RUS Br TRI TB FIWA - File

NCHRP

National Cooperative Highway Research Program

RESEARCH RESULTS DIGEST

January 1993 Number 189

These **Digests** are issued in the interest of providing an early awareness of the research results emanating from projects in the NCHRP. By making these results known as they are developed, it is hoped that the potential users of the research findings will be encouraged toward their early implementation in operating practices. Persons wanting to pursue the project subject matter in greater depth may do so through contact with the Cooperative Research Programs Staff, Transportation Research Board, 2101 Constitution Ave., N.W., Washington, D.C. 20418.

Areas of Interest: IIC Bridges, Other Structures, and Hydrology and Hydraulics, IIIC Maintenance, IVB Safety and Human Performance

Responsible Staff Officer: Lloyd R. Crowther

Instrumentation for Measuring Scour at Bridge Piers and Abutments

An NCHRP digest of the findings from the Phase I final report under NCHRP Project 21-3, "Instrumentation for Measuring Scour at Bridge Piers and Abutments," conducted by Resource Consultants, Inc. The digest was prepared by James Lefter, Consultant.

INTRODUCTION

Highway bridge failures cost millions of dollars each year as a result of both direct costs necessary to replace and restore bridges and indirect costs related to disruption of transportation facilities. Of even greater consequence is loss of life from bridge failures. Stream instability, long-term stream aggradation or degradation, general scour, local scour, and lateral scour or erosion cause 95 percent of these failures.

There are many scour-vulnerable bridges on spread footings or shallow piles in the United States. During a flood, scour is generally not visible and, during the falling stage of a flood, scour holes generally fill in. Therefore, visual monitoring during a flood and inspection after a flood cannot fully determine that a bridge is safe.

THE PROBLEM AND ITS SOLUTION

NCHRP Project 21-3, "Instrumentation for Measuring Scour at Bridge Piers and Abutments," was initiated in 1989 to develop, test, and evaluate instrumentation that would be technically and economically feasible for use in monitoring and measuring maximum scour depth at bridge piers and abutments.

The research is being conducted in three phases. Phase I (FY '90), which identified and evaluated instruments, included some small-scale laboratory testing. Testing was done in indoor and outdoor flumes at the Hydraulics Laboratory at Colorado State University. Currently underway, Phase II (FY '92) will modify, improve, and field test the most promising techniques identified in Phase I. It is scheduled for completion in March 1994. Phase III will extend development and deployment of devices for remote scour monitoring.

The following categories of devices were identified during Phase I as capable of measuring and monitoring the maximum depth of scour at bridge piers and abutments: (a) sounding rods, (b) sonar, (c) buried/driven rods, and (d) other buried devices. Evaluations were based on four mandatory and eight desirable criteria developed during the research effort. Mandatory requirements for devices were: (1) capability for installation on or near a bridge pier or abutment, (2) ability to measure maximum scour depth within an accuracy of ± 1 ft, (3) ability to obtain scour depth readings from above water or from a remote site, and (4) ability to operate during a storm or flood conditions. The devices, evaluation criteria, and preliminary evaluations are summarized in Table 1. Phase I was completed in March 1992.

FINDINGS

Historical Development of Instruments

Historically, equipment used for scour observations was simple: sounding rods for shallow flows and lead sounding weights on a line for deeper flows. Both of these devices were developed to sound for navigation depths hundreds of years ago, and were adapted for depth soundings in connection with stream flow measurements during the 19th century. The main adaptations involved streamlining the sounding weights and using stay lines or vertically supported sounding rods, so that the weights or rods would not be swept downstream in high velocities.

Major advances in instrumentation, which occurred during the Second World War, included sonic sounders, electronic positioning equipment, and radar. By the mid-1950s, many devices using these technologies became commercially available and were introduced into scientific studies of rivers. In the early 1960s, Richardson and others developed a sonic sounder for use in the laboratory and in shallow flows in the field. The sounder would work in flows up to 6 ft deep. Commercial sounders, such as the Bludworth and Raetheon (use of trade names is for identification purposes only, and does not imply endorsement), became available about the same time and soon were used extensively in hydrographic surveys.

