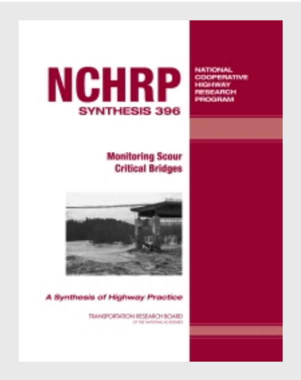

Monitoring Scour Critical Bridges

DETAILS

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP SYNTHESIS 396

Monitoring Scour Critical Bridges

A Synthesis of Highway Practice

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SUBJECT AREAS
Bridges, Other Structures, and Hydraulics and Hydrology, and Maintenance

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in Cooperation with the Federal Highway Administration

TRANSPORTATION RESEARCH BOARD

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2009
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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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Cover figure. *Courtesy:* U.S. Geological Survey.

FOREWORD

Highway administrators, engineers, and researchers often face problems for which information already exists, either in documented form or as undocumented experience and practice. This information may be fragmented, scattered, and unevaluated. As a consequence, full knowledge of what has been learned about a problem may not be brought to bear on its solution. Costly research findings may go unused, valuable experience may be overlooked, and due consideration may not be given to recommended practices for solving or alleviating the problem.

There is information on nearly every subject of concern to highway administrators and engineers. Much of it derives from research or from the work of practitioners faced with problems in their day-to-day work. To provide a systematic means for assembling and evaluating such useful information and to make it available to the entire highway community, the American Association of State Highway and Transportation Officials—through the mechanism of the National Cooperative Highway Research Program—authorized the Transportation Research Board to undertake a continuing study. This study, NCHRP Project 20-5, "Synthesis of Information Related to Highway Problems," searches out and synthesizes useful knowledge from all available sources and prepares concise, documented reports on specific topics. Reports from this endeavor constitute an NCHRP report series, *Synthesis of Highway Practice.*

This synthesis series reports on current knowledge and practice, in a compact format, without the detailed directions usually found in handbooks or design manuals. Each report in the series provides a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems.

PREFACE

By Jon M. Williams
Program Director, IDEA and Synthesis Studies
Transportation Research Board

Scour is the primary cause of bridge failure in the United States. There are more than 20,000 highway bridges that are rated "scour critical." Selected bridges have been monitored for more than ten years and valuable field data have been obtained from these bridges. This report presents the current state of practice for fixed scour bridge monitoring. It will be useful for bridge owners, in particular those responsible for bridge maintenance and safety.

Information for this report was obtained through literature review, survey of the state transportation agencies, and selected interviews.

Beatrice Hunt, STV Incorporated, New York, N.Y., collected and synthesized the information and wrote the report. The members of the topic panel are acknowledged on the preceding page. This synthesis is an immediately useful document that records the practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As progress in research and practice continues, new knowledge will be added to that now at hand.

CONTENTS

MONITORING SCOUR CRITICAL BRIDGES

SUMMARY

Scour is the primary cause of bridge failures in the United States. Figure 1 shows statistics compiled by the Structures Division of the New York State Department of Transportation (DOT) and calculated using the National Bridge Failure Database. From 1966 to 2005, there have been at least 1,502 documented bridge failures. Of those bridge failures, 58% were the result of hydraulic conditions. Second on the list, but substantially behind, were collisions by ships, trucks, or trains, and overload. Earthquakes were a distant eighth on the list.

According to the FHWA, the number of bridges declared "scour critical" total more than 20,904. During and following the successful completion of NCHRP Project 21-03, *Instrumentation for Measuring Scour at Bridge Piers and Abutments,* more than 120 of these bridges were instrumented for scour measurements. Often these bridges are instrumented because the scour estimates appear overly conservative and it is prudent to observe scour activity during flood events before spending resources on other types of countermeasures. Other bridges are scheduled to be replaced, and monitoring is an alternative measure to help ensure the safety of the traveling public until the new bridge is completed.

This synthesis is a report of the state of knowledge and practice for fixed scour monitoring of scour critical bridges. It includes a review of the existing knowledge and research and an examination of current practice. The project included a survey of transportation agencies and other bridge owners to obtain their experiences with fixed scour monitoring systems. For those agencies that have not employed scour monitoring systems, their opinions were requested regarding problems and suggestions. Thirty-seven state DOTs responded to the survey. Information on scour monitoring for non-responding states was obtained from the literature review.

Many of these instrumented bridges have been monitored for more than ten years and some valuable field data have been accumulated. Exploring what data and associated evaluations are available will be useful for improving the technologies of predicting bridge scour as well as monitoring scour.

Thirty-two of the 50 states use, or have employed, fixed scour monitoring instrumentation on their highway bridges. A total of 120 bridge sites were identified that are using or have employed fixed monitors. The respondents to the survey provided information on their experiences with fixed scour monitoring installations and detailed data on at least one representative bridge site. Not surprisingly, the states that had the largest number of scour monitoring installations were also locations with extreme weather conditions, Alaska and California. The monitoring systems used by the states, with the exception of time domain reflectometry, are described in the current FHWA guidelines on scour countermeasures and monitoring, *Hydraulic Engineering Circular 23.* The third edition of these guidelines, expected to be published in 2009, includes an expanded chapter on scour monitoring, with information on time domain reflectometers. The problems reported by the states were very similar. The difficulties with maintenance and repairs to the scour monitoring systems were the most common theme throughout the survey responses. The leading cause of damage to the systems was debris flows and accumulation. Other common problems were vandalism and corrosion.

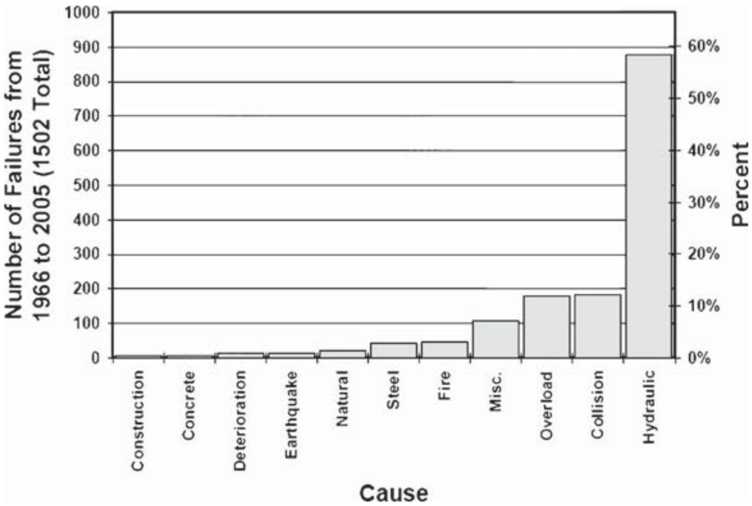


FIGURE 1 Causes of bridge failures in the United States (*Courtesy:* New York State DOT and Texas A&M University).

The advancements that bridge owners would like to see for future fixed scour monitoring technology included the development of durable instrumentation, with increased reliability and longevity, decreased costs, and minimum or no maintenance. This equipment would include instrumentation that measures streambed scour and other hydraulic variables including water elevations and velocities. These would provide information for hydraulic design and analysis, and for the improvement of scour prediction methodologies.

CHAPTER ONE

INTRODUCTION

PROBLEM STATEMENT AND SYNTHESIS OBJECTIVES

This synthesis reports on the state of knowledge and practice for fixed scour monitoring of scour critical bridges. It includes a review of the literature and research and an examination of current practice. A survey of transportation agencies and other bridge owners to obtain their experiences with fixed scour monitoring systems is included. For those agencies that have not employed these systems, the project solicited their opinions regarding problems with these systems and what they would like to see for systems.

There are more than 20,904 scour critical bridges in the United States, some of which are monitored by fixed instrumentation. During and following the successful completion of NCHRP Project 21-03, *Instrumentation for Measuring Scour at Bridge Piers and Abutments* (Lagasse et al. 1997), more than 120 of these bridges have been instrumented for scour measurements. Often these bridges are instrumented because the scour estimates appear overly conservative and it is prudent to observe scour activity during flood events before spending resources on other types of countermeasures. Other bridges are scheduled to be replaced, and monitoring is a cost-effective alternative to help ensure the safety of the traveling public until the new bridge is in place.

Many of these instrumented bridges have been monitored for more than ten years and some very valuable field data has been acquired. Exploring what data and associated evaluations are available will be useful for improving the technologies of predicting bridge scour as well as monitoring scour. The focus of this study is on fixed instrumentation.

Information gathered and synthesized included but was not limited to:

- Fixed scour monitoring instruments currently being used.
- Experience with these fixed instruments including:
  - Reliability of scour monitoring installations;
  - Advancements since the completion of NCHRP Project 21-03, including innovations to the recommended instrumentation;
  - Suggested improvements to equipment used at future sites;
  - Evaluation of the benefits of instrumentation;
  - Costs, including purchase, installation, and maintenance;
  - Longevity and reliability of individual devices;
  - Office responsible for scour monitoring; and
  - The usefulness of the information obtained from monitoring for changes in the bridge scour critical rating (Item 113), the Plan of Action, or to verify scour predictions.
- The identification of bridges that have been or are being monitored with fixed instrumentation.
- Fixed instrumented data being collected and preserved, such as velocity, water depth, and scour depth. This includes a detailed description of these data and some illustrative samples.
- For sites where scour depth has been observed and preserved, data on site-specific conditions for sites associated with instrumented bridges, such as bridge and channel geometry, soil conditions, etc.
- Based on other existing databases, suggestions on how a national database might be structured and what elements it might contain.
- Potential sites for future in-depth monitoring case studies.
- Future research needs associated with fixed monitoring, such as:
  - Measured vs. computed pier scour depths for different soil types, riverine and tidal environments, and complex pier scour;
  - Assembling and maintaining a national scour database, and what items might be in the database;
  - Incentives for owners to keep rather than discard data collected; and
  - Bridges with tidal influences.

This synthesis serves to document the success or failure of the various scour monitors that have been deployed and to obtain ideas as to what can be done to improve the reliability of existing monitoring equipment. In addition, it can serve as the foundation for a national database and a valuable resource to engineers and researchers for assessing the accuracy of various scour estimating procedures currently in use.

LITERATURE AND DATA SOURCES

The sources of information used for developing this synthesis included a literature search, a survey of bridge owners in the United States, and interviews with owners and others with experience in fixed scour monitoring instrumentation for bridges. The literature search and sources included such databases as Transportation Resource Information Services

(TRIS), the U.S. Geological Survey (USGS) National Bridge Scour, Abutment Scour (South Carolina), and others. A detailed survey of the evolution of scour measuring instrumentation was presented at the TRB Third Bridge Engineering Conference (Lagasse et al. 1991). The final report for NCHRP Project 21-03 (Lagasse et al. 1997) includes an extensive bibliography on instrumentation for measuring and monitoring scour. The most recent FHWA guidelines on scour monitoring instrumentation can be found in *Hydraulic Engineering Circular 23* (HEC-23), *Bridge Scour and Stream Instability Countermeasures—Experience, Selection, and Design Guidance* (Lagasse et al. 2001a). This also includes a list of references. It is expected that a third edition of HEC-23 will be published in 2009. The documents listed in the Reference section in this report include some of the key references for fixed scour monitoring instrumentation, new references that have been published since the publication of the FHWA HEC-23 guidelines, and some additional references that provide more detailed information on scour monitoring installations that were used in the development of this report.

A survey on the use of fixed scour monitors was prepared and distributed to bridge owners, and can be found in Appendix A. This survey was distributed by TRB to the 50 state departments of transportation (DOTs); Washington, D.C.; and Puerto Rico. The surveys were e-mailed to the DOT State Bridge Engineer, and they were asked to forward copies to those departments in their agency with experience in scour monitoring instrumentation. The survey was also sent to various agencies and others that were identified during the course of this study as being involved with fixed instrumentation for bridge scour. A list of the respondents to the survey and the department within each agency that completed the survey can be found in Appendix B. A summary of the detailed responses to the surveys can be found in Appendix C.

REPORT ORGANIZATION

This synthesis report is divided into eight chapters.

- Chapter one introduces the subject of fixed scour monitoring instrumentation for bridges and includes the purpose of the synthesis, the literature and data sources that were used, and the report organization.
- Chapter two includes a general overview of the topic, establishing the fundamental issues related to fixed scour monitoring instrumentation. It includes key terminology and a summary of the survey findings.
- Chapter three is an overview of the bridges being monitored in the United States.
- Chapter four provides details on experience with fixed scour monitoring systems and their use for the verification of the scour prediction equations.
- Chapter five discusses the data obtained from the installations. Sample data can be found in Appendix E.
- Chapter six includes case studies on existing sites and information on scour monitoring system locations that have recorded scour depths.
- Chapter seven discusses on-going research in fixed scour monitoring instrumentation and innovative practices and enhancements.
- Chapter eight is a summation of practices and a discussion of future scour research needs associated with fixed scour monitoring instrumentation, including consideration of potential sites for future monitoring and the national scour database.

CHAPTER TWO

SCOUR MONITORING OVERVIEW AND APPLICATION

OVERVIEW AND BACKGROUND

The FHWA reports there are approximately 590,000 highway bridges in the U.S. National Bridge Inventory. Of these, about 484,500 bridges are over water (Gee 2003), with more than 20,904 of them having been declared scour critical (Gee 2008a). A bridge is considered scour critical when its foundations have been determined to be unstable for the calculated or observed scour condition.

Three FHWA Hydraulic Engineering Circulars (HEC) are the guidelines for bridge scour, stream stability, and scour countermeasures: HEC-18, *Evaluating Scour at Bridges* (Richardson and Davis 2001) provides guidance for the design, evaluation, and inspection of bridges for scour; HEC-20, *Stream Stability at Highway Bridges* (Lagasse et al. 2001) provides instruction on the identification of stream instability problems at highway stream crossings; and HEC-23, *Bridge Scour and Stream Instability Countermeasures—Experience, Selection, and Design Guidance* (Lagasse et al. 2001a) provides guidelines for the various types of scour countermeasures. For conducting new or rehabilitation designs for bridges, HEC-18, HEC-20, and HEC-23 are used. Countermeasure solutions can be developed when there are concerns with regard to scour or stream stability at or in the vicinity of a bridge.

This chapter includes a general background and the resources relative to the state of the art in bridge scour monitoring technology. The most recent guidance from FHWA on scour monitoring instrumentation can be found in HEC-23. More details on the earlier types of fixed scour monitors can be found in the *NCHRP Report 396: Instrumentation for Measuring Scour at Bridge Piers and Abutments* (Lagasse et al. 1997) for Project 21-3 and the corresponding installation, operation, and fabrication manuals (Schall et al. 1997a,b).

Scour countermeasures, as defined in HEC-23, are "measures incorporated into a highway-stream crossing system to monitor, control, inhibit, change, delay, or minimize stream instability and bridge scour problems."

Based on their functionality, HEC-23 categorizes scour countermeasures into three general groups—hydraulic, structural, and monitoring. Hydraulic countermeasures include both river training structures that modify the flow and armoring countermeasures that resist erosive flow. Structural countermeasures consist of modifications of the bridge foundation. These can be classified as foundation strengthening or pier/abutment geometry modification. Monitoring countermeasures can be fixed instrumentation, portable instrumentation, or visual monitoring.

SCOUR MONITORING ALTERNATIVE

HEC-23 contains the most recent guidance on scour monitoring, and defines it as "activities used to facilitate early identification of potential scour problems. Monitoring could also serve as a continuous survey of the scour progress around the bridge foundations." There are limited funds to replace or repair all scour critical and unknown foundation bridges; therefore, HEC-23 states that an alternative solution is to monitor and inspect the bridges following high flows and storms. A well-designed monitoring program aims at providing an efficient and cost-effective short-term alternative to hydraulic and structural scour countermeasures. Monitoring can also be used in conjunction with hydraulic and/or structural countermeasures.

Recommended in HEC-23 are three types of scour monitoring: fixed instrumentation, portable instrumentation, and visual monitoring. Fixed monitors can be placed on a bridge structure, or in the streambed or on the banks near the bridge. The use of scour monitoring technology in the United States has led to the development of several fixed instruments suitable for different types of sites and structures. The recommended fixed monitors include sonars, magnetic sliding collars, float-out devices, and sounding rods. The survey results found that tilt sensors and time domain reflectometers (TDRs) have also been installed at several bridges. These are summarized in Table 1 and described in detail in the following section. Portable instrumentation monitoring devices can be manually carried, used along a bridge, and transported from one bridge to another. Portable instruments are more cost-effective in monitoring an entire bridge or multiple bridges than fixed instruments; however, they do not offer a continuous watch over the structures. It is often problematic for individuals to go to a bridge to take measurements during a storm event. The allowable level of risk affects the frequency of data collection using portable instruments. Examples of portable instruments are sounding rods, sonars on floating boards, scour boats, and scour trucks. Visual inspection monitoring can be performed at standard regular intervals and can include increased monitoring during high flow events (flood

TABLE 1
TYPES OF FIXED SCOUR MONITORING INSTRUMENTATION

Fixed Instrument	Mechanism
Sonar (fathometer)	A transducer provides streambed elevations
Magnetic Sliding Collar	A driven rod with sensors on a vertical support with a sliding collar placed at the streambed level
Float-Out Device	Buried transmitter that will float to the surface if scour exposes it
Tilt or Vibration Sensor	Record movements of the bridge
Sounding Rod	Manual or mechanical device (rod) to probe streambed
Piezoelectric Film	Polymer film installed on a buried/driven rod that records the progression of the scour hole
Time Domain Reflectometry	The round-trip travel time of an electromagnetic pulse in two buried parallel pipes provides information on changes in streambed elevation

watch), land monitoring, and/or underwater inspections. Similar to portable monitoring, there are limitations on when inspectors can visit the bridges during storms. The scour hole that forms during a high-flow event is often filled in during the receding stage as the stream flow returns to normal. This "scour-and-infill" cycle is not commonly detected using portable devices, nor during measurements taken by divers after a storm.

A bridge can have one or more types of scour monitoring techniques that also can be used in combination with other hydraulic and/or structural scour countermeasures. Scour monitoring can be a permanent or a temporary interim countermeasure.

FIXED INSTRUMENTATION AND SCOUR MONITORING

According to FHWA guidelines, existing bridges found to be vulnerable to scour should be monitored and/or have scour countermeasures installed. FHWA's HEC-18 (Richardson and Davis 2001) first recommended the use of fixed instrumentation and sonic fathometers (depth finders) as scour monitoring countermeasures in their Second Edition (Richardson et al. 1993). Two of the fixed scour monitoring instruments discussed in this report were recommended in *Instrumentation for Measuring Scour at Bridge Piers and Abutments* (Lagasse et al. 1997). The purpose of that project was to study devices that measure and monitor maximum scour at bridges. The project developed, tested, and evaluated methods both in the laboratory and in the field. This project extensively tested two systems—the sonic fathometer and the magnetic sliding collar devices. Each of these fixed instruments measures and monitors scour. Additional fixed scour monitoring systems that were tested under this project included sounding rods and other buried devices. Subsequent to the NCHRP project, two additional fixed monitors were developed and installed—float-out devices and tilt sensors, both of which are now being used extensively. Some of the survey respondents in this study took the research recommendations and custom-designed scour monitoring systems that met difficult site-specific requirements and developed programs for the monitoring of these bridges that satisfied FHWA and state criteria. Table 1 summarizes the types of fixed scour monitor instrumentation that are being used in the United States as found in the synthesis survey.

The different types of fixed scour monitoring instruments are described in the sections that follow. A scour monitoring system at a bridge can be comprised of one or more of these types of devices. Scour monitoring systems are configured uniquely for each bridge under consideration. This occurs because of differences in bridge construction and in hydraulic and environmental influences peculiar to each site.

The various devices are either mounted on the bridge or installed in the streambed or on the banks in the vicinity of the bridge. The scour monitoring device transmits data to a data logger at its remote unit. The data from any of these fixed instruments can be downloaded manually at the site or it can be telemetered to another location. The early scour monitoring devices measured streambed elevations using simple units mounted on-site and read manually. Almost all of the more recent installations use remote technology. Each bridge can have one or more remote sensor units that transmit data to a master unit on or near the bridge (Figure 2). The

FIGURE 2 Master station with data logger.

scour monitoring data are then transmitted from the master unit to a central office and/or posted on the Internet.

Sonars

Sonar scour monitors are mounted onto the pier or abutment face (Figures 3–6) to take streambed measurements, and each is connected to a data logger (Figure 2). The sonar instrument measures the distance from the sonar head to the riverbed and back based on the travel time of a sound wave through water. The data logger controls the sonar system operation and data collection functions. The data logger is programmed to take measurements at prescribed intervals. Sonar sensors normally take a rapid series of measurements and use an averaging scheme to determine the distance from the sonar transducer to the streambed. These instruments can track both the scour and refill (deposition) processes. The early sonar monitors used existing fish finders. Currently, new sonar monitors range from the fish finders to smart sonar transducers, both of which are commercially available.

Magnetic Sliding Collars

Magnetic sliding collars (Figures 7 and 8) are rods or masts that are attached to the face of a pier or abutment and driven or augered into the streambed. A collar with magnetic sensors

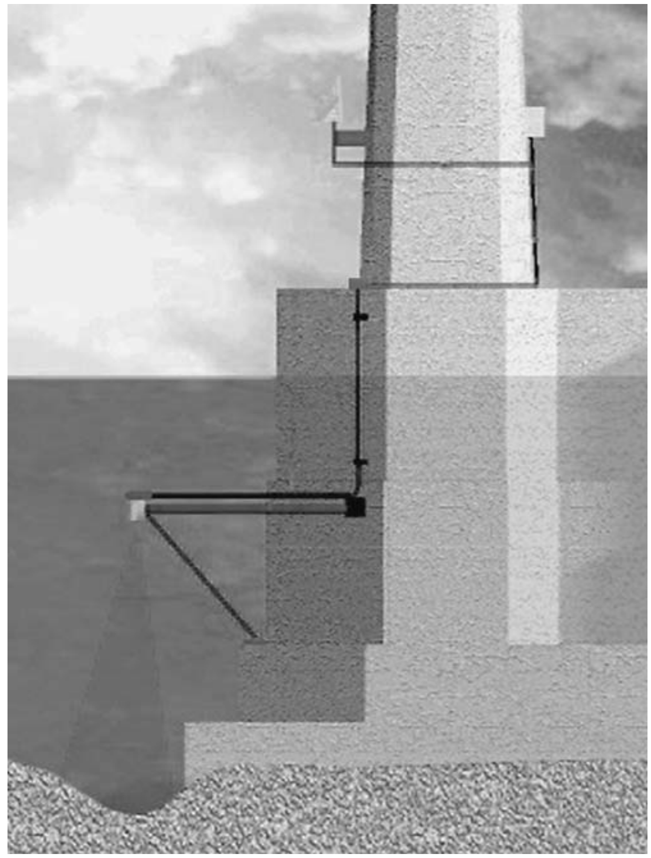


FIGURE 4 Schematic of a sonar scour monitoring system (see Figure 3) (*Courtesy:* Hardesty & Hanover, LLP).

FIGURE 3 Scour monitoring system mounted on a pier on the Robert Moses Causeway over Fire Island Inlet, New York (circled) (*Copyright:* Raimondo di Egidio 2002).

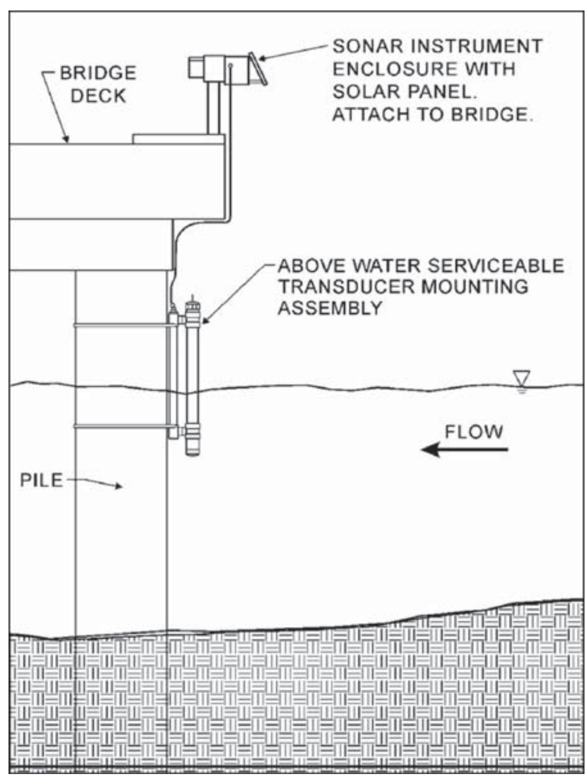


FIGURE 5 Schematic of sonar scour monitoring system (Lagasse et al. 2001a).

FIGURE 6 Detail of conduit to underwater sonar monitor (*Copyright:* Raimondo di Egidio 2002).

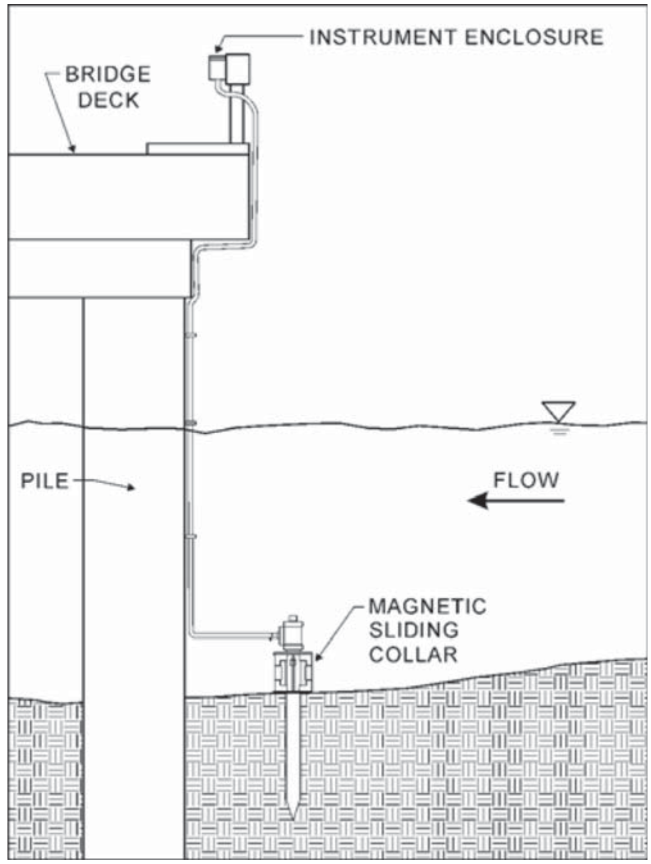


FIGURE 7 Schematic of a magnetic sliding collar (Lagasse et al. 2001a).

is placed on the streambed around the rod. If the streambed erodes, the collar moves or slides down the rod into the scour hole. The depth of the collar provides information on the scour that has occurred at that particular location.

The early version of the sliding magnetic collar used a battery-operated manual probe that was inserted down from the top and a buzzer sounded when the probe tip sensed the level of the magnetic collar. More recent collars have a series of magnetically activated switches at known distances. Magnets in the steel collar come into proximity with the switches as it slides into the scour hole, the switches close and their position is sensed by the electronics. The data logger reads the level of the collar by means of the auto probe and senses scour activity. Although sonar scour monitors can be used to provide the infill scour process at a bridge, magnetic sliding collars can only be used to monitor the maximum scour depth.

Float-Out Devices

Buried devices can be active or inert buried sensors or transmitters. Float-out devices (Figures 9 and 10) are buried transmitters. This device consists of a radio transmitter buried in the channel bed at pre-determined depth(s). If the scour reaches that particular depth, the float-out device floats to the stream surface and an onboard transmitter is activated. It transmits the float-out device's digital identification number

FIGURE 8 Magnetic sliding collar installation.

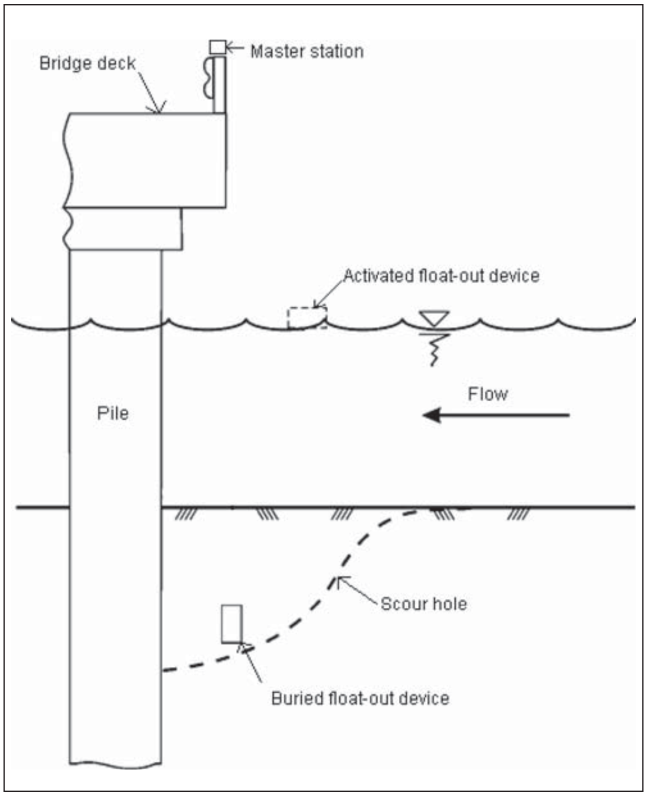


FIGURE 9 Schematic of a float-out device (Texas Transportation Institute).

with a radio signal. The signal is detected by a receiver in an instrument shelter on or near the bridge. The receiver listens continuously for signals emitted by an activated float-out device. A decoded interface decodes the activated float-out device's unique digital identification number that will determine where the scour has occurred. A data logger controls and logs all activity of the scour monitor. These are particularly easy to install in dry riverbeds, during the installation of an armoring countermeasure such as riprap, and during the construction of a new bridge. The float-out sensor is a small low powered digital electronics position sensor and transmitter. The electronics draws zero current from a lithium battery, which, according to the manufacturer, provides a 9-year life expectance when in the inactive state buried in the streambed.

Tilt Sensors

Tilt sensors (Figures 11 and 12) measure movement of the bridge itself. A pair of tilt sensors or clinometers will monitor the position of the bridge. One (*X*) monitors bridge position parallel to the direction of the traffic (longitudinal direction of the bridge), and the second (*Y*) monitors the position perpendicular to traffic (usually parallel with the stream flow). Should the bridge be subject to scour causing one of the support piers to settle, one or both of the tilt sensors would detect

FIGURE 10 Float-out devices color coded and numbered for identification.

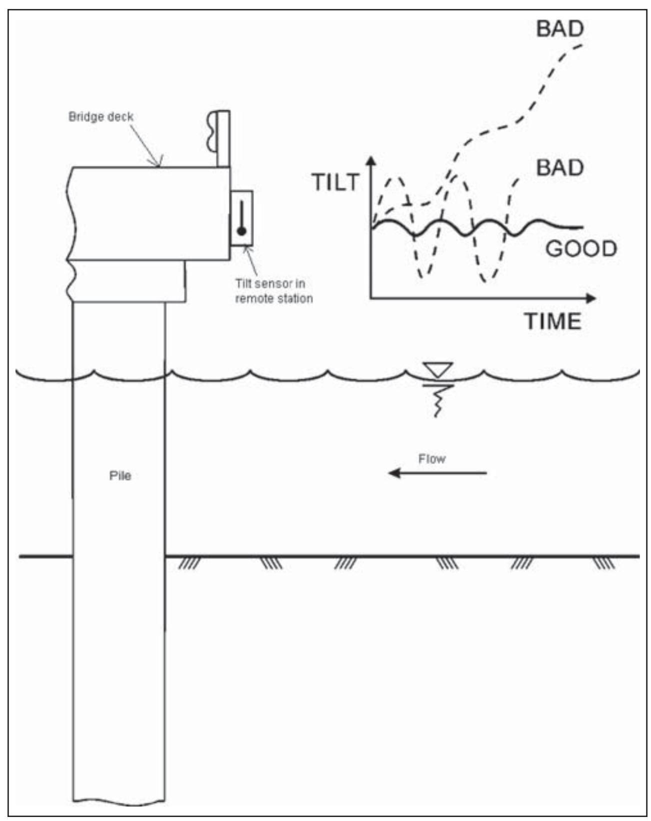


FIGURE 11 Schematic of tilt sensor device (Texas Transportation Institute).

FIGURE 12 Tilt sensor installation with detail of the sensor.

a change in position. Should the change as detected by the *X, Y* tilt sensor in bridge position exceed a programmable limit, the data system would send out an alert status message.

The California DOT (Caltrans) (Avila et al. 1999) notes that the tilt sensors monitor the ever-changing position that normally occurs because bridges must be redundant enough to withstand some amount of movement without failure. It is difficult to set the magnitude of the angle at which the bridge is in danger. Bridges are not rigid structures and movement can be induced by traffic, temperature, wind, hydraulic, and earthquake loads. It is necessary to observe the "normal" movement of the bridge and then determine the "alarm" angle that would provide sufficient time for crews to travel to the bridge to inspect and close the bridge to traffic, if necessary. Caltrans has accomplished this by installing the tilt sensors and monitoring normal changes in bridge position for several months and setting the "alarm" angle based on the unique signature of each pier monitored on any given bridge.

Time Domain Reflectometers

In Time Domain Reflectometry an electromagnetic pulse is sent down one pipe and returns through a parallel pipe, both of which are buried vertically in the streambed (see Figures 13a and b). When the pulse encounters a change in the boundary conditions (i.e., the soil–water interface), a portion of the pulse's energy is reflected back to the source from the boundary. The remainder of the pulse's energy propagates through the boundary until another boundary condition (or the end of the probe) causes part or all of the energy to be reflected back to the source. By monitoring the round-trip travel time of a pulse in real time, the distance to the respective boundaries can be calculated and this provides information on any changes in streambed elevation. Monitoring travel time in real time allows the processes affecting sediment transport to be correlated with the change in bed elevation. Using this procedure, the effects of hydraulic and ice conditions on the erosion of the riverbed can be documented.

Sounding Rods, also known as BRISCO™ Monitors

Sounding-rod or falling-rod instruments are manual or mechanical (automated) gravity-based physical probes. As the streambed scours, the rod, with its foot resting on the streambed, drops following the streambed, causing the system counter to record the change. The foot must be of sufficient size to prevent penetration of the streambed caused by the weight of the rod and the vibration of the rod from flowing water. These were susceptible to streambed surface penetration in sand bed channels. This influences their accuracy.

The BRISCO™ Monitor is a sounding-rod instrument (Figure 14). It was among the first types of scour monitors and was installed mostly in colder climates. They were developed by Cayuga Industries in upstate New York shortly after the failure of the New York State Thruway over Schoharie Creek in 1987 as a result of scour. The system consists of a probe resting on the river bottom connected by a cable to a reel. There is an electrical monitor of the movement of this reel that transmits to a digital readout that is placed on the pier.

NCHRP Project 21-3 on fixed instrumentation (Lagasse et al. 1997) noted that BRISCO™ Monitors were available, but had not been tested extensively in the field. The project included some preliminary lab and field testing of the BRISCO™ Monitor; hereafter know as a sounding rod instrument; however, the sonar monitors and magnetic sliding collar showed better results and were the focus of the final part of the project. It has been documented that Cayuga Industries is no longer producing these devices.

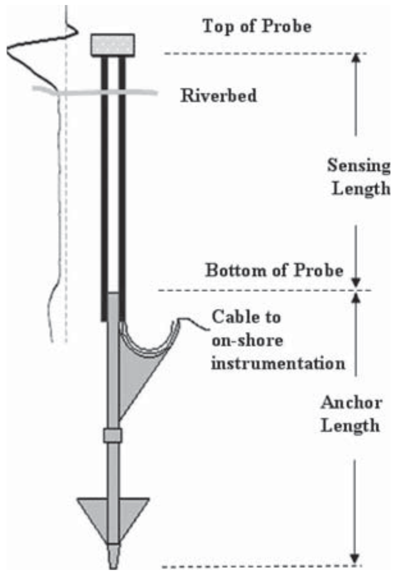
If a series of streambed elevations over time are of interest, sonars, magnetic sliding collars, and sounding rod monitors can be used. If a bridge owner is interested only when a certain streambed elevation is reached, float-outs can be employed. For specific information on a pier or abutment, tilt sensors measure the movement of the structure. Survey respondents also used fixed instrumentation to gather information on water elevations, water velocities, and temperature readings.

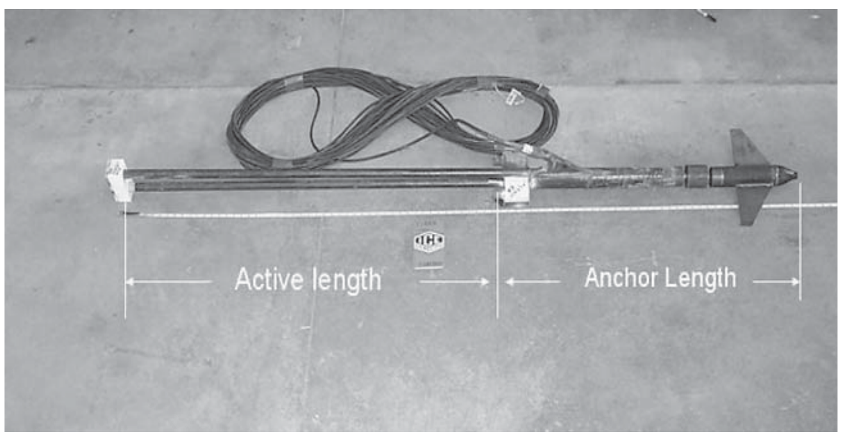
Data from any of these fixed instruments can be downloaded manually at the site or can be telemetered to another location. A scour monitoring system at a bridge can use one of these devices or include a combination of two or more of these fixed instruments, all transmitting data to a central control center. These types of scour monitors are being used in a wide variety of climates and temperatures, and in a host of bridge and channel types throughout the United States.

SUMMARY OF FIXED SCOUR MONITORING INSTALLATIONS

A total of 120 bridges were found to use fixed scour monitoring instrumentation in the United States. These were identified through the synthesis survey, a literature search,

(a)



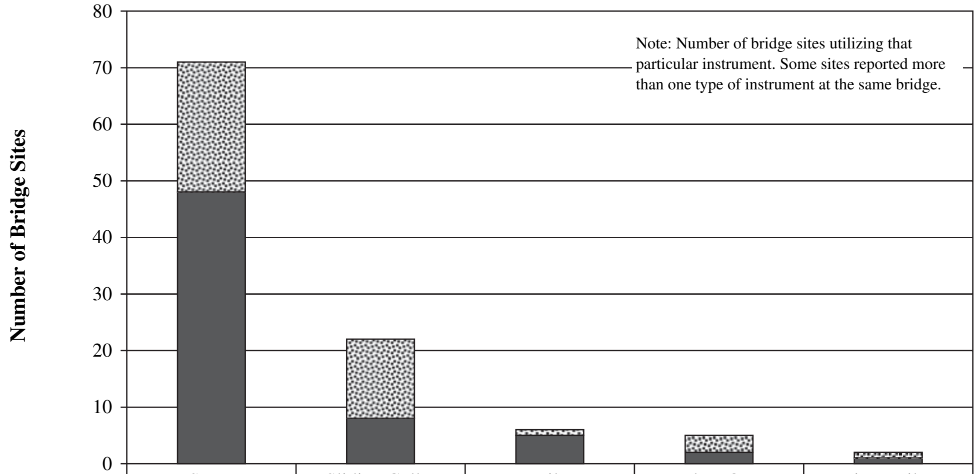


(b)

FIGURE 13 (*a*) Schematic of time domain reflectometer; (*b*) Time domain reflectometry probe (*Courtesy:* U.S. Army Corps of Engineers Cold Regions Research and Engineering Laboratory).

FIGURE 14 Sounding rods installed to monitor riprap in New York.

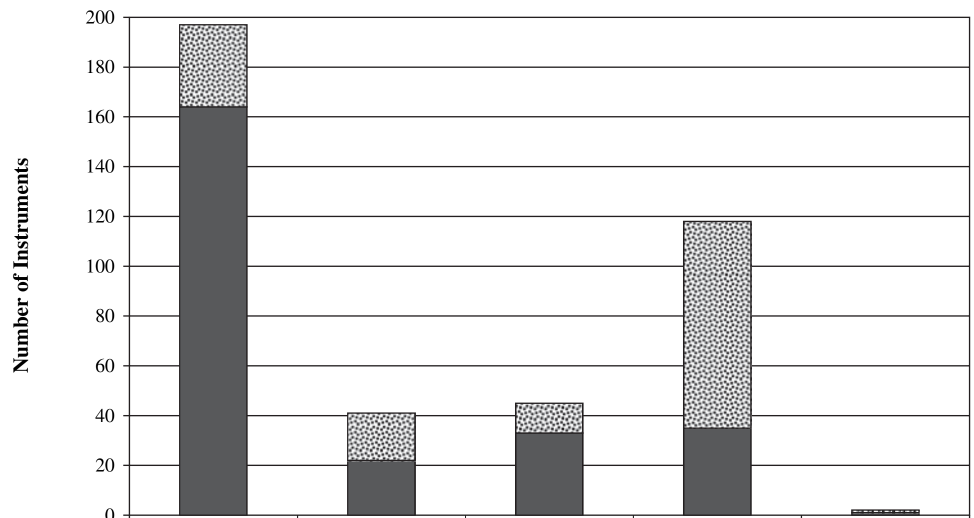
and other sources. Figure 15 shows the number of bridge sites for each type of scour monitoring instrument. The sonar scour monitoring system is the most commonly used device, at 71 bridge sites. The magnetic sliding collar is next, with 22 sites, followed by the float-out devices and tilt sensors with five and six sites, respectively. Piezoelectric and TDR monitors each had 2 bridge installations. Figure 16 shows the total number of instruments reported for each type of scour monitoring device. Sonar devices were first, with 197 units in total. Float-out devices were second with 118 installed, or to be installed. The number of tilt sensors and sliding collars were 45 and 41 devices, respectively. Although float-out devices are a more recent technology, they are less expensive to manufacture and usually less expensive to install, and often numerous devices are placed



	Sonar	Sliding Collar	Tilt	Float Out	Piezo. Film
Literature Search	23	14	1	3	1
Synthesis Survey	48	8	5	2	1

Type of Instruments

FIGURE 15 Total number of bridge sites with fixed scour monitoring instrumentation.



	Sonar	Sliding Collar	Tilt	Float Out	Piezo. Film
Literature Search	33	19	12	83	1
Synthesis Survey	164	22	33	35	1

Type of Instruments

FIGURE 16 Total number of fixed scour monitoring instruments installed.

near the bridge substructure. The other types of devices are usually one or two per pier location. Often there is only one device per bridge.

The survey was distributed by TRB to the DOT State Bridge Engineers of the 50 state DOTs and Washington, D.C. and Puerto Rico. The principal investigator subsequently sent surveys to several agencies, institutions, and consultants who had scour monitoring projects as identified through the literature search. A sample survey can be found in Appendix A, the respondents in Appendix B, and a detailed listing of the survey responses in Appendix C. Tables and figures summarizing the findings from the surveys can be found in the remainder of this report.

CHAPTER THREE

OVERVIEW OF BRIDGES BEING MONITORED

OVERVIEW OF SURVEY AND LITERATURE SEARCH

This overview of bridges with fixed scour monitoring systems includes data from the respondents of the survey, as well as information obtained from the literature search and other sources. This study identified 32 states and the District of Columbia that have installed fixed scour monitoring systems on one or more of their highway bridges. This includes systems that are currently active, those that are no longer in service, and states with plans to install monitoring systems. These states are listed and shown on a map of the United States in Figure 17. The bridges that have been identified by survey responses and through the literature search are listed in Tables 2 and 3, respectively. Additional information on fixed instrumentation and scour critical statistics for all the states, the District of Columbia, and Puerto Rico can be found in Appendix D.

A total of 81 completed scour monitoring surveys were received and these represented 37 different states. Several states completed surveys for more than one bridge site, including different districts and agencies. A list of the respondents can be found in Appendix B. Of the respondents, 29 reported using fixed or portable instrumentation for scour monitoring, and 21 stated they did not. The group that used instrumentation included 25 that stated they used fixed instrumentation and 14 that said they used portable instrumentation. Completed surveys were received from a total of 56 sample bridge sites that used fixed instrumentation, and these were from 19 different states.

The states that use fixed scour monitoring instrumentation were asked about their general scour monitoring experience and to complete specific detailed questions on at least one sample bridge site. An abridged survey was sent to several states that had several bridges with fixed scour instrumentation. They were also asked to provide additional, less detailed information on other bridge sites they are monitoring. The following states submitted completed full surveys for multiple bridge sites: Alaska, Florida, Georgia, Hawaii, New Jersey, and New York. Caltrans submitted the abridged survey for seven additional bridge sites. The majority of the sample bridges (51) were state owned and maintained by their DOTs. Five bridges were owned by a city, county, or other agencies.

The respondents for the 56 monitored bridge sites where surveys were completed reported a wide range of conditions. Table 4 includes a list of these bridges with statistics on each location. The average daily traffic (ADT) for the monitored bridges ranged from 100 to 175,000 vehicles per day. The mean ADT was 21,635, and the median was 8,190 vehicles per day. The total length of the bridges varied from small to long span bridges. The smallest bridge was 12 m (41 ft) long, whereas the longest was 3,921 m (12,865 ft) in length. The mean bridge length was 302 m (992 ft), and the median was 120 m (394 ft). The bridges being monitored were constructed between 1901 and 1988. The mean and median years were 1959 and 1963, respectively. The scour monitors reported in these surveys had been or were scheduled to be installed between 1991 and 2008.

The majority of owners reported a history of scour and a scour critical rating for the bridges being monitored. Sixty percent of the bridges being monitored were on pile foundations, 35% were on spread footings, and drilled shafts, unknown foundations, and other were each 2%. The foundation depths were reported to be 67% as-built depths, 22% design depths, and 11% unknown. Borings and/or soil and rock data were available for all but six of the bridge sites.

SITE-SPECIFIC FACTORS AND THE SELECTION PROCESS

When deciding which fixed scour monitoring system to use, many factors need to be considered. These considerations range from waterway characteristics to bridge geometry to soil conditions. The decision-making process requires the multi-disciplinary effort of hydraulic, structural, and geotechnical engineers. FHWA HEC-23 (Lagasse et al. 2001a) contains a table to aid in the selection of a fixed scour monitoring system. It includes both advantages and disadvantages of various conditions as they pertain to fixed scour monitoring.

Table 5 is a matrix that summarizes some of these site-specific factors from the surveys. This matrix highlights some of the factors that could be considered when deciding which type of fixed scour monitoring instruments work best for your site. The following is a discussion of the conditions that affect the selection of an appropriate fixed scour monitoring system. The final chapter of this report contains a discussion of best practices and includes additional selection tables based on the information obtained in this study. Chapter eight includes

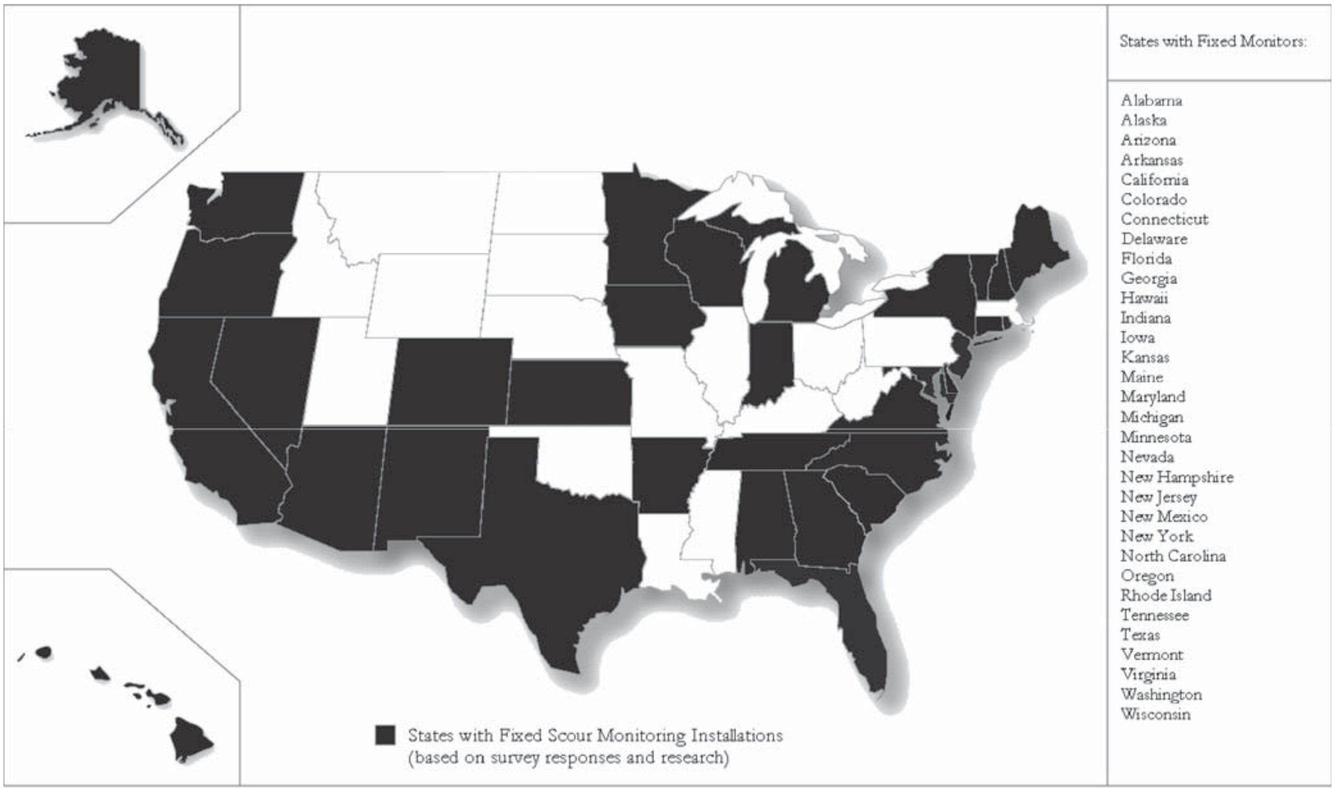


FIGURE 17 States with fixed scour monitoring installations.

two additional tables that can be used for the selection of fixed instrumentation and are based on the survey respondents and literature search.

Bridge Geometry and Size

The bridge owners reported that 89% of the structures monitored with fixed instruments were piers. Abutments were 3% and others were 8%. Others included bulkhead and downstream sheetpile protection. Complex pier geometry can make it difficult to mount equipment directly onto the structure. Protrusions from footings or steel sheeting can block monitor readings. As-built bridge plans or measurements from divers can provide important information for the design of the components of the scour monitors. In the case of sonar scour monitors, adjustable mounting brackets have been developed for flexibility during the installation and to allow the monitors to take readings beyond the footing or any steel sheeting. Sample plans for a tripod telescopic bracket can be found in Appendix G. Other important considerations in the selection of the scour monitor include bridge height off the water and foundation type.

Waterway Type, Flow Habit, and Water Depth

Understanding the waterway characteristics will enable the bridge owner to determine what type of information is needed and which monitors would work best at the site. The type of waterway, tidal or riverine, is an important consideration. Both flood and ebb conditions need to be taken into account in the tidal environment. The instrumented bridge sites included 78% riverine and 22% tidal environments. Riverine waterways often contain debris flows that can prevent the system from taking readings and/or damage the instrumentation. In tidal waters, scour monitors can be placed on both sides of the bridge to monitor the scour conditions owing to incoming and outgoing tides.

The flow habit is another important factor to consider. With ephemeral and intermittent waterways, the streambed is dry some or most of the time. Perennial waterways always have some flow. Both types of conditions affect the type of installation procedures that can be used to place a monitoring system at the site. The bridge owner also needs to assess whether continuous monitoring is needed and practical. Certain monitors such as sonars and magnetic sliding collars yield a continuous set of data. Other types of monitors such as float-out devices are activated only when certain scour depths are reached. Sixteen percent of the survey respondents reported ephemeral and intermittent conditions at their bridge sites and used a combination of continuous and non-continuous monitors. Eight-four percent of the bridges were in perennial or perennial but flashy conditions, and all but one of those bridge sites employed continuous monitors only.

TABLE 2
BRIDGES WITH FIXED SCOUR MONITORS I
Information from Synthesis Surveys

State	Bridge	Type(s) of Fixed Scour Monitors	Date of Installation	Waterway Type	Flow Habit	Waterway Depth
Alabama						
	US-82	1 Float-Out	N/A	Riverine	Perennial	51–75 ft
Alaska						
	Tanana River Bridge No. 202	1 Sonar	2003	Riverine	Perennial	10–30 ft
	Kashwitna River Bridge No. 212	1 Sonar	2002	Riverine	Perennial	<10 ft
	Montana Creek Bridge No. 215	2 Sonars	2002	Riverine	Perennial	<10 ft
	Sheridan Glacier No. 3 Bridge No. 230	1 Sonar	2002	Riverine	Perennial	<10 ft
	Copper Delta Bridge No. 339	1 Sonar	2002	Riverine	Perennial	<10 ft
	Copper Delta Bridge No. 340	1 Sonar	2002	Riverine	Perennial	<10 ft
	Copper Delta Bridge No. 342	8 Sonars	2005	Riverine	Perennial	10–30 ft
	Salcha River Bridge No. 527	1 Sonar	2002	Riverine	Perennial	<10 ft
	Knik River Bridge No. 539	1 Sonar	2002	Riverine	Perennial	10–30 ft
	Slana Slough Bridge No. 654	1 Sonar	2005	Riverine	Perennial	<10 ft
	Slana Slough Bridge No. 655	1 Sonar	2004	Riverine	Perennial	<10 ft
	Mabel Slough Bridge No. 656	1 Sonar	2002	Riverine	Perennial	<10 ft
	Tok River Bridge No. 663	2 Sonars	2004	Riverine	Perennial	<10 ft
	Kasilof River Bridge No. 670	2 Sonars	2005	Riverine	Perennial	<10 ft
	Kenai River at Soldotna No. 671	1 Sonar	2005	Riverine	Perennial	<10 ft
	Eagle River Bridge No. 734	1 Sonar, Ultrasonic Piezoelectric Film	2005	Riverine	Perennial	10–30 ft
	Red Cloud River Bridge No. 983	1 Sonar	2005	Riverine	Perennial	10–30 ft
	Glacier Creek Bridge No. 999	1 Sonar	2005	Riverine	Perennial	10–30 ft
	Nenana River at Windy Bridge No. 1243	1 Sonar	2005	Riverine	Perennial	10–30 ft
	Lowe River Bridge No. 1383	1 Sonar	2002	Riverine	Perennial	<10 ft
Arkansas						
	Red River at Fulton	1 Sonar; 1 Ultrasonic Distance; camera	2006	Riverine	Perennial	10–30 ft
California						
	Toomes Creek	5 Tilt Sensors	2002	Riverine	Ephemeral	<10 ft
	St. Helena Creek	1 Magnetic Sliding Collar, 1 Tilt Sensor	2002	Riverine	Perennial but Flashy	<10 ft
	Merced River	2 Sonars	1997	Riverine	Perennial	<10 ft
	SR-101 Bridge over the Salinas River	Magnetic Sliding Collars, Float-Outs		Riverine	Ephemeral	10–30 ft
	Cholame Creek	6 Float-Outs, 1 Tilt Sensor	1999	Riverine	Ephemeral	<10 ft
	Tick Canyon Wash	16 Float-Outs	1999	Riverine	Intermittent	<10 ft
	San Mateo Creek—L/R	8 Tilt Sensors	2001	Riverine	Perennial	<10 ft
	San Gorgonio River	2 MSC; 6 Circuit Cables at Levee	2005	Riverine	Perennial but Flashy	10–30 ft
	Santa Clara River	1 Sonar, 16 Tilt Sensors, 32 Float-Outs	2000	Riverine	Perennial but Flashy	<10 ft
Florida						
	SR-105 and SR-A1A	8 Sonars	2002	Tidal	Intermittent	10–30 ft
	John's Pass Bridge	2 Sonars	1997	Tidal	Intermittent	31–50 ft

(*continued on next page*)

TABLE 2
(*continued*)

State	Bridge	Type(s) of Fixed Scour Monitors	Date of Installation	Waterway Type	Flow Habit	Waterway Depth
Georgia						
	Otis Redding Bridge	6 Sonars	2001	Riverine		<10 ft
	Georgia Highway 384 over Chattahoochee River	4 Sonars	2001	Riverine		<10 ft
	US Highway 27 over Flint River	6 Sonars	2001	Riverine		10–30 ft
	US Highway 17 over Darien River	3 Sonars	2001	Tidal		10–30 ft
Hawaii						
	Kaelepulu Bridge, Oahu	2 Magnetic Sliding Collars	2002	Tidal	Perennial but Flashy	<10 ft
	Kahaluu Bridge, Oahu	1 Sonar	2003	Tidal	Perennial	<10 ft
Indiana						
	US-52 over Wabash River and SR-43	1 Sonar, 1 Magnetic Sliding Collar	1997	Riverine	Perennial	10–30 ft
Kansas						
	Amelia Earhart Bridge (US-59)	2 Sonars	2000	Riverine	Perennial	76–100 ft
Maryland / Virginia / Washington DC						
	Woodrow Wilson Memorial Bridge (US-495)	5 Sonars	1999	Tidal	Perennial	31–50 ft
Minnesota						
	TH 16 over Root River, Rushford Village		1993	Riverine	Perennial but Flashy	<10 ft
Nevada						
	SR-159 over Red Rock Wash	2 Sonars, 2 Float-Outs	1997	Riverine	Intermittent	<10 ft
North Carolina						
	Herbert C. Bonner (NC-12)	4 Sonars	1992	Tidal	Perennial	51–75 ft
New Jersey						
	Route 35 over Matawan Creek	1 Sonar, 1 Magnetic Sliding Collar	1999	Tidal	Intermittent	10–30 ft
	Route 46 over Passiac River	1 Sonar, 1 Magnetic Sliding Collar	2000	Riverine		10–30 ft
New York						
	Wantagh Parkway over Goose Creek	4 Sonars	1998	Tidal	Perennial	10–30 ft
	Robert Moses Causeway over Fire Island Inlet	13 Sonars	2001	Tidal	Perennial	31–50 ft
	Route 262 over Black Creek	1 Brisco	1993	Riverine	Perennial	<10 ft
	Wantagh Parkway over Sloop Channel	10 Sonars	1998	Tidal	Perennial	10–30 ft
	NYS Thruway over Cattaraugus Creek (US-90)	6 Magnetic Sliding Collars	1999	Riverine	Perennial but Flashy	10–30 ft
	Willis Avenue Bridge over Harlem River	15 Sonars	2007	Tidal	Perennial	31–50 ft
Texas						
	FM 1157 Bridge over Mustang Creek	Sonars	1998	Riverine	Perennial	<10 ft
Vermont						
	Vt Route 5 over White River	2 Time Domain Reflectometers	1997; 2001	Riverine	Perennial but Flashy	76–100 ft
Washington						
	Klineline Bridge #1	2 Sonars; 2 Tilt Sensors	2006	Riverine	Perennial	<100 ft

TABLE 3
BRIDGES WITH FIXED SCOUR MONITORS II
Information from Literature Search and Other Sources

State	Bridge	Type(s) of Fixed Scour Monitors	Date of Installation
Arizona			
	I-10 over Gila River, Bridge No. 0185	12 Float-Outs, 1 Sonar	1997–98
	I-17 over Verde River, Bridge No. 00505	4 Float-Outs, 1 Sonar	1997–98
	Franconia	3 Float-Outs, 1 Brisco	1997–98
	San Pedro River, Bridge No. 1530	1 Sonar	1997–98
		Float-Outs	1997–98
California			
	Colorado River	2 Magnetic Sliding Collars	
	Santa Rosa River	6 Float-Outs, 2 Tilt Sensors	
	Putah River	4 Tilt Sensors	
	Kidder Creek	3 Float-Outs	
	Scott River	3 Float-Outs	
	Temecula Creek	9 Float-Outs	
	Eel River	5 Tilt Sensors	
Colorado			
	Orchard Bridge over South Platte River	1 Manual Sliding Collar, 1 Sonar	
	South Platte River Bridge	1 Magnetic Sliding Collar, 1 Sonar	
Connecticut			
	Mystic River Bridge	Brisco	
Delaware			
	SR-1 over Indian River Inlet	2 Sonars and Tilt Meters	2007–08
Florida			
	Nassau Sound Bridge	1 Magnetic Sliding Collar	
Indiana			
	SR-26 Bridge over Wildcat Creek	1 Sonar, 1 Magnetic Sliding Collar	1997
Iowa			
	US-34 Mississippi River Bridge	2 Briscos	1991
Maine			
		1 Magnetic Sliding Collar	
Michigan			
	US-31 over the Muskegon River	1 Manual Sliding Collar	
Minnesota			
	US-14 over Straight River near Owatonna	1 Manual Sliding Collar	1993
	TH 76 over Root River, Houston	1 Manual Sliding Collar	1993
New Hampshire			
		Brisco	
Nevada			
	I-15 over California Wash, Bridge No. 839S	3 Float-Outs, 1 Sonar	1997–98
	I-15 over Toquop Wash, Bridge No. 571N	3 Float-Outs, 1 Sonar	1997–98
	West Charleston Blvd at Red Rocks, Bridge No. 1805	3 Float-Outs, 1 Sonar	1997–98
	US-95 over Piute Wash, Bridge No. 420	8 Float-Outs, 1 Sonar	1997–98
	Virgin River	24 Float-Outs—to be installed	TBD

(*continued on next page*)

TABLE 3
(*continued*)

State	Bridge	Type(s) of Fixed Scour Monitors	Date of Installation
New Mexico			
	Bernado Bridge over the Rio Grande	Magnetic Sliding Collars	
	San Antonio Bridge over the Rio Grande	Sonars	
New York			
	State Rte 30/145 over Schoharie Creek	1 Manual Sliding Collar	1994
	US-418 Bridge over the Hudson River	1 Sonar	1994
Oregon			
	US-Hwy 101 over Alsea Bay	Sonars	early 90s
	Highway 92 over Wallowa River	Sonars	
	Interstate 84 over Sandy River	Sonars	
	Hwy 226 over Crabtree Creek	Sonars	
	Hwy 22 at Mill Creek	Misc. site	
	Interstate 5 at Little Muddy Creek	Misc. site	
	Highway 101	Test site for new methods	
	Sandy River near Troutdale	1 Piezoelectric Film	
Rhode Island			
	Westerly Bridge	4 Magnetic Sliding Collars	
	Jamestown–Verrazzano	4 Sonars	
Texas			
	US Highway 380 Bridge/Double Mountain Fork/Brazos River	1 Magnetic Sliding Collar	
	US Highway 59 Bridge over the Brazos River	1 Sonar	
	US Highway 59 Bridge over the Trinity River	1 Sonar	
	US Highway 90 Bridge over Trinity River	1 Sonar	
Vermont			
	Bridge Street Bridge over White River Junction	1 Brisco	1991
	Route 5 Bridge over White River	1 Brisco	1960s
Wisconsin			
		1 Magnetic Sliding Collar	
		1 Magnetic Sliding Collar	
	County Highway B Bridge, Crawfish River	2 Manual wire-weight gages	2002
	Balsam Road Bridge, Big Eau Pleine River	2 Sonars	1998
	Wisconsin Highway 35 Bridge, Tank Creek	1 Sonar	1999

TABLE 4
BRIDGE SPECIFIC DATA
Sample Set of 56 Surveyed Bridges with Fixed Scour Monitors

State	**Bridge Name**	**Bridge Identification Number (BIN)**	**Type(s) of Fixed Scour Monitors**	**ADT**	**Year Built**	**Year Rebuilt**	**Bridge Length (m)**	**(ft)**	**NBIS Item 113**	**Foundation Type**	**Known Foundation Depth**
Alabama											
	US-82		1 Float-Out	9,000	1962	N/A	345	1,133	N/A	Piles	As-built depths
Alaska											
	Tanana River Bridge No. 202	202	1 Sonar		1965		398	1,305			
	Kashwitna River Bridge No. 212	212	1 Sonar	2,359	1962		65	213	7	Piles & Spr Ftg	As-built depths
	Montana Creek Bridge No. 215	215	2 Sonars		1962		43	140			
	Sheridan Glacier No. 3 Bridge No. 230	230	1 Sonar		1968		61	201			
	Copper Delta Bridge No. 339		1 Sonar		1977	N/A	122	401	7	Piles	As-built depths
	Copper Delta Bridge No. 340	340	1 Sonar		1977	N/A	73	241		Piles	As-built depths
	Copper Delta Bridge No. 342	342	8 Sonars		1977	1988	269	881	7	Piles	As-built depths
	Salcha River Bridge No. 527	527	1 Sonar		1967		154	504			
	Knik River Bridge No. 539	539	1 Sonar	3,407	1975	N/A	154	506	7	Piles	As-built depths
	Slana Slough Bridge No. 654	654	1 Sonar	400	1979		47	153			
	Slana Slough Bridge No. 655	655	1 Sonar	400	1979	2006	12	41			
	Mabel Slough Bridge No. 656	656	1 Sonar	400	1979		12	41			
	Tok River Bridge No. 663	663	2 Sonars		1969		73	241			
	Kasilof River Bridge No. 670	670	2 Sonars	4,610	1965		87	284			
	Kenai River at Soldotna No. 671	671	1 Sonar				120	394			
	Eagle River Bridge No. 734	734	1 Sonar, Ultrasonic Piezoelectric Film	351	1959		64	211	7	Spread footing	As-built depths
	Red Cloud River Bridge No. 983	983	1 Sonar	100			19	63			
	Glacier Creek Bridge No. 999	999	1 Sonar	3,711			68	222	7	Spread footing	As-built depths
	Nenana River at Windy Bridge No. 1243	1243	1 Sonar	1,912	1973		119	389			
	Lowe River Bridge No. 1383	1383	1 Sonar	461	1978		92	303			

(*continued on next page*)

TABLE 4
(*continued*)

State	Bridge Name	Bridge Identification Number (BIN)	Type(s) of Fixed Scour Monitors	ADT	Year Built	Year Rebuilt	Bridge Length (m)	(ft)	NBIS Item 113	Foundation Type	Known Foundation Depth
Arkansas											
	Red River at Fulton	3981	1 Sonar; 1 Ultrasonic Distance; Camera	20,900	1959		394	1,294	3	Spread footing	As-built depths
California											
	Toomes Creek	08-0005	5 Tilt Sensors	8,190	1917	1952	117	385			
	St. Helena Creek	14-0016	1 Magnetic Sliding Collar, 1 Tilt Sensor	7,030	1934		57	187			
	Merced River	39-0071	2 Sonars	2,230	1953		144	473			
	SR-101 Bridge over the Salinas River	44-0002 L/R	Magnetic Sliding Collars, Float-Outs	12,350	1939	1960 (L) All 1999	384	1,260			
	Cholame Creek	49-0095	6 Float-Outs, 1 Tilt Sensor	5,370	1959		56	184			
	Tick Canyon Wash	53-1547	16 Float-Outs	89,000	1963		35	114			
	San Mateo Creek—L/R	57-0001 L/R	8 Tilt Sensors	22,500	1968		154	506			
	San Gorgonio River	56 0003	1 MSC; 6 Circuit Cables at Levee	86,000	1940		73	239	8	Spread footing	As-built depths
	Santa Clara River		1 Sonar, 16 Tilt Sensors, 32 Float-Outs		1930	1965	558	1,830	3	Piles	As-built depths
Florida											
	SR-105 & SR A1A	720062	8 Sonars		1949	N/A	37	120	5	Piles	As-built depths
	John's Pass Bridge	150076	2 Sonars		1971	N/A	253	830	3	Piles	As-built depths
Georgia											
	Otis Redding Bridge	N/A	6 Sonars							Spread footing	Design depths
	Georgia Highway 384 over Chattahoochee River	N/A	4 Sonars							Piles	Design depths
	US Highway 27 over Flint River	N/A	6 Sonars							Spread footing	Design depths
	US Highway 17 over Darien River	N/A	3 Sonars							Piles	Design depths
Hawaii											
	Kaelepulu Bridge, Oahu	3.00083E+12	2 Magnetic Sliding Collars		1960		61	200		Spread footing	Unknown
	Kahaluu Bridge, Oahu		1 Sonar				97	318		Spread footing	Unknown
Indiana											
	US-52 over Wabash River and SR-43	21480	1 Sonar, 1 Magnetic Sliding Collar	16,498	1969	1984	305	1,002	8	Piles	Design depths
Kansas											
	Amelia Earhart Bridge (US-59)	B0003-0013	2 Sonars	8,960	1938	N/A	762	2,500	5	Piles	Design depths

(*continued on next page*)

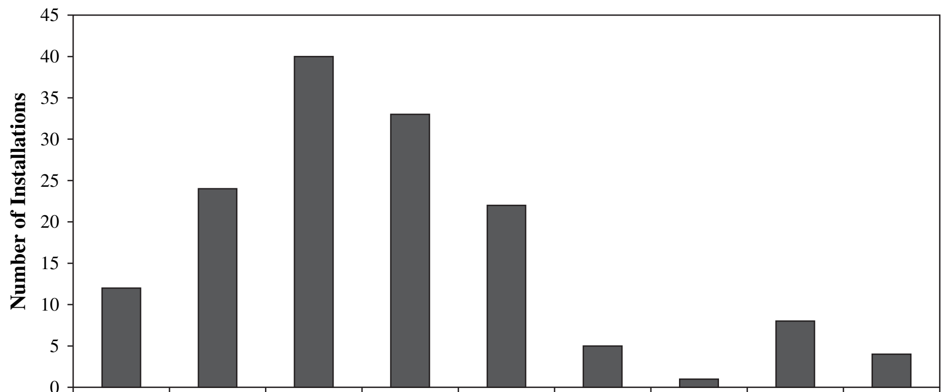
TABLE 4
(*continued*)

State	Bridge Name	Bridge Identification Number (BIN)	Type(s) of Fixed Scour Monitors	ADT	Year Built	Year Rebuilt	Bridge Length (m)	(ft)	NBIS Item 113	Foundation Type	Known Foundation Depth
Maryland/Virgina											
	Woodrow Wilson Memorial Bridge (US 495)		5 Sonars	175,000	1961	2006	1,798	5,900	5	Piles	As-built depths
Minnesota											
	TH 16 over Root River, Rushford Village	23015	1 Magnetic Sliding Collar	2,000	1988		219	718	8	Piles	As-built depths
Nevada											
	SR-159 over Red Rock Wash	B1805	2 Sonars, 2 Float-Outs	2,650	1985	N/A	61	200	5	Piles	As-built depths
North Carolina											
	Herbert C. Bonner (NC-12)	270011	4 Sonars	5,100	1962	N/A	3,921	12,865	3	Piles	As-built depths
New Jersey											
	Route 35 over Matawan Creek	1313-161, 162	1 Sonar, 1 Magnetic Sliding Collar	30,000	1986		137	450		Piles	Unknown
	Route 46 over Passiac River	1607-168	1 Sonar, 1 Magnetic Sliding Collar	70,000	1920		137	450		Unknown	Unknown
New York											
	Wantagh Parkway over Goose Creek	1058509	4 Sonars	12,900	1930	1998	164	537	3	Piles	Design depths
	Robert Moses Causeway over Fire Island Inlet	1058770	13 Sonars	16,809	1966	2001	1,290	4,233	6	Piles	As-built depths
	Route 262 over Black Creek		1 Brisco	N/A	1949	1981	23	75	3	Spread footing	As-built depths
	Wantagh Parkway over Sloop Channel	1058499	10 Sonars	12,900	1930	1999	226	740	3	Piles	Design depths
	NYS Thruway over Cattaraugus Creek (US 90)	5511570	6 Magnetic Sliding Collars	31,730	1954	1992	203	667	7	Piles	As-built depths
	Willis Avenue Bridge over Harlem River	2-24005-9A/B	15 Sonars	75,000	1901	2007	979	3,212			Design depths
Texas											
	FM 1157 Bridge over Mustang Creek	N/A	4 Sonars	N/A	1958					Spread footing	Unknown
Vermont											
	Vt Route 5 over White River	N/A	2 Time Domain Reflectometers		1966		337	1,105		Piles	As-built depths
Washington											
	Klineline Bridge #1	8356100	2 Sonars, 2 Tilt Sensors	17,000	1929	1954	40	132	2	Spread footing	Design depths
			Median	**8,190**	**1963**	**1992**	**120**	**394**			
			Mean	**21,635**	**1959**	**1987**	**302**	**992**			

TABLE 5
BRIDGE SITES WITH FIXED SCOUR MONITORING SYSTEMS[1]

SITE CONDITIONS	FIXED SCOUR MONITORING SYSTEM[2]						Total
	Sonar Sensors	Magnetic Sliding Collars	Tilt Sensors	Float-Out Devices	Piezoelectric Film	Time Domain Reflectometers	
Bridge Geometry							
Substructure Monitored							
Abutment		1		2			**3**
Pier	47	10	3	2	2	1	**65**
Foundation Type							
Pile	33	4	2	2		1	**42**
Spread Footings	19	3	1	1			**24**
Drilled Shafts							**0**
Unknown							**0**
Other							**0**
Waterway Characteristics							
Waterway Type							
Tidal	11	1					**12**
Riverine	37	8	3	3	2	1	**54**
Flow Habit							
Ephemeral	24		1				**25**
Intermittent	17	1	1	1			**20**
Perennial but flashy	4	4	1	1		1	**11**
Perennial	37	3		1	1		**42**
Water Depth							
<10 ft (<3 m)	19	4	2	2			**27**
10–30 ft (3.1–9.1 m)	17	5	1		1		**24**
31–50 ft (9.2–15.2 m)	4						**4**
51–75 ft (15.3–22.9 m)	1			1			**2**
76–100 ft (23–30.5 m)							**0**
Soil Conditions							
Clay	9	2	1	2			**14**
Fine Sand/Silt	20	7	1	1			**29**
Coarse/Medium Sand	35	4	4	2		1	**46**
Gravel	25	5	4	1			**35**
Cobbles	22	6	1				**29**
Organics	2	1	1				**4**
Riprap	6		1	1			**8**
Extreme Conditions							
Debris	34	6	3	1			**44**
Extreme temperatures	1			1			**2**
Sediment loading	29	5	2				**36**
Ice flows	25	3				1	**29**
Air entrainment				1			**1**
High velocity flows	35	2	2			1	**40**
Power Source (for monitoring system)							
Solar	40	3	2	2			**47**
Commercial	9	2	2	2		1	**16**
Back-up battery	23						**23**
Access (to monitoring system)							
Security clearance							**0**
Lane closures	8	1		1			**10**
Boat	30	3		1			**34**
Keys to doors/gates	21	1	2	1			**25**
Data Retrieval (from monitoring systems)							
Locally	24	4					**28**
Telephone	13	3	3	1			**20**
Cellular	5	1		1		1	**8**
Satellite	26						**26**
Installation Experience by State							
	AK, AR, CA, FL, GA, HI, IN, KS, MD, NC, NJ, NV, NY, TX, VA, WA	CA, HI, IN, MN, NJ, NY	CA, WA	AL, CA, NV	AL	VT	

Notes: Some bridge sites have multiple types of fixed scour devices in one scour monitoring system.
1. Results based on <u>**56**</u> complete surveys that indicated the use of fixed scour monitoring systems at specific bridge sites. Additional bridge sites were reported but not in full detail. See Tables 2 and 3 for a complete list of reported bridge sites with fixed scour monitoring instrumentation.
2. Vibration sensors and buried/driven rods were also in the survey. However, none of the survey respondents reported using these fixed scour monitoring systems.



	Clay	Fine Sand to Silt	Coarse to Med. Sand	Gravel	Cobbles	Organics	Concrete	Riprap	Rock
No.	12	24	40	33	22	5	1	8	4

FIGURE 18 Soil conditions at scour monitoring locations.

Water depth can be another limiting factor. In deeper waterways it can be expensive and difficult to bury monitors in the streambed. Driven rods can also not be practical in deeper channels owing to the long, unsupported length of the rods.

Soil Conditions

The type of soil being monitored is important. Clays tend to erode at a slower rate than sands. Clays can reach their maximum scour depths after numerous events, whereas sands can reach the maximum scour depths in one event. Sands are also more prone to infilling of a scour hole after an event. Infill is often less dense and does not have the same capacity as the original soil. Infilling is difficult to detect through diving inspections or occasional portable field measurements. The scour hole usually fills in within a short period of time following a storm event. A majority of the survey respondents reported sand as the predominant soil and used fixed scour monitors with continuous data recording capabilities (Figure 18).

The type of soil present is also a good indicator of where monitors could be placed with relation to the structure. In clays, the greatest scour occurs behind the pier as it faces the flow. In sands, the greatest scour is usually located on the upstream face of the pier.

A scour monitor should be placed at a location that will allow the engineer to decide if the bridge foundation is becoming dangerously close to failure. With this concern in mind it becomes critical to place the scour monitor at the location of the potential deepest scour depth around the foundation.

This location cannot be obvious and deciding where to place the scour monitor should be studied carefully on a case-by-case basis while taking advantage of existing knowledge. In sands, it is likely that the location extends fairly broadly in front and to the side of the pier; in clays, that is not necessarily the case. Laboratory experiments indicate that in clay the scour hole around a cylindrical pier can be non-existent in front of the pier, although it is significant on the side of the pier where the mean shear stress is maximum and behind the pier where the turbulence intensity is high (Briaud et al. 2003). Placing the scour monitor in front of the pier in this case would indicate no scour when the scour hole would be significant around the sides and in the back (Figure 19). The shape of the pier is also a factor. Long rectangular piers develop a scour hole at the front of the pier but little scour behind the pier because the flow is streamlined by the time it gets to the back.

A second problem associated with locating the scour monitor is that the scour hole around the bridge support cannot be the same depth all around the pier. Considering all factors, it appears that the best place for placing the monitor is to the side of the pier immediately behind the front edge. This can also help in reducing the impact of debris. Nonetheless, it is important to consider each case independently.

FIGURE 19 Flume test showing scour hole behind a pier in cohesive soil (*Courtesy:* Texas A&M University).

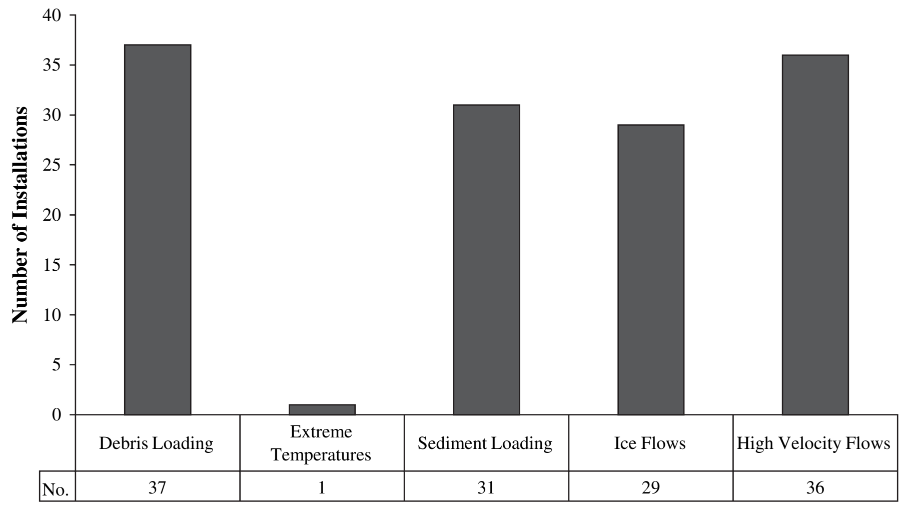


FIGURE 20 Extreme site conditions at scour monitoring locations. (*Note:* Air entrainment was surveyed, but no cases were reported.)

Scour History

Most of the survey respondents who used fixed scour monitoring systems reported a history of scour and/or scour critical ratings at their bridge sites. The scour observations and evaluations were used in the decision-making process to determine the number and locations of the individual monitoring instruments.

Power

Fifty-seven percent of the survey respondents used solar power. Thirty percent reported back-up battery power and 13% used commercial power. The respondents indicated that solar power was used at remote bridge crossings where power supplies were not readily available or on long span bridges to reduce the cost of long conduit runs. Batteries were used as temporary back-ups at numerous sites. Commercial power can be used by tapping into the electrical systems at the bridge, particularly on movable bridges.

Extreme Conditions and Hazardous Locations

Survey respondents indicated that high velocity flows, debris, ice forces, sediment loading, and/or severe water temperatures were extreme conditions that were present at their bridge sites (Figure 20). However, survey results indicated that debris (41%) and ice (28%) forces caused the most damage and interference to the scour monitoring systems (Figure 21). Based on survey responses, the extent and frequency of

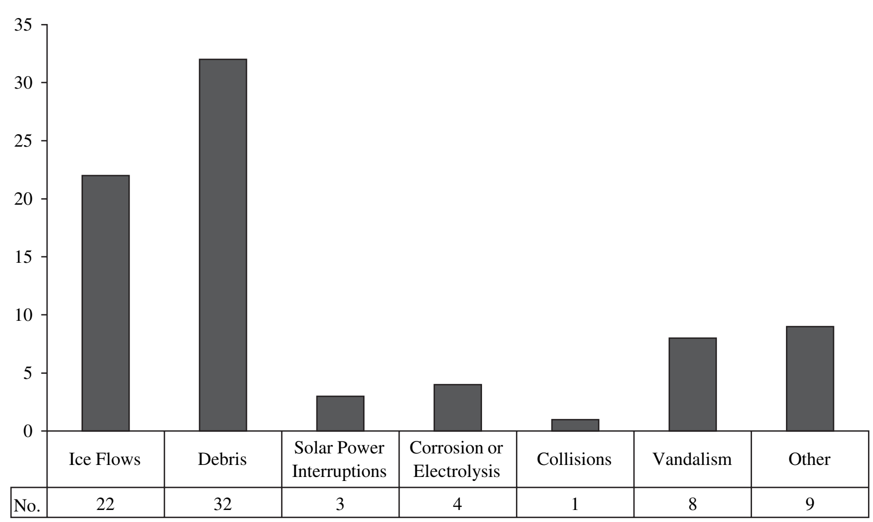


FIGURE 21 Site conditions that caused interference or damage to the fixed scour monitoring systems. (*Note:* "Other" responses included damage owing to vibration, high water velocities, and equipment being buried over time.)

damage was often not anticipated by the bridge owner. This resulted in much higher maintenance and repair costs than were anticipated. One respondent indicated that repair costs were double what they had budgeted. Numerous cases were also reported where new replacement instruments had to be installed after high velocity flows, debris, and/or ice forces caused the existing instrument to separate from the structure.

The materials used to produce the scour monitoring instrumentation need to be robust when there are extreme conditions. Many survey respondents indicated that this is an area of concern because some of the materials being used do not last long enough when severe conditions are present.

Fixed monitors often need to be placed in hazardous locations to monitor bridge scour. Debris or ice flows can collide with the monitors that are mounted underwater on the substructure and damage or destroy the devices. Debris and ice flows generally float on the top of the waterway; therefore, locating the monitors closer to the streambed can help protect the instrument from collision. Fixed monitors are generally placed in the location of the potential maximum scour. Often this is considered to be the center of the pier on the upstream side of the bridge. Depending on the angle of flow, this can also be the position where the maximum debris and ice flows collide with the bridge. Placement of the scour instrument to the side of the pier can help to protect it. As discussed in the section on soil conditions, if the streambed material is cohesive, the maximum scour hole can be to the side or back of the pier.

Alaska has developed a retractable arm for mounting their sonar scour monitors. The retractable bracket is mounted under the bridge deck and the arm periodically extends out, takes the readings, and retracts under the protection of the deck. Alaska has also mounted sonar monitors in the snow (Figure 22). In Maryland, protective stainless steel shields for the sonar transducer mountings were placed on the upstream side of the approach piers on the Woodrow Wilson Memorial Bridge to protect monitors from the floating debris and boat traffic (Hunt et al. 1998). Shields were not placed on the two bascule piers being monitored because they were protected by navigation fenders of the main channel.

Corrosion and marine growth in the harsh tidal environments have led to the use of certain materials as well as more stringent maintenance procedures. The survey respondents reported the use of AISI 316 stainless steel, similar materials to avoid electrolysis, zinc anodes, and anti-fouling paint to help keep the underwater components of the monitoring installations operational. They noted that marine growth (Figure 23) needs to be periodically cleaned from the monitoring devices. This can be done during the underwater inspections of the bridge, but often needs to be done at shorter intervals if the bridges are on the National Bridge Inspection Standards (NBIS) five-year underwater inspection cycles (Figure 24).

FIGURE 22 Sonar monitor mounted on pier in the snow in Alaska.

Access and Vandalism

Selection of the various components of the scour monitoring system requires a careful balance between access and prevention of vandalism. Complex access requirements can

FIGURE 23 Underwater sonar bracket installation in the tidal environment showing the marine growth.

FIGURE 24 Underwater sonar bracket installation in the tidal environment showing corrosion.

make it difficult to install, maintain, and repair a fixed scour monitoring system. Figure 25 shows a variety of locations where the master and remote stations have been placed to provide access for maintenance and to protect the stations from vandalism. Master and remote stations can be mounted on bridge abutments, piers, catwalks, sidewalks, or inside the towers on movable bridges. Master stations can also be mounted on buildings, bulkheads, or other structures in the vicinity of the bridge. Additional parties or equipment can be required, such as divers, boats, and barges, both to install, and later to access the system for maintenance and repairs. These items must be given serious consideration especially when planning a maintenance and repair program and budget. Examples of access limitations include security clearances, traffic lane closures, boats, barges, keys to doors or gates, and under bridge inspection trucks (Figures 26 and 27). Survey

FIGURE 25 Locating the master and remote stations (*clockwise from left to right*). Master stations mounted inside a bascule pier machinery room and on a building near the bridge, remote stations on a pier stem, a catwalk under the bridge, and on a pier pile cap.

FIGURE 26 Installation of solar panels, remote stations, and conduit requires a snooper truck.

responses showed that 47% of the scour monitoring systems required access by boat. The high costs of owning or renting a boat and the increased personnel needed to operate the boat have made maintenance of some monitoring installations difficult or, without funding, some have been abandoned. Additionally, there are waterways in the northern states that cannot be navigable during the winter, so that maintenance and repairs to the systems can only be done during certain months of the year.

FIGURE 27 Installation of an underwater sonar bracket requires divers and a boat.

Access is important, but if a scour monitoring system is too readily accessible, vandalism can occur. Ten percent of the respondents indicated that damage to their scour monitoring systems was the result of vandalism. These unexpected repairs increased the cost of maintaining the system. One survey respondent reported that monitoring was discontinued because of repeated vandalism.

Environmental Concerns

The installation of fixed instrumentation on a bridge can require permitting. Consideration needs to be given to environmental concerns. Installation of fixed instrumentation such as magnetic sliding collars and float-out devices require drilling. In addition, the magnetic sliding collars and float-out devices have mercury switches that need to be contained to protect the fish habitat.

RAILROAD BRIDGES

Inquiries were made with Association of American Railroads, FRA, and Burlington Northern and Santa Fe regarding the use of fixed scour monitoring systems on railroad bridges in the United States; however, none were identified from these inquiries and the literature search. Several of the railroad owners described their procedures regarding monitoring and scour critical bridges. Their monitoring is most frequently visual (inspection) monitoring. Many railroads have procedures that require trains to be operated at restricted speeds when approaching, and running over, scour critical bridges during periods of heavy rain. As used in railroad operating rules, “restricted speed” means a speed of less than 20 mph *that allows stopping within half the range of vision,* short of listed hazards, while watching for a broken rail. Railroad dispatchers can communicate with trains by means of radio to control their movements. They can instruct their trains to reduce their speeds or stop and inspect a bridge.

The fixed instrumentation commonly used on many railroad lines is a simple device called a high water detector. Although these devices do not monitor scour, they can certainly indicate the presence of conditions that could cause scour. The high water detector will sense a threshold water elevation at its location near, and upstream from, the track and bridge. At a particular bridge, if the water level gets high enough, an alert can be sent to trains, the train dispatcher, and/or maintenance personnel, who can then take appropriate action. Timely inspections can then be initiated. This warning device can activate a stop signal when the water surface elevation has reached a level that can damage the track or bridge. It is likely that high water detectors are most commonly used in the western United States where dry washes can turn into rapidly flowing rivers for a few hours or days after a rainstorm. Additionally, the railroads often have inspection programs during and after major storms. These programs typically involve inspection from an on-track vehicle running ahead of trains.

In Japan, the East Japan Railway Company has used clinometers to monitor scour at their bridges (Suzuki et al. 2007). They report that they cancel trains based on observations of the inclination of bridge piers owing to scour. They have placed clinometers as scour monitoring devices on top of the bridge pier to monitor the inclination angle in real time. The threshold angle for train suspension is derived from a geometric relationship between the inclination angle of the bridge pier and the maintenance limits of track irregularity. When an inclination angle of a bridge pier exceeds the threshold angle, the device triggers an alarm to suspend train operation. Suzuki reports that the problem with using this type of device is that it cannot issue an alarm before a bridge pier is inclined. He points out that even if the inclination angle of a bridge pier is minute, reconstruction of the pier tends to take a long time, is expensive, and includes suspension of train service. They reported a case in 1995 of an inclined bridge pier that resulted in the suspension of train operation for four days for emergency reconstruction, and more than one year to reconstruct the inclined pier. They are currently working on a project to develop a new technology to alert if there is scour damage before the inclination of a pier. Information on this project can be found in chapter seven in the section on current studies on instrumentation.

CHAPTER FOUR

EXPERIENCE WITH SCOUR MONITORING SYSTEMS

The survey asked bridge owners various questions about their experiences with fixed scour monitoring instrument systems. This chapter includes a summary of their responses, as well as trends from the survey and the literature research. The detailed responses of the survey respondents experience and suggestions can be found in Appendix C.

REASONS FOR INSTALLATION OF MONITORING SYSTEM

The bridge owners were asked to indicate why they installed fixed scour monitors at their bridges. Thirty-nine of the 56 survey respondents indicated that their bridges had scour critical ratings. Sixteen indicated research projects, seven bridge replacements, and three other reasons (an observed scour hole, a sudden settlement of a pier, and the potential for a gravel pit failure downstream of the bridge).

Other factors that contributed to their decision to use fixed scour monitors at their bridge sites included:

- The importance of the transportation system
- Scour evaluations
- A history of scour
- Pier failure
- Spread footings
- Short piles at the piers
- Unknown foundations
- High water velocities
- Public safety concerns
- A need for continuous monitoring during storms
- Observations during routine inspections
- Bridge is scheduled to be replaced
- Stage construction requirements
- Difficulties involved with hydraulic or structural countermeasures
- Relatively low ADT
- Potential headcut from downstream controls
- Research team insisted on monitoring.

As shown in chapter three, Table 4, the NBIS Item 113 Rating for Scour Critical Bridges ranged from 2 to 8 on the sample bridges that are being monitored. There was only one rating of 2 and seven ratings of 3, which indicate that a bridge is scour critical. The other bridges were rated 5 to 8, which are not scour critical ratings. Not all bridges reported Item 113 ratings, and it is not known if some of the 39 bridge sites that reported monitors were installed as a result of scour critical ratings were indicating there was a scour problem and/or did not reference the NBIS rating system. Additional scour countermeasures can also have been installed at these bridges to remove them from scour critical status or the bridges can have been replaced and they reported the new coding.

Fewer than half (47%) indicated that the scour monitoring data obtained had been useful for changes or verification of their bridge scour ratings, whereas 51% said it had not been useful. Alaska mentioned that the scour monitors had identified large dune bedforms and seasonal sediment “starvation.” The large annual scour and fill cycles have been recorded in the monitoring data and have been used to evaluate the predictive scour equations. California stated that the data confirmed that the scour did not adversely affect one particular bridge and that the lack of an alarm indicated that the downstream headcut was not migrating toward the bridge.

OFFICE RESPONSIBLE FOR MONITORING

The office responsible for scour monitoring varied, but was most often the structures or maintenance group of the state DOT. Others that were mentioned included the state hydraulics group, universities, the USGS, and consultants.

PURCHASE, INSTALLATION, MAINTENANCE, AND REPAIR COSTS

The bridge owners provided information on the costs of the scour monitoring systems. This can be found in Appendix C. A summary of estimated cost information based on the survey results can be found in Table 6. It was developed using the format of the monitoring cost table found in FHWA HEC-23 (Lagasse et al. 2001a).

The costs of the scour monitoring installations varied widely owing to different site conditions, the type of contract, and the method of installation. The survey question on installation costs asked the respondents to provide information on the cost of materials and the labor, per monitor location and/or the total cost. Cost information was provided by 11 different states representing 41 bridge sites.

The cost information for materials was the data most often provided by the survey respondents. The installation,

TABLE 6
ESTIMATED COST INFORMATION

Typed of Fixed Instrumentation	Instrument Cost with Remote Technology ($)*	Instrument Cost for Each Additional Location ($)	Installation Cost	Maintenance/ Operation Costs
Sonar	12,000–18,000	10,000–15,500	Medium to high; 5- to 10-person days to install	Medium to high
Magnetic Sliding Collar	13,000–15,500	10,500–12,500	Medium, minimum 5-person days to install	Medium
Tilt Sensors	10,000–11,000	8,000–9,000	Low	Low
Float-Out Device	10,100–10,600	1,100–1,600	Medium; varies with number installed	Low
Sounding Rods	7,500–10,000	7,500–10,000	Medium; minimum 5-person days to install	High
Time Domain Reflectometers	5,500–21,700	500	Low	Medium

*Cost per device will decrease when multiple devices share remote stations and/or the master station.

operation, maintenance, and repair costs are more difficult to ascertain.

Instrument costs generally include the basic scour monitoring instrument and mounting hardware, as well as power supply, data logger, and instrument shelter/enclosure, where applicable. This cost cannot include miscellaneous items to install the equipment such as electrical conduit, brackets, and anchor bolts that can be included as part of the contractor installation cost. Some of the material costs included other devices such as water stage, and one bridge included monitoring, maintenance, and repairs during a 2-year period that the bridge is expected to be monitored.

The installation costs were often not available because the labor was provided by students or state maintenance groups, or the cost was included with other construction items. Scour monitors can be installed at certain sites by the state maintenance group with equipment it owns. More complicated installations and sites can require specialized contractors and construction equipment to install the scour monitoring devices.

Maintenance and repair costs were only given by one respondent, Florida DOT, District 7. For their sonar scour monitoring system the operation and maintenance was estimated at $18,000, and inspection and repairs were about $9,000. They stated that these were the result of durability problems with the sensors and to vandalism. The respondents provided numerous comments on maintenance and repairs. The general comments on the cost of maintenance ranged from modest to expensive. Repair costs were estimated to be expensive, particularly for underwater divers for the reinstallation of sonar monitors. The installation of the monitors can be under a bridge rehabilitation, research, or emergency project. When that project is completed and the funding ends there can be no mechanism under which to fund long-term maintenance and repairs. Comments included the need for a commitment to maintain the equipment and also a maintenance contract with a firm familiar with the equipment that can make repairs in an expedient manner. Traffic conditions and lane closures were also cited as difficulties in maintaining the monitoring system. Contractor installation and repair costs also vary greatly in different regions of the United States.

The cost of the scour monitoring installations can vary dramatically owing to different factors such as site conditions, the experience of the personnel installing the equipment, the type of contract, and the installation requirements. Larger bridges and deeper waterways are more expensive to instrument than smaller bridges in ephemeral or low water crossings. Scour monitors can be installed at certain sites by the state maintenance group, another agency with equipment it owns, or by students. More complicated installations and sites can require specialized contractors and construction equipment to install the scour monitoring devices.

Factors that contribute to increased scour monitoring installation, inspection, maintenance, and repair costs include larger bridges; complex pier geometries; bridges with large deck heights off the water; deeper waterways; long-distance electrical conduit runs; more durable materials required for underwater tidal installations; the type of data retrieval required (i.e., Internet or satellite); lane or bridge closures and maintenance-of-traffic; and installation and access equipment such as boats, barges, snooper trucks, drills, and diving teams.

Most recent installations of fixed instrumentation have used remote technology to download data to avoid repeated visits to the bridge site. Although this increases the initial equipment cost, it can substantially reduce the long-term operational costs of data retrieval. Site data retrieval involves sending crews to the bridge and access can include security clearance, lane or bridge closures, and equipment such as snooper trucks or boats. Remote technology can also increase safety to the traveling public because it permits real-time monitoring during the storm events that can result in earlier detection of scour.

EVALUATION OF BENEFITS

The majority of states mentioned safety for the traveling public as the main benefit of scour monitoring systems. Additional benefits included a reduced number of underwater and/or regular inspections, early identification of problems prior to a diving inspection, and insight into site-specific scour processes. In several states the system is a component of a comprehensive program that includes a Plan of Action for emergency conditions and underwater inspections. A point was made that the system serves to warn of a problem at the bridge site; however, response time and engineering judgment by those persons responsible for the bridge are the most important part of the alarm system.

VERIFICATION OF SCOUR PREDICTION

The bridge owners were asked if their scour monitoring data had been useful in verifying scour prediction equations. Alaska, Georgia, and Hawaii provided detailed responses and have published papers on the subject. Several other states also provided comments on the usefulness of the data.

Alaska

The USGS in Alaska responded that the scour monitoring data have been useful in verifying scour predictions. It reported that the data were useful in separating the components of scour and to evaluate the predictive equations. The variation in the data from the seasonal bed elevation ranged from no change to large changes for the 20 bridges instrumented with sonar and water stage devices. They also reported short period scour associated with high flows. In addition to the near real-time data, channel bathymetry and velocity profiles are collected at each site several times per year. The Cooper Delta Bridge No. 342 has eight instrumented piers and they noted that this provided visualization of scour for the entire bridge cross section. The scour monitoring data from the instrumented bridges in Alaska has fostered a number of USGS reports (Conaway 2005, 2006a,b).

The USGS in Alaska noted that bridge scour monitoring is being used to assess real-time hazards and that it also illustrates the complexities of streambed scour and the difficulty of predicting scour using existing methods (Conaway 2006a). The stage and bed-elevation data at the Old Glenn Highway Bridge over the Knik River near Palmer, Alaska, was compared with results from predictive scour calculations using variables generated by a hydrodynamic model, the USGS's Multi-Dimensional Surface Water Modeling System. Chapter six of this report contains the case history and a discussion of the observed scour for this site.

Conaway reported that the data of the Old Glenn Highway Bridge showed an annual cycle of channel aggradation and degradation to an equilibrium level that is punctuated by shorter periods of scour and fill. The annual vertical bed-elevation change exceeds 6 m (20 ft) at the bridge. Data from a pier-mounted sonar together with hydraulic variables measured during high flows and variables computed with a multi-dimensional hydrodynamic model were used to evaluate seven predictive equations for live-bed contraction scour and two abutment scour computations. Two scour events were simulated with the hydrodynamic model; one related to rainfall, the other for a period of increased glacial melting. Streambed scour for these two events varied considerably in timing and duration, although both had similar streamflow discharges. Total computed scour exceeded measured values by 40% to 60% depending on the equations selected. Conaway concluded that the long-term monitoring data indicate the scour at this site is the result of changes in hydraulic variables and is also affected by the timing and duration of streamflow, as well as the source of the high flow. He noted that these factors are not typically included in the engineering assessment of streambed scour.

Georgia

The Georgia Institute of Technology (Georgia Tech) and the USGS, in cooperation with the Georgia DOT and the FHWA, are conducting an investigation to improve regional bridge scour predictions by combining field monitoring, physical modeling in the laboratory, and three-dimensional (3D) numerical modeling of bridge scour (Gotvald 2003 and Sturm et al. 2004). The integration of these three components is intended to improve bridge scour predictions using one-dimensional methods. A report for Phase 1 of this project was published in 2004, and Phase 2 is currently in progress.

Bridge scour field data were collected at four sites located in different regions of Georgia using fixed instrumentation and mobile instrumentation. The fixed instrumentation at each bridge included four to seven fathometers, one rain gauge, and one stage sensor. Two bridges were also instrumented with acoustic velocity meters. These field data were used to calibrate the physical and 3D numerical models. Two bridges were modeled in the laboratory.

Sturm et al. reported that the field results revealed several important aspects of bridge scour processes including the dynamics of live-bed scour, simultaneous occurrence of contraction and pier scour, and the cyclical scour and fill associated with the tidal cycle. He noted that the field data also proved to be invaluable for comparison with laboratory model results and stated that this validated the need for additional continuous and simultaneous measurements of scour depths and flow fields.

Sturm concluded that the 3D model is a powerful tool for understanding the complex flow field at bridge foundations and the coupling between the flow field and measured scour patterns. They reported that comparisons of laboratory scour depths with existing scour formulas highlighted some of the difficulties in scaling of scour depths from the laboratory to the field; however, a successful modeling strategy was applied. The laboratory model successfully reproduced the measured maximum scour depths in the field for both the bank-full and extreme flood events, and the details of cross-sectional changes immediately upstream of the bridge. The laboratory erosion tests illustrated the regional variability of erosion parameters and as the variability associated with sediment stratification at a particular site. Erosion parameters were successfully correlated with some easily measured sediment properties.

Sturm et al. concluded that these advances in field data collection, 3D numerical modeling, and laboratory modeling of bridge scour, as well as in measurement and prediction of sediment erodibility properties, can be useful to improve scour prediction techniques. Phase 2 of the project will focus on contraction scour and the development of scour prediction methodology.

Hawaii

The Hawaii DOT funded a project that uses scour monitoring data to evaluate the accuracy of some of the FHWA HEC-18 scour equations. This work was conducted by the University of Hawaii in Manoa, Honolulu. In addition to their synthesis surveys, they submitted a paper called "A Validation Study of the Empirical Bridge Scour Equations" (Teng et al. 2005). Scour monitors were installed at two bridges in Hawaii. In January 2004 a storm was recorded by the sonar monitors at the Kaelepulu Bridge, and the field data were compared with the predicted scour from the existing scour equations.

The U.S. Army Corps of Engineers HEC-RAS software was used and the analysis was done to simulate the flow conditions and predict the scour depths at Kaelepulu Bridge under the storm conditions. The predicted scour depths of 2.4 m and 3.4 m (8 ft and 11 ft) were larger than the recorded scour depths of 0.46 m (1.5 ft) near the abutment and 0.3 m (1.0 ft) near the center pier at the bridge. They noted that one possible reason for this large difference is that in the numerical simulation, they assumed that the streambed material was fine sand in order to obtain the most conservative estimate for the bridge scour. During the installation of the sliding magnetic collars at the bridge site, boring tests were conducted and boring samples at the site showed fine sand at the streambed surface but large coral rocks at deeper depths. For this case, the parameter K_4 for predicting local scour at piers can be reduced. They noted however that even if they used the minimum allowable value of K_4, the predicted scour depth at the pier would still be about 4 times larger than the measured scour depth. For abutment scour, the empirical equation does not consider the size of the streambed material at all. They pointed out that other possible differences could be in the estimate of the flood hydrograph from the rainfall record and of the geometry and dimensions of the stream reach near the bridge.

Teng et al. reported that the results showed that the predicted scour depth at this bridge based on the existing empirical equations could be more than four times larger than the recorded scour depth in the field. She pointed out that their study was only a preliminary study. The field data were collected at one bridge site from one flood event only; therefore, it is not sufficient for a validation of the scour equations. They noted that bridge scour is a very complex and difficult problem to model theoretically because it involves the interaction of solid structure, movable bed material, and water flow. They recommended additional field monitoring and data collection at more bridge sites.

Other States

The remainder of the respondents did not provide any data in this regard; however, their comments on the usefulness of monitoring data for the verification of scour predictions are described here.

California reported that tilt meters have been able to track the daily thermal movements and the influence of construction activities adjacent to the bridge site. This site experienced record flows in January 2005, but no alarms or excessive movements were tracked. The float-out devices at the site were not activated.

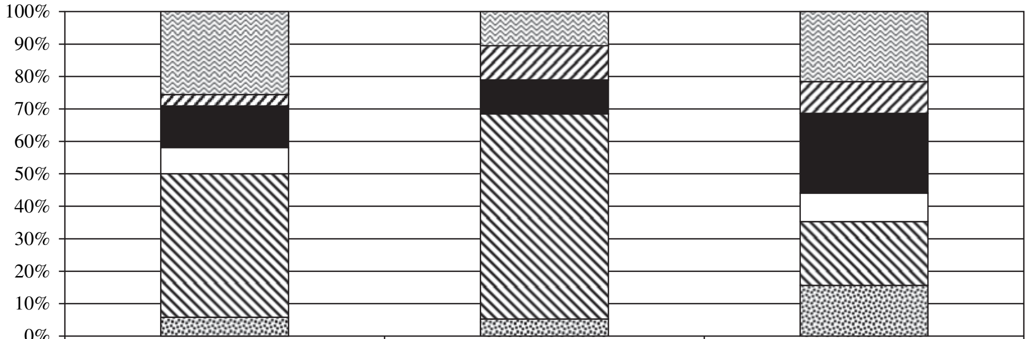
Florida reported that it had observed the tidal scour and infill processes. Their scour monitoring instruments have recorded the movement of loose soil and its redeposition by the tidal change currents.

Maryland reported that there was no significant scour recorded at any of the five piers being monitored. The velocity meter readings show that velocities have been low over the monitoring period, from 1999 to 2006, when the bridge was replaced. They noted that this has been useful in indicating that the bridge is stable, that bridge closures have not been necessary, and to ensure the safety of the traveling public.

The New York State Thruway Authority reported that a change in the monitored streambed elevation prompted further investigation of potential scour at the bridge. The results showed that the footing of the bridge was not exposed.

The USCOE Cold Regions Research and Engineering Laboratory reported that ice is not included in current scour prediction and the data it has collected on the Vermont bridge with instrumentation has been invaluable for developing numerical models and calibrating flume studies.

Clark County in Washington State reported that "absolutely" the monitoring data have been useful for verifying the scour predictions.



	Design	Manufacture	Installation
USGS	22	6	22
Contractor	3	6	10
In-House	11	6	25
Consultant	7	0	9
Vendor	38	36	20
Other	5	3	16

FIGURE 28 Parties involved in the design, manufacture, and installation of fixed scour monitoring systems. (*Note:* "Other" responses included various universities and federal agencies.)

INSTALLATION EXPERIENCE

The type of contract used to install the scour monitoring systems varied and included bridge scour countermeasures, bridge rehabilitation, research, USGS projects, and emergency scour conditions.

Figure 28 shows which parties were involved with the design, manufacture, and installation of the scour monitoring systems. The groups included the owner (in-house department), monitoring system vendor, contractor, and consultant. The monitoring system vendors manufacture the system or components of the system and can be responsible for or assist in the installation and calibration. The consultant would be a consulting engineering firm. The design and manufacture of the systems were done primarily by the monitoring system vendor, whereas the installations were done by a variety of groups including the bridge owners, the USGS, and contractors.

Additional Scour Countermeasures

According to FHWA HEC-23, scour monitoring can be used in conjunction with other scour countermeasures. Twelve sites reported the use of additional scour countermeasures at their bridges. These included hydraulic, structural, and portable monitoring countermeasures: riprap protection; stone-filled steel sheet piling around the piers; a downstream sheetpile check dam; lateral stiffening and bracing between the pier bents; crutch bents at the piers; and portable sonar monitors to confirm the measurements taken by the fixed scour monitoring devices. One bridge in North Carolina reported extremely severe conditions. Some areas near the bridge had scoured and filled as much as 16.5 m (54 ft). Water velocities were in the 3.7 to 4.6 mps range (12 to 15 fps). Numerous scour countermeasures were employed at this bridge and they included armor stone around the bents, new steel helper-bents, concrete cylinder pile helper-bents, gabion mats, A-Jaxs concrete armor units, and sand bag scour protection.

Additional Instrumentation

Most fixed scour monitoring installations included water stage sensors. Additional instrumentation included temperature sensors, velocity meters, inclinometers, and wind sensors. Most of these sensors were integrated into the scour monitoring systems. The temperature sensors are used for sound velocity correction for the sonar scour monitoring systems. The installation at the Woodrow Wilson Memorial Bridge over the Potomac River in Washington, D.C., included four velocity meters and one water stage in addition to the five sonar scour monitors (Figures 29 and 30).

FIGURE 29 Elevation of the original Woodrow Wilson Memorial Bridge.

FIGURE 30 Close up of velocity meter mounted on the fender of the Woodrow Wilson Bridge.

LESSONS LEARNED FROM STATES THAT USE INSTRUMENTATION

A wide variety of responses were obtained when the bridge owners were asked about lessons learned from the use of fixed scour monitoring instrumentation.

The majority of states expressed concern regarding the maintenance of the scour monitoring systems. They learned that maintenance needs of the system were often greater than anticipated. One state noted that the devices take readings and report real-time data, but that maintaining an operational system was very difficult. An on-going maintenance contract with a firm having special expertise with the scour monitoring equipment was recommended by another state. They pointed out that the contract should cover the entire period of the monitoring effort. The scour monitoring selection, design, and installation is only a small part of the endeavor. Developing and maintaining a response protocol and responsibilities, as well as long-term functioning of the system, were the major challenges.

The states also found the need to install more robust, protected devices. Several noted the need for stronger, custom-designed brackets. The materials used for the brackets should be carefully evaluated. The brackets could prevent movement, but be easy to remove to provide maintenance and repairs. Several states noted that the protection of the cables that transmit the data from the sensor to the data logger was their major concern, and that water, debris, and ice forces have interfered with the functioning of the system.

One respondent noted that the scour instrumentation group was too dependent on a single individual for support and they needed to determine the proper alarm trip items for each substructure unit being monitored. They also reported that their systems were programmed to automatically call in if there was a scour problem. They found that no calls gave staff the assurance that there were no scour problems; however, they noted that it could also occur when the system was not working.

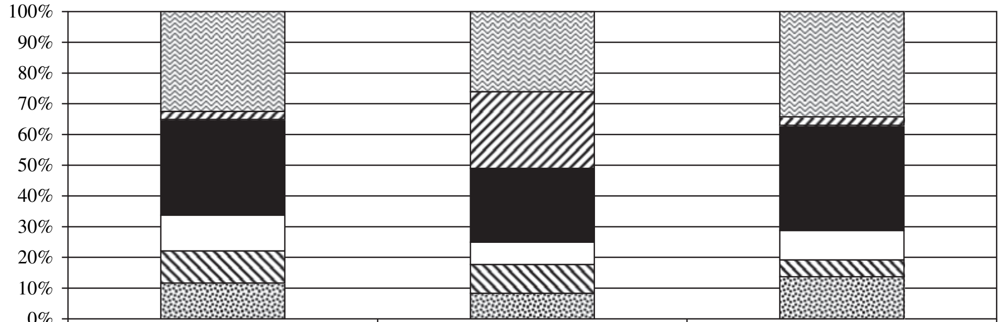
One state reported that the scour monitoring systems were more expensive than initially thought, but an alternative where physical countermeasures were used was impractical. They also noted that they can be used for the verification of the scour calculations, to demonstrate that a scour problem does or does not actually exist.

CHALLENGES AND PROBLEMS

Problems encountered during installation included difficulties in attaching the brackets to the substructure, working from a boat, climbing the superstructure, access to the river, traffic lane closure restrictions, budget limitations for staff overtime work, difficult installation requiring extensive equipment and experienced personnel, radio telemetry interference as a result of an in-line cellular telephone tower, and environmental impacts and disposal regulations for the excavation for the float-out devices.

The parties involved in the maintenance, repair, and inspection of the fixed scour monitoring systems can be found in Figure 31. The largest groups are in-house bridge owners and the USGS. Problems and issues after installation included the need for specialized equipment and personnel for maintaining the system; budgets that do not anticipate unscheduled repairs; the difficult logistics of the replacement of batteries; vandalism; high water velocities that cause excessive strain to the mounting brackets; power, communication, and vandalism problems in remote locations; and the need for an instrument bracket that will withstand ice and debris, but is long enough to clear protruding footings.

The various problems and challenges have caused a significant amount of uncertainty as to whether agencies will use fixed scour monitoring systems in the future. The survey



	Maintenance	Repair	Inspection
USGS	25	25	25
Contractor	2	24	2
In-House	24	23	25
Consultant	9	7	7
Vendor	8	9	4
Other	9	8	10

FIGURE 31 Parties involved in the maintenance, repair, and inspection of fixed scour monitoring systems. (*Note:* Other responses included various universities and federal agencies.)

asked if they planned to use additional fixed or portable scour monitors in the future. Thirty-six percent of the respondents stated that they planned to use monitors, 19% said no, and 45% were not certain.

INSTRUMENT RELIABILITY AND LONGEVITY

Approximately 63% of the respondents reported that their fixed scour monitoring installations were operational. The remainder reported that the monitoring was discontinued, that the system needed repairs, was vandalized, or that the bridge was replaced. Appendix D, Table D1, includes information provided by the respondents on whether their systems are functioning. A wide variety of factors interrupted or damaged the fixed scour monitoring systems. Figure 21 in chapter three showed the percentages for numerous factors disturbing service. The most common problem was the debris flows and accumulation.

Survey respondents were asked to comment on reliability and longevity of their scour monitoring systems. The comments on problems included vandalism, access limitations to replace batteries, marine growth, debris, and damage to the sensor attachments owing to high water velocities. The section on lessons learned in this chapter included a number of items on problems encountered and needs for future monitoring systems.

Regularly scheduled maintenance and inspection procedures for their scour monitoring systems were reported by 63% of the respondents. The Florida districts reported that the underwater sonar sensors require maintenance or replacement one to two times per year as a result of marine growth accumulation.

PROGRAMS, MANUALS, AND GUIDELINES CONCURRENTLY DEVELOPED

Emergency Protocol

An emergency protocol can be set up through a Plan of Action for a bridge or system of bridges, or through other documents. The respondents were asked to describe what they considered an emergency situation and what the emergency protocol would be for their bridge site(s). The majority of respondents stated that structural stability analyses were conducted for their bridge piers and abutments and threshold scour elevations were established that would trigger the emergency protocol, should they occur. Specific water surface elevations, or tropical storm or hurricane watches and warnings, were also used to determine if there were emergency situations. Emergency responses to these situations included visual monitoring, increased frequency for downloading the data of the fixed scour monitoring systems, underwater inspections, bridge closures, and the design and installation of hydraulic and/or structural scour countermeasures.

Most bridge owners reported that an emergency Plan of Action, similar to that developed by FHWA, had been established for their monitored bridge sites.

General Protocol

About half of the respondents indicated that they conduct independent checks to confirm the validity of the scour monitor readings. These independent checks were most often underwater diving inspections. The use of portable scour monitoring instrumentation was also reported.

Appendix G contains sample programs, guidelines, and manuals for fixed scour monitoring systems.

ADVANCEMENTS AND INNOVATIONS

Automated alarm systems can be installed as part of the scour monitoring systems. They serve to notify the owner, or designated parties if a scour threshold reading has been obtained. This information can be transmitted through a variety of forms from the bridge, and notification of a designated scour reading can be sent to a pager, telephone, fax, or computer. The respondents indicated that these automated systems were included in about half of their installations; however, some of these systems were not activated. Often the owner prefers to have a person download the data in order to check existing conditions.

There were few special innovative features or materials reported. Most of these were not in practice during the NCHRP project on fixed scour monitors (Lagasse et al. 1997), but were developed subsequent to that, and are described in FHWA HEC-23 (Lagasse et al. 2001a). The innovative features reported by the survey respondents included remote downloading capabilities by means of telephone or satellite, water temperature sensors for sound velocity correction on sonar scour monitors, water stage sensors, and radio transmission of data from remote stations to a permanent facility. In channels with high water velocities and/or tidal waters, the use of stainless steel (AISI 316) or aluminum mountings for the underwater components were reported to be more successful than the polyvinyl chloride used during the NCHRP project on scour monitoring instrumentation.

INFORMATION FROM STATES THAT HAVE NOT USED INSTRUMENTATION

Bridge owners who do not use scour monitors were asked to indicate what were the problems or limitations for why they had chosen not to use this technology. They were also asked to discuss innovations and advancements they would like to see in fixed monitoring technology.

The most common concern was the high cost of fixed monitors. This was followed by problems with reliability and their desire for little or no maintenance requirements for a monitoring system. Other factors that owners described as contributing to problems with fixed scour monitors included ice, debris, lightening, inadequate funding, the long time required for installation, the poor quality of the data, and difficulties in the acquisition of the data. They also described various needs for their monitoring systems that included good reporting capabilities; remote access; negligible operating costs; and systems that can withstand extremely high temperatures, are protected from vandalism, particularly over ephemeral streams, have the ability to take measurements through silty and murky water, and devices where all parts are outside of the water.

CHAPTER FIVE

DATA COLLECTION AND ANALYSIS

DATA COLLECTION

Frequency of Data Collection

The data collection procedures for the fixed scour monitoring systems varied among the respondents. The survey asked the owners about the protocol for several items regarding the data collection. This included the frequency with which the fixed monitors record data and how often the data are collected and reviewed under normal procedures and during emergency situations.

The fixed scour monitor instruments that take periodic readings can be programmed for any desired interval. The respondents reported that the intervals for their readings ranged from every 15 minutes to one time per month. Most of the monitors were programmed to take readings one to two times per hour.

The streambed elevation data are typically stored in a data logger and can be collected and reviewed by the owner or his/her designee at any desired interval. These data can be downloaded at the bridge site or from a remote site by means of telemetry. The respondents to the survey indicated that the interval at which their data are collected and reviewed under normal circumstances can be daily, weekly, or monthly. About half of the responses checked the category "other" and noted that this was done during floods or as needed.

During emergency situations, the frequency with which data are collected also varied. It included every 15 minutes, hourly, twice daily, daily, and bi-weekly.

Methods of Data Collection

The data can be downloaded and retrieved automatically by means of telemetry or at the bridge site. The telemetry can be set up using a landline telephone, cellular telephone, or through a satellite connection. The respondents used one of the three systems. The majority of the respondents used telemetry to retrieve the bridge scour monitoring data. The automatic system can be to a base computer or to a network for retrieval through an Internet connection. The Internet was the most common system used by 61% of the survey respondents. The second most-used method, used by 28%, was telemetry to a base computer. The remaining 11% downloaded the data at the bridge site. Earlier installations most often involved manual downloading of the data at the bridge sites.

Respondents provided multiple modes for downloading the data at a particular bridge. Satellite and local retrieval at the bridge site were the most frequently reported modes. These were followed by the landline telephone. The cellular telephone was not as common and was usually used when the landline telephone was not available.

In recent years, the installations include posting of the data on a secured Internet site. The Arkansas State Highway and Transportation Department (ASHTD) reported that its system was designed so that it could be remotely monitored in real time from any ASHTD facility with an Intranet connection or with an Internet with a virtual private network connection. It noted that sonar images, camera stills, video, and bridge state can be obtained at any time.

Other states that are using the Internet for data storage and retrieval include Alaska, California, and New York. Real-time data for Alaska are posted on the USGS website (http://ak.water.usgs.gov/usgs_scour). This site includes elevations of the bridges in the scour monitoring program, historic cross sections at the bridges, and information on the real-time sonar scour data.

DATA ANALYSIS

The type of fixed scour monitoring system employed depends on what kind of information is desired. If a series of streambed elevations over time are of interest, sonars, magnetic sliding collars, and sounding rod monitors can be used. If a bridge owner is interested only when a certain streambed elevation is reached, float-outs can be employed. For specific information on pier or abutment movements, tilt sensors record changes in the position of the bridge in two directions. Survey respondents also gathered information on water elevations, velocities, and temperature readings.

Once the data are gathered, the analysis can be done using a variety of methods. Survey respondents indicated that data were typically recorded as either text files or spreadsheets. These types of file formats make it easy for the engineer to analyze large amounts of data. Graphs and plots are simple to generate through a spreadsheet program such as Microsoft Excel. Sample plots were provided by Florida, Maryland, and New York and can be found in Appendix E. The graphs can show streambed elevations, water stage elevations, and velocity versus time. All three installations used sonar scour monitors to record continuous sets of data.

If a scour monitoring system is continuously gathering data over a period of months or years, a large amount of data are generated. Data reduction techniques have been employed to view trends over long periods of time. The Wantagh Parkway over Goose Creek Bridge in Long Island, New York, is one such example. Since 1998, the monitors have recorded the streambed and water stage elevation every hour, 24 hours a day. In 2004, the system was refurbished and the new software that was installed was programmed to take readings every half hour. To make the data easier to interpret, spreadsheet programs were developed to extract daily and monthly minimum values. Samples of these reduced data graphs are included in Appendix E.

A continuous set of data were available from 11 of the survey respondents. An additional three indicated that they were not certain if the data are available.

CHAPTER SIX

CASE STUDIES AND SITES WITH OBSERVED SCOUR DEPTHS

CASE STUDIES OF EXISTING SITES

The following case histories were selected for this report because they cover a range of geographical locations and types of fixed scour monitoring instrumentation.

Alaska

To better understand the scour process and to monitor bed elevation at bridge piers, the USGS and the Alaska Department of Transportation and Public Facilities operate a network of streambed scour monitoring stations in Alaska (Conaway 2005, 2006a, b). To date they have instrumented 20 bridges with sonar and river stage instrumentation (Figure 32). In 2008, 16 bridges remained in the monitoring program. A list of the bridges and scour monitoring information can be found in Appendix D. These stations provide state engineers with near real-time bed elevation data to remotely assess scour at bridge piers during high flows. The data also provide a nearly continuous record of bed elevation in response to changes in discharge and sediment supply. Seasonal changes as well as shorter duration scour and fill have been recorded. In addition to the near real-time data, channel bathymetry and velocity profiles are collected at each site several times per year.

Each bridge is instrumented with a retractable, pier-mounted sonar device. At locations with multiple scour critical piers, sonar transducers have been mounted at each pier. The sonar transducers were mounted either at an angle on the side of the piers near the nose or on the pier nose to collect data just upstream of the pier footing. Many of Alaska's bridges are situated in locations too remote for landline or cellular telephone coverage. The scour monitoring instrumentation on the remote bridges has incorporated ORBCOMM, a constellation of low-earth-orbiting satellites. Data are sent from the bridge to a passing satellite, which then relays it to an earth station, which forwards the data to specified e-mail addresses. The network of scour monitoring sites is dynamic, with locations being added and removed annually based on monitoring priority and the installation of scour countermeasures. Instrumentation is subject to damage by high flows, debris, and ice, and repairs at some sites can only be made during low-flow conditions.

In 2002, one sonar scour monitor was installed at the Old Glenn Highway Bridge over the Knik River near Palmer (Figure 33). There are two bridges that cross the Knik River at this location. The active bridge was built in 1975, is 154 m (505 ft) in length, and is supported by two piers. The roadway approaches to the active bridge significantly contract the channel. Approximately 30 m (98 ft) upstream is the original bridge, which is no longer open to vehicular traffic. Two guide banks extend upstream of both bridges and route flow through a riprap-lined bridge reach. The piers are approximately aligned with the flow. The Knik River is a braided sand and gravel channel that transports large quantities of sediment from the Knik Glacier. The braided channel narrows from approximately 4.8 km (3 mi) wide at the glacier mouth to 0.12 km (0.07 mi) at the Old Glenn Highway Bridge, where the channel is subject to a 4:1 contraction during summer high flows.

The right-bank pier of the new bridge was instrumented with a retractable, pier-mounted sonar monitor. This retractable arm was designed to prevent ice and debris flows from damaging the sonar bracket, as had occurred in other scour monitoring installations in Alaska. Stage data were measured by a nearby USGS stream gage. The sonar was mounted at an angle on the side of the pier near the nose to collect data just upstream of the pier footing. Data are collected every 30 minutes and transmitted every 6 hours by means of satellite. When bed elevation or stage thresholds are exceeded, data transmissions increase in frequency.

The Knik River was the only bridge site within the monitoring network that had large changes in bed elevation each year. Annual scour ranged from 5.2 to 6.0 m (17.2 to 20 ft). The near real-time data and historic cross-section data for the Knik River and other bridge scour monitoring sites in Alaska is available on the USGS website (http://ak.water.usgs.gov/usgs_scour).

California

Caltrans has used a variety of scour monitoring techniques to instrument its bridges. Six different types of fixed instrumentation have been installed on 24 bridges including (1) stage gage, (2) sliding rod (sounding rod), (3) sliding collar, (4) sonar, (5) float-out devices, and (6) clinometer. More recent installations generally use float-out devices and/or clinometers (tilt meters). Caltrans notes that they fix or replace all scour critical bridges. Monitoring is used as an interim measure.

The bridge scour monitoring devices in California all include telemetry to allow remote access to the scour monitoring data. The communications from the bridge sites go

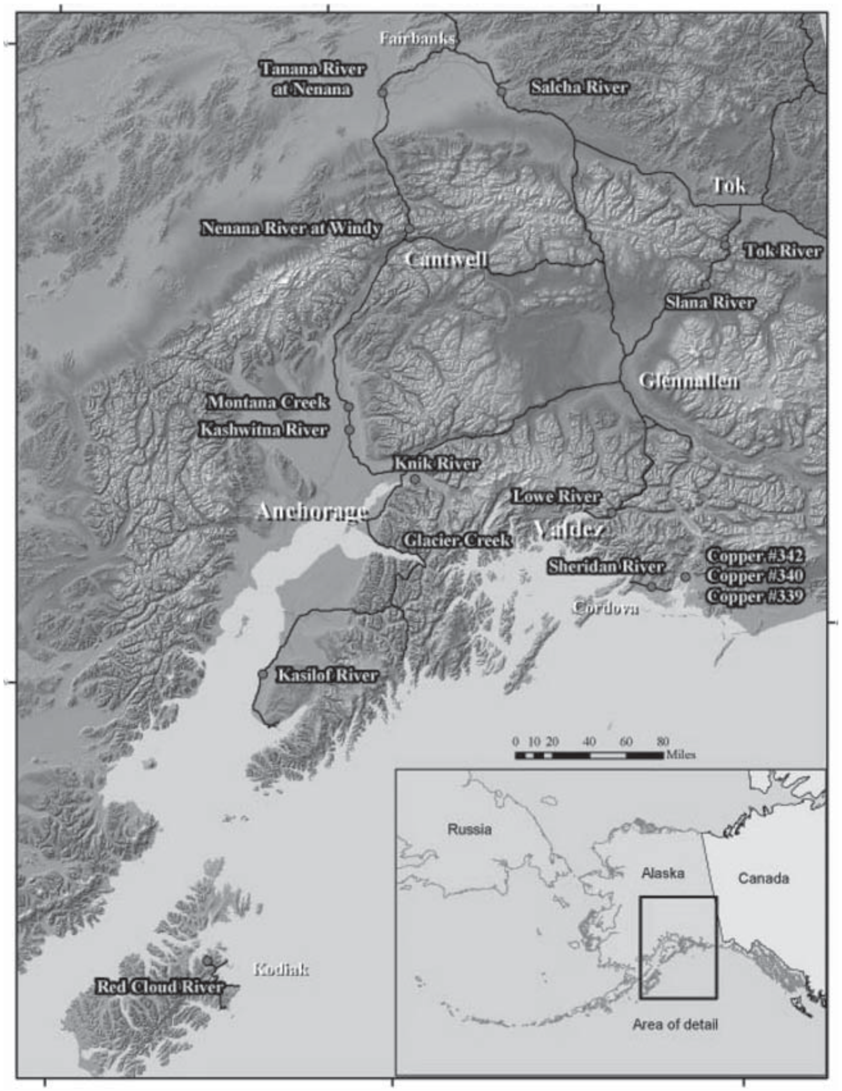


FIGURE 32 Active streambed monitoring locations in Alaska (*Courtesy:* U.S. Geological Survey).

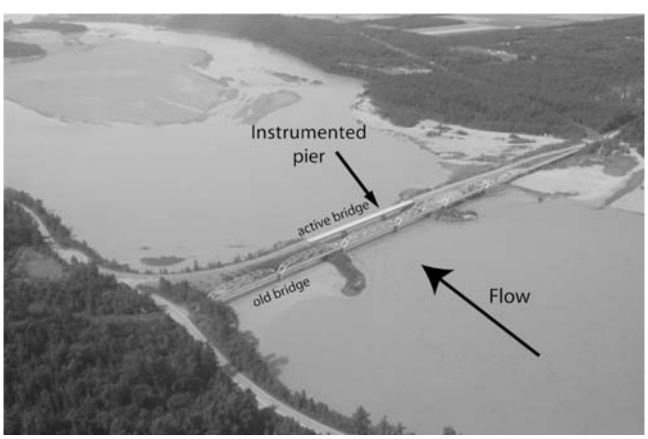


FIGURE 33 Oblique aerial photograph of the Knik River Old Glenn Highway bridges during a summer high flow (*Courtesy:* U.S. Geological Survey).

to the Caltrans central office in Sacramento. The existing devices include four different types of communication systems including (1) modem and cellular telephone, (2) modem and land line, (3) voice modem and cellular telephone, and (4) satellite. Internet sites have been created for the Caltrans scour monitoring data to be displayed. It reports that in some remote areas, cellular and land line telephone coverage is sparse and a major disadvantage is their availability during disasters such as an earthquake.

Caltrans generally installs two float-outs at different elevations at each pier, so that two different scour depths can be monitored. In Caltrans' first experience, seven pairs of float-outs were installed near seven piers of the southbound Highway 101 Bridge over the Salinas River near Soledad (Figures 34 and 35). This collection of float-outs was manufactured to transmit only two frequencies, one for the yellow flag and one for the red flag float-out. Scour

FIGURE 34 Close-up of sonar scour monitor installation on the Highway 101 Bridge over the Salinas River (Lagasse et al. 2001a).

FIGURE 36 Tilt sensor installation on California bridge.

occurred at one of the yellow flag float-outs; it floated out as designed and a telephone call was triggered. However, it was not possible to tell which specific pier had scoured. Caltrans now specifies that each float-out has a unique frequency to identify which specific pier has scoured to a pre-set elevation.

The clinometers used by Caltrans are very sensitive tilt meters designed to measure the movement of the bridge itself (Figures 36 and 37). Caltrans reported that it has become the most common device installed for monitoring, because there is no need to estimate a scour depth that will compromise the bridge's integrity. It notes that the bridge must be redundant enough to withstand some movement without failure to allow maintenance forces sufficient time to sense the movement and dispatch crews to close the bridge to traffic. The challenge that Caltrans faced was to observe the "normal" movement of the bridge and then determine the "alarm" angle that would provide sufficient time for crews to travel to and close the bridge to traffic. Caltrans accomplished this by installing the clinometers, monitoring normal pier movement for several months (ideally, one year is suggested), and setting the alarm angles based on the unique "signature" of each monitored pier on any given bridge.

Caltrans describes the advantages of using fixed instrumentation as (1) protecting the safety of the traveling public, (2) reducing resource usage, (3) providing better data, (4) reducing capital and human resource cost, and (5) calibrating current scour equations. They noted disadvantages as

FIGURE 35 Installation of float-out devices with hand auger on the Highway 101 Bridge over the Salinas River (Lagasse et al. 2001a).

FIGURE 37 Detail of clinometer and data logger.

including sending false alarms and not protecting investment in the infrastructure.

In a discussion regarding the performance of the scour monitors, Caltrans reported that, in general, the instruments perform well. They have more trouble with the communication end. The most common problems are modems failing, difficulty with cell phone transmissions at remote sites, damage to or rotation of solar panels causing batteries not to recharge, and information technology security patches etc., causing trouble with the main computer at Instrumentation Services. Another big problem Caltrans faces is vandalism. Solar panels have been stolen from bridges, shot with bullets, and hit with blunt objects. Satellite antennas have also been hit, knocking them out of position. The funds to replace vandalized parts have been difficult to obtain from the appropriate department because it is a new technology.

Regarding lessons learned from the scour monitoring program, Caltrans reported that it takes a constant coordinated effort between Hydraulics, District Maintenance, and Instrumentation Services to keep the system continually online and to make repairs in a timely manner. All three groups must make it a priority to minimize down time.

Florida

The Florida DOT (FDOT) reported that it used fathometer echo sounders for scour monitoring at the St. John's Pass Bridge in St. Petersburg, Florida (Lasa et al. 1999). The system included transducers to measure water temperatures, tide elevations, and water velocity. The St. John's Pass Bridge spans an inlet, which connects the Gulf Intracoastal Waterway and the Gulf of Mexico (Figure 38). The bridge had severe scour problems and structural countermeasures were installed.

FIGURE 38 Elevation of St. John's Pass Bridge, St. Petersburg, Florida.

These countermeasures included crutch bents supported by concrete drilled shafts at the piers. The echo transducers were attached to the drilled shaft at each pier and the data logger and a telephone transceiver were attached to a support column directly above the shaft (Figure 39). The unit was powered by a solar panel that was installed on top of the bridge.

Immediately after installation at the first pier the divers working for FDOT physically measured the water depth from the transducer to the inlet bottom. In addition, the divers verified that no physical obstructions were present in the path of the beam. It was observed that the sound reflection point at the bottom was a cavity of conical shape apparently produced by the movement of water. The distance measured by the divers was 0.15 m (0.5 ft) more than the distance recorded by

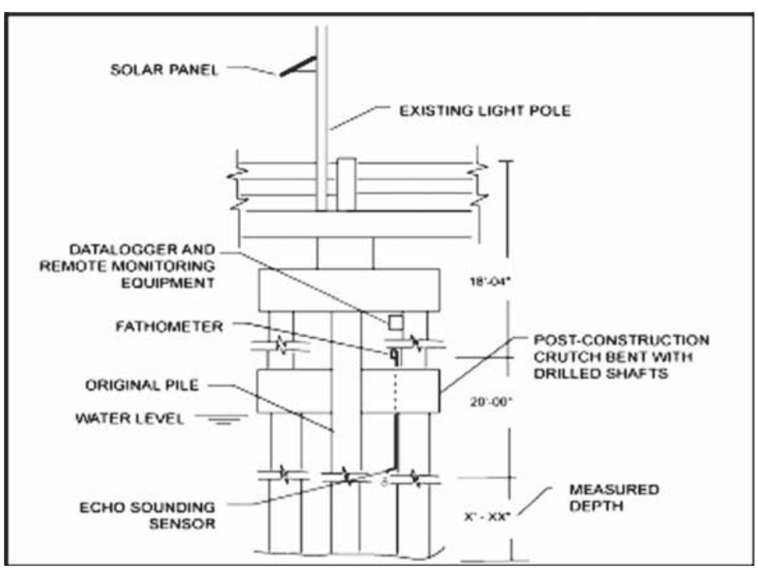


FIGURE 39 Schematic of sonar monitor attached to crutch bent at St. John's Pass Bridge.

the data logger. They attributed the difference in measurements to the geometry of the echo reflection point area (because of its conical shape). The physical measurement was obtained at the center of the scoured cavity. At this point, it was decided not to redirect the beam because the development of the scoured cavity as a hole was of interest to the engineers.

After approximately 45 days some modifications were made to make the sensor support bracket more rigid at the first pier installation. Also, FDOT observed that downloading data at high speed (9600 baud or higher) introduced a significant number of errors and sometimes allowed abrupt communication interruptions. The data transfer did not show these errors when downloading with a direct high speed connection at the bridge. They concluded the errors were the result of the cellular connection.

After about three months a second pier was added to the system. The new sensors consisted of depth and water velocity transducers. The water velocity sensor was a mechanical type (paddle wheel with transducer). A standard telephone line was also installed to improve the accuracy of data transmissions at high speed.

Occasionally, the unit recorded erroneous readings indicating changes ranging from 3 to 30.5 m (10 to 100 ft). Typically, the erroneous readings appeared at different times and days, and were not consecutive. Data for these readings were discarded and the cause was not determined; however, it is suspected that these data were produced as a result of moving debris, introduction of noise, or, most likely, movement of the sensors.

Lasa et al. (1999) concluded the following from the installation at the St. John's Pass Bridge. Depth measurements obtained using echo-sounding devices were sufficiently accurate to define the scour movement near the bridge supports. Gradual bottom changes as well as abrupt changes were recognized from the data. However, detailed engineering and installation of the fixed support of the sensors are necessary to avoid any movement of the sensors that can result in erroneous readings.

Based on the physical measurements, the accuracy of the monitoring system was satisfactory, with a resolution of plus or minus 0.15 m (6 in.) at a measuring distance between 9.1 and 12.2 m (30 and 40 ft). Accuracy of the measurements could be increased by reducing the measured depth to a distance between 1.5 and 3 m (5 and 10 ft), or as considered reasonable for the specific site.

The telemetry system using analog cellular communication limited the data transmission speed to 2400 baud. This limitation does not affect the monitoring process and affects only slightly the download process, because the normal amount of weekly data to be transferred does not exceed 50 k bytes. Digital cellular technology can increase the transmission speed. However, this service is not available at many locations.

The use of continuous monitoring allows for the identification of scour movements as soil is removed and redeposited around the bridge footings or piles. Periodic maintenance of the sensors was required owing to the tidal location of this site and the marine growth that accumulated around the sensors. It was estimated that the sensors would require cleaning and recoating on a 2- to 3-year basis. They noted that extended maintenance periods can be possible based on the quality of the water at other installation sites.

Lasa et al. (1999) recommended that research to identify an economically feasible and compatible water velocity sensor could continue to provide data for predicting future scour development. In addition, other types of sensors such as strain and movement gauges, and embedded concrete temperature sensors, could be added to the system to provide continuous bridge condition assessments.

New York

The New York State DOT (NYSDOT) has installed 27 sonar scour monitors at three bridges on the South Shore of Long Island in Nassau and Suffolk Counties in New York (Hunt 2003). Wantagh Parkway over Goose Creek was a 28.3 m (93 ft) bascule bridge (Figure 40), Wantagh Parkway over Sloop Channel was a 175.6 m (576 ft) fixed concrete pile

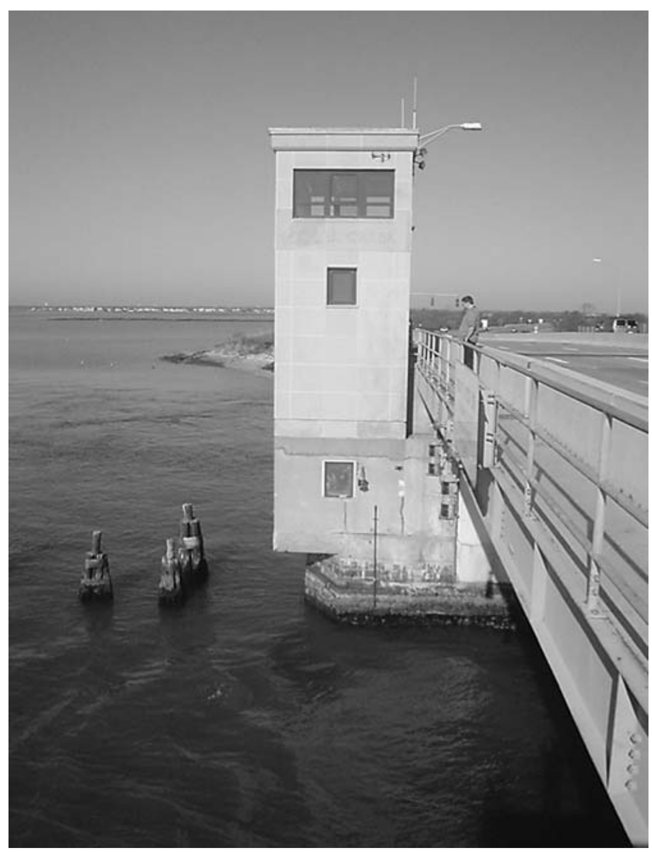


FIGURE 40 Conduit to sonar monitor at Wantagh Parkway over Goose Creek, Long Island.

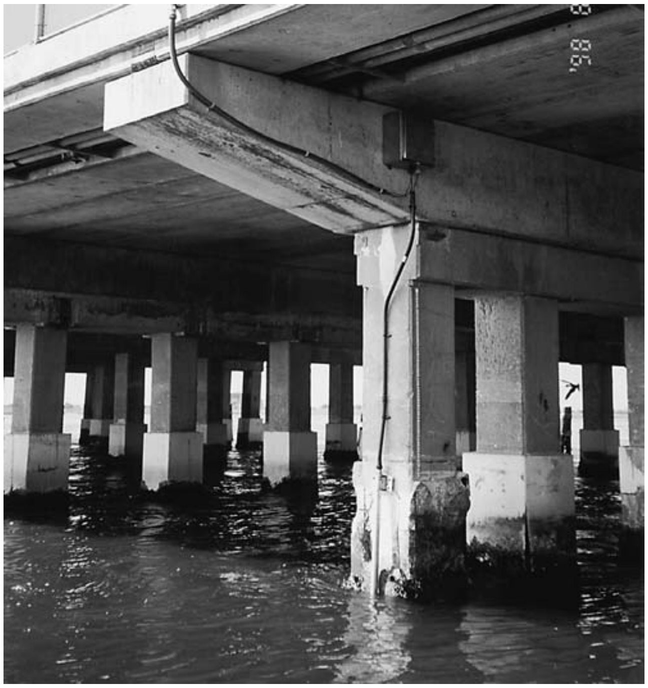


FIGURE 41 Remote station and conduit to sonar monitor at Wantagh Parkway over Sloop Channel, Long Island.

bent bridge (Figure 41), and Robert Moses Causeway over Fire Island Inlet, a 326 m (1,068 ft) bridge (Figures 42–44). These monitors have served as both short- and long-term solutions to the scour problems at these bridges. In 1998, following a partial pier collapse at Wantagh Parkway over Goose Creek, it was found that the streambed at one pier had experienced approximately 8.8 m (29 ft) of localized scour since it was built in 1929. To ensure that these bascule piers were safe, several options were investigated and a scour monitoring system and program was designed for the bridge.

FIGURE 42 Elevation of Robert Moses Causeway over Fire Island Inlet, Long Island (*Copyright:* Raimondo di Egidio).

FIGURE 43 Remote station, solar panel, and conduit to sonar monitor for Robert Moses Causeway over Fire Island Inlet, Long Island (*Copyright:* Raimondo di Egidio).

A nearby bridge, Wantagh Parkway over Sloop Channel, was also examined and was found to have similar problems with respect to scour of the piers. As a result, four scour monitors were installed at the bascule piers of Goose Creek, and ten monitors were installed at Sloop Channel. In addition, one water stage sensor was installed at each bridge. The scour monitors were approved by NYSDOT within one week of

FIGURE 44 Detail of conduit to underwater sonar monitor, Robert Moses Causeway over Fire Island Inlet, Long Island.

the failure, and they were designed, custom-built, and arrived at the site ten weeks later. The sonar mounting brackets were made of stainless steel as a result of the harsh tidal environment. For data retrieval, the system employed remote telemetry by means of a modem and telephone land line. The power was supplied using solar panels for the fixed bridge at Sloop Channel and by the electric system on the bascule bridge at Goose Creek.

A scour monitoring program and manual was developed for the Wantagh Parkway Bridges. This was the first procedural manual to be developed for scour monitors. The manual provided the opportunity to work through various scenarios should these bridges continue to experience scour. The program included round-the-clock monitoring even during storms. It included critical streambed elevations for each pier; procedures for normal and emergency situations; a Plan of Action should certain scour elevations be reached; and inspection, troubleshooting, maintenance, and servicing instructions. An effective communication system for all responsible parties was established. The main text and several appendices from this manual can be found in Appendix G.

The installation of sonar scour monitors at Robert Moses Causeway over Fire Island Inlet was a long-term solution to the scour issues at the bridge. The flow rate was estimated to be more than 13,932 cms (492,000 cfs) for the 100-year storm. Riprap scour protection had been placed at some piers over the years, and according to the FHWA guidance, riprap should be monitored when used as a countermeasure at piers. In 2001, sonar scour monitors were placed at 13 piers, a water stage was installed, and the Long Island scour monitoring manual was revised to include the new system. This was a complex design and installation owing to the proximity of the bridge to the Atlantic Ocean, the deep-water conditions, the pier configurations, and the high flow rates. To ensure that the underwater sonar brackets could clear the pier footings to measure the streambed elevations, this design incorporated a new type of adjustable tripod stainless steel bracket (Figure 45 and Appendix G).

The scour monitoring systems at Goose Creek and Fire Island have been in operation since 1998 and 2001, respectively. Sample data from Goose Creek can be found in Appendix E. The Sloop Channel Bridge was replaced in 1999, and the monitoring system was salvaged and has been used for spare parts for the two bridges remaining in the program. The scour monitoring program includes the daily routine monitoring of these bridges, including data acquisition and analysis; round-the-clock monitoring during scour critical events; the preparation of bi-weekly graphs of the streambed elevations and tide gauge data; periodic data reduction analyses and graphs; and routine maintenance, inspection, and repairs. In 2004, a total refurbishment of the Goose Creek system was completed. This included the installation of the latest operating system software and a new bracket for the sonar transducer at one monitor location. An underwater contractor installed the new bracket and also strengthened the scour

FIGURE 45 Adjustable sonar bracket prior to underwater installation on Wantagh Parkway over Goose Creek, Long Island.

monitor mounting brackets at the other pier locations. The condition of the scour monitors and the accuracy of their streambed elevation readings are checked during the regularly scheduled diving inspections and fathometer surveys at each bridge. Also, all debris and/or marine growth that accumulate on the underwater components are cleared away during the diving inspections.

Washington State

In 2006, the Klineline Bridge in Vancouver, Washington, was instrumented with two sonar devices, two tilt meters, and one water stage. This concrete bridge was built in 1928 and is owned by Clark County Public Works. It carries Old Highway 99 over Salmon Creek and has a history of scour including pier settlement in 1949 and a pier collapse in 1956. Salmon Creek is riverine and is subject to debris loading and high velocity flows. The average water depth is less than 3 m (10 ft) and the subsurface conditions are sand and gravel. In 1996, a dike breach in a nearby pond resulted in a head cut that has continued to travel toward the bridge (Figure 46). Steel sheet piling and concrete aprons have been installed downstream of the bridge to protect it from the head cut. In 2004, the county decided to replace the bridge owing to structural deficiencies and the scour critical rating. Intermittent road

FIGURE 46 General elevation of Klineline Bridge, Vancouver, Washington.

FIGURE 48 Two sonar scour devices monitor streambed elevations adjacent to the pier concrete block protection on the Klineline Bridge.

closures were necessary as a result of high water in 2006. During a low flow inspection that year, significantly increased scour was observed including 1.2 m (4 ft) of exposure on the 1.5 m (5 ft) deep spread footing at one pier (Figure 47).

An emergency scour countermeasure program was developed to keep the bridge in service until construction of the replacement could be started the following year. The program included the armoring of the piers with tied, interlocking concrete blocks and the installation of three types of fixed devices to monitor riverbed changes, structural movement, and flow. In 2006, the bridge was closed for 10 days during the season's first storm event as a result of the high water conditions. When it reopened, it had been instrumented with the fixed monitors installed by a contractor. The streambed elevations adjacent to the concrete blocks at one pier were monitored in two locations by two sonar devices (Figures 48 and 49). To monitor movements, one tilt meter was placed on the bridge and a second was installed on the downstream sheet pile to monitor the migrating head cut (Figures 50 and 51).

FIGURE 49 Close-up of a sonar scour monitor on the Klineline Bridge.

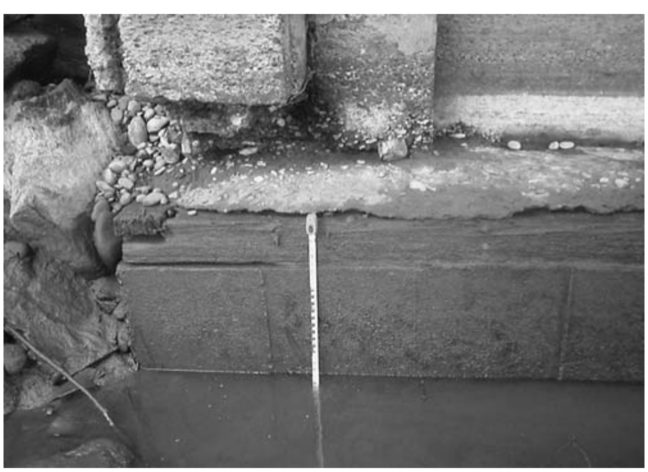


FIGURE 47 Inspection photograph of exposed pier spread footing on the Klineline Bridge on Highway 99 over Salmon Creek.

FIGURE 50 Tilt meter on downstream sheet pile to monitor the movement of the headcut toward the Klineline Bridge over Salmon Creek.

FIGURE 51 Conduit from sheet pile to tilt meter mounted on a pier of the Klineline Bridge.

A water stage was installed to monitor flow, the rate of change of flow, and river depth changes.

The sonar mounting brackets each include a simple water level float switch located about 0.18 m (7 in.) above the transducer inside of the square tubing. In this way, the system only operates the sonar when the devices are underwater.

Figure 50 shows the steel conduit connected to the sheet pile downstream of the bridge. The conduit contains a steel cable and is connected to a lever arm located on the top side of one of the bridge piers (Figure 51). The tilt sensor is in an enclosure mounted on the lever arm under the bridge deck and it provides measurements of any movement of the sheet pile and migrating head cut.

The scour monitoring system is remote and there are predetermined values that trigger alarms. There are three levels of warning prior to reaching the last level for bridge closure. When certain threshold readings are obtained, fire and sheriff's units can be in place within minutes to block traffic and close the bridge.

Clark County reported that the scour monitoring system is working well and they can use the equipment on other bridges once the Klineline Bridge is replaced. They have been able to keep the roadway open during the rainy season

FIGURE 52 Scour monitor and concrete block rotation from continued scour near the Klineline Bridge over Salmon Creek.

based on the information provided by the scour monitoring system. Two weeks after installation of the monitoring system the bridge experienced a storm of approximately an 87-year recurrence interval. Continued scour at one pier has resulted in rotation of the concrete block protection (Figure 52). The county reported problems obtaining readings owing to debris (Figure 53) and interrupted telephone service. Regularly scheduled maintenance has been used to clear the debris.

SITES WITH OBSERVED SCOUR DEPTHS

All the survey respondents reported that the monitored sites had a history of scour problems. The following information was provided by the states that have observed scour since the installation of their scour monitoring systems or was obtained from the literature search.

FIGURE 53 Debris build-up at sonar monitoring bracket on the Klineline Bridge.

Alaska

The Knik River near Palmer was the only site within the 20 bridge monitoring network (see Figures 32 and 33) that had large changes in bed elevation each year (Conaway 2006a). Alaska DOT reported that the fixed scour monitors were helpful in providing insights into site-specific scour processes. The USGS reported that the data for the Old Glenn Highway Bridge over the Knik River near Palmer showed an annual cycle of channel aggradation and degradation to an equilibrium level that is punctuated by shorter periods of scour and fill. It observed that the annual vertical bed elevation change exceeded 6 m (20 ft) and concluded that it was an interplay of sediment supply, discharge, and the influence of instream hydraulic structures. It concluded that scour at this site is complex and is a combination of pier, contraction, and abutment scour, with abutment scour being the primary factor. Channel contraction at this site is nearly four to one at high flows, and upstream guide banks direct flow through the bridge reach. More information on this site can be found in chapter four under scour prediction and in this chapter in the case studies section.

The annual scour at the Old Glenn Highway Bridge ranged from 5.2 to 6.0 m (17.2 to 20 ft). The braided channel narrows from approximately 4.8 km (3 mi) wide at the glacier mouth to 0.12 km (0.07 mi) at the bridge, where the channel is subject to a 4:1 contraction during summer high flows. It drains an area of approximately 3,100 km^2 (1,925 mi^2), more than half of which consists of glaciers.

Conaway states that the current morphological and alluvial characteristics of the Knik River can be partially attributed to large glacial-outburst floods that occurred nearly every year from 1914 to 1966. The maximum measured discharge from these events was 10,200 m^3/s (360,213 cfs). Since the installation of the monitoring equipment, discharge at the Knik River has ranged from 17 to 1,710 m^3/s (600 to 60,389 cfs) for the years 2002 to 2005. During the winter months, the streambed at the monitored bridge pier aggraded to an elevation between 9.8 and 10.4 m (32.1 and 34.1 ft) each year (Figure 54). From the beginning of the data collection each year in early May until the latter part of June the bed degraded at an average rate of 0.06 m/day (0.2 ft/day), about 2.4 m (7.9 ft) each year. Over this same period of time, the stage increased at a rate of 0.02 m/day (0.07 ft/day), 0.03 m/day (0.1 ft/day), and 0.02 m/day for 2003, 2004, and 2005, respectively. Following this period of seasonal channel degradation the bed elevation at the pier remained relatively stable at an equilibrium elevation of 7.8 m (25.6 ft), with brief periods of scour and fill during high flows. The channel began to aggrade each year in September as stage decreased.

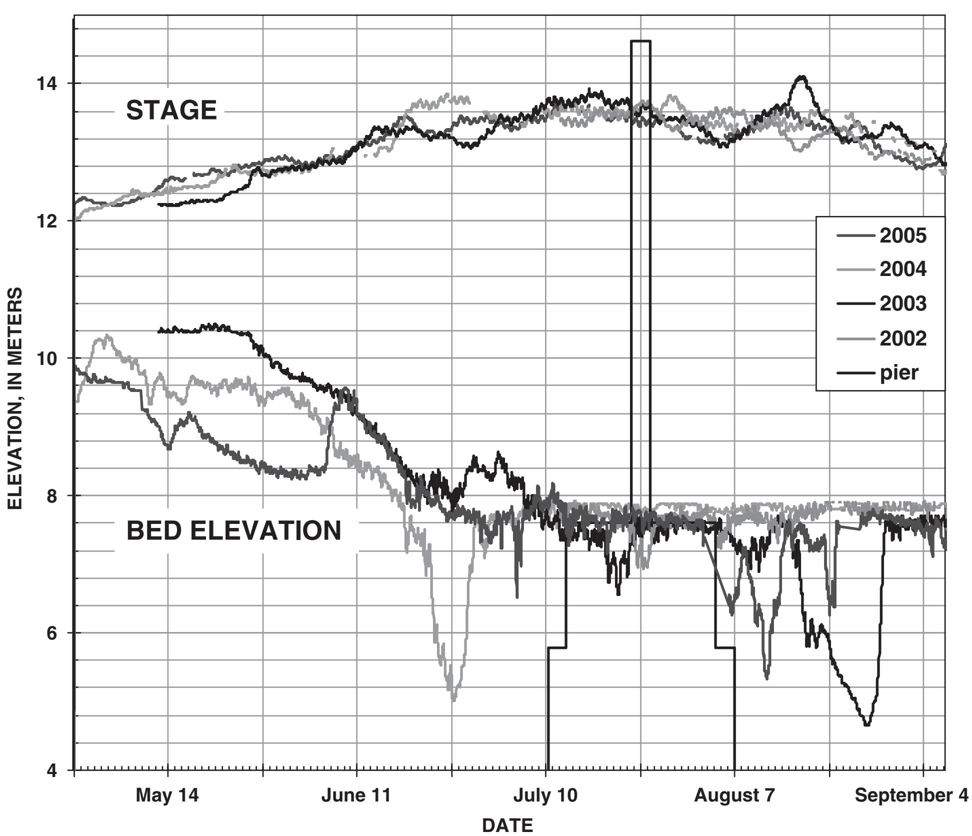


FIGURE 54 Stage and bed elevation at the monitored bridge pier for 2002 to 2005 at the Old Glenn Highway Bridge over the Knik River (*Courtesy:* U.S. Geological Survey).

The cross section defined by the upstream bridge opening was surveyed periodically to document changes in bed elevation across the channel. These cross sections and the sonar data show an annual cycle in channel change. Scour at this site is not uniformly distributed across the channel and Conaway (2006a) concluded it was a combination of live-bed contraction and abutment scour along the guide banks.

Conaway reports that two distinct scour and fill events from 2003 and 2004 highlight differences in timing and duration of scour. Both scour events were associated with a period of high temperatures and subsequent increased glacial melt; however, in 2003 the warm weather was followed by 10 days of rainfall and cooler temperatures. The magnitude of the scour for both events was approximately 3 m (9.8 ft) from the equilibrium bed elevation. The maximum scour occurred slightly after the peak in stage in 2003, and in 2004 maximum scour was concurrent with peak stage. The duration of scour, measured from when the bed elevation begins to decrease until fill begins, was 11.5 days in 2003 and 4 days in 2004. He noted that the scour in 2003 was of greater duration because the discharge and sediment supply from the glacier was reduced by the cooler temperatures. The channel infilled 3 m (9.8 ft) in 2 days after warmer temperatures resumed, likely accompanied by an increase in sediment load. In 2004, stage increased rapidly prior to scour and was then steady with diurnal fluctuations. The scour began after the bed had degraded to the elevation of the top of the pier footing. Filling of the channel began before the stage began to decrease. Conaway concluded that because bed elevation changes in alluvial systems are the response to changes in sediment supply and flow hydraulics, and flow hydraulics were relatively constant during this event, an increase in sediment supply from the glacial melt water is thought to have initiated the filling.

California

FHWA HEC-23 (Lagasse et al. 2001a) and the survey from Caltrans reported on the SR-101 bridges over the Salinas River near Soledad. This was one of five California bridges instrumented in preparation for El Niño driven storm events in 1997 and 1998. This work was done by Caltrans with funding from FHWA. SR-101 has two bridges at this crossing, one built in 1939, and the second in 1960. The bridges are 384 m (1,260 ft) in length. The monitors were placed here owing to a sudden 0.9 m (3 ft) settlement observed at one pier of the older bridge.

The SR-101 Bridge experienced several scour events in February 1998, which triggered threshold warnings. In one case, the automated sliding collar dropped 1.5 m (5 ft), causing a pager call-out. Portable sonar measurements confirmed the scour recorded by the sliding collar. Several days later, another pager call-out occurred from a float-out device buried about 4 m (13 ft) below the streambed. In both cases, the critical scour depth was about 6 m (20 ft) below the streambed, and no emergency action was needed to ensure public and bridge safety. Because the pager call-out was ineffective in alerting maintenance personnel during non-office hours, a programmed voice synthesizer call-out to human-operated 24-hour communications centers was implemented at other bridges. This installation included a water stage measurement device.

Florida

The data from the sonar monitors at the St. John's Pass Bridge indicated there is loose soil scour and infill by tidal change currents. Sample data for the St. John's Pass Bridge can be found in Appendix E. FDOT reported on the data obtained from the sonar installations on two piers at the bridge (Lasa et al. 1999). They made observations on the measurements of streambed and tide elevations and water temperature.

Lasa et al. reported on scour and infill at one pier for a period of 21 days. They noted that the daily average measured depths varied about 0.3 m (1 ft) with a maximum daily change of 0.09 m (0.3 ft). At one point they observed fill of 1.9 m (6.2 ft) in one day and it gradually washed away. On day 21 the depth appeared to be normal.

The scour sensor on the second pier reported similar data. At approximately 65 days a slow accumulation of soil on the bottom was observed. During the following 100 days the bottom around the pier gradually rose approximately 0.9 m (3 ft). Similar temporary fill deposits were observed at both piers, although not during the same period.

Tide elevations and water temperature were also measured. After analyzing the fathometer data, it appeared that the observed changes in water temperature did not significantly affect the depth measurements obtained by the fathometer.

Lasa et al. reported that the routine normal depth variations of the bottom were clearly identified in the evaluation of the data that was measured hourly. As expected, most of the depth changes occurred between the times of slack tides. This is considered normal because at this particular location extremely strong currents are produced during the periods of tide change.

The tide elevation measurements were plotted and compared with standard tide charts. Although the exact times of low and high tides did not always concur with the times of the standard charts, for the most part they were very accurate in determining actual times of water movement. Lasa et al. noted that this discrepancy was expected because the standard charts only offer tide elevation changes under normal conditions, and do not consider wind and other factors.

Georgia

The Georgia DOT report contained information on observed scour at three of four bridges monitored during their 2-year study (Sturm et al. 2004).

Data were collected during five moderate highwater events at Georgia Highway 384 over the Chattahoochee River near Cornelia. The peak discharge for a July 2003 event was slightly greater than the 2-year recurrence interval for this site. The event resulted in an additional 0.6 m (2 ft) of scour in comparison with the pre-existing scour hole at the nose of one pier. The peak velocity recorded by an acoustic velocity meter was approximately 2.1 mps (7 fps).

The Fifth Street Bridge over the Ocumlgee River at Macon provided data during multiple moderate highwater events. The highest peak, in May 2003, was below the 2-year occurrence interval and the instruments measured 0.9 m (3 ft) of scour at one pier.

At the Georgia Highway 17 Bridge over the Darien River in Darien, 0.3 m (1 ft) of scour and fill was seen on a few occasions at two locations. The scour and fill coincided with the tide cycle. Sturm et al. reported that the scour and fill seen on a daily basis was minimal; however, on a yearly basis the scour and fill was as much as 1.5 m (5 ft) at one pier location.

Hawaii

The two magnetic sliding collars installed on Kaelepulu Bridge in Kailua, Hawaii, successfully recorded the scour development during a relatively large storm on January 2, 2004. During a 24-hour period, 12 mm (4.72 in.) of rain was recorded at a nearby gage. During the time that the peak flow passed the bridge the magnetic sliding collars recorded a drop of 0.5 m (1.5 ft) near the abutment, and 0.3 m (1 ft) near the center pier. This observed scour was compared with the predicted scour and is discussed in chapter four under verification of scour prediction.

Maryland

The Maryland State Highway Authority provided streambed scour data for the Woodrow Wilson Memorial Bridge over the Potomac River during Tropical Storm Isabel. This was recorded on September 16–26, 2003, and the data can be found in Appendix E.

New York

General degradation and seasonal infilling have been recorded by the sonar scour monitors at the Wantagh Parkway over Goose Creek Bridge site from 1998 to 2008. The streambed elevations tend to vary seasonally, with lower elevations during the winter months, and infill during other periods. Lowering of the streambed was recorded during Hurricane Floyd in 1999 and also during various storms. A period of deposition and scour also occurred in the winter of 2003. This was most likely the result of pile driving activity at a neighboring bridge site less than 0.8 km (0.5 mi) south of the bridge. Sample data for the Wantagh Parkway over Goose Creek Bridge can be found in Appendix E.

Texas

FHWA HEC-23 (Lagasse et al. 2001a) and the University of Texas (Haas and Weissman 1999) reported on observed scour at the U.S. 380 Bridge over the Double Mountain Fork of the Brazos River. This bridge is located about 6.4 km (4 mi) west of Rule, in Haskell County. In 1994, the Texas DOT installed a manual readout sliding collar device on the bridge. This was done with technical assistance from the NCHRP 21-03 (Lagasse et al. 1997) research team and funding from the FHWA.

The U.S. 380 Bridge had a history of scour and more than 6.1 m (20 ft) of scour had been reported at the bridge. The support pipe for the sliding collar was driven 5.8 m (19 ft) into the refilled scour hole in the streambed. The sliding collar recorded approximately 1.5 m (5 ft) of scour during the first significant storm event. It is not known whether the system is still operational because it is a manual readout device and the University of Texas report notes that maintenance personnel do not routinely visit the site to collect the data.

Washington State

Clark County reported that the Klineline Bridge had a long history of pier scour. Concrete blocks were installed in scour holes approximately 1.2 m (4 ft) deep adjacent to one pier. Scour monitoring devices were also installed, and two weeks later the bridge experienced an approximately 87-year storm. This resulted in rotation of the concrete blocks from the additional scour and debris build-up.

CHAPTER SEVEN

ON-GOING RESEARCH AND INNOVATIVE SOLUTIONS FOR SCOUR MONITORING

This chapter discusses improvements suggested by the survey respondents and needs of the equipment. Scour monitoring solutions reported in the surveys and in the search for recent literature were discussed in chapter four. Suggestions that have been made regarding possible alternatives for improving scour monitoring technology are also included. Information on current guidelines, programs, and manuals for scour monitoring systems is documented in Appendix G.

CURRENT STUDIES ON SCOUR MONITORING INSTRUMENTATION

In addition to NCHRP Project 21-03 on fixed scour instrumentation (Lagasse et al. 1997), several state DOTs have or are currently conducting research in this area. States that have conducted research in this area in the past include Iowa, New Jersey, New York, Oregon, Texas (University of Texas), and Vermont. The reports from these studies can be found in the references. The following sections discuss some of the more recent on-going projects.

Arkansas

The ASHTD reported that they are currently conducting a project called "Development of a Bridge Scour Monitoring System." Arkansas has identified approximately 100 bridge sites that are scour critical and therefore require an FHWA Plan of Action. They report that their current method of monitoring is ineffective because it is dependent on personnel visiting the site and taking measurements, which can be before or after the maximum scour has occurred. Its objective is to recommend or develop scour monitoring systems that can be used to continuously monitor and record scour depths with corresponding water surface elevations at a bridge site. The agency designed and installed a system using sonar for streambed monitoring, an ultrasonic distance sensor for stage, and a Pan Tilt Zoom network camera for sonar and video still images. The system automatically transmits data to the Internet so that it can be accessed by the proper authorities. The project started in the year 2005 and is on-going.

Michigan

The Michigan DOT reports that in an effort to reduce uncertainty associated with scour prediction models it has a project to collect field-scale data related to pier scour. The research project is being done by Wayne State University and Lawrence Technological University. The goal is to reduce uncertainty to help reduce the cost of bridge construction without sacrificing safety. The project includes the instrumentation of a bridge over the Flint River with one sonar device and one water stage. Bridge scour data were collected once per hour and transmitted by means of cellular telemetry back to the project computer. The results are stored on a network storage device shared between the universities and the Michigan DOT. The project started in the year 2008 and is on-going.

Minnesota

The Minnesota DOT is conducting a project called "Bridge Scour Monitoring Technologies: Development of Evaluation and Selection Protocols for Application on River Bridges in Minnesota," which was awarded to University of Minnesota in 2008. The project is to take the first steps toward developing robust scour monitoring for Minnesota river bridges. The project methodology includes the identification of the variables of scour critical bridges that affect the application of scour monitoring technology and incorporation of the findings into a "Scour Monitoring Decision Framework" that will aid the Minnesota DOT in selecting the best technologies for specific sites. The final component of the project involves testing the Decision Framework on five bridges in a case study-type demonstration.

Ohio

The Ohio DOT is conducting a project called "Field Monitoring of Scour Critical Bridges: A Pilot Study of Time Domain Reflectometry for Real-Time Automatic Scour Monitoring Systems." The project was awarded in 2008 to Case Western Reserve University and GRL Engineers, Inc. The Ohio DOT reports that the effectiveness of current scour countermeasures is still unclear and collecting scour data directly from the field is necessary to improve the current specifications. They also note that existing field scour measurement equipment is not completely satisfactory in that it is not sufficiently rugged, does not provide real-time monitoring during flood events, and it is not automated. The project will develop and deploy a rugged and inexpensive TDR real-time automatic scour monitoring system with several innovations.

Tennessee

The Tennessee DOT reported in its survey with the University of Memphis that they were working on a research project using thermocouples spaced along a piling to determine the elevation of the streambed. This instrument is similar to the piezoelectric film monitors, except the thermocouple measures the ground temperature instead of the water temperature. They have built a few prototypes that have been placed in a stream near a bridge. They reported that they encountered several problems including vandalism, lightening, and debris washing the whole piling downstream. They have recently been reassessing the software and communication options for remote data storage. They note that their experience with fixed scour monitors is "maintenance intense to insure the instrument does what you want it to do."

Texas

In 2007, Texas DOT awarded a contract to Texas Transportation Institute/Texas A&M University for the development of fixed scour monitors for bridges. The 3-year project is called "Realtime Monitoring of Scour Events Using Remote Monitoring Technology." They note that scour monitors are still in development and there is a need to make them less expensive, easier to install, more robust, and to optimize the remote and wireless data collection and warning systems. These are the goals of this project and it can include improvements to existing devices or development of new devices. The project will include the evaluation of existing technology, the development of new technology, laboratory testing, field installations and demonstrations, and the use of data to evaluate scour depth predictions.

Japan

Inclinometers have been used to measure scour on railroad bridges in Japan (Suzuki et al. 2007). The early installations are discussed in chapter three. Suzuki points out that the current technology does not give enough advance warning of scour problems. He notes that even if the inclination angle of a bridge pier is minute, reconstruction of the pier tends to take a long time, is expensive, and includes suspension of train service. They are currently working on a project to develop a new device to alert of scour damage prior to the inclination of a pier. The system is a vibration-based health monitoring method that employs accelerometers set on the top of the bridge piers. They are using train-induced vibration analysis measured by two piezoelectric accelerometers to evaluate the stability of the bridge pier. The gradient of the linear regression line between vertical and transverse acceleration responses is being investigated as an indication of the stability of the pier. The study includes a 3D analytical model, physical model experiments using stable and damaged piers, and field monitoring of bridges with various parameters. Preliminary results indicate that this proposed indicator is related to sediment loss at the foundation, and the method has potential for health monitoring of railway bridge piers. They recommend that these accelerometer devices be installed in conjunction with the inclinometer scour monitoring device.

Debris Scour

Many of the owners who use or do not use fixed scour monitoring instrumentation stated in their surveys that debris is a problem with fixed monitors. NCHRP Project 24-26 on the "Effects of Debris on Bridge-Pier Scour" began in 2004 and is expected to be completed in 2009. The objective of this study of debris at bridge piers is to develop guidelines for predicting the size and geometry of the debris, and for quantifying the potential scour. The data from this study will provide information on debris that can be useful for analyzing a site, and for the design of the scour monitoring devices that can better withstand potential debris forces.

INNOVATIVE SOLUTIONS FOR SCOUR MONITORING SYSTEMS

It should be noted that solutions to some of the concerns expressed by bridge owners are already being implemented in the new monitoring installations or are currently under development. Remote access for downloading scour data is currently being used successfully on numerous sites throughout the United States. In Alaska, one of the monitoring system vendors has designed and fabricated a movable sonar scour monitoring system for a bridge with debris problems. This bridge had two fixed sonar scour monitors torn from it as a result of debris flows. This new system consists of a winch mounted below the bridge deck, which lowers the sonar scour measuring device into the water at set intervals. When the sonar assembly reaches the water, it stops the winch and the sonar can take a series of readings. The winch then raises the sonar back up, where it is stored and protected under the bridge deck.

An adjustable mounting bracket has been developed for use in underwater sonar monitoring installations where the geometry of the pier or abutment is uncertain. This enables those installing the monitor to adjust the bracket so that the sonar device clears the footing to take readings of the streambed below. (Refer to Appendix G for a plan depicting this bracket.) This bracket design is in stainless steel for installation in tidal waterways.

The downloading of data was at the bridge site for the earlier installations of fixed scour monitors. The design of a remote downloading technology using landline or cell telephones was first used in 1997 in the design of the scour monitoring system for the Woodrow Wilson Memorial Bridge in Washington D.C. (Hunt et al. 1998). Alaska has used satellite communications to retrieve the data in remote areas that do not have reliable telephone service (Conaway 2006). The data for all three communications can be retrieved to a base computer(s) equipped with the software to download the data. More recent installations are using the Internet to host and retrieve the data. This allows more flexibility for accessing the data and makes it easier for numerous persons to retrieve and analyze the data from a variety of locations.

CHAPTER EIGHT

CONCLUSIONS

SYNTHESIS OF PRACTICES

The use of fixed instrumentation as a scour countermeasure is a process that begins with the evaluation of the scour countermeasure alternatives for a particular bridge site, includes the design and installation of the instrumentation and the development of a scour monitoring program, and can continue for many years with the scour monitoring program for the bridge. Owners and others that have completed the synthesis surveys have reported successes and failures at various steps of the process. This chapter presents a synthesis of the reported best practices and the lessons learned with the use of fixed scour monitoring instrumentation at bridges.

Evaluation of Scour Countermeasure Alternatives

Scour monitoring is often the preferred alternative for a variety of reasons. For bridges that are scheduled to be replaced, scour monitors can be selected because they can be less expensive than traditional structural or hydraulic countermeasures. The placement of armoring in a waterway can also result in environmental concerns and complicated permitting issues. In addition, armoring of the channel bottom can interfere with the construction of the new bridge.

Fixed instrumentation is also being used on scour critical bridges where there are no bridge replacement plans. Scour monitors can be installed at these bridges as an interim countermeasure, before the installation of other hydraulic and/or structural countermeasures that can take longer to design and install. The fixed monitors can also be installed in conjunction with other types of hydraulic and/or structural countermeasures, to confirm that they are functioning to protect the bridge. For example, if riprap is installed for pier protection, the 2001 FHWA *Hydraulic Engineering Circular 23: Bridge Scour and Stream Instability Countermeasures* guidance states that it should be monitored.

The selection, location, and design are dependent on many factors. These include cost, environmental, construction, and maintenance considerations. Some advantages cited in the surveys include:

- Provides safety for the traveling public
- Allows for continuous monitoring of streambed elevations and scour conditions
- Can be quickly designed and installed
- Is a cost-effective system relative to other hydraulic and structural scour countermeasures
- Remote downloading of data reduces required visits to the bridge
- Reduces the number of diving inspections and/or bathymetric surveys owing to the information provided by the monitors
- Increases the capability of measuring both scour and the refill processes
- Allows for the development of a prescribed Plan of Action to guide decision making during a flood event
- Is appropriate for large bridges and deep water conditions
- Can be used to extend the life of a bridge
- Can be used in combination with other scour countermeasures
- Provides data useful for replacement bridges
- Provides data for scour research.

The various types of fixed instrument devices are summarized in Table 7. The best type of application, as well as some of the advantages and disadvantages of each type of device are listed.

The scour monitoring system is custom designed for each bridge site. The type of monitoring instrument employed depends on the geometry of the bridge substructure and on the channel characteristics. Guidance on the selection of a scour monitoring system is provided in FHWA HEC-23. Factors such as the depth of the water, the size of the bridge, the geometry of the substructure unit, the frequency with which readings will be taken, and the extent of debris, ice, air entrainment, and/or turbidity in the channel need to be considered in the selection of a scour monitoring system.

The fixed instrumentation selection matrix, Table 8, was developed to compliment the countermeasure selection matrix in FHWA HEC-23. If fixed instrumentation is to be used to monitor a bridge, this table provides additional items to be considered in deciding between the various fixed instrument options. It was developed based on the results of the synthesis study state survey and literature search. Table 8 includes the following categories for suitable river environment for the various fixed instruments:

- Type of waterway—riverine/tidal,
- Flow habit,

TABLE 7
FIXED INSTRUMENTATION SUMMARY

Type of Fixed Instrumentation	Best Application	Advantages	Limitations
Sonar	Coastal regions	Records infilling; time history; can be built with off-the-shelf components	Debris, high sediment loading, and air entrainment can interfere with readings
Magnetic Sliding Collar	Fine bed channels	Simple, mechanical device	Vulnerable to ice and debris impact; only measures maximum scour; unsupported length, binding
Tilt Sensors	All	May be installed on the bridge structure and not in the streambed and/or underwater	Provides bridge movement data that may or may not be related to scour
Float-Out Device	Ephemeral channels	Lower cost; ease of installation; buried portions are low maintenance and not affected by debris, ice, or vandalism	Does not provide continuous monitoring of scour; battery life
Sounding Rods	Coarse bed channels	Simple, mechanical device	Unsupported length, binding, augering
Time Domain Reflectometers	Riverine ice channels	Robust; resistance to ice, debris, and high flows	Limit on maximum lengths for signal reliability of both cable and scour probe

- Water depth,
- Bed material, and
- Extreme conditions.

The functional applications and bridge geometry include information on the characteristics of the bridges for the different types of instruments: (1) Substructure monitored, and (2) Foundation type.

The table includes additional items regarding the monitoring system capabilities that can be mandatory or desirable criteria for a particular bridge site: (1) Continuous monitoring, and (2) Remote technology.

The last two columns include the installation experience by state for each type of fixed monitor for those that responded to the synthesis survey and also from the literature search.

Design of Scour Monitoring System

There are a variety of options to consider in the design of a fixed scour monitoring system for a particular bridge site. Careful evaluation of the bridge and site conditions can help ensure that the system will provide the necessary data and is robust enough to function for the intended duration of the scour monitoring.

The locations of the monitors on the bridge are selected in consideration of accessibility, protection against vandalism, and any potential debris or ice debris forces. The heightened security at the bridges in the past few years has made accessibility a major issue. Traffic safety, lane closures, and traffic detours for servicing the monitors also need to be considered. The increased use of cameras for bridge security can be employed to protect the scour monitors from vandalism.

The location and number of the monitors will vary depending on the extent of the existing and potential scour problem, the amount of risk the owner is willing to take, and the funding available for the scour monitors. The monitors are generally placed in locations where maximum scour is expected to occur.

Accessibility is important to ensure access to the monitoring system when maintenance is required. It is necessary for servicing the system, inspection, and repairs. The daily data record produced by the system can also provide information on the health and operational status of the scour system. There are instances, however, where the data appear reasonable, yet one of the sensors is not functioning properly. Regularly scheduled routine maintenance and inspections help to ensure that the system is functioning properly and the streambed readings are accurate.

The design of the monitoring instrument and the method with which it is attached to the bridge is site-specific. As-built plans and diving inspections can provide information on the geometry of the underwater portion of the pier or abutment. When there are uncertainties regarding underwater dimensions and clearances, adjustable arms can be designed for the mounting bracket. During installation, the contractor can then adjust these brackets so that a device such as the sonar projects out sufficiently to clear the footing and take streambed readings. Once the location of the device and the spot to be monitored are selected, the best approach would be for the design engineer to work with the structural and electrical engineers to detail the mounting and the conduit for the monitoring system. Items such as types of materials, bolts and their embedment depths, and conduit routing and attachments are best detailed by these specialists. Using robust, although often more expensive materials and methodologies, will most likely result in improved sensor integrity as well as significant savings in

TABLE 8
FIXED INSTRUMENTATION SELECTION MATRIX (Countermeasure characteristics)

	FUNCTIONAL APPLICATIONS					SUITABLE RIVER ENVIRONMENT [2]													
	Local Scour		Contraction Scour	Stream Instability		Waterway Type		Flow Habit	Water Depth	Bed Material	Extreme Conditions	Foundation Type	Capabilities		Maintenance	Survey Respondents		Installation Experience	
Type of Fixed Instrumentation	**Abutments [1]**	**Piers**	**Floodplain and Channel**	**Vertical**	**Lateral**	**Tidal**	**Riverine**	**E=Ephemeral I=Intermittant P=Perennial PF=Perennial/ Flashy**	**A = < 3 ft B = 10-30 ft C = 31-50 ft D = 51-75 ft E = 76-100 ft**	**F = Fine bed S = Sand bed C = Coarse bed R = Riprap**	**D=Debris T=Temperatures S=Sediment loads I=Ice flows V=High Velocity Flows**	**P=Piles SF=Spread Ftg DS=Drilled Shafts U=Unknown**	**Continuous Monitoring**	**Remote Technology**	**H = High M = Moderate L = Low**	**No. of Bridge Sites**	**No. of Instruments**	**Installation Experience by State from Surveys** *(Note: States in **bold** have indicated they plan to use fixed instrumentation in the future)*	**Additional Installation Experience by State Other Sources**
Sonar	◗	●	●	●	◗	●	●	✓	✓	✓	T, I, V	✓	Yes	Yes	M - H	48	164	**AK**, AR, **CA**, **FL,** GA, **HI,** IN, KS, MD, NC, NJ, NV, **NY, TX, VA, WA**	CO, NM, OR, RI, WI
Magnetic Sliding Collar	●	●	●	●	◗	◗	●	✓	A, B	F, S, C	✓	✓	Yes	Yes	M	8	22	**CA, HI**, IN, **MN,** NJ, **NY**	CO, FL, ME, MI, NM, RI, TX, WI
Tilt Sensors	●	●	●	●	●	●	●	✓	✓	✓	✓	✓	Yes	Yes	L	4	35	**CA, WA**	
Float Out Device	●	●	●	●	●	○	●	E, I	A, B	F, S	✓	✓	No	Yes	L	3	35	AL, **CA,** NV	AZ
Sounding Rods [1]	◗	●	●	●	◗	◗	●	✓	A, B	C	T, S	SF	Yes	No	H	0	0		AR, IA, NY
Time Domain Reflectometers [1]	◗	●	●	●	●	○	●	P, PF	A, B	F, S, C	✓	✓	Yes	Yes	M	1	2	**VT**	

● well suited/primary use
◗ possible application/secondary use
○ unsuitable/rarely used
N/A not applicable
✓ suitable for the full range of the characteristics/conditions

[1] There were limited survey replies for monitoring of abutments, sounding rods and time domain reflectometers, therefore information from the literature was used for this table.

[2] The following items listed in the FHWA HEC-23 countermeasure matrix are applicable to the full range of the characteristics for fixed instrumentation and were not included in the survey:

River type: braided, meandering, straight
Stream size: wide, moderate, small
Bend radius: long, moderate, short
Bank condition: vertical, steep, flat
Floodplain: wide, moderate, narrow/none

future repair costs, especially on bridges over deep waters. This is the result of the high costs associated with underwater installations, maintenance, and repairs.

Severe environmental conditions that can interfere with the functioning of the monitors, such as debris, ice, and tidal waters, need to be considered when choosing the materials and type of mountings for the fixed instruments. Many fixed monitors will not operate under frozen water conditions. Owing to the cold weather and tidal waterways in the northeast installations, AISI Grade 316 stainless steel has been used. A lower grade of stainless steel (AISI Grade 304) was employed during an emergency installation in New York, and a few years later the mountings had extensive corrosion. On one Alaska bridge installation there were instances where floating debris ripped the sonar sensor from the substructure. In Alaska, they have developed a "retractable arm" that lowers the sonar into the water at designated times to take readings, and then retracts back to a designated location under the bridge.

The power source will vary depending on what is available and most reliable for a particular bridge site. The monitoring system can be solar powered or connected to electrical power at the bridge, if available. The monitoring systems require low power; therefore, solar power is adequate and in more recent installations, the preferred power source. Initially in the early installations there was concern regarding the use of solar panels owing to potential vandalism. Numerous panels have been installed when there was no other power source, and these have performed better than the locations using traditional electrical power. The locations powered by alternating current have required replacement float chargers, most likely the result of power surges.

Remote monitoring has been installed using cellular telephone, telephone landline, or satellite technology. The telephone lines have proved to be the most reliable. They do not require power and are continuously available. Cellular telephones are also reliable, but they are not continuous, and need to be turned on and off at regular intervals using solar panels. Satellite service has been used when the other two options were not available. Satellite service, although less expensive than cellular systems, has a disadvantage—it can provide only one-way communication from the bridge. The system can send data from the bridge; however, incoming commands to examine, modify, or repair the system cannot be transmitted to the bridge, as is done with the other methods. More recent monitoring systems transmit data to a server and it is posted on the Internet so that those with authorized passwords can access the data. This provides greater flexibility because the data can be retrieved and analyzed from any location with a computer and Internet access.

The mechanism for the design and installation of the scour monitoring instrumentation and the program can be accomplished under numerous types of contracts. The plans and specifications can be developed as part of a larger bridge rehabilitation program. In this case, careful attention is required for the timing of the installation of the scour monitors, as well as the protection of the monitors during the construction. The scour monitors can be installed as a stand-alone contract, accomplished under emergency conditions, or if funding is available for this type of scour countermeasure system. Numerous monitoring systems have been installed as part of research projects. These often include devices that measure scour and other hydraulic variables, which can provide data useful for scour research. One problem with the research installations is that they are often limited by the duration of the project, which is often two to four years. Provisions for funding the continued operation of the scour monitoring system can be made so that the bridge owner is able to continue to retrieve the data and maintain the monitoring system upon the completion of the research.

The data from the monitors can be taken at programmed intervals and downloaded at any time. The data can be set up to automatically alert the owner or designated others of emergency situations. The systems can provide round-the-clock monitoring, even during storms.

Installation of the Monitoring System

Scour monitoring systems are a relatively new technology. Electrical and underwater contractors most often install the system. It should be noted that on larger bridges in deep waters, the contractor installation costs often equal or exceed the cost of the manufacture of the scour monitoring system. Most likely, the contractor has not performed this type of work, so it is necessary that the plans and specifications be very detailed to ensure the successful installation of the system. The inclusion of good details can also aide in keeping the bid prices reasonable because the contractor will better understand the extent of the work. It is also advisable to have one of the designers of the monitoring system on-site or in close contact with the contractor throughout the installation. There are often many unknowns both in the underwater conditions and in the as-built geometry of the substructure unit. New site information on existing scour can result in changes to the location of the scour monitors. Having the system designer available during the installation ensures that the proper changes are made in the field.

There can be numerous unknowns for underwater installations. If the underwater contractor is not receiving a lump sum payment, but the work is based on the time to install (time and materials), the designer can specify the means and method of installation. For example, installation equipment such as the type of drill the contractor uses to install the underwater components can be specified. A pneumatic drill has been used effectively to minimize the time it takes for the installation of anchor bolts into concrete substructure units. There could be extensive time delays when the contractor uses drills that are not appropriate for underwater construction.

Because the construction inspector cannot view the underwater components, it is advisable to have these components of the installation inspected by an independent contractor before completion of the contract. This will ensure that all bolts and attachments are in place and that the mounting is properly secured to the substructure unit. Underwater installation photographs by the contractors ensure the proper installation and also provide as-built information for future inspections, maintenance, and repairs.

In smaller waterways, and in areas of installation that are less complicated, there have been cases where the department of transportation (DOT) maintenance group or others have installed the scour monitoring system. Here also, it is suggested that a member of the monitoring design team work with these groups.

As with all bridge reconstruction projects, it is good practice to develop a set of as-built plans following the installation of the system. This is particularly true for the underwater components of the system. This will aid in future maintenance, inspections, and repairs to the system.

Plan of Action

The federal requirements for bridge inspection are set forth in the National Bridge Inspection Standards (NBIS). The NBIS require bridge owners to maintain a bridge inspection program that includes procedures for underwater inspection. This information can be found in the FHWA Federal Register, Title 23, Code of Federal Regulations, Highways, Part 650, Bridges, Structures, and Hydraulics, Subpart C, National Bridge Inspection Standards (23 CFR 650, Subpart C). The most recent ruling was enacted on January 13, 2005. The revisions underscore actions required for bridges that are determined to be scour critical. These include the preparation of a Plan of Action to monitor known and potential deficiencies and to address critical findings and monitoring of bridges in accordance with the plan for bridges that are scour critical (23 CFR 650.313).

FHWA HEC-23 contains guidance on the development of a Plan of Action. The two primary components of the Plan of Action are instructions regarding the type and frequency of inspections to be made at the bridge and a schedule for the timely design and construction of scour countermeasures. A Plan of Action includes the following: (1) management strategies, (2) inspection strategies, (3) bridge closure instructions, (4) countermeasure alternatives and schedule, and (5) miscellaneous information. Scour monitoring programs with flood, portable, and/or fixed monitoring are important components of a Plan of Action. In 2006, the FHWA posted a revised Plan of Action standard template on their website. The section on Monitoring Programs includes items for detailed documentation of regular/increased inspections, fixed scour devices, and flood monitoring. In 2007, a new National Highway Institute (NHI) course (FHWA-NHI-135085) entitled "Plan of Action (POA) for Scour Critical Bridges" was developed. The course provides guidance on developing a POA and case studies for the development of a POA. One case study uses fixed instrumentation for monitoring. The course and Standard Template can be downloaded from the FHWA website.

Implementation of Scour Monitoring Program

The implementation of the scour monitoring program is a critical aspect of the program. Owing to the interdisciplinary nature of scour monitoring, and perhaps the result of in part the newness of the FHWA bridge scour program and of these devices, it is not always obvious which division of the owner will be responsible for the scour monitoring program. It is important during the design process for the owner to identify the group(s) that will be responsible for the scour monitoring program. This could be the owner or it can be outsourced. The process includes the design of the system protocol; routine and emergency monitoring; analysis of the data and determination of the safety of the bridge; the chain of command to make decisions during an emergency situation; maintenance, inspection, and repairs to the system; and the funding for the continued operation of the scour monitors. This information should be documented in the scour monitoring program manual and Plan of Action for the bridge. The manual needs to be updated on a regular basis to reflect any changes in the program. The responsibility for the monitoring system has been the most difficult aspect in the implementation of the scour monitoring programs reported in the synthesis surveys.

If a clear protocol detailing responsibilities is in place, this can help to provide proper maintenance to prevent a sensor or system failure. If the person(s) responsible for monitoring is transferred to another position, or if they retire, a new person(s) needs to be given the responsibility and training for the system. There have been instances where the telephone service has been interrupted owing to non-payment of the telephone bill. This was the result of job transfers and, in one case, the invoice was being sent to someone not involved in the scour program. In one situation, the area code in a city changed and the data could not be accessed because the new area code needed to be programmed into the new monitoring system.

Routine and Emergency Monitoring and Data Analysis

The development of a clear set of detailed instructions for those responsible for the routine and emergency monitoring of the bridge is essential. There could be a chain of command so that responsibility is transferred when those who are responsible are on vacation, ill, unable to monitor, or are no longer in their particular position. The routine and emergency procedures are very site specific. Often an owner will start with a conservative program with high frequencies for routine and emergency monitoring. After a period, the records will be reviewed and the frequency of monitoring can be adjusted.

A clear chain of command of those responsible for emergency situations needs to be in place. Those responsible for analyzing the data should have instructions as to who they should contact "round-the-clock" should the scour readings indicate a problem. The Plan of Action would indicate possible procedures to follow, which can include closure of the bridge, land monitoring, underwater inspections, the emergency installation of contingency countermeasures such as riprap, etc.

The scour monitoring systems that are continuous are capable of producing a large amount of data. Consideration needs to be given to the intervals at which the data would be recorded and collected. Data reduction methods using computer spreadsheet programs provide valuable assistance for analyzing and storing the data. They help identify trends and can be useful when comparing data with other bridge sites.

Changes in the watershed can also affect the data. It is important that those responsible for analyzing and interpreting the data be kept informed about new developments, construction, dredging, mining, or other situations that might cause scour or siltation at the bridge.

Maintenance, Inspection, and Repairs

It is important to develop a regular maintenance and inspection program. The maintenance crews for the owner can be responsible for routine, above-water maintenance. The frequency of underwater and structural inspections and fathometer surveys at each bridge will vary. The owner can add inspection and maintenance requirements for the scour monitoring system to the underwater and structural inspection contracts. If the bridge is a movable bridge and there are also electrical inspectors these can aide in the above-water inspection of the electrical components of the system. The inspection guidelines and requirements could include detailed checklists and sketches to guide the inspectors, and to ensure that the scour monitoring system is examined periodically. Provisions can be made in these contracts for minor repairs as well. During the inspections, it is advisable that a member of the scour monitoring team coordinate with the inspection crew to ensure that all important components are inspected, and to help interpret their findings. If possible, this person would be on-site during the inspection. The streambed elevations recorded during diving inspections and fathometer surveys can also be used as ground truth measurements to check the accuracy of the scour monitoring devices.

RESEARCH NEEDS

Scour Monitoring Instruments

The advancements that bridge owners would like to see for future fixed scour monitoring technology include the development of durable instrumentation, with increased reliability and longevity, decreased costs, and minimum or no maintenance. This equipment would include instrumentation that measures scour, and also water elevations and velocities. A discussion of states that are currently sponsoring research on the development of scour monitoring devices can be found in chapter seven. A pooled fund project for the development of scour monitoring devices can be considered because these instruments can be used under similar conditions in numerous states. The owners reported mostly the same problems with respect to the existing scour monitoring devices and they are attempting to address comparable challenges. A pooled fund project would provide in-depth testing and analysis of scour monitoring devices technology.

One bridge owner noted that the current fixed scour monitors will take a measurement in one location, and this point measurement can or cannot be the deepest point. The deepest point of a scour hole can also change from one event to another. They recommended the development of an instrument that measures the depth and location of the deepest point of a scour hole, or one that would map an entire scour hole. The multi-beam sonar technology that is currently being employed for fathometric surveys can be an option, although expensive, if this type of measurement is required.

Scour Monitoring Protocols

As discussed in chapter four, the problems with maintenance of the scour monitoring system and program were the main concern expressed by the bridge owners with systems, and also by some who have not used them. The development of a detailed handbook on the implementation of a scour monitoring program would help owners anticipate both the advantages and responsibilities of a successful scour monitoring system. The focus of the scour monitoring technology has been on the development and improvement of the devices. The recently published FHWA guidance on the Plan of Action discussed earlier in this chapter could be useful in the development of a detailed, hands-on protocol for emergency actions for scour monitoring programs. An additional, more practical manual with guidance to ensure that the scour monitoring system remains active would help DOTs and other bridge owners that can be considering the use of fixed scour monitoring systems.

Bridges with Tidal Influences

Although the 1997 NCHRP study on fixed monitors (*NCHRP Report 396: Instrumentation for Measuring Scour at Bridge Piers and Abutments*) tested only two tidal bridge sites, since that time, many bridges over tidal waterways have been instrumented with fixed scour monitors. Some of the same devices that are employed in riverine bridges are being used on tidal bridges. Twelve of the 56 sample sites that replied to the survey reported that their bridges with fixed monitors were over tidal waterways. All of the sites used sonar monitors with one exception. One site used magnetic sliding collars and one site had both sonar and collar installations. In the case of bridges over tidal waterways, the worst scour can be on the ebb or the flood tide of the bridge. Scour monitors were installed on one or both sides, depending on where the scour had or was expected to occur. The survey respondents reported on the use of robust materials to protect the underwater components of fixed scour devices in tidal installations. These included AISI 316 stainless steel and protective shields. Materials and techniques need to be developed to protect monitoring devices from corrosion and marine growth in the harsh tidal environment.

Unknown Foundations

Guidance on bridges with unknown foundations can be found in FHWA HEC-18 (Richardson and Davis, *Evaluating Scour at Bridges*) and on the FHWA bridge scour technology website. A bridge with unknown foundations is one where the type and/or condition of the substructure is not known. These bridges are classified as "U" in the scour critical code (Item 113) of the Coding Guide. The screening program in the National Bridge Scour Evaluation Program has identified more than 67,240 bridges with unknown foundations. The bridge information necessary to analyze the stability and determine if it is scour critical includes the type (spread footing, piles, or columns), material (steel, concrete, or timber), dimensions (length, width, or thickness), reinforcing, and/or elevation of the foundation.

The FHWA is taking action toward enhancing the current guidance to address bridges in the unknown foundations category of the National Bridge Scour Evaluation Program. Unknown foundation bridges, with the exception of Interstate bridges, have been exempted from evaluation for scour by the FHWA. They do suggest, however, that until this guidance is available, that DOT management officials consider monitoring these bridges during and after a flood event as they can deem it necessary. The monitoring can be using flood, portable, and/or fixed instrumentation methodologies. The FHWA guidance states that a Plan of Action should be developed for bridges with unknown foundations. This Plan of Action includes a plan for the timely installation of countermeasures to reduce the risk from scour and also the development and implementation of a scour monitoring and/or inspection program.

The FHWA is currently sponsoring a synthesis on unknown foundations, which should provide a better perspective of technologies, methods, and managerial practices being used in this area. In November 2005, the FHWA sponsored an Unknown Foundations Summit. This summit served to share knowledge on current technologies available through the industry and management strategies that have been used by DOTs to deal with bridges with unknown foundations. During a follow-up meeting to the summit, four teams were established to work on developing policy and guidance and training and research needs on the subject of unknown foundations.

Suggestions for a National Scour Database

There are two existing databases, the National Bridge Scour Database and the National Bridge Inventory (NBI) that can be modified for a national scour database to include data from the fixed scour monitoring instrumentation. The proposed new 20-year program, Long-Term Bridge Performance (LTBP) can also be considered for use as a national database for scour monitoring data.

A discussion of information that could be assembled in a national scour database that includes the scour monitoring data is outlined in Appendix H. Following is a discussion of the three databases and observations regarding the inclusion of scour monitoring data.

National Bridge Scour Database

The National Bridge Scour Database is a cooperative effort of the U.S. Geological Survey (USGS), FHWA, NCHRP, and the University of Louisville. The database is posted on the USGS website: http://water.usgs.gov/osw/techniques/bs/BSDMS/BSDMS_1.html. It contains scour data for 93 bridges in 20 states. The database is comprised of detailed data tables containing site, pier scour, contraction scour, and abutment scour information, as well as miscellaneous supporting files. This database was developed to assist in the documentation, compilation, and analysis of observed scour. It was hoped that this would provide the data needed to improve the understanding and prediction of the scour processes. Currently, there is no funding to modify, maintain, and update the National Bridge Scour Database.

National Bridge Inventory

The National Bridge Inspection Program was initiated in 1969, requiring regular and periodic inspections of all highway bridges. In 1971, the NBIS came into being. The primary purpose of NBIS is to locate and evaluate existing bridge deficiencies to ensure the safety of the traveling public. The NBIS sets national policy regarding bridge inspection and rating procedures, frequency of inspections, inspector qualifications, report formats, and the preparation and maintenance of a state bridge inventory. Each state or federal agency must prepare and maintain an inventory of all bridges subject to the NBIS. Certain Structure Inventory and Appraisal (SI&A) data must be collected and retained by the state or federal agency for collection by the FHWA as requested. A tabulation of these data is contained in the SI&A sheet, which can be found in the FHWA's "Recording and Coding Guide for the Structure Inventory and Appraisal of the National's Bridges" (December 1995). The NBI is the aggregation of SI&A data collected to fulfill the requirements of the NBIS. The organization of the NBI database could be used for the elements that both share in common and modified for additional elements relative to hydraulics and scour.

FHWA LTBP

The FHWA initiated a major program in early 2006 with the objective of improving knowledge regarding bridge performance over a long period of time. The FHWA LTBP program will instrument, monitor, and evaluate a large number of bridges throughout the United States to capture performance data over a 20-year period of time and, on the basis of the information collected from these structures, provide significantly improved life-cycle cost and performance and predictive models that can be used for bridge and asset-management decision making. The LTBP program will also conduct forensic investigations on decommissioned bridges, as the opportunity arises.

The report notes that the NBI database is one of the most comprehensive sources of long-term bridge information in the world. In recent years, a majority of the states have implemented element-level inspection programs to support state and local level bridge management programs. They note that a basic limitation of both the NBI and element level approach is that the data collected relies on visual inspection techniques. With visual inspection, hidden or otherwise invisible, deterioration damage is missed. The LTBP program will include detailed inspection, periodic evaluation and testing, continuous monitoring, and forensic investigation of representative samples of bridges throughout the United States to capture and document their performance. The report concludes that there is a need for quantitative performance databases, which include relevant data to implement true life-cycle-cost analysis. The same data are necessary to implement performance-based specifications. It is anticipated that the LTBP program will create such databases by collecting high-quality, quantitative performance data on bridges, which can then be integrated into the bridge management processes of the future. The continuous monitoring portion of this project will provide useful hydraulic and scour data. The database will include the collection of data on bridge scour, movement, and settlement.

USGS Recommendations on Scour Data

The USGS, in a memorandum on guidance for bridge scour studies (2003), notes that although the primary objective of scour monitoring is to provide for the safety of the public without closing bridges during high flows and without installing expensive countermeasures, it provides an excellent opportunity to meet the operational needs of the bridge while collecting much needed data on scour. Real-time monitoring using fixed or portable instrumentation for the DOT only requires the elevation of the streambed to evaluate the stability of the bridge foundations. The USGS notes that when the streambed elevation measurements are combined with hydraulic measurements, the data becomes valuable for bridge scour research. Sites with fixed scour monitoring equipment, if supplemented with a continuous-record streamgaging station, can provide valuable data on the initiation and rate of scour, as well as, under what conditions scour holes refill (if the installed technology allows measuring the refilling process). In addition, mobile field teams making measurements at bridge sites can supplement the streambed elevation measurement with a discharge measurement and other hydraulic observations to complete a limited-detailed data set. The USGS states that scour monitoring projects can represent a significant opportunity to collect field data that can be used for scientific research, while meeting a fundamental need of many highway departments. The extension of scour monitoring to include hydraulic measurements for research purposes is an ideal application for federal–state cooperative funds. The USGS concludes that there is also potential for projects that develop and test equipment that can be used for scour monitoring. They note that instruments that work effectively in steep mountain streams and in streams with ice are needed.

Potential Sites for Future Monitoring

Potential sites for future in-depth monitoring case studies were examined. These can include sites that have a large amount of information available, sites that have experienced or are likely to experience scour depths, and sites where there can be funding to install scour monitors.

From the survey responses, extensive testing and analyses had been performed for the bridge sites in Maryland, Florida, Alabama, and Long Island, New York. This information includes hydraulic computer modeling, hydraulic and scour analyses, borings, pier stability tests, and/or flume tests.

There are a number of new bridges under construction that can also be considered possible candidates for fixed scour monitoring systems.

The Maryland bridge is the new Woodrow Wilson Memorial Bridge over the Potomac River. The existing bridge was monitored with sonar scour monitors from 1999 until it was demolished in 2006. The Florida bridge, St. John's Pass, is also scheduled to be replaced. It was one of the test sites for the NCHRP scour monitoring project. The two Wantagh Parkway bridges in Long Island that were discussed in this report under case studies are going to be replaced. Extensive information is available for all these sites and the installation of a scour monitoring system during construction often reduces the cost and can provide a better, more secure installation.

Other sites that can be considered for instrumentation include the new bridge over Indian River Inlet in Delaware. Historically, this site has had extensive scour with as much as 30.5 m (100 ft) of scour in certain locations. The existing bridge has two piers in the channel and they are protected by riprap. The new bridge will not have piers in the inlet, but a system could be designed to monitor the bulkhead. Also, there has been discussion that the inlet can be widened at a future date.

Other new bridges that could be scour monitoring case studies include crossings of the Mississippi and Missouri

Rivers, and the new Tacoma Narrows Bridge in Tacoma, Washington.

Consideration could also be given to structural bridge health monitoring. These systems have many similarities to the fixed scour monitoring systems, including the data loggers. The possibility of integrating these two systems on a bridge can be beneficial, particularly in terms of cost reduction and maintenance concerns.

CONCLUSIONS

Scour monitoring with fixed instrumentation has been used in 32 states and the District of Columbia. A scour monitoring program can be an efficient, cost-effective alternative or complement to traditional scour countermeasures. The system and program are custom-designed for each bridge and site. There have been many innovations in scour monitoring technology and this report outlines some of the lessons learned in installations in a wide variety of locations.

The systems can provide round-the-clock monitoring, even during storms; scour data for bridge scour research, velocity, and water stage records, and the integration of the newest scour prediction techniques with physical data collection.

The data traditionally collected by the majority of scour monitoring systems is in the form of streambed elevations. More recent installations include tilt sensors that measure movement of the bridge as a result of scour or other causes. Instrumentation that measures additional hydraulic variables was reported in a small number of installations. The development of monitoring systems that also measure water velocity and stage will provide data that can be used for the improvement of current scour prediction methodologies. These data can be stored in one of the existing national databases, or in the new FHWA Long-Term Bridge Performance Program database that is currently under development.

The main problems reported by the states in the use of fixed scour instrumentation include the maintenance and repairs to the systems and the funding to continue the operation and scour monitoring program. A thorough and systematic plan developed before the installation of the scour monitoring system can result in a program that is successful to ensure the safety of the bridge and of the traveling public.

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GLOSSARY

Contraction scour—Contraction scour, in a natural channel or at a bridge crossing, involves the removal of material from the bed and banks across all or most of the channel width. This component of scour results from a contraction of the flow area at the bridge that causes an increase in velocity and shear stress on the bed at the bridge. The contraction can be caused by the bridge or from a natural narrowing of the stream channel (Richardson and Davis 2001).

Fixed scour monitors—Monitors placed directly on a bridge structure or in the vicinity of the bridge. Suggested fixed monitors include magnetic sliding collars, sonar monitors, float-out devices, and tilt and vibration sensors.

Float-out scour monitors—Buried at strategic points near the bridge, float-outs are activated when scour occurs directly above the monitor. The monitor floats to the stream surface. An onboard transmitter is activated and transmits the float-out device's digital identification number to a data logger.

Hydraulic Engineering Circulars (HEC)—Manuals published by the FHWA offering guidance on evaluation of scour at bridges (HEC-18), stream stability (HEC-20), and scour and stream stability countermeasure design (HEC-23).

Infilling—Re-deposition of loose, less dense soil into a scour hole

Local scour—Removal of material from around piers, abutments, spurs, and embankments caused by an acceleration of flow and resulting vortices induced by obstructions to the flow (Richardson and Davis 2001).

Portable scour monitors—Monitoring devices that can be manually carried, used at a bridge, and transported from one bridge to another.

Pressure sensor—Measures the water elevation at a bridge.

Scour—Erosion of streambed or bank material owing to flowing water; often considered as being localized (see local scour, contraction scour, total scour) (Richardson and Davis 2001).

Scour countermeasures—Measures incorporated into a highway-stream crossing system to monitor, control, inhibit, change, delay, or minimize stream instability and bridge scour problems (Lagasse et al. 2001).

Scour critical—Coding as per the National Bridge Inspection Standards (Item 113). A bridge is considered scour critical when its foundations have been determined to be unstable for the calculated or observed scour condition.

Scour monitoring—Technology that can include fixed and portable instrumentation, as well as visual monitoring

Sliding collar monitors—Rods that are attached to the face of a pier or abutment. The rods have a collar that is placed on the streambed, and if the streambed erodes, the collar moves down into the scour hole.

Sounding rod monitor—A fixed scour monitoring device. It consists of a sounding rod or falling rod attached to the bridge pier or abutment. As the streambed scours, the rod, with its foot resting on the streambed, will drop following the streambed and the system records the change in elevation.

Tilt sensors—Instrumentation that measures the rotation of a structural component of a bridge

Total scour—The sum of long-term degradation, general (contraction) scour, and local scour.

Vibration sensors—Measure bridge movement and the information is recorded by a data logger.

APPENDIX A

Survey

Appendix A contains a blank copy of the synthesis survey that was sent to state departments of transportation in the United States. Detailed results of the survey can be found in Appendix C.

NCHRP SYNTHESIS TOPIC 36-02

PRACTICES FOR MONITORING SCOUR CRITICAL BRIDGES

PURPOSE OF THIS SYNTHESIS:

In the United States, there are 26,000 scour critical bridges, some of which are monitored by fixed instrumentation. Following the successful completion of NCHRP Project 21-03 *Instrumentation for Measuring Scour at Bridge Piers and Abutments*, approximately 100 of these bridges have been instrumented for scour measurements. Often these bridges are instrumented because the scour estimates seem overly conservative, and it is prudent to observe scour activity during flood events before spending resources on other types of countermeasures. For other bridges scheduled to be replaced, monitoring (prior to replacement) is a cost-effective alternative to ensure the safety of the traveling public. Valuable field data are often accumulated from instrumented bridges, and some of these bridges have been monitored for more than eight years. This data—and the exploration and evaluation of it—will prove useful in the improvement of technologies associated with both predicting and monitoring bridge scour.

The focus of this study is fixed monitoring instrumentation. This synthesis will serve to document the success or failure of the various scour monitors that have been deployed and to obtain ideas that can help improve the reliability of existing monitoring equipment. This synthesis will also serve as a foundation for the development of a national database that will serve as a valuable resource to engineers and researchers for assessing the accuracy of various scour estimating procedures currently in use.

The purpose of this questionnaire is to collect specific information on fixed scour monitors from sources ranging from the municipal to the international level. Allow approximately one and one-half hours to complete this questionnaire. **Additionally, those respondents who believe their scour monitoring project would make a good case study are invited to indicate their willingness to contribute detailed information about their projects.** They will be contacted individually by the researcher to obtain the case study information.

The results of this synthesis will be shared and distributed through AASHTO, the Federal Highway Administration, the Transportation Research Board, and others, with the goal of assisting in the development and implementation of scour monitoring programs. It is a rare opportunity to do substantive research in the field of scour monitoring instrumentation. This field is vital to the health of the nation's transportation system, and the results from this project will provide a means to disseminate the experience of engineers from around the world in a straightforward fashion.

Kindly answer the following questions to the best of your knowledge. All departments within your agency that have significant experience with scour monitoring instrumentation should be given the opportunity to comment or answer survey questions that pertain to his or her expertise. Additional copies of this survey may be made as needed. *If multiple bridges are or were monitored by your agency, please choose from the following two options: (1) complete Sections 3 through 7 for* <u>*each bridge*</u>*, or (2) select one bridge for* <u>*each category of instrumentation*</u> *employed and complete Sections 3 through 7. If you select Option 2, please attach a list that includes the names of the bridges being monitored and the type of instrumentation.* If providing an exact answer will require more time than you can allow, please offer your best estimate or leave that question blank. If you have any questions regarding the proper interpretation of this survey, do not hesitate to call or e-mail me. We appreciate your support and thank you for your time and effort. When you have completed this survey, please return it by **March 4, 2005** by any convenient means to:

Beatrice E. Hunt, PE
Hardesty & Hanover, LLP
1501 Broadway
New York, NY 10036, USA
TEL: 212-944-1150 FAX: 212-391-0297
E-mail: bhunt@hardesty-hanover.com

If you would like more space to answer a question, please feel free to include an attachment and reference the question number(s) in the survey. Note that the blank lines in the electronic survey will expand automatically to allow additional space.

Section 1 Respondent Information

1.1 Agency/Organization ______________________

1.2 Address ______________________
Street Address

____
City *State* *Zip Code* *Country*

1.3 Contact Name ______________________

1.4 Department/Group ______________________

1.5 Job Title ______________________

1.6 Telephone ______________________

1.7 Fax ______________________

1.8 E-mail ______________________

1.9 Type of Agency/Organization

☐ Federal Agency ☐ County Agency ☐ State/Provincial Agency ☐ Municipal Agency
☐ Engineering/Design/Planning Firm ☐ Construction Company
☐ Monitoring System Vendor ☐ Professional/Trade Organization
☐ Other: ______________________

Section 2 General

2.1 Does or has your agency/organization used instrumentation for scour monitoring?

☐ Yes ☐ No

2.2 If yes, what type(s) of scour monitoring have you employed? (*Check all that apply.*)

☐ Portable Instrumentation ☐ Fixed Instrumentation

If you have not used fixed scour monitoring instrumentation, please respond to Questions 2.3, 2.4, 5.14, 8.1, and 9.8 only. If you have used fixed instrumentation, please proceed to Sections 3 through 9.

2.3 If you have not used fixed instrumentation for scour monitoring, are there particular problems/limitations why you have chosen not to use this technology?

____

2.4 What innovations/advancements would be beneficial for you to consider using fixed scour monitoring instrumentation?

____

Section 3 Specific Bridge Information

If multiple bridges are or were monitored by your agency, please choose from the following two options: (1) complete Sections 3 through 7 for each bridge, or (2) select one bridge for each category of instrumentation employed and complete Sections 3 through 7. If you select Option 2, please attach a list that includes the names of the bridges being monitored and the type of instrumentation.

3.1 Bridge Name ______________________

3.2 Route Number ______________________

3.3 Average Daily Traffic (ADT) ______________________

3.4 Bridge Location ______________________
City *State* *Country*

3.5 Name of Waterway ______________________

3.6 Year Built ______________ Year Rebuilt (*if applicable*) ______________

3.7 Bridge Identification Number (BIN) ______________________

3.8 Who owns the bridge? ______________________

3.9 Who maintains the bridge? ______________________

3.10 What is the total length of the bridge? __________ ☐ ft ☐ m

3.11 What type of structure is it? (*Check all that apply.*)

☐ Fixed Bridge ☐ Movable Bridge ☐ Highway Bridge ☐ Railroad Bridge
☐ Culvert ☐ Bulkhead ☐ Wharf/Fishing Pier
☐ Other: ______________________

3.12 What types of fixed scour monitors were/are installed at the bridge? (*Check all that apply and indicate the number for each type of monitor after the name.*)

☐ Sonars: _____ ☐ Magnetic Sliding Collars: _____ ☐ Tilt Sensors: _____
☐ Briscos: _____ ☐ Float-out Transmitters: _____ ☐ Vibration Sensors: ____________
☐ Sounding Rods: _____ ☐ Buried/Driven Rods: _____ ☐ Piezoelectric Polymer Film: _____
☐ Others: ____________________

3.13 Please list the name and contact information of the vendor who provided the fixed monitors.

____

3.14 Why were scour monitors installed at this bridge? (*Check all that apply.*)

☐ Scour critical rating ☐ Bridge to be replaced in about _____ years
☐ Research project for: ____________________ ☐ Others: ____________________

3.15 If applicable, what are the ratings for NBIS Items 60 and 113 for the substructure units being monitored?

Item 60: ____________________ Item 113: ____________________ ☐ Not certain

3.16 Has the monitoring data obtained been useful for changes or verification of the bridge scour ratings?

☐ No ☐ Yes; specify: ____________________

3.17 What is the foundation type?

☐ Piles ☐ Spread Footings ☐ Drilled Shafts ☐ Unknown

3.18 Is the foundation depth known?

☐ Yes—as-built depths ☐ Yes—design depths ☐ Unknown

3.19 What part of the structure is being monitored? (*Check all that apply.*)

☐ Pier(s) Number of piers: _____ No. of monitors per pier: _____
☐ Abutment(s) Number of abutments: _____ No. of monitors per abutment: _____
☐ Others: ____________________

Section 4 Site Conditions

4.1 Is the waterway riverine or tidal? ☐ Riverine ☐ Tidal

4.2 What is the flow habit of the waterway?

☐ Ephemeral ☐ Intermittent ☐ Perennial but flashy ☐ Perennial

4.3 Are any of the conditions listed below present at the site? (*Check all that apply.*)

☐ Debris loading ☐ Extreme temperatures ☐ Sediment loading
☐ Ice flows ☐ Air entrainment ☐ High velocity flows

4.4 Is there a history of scour at the site?

☐ Yes ☐ No ☐ Unknown

4.5 What is the average water depth in the main channel?

☐ <10 ft (<3 m) ☐ 10–30 ft (3.1–9.1 m) ☐ 31–50 ft (9.2–15.2 m)
☐ 51–75 ft (15.3–22.9 m) ☐ 76–100 ft (23–30.5 m) ☐ >100 ft (>30.5 m) ☐ Unknown

4.6 Major flood events (if any) since the monitors were installed:

Date(s) of Flood (*Indicate dd/mm/yy*)	Maximum Discharge (*Indicate cfs or cms*)	Return Interval (*Indicate year*)	Approx. Velocity* (*Indicate fps or mps*)

*Approaching pier/abutment

4.7 What are the subsurface conditions in the area of the bridge? (*Check all that apply.*)

☐ Clay ☐ Fine Sand/Silt ☐ Coarse/Medium Sand ☐ Gravel
☐ Cobbles ☐ Organics ☐ Concrete ☐ Riprap
☐ Bedrock; type of rock: ______________ ☐ Others: ____________________

4.8 Are there borings and/or other soil/rock data available for this location?

☐ No ☐ Yes; describe: ____________________
☐ Others: ____________________

Section 5 Design and Installation

5.1 Describe the location of the fixed monitors with reference to the bridge. (*Check all that apply.*)

☐ Upstream ☐ Buried; _____ feet/meters away from bridge substructure

☐ Downstream ☐ Mounted on substructure ☐ Others: ______________________

5.2 When were the monitors installed (*example: Month/YYYY*)? ______________________

5.3 What were the costs of installation? (*Include all available costs and specify type of currency.*)

Materials: ______________________ Labor: ______________________

Per monitor location: ______________________ Total: ______________________

5.4 What type of contract was the scour monitoring system installed under—bridge rehabilitation, stand-alone project for scour monitoring, or some other type of contract? (*Check all that apply.*)

☐ Bridge Rehabilitation ☐ Scour Countermeasures ☐ Emergency Scour

☐ USGS Research Project ☐ FHWA Demonstration Project 97 (DP-97)

☐ Research: ______________________ ☐ Others: ______________________

5.5 What factors contributed to the decision to use fixed scour monitors for this location?

____

For Questions 5.6 to 5.8 below, please check all groups that apply.

5.6 Who designed the scour monitoring system?

☐ Contractor ☐ In-House Staff—Department/Group Name: ______________________

☐ Consultant ☐ Monitoring System Vendor ☐ Others: ______________________

5.7 Who manufactured the scour monitoring system?

☐ Contractor ☐ In-House Staff—Department/Group Name: ______________________

☐ Consultant ☐ Monitoring System Vendor ☐ Others: ______________________

5.8 What parties were involved in the installation of the scour monitoring system?

☐ Contractor ☐ In-House Staff—Department/Group Name: ______________________

☐ Consultant ☐ Monitoring System Vendor ☐ Others: ______________________

5.9 Do the monitors have an automated alarm system (automatic alert that sends a signal)?

☐ Yes ☐ No ☐ Yes—but currently not in use ☐ Not certain

5.10 If there is an automated alarm system, please list the agency/organization and department/group that is contacted when the automated system is activated:

____

5.11 If there is an automated alarm system, how are the responsible persons contacted?

☐ E-mail ☐ Fax ☐ Telephone ☐ Pager ☐ Others: ______________________

5.12 How is the fixed monitoring system powered?

☐ Solar power ☐ Commercial power ☐ Others: ______________________

5.13 If there are any other types of scour countermeasures (structural, hydraulic, etc.), monitoring equipment, or portable monitors utilized at the bridge, please list them:

____

5.14 Are other measurement instruments installed at the bridge? (*Check all that apply and indicate the number installed for each type of device.*)

☐ Water Stage Sensors _____ ☐ Velocity Meters _____ ☐ Inclinometers ______________

☐ Water Quality Monitors _____ ☐ Structural Monitors; specify: ______________________

☐ Temperature Sensors _____ ☐ Wind Sensors _____ ☐ Others: ______________________

5.15 If any instruments were checked in the previous question, indicate whether they are part of the scour monitoring system, and if known, the manufacturer. If "Others" was checked, please describe the type of instruments.

____

5.16 Does the monitoring system contain any special innovative features or materials? Please describe:

____

Section 6 Data Collection and Analysis

6.1 How often do the fixed monitors take readings?

☐ Every 30 min. ☐ Once hourly ☐ Daily ☐ Weekly ☐ Monthly

☐ When activated by: ________________ ☐ Others: ________________

6.2 How often is the data collected and reviewed by a person(s)?

☐ Every 30 min. ☐ Once hourly ☐ Daily ☐ Weekly ☐ Monthly

☐ Others: ________________

6.3 How often is the data collected and reviewed during emergency situations?

☐ Every 30 min. ☐ Once hourly ☐ Daily ☐ Weekly ☐ Monthly

☐ Others: ________________

6.4 Please describe what is considered an emergency situation and the emergency protocol for this site. For example, is it a pre-determined data value, a major storm event, and/or a water surface elevation that would prompt an emergency response? Does the emergency response consist of lane/roadway segment/bridge closures and/or additional monitoring?

____

6.5 How is data downloaded or retrieved? (*Check all that apply.*)

☐ Automatically downloaded via telemetry to a base computer and retrieved at that computer

☐ Automatically downloaded via telemetry to a network and retrieved via internet connection

☐ Not automatic—downloaded by the person(s) monitoring the bridge

6.6 By which mode is the data downloaded? (*Check all that apply.*)

☐ Locally at the bridge site ☐ Via telephone landline (dial-up)

☐ Via cellular ☐ Via satellite ☐ Others: ________________

6.7 Please list the agency/organization and department/group responsible for monitoring the bridge.

____

6.8 Is a continuous set of data available? ☐ Yes ☐ No ☐ Not certain

6.9 In what format is the data recorded?

☐ Text File ☐ Spreadsheet ☐ Database ☐ Others: ________________

6.10 How is the data used, and what outputs are generated (i.e., graphs, data reduction, reports, design, and/or analysis)? Please describe:

____

6.11 Describe if the monitoring data has been useful in verifying scour predictions.

____

6.12 What is the scour rating of this bridge according to the FHWA National Bridge Scour Evaluation Program, FRA requirements for identification of scour critical bridges, or other systems?

☐ Low Risk ☐ Scour Susceptible ☐ Scour Critical ☐ Unknown Foundation

☐ Others: ________________

6.13 Has an emergency Plan of Action, similar to that developed by FHWA, been established?

☐ Yes ☐ No ☐ Not certain

Specify: ________________

6.14 If applicable, has the information obtained from the monitoring been useful for the development or revisions to a Plan of Action? Please describe:

____

6.15 How were critical/emergency scour depths determined for the bridge? Please describe:

____

6.16 Are independent checks performed in order to confirm the validity of the readings from the fixed monitors? Examples of independent checks would be readings from portable monitors, diving inspections, or fathometric surveys. Please check the appropriate box and explain.

☐ Yes ☐ No ☐ Not certain

____

6.17 Has data been recorded during a hurricane or other extreme event? *If you can provide these data, please indicate this in Section 9.2.*

☐ Yes ☐ No ☐ Not certain

6.18 Have analyses and/or tests been performed for this site? (*Check all that apply.*)

☐ Hydraulic and Scour Analysis ☐1-D; ☐2-D; ☐3-D Hydraulic Computer Modeling
☐ Borings ☐ EFA Testing ☐ Pier Stability Analysis
☐ Physical Testing (i.e., flume tests); specify: ______________________________
☐ Others: ______________________________

Section 7 Operation, Maintenance, Inspection, and Repairs

7.1 Is the monitoring system currently operational? (*If partially operational, check "yes" and all that apply.*)

☐ Yes ☐ No—needs repair ☐ No—monitors vandalized ☐ No—bridge not in service
☐ No—monitoring discontinued ☐ No—monitors salvaged ☐ No—insufficient funding
☐ Not certain—still in place ☐ Not certain
☐ Others: ______________________________

7.2 Based on the response to Question 3.12, how many fixed monitors are still currently in operation?

☐ Sonars: _____ ☐ Magnetic Sliding Collars: _____ ☐ Tilt Sensors: _____
☐ Briscos: _____ ☐ Float-out Transmitters: _____ ☐ Vibration Sensors: ____________
☐ Sounding Rods: _____ ☐ Buried/Driven Rods: _____ ☐ Piezoelectric Polymer Film: _____
☐ Others: ______________________________

7.3 Have any of the following interfered with the operation of or caused damage to the fixed monitors? (*Check all that apply.*)

☐ Ice flows ☐ Debris ☐ Interruptions with solar power
☐ Corrosion/electrolysis ☐ Collisions (ships, etc.) ☐ Others: ____________
☐ Vandalism; specify vandalized components: ______________________________

7.4 Are there regularly scheduled maintenance and inspection procedures for the scour monitoring system? If so, please briefly describe the procedures. For example, indicate what parts are serviced and how often.

☐ Yes ☐ No ☐ Not certain

____

7.5 When maintaining or repairing the scour monitoring system, what is required to access the system? (*Check all that apply.*)

☐ Security Clearance ☐ Lane Closures ☐ Boat(s) ☐ Keys to Doors/Gates
☐ Others: ______________________________

For Questions 7.6 to 7.8 below, please check all groups that apply.

7.6 What parties are involved in the routine maintenance of the fixed scour monitors?

☐ Contractor ☐ In-House Staff—Department/Group Name: ____________
☐ Consultant ☐ Monitoring System Vendor ☐ Others: ____________

7.7 What parties are involved in the repair of the fixed scour monitors?

☐ Contractor ☐ In-House Staff—Department/Group Name: ____________
☐ Consultant ☐ Monitoring System Vendor ☐ Others: ____________

7.8 What parties are involved in the inspection of the fixed scour monitors?

☐ Contractor ☐ In-House Staff—Department/Group Name: ____________
☐ Consultant ☐ Monitoring System Vendor ☐ Others: ____________

Section 8 Overall Experience, Comments, and Recommendations

The purpose of this section is to gather the experience of the bridge owners in order to further the technology and practice of scour monitoring. Please give this section some thought and consideration. Using your feedback, we hope to discover more efficient and cost-effective scour monitoring solutions.

8.1 Do you plan to use additional fixed or portable scour monitors in the future?

☐ Yes ☐ No ☐ Not certain

8.2 Were any problems encountered during the installation of the scour monitoring systems? If so, please describe the problems and any solutions that were devised.

____

8.3 Please comment on the reliability and longevity of the scour monitoring systems, including all components such as the power delivery (solar panels, wiring, batteries, chargers, etc.), software, materials (steel, stainless steel, PVC, etc.), and hardware (nuts, bolts, anchor studs, washers, etc.). For example, how many repairs are needed per year and what types of repairs have been required?

8.4 Please comment on the costs of operation, maintenance, repair, and inspection with respect to the original installation costs. If you are able to list costs, please indicate the time period (i.e., yearly, since installation, etc). Were these additional costs anticipated?

8.5 Were there any additional problems or issues with the scour monitoring systems that were not mentioned in this survey? Were these problems unique to the structure geometry, soil, or waterway conditions?

8.6 What lessons have you learned with the fixed scour monitoring systems?

8.7 What benefits have you gained using fixed scour monitors?

8.8 What advancements do you think are important for the future of fixed scour monitoring technology?

8.9 How long do you intend to keep the data obtained from this scour monitoring project?

Section 9 Request for Materials

If you have any of the following materials and can submit them with the survey, or in the near future, please indicate so below. Submittals may be in any form that is convenient, electronic, or hard copies.

9.1 Sample data including any spreadsheets, graphs, and/or figures.

☐ Yes ☐ No

9.2 Sample data recorded during a hurricane/other extreme event, including any available storm data.

☐ Yes ☐ No ☐ Not applicable

9.3 Plans and specifications showing innovations to scour monitoring systems.

☐ Yes ☐ No ☐ Not applicable

9.4 Scour monitoring program write-ups including instructions and/or manuals.

☐ Yes ☐ No ☐ Not applicable

9.5 A Plan of Action manual, similar to that developed by FHWA, for the bridge(s).

☐ Yes ☐ No ☐ Not applicable

9.6 Are there any papers, reports, or case studies published or unpublished on this project(s)?

☐ Yes ☐ No ☐ Not applicable

If a copy is not being submitted, please indicate how this material may be obtained:

9.7 Please list any additional materials you are submitting or recommended references:

9.8 If you know of any other fixed scour monitoring installations outside of your agency that are not DOT and/or documented in FHWA HEC-23, *Bridge Scour and Stream Instability Countermeasures,* would you please provide contact information on the bridge owner and if known, the structure name(s)?

9.9 If you believe your scour monitoring project would make a good case study and are willing to contribute detailed information about your project, please indicate so below. You will be contacted by the researcher to obtain the case study information.

☐ Yes ☐ No

If there are any issues not covered in this survey that you would like to comment on, please feel free to add sheets as necessary.

Please respond by March 4, 2005

THANK YOU FOR SUPPORTING THIS IMPORTANT EFFORT

APPENDIX B

Survey Respondents

State	Agency/Institution/Firm	Department	Title
Alabama	Alabama DOT	Bridge Bureau	Bridge Engineer
Alaska	Alaska DOT & Public Facilities	Hydraulics	State Hydraulics Engineer
	U.S. Geological Survey	Alaska Science Center	Hydrologist
Arizona	Arizona DOT	Bridge Group	Senior Bridge Hydraulics Engineer
Arkansas	Arkansas State Highway and Transportation Department	Bridge Division	Civil Engineer IV
California	California State DOT	Division of Engineering Services—Scour Mitigation Branch	Senior Bridge Engineer
	Avila and Associates Consulting Engineers, Inc.		President
Florida	Florida DOT, Districts 1 & 7	Facility and Inspection	Assistant Structure Coordinate
	Florida DOT, District 2	Bridge Department	Consultant Project Manager/Scour Coordinator
	Florida DOT, District 4	Structures and Facilities Office	District Bridge Inspection Administrator
	Florida DOT, District 5	Structures and Facilities (Structures Maintenance)	Bridge Engineer
	Florida's Turnpike	Structures Maintenance	Structures Systems Manager
Georgia	Georgia DOT	Bridge Design	State Bridge Engineer
	U.S. Geological Survey	Department of Water Resources	Hydrologist
Hawaii	University of Hawaii at Manoa/Hawaii DOT	Civil Engineering Department/Hydraulic Design	Associate Professor/Section Head
Illinois	Illinois DOT	Highways/Bridges	Hydraulics Engineer
Indiana	Indiana DOT	Central Office Bridge Inspection Unit/ Division of Program Development	Bridge Inspection Engineer
Iowa	Iowa DOT	Office of Bridges and Structures	Transportation Engineer Manager
Kansas	Kansas DOT	Bureau of Design	Bridge Evaluation—Squad Leader
Maine	Maine DOT	Bridge Maintenance	Bridge Maintenance Engineer
Maryland	Maryland State Highway Association	Office of Bridge Development, Structures Hydrology and Hydraulics	Hydraulic Engineer
Massachusetts	Massachusetts Highway Department	Bridge Section	Bridge Engineer
Minnesota	Minnesota DOT	Bridge Office	Bridge Hydraulics Engineer
Mississippi	Mississippi DOT	Bridge Division	Bridge Engineer

(*continued on next page*)

(*continued*)

State	Agency/Institution/Firm	Department	Title
Montana	Montana DOT	Bridge Bureau	Bridge Engineer
Nebraska	Nebraska Department of Roads	Bridge Division—Hydraulics	Assistant Bridge Engineer—Hydraulics
Nevada	Nevada DOT	Structural Design Division	Assistant Chief Bridge Engineer
New Jersey	Rutgers University	Civil and Environmental Engineering	Teaching Assistant
New Mexico	New Mexico DOT	Bridge Bureau	State Bridge Engineer
New York	New York State DOT Main Office	Structures Division—Bridge Safety Assurance Unit	Civil Engineer II
	New York State DOT Region 10	Structures Group	Regional Structures Engineer
	New York State Thruway Authority	Maintenance Engineering	Director, Bridge Management Bureau
	STV Incorporated	Transportation & Infrastructure Division	Principal Hydraulic Engineer
North Carolina	North Carolina DOT	Bridge Maintenance Unit	Assistant State Bridge Inspection Engineer
North Dakota	North Dakota DOT	Bridge Division	Hydraulics Engineer
Ohio	Ohio DOT	Structural Engineering	Bridge Hydraulics Engineer
Oklahoma	Oklahoma DOT	Bridge Design	
Pennsylvania	Pennsylvania DOT	Bridge Quality Assurance Division	Assistant Chief Bridge Engineer
South Carolina	South Carolina DOT	Bridge Maintenance	Bridge Inspection/Management Engineer
South Dakota	South Dakota DOT	Office of Bridge Design, Division of Planning/Engineering	Chief Bridge Engineer
Tennessee	Tennessee DOT	Transportation	Civil Engineering Manager II
Texas	University of Texas at San Antonio	Department of Civil Engineering	Associate Professor
Utah	Utah DOT	Structures Division	State Bridge Engineer
Vermont	Cold Regions Research and Engineering Lab (CRREL) and Vermont Agency of Transportation	CRREL Ice Engineering	Research Civil Engineer
Virginia	Virginia DOT	Structure and Bridge Division	Assistant State Structure and Bridge Engineer
Washington	Washington State DOT	Bridge and Structures Department, Bridge Management	Bridge Management Engineer
	Clark County Public Works	Public Works—Engineering Services	Bridge Program Manager
Wyoming	WYDOT	WYDOT Bridge Program	Hydraulic Engineer

APPENDIX C

Summary of Survey Responses

The following states submitted surveys. The states that reported the use of fixed scour monitors are in bold. Those that did not report it, but where information was obtained from the literature search and other sources that they have used them in the past are denoted by (*):

1. **ALABAMA**
2. **ALASKA**
3. ARIZONA*
4. **ARKANSAS**
5. **CALIFORNIA**
6. **FLORIDA—Divisions 2, 4, 5, 7, and Florida Turnpike Enterprise**
7. **GEORGIA**
8. **HAWAII**
9. ILLINOIS
10. **INDIANA**
11. IOWA*
12. **KANSAS**
13. MAINE*
14. **MARYLAND**
15. MASSACHUSETTS
16. **MINNESOTA**
17. MISSISSIPPI
18. MONTANA
19. NEBRASKA
20. **NEVADA**
21. **NEW JERSEY**
22. NEW MEXICO*
23. **NEW YORK—DOT Regions 1, 10, 11, NYCDOT and NYS Thruway Authority**
24. **NORTH CAROLINA**
25. NORTH DAKOTA
26. OHIO
27. OKLAHOMA
28. PENNSYLVANIA
29. SOUTH CAROLINA
30. SOUTH DAKOTA
31. **TENNESSEE**
32. **TEXAS**
33. UTAH
34. **VERMONT**
35. **VIRGINIA**
36. **WASHINGTON**
37. WYOMING

States that have not replied to date, but that are known to have used or currently have fixed scour monitoring installations include.

1. COLORADO
2. DELAWARE
3. MICHIGAN
4. NEW HAMPSHIRE
5. OREGON
6. RHODE ISLAND
7. WISCONSIN

Note that the District of Columbia did not respond; however, a survey was completed by the Maryland SHA for a bridge for Maryland, Virginia, and District of Columbia.

The following is a summary of the responses and comments received from the state departments of transportation. The question numbers correspond to the survey (see Appendix A) and the questions are in bold letters.

Section 1 Respondent Information

This information was so that the researchers could contact the respondent for additional information, if necessary.

Section 2 General

2.1 Does or has your agency/organization used instrumentation for scour monitoring?
Yes—29
No—21

2.2 If yes, what type(s) of scour monitoring have you employed?
Portable Instrumentation—14
Fixed Instrumentation—25

2.3 If you have not used fixed instrumentation for scour monitoring, are there particular problems/limitations why you have chosen not to use this technology?

AR—We have yet to develop a plan of action for our scour critical bridges, but are scheduled to do so in 2005.

AZ—An attempt to install fixed instrumentation for a few sites (less than 10) has been made in the 1990s; couple of sonar, couple of collar and float types.

GA—Cost and reliability

IA—Cost, accuracy

IL—None in particular. Districts have determined no "need" for remote instrumentation. We have no "remote" bridges, flood time to peak generally allows physical in-flood and post-flood monitoring. Cohesive soils at most major bridges allow inspection cycle to identify problem sites. Generally, IDOT approach is to install countermeasures once scour problem is identified. The scour instrumentation demo class was held in Illinois several years ago.

MA—Long-term maintenance to ensure that it remains functioning

ME—Ice and debris are a problem with fixed instream instrumentation.

NC—Cost, reliability, time required for installation. Qualitity of data received.

NE—We are not aware of any specific problems/limitations.

ND—Low cost

NM—Maintenance issues; training personnel how to use the equipment; costs.

TN—Debris impact, lightening, expense, and data transfer

OK—Funding needs

PA—We take corrective action instead of monitor. Many small bridges are monitored by visual observation and measurement during/after major events manually.

VA—A fixed monitoring system was affixed to one of our bridges in the Tidewater area of the state over 20 years ago. For those who can remember the system they recall it as sometimes operational. The device was swept away three or four years after installation. Since then, the Department has been fairly disinterested in these devices until recently. We are looking at what other states are doing and what benefits that they feel they are getting from such installations.

WA—The cost of permits and ESA consultation is $30K per site to install a monitor.

WY—To date this has not seemed necessary.

2.4 What innovations/advancements would be beneficial for you to consider using fixed scour monitoring instrumentation?

AR—We are currently undergoing an in-house research project (see attachment).
AZ—Instrumentation that can withstand extremely high temperature, requiring minimal personnel involvement and that can be protected from vandalism for ephemeral streams.
FL–D5—The instrument(s) have to be cost-effective and reliable.
GA—Proven performance, lower cost
IA—Remote monitoring with costs less than $10,000
MA—Improved survivability, vandal proof, ice flow proof, negligible operating cost
ME—Affordable instruments that could be located at bridge superstructure level with no parts in the stream.
MI—An affordable, easy-to-operate system that gives reliable results would have applications.
NC—Major reductions in cost (systems must be developed for small bridges where large expenditures will not be tolerated. The technology can then be exported to large bridges where expenditures are not as much of a problem. It is now done the other way, where ideas are developed for large bridges with no thought for the cost of using for smaller bridges.) Mechanical type scour monitoring devices do not appear to work long enough to bother with the installation. Any advancement must be inexpensive, provide accurate real-time information, be easy to install, be mostly wireless for communication, and provide long-term realibility. Also, systems must be maintenance free or at least need a very minimum amount of maintenance. Minimum maintenance may be considered with some maintenance required every 5 years. If maintenance is required more often than indicated above, it is unlikely to get done.
NE—Hand held, point-and-read device
NM—Do not know
OK—Cost-efficient—ability to measure velocity and depth to ground through silty and murky water.
PA—Very high reliability particularly when debris is present.
SC—Electronic access
SD—If we had a scour critical bridge and if the mitigation plan called for monitoring scour over an extended period, we would probably install fixed monitoring equipment.
TN—Something cheap with good reporting capabilties
TX—New sensors, better ways of mounting sensors
UT—It would be good to evaluate how calculated scour compares with actual field monitored rates.
VA—VDOT is currently considering introducing some sort of scour monitoring instrumentation. We have looked at some systems and are communicating with other states to determine the advantages of installing such devices.
WA—FHWA; go through ESA consultation and obtain an insidental take statement.

Section 3 Bridge Specific Information

3.1–3.2 Bridge Name, Route Number

AK (1/2.9)—Knik River Bridge No. 539, Route CDS #136000 (Old Glenn Highway)
AK (2.1)—Tanana River Bridge No. 202, CDS #170000 (Parks Highway)
AK (2.2)—Kashwitna River Bridge No. 212, CDS #170000 (Parks Highway)
AK (2.3)—Montana Creek Bridge No. 215, CDS #170000 (Parks Highway)
AK (2.4)—Sheridan Glacier No. 3 Bridge No. 230, CDS #210000 (Copper River Highway)
AK (2.5)—Copper Delta Bridge No. 339, CDS #210000 (Copper River Highway)
AK (2.6)—Copper Delta Bridge No. 340, CDS #210000 (Copper River Highway)
AK (2.7)—Copper Delta Bridge No. 342, CDS #210000 (Copper River Highway)
AK (2.8)—Salcha River Bridge No. 527, CDS #190000 (Richardson Highway)
AK (2.10)—Slana River Bridge No. 654, CDS #230000 (Tok Cutoff Highway)
AK (2.11)—Slana Slough Bridge No. 655, CSD #230000 (Tok Cutoff Highway)
AK (2.12)—Mabel Slough Bridge No. 656, CDS #230000 (Tok Cutoff Highway)
AK (2.13)—Tok River Bridge No. 663, CDS #230000 (Tok Cutoff Highway)
AK (2.14)—Kasilof River Bridge No. 670, CDS #110000 (Sterling Highway)
AK (2.15)—Kenai River at Soldotna No. 671, CDS #110000
AK (2.16)—Eagle River Bridge No. 734, CDS #296000 (Glacier Highway)
AK (2.17)—Red Could River Bridge No. 983, CDS #68040 (Anton Larson Bay Road)
AK (2.18)—Glacier Creek Bridge No. 999, CDS #132500 (Alyeska Highway)
AK (2.19)—Nenana River at Windy Bridge No. 1243, CDS #170000 (Parks Highway)
AK (2.20)—Lowe River Bridge No. 1383, CDS #190000 (Richardson Highway)
AL—US-82
AR—Red River at Fulton, Interstate 30
CA (DOT)—Santa Clara Bridge
CA (Av)—San Gorgonio River, Interstate 10

CA (2.1)—Toomes Creek, 99
CA (2.2)—St. Helena Creek, 29
CA (2.3)—Merced River, 59
CA (2.4)—Salinas River, 101
CA (2.5)—Cholame Creek, 46
CA (2.6)—Tick Canyon Wash, 14
CA (2.7)—San Mateo Creek, 5
FL—D7–John's Pass Bridge
FL—D2–Route 105 and A1A
GA (1)—Otis Redding Bridge
GA (2)—Georgia Highway 384
GA (3)—US Highway 27 (Business Route)
GA (4)—US Highway 17
HI (1)—Kaelepulu Bridge, Kawailoa Road
HI (2)—Kahaluu Bridge, 83 (47-525 Kamechamecha Highway)
IN—Wabash River and SR-43, US-52
KS—Amelia Earhart Bridge, US-59
MD—Woodrow Wilson Memorial Bridge, US-495
MN—BR 23015, MN TH 16
NC—Herbert C. Bonner Bridge, NC 12
NJ (1)—Route 35 over Matawan Creek, NJ 35
NJ (2)—Route 46 over Passaic River, US 46
NV—Red Rock Wash, Route 159
NY–R1—Black Creek, Route 262
NY–R10 (1)—Wantagh Parkway over Goose Creek, 980T
NY–R10 (2)—Robert Moses Causeway over Fire Island Inlet, 908J
NY–R10 (3)—Wantagh Parkway over Sloop Channel, 980T
NYCDOT—Willis Avenue Bridge over the Harlem River
NY–STA—–Cattaraugus Creek Bridge, 90 IX
TX—Mustang Creek Bridge, FM1157
VT—VT Route 5
WA—Klineline Bridge #1, Route 91110

3.3 **Average Daily Traffic (ADT)** (some respondents added the year, shown in parenthesis)
AK (1/2.9)—3,407 (2003)
AK (2.2)—2,359 (2004)
AK (2.10)—400 (2004)
AK (2.11)—400 (2004)
AK (2.12)—400 (2004)
AK (2.14)—4,610 (2004)
AK (2.16)—351 (2004)
AK (2.17)—100 (2004)
AK (2.18)—3,711 (2004)
AK (2.19)—1,912 (2004)
AK (2.20)—461 (2004)
AL—9,000
AR—20,900
CA (Av)—86,000
CA (2.1)—8,190
CA (2.2)—7,030
CA (2.3)—2,230
CA (2.4)—12,350
CA (2.5)—5,370
CA (2.6)—89,000
CA (2.7)—22,500
IN—16,498
KS—8,960
MD—175,000
MN—2,000
NC—5,100

NJ (1)—30,000
NJ (2)—70,000
NV—2,650
NY–R10 (1 & 3)—12,900
NY–R10 (2)—16,809
NYCDOT—75,000
NY–STA—31,730
WA—17,000

3.4–3.5 Responses varied by bridge.

3.6 **Year Built, Rebuilt**

AK (1/2.9)—1975
AK (2.1)—1965
AK (2.2)—1962
AK (2.3)—1962
AK (2.4)—1968
AK (2.5)—1977
AK (2.6)—1977
AK (2.7)—1977; 1988
AK (2.8)—1967
AK (2.10)—1979
AK (2.11)—1979, 2006
AK (2.12)—1979
AK (2.13)—1969
AK (2.14)—1965
AK (2.16)—1959
AK (2.17)—1974
AK (2.18)—1965
AK (2.19)—1973
AK (2.20)—1978
AL—1962
AR—1959
CA—1930, 1965, 2006
CA (Av)—1940
CA (2.1)—1917, 1952 widened
CA (2.2)—1934
CA (2.3)—1953
CA (2.4)—1939 R/1960 L
CA (2.5)—1959
CA (2.6)—1963
CA (2.7)—1968
HI (1)—before 1960
IN—1969, 1984 rehabilitation
KS—1938
FL–D7—1971, 1981
FL–D2—1949
NC—1962
MD—1961, 2006
MN—1988
NJ (1)—c1998
NJ (2)—c1920
NV—1985
NY–R1—1949
NY–R10 (1)—1930, 1998
NY–R10 (2)—1966, 2001
NY–R10 (3)—1930, 1999
NYCDOT—1901, 2007
NY–STA—1954, 1992
TX—1958

VT—1966
WA—1929

3.8–3.9 Who owns/maintains the bridge?

AK (all)—State of Alaska DOT & PF
AL—ALDOT
AR—State of Arkansas
CA (DOT)—State of California
CA (Av)—Caltrans
FL–D7—FDOT
FL–D2—FDOT District 2
HI (1)—City and County of Honolulu
HI (2)—HI—DOT
IN—INDOT
KS—State of Kansas
NC—NCDOT
MD—FHWA/MDSHA, VDOT, and DDOT
MN—Mn/DOT
NJ (1)—NJDOT
NJ (2)—NJDOT
NY–R10 (1-3)—NYSDOT
NYCDOT—NYCDOT
NY–STA—NYS Thruway Authority
NV—NDOT
TX—TXDOT
WA—Clark County

3.10 What is the total length of the bridge?

AK (1/2.9)—506 ft
AK (2.1)—1,305 ft (height: 61 ft)
AK (2.2)—213 ft (height: 27 ft)
AK (2.3)—140 ft (height: 22 ft)
AK (2.4)—230 ft (height: 22 ft)
AK (2.5)—401 ft
AK (2.6)—241 ft
AK (2.7)—881 ft (height: 48 ft)
AK (2.8)—504 ft (height: 40 ft)
AK (2.10)—153 ft (height: 19 ft)
AK (2.11)—41 ft (height: 18 ft)
AK (2.12)—41 ft (height: 19 ft)
AK (2.13)—241 ft (height: 23 ft)
AK (2.14)—284 ft (height: 33 ft)
AK (2.15)—394 ft (height: 45 ft)
AK (2.16)—211 ft (height: 24 ft)
AK (2.17)—63 ft (height: 14 ft)
AK (2.18)—222 ft (height: 31 ft)
AK (2.19)—389 ft (height: 43 ft)
AK (2.20)—303 ft (height: 31 ft)
AL—1,133 ft
AR—1,294 ft
CA (DOT)—1,830 ft
CA (Av)—239 ft
CA (2.1)—385 ft (height off water—0.7 ft)
CA (2.2)—187 ft (height off water—10 ft)
CA (2.3)—473 ft (height off water—13 ft ±)
CA (2.4)—1,260 ft (height off water—7.75 ft)
CA (2.5)—184 ft (height off water—25 ft ±)
CA (2.6)—114 ft (height off water—6 ft)
CA (2.7)—506 ft (height off water—40 ft)
FL—830 ft (District 7)

FL—120 ft (District 2)
HI (1)—200 ft
HI (2)—318 ft
IN—1,002 ft
KS—2,500 ft
MD—5,900 ft
MN—718 ft
NC—12,865 ft
NJ (1)—450 ft
NJ (2)—450 ft
NV—200 ft
NY—75 ft (Region 1)
NY–R10 (1)—537 ft
NY–R10 (2)—4,233 ft
NY–R10 (3)—740 ft
NYCDOT—3,212 ft
NY–STA—667 ft
VT—1,105 ft
WA—132 ft

3.11 What type of structure is it? (*Check all that apply*.)
Fixed Bridge = 39
Movable Bridge = 4
Highway Bridges = 47
Railroad Bridge = 0
Culvert = 0
Bulkhead = 1
Fishing Pier = 0
Other = 1—Monitored levee

3.12 What types of fixed scour monitors were/are installed at the bridge? (*Check all that apply.*)
Sonars = 164 instruments over 48 bridge sites
Magnetic Sliding Collars = 22 instruments over 8 bridge sites
Tilt Sensors = 35 instruments over 4 bridge sites
Briscos = 1 instrument over 1 bridge site
Float-Out Transmitters = 34 instruments over 3 bridge sites
Vibration Sensors = 0
Sounding Rods = 0
Buried/Driven Rods = 0
Piezoelectric Polymer Film = 1 over 1 bridge site
Time Domain Reflectometers = 2 over 1 bridge site

3.13 Please list the name and contact information of the vendor who provided the fixed monitors.
AK, CA (DOT and Av), FL, HI, KS, MD, NC, NJ, NV, NY (NYSDOT, NYCDOT, and NYSTA), WA—ETI Instrument Systems, Inc., Fort Collins, CO
AR—N/A—system was designed in-house using off-the-shelf components
FL—Environmental Data Systems Corp., FL
GA—Airmar (603) 673-9570
MN—Ayres Associates and ETI Instrument Systems, Fort Collins, CO
NY—Cayuga Industries, Schenectady, NY
TX—Design Analysis Associates, Logan UT (ultrasonic sensors) and Campbell Scientific, Logan, UT (data logger and communications)
VT—Cold Regions Research and Engineering Lab (CRREL), Hanover, NH

3.14 Why were scour monitors installed at this bridge? (*Check all that apply*.)
Scour Critical Rating = 39
Bridge Replacement = 7
Research Project = 16
Other = 2—(1) sudden 3 ft settlement of pier; (2) potential for gravel pit failure downstream

3.15 If applicable, what are the ratings for NBIS Items 60 and 113 for the substructure units being monitored? (Item 60/Item 113)

AK (all)—(7/7)
AR—5/3
CA (DOT)—/3
CA (Av)—6/8
CA (2.1)—7/3
CA (2.2)—7/3
CA (2.3)—7/2
CA (2.5)—7/3
CA (2.6)—7/3
FL–D7—/3
FL–D2—/5
IN—6/8
KS—6/5
MD—/5
MN—7/8
NC—4/3
NY–R1—/3
NY–R10 (1)—7/3
NY–R10 (2)—7/6
NY–R10 (3)—7/3
NY–STA—7/7
NV—7/5
WA—/2

3.16 Has the monitoring data obtained been useful for changes or verification of the bridge scour ratings? If yes, specify.

Yes = 23
No = 24
Not certain = 1

AK (1/2.9)—Has identified large dune bedforms and seasonal sediment "starvation." Large annual scour and fill cycles have been recorded in the data and used to evaluate predictive scour equations.
AK (2.1)—Little bed elevation change at moderately high flows.
AK (2.2)—Little bed elevation change at moderately high flows.
AK (2.3)—Little bed elevation change at high flows.
AK (2.4)—Up to 10 ft of seasonal bed degradation.
AK (2.5)—Up to 10 ft of scour observed as well as seasonal patterns.
AK (2.6)—Up to 10 ft of seasonal scour observed as well as 5 ft short-term scour associated with high flows.
AK (2.8)—Little bed elevation change at high flows.
AK (2.10)—Less than critical scour has been recorded at this site that previously showed scour potential using predictive models.
AK (2.11)—Less than critical scour has been recorded at this site that previously showed scour potential using predictive models.
AK (2.12)—Less than critical scour has been recorded at this site that previously showed scour potential using predictive models.
AK (2.13)—Less than critical scour has been recorded at this site that previously showed scour potential using predictive models.
AK (2.14)—Measured scour does not support calculated scour thus far.
AK (2.16)—Measured scour does not support calculated scour thus far.
AK (2.18)—Little bed elevation change at moderately high flows.
AR—It's too early in the project to know.
CA (DOT)—Data confirms that the scour does not adversely impact the bridge.
CA (2.6)—No alarm indicates no headcut action.
VT—The data are used to quantify the accelerated scour rate due to an ice cover/ice jams.
WA—Used to determine if bridge needs to be closed or not. Rating was already 'scour critical—rating 2—immediate action required.'

3.17 What is the foundation type?

Piles = 37
Spread Footings = 22
Drilled Shafts = 1
Unknown = 1
Other = 1

3.18 Is the foundation depth known?

Yes—As-Built Depths = 67
Yes—Design Depths = 22
Unknown = 11

3.19 What part of the structure is being monitored? (*Check all that apply*.)

Total bridges with piers = 54
Total bridges with abutments = 2
Total sites with other = 5

(No. of Piers/No. of monitors per pier, unless noted)
AK (1/2.9)—1/1
AK (2.1)—1/1
AK (2.2)—1/1
AK (2.3)—2/1
AK (2.4)—1/1
AK (2.5)—1/1
AK (2.6)—1/1
AK (2.7)—1/8
AK (2.8)—1/1
AK (2.10)—1/1
AK (2.11)—1/1
AK (2.12)—1/1
AK (2.13)—2/1
AK (2.14)—2/1
AK (2.16)—1/1
AK (2.17)—1/1
AK (2.18)—1/1
AK (2.19)—1/1
AK (2.20)—1/1
AL—1/1
AR—?/1
CA (DOT)—8/5
CA (Av)—2 /1; Levee monitored with six closed loop circuit cables
CA (2.1)—5/1
CA (2.2)—1/1
CA (2.3)—2/1
CA (2.4)—1
CA (2.5)—1/1
CA (2.6)—2 and others—streambed d/s of bridge to indicate possible headcut
CA (2.7)—8/1—note twin bridges (four piers per bridge)
FL–D7—2/1
FL–D2—2/2
GA (1)—2/3
GA (2)—1/4
GA (3)—2/3
GA (4)—1/3
HI (1)—1 pier/1 monitor; 1 abutment/1 monitor
HI (2)—1 pier/1 monitor
IN—/-
KS—1/2
MD—5/1
MN—1/1

NC—8/2
NJ (1)—1/2
NJ (2)—1/2
NY–R1—1/1
NV–1 pier/2 monitors, 2 abutments/1 monitor per abutment
NY–R10 (1)—2/2
NY–R10 (2)—13/1
NY–R10 (3)—8/1–2 (total of 10 monitors)
NYCDOT—4 piers/1–5 per pier; 7 bulkheads
NY-STA—4/2
TX—4/1
VT—2/1
WA—1/2; downstream sheetpile—1

Section 4 Site Conditions

4.1 Is the waterway riverine or tidal?
Tidal = 12
Riverine = 43

4.2 What is the flow habit of the waterway?
Ephemeral = 3
Intermittent = 5
Perennial but flashy = 7
Perennial = 35

4.3 Are any of the conditions listed below present at the site? (*Check all that apply.*)
Debris = 37
Extreme Temperatures = 1
Sediment Loading = 31
Ice Flows = 29
Air Entrainment = 0
High Velocity Flows = 36

4.4 Is there a history of scour at the site?
Yes = 24
No = 15
Unknown = 8

4.5 What is the average water depth in the main channel?
<10 ft = 29
10–30 ft = 19
31–50 ft = 4
51–75 ft = 1
76–100 ft = 0
>100 ft = 0

4.6 Major flood events (if any) since the monitors were installed (date/discharge; return interval; velocity):
CA—9/1/05
AK (2.1)—Q = 70,000 cfs; 2 yr; V = 10 fps
AK (2.2)—Q = 9,000 cfs; 200 yr; V = 11 fps
AK (2.3)—Q = 11,200 cfs; >200 yr; V = 12 fps
AK (2.4)—Q = 10,300 cfs; >5 yr; V = 9 fps
AK (2.5)—>100 yr; V = 11 fps
AK (2.6)—>100 yr; V = 8 fps
AK (2.7)—>100 yr; V = 12 fps
AK (2.8)—Q = 27,000 cfs; >5 yr; V = 8 fps
AK (2.9)—Q = 30,000 cfs annual peak; 1.1 yr (?); exposes footing
AK (2.20)—10/10/06; Q = 28,000 cfs; 500 yr; V = 15 fps
FL–D2—9/5/04, 9/25/04

HI (1)—2/1/04; Q = 930 cfs; 2–5 yr; V = 2 fps
IN—6/97, 1/99
KS—2/25/01
MD—Hurricane Floyd (1999) and Tropical Storm Isabel (2003)
NY–R10—Hurricane Floyd (1999)
NY–STA—5/13/04
WA—11/7/06; 3,700 cfs; 87-year

4.7 What are the subsurface conditions in the area of the bridge? (*Check all that apply.*)
Clay = 12
Fine Sand/Silt = 24
Coarse/Medium Sand = 40
Gravel = 33
Cobbles = 22
Organics = 5
Concrete = 1
Riprap = 8
Rock = 4

4.8 Are there borings and/or other soil/rock data available for this location?
AK (All)—Yes, borings for foundation investigation/design
AL—Yes, borings and pile driving records
CA—Yes, borings
CA (Avila)—Yes; gravel bed stream down for days (>150 ft)
CA (2.1)—Yes, LOTB for construction
CA (2.2)—Yes, two diamond core rotary borings drilled and logged (one at each abutment)
CA (2.4)—Yes, LOTB for construction
CA (2.5–2.7)—Yes, LOTB
FL–D7—Yes, Phase III Geotechnical Scour Evaluation
FL–D2—Yes, Phase III Geotechnical Scour Evaluation
GA (1)—Yes; GADOT has some boring data for this site
GA (2)—No
GA (3)—Yes
GA (4)—No
HI (1)—Yes; boring log up to 30 ft near the abutment
HI (2)—Yes; boring log up to 110 ft near the center pier
IN—Yes, borings and design plans
KS—No
MD—Yes
MN—Yes; boring information on bridge plan sheet
NC—No
NJ (1 & 2)—No
NV—Yes, borings
NY–R10 (1–3)—Yes, soil borings
NYCDOT—Yes, soil borings
NY-STA—Yes, borings
VT—Yes
WA—Yes; boring logs for bridge replacement are contained in the geotech report

Section 5 Design and Installation

5.1 Describe the location of the fixed monitors with reference to the bridge. (*Check all that apply.*)
Upstream = 5
Downstream = 0
Buried = 2
Mounted on substructure = 10

5.2 When were the monitors installed?
AK (1/2.9)—2002
AK (2.1)—2003

AK (2.2)—2004
AK (2.3)—2005
AK (2.4)—2005
AK (2.5)—2005
AK (2.6)—2005
AK (2.7)—2005
AK (2.8)—2002
AK (2.10)—2002
AK (2.11)—2002
AK (2.12)—2002
AK (2.13)—2002
AK (2.14)—2002
AK (2.16)—2002
AK (2.17)—2005
AK (2.18)—2004
AK (2.19)—2002
AK (2.20)—2005
AR—2006
CA (DOT)—2000
CA (Av)—2005
CA (2.1)—2002
CA (2.2)—2002
CA (2.3)—1997
CA (2.5)—1999
CA (2.6)—1999
CA (2.7)—2001
FL–D7—1997
FL–D2—2002
GA (1–4)—2001
HI (1)—2002
HI (2)—2003
IN—1997
KS—2000
MD—1999
MN—1993
NC—1992
NJ (1)—1999
NJ (2)—2000
NV—1997
NY–R1—1993
NY–R10 (1 & 3)—1998
NY–R10 (2)—2001
NYCDOT—2007 (to be installed)
NY–STA—1999
TX—1998
VT—1997 and 2001
WA—2006

5.3 What were the costs of installation?

AK (1/2.9)—$10,000 materials, $7,000 labor
AK (2.1)—$10,000 materials, $7,000 labor
AK (2.2)—$10,000 materials, $7,000 labor
AK (2.3)—$10,000 materials, $7,000 labor
AK (2.4)—$10,000 materials, $7,000 labor
AK (2.5)—$10,000 materials, $7,000 labor
AK (2.6)—$10,000 materials, $7,000 labor
AK (2.7)—$15,000 materials, $7,000 labor
AK (2.8)—$10,000 materials, $7,000 labor
AK (2.10)—$10,000 materials, $7,000 labor
AK (2.11)—$10,000 materials, $7,000 labor

AK (2.12)—$10,000 materials, $7,000 labor
AK (2.13)—$10,000 materials, $7,000 labor
AK (2.14)—$10,000 materials, $7,000 labor
AK (2.16)—$10,000 materials, $7,000 labor
AK (2.17)—$10,000 materials, $7,000 labor
AK (2.18)—$10,000 materials, $7,000 labor
AK (2.19)—$10,000 materials, $7,000 labor
AK (2.20)—$10,000 materials, $7,000 labor
AR—$11,500 materials; $40,000 labor
CA (DOT)—$52,000 materials
CA (Av)—$60,000 materials; DOT forces for labor
CA (2.1)—$5,000 materials
CA (2.2)—$13,000 materials; in-house labor
CA (2.7)—$56,000 materials
FL–D2—$50,000 total (approximate)
HI (1)—$1,000 materials; students and donated service for labor
HI (2)—$2,000 materials; students and donated service for labor
IN—Installed by Purdue University and INDOT personnel
KS—Unknown, installed by USGS
MD—$90,000 materials; $110,000 labor; $40,000 per monitor location (1998 USD)
MN—$3,600 per monitor location for materials and technical assistance; additional labor by Mn/DOT; total for 3 bridges: $10,800
NC—Unknown
NY–R10 (1)—$65,659.20 materials; $56,100 labor; $30,440 per monitor location (1998 USD)
NY–R10 (2)—$196,066 materials; $446,849 labor; $49,455 per monitor location (2001 USD)
NY–R10 (3)—$159,238 materials; $129,368 labor; $28,860 per monitor location (1998 USD)
NYCDOT—$243,550 materials; $756,450 labor; $55,556 per monitor location (2007 USD)—note labor includes monitoring for 3 years
NY–STA—$8,000 per location (includes labor and materials)
TX—$9,000 materials; $3,000 labor does not include research costs
VT—$500/TDR materials; $600 labor (depends on water depth and distance from shore; here assume less than 5 ft of water and 150 ft to shore); standard data collection platform has 8 channels and costs $5,000 plus development of data collection program that can be amortized over multiple projects; first time set up with less than 8 TDRs (2 total) $30,000 but very site specific.
WA—$15,000 materials; unknown labor since part of larger repair project

5.4 What type of contract was the scour monitoring system installed under—bridge rehabilitation, stand-alone project for scour monitoring, or some other type of contract? (*Check all that apply.*)

Bridge Rehabilitation = 4
Scour Countermeasures = 23
Emergency Scour = 4
USGS Research = 30
FHWA Demonstration Project = 0
Research = 7
Other = 1

5.5 What factors contributed to the decision to use fixed scour monitors for this location?

AK (1/2.1; 2.9–2.17; 2.19–2.20)—Relatively low ADT, difficulties involved with permanent fix
AK (2.2–2.4; 2.8; 2.18)—Difficulties involved with permanent fix
AK (2.5–2.7)—Difficulties involved with permanent fix and shifting channel
AL—Historical scour
CA (DOT)—Safety to the traveling public until the bridge replacement could be completed. Multi-season stage construction required.
CA (Av)—Long term (float-out battery life too short); located downstream due to looking for a headcut coming from downstream.
CA (2.1)—Due to environmental constraints mitigation work in the channel wasn't feasible.
CA (2.2)—Pier 5 borderline scour critical. Want to monitor until bridge is replaced for other reasons (not scheduled for replacement due to scour).
CA (2.7)—Scour critical bridges scheduled for emergency repairs—monitoring was for interim.
FL–D7—Scour critical rating and safety concerns

FL–D2—A combination of information taken from the routine inspections, scour evaluations, and the fact that the bridges considered scour critical.
GA (1–4)—The need to measure maximum pier scour.
HI (1 and 2)—The desire for automatic recording of scour depth during real flood events.
IN—Insisted upon by Research Leader & JTRP board.
KS—Large scour hole upstream of this pier. This location just downstream of railroad pier.
MD—Importance of transportation system; scour during previous storms; short piles under some of the piers on the Maryland side of the main channel; results of scour study. See supplemental discussion under item 3.13.
MN—District willingness to try fixed monitoring devices and interest in verifying scour.
NC—History of scour at the site
NV—Scour critical bridge, potential headcut from downstream detention basin.
NY–R4—Pier footing is spread/earth, high velocity, history of scour.
NY–R10 (1)—Fixed scour monitors provide continuous monitoring. This is particularly important during a storm event as divers are not able to inspect a bridge during a storm. In addition, the Goose Creek Bridge is scheduled to be demolished and rebuilt. Permanent scour countermeasures (such as riprap) would have to be removed during the new construction, which would add to the cost of the project.
NY–R10 (2)—Fixed scour monitors provide continuous monitoring. This is particularly important during a storm event as divers are not able to inspect a bridge during a storm. There are plans to replace the bridge, although the date of that work is not yet set. Permanent scour countermeasures (such as riprap) would have to be removed during the new construction, which would add to the cost of the project.
NY–R10 (3)—Fixed scour monitors provide continuous monitoring. This is particularly important during a storm event as divers are not able to inspect a bridge during a storm. In addition, the bridge was scheduled to be demolished and rebuilt. The bridge was demolished one year after the installation of the monitors and an off-line temporary bridge installed until a new on-line permanent bridge could be completed. Permanent scour countermeasures (such as riprap) would have to be removed, which would make the new construction difficult and add to the cost of the project.
NYCDOT—Fixed scour monitors provide continuous monitoring. The monitors will be placed on the existing bridge and Manhattan bulkhead during the construction of the new bridge. A hydraulic and scour analysis indicated that the potential scour during construction caused by the additional constriction of the channel could undermine the existing bridge and bulkheads. Permanent scour countermeasures (such as riprap) would complicate the construction of the new bridge and there were numerous environmental and permitting issues.
NY–STA—Scour Report, dated May 1996
TX—Previously observed scour history, direct foundation.
WA —High ADT, desire to keep the roadway open during medium to low flows and to allow closures only during high flow events while waiting on the bridge replacement approval/bidding.

5.6 Who designed the scour monitoring system?
Contractor = 3
In-House Department = 11
Consultant = 7
Monitoring System Vendor = 38
USGS = 22
Other = 5

5.7 Who manufactured the scour monitoring system?
Contractor = 6
In-House Department = 6
Consultant = 0
Monitoring System Vendor = 36
USGS = 22
Other = 16

5.8 Who installed the scour monitoring system?
Contractor = 10
In-House Department = 25
Consultant = 9
Monitoring System Vendor = 20
USGS = 22
Other = 16

5.9 Do the monitors have an automated alarm system (automatic alert that sends a signal)?

Yes = 7
No = 10
Yes, but not in use = 29
Not Certain = 2

5.10 If there is an automated alarm system, please list the agency/organization and department/group that is contacted when the automated system is activated and how are the responsible persons contacted?

AK (All)—System is under development
AL—ALDOT and Alabama State Troopers are contacted via telephone.
AR—District HQ, Bridge Division, Heavy Bridge, Research—is that DOT???
CA (DOT)—TransLab Instrumentation and the Scour Mitigation Branches via e-mail, telephone, or pager
CA (Av)—Caltrans
HI (1&2)—Hydraulics Laboratory, Department of Civil and Environmental Engineering, University of Hawaii at Manoa.
NJ (1&2)—Research office at Rutgers University
TX—TxDOT
WA—Bridge Program Manager, Clark County Public Works, Engineering Services

5.12 How is the fixed monitoring system powered?

Solar = 43
Commercial = 10
Battery = 23

5.13 Are there any other types of scour countermeasures or portable monitors utilized at the bridge?

CA (2.5)—Sheetpile check dam.
FL–D2—Lateral stiffening and/or bracing was installed at all intermediate bents due to the scour critical elevation being reached as a result of Hurricane Jeanne on 9/5/2004.
GA (1–4)—Used portable monitors to collect additional data during flood events.
MN—Riprap has been installed on one of the bridge abutments after the scour monitoring device was installed/damaged.
NJ (1–2)—Tethered floating depth sounder.
NV—Riprap
NY–R10 (1)—Riprap had been installed at the piers over the years. Portable sonar monitors to confirm the measurements taken by the fixed sonar monitoring devices.
NY–R10 (2)—Riprap had been installed at the piers over the years. Some remains and some has shifted.
NY–R10 (3)—Riprap had been installed at the piers over the years. Portable sonar monitors to confirm the measurements taken by the fixed sonar monitoring devices.
NY–STA—Steel sheet piling (stone filled) around each pier. Monitor on outside of sheet piling.
TX—Water level
WA—River flow gage upstream of bridge site.

5.14 Are other measurement instruments installed at the bridge? (*Check all that apply and indicate the number installed for each type of device*.)

Water Stage Sensors = 45
Velocity Meters = 6
Inclinometers = 9
Water Quality Monitors = 0
Structural Monitors = 1
Temperature Sensors = 20
Wind Sensors = 1

5.15 If any instruments were checked in the previous question, indicate whether they are part of the scour monitoring system, and if known, the manufacturer.

AK (All)—Water stage sensors and temperature sensors by ETI Instrument Systems, Inc.
AR—Water stage by Senix Corp; Sonar by Interphase; PTZ camera by Axis.
CA (DOT)—All part of the original monitoring system.
CA (Av)—Water stage sensors are part of scour monitoring system and manufactured by ETI Instrument Systems, Inc.
FL–D2—Water stage sensors, wind, and water temperature sensor is part of the scour monitoring system. This was manufactured by Weatherlink.
GA (1–4)—Water stage sensor by Design Analysis and velocity meter by Nortek.
HI (1–2)—Water stage sensors are part of scour monitoring system and manufactured by ETI Instrument Systems, Inc.

IN—USGS gage about 1 mile downstream of bridge.

MD—The water stage recorder and velocity meters are a part of the scour monitoring contract and are furnished by ETI Instrument Systems, Inc. (See supplemental comment 5.7.) The tilt meter is monitored under a separate contract.

NJ (1–2)—Water stage sensors part of monitoring system from ETI Instrument Systems, Inc.

NY–R10 (1 and 3)—The water stage sensor is part of the scour monitoring system although it was installed at a later time. It is used to compare a change in water surface elevation with a change in streambed elevation. The temperature sensor was installed with the scour monitoring devices.

NY–R10 (2)—The water stage and temperature sensors are part of the scour monitoring system. The water stage sensor is used to compare a change in water surface elevation with a change in streambed elevation.

NYCDOT—The water stage and temperature sensors are part of the scour monitoring system. The water stage sensor is used to compare a change in water surface elevation with a change in streambed elevation.

TX—Water stage sensors are part of scour monitoring system and supplied by Campbell Scientific.

5.16 Does the monitoring system contain any special innovative features or materials? Please describe:

AK (1/2.9)—Water and Temperature Sensors provided by ETI Instrument Systems, Inc., Fort Collins, CO

AK (2.13 and 2.15)—Retractable transducer bracket for ice problems.

AK (2.14)—Winch system to raise and lower sonars protecting them from ice in winter.

AK (2.16)—Spring loaded sonar housing to deflect debris.

AK (2.19)—Wireless link from Satellite modem to sonar data collection controller on bridge.

AK (2.20)—Wireless link from Satellite modem to sonar data collection controller on bridge.

AR—It is linked to a permanent laptop that is integrated to our central office for real-time analysis. Laptop/scour system can be accessed/controlled/changed via wireless Internet.

CA (DOT)—Remote bridge-mounted systems radio transmits data to master station located at permanent facilities.

CA (Av)—Levee monitoring system and cross channel monitoring system.

FL–D7—Cameras, water temperature sensor for sound velocity correction.

FL–D2—Yes—The water temperature sensor. Readings are automatically adjusted according to changes in the water temperature.

GA (1–4)—The scour data could be viewed on the USGS NWIS website. The data were updated every 30 min during flood events.

MD—Remote download capability via telephone

NY–R10 (1–3)—The monitoring system utilizes a voice synthesizer. You can call a telephone number and have the data read aloud to you by a “person.” This is very useful when the person monitoring the bridge does not have access to a computer or is on the road and requires quick access to the data.

VT—See TDR reference

Section 6 Data Collection and Analysis

6.1 How often do the fixed monitors take readings?

Every 30 min = 33
Once hourly = 8
Daily = 2
Weekly = 0
Monthly = 1
When activated by = 1 (float-out switch)
Other = 30 (Responses include: every 15 min, 4 times daily, when an elevation drop occurs; when personnel were at the bridge; 15 min (subject to change); significant change in stage; when activated by alarm system every 15 min.

6.2 How often is the data collected and reviewed by a person(s)?

Every 30 min = 0
Once hourly = 0
Daily = 31
Weekly = 27
Monthly = 1
Other = 35 (Responses include: during a flood, 6 months; periodically, as needed and occasionally by a student; whenever personnel were at the bridge and data were collected; when there is a challenge; as needed; weekly during the research contract and as needed during flooding events by DOT; review TBA; conditions visually monitored with web cams; data are collected every 24 h and can be accessed at Engineers discretion; varies.)

6.3 How often is the data collected and reviewed during emergency situations?

Every 30 min = 4
Once hourly = 27
Daily = 2
Weekly = 0
Monthly = 0
Other = 23 (Responses include: during a flood, 5 min; every 15 min, twice daily, unknown, bi-weekly, as needed; as often as needed; DOT decision; all data/video are real time; objective is to document the effect of the ice cover on the scour process; ongoing through alarm system and staff; at engineers discretion; every 15 min.)

6.4 Please describe what is considered an emergency situation and the emergency protocol for this site.

AK (All)—If measured scour exceeds certain thresholds. First threshold for increased monitoring, second threshold for warning, third for closure.

AL—closure until an underwater inspection is completed.

AR—There is a scour critical Plan of Action for this bridge. If scour occurs to within 2 ft of the bottom of the footing, the bridge closure procedure will be in effect. The bridge closure procedure is an AHTD written office policy. Due to the importance of this bridge, monitoring is critical.

CA (DOT)—Extreme water surface will prompt additional monitoring. Replacement under construction. Construction staff tasked with additional monitoring. Tilt meters greater than 2 degrees of rotation triggers investigation. Float out activation triggers monitoring. Bridge closure if excessive bridge movement.

CA (Av)—A break in the levee is the first line of defense, cross channel monitoring downstream is the second, and if a headcut gets to the bridge would be the third (then I-10 is shut down by CHP to all traffic).

CA (2.1)—Pre-determined amount of movement (tilt) would trigger a visual investigation with potential for bridge closure if necessary.

CA (2.2)—Pre-determined WSE and/or tilt activates alarm, which prompts site visit and potential for closure.

CA (2.3)—Two benchmark flows

CA (2.5)—Tilt sensor will alert if sensor goes beyond 2 sigmas.

CA (2.6)—If and when a headcut reaches the d/s side of the vicinity of the bridge it triggers a group of float-outs—an emergency response team would then close the bridge.

CA (2.7)—Pre-determined amount of movement (tilt) would trigger a visual investigation with potential for bridge closure if necessary.

FL–D2—When a predetermined elevation is reached (scour critical/action elevation), whether it be during or after a major storm or any other time, the bridge would be closed and monitored until countermeasures can be designed and installed.

GA (1–4)—Since this is not a scour critical bridge there was no emergency protocol. However, if the bed elevation reached the elevation of the bottom of the footing, then GADOT would have been notified.

HI (1 and 2)—Major storm event or the collar sensors have dropped more than 2 ft.

IN—None. This was a research study only.

MD—An action plan has been prepared to define various stages of concern. This plan is based on structural stability calculations for the selected piers. To date, there has not been significant scour approaching the first level of emergency response.

NJ (1 and 2)—When depth change exceeds 1 ft in 1 h.

NV—Major storm. Automatic signals were to be sent by float-outs and sonar when specific scour depths were reached. Response plan was defined based on successive scour depths reached. Closures possible depending on scour evidence.

NY–R4—Flood warning issued for county by NWS. Bridge will be closed if water level reaches a "critical condition" determined by the Regional Hydraulic Engineer (usually low chord elevation).

NY–R10 (1–3)—In the event of a tropical storm watch or hurricane watch, the streambed readings are retrieved within 4 h of the initiation of the watch, and continue to be checked every 4 h throughout the storm and every 12 h for 3 days after the termination of the storm watch. If a tropical storm warning or hurricane warning is issued, the streambed readings are checked every 2 h, until such time as the warning is lifted, and then as described under storm watch.

If a high tide event occurs, actions are taken in response to the following high tides:

-After tides are 2 ft or more above high tide for a period of 6 h, the streambed readings are checked every 4 h, and continue for 4 h after the resumption of normal tides.

-When tides are 4 ft or more above high tide for any duration, the streambed readings shall be checked every 2 h, and continue for 6 h after the resumption of normal tides.

NYCDOT—A diving inspection should be performed after a 10-year or greater storm (water surface elevation is specified). An increased frequency of scour monitoring would also be employed prior to and following the storm.

TX—Flooding event.

WA—Pre-determined values were chosen for alarming triggers. Bridge closure is the result of the last level of warning. There are three prior levels of warning reached prior to that.

6.5 How is data downloaded or retrieved? ***(Check all that apply.)***

Automatically downloaded via telemetry to a base computer and retrieved at that computer = 16
Automatically downloaded via telemetry to a network and retrieved via Internet connection = 35
Not automatic—downloaded by the person(s) monitoring the bridge = 6

6.6 By which mode is the data downloaded? (*Check all that apply.*)

Locally = 26
Telephone = 17
Cellular = 5
Satellite = 26
Other = 2

6.7 Please list the agency/organization and department/group responsible for monitoring the bridge.

AL—ALDOT Maintenance and the Alabama State Troopers are alerted through an automated alarm system
AK (All)—Alaska DOT&PF and USGS–Alaska Division
AR—Arkansas State Highway and Transportation Department, District HQ/Maintenance Division/Research
CA (D)T—TransLab Instumentation and the Scour Mitigation Branches
CA (Av)—Caltrans, Structure Hydraulics
CA (2.2–2.3; 2.5–2.6)—Caltrans
FL–D2—FDOT State Material Office forwards to the Bridge Department
GA (1–4)—USGS
HI (1–2)—Hydraulics Group, Civil and Environmental Engineering Department, University of Hawaii at Manoa
IN—Purdue University, School of Civil Engineering
KS—USGS
MD—Maryland SHA, Office of Bridge Development and Parsons Brinckerhoff
MN—Mn/DOT District 6
NC—Bridge Maintenance Unit
NJ (1–2)—Rutgers University, Department of Civil and Environmental Engineering
NV—NDOT Structural Design Division
NY–R1—NYSDOT Region 4 Bridge Maintenance, Inspection, or Hydraulic Engineer
NY–R10 (1–3)—NYSDOT Region 10 Structures Group
NYCDOT—NYCDOT Movable Bridge Group
NY–STA—NYS Thruway Authority—Buffalo Division
TX—TxDOT
WA—Clark County Public Works

6.8-9 Is a continuous set of data available and in what format is the data recorded?

AL—No
AK (All)—Yes, text file, spreadsheet, database, and web
AR—Yes, database
CA (DOT)—Yes, text files
CA (Av)—Yes, others
FL–D2—Not certain
FL–D7—Yes, text files and spreadsheets
GA (1–4)—Yes, text file, spreadsheet, database
HI (1&2)—No, text files
IN—Not certain
KS—Not certain
MD—Yes, text files and spreadsheets
MN—No, paper forms
NC—No
NJ (1–2)—No, text file
NV—No longer recorded
NY–R10 (1–3)—Yes, text files and spreadsheets
NY–STA—Yes, hand recorded data
TX—No, text file
VT—Yes, database
WA—Yes, text file and spreadsheet

6.10 How is the data used, and what outputs are generated (i.e., graphs, data reduction, reports, design, and/or analysis)?

AK (All)—Tabular results and graphs, data has fostered a number of USGS reports.
AR—Graphs, video stills, sonar image stills.
CA (DOT)—Data are plotted for quick visual inspection by a hydraulic engineer.
CA (Av)—Groovy graphics—you've got to see the Caltrans system!
GA (1–4)—The data were used to calibrate a physical model and 3-D numerical model, which were done by Georgia Tech.
HI (1)—The data are used for validation of the existing scour equations.
HI (2)—No significant data have been obtained at this site yet.
IN—Possibly tables and graphs, but not certain
FL–D7—Graphs and reports
MD—Graphs, plots, and reports
NJ(1–2)—As part of report of pilot study
NY–R10 (1–3)—Graphs, plots, and reports
NY–STA—Data are reviewed, not plotted
TX—TxDOT use
VT—Data are stored in a database with generated plots on the website.
WA—Yes to all—graphs, database, text file, etc.

6.11 Describe if the monitoring data has been useful in verifying scour predictions.

AK (1/2.9)—Yes. Tabular and graphs, data have fostered a number of USGS reports. Analysis is not yet complete. Useful to separate components of scour and evaluate predictive equations.
AK (2.1)—Yes. Indicates little bed elevation change seasonally and up to a 2-year recurrence interval flow.
AK (2.2)—Yes. Indicates no bed elevation change seasonally and only 4 ft of scour at a 200-year recurrence interval flow.
AK (2.3)—Yes. Indicates no bed elevation change seasonally and only 3 ft of scour at a 200-year recurrence interval flow.
AK (2.4)—Yes. Indicates large bed elevation change seasonally.
AK (2.5)—Yes. Indicates large bed elevation change seasonally.
AK (2.6)—Yes. Indicates large bed elevation change seasonally and short period scour associated with high flows.
AK (2.7)—Yes. Indicates large bed elevation change seasonally and short period scour associated with high flows. Eight piers instrumented allows for visualization of scour for the entire cross section.
AK (2.8)—Yes. Indicates no bed elevation change seasonally and only 2 ft of scour at a 5-year recurrence interval flow.
AK (2.10–2.17)—Yes. Useful to separate components of scour and evaluate predictive equations.
AK (2.18)—Yes. Indicates no bed elevation change seasonally and only 4 ft of scour at a 200-year recurrence interval flow.
AK (2.19–2.20)—Yes. Useful to separate components of scour and evaluate predictive equations.
CA (DOT)—Tilt meters have been able to track daily thermal movement and the influence of daily construction activities adjacent to the site. During January 2005 record flows, no alarms or excessive movement was tracked. No float-outs activated.
CA (Av)—Not yet, but yes at other bridges.
CA (2.2)—Not so far.
CA (2.4)—No—Sonars impacted by large sediment/debris loads. Float-outs placed but only tripped during pile driving operations near site while replacement bridge was installed.
FL–D7—Observed loose soil moved away and redeposited by tidal change currents.
GA (1–4)—The model compared well with models done by Georgia Tech.
HI (1)—Yes. The field data were compared with the predicted scour depth, and the scour equations were found to overestimate the scour depth at this location during the January 2, 2004 storm.
IN—Not useful at all. The sonar broke away during flooding and the collar did not give useful data. Generally this was a waste of time and money.
KS—This research proved it is possible to monitor streams in real time but difficult to maintain the equipment due to high flows, ice, and drift destroying the devices.
MD—To date there has been no significant scour recorded at any of the piers. The velocity meters indicate that velocities have been low over the monitoring period. This has been very useful in indicating that the bridge is stable, that bridge closures have not been necessary and the traveling public is assured of safe passage.
MN—No. Monitor was damaged within a year of installation.
NY–STA—Recently, change prompted further investigation. Results showed footing not exposed.
TX—TxDOT use.
VT—Ice is not included in scour prediction and the data have been invaluable for developing numerical and calibrating flume studies.
WA—Absolutely.

6.12 What is the scour rating of this bridge according to the FHWA National Bridge Scour Evaluation Program, FRA requirements for identification of scour critical bridges, or other systems?

Low Risk = 5
Scour Susceptible = 2
Scour Critical = 39
Unknown Foundations = 2
Others = 22

6.13 Has an emergency Plan of Action, similar to that developed by FHWA, been established?

Yes = 36
No = 12
Not Certain = 7

6.14 If applicable, has the information obtained from the monitoring been useful for the development or revisions to a Plan of Action? Please describe:

AK (All)—It will be useful in the future.
AR—Too soon to tell.
CA (DOT)—Not to the Plan of Action as of yet, but to some of our monitoring procedures.
FL–D7—No, since we placed the rip-rap rubble the information obtained is less useful.
MD—The monitoring effort confirms that scour has not been a problem to date; however, the scour study indicated that scour could be of concern for some of the Maryland piers in the event of a major flood event. In the event of a closure, the SHA Statewide Operations Center would coordinate with other jurisdictions in developing a plan for accommodating traffic. We just had a recent experience where a tiltmeter was giving a false reading. SHA coordination in resolving this issue was very good.
TX—Problems with maintenance and attachment affected by debris.
WA—Yes.

6.15 How were critical/emergency scour depths determined for the bridge? Please describe:

AK—Initial values from calculations at 100-year and 500-year flood levels. To be modified.
AL—Structural analysis
AR—There is a scour critical Plan of Action for this bridge. If scour occurs to within 2 ft of the bottom of the footing, the bridge closure procedure will be in effect. The bridge closure procedure is an AHTD written office policy. Due to the importance of this bridge, monitoring is critical.
CA (DOT)—HEC-18 criteria
CA (Av)—Top of spread footing
CA (2.2)—Pile capacity at maximum predicted scour depth.
CA (2.3)—Based on calculated scour equations outlined in HEC-18.
FL—Florida Pier Program
IN—Scour depths were calculated using HEC-18, and Purdue University Lab testing.
NC—Determined by soils engineers to have enough pile embedment remaining so that the bridge is safe against settlement.
NJ (1–2)—Any sudden change greater than 1 ft
NY—R10 (1–3)—Analysis and judgement
NYCDOT—Analysis and engineering judgement
NY–STA—Scope to be determined and is scheduled for Spring/Summer 2005.
NY–STA—Hydr. analysis—Conversion of scour readings to actual scour.
TX—Based on the design of the spread footings.
WA—Engineers and suppliers determined what is critical and how to use available information.

6.16 Are independent checks performed in order to confirm the validity of the readings?

Yes = 40
No = 9
Not Certain = 4

AK(1/2.9)—ADCP measurements, 4–6 measurements per summer flow season.
AK (2.1)—ADCP measurements, 2 measurements per summer flow season.
AK (2.2; 2.3; 2.8)—ADCP measurements, bridge soundings, 2 measurements per summer flow season.
AK (2.4–2.7)—ADCP measurements, bridge soundings, 4 measurements per summer flow season.
AK (2.10–2.13; 2.18)—Fathometric surveys
AK (2.14; 2.16; 2.17; 2.19; 2.20)—Fathometric surveys and ADCP discharge measurements.

AR—Sonar can be checked against portable, boat-mounted unit.
CA—High stream flows quickly receeded. Residual scour hole visible. No reason to believe the float outs were exposed.
FL–D7—Diver inspections and manual measurements
FL–D2—Soundings are taken by inspectors every two years along with an underwater inspection. This may be done more often in the case of major storms or major changes in the readings taken by the monitoring device.
GA (1–4)—Portable instrumentation was used. Also, fathometric surveys were done.
HI (1)—Portable monitors (floating fish finder type) and surveying poles.
HI (2)—Portable monitors (floating fish finder type).
IN—Checked by underwater inspections, 12-4-1994 and 11-1-2002. The older, downstream, EBL bridge was found to have minor scour, with the footing of Pier #5 exposed, during the underwater inspections.
MD—underwater inspections every 4 years and special ones as needed.
NJ (1–2)—Portable depth sounder (sonar).
NY–R10 (1–3)—Diving inspections and fathometric survey results are compared with readings from the scour monitors.
NYCDOT—Diving inspections and fathometric survey results are compared with readings from the scour monitors.
TX—During the research phase.
WA—Physical inspections in river and also survey data confirmation of tilt/movement.

6.17 Has data been recorded during a hurricane or other extreme event? (*If you can provide this data, please indicate this in Section 9.2.*)
MD—Tropical Storm Isabel (refer to Appendix D)
NY—R10 (1 and 3)—Hurricane Floyd (refer to Appendix D)

6.18 Have analyses and/or tests been performed for this site? (*Check all that apply.*)
Hydraulic and Scour Analysis = 39
1-D; 2-D; 3-D Hydraulic Computer Modeling = 32
Borings = 11
EFA Testing = 2
Pier Stability Analysis = 13
Physical Testing (i.e., flume tests) = 1

Section 7 Operation, Maintenance, Inspection and Repairs

7.1 Is the monitoring system currently operational? (*If partially operational, check "yes" and all that apply.*)
Yes = 35
No—needs repair = 6
No—monitors vandalized = 4
No—bridge not in service = 1
No—monitoring discontinued = 13
Not certain—still in place = 1
No—salvaged = 4
No—insufficient funding = 0
Not certain = 1
Others = 18

Comments:
AK (1/2.9; 2.1–2.8; 2.10; 2.13–2.14; 2.18)—Monitors are in standby mode during winter ice conditions.
MN—Monitor damaged beyond repair (12/1993).
CA (2.4)—Bridge replaced.

7.2 Based on the response to Question 3.12, how many fixed monitors are still currently in operation?
Sonars = 78 (48% currently in service)
Magnetic Sliding Collars = 7 (32% currently in service)
Tilt Sensors = 34 (32% currently in service)
Briscos = 1 (100% currently in service)
Float-out Transmitters = 32 (94% currently in service)
Others = 5

AR—Others include ultrasonic distance sensor and PTZ network camera.
VT—Others include four TDRs.

7.3 Have any of the following interfered with the operation of or caused damage to the fixed monitors? (*Check all that apply.*)

Ice flows = 22
Debris = 32
Interruptions with solar power = 3
Corrosion/electrolysis = 4
Collisions (ships, etc.) = 1
Vandalism = 8
Other = 9 (Responses include: vibration, instruments were buried, one broken solar panel, sediment/deposition, overgrown vegetation)

CA (2.3)—Vandalized components solar panel
HI (1)—Vandalized components, mainly cable conduits and the sliding collars
HI (2)—Vandalized components include cable conduits, data logger and solar panel
NJ (1)—Vandalized components include stolen solar panel and cut cables
NJ (2)—Other problems include landline difficulties
NY–R10 (2)—Conduit to transducer was broken
WA—Telephone service interrupted

7.4 Are there regularly scheduled maintenance and inspection procedures?

Yes = 35
No = 11
Not Certain = 4

AK (1/2.9, 2.1)—USGS performs routine stream gaging at site and maintains as needed.
AK (2.2–2.8; 2.18)—USGS maintains as needed.
AK (2.10–2.14; 2.16–2.17; 2.19–2.20)—Sonar and datalogging equipment is inspected at least twice yearly.
AR—All sensors can be accessed remotely in real time. Maintenance/inspection can be done constantly.
CA (Av)—Owner checks battery life and regularly changes batteries.
CA (2.6)—Possible that maintenance crew clears ovegrown vegetation regularly.
GA (1–4)—The site is inspected every two months.
HI (1–2)—If we do not receive the daily phone call from the sensor, we go to inspect the sensors.
IN—No, research project ended
FL–D7—Sensors require maintenance or replacement two times per year due to marine growth accumulation.
FL–D2—Annual cleaning and/or replacement of the sensors is done due to marine growth or as needed if there is a problem.
NY–STA—As changes take place, system is tested.
VT—Components are tested each fall with independent instrumentation.
WA—Regularly clear debris.

7.5 When maintaining or repairing the scour monitoring system, what is required to access the system?

Security Clearance = 3
Lane Closure = 8
Boat = 35
Keys to Doors/Gates = 19
Other = 10

CA (2.2)—Ladder in low flow
HI (1)—Need work permit at the site from city and county of Honolulu.
HI (2)—Need work permit at the site from Hawaii State DOT.
NV—Under Bridge Inspection Truck (UBIT).
VT—Low water for the TDR, data collection platform is on shore.

7.6 Who <u>maintains</u> the scour monitoring system?

Contractor = 2
In-House Staff = 24
Consultant = 9
Monitoring System Vendor = 8
USGS = 25
Other = 9

7.7 Who repairs the scour monitoring system?

Contractor = 24
In-House Staff = 23
Consultant = 7
Monitoring System Vendor = 9
USGS = 25
Other = 8

7.8 Who inspects the scour monitoring system?

Contractor = 2
In-House Staff = 25
Consultant = 7
Monitoring System Vendor = 4
USGS = 25
Other = 10

Section 8 Overall Experience, Comments and Recommendations

8.1 Do you plan to use additional fixed or portable scour monitors in the future?

Yes = 15
No = 8
Not Certain = 19

8.2 Were any problems encountered during the installation?

AK (All)—Difficulty working from boat, climbing on superstructure

AR—It was damaged by debris in its initial set-up, but has been repaired. Lower attach point was redesigned and repaired in place.

CA (DOT)—Access to the site hampered by traffic lane closure restrictions from above and access to the river from below. Additionally, impeded by budget limitations for overtime work from staff. Radio telemetry interference due to inline cellular telephone tower. Used directional antenae to transmit. Used hollow stem auger without drilling mud to place floatouts, but still have to have biologist on site for proper environmental impacts and must dispose of cuttings off site.

CA (Av)—Pier footings higher than as-builts showed. Adjusted the rod location.

FL–D7—Adequate brackets need to be designed on a case-by-case basis to support the sensors. Brackets need to be strong to prevent movement, but easy to remove to provide maintenance.

HI (1)—The drilling of the steel pipes into the river bed requires the skills and equipment of a professional geotechnical engineering crew.

IN—Hard to install; involved a lot of equipment and personnel.

MN—Problems driving the tube due to either submerged debris or rocks.

NY—R10—Attachment problem (drilling into the piers and movement of the riprap already at the pier).

TX—Pier access, bridge load restricted, no snooper equipment, lightweight truss trailes used.

VT—The cable connecting the TDR to the on-shore platform is problematic as debris can collect on the cables and result in a system failure. The approach is to bury the cable.

WA—Designing on the fly with not a lot of experience in the area, so hit the learning curve on the steep end.

8.3 Please comment on the reliability and longevity of the scour monitoring systems:

AK (1/2.9)—This particular site has been relatively trouble free. Other sites not as reliable.

AK (2.1)—Heavy debris and ice at this site. Two previous installations destroyed by ice and debris.

AK (2.2–2.8; 2.18)—Heavy debris and ice at this site. False returns from debris are common.

AK (2.10–2.14; 2.16–2.17; 2.19)—This particular site has been relatively trouble free. Other sites not as reliable.

AK (2.20)—Site equipment lost during 10/2006 flood. Sonar mounting difficult because of large boulders.

AR—Too soon to tell.

CA—Solar panel rotated out of proper alignment. This was likely due to adjacent bridge replacement construction. During 4 days of continuous rain, part of the system was not able to transmit. Acoustic stage gage is not functional. Never really worked right.

FL–D7—Two to three repairs or replacements of the sensors per year due to marine growth or vandalism.

FL–D2—Five of the 8 sonars originally installed have broken at their attachment to the piling due to high water velocities. Would prefer to see an extended maintenance from the vendors. Also, aluminum encasements work better than PVC where there are high water velocities.

GA (1–4)—Usually need repairs after extreme events such as hurricanes.

HI (1)—The monitoring systems were well designed and manufactured by ETI. However, since the bridge site in the current project is in a tidal inlet, some corrosion and rusts with the steel pipes have occured.

HI (2)—The monitoring systems were well designed and manufactured by ETI. However, since the bridge site in the current project is in a tidal inlet, some corrosion and rusts have occured. In addition, marine organisms such as shells and algae have grown on the sonar sensor hindering the sensor's performance.

IN—Sonar broke away during flooding.

KS—The main problems involved debris build-up blocking sonar path, damaging the equipment and sonar reflecting off of footings instead of channel bottom.

MD—The primary problem has been the power source (rechargable batteries). It is our view that we have had reasonable service from the meters themselves, since they were installed in 1998. Problems with repairing batteries are difficult due to access limitations.

MN—Monitors not robust enough—vulnerable to debris and ice.

NC—The site where these scour monitoring devices were tested is extremely severe. There are records where some areas of this bridge have scoured and filled as much as 54 ft. Many scour countermeasures have been used at this site. They range from Armor Stone placed around bents, new steel helper bents, Concrete Cylinder Pile Helper Bents, and Gabion Mat Scour Protection. Currently, A-Jax and sand bag scour protection is being installed around one bent. The water velocity at this site can be in the 12 to 15 fps range. The one installation in NC was not reliable. One part only lasted 83 days. From what I have seen from vendors, literature, and information from other states, reliability and longevity are major issues with most of the systems that are available. Initial cost is a major issue with many of the systems.

NJ (1–2)—Need to be protected from the public and need to check up on system at least once monthly.

NV—Vandalism could not be prevented so reliability/longevity was poor

NY–R10 (2)—The solar panels have been reliable. There has been corrosion and electrolysis of the underwater components of the transducer mounts. There also has been siltation at two piers so that the transducer cannot take readings. At one pier location the conduit to the underwater components has been broken.

TX—Problems with sensor attachments to piers. Need redesign.

VT—The TDRs are very robust and being buried in the river they are protected from floating ice and debris. The bulk of the maintenance is refining the data collection system and the web cams.

WA—Working great—protected them with steel tubing for debris resistance. Float switch issues so one sonar doesn't shut off when perched above water during low-flow.

8.4 Please comment on the costs of <u>operation, maintenance, repair and inspection</u> with respect to the original installation costs.

AK (1)—Monitoring for scour is as expensive if not more expensive long-term than providing a permanent physical countermeasure in many cases.

AK (All 2)—Monitoring for scour is an expensive initial investment.

AR—Too soon to tell.

CA (DOT)—Constant traffic needs makes it very difficult to perform any maintenance to the system. Insufficent commitment to maintain the equipment.

CA (Av)—Rather an expensive prospect; $60K (not including engineering) just for materials with another $60K for plans, specs, encroachment permits etc.

Fl–D7—Operation and maintenance estimated at $18,000, and repair and inspection estimated at $9,000.

FL–D2—Operation and maintenance are in line with expectations. Cost of repairs was approximately double what was anticipated.

HI (1)—Vandalism has been a serious problem since the site is near a public beach park. The amount of work associated with maintenance and repair was more than initially expected.

HI (2)—Vandalism has been a serious problem since the site is near a public park. The amount of work associated with maintenance and repair was more than initially expected.

IN—First installed in May 1997, reinstalled sonar device several times after it broke away during highwater events.

IN—High cost due to having to reinstall sonar device.

MD—This was SHA's first experience with a fixed monitoring system. The ongoing expenses have been reasonable. If we utilize a fixed system on a future bridge, an important item to include is a continuing maintenance contract with a firm familiar with the equipment and able to make repairs in an expedient manner.

NC—We do not have actual maintenance costs. However, from the knowledge that I have about these systems, operation, inspection, and maintenance are going to be often and expensive. If there is going to be widespread use of scour monitoring systems, all costs and time to monitor, inspect, and maintain must be reduced drastically.

NV—These costs would have been substantial if we had attempted to keep up with the vandals

NY–R10 (1–2)—Maintenance is modest but repairs are expensive, due to access by divers and need to work in difficult environment.

TX—TxDOT needs to take responsibility for maintenance or hire outside contractor.

VT—General maintenance of the software and visiting the site for physical ice thickness measurement, water depths, etc.

8.5 Were there any additional problems or issues?

AK (All)—Developing an instrument bracket that will withstand ice/debris and still reach beyond the upstream extent of footing/pile cap.

FL–D7—Budget does not anticipate unscheduled repairs. Problems mostly related to durability of sensors and vandalism.

FL–D2—High water velocities caused excessive strain on mounting brackets.

MD—Any maintenance effort involving specialized equipment and requiring personnel with specialized training in operating and maintaining the equipment can be expected to be a problem area in the event of equipment malfunction. Similar experiences have been noted by other states with pumping stations, special designs for sewage treatment systems in rest areas, etc.

NV—Remote sites are where this technology would be most valuable, but are also where power, communications, and vandalism are the greatest issues.

8.6 What lessons have you learned with the fixed scour monitoring systems?

AK (All)—More expensive than initially thought, but an alternative where physical countermeasures are impractical. Can be used to demonstrate that a scour problem does or does not actually exist (verification of calculations).

AR—Instrumentation is easy, protecting data cables coming from sensor in water is tough part.

CA (DOT)—Instrumentation group is too dependant upon a single individual for support. Need to determine the proper alarm trip levels for each item we are monitoring. Staff tends to think if we do not hear anything, then every thing is okay, but there could be a problem with the system not calling in.

FL–D7—Maintenance needs were greater than anticipated.

FL–D2—More concentration on mounting brackets and material used.

GA (1–4)—Protecting the sensor cables from debris is very important.

HI (1–2)—They are effective and efficient systems for collecting scour depth data during real flood. They need to be inspected and maintained often.

IN—Do NOT want to use either device.

KS—Bridge scour could be monitored and reported real time, but maintaining the operation of them was very difficult.

MD—It is important to establish an on-going maintenance contract with a firm having special expertise with the scour monitoring equipment to cover the entire period of the monitoring effort.

MN—Need to be very robust; need to have personnel responsible for follow up. Probably will not use sliding collar or similar device in Minnesota.

NC—None.

NV—When used as part of a Plan of Action/Emergency Response Plan, monitor selection and installation is only a small part of the endeavor. Developing and maintaining response protocol and responsibilities as well as long-term upkeep of the system are major challenges.

NY–R10 (1–3)—Seasonal pattern of infill

TX—Attachments need to be resistant to debris.

VT—TDR have provided insight into the scour under ice fissure.

8.7 What benefits have you gained using fixed scour monitors?

AK (All)—Some insights into site specific scour processes

AR—Will know in real time what the status of bridge is.

CA (DOT)—Used as a safety valve, but can only tell us that the site is in serious trouble. We may not respond in a timely fashion. Engineering judgement is the most important portion of the alarm system.

CA (Av)—Allows us to monitor the bridge and keep the route open longer than if there were no monitoring devices (because you would have to shut down the bridge prematurely).

FL–D7—Confidence level for safety concerns. Saving cost in inspection—two men crew approximately 2 h travel time plus 1 h to take measurements.

FL–D2—We can have a faster response to degradation of the groundline, especially during high water velocity when it is difficult to put divers in the water or take soundings.

GA (1–4)—A better understanding of the scour process.

HI (1–2)—They helped the project team to collect valuable scour depth data during a storm, and the data were used to examine the accuracy of the existing scour equations.

IN—None

MD—The scour monitors serve to provide real-time data during periods of high water regarding the scour potential at the bridge. The fixed monitors, when used in a comprehensive program including underwater inspections and a plan of action for emergency conditions, serve to assure the safe passage of the public using the bridge.

MN—Found out that type of monitoring system does not work on streams with heavy debris.

NC—None

NY–R10 (1–3)—Safety assurance and peace of mind

NYCDOT—Safety assurance during construction of the new bridge
TX—Climbing the learning curve on fixed scour monitoring and evaluation feasibility.
WA—Been able to keep roadway open during rainy season.

8.8 What advancements do you think are important for the future of fixed scour monitoring technology?

AK (All)—An instrument that measures depth and location of the deepest point of the scour hole, or maps the entire scour hole. The deepest point likely changes from event to event. Currently, we are taking a point measurement that may or may not be the deepest point. A non-contact method for measuring bed elevation.
AR—Means of data retrieval such as wireless, fiber, cellular data networks, etc.
CA (DOT)—Inclusion of live video. Positive feedback from floatout devices.
CA (Av)—Reliable cell phone coverage
FL–D7—Identification of durable sonar and water elevation sensors with reasonable cost. Development of economically feasible water velocity sensor. Also keep a good record of estimate or calculated change.
FL–D2—To develop economically reasonable water velocity sensor.
GA (1–4)—An integrated scour monitoring system. I had to piece together many different components from different vendors.
HI (1–2)—Wireless data transmission, smaller sensors, fewer components, can be protected from vandalism, minimum corrosion in salt water.
MD—The system devised for the Woodrow Wilson Bridge has been a good one, the principal issue being the loss of power from the rechargable batteries. We need to find out what improvements can be made to assure that batteries remain operational.
MN—Robust, inexpensive, easy data collection, ability to install, easy to maintain.
NC—Decrease in cost, reliability, longevity, minimum or no maintenance.
NY–R10 (1–3)—Continue to improve reliability and durability of equipment.
TX—Development of more reliable sensing technologies.
VT—In theory, the TDR technology is scalable to monitor deeper scour holes.
WA—Sonar accuracy.

8.9 How long do you intend to keep the data obtained from this scour monitoring project?

AK (All)—Do not know.
AR—Will be archived
CA (Av)—Caltrans responsibility
GA (1–4)—It will remain in the USGS database.
HI (1–2)—As long as possible.
IN—Purdue published their study, as far as I am concerned we are done with this.
MN—Do not plan to discard data, although very little was collected before device was destroyed.
NC–R10—NC does not have the data. (The monitors were installed and maintained by the USGS and the University of Florida.)
NJ (1–2)—Indefinitely.
NV—The data has been discarded already since no events have occurred during the active life of the project.
NY–R10 (1–3)—Indefinitely
NY–STA—Not sure
VT—Currently have 4 years of funding by the Vermont Agency of Trasportation. Annual costs are small compared with the benefit of documenting the correlation between the ice and scour process.
WA—Until the bridge is replaced and then may use equipment elsewhere in county on other scour critical bridges.

Section 9 Request for Materials

9.1–9.9 Responses varied by bridge.

APPENDIX D

Bridges with Fixed Scour Monitors

Three tables are included to supplement the tables found in chapter three. Table D1 lists the 50 states, the District of Columbia, and Puerto Rico and summarizes their experience with fixed instrumentation, their responses to the survey, and the scour critical bridge statistics from the FHWA. Tables D2 and D3 are summary tables of the bridge sites with fixed scour monitoring instrumentation for the states of Alaska and California.

TABLE D1
EXPERIENCE WITH FIXED SCOUR MONITORS, RESPONSES TO SURVEY, AND SCOUR CRITICAL BRIDGES

State/District	Submitted Survey	Use Fixed Monitors	Submitted Bridge Survey(s)	No. Bridges over Water[1]	No. Scour Critical Bridges[1]	No. Bridges Monitored	No. Bridges Submitted[2]	Monitors Operational		
								Yes	No	Unknown
Alabama	1	1	1	14,114	191	1	1	1		
Alaska	1	1	1	810	150	20	20	16	4	
Arizona	1	1		5,561	840	5				
Arkansas	1	1	1	11,623	253	1	1	1		
California	1	1	1	15,386	324	16	9	6	3	
Colorado		1		6,793	417	2				
Connecticut		1		2,365	411	1				
Delaware		1		576	125	1				
District of Columbia		1	1	94	1	1	1		1	
Florida	1	1	1	8,340	250	3	2	2		
Georgia	1	1	1	12,119	76	4	4			4
Hawaii	1	1	1	860	64	2	2		2	
Idaho				3,209	265					
Illinois	1			21,641	614					
Indiana	1	1	1	15,903	1,699	2	1		1	
Iowa	1	1		23,482	781	1			1	
Kansas	1	1	1	23,803	441	1	1		1	
Kentucky				11,225	39					
Louisiana				9,891	845					
Maine	1	1		1,867	235	1				
Maryland	1	1	1	3,163	594	1	1		1	
Massachusetts	1			2,464	865					
Michigan		1		7,575	680	1				
Minnesota	1	1	1	11,331	480	3	1			1
Mississippi	1			14,790	762					
Missouri				20,912	101					
Montana	1			3,578	51					
Nebraska	1			14,808	441					
Nevada	1	1	1	889	102	6	1		1	
New Hampshire		1		1,755	44	1				
New Jersey	1	1	1	3,551	367	2	2			2
New Mexico	1	1		3,001	24	2				
New York	1	1	1	12,090	666	8	6	4	1	1
North Carolina	1	1	1	14,180	81	1	1		1	
North Dakota	1			4,129	84					
Ohio	1			23,326	191					
Oklahoma	1			20,835	501					
Oregon		1		5,495	1,442	8				
Pennsylvania	1			17,328	5,544					
Puerto Rico				1,605	109					
Rhode Island		1		337	131	2				
South Carolina	1			7,784	1,701					
South Dakota	1			5,373	0					
Tennessee	1	1		16,520	1,055	1				
Texas	1	1	1	40,772	650	5	1		1	
Utah	1			1,682	172					
Vermont	1	1	1	2,304	298	3	1	1		
Virgina	1	1	1	9,818	55	1	1		1	
Washington	1	1	1	5,133	965	1	1	1		
West Virginia				5,742	225					
Wisconsin		1		10,689	68	5				
Wyoming	1			1,925	2					
Total	37	33	20	484,546	26,472	113	58	32	19	8

[1] Statistics from the FHWA Bridge Scour Evaluation Program (2003).
[2] Numbers are 2 higher than total and sample bridges because one bridge (Woodrow Wilson Bridge) is in Maryland, Virginia, and District of Columbia.

TABLE D2
MONITORED SCOUR CRITICAL BRIDGES—ALASKA

Br. no.	Bridge name	Comment	Type	Length	Height	# Piers	Piers Monitored	Notes	CDS Route	CDS Mile
202	TANANA RIVER AT NENANA	Large debris problems, have lost two brackets/instruments thus far. Reinstall 2005	1,2,7,8	1307	61	4	1	Monitor 03	170000	269.5
212	KASHWITNA RIVER	flashy	1,2,5	213	27	2	1	Monitor 04	170000	47.9
215	MONTANA CREEK	flashy	1,2,5	140	22	2	1	Monitor 04	170000	61.1
230	SHERIDAN GLACIER NO 3	Misaligned flow, large debris problem, spans shorter than typical debris length	to be installed 2005	201	22	4	1	Monitor 05	210000	14.9
339	COPPER DELTA	Added based on 2002 soundings, flow shift captured more discharge	to be installed 2005				1	Monitor 05	210000	36.2
340	COPPER DELTA	Added based on 2002 soundings, flow shift captured more discharge	to be installed 2005	214		2	1	Monitor 05	210000	36.5
342	COPPER DELTA	Bridge previously tripled in length. Outboard piles added at piers 4 through 9. Pier 6 damaged by iceberg, outboard pile replaced. This bridge currently takes majority of delta discharge, large spur dikes used. 6.0 ft of scour measured at tip of spur dike.	to be installed 2005	881	48	10	8	Monitor 05	210000	37
527	SALCHA RIVER	Large debris problems	1,2,5	504	40	3	1	Monitor 02	190000	324.7
539	KNIK RIVER	Large sediment supply, dunes, max. scour likely in fall/spring when sediment input is lost. Large contraction	1,2,5	506		2	1	Monitor 02	136000	8.6
654	SLANA RIVER	Earthquake damage, pier work planned.	1,2,5	153	19	2	1	Monitor 01	230000	74.1
655	SLANA SLOUGH	Earthquake damage, bridge to be replaced	1,2,5	41	18	0		Monitor 01	230000	74.5
656	MABEL CREEK	Earthquake damage, bridge to be replaced	1,2,5	41	19	0		Monitor 01	230000	75
663	TOK RIVER	Retractable transducer bracket for ice problems	1,2,5	241	23	3	1	Monitor 01	230000	101.1
670	KASILOF RIVER	Measured scour does not support calculated scour thus far. Retractable transducer bracket for ice probes	1,2,5	284	33	2	2	Monitor 01	110000	67.1
671	KENAI RIVER AT SOLDOTNA	Replacement bridge under construction; retractable transducer bracket for ice problems	1,2,5	394	45	3	1	Monitor 01	110000	79.9
735	EAGLE RIVER	Transmitter problems, DP47 site	1,3,4,5,6	211	24	1	1	Monitor 00	296000	16.5
983	RED CLOUD RIVER	Shallow piles	to be installed 2005	63	14	1	1	Monitor 05	68040	7.3
999	GLACIER CREEK	High sediment load	1,2,7	222	31	3	1	Monitor 04	132500	2.3
1243	NENANA RIVER AT WINDY	Uses short-hop spread spectrum to datalogger/transmitter	1,2,5,8	389	43	1	1	Monitor 03	170000	180.4
1383	LOWE RIV LWR KEYSTONE	Difficult site, boulder/cobble bed	1,2,7	303	31	2	1	Monitor 04	190000	19.3
		Key:	1 - Bottom Transducer (sonar)						USGS Annual Monitoring	
			2 - Stage Transducer (pressure)						Retrofit or monitor in place	
			3 - Stage Sensor (ultrasonic)						Work in design	
			4 - Piezoelectric Film Array						Do not need to visit	
			5 - Orbcomm Satellite							
			6 - Cellular							
			7 - Landline							
			8 - Spread Spectrum							
			All have Air Temp and Battery Voltage reported							

Prepared by Mark Miles, Alaska DOT & PF and Jeff Conaway, U.S. Geological Survey.

TABLE D3
MONITORED SCOUR CRITICAL BRIDGES—CALIFORNIA

	Bridge No.	Bridge Name	Location	Comments (scour and monitor problems)	Type of Monitor(s)	Monitored	Year Installed	Year Removed or Abandoned	Cost	Length	Height	Item 113	Foundation	Subsurface	Route No.	ADT	Data Download	Status
1	49-0095	Cholame Creek	San Luis Obispo County near Shandon	Sediment loads; sheetpile checkdam for migrating headcut	1 Tilt sensor & 1 stage gage	1 Pier	1999	N/A	$28,000+/- (total) $13,000+/- (mats)	184	~25 ft	3	Piles	Silt, F Sand	46	5,370	Base Computer and Internet	Operational
2	14-0016	St. Helena Creek	Lake County near Middletown	One pier borderline scour critical and decided to monitor until the bridge is replaced for other reasons; debris loading and high velocity flows; not able to install magnetic sliding collar because streambed was too rocky	1 Tilt sensor & 1 stage gage	1 Pier	2002	N/A	$13,000 (materials)	187	~10 ft	3	Piles & Spread Footings	Silt, F/C/M Sand, Cobbles, Weathered Stone; Riprap	29	7030	Base Computer and Internet	Operational
3	56-0003 and 56-0003Z	San Gorgonio Wash	City of Banning, Riverside County	Used to warn of headcut coming from downstream	2 Magnetic sliding collars, 6 closed loop circuit cables & 1 stage gage	2 Piers, downstream levee and streambed	2005	N/A	$60,000 (materials)	72.8	~14 ft	8	Spread Footings	C/M Sand, Gravel, Cobbles	10	86,000	Base Computer and Internet	Operational
4	54-1000	Colorado River	San Bernardino, County/Parker, AZ	Monitoring long-term degradation at Piers 8-10. Channel degradation and/or thalweg migration below 328 feet in combination with local sour could result in instability. Converting from cellular to landline in 2008 due to reception problems. Bridge is one half owned by Arizona DOT.	3 Magnetic sliding collars and 1 stage gage	Long-term degradation	2002	N/A	$18,500 (materials)	200 m	~30 ft	3	Piles and Spread Footings on Piles	Silt, F/C/M Sand, Gravel	62	3400	Base Computer and Internet	Operational
5	12-0004	Biggs Extension Canal	Butte County	Man-made drainage canal	3 Tilt sensors	1 Pier and 2 Abutments	2005	N/A	Some equipment salvaged from San Mateo Creek/$7,000 (materials)	11.3 m	~7 ft when empty	3	Spread Footings	Sandy Clay	99	11,000	Base Computer and Internet	Operational
6	10-0123	Greenwood Creek	Mendocino County near Elk		2 Tilt sensors & 1 stage gage	2 Piers	2007	N/A	$15,000 (materials)	153.9 m	~55 ft	3	Spread Footings on Piles	Sand, Gravel, Cobbles	1	1375	Base Computer and Internet	Operational
7	53-2245	North Fork San Gabriel	Los Angeles County	Difficult getting paperwork signed and approved because of Sole Source Justification (Purchasing from ETI without competitive bidding because don't know of any other manufacturers of compatible system) and IT concerns about satellite data coming through the Caltrans firewall.	1 Tilt sensor & 1 stage gage	1 Pier	To be installed	N/A	$19,000 (materials)	67.1 m	~45 ft	3	Spread Footings on Piles	Sand, Gravel, Cobbles, Small Boulders	39	120	Base Computer and Internet - data transmitted by satellite	To be installed
8	56-0004 L/R	Whitewater River	Riverside County	Field review indicates that extensive scour has occurred at bridge foundations. Calculations indicate that scour may undermine one or more of the spread footings during a flow equal to or greater than a 2-year event. RSP was also placed as a mitigation measure.	14 Tilt sensors, 1 stage gage	14 piers, 7 per bridge	2008	N/A	$63,000 (materials)	154.7 m	~20 ft	2	Spread Footings	Course sand and small gravel with scattered large gravel and cobbles	10	29,500	Base Computer and Internet	Operational
9	53-1547	Tick Canyon Wash	Los Angeles County	Possible migration of downstream headcut; problems with overgrown vegetation; maintenance crews clear it regularly	16 Float-outs & 1 stage gage	2 Piers and possible headcut downstream	1999	2006		114	~10 ft	3	Piles	C/M Sand, Gravel, Riprap	14	89,000	Base Computer and Internet	Construction of Check Dam where float-outs had been
10	08-0005	Toomes Creek	Tehama County near Vina	Mitigation in channel not feasible due to environmental concerns; debris and sediment loads; one broken solar panel	5 Tilt sensors	5 Piers	2002	2006	Some equipment salvaged from San Mateo Creek/$5,000 (materials)	385	~15 ft	3	Spread Footing	Silt, F/C/M Sand, Gravel, Riprap	99	8,190	Base Computer and Internet	Bridge replaced
11	52-0007 L/R	Santa Clara River	Ventura County between Oxnard and Ventura	Debris and sediment loads; high velocity flows; interuptions with solar power	8 Tilt sensors, 32 float outs, & 1 stage gage	8 Piers	2000	2006	$67,000+/- (total) $52,000 (materials)	1,830	~30 ft	3	Spread Footing on Piles	C/M Sand	101	71,700	Base computer & Internet	Bridge replaced
12	39-0071	Merced River	Snelling	Solar panel vandalized	2 Sonars	2 Piers / one per pier	1997		$39,000+/- (total) $7,000+/- (mats)	473	~20 ft	2	Spread Footing	C/M Sand, Gravel, Cobbles	59	2,230	At site	Discontinued
13	44-0002 L/R	Salinas River	Soledad	Sudden 3 ft settlement of pier of right bridge; sonars impacted by large sediment/debris loads	Sonars, 14 float outs and magnetic sliding collar	7 Piers / two float outs per pier				1,260	~30 ft		Piles	Clay, Silt, F/C/M Sand, Gravel, Cobbles, Organics	101	12,350	Base computer	Bridge replaced
14	57-0001 L/R	San Mateo Creek	Oceanside	Scour critical bridge scheduled for emergency repairs - monitoring was for interim until structural countermeasures could be installed	8 Tilt sensors	8 Piers / one per pier - Note: 4 per bridge	2001	2002	$56,000 (materials)	506	~50 ft	3	Piles	C/M Sand, Gravel, Cobbles	5	22,500	Base computer	No - salvaged
15		Santa Rosa River			6 Float-outs, 2 tilt sensors				$29,000+/- (total) $15,000+/- (mats)									Inactive
16		Putah River			4 Tilt sensors				$52,000+/- (total) $25,000+/- (mats)									Inactive
17		Kidder Creek			3 Float-outs				$30,000+/- (total) $12,000+/- (mats)									Inactive
18		Scott River			4 Float-outs				$30,000+/- (total) $12,000+/- (mats)									Inactive
19		Temecula Creek			9 Float-outs				$33,000+/- (total) $13,000+/- (mats)									Inactive
20		Eel River			5 Tilt sensors													Inactive
21	11-0029	Stoney Creek	Glenn County near Orland	Sonor installed on Pier 5 in 1997 to monitor the rock countermeasures around the pier. This was paid for by FHWA under DP 97. Tilt sensors installed later (Northwestern University?) on all piers and remained until bridge was demolished. Warnings of high upstream releases from Black Butte Dam were given and an individual would be sent to watch the bridge during high stage levels.	Sonar, 18 tilt sensors	18 Piers	1997	2005	Paid for by others	454.8 m	~20 ft	3	Piles	Sand and Cobbles	32	7650	Base Computer and Internet	Bridge replaced
22		Russian River			Tilt sensor(s)													Inactive
23	04-0134	Eel River (Fernbridge)	Humboldt County	Community objected to devices on historic bridge (1911); gravel mining in area and couldn't see through sediment	Sonar					734 m	45 ft	3	Footing on piles	Dense tan sand and gravel with some clayey silt	211	4500		Inactive
24	53-0687 L/R	Santa Clara River	Los Angeles County near Santa Clarita		12 Float-outs, 2 tilt sensors, 1 stage gage	2 Piers	1999	2003	$39,000 including labor	742 ft	~45	3	H Piles	Silt, F/C/M Sand, Gravel, Cobbles	5	59,500	Base Computer and Internet	Bridge replaced

APPENDIX E

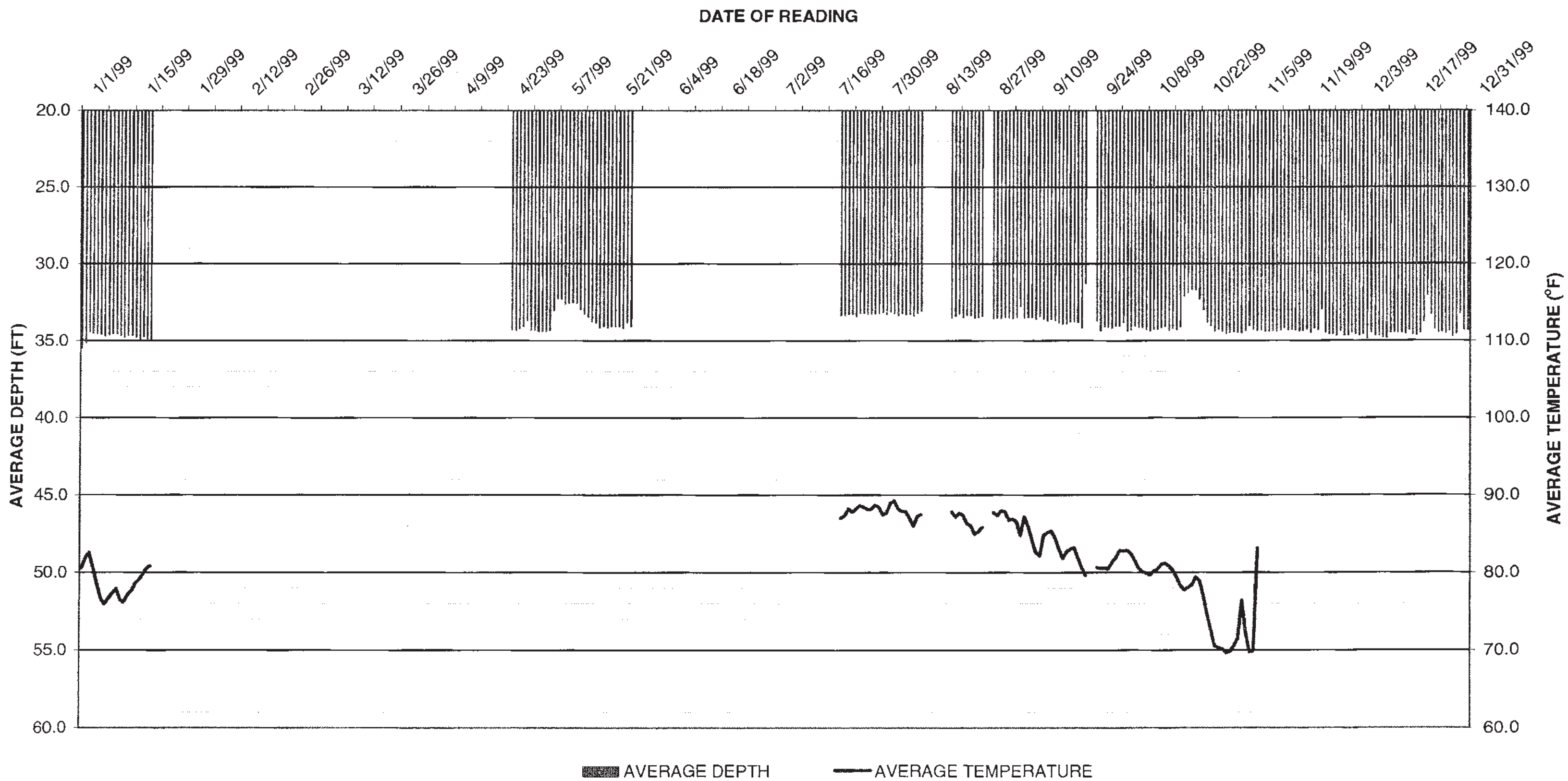
Sample Data

Appendix E contains sample data submitted by the survey respondents. An index has been provided below listing the data presented in this appendix.

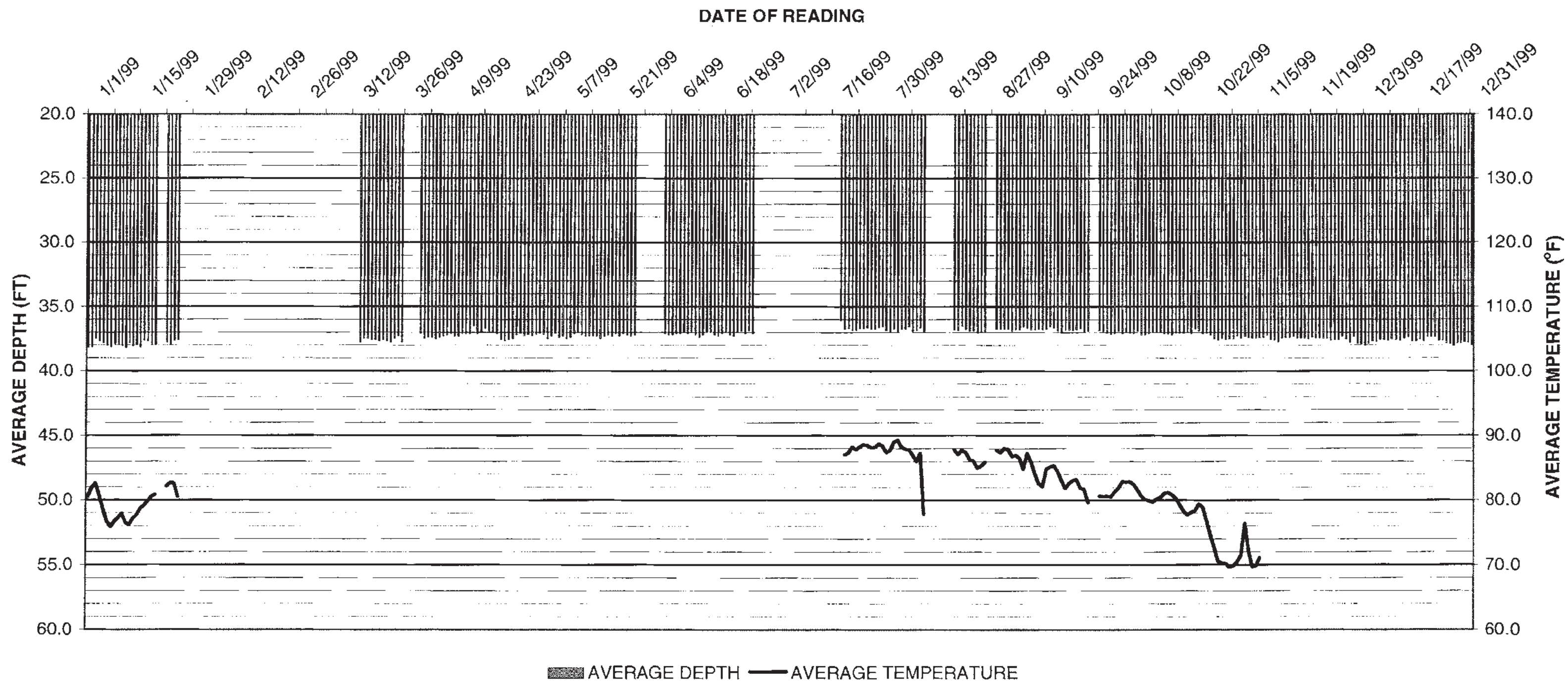
TABLE E1
INDEX OF BRIDGE SITES WITH SAMPLE DATA

State	Bridge Name	Sample Data
Florida		
	John's Pass Bridge	1999 Scour Performance History
		2004 Scour Performance History
Maryland		
	Woodrow Wilson Memorial Bridge	1998–2003 Historic Scour
		1999–2004 Historic Velocities
		Tropical Storm Isabel, Sept. 2003—Scour
		Tropical Storm Isabel, June–Dec. 2003—Scour
New York		
	Wantagh Parkway over Goose Creek	1998–2008 Daily Minimum Scour and Water Stage
		1998–2008 Historic Scour—Monthly Minimums
		Bi-weekly Scour and Water Stage
		Hurricane Floyd, Sept. 1999—Scour and Water Stage
		Nor'easter, April 2007—Scour and Water Stage

JOHN'S PASS BENT 4 (UNIT 1)
1999 SCOUR PERFORMANCE HISTORY
(AVERAGE DAILY VALUES)

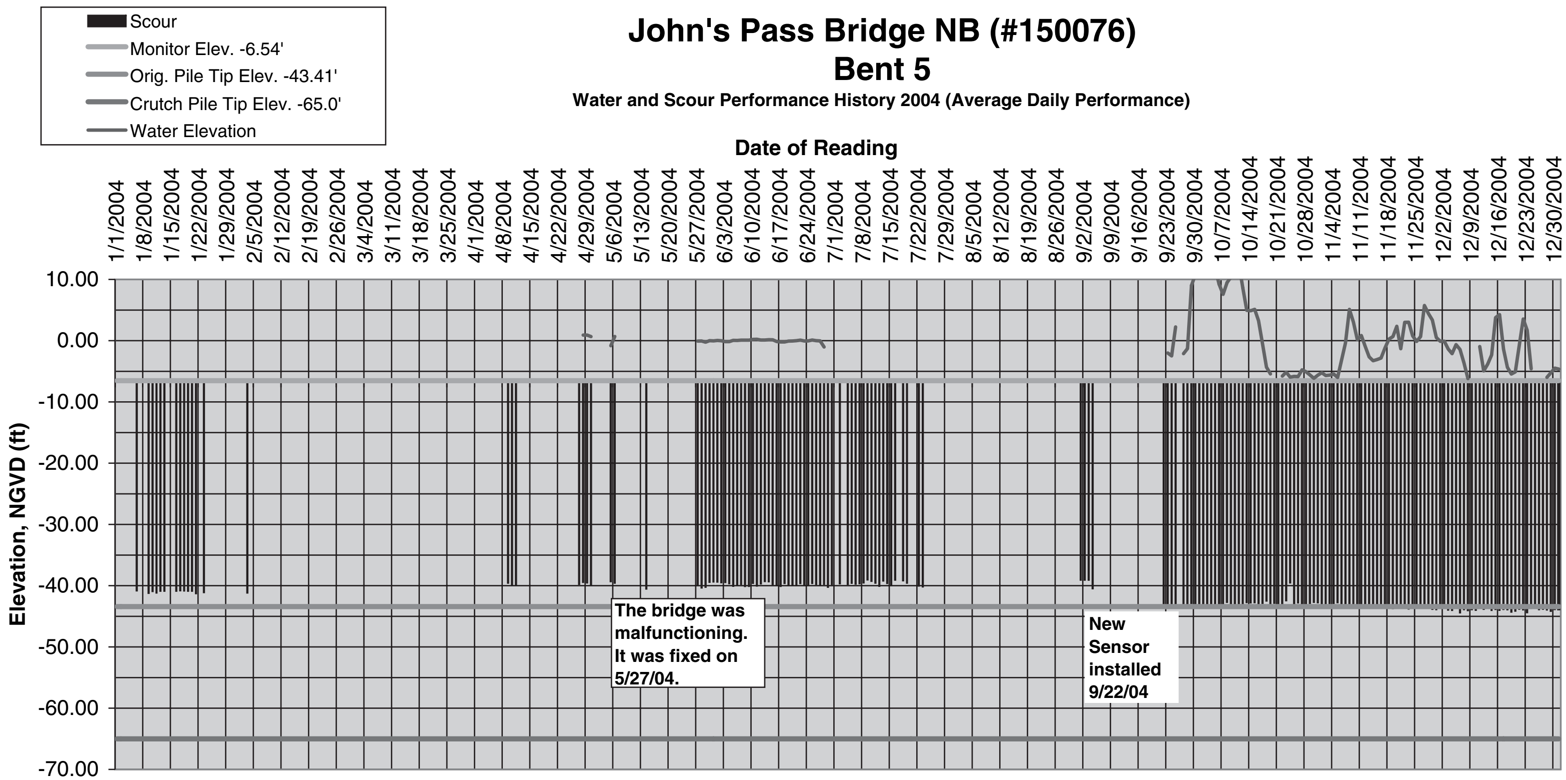


JOHN'S PASS BENT 5 (UNIT 2)
1999 SCOUR PERFORMANCE HISTORY
(AVERAGE DAILY VALUES)

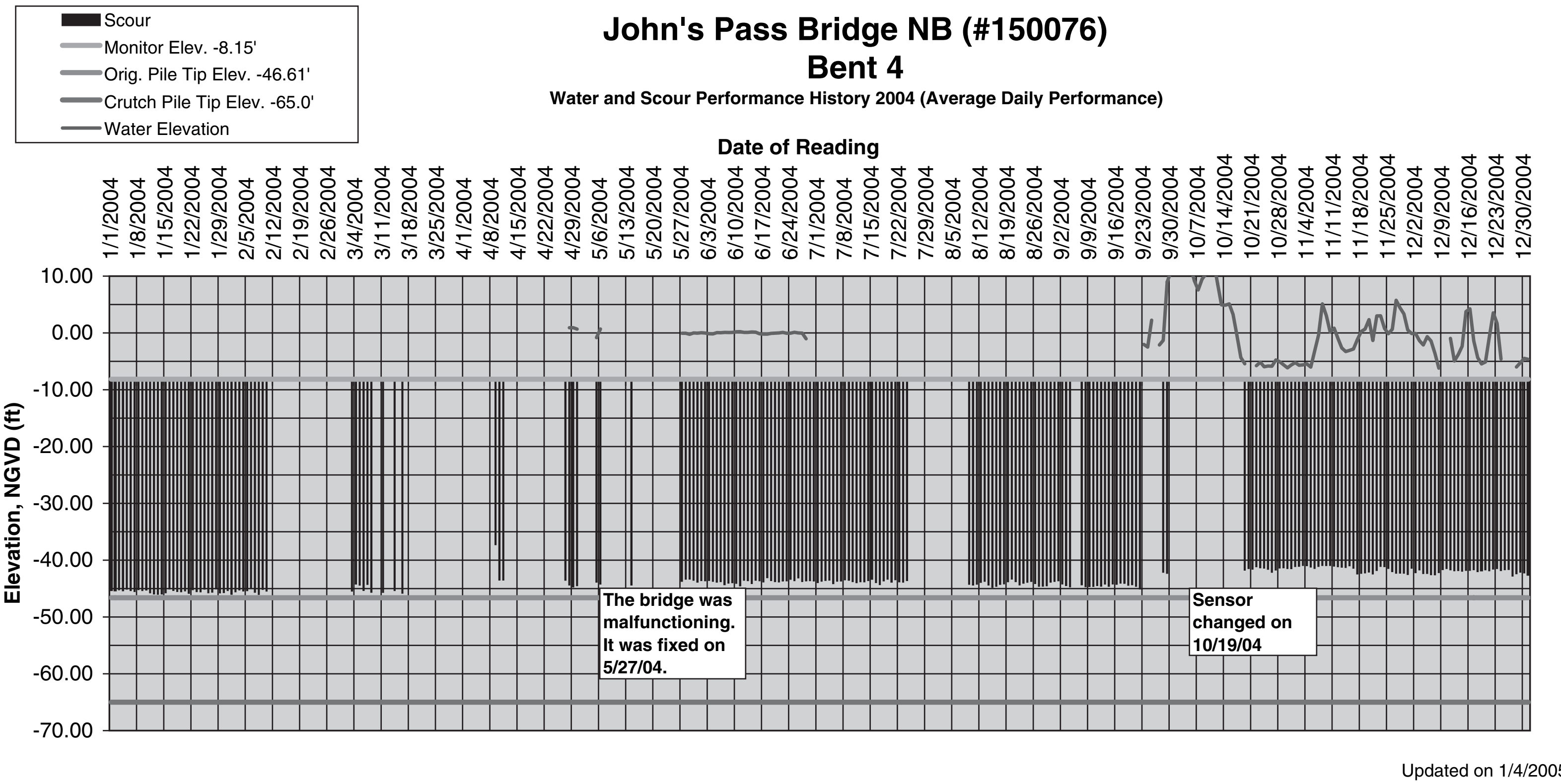


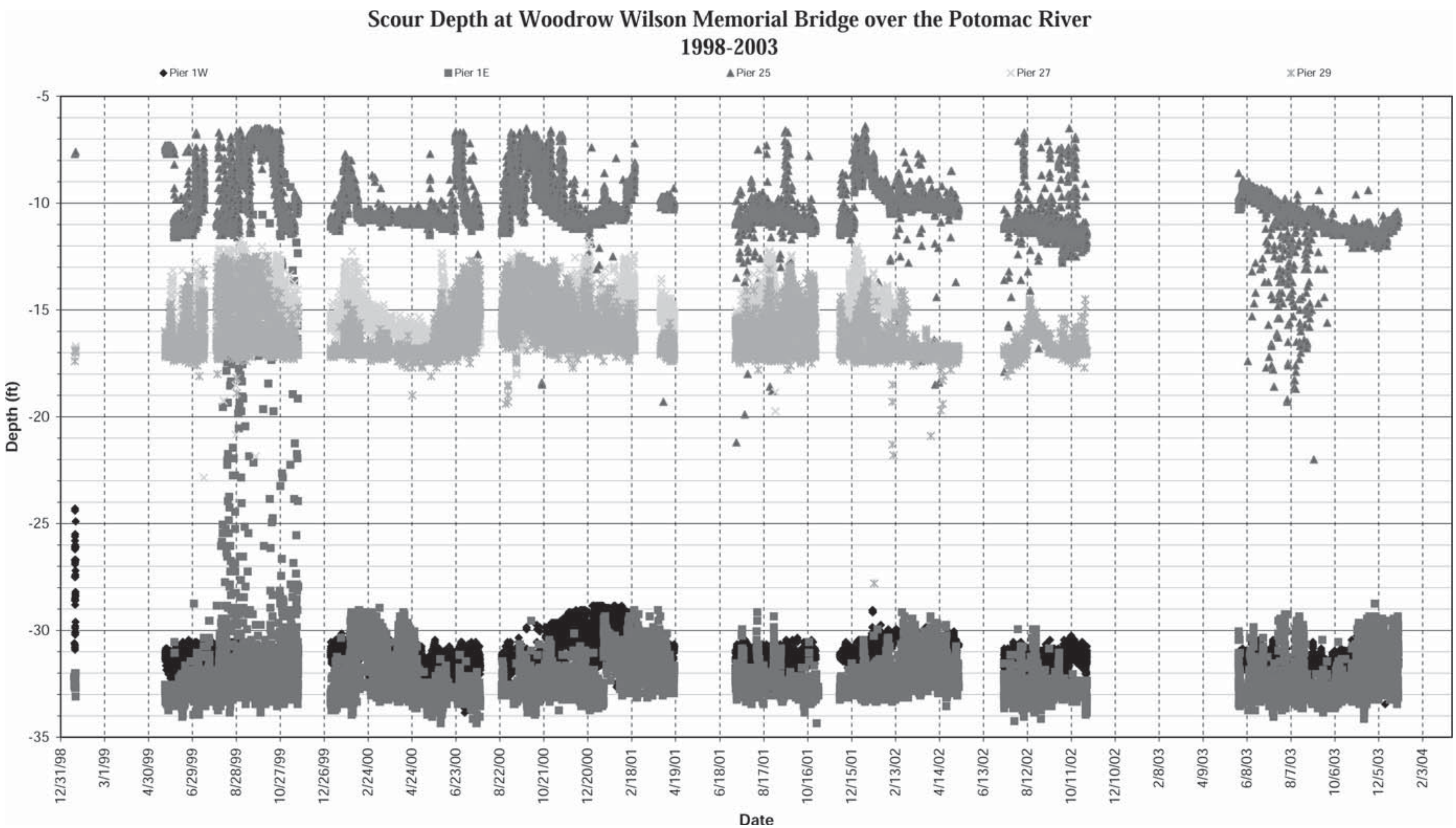
John's Pass Bridge NB (#150076)
Bent 5

Water and Scour Performance History 2004 (Average Daily Performance)



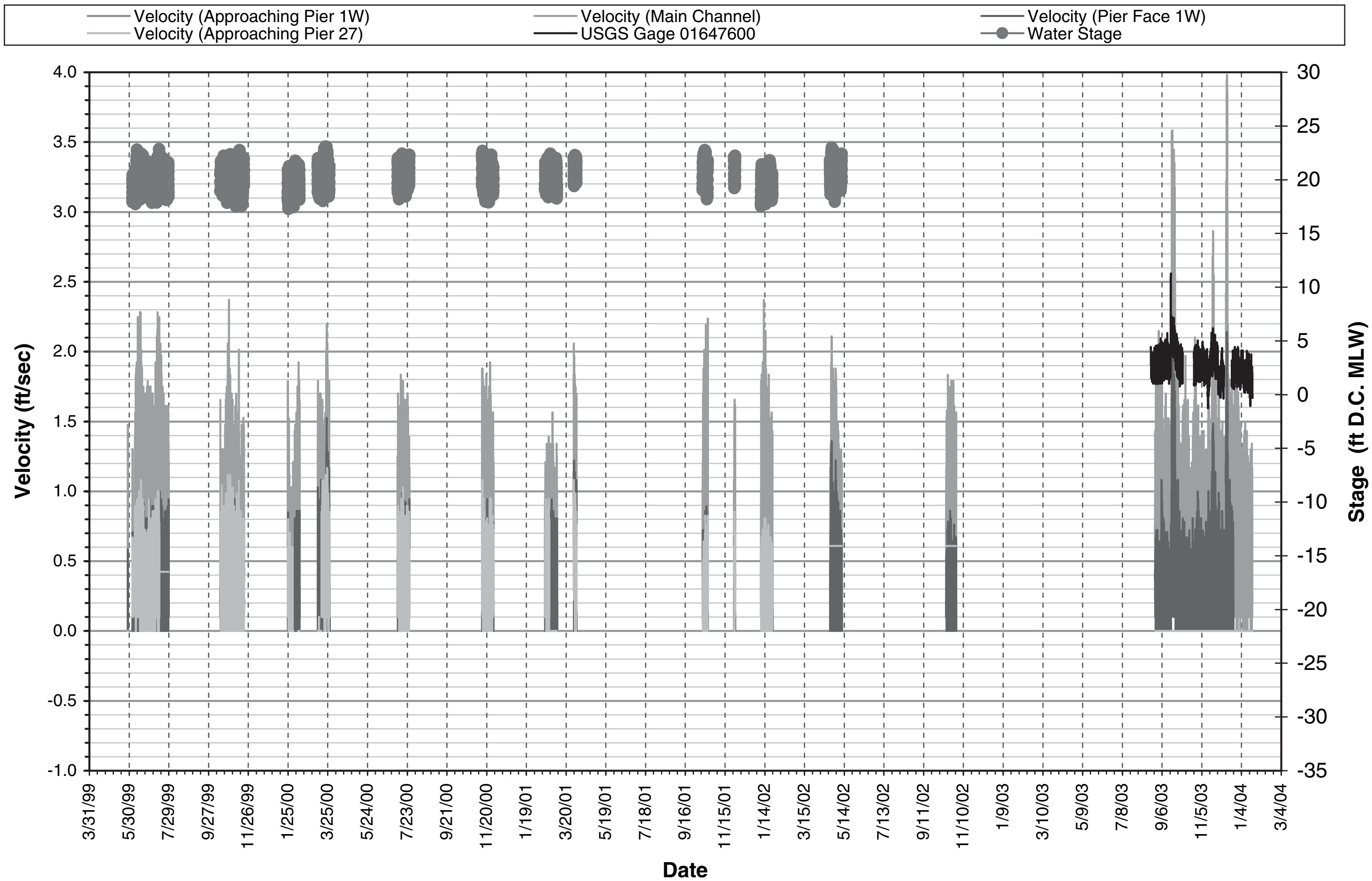
Updated on 1/4/2005


John's Pass Bridge NB (#150076)
Bent 4
Water and Scour Performance History 2004 (Average Daily Performance)
Scour
Monitor Elev. -8.15'
Orig. Pile Tip Elev. -46.61'
Crutch Pile Tip Elev. -65.0'
Water Elevation
Date of Reading
Elevation, NGVD (ft)
The bridge was malfunctioning. It was fixed on 5/27/04.
Sensor changed on 10/19/04
Updated on 1/4/2005

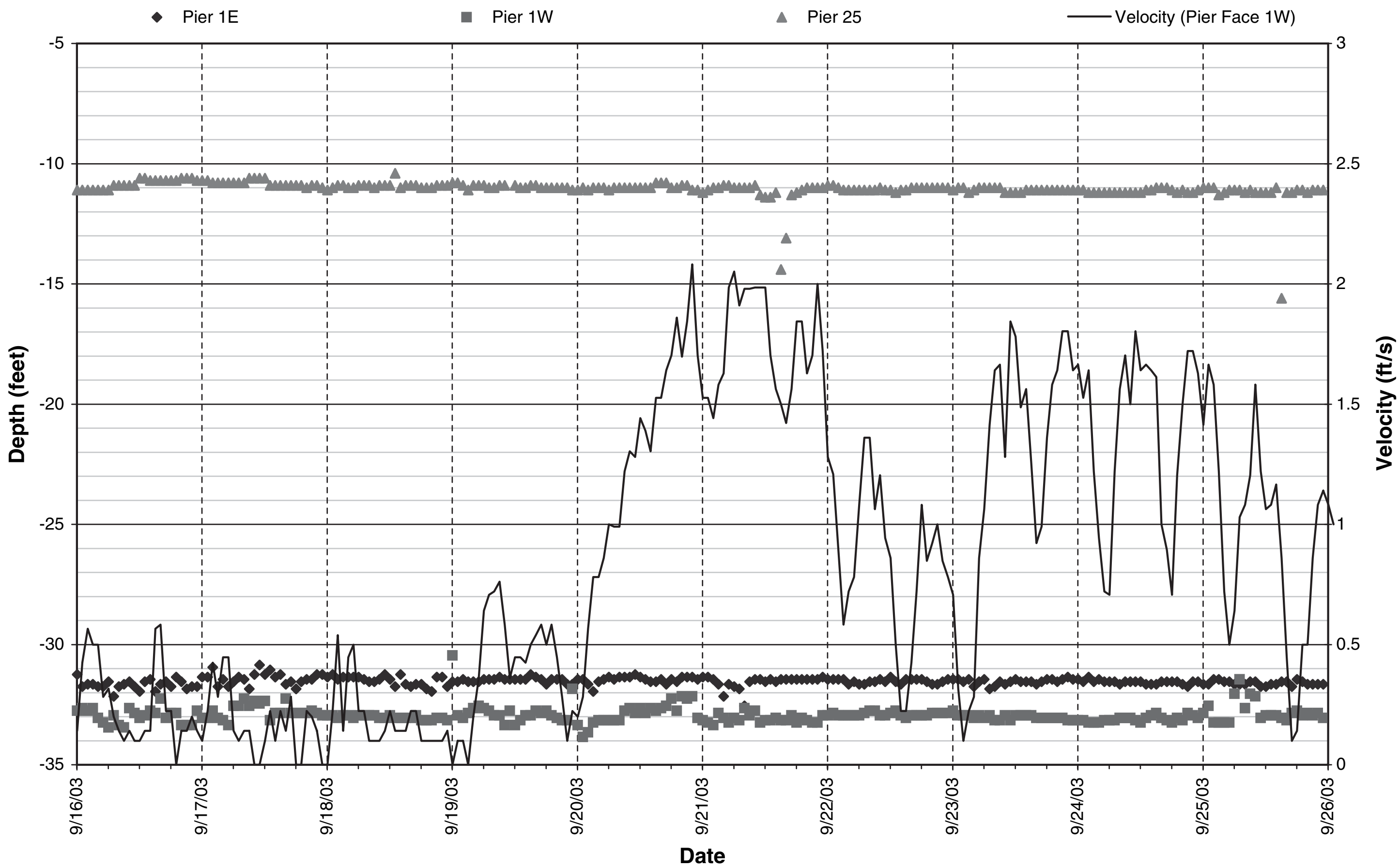


Scour Depth at Woodrow Wilson Memorial Bridge over the Potomac River
1998-2003
Pier 1W
Pier 1E
Pier 25
Pier 27
Pier 29
Depth (ft)
-5
-10
-15
-20
-25
-30
-35
12/31/98
3/1/99
4/30/99
6/29/99
8/28/99
10/27/99
12/26/99
2/24/00
4/24/00
6/23/00
8/22/00
10/21/00
12/20/00
2/18/01
4/19/01
6/18/01
8/17/01
10/16/01
12/15/01
2/13/02
4/14/02
6/13/02
8/12/02
10/11/02
12/10/02
2/8/03
4/9/03
6/8/03
8/7/03
10/6/03
12/5/03
2/3/04
Date

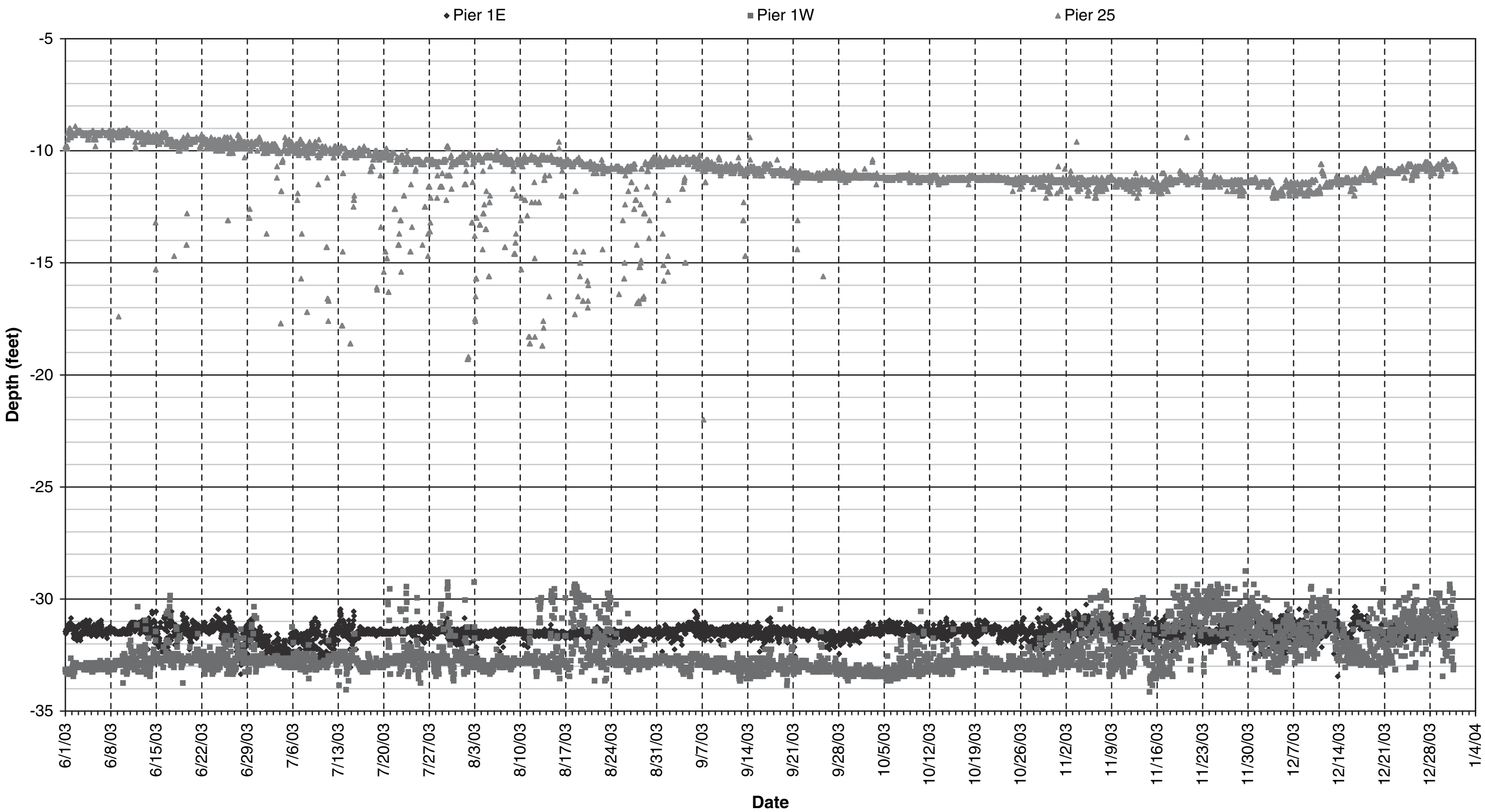
Velocity for Woodrow Wilson Memorial Bridge over the Potomac River



Scour Depth at the Woodrow Wilson Memorial Bridge over the Potomac River
September 16-26, 2003: Tropical Storm Isabel

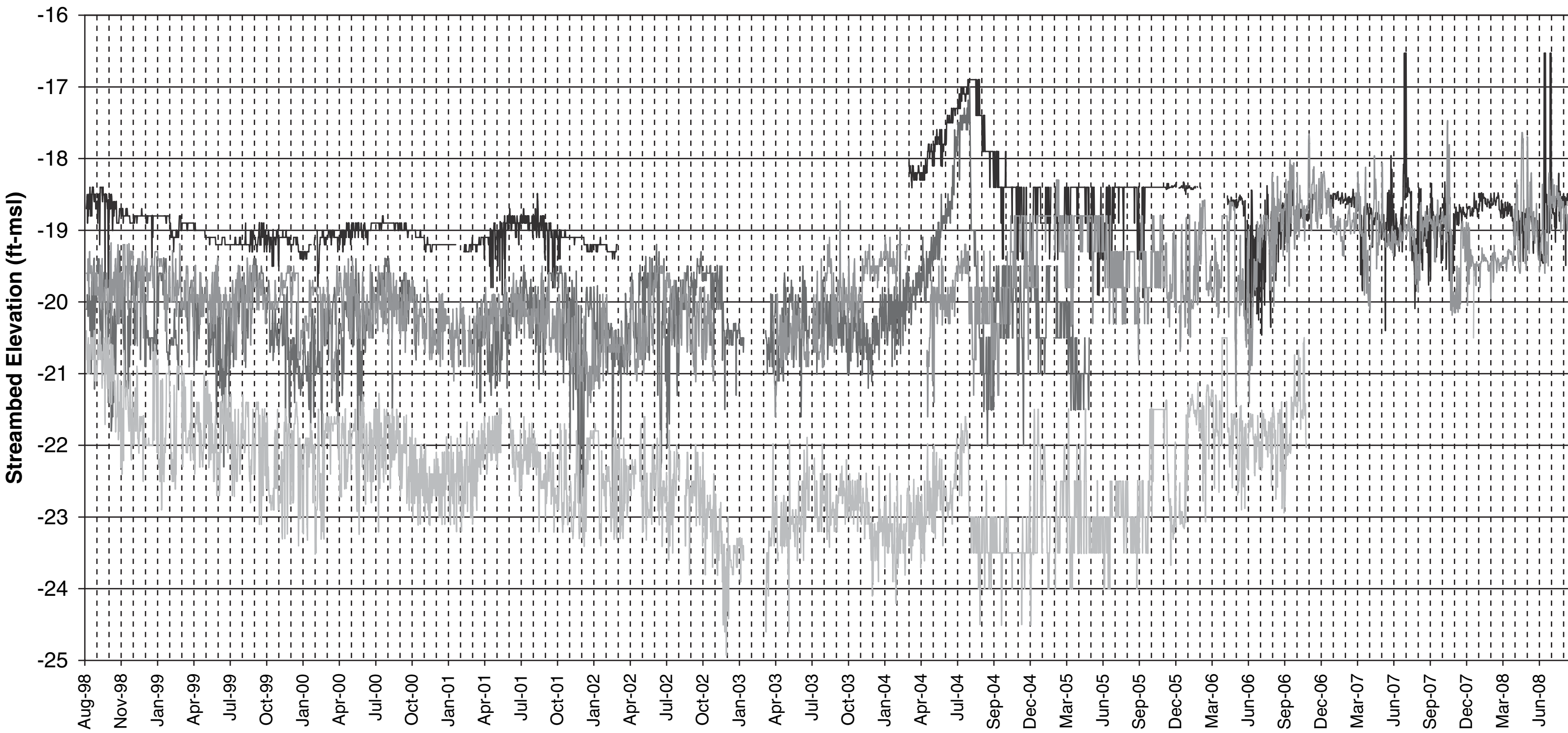


Scour Depth at the Woodrow Wilson Memorial Bridge over the Potomac River
June through December, 2003



Sonar Scour Monitor Data for Wantagh Parkway over Goose Creek

Daily Minimum Streambed Elevation



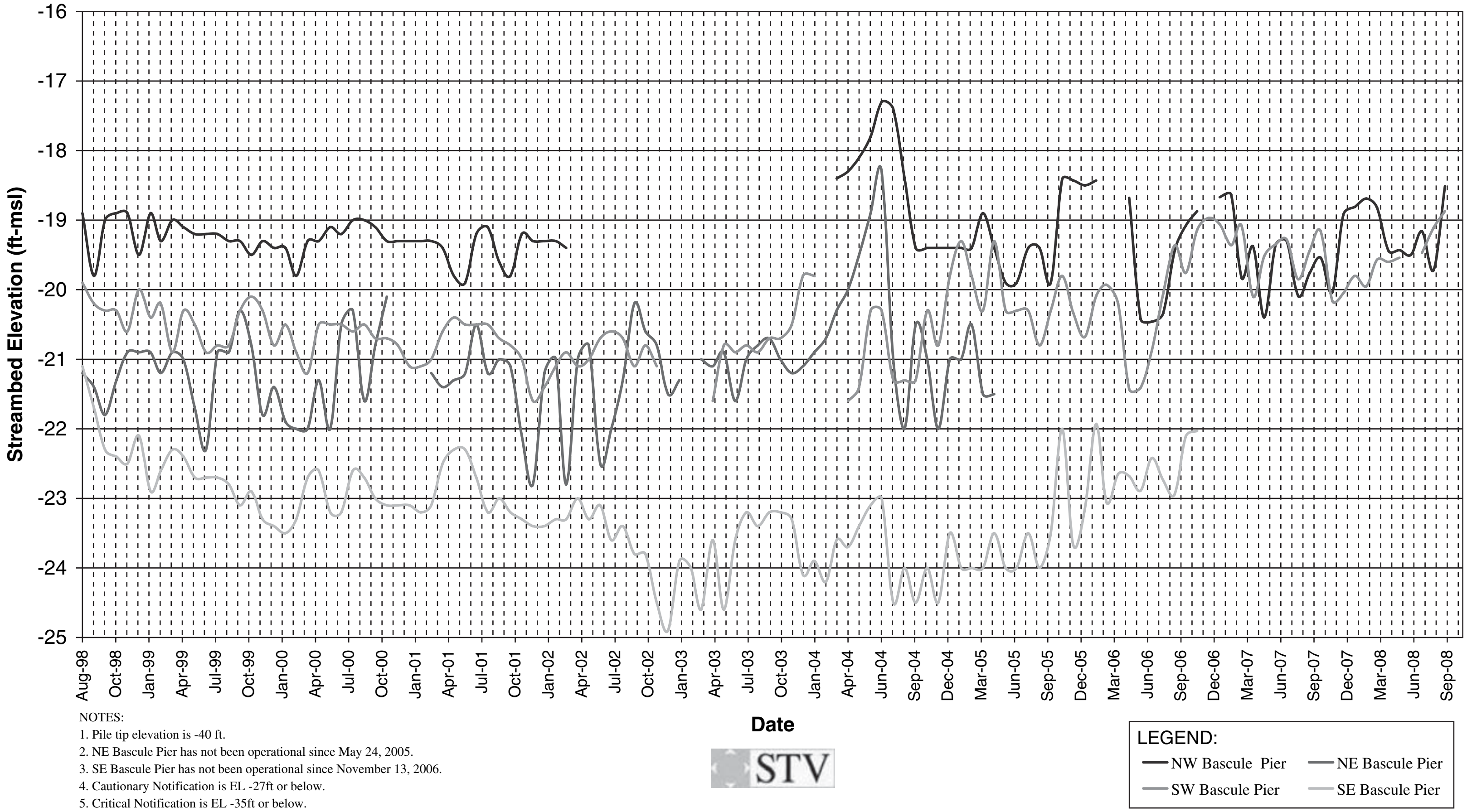
NOTES:
1. Pile tip elevation is -40 ft.
2. NE Bascule Pier has not been operational since May 24, 2005.
3. SE Bascule Pier has not been operational since November 13, 2006.
4. Cautionary Notification is EL -27ft or below.
5. Critical Notification is EL -35ft or below.

STV

LEGEND:
NW Bascule Pier
NE Bascule Pier
SW Bascule Pier
SE Bascule Pier

Sonar Scour Monitor Data for Wantagh Parkway over Goose Creek

Monthly Minimum Elevations

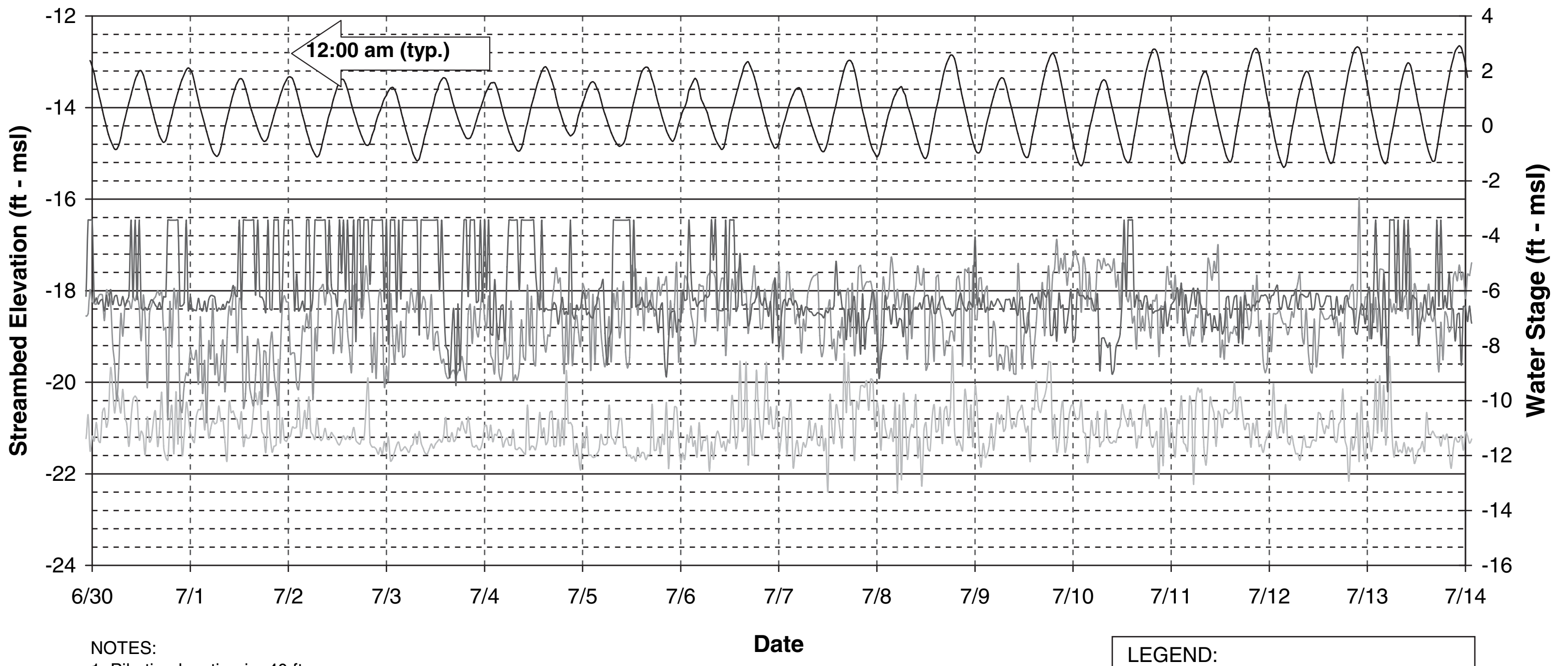


NOTES:
1. Pile tip elevation is -40 ft.
2. NE Bascule Pier has not been operational since May 24, 2005.
3. SE Bascule Pier has not been operational since November 13, 2006.
4. Cautionary Notification is EL -27ft or below.
5. Critical Notification is EL -35ft or below.

STV

Sonar Scour Monitor Data for Wantagh Parkway over Goose Creek

June 30- July 14, 2006

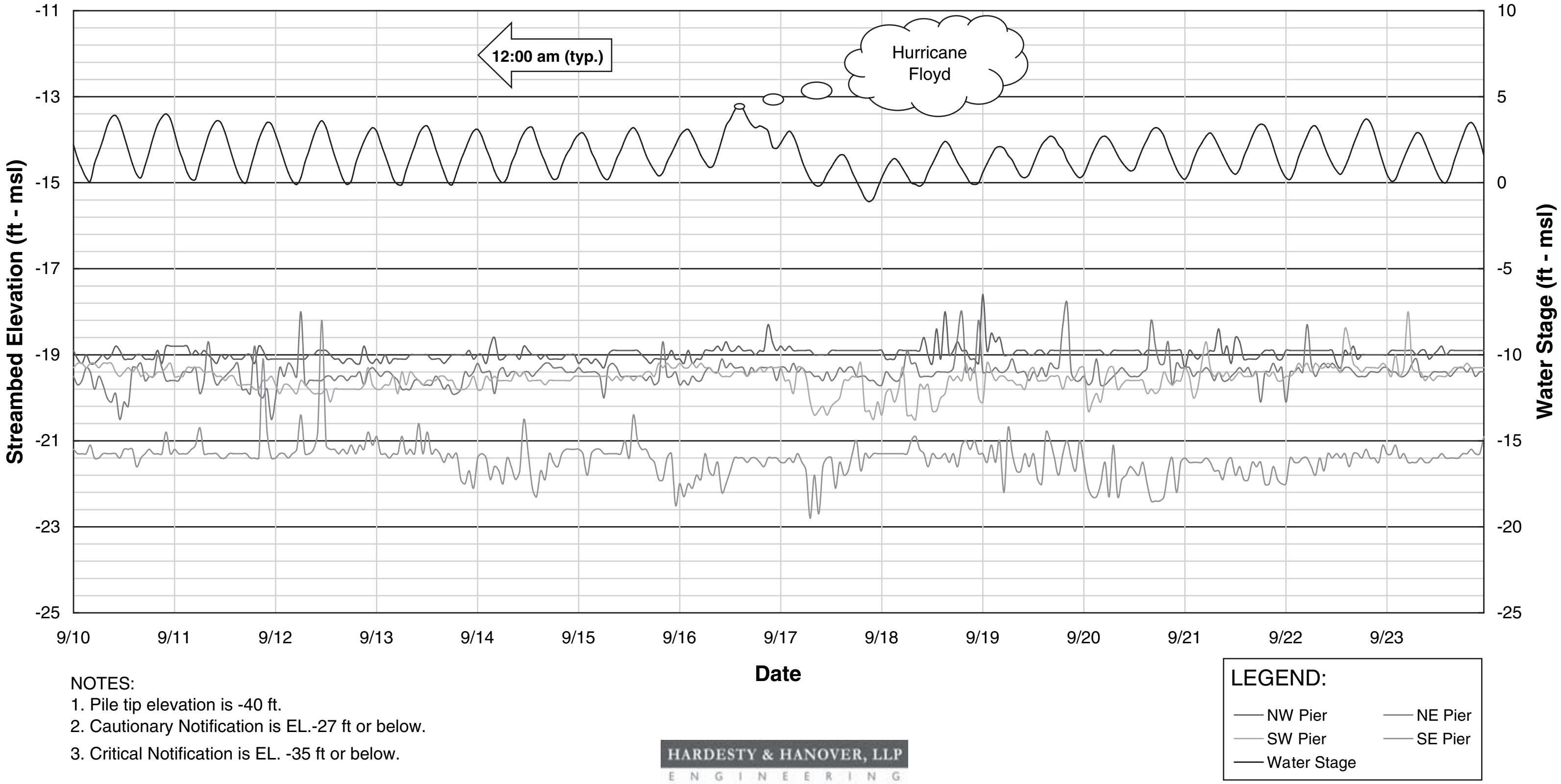


NOTES:
1. Pile tip elevation is -40 ft.
2. Cautionary Notification is EL. -27 ft or below.
3. Critical Notification is EL. -35 ft or below.
4. NE Bascule has not been operational since May 24, 2005.

HARDESTY & HANOVER, LLP
ENGINEERING

Sonar Scour Monitor Data for Wantagh Parkway over Goose Creek

September 10-24, 1999

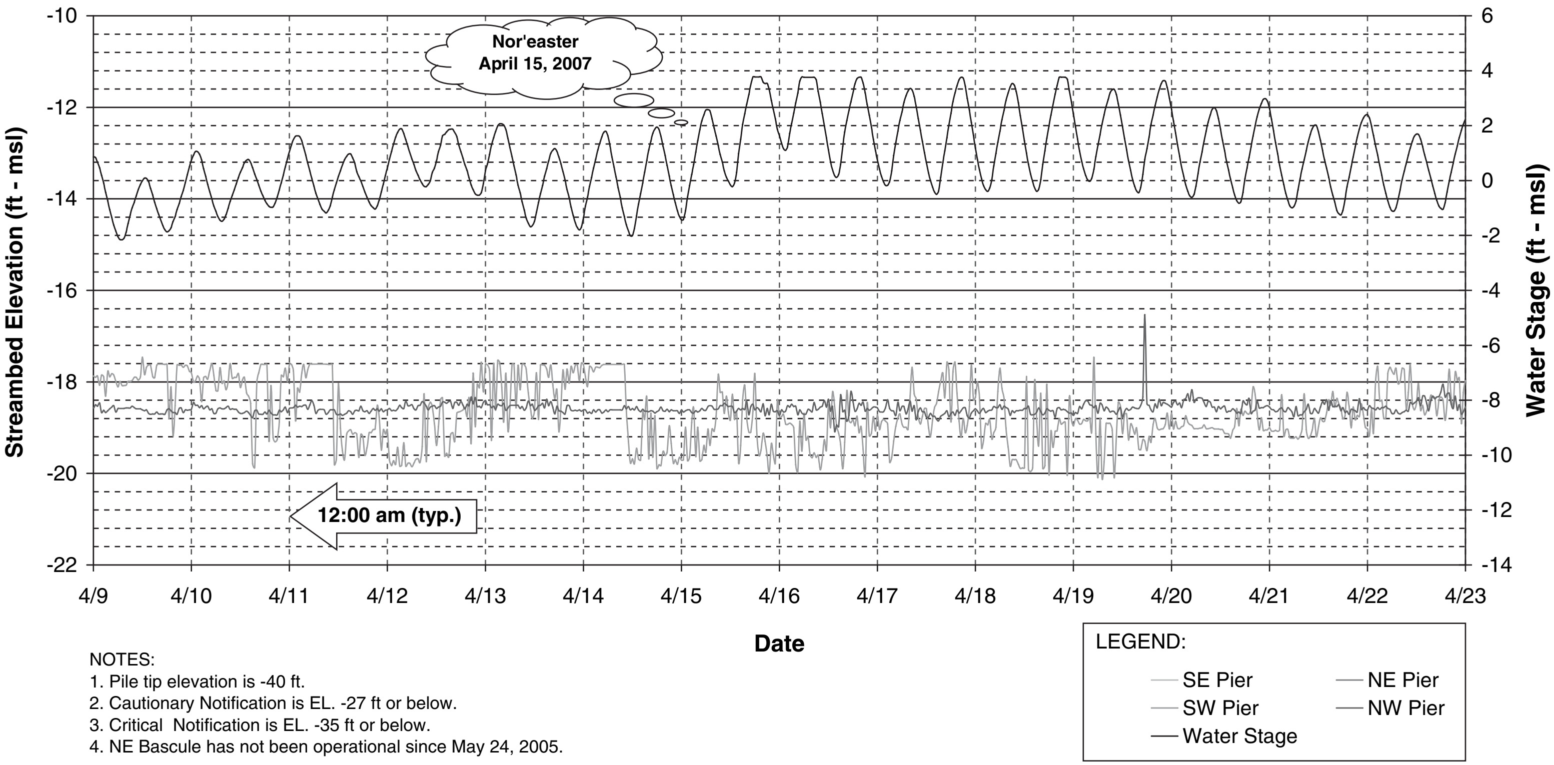


NOTES:
1. Pile tip elevation is -40 ft.
2. Cautionary Notification is EL.-27 ft or below.
3. Critical Notification is EL. -35 ft or below.

HARDESTY & HANOVER, LLP
ENGINEERING

Sonar Scour Monitor Data for Wantagh Parkway over Goose Creek

April 9 - 23, 2007



NOTES:
1. Pile tip elevation is -40 ft.
2. Cautionary Notification is EL. -27 ft or below.
3. Critical Notification is EL. -35 ft or below.
4. NE Bascule has not been operational since May 24, 2005.

HARDESTY & HANOVER, LLP
ENGINEERING

APPENDIX F

Case Studies

Abbreviated case studies may be found in chapter six. The following bridge sites (see Table F1) have published case studies on their scour monitoring installations.

TABLE F1
POSSIBLE CASE STUDIES

State	Bridge Name
Alaska	
	20 Bridge Sites
California	
	Interstate 10 over San Gorgonio River
Florida	
	John's Pass Bridge
	SR-105 and SR A1A
Hawaii[1]	
	Kaelepulu Bridge
	Kahaluu Bridge
Maryland	
	Woodrow Wilson Memorial Bridge
New York	
	Wantagh Parkway over Goose Creek
	Robert Moses Causeway over Fire Island Inlet
Vermont	
	Vermont Route 5 over White River

Note: An article from conference proceedings has been submitted which compares predicted versus measured scour. It is summarized in chapter six in the section on observed scour.

CASE STUDY: SCOUR MONITORING OF THREE LONG ISLAND BRIDGES

A partial bridge pier failure due to scour resulted in the investigation of the cause, the design of repairs, and the preparation of a plan of action. This event led to the development of a scour monitoring program that uses sonar scour monitors to ensure stability of the bridge and the safety of the traveling public. Twenty-seven sonar scour monitors were installed at three bridges to provide a continuous ongoing record of streambed elevations. The monitors were designed and installed quickly, and were relatively inexpensive compared with other types of scour countermeasures.

In 1998, a pier failure at Wantagh Parkway over Goose Creek in Nassau County, New York, initiated the emergency investigation of the cause and the subsequent design repairs for the bridge (Figure F1). This was a 28.3-m (93-ft) bascule bridge with concrete pile bent approach piers and 15 spans. The streambed at one pier was found to have had experienced approximately 8.8 m (29 ft) of localized scour since it was built in 1929. The scour was not the result of a single storm event, but rather the erosion from various events over the years and the degradation caused by the daily tidal action at Goose Creek. This resulted in the downward movement of two piles and the fracturing of the pile cap above them. The outermost pile of this bent was left with only 0.37 m (1.2 ft) of embedment in the sand (Figures F2 and F3). The owner, the New York State Department of Transportation (NYSDOT) decided to replace the bridge approach spans immediately, but the bascule piers would remain in service for about eight years. To ensure that these bascule piers were safe, several countermeasure options were investigated, and a scour monitoring system and program was designed for the bridge.

Due to the situation of the Wantagh Parkway over Goose Creek, a bridge just south of it, the Wantagh Parkway over Sloop Channel, was also examined. Built at the same time with similar pile depths, the Sloop Channel crossing had higher flow rates. This fixed concrete pile bent bridge was 175.6 m (576 ft) long. It was found to have similar problems with respect to scour of the piers. As a result, four scour monitors were installed at the bascule piers of Goose Creek and ten monitors were installed at Sloop Channel. In addition, a water stage sensor was installed at each bridge.

FIGURE F1 General elevation of the Wantagh Parkway over Goose Creek.

FIGURE F2 Failure of pier pile cap at Wantagh Parkway over Goose Creek.

The sonar scour monitors were installed on either side of each bascule pier at Goose Creek. There were numerous piers with scour at Sloop Channel. A study of the historic diving inspections and fathometer surveys, the history of the riprap placement at the piers, the as-built pile tip elevations, and the most recent emergency diving inspection were used to determine which pier locations were most critical. The scour monitors, approved by NYSDOT within one week of the failure, were designed, custom-built, and delivered to the site ten weeks later (Figure F4). A temporary bridge was erected at Sloop Channel one year after the monitors were installed. The monitors were salvaged from Sloop Channel and placed in storage, serving as spare, repair parts for Goose Creek, or available to be used in rebuilding monitors for other bridges in the region should they require sonar scour monitors.

A scour monitoring program and manual was developed for the two Wantagh Parkway Bridges. This was the first procedural manual ever to be developed for scour monitors. The manual provided various options available for pursuit should these bridges continue to experience scour. Pier stability analyses were conducted for the bridges to determine scour cautionary and critical depths. The manual included cautionary and critical streambed elevations for each pier; procedures for normal and emergency situations; a plan of action should certain scour elevations be reached; and troubleshooting, maintenance, servicing, and inspection instructions. An effective communication system for all responsible parties was established.

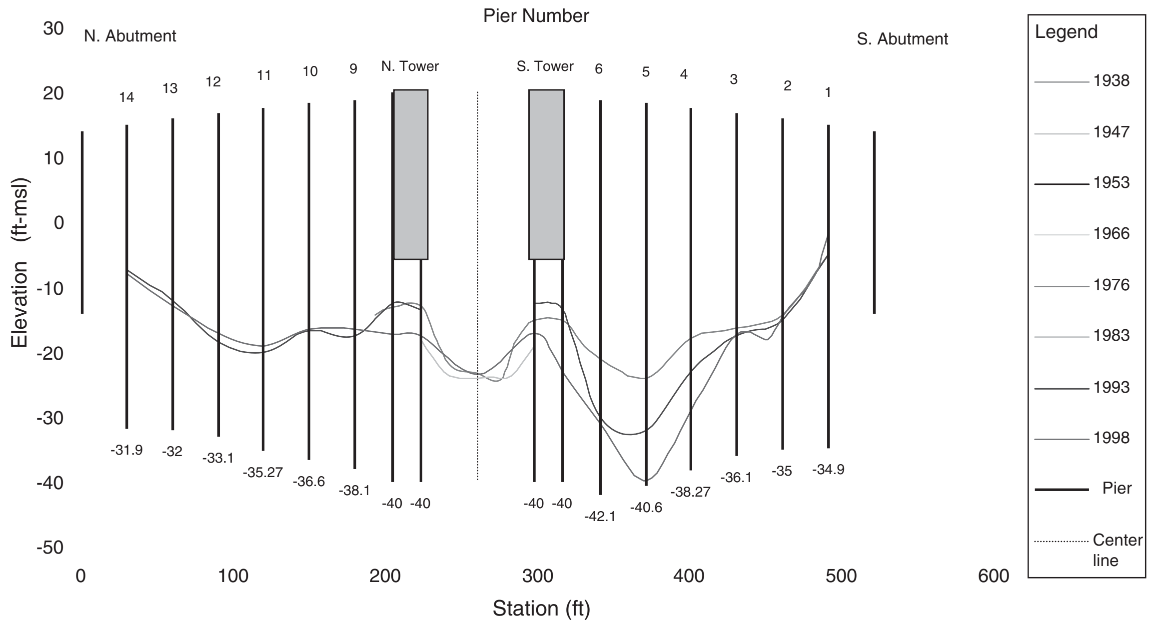


FIGURE F3 Plot of historic scour at Wantagh Parkway over Goose Creek; time sequence of channel elevations—East Fascia.

The 2001 installation of sonar scour monitors at Robert Moses Causeway over Fire Island Inlet in Suffolk County, New York, is a long-term solution to the scour problems at that bridge. The bridge is a 326-m (1,068-ft) tied arch flanked by 24 approach spans for a total length of 1,290 m (4,232 ft) (see Figure F5). Built in 1966, it has extremely high flow rates. For the 100-year storm, the flow rate is more than 13,932 cms (492,000 cfs). Riprap scour protection had been placed at some piers over the years, and according to HEC-23, riprap should be monitored when used as a countermeasure at piers. Sonar scour monitors were placed at 13 piers, a water stage was

FIGURE F4 Scour monitoring system mounted to a pier on the Wantagh Parkway over Sloop Channel.

FIGURE F5 General elevation of Robert Moses Causeway over Fire Island Inlet.

FIGURE F6 Detail of a sonar scour monitoring device mounted to a pier.

FIGURE F7 Marine growth on a sonar scour monitor.

FIGURE F8 Damage due to corrosion and electrolysis.

installed, and the Long Island scour monitoring manual was revised to include this system (see Figure F6 and Appendix G). To establish critical depths, a pier stability analysis was conducted using the Florida Pier analysis software for the piers that were considered to be the most likely candidates to experience potential scour failure. These piers were selected based on several factors including their location in the inlet, height, history of scour, and superstructure loadings (see Figures F7 and F8). A scour analysis study was simultaneously conducted for a group of bridges on the South Shore of Long Island. The computed potential scour was used in the selection of the pier locations to be monitored. This was an extremely complex design and installation owing to the proximity of the bridge to the Atlantic Ocean, the deep-water conditions, the pier configurations, and the high flow rates.

The scour monitoring systems at Goose Creek and Fire Island have been in operation for seven and four years, respectively. The scour monitoring program includes the daily routine monitoring of these bridges, including data acquisition and analysis; round-the-clock monitoring during scour critical events; the preparation of weekly graphs of the streambed elevations and tide gauge data; periodic data reduction analyses and graphs; and routine maintenance, inspection, and repairs. In 2004, a total refurbishment of the Goose Creek system was completed. This included the installation of the latest operating system software and a new bracket for the sonar transducer at one monitor location. An underwater contractor installed the new bracket and also strengthened the scour monitor mountings at the other three pier locations. The condition of the scour monitors and the accuracy of their streambed elevation readings are checked during the regularly scheduled diving inspections at each bridge. Also, all debris and/or marine growth on the underwater components are cleared away during these inspections.

APPENDIX G

Available Plans, Programs, Guidelines, and Manuals

Table G1 contains a list of available plans, programs, guidelines, and manuals from survey respondents. Items followed by a superscript have been included in this appendix as samples.

TABLE G1
AVAILABLE DRAWINGS, PLANS, GUIDELINES AND MANUALS

State	Bridge Name	Plans, Drawings, or Specifications	Guidelines, Manuals, Plans of Action, Reports, etc.
Alaska			
	20 bridges	Plans	Programs and Report
California			
	Santa Clara River	No	Plan of Action and Report
	I-10 over San Gorgonio River	Yes	Program
Florida			
	John's Pass Bridge	No	Programs, Plan of Action, and Report
	SR-105 and SR A1A	No	Programs and Plan of Action
Georgia			
	Four bridges	No	Report
Indiana			
	US-52 over Wabash River and SR-43	No	Report (Purdue University)
Maryland			
	Woodrow Wilson Memorial Bridge	Plans	Guidelines, Manuals, and Plan of Action[1]
New York			
	Wantagh Parkway over Goose Creek	Plans and Specifications[1]	Manuals[1], Plan of Action[1], and Report
	Robert Moses Causeway over Fire Island Inlet	Plans and Specifications	Manuals[1], Plan of Action, and Report
	NYS Thruway over Cattaraugus Creek	No	Programs and Report
Nevada			
	Four bridges	No	Program [1]
Texas			
	Five bridges	No	Yes
Vermont			
	Vt Route 5 over White River	No	Report

1. Samples have been included in this appendix.
2. References to the reports listed above may be found in the Bibliography or Reference section of this synthesis study.

Plan of Action
for
Scour Monitoring of the Woodrow Wilson Bridge
(March 2005 Update)

1. BACKGROUND

At this time, March 2005, construction of the new Woodrow Wilson Bridge is well underway, and the construction schedule calls for shifting traffic from the existing bridge to the new bridge during autumn 2006. Until the traffic is shifted, the existing bridge will continue to be monitored for scour to assure that it remains in a safe operating condition for its remaining service life.

Scour monitoring was initiated in 1999 and sonar devices were installed on five piers. Monitoring of these 5 piers (see table below) has continued up to the present time, and will continue until traffic is shifted off the bridge. There have been some gaps in the records due to technical problems with the meters and the remote communication system; however, the record to date indicates that measured scour is very small and has not represented a significant concern regarding the stability of the bridge.

2. MONITORING RESPONSIBILITIES

The Office of Bridge Development (OBD) has primary responsibility for oversight of the monitoring system:

- The Structure Hydrology and Hydraulics Unit (H&H) will download the data from the bridge at least once per month. More frequent readings will be obtained in the event of a flood event, or if the scour plots indicate any significant change in the channel elevations.
- If there is a problem in downloading the data, H&H will contact Bea Hunt of the consultant firm of Hardesty & Hanover. There are additional contact names for Hardesty & Hanover listed in Section 5 of this document. Hardesty & Hanover will make remote checks to troubleshoot the electronic system. They may also contact the subcontractor, ETI Instrument Systems, Inc. to troubleshoot the system remotely. If a visit to the site is required, Hardesty & Hanover will make appropriate arrangements for repairs after receiving approval from OBD to make the field visit and carry out the repair work.
- H&H will work cooperatively with the Bridge Inspection and Remedial Engineering Unit to expeditiously authorize funds for any needed repair work.
- The firm of Whitman, Requardt and Associates (WRA) has the overall contract for maintaining the Woodrow Wilson Bridge. All funding transactions will be carried out through arrangements with WRA.

3. MONITORING DURING FLOOD EVENTS

In the event of a flood event, the downloading of scour readings will be increased as necessary to assure continued safe operation of the bridge.

Previous evaluation structure stability studies have been carried out for the purpose of determining alert depths, action depths, and failure depths as depicted in the table below.

Action Plan Scour Critical Depths
(Established in a 1999 Report by WRA entitled Pier Analysis and Target Scour Depths)

Pier ID Number	Channel Elevation	Alert Depth	Action Depth	Failure Depth
1W	– 34.7	– 45	?	
1E	– 36	– 45	?	
25E	– 10	– 13	– 23	– 32
27 E	– 17	– 17	– 24	– 33
29 E	– 16	– 17	– 24	– 29.4
V1	– 34.7	– 45	?	
M1	– 36.2	– 45	?	

4. ALERT DEPTH

If the “Alert Depth” elevations are recorded by the scour equipment, OBD will initiate a more intense monitoring program which may include:

- Confirm scour depths by on-site inspectors using portable scour equipment (This will be more easily accomplished for Piers 25E, 27E, and 29E; it may be more difficult for Piers 1E and 1W, the bascule piers for the existing bridge),
- Increased frequency of downloading scour data,
- Diving inspections of scoured piers, if conditions permit,
- Notification of appropriate agencies of the possible need for a traffic detour plan. The SHA Statewide Operations Center will coordinate with other jurisdictions in developing a plan for rerouting of traffic.

The alert depth elevations for Piers 27E and 29E have occurred more or less continuously at various times during the monitoring period, and in fact were recorded during bridge inspections before the monitoring system was initiated. These alert depths were established in a very conservative manner. With the experience gained through the monitoring program, they are no longer considered to be critical values to trigger the “alert depth” actions noted above. However, any further lowering of the channel bed for these piers will be monitored at frequent intervals to determine whether a trend of increased scour is occurring and whether the “alert depth” program should be initiated.

Please note that Piers V1 and M1 are the piers for the main bascule span for the new bridge and do not have scour meters. These piers will also be included in increased monitoring activities triggered by any “alert depth” actions.

5. ACTION DEPTH

If scour proceeds to the “Action Depth” elevation, OBD will take immediate action to protect the bridge and ensure the safety of the public. Such actions may include:

- Placement of scour countermeasures (riprap) and/or
- Bridge closure and rerouting traffic in accordance with the plan established by the SHA Statewide Operations Center.

6. CONTACT PERSONNEL

Name	Work Number	Cell Number	Home Number
Director OBD			
SHA			
SHA			
SHA			
SHA			
SHA Statewide Operations Center			
Hardesty & Hanover			
Hardesty & Hanover			
Hardesty & Hanover			
Hardesty & Hanover			
Whitman Requardt and Associates (WRA)			

SCOUR MONITORING PROGRAM MANUAL

Sonar Scour Monitoring System for
Wantagh Parkway over Goose Creek Bridge &
Robert Moses Causeway over Fire Island Inlet

Prepared for:
New York State Department of Transportation
Region 10

Prepared by:
STV
New York, NY

October 1998
Second Edition: July 2002
Third Edition: July 2006
Fourth Edition: August 2007

TABLE OF CONTENTS

Appendices Index:

Note: This Manual is to be used in conjunction with *Scour Tracker™ AS-3 Scour Monitoring System* manuals by ETI Instrument Systems, Inc. They have provided a manual for each bridge that has a sonar scour monitoring system installation (see Appendix B).

SCOUR MONITORING PROGRAM

Sonar Scour Monitoring Systems

1. DESCRIPTION OF THE SYSTEMS

Fixed sonar scour monitoring systems have been installed at several bridges in Long Island. The scour monitoring systems employ transducers to take streambed elevation measurements at designated piers. The system at each bridge consists of one master control station, a remote station at each pier location being monitored, a water temperature sensor, a water stage sensor, and an automatic alerting system (see Appendix A, As-Built Scour Monitoring Plans). All the data gathered is transmitted to the master control station. A portable computer is set-up at the designated office to retrieve the data from the systems. The scour monitor electronics measure the lapsed time that an acoustic pulse takes to travel from the transducers to the streambed and back. These measurements are converted into distances using the velocity of sound, adjusted for temperature. The transducers are programmed to take measurements at specified intervals.

The master control station contains the data acquisition module that communicates with the remote sensor stations, controls their operation, and collects and stores their data in the desired format. The data is transmitted via modem from the master control station to the portable computer at the designated base office. Each remote station includes a sonar transducer sensor, scour monitoring electronics, and a wireless data link communication with the master control station. Solar panels that maintain battery power have also been installed at non-movable bridges that do not have electric power to power the monitors. The number and locations of the current sonar scour monitoring sensors at each bridge may be found in Appendix B. To see photographs of currently installed scour monitor systems, refer to Appendix F.

The Monitoring System Vendor, ETI Instrument Systems, Inc., has provided a manual with descriptions and drawings of the equipment, as-built locations, and instructions for programming and retrieving data using the operating software. This manual is entitled *Scour Tracker™ AS-3 Scour Monitoring System* and a copy has been provided for each bridge that has a scour monitoring installation (hereafter referred to as the *AS-3 Manual*).

This scour monitoring program is state-of-the-art, using equipment and concepts recommended by the Federal Highway Administration and the Transportation Research Board. There are no guarantees that the program will provide complete notification of a scour failure. However, it does exceed all current inspection and monitoring programs currently established for scour. The program that follows is a guideline to establish a baseline for analyzing and reacting to various scour levels.

2. INSTALLATION OF THE SYSTEMS

The systems were installed by independent Contractors. The sonar transducers at each pier location were installed at specified positions and elevations as shown on the Plans and as directed by the Engineer. The installations were supervised and calibrated by ETI Instrument Systems, Inc. The As-Built information may be found in the *AS-3 Manual,* and in Appendix A of this Manual.

3. PROGRAMMING OF THE SYSTEMS

The data collection systems were programmed to take streambed measurements at specified intervals at each pier. Intervals have been set for each bridge currently in the system. For example, Goose Creek and Fire Island collect data every ½ hour. Instructions for programming the systems may be found in the *AS-3 Manuals*. The alerting system will activate should any scour sensor detect a decrease of two (2) feet or more from the baseline elevation. The baseline elevation is a measurement taken at the time of the installation of the monitors. A printout of the data will indicate that the system has been activated. The systems will automatically set a new baseline elevation when the alerting system is activated (see Section 5.3).

Each sensor station contains a data logger that activates the sonar at the prescribed interval, processes the sonar measurement signals, and stores the data until requested by the master control station. This process includes taking a series of sonar soundings and eliminating those soundings that are out of tolerance. If the sonar sensor is unable to obtain a "lock" on the streambed, the depth recorded defaults to the initial streambed depth. The processing routines programmed into the data logger include:

1. Activation of the sonar device at specified intervals.
2. Computation of a streambed elevation (ten readings are taken, the highest and lowest values are discarded, and the result is the average of the remaining eight readings).

3. Recording of a "no lock" condition when an echo is not received.

4. Recording of an "outside limits" condition if an average depth cannot be computed within the programmed measurement time.

The portable computer and software provided by the Monitoring System Vendor are used to program the scour monitoring electronics and to retrieve data. A time-stamped record of the streambed elevations, including the scour and backfill process, is recorded and can be retrieved from the base office for future analysis. Data is recorded in sequential data record format which can be analyzed and presented by spreadsheet or other means. Included with the portable PC software is presentation software, *Visual Log*, which displays historical data in both graphical and tabular format. To view sample data in both tabular and graphical form, see Appendix E.

4. BENCHMARKS AND DATUM

Benchmarks were established during the installation of the scour monitors. The datum shall be National Geodetic Vertical Datum (N.G.V.D.) 1929, Elevation 0.0, which is also Mean Sea Level. This datum shall also be used in obtaining data with the portable scour monitors and during Diving Inspections and fathometer surveys.

5. DATA ACQUISITION

5.1 Computer Set-Up

1. The designated computer shall be connected to a telephone line, capable of receiving incoming telephone calls. This should be a voice line, not a data line.

2. The computer may be left on at all times to ensure immediate retrieval of data should a scour event occur.

3. To collect the data, the PC208W software shall be installed and properly set-up on a computer designated for the scour monitoring system.

4. In order to print the data, there shall be a color printer in the designated office.

5. The computer shall be properly secured against theft or damage.

5.2 Normal Circumstances: Downloading of Data

The system may be programmed such that the data is automatically downloaded to the designated computer each night, or at any specified interval. If there is a concern and data is needed immediately or more frequently, the Department, the Scour Monitoring Consultant, or the Monitoring System Vendor may also retrieve the data at any time by calling the data collection system(s) using a computer that contains the appropriate software. Each bridge may also be called from any telephone. When this is done, a voice synthesized message will provide elevations from the latest readings (i.e. one elevation per monitoring location). See Appendix E for sample raw data output from bridges currently in the system. The procedure for downloading data is in Appendix B.

The Department has requested that the Scour Monitoring Consultant install the computer in the Consultant's office, receive the data, and analyze it. The Scour Monitoring Consultant will call and check the data as outlined in Appendix B of this Manual, or as directed by the Regional Structures Engineer. A report shall be submitted to the Department as outlined in Appendix B of this Manual, or as directed by the Regional Structures Engineer. This Manual shall be updated to reflect any changes in the scour monitoring program.

To ensure accuracy, ground truth measurements shall be taken at installation and during Diving Inspections and/or Fathometric Surveys. A ground truth measurement is a measurement of the scour condition by some alternate technique to evaluate instrument performance. An example of an alternate method would be a tape measurement taken by a diver from the face of the transducer to the streambed. The measurements obtained with the scour monitoring devices should be within one foot of the ground-truth measurements. If the measurements are not within this limit, refer to System Malfunction for possible outcomes, Section 15 of this Manual.

5.3 Alerting Systems

The alerting system of the scour monitors may be programmed to call Region 10's INFORM Group in Hauppauge, New York. This station is staffed 24 hours/day, seven days/week. The scour monitor alert system may be programmed to automatically dial the INFORM group should two (2) feet of scour occur from a set baseline at a monitoring location. **Note: at the time of publication of this Manual, this feature had not been activated.** Below are the instructions for this Group should this procedure be used.

The outgoing message from the scour monitoring system works as follows:

> The system dials the telephone number that has been programmed into it. When the programmed telephone is answered, a synthesized voice says:
>
> *"Press the pound key (#) to hear call back message 1."*
>
> The command will repeat until the pound key is pressed. When the # key is pressed, the message will provide the following:
>
> *"Scour monitor warning from bridge (number) ______. The current streambed elevation at Pier _____ is at the alarm level of ______ feet."*

The INFORM group should receive proper training on what to do in the event of a scour monitor warning. The person at the INFORM center shall immediately call and relay this information to the following persons from Region 10, in the order listed below, until a person is reached:

1. Regional Structures Engineer
2. Bridge Management Engineer
3. Hydraulic Engineer
4. Assistant Bridge Management Engineer
5. Regional Design Engineer
6. Deputy Regional Design Engineer

(Note: This does not include answering machines. If calls to beepers are not answered within 20 minutes, the next person on the list should be contacted.) The names and telephone and beeper numbers may be found in Appendix D.

Appendix D, Contact Information, provides the bridge telephone number for the bridges being monitored as well as the office and home telephone numbers of those responsible for implementing this program. This Appendix is included in the Manuals of those responsible for implementing this program.
Should two (2) feet of scour occur, the system may be programmed to automatically download the data to the designated computer. (See Section 6, Analysis of Data, should this occur.) The Regional Structures Engineer may also instruct the Scour Monitoring Consultant to download the data manually rather than use the automatic system.

5.4 Special Flood Events

The Regional Structures Engineer or a specified designee shall be responsible for the following actions during and following special flood events:

1. In the event of a tropical storm watch or hurricane watch, the streambed readings shall be retrieved within four (4) hours of the initiation of the watch, and shall continue to be checked every four (4) hours throughout the storm and every twelve hours for three (3) days after the termination of the storm watch.

2. If a tropical storm warning or hurricane warning is issued, the streambed readings shall be checked every two (2) hours, until such time as the warning is lifted, and then as described under storm watch.

3. If a high tide event occurs, actions must be taken in response to the following high tides:

    a) After tides are two (2) feet or more above high tide for a period of six (6) hours, the streambed readings shall be checked every four (4) hours, and continue for four (4) hours after normal tides return.

    b) When tides are four (4) feet or more above high tide for any duration, the streambed readings shall be checked every two (2) hours, and continue for six (6) hours after normal tides return.

The Regional Structures Engineer shall (a) determine when a storm watch or warning has been issued, (b) determine when a high tide event has occurred, and (c) contact those responsible for retrieving and analyzing the data.

The monitoring system may be called from any telephone using the procedure described in Section 5.5 below. For interpretation of the data, see Sections 6, 7 and 9.

5.5 Calling the Systems

The monitoring systems may be dialed from the designated computer or from any telephone at most times; however, service will be unavailable when the transducer is taking or transferring data once every 30 minutes. This occurs on the hour and half hour at each bridge. In order to allow for the transfer of data, it is recommended that the bridges not be called during the time interval between 0–15 minutes and 30–45 minutes past the hour.
The telephone numbers for the bridges may be found in Appendix D, Contact Information. This Appendix is included in the Manuals of those responsible for implementing this program.

The outgoing message from the scour monitoring system when the telephone numbers are dialed, works as follows:

"Streambed elevation at Pier ____ is ____ feet. Pier ____ elevation is _____ feet…"

This message continues until all the elevations at all the piers at that particular bridge have been reported.

The message then continues and offers the following three options:

- *"Press pound (#) to hear again"*
- *"Enter security code and then press the pound (#) key"*
- *"Press star (*) to disconnect"*

The security code provides access to the area in which one can change the operating parameters. In order to avoid making unintentional changes to the system, the Monitoring System Vendor shall make all required changes to the system. Contact ETI Instrument Systems, the Monitoring System Vendor, to request any changes in the operating parameters.

If no key is pressed, the message terminates with:

"Good-bye."

6. ANALYSIS OF DATA

The actions described in Section 7 shall be implemented if certain streambed elevations are obtained. For specific criteria for scour notifications for each bridge, see Appendix C.

If any of these events occur, the condition should be treated as a **CAUTIONARY or a CRITICAL SCOUR NOTIFICATION**. The following persons shall be notified, in the order listed, until one is reached: (Note: This does not include answering machines. If calls to beepers are not answered within 20 minutes, contact the next person on the list.)

1. NYSDOT Region 10, Structures Unit:

Regional Structures Engineer

Bridge Management Engineer

Hydraulic Engineer

Assistant Bridge Management Engineer

Regional Design Engineer

2. STV Incorporated:

Senior Hydraulic Engineer/Project Manager

Senior Structural Engineer

Project Engineer

Electrical Engineer

The office numbers listed in Appendix D, Contact Information, are for use on working days between the hours of 8:00 a.m. and 4:10 p.m. for NYSDOT, and 8:45 a.m. to 5:00 p.m. for STV. Appendix D, also lists home and cell telephone numbers that may be used during other times. This Appendix is included in the Manuals of those responsible for implementing this program.

See Section 7 for existing streambed elevations and a discussion of **CAUTIONARY** and **CRITICAL SCOUR NOTIFICATIONS.** See Section 9 for the Plan of Action.

7. SCOUR CAUTIONARY AND CRITICAL DEPTHS: NOTIFICATIONS

If the streambed reaches the depths listed under **CRITICAL** SCOUR NOTIFICATION in the tables in Appendix C, the Department shall review the data and consider the necessary steps, if any, to be taken. The Region may alert the authorities so that the public is diverted from using the bridge. The Plan of Action in Section 9 and Appendix H shall be followed.

If any of the depths listed under **CAUTIONARY** SCOUR NOTIFICATION in the tables in Appendix C are reported at the bridge, the Department shall immediately convene a meeting to discuss the installation of scour countermeasures. Interim mitigation measures may be taken, which may include the following:

1. Check the scour monitoring data every hour for a period of 12 hours. After that time, the data shall be checked every 12 hours for the next 72 hours.

2. Confirm these scour depths with alternate methodologies.

3. Implement or increase the frequency of the land field monitoring of the piers.

4. Conduct a Diving Inspection of the problem pier(s) and adjacent piers. Consideration should be given to increasing the frequency of Diving Inspections and underwater surveys.

5. Consider the addition of pier protection.

6. Consider the addition of pier strengthening.

If there are no cautionary or critical notifications in a given month, the Scour Monitoring Consultant Hydraulic Engineer shall call the Regional Structures Engineer to discuss the data and the condition of the systems every three months.

8. PORTABLE SONAR MONITORING DEVICES

Region 10 shall be responsible for the operation and maintenance of the portable sonar scour monitors. The Department may take streambed readings with the portable devices following major storm events and/or should a large drop occur in the streambed elevations. Additional readings are required during an emergency (see Plan of Action, Section 9 and Appendix H). The Department currently owns two portable devices which are located in the Region 10 Structures Office.

9. PLAN OF ACTION

Since 1988, the FHWA, in conjunction with state departments of transportation, has committed resources to coordinate and conduct a National Bridge Scour Evaluation Program. This program has helped bridge owners to rate the bridges in the National Bridge Inventory (NBI) using rating codes for Item 113—Scour Critical Bridges. Item 113 identifies bridges as "low risk, scour susceptible, or scour critical." A "scour critical" bridge is one whose foundation has been determined to be unstable for the calculated or observed scour conditions. An unstable foundation exists when: (a) scour reaches the threshold limits of footings or piles, or (b) scour reaches below spread footings or pile tips.

While continuing to encourage DOTs to complete their scour screening and evaluations, the FHWA formally moved into the next phase of the scour program as documented in their July 24, 2003 memorandum, which encourages bridge owners to develop and implement a Plan of Action (POA) for each bridge coded scour critical as defined by NBI Item 113 of the FHWA's Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges. The updated National Bridge Inspection Standards (NBIS) regulation, 23 CFR 650.313.e.3, requires DOTs to prepare a POA to monitor known and potential deficiencies and to address critical findings for bridges identified as scour critical. On March 29, 2005, the FHWA issued a memorandum titled: "Compliance with the National Bridge Inspection Standards—Plan of Action for Scour Critical Bridges." This states that the NBIS was enacted on January 13, 2005 and one of the immediate actions that require attention is the rule that pertains to the preparation of a POA for a bridge identified as scour critical during the national bridge scour evaluation program. The POA outlines important information about the bridge, scour critical conditions, contact information, and scour countermeasure alternatives. The POA makes information readily available should the bridge scour reach the point of critical depth and require immediate attention.

The bascule piers of the Wantagh Parkway Bridge over Goose Creek have been identified as scour critical from observed and calculated scour conditions and through a pier stability analysis. Scour has been observed and potential scour has been computed for the Robert Moses Causeway over Fire Island Inlet; however, a pier stability analysis must be performed prior to determining a scour critical rating for the Causeway. The FHWA POA template dated June 2006 was modified to include several additional items from the NYSDOT POA template. It was completed for each bridge and is included in Appendix H.

9.1 Closure of the Bridges

If a bridge closure is recommended, NYSDOT forces shall be responsible for a complete shutdown of the roadways as per NYSDOT procedures. In the event of closure, the following persons at the Transportation Maintenance group shall be notified to implement the closure plan. These persons shall be notified in the order listed below until one person is reached. (Note: This does not include answering machines. If calls to beepers are not answered within 20 minutes, contact the next person on the list.)

1. Res. 06 Resident Engineer
2. Bridge Maintenance Engineer
3. Regional Transportation Maintenance Engineer

Appendix D, Contact Information, provides office, cell, and home telephone numbers and is included in the Manuals of those responsible for implementing this program.

Once a bridge closure has occurred, it shall be necessary to confirm the measurements of the devices as outlined in Sections 9.2 and 9.3.

9.2 Portable Sonar Scour Monitor Measurements

Region 10 shall insure that the Department sends engineers to the bridge(s) for a visual inspection as soon as it is deemed safe to do so to confirm the measurements taken by the fixed sonar monitoring devices. When there are emergency conditions, both portable devices, owned by the Department, shall be taken to the site.

If the portable devices confirm the scour critical measurements that were taken by the fixed devices, the bridge shall remain closed and a Diving Inspection shall be conducted.

If the portable devices indicate streambed elevations that are higher those reported by the fixed devices, the elevations shall be reported to the Department, and a decision shall be made regarding the necessity of a Diving Inspection.

9.3 Diving Inspections

A Diving Inspection may be required after the report of a critical scour depth. The Diving Inspection shall include the inspection requirements outlined in Section 13. Particular details shall be noted and manual measurements taken of the streambed elevations at the pier directly beneath the sonar monitor.

The Diving Consultant for the emergency Diving Inspection contract shall do this work. If there is an event that requires a Diving Inspection, the Diving Consultant Project Manager shall be contacted. In addition, the Bridge Management Engineer may be contacted. If neither is available, the INFORM Group shall be contacted for the purpose of contacting Regional Structures Unit personnel.

Appendix D, Contact Information, provides office, cell, and home telephone numbers and is included in the Manuals of those responsible for implementing this program.

10. ACCESS

Often, access to the scour monitoring systems is limited. General guidelines for consideration are listed below. Bridge-specific access limitations may be found Appendix I. It is recommended that the items listed below, as well as those listed in Appendix I are considered before performing maintenance, repairs or inspections.

- Keys may be required to open instrumentation boxes or doors.
- A boat, ladder, and/or manlift may be required to access instrumentation mounted on piers, fenders, or abutments, or under the bridge deck.
- Security clearance may be required to access parts or all of the bridge. Contact the appropriate authorities and notify them when and where the work is scheduled to take place.
- Lane closures may be required. Proper maintenance and protection of traffic as well as inspection/repair crew safety will be needed.

11. MAINTENANCE

The Regional Structures Engineer shall be responsible for notifying the appropriate NYSDOT Bridge Maintenance group for the routine maintenance of the fixed sonar monitoring devices. The following items are included as maintenance requirements for the bridge:

- ✓ Appendix D “Contact Information” shall be updated annually (i.e. January 31st) to ensure that all names, addresses, and contact numbers are current. The Group responsible for this update shall contact all the individuals listed in Appendix D to make them aware or remind them of their responsibilities regarding the Scour Monitoring Program.
- ✓ Indoor instrument boxes and electrical conduit shall be visually inspected for corrosion, overheating, insects, moisture, etc.
- ✓ The thermostat reading or temperature reading shall be recorded for areas containing instruments.
- ✓ The desiccants in the instrument boxes shall be replaced as necessary. The desiccants are heavy brown paper bags filled with silica gel. The Department has been supplied with a second set of desiccants to replace those at the bridges. The desiccants that are removed are reusable, and may be dried in an oven at 200 degrees for 12 hours and stored for future use.

A Scour Monitoring Maintenance Checklist has been included in Appendix G. The electronic version of this form may be obtained from the Regional Hydraulic Engineer or the Scour Monitoring Consultant. This form shall be completed after all routine maintenance, and kept on file in the Regional Structural Engineer’s office.

The Monitoring System Vendor, ETI Instrument Systems, conducted several trainings seminars at Region 10 and at the bridge sites since the installation of the systems.

The Scour Monitoring Consultant and/or the Monitoring System Vendor may be contacted should there be any questions with regard to maintenance of the system. The contact names, telephone numbers, and e-mails may be found in Appendix D.

12. GENERAL INSPECTION

The Regional Structures Engineer shall be responsible for notifying the appropriate group for the inspection of the fixed sonar monitoring devices. This work shall be performed by the appropriate Bridge Maintenance Group or the Consultant retained for the biennial inspection of the bridge. The following items are included in the list of required work:

- ✓ Inspect all outdoor instruments boxes for corrosion, damage, vandalism, leaks, etc.
- ✓ Inspect the outdoor/above water conduit and cable for corrosion, damage, vandalism, leaks, etc.
- ✓ Remove any spiders, mice nests, bird droppings, etc. from all outdoor instrument boxes. Check the door gasket and/or seal.
- ✓ Check and clean the solar panels (if applicable).

A Scour Monitoring General Inspection Checklist has been included in Appendix G. The electronic version of this form may be obtained from the Regional Hydraulic Engineer or the Scour Monitoring Consultant. This form shall be completed after all general inspections and kept on file in the Regional Structural Engineer's office.

The Scour Monitoring Consultant and/or the Monitoring System Vendor may be contacted should there be any questions with regard to the general inspection of the system. The contact names, telephone numbers, and e-mails may be found in Appendix D. If the general inspection reveals that the system requires maintenance and/or repair, this work shall be performed by an Electrical Contractor or other appropriate group. The Monitoring System Vendor may need to be retained for repairs or new components, and the Scour Monitoring Consultant may be required for repairs or design of new countermeasures. This work shall be as directed by the Regional Structures Engineer.

13. UNDERWATER INSPECTION

Diving Inspections and fathometer surveys shall be conducted at the frequency established by the Regional Structures Engineer for each bridge. Additional Diving Inspections may be required after a major storm event. The datum and benchmarks to be used shall be as described in Section 4. The following items shall be included as part of the Diving Inspection/Fathometric Survey:

- ✓ If the location being monitored is in close proximity to bridge dolphins, special care should be taken to ensure accurate streambed elevations. Estimations and/or interpolating should not be used in this area.
- ✓ The scour monitors shall be inspected during each Diving Inspection. This includes the annual inspections and any interim inspections following floods.
- ✓ The inspectors shall obtain depth measurements at the location of each scour monitor with the instrumentation they are using for the underwater inspection, and these shall be compared to the sensor readings.
- ✓ Removal of debris or moss buildup - debris may collect on the transducer or the conduit leading up to the bridge deck. If the debris is on the transducer, or is bending or crushing the pipe, it should be removed.
- ✓ Any algae or marine organisms must be removed from the transducer face.
- ✓ Remove all submerged, waterlogged debris that may potentially sink beneath a transducer.
- ✓ Re-coat the transducer with anti-fouling paint, as needed. The paint shall be transducer anti-fouling paint that is available at most marine supply stores.
- ✓ Replace zinc anodes (if applicable).

A Scour Monitoring Underwater Inspection Checklist has been included in Appendix G. The electronic version of this form may be obtained from the Regional Hydraulic Engineer or the Scour Monitoring Consultant. The form shall be completed after all underwater inspections and kept on file in the Regional Structural Engineer's office.

The Scour Monitoring Consultant and/or the Monitoring System Vendor may be contacted should there be any questions with regard to the underwater inspection of the system. The contact names, telephone numbers and e-mails may be found in Appendix D. The Regional Structures Engineer may request that the Scour Monitoring Consultant and/or Monitoring System Vendor provide inspection support services to the Diving Consultant. If the Diving Inspection/Fathometric Survey reveals that the system requires maintenance or repair, this work shall be performed by an Underwater Contractor. The Monitoring System Vendor may need to be retained for repairs or new components, and the Scour Monitoring Consultant may be required for repairs or design of new countermeasures. This work shall be determined by the Regional Structures Engineer.

14. MISCELLANEOUS CONSTRUCTION WORK AT THE BRIDGES

If any construction work is done near the fixed scour monitors, including work unrelated to the bridge, provisions shall be made to protect the sonar monitoring system. Upon completion of the work, the monitors shall be checked to ensure the monitors had not been damaged. If they are damaged, they shall be repaired at the expense of the Contractor.

In the event that stone fill, riprap, or any type of armor protection is placed near or around piers or abutments with fixed monitoring devices, the Contractor shall exercise reasonable care to avoid damaging these devices. The monitors shall be checked after the conclusion of the placement of the armor protection.

15. SYSTEM MALFUNCTION

In the event of a scour monitoring system malfunction, the Regional Structures Engineer shall be responsible for notifying the appropriate groups for troubleshooting of the fixed sonar monitoring devices. This work may be done by the Transportation Maintenance Group, Region 10, an Underwater Contractor, or an Electrical Contractor. The *AS-3 Manual* shall be used as a reference when troubleshooting.

If the system cannot be repaired using the suggestions outlined below, the Regional Structures Engineer shall contact the Scour Monitoring Consultant and/or the Monitoring System Vendor (see Appendix D). If the problem cannot be resolved via instructions given by telephone, arrangements should be made for the Scour Monitoring Consultant and/or the Monitoring System Vendor to visit the site.

Most of this information is taken from National Cooperative Highway Research Program, Project 21-3, *Installation, Operation, and Fabrication Manual, Sonar Scour Monitor* (see Section 18). Additional site-specific items have been added, where applicable.

1. If the sonar instrument does not turn on at the scheduled sample intervals:

- ✓ Check the battery voltage and all power connections.
- ✓ Review the past data and look for anomalies in the daily battery voltages. If there are anomalies, see if there have been any events (i.e., a power outage or damage to the system) that might have caused the problem.
- ✓ If the battery voltage is less than 12.2 volts, this is an indication that there is a problem.
- ✓ If the battery voltage is low (less than 11 volts), check the output of the solar panel, if applicable, with the sun shining, and make sure it is producing at least 15 volts before the regulator and about 13.5 volts after the regulator.
- ✓ If the solar panel is functioning properly, either (1) the battery is faulty or was drawn down by lack of solar energy for recharging (e.g., an extended period of overcast weather), or (2) the data logger is leaving the sonar on for too long, or cycling too frequently, either from an error in programming or a faulty data logger.
- ✓ In either case, replace the battery with a fully charged battery and evaluate the data logger functioning for a short sample interval (e.g., 5 minutes). If the data logger appears to be functioning properly, re-program for the regular sample interval and periodically check the battery voltage (e.g. every week) to insure proper operation.
- ✓ If the data logger appears to be malfunctioning, check the programming and/or follow the troubleshooting instructions from the manufacturer.

2. If the sonar readings are erratic:

- ✓ Check for high (14.0+ volts) battery readings.
- ✓ Check to make sure the charger is functioning properly.
- ✓ Check for debris under the transducer. Remove debris as required.
- ✓ Check for algae or marine organisms on the transducer. Clean and/or add anti-fouling paint as required.

3. If the sonar readings remain fixed at a single elevation for a prolonged period of time:

- ✓ Check the battery voltage and all power connections (see Item 1).
- ✓ Check the transducer to ensure that it is still securely connected to the bracket. Check all wiring.

4. If a call to the automated telephone service results in a busy signal, no dial tone, or if it ring but there is no answer:

- ✓ Contact the local telephone provider’s service department. Ask the telephone service representative to check the line to determine whether it is an internal or external problem. A technician will be sent to the site if the problem is external. The service is provided free of charge. The contact number for the telephone provider is listed in Appendix D, Contact Information, under “Bridge Telephone Numbers.”
- ✓ If it is determined that it is a problem with an outside line, schedule a repair.
- ✓ If it is determined that it is a problem with an inside line, check connections with the telephone line and modem.

5. If a call to the automated telephone service results in “0” elevation readings:

- ✓ Wait a few minutes and try again. The system may have been in the process of downloading data.

16. CONTACTS

Each bridge location with a scour monitoring system should have a list of contacts as outlined below. All contact information for current bridge locations may be found in Appendix D.

16.1 NYSDOT Region

- Regional Structures Engineer
- Bridge Management Engineer
- Hydraulic Engineer
- Regional Design Engineer
- Assistant Bridge Management Engineer
- INFORM Group

16.2 Scour Monitoring Consultant

- Project Manager / Senior Hydraulic Engineer
- Senior Structural Engineer
- Project Engineer
- Electrical Engineer

16.3 Monitoring System Vendor

- President
- Engineering Manager

16.4 Underwater Inspection Consultant

- Inspection Consultant

17. REVISIONS

This document shall be revised to reflect any changes resulting from field conditions, new information obtained with future testing or analyses, and/or new technology. A distribution list shall be compiled of the contact person at each agency/company who received this document and is responsible for its distribution. That person shall be sent all future revisions. This list shall be added to this document as Appendix J and shall be updated once a year by January 31st to reflect any changes.

18. REFERENCES

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Nevada Department of Transportation

GENERAL SCOUR MONITORING DEVICE OPERATION

SONAR

Will take readings every hour. Data will be downloaded to HQ computer once a day (between ±2:30 a.m. and ±4:30 p.m.). Sonar data received by the computer will be as described below.

Sonar will record elevations for depth readings between 3 feet and 40 feet (if less than 3, no elevation recorded; if more than 40, elevation at 40 will be recorded).

To trigger a call to the pager group and computer, the transducer must be submerged (float switch activated) and the elevation reading must be below the pre-programmed elevation at the time the hourly reading is taken. Once a call has been triggered by a given elevation, another call will not be triggered until the next lower elevation has been reached. Equipment can be programmed to make calls at a series of elevations (e.g., when scour depth reaches 5', 10', 12', etc.). When a call is made, the pagers will be called twice (one minute between calls) before the computer is called.

- The message received by the pagers will be the numeric bridge number followed by the name of the Wash that the bridge spans (i.e., *"420, Piute Wash"* for B-420, *"571, Toquop Wash"* for B-571N, *"839, California Wash"* for B-839S, and *"1805, Red Rock Wash"* for B-1805). The pagers will be called repeatedly as each successive pre-programmed elevation is reached, but only hourly as readings are taken.
- The message received by the HQ computer will be as described below. The computer will be called repeatedly as each successive pre-programmed elevation is reached, but only hourly as readings are taken.

Element	Description
1	Array ID = 1 for Sonar Hourly Readings, = 2 for Scour Event
2	Year
3	Day (Julian)
4	Time (Military)
5	Elevation of the stream bed as determined by the average of 10 sonar readings (*this is not meaningful data unless water level switch is underwater*)
6	Minimum elevation measured over 10 consecutive soundings
7	Maximum elevation measured over 10 consecutive soundings
8	Water level switch status; 0 = inactive, 1= active (underwater)
9	Battery voltage (Replace battery if voltage falls below 12.2)

FLOAT-OUTS

No signals will be sent until a float-out is released by a scour event. The bridge phone will call the pager group (twice) and the computer for each float-out as it is released.

- Message received by pagers will be the name of the Wash that the bridge spans (i.e., *"Piute Wash"* for B-420, *"Toquop Wash"* for B-571N, *"California Wash"* for B-839S, and *"Red Rock Wash"* for B-1805). Pagers will be called immediately as each individual float-out is released.
- Message received by HQ computer will be as described below:

Element	**Description**
1	Array ID = 3 (to indicate float-out signal)
2	Year
3	Day (Julian)
4	Time (Military)
5	Float-out number (channel) 1 status (1 = active, 0 = inactive)
6	Float-out number (channel) 2 status (1 = active, 0 = inactive)

NOTES:

- The pagers may occasionally receive false alarm calls (e.g., if the group page number is accidentally dialed as a wrong number). These calls can be identified as false alarms because the bridge number portion of the message will either not be there or will be a different number.
- As described above, messages received by pagers will be the same whether the signal is from the sonar or from a float-out. System modifications may be made in the future to make pager calls from sonar and float-outs distinguishable.
- A “window” will exist each day from 9:15 a.m. to 9:30 a.m. During this time, the bridge can be called for the purposes of reprogramming system parameters, etc. (ETI can also call the bridge at this time).

B-420 SCOUR MONITORING DEVICE DATA

Location: Bridge B-420, US 95 at Piute Wash
Bridge Phone #: 702-720-3038 (3039?)

- Sonar installed on upstream nose of southernmost pier.
- One channel 1 float-out installed 3 feet below bottom of 6 foot riprap layer at downstream end of each abutment wall.
- One channel 2 float-out installed 3 feet below bottom of 6 foot riprap layer at upstream nose of each of three northernmost piers.

Elevation data from contract 1904 and field measurements during installations:

Piers and Abutment Walls (Stem walls with Piles)
bottom of bridge = top of pier cap: 2499.3
bottom of stem wall: 2488.6
pile tip (steel H-piles): 2470.8

Sonar (This data is programmed in the monitoring equipment)
sonar transducer elevation: 2494.3
ground elevation (riprap) referenced by sonar at time of installation: 2492.0
elevation readings that trigger successive pager/computer calls: 2489.0, 2486.0, 2480.0

Pier and Abutment Float-Outs
ground (riprap) elevation at float-out locations at time of installation: 2492.0
float-out elevation: 2483.0

B-420 SCOUR RESPONSE PLAN

Location: Bridge B-420, US 95 at Piute Wash

Scour Event Pager Message: *"420, Piute Wash" [*false alarm if 420 is missing or different]

Pager Group Members:	Phone #	Cell Phone #
Maintenance Supervisor 1		
Maintenance Supervisor 2		
Maintenance Superintendent		
District Maintenance Engineer		
Principal Bridge Maintenance Engineer		

Responses to Sonar Calls:

- **First** call at elevation reading of **2489.0**
  Scour Location: Midpoint of 6.0' riprap layer (scour depth = 3.0')
  Response: Mobilize to monitor and potentially close bridge

- **Second** call at elevation reading of **2486.0**
  Scour Location: Bottom of 6.0' riprap layer (scour depth = 6.0')
  Response: Close bridge

- **Third** call at elevation reading of **2480.0**
  Scour Location: Midpoint of piles (scour depth = 12.0')
  Response: Bridge already closed

Responses to Float-Out Calls:

- **First** call from channel 1 float-out
  Scour Location: Downstream end of abutment 3.0' below bottom of 6.0' riprap layer (scour depth = 9.0')
  Response: Close bridge

- **First** call from channel 2 float-out
  Scour Location: Upstream nose of pier 3.0' below bottom of 6.0' riprap layer (scour depth = 9.0')
  Response: Close bridge

- Subsequent float-out calls
  Scour Location: See above
  Response: Bridge already closed

B-571N SCOUR MONITORING DEVICE DATA

Location: Bridge B-571N, I-15 at Toquop Wash
Bridge Phone #: 702-720-3036

- Sonar installed on upstream nose of east channel pier (pier 3).
- One channel 1 float-out installed under concrete slope paving at upstream nose of east channel pier (pier 3).
- One channel 2 float-out installed under concrete slope paving at upstream nose of west channel pier (pier 2).

Elevation data from contract 905 and field measurements during installations:

Piers
top of pier walls (upstream nose): 1546.2 (pier 2), 1545.4 (pier 3)
top of spread footings: 1506.7 (pier 2), 1505.9 (pier 3)
bottom of spread footings: 1503.7 (pier 2), 1502.9 (pier 3)

Sonar (This data is programmed in the monitoring equipment)
sonar transducer elevation: 1515.4
ground elevation referenced by sonar at time of installation: 1512.4
elevation readings that trigger successive pager/computer calls: 1512.0, 1510.0, 1506.0, 1503.0

Float-Outs
ground elevation at float-out locations at time of installation: 1512.5±
top of concrete slope paving: 1512.0±
float-out elevation: 1510.5±

B-571N SCOUR RESPONSE PLAN

Location: Bridge B-571N, I-15 at Toquop Wash

Scour Event Pager Message: *"571, Toquop Wash"* [false alarm if 571 is missing or different]

Pager Group Members:	Phone #	Cell Phone #
Maintenance Supervisor 1		
Maintenance Supervisor 2		
Maintenance Superintendent		
District Maintenance Engineer		
Principal Bridge Maintenance Engineer		

Responses to Sonar Calls:

- **First** call at elevation reading of **1512.0**
  Scour Location: Minimal scour. Call indicates that large flow event is taking place.
  Response: Mobilize to monitor and potentially close bridge

- **Second** call at elevation reading of **1510.0**
  Scour Location: 2.0' below concrete slope paving (scour depth = 2.0')
  Response: Close bridge

- **Third** call at elevation reading of **1506.0**
  Scour Location: Top of spread footing (scour depth = 6.0')
  Response: Bridge already closed

- **Fourth** call at elevation reading of **1503.0**
  Scour Location: Bottom of spread footing (scour depth = 9.0')
  Response: Bridge already closed

Responses to Float-Out Calls:

- **First** call from channel 1 float-out
  Scour Location: Upstream nose of east pier beneath concrete slope paving (scour depth = 2.0')
  Response: Close bridge

- **First** call from channel 2 float-out
  Scour Location: Upstream nose of west pier beneath concrete slope paving (scour depth = 2.0')
  Response: Close bridge

B-839S SCOUR MONITORING DEVICE DATA

Location: Bridge B-839S, I-15 at California Wash
Bridge Phone #: 702-720-3037

- Sonar installed on upstream nose of easternmost pier (pier 4).
- One channel 1 float-out installed 3 feet deep in 6 foot riprap layer at upstream nose of easternmost pier (pier 4).
- One channel 2 float-out installed 3 feet deep in 6 foot riprap layer at each upstream nose of center pier (pier 3) and westernmost pier (pier 2).

Elevation data from contract 1108 and field measurements during installations:

Piers
bottom of bridge: 1818.7±
top of pier walls (upstream nose): 1818.3 (pier 2), 1817.9 (pier 3), 1817.6 (pier 4)
top of spread footings: 1806.3 (piers 2 & 4), 1806.7 (pier 3)
bottom of spread footings: 1805.0

Sonar (This data is programmed in the monitoring equipment)
sonar transducer elevation: 1812.0
ground elevation (riprap) referenced by sonar at time of installation: 1810.0±
elevation readings that trigger successive pager/computer calls: 1808.0, 1805.0

Float-Outs
ground (riprap) elevation at float-out locations at time of installation: 1810.0±
float-out elevation: 1807.0±

B-839S SCOUR RESPONSE PLAN

Location: Bridge B-839S, I-15 at California Wash

Scour Event Pager Message: *"839, California Wash" [*false alarm if 839 is missing or different]

Pager Group Members:	Phone #	Cell Phone #
Maintenance Supervisor 1		
Maintenance Supervisor 2		
Maintenance Superintendent		
District Maintenance Engineer		
Principal Bridge Maintenance Engineer		

Responses to Sonar Calls:

- **First** call at elevation reading of **1808.0**
  Scour Location: 2.0' into 6.0' riprap layer (scour depth = 2.0')
  Response: Mobilize to monitor and potentially close bridge

- **Second** call at elevation reading of **1805.0**
  Scour Location: Bottom of spread footing (scour depth = 5.0')
  Response: Close bridge

Responses to Float-Out Calls:

- **First** call from channel 1 float-out
  Scour Location: Nose of east pier at midpoint of 6.0' riprap layer (scour depth = 3.0')
  Response: Mobilize to monitor and potentially close bridge

- **First** call from channel 2 float-out
  Scour Location: Nose of center or west pier at midpoint of 6.0' riprap layer (scour depth = 3.0')
  Response: Mobilize to monitor and potentially close bridge

- **Second** call from channel 2 float-out
  Scour Location: Nose of center or west pier at midpoint of 6.0' riprap layer (scour depth = 3.0')
  Response: Mobilize to monitor and potentially close bridge

B-1805 SCOUR MONITORING DEVICE DATA

Location: Bridge B-1805, FAS 159 (W. Charleston Blvd.) at Red Rock Wash
Bridge Phone #: 702-720-3039 (3038?)

Sonar installed on upstream nose of pier.
- Two channel 1 float-outs installed just downstream of pier.
- Two channel 2 float-outs installed just downstream of bridge ±15 ft. from north abutment toe.

Elevation data from contract 2103 and field measurements during installations:

Pier
bottom of bridge at pier: 3217.2
top of pier pile cap: 3194.5
bottom of pier pile cap: 3191.0
pier pile tip (cast in drilled hole concrete pile): 3179.0

North Abutment
bottom of bridge at abutment: 3216.9
top of abutment pile cap: 3212.5
bottom of abutment pile cap: 3210.3
abutment pile tip (cast in drilled hole concrete pile): 3186.0

Sonar (This data is programmed in the monitoring equipment)
sonar transducer elevation: 3209.9
ground elevation (in riprap mound) referenced by sonar at time of installation: 3207.5
elevation readings that trigger successive pager/computer calls: 3195.0, 3185.0

Pier Float-Outs
ground elevation at pier float out location at time of installation: 3205.2
upper pier float-out elevation: 3195.2
lower pier float-out elevation: 3185.2

Abutment Float-Outs
ground elevation at abutment float out location at time of installation: 3202.3
upper abutment float-out elevation: 3192.3
lower abutment float-out elevation: 3185.3

B-1805 SCOUR RESPONSE PLAN

Location: Bridge B-1805, FAS 159 (W. Charleston Blvd.) at Red Rock Wash

Scour Event Pager Message: *"1805, Red Rock Wash"* [false alarm if 1805 is missing or different]

Pager Group Members:	Phone #	Cell Phone #
Maintenance Supervisor 1		
Maintenance Supervisor 2		
Maintenance Superintendent		
District Maintenance Engineer		
Principal Bridge Maintenance Engineer		

Responses to Sonar Calls:

- **First** call at elevation reading of **3195.0**
  Scour Location: Top of pier pile cap (scour depth = 10.0')
  Response: Mobilize to monitor and potentially close bridge

- **Second** call at elevation reading of **3185.0**
  Scour Location: Midpoint of pier piles (scour depth = 20.0')
  Response: Close bridge

Responses to Float-Out Calls:

- **First** call from channel 1 float-out
  Scour Location: Downstream end of pier at top of pile cap (scour depth = 10.0')
  Response: Mobilize to monitor and potentially close bridge

- **First** call from channel 2 float-out
  Scour Location: Downstream end of NE abutment (scour depth = 10.0')
  Response: Mobilize to monitor and potentially close bridge

- **Second** call from channel 1 float-out
  Scour Location: Downstream end of pier at midpoint of piles (scour depth = 20.0')
  Response: Close bridge

- **Second** call from channel 2 float-out
  Scour Location: Downstream end of NE abutment (scour depth = 20.0')
  Response: Close bridge

SCOUR CRITICAL BRIDGE - PLAN OF ACTION

1. GENERAL INFORMATION

Structure number: 1-05850-9	**City, County, State:** Wantagh, Nassau County, NY	**Waterway:** Goose Creek
Structure name: Wantagh Parkway Bridge over Goose Creek	**State highway or facility carried:** Wantagh Parkway	**Owner:** NYSDOT
Year built: 1929	**Year rebuilt:** N/A	**Bridge replacement plans (if scheduled):** 2007 **Anticipated opening date:** 2008

Structure type: ☒ Bridge ☐ Culvert
Structure size and description: Double leaf bascule bridge; 109.7m (360 ft) in length; 28.3m (93 foot) bascule span; concrete pile bents.
Number of spans: 9 **Continuous over pier (Y, N, N/A):** N **Redundant (Y/N):** N

Over tidal waters? (Y/N): Y

Foundations: ☒ Known, type: Piles Depth: EL. -12.2 m (-40.0 ft) – for scour critical bascule piers
☐ Unknown
Abutment foundation type (piles, spread footing, unknown): Piles
Pier(s) foundation type (piles, spread footing, unknown): Piles

Subsurface soil information (*check all that apply*): ☒ Non-cohesive ☐ Cohesive ☐ Rock
Streambed material (rock, boulders, cobbles, glacial till, alluvium): Sand/Riprap

Bridge ADT: 12,597	**Year/ADT:** 2002	**% Trucks:** <10

Does the bridge provide service to emergency facilities and/or an evacuation route (Y/N)? Y
If so, describe: Evacuation

2. RESPONSIBILITY FOR POA

Author(s) of POA (name, title, agency/organization, telephone, pager, email): NYSDOT Region 10 and Hardesty & Hanover, LLP Date: July 2006 Date of last update: January 2006

Concurrences on POA (name, title, agency/organization, telephone, pager, email): NYSDOT Region 10, Structures Unit – Regional Structures Engineer and Regional Hydraulic Engineer

POA to be updated every 12 **months** Date of next update: January 2007

3. SCOUR VULNERABILITY

a. Current Item 113 Rating: ☒ 3 ☐ 2 ☐ 1 Other: ____

b. Source of Scour Critical Rating: ☒ Observed ☐ Assessment ☒ Calculated
☒ Other: Assigned by the Region (R)

c. Scour Evaluation Summary: A scour analysis in support of an emergency bridge design and replacement was completed in May 1998. In 2000, a "South Shore Hydraulic & Scour Analysis" was conducted This consisted of a 2-D hydraulic model and scour analyses of 19 bridges, including Wantagh Parkway over Goose Creek Bridge. The results of both analyses indicated that the calculated scour was below the bottom of the existing pile tips elevations for the bascule piers, therefore a foundation structural analysis was required. NYSDOT Geotechnical Engineering Bureau conducted this analysis and the results may be found in this Manual, Appendix C.1.1. Both hydraulic studies are on file in NYSDOT Region 10, Structures Unit.

d. Scour History: In April 1998 Wantagh Parkway over Goose Creek was closed due to a partial pier failure. It was found that the streambed at one pier had experienced approximately 8.8m (29 feet) of localized scour since it was built in 1929. This resulted in the downward movement of two piles and the fracturing of the pile cap above them. The outermost pile of this bent was left with 0.37m (1.2 feet) of embedment in the sand. NYSDOT decided to immediately replace the bridge approach spans, but the bascule piers would remain in service for about nine years. A hydraulic and scour analysis indicated that the potential scour at the bascule piers was below the pile tip elevations. The bridge was assigned an NBIS rating of Item 113, Code 3.

e. NYSDOT Hydraulic Vulnerability Assessment Program Classification Score: N/A

4. RECOMMENDED ACTION(S) (see Sections 6 and 7)

	Recommended		Implemented	
a. Increased Inspection Frequency	☒ Yes	☐ No	☒ Yes	☐ No
b. Fixed Monitoring Device(s)	☒ Yes	☐ No	☒ Yes	☐ No
c. Flood Monitoring Program	☒ Yes	☐ No	☒ Yes	☐ No
d. Hydraulic/Structural Countermeasures	☐ Yes	☒ No	☐ Yes	☐ No

5. NBIS CODING INFORMATION

.	Current	Previous
Inspection date (these were General Inspections):	05/27/05	06/08/04
Item 113 Scour Critical	3	3
Item 60 Substructure	7	7
Item 61 Channel & Channel Protection	7	7
Item 71 Waterway Adequacy	6	6
Comments: (drift, scour holes, etc. - depict in sketches in Section 10)	See Attachment D	_____

6. MONITORING PROGRAM

☒ **Regular Inspection Program** ☐w/surveyed cross sections

Items to Watch: Bascule Pier movements, settlement

☒ **Increased Inspection Frequency of ____ mo.** TBD by the Regional Structures Engineer

☐w/surveyed cross sections

Items to Watch: Same as above

☒ **Underwater Inspection Required**

Items to Watch: Scour holes in the vicinity of the bascule piers; See Manual, Section 13 and POA Attachment D

☒ **Increased Underwater Inspection Frequency of** 12 **mo.** and after major storms, TBD by the Regional Structures Engineer

Items to Watch: Same as above

Note for Underwater Inspections: All diving inspection and fathometer surveys are on file with the Regional Hydraulic Engineer

☒ **Fathometer Survey**

☒ **Fixed Monitoring Device(s)**

Type of Instrument: Sonar scour monitors
Installation location(s): Bascule Piers (one each on ebb and flood sides)
Sample Interval: ☒ 30 min. ☐ 1 hr. ☐ 6 hrs. ☐ 12 hrs. ☐ Other: _____
Frequency of data download and review: ☐ Daily ☐ Weekly ☐ Monthly ☒ Other 3x/week
Scour watch elevation(s) for each pier/abutment: -27 ft (-8.2 m)
Scour critical elevations(s) for each pier/abutment: -35 ft (-10.7 m)
Survey ties: MSL, NGVD 1929

☒ **Flood Monitoring Program**

Type: ☒ Visual inspection
☒ Instrument (*check all that apply*): Note: Fixed sonar monitors with remote monitoring
☐ Portable ☐ Geophysical ☒ Sonar ☐ Other: _____
Flood monitoring required: ☒ Yes ☐ No

Note: A Coastal Flood Program has been established for 19 bridges in Region 10, including Wantagh Parkway Bridge over Goose Creek. This program includes the inspection of each bridge after major hurricanes or storms. It is a visual inspection of each bridge for any displacement, movement and/or cracks which may be indicative of larger problems from storm wind and/or water forces. The inspection is conducted as soon as post storm weather permits. The flood watch is activated any time a tropical storm, hurricane or high tide event occurs as described in the Manual, Section 5.4.

Flood monitoring event defined by (*check all that apply*):

☐ Discharge _____ ☒ Stage See Manual, Section 5.4

☐ Elev. measured from _____ ☐ Rainfall _____ (in/mm) per _____ (hour)

☒ Flood forecasting information: See Manual, Section 5.4 ☒ Flood warning system: See Manual, Section 5.4

Frequency of flood monitoring: ☐1 hr. ☐3 hrs. ☐6 hrs. ☒ Other: See Manual, Section 5.4

Post-flood monitoring required: ☐ No ☒Yes, within _____ days

Frequency of post-flood monitoring: ☐Daily ☐Weekly ☐Monthly ☒Other: Varies, See Manual, Section 5.4

Criteria for termination of flood monitoring: Varies, See Manual, Section 5.4

Criteria for termination of post-flood monitoring: Varies, See Manual, Section 5.4

Scour watch elevation(s) for each pier/abutment: -27 ft (-8.2 m)

Scour critical elevation(s) for each pier/abutment: -35 ft (-10.7 m)

Note: Additional details for action(s) required may be included in Section 8.

Action(s) required if scour watch elevation detected (*include notification and closure procedures*): See Manual, Sections 5.4 and 6 to 10.

Action(s) required if scour critical elevation detected (*include notification and closure procedures*): See Section 8 and Attachment E.

Agency and department responsible for monitoring:
Scour Monitoring Consultant

Contact person (*include name, title, telephone, pager, e-mail*): (1) Senior Hydraulics Engineer; (2) Hydraulics Engineer

7. COUNTERMEASURE RECOMMENDATIONS

Prioritize alternatives below. Include information on any hydraulic, structural or monitoring countermeasures.

☒ **Only monitoring required (see Section 6)**

☒ **Scour countermeasures considered (see Section 10, Attachment F):**

Priority Ranking	Estimated cost
(1) Riprap	$ N/A
(2) _____	$ _____
(3) _____	$ _____
(4) _____	$ _____
(5) _____	$ _____

Basis for the selection of the preferred scour countermeasure: Bridge to be replaced; scour mechanism was determined to be mostly degradation and thus riprap or armoring would entail armoring of the entire channel

Countermeasure implementation project type:

☐ Proposed Construction Project ☐ Maintenance Project

☐ Programmed Construction - Project Lead Agency:

☐ Bridge Bureau ☐ Road Design ☒ Other Emergency Contract

Agency and department responsible for countermeasure program (if different from Section 6 contact for monitoring): NYSDOT Region 10, Structures Unit

Contact person (*include name, title, telephone, pager, e-mail*): Regional Structures Engineer

Target design completion date: Dec 2006

Target construction completion date: Dec. 2008

Countermeasures already completed: Sonar scour monitors installed in Aug. 1998; ongoing scour monitoring program since installation

8. BRIDGE CLOSURE PLAN

Scour monitoring criteria for consideration of bridge closure:

☐ Water surface elevation reaches _____ at _____

☐ Overtopping road or structure

☒ Scour measurement results / Monitoring device (See Section 6)

☒ Observed structure movement / Settlement

☐ Discharge: _____ cfs/cms

☐ Flood forecast: _____

☐ Other: ☐ Debris accumulation ☐ Movement of riprap/other armor protection

☐ Loss of road embankment

Emergency repair plans (*include source(s), contact(s), cost, installation directions*): TBD by Regional Structures Engineer, See Manual, Section 7

Agency and department responsible for closure: NYSDOT, Region 10, Transportation Maintenance Group

Contact persons (name, title, agency/organization, telephone, pager, email): (1) Regional Transportation Maintenance Engineer, (2) Res. 06 Resident Engineer, (3) Bridge Maintenance Engineer, See Manual, Appendix D

Criteria for re-opening the bridge: To be determined by the Regional Structures Engineer pending results of diving inspection of Bascule Piers

Agency and person responsible for re-opening the bridge after inspection: (1) Regional Transportation Maintenance Engineer, (2) Res. 06 Resident Engineer, (3) Bridge Maintenance Engineer

9. DETOUR ROUTE

Detour route description (route number, from/to, distance from bridge, etc.) - Include map in Section 10, Attachment E.

Bridges on Detour Route:

Bridge Number	Waterway	Sufficiency Rating/ Load Limitations	Item 113 Code
1059159	False Channel	79	6
1059149	Fundy Channel	82	6
1059129	Sloop Channel	47 – R-posted	6

Traffic control equipment (detour signing and barriers) and location(s): See POA, Attachment E

Additional considerations or critical issues (susceptibility to overtopping, limited waterway adequacy, lane restrictions, etc.) : None

News release, other public notice (include authorized person(s), information to be provided and limitations): Office of the Regional Director, Region 10, NYSDOT

10. ATTACHMENTS

Please indicate which materials are being submitted with this POA:

☒ **Attachment A: Boring logs and/or other subsurface information**

☒ **Attachment B: Cross sections from current and previous inspection reports**

☒ **Attachment C: Bridge elevation showing existing streambed, foundation depth(s) and observed and/or calculated scour depths**

☒ **Attachment D: Plan view showing location of scour holes, debris, etc.**

☒ **Attachment E: Map showing detour route(s)**

☒ **Attachment F: Supporting documentation, calculations, estimates and conceptual designs for scour countermeasures.** – See Manual, Appendix A

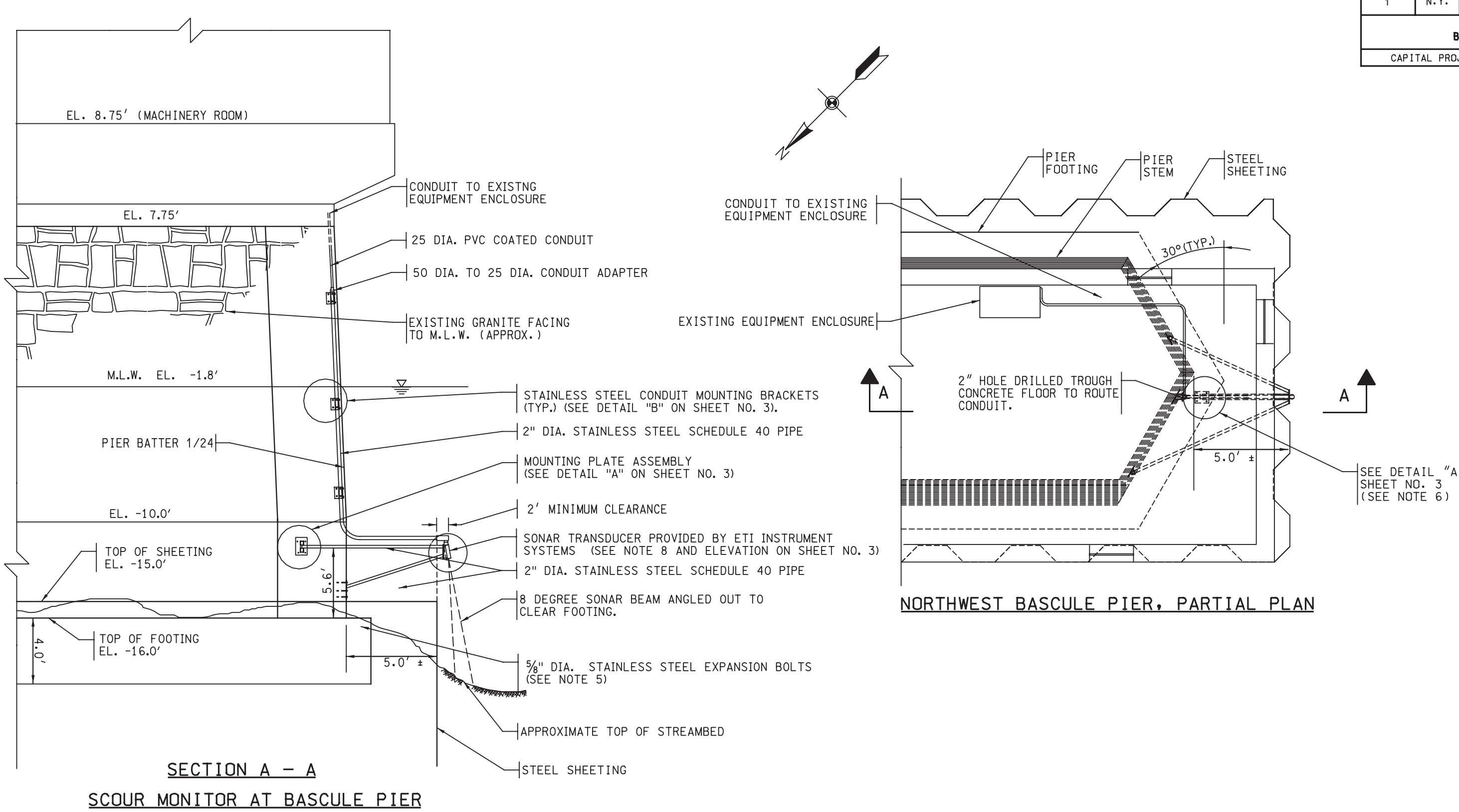
☒ **Attachment G: Photos –** See Manual, Appendix F

☐ **Attachment H: Other information:**

FED. ROAD REG. NO.	STATE	FEDERAL AID PROJECT NO.	SHEET NO.	TOTAL SHEETS
1	N.Y.		2	4

WANTAGH PARKWAY
BRIDGE OVER GOOSE CREEK

CAPITAL PROJECT IDENTIFICATION NUMBER 0B03.04



NORTHWEST BASCULE PIER, PARTIAL PLAN

SECTION A – A

SCOUR MONITOR AT BASCULE PIER

NOTES:

1. ALL STAINLESS STEEL PIPES SHALL BE ASTM A312M GRADE TP316.
2. ALL STAINLESS STEEL TUBES SHALL BE ASTM A269 GRADE TP316.
3. ALL STAINLESS STEEL PLATES SHALL BE ASTM A240M GRADE 316.
4. THE STAINLESS STEEL CONNECTING PRODUCTS SHALL BE ASTM A193M GRADE B8.
5. ALL 5/8" DIA. EXPANSION BOLTS SHALL BE TYPE 316 S.S. RAWL-STUD CAT. NO. 7326 OR EQUIVALENT. MIN. DEPTH OF EMBEDMENT SHALL BE 6.0", UNLESS OTHERWISE NOTED.
6. PIER SURFACE AT MOUNTING LOCATION TO BE CLEARED OF ANY DEBRIS AND RIPRAP PRIOR TO INSTALLATION OF BRACKET.
7. ALL WELDS SHALL BE 2" MINIMUM.
8. TRANSDUCERS TO BE A MINIMUM OF 6.0' ABOVE TOP OF EXISTING STREAMBED OR AS DIRECTED BY THE ENGINEER. AS-BUILT ELEVATIONS SHALL BE REPORTED TO THE ENGINEER.
9. CONDUIT ADAPTER SHALL BE STAINLESS STEEL LOCATED 3.0' ABOVE M.S.L. (MIN.)
10. 1" PVC ELECTRICAL CONDUIT IS ROUTED ALONG CEILING IN MACHINERY ROOM, ABOVE LOCKERS, BETWEEN THE LOCKERS AND THE WALL AND THROUGH A 2" HOLE DRILLED THROUGH THE CONCRETE FLOOR.

AS-BUILTS

CONTRACT NO. D 015319 BIN 1058509

SCOUR MONITOR DETAILS 1
AT NW BASCULE PIER

STATE OF NEW YORK
DEPARTMENT OF TRANSPORTATION
WANTAGH PARKWAY
BRIDGE OVER GOOSE CREEK

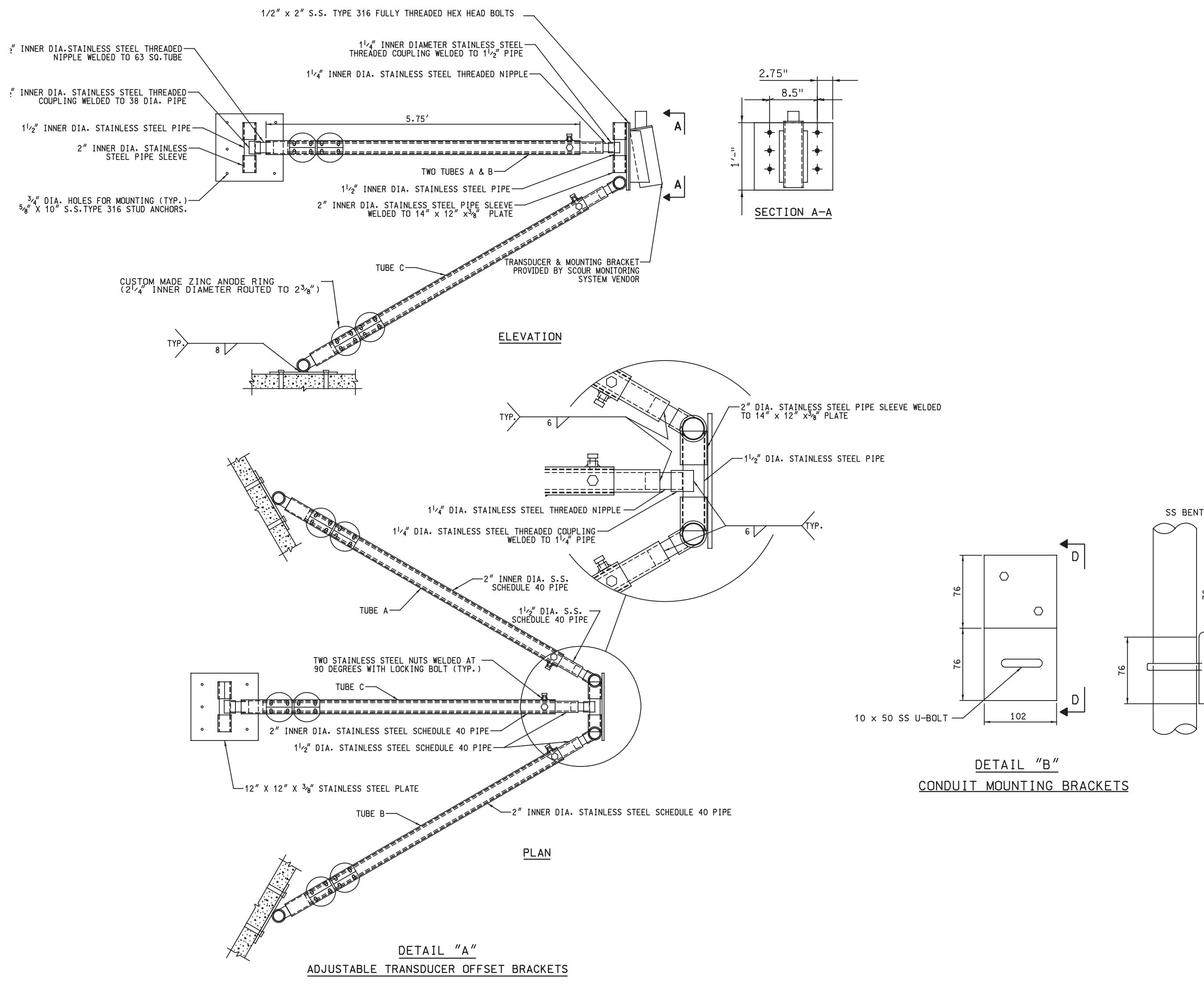
DRAWING NO.	DATE	SCALE	SHEET
2	03-05-04	N.T.S.	NO. 2

HARDESTY & HANOVER, LLP
CONSULTING ENGINEERS NEW YORK, N.Y.

FED. ROAD REG. NO.	STATE	FEDERAL AID PROJECT NO.	SHEET NO.	TOTAL SHEETS
1	N.Y.		3	4

WANTAGH PARKWAY
BRIDGE OVER GOOSE CREEK

CAPITAL PROJECT IDENTIFICATION NUMBER 0B03.04



NOTES:

1. ADDITIONAL 3/4" DIA. S.S. NUTS WERE USED TO ACT AS SHIMS SINCE THE 10" DIA ANCHOR BOLTS DID NOT HAVE ENOUGH THREAD. THE NUTS ACTED AS SPACERS.
2. CONDUIT MOUNTING BRACKETS (DETAIL B) NEEDS IMPROVEMENT. THE BRACKET MUST BE WIDE ENOUGH SO THAT THE STUD ANCHOR BOLTS ARE SPACED FURTHER APART THAN THE WIDTH OF THE 50 DIA. (2") S.S.PIPE. THE BOLTS ARE DIFFICULT TO INSTALL ONCE THE PIPE IS IN PLACE.
3. THE TRANDUCER MOUNTING BRACKET WAS SALVAGED FROM THE OLD BRACKET SYSTEM, REFURBISHED AND COATED WITH ANTI-FOULING PAINT.
4. THE OUTER DIA. OF THE 2" S.S. TYPE 316 PIPE IS 2 3/8". THE OUTER DIA. OF THE 1 1/2" S.S. TYPE 316 PIPE IS 1 7/8".

AS-BUILTS

CONTRACT NO. D 015319 BIN 1058509

SCOUR MONITOR DETAILS II
AT NW BASCULE PIER

STATE OF NEW YORK
DEPARTMENT OF TRANSPORTATION

WANTAGH PARKWAY
BRIDGE OVER GOOSE CREEK

DRAWING NO.	DATE	SCALE	SHEET NO.
3	03-05-04	N.T.S.	3

HARDESTY & HANOVER, LLP
CONSULTING ENGINEERS NEW YORK, N.Y.

APPENDIX H

Database Information

SUGGESTIONS FOR A NATIONAL SCOUR DATABASE

Using existing databases found through the literature search and the data from the scour monitoring systems made available by the survey respondents, the following are suggestions on how a national database might be structured and what elements it might contain. Chapter 8 contains a discussion of the current U.S. databases that may be modified to include scour data for use as a national scour database.

This following includes information on assembling and maintaining a scour database. Databases that served as examples included the United States Geological Survey (USGS) National Bridge Scour, the Abutment Scour (South Carolina), and the National Water Information System (NWIS) databases.

Information that could be assembled in a national scour database for the scour monitoring data are outlined below. The organization of the National Bridge Inventory database could be used for the elements that both share in common. Additional elements relative to hydraulics and scour would be added in a bridge scour section.

A national scour monitoring database for the scour monitoring data could contain the following elements for each bridge site:

Bridge Information

- Name of Bridge
- Bridge Location
- Bridge Number
- Bridge Length
- Number of Spans
- Type of Bridge
- Average Daily Traffic (ADT)
- Year Built (and Rebuilt)
- NBIS Items 60 and 113 ratings
- Measured scour (minimum, moderate, severe)

Scour Monitoring Information

- Type and Number of Scour Monitors Employed
- Installation Date of Scour Monitors
- Status—Active or Inactive and Why

Site Specific Information

- Waterway Characteristics
  - Waterway Type—Tidal/Riverine
  - Flow Habit
  - Water Depth
  - River Type—Braided, Meandering, Straight
  - Stream Size
  - Bend Radius
  - Bank Condition
  - Floodplain Width
  - Drainage Area
  - Slope in Vicinity
- Soil Conditions
- Extreme Conditions (Low/Medium/High)
  - Debris
  - Ice Flows
  - High Velocity Flows

- Functional Applications
    - Local Scour
    - Contraction Scour
    - Stream Instability
- Documentation
    - As-built or design plans
    - Borings
    - Soil classification tests
    - Stream cross-sections
    - Fathometer surveys
    - Photographs

Narrative information could be added about the site, the scour history of the bridge and any emergency Plan of Action. Photographs of the bridge and site might also be included. Additional information could be included in this database, such as some of the other items in the National Bridge Scour Database. At the same time, the desire for a large amount of data needs to be balanced with the need to minimize the time required of respondents, and therefore increase the number of responses.

ASSEMBLING AND MAINTAINING THE DATABASE

The data could be assembled much like a search engine. For example, if a person is looking for sites with predominantly clay soils in debris-prone waterways, a list of similar sites could be readily generated for comparison. A main homepage could be set up where the user is allowed to choose specific bridge, waterway, and soil characteristics to narrow down their search. The search engine would list bridge sites that match the user's criteria in order of relevance. The user could then click on each bridge listing to view site-specific data. Links to sample data and graphs, agency information, manuals, Plans of Action, and scour monitoring vendor information could be listed as references for each bridge site. A contact name could be listed for each bridge for those who wanted to obtain more information about a particular site. This would also allow for an exchange of ideas and experiences between bridge owners, agencies and others.

Those responsible for maintaining the database might update the status, agency contact information, and available references for each bridge. This information could be updated once per year. The data could be collected one to two times per year. States submit their Bridge Scour Evaluation Program data to FHWA two times per year. Scour monitoring data could be requested and submitted at the same time. Some of the survey respondents indicated that they do not intend to keep the data for any period of time. Others said they plan to keep their data indefinitely. Those maintaining the database could collect this data annually or semi-annually as well. Reminders could be sent periodically via e-mail so that the respondents could reply and add an attachment with the scour monitoring data. Other measurements taken at the site such as water stage and velocity could also be collected for the database. If possible, all data could be converted into more user-friendly formats such as tables and graphs, and used as reference material for those searching the database.

APPENDIX I

Research Problem Statements

Following are two research problem statements on the subject of bridge scour monitoring instrumentation. The first has already been submitted by Members of TRB Committee AFF40, Dynamics and Field Testing of Bridges Committee and is on the broader topic of Structural Health Monitoring. The second is a draft statement prepared by synthesis panel member Stan Davis during the construction of the new Woodrow Wilson Memorial Bridge. Scour monitors have not been installed at the new bridge, but the statement contains some excellent points in support of the installation of a scour monitoring system that may be used on the Wilson or another bridge. Chapter 8 contains additional discussion of other research needs, and Appendix H is about the development of a national database that includes the scour monitoring data.

RESEARCH PROBLEM STATEMENT #1:

REMOTE STRUCTURE MONITORING TECHNIQUES FOR HEALTH MONITORING

I. Research Problem Statement

The ability to monitor the condition of a structure and to detect damage at the earliest possible stage is of significant interest in many engineering disciplines. Currently, the most widely used damage detection methods rely on subjective, incremental visual assessments or localized testing techniques. These methods require the location, or possible location, of damage to be known prior to the assessment. Often, these locations can be estimated through appropriate engineering analysis. However with the increasing complexity of many of the nations bridges, the potential damage locations are not known or are too numerous to be economically tested or inspected using conventional damage detection techniques. As a result, health-monitoring techniques have been developed and employed as a means to economically and reliably provide for an overall, continuous condition assessment of complex bridge structures. Complicating the issue is the fact that increased numbers of sensors require more complex- infrastructure for installation and monitoring. Furthermore, these complex systems are subject to faults that require maintenance or failure, both of which will reduce the reliability and economy of the overall health-monitoring system.

While the end product of health-monitoring provides for an assessment of the global and local conditions within a bridge, the data collected must allow for the detection of changes in key bridge performance metrics such as scour, substructure movement, cracking, seismic damage, corrosion, and overloads. This requires the monitoring of behavioral information related to deflection, rotation, strain, and modal parameters (i.e., resonant frequencies, mode shapes, and modal damping). Measurement of these parameters is relatively easy, and significant research has been conducted to improve sensor technology. As such, the focus of this research is not to advance sensor technology.

Damage detection and health-monitoring has been practiced in a qualitative manner, in some form or another, since the beginning of man. However, successful quantitative tools were not developed until computers became widely available. In some industries, the general development of quantitative damage assessment tools has been the subject of much research. These efforts have yielded significant advances in the past 30 years, specifically in the mechanical, nuclear, oil, and electrical power industries. For example, vibration-based damage detection technology has been developed for monitoring of rotating machinery and similarly the aerospace industry applied health-monitoring techniques to monitor space shuttle performance.

While the advancements in sensors, computer technology, and post-processing algorithms have been significant; there are two remaining needs. First, a need to develop an infrastructure capable of providing connectivity locally at the bridge site and more globally to the intelligent transportation system command centers. This need is amplified as the bridge industry attempts to apply health-monitoring techniques to larger, more complex bridge structures, which require increasing numbers of sensors to attain a reliable level of performance for damage or event detection. The cost of hard wiring and maintaining an infrastructure system to allow communication between the sensor and the computers monitoring the subject structure increases with the numbers of sensors. The development of a remote monitoring system permits the deployment of additional sensors at minimal cost, without the long-term need for infrastructure maintenance costs. Furthermore, remote monitoring systems permit the rapid deployment and connectivity of additional sensors to monitor specific bridge concerns or events on an as-needed basis.

The second need, and probably the least investigated, is the need for a general design methodology to achieve system integration, measurement calibration and validation for sensing and monitoring. As noted below there has been research into remote monitoring to determine its viability, but there has been little development into the monitoring design to determine heuristics of sensor use, number, location, and sampling rate. Ultimately, there is a need to improve monitoring design for this methodology to become an effective tool for the bridge owner.

Bridge owners to facilitate their efforts to maintain reliable transportation networks in which a bridge plays an important role will use the work product from this research. Advancements in remote monitoring systems and system design will permit health monitoring to be economically employed at larger, more complex bridges, where early detection of scour, substructure movement, corrosion, cracking, and seismic damage is paramount. The work product will consist of a guide for the development of a remote monitoring infrastructure for bridge health monitoring.

II. Literature Search Summary

A literature search using the following key words was performed: health monitoring, structure monitoring, remote monitoring, bridge health, and several other combinations that yielded several hits. Searches were conducted using TRIS online and Research in Progress databases. Up to 90 hits were recorded. Most nearly all hits pertain to more conventional health-monitoring, wherein wire infrastructure is utilized between sensors and the data station; advances in sensor technology; or advances in post processing algorithms. The authors of this Research Needs Statement concede that significant research and case studies have been performed with regard to the study of sensor technology, post processing algorithms and case studies. For example, Departments of Transportation in Connecticut and New York have studied remote monitoring and found it to be a feasible methodology. Connecticut is currently monitoring several bridges. However, as described in Section V, Research Objective, the objective of this research is not to study these areas of health-monitoring further but rather improve the remote monitoring infrastructure so as to take maximum advantage of the improvements in these areas while developing a guide specification for system integration.

Two hits of note were compiled. The first was a 2003 joint Rhode Island/FHWA study entitled, Remote Bridge Monitoring: A Survey authored by V.N. Parameswaran, A. Shukla, and E. McEwen. The survey reported a summary of state-of-the-art techniques for bridge monitoring, critical Rhode Island bridge details for which monitoring would be required, and appropriate sensor configuration and monitoring schemes to accomplish the monitoring of the proposed Providence River Bridge. Another project recently undertaken by ISIS Canada is closely aligned with the research objectives stated herein. The study was focused on five efforts, as follows: 1) wireless transmission; 2) various sensor interfaces and data compression; 3) dial-out remote monitoring; 4) remote connection to Internet and satellite; and 5) microchip data acquisition systems. Additionally, the Association of American Railroads Transportation Technology Center Inc. (TTCI) has tested some wireless products and systems for communications; track monitoring; crossing monitors; train tracking and control; remote monitoring of hot boxes, track heaters, lubricators, and other devices, etc.

The existing database must be utilized to achieve Task I and II, but the results of the proposed research will be unique and will represent a useful piece of work for bridge owners contemplating future health monitoring applications on their bridges.

III. Research Objective

Ultimately, the project goal is to improve the performance, safety and economy of our nations bridges for the benefit of its citizens. Specifically, this project will develop and deliver a guide for the use of remote technologies for short and long-term health monitoring of critical bridge structures using state-of-the-art technologies. This will be accomplished through four distinct work tasks, including

Task I Literature Search. Synthesis of technical information for remote monitoring of bridges: The literature search indicates that many advances in sensor technology and post processing algorithms have taken place. Several states have undertaken pilot studies to implement health-monitoring systems on critical bridges. While this work is beneficial to the study, it will not form the focus of the study. Rather, this literature will be studied to determine if remote monitoring was used and if so, what successes or failures did they have. Deliverable: Synthesis report.

Task II Remote System Design. A synthesis of available remote monitoring systems, sensors, data acquisition equipment, etc will be performed. Specifically, the connectivity of the available sensors and data acquisition systems will be studied to determine how a remote monitoring system can be employed and reliable data transmission achieved. The performance of various remote monitoring systems will be studied to gauge performance characteristics under extreme temperature variations; traffic vibrations; extreme loading events such as permit loading, floods, earthquakes, and high winds; moisture; vandalism; corrosion; magnetic, radio wave, solar, or microwave interference; and etc. Deliverable: Design specifications for various remote-monitoring systems for bridge health-monitoring.

Task III System Validation. Develop an off-the-shelf remote monitoring system. Based on the study of Task 1 and II, the researchers will validate the performance of a health-monitoring system using various remote monitoring systems. The systems will be tested under controlled conditions at field test sites to study the remote monitoring systems hysteric behavior, durability, reliability, and maintenance. Deliverable: A Remote Monitoring Design Guide including summary report of system performance, with final recommendations for specifications to achieve remote monitoring system design for site specific designs. Key to this effort will be the development of criteria of what to monitor, how many sensors to employ and the sampling rate to achieve desired results, without mistakenly interpreting results. Task IV Long Term System Validation: Illustrated Example of the Remote Monitoring System. Using the remote monitoring system proposed in Task III, the final configuration will be implemented at a test bridge and its performance evaluated over a period of 1 year. Deliverable: Summary report of system performance, with recommendations for improvement to the recommended specifications and long-term projected cost-benefit analysis to owner.

IV. Estimate of Problem Funding and Research Period

Recommended Funding:
An estimate of the funds necessary to accomplish the objectives stated above is $200,000 for labor and $50,000 for equipment procurement.

Research Period:
The research period is 2 months for Task I, 2 months for Task II, 3 months for Task III and 12 months for Task IV, for a total project duration of 20 months, including NHCRP review time.

V. Urgency, Payoff Potential, and Implementation

Members of TRB Committee AFF40, Dynamics and Field Testing of Bridges Committee suggested this research needs statement. It is also aligned with a Thrust/Business Need as addressed by NCHRP 20/07. Specifically, the Maintenance, Rehabilitation and Construction thrust/business needs area listed the following as a research need: Remote structure monitoring techniques and systems for scour detection, substructure movement, cracking, seismic damage, corrosion, and overloads.

The members of the committee considered this topic to be interest to bridge owners and public stakeholders, as a means to improve bridge reliability through use of bridge performance data to maximize maintenance and rehabilitation dollars over the bridges life span. The investment into monitoring offering the most significant payoff is the reliable and timely interpretation of sensor output during and immediately following a hazard, to assure bridge safety. At the same time, the potential intrinsic benefits of remote monitoring is the accumulation of bridge performance data for slower occurring events such as scour, deterioration of concrete due to chemical attacks, corrosion, gradual loss of prestress, etc. Significant research has been conducted on improving many aspects of the available health monitoring systems, with the exception of research into remote monitoring. Consequently, the funds expended through this study can be maximized to bring state-of-the-art sensor technology, computers, and post-processing algorithms to bear for health monitoring of our bridge structures. The remote monitoring infrastructure is the key to taking advantage of these advancements in the most economical manner.

The Remote Monitoring Design Guide will be useful to all bridge owners contemplating implementation of a remote monitoring system for health monitoring. The past work and health monitoring guides developed by FHWA and others will be useful in guiding the selection of sensors for particular applications. However this guide will allow states to economically and rapidly install monitoring systems on critical bridges.

VI. Person(s) Developing the Problem

TRB Committee AFF40 developed this problem statement. Committee Chair Richard A. Walther is serving on behalf of the committee as the problem statement developer. Mr. Walthers contact information is as follows:

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DRAFT

RESEARCH PROBLEM STATEMENT #2:

PROPOSAL: MONITOR THE NEW WOODROW WILSON BRIDGE FOR SCOUR

1. Cost: 300K to 400K
2. Source of Funding: Pooled fund project or SPR funds
3. Study Period: 5 years or more
4. Equipment needed: scour (sonar) meters; velocity meters; water surface elevation recorder; data logger and telemeter equipment. Data logger to be stored in a convenient location such as the area surrounding the bascule lifting machinery
5. Product: Research report and database documenting variation of bridge scour with river characteristics, subsurface soils and bridge geometry for a major bridge. Ideally, this report would be a part of a national effort of scour monitoring of major bridges.

WHY IS SCOUR MONITORING OF VALUE?

1. Consideration of scour in foundation design is a critical element in the design of major bridges.
2. Existing equations and methodologies for evaluating scour are based, for the most part on small-scale flume studies conducted in hydraulic laboratories. There is a concern that these existing procedures may over-estimate/underestimate scour depths for major bridges, and lead to either significant unnecessary costs of foundations or to conditions of instability during major floods.
3. Actual scour data obtained from monitoring stations on major bridges will serve to provide information for use in calibrating existing scour estimating procedures.
4. The collection of real time data can serve to measure scour during the passage of a flood hydrograph so as to gain insight into the mechanics of the scouring process. Information on the data collected for the existing Woodrow Wilson Bridge can be included in the research proposal to highlight how the scour data is documented.

WHY MONITOR THE NEW WOODROW WILSON BRIDGE?

The new bridge has all of the elements needed for a comprehensive evaluation of scour. **The great extent of useful data on this bridge probably exceeds that of any other major bridge structure in this country:**

1. Long term stream gaging records of a major river (drainage area of 11,900 sq. miles)
2. Calibrated water surface profile by the Corps of Engineers for a major flood.
3. HEC-RAS studies for existing and proposed conditions, calibrated to the high water marks collected by the Corps of Engineers
4. Flood velocities at the structure for major storm events in the range of 8 to 10 feet per second resulting in significant scour
5. Complex, large piers
6. Extensive subsurface studies documenting soil profiles and properties; considerable range of clay, silt, and cohesionless soil properties.
7. 5 year scour monitoring records for the existing WWB
8. Personnel who are intimately familiar with the details of a major scour monitoring effort (who set up the monitoring for the existing bridge) are readily available to do the work.
9. The bridge site at Alexandria, Virginia, is conveniently and easily accessible (within an hour drive of Baltimore)
10. A comprehensive scour report developed by a team of hydraulic, geotechnical, and structural engineers over a two year period. Various methodologies for estimating scour were utilized and compared including:
11. Large scale flume studies (Turner Falls, Mass Hydraulic Lab)
12. Small scale flume studies (FHWA Hydraulic Lab)
13. FHWA (HEC-18) scour equations for wide piers
14. FHWA (HEC-18) scour equations for complex piers
15. SRICOS Method for estimating scour in cohesive soils
16. Erodibility Index method for estimating scour in cohesive soils
17. Scour analyses of alternative systems for pier protection from ship collisions (advantage of the ring system as compared with the dolphin protection system)

WHY IS A LONG-TERM DATA COLLECTION PERIOD REQUIRED?

Daily flows in the Potomac River at the bridge are tidal flows with very low velocities of about 1 foot per second. These velocities are too small to develop significant scour holes. Due to the size of the Potomac River Drainage Basin (11,900 square miles) and the waterway area of the river at the bridge site, it will take a significant storm event to generate flow velocities great enough to produce scour holes at the piers.

WHY NOT COLLECT SCOUR DATA MANUALLY BY A TEAM OF BRIDGE INSPECTORS DURING PERIODS OF PEAK FLOW?

There are many logistical problems associated with getting a trained crew of bridge inspectors with the appropriate monitoring equipment at a site during a major flood. This approach was tried in a cooperative project with the USGS for a tri-state area (MD, VA, DE) for a 3-year period with very minimal results. We understand that efforts by the USGS to mobilize scour teams in other areas of the country have also proven to be difficult to accomplish with meaningful results. Using SHA bridge inspectors is not considered to be a productive approach because:

- Significant resources will be required for continual training sessions, and
- These inspectors all have major responsibilities associated with the protection of the public during periods of major flooding.

Summary of site data and scour analyses performed to date: Finite element runs, HEC-RAS studies, lab flume models, soils profiles, 5 years of scour monitoring data of original bridge (demolished in 2006).

Abbreviations used without definitions in TRB publications:

AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	Air Transport Association
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation