure that more than one person knows how to do forensic radar analyses to determine rainfall produced.
New York	New York's primary challenge is the timely reopening of bridges after they have been closed due to a flood event. The bridge must be inspected for scour before reopening, and the conditions must be safe for divers/inspection teams before they can physically inspect the bridge for scour.
Oregon	Oregon's biggest challenges are large structures, high velocities, and pier geometry. Each presents its own issues, including drift due to wind or velocity and difficult access to the nose of the pier.

State	Response
South Carolina	South Carolina’s main challenges are collecting data away from sites with gages; collecting velocity data; having personnel at a site to use portable technologies during flooding; and the ability to cover multiple sites during large floods.
South Dakota	South Dakota reported that it is difficult to obtain channel bed elevations during an event due to velocity and turbidity.
Texas	Texas reports that one unique challenge is the state’s large number of bridges—around 60,000 bridge-class structures include roughly 20,000 span-style bridges over water. Additionally, there are limitations to field observation during peak flooding due to safety concerns. Texas reported that it is aware of the hydro-flattening effect that can occur when LiDAR fails to reach the bottom of a waterway. It would like to have a more robust methodology and workflow for measuring bathymetry, including methods for routine inspections and emergency responses using unmanned, remote sensing methods. Texas is following the innovative work coming out of Colorado with great interest.
Utah	Utah’s primary challenge is that it does not have real-time monitoring during an event or a notification system in place for flood events.
Vermont	While Vermont reported that its methods are effective, it notes there are not enough USGS gage stations or other flow monitoring systems to cover its network of bridges.
Washington	Washington’s primary challenge is that small streams do not have gages, so judgment calls must be made based on the data from surrounding rivers.
Wyoming	One challenge Wyoming faces is determining the “scourability of rock” and how it may limit scour.

2.4. State Research and Additional Insights from Respondents

In Question 4 of the survey, several states cited research they have conducted on various aspects of scour monitoring. The table below provides a list of state research reports, which are hyperlinked to their corresponding citations in Chapter 3. Literature Search. Responses to Question 4 are summarized in the tables below. **Note:** Washington State DOT has a pending research paper on using the Erodibility Index method to evaluate erodibility of all earth materials, which will provide guidance on using flow conditions and geotechnical data to answer binary yes/no on whether a material is erodible, along with guidance on applying this to long-term degradation. The paper deadline is June 2027.

Table 2.28. State Research Reports

State	Publication	Description
California	Development of Data Collection Systems for Large-Scale Particle Image Velocimetry (LSPIV). Citation.	Technical Report
California	PI-0377: Crewed Aircraft LiDAR Bathymetry in Turbid Water. Citation.	Preliminary Investigation
Colorado	The Applicability of Time-Integrated Unit Stream Power for Estimating Bridge Pier Scour Using Noncontact Methods in a Gravel Bed River. Citation.	Journal Article
Colorado	Implementing a Rapid Deployment Bridge Scour Monitoring System in Colorado, 2019. Citation.	USGS Scientific Investigations Report
Colorado	Real-Time Streambed Scour Monitoring at Two Bridges over the Gunnison River in Western Colorado, 2016-17. Citation.	USGS Scientific Investigations Report
Michigan	Electronic Water Level Sensors for Monitoring Scour Critical Structures. Citation.	Final Report
Michigan	Unmanned Surface Vessels for Bridge Scour Monitoring. Citation.	Final Report
Montana	Evaluating the Use of Video Cameras to Estimate Bridge Scour Potential at Four Bridges in Southwestern Montana. Citation.	USGS Fact Sheet
Oregon	Real-time Continuous Bridge Scour Monitoring for Improved Safety and Cost Savings. Citation.	Research in Progress
South Carolina	SPR 692 Real Time Measurement of Scour Depths around Bridge Piers and Abutments. Citation.	Technical Report
Texas	Flood Assessment System for TxDOT. Citation.	Technical Report

Some survey respondents included attachments in their responses to Question 4, including guidance documents, presentations, and other resources. These attachments are listed in Table 2.29 and are available to view on the WTRC website.

Table 2.29. Survey Attachments Available to View on the WTRC Website

State	Attachment	Description
Kentucky	Scour Assessment	Current Procedures
Minnesota	Bridge Scour Tech Transfer Workshop – Monitoring	Presentation
Minnesota	Underwater Monitoring of Bridges in Minnesota Webinar	Presentation
Mississippi	Pearl River at US 98 02-04-25	Presentation
Texas	Scour Detection During High Water	Article
Utah	Innovative Technologies Used to Develop Hydraulic Modeling	White Paper
Utah	CHANGE Presentation	Presentation

Although the survey did not specifically ask about research or pilot projects currently in progress or in planning, 10 states mentioned such endeavors, and these are presented in Table 2.30. Similarly, six states reported areas of interest to them, or gaps they feel need to be addressed. These are described in Table 2.31.

Table 2.30. States with Research Projects in Progress or in Planning

State	Description of Project
California	California is in the process of acquiring, via a research project, a remote-controlled drone mounted with its MBES, which should work in mild flows. Additionally, California has developed the technique of using large-scale particle image velocimetry (LSPIV) to capture surface velocities and discharge measurements from an aerial drone, but this has not been employed yet during an actual flood event.
Indiana	Indiana is currently working with FHWA to develop a better plan for inspection when extreme events occur.
Minnesota	USGS in Minnesota is experimenting with cameras instead of gages at certain flash flood locations, but they have not yet been implemented.
Missouri	Missouri currently has a research project exploring the possibility of obtaining hydraulic parameters such as velocity, depth and elevation using drones.
Nebraska	Nebraska currently has a research project on the geomorphology of the Niobrara River and Spencer Dam failure that occurred back in 2019 during a massive flood event. This is not complete at this time, but Nebraska is willing to share once it is done. In addition, Nebraska DOT's Bridge Hydraulic Section was recently awarded a set budget to order bathymetric survey equipment to help with two things: • Measure scour around bridge structures. • Take bathymetric surveys to supplement LiDAR surveys for hydraulic designs. Nebraska is trying two approaches at this equipment. The first is the cheaper route, a fish finder sonar equipment (Deeper Pro) that attaches to a rod and reel and is cast out. Multiple casts will be taken to retrieve the necessary survey coverage off the terrain, which will then be uploaded and analyzed for scour or for hydraulic design. The second and more expensive approach will be higher-grade bathymetric equipment that will be mounted on a remote-controlled boat.
Nevada	Nevada has an emergency program that will be used for future inspections and planning. It will have updated flow gage triggers, and Nevada will use rain, snow, and snow melt measurements to help decide whether to perform scour evaluations.
North Dakota	North Dakota is seeking to gage all of its scour critical structures that are not already on USGS stream gages. Funding is in place, and the RFP stage will begin soon. This project is similar to the Iowa Flood Center.

State	Description of Project
Oregon	Oregon has an active research project for live scour monitoring: SPR 859 Real-Time Continuous Bridge Scour Monitoring for Improved Safety and Cost Savings U.S. Geological Survey.
Texas	Texas is currently working on research with Texas A&M to develop SRICOS amplification factors to account for pressure scour conditions. It is also investigating the potential utility of using slake durability testing as an erodibility screening tool for intermediate geo-materials. Additionally, TxDOT has recently invested over $10 million to develop a statewide flood assessment system. As part of this effort, it has installed 80 RQ-30 gages, which use radar to measure water surface elevation and velocity. The assessment system includes data assimilation that refines the National Water Model estimates based on RQ-30 measurements. The graphical user interface shows where roads are inundated and where bridges are in danger of overtopping. This approach accounts for the height of a bridge over the bare earth terrain, and it defines bridge geometry in an automated fashion using a query from the National Bridge Inventory. Roadway geometry is taken from Open Street Map, and high-performance computing was utilized to create a continuous roadway elevation model by clipping best available LiDAR (statewide) within the roadway boundaries. This system is still a research product; user acceptance testing is commencing soon, and Texas envisions this as an internal map service geared towards emergency managers.
Utah	Utah reported that aside from using streamgages and sharing data with local municipal governments, it is not aware of other standard practice, training, or special instrumentation available to UDOT to measure velocity and flow depth data. Training, standard operating procedures, and measurement technology could be developed to help in this data collection effort.

Table 2.31. Methods and Technologies DOTs Are Currently Exploring or Interested in Exploring

State	Area of Interest
Delaware	Delaware does not currently deploy drones or sonar during flood events, but the state is interested in future technologies that could safely capture high-flow channel conditions. Delaware is interested in drones, sonar, and other safe, flexible tools to help better understand scour behavior during turbulent or high-flow conditions without staff safety risks
Kansas	Kansas has looked into purchasing an unmanned boat with sonar to measure scour depts during or immediately after large flooding events. The state is most interested in MDOT's EMILY system.
Minnesota	Minnesota is interested in guidance for monitoring difficult-to-access bridges with no boat access or very high bridge decks as well as monitoring flash flood locations. FHWA suggested using drones, and Minnesota is interested in learning more about drone technology for scour monitoring.
Montana	Montana reported that it would be helpful to have a reliable method to measure surface velocities and thalweg location during a flood event, especially if there was a way to correlate the water surface velocity to the velocity above the streambed. Additionally, Montana is looking into whether to obtain a device to measure critical shear to be used in the cohesive soil calculations.
Oregon	Oregon’s Scour Program supports all NBI structures over water in the state. Over the past year, a major focus has been developing Plans of Action (POAs) that provide the appropriate level of data for both state and local bridge owners. This effort led to the creation of risk ratings for scour-critical structures, categorized as low, moderate, or high. These ratings determine the type and frequency of scour monitoring required. Depending on the POA, monitoring may include active inspections during a flood event, and/or post-event inspections.
Texas	Texas is open to utilizing traditional and innovative scour analysis techniques to estimate future scour for bridge design purposes. Each method is summarized in TxDOT’s Scour Analysis Guide. Texas is aware of the hydro-flattening effect that can occur when LiDAR fails to reach the bottom of a waterway and would like to have a more robust methodology and workflow for measuring bathymetry. This includes methods for routine inspections, but also methods for emergency response where the state would prefer to use an unmanned, remote sensing method. Texas is aware of the innovative work coming out of Colorado and is following it with great interest.
Utah	Utah does not currently have real-time monitoring during an event or a notification system in place for events. Training, standard operating procedures, and measurement technology could be developed to help in this data collection effort.

2.5. Agency Office Primarily Responsible for Bridge Scour Assessment and Management

Most states assign bridge scour responsibilities across hydraulics, bridge engineering, and bridge inspection units. Hydraulics teams generally perform scour analyses and modeling, while bridge inspection and management offices typically monitor scour-critical structures and coordinate plans of action. Some DOTs centralize these functions within a single bridge or structures division, while others distribute them across specialized units. The following table lists the offices primarily responsible, as identified by each responding state.

Table 2.32. Agency Department, Division, or Office Primarily Responsible for Scour Assessment and Management

State	Department with Primary Responsibility
Alabama	Maintenance Bureau, Bridge Scour Section.
California	In California, the Hydraulic Branch in the Office of Specialty Investigations within Structure Maintenance and Investigations is responsible for scour assessments and management.
Colorado	The state hydraulic engineer is responsible for the implementation and facilitation of the Scour Critical Program. Asset management and tracking of bridges, culverts, and structures ultimately is under the office of the State Bridge Engineer and the Bridge Asset Manager. All three of these positions work closely together, along with regional personnel, to ensure that scour is tracked and considered for all on-system structures.
Connecticut	Hydraulics and Drainage reviews or performs scour assessments. The CTDOT Bridge Safety and Evaluation section, also within the office of Engineering, is responsible for bridge inspections and typically recommends work at a bridge based on conditions observed during routine inspections.
Delaware	The Bridge Design Section within DelDOT holds primary responsibility for bridge scour evaluation, modeling, and mitigation during the design, retrofit, or replacement of structures. The Bridge Management Section coordinates with design staff to track scour-critical structures and monitor field conditions over time.
Idaho	Bridge Asset Management - HQ Bridge Section.
Indiana	INDOT Hydraulics and INDOT Bridge Inspection.
Kansas	Bureau of Structures and Geotechnical Services, Bridge Hydraulics and Bridge Inspection.
Kentucky	Division of Maintenance, with a scour engineer for the state.
Maine	Bridge Maintenance.
Michigan	Multidisciplinary team consisting of the Bureau of Bridges and Structures (Bridge Management and Geotechnical Services) and Bureau of Development (Hydraulic Unit).
Minnesota	Bridge Office Hydraulics Unit.
Mississippi	Bridge Division: Inspection Program & Hydraulics Branch–Scour Program.

State	Department with Primary Responsibility
Missouri	The Bridge Division—in particular the Bridge Management and Bridge Inspection sections—have the primary responsibility for assessing scour condition in the field. They work with the Structural Hydraulic and Preliminary Design Engineer to determine any necessary scour action plans.
Montana	Hydraulics.
Nebraska	The bridge scour assessment is completed by the Bridge Hydraulic Section, which teams up with the Geotechnical Section and the Load Rating Section in Bridge Division to accurately assess the scour critical limit on each bridge and then rate it accordingly.
North Dakota	NDOT Structures Bridge Inspections, NDOT Hydraulics, NDOT District Engineers, NDOT Maintenance Crews.
New Hampshire	Bureau of Bridge Design. Existing Bridge section would handle assessment and inspections. Bridge Design and Bridge Maintenance would both handle the management and mitigation of scour.
New Jersey	When a structure is deemed scour critical, the Geotechnical Engineering unit reviews H&H reports, scour analysis report, and scour countermeasure design.
New Mexico	Bridges are inspected, rated, and monitored by the Bridge Management Bureau under the Bridge Bureau. They are the primary group responsible for scour assessment and management, with input from both Drainage and Geotechnical. Bridge Management personnel track the channel elevations and are typically the ones who notice scour holes or other evidence of scour at. The Drainage Design Bureau determines the predicted scour used in design and can evaluate potential future scour concerns after observing scour at a bridge.
New York	NYSDOT Bridge Evaluation Services/Bridge Inspection Unit and Office of Structures Hydraulics Unit.
North Dakota	Bridge Division.
Oregon	Bridge Operations, Bridge Scour Program. These are part of the same group doing bridge inspections.
South Carolina	Hydraulic Design Support Office.
South Dakota	Office of Bridge Design.
Texas	Bridge Division, Geotechnical Branch has the overall responsibility. The Design Division, H&H Section provides support for scour analyses (i.e., predicting future scour depth).
Utah	Responsibility is shared among Bridge Management, Geotechnical Design, Central Hydraulics.
Vermont	Assessments are conducted by the Scour Committee, made up of Bridge Management, Hydraulics, and Geotech. Scour management is dictated by regional districts/bridge owners, following the Scour Plan of Actions (POA).

State	Department with Primary Responsibility
Washington	Within WSDOT, the Development Division has the Bridge Office, the Hydraulics Office, and the geotechnical office. The Bridge Office has a bridge preservation team, and within it is the bridge scour engineer, who conducts scour assessments and determines through coding if a bridge is scour critical. The Hydraulics Office has a team that focuses on scour and floodplains, and when an area needs a scour analysis with hydraulic modeling, it is done within the Hydraulics Office in coordination with the geototechical office.
Wyoming	Bridge Scour assessment is the responsibility of Hydraulics, and management is overseen by Bridge Operations.

2.6. List of Survey Respondents

The following table provides contact information provided by survey respondents in Question 6.

Table 2.33. Survey Respondent Contact Information

State	Survey Respondent or State Contact
Alabama	Johnathon R. Roberts, P.E. Assistant State Maintenance Engineer Bridge Scour and Environmental Section Alabama DOT, Maintenance Bureau 334-242-6624, robertsj@dot.state.al.us
California	Kevin Flora, Ph.D., P.E., BC.WRE Branch Chief, State Hydraulics California Department of Transportation, Structure Maintenance & Investigations 916-799-1423, kevin.flora@dot.ca.gov
Colorado	Michael Tanner, PE, CFM State Hydraulic Engineer Colorado DOT michael.tanner@state.co.us
Connecticut	Michael Hogan Connecticut DOT michael.hogan@ct.gov
Delaware	Bryce Baker, M.C.E., P.E. Bridge/Hydraulic Resource Engineer Delaware DOT, Bridge Design Section bryce.baker@delaware.gov
Idaho	Alan Buehrig Bridge Asset Management Engineer Idaho TD Alan.Buehrig@itd.idaho.gov

State	Survey Respondent or State Contact
Indiana	Bill Schmidt INDOT Hydraulics Director Indiana DOT, Hydraulics 314-232-5148, wpschmidt@indot.in.gov Tony Marino Indiana DOT, Bridge Inspection amarino@indot.in.gov
Kansas	Caitlyn Spencer, P.E., CFM Bridge Hydraulic Engineer Kansas DOT, Bureau of Structures and Geotechnical Services, Bridge Design Section 785-296-0419, caitlyn.spencer@ks.gov John Culbertson, Bridge Inspection Engineer Kansas DOT john.culbertson@ks.gov
Kentucky	Jenny Begley, P.E. Scour Engineer Kentucky TC, Division of Maintenance 270-307-2860, jenny.begley@ky.gov
Maine	Ben Foster Maine DOT Ben.Foster@maine.gov
Michigan	Erik J. Carlson, P.E. Michigan DOT, Hydraulics Unit 517-230-8180, CarlsonE2@michigan.gov Andrew Zwolinski Michigan DOT, Bureau of Bridges and Structures 517-256-7131, ZwolinskiA@michigan.gov
Minnesota	Solomon Woldeamlak, PhD, PE State Waterway Engineer Minnesota DOT, Bridge Office solomon.woldeamlak@state.mn
Mississippi	Van Wilson (K. Van Wilson), P.E., CFM Scour Program Manager Mississippi DOT, Hydraulics Branch – Bridge Division 601-359-7285, vwilson@mdot.ms.gov
Missouri	Travis Stump Structural Hydraulic and Preliminary Design Engineer Missouri DOT 573-522-8716, travis.stump@modot.mo.gov

State	Survey Respondent or State Contact
Montana	Annette Compton Hydraulics Operations Engineer Montana DOT, Hydraulics Section / Highways Bureau 406-444-5988, ancompton@mt.gov Kurt Marcoux State Scour Engineer Montana DOT kmarcoux@mt.gov
Nebraska	Kirk Harvey, PE Assistant Bridge Engineer – Hydraulics Nebraska DOT 402-479-3755, kirk.harvey@nebraska.gov
North Dakota	Brandon Henning Principal Structures Engineer – Inspection/Maintenance Structures Division, Nevada DOT 775.888.7551, bhenning@dot.nv.gov Thomas Young, P.E. Chief Hydraulic Engineer Hydraulics Division, Nevada DOT 775-888-7623, tyoung@dot.nv.gov
New Hampshire	Jim Commerford, P.E. Hydraulic Engineer New Hampshire DOT, Bureau of Highway Design 603-271-7522, James.S.Commerford@dot.nh.gov
New Jersey	Remoon M. Farag, PE, Assoc. DBIA New Jersey DOT, Geotechnical Engineering Unit 609-963-2605, remoon.farag@dot.nj.gov
New Mexico	Steven Morgenstern, PE, CFM, ENV SP Manager, Drainage Design Bureau New Mexico DOT 505-231-7688, steven.morgenstern@dot.nm.gov
New York	Derek Intschert, P.E. Professional Engineer 2, Hydraulic Engineering Unit Supervisor New York State DOT 518-485-8566, derek.intschert@dot.ny.gov
North Dakota	Monte Deis, P.E. Preliminary Engineering & Hydraulics Engineer North Dakota DOT, Bridge Division 701-328-2137, mdeis@nd.gov
Oregon	Wesley Nickerman P.E. Senior Bridge Hydraulic Engineer Oregon Department of Transportation, Hydraulic Engineering Section wesley.a.nickerman@odot.oregon.gov, 541-239-7068

State	Survey Respondent or State Contact
South Carolina	Thomas Knight South Carolina DOT knighttp@scdot.org
South Dakota	Steve Johnson South Dakota DOT Steve.Johnson@state.sd.us Todd Thompson South Dakota DOT Todd.Thompson@state.sd.us Kevin Marton, P.E. Bridge Hydraulics Engineer South Dakota DOT, Office of Bridge Design 605-773-4995, Kevin.Marton@state.sd.us
Texas	Chun Ho Lee Bridge Division, Geotechnical Branch Texas DOT chunho.lee@txdot.gov Badal Mahalder Design Division, H&H Section Texas DOT
Utah	Bridge Management: Becky Daniels, rnix@utah.gov Region 1 Hydraulics: Jeff Erdman, jerdman@utah.gov Region 2 Hydraulics: Nick Stephens, nickstephens@utah.gov; Logan Falslev, lfalslev@utah.gov Region 3 Hydraulics: Cody Alberts, calberts@utah.gov
Vermont	Jeff DeGraff, P.E. State Hydraulic Engineer Vermont AOT, Highways Division, Project Delivery Bureau, Structures and Hydraulics 802-793-3447, jeff.degraff@vermont.gov
Washington	Robert Humphries, LEG Geomorphologist Washington State DOT robert.humphries@wsdot.wa.gov
Wyoming	Jeri D. Yearout, P.E. Principal Hydraulic Engineer Wyoming DOT 307-777-4045, jeri.yearout@wyo.gov

3. Literature Search

To complement the survey findings, a literature search was conducted to identify publicly available research and resources on scour monitoring and estimation methods and technologies. These materials are organized into the following topic areas:

- Overview Articles, Frameworks, and Critical Reviews.
- Vibration-Based Monitoring Techniques.
- Sonar Tools and Technologies.
- Remote Sensing: Radar, LiDAR, LSPIV, and InSAR.
- Embedded Sensors (Non-Vibration-Based).
- Emerging Technologies: AI and Machine Learning.
- Commercial Tools and Vendor Solutions.

3.1. Overview Articles, Frameworks and Critical Reviews

This introductory section includes broad reviews, conceptual frameworks and comparative evaluations of various scour monitoring methods, offering context on the strengths, limitations and implementation challenges of traditional and emerging techniques.

"Advancing Bridge Resilience: A Review of Monitoring Technologies for Flood-Prone Infrastructure," Karina Buka-Vaivade, Vanni Nicoletti and Fabrizio Gara, *Open Research Europe,* Vol. 5, page 26, 2025.
https://pmc.ncbi.nlm.nih.gov/articles/PMC12004067/
From the abstract: This review examines state-of-the-art Structural Health Monitoring (SHM) technologies tailored to mitigate flood risks, focusing on their real-world applications in flood-prone bridges. A central feature of this review is the extensive use of case studies, illustrating diverse SHM methods applied globally to monitor challenges such as debris accumulation, hydrodynamic forces, and scour—primary causes of bridge failures. These examples provide detailed insights into technologies like sonar-based devices, scour probes, photographic monitoring, rotation- and vibration-based techniques. By showcasing specific case studies—such as bridges monitored using smart magnetic rocks, Interferometric Synthetic Aperture Radar (InSAR), and fibre optic sensors—the review highlights practical outcomes, demonstrating how SHM systems enhance resilience through early detection and predictive maintenance. It also explores the challenges of implementing these systems, including environmental sensitivity, cost, and data complexity, while identifying gaps in integrating hydraulic and structural data for holistic risk assessments. This review advocates for multidisciplinary collaboration and advanced data-driven solutions, such as AI-based predictive maintenance, to address climate change impacts and increasing flood risks.

"Perspective on Structural Health Monitoring of Bridge Scour," Simon Laflamme, *Measurement Science and Technology,* Vol. 35, 2024.
https://iopscience.iop.org/article/10.1088/1361-6501/ad23be/pdf
From the abstract: … A short review of early works provides the reader with a historical perspective on the development and application of bridge scour monitoring devices. After, a discussion on contemporary measurement techniques reveals how these early devices have evolved, and how vibration-based monitoring techniques have gained significant attention. Lastly, thoughts on future

needs for these structural health monitoring solutions are shared, and include remarks on the required characteristics to construct the next generation of high-performance bridge scour measurement device and monitoring systems.

"A Bridge Scour Risk Management Approach to Deal with Uncertain Climate Future," Manu Sasidharan, Ajith Kumar Parlikad, Jennifer Schooling, Georgios M. Hadjidemetriou, Matthew Hamer, Andy Kirwan, and Steve Roffe, *Transportation Research Part D: Transport and Environment,* Vol. 114, 2023.
https://www.sciencedirect.com/science/article/pii/S1361920922003935
From the abstract: Riverine bridges are under a substantial threat of scour due to the magnitude and frequency of floods arising due to climate change. Infrequent inspections, inadequate data on foundation depths, and the lack of consideration of hydrologic and climate parameters often result in uncertainties within current scour risk assessments. This paper presents an approach for assessing the risk progression of local scour in peak flow conditions that consider uncertainties associated with location, downscaling of climate predictions, and hydrologic, hydraulic and scour prediction models. A rational scour risk rating based on warning time to failure is introduced that can provide a useful addition to the existing bridge condition indexes. The case study on a set of railway bridges in Southeast England shows that climate change could accelerate the scour risk progression, even in the low-emission scenario. The approach and results form a vital basis for scour risk mitigation and climate adaptation planning.

"Quantifying the Value of SHM Information for Bridges Under Flood-Induced Scour," P.F. Giordano, L.J. Prendergast and M.P. Limongelli, *Structure and Infrastructure Engineering,* Vol. 19, Issue 11, pages 1616–1632, 2023.
https://nottingham-repository.worktribe.com/index.php/preview/6790479/Repository_InPress.pdf
From the abstract: Bridge scour is a leading cause of failure for bridges over waterways and is notoriously difficult to detect with accuracy. Dynamic Structural Health Monitoring (SHM) of bridges for scour has gained traction in recent years as monitoring systems have improved and the reliability of measurements increased. Due to the large number of bridges on typical networks and the limited financial resources within asset management agencies, decision-makers must prioritize certain structures when it comes to management in the event of flooding. The decision to install a dynamic SHM system on a bridge must be balanced by the financial benefit of doing so, as limited resources often need to be carefully rationed. In this paper, a methodology is proposed to evaluate such benefit based on the Value of Information (VoI) from Bayesian decision analysis. A case study is presented whereby a dynamic SHM system is considered to be installed on a typical bridge with the aim to support emergency management operations during flooding. The proposed methodology allows computation of the financial benefit of installing a dynamic SHM system over a certain reference period, thus accounting for multiple flood events and scenarios. The various elements of the procedure are discussed in detail.

"Scour Detection with Monitoring Methods and Machine Learning Algorithms—A Critical Review," Sinem Tola, Joaquim Tinoco, José C. Matos, and Eugene Obrien, *Applied Sciences*, Vol. 13, Issue 3, Article 1661, 2023.
https://www.mdpi.com/2076-3417/13/3/1661
From the abstract: Foundation scour is a widespread reason for the collapse of bridges worldwide. However, assessing bridges is a complex task, which requires a comprehensive understanding of the phenomenon. This literature review first presents recent scour detection techniques and approaches. Direct and indirect monitoring and machine learning algorithm-based studies are investigated in detail in

the following sections. The approaches, models, characteristics of data, and other input properties are outlined. The outcomes are given with their advantages and limitations. Finally, assessments are provided at the synthesis of the research.

Evaluating the Benefit of Structural Health Monitoring for Improving Bridge Resilience Against Scour, Enrico Tubaldi, Andrea Maroni, Neil Ferguson, and Daniele Zonta, National Centre for Resilience, 2020.
https://eprints.gla.ac.uk/225801/1/225801.pdf
From the abstract: … The research questions to be answered by the project is: "What is the expected impact of SHM on bridge scour early warning and risk assessment?" In particular, this report presents the critical review of the various monitoring techniques available in the literature or deployed in bridges across UK and in particular in Scotland. The considered techniques include visual inspections carried out by divers, techniques providing a direct measurement of the scour at a location (such as smart probes), and techniques measuring the effects of scour (e.g. satellites monitoring bridge settlements due to scour or dynamic identification techniques looking at changes of bridge dynamic properties). The report also shows a comparison among the techniques based on their different features, such as cost and ease of installation, capability to provide continuous measurements, accuracy, distribution of information they provide, and contribution to the four dimensions of critical infrastructure resilience (robustness, redundancy, resourcefulness, rapidity).

"Recent Development and Remaining Challenges In Determining Unique Bridge Scour Performance Indicators," Kenneth Gavin, Luke J. Prendergast, Irina Stipanovič, and Sandra Škarič-Palič, *The Baltic Journal of Road and Bridge Engineering,* Vol. 13, No. 3, 2018.
https://bjrbe-journals.rtu.lv/bjrbe/article/view/bjrbe.2018-13.417
From the abstract: There have been significant developments in the area of vibration based bridge scour monitoring in recent years. Traditional scour monitoring using either visual assessment or diving inspections are now recognised to be very unreliable and highly subjective. There has been a concerted effort to move towards reliable systems capable of either direct measurement of scour or indirect measurement, based on monitoring the response of the structure to damage. The developments have unearthed new challenges and problems. This paper describes some recent developments in the field. In addition, remaining challenges that act as a barrier to the successful wide-scale deployment of the methodologies are discussed. In particular, it addresses issues related to how to measure key performance indicators (such as the vibration response of the structure) and the potential of these approaches in real-world applications.

Real Time Measurement of Scour Depths Around Bridge Piers and Abutments, A. A. Khan and H. S. Atamturktur, South Carolina Department of Transportation, Office of Materials and Research, 2015.
https://scltap-scdot.s3.amazonaws.com/documents/SPR692-report.pdf
Note: Cited by South Carolina in the survey.
From the abstract: ... The available techniques for monitoring scour are reviewed to highlight the governing physics, to evaluate field performance, and to identify the effect of environmental factors on accuracy and reliability. From this assessment, two devices are selected for further study: a sonar fathometer and a Time Domain Reflectometry (TDR) device. A novel device, called a Vibration-based Turbulent Pressure (VTP) sensor, is proposed which exploits the turbulence in open channels to locate the bed level. This sensor vibrates at a significantly higher amplitude when in the channel flow relative to an identical sensor located in the sediment. The vibration-based method, time domain reflectometry, and sonar devices are evaluated against simulated field conditions in order to determine their relative

sensitivities to environmental conditions. These tests reveal that sonar and time domain reflectometry devices can be influenced by channel salinity and temperature. In addition, the sonar device is shown to be sensitive to the suspended sediment concentration in the channel, its height relative to the bed, and bed topography within the sonar beam. The vibration-based method is shown to be the least sensitive to environmental factors in the channel. In addition, the VTP device can provide reliable results in highly misaligned flows. Finally, the performance of TDR, sonar, and the vibration-based technique is evaluated under field conditions. The field tests reveal that all instruments perform at their accuracy level. The sonar must be deployed close to the bed to guarantee that the beam will be contained within the scour hole and would not have large width. In addition, the site should not have high suspended load concentration. The TDR is insensitive to suspended sediment; however, salinity greater than 0.5 parts per thousand renders the instrument inoperable. The VTP is proven to be insensitive to all the environmental factors. However, field deployment reveals that debris accumulation may cause the instrument to report false bed location.

3.2. Vibration-Based Monitoring Techniques

This area of inquiry includes theoretical and field-validated research on vibration-based scour monitoring, a non-invasive technique suited to locations that are difficult to access.

"Monitoring and Simulation of Bridge Pier scour and Deposition Processes in Flood Events," Fong-Zuo Lee, Jihn-Sung Lai, Yung-Bin Lin, and Kuo-Chun Chang, *Environmental Earth Sciences,* Vol. 84, Article 338, 2025.
https://link.springer.com/article/10.1007/s12665-025-12196-2
From the abstract: Bridge failure caused by flood-induced scour around piers remains the primary threat to traffic disruption and life losses. Real-time monitoring of scour variations is crucial to avoid bridge failure. The scour monitoring system is developed and implemented in the field, consisting of vibration-based MEMS (micro-electromechanical systems) arrayed sensors for water level and flow velocity measurement. The scour monitoring system records scour and deposition depth changing over time at the bridge pier in flood events. A numerical simulation module combining one-dimensional and two-dimensional mobile-bed hydrodynamic models is established to calculate scour and deposition depths based on field hydrological conditions. The field-measured data from the real-time scour monitoring system are employed for model validation. Due to the complexity of hydraulic sediment transport mechanisms around the pier, several local scour formulas have been evaluated to verify their applicability. Using field-measured scour depth data, a suitable local scour formula for the Mingchu Bridge in the Cho-Shui River is developed. The real-time scour monitoring system coping with the numerical simulation module developed in this study can provide accurate information on scour and deposition processes at the bridge pier, which is helpful for decision-makers to assess the risk of bridge damage and the timing of bridge closure. Finally, the proposed bridge safety curve referring to four bridge warning stages based on the pier foundation characteristics, as a determinate relationship between scoured bed level and discharge, has been established to assist bridge managers in making rational decisions on bridge closures during floods.

"A Review of Bridge Scour Monitoring Techniques and Developments in Vibration Based Scour Monitoring for Bridge Foundations," Alan Kazemian, Tien Yee, Metin Oguzmert, Mahyar Amirgholy, Jidong Yang and Dale Goff, *Advances in Bridge Engineering,* Vol. 4, article 2, 2023.
https://aben.springeropen.com/articles/10.1186/s43251-023-00081-6
From the abstract: … Most scour monitoring systems require underwater installation, which is inherently difficult to implement for existing structures. Data obtained from such systems may not necessarily be accurate due to factors such as site temperature fluctuations, or the presence of large debris in the channel causing faulty readings during times of high flooding. Inaccuracy in this data is a problem because it could display erroneous results, leading to a false sense of security. Researchers worldwide are exploring vibration-based techniques to monitor scour to overcome this challenge. These techniques can possibly monitor scour without any underwater installation and may be more efficient than the traditional underwater technologies currently implemented. This review piece aims to present a summary of the several types of scour monitoring techniques traditionally used to monitor scour of bridge structures and the advancement in technology for existing monitoring techniques based on the vibration characteristics of bridges. The importance of monitoring scour progression focused on vibration-based techniques will be discussed as well as providing a fair appraisal of these techniques. This review piece shows evidence through laboratory and field experiments that monitoring a structure based on vibrational changes due to scour is possible, and with the advances in technology over the most recent decade, it is now possible to design cost-effective and accurate scour monitoring systems for future field implemented structural health monitoring projects. This evidence is relevant to future researchers for the implementation of prospective bridge vibration-based systems.

"A Review of Vibration-Based Scour Diagnosis Methods for Bridge Foundation," Zhenhao Zhang, Guowei Lin, Xiaopeng Yang, Shilin Cui, Yan Li, Xueqing Shi and Zhongyu Han, *Sustainability*, Vol. 15, Issue 10, page 8210, 2023.
https://www.mdpi.com/2071-1050/15/10/8210
From the abstract: Foundation scour poses a serious threat to bridge safety in the whole life cycle and leads to many bridge failure incidents. Recently, as an important subfield of bridge structural health monitoring, vibration-based scour diagnosis methods have garnered widespread attention, particularly due to their rapid and low-cost features, which overcomes the difficulties of complex equipment installation associated with the traditional approaches. Recent advances of this method within the last decade are reviewed in this paper. Firstly, the principle of scour diagnosis and vibration excitation methods are introduced. Then, existing qualitative and quantitative studies on scour diagnosis are reviewed, respectively. The former refers to identifying the scour location based on the bridge dynamic characteristics or dynamic response changes, and the latter refers to identifying scour depth based on model updating or machine learning methods. Based on the above review, some important but neglected issues are summarized and discussed in depth, and some challenges and future trends are proposed, including innovative excitation methods, mitigation of environmental conditions interference, soil–structure interaction prediction and application of machine learning techniques.

“Advances in Vibration-Based Scour Monitoring for Bridge Foundations,” Tianyang Lan, Weimin Xu, Shichao Zhao, Feng Liu, and Yang Liu, *IOP Conference Series: Materials Science and Engineering*, Vol. 1203, Article 022127, 2021.
https://iopscience.iop.org/article/10.1088/1757-899X/1203/2/022127/pdf
From the abstract: Scouring around bridge foundations is one of the main factors causing structural damage of bridges. Traditional scour monitoring techniques generally require a large number of sensing devices set up underwater, which is difficult to be implemented for actual bridges. To address this issue, scour monitoring technology based on structural vibrations is paid attention gradually, because this technique can work well with less equipment and can be free from the influence of the submerged environment. This study presents a systematic summary and analysis of the selection of scour indicators, sensor deployment principles and other related research involved in scour monitoring technology based on structural vibration. On this basis, the research status of the bridge scour monitoring method based on vehicle excitation is further summarized. Finally, the prospects for the application of vibration-based bridge foundation scour monitoring technology are presented, discussing the technologies that are currently missing and urgently needed for this monitoring method and the challenges faced today.

“Laboratory Investigation of a Bridge Scour Monitoring Method Using Decentralized Modal Analysis,” Muhammad Arslan Khan, Daniel P. McCrum, Luke J. Prendergast, Eugene J. Obrien, Paul C. Fitzgerald and Chul-Woo Kim, *Structural Health Monitoring,* Vol. 20, Issue 6, pages 3327–3341, 2021.
https://nottingham-repository.worktribe.com/index.php/preview/5227757/Repository_Published.pdf
From the abstract: Scour is a significant issue for bridges worldwide that influences the global stiffness of bridge structures and hence alters the dynamic behavior of these systems. For the first time, this paper presents a new approach to detect bridge scour at shallow pad foundations, using a decentralized modal analysis approach through re-deployable accelerometers to extract modal information. A numerical model of a bridge with four simply supported spans on piers is created to test the approach. Scour is modelled as a reduction in foundation stiffness under a given pier. A passing half-car vehicle model is simulated to excite the bridge in phases of measurement to obtain segments of the mode shape using output-only modal analysis. Two points of the bridge are used to obtain modal amplitudes in each phase, which are combined to estimate the global mode shape. A damage indicator is postulated based on fitting curves to the mode shapes, using maximum likelihood, which can locate scour damage. The root mean square (RMS) difference between the healthy and scoured mode shape curves exhibits an almost linear increase with increasing foundation stiffness loss under scour. Experimental tests have been carried out on a scaled model bridge to validate the approach presented in this paper.

“Wavelet-Based Operating Deflection Shapes for Locating Scour-Related Stiffness Losses in Multi-Span Bridges,” Eugene J. Obrien, Daniel P. McCrum, Muhammad Arslan Khan and Like J. Prendergast, *Structure and Infrastructure Engineering,* Vol. 19, Issue 2, pages 238–253, 2021.
https://www.tandfonline.com/doi/full/10.1080/15732479.2021.1937235#abstract
From the abstract: … In this paper, a new approach to detect scour at multiple locations is proposed, using wavelet-based Operating Deflection Shape (ODS) amplitudes. A numerical model of a bridge with four simply supported spans resting on piers is used to test the approach. Scour is modelled as a reduction in vertical foundation stiffness under one or multiple bridge piers. A fleet of passing trucks, modelled as half-car vehicles, are used to excite the bridge to enable structural accelerations be calculated at each support. The approach is shown to be effective with acceleration measurements at each support location in a multi-span bridge. Using a fleet of passing vehicles, the temporal accelerations measured at each support are averaged and transformed into the frequency–spatial domain, in order to

estimate the wavelet-based ODS for a given scour case. A damage indicator is postulated based on differences between the ODS of healthy and scoured bridge cases. The damage indicator enables visual identification of the location of scoured piers considering a range of natural frequencies of the system.

“Wireless Sensor Network-Based Monitoring of Bridge Pile Foundations for Detecting Scouring Depth,” Han-Tang Huang, H. Ping Tserng, Ruei-Yu Hou and Miroslaw Skibniewski, *Journal of Marine Science and Technology,* Vol. 29, Issue 1, 2021.
https://jmstt.ntou.edu.tw/journal/vol29/iss1/6/
From the abstract: ... This paper presents a wireless sensor network (WSN) - based solution developed to measure micro-vibrations of a bridge pier. Test measurement values are converted with the use of the Fast Fourier Transform (FFT) method to obtain natural frequencies. Scouring depth of the pier is estimated with the use of a Finite Element Method model. WSN is used to collect the signal and to test data transmission stability in different locations, as well as FFT and Welch method are used to convert the obtained signal into spectral signals allows an automatic determination and storage of pier vibration frequency data. Relevant parameters in a Finite Element Method (FEM) model use the in-situ natural frequencies as calibration parameters, and the soil equivalent spring model was set up by using in-situ drilling data. The maximum spring depth represents the depth of the scouring. The scouring depth and natural frequency data are used as follow-up indicators of bridge scouring condition. WSN is used to monitor condition of piers provides a practical method and tool for mitigating potential bridge collapse.

3.3. Sonar Tools and Technologies

The following publications focus on continuous scour monitoring using sonar to take real-time measurements of streambed elevation and scour depth.

“Bridge Scour Morphology Identification and Reconstruction Using 3D Sonar Point Cloud Data,” Zelin Huang, Yanjie Zhu, Wen Xiong and C.S. Cai, *Automation in Construction*, Vol. 175, 2025.
https://www.sciencedirect.com/science/article/abs/pii/S0926580525002456?via%3Dihub
From the abstract: 3D multibeam sonar is a feasible solution for detecting bridge scour. However, the reliance on technicians for the identification of the morphological characteristics of local scour pits is time-consuming and subjective, and the absence of surface data hinders scour morphology analysis. Hence, an algorithm is proposed for the unsupervised identification and precise reconstruction of bridge scour morphology. This algorithm segments the scour area using local ternary patterns, optimizes parameters through the dung beetle optimizer, extracts local scour pits with k-means, and introduces an adjustable ball-pivoting algorithm for surface reconstruction by adjusting the mesh ensemble connections. Algorithm testing on the simulated scour data yielded a F1-score of 0.9017 for identification and improved point cloud density, whereas performance evaluation on the Wuhu Yangtze River Bridge in China demonstrated accurate identification of scour morphology and adaptive reconstruction. Thus, the proposed algorithm can enhance the automation and efficiency of scour detection using 3D sonar.

Real-Time Pier Scour Monitoring and Evaluation, Idaho Water Science Center, USGS, 2024.
https://www.usgs.gov/centers/idaho-water-science-center/science/real-time-pier-scour-monitoring-and-evaluation
From the web page: … As of 2017, the National Bridge Inventory listed 265 of Idaho's nearly 4,500 bridges (about 6 percent) as "scour critical." When rivers rise quickly, bridge inspectors have little or no time to mobilize and monitor bridges at risk of scour. Real-time bridge scour monitoring offers a way to remotely monitor sites and to collect long-term data for evaluation. This lowers monitoring costs and reduces the need for field crews to inspect bridges in potentially hazardous situations.
In cooperation with the Idaho Transportation Department, we have installed sonar devices at three Idaho bridges near existing USGS streamgage stations. … The devices transmit streambed elevation every 15 minutes to the nearby streamgages. That data, along with the other data collected by the streamgages, is then be published to the USGS National Water Information System for public access. We will also collect hydraulic and geomorphic data to better understand the characteristics of each site. We will continue this pilot study into 2022 and will publish our findings then. Study results will help ITD to decide whether to continue monitoring these sites or to expand the network to other Idaho bridges.

Related resource:

> **Geomorphic Assessment at Three Real-Time Bridge Scour Monitoring Sites in Idaho, 2020-2021 Data Release**, Idaho Water Science Center, USGS, 2024.
> https://www.usgs.gov/data/geomorphic-assessment-three-real-time-bridge-scour-monitoring-sites-idaho-2020-2021
> *From the web page:* This data release presents ancillary documents (bridge plans, field forms, and photos); a Hydraulic Toolbox executable and project file; and site-specific geomorphic survey data to supplement the larger study, Real-Time Pier Scour Monitoring and Observations at Three Scour-Critical Sites in Idaho, Water Year 2020–22. This data release summarizes the process steps and qualitative summary for the data provided and used within the study. The Hydraulic Toolbox project file presents the summarized geomorphic survey and hydraulic streamflow data to allow the user to view, estimate, and summarize pier scour using the general pier scour design equations.

Unmanned Surface Vessels for Bridge Scour Monitoring, Brian Schroeder, Pete Haug, Anthony Alvarado, and Stephanie Baribeau, Michigan Department of Transportation Research Administration, 2019.
https://www.michigan.gov/mdot/-/media/Project/Websites/MDOT/Programs/Research-Administration/Final-Reports/SPR-1682-Report.pdf
Note: Cited by Michigan in the survey.
From the abstract: Scour at bridge substructure units can cause undermining of footings and exposure of piles, which can lead to bridge failure. Monitoring of the streambed elevations around a scour critical bridge to identify whether or not scour is occurring during a high-flow event is critical. Working on or near the water may be dangerous during these events. The study investigated various techniques to monitor bridge scour during high-flow events. Sonar has been the leading technique when completing underwater investigations. Different sonar devices were compared: single-beam echo sounder, multi-beam echo sounder, and side-scan. Based on parameters of cost, water depths less than 30 feet, data retrieval, processing, and quality, a single-beam echo sounder, sidescan, and the post-processing software SARHawk, was recommended. Multiple access techniques were assessed based on personnel safety, ease of deployment, and efficient mobilization. Research concluded that a remotely operated unmanned surface vessel (USV) can best complete the following:

- Operate in turbulent waters with high current near substructure units or debris
- Obtain depth readings in water 3 to 30 feet deep
- Transmit real-time images and data to shore station
- Deploy rapidly and transport easily

Several USVs on the market were compared by means of a rating system and equipment testing. The USVs were rated on parameters outlined in specification sheets, in-person testing, and cost. The rating system identified the company and model of USV recommended.

Real-Time Streambed Scour Monitoring at Two Bridges over the Gunnison River in Western Colorado, 2016–17, Mark F. Henneberg, U.S. Geological Survey Investigation Report 2018-5123, 2018. https://doi.org/10.3133/sir20185123
Note: Cited by Colorado in the survey.
From the abstract: The Colorado Department of Transportation maintains roadways crossing over large streams and rivers where sediment transport and channel alignment changes can affect the structural stability of bridges. Structural stability during and immediately after peak streamflow can be assessed by measuring streambed scour; however, placing personnel or boats in the water during high-streamflow events using traditional methods can be difficult, hazardous, and time consuming. To address this need, the U.S. Geological Survey, in cooperation with Colorado Department of Transportation, installed instrumentation at two bridges in western Colorado to measure streambed elevations in real-time during snowmelt-runoff periods (May through June) in 2016 and 2017. The bridges include U.S. Highway 50 eastbound over the Gunnison River at milepost 70.0 (bridge I–04–K) and Colorado Highway 141 over the Gunnison River at milepost 153.7 (bridge I–03–A).

Bridge I–04–K was outfitted with two echosounders, each mounted on the north side of pier 3. Data collected during the 2016 snowmelt runoff did not indicate scour had occurred. Data collected during 2017 snowmelt runoff indicated minor scour and fill occurred under the downstream echosounder. Bridge I–03–A was outfitted with two echosounders, each mounted on opposite sides of pier 4, at the transition of the upstream nose to the straight section of the pier wall. Data recorded during 2016 did not indicate any scour under the echosounders. Debris accumulation around the nose of the pier and under the echosounders resulted in inconsistent streambed elevation data. Data recorded during 2017 did not indicate any scour under the echosounders. Probing of the pier wall and streambed interface and underwater photographs obtained in 2016 revealed undermining along the length of the pier wall. The undermining extended side-to-side to a depth of about 2 feet. Underwater photographs were obtained again in 2017; no changes from the previous year were observed.

Cross-section surveys were completed at each bridge to measure and document changes in channel geometry during the study. Surveys were performed in spring 2016 before snowmelt runoff, spring 2017 before snowmelt runoff, and fall 2017. Streambed elevations from cross-section surveys at both bridges were evaluated using two-tailed, paired t-tests and Wilcoxon rank sum tests to identify significant changes between the surveys. Both tests indicated significant changes in mean streambed elevations for the cross-sections and around the monitored piers at bridges I–04–K and I–03–A during the 2-year study.

3.4. Remote Sensing: Radar, LiDAR, and InSAR

This topic area covers non-contact scour detection using radar and satellite-based techniques, which can detect structural deformation and changes in conditions that may indicate scour risk, especially useful for monitoring scour-critical bridges over time.

PI-0377: Crewed Aircraft LiDAR Bathymetry in Turbid Water Preliminary Investigation (PI), Caltrans Division of Research, Innovation and System Information, July, 2025.
https://dot.ca.gov/-/media/dot-media/programs/research-innovation-system-information/documents/preliminary-investigations/pi-0377-bathymetry-pi-final-report-a11y.pdf
Note: Cited by California in the survey.
From the Executive Summary: Caltrans frequently conducts underwater terrain mapping, or bathymetry, for safety inspections, such as bridge scouring. Mapping is typically performed using sonar-equipped boats, a method that can be time-consuming and limited in coverage. To improve efficiency, Caltrans is exploring alternatives—particularly airborne LiDAR bathymetry (ALB) using crewed aircraft for mapping the turbid freshwater conditions common at Caltrans sites.

This Preliminary Investigation (PI) provides a comprehensive review of the current state of crewed aircraft-based LiDAR bathymetry technologies with a focus on their suitability for turbid freshwater environments. It evaluates the capabilities and limitations of available ALB systems, including performance in turbid water, technical specifications, operational requirements, and estimated costs. These insights can help assess whether crewed ALB is a practical, cost-effective alternative to traditional methods.

Flood Assessment System for TxDOT, David Maidment, Paola Passalacqua, Matt Bartos, Sujana Timilsina, Jeil Oh, Andy Carter, Tim Whiteaker, Harry Evans, Christine Thies, Larry Jantzen, Matt Ables, Attila Bibok, Barney Austin, Tim Osting, Scott Grzyb, Jody Avant, Jon Thomas, Michael Nyman, Kristine Blickenstaff, The Center for Transportation Research, University of Texas at Austin, 2025.
https://www.usgs.gov/data/radar-based-field-measurements-gage-height-and-surface-velocity-and-resulting-cross-sectional
Note: Cited by Texas in the survey.
*From the abstract: T*he National Weather Service (NWS) operates a National Water Model that continually forecasts water flow throughout the stream network of the United States, including 190,000 miles of streams divided into 100,000 stream reaches in Texas. The NWS has also deployed real-time flood inundation mapping to about half of Texas and will complete coverage of the state by 2025. This project builds on these services to show flood impact on the road and bridge system. To help densify the streamflow observation network for Texas, 80 radar streamflow gauges were installed on TxDOT bridges, whose data are now ingested by the NWS. The researchers created a data assimilation scheme that adjusts the forecasts of the National Water Model in real-time using data from the TxDOT gauges. A Flood Assessment System for TxDOT was created that comprises a web-based overlay of current and predicted flood information. This system includes a prototype bridge warning service describing real-time water levels at 19,000 span bridges in Texas. A road elevation model was created for the 11-county TxDOT Austin District which comprises 3.8 billion LiDAR points covering 38,000 miles of roadway. The state-wide bridge warning system and the road elevation model are a first for TxDOT and for Texas.

Related Resource:

Streamflow II Project: TxDOT Research Project 0-7095 University of Texas and the USGS, ArcGis Story Map, 2023.
https://storymaps.arcgis.com/stories/0c2e432360ff4b619e80c6c3f5fde441
From the Project Overview: Texas has the highest number of flood-related fatalities in the United States, including drivers in vehicles. This alarming statistic served as a catalyst for scientists at the University of Texas to delve into innovative ideas, conduct research, and develop technology with the potential to directly save lives.
The Streamflow II Project (0-7095) builds on the science and findings from Streamflow I, which focused on the development of flooding maps and the installation of gauges on existing TxDOT waterway bridges. Streamflow II has focused on developing flood inundation forecasting which would anticipate bridge and road flooding on the TxDOT roadway system.

The Applicability of Time-Integrated Unit Stream Power for Estimating Bridge Pier Scour Using Noncontact Methods in a Gravel-Bed River, Arizona Water Science Center; Colorado Water Science Center, USGS, 2022.
https://www.usgs.gov/publications/applicability-time-integrated-unit-stream-power-estimating-bridge-pier-scour-using
From the Publications page: In near-field remote sensing, noncontact methods (radars) that measure stage and surface water velocity have the potential to supplement traditional bridge scour monitoring tools because they are safer to access and are less likely to be damaged compared with in-stream sensors. The objective of this study was to evaluate the use of radars for monitoring the hydraulic conditions that contribute to bridge–pier scour in gravel-bed channels. Measurements collected with a radar were also leveraged along with minimal field measurements to evaluate whether time-integrated stream power per unit area (Ω) was correlated with observed scour depth at a scour-critical bridge in Colorado. The results of this study showed that (1) there was close agreement between radar-based and U.S. Geological Survey streamgage-based measurements of stage and discharge, indicating that radars may be viable tools for monitoring flow conditions that lead to bridge pier scour; (2) Ω and pier scour depth were correlated, indicating that radar-derived Ω measurements may be used to estimate scour depth in real time and predict scour depth based on the measured trajectory of Ω. *The approach presented in this study is intended to supplement, rather than replace, existing high-fidelity scour monitoring techniques and provide data quickly in information-poor areas.*

"The Applicability of Time-Integrated Unit Stream Power for Estimating Bridge Pier Scour Using Noncontact Methods in a Gravel-Bed River," Laura A. Hempel, Helen F. Malenda, John W. Fulton, Mark F. Henneberg, Jay R. Cederberg, and Tommaso Moramarco, *Remote Sensing*, Vol. 14, Issue 9, Article number 1978, 2022.
https:// doi.org/10.3390/rs14091978
From the abstract: In near-field remote sensing, noncontact methods (radars) that measure stage and surface water velocity have the potential to supplement traditional bridge scour monitoring tools because they are safer to access and are less likely to be damaged compared with in-stream sensors. The objective of this study was to evaluate the use of radars for monitoring the hydraulic conditions that contribute to bridge–pier scour in gravel-bed channels. Measurements collected with a radar were also leveraged along with minimal field measurements to evaluate whether time-integrated stream power per unit area (Ω) was correlated with observed scour depth at a scour-critical bridge in Colorado. The results of this study showed that (1) there was close agreement between radar-based and U.S.

Geological Survey streamgage-based measurements of stage and discharge, indicating that radars may be viable tools for monitoring flow conditions that lead to bridge pier scour; (2) Ω and pier scour depth were correlated, indicating that radar-derived Ω measurements may be used to estimate scour depth in real time and predict scour depth based on the measured trajectory of Ω. The approach presented in this study is intended to supplement, rather than replace existing high-fidelity scour monitoring techniques and provide data quickly in information-poor areas.

Evaluating the Use of Video Cameras to Estimate Bridge Scour Potential at Four Bridges in Southwestern Montana, USGS Fact Sheet, 2022.
https://pubs.usgs.gov/fs/2022/3040/fs20223040.pdf
Note: Cited by Montana in the survey.
From the publication: ... From 2019 to 2021, the U.S. Geological Survey (USGS), in cooperation with the Montana Department of Transportation, installed cameras and LSPIV recording equipment at four sites where the USGS and Montana Department of Transportation are monitoring bridge scour using other methods (fig. 1). The goal of the study was to determine if LSPIV can increase the accuracy of current bridge scour prediction methods. Scour around piers is one of the primary failure mechanisms for bridges and threatens public safety and interstate commerce. LSPIV has potential to improve prediction of sediment scour under and around bridge piers during flood events. Traditional methods of bridge scour monitoring such as sounding from bridges and bathymetry during floods are risky and challenging because traditional instrumentation for surveying depths and velocities requires physical access to areas around piers. LSPIV provides noncontact, hourly monitoring of surface velocity and direction. The data generated by LSPIV can be stored or transmitted and could improve safety and estimates of hydraulic forces near bridge piers in real time.

Development of Data Collection Systems for Large-Scale Particle Image Velocimetry (LSPIV). Kin S. Yen and Ty A. Lasky, Advanced Highway Maintenance and Construction Technology Research Center, Department of Mechanical and Aerospace Engineering, University of California at Davis, 2021.
https://dot.ca.gov/-/media/dot-media/programs/research-innovation-system-information/documents/final-reports/ca21-3183-v2-finalreport-a11y.pdf
Note: Cited by California in the survey.
From the executive summary: To calibrate hydraulic models used for bridge scour analysis and design, it is necessary to collect information about the flow characteristics of a river during flood events. However, using a manned boat can be difficult and time-consuming to deploy. Deploying instruments from a bridge deck can also be challenging and may require lane closure due to space constraints. A new method is needed to measure discharge, collect flow velocity (magnitude and direction) information at the water surface, and channel discharge in a river which can be used over a large spatial extent (1,000 - 2,000 feet) and is quick to use, safe for Caltrans personnel, and easily deployable. The purpose of this research was to examine hardware, software, and deployment options to best implement current Large-Scale Particle Image Velocimetry (LSPIV) technology for estimate flood flows to meet Caltrans' hydraulic needs. Specifically, the most appropriate camera type (infrared and commercial off-the-shelf), Light Detection and Ranging, or other instrument for measuring the water slope, required camera accessories, post-processing LSPIV software and the hardware needed for deploying the system using both a retractable mast and an unmanned aerial system (UAS) were determined and implemented during this research project.

"Remote Monitoring to Predict Bridge Scour Failure Using Interferometric Synthetic Aperture Radar (InSAR) Stacking Techniques," Sivasakthy Selvakumaran, Simon Plank, Christian Geiß, Cristian Rossi and Campbell Middleton, *International Journal of Applied Earth Observation and Geoinformation*, Vol. 73, pages 463–470, 2018.
https://www.sciencedirect.com/science/article/pii/S0303243418303052
From the abstract: … This paper presents evidence of how InSAR techniques can be used to monitor bridges at risk of scour, using Tadcaster Bridge, England, as a case study. Tadcaster Bridge suffered a partial collapse due to river scour on the evening of December 29th, 2015 following a period of severe rainfall and flooding. 48 TerraSAR-X scenes over the bridge from the two-year period prior to the collapse are analysed using the small baseline subset (SBAS) interferometric synthetic aperture radar (InSAR) approach. The study highlights a distinct movement in the region of the bridge where the collapse occurred prior to the actual event. This precursor to failure observed in the data over a month before actual collapse suggests the possible use of InSAR as a means of an early warning system in structural health monitoring of bridges at risk of scour.

3.5. Embedded Sensors (Non-Vibration-Based)

These studies focus on in-situ sensors that offer continuous monitoring with minimal power needs, installed on or near bridge foundations to capture early changes in soil conditions and water levels associated with scour.

"Photoelectric Sensors for Wireless Monitoring of Bridge Scour – Laboratory Investigation and Field Validation," Mohammed Farooq, Fae Azhari, and Nemkumar Banthia, *Structure and Infrastructure Engineering,* Vol. 21, Issue 6, 2025.
https://www.tandfonline.com/doi/abs/10.1080/15732479.2023.2261434
From the abstract: Scour, or the erosion of bed material is a major cause of bridge failure across the world. Monitoring scour levels at bridge foundations reduces the risk of failure through timely condition-based maintenance. This paper evaluates the use of photoelectric sensors for scour detection through laboratory studies and subsequent field investigation. Two types of photoelectric sensors, namely diffusive-reflective and through-beam, were independently investigated. The sensors were installed at six distinct depths on a simulated bridge pier in a laboratory flume. Scour resulting from hydrodynamic action triggered the sensors at different levels, enabling scour depth detection. An inverse response from the sensors detected scour refill. Following successful laboratory tests, a photoelectric scour-sensing prototype was installed in a small creek in August 2019 which continued to monitor scour until April 2022. The prototype response confirmed laboratory results and continues to perform well under various field conditions such as rain, debris, and snow. The very low-cost system required minimal power and bandwidth, and the sensing component was robust to flow parameters. Long-term field studies are required to evaluate their susceptibility to biofouling and develop biofouling countermeasures.

Research in Progress: Real-time Continuous Bridge Scour Monitoring for Improved Safety and Cost Savings, United States Geological Survey, 2025.
https://rip.trb.org/View/2592197
Note: Cited by Oregon in the survey.
From the web page: Current Oregon Department of Transportation (ODOT) methods for monitoring bridge scour are time-consuming, labor intensive, not always accurate, very dangerous to perform during

extreme storm events, and unrealistic to apply to all of the scour critical bridges. Development of a deployable remote real-time monitoring system could alleviate these issues as well as provide an early warning system for Region and District personnel. This project will (1) develop methods for identifying scour early and safely using deployable automated Real-Time Scour monitoring systems, (2) use data collected to improve bridge design, and (3) provide a planning matrix to address the scour critical bridge inventory with this advanced real-time technology.

Electronic Water Level Sensors for Monitoring Scour Critical Structures, Branko Kerkez, Kate Kusiak Galvin, Travis Dantzer, Michigan Department of Transportation Research Administration, 2024.
https://www.michigan.gov/mdot/-/media/Project/Websites/MDOT/Programs/Research-Administration/Final-Reports/SPR-1740-Report.pdf
Note: Cited by Michigan in the survey.
From the abstract: This report details a research project aimed at developing and deploying a cost-effective water level sensor network for monitoring scour critical bridges in Michigan. The project involved a comprehensive review of existing water level monitoring technologies, followed by the selection and pilot deployment of Open-Storm sensors on over 30 bridges across the state. Real-time water level data was collected and transmitted, and system performance was continuously monitored. The results demonstrated that the sensors provided valuable real-time information, enhancing bridge inspection efficiency and decision-making. Positive feedback from bridge engineers highlighted the benefits of the technology in improving situational awareness and resource allocation. The report concludes with recommendations for scaling the technology statewide and integrating it with predictive models and other data sources to further enhance bridge scour management practices.

"Implementing a Rapid Deployment Bridge Scour Monitoring System in Colorado, 2019," Mark F. Henneberg and Rodney J. Richards, U.S. Geological Survey Scientific Investigations Report 2022-5023, 2022.
https://doi.org/10.3133/sir20225023
Note: Cited by Colorado in the survey.
From the abstract: The U.S. Geological Survey, in cooperation with the Colorado Department of Transportation, installed and operated real-time scour monitoring instrumentation at two bridges in Colorado in 2016 and 2017 to measure streambed elevations in real-time. The instrumentation included acoustic echosounder depth sensors mounted to the bridge substructure units with rigid conduit and fittings. Although functional, the rigid mounting configuration took several days to install at each site, which limits the instrumentation to long-term deployments at previously determined sites. To address this limitation and allow for greater flexibility in bridge selection, a rapid deployment bridge scour monitoring system (RDBSMS) was developed by the U.S. Geological Survey in cooperation with the Colorado Department of Transportation. The RDBSMSs were installed at two other bridges in Colorado in 2019, which were selected by using specific scoring criteria to rank candidate bridges and the potential for high streamflow based on accumulated snowpack. A matrix was developed to rank candidate bridges based on factors including depth, foundation type, average daily traffic, detour route, and scour critical condition. Colorado Department of Transportation bridges F-05-R and P-01-G were selected as the final candidate bridges for installation and testing of the rapid deploy scour monitoring system.

"Electromagnetic Sensors for Underwater Scour Monitoring," Andrea Maroni, Enrico Tubaldi, Neil Ferguson, Alessandro Tarantino, Hazel McDonald, and Daniele Zonta, *Sensors,* Vol. 20, Issue 15, Article 4096, 2020.
https://pmc.ncbi.nlm.nih.gov/articles/PMC7436009/
From the abstract: Scour jeopardises the safety of many civil engineering structures with foundations in riverbeds and it is the leading cause for the collapse of bridges worldwide. Current approaches for bridge scour risk management rely mainly on visual inspections, which provide unreliable estimates of scour and of its effects, also considering the difficulties in visually monitoring the riverbed erosion around submerged foundations. Thus, there is a need to introduce systems capable of continuously monitoring the evolution of scour at bridge foundations, even during extreme flood events. This paper illustrates the development and deployment of a scour monitoring system consisting of smart probes equipped with electromagnetic sensors. This is the first application of this type of sensing probes to a real case-study for continuous scour monitoring. Designed to observe changes in the permittivity of the medium around bridge foundations, the sensors allow for detection of scour depths and the assessment of whether the scour hole has been refilled. The monitoring system was installed on the A76 200 Bridge in New Cumnock (S-W Scotland) and has provided a continuous recording of the scour for nearly two years. The scour data registered after a peak flood event (validated against actual measurements of scour during a bridge inspection) show the potential of the technology in providing continuous scour measures, even during extreme flood events, thus avoiding the deployment of divers for underwater examination.

A New Method for Detecting the Onset of Scour and Managing Scour Critical Bridges, John Orsak, Federal Railroad Administration, 2019.
https://rosap.ntl.bts.gov/view/dot/42437
From the abstract: This project explores monitoring railroad bridges using a hybrid sensor that measures acceleration, tilt, and temperature. The objective of the research is to detect scour and changing soil conditions at an early stage before railroad operations are affected. The sensors were installed on six railroad bridges and have been in operation since 2013. An overview of the data is presented including recommendations for continued monitoring. A methodology has been created for how to analyze the data and send alerts if changing conditions are detected. Scour conditions are not known to have occurred on any of the bridges, but the data collected can provide insight into the structural response of bridge piers.

3.6. Emerging Technologies: AI and Machine Learning

AI models are increasingly used to predict scour depth and assess risk using historical and real-time data. These citations include reviews of AI modeling techniques and case studies applying deep learning, genetic programming, and hybrid approaches that offer promise for early warning systems and more accurate scour prediction.

"Scour Depth Prediction Around Bridge Abutments: A Comprehensive Review of Artificial Intelligence and Hybrid Models," Nadir Murtaza, Diyar Khan, Aïssa Rezzoug, Zaka Ullah Khan, Brahim Benzougagh, and Khaled Mohamed Khedher, *Physics of Fluids,* Vol. 37, Issue 2, 2025.
https://pubs.aip.org/aip/pof/article-abstract/37/2/021306/3336711/Scour-depth-prediction-around-bridge-abutments-A?redirectedFrom=fulltext
From the abstract: Scouring around the bridge structure is a major concern of the globe. Therefore, a precise estimation of the scour depth is essential to minimize bridge failure and provide preventive measures. This review paper aims to analyze the critical review of various artificial intelligence (AI) techniques utilized in the literature to estimate bridge abutment scour depth including artificial neural networks (ANN), adaptive neuro-fuzzy inference systems (ANFIS), gene expression programming (GEP), support vector machines (SVM), and extreme learning machines (ELM). The predictive power of each technique was assessed in terms of different performance indicators, such as correlation coefficient (R), mean square error (MSE), predicted values, Taylor's diagram, sensitivity analysis, and violin plot. This review paper highlights that by comparing different AI techniques, ELM and GEP techniques have superior performance, especially in predicting scour depth and dealing with complex and large datasets. However, various limitations and proposed solutions have been reported for techniques, such as ANN, ANFIS, SVM, and group method of data handling (GMDH). The main challenges in the ANN, ANFIS, SVM, and GMDH techniques were overfitting and hyperparameter tuning. Based on the performance of each technique, the current review paper found the satisfactory performance of the ELM technique because of its computation speed and precise estimation capability. Moreover, the proposed solutions would be helpful to researchers working in the field of hydraulics engineering, particularly scouring around the bridge abutment.

"Towards an AI-Based Early Warning System for Bridge Scour," Negin Yousefpour and Oscar Correa, *Georisk: Assessment and Management of Risk for Engineered Systems and Geohazards,* Vol. 17, Issue 4, 2023.
https://www.tandfonline.com/doi/full/10.1080/17499518.2023.2222371
From the abstract: Scour is the number one cause of bridge failure in many parts of the world. Considering the lack of reliability in existing empirical equations for scour depth estimation and the complexity and uncertainty of scour as a physical phenomenon, it is essential to develop more reliable solutions for scour risk assessment. This study introduces a novel AI approach for early forecast of scour based on real-time monitoring data obtained from sonar and stage sensors installed at bridge piers. Long-short Term Memory networks (LSTMs), a prominent Deep Learning algorithm successfully used for time-series forecasting in other fields, were developed and trained using river stage and bed elevation readings for more than 11 years, obtained from Alaska scour monitoring programme. The capability of the AI models in scour prediction is shown for three case-study bridges. Results show that LSTMs can capture the temporal and seasonal patterns of both flow and river bed variations around bridge piers, through cycles of scour and filling and can provide reasonable predictions of upcoming scour depth as early as seven days in advance. It is expected that the proposed solution can be implemented by transportation authorities for development of emerging AI-based early warning systems, enabling superior bridge scour management.

"The Artificial Intelligence of Things Sensing System of Real-Time Bridge Scour Monitoring for Early Warning during Floods," Yung-Bin Lin, Fong-Zuo Lee, Kuo-Chun Chang, Jihn-Sung Lai, Shi-Wei Lo, Jyh-Horng Wu, and Tzu-Kang Lin, *Sensors,* Vol. 21, Issue 14, 2021.
https://pmc.ncbi.nlm.nih.gov/articles/PMC8309823/
From the abstract: In the present study, a scour monitoring system designed with vibration-based arrayed sensors consisting of a combination of Internet of Things (IoT) and artificial intelligence (AI) is developed and implemented to obtain real-time scour depth measurements. These vibration-based micro-electro-mechanical systems (MEMS) sensors are packaged in a waterproof stainless steel ball within a rebar cage to resist a harsh environment in floods. The floodwater-level changes around the bridge pier are performed using real-time CCTV images by the Mask R-CNN deep learning model. The scour-depth evolution is simulated using the hydrodynamic model with the selected local scour formulas and the sediment transport equation. The laboratory and field measurement results demonstrated the success of the early warning system for monitoring the real-time bridge scour-depth evolution.

"Prediction of Local Scour Around Bridge Piers: Artificial-Intelligence-Based Modeling Versus Conventional Regression Methods," Reda Abd El-Hady Rady, *Applied Water Science,* Vol. 10, Article 57, 2020.
https://link.springer.com/article/10.1007/s13201-020-1140-4
From the abstract: This paper presents the use of two artificial intelligence modeling methods, namely genetic programming (GP) and adaptive neuro-fuzzy inference system (ANFIS), to predict pier scour depth based on clear water conditions of 320 data sets of laboratory and field data measurements. The scour depth was modeled as a function of five main dimensionless parameters: pier width, approaching flow depth, Froude number, standard deviation of grain size distribution, and channel open ratio. A functional relationship was established using the trained GP model, and its performance was verified by comparing the results with those obtained by the ANFIS model and seven conventional regression-based formulas. Numerical tests indicated that the GP model yielded much superior agreement than the ANFIS model or any other empirical equation. The advantage of the GP model was confirmed by applying the derived GP equation to predict the scour depth around the piers of Imbaba Bridge, Egypt.

3.7. Commercial Tools and Vendor Solutions

This final section of resources highlights a few commercially available scour monitoring systems, including wireless sensor platforms, telemetry-integrated monitoring, and early warning technologies. Vendors cite having tools that support multiple modalities and integrate with DOT maintenance protocols. *(Note: WTRC, the authors and this publication do not explicitly or implicitly promote or endorse any vendor or product.)*

AI-Driven Scour Depth Prediction: A Comprehensive Review, Visive.ai., 2025.
https://www.visive.ai/news/ai-driven-scour-depth-prediction-a-comprehensive-review
From the website: Explore how artificial intelligence, particularly through gene expression programming and artificial neural networks, is transforming the prediction of scour depth around bridge abutments, ensuring safer and more durable infrastructure.

Monitoring Scour at Bridges and Offshore Structures, Fondriest Environmental, Inc., 2025.
https://www.fondriest.com/environmental-measurements/environmental-monitoring-applications/monitoring-scour-bridges-offshore-structures/
From the website: … To be effective, bridge scour should be continuously monitored with the data made available in real time. The easiest and most efficient way to do this is with an integrated telemetry system. A data logger can support multiple sonar and water level sensors and log scour data from each at pre-defined intervals. With telemetry, whether radio, cellular or satellite, the system can then securely transmit the scour data to the Internet in real time for viewing from any computer.
…
In compliance with the NBI and often in conjunction with the U.S. Geological Survey, state DOTs can establish a thorough plan of action for scour-critical bridges within their boundaries. This plan of action is developed for each bridge individually, detailing the best countermeasure methods to remedy current bridge scour and prevent or slow its future expansion. To this end, the FHWA guidance manuals list monitoring, inspection and maintenance as the most effective scour countermeasures.

Scour Critical Bridge Monitoring, Resensys, 2025.
https://resensys.com/r20/wireless-sensor-document-application/scour-inspection-bridges-tilt-solar-camera-water-level.html
Resensys solutions offer a range of benefits that make monitoring more efficient, reliable, and cost-effective, including wireless and maintenance-free sensors and devices that are small, lightweight and easy to install.
From the website: Resensys provides cutting-edge wireless technology and tools designed to meet the specific needs of scour critical bridges. The system contributes real-time data on water levels, soil erosion, and bridge movement, enabling proactive measures to protect bridge.

4. Gaps, Additional Analysis, and Next Steps

The findings from this synthesis of practice highlight wide variations in how states estimate and monitor bridge scour, particularly during high-flow events. While some agencies are investing in real-time sensors, sonar systems, or drone-based tools, others continue to rely on manual inspections or modeling based on limited data inputs. Few states collect velocity or depth measurements during flood events, citing challenges such as access, cost, and safety concerns.

4.1. Gaps in Findings

Common gaps identified in survey responses include:

- Lack of real-time monitoring at most bridges—even when tools exist, they are often deployed only at select scour-critical sites.
- Limited gage coverage. Many states noted that existing USGS streamgages are insufficient to support accurate analysis across vast bridge networks.
- Inadequate velocity and flow depth data during disasters. Few states measure these parameters in real time, often relying instead on estimates or models resulting in overestimation or underestimation of factors used in modeling, which may, in turn, affect decision-making.
- Limited personnel for post-flood forensic analysis. Some states noted that specialized post-event analyses require technical expertise that may reside with only a handful of personnel. This creates a risk of knowledge gaps if those individuals are unavailable or depart the agency, highlighting the need for cross-training and clear documentation of methods.

4.2. Colorado DOT Analysis

Early in the synthesis process, the complete survey responses were provided to the WTRC project subcommittee. Two Colorado DOT staff members performed an internal analysis on the results and compiled a spreadsheet tabulating states' responses in three tables:

- Technologies and methods currently used to measure or estimate bridge scour.
- Technologies and methods to measure hydrological variables during disaster events.
- Effectiveness; challenges and gaps.

Colorado's analysis, linked as Appendix C, closely aligns with the findings reached independently in this synthesis report.

4.3. Next Steps

The wide-ranging survey responses highlight the need for collaboration and information sharing among DOTs in regard to bridge scour. While some states are on the leading edge of scour monitoring technologies, others rely on primarily manual methods. To improve scour assessment capabilities during extreme weather events, state DOTs may consider taking the following actions:

- Expand monitoring coverage to increase the number of instrumented sites, especially at scour-critical bridges, to improve emergency response and reduce risk.
- Pilot or adopt newer technologies that can survive turbulent conditions, which may be more practical than surface-mounted devices and safer than taking measurements in the field during or after an event.
- Invest in low-cost assessment tools for quick-reaction teams who do not need significant training in this area, such as maintenance staff, to respond to situations and determine whether a more thorough data collection process would be required to obtain critical parameters for more accurate modeling.
- Invest in training and SOP development. Several states noted the need for internal training and standard operating procedures for deploying and interpreting advanced tools.
- Collaborate with USGS, universities, and local agencies to expand access to hydraulic data and support cross-training efforts.
- Evaluate cost-benefit tradeoffs—while some technologies carry high upfront costs, they may reduce inspection burdens and improve safety during flood events.
- Track the progress of pilot projects from other states. Multiple DOTs are currently piloting new scour detection methods, including unmanned vessels, radar-based measurements, and drone-mounted sonar. Following the results of these projects can help other agencies decide whether to adopt similar technologies.
- Pursue or support future research on using emerging tools like sonar, sensors, and drones in challenging conditions and developing practical guidance for when and where to use these tools across large bridge networks.

Appendix A. Survey Text

The following survey was distributed to all 51 state DOT research offices through the AASHTO Research Advisory Committee (RAC) mailing list:

Survey on Techniques to Estimate Bridge Scour in Hydrological Disaster/Extreme Weather Events

Colorado DOT and the Western Transportation Research Consortium (WTRC) Transportation Pooled Fund study are exploring a new innovative drone-based technique to estimate scour at critical bridges in all flow conditions with the emphasis on conditions during hydrological disaster/extreme weather events. We are interested in knowing what techniques and technologies other states currently use, especially in high-flow, turbulent, and other emergency conditions.

Background:
Evaluating scour at scour-critical bridges is easily done in calm conditions, but direct measurement is difficult or impossible during a hydrological extreme event where high flow and turbulent conditions exist. Scour estimate tools such as HEC-18, HEC-RAS, FHWA Hydraulic Toolbox, etc. are used in place of direct measurements, but their scour estimates are only as good as the assumed inputs used. Newer technologies such as drones, sonar, lidar, and embedded sensors can be applied to get more accurate flow inputs for models, and these technologies can be used in rougher conditions.

Survey Questions:

7. What methods and technologies does your agency now use or plan to use to measure or estimate bridge scour in normal flow conditions?
8. What methods and technologies does your agency employ/deploy to obtain required data such as surface velocity, flow rate, flow depth, etc. for scour analysis during hydrological disaster events such as flash flooding?
9. How effective have these techniques and technologies been? What challenges and gaps has your agency identified?
10. Please provide any research/technical reports or documentation on this topic that you can share.
11. Which department, division, or office in your agency has the primary responsibility for bridge scour assessment and management?
12. Who may we contact at your agency with follow-up questions?

We welcome any additional comments you would care to provide on this topic.

Please email your responses to WTRC's administrative coordinator, Brian Hirt, at brian.hirt@ctcandassociates.com

We welcome any additional comments you would care to provide on this topic.

Thank you.

Appendix B. Tabulated Survey Data

The research team's tabulated survey data may be downloaded as a Microsoft Excel file.

Appendix C. Colorado DOT's Tabulated Survey Data

Colorado DOT's tabulated survey data may be downloaded as a Microsoft Excel file.