Because pier and abutment scour are major concerns for operation and maintenance, many bridges are now inspected on a regular basis. Techniques for determining the extent of local scour include visual inspection by divers, direct measures of scour with mechanical and electronic devices, and indirect observations using ground-penetrating radar and other geophysical techniques. However, there are no standard methods or equipment for collecting scour data in the U.S. This is partly because, until recently, there has been no coordinated long-term effort to study scour processes. Additionally, most scour studies are site-specific, and the equipment and techniques used are tailored to the geometry of the site and the peculiarities of the existing hydrology and hydraulic conditions. Nonetheless, a few trends can be identified.

Available Devices

The literature search, identification, and preliminary evaluation of devices grouped scour-monitoring and measuring devices into four broad categories: Sounding Rods, Sonar, Buried/Driven Rods, and Other Buried Devices. The research team recommended that at least one device from each of these four categories be procured or developed and tested. It suggested that testing should concentrate on the worst-case conditions that can be generated in the flume. The team was advised to look for and report on limitations of the various devices tested, and to evaluate the desirability of devices based on engineering judgement when actual conditions could not be simulated in the laboratory.

Mechanical Sounding Rods. The laboratory investigations indicate that the mechanical sounding rods are susceptible to bed surface penetration, which influences their performance and accuracy. From this investigation, and from tests with enlarged baseplates, it is apparent that the bearing stress of the sounding rod device needs to be kept below a threshold maximum when it is installed on sand bed channels.

The test data on the sounding rod class of device indicate that these devices may be best suited for piers or abutments where the instrument can be mounted in a vertical orientation. If the device is to be mounted in a sand bed channel, the device must be equipped with a footplate large enough to distribute the vertical force to the soil without settlement. Installing a sounding rod through a pier footing is not recommended because the device has a tendency to jam or stick and because the rod might not be located where maximum scour would be expected.

Vertically supported sounding rods are rated fairly highly, but they are not suitable for all rivers.

TABLE 1. Revised evaluation of devices for mandatory and desirable criteria

	MANDATORY CRITERIA								DESIRABLE CRITERIA									
DEVICE	1a	1b	1c	1d	2	3a	3b	4	5	6	7a	7b	8a	8b	9	10	11	12
	INSTALL ON OR NEAR VERT. PIER	INSTALL ON OR NEAR SLOPING PIERS OR PIERS W/FOOTINGS	INSTALL ON OR NEAR VERT. ABUT.	INSTALL ON OR NEAR SPILL-THRU ABUT.	MEASURE SCOUR TO ± 1'	READ FROM ABOVE WATERLINE	REMOTE DATA COLLECTION	OPERATABLE DURING FLOODS	EASE OF INSTALLATION	RANGE OF DISCHARGES	WITHSTAND ICE AND SURFACE DEBRIS IMPACT	OBTAIN SCOUR DATA WITH ICE/DEBRIS	LOW COST (WITHOUT DATA LOGGING)	LOW COST (WITH DATA LOGGING)	VANDAL RESISTENT	OPERATION AND MAINTENANCE	RELIABILITY	SUB-SURFACE DETECTION
2 SOUNDING ROD	G	F	G	P	G	G	G	G	F	G	G	F	F	F	F	G	G	P
1 SONAR LOW-COST	G	G	G	P	G	G	F	G	*G	F	F	P	G	F	F	**F	P	P
MOD.-COST	G	G	G	P	G	G	G	G	*G	F	F	P	F	F	F	**F	F	P
3 BURIED / DRIVEN ROD PIEZOELECTRIC	G	G	G	G	G	G	G	G	P	G	G	G	F	F	G	U	U	P
TIP SWITCH	G	G	G	G	G	G	G	G	P	G	G	G	F	F	G	U	U	P
MAGNETIC SLIDING COLLAR	G	G	G	G	G	G	G	G	P	G	G	F	F	F	G	U	U	P
4 OTHER BURIED DEVICES TETHERED	G	G	G	G	G	U	U	G	U	G	F	F	G	F	F	U	U	P
UN-TETHERED	G	G	G	G	G	U	U	G	U	G	G	G	F	F	G	U	U	P

* ASSUMES TYPICAL TRANSDUCER MOUNTING
RATING WOULD BE "FAIR" IF BRIDGE DECK SERVICABLE TRANSDUCER MOUNTS WERE USED

** ASSUMES TYPICAL TRANSDUCER MOUNTNGS.
RATING WOULD BE "GOOD" IF BRIDGE DECK SERVICABLE TRANSDUCER MOUNTS WERE USED

G = GOOD
F = FAIR
P = POOR
U = UNKNOWN

Although field installations provide some performance data on vertically supported sounding rods, a number of questions regarding the interaction of the rod with the flow and with the stream bed remain. Most important is whether the rods can function in sand bed, debris-laden channels. The Brisco Monitor (TM) has been installed on several bridge abutments and piers in New York, but the stream beds have been of coarse or cohesive material.

Sonar. Sonic technology has been evaluated through numerous applications to the scour monitoring problem and through adaptation of sonar devices to such related activities as river and reservoir cross-section and bottom profiling. Results and performance data are available in the literature and from active field installations for the bridge scour application. Testing of sonar devices concentrated on the following factors: effects of debris (or ice) on performance and accuracy; effects of high sediment concentrations on performance and accuracy; mechanics of mounting the transducer on the bridge structure (pier or abutment) so that it is accessible and easy to replace; and identifying effects of cone angle and mounting angle on the accuracy of the instrument (i.e., how does the device "see" the scour hole, and will it "see" the maximum depth of scour?).

Testing of the sonic fathometers indicated that low-cost sonic sensors can work effectively provided that the device is mounted so it is aimed at the location where maximum scour will occur. The signal must be unobscured by debris or ice, and there must also be no interference from piers or abutments. Problems associated with the entrainment of air, which were experienced in the laboratory flume, may not be a major concern for most bridge sites. For any installation using low-cost instruments, such as those tested in this study, temperature correction will be necessary when the water temperature is less than 80° F. Finally, there may be cases in the field where highly turbulent, air-entrained flow conditions will preclude the use of these instruments. The use of higher-cost fathometers may be advantageous if special data logging is required. Such fathometers may be designed to be temperature compensating and to minimize algae growth on the transducer head. They are available as part of a coordinated, integrated system.

Buried Devices. These are devices that need to be mounted below the bed on or adjacent to the pier or abutment, to at least the expected depth of scour. Conductance meters, mechanical meters, and optical meters all fall into this category.

Mechanical devices are illustrated by the Scubamouse (a sliding collar with a radioactive source on a driven rod—developed in New Zealand). But for this particular device, remote readout capability is not currently available. Environmental concerns relative to the use of a radioactive collar may also restrict the use of a Scubamouse-type device in the U.S. A nonhazardous magnetic trip switch on a sliding collar device was tested successfully in the laboratory during this research effort.

One of the problems with the optical device (e.g., Sanyo optical sand bed sensor) is determining the upper limits of sediment concentrations beyond which it does not function. The Sanyo device was too expensive (about $10,000) to procure for this project, especially in light of the desirable criteria for relatively low cost.

Motion-activated (Buried/Driven Rod) sensors are devices with some type of motion sensor at various intervals along the rod so that when exposed by scour the sensor is free to move and motion is detected. Several types of buried/driven rods were tested during the near-prototype phase of laboratory testing. Magnetic sliding collars slide down a supporting pipe, activating magnetic switches as scour develops under the collar. Concerns about such a device included installation, adequate assurance of free motion during scour activity, erratic indications due to turbulence in the scour hole, and operation under potentially high sediment concentrations and high debris loading.

The research team developed alternate concepts for motion detectors and tested them in the laboratory:

- A piezoelectric polymer film transducer that generates a voltage and current when vibrated. Therefore, as scour develops and uncovers strips of the film, the film is vibrated by turbulence, signalling that scour occurred at the elevation of the sensor.
- Mercury tip switches that flip open when surrounding material is eroded, breaking contact, and thus signalling scour erosion. However, mercury could be considered an environmental hazard.

There is no evidence that buried/driven devices either enhance or reduce scour at the pier. The piezoelectric film, mercury tip switches, and magnetic switches actuated by a sliding collar performed as they were designed, and provided an accurate indication of the progression of the scour hole. The tests showed that these devices offer a viable method for measurement of scour at bridge piers and abutments. Furthermore, it was demonstrated that these devices have the ability to sense and record data using a data logger. However, due to the below-grade installation requirements, all of these devices were rated poor for ease of installation, particularly at existing bridges.

Other Buried Devices. These devices are buried in the stream bed at various elevations and either float out of a hole or drop into a scour hole as scour occurs. Such devices could include radio transmitters, pressure transducers, or a tethered target. Devices that drop into the hole would likely have to be tethered at an upstream location. Research in the use of such devices for scour monitoring focused primarily on the physical motion of the device and its interaction with the flow and stream bed.

Near-prototype tests of dummy-buried tethered and untethered devices indicated that these types of instruments could be developed and adapted

TABLE 2. Applicability of scour-measuring devices for pier and abutment geometry

DEVICE TYPE	PIERS: SPREAD FOOTING	PIERS: SLOPING COLUMN	PIERS: VERTICAL COLUMN	ABUTMENTS: VERTICAL	ABUTMENTS: SPILL-THROUGH	REMARKS
SOUNDING ROD	–	–	YES	YES	–	
SONIC FATHOMETER LOW COST	•POSSIBLE	•POSSIBLE	YES	YES	–	• PROVIDED MOUNTING ANGLE IS NOT MORE THAN 15°
MODERATE COST	•POSSIBLE	•POSSIBLE	YES	YES	–	• PROVIDED MOUNTING ANGLE IS NOT MORE THAN 15°
BURIED/DRIVEN ROD (INCLUDES PIEZO,TIP & MAG)	YES	YES	YES	YES	YES	
OTHER BURIED DEVICES	YES	YES	YES	YES	YES	

for measuring scour at bridge piers and abutments. Further research and development will be needed to design and fabricate prototype devices, which would incorporate the required electronics, transmitters, receivers, and power sources. Although more work is required to install a prototype device of this nature in the field, the results of these investigations indicate that the devices could be designed so that their removal by the flow correlates closely with the development of a scour hole.

DEVICE INSTALLATION

A wide range of geometries exists at piers and abutments, and this range presents difficulties in developing scour-measuring devices. Spill-through abutments, different or unique pier shapes, and footings that extend beyond the pier or abutment create difficult problems. For new bridges, the problems could be overcome by developing instruments incorporated into the structure. For example, conduit and mounting brackets for a housing, a transducer, and a power cable for sonic sounders might be installed on either the bridge deck or the stream bank. For existing bridges, devices will have to be developed that can be placed on or adjacent to footings or pile caps, or that are able to sense bed elevation from a remote location.

INSTRUMENT COSTS

A clear understanding of the advantages and disadvantages of each class of device cannot be determined in the context of a testing program alone. Rather, the advantages and disadvantages must be weighed along with cost, installation, maintenance, data recording and retrieval, durability, ease of use, and other concerns. Cost analysis of scour-measuring instruments should compare the costs of various instrumentation schemes and identify the costs associated with the purchase, installation, and maintenance of any particular instrument. If all devices were commercially available at this time, these cost-analysis goals could be met easily. However, some of the devices evaluated in this research are commercially available, while others are at various stages of research and development. In order to provide some relative cost information, a number of assumptions were made. These are detailed in the Report but are not developed enough to include in this Digest.

SCOUR MEASURING

To better understand the scour process as it occurs at bridge piers and abutments, actual field data must be collected—including discharge, velocity, rate of scour hole development and refill, lateral size and shape of the scour hole, and other pertinent hydraulic and sediment data. Clearly, for this goal, the scour-measuring device will be only one of several data-acquisition devices needed for a complete understanding of the scour process. In terms of the scour-measuring device itself, it will be required to continuously measure the stream bed and record time-stamped scour data with accuracies of ± 1 ft. The data must be stored digitally either for manual retrieval or for transmission to a central computer site. Any of the scour-measuring devices can be used for this goal, provided that the appropriate data-logging hardware and a continuous power supply are incorporated into the installation.

TABLE 3. Applicability of scour-measuring devices for flow and geomorphic conditions

DEVICE TYPE	STREAM BED CHARACTERISTICS: SAND BED	STREAM BED CHARACTERISTICS: COBBLE BOULDER	STREAM BED CHARACTERISTICS: SILT/CLAY	FLOW CHARACTERISTICS: PERENNIAL	FLOW CHARACTERISTICS: EPHEMERAL
SOUNDING ROD	WITH FOOTPLATE	YES	YES	YES	YES
SONIC FATHOMETER (INCLUDES LOW & HIGHER COST DEVICES	YES	YES	YES	YES	YES
BURIED/DRIVEN ROD (INCLUDES PIEZO.TIP & MAG)	YES	LARGE BED MATERIAL MAY PRECLUDE INSTALLATION	YES	NEW BRIDGE ONLY	YES
OTHER BURIED DEVICES	YES	LARGE BED MATERIAL MAY PRECLUDE INSTALLATION	YES	NEW BRIDGE ONLY	YES

However, the sonic fathometer and piezoelectric devices stand out because they potentially have the ability to record the post-flood refilling process as well as the scour process. This ability will provide valuable information on the rate of scour and refill. The lateral size and shape of the scour hole could be obtained using several sonic transducers aimed at specific locations on the bed, or by using multiple buried/driven rods with piezoelectric film sensors.

Bridge Pier and Abutment Geometry. From the evaluations, it is clear that no single device is applicable to all bridge pier and abutment geometries. However, most of these geometries can be accommodated with one of the four types of scour-measuring devices evaluated and tested in this study. Table 2 presents recommendations for installation of each of the devices tested based solely on the bridge pier and abutment geometry.

Flow and Geomorphic Conditions. The applicability of each class of sensors to flow and geomorphic conditions is presented in Table 3. Although some of these limitations stem from the abilities of the device itself, some of the limitations pertain to whether the device is installable given the geomorphic and flow conditions. In some cases the buried/driven rod (or other buried rod) devices may not be installable in the channel on perennial streams unless they are installed during construction of new bridges. Factors such as debris, ice, durability, reliability, data-logging and telemetry needs, suspended and bed load transport, and other environmental factors must also be considered before using any scour-monitoring device.

New Bridges. The applicability of the four sensor types based on bridge pier and abutment geometry and various geomorphic and flow conditions for new bridges is presented in Table 4. This table assumes that installation of the devices will be integrated into the design and construction of new bridges. Table 5 presents this information for existing bridges.

CONCLUSIONS

Based on the findings of this research, which included extensive small- and large-scale laboratory testing, devices incorporating one or more of the four techniques previously discussed can be developed to measure scour at bridge piers and abutments. It is also apparent from evaluating each type of instrumentation based on operating ranges, debris, ice, durability, and applicability to a variety of stream types and bridge geometries, that no *single* methodology for measuring scour at bridge piers and abutments can be used to solve the scour-measuring problems for *all* situations encountered in the field.

Further development and testing will consider devices using all four technologies examined. Only then will it be possible to equip most bridges and highway crossings encountered in the field with systems capable of accurately and reliably measuring and recording the maximum depth of scour. Of the four types of scour-monitoring systems investigated, only one version of the sounding rod (Brisco Monitor) and a moderately priced sonic fathometer (Data Sonics) are currently at a stage of development that permits installation at bridge sites in the U.S. Although these two systems can be obtained commercially, their applicability, long-term reliability, and durability on a wide variety of stream and bridge types need to be demonstrated—specifically: (1) demonstrate functioning of the sounding rod devices in sand bed, debris-laden channels; (2) determine the maximum length of unsupported sounding rod so that binding will not adversely affect the performance; and (3) examine, in the field, the ability of the sonic devices to accurately and reliably measure scour at bridges where there are high concentrations of debris, suspended sