FHWA-NJ-2003-009

Evaluation of Bridge Scour Monitoring Methods

FINAL REPORT
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16. Abstract

The main objective of this study is to implement and evaluate the National Cooperative Highway Program (NCHRP) Project 21-3 "Instrumentation for Measuring Scour at Bridge Piers and Abutments" (Lagasse et. al., 1997) designated system(s) for monitoring bridge scour. The proposed project identifies the method(s) and procedure(s) that most accurately identify the severity of scour in bridge foundations. Two systems were considered: 1) Magnetic Sliding Collar (MSC) and 2) Sonar systems. For this purpose more than ten bridge sites, rated scour critical by the New Jersey Department of Transportation (NJDOT), have been inspected for possible installation of equipment. Two bridge sites were selected: Route 35 over Matawan Creek, Aberdeen, NJ and Route 46 Over Passaic River, Elmwood Park, NJ. Both bridges were selected based on scour activity, accessibility, and streambed conditions as noted in bridge inspection reports. On each bridge, both MSC and Sonar systems were installed. Continuous scour data monitoring was initiated. It was observed that both instruments could be easily installed with the proper equipment and some technical skills by the inspection personnel of NJDOT. It was found that the MSC and Sonar devices complement each other to provide a clear and accurate picture of the scour activity at each site.

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INTRODUCTION

Scour is the erosion of sand and rock by the action of flowing water, which causes stream stability problems, as well as bridge failures. Although bridges rest on normally stable foundations of piers, abutments, and caissons, when scour occurs at a dangerous level, it causes bridges to become unstable and unsafe for traffic. Over the last two decades, an excessive number of bridges, which constitute a major part of our national investment, failed due to scour around their abutments and piers. According to the National Bridge Inventory, there are more than 575,000 bridges in the United States, and about 84% of them are over waterways and require scour mitigation.(7) The resulting vertical and lateral changes in channel dimensions can jeopardize bridge foundations and integrity. Major decisions must be made to allocate the limited funds available for repair, rehabilitation, and replacement. The decision process involves a prioritization of needs, particularly with the selection of structures to be repaired, rehabilitated, or replaced. These decisions should be based on an evaluation of the structural integrity of the bridge foundation due to scour. Therefore, there is a need for efficient (accurate, inexpensive, long-lasting, easy-to-install, and non-obstructive to occupants or users) scour monitoring devices and techniques. Additional information about bridge scour would allow for a reduction of uncertainty and more rational operation, maintenance, and repair decisions. Such needs include the requirements to warn against excessive scour occurrence, allowing prevention or rapid evacuation in a timely manner.

Few studies have been developed for evaluating bridge scour using advanced nondestructive equipment and instrumentation. However, the evaluation of bridge scour is emerging as an increasingly important topic in the effort to deal with the deteriorating infrastructure and rehabilitation of bridges. The scour-critical bridges are rendered unsafe due to excessive undermining. The disposition of these bridges involves clear economic and safety implications. To avoid high costs of replacement or repair, the evaluation must accurately reveal the present scour conditions and predict any further changes (or deterioration) in the applicable time span. Therefore, with the increased emphasis on bridge management systems using state-of-the-art equipment, there is a need for accurate and inexpensive methods to determine the actual scour conditions. The effort to prioritize and schedule repair and rehabilitation of scour requires accurate, as well as systematic, assessment and monitoring of scour conditions.

This study provides an evaluation of two early detection systems with the capability of notifying the authorities when scour level nears an unsafe threshold. Both systems were deployed on two bridges located in New Jersey where they were evaluated for various technical aspects including deployment, data collection, data processing, security, accuracy, etc. The following section reviews some of the major equipment available in the literature.

OBJECTIVE

The main objective of this study is to implement and evaluate the National Cooperative Highway Program (NCHRP) Project 21-3 “Instrumentation for Measuring Scour at Bridge Piers and Abutments” designated system(s) and procedure(s), which most accurately identifies the severity of scour in bridge foundations.(12) This included selecting specific bridge sites and applying the most reliable equipment and methods under closely controlled conditions. The accuracy of each system and the effect of various parameters were studied. Parameters include environmental conditions (temperature, rainfall intensity, flooding events, ice, etc.), bridge type (single span, rural versus principle arteries), and foundation type. The end result was to provide a methodology which will enable New Jersey Department of Transportation (NJDOT) to successfully select the appropriate equipment and effectively evaluate and mitigate bridge scour.

PURPOSE

The purpose of this report is to describe the methods and procedures which most accurately identify the presence of scour around bridge foundations. They include selecting specific bridge sites and applying the most reliable equipment and methods under closely controlled conditions.

SCOPE

The scope of this project was to determine the feasibility of the scour measurement for New Jersey Bridges. The State Department of Transportation furnished a list of bridges marked for additional scour investigation.

BACKGROUND

Throughout the literature there are common elements to scour monitoring systems. These include the instruments that detect streambed elevation and the means of collecting and storing the data. Manually operated fixed systems offer a basic means of measuring the scour depth at a bridge. One example of a fixed manual system is a scour chain or Brisco Scour Monitoring Device. A weight is lowered along a fixed tube mounted on a bridge pier. The scour depth is denoted by the length of chain that is lowered. Manually operated portable systems such as small floating sonar depth sounder and record depth measurements about a pier. Fixed automatic systems are permanently fixed to a bridge and have the ability to continuously monitor the streambed elevation. There are two types of sensors that can be connected to this system: 1) the magnetic sliding collar and 2) the sonar transducer. The literature points out that the sonar readings are affected by waterborne debris and air bubbles. Furthermore, the MSC is prone to jamming with tree limbs and other debris. Typically, the two types of sensors are not installed concurrently at a similar location on a bridge. Therefore, data may be incorrect if only one type of instrument is being monitored.

There are two approaches to operate a fixed automatic system: 1) data storage and 2) remote access. In the data storage mode, data is monitored continuously and stored to a non-volatile memory. A field technician visits the site on a regular schedule to download the stored data. The most notable drawback of this mode is the need for a dedicated person to travel to a remote site. During an extreme river flow, it is not possible to determine the extent of scour activity at the bridge until some time in the future when the data can be downloaded. Most, if not all, of the problems related to fixed instrumentation data can be prevented with remote data access. Remote access is achieved using a cellular telephone modem, landline, or a long range radio transceiver. Remote access, which allows researchers not only to retrieve the data remotely, also provides a means of checking the performance of the system and the adequacy of the data.

The most important reason for the use of scour monitoring systems is to prevent loss of life due to an extreme scour event. The fixed system with remote access enables the owner to determine the extent of scour damage before a catastrophic bridge collapse is imminent. When scour is detected, the bridge can be closed and traffic rerouted. Furthermore, to achieve a high reliability of data, both the sonar and magnetic sliding collar sensors were installed simultaneously to monitor scour at a pier location.

AVAILABLE SCOUR MEASUREMENT DEVICES

Permanent instruments used for scour measuring and monitoring are classified into four categories.

1. Sounding rods,
2. Buried or driven rods with magnets inside and sliding collar
3. Fathometers such as sonar depth finder devices.
4. Other buried devices and sensors under streambed.

SCOUR MEASUREMENT DEVICES USED IN THIS STUDY

The Magnetic Sliding Collar (MSC) and Sonar provide accurate, unattended measurement of streambed scouring near bridge piers and abutments. These instruments were custom built by ETI Scour Measurement Systems, Fort Collins, Colorado, for use on both bridges. Figure 1 shows the basic configuration of the scour monitoring system. The following section briefly describes each system:

1. A MSC sensor monitors the downward movement of a magnetic collar around a

stainless steel support structure as the streambed soil scours away. Inside there is an Auto Probe, which consists of magnetically actuated switches spaced at six-inch intervals. The switches close as the magnetic collar comes in proximity and the closures are monitored and recorded by the electronics unit.

2. A sonar sensor monitors streambed depth by sonar depth finding. At a given time interval, the system's electronics send acoustic pulses from a sonar transducer to the streambed. By measuring the time for the reflected pulse to be received by the transducer, the distance from the streambed to the transducer is determined.

3. A stage sensor measures the elevation of the stream surface.

4. A weatherproof enclosure houses the instrumentation and communications electronics. The enclosure is mounted at an accessible location on the bridge or on its piers and is connected to the sliding collar support structure, the sonar transducer, and the stage sensors via cables run in conduit.

Scour data, including date and time stamp, is recorded on a Campbell CR10X Datalogger. A modem with landline telephone connection communicates the data to a PC at a base location. Alternatively, a cellular modem can be installed to limit cables that are vulnerable to vandalism.

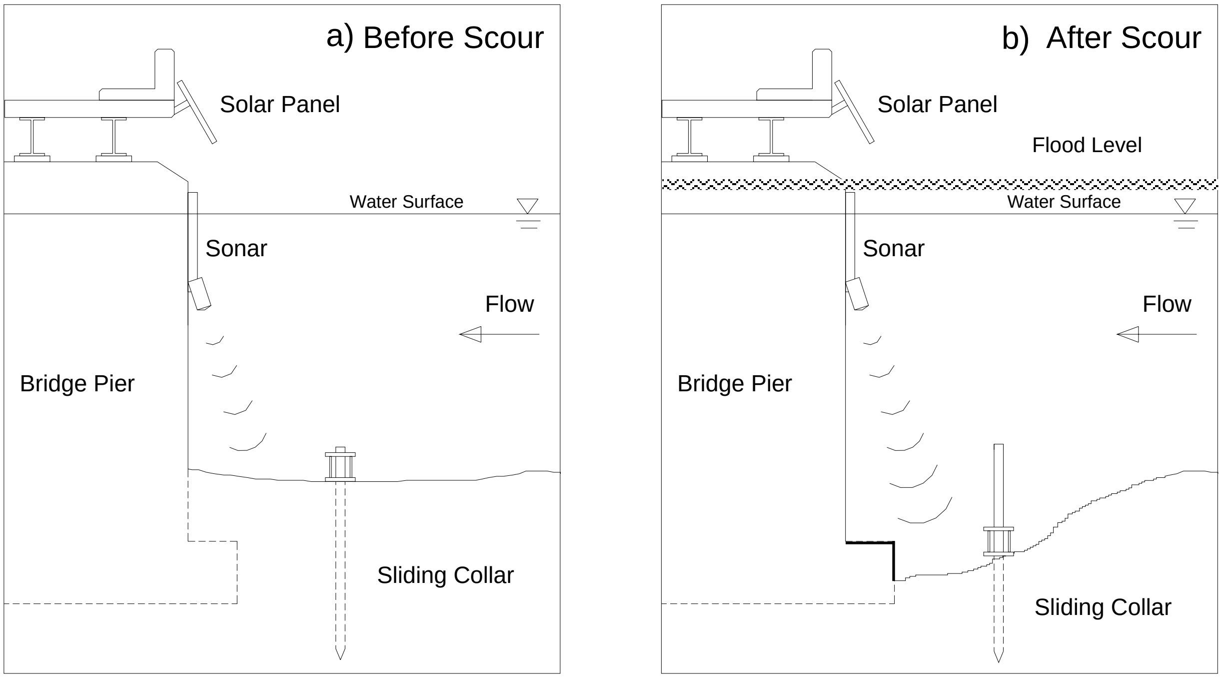


Figure 1. Scour monitoring system, basic configuration and operation.

The Magnetic Sliding Collar Device (MSC)

The magnetic sliding collar (MSC) system (Figure 1) consists of a stainless steel pipe and a sliding collar. The steel pipe was placed vertically into the streambed with a sliding collar which slides as the scour progresses. The location of the collar was determined by sensing the magnetic field created by magnets attached to the collar. The device measures the maximum scour that occurs during a given flood; if the scour hole refills, the collar becomes buried. Both manual and automated readout devices were developed during the NCHRP Project 21-3. The MSC is well suited for bridges over shallow streams. It can be used to measure scour at piers and vertical wall abutments; however, it is not generally adaptable for use at spill-through or sloping abutments.

The maximum scour depth that can be monitored by the sliding collar device is about 3 m (9 ft) (or the length of the embedded MSC pipe). A minimum of 1m (3 ft) penetration of the pipe below the anticipated scour is recommended. The suggested total length of the steel pipe in the streambed is greater than 5m (16 ft). The depth and velocity of the water at the bridge during the time of installation must also be considered. Without diver support, the maximum practical water depth is about 3m (10 ft).

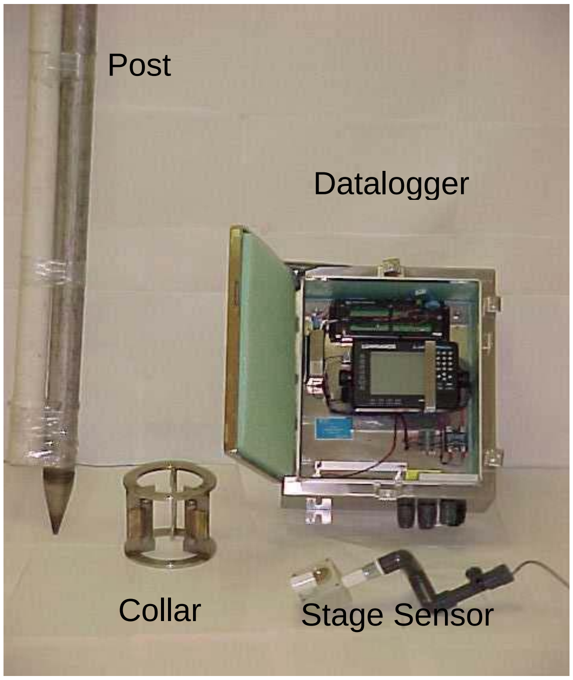


Figure 2. Magnetic Sliding Collar System (MSC) with various components.

MSC Major Components

1. Stainless steel support structure having a 2-inch diameter and 10-foot length, watertight, with heavy-duty point for driving into streambed and with cable entry "T" fitting.
2. Auto Probe: Consists of magnetically actuated switch modules and wiring, placed every six inches inside the stainless steel support structure. The switches and wiring are sealed with non-corrosive RIW inside flexible tubing, which in turn is sealed inside a 1/2-inch Poly-Vinyl Chloride (PVC) pipe.
3. Magnetic Collar: A 6.5-inch outside diameter by 7-inch length; a 2.5-inch inside diameter allows it to slide freely on the support structure.
4. Cables and conduits are run from the support structure to electronics unit located in the stainless steel enclosure.

Specifications of equipment are shown in Table 1.

Table 1. Specifications of Magnetic Sliding Collar (MSC).

Sensors:	
Type	Magnetically actuated switches
Resolution	6 inches
Accuracy	± 3 inches
Support Structure (Driven Rod):	
Type	Stainless Steel, Schedule 80 Thickness
Length	10 feet
Features	Attached driving point and head with cable entry “T” fitting

Low-Cost Sonic System (Fathometer)

The sonar scour monitoring system (as shown in Figure 3) is a conventional sonar instrument connected to a data logger that can provide an ongoing record of scour depth. It measures depth based on the travel time of a sound wave through water. This device is made of low-cost, recreational-type sonar, connected to a datalogger that powers up the sonar and records data for the specified period. It can be programmed to take measurements on a regular basis (for example, every 60 minutes), and can track both the scour and refill process.

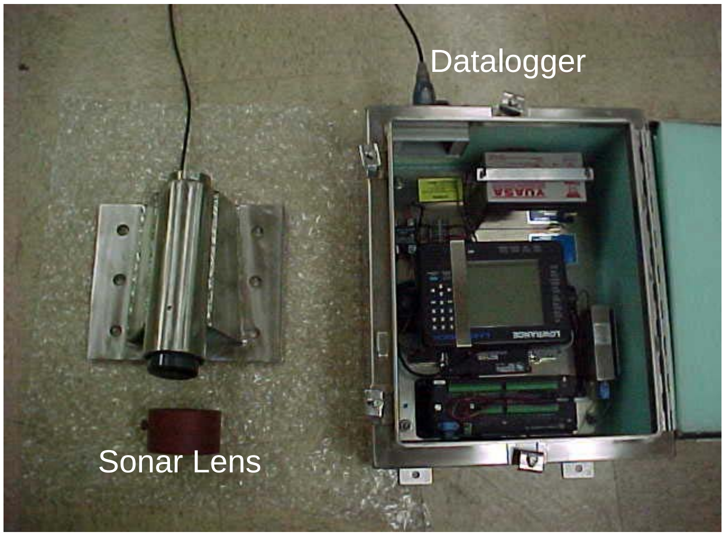


Figure 3. Sonar with various components.

The Following Components are Essential to the Sonar System Operation:

1. Sonar transducer mounted within stainless steel housing. The transducer is angled away from the pier to provide sufficient sonar beam clearance while allowing the reception of the reflected pulse.
2. Data cabling and conduit from the transducer to the electronics enclosure.
3. Sonar control unit mounted inside the electronics enclosure.

SITE SELECTION

Site Visit and Investigation

A review of the periodic (2-year) bridge inspection reports for greater New Jersey yielded a preliminary list of candidate bridges. Each candidate bridge required a field visit to determine the extent of scour and feasibility of instrumentation. With the aid of a portable floating sonar system (Lowrance 150X, made by ETI Instrument Systems, Fort Collins CO, 1999) the Rutgers inspection team patrolled the perimeter of the immersed piers, as well as the immediate area adjacent to them. Depth and relative location data were recorded for points around the piers. The data was assembled and processed with AutoCAD® 3D mesh or MathCAD® contour plots to gain a visual perspective of the streambed features. The contours provide evidence of scour activity and key dimensional elements such as approximate stream flow and cross section.

In addition to key scour dimensions, the site visits allowed for a detailed appraisal of certain site characteristics that were not evident from the bridge contract plans provided by NJDOT or aerial photographs (obtained online from the Microsoft Terraserver & USGS.(22) Features such as proximity of telephone lines, power supply, pier accessibility, presence of rip-rap (as tested with a rigid pole and hammer), nearest location to launch a motor boat, vulnerability to vandalism, tidal features, bed material, debris, etc. were also observed.

With the scour data, physical properties, and peripheral features recorded, the feasibility of installation could then be determined for each candidate bridge. Bridges with clear evidence of rip-rap or insufficient stream flow/depth would be excluded from the study. In cases where the presence of riprap was indiscernible, a second site visit was conducted with a more aggressive probing for pier scour countermeasures. A rigid rod consisting of a 3/4 inch copper pipe was driven into the streambed with constant hand pressure. The approximate penetration depth was recorded.

Once a bridge and a specific pier were finally selected for instrumentation, notice was given to the local telephone company to begin the service installation. In the two instrumented bridges, the phone utility required an initial inspection visit accompanied by the Rutgers project team. Location and specific requirements were discussed. The service installation was then completed within approximately two weeks. It should also be noted that Central and Northern New Jersey are densely populated suburbs with telephone service available within 200 feet of the bridge abutments. More remote areas would require a cellular telephone system or manual data collection visits.

In both bridge cases, it was deemed impractical and not cost effective to have power service installed to the instrumented bridge piers. The utility workers noted certain site constraints and excessive installation costs. In addition, the monitoring system complete with sonar transducer, sliding magnetic collar, datalogger, stage sensor, and Lowrance 350A transceiver would be adequately powered by a 2x2 foot solar panel. In field operation, a system which powers up for 2 minutes every hour would subsist on a battery charge for up to two weeks.

Aerial Photos and Topographical Maps

Aerial photos are useful as a means of orientation and to determine the stream alignment, possible boat launching sites, and adjacent flood plains. The Microsoft Terraserver website provides an extensive database of USGS aerial photos of about every square mile of land in New Jersey.(22) The photos are zoom-able from a resolution of 64m per pixel to a magnification of 1m per pixel. At the finest resolution (1m), the scale is about 1 screen inch to 100 yards. A typical bridge is about 2 or 3 inches long in the photos.

In addition to high resolution aerial photographs, the Terraserver website also offers a digital version of official USGS topographical maps. The maps, compiled every five or ten years detail features of almost every square mile of New Jersey. The maps include identification and outlines of major structures as well as the usual street names and municipalities. Landscape relief contours provided are useful for identifying steep grades not evident from proprietary street maps. Used as a complement to the aerial photographs, the USGS topographical maps complete the picture as far as pre-visit site orientation is concerned.

Bridge Inspection Reports

Inspection reports were the key identifiers of scour critical bridges studied in this project. Under NJDOT Regulations underwater inspection for scour is required. Bridges are inspected every two years by engineering consultant firms as ordered by NJDOT. The reports include general structure and site description, load sufficiency ratings, underwater evaluation, and repair recommendations.

These inspection reports are typically 40-60 pages in length. One section is devoted to underwater investigation. Depth soundings and stream depth profiles are provided. The depth data and the datum are useful for comparison with readings taken during site visits.

Presence of rip-rap is critical information needed before any bridge site is selected for instrumentation. The underwater report will state the presence of riprap or make a recommendation to install additional scour countermeasures. The inspection report should take precedence over the contract drawings. Most of the bridges considered had contract drawings that provided no indication of riprap. The inspection report, however, details riprap location and extent. This was confirmed by site visits prior to the installation of equipment.

Contract Drawings

The contract drawings are the as-built plans submitted at the completion of construction by the general contractor in which basic dimensions and structural features are described. Scour pertinent features accompany the footing and pier details. Often, rip-rap details are vague and qualitative. For example, the plans for one of the studied bridges require 5 cubic yards of rip-rap about a particular pier with a heaped mound depicting the placement. The fact of the matter is that rip-rap placement is qualitative. The only way to be certain of riprap is to review the underwater inspection reports and conduct field penetration tests.

Initial Site Visit

After reviewing the NJDOT provided contract drawings, cyclical underwater inspection reports, and vicinity aerial photographs (Microsoft Terraserver and USGS), an initial site visit is conducted. The reports direct attention to the most probable piers for scour activity. A typical initial visit would include: 1) mapping a profile of the streambed with the portable sonar, 2) probing near the piers to detect scour countermeasures, such as rip-rap, 3) investigating access to utilities for possible permanent installation, and 4) noting site characteristics such as flow magnitude and direction. To preclude the presence of riprap on any of the bridges studied, a driven rod test was performed. A rigid pole of approximately one half-inch in diameter was driven into the soil bed initially by hand and subsequently by hammer taps. The pole was driven to a depth of two feet in most cases without rip-rap. Two feet of free soil clearance was considered as an adequate margin for scour monitoring.

Portable Sonar Depth Sounder

ETI Instruments of Fort Collins, Colorado furnished a portable sonar depth sounder for preliminary site inspections. The device consisted of the Lowrance 150X sonar fish finder with a depth profiler and integral battery pack. The transducer is mounted within a tethered float. The float can be easily positioned with a telescoping pole over the point where the depth is desired. The readout is in decimal feet with a resolution of 1/10 of a foot. Typically, the float is held at a location for about ten seconds to get a consistent reading. The only drawback to the portable and permanent sonar system is the corruption of the signal at depths of less than three feet. Within a shallow column of water, the acoustic signal tends to reflect between the streambed and water surface doubling the depth. When practical, the sonar readings were verified with a tape measure and a plumb bob.

Tide Prediction Charts

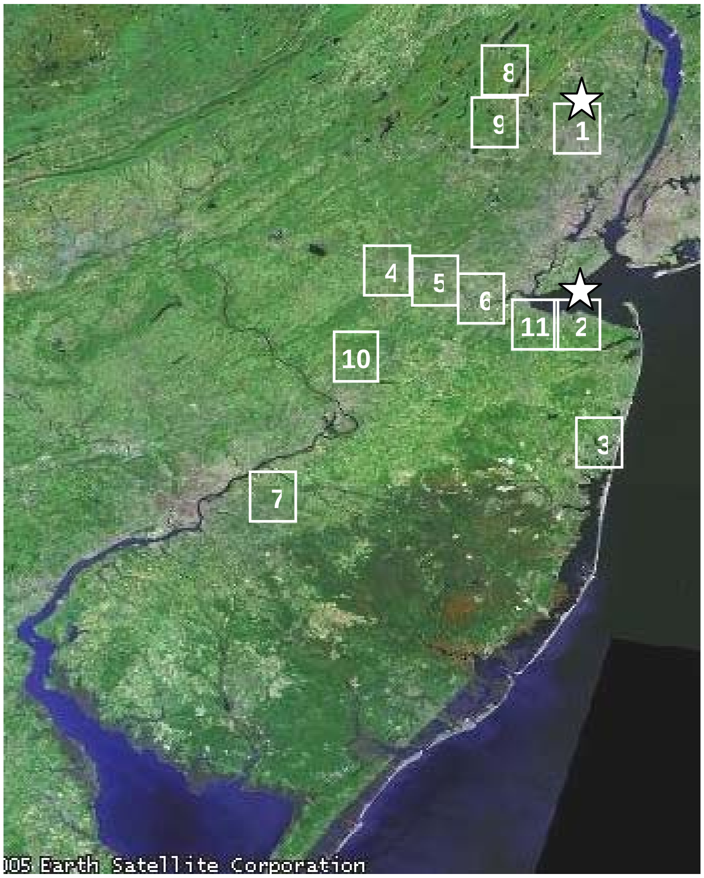
The National Oceanographic and Atmospheric Administration publishes tide prediction charts for coastal points within the United States.(23) Bridges considered in this report as part of the New Jersey Bridge Scour Study (NJBS) are equipped with ultrasonic stage sensors. The stage sensors provide the stream depth for every data point recorded. Tide prediction charts and real time tide height information are useful tools for checking the accuracy of the stage sensors. Furthermore, the tide prediction information is useful for site inspection operations. High tide is the optimum time to launch a motorboat from a trailer, whereas in low tide it would be difficult. By checking and coordinating it with the high tide, the inspection team operates efficiently.

USGS River Flow Monitoring Data

The USGS has installed flow-monitoring stations at points along certain streams in the United States. Most often the monitoring stations are located upstream from the study bridges. The exact flow data may not be accurate; however, the general flow trend caused by storms correlates to the flow at these bridges.

DESCRIPTION OF THE STUDY AREA

The area where the study was performed includes the State of New Jersey. The bridges that are investigated are on the following rivers: Matawan, Manasquan, Passaic, Rancocas Creek, and Raritan. Figure 4 illustrates the location of bridges that were inspected in this study for possible instrumentation for scour detection. Table 2 gives more detailed information about the bridges that were investigated.



1. *Route 46 Bridge Passaic River over Dundee Lake
2. *Route 35 Matawan Bridge
3. Route 70 Bridge Manasquan River
4. Route 18 Raritan River Bridge
5. U.S. 1 Raritan River Bridge
6. New Jersey Turnpike Raritan River Bridge
7. Interstate 295 Rancocas Creek Bridge
8. Route 80 Passaic River Bridge
9. Route 46 Passaic River Bridge at Fairfield
10. Route 27 Millstone River Bridge
11. Route 35 Cheesequake Bridge

* indicates instrumented bridges.

Figure 4. Aerial Map of New Jersey with bridge sites considered for study (Earth Satellite Corp. 2005).

Route 46 over the Passaic River and the Route 35 Bridge over Matawan Creek were chosen for scour instrumentation. More information as to the reason for these selections is given in the following bridge description section which follows. For example, both selected bridges (Table 3) did not show evidence of rip-rap and portable sonar sounding revealed relatively large depth gradients around the piers.

BRIDGES INVESTIGATED FOR SCOUR ACTIVITY

Table 2. Bridges studied for Scour Project.

Selected Bridges	**NJDOT Str. Number**	**Municipality**	**County**
Route 35 Matawan Bridge	1313-161,162	Aberdeen	Monmouth
Route 46 Bridge Passaic River over Dundee Lake	1607-168	Elmwood Park	Passaic and Bergen
Other Bridges Investigated			
Route 70 Bridge Manasquan River	1511-150	Brielle	Monmouth
Route 18 Raritan River Bridge	1237-155	New Brunswick	Middlesex
U.S. 1 Raritan River Bridge	1203-156,150	New Brunswick	Middlesex
New Jersey Turnpike Raritan River Bridge	N/A	Edison	Middlesex
Interstate 295 Rancocas Creek Bridge	0327-167, 168	Burlington	Burlington
Route 80 Passaic River Bridge	0726-155,156	Wayne	Passaic
Route 46 Passaic River Bridge at Fairfield	0722-157,158	Fairfield	Essex
Route 27 Millstone River Bridge	1105-152	Princeton	Mercer
Route 35 Cheesequake Bridge	1222-150	Old Bridge	Middlesex

Table 3. Bridges Parameters.

Selected Bridges	Rip-Rap	Scour Observed	Tidal
Route 35 Matawan Bridge	No	Yes	Yes
Route 46 Bridge Passaic River at Elmwood Park	No / Deteriorated	Yes	No
Other Bridges Investigated			
Route 70 Bridge Manasquan River	Yes	Yes	Yes
Route 18 Raritan River Bridge	No	Yes	Yes
U.S. 1 Raritan River Bridge	Unknown	Yes	Yes
New Jersey Turnpike Raritan River Bridge	Yes	No	Yes
Interstate 295 Rancocas Creek Bridge	No	No	Yes
Route 80 Passaic River Bridge	No	No	No
Route 46 Passaic River Bridge at Fair Lawn	No	No	No
Route 27 Millstone River Bridge	No	No	No
Route 35 Cheesequake Creek Bridge	Yes	Yes	Yes

Route 35 Matawan Bridge

Route 35 crosses Matawan Creek in the town of Aberdeen, Middlesex County, NJ about 15 miles East of Rutgers University's New Brunswick Campus (Figure 6). The three-span, continuous steel girder bridge crosses a stream width of 100 ft. Matawan Creek is the sole outlet of the nearby tidal salt marsh. The foundation is composed of driven piles with cast in place concrete pier caps. The bridge was constructed in 1987.

Figure 5. Matawan Bridge North Elevation.

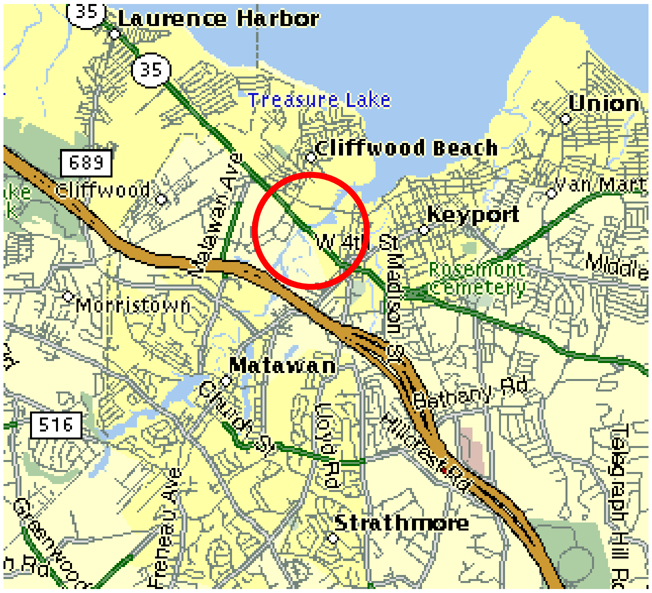


Figure 6. Location of Route 35 Matawan Bridge, Town of Aberdeen, Monmouth County, NJ (MapQuest.com).

The flow underneath the Matawan Bridge is tidal with a 5 ft stage difference. The bridge is located approximately 500 feet upstream from Raritan Bay, which is subject to the tides and storm surges of the open waterway. The streambed has smoothly sloping sides with maximum depth at about midspan. The soil type includes fine sands and organic silty clays. The banks consist of rip-rap in the form of rock boulders. The riprap does not extend into the streambed. The substructure consists of 12 precast 14" diameter concrete piles driven to an unknown depth. Some scour activity has been observed around the piers.

The key advantages of the Matawan Bridge Site include: pile clusters in fine sands and silty clay with water flowing through, easy access to the piers via fender system, and availability of both power and telephone services.

One key disadvantage to most of the bridges studied was the presence of concrete rip-rap. Often, evidence of this scour countermeasure is not found in any contract drawings and placement after bridge construction is not documented. However, the Matawan Bridge did not have rip-rap around the piers.

SITE INFORMATION

Tide Information

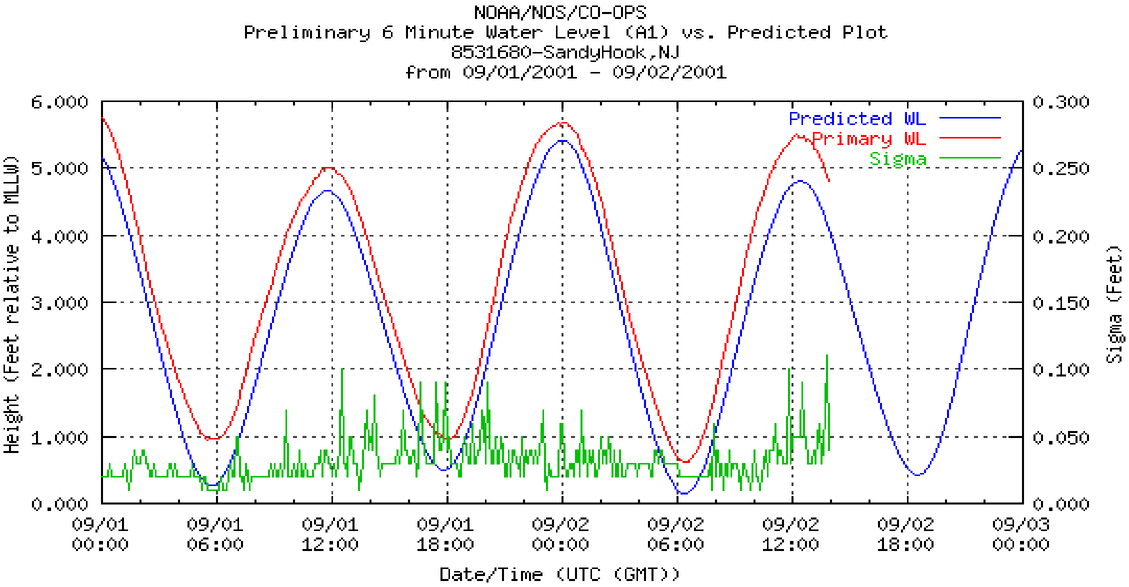
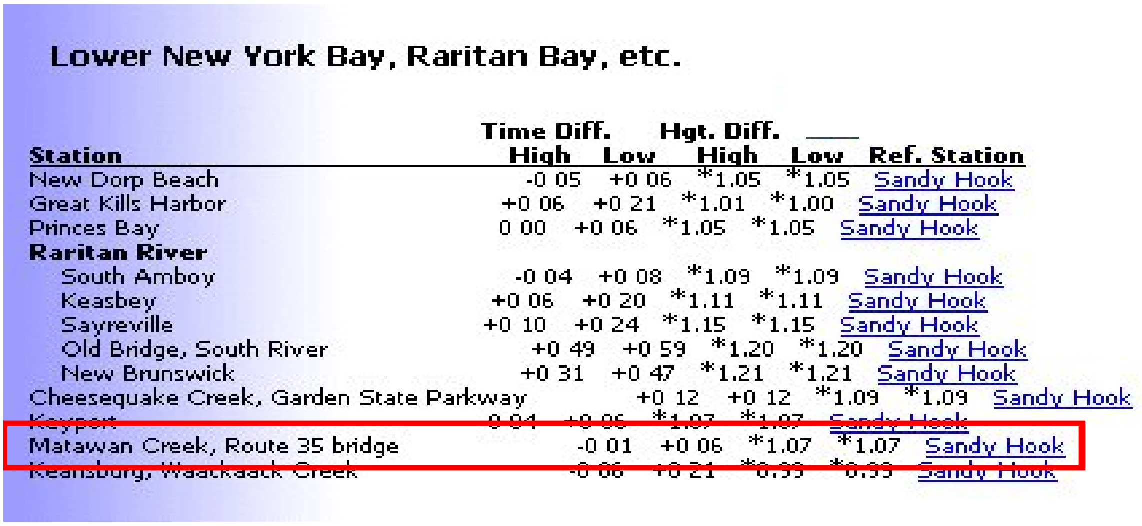


Figure 7. NOAA Tidal Data for Sandy Hook, NJ. (Website:http://co-ops.nos.noaa.gov/cgi-bin/station_info.cgi?stn=8531680+Sandy+Hook,+NJ)



Lower New York Bay, Raritan Bay, etc.

	Time Diff.		Hgt. Diff.		
Station	**High**	**Low**	**High**	**Low**	**Ref. Station**
New Dorp Beach	-0 05	+0 06	*1.05	*1.05	Sandy Hook
Great Kills Harbor	+0 06	+0 21	*1.01	*1.00	Sandy Hook
Princes Bay	0 00	+0 06	*1.05	*1.05	Sandy Hook
Raritan River					
South Amboy	-0 04	+0 08	*1.09	*1.09	Sandy Hook
Keasbey	+0 06	+0 20	*1.11	*1.11	Sandy Hook
Sayreville	+0 10	+0 24	*1.15	*1.15	Sandy Hook
Old Bridge, South River	+0 49	+0 59	*1.20	*1.20	Sandy Hook
New Brunswick	+0 31	+0 47	*1.21	*1.21	Sandy Hook
Cheesequake Creek, Garden State Parkway	+0 12	+0 12	*1.09	*1.09	Sandy Hook
Keyport	0 04	+0 06	*1.07	*1.07	Sandy Hook
Matawan Creek, Route 35 bridge	-0 01	+0 06	*1.07	*1.07	Sandy Hook
Keansburg, Waackaack Creek	-0 06	+0 21	*0.99	*0.99	Sandy Hook

Figure 8. Tidal Correction Data for Matawan Creek Bridge, Route 35. (http://co-ops.nos.noaa.gov/tpred2.html#NJ).

The tidal benchmark nearest to the bridge site is determined, and a correction factor can be obtained, as shown in Figure 8. For example, the Route 35 Matawan Creek

Bridge is about 15 miles west of the Sandy Hook, NJ, a tidal benchmark. The correction factor for this satellite location can be obtained from the NOAA Tidal Information Site. From the above correction table, the Matawan Creek Bridge Route 35 high tide is ahead by one minute with a magnitude 7.0 percent greater than the Sandy Hook, NJ benchmark station.

Matawan Bridge Aerial Photo

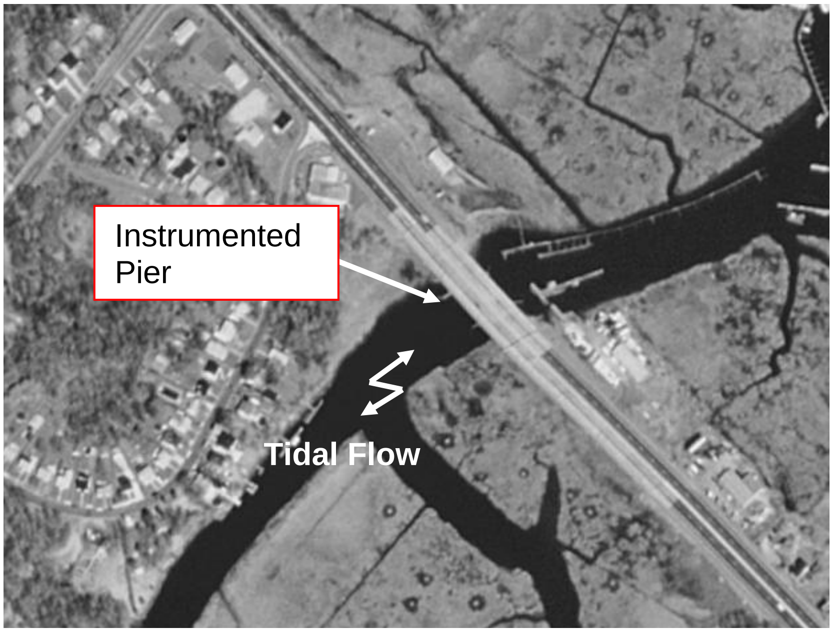


Figure 9. Aerial photo of Matawan Bridge, Aberdeen Twp., Monmouth County, NJ. (www.terraserver.com)

Aerial photos of the Matawan Creek (Figure 9) were used to determine the angle of stream flow with respect to the pier. The indicated pier in Figure 9 was chosen for instrumentation due to its angle of exposure to the stream flow.

SYSTEM INSTALLATION AT MATAWAN BRIDGE

Sonar Installation

The instrumentation of the Matawan Bridge was located toward the outside curve of the stream path for direct flow during flood conditions. The southwestern pier fit this criterion.

The tidal stage of the Matawan Creek was critical in the timing of the installation. The sonar mounting plate was designed for underwater placement. However, it was decided to install the plate at a low tide stage with standard drilling tools (Figure 10 to Figure 14). Underwater drilling tools and labor were considered impractical.

Another option was to construct a submersion frame where the sonar could be lowered into the water as well as mounted above the water. However, the relatively shallow water at low tide, usually 4ft, precluded the use of such a frame. Laboratory tests conducted at the RU Civil Engineering Fluids Laboratory determined that the sonar readings were erroneous at depths of less than 4 feet. The acoustic signal reverberated repeatedly between the source and the target, randomly doubling or tripling the depth. The installed frame would have placed the sonar face 5.5 inches from the streambed. To ensure the most accurate data possible, the plate was installed at a low tide stage with the sonar transducer lens 5.5 ft above the streambed (Figure 10 to Figure 12). Drilling was conducted from a small boat using a hammer drill. Finally, the conduit was placed, secured with brackets, and routed to the control box.

Magnetic Sliding Collar (MSC) Installation

The most critical task was driving the magnetic sliding collar MSC guide post into the streambed. For that purpose, a 90 cubic feet per minute towable diesel air compressor, a Rhino™ PD-55 pneumatic post driver, and 200 feet of 3/4 inch hose were rented (Figure 13).

The rigid stainless steel MSC heavy-duty post is about 8 ft long with a cone tip and threaded fitting end. In addition, threaded steel pipes and couplers were needed as part of the driving rig. The actual magnetic collar was guided up the post with a loop of rope before the final placement. The pipes were threaded into the MSC fitting, to be removed after driving. The Rhino post driver was placed atop the steel pipe, and the MSC setup was positioned.

Figure 10. Installation of the stainless steel sonar frame during low tide stage.

Figure 11. Placing sonar in stainless steel conduit

Figure 12. Sonar mounting plate as tide rises.

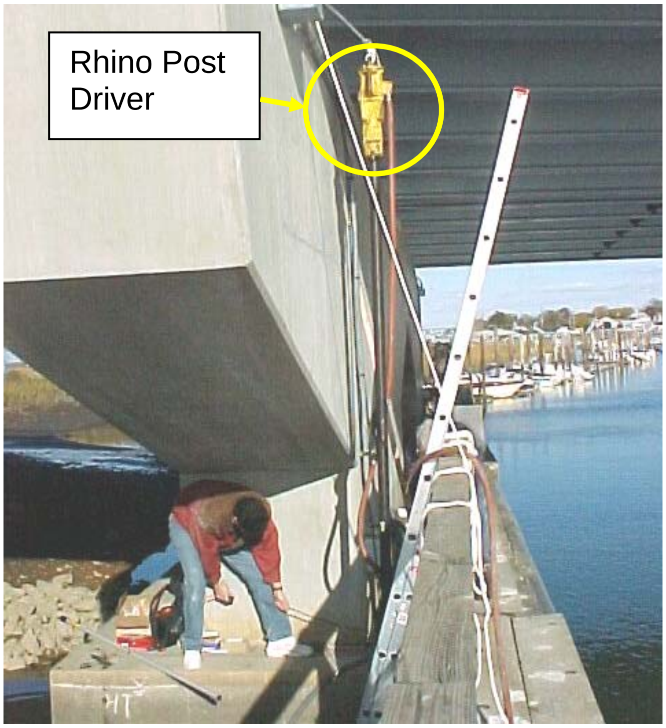


Figure 13. The Rhino™ Post Driver on top of the steel pipe to drive the stainless steel MSC pipe into riverbed.

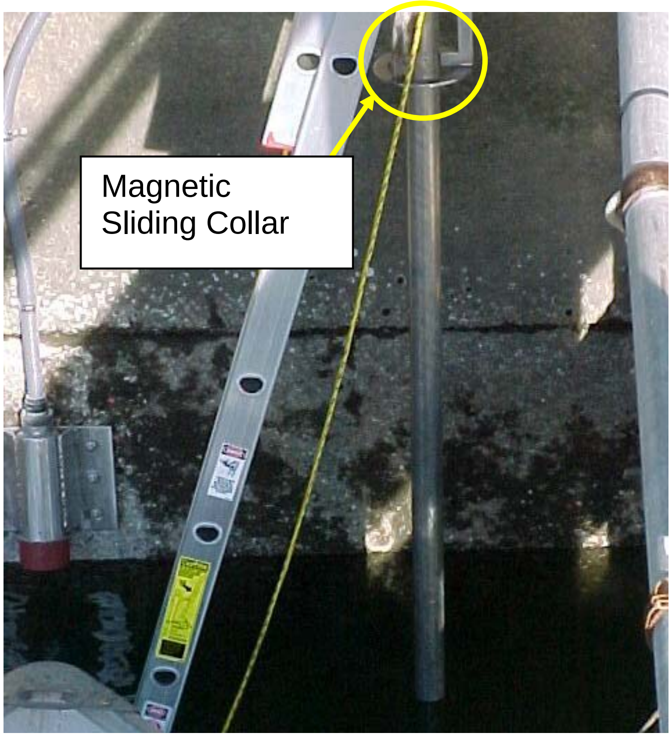


Figure 14. MSC and steel pipe ready to be driven.

The positioning of the MSC is critical due to the nature of post driving (Figure 14). Once driving started, the placement was fixed and the post could not be easily removed.

Driving of the MSC is the most labor-intensive phase of installation involving many pieces of equipment and the positioning of a heavy rig. A number of team members were involved in the installation process: One team member was stationed on the bridge deck with a van and towable air compressor; a second team member monitored the angle of entry, third member operated the Rhino control valve; a fourth member guided the descent of the rig with a tension line; a fifth member stabilized the setup from a ladder; and a sixth member communicated with the compressor operator. The whole process took only a few seconds to drive 8 feet into the fine sand and silty clays. When a pre-marked depth level was reached the Rhino valve operator stopped the advancement and the threaded steel-driving pipe was unscrewed and removed. The magnetic collar safety rope was cut and the conduit was secured with clamp brackets along the pier to the control box.

Datalogger Installation

With most of the instruments installed, the control box was connected with the incoming conduits (Figure 15). The stainless steel enclosure was outfitted with moisture seals and closure clamps to prevent equipment damage. After reviewing the 100-year-flood stage data, it was determined that the box needed to be placed 10 ft above the ledge of the pier cap to ensure data collection during a severe flood condition. After all, the highest magnitude scour would occur during a flood that could also destroy equipment and critical data.

Sonic Stage Sensor Installation

The sonic stage sensor was installed near the control box over the water by clamping to the flange of an outside girder (Figure 16). Its function is to collect water stage data for comparison with other data fields during the study. The stage is important in estimating the flow rate during a flood event.

After installation of the sensors and hardware, the wiring and internal configuration from each of the separate conduits were connected to their respective interfaces on the datalogger. This included installation of the battery as well as modular phone line. The scour software required the input of initial conditions and exact elevations of sensor.

Solar Panel Installation

Figure 17 shows the installed solar panel. For proper sun exposure the panel was placed on the southern face of the bridge fixed to an outside girder right above the control box. A custom frame was attached to the solar panel unit, and the setup was clamped to the flange. Tests indicated that the panel supplies sufficient power even during partial and/or dim exposure.

Figure 15. Installation of datalogger by Rutgers and ETI staff.

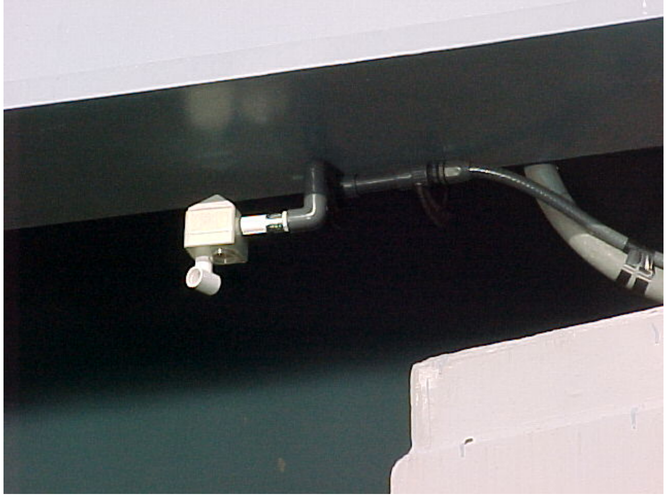


Figure 16. Stage sensor installed on the bottom of the girder flange.

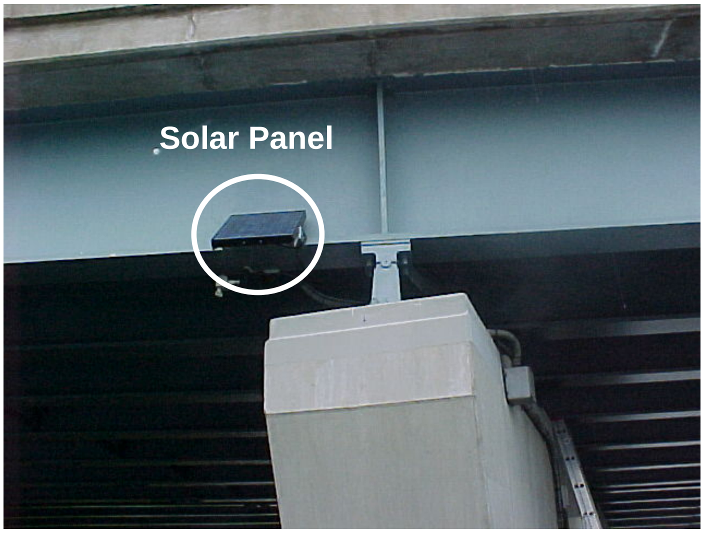


Figure 17. Solar Panel at Matawan Bridge.

The datalogger operates intermittently, collecting and storing data and then going into a suspended low power mode. Prior to the installation of the solar panel, multiple trips to the site were needed to exchange the spent battery for a newly charged one. On average, a newly charged battery endures for two and a half weeks, during which it is more likely that the solar panel will be exposed to dim light.

Operation and Follow Up

The bridge site was visited regularly after installation. The site visits were to ensure proper protection of the equipment. During a Mid-winter trip, 4 inch thick ice flows bearing against the sonar mounting plate, were observed (Figure 18). Although the ice formation did not cause any physical damage to the Sonar unit, data disturbance during sonar data collection was observed.

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Figure 18. Sonar surrounded by ice. Matawan Bridge, Feb 2000.

MATAWAN RESULTS

As of September 2001, the Matawan Bridge datalogger had successfully recorded 25 months of data at intervals of 1 hour (Figure 19 to Figure 21). Also, Table 4 shows the comparison of sonar scour data for each month. Since the sonar sensor at the Matawan Bridge was to be exposed to open air during low tide, an algorithm was developed to discard open air readings. Therefore, the sonar data during low tide is a copy of the last real in-water reading.

It can be observed from the sonar and MSC depth change plots of Figure 19 and Figure 20 that the Matawan Bridge does not have scour activity. The streambed elevation did not change by more than 0.3 feet in the nearly four years of observation. The only concern for scour would be for extreme flood events, for example 100 year flood or hurricane storm surge.

Figure 21 shows a sample of the regular tidal flow at Matawan. The tidal ebb and flow seems to have no effect on the soil at the pier. The lack of any appreciable scour activity also indicates that Matawan Creek is not a major rainfall drainage path.

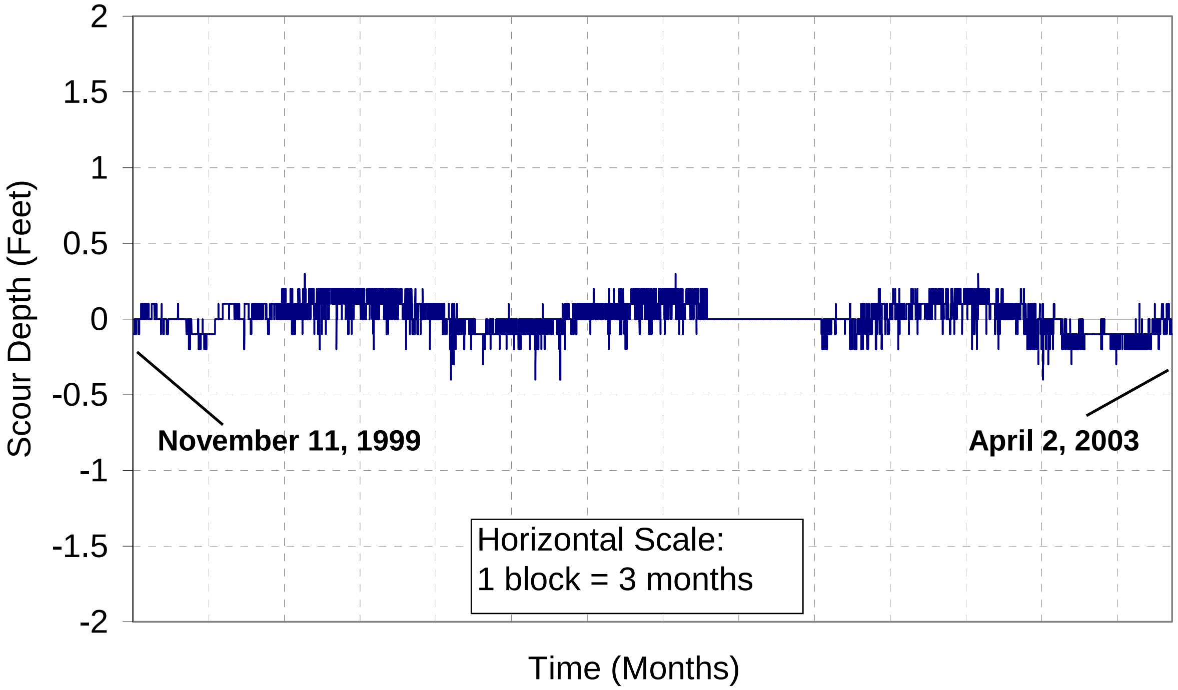

Figure 19. Hourly Scour data for Matawan Bridge

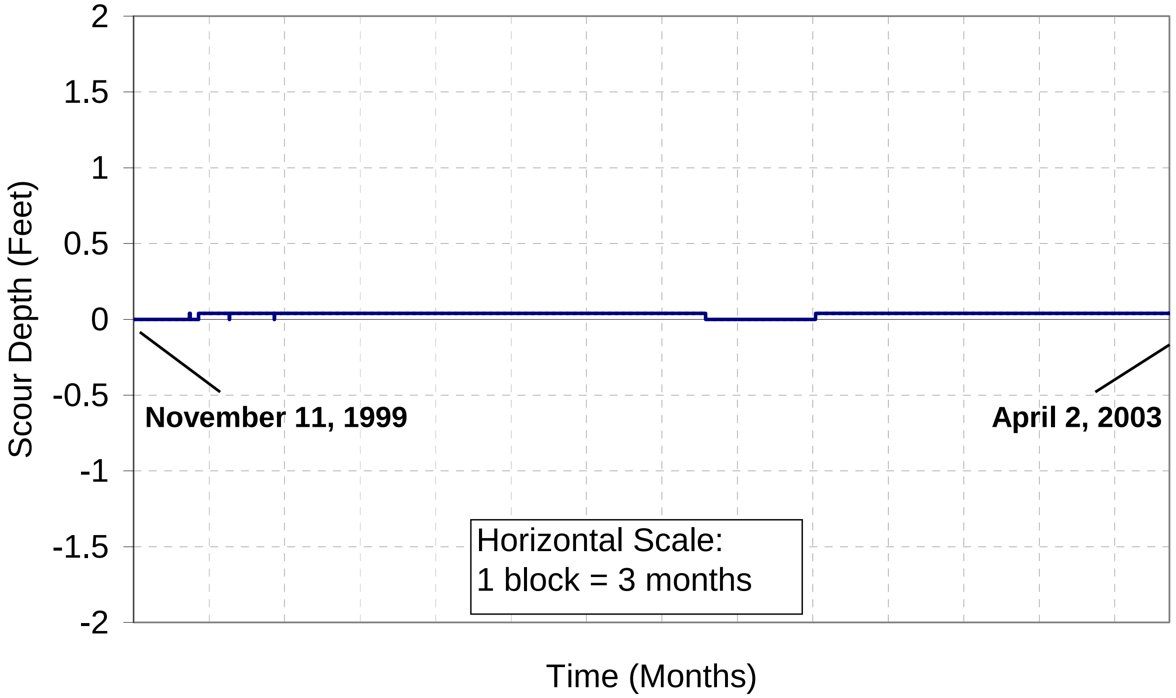

Figure 20. Matawan Bridge Magnetic Sliding Collar Data.

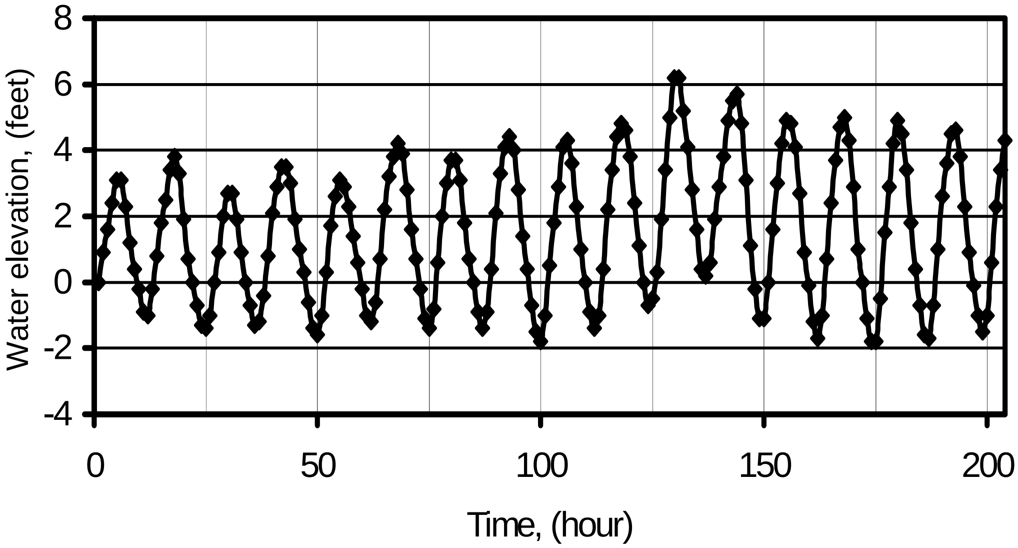

Figure 21. Typical Tide versus Time data for Matawan Bridge collected using stage sensor.

Table 4. Monthly scour depth for Matawan Bridge.

Month	**Change (ft)**	**Month**	**Change (ft)**
Sep-99	0.0	Oct-00	-0.1
Oct-99	0.0	Nov-00	-0.1
Nov-99	-0.1	Dec-00	-0.1
Dec-99	-0.1	Jan-01	-0.3
Jan-00	-0.1	Feb-01	-0.2
Feb-00	-0.1	Mar-01	-0.1
Mar-00	-0.1	Apr-01	-0.3
Apr-00	-0.1	May-01	-0.3
May-00	0.0	Jun-01	-0.1
Jun-00	0.0	Jul-01	-0.1
Jul-00	-0.1	Aug-01	-0.1
Aug-00	-0.1	Sep-01	0.0
Sep-00	0.0		

As Table 4 indicates, Matawan creek does not exhibit scour activity. There was no appreciable depth change during the monitoring period.

Route 46 Bridge at Elmwood Park, Structure No. 1607-168

New Jersey State Highway 46 crosses the Passaic River (Dundee Lake) near the towns of Elmwood Park and Clifton, Passaic County about 50 miles north of Rutgers University's New Brunswick Campus (Figure 22). The high arch spanned bridge crosses a stream width of 450ft at the point of a 45-degree turn, as seen in the aerial photo from Microsoft Terraserver (Figure 23). A map of the general area near the bridge is shown in Figure 24 for reference.

Figure 22. Route 46 Passaic Bridge at Elmwood Park, North Elevation.

The bridge was selected based on the streambed profile, its alignment with respect to stream flow, and recommendations for scour evaluation as stated in the cyclical inspection report.

A routine cyclical inspection report, dated April 1997, stated that:

> "Based on the preliminary scour evaluation, the structure is considered to be a high priority for in-depth (Stage II) scour evaluation, because of the type, size, depth, and reinforcing (if any) for the footings are unknown. Substructure elements are poorly aligned and the bridge acts a horizontal constriction to flood flow. Additionally, the structure is located near a bend and scour problems such as sedimentation may eventually affect the structure." (14)

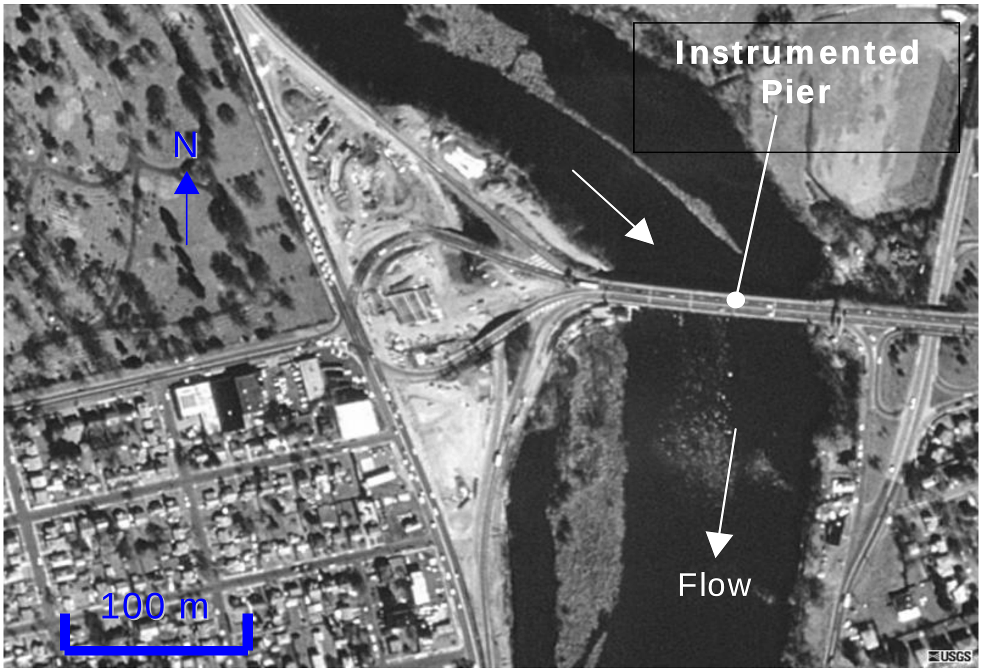

Figure 23. Route 46 Passaic River Bridge. TerraServer Aerial Photo. (www.terraserver.com, 1994).

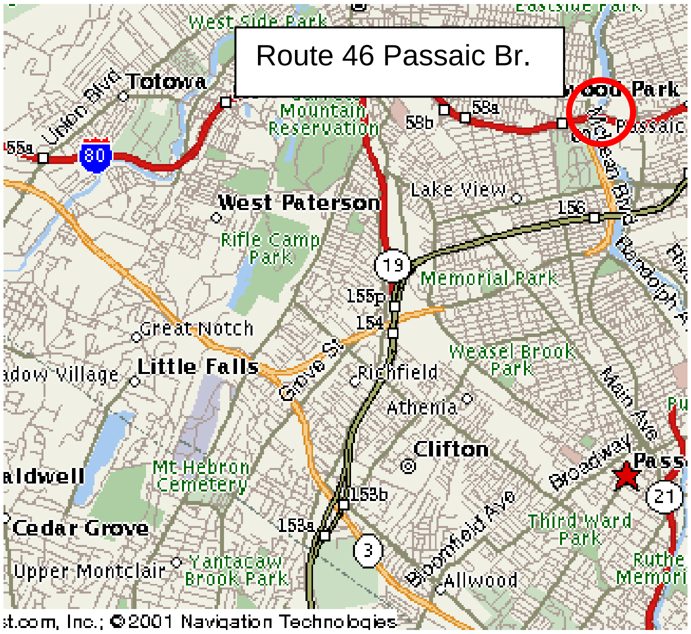

Figure 24. Route 46 Passaic River Bridge, Bergen County, NJ (MapQuest.com).

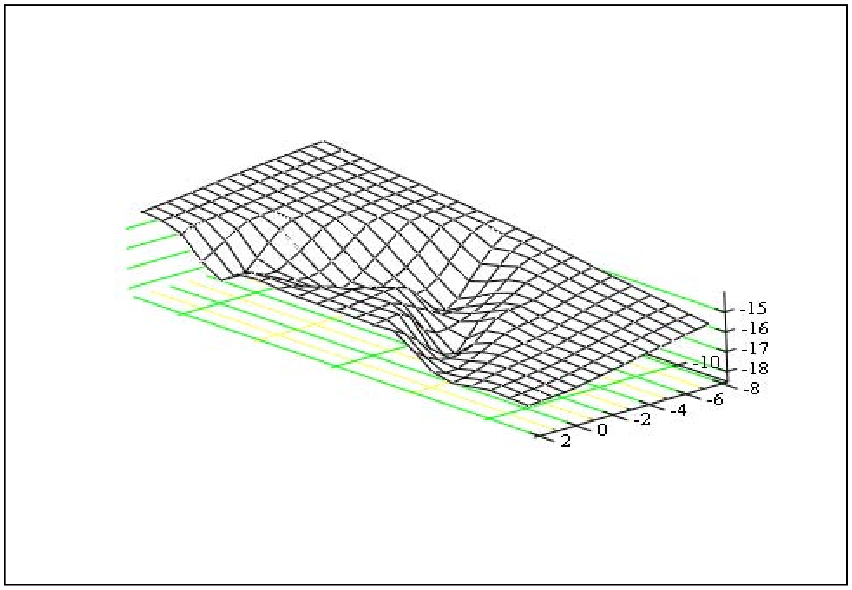

Figure 25. 3-D plot of a scour hole in front of the pier, Route 46 Passaic River Bridge at Dundee Lake, Elmwood Park, NJ.

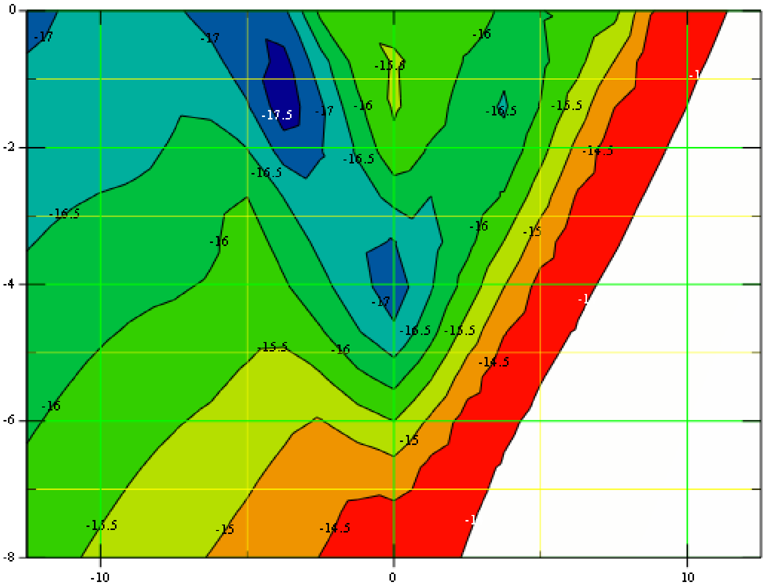

Figure 26. Contour plot of scour depth in front of the pier, Route 46 Passaic River Bridge, Dundee Lake, Elmwood Park, NJ.

Initial inspections of the streambed around the piers showed evidence of a severe difference in bed elevations between the upstream and downstream sides. (Figure 25 and Figure 26). The closest USGS monitoring station is located at Little Falls (USGS Sta. 01389500) about 12 miles upstream from Route 46 (Figure 27). The mean flow is 1640 ft3/s with a 100-year peak of 9500 ft3/s.The drainage area for the Passaic River is 762 sq. miles.

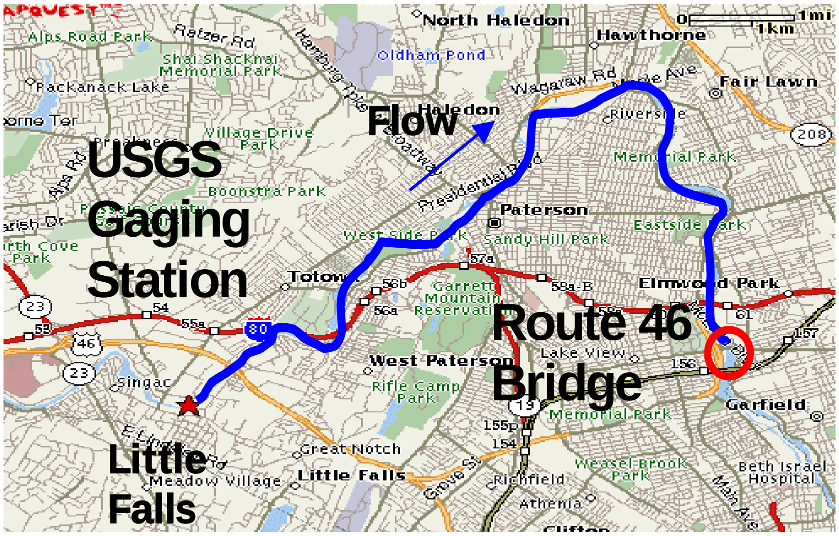

Figure 27. Map of USGS gauging station proximity to Route 46 Passaic River Bridge (www.mapquest.com, 2001).

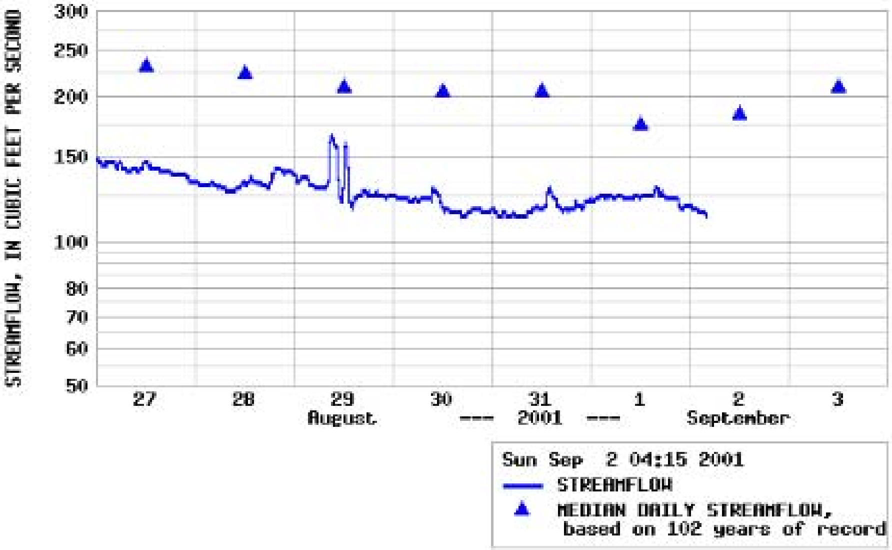

Figure 28. USGS Stream flow data for the Little Falls, NJ station approximately 12 miles upstream from the Route 46 Passaic River Study Bridge. USGS.

SYSTEM INSTALLATION AT ROUTE 46 PASSAIC BRIDGE

All of the phases of installation that were implemented for the Matawan Bridge were duplicated for the installation of the Route 46 Bridge over the Passaic River. There were, however, some site-specific criteria that made the installation process more challenging. The Route 46 Bridge connecting Clifton and Elmwood Park is a false concrete arch structure, with true steel girders. Apparently, the structure was refurbished in 1995 with new beams while maintaining the previous piers. According to documents and contract drawings, the original piers date back to c1935. The original contract drawing specifies rip-rap placement at all faces of the piers and abutments. Site inspection was unable to detect exposed rip-rap or the remains of any countermeasures. It was determined from driven pole tests that there were at least 2 feet of soil at the upstream face of the pier. It may be possible that the soil was deposited above any existing rip-rap.

In addition, portable sonar readings indicated a large difference in bed elevations between the upstream and downstream side. For the case of pier 3 the difference was 12 ft. Based on the large gradient, pier 3 was chosen for instrumentation.

Site Specific Criteria

The Route 46 Bridge had limited access to the piers, greater upstream depths, and difficult pier geometry. The pier had a recessed walkway of about 10 feet above the water. The walkway ran the length of the bridge at a width of 3 feet. This provided an adequate staging area.

A small motorboat was vital to this installation as there was no land access to the pier. A ladder was secured to the face of the pier for access to the recessed walkway.

Due to the 14-foot depth near the upstream face of Pier 3, a platform was required for the MSC installation. A floating dock barge (Figure 29) was constructed to aid in positioning the MSC. The barge consisted of two large dock floats and a plywood deck. The barge was anchored in such a manner that a 32 ft ladder could be secured between the barge and the pier. The ladder would aid in guiding the Rhino and MSC pipes. A hatch opening was provided at the location of MSC pole driving so that team members could stand on either side of the pile rig to stabilize and guide its descent. The MSC rig was driven just as in the case of Matawan (Figure 30).

Due to the deep-water conditions, an aluminum frame was constructed to install the sonar under the water. Using this frame, the sonar device was installed above water while having the transducer head immersed (Figure 31).

The conduits were strung, the control box installed, and stage sensor attached to one of the concrete arches. After primary installation, the phone line was installed via a lead wire pulled above deck and draped down toward the control box.

Solar Panel Installation

The geometry of Route 46, especially the deeply recessed piers in relation to the deck, offered a challenge for the solar panel installation. In contrast to the previous installation of Matawan Bridge, the fascia girders were not well suited for a girder-mounted solar panel. Considering the potential for vandalism, installation near the outside railing of the bridge (at pedestrian level) was avoided. The alternative was to mount the solar panel high above the sidewalk on a light post. Special brackets were furnished by ETI Inc. to mount the solar panel. The wire was draped over the side of the bridge and placed underneath to the control box.

Figure 29. Floating platform used for instrumentation of Route 46 Passaic Bridge.

Figure 30. Installation of MSC at Route 46 Passaic Bridge (August 2000).

Figure 31. Sonar mounting frame.

ROUTE 46 PASSAIC BRIDGE RESULTS

Twenty-three months of data have been collected from the Route 46 Bridge (Figure 32 through Figure 34). Note: Data from 9/23/01 through 2/5/03 was lost; however, most of the sonar data for this period was recovered from backup sources.

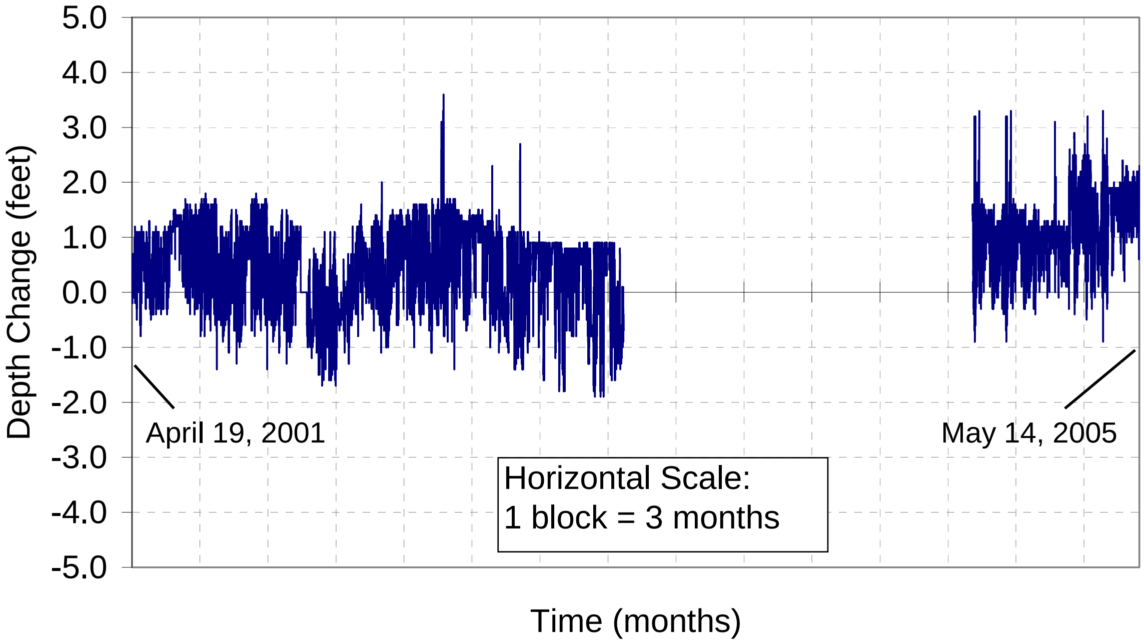

Figure 32. Hourly Scour Data for Route 46 Passaic River Bridge.

Figure 32 illustrates the basic fluctuations of the sonar data. These fluctuations are in part due to debris or errant sonar signals and were largely reduced by the addition of a 10-point reading algorithm. If the data is inconsistent within the ten samples, another ten samples are taken until the readings are within a set tolerance (+/- 0.1 ft). Also, note that the sonar, as opposed to the MSC, detects the refill process of the streambed. As the bed is scoured the elevation change becomes negative. Furthermore, as the scour hole tends to refill, the increasing elevation is also recorded. Figure 35 shows an example of a scour event where the sonar detected the refill. As shown in Figure 32, the Passaic depth change due to scour was limited to +/- 4 feet during the monitoring period.

Sometimes the smoothed average data, such as in Figure 33, provides a clearer picture of the bed depth change over time. This average view reduces the errant signals caused by slow moving debris. Slow debris may momentarily rest under the sonar sensor. The 10-point algorithm does not correct for slow debris, since the signal may be consistent over the reading period. A visual comparison of Figure 32 and Figure 33 will reveal that the smoothed data does eliminate the sharp spikes, providing a better long-term picture.

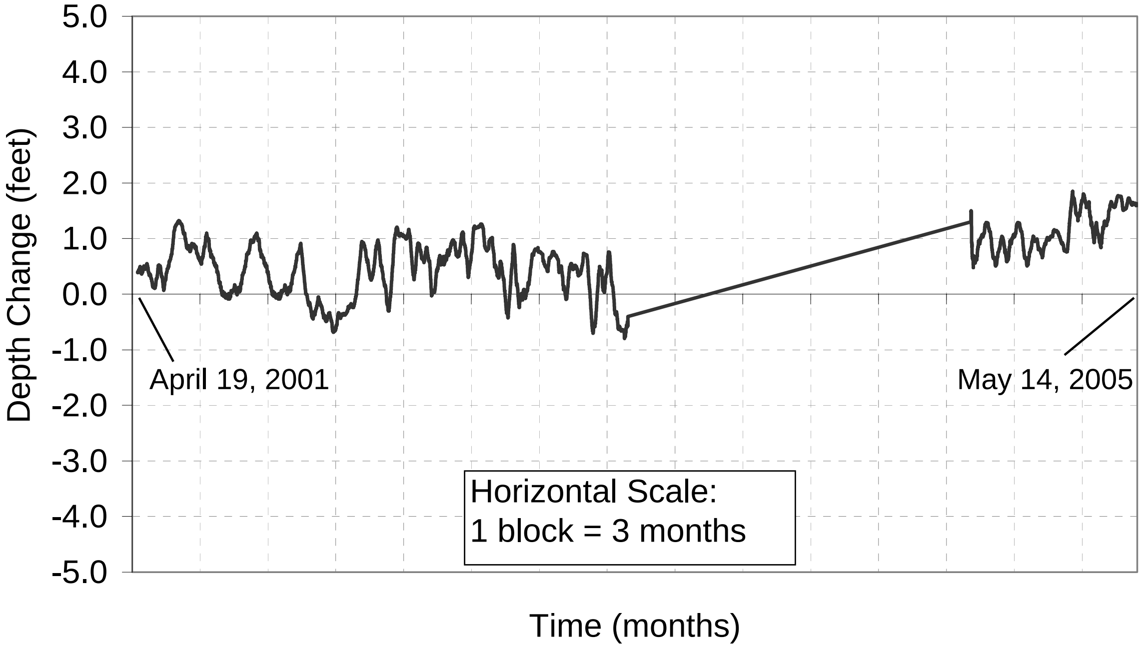

Figure 33. Average Weekly Scour Data for Passaic Bridge.

The magnetic sliding collar device was installed adjacent to the sonar signal path. However, the MSC was offset by 3 feet to avoid interference with the sonar. Figure 34 shows the MSC hourly data for Passaic Bridge. There is no need for smoothing the MSC data since the device provides very consistent readings, except in the event of a scour event (Figure 35). The MSC is basically a falling weight resting on the streambed, guided by a driven rod. Therefore, as the bed material is scoured away, the MSC registers a negative depth change only. As the refill process occurs, the collar is buried and no further indication that there is a change in depth until an even deeper scour event occurs.

The Passaic Bridge was subjected to one scour event during the monitoring period. The event was recorded on August 9, 2001 according to the datalogger clock. It was later determined that the clock was incorrect. Most likely, the clock was not set properly before putting the datalogger into operation. The event captured by both the sonar and MSC sensors is shown in Figure 35. There was a sudden drop of 1.6 feet in the streambed. Later analysis was conducted to find any evidence of strong river flow to correlate to the scour event. The USGS stream flow monitoring data (Figure 36) upstream of the bridge did show a sudden rise in flow. However, the flow rose on August 14, 2001. Another source, the National Weather Service data, was referenced (Figure 37). The NWS recorded rainfall amounts of more than 1 inch on August 12, 2001 at two locations within the Passaic River drainage area. A heavy rainfall is likely to cause a flow increase with a certain time delay for runoff. Therefore a scour event occurring on 8/9/01 is not likely caused by a storm occurring 8/12/01. The problem was later resolved when the datalogger clock was checked. The clock was incorrectly set 4 days behind when the system was put into service. The adjusted date is shown in Figure 35.

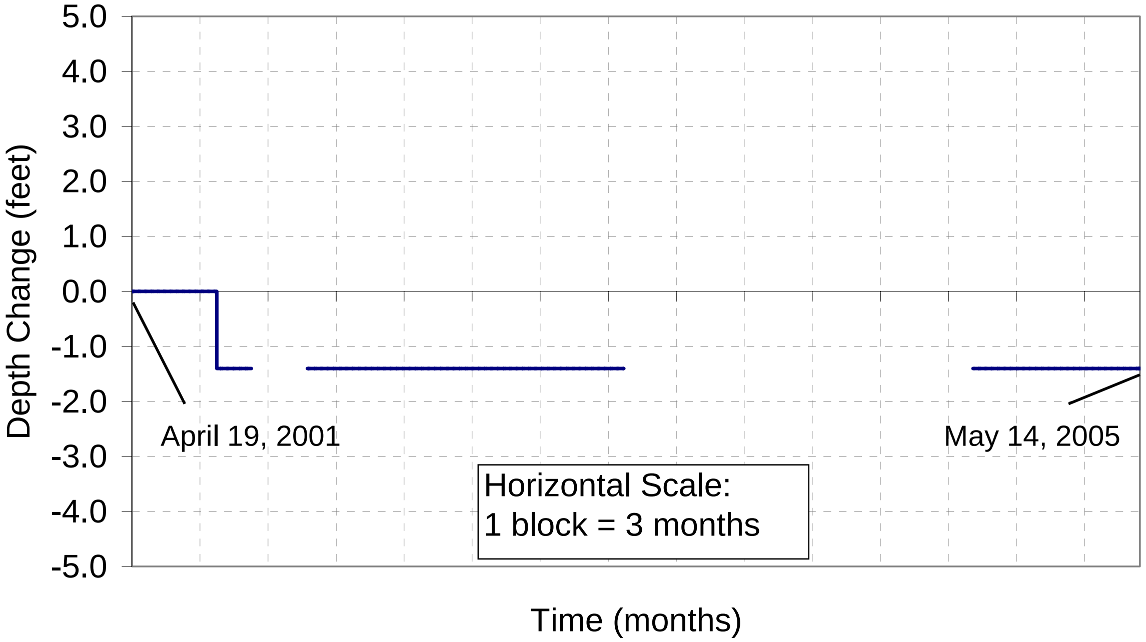

Figure 34. Hourly Magnetic Sliding Collar Data for Route 46 Passaic Bridge.

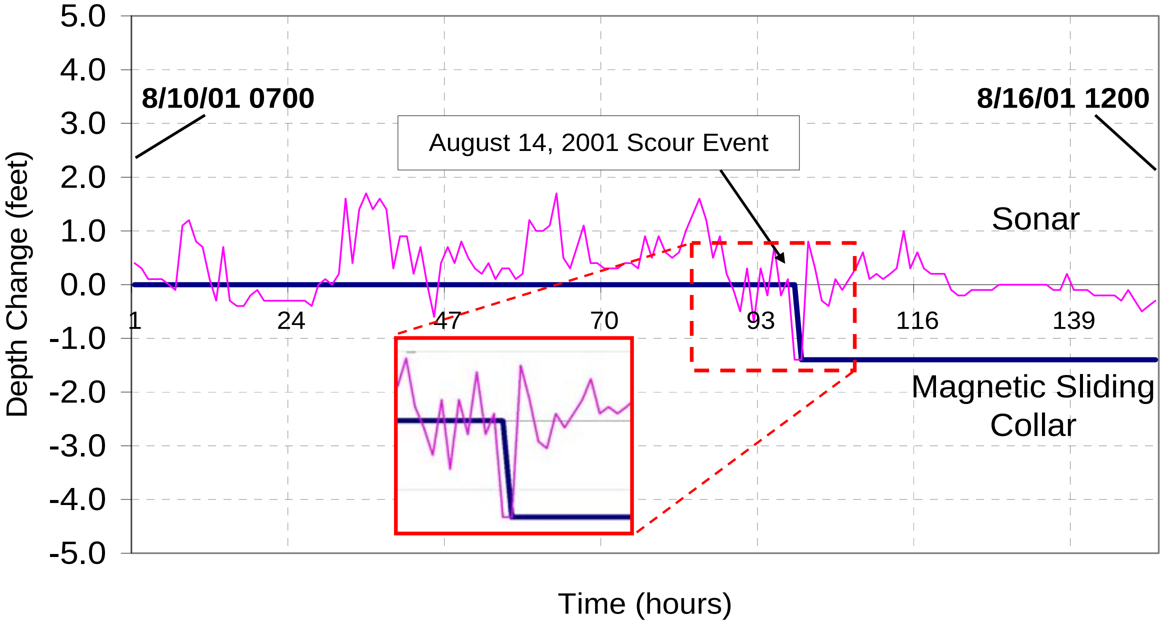

Figure 35. Passaic Bridge Scour Event, August 14, 2001

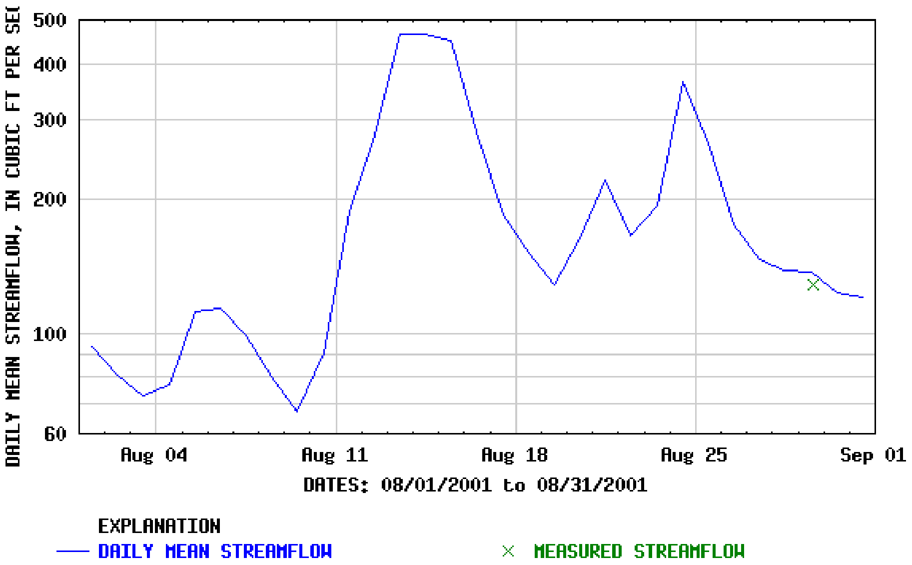

Figure 36. USGS Passaic River stream flow data upstream of Route 46 Passaic River Bridge, August 2001 (www.usgs.gov).

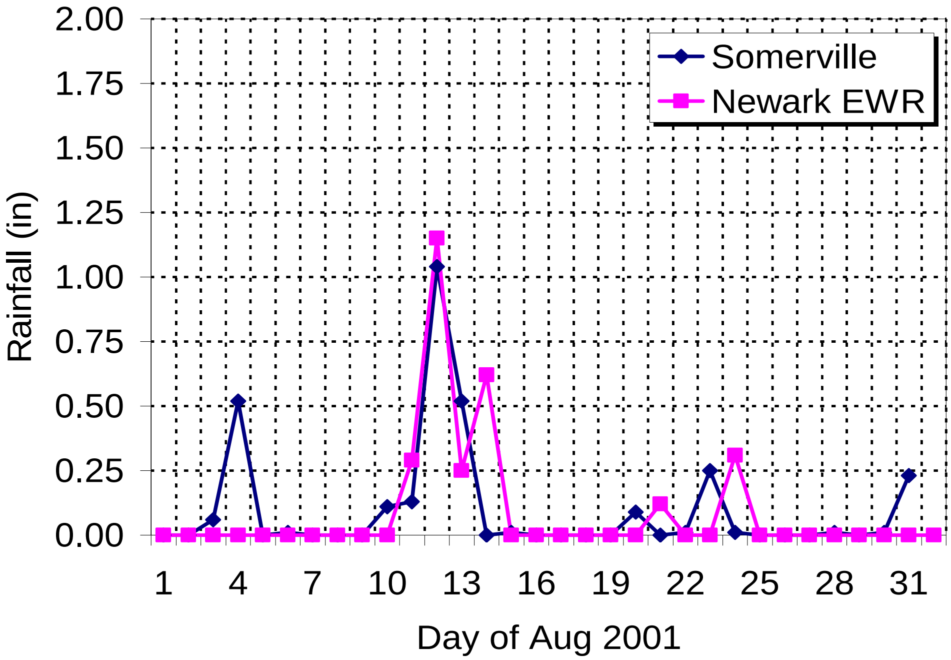

Figure 37. National Weather Service Rainfall Data for New Jersey (http://www.noaa.gov).

The amount of delay for rainfall to affect the stream flow for the Passaic River can be observed from Figure 36 and Figure 37. For example, a heavy rain on 8/12/01 of more than 1 inch causes an increased flow from 8/12 to 8/16. The weather and stream flow information is useful to verify the data and understand the hydraulic delay properties of the watershed.

The following two plots provide another example of a rain condition that led to a scour event at the Passaic Bridge. Figure 38 shows the daily rainfall at Newark International Airport (EWR) for January 2003. A heavy day of rain occurs on 1/2/03 followed by a scour event detected by the Passaic sonar sensor (Figure 39). All depth change measurements are relative to the elevation of the streambed when the system was first initialized. Figure 39 shows no scour activity using the MSC system, while the sonar records a depth change of -1 foot. The likely explanation is that the sonar is showing the scour of soil that was re-deposited at the pier since the last scour event. The MSC will only detect a scour event that is greater than the previous event. The reference elevation for the Passaic Bridge is -16.8 feet.

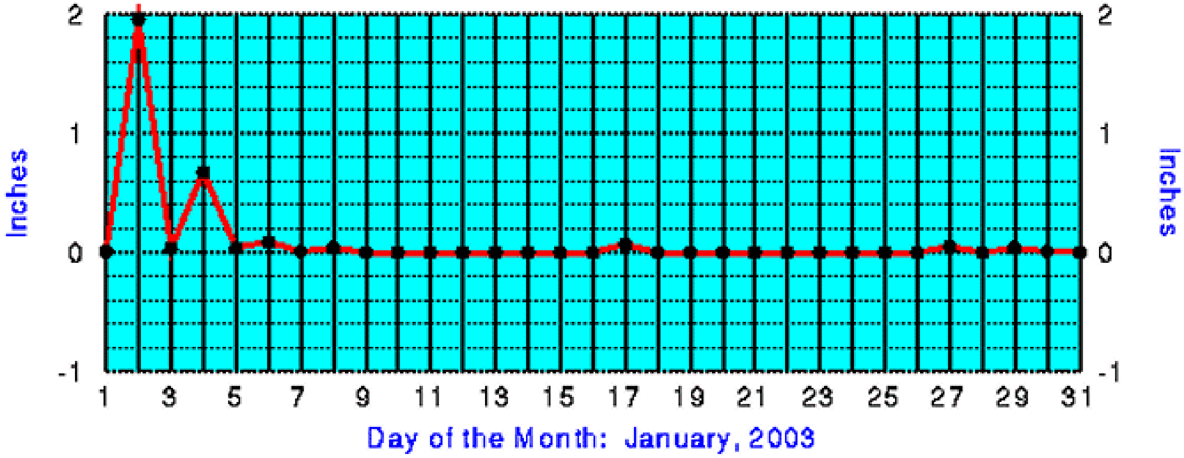

Figure 38. Precipitation Data for nearby Passaic Bridge, January 2003. Courtesy: National Weather Service NOAA (www.noaa.gov).

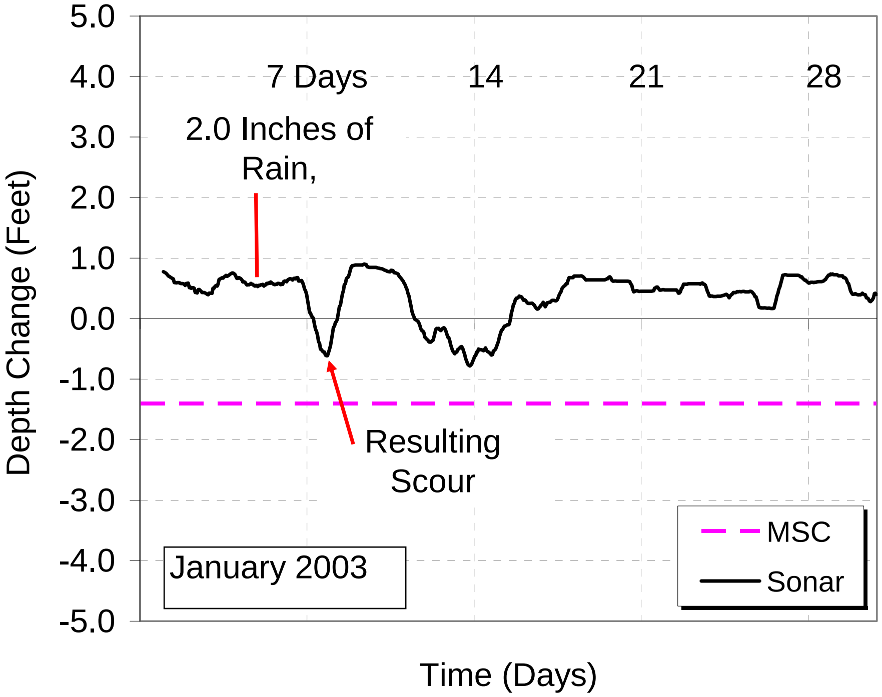

Figure 39. Passaic Bridge Scour Event January 2003.

Also, twenty-three months of sonar scour data are presented in Table 5 for the Passaic Bridge. The reference elevation for the Route 46 Passaic streambed is -17.6 ft.

Table 5. Monthly depth change for Route 46 Bridge.

Month	Change (ft)	Month	Change (ft)
Apr-01	0.0	Apr-02	-0.5
May-01	+0.4	May-02	-0.3
Jun-01	+0.4	Jun-02	-0.2
Jul-01	-0.6	Jul-02	-0.3
Aug-01	-0.6	Aug-02	-0.6
Sep-01	-0.5	Sep-02	+0.1
Oct-01	-0.6	Oct-02	-0.3
Nov-01	-0.5	Nov-02	-0.6
Dec-01	N/A*	Dec-02	-0.8
Jan-02	N/A*	Jan-02	-1.0
Feb-02	-0.9	Feb-03	-1.1
Mar-02	-0.9	Mar-03	-1.1

Note: Data for the period of December 2001 through February 2002 for the Passaic Bridge has been lost due to a computer failure.

Table 6. Data comparison and extremes for three years of data.

Parameter (feet)	Matawan Bridge	Passaic Bridge
Sonar Sensor		
Initial Sonar Elev.	-5.40	-16.80
Extreme Sonar Elevation	-5.80	-18.70
Average Sonar	-5.39	-16.39
Scour – Depth Change (Extreme less Initial)	0.01	-1.9
Magnetic Sliding Collar		
Initial MSC Elev.	-5.40	-16.8
Average MSC Elev.	-5.40	-17.93
Extreme MSC Elev.	-5.40	-18.2
Scour – Depth Change (Extreme less Initial)	0.00	-1.4

Table 6 shows a summary of the bridge measurements taken for both bridges. Note that for Passaic Bridge the sonar and MSC scour depth change values are different. The systems are located in close proximity to each other. There may be local scour that creates minor differences in depth. A more likely explanation is based on the design of the MSC. The MSC guide post contains a series of magnetically actuated switches that register the passage of the magnetic collar. The measurement resolution is equal to the spacing of these switches, 6 inches. Therefore, if the sonar and MSC readings are within 6 inches (0.5 feet) it can be said that they correlate well.

CONCLUSIONS

Many bridges are affected by scour. It is not feasible to immediately repair or replace all of these bridges for financial reasons and the difficulty in observing a slow developing process such as scour. It is important to develop continuous scour monitoring techniques, which will enable us to decide which bridge needs rapid repair or replacement. The sonar and magnetic sliding collar systems used in the research were successful in recording continuous scour data from the study bridges.

There are many different types of bridge configurations; therefore, two different methodologies were evaluated in this research. Each instrument has its advantages and limitations, and these factors must be considered in selecting the best one for different bridge sites.

The main disturbances to these systems are vandalism, ice, and debris. Both systems are vulnerable to ice and debris. False scour measurements may be recorded when foreign matter accumulates between the transducer and the streambed or around the collar. However, both instruments are strongly resistant to physical damage due to debris and ice. Considerations should be given to protect the system from vandalism. Moreover, frequent visits to check on the equipment are needed to ensure continuous operation. Perhaps installed a camera on site would be useful in identifying vandals.

RECOMMENDATIONS

Both the Active Sonar and Magnetic Sliding Collar systems have performed well during the study. Both systems continue to provide streambed elevation data for 4 years in the case of the Route 46 Passaic River Bridge and 3.5 years for the Matawan Bridge.

The main issues of the dual sensor system as implemented in this study are:

1. Readings are available for one location and for one pier only. There is no data for other piers or other locations of the studied pier. Follow up scour readings should be done about the entire studied bridges to gage the relevance of the

collected data. Scour at other piers should also be correlated to ensure that the sensors are installed at the most scour critical location.

2. The sonar and MSC systems cannot monitor the exact same location. The two sensors are placed a minimum distance apart to prevent interaction. For example, the sonar transducer may be directed onto the head of the MSC pipe and return a constant reading. Therefore, the sensors will not have the same exact readings, nor will they necessarily respond with the same magnitude difference when a scour event occurs.
3. Sonar readings can be erratic and difficult to discern. The sonar system is vulnerable to interference. Some examples include, air bubbles, waterborne debris and ice. Furthermore, it may be difficult to read the depth of a scour event because of debris and turbid water that follows a significant rainfall. However, this issue has been addressed in the software of the system which omits data that is not logical. The data sampling rate is automatically increased during a scour event to compensate for omitted data.
4. The magnetic sliding collar system offers a good max depth indication of scour. However, due to the spacing of the magnetic array inside the pipe, the resolution of depth readings is only 0.5 feet. The MSC offers less of an indication than the sonar system that it remains functional. Furthermore, the sliding collar can only move down as scour removes the bed material underneath. The magnitude of post-scour backfill is unknown.
5. Installation of the sonar transducer, conduits, and datalogger enclosure can be done with a relatively small crew with a boat and standard equipment. However, the Magnetic Sliding collar requires a great deal more effort to install. First, the driving of the stainless steel MSC post requires a pneumatic post driver which is difficult to acquire. Also required is a tow-able 90 cubic feet per minute air compressor with enough hose to reach the instrumented pier from above deck. Third, the heavy and unstable post/driver assembly requires significant labor to stabilize. In the absence of a catwalk or pile cap, a special platform is required at additional cost and effort.
6. The collected data is reliable. Field truth measurements with portable sonar and tape measure with plumb bob indicate accurate readings. Additionally, sonar interference is sporadic and short term. Interference also offers a means to check if the transducer is functioning correctly.
7. The only recorded scour event during the study occurred August 14, 2001 at 07:58 at Route 46 Passaic River Bridge. Both the sonar and magnetic sliding collar concur that the streambed elevation changed from -16.7 to -18.2 feet. The resulting scour depth was 1.5 feet. Local rainfall information was reviewed. A large thunderstorm produced heavy rains in the Passaic River drainage area before August 14, 2001.
8. The memory capacity of the datalogger used in the study is capable of storing readings covering about a 4 month period. If data that is about 4 months old is not retrieved, it will be overwritten with the latest data in what is called a ring buffer setup. Therefore, it is critical that the bridge datalogger be called or be setup to call out to the office at least every 3 months to ensure continuous and complete data.

9. The agency responsible for bridge maintenance, in this case the New Jersey Department of Transportation, needs to record the presence of the system on the two bridges and report the sensor locations to any parties that may be involved in inspection or repair.
10. Protection against vandalism can be achieved by limiting public access to the bridge location where sensors and enclosures are located.
11. Both study bridges experienced loss of data due to either vandalism or telephone service problems. It was discovered in June 2004 that the solar panel at Matawan Bridge was stolen. Loss of a power source will lead to system shutdown in about two weeks. Data can be maintained by the internal battery for about 4 months. The Passaic Bridge experienced a loss of telephone service about July 2004. The datalogger can maintain about 4 months of data, but must be downloaded manually by site visit if communications are lost. Therefore, it is critical to check the communications and power supply regularly to ensure continuous operation.

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APPENDIX

TECHNICAL MANUAL

Scour Tracker ™

Sliding Magnetic Collar
And
Active Sonar

Custom Configured for
New Jersey Bridge Scour Project
Rutgers University

ETI Instrument Systems, INC.
Scour Measurement Systems
1317 Webster Avenue
Fort Collins, Colorado 80524
970.484-9393

SMC-3/AS-3 Technical Manual

Table of Contents

Section 1

DESCRIPTION

1.1 General

The Scour Tracker *SMC-3/AS-3* provides accurate, unattended measurement of streambed scouring near bridge piers and abutments. It is one of a family of scour measurement systems designed and distributed by ETI Scour Measurement Systems that accommodate a variety of requirements and environments.

The Scour Tracker *SMC-3/AS-3* is modular in design and easy to operate. The Rutgers University *SMC-3/AS-3* system includes two devices for monitoring scour activity:

- An SMC-3 (Sliding Magnetic Collar) sensor that monitors the downward movement of a magnetic collar around a stainless steel support structure as the streambed soil scours away. Inside the stainless steel support structure is an AutoProbe, which consists of magnetically actuated switches spaced at six-inch intervals. The switches close as the magnetic collar comes in proximity, and the closures are monitored and recorded by the electronics unit.

- An AS-3 (Active Sonar) sensor that monitors streambed depth by sonar depth finding. At a given interval, the system's electronics send acoustic pulses from a sonar transducer to the streambed. By measuring the time for the reflected pulse received by the transducer, the distance from the streambed to the transducer is determined.

- A stage sensor measures the elevation of the stream surface.

- A weatherproof enclosure houses the instrumentation and communications electronics and the power components. The enclosure is mounted on an accessible location on the bridge or its piers and is connected to the sliding collar support structure, the sonar transducer, and the stage sensors via cables run in conduit.

Installing the sliding magnetic collar (SMC) assembly involves driving the SMC support structure, with the sliding collar in place at the upper limit of the support structure, into the streambed to a depth such that the collar is at the top of the structure and resting on the streambed. As the streambed is eroded away, the collar slides down the support structure and activates each switch as it comes into proximity.

Scour data, including a date-time stamp, is recorded on a CR10X datalogger. A modem and land-line telephone communicates the data to PC at a base location.

1.2 Major Components

Major components of the *SMC-3/AS-3* include:

A. The Sliding Magnetic Collar Assembly

1. Stainless steel support structure, two-inch diameter by 10 feet in length, watertight, with heavy-duty point for driving into streambed, and with cable entry "T" fitting.
2. Auto Probe, consisting of magnetically actuated switch modules and wiring, placed every six inches inside the stainless steel support structure. The switches and wiring are sealed with non-corrosive RIW inside flexible tubing, which is sealed inside a 1/2-inch PVC pipe. The PVC pipe runs the full length inside the two-inch stainless steel support structure.
3. Magnetic collar, 6.5-inch outside diameter by 7 inches in length; 2.5-inch inside diameter allows it to slide freely on the support structure.
4. Cabling and conduit from the support structure to electronics unit enclosure.

B. The Sonar Assembly

1. Sonar transducer mounted on a heavy-duty stainless steel bracket for Matawan and Passaic. The housing for the transducer is angled away from the pier to provide sufficient sonar beam clearance while allowing for reception of the reflected pulses.
2. Data cabling and conduit from the transducer to the electronics enclosure.
3. Sonar control unit mounted in the electronics enclosure.

C. The Stage Sensor Assembly

1. Stage sensor and PVC mounting structure.
2. Cabling and conduit from the stage sensor to the electronics enclosure.

D. Electronics Enclosure

1. A lockable, weatherproof enclosure that includes power, recording, monitoring, and telecommunications components.

Section 2

INSTALLATION

2.1 Unpacking

The sliding magnetic collar stainless steel support assembly with Auto Probe and cable are shipped with a two-inch diameter PVC pipe 10-foot in length to protect the cable. Use caution when unpacking by observing the following:

a.) The PVC fittings and pipe are only pressed together, not glued. Carefully pull the PVC pipe out of the PVC 90-degree fitting. Continue to use care as you pull the pipe from around the cable.

b.) The 90 Degree PVC fining was pressed onto the threaded nipple and will require the use of a screwdriver to help remove the PVC fitting. Do not unscrew the 90-degree fitting because doing so will twist the cable. Once the 90-degree fitting has been removed, the threaded nipple can be unscrewed.

Note: When installing the stainless steel support assembly it is important to seal the cable-outlet fitting so that water does not enter the support. If water were to enter the support it would freeze and split the support pipe and damage the AutoProbe. The cable conduit from the top of the support should be well supported to protect it from being damaged or ripped away by floating debris.

2.2 Site Preparation

When selecting a location for installing the Scour Tracker *SMC-3/AS-3* sliding collar support structure, consider that there may have been a prior scour hole which may contain a buried tree branch, rock, or other debt. Those obstructions could prevent the support structure from being inserted to its full length into the streambed. To avoid this, first probe the potential streambed location to the full support structure depth using a smooth, sturdy, round metal rod, such as a *3/8 - inch* ground rod. If the test probe indicates that the location is unobstructed, the sensor support structure can then be installed into the streambed.

Make sure the sensor support structure is placed far enough from the pier, buried piling, or other structure to avoid the possibility of interference with the sliding collar. Optimum placement is at the point where scour is most likely to occur.

2.3 Installing the Electronics Enclosure

The electronics enclosure for the *SMC-3/AS-3* is a weatherproof lockable box that contains the electronics and power system. It is normally bolted to a convenient location on the bridge or abutment where it can be serviced easily. Additionally, check the local flood stage information to determine the 50 or 100-year flood stage and locate the enclosure in a safe location in the event of a major flood event. Install the enclosure using the 3/8-inch anchor bolts. Pre-drill holes with a similar sized hammer drill bit to a full depth approximately the length of the anchor bolt.

2.4 Driving the Sliding Collar Support Structure

After test probing, drive the support structure into the streambed with the use of a "rhino." The rhino PD-55 is a vibration-type, pneumatically driven post driver. In a soft streambed, the rhino's heavy driving head and rapid air-hammer action will insert the pipe structure to its fill depth in a matter of minutes. Once the rhino driving process begins, it is important to continue without interruption to avoid a seizing action by the soil on the support structure.

(For systems with support structures greater than 10 feet in length, or if the streambed is hard soil with a high "N" number, or if it is likely to contain rocks or material that could hinder insertion, then a geotechnical firm should be contracted to auger a hole to the proper depth)

The sensor support structure is shipped fully assembled with the AutoProbe inserted. The AutoProbe data cable extends from the "T" and is protected during shipment by a PVC fining and pipe. Prior to inserting the support structure into the streambed, the sliding collar must be installed onto the structure and temporarily secured at the upper limit. Also, the data cable from the AutoProbe insert must be routed through the red flexible conduit. The red flexible conduit is then attached to the "T" fining at the top of the support structure via a stainless steel hose clamp. As the support structure is driven into the streambed, the red flexible conduit must be attended to keep water from entering it.

2.5 Mounting the Sonar Support Assembly

Matawan & Passaic Bridges: Install the stainless steel sonar support assembly (Six ¾ inch predrilled holes with threaded mounting tube at 8 degrees from vertical) to the pier with the stainless steel anchor bolts provided.

2.6 Mounting the Stage Sensor Assembly

The stage sensor assembly should be mounted on the underside of the bridge deck and positioned directly downward to the stream To avoid interference of the stage sensor's beam from the pier, it should be mounted at least five feet from the pier. Attach the PVC assembly to the pier using the clamps and anchor bolts provided.

2.7 Installing Conduit / Cable Assembly to the Sensors

A. Sliding Magnetic Collar:

After the support structure is fully inserted into the streambed, the conduit/cable assembly can be routed up the pier and attached to it. The red flexible conduit is to be attached to 1/2-inch gray flex conduit and routed to the electronics enclosure where it enters the enclosure through a conduit fitting shown in figure 1. As the conduit is routed up the pier, attach the conduit to the pier with two-hole conduit clamps at close intervals using drilled anchors.

B. Sonar:

The sonar data cable is run from the PVC transducer assembly (Stainless steel assembly on Matawan & Passaic) to the electronics enclosure through 1-inch gray flexible conduit, and enters the enclosure through a strain relief fitting as shown figure 1.

C. Stage Sensor:

The stage sensor cable is routed through 1/2-inch gray flexible conduit to the electronics enclosure, and enters the enclosure as shown in figure 1.

2.8 Cable Connections

Following are instructions that describe the final connections that must be done at the site after driving the support structure into the streambed.

Routing Cabling Into the Electronics Enclosure and Connecting Them:

The lower end of the electronics enclosure is equipped with five PVC strain-relief fittings to provide cable entry (see figure 1). Route the cables through the fittings as follows:

The small upper right fitting is for the AC input cable. The larger black fitting just below it is for the sonar data cable. The leftmost fitting is for the stage sensor. The upper fitting in the middle is for the telephone cable, and the one just below it is for the sliding magnetic collar cable.

Telephone Cable. Route the telephone cable through its fitting and attach it to the phone connector located on the lower right end of the modem. Remove slack by pulling the cable gently back through the fitting.

Sliding Magnetic Collar Sensor Cable. Route this cable through its strain-relief fitting to a length that will allow routing as shown in the figure. Strip the insulation back to a point near the entry inside the enclosure. Terminate the metal mesh shield to earth ground (the electronics enclosure should be connected to earth ground). Connect the white wire to datalogger terminal IL. Connect the black wire to datalogger terminal AG.

Sonar Sensor Cable. Route this cable through its strain-relief fitting to a length that will allow routing as shown in the figure. Loosen the large black knob on the sonar electronics module so that it can be rotated. Rotate the electronics module to expose the cable receptacle on the underside. Connect the sonar data cable to the electronics module; then rotate the electronics module into its normal position and tighten the black knob.

Stage Sensor Cable. Route this cable through its strain-relief fitting to a length that will allow routing as shown if the figure. Connect the six wires from the stage sensor as follows:

- Connect the red wire to the datalogger terminal marked 12V, which is located on the extreme lower right of the datalogger.
- Connect the black lead to one of the terminals labeled G. Also connect the clear wire to the terminal labeled G.
- Connect the white wire to the terminal labeled 5H (which is also terminal 9).
- Connect the brown wire to the terminal labeled 5L (which is also terminal 10).
- Connect the green wire terminal E1.

AC Power Input Cable. Utility AC power is routed through the strain-relief fitting and connected to the terminals of the GFI outlet in the right hand corner of the enclosure.

A float charger plugs into the AC GFI outlet. The two wires from the float charger connect to the battery terminals. Make sure to connect the red positive wire to the battery's positive terminal and the black wire to the battery's negative terminal.

There are other connections on the datalogger that have been done at the factory prior to shipment.

Battery Connections:

CAUTION!

Do not reverse battery + and - battery connections.
It ***WILL*** damage the system and render it inoperable!

Leads to the two battery terminals are the last connections to be made. The red and black wires that connect the datalogger to the battery are clearly marked. They are connected by sliding the wire connectors onto the battery terminals. The red lead connects to positive (+) battery terminal and the black lead connects to negative (-) battery terminal.

Section 3

OPERATION

3.1 General

The *SMC-3/AS-3* is configured with a CR10X Datalogger for recording scour data. The datalogger also is interfaced to a modem and telephone. It is configured to:

- Place a data call twice each day to the customer's base office PC, which must be connected to a dedicated telephone line and configured to automatically answer. The data call will include the date and time, the current elevation and reference elevation of the streambed as measured by the magnetic collar and the sonar, the battery voltage, and the stream surface elevation.
- Place a data call to the customer's base PC when a scour event occurs.
- Receive incoming data calls anytime

3.2 Loading Scour Operating Software onto a PC

A diskette containing PC2O8W Widows- based operating software is shipped with the *SMC3/AS-3.* PC2O8W should be loaded onto a dedicated PC that has a modem and a dedicated phone line for answering incoming data calls from the system The system will place at least two data calls each day to the dedicated PC.

To load the PC2O8W operating system onto the dedicated PC, place the first of the PC2O8W diskettes in the diskette drive and type a:\setup for a Widows 3.x PC or follow the corresponding procedure for Windows 95 or Windows 98 PCs.

3.3 PC2O8W Setup

Once PC2O8W is loaded onto the PC, the PC must be configured to accept incoming data calls from the *SMC-3/AS-3.* Double-click the PC2O8W icon to start PC2O8W. A button bar that shows eight selectable options will appear at the top of the screen Click the SETUP button.

a) At the left of the screen there is a white area labeled DEVICE MAP. COM2 should already be listed in the white area. If COM2 is not the port your PC's modem is attached to, then click ADD COM PORT until the proper corn port appears in the white area. In the HARDWARE tab for the COM2 screen, set the baud rate to 1200. Also click the box labeled ALLOW CALLBACK ON THIS

PORT and enter 5000 for EXTRA RESPONSE TIME at the bottom of the screen. Then click COM2 (or whichever port you are using) under DEVICE MAP to highlight it and then click ADD DEVICE at the top. A menu will appear giving you several options; click PHONE MODEM. A second screen will appear labeled ATTACH SELECTED DEVICE TO. Double-click the port the PC's modem is attached to. Then select BAUD RATE 1200. Use the default modem unless your modem is specifically listed in the modem pick list. Under EXTRA RESPONSE TIME at the bottom, enter 5000.

b) Now click MODEM1 under DEVICE MAP at the left of the screen to highlight it. Then click ADD DEVICE at the top and Select CR10X DATALOGGER; then double-click MODEM1 under the screen labeled ATTACH SELECTED DEVICE TO.
c) REMOTE1 appears under MODEM1 in the DEVICE MAP at the left of the screen and there are some new blank areas on the right side of the HARDWARE tab screen. The name "REMOTE 1" can be changed to a more meaningful name for the datalogger, such as MATAWAN (must be eight characters or less), by highlighting it in the CR10X DATALOGGER NAME box and changing it. Enter the telephone number of the phone at the SMC-3/AS-3 in the DIALED USING PHONE NUMBER box. Enter 101 in the CALL-BACK ID NUMBER box. Enter 5000 in the EXTRA RESPONSE TIME box.
d) Other fields on the HARDWARE tab screen should be as follows:
    - SCHEDULE ON must be blank.
    - SECURITY CODE and CLOCK OFFSET must be 0.
    - MAX TIME ON-LINE should be 600.
    - MAXIMUM PACKET SIZE should be 2048.
e) Click the DATA COLLECTION tab at the bottom to bring up the next screen COLLECT should be DATA LOGGED SINCE CALL. FILE MODE should be APPEND TO END OF FILE. FILE FORMAT should be ASCII, COMMA-SEPARATED. NUMBER OF ARRAYS TO COLLECT should be 0. COLLECT FINAL STORAGE AREA 1 should be checked. At the bottom of the screen you see that the file in which data records are to be stored is called MATAWAN.DAT. Click BROWSE to change the name of the data file to whatever you wish.
f) Repeat Steps b through e for the PASSAIC Bridge. (The CALL-BACK ID NUMBER Passaic is 102).
g) Do not make any changes to the SCHEDULE tab screen
h) Click SAVE EDITS at the top of the screen and then exit from the SETUP program of PC2O8W.

3.4 Normal Operation

In normal operation the PC is connected to a dedicated phone line and is running the PC2O8W software. To configure PC2O8W to listen for incoming calls, click the STATUS button on the PC2O8W button bar. Click LOG STATUS MESSAGES at the bottom. This provides a record of all system messages related to communications activity. This activity is stored in a file called SWF$.LOG, which may be viewed using the VIEW program described in Section 3.7. (Do not confuse this SWF$.LOG file with the file that contains data records from the scour sensors. As data calls come in from the system, the data records are appended to the end of the file named MATAWAN.DAT, which were selected under SETUP.)

It is recommended that the customer develop a procedure for analyzing data records on a regular basis. The streambed elevation as determined by the sliding magnetic collars and sonar should be monitored. They may he slowly decreasing if the streambed slowly scours. If the streambed elevation has decreased sufficiently to approach a scour event (every foot on the Rutgers system), then personnel monitoring the systems can be aware.

(The Rutgers system takes readings every 15 minutes checking for scour, but records data only once each hour if no scour is detected; therefore, there will be 12 records transmitted each day as a matter of routine. If scour were to occur, there would be an extra record for each scour event. The Rutgers system calls in twice daily at 2:00 am and 2:00 pm. The format of the records follows this section.)

3.5 Scour Event

The Rutgers system determines that a scour event has occurred if a sliding magnetic collar has descended one foot or more from its reference position, or if the sonar detects a streambed decrease of one foot or more from the sonar reference position. The initial reference position is the elevation at which it was installed. When a drop of one foot or more in streambed elevation is detected by either the sliding magnetic collar or the sonar, the system quickly takes three more measurements (one per minute) to ensure it is not a false reading. If the reading remains valid for three consecutive measurements, then a scour event is assumed to have occurred and the system places a data call to the PC. At that time the system resets the reference position to the current streambed elevation.

The dedicated PC is most useful if it is placed in an office that is staffed 24 hours a day. Then, should scour occur, the data on the PC can immediately be observed and analyzed to determine the extent of scour and on what pier it occurred.

3.6 Calling the System

The system can he called at any time to download new operating software to the datalogger, or upload the latest data to the PC, or both.

To call the system, exit the STATUS program and click the CONNECT button on the PC2O8W button bar. Click CONNECT at the bottom of the screen and the PC will dial the phone number of the system when the PC is connected to the system, datalogger clock time will be displayed at the right side of the screen. To collect the latest Data, click COLLECT at the upper portion of the screen. A bar displays the progress of the collection in percent. After the data has been collected, click DISCONNECT at the bottom of the serene. Once you are finished with the CONNECT screen, return the PC to the STATUS mode described earlier.

3.7 Displaying Data With the VIEW Program

Data can be displayed (but not edited) by clicking the VIEW button on the PC2O8W button bar and following usual Windows procedures for selecting files. The data may be viewed in several ways. The default is a listing of records with the values separated by commas. By clicking a button at the top of the display the data is displayed in easier-to-read tabular format.

Either one or two columns can be displayed in graphical form by clicking another button at the top of the display. The data are automatically normalized to the plotting with the minimum value at the bottom and the maximum value at the top.

Rutgers Data Record Format

Data records are composed of a series of comma-separated ASCII values that can be displayed and analyzed by a variety of PC-based processors, including spreadsheets and word processors.

Field Description:

1. Record type (type 1=normal daily record, no scour; type 2=sonar Scour event); type 3=sliding magnetic collar scour event go
2. Year (four-digit)
3. Day (Julian, ex: 32 is February 2)
4. Hour and Minute (ex: 1423 is 2:23 pm)
5. Current streambed elevation measured by the sliding magnetic collar
6. Reference elevation for the sliding collar (a drop of one foot from this is scour)
7. Current streambed elevation measured by the sonar
8. Reference elevation for the sonar (a drop of one foot from this is scour)
9. Battery voltage
10. Stream surface elevation as measured by the stage sensor

A typical Rutgers system record could be:

```
1,1999,264,1 800,25.0,25.5,25. 1,25.8,12.9,34.6
```

Section 4

MAINTENANCE AND TROUBLESHOOTING

Routine maintenance of the *SMC-3/AS*-3 system consists mainly of inspecting and cleaning various components. Observing the following precautions will help ensure trouble-free operation:

- Inspect enclosure gaskets. Make sure they we clean and in good condition
- Enclosure must be dry inside. This is a must!
- Inspect battery terminals Make sure they are clean and free of corrosion.
- Inspect cable inlet fittings. Make sure they are tight and keeping moisture out.
- Check conduit for abuse.

If System Stops Recording Data:

- Check for proper battery voltage, which should be above 12.2 volts.

- If voltages are at the proper levels, check to make sure the sensors have the correct resistance. Disconnect the sensor cable from the datalogger and place an ohmmeter across the leads. The resistance changes as the magnetic collar slides down the mast, but should be in the range of 500 to 52000 ohms. Values different from these can indicate a damaged cable or sensor. Each foot of collar travel increases the resistance by 1000 ohms until the collar is past the last sensor. (There is a 37,400-ohm terminating resistor that will cause the resistance reading at the bottom to jump from 14,000 to 51,400 ohms.)

Section 5

SPECIFICATIONS

5.1 Sliding Magnetic Collar Components

Sensors:

Type	Magnetically actuated switches
Resolution	6 inches
Accuracy	± 3 inches

Support Structure:

Type	Stainless Steel, Schedule 80
Length	10 feet
Diameter	2 inches
Features	Attached driving point and head with cable entry “T” fitting

AutoProbe Collar Position Insert:

Type	Magnetically actuated switches at six-inch intervals
Configuration	Switches and module inside ½ inch PVC pipe.

Sliding Magnetic Collar:

Type	Open-type collar
Outside Diameter	6.5 inches
Inside Diameter	2.5 inches
Height	7.0 inches
Magnets (2 sealed)	3 inches long x 0.75 inch diameter

Cable:

Type	Direct Burial, 18 AWG
Length	Location Specific

5.2 Electronics and Power System Components

Datalogger:

Type	Campbell Scientific CRI0X
Input Channels	6
Accuracy	0.2% full scale
Full-scale range	± 2500 millivolts
Resolution	333 microvolts
Excitation Output	3 channel
Range	2.5 volts
Power Requirements	10-l6 volts DC
Current	0.005 amps
Physical Size	7.8 x 3.5 x 1.5 (inches)
Operating Software	PC208W (Campbell Scientific)
Memory	ROM - 32KB, RAM –64KB
Controls	Modem and telephone
Programmable functions	Sample interval, time window for data calls, Originate scour-in-progress call
Interface	RS-232, modem to land-line telephone

Electronics Enclosure:

Type	Stainless steel, hinged cover type 4X with lockable hasp
Size	14x12x8(inches)

APPENDIX B - LITERATURE REVIEW DETAILS

Since 1987 and after the bridge failure in New York, many researchers attempted to study the scour phenomena. Lagasse et al. (1991) performed a comparison of different fixed scour measurement devices including the sonar transducer and magnetic sliding collar (MSC).(18) The study served as a means of testing the adequacy of the instruments in enduring environmental factors and delivering usable data. A variety of bridge and stream geometries were tested. The magnetic sliding collar and sonar systems were installed independently on different bridges. In one case, however, both a manual and automated readout MSC were installed for comparison. MSC installation included 6 manual and 2 automated readout devices. The results of the trials refer to ice and debris damage at most of the manual readout sites due to extended piping needed to accommodate the insertion of a readout probe. The automated probe has an internal integrated sensor of magnetically actuated reed switches, leaving only the tip of the driven rod exposed and thus reducing the vulnerability of debris damage. Unknown bed material composition was also cited as an installation problem. For both the manual and automated readout MSC systems, the connecting conduit from rod to topside is susceptible to debris and vandalism damage. A low cost sonic fathometer system was installed on a test bridge in Western Florida. The instrument performed well over the 4-year test period. Major problems included marine creature growth (reduced by the pre-application of expansive anti-fouling paint) and debris obstruction of the sonar beam path. The installed location of the transducer was near the water surface leaving it exposed to floating debris and vandalism damage. The automatic reading and data storage performed well during storm surge conditions. Other bridges cited include: South Platte River, Colorado; Rio Grande River, New Mexico; upstate New York; and three sites in Texas. The principal configuration is a low cost, off the shelf, sonic fish finder with data port, sonar panel, enclosure, and mounting equipment.

Schall et al. (1996) installed scour detection instruments at two tidal bridges on each coast of Florida.(19) The purpose of the study was to evaluate the performance under open water marine conditions such as tidal effects, salt water, growth of marine life, corrosion, and (open water) debris. Previously, scour monitoring systems were installed on river locations. The goal of the study was to evaluate the sonic fathometer and the magnetic sliding collar system (MSC) for determining the maximum depth of scour. By design the MSC is limited to reading the maximum depth of scour only. The collar moves down the post with the drop in streambed elevation. The Johns Pass Bridge in St. Petersburg, FL was instrumented with a low cost sonic Fathometer. An innovative installation feature cited in NCHRP Project 21-3 was implemented: the sonar transducer was mounted on the end of a long rod. This eliminated the need for diver support. The transducer (referred to as “above-water serviceable transducer housing”) could easily be raised and serviced to remove marine growth.

The United States Geological Survey has reported three types of scour: 1) general scour or fill, 2) contraction scour (due to structures reducing flow area), and 3) local scour (due to vortices and eddies). The study was conducted during the construction of Highway 101 Bridge at Waldport, Oregon between 1988 and 1990. (24) The bridge is situated on a tidal estuary on the River Alsea. The goal was to monitor the scour near the cofferdams and bents of the new construction. The preliminary site investigation included: bed elevation profile investigation (conducted by sonar transducer, datalogger, and boat with reference to fixed structures), and local scour investigation (including both sonar readings and ground truth research). The fixed monitoring setup included: immersed velocity sensors, sonic fathometer, and datalogger. The sonar transducer was fixed to four different piles and cofferdams at the bridge site and directed at the target scour hole. Data was continuously collected by the automated system. The sampling rate was one reading every 15-minutes with filtering for erroneous readings. Other peripheral measurements were taken, including tributary discharge rates, tributary river stages, and tidal flow magnitude. The data was verified against manual ground truth measurements, and it was found to be within a +/- 0.25-inch accuracy for most of the monitoring sites and a +/- 1.5 ft for one pile location. Scattered Sonar Signal was reported due to sand or debris. No physical equipment performance information was given as far as corrosion or transducer damage and data was continuously collected for the two-year duration of the project. The study represented one of the earlier applications of sonic fathometers for continuously monitoring and recording data. The study proved the reliability and accuracy of the sonar scour measurement systems.

Building on the 1988-1990 Highway 101 Bridge Over Alsea River Estuary instrumentation experience, the USGS published another report that included the evolution and advancement of many of the equipment features.(24) A total of 9 bridges were instrumented with sonar, scour chains, and scour detection arrays. The key evolution present was the new Lowrance 350A depth sounders which output a digital signal to a similarly capable data logger. Improvements in data logger software included data exclusion (for erroneous readings which differ from previous data by a given factor) and multiple readings taken over a specific interval, then averaged. The data exclusion offers a simple correction to the fundamental erroneous data flaw of sonar systems. The sonar system sends an ultrasonic pulse that is directed to the scour location. In its course of travel it may be scattered or reflected by water-borne particles. The reading is then distorted and an erroneous one is recorded.

The disadvantages of the sonar system cited in the report are:

1. Difficulty in duplication of the equipment
2. The post processing of the datalogger possibly utilizing the advanced signal processing capabilities of the sonar unit
3. Not suitable for shallow streams less than 2 feet in depth, ice jams, heavy debris conditions, or turbid water

The report recommends alternate instrumentation to evaluate scour where sonar systems are not applicable. This study instruments one bridge with one type of system. There has been no cross sampling with redundant systems to take advantage of two sets of equipment specifications.

Forty-eight bridges in New Hampshire were investigated by the USGS out of which 20 were actively tested for scour.(26) The means of study include: flood dispatch teams, fixed instrumentation, and ground penetrating radar. Of the 20 bridges studied, 4 were equipped with fixed 3instruments. The report examines the data from all studied bridges and gives a comparison of the accuracy and performance of the instruments. Sites for fixed instrumentation were selected based on a set of discriminating criteria. Such criteria include:

1. Piers aligned within 15 degrees of stream flow.
2. A straight approach to a certain distance upstream.
3. Accessibility of the bridge for installation and maintenance.
4. The streambed material susceptibility to scour.
5. A stream gauging station is located nearby for discharge and velocity data
6. Piers not susceptible to debris.

For those bridges with fixed instrumentation, sonar fathometers account for 3 bridges and a Brisco Monitor sliding rod accounts for one single bridge. Two different sonar-sounding systems were installed: the Datasonics PSA-902 Acoustic Altimeter and the Raytheon ST-50 Depth Sounder. The principal difference between these two sonar system is that the former can take up to 16 sequential soundings per interval, while the latter can only take one range measurement per sample. Both sonar systems take readings on a 30-minute interval. The data is then written to their respective data loggers. Data is manually retrieved by a site visit about every 3 months. The key disadvantage of the fixed instrumentation cited in the NHDOT report are: (1) The sensors can measure scour only at the point beneath the instrument whereas field teams can position instruments across the entire bridge profile, (2) fixed instruments are vulnerable to outside interference such as air particles or debris, hence, sonar was only applied to low debris prone bridges, (3) lightening presents a danger to fixed instruments exposed to the weather, (4) severe temperatures can render both the data and the system useless by physical damage or battery function impairment, (5) fixed instruments are vulnerable to theft or vandalism. NHDOT cites two cases when the solar panels were stolen resulting in loss of data and disabled systems.

Lagasse et al. (1997) published the most comprehensive report on fixed instrumentation to date in the field of bridge scour.(12) The report chronicles the history or basically every means of scour measurement along with the performance of the different types of systems.

The report describes in great detail:

1. The composition of certain pre-assembled turnkey systems. Every detail from equipment type, specifications, accuracy, compatibility, power requirements, and installation are described. An itemized component list is provided.
2. Past performance and evolution of different systems (calling upon the experience of the authors).
3. Site selection criteria and sensor-specific environmental limitations. For example, the depth and debris limitation of sonar systems.
4. Installation recommendations and considerations.
5. Equipment maintenance and upkeep.
6. Instructions for Remote Data Retrieval Capability.
7. Cost Analysis of Each Prototype.
8. Laboratory Test Results of Experimental Equipment.
9. Development of Error reducing algorithms.
10. Development of Scour Warning Alarm Function. The data logger can be programmed to call the office of the client to warn of dangerous scour conditions.
11. Demonstration and Testing of Wireless Remote Data Access.

The report features for the first time a review of a concurrent installation of both sliding magnetic collar and sonar system installation. The authors installed both systems on a sloping abutment at Highway 37 Bridge on the Platte River South near Kersey, Colorado.

APPENDIX C – OTHER BRIDGE SITE INVESTIGATION DETAILS

Prior to selecting Route 35 Matawan Creek and Route 46 Passaic River at Dundee Lake, 9 other bridge sites were investigated. The following is a summary of the scour related features of each bridge.

Route 35 Cheesequake Creek Bridge, Structure No. 1222-150.

The Route 35 Bridge crosses the Cheesequake Creek in Old Bridge Township, Middlesex County, New Jersey (Figure 40). The creek is the only inlet for a tidal marsh, and a strong alternating flow condition exists. The soil consists of finely grained sands, and the stage difference is +/- 5 feet. The present bridge was constructed in the early 1930's using timber piles of unknown length. Early inspections using the portable sonar detected scour activity on the south end of the bascule and connection bascule piers. Though the bridge inspection reports and contract drawings made no mention of rip-rap, a physical inspection using a driving rod detected concrete countermeasures. Otherwise, this bridge offered all of the necessary services for a simple installation.

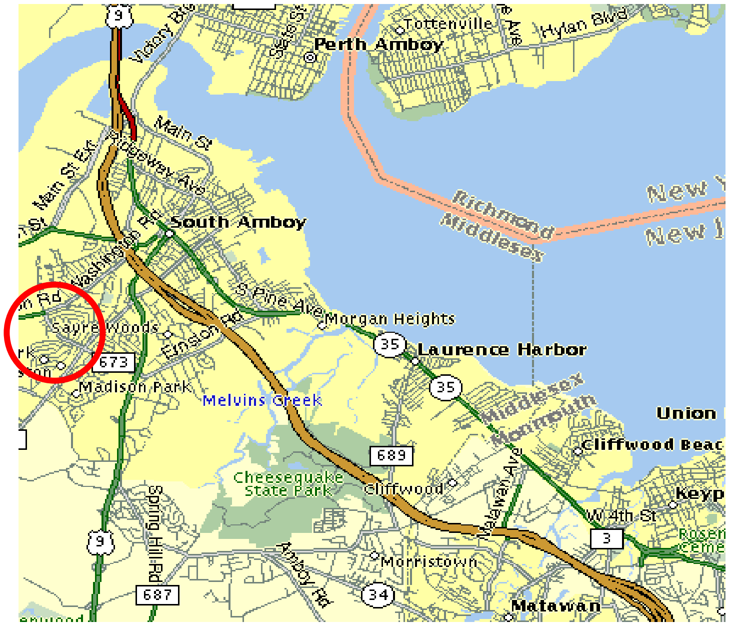


Figure 40. Location of Route 35 Cheesequake Creek Bridge

Route 27 Millstone River Bridge

The Millstone River at Route 27 is a small stream that is fed primarily by the outflow of the nearby Carnegie Lake Dam and the Millstone River (Figure 41). The streambed consists of boulder sized rocks and similar smaller gradations. The flow is very light during the late fall observation time. The piers of the bridge are skewed to the direction of the normal flow but may be aligned for flood condition flow. The bridge inspection report suggested this bridge as a potential candidate for scour activity. However, a close-up inspection revealed shallow, light flow, with a minor depression in the rocks, near the upstream face of the center pier.

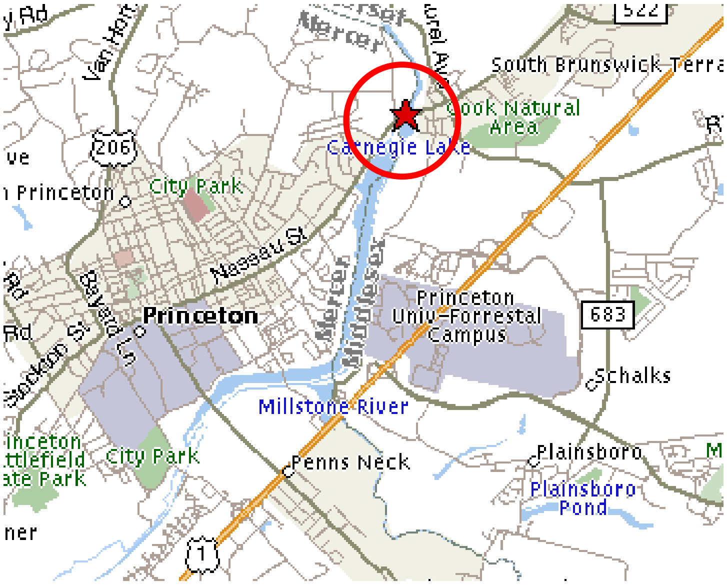


Figure 41. Route 27 Millstone River Bridge

Route 70 Bridge

New Jersey State Highway 70 crosses the Manasquan Inlet near the town of Brielle, Monmouth County (Figure 42). The substructure consists of simple spans supported by pile bents crossing a 600ft width. The bed materials consist of fine to coarse-grained sands. The flow is tidal with a daily variation of 5 feet. The main classification of the waterway is a tidal inlet.

The nearest USGS monitoring station is located at Squankum, NJ (USGS Sta. 01408000), approximately 8 miles upstream from the Route 70 Bridge. The 25-year peak flow for the Manasquan River is 2040 ft^3/s on November 8, 1977.

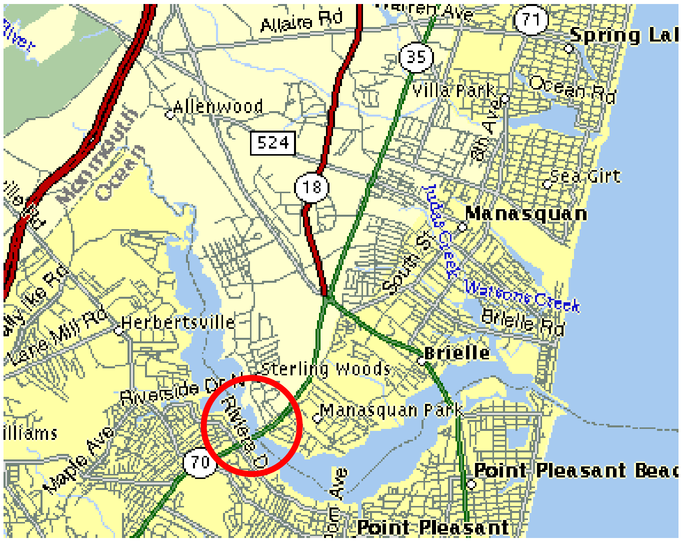


Figure 42. Location of Route 70 Bridge.

Route 18 Raritan River Bridge

The Route 18 Bridge (Figure 43) is a three pier, four span, curved girder bridge. The soil consists of hardened, clay type stone and other gravels. The depth is generally between 1 and 4 feet depending on the tidal effects. The flow is light to moderate having infrequent floods with depths of above 10 feet. There appears to be some scour activity from the Hurricane Floyd Flood of 1999 as indicated by an upstream depression visible during low tide at one of the piers. However, the normal stream depth is shallow with periodic tidal extremes that can expose the scour hole completely. Therefore, the lack of consistent water depth limits the effectiveness of the sonar system.

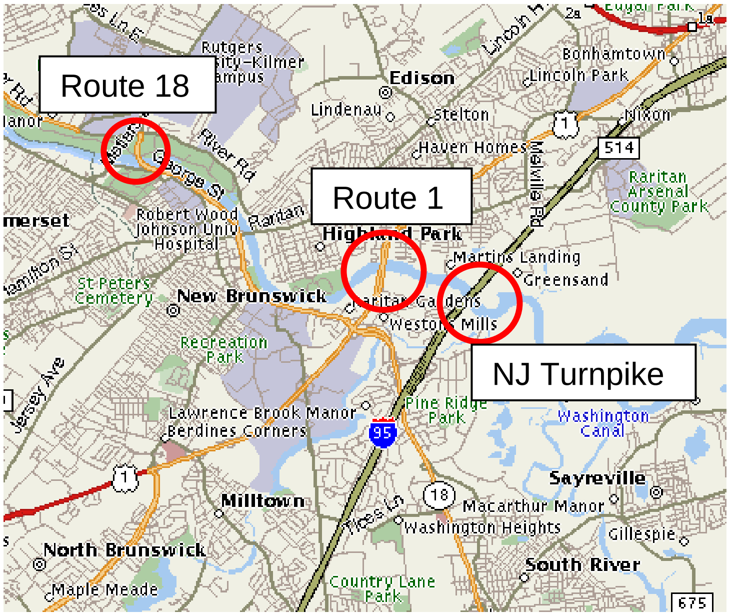


Figure 43. Route 18, Route 1 and NJ Turnpike bridges on Raritan River, Middlesex County, NJ.

U.S. 1 Raritan River Bridge

US1 (Figure 43) crosses the Raritan with two streambed piers. The bridge is located on a curve in the river with piers skewed to the normal flow. The portable sonar inspection was inconclusive due to debris and the presence of rip-rap is unknown. In addition, access to the river with a small craft is limited and support services (telephone and power) are unavailable.

New Jersey Turnpike Raritan River Bridge

The turnpike bridge over the Raritan River (Figure 43) is a three span, 2-pier bridge with protective sheet piles and an extensive fender system. A sonar inspection did not reveal any apparent scour condition. In addition, the sheet pile fenders extended the full face of the piers. Flow on the Raritan is generally moderate with tidal effects. The sheet piles as countermeasures disqualified this bridge for study.

Interstate 295 Rancocas Creek Bridge

Rancocas Creek at the Interstate 295 Bridge (Figure 44) is a wide river with accompanying marshes. The soil type is primarily silty and fine to medium grained sands. The flow is tidal, being located 5 miles from the Delaware River in Burlington County, NJ. Portable sonar inspections of the piers show little, if any, scour effects. Furthermore, the remote location of the bridge would make installation and maintenance difficult.

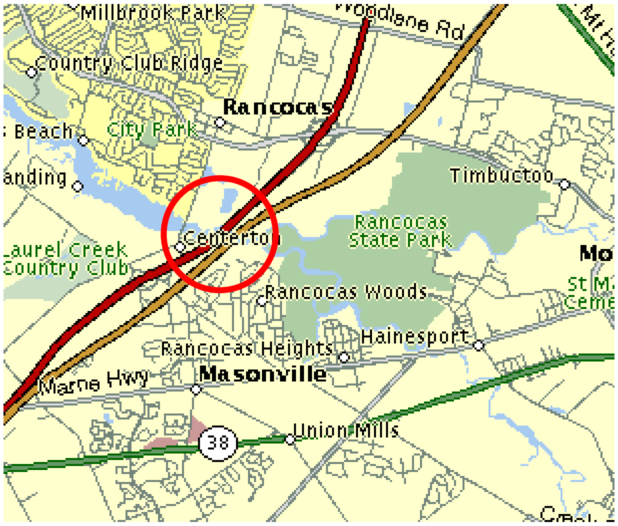


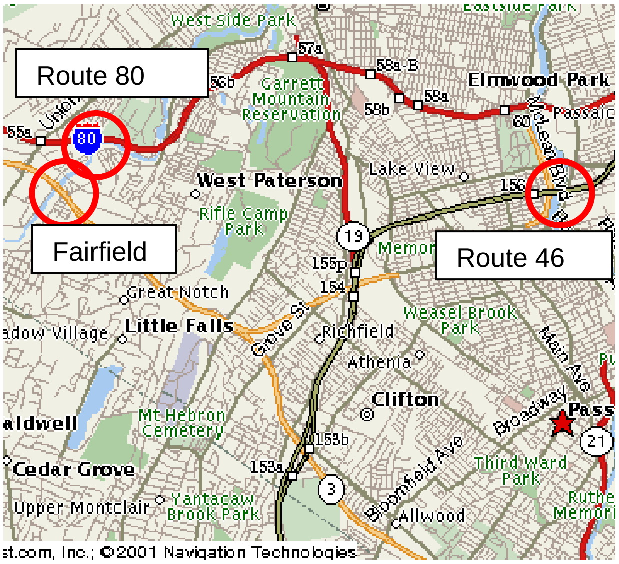
Figure 44. Interstate 295 Rancocas Creek Bridge, Burlington County, NJ.

Route 80 Over Passaic River Bridge, Structure No. 0726-155,156

The Route 80 Bridge over the Passaic River near Fair Lawn (Figure AC6) crosses a wide river profile with shallow depths. The bed material is gravel and rocks. The lack of scour activity and limited depths precludes this as a useful site.

Route 46 Passaic River Bridge at Fairfield, Structure No. 0722-157, 158

The Route 46 Bridge (Figure 45) crosses the Passaic River about one quarter mile downstream of the Route 80 Bridge. The stream narrows toward the bridge and the depth increases. Access to the piers was simple with the small motorboat. Readings were taken with the portable sonar. It was found that the bridge had scour activity as indicated by the contour plots of the streambed shown in Figure 46 and Figure 47. Driven rod tests for rip-rap were inconclusive. The contract drawings, dated 1944 did contain a stipulation for concrete rip-rap to be placed at all faces of the piers. With the presence of rip-rap instrumentation was foregone.



.

Figure 45. Rt. 46 Fairfield, Route 80 and Route 46 Passaic River Bridges, Bergen County, NJ.

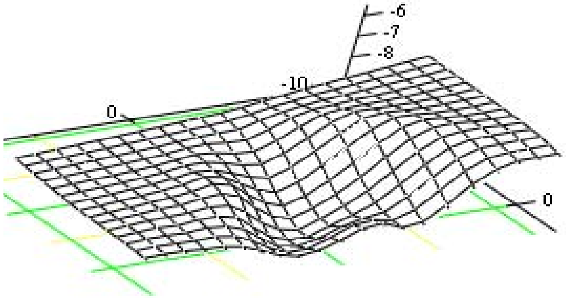


Figure 46. 3-D view of scour hole in front of the pier of Route 46 Passaic River, Fairfield, NJ.

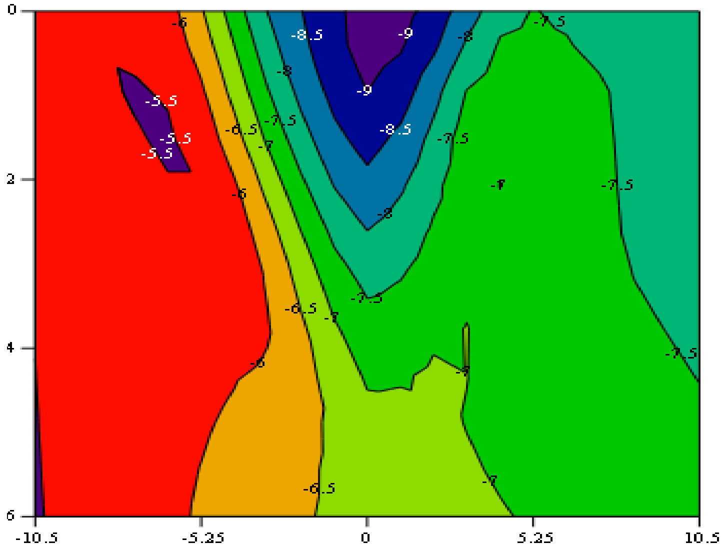


Figure 47. Contour plot of scour depth in front of the pier of Route 46 Passaic River Bridge, Fairfield, NJ.

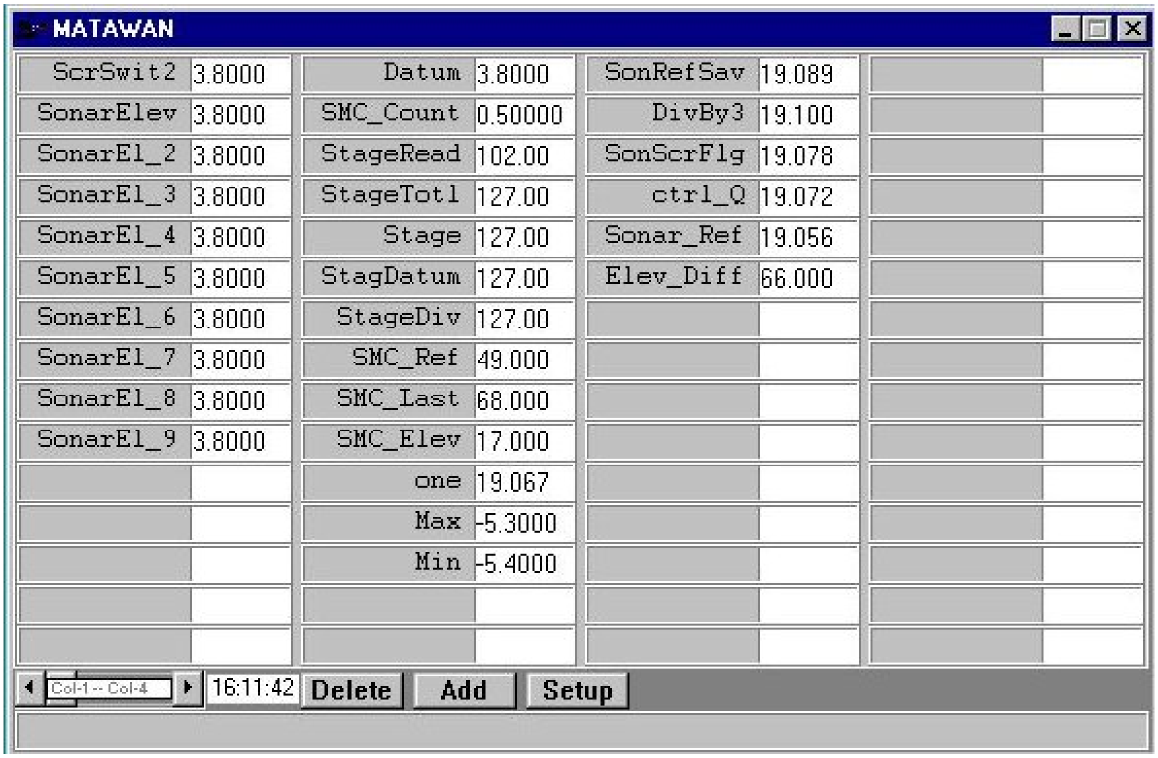
APPENDIX D – SYSTEM OPERATION AND FEATURES

SYSTEM OPERATION AND FEATURES

PC208W Operating Notes

Displaying Variables on the NUMERIC Screen

The following is an example of the PC208W numeric window for Matawan Bridge (Figure 48).



ScrSwit2	3.8000	Datum	3.8000	SonRefSav	19.089
SonarElev	3.8000	SMC_Count	0.50000	DivBy3	19.100
SonarEl_2	3.8000	StageRead	102.00	SonScrFlg	19.078
SonarEl_3	3.8000	StageTotl	127.00	ctrl_Q	19.072
SonarEl_4	3.8000	Stage	127.00	Sonar_Ref	19.056
SonarEl_5	3.8000	StagDatum	127.00	Elev_Diff	66.000
SonarEl_6	3.8000	StageDiv	127.00		
SonarEl_7	3.8000	SMC_Ref	49.000		
SonarEl_8	3.8000	SMC_Last	68.000		
SonarEl_9	3.8000	SMC_Elev	17.000		
		one	19.067		
		Max	-5.3000		
		Min	-5.4000		

Figure 48. PC208W Numeric Screen for the Route 35 Matawan Bridge. Explanations of Data fields discussed in each individual sensor description.

Once you have connected to the scour monitor and the CONNECT screen is displayed, clicking the NUMERIC button on the left of the screen will display the numeric content of the system variables. At the bottom of the NUMERIC screen there are three buttons (DELETE, ADD, and SETUP) that control which variables are displayed If you click a displayed variable location and then select DELETE, that variable will be deleted from the screen. You can delete a sequential series of variables by clicking the first, holding the SHIFT key down, clicking the last, and then hitting the DELETE button. There are only a few program variables that need to be displayed to view system operation. There are quite a few other program variables that are used only locally in the program and are not useful in observing system operation. Therefore, we recommend deleting all variables presently displayed on the NUMERIC screen and replacing them with a choice few to be described later.

After you have deleted all variables displayed on the NUMERIC screen, you can then transfer meaningful variables to the screen. First click the ADD button at the bottom. This will bring up a list of all program variables. It can be moved to the right of the screen by clicking and dragging its title bar. The following are the variables we recommend:

1. In the ADD listing of variables, click and drag variables 2 through 11 over to column one on the screen, starting in the column’s first position. These are the 10 individual sonar readings that are taken three seconds apart every hour. The values are the distance measured from the sonar transducer to the streambed.
2. Click and drag variable *44* under the 10 sonar readings. This is the present sonar elevation, which is the average of the sonar readings subtracted from the sonar transducer elevation.
3. Click and drag variable *50* under variable *44*. This is the sonar reference elevation against which the sonar elevation is measured to determine if scour has occurred.
4. Click and drag variable *40* under variable *50*. This is the last hour's sonar elevation.
5. Click and drag variable *56* to the first location of column two on the screen. This is present position of the sliding magnetic collar on the mast.
6. Click and drag variable *58* under variable *56*. This is the reference position of the sliding magnetic collar against which the present position of the collar is measured to determine if scour has occurred.
7. Click and drag variable *59* under variable *58*. This is the last hour's sliding collar position.
8. Click and drag variables *70* through *77* over to column three, starting in the first position of the column. These are the eight individual stage sensor readings taken each hour. The values are the distance in feet from the stage sensor to the water.
9. Click and drag variable *68* under variable *77*. This is the stage elevation (elevation of the stream surface), which is the average of the stage sensor readings subtracted from the stage sensor elevation.
10. Click and drag variable *55*, and place it wherever you would like on the screen. This is the system's battery voltage.

Program Functionality

<u>Sliding Magnetic Collar</u>

At 40 minutes past the hour excitation voltage is applied to the sliding magnetic collar's circuitry to determine its present position on the mast. The present position is rounded to the nearest six inches and checked to see if it is within expected limits, i.e., less than

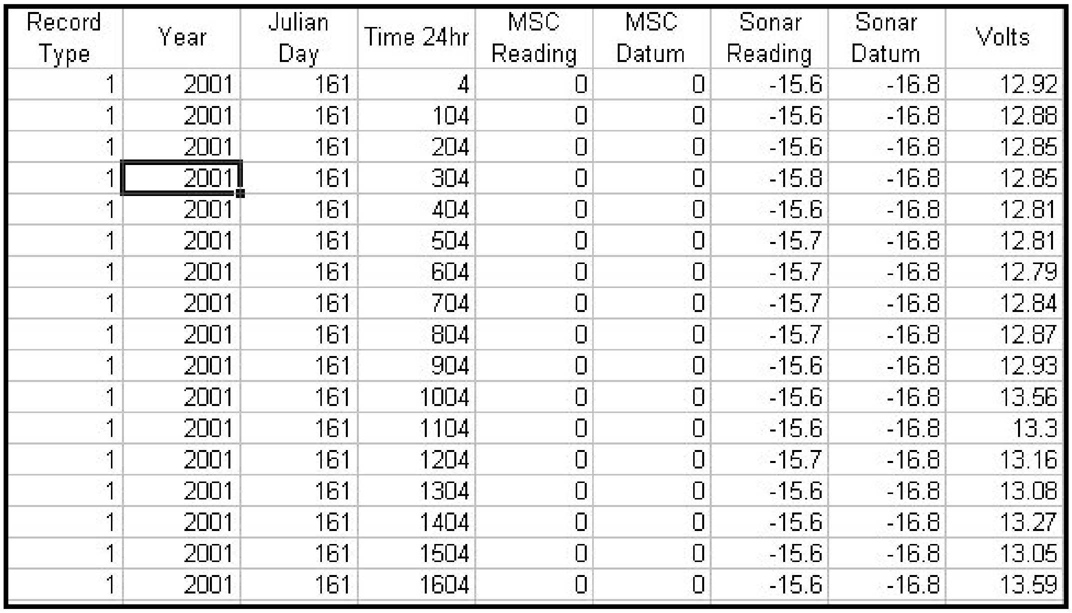
11 feet and greater than 0 feet. If it is not within those limits (a very unlikely occurrence), the present reading is set to the last hour's reading. The reading is then compared to the SMC reference position to see if it has dropped by one foot or more. If it has, two more readings are taken immediately just to be sure it was not a spurious indication of scour. If all three readings indicate scour, a scour record type 3 is written to the memory and a flag (flag 2) is set to trigger a call-out. The reference sliding collar position is then reset to the present sliding collar position.

At 45 minutes past the hour a series of eight readings (six seconds apart) are taken on the stage sensor, which measure the distance from the stage sensor to the water surface. Each reading is examined to see if it is within reasonable limits, i.e. less than 22 feet (its upper limit) and greater than five feet (its lower limit). If a reading is not within those limits, the last hour's reading is used. The eight readings are summed, the highest and lowest readings discarded, and the result divided by six. That value is then subtracted from the stage sensor elevation, which gives the elevation of the water surface, and then rounded to the nearest tenth of a foot.

Occasionally, anomalous measurements occur with the stage sensor. If plotted on a spreadsheet, there will be obvious interruptions to the normal smooth sinusoidal display of the Matawan tidal flow. These anomalous readings are likely caused by strong winds that can affect the return echo of the acoustic-based operation of the stage sensor. Modifying the stage algorithm will lessen the effect of the winds. To correct this problem, take more readings (for example taking 24 readings each hour), prohibit readings that depart from the previous hour by a given amount, or tighten the limits on the expected reasonable value.

Sonar Sensor

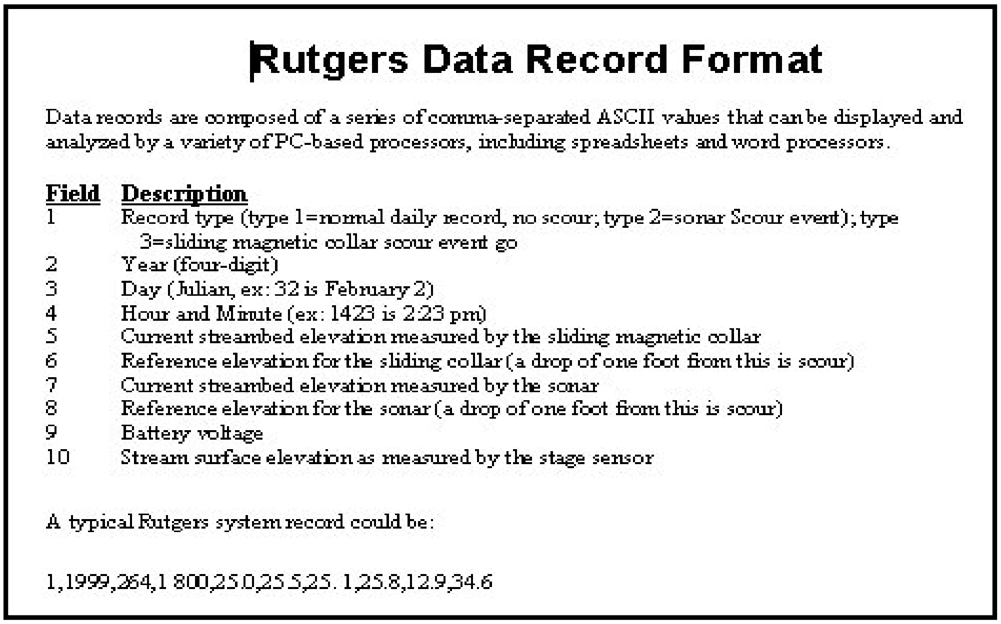
At 50 minutes past the hour, the stage elevation is observed by the program to determine if the sonar transducer is underwater. If it is, a series of 10 readings is taken on the sonar sensor, which measures the distance from the sonar transducer to the streambed. Each of the 19 readings is examined for validity. Each reading must be greater than 2.5 feet and less than 20 feet. In addition, a reading cannot be more than three feet from the last hour's sonar measurement. If a reading does not fall within these bounds, then the last hour's sonar measurement is substituted for that reading. The 10 readings are summed, the highest and lowest readings discarded, and the result divided by eight. This value is subtracted from the sonar transducer elevation to give the present streambed elevation. This elevation is compared to the sonar reference elevation to determine if scour has occurred, i.e. a drop in streambed elevation of a foot or more. If the difference is one foot or greater, then five more sets of 10 readings are taken immediately to make sure the measurement was not spurious and that scour has indeed occurred. Each set of readings takes a little less than a minute. If any of those five sets of measurements show a normal measurement (no scour), it is assumed that no scour has occurred. However, if all five sets of readings indicate scour, then a scour record type 2 is written to datalogger memory and flag 2 is set to indicate a call-out is needed. Also if scour has occurred, the sonar reference elevation is set to the present streambed elevation.



Record Type	Year	Julian Day	Time 24hr	MSC Reading	MSC Datum	Sonar Reading	Sonar Datum	Volts
1	2001	161	4	0	0	-15.6	-16.8	12.92
1	2001	161	104	0	0	-15.6	-16.8	12.88
1	2001	161	204	0	0	-15.6	-16.8	12.85
1	2001	161	304	0	0	-15.8	-16.8	12.85
1	2001	161	404	0	0	-15.6	-16.8	12.81
1	2001	161	504	0	0	-15.7	-16.8	12.81
1	2001	161	604	0	0	-15.7	-16.8	12.79
1	2001	161	704	0	0	-15.7	-16.8	12.84
1	2001	161	804	0	0	-15.7	-16.8	12.87
1	2001	161	904	0	0	-15.6	-16.8	12.93
1	2001	161	1004	0	0	-15.6	-16.8	13.56
1	2001	161	1104	0	0	-15.6	-16.8	13.3
1	2001	161	1204	0	0	-15.7	-16.8	13.16
1	2001	161	1304	0	0	-15.6	-16.8	13.08
1	2001	161	1404	0	0	-15.6	-16.8	13.27
1	2001	161	1504	0	0	-15.6	-16.8	13.05
1	2001	161	1604	0	0	-15.6	-16.8	13.59

Figure 49. Sample Route 46 Passaic Data File.

At the beginning of each hour a type 1 record is written to memory. Each of the type 1, 2, and 3 records has the same format. The only difference is the value of the first variable in the record. Type 1 is the normal hourly record; type 2 is a sonar scour record, and type 3 is a sliding magnetic collar scour record. The remainder of the record is a date-time stamp consisting of the year, Julian day, hour, and minute; the sliding collar position and its reference position; the sonar streambed elevation and its reference elevation; the battery voltage; and the stream stage elevation (Figure 49).



Rutgers Data Record Format

Data records are composed of a series of comma-separated ASCII values that can be displayed and analyzed by a variety of PC-based processors, including spreadsheets and word processors.

Field	**Description**
1	Record type (type 1=normal daily record, no scour; type 2=sonar Scour event); type 3=sliding magnetic collar scour event go
2	Year (four-digit)
3	Day (Julian, ex: 32 is February 2)
4	Hour and Minute (ex: 1423 is 2:23 pm)
5	Current streambed elevation measured by the sliding magnetic collar
6	Reference elevation for the sliding collar (a drop of one foot from this is scour)
7	Current streambed elevation measured by the sonar
8	Reference elevation for the sonar (a drop of one foot from this is scour)
9	Battery voltage
10	Stream surface elevation as measured by the stage sensor

A typical Rutgers system record could be:

```
1,1999,264,1 800,25.0,25.5,25. 1,25.8,12.9,34.6
```

Figure 50. Typical format for data file.

Call-outs to a PC

Notice that presently in the program, the setting of the scour flag (flag 2) has been "commented out" until a PC with a modem and a dedicated telephone has been identified. A semicolon preceding a program instruction indicates a comment line and not an active instruction. The program also has a section of code commented out that refers to its capability to call a pager in the event of scour.

Power

With the numeric data readout window opened during connection, the system power voltage can be read. The average operating voltage is 13.20 volts DC. The data file also has a record of the voltage as recorded every hour. System problems such as solar panel malfunction and battery health can be gauged from the voltage information.

SYSTEM MAINTANANCE

Datalogger

Regular system maintenance includes dialing the datalogger for each bridge from the office. Downloading the data will clear the cache and open up space for future data. Typically, the datalogger can store 4-6 months of data before it begins to over-write the un-downloaded data. The Campbell CR10X Datalogger can store 64KB of data. When the modem is connected the operating system can be updated if necessary (Table 7).

Table 7. Datalogger properties.

Type	Campbell Scientific CRI0X
Input Channels	6
Accuracy	0.2% full scale
Full-scale range	± 2500 mV
Resolution	333 micro volts
Excitation Output	3 channel
Range	2.5 volts
Power Requirements	10-16 volts DC
Current	0.005 amps
Physical Size	7.8 x 3.5 x 1.5 (inches)
Operating Software	PC208W (Campbell Scientific)
Memory	ROM - 32KB, RAM –64KB
Controls	Modem and telephone
Programmable functions	Sample interval, time window for data calls, originate scour-in-progress call
Interface	RS-232 Serial and modem to land-line telephone

Vandalism

The chances of vandalism are high when the instrumentation is near high public foot traffic. On August 24, 2001 a routine call placed to the Matawan Bridge would not connect. A subsequent follow up trip to the bridge revealed that the telephone system box and cable were severed (Figure 51 and Figure 52). Apparently the conduit was pulled down, cutting the connection. The original installation date was November 1999.

On a typical summer weekend fishermen used the piers at Matawan Bridge for crab trapping. Often they secure their trap lines to the bridge fender and the instrumentation conduits. Repair included providing additional wall anchors for conduits, extensive wire ties, and remounting the telephone box with new anchors (Figure 53).

Figure 51. Matawan Bridge Vandalism. Aug 2001. Severed telephone cable and dismounted telephone box

Figure 52. Matawan Bridge Litter, Aug 2001. Trash from local crab fisherman.

Figure 53. Matawan Bridge Repairs. Aug 2001.

Besides the unattached wires and damaged conduits, there were no signs of direct tampering to the equipment enclosure or nearby sensors. The stage sensor, sonar, sliding collar, and solar panel were intact. Only moderate signs of weathering were evident on the stainless steel enclosure. The padlocks showed signs of corrosion and hence were replaced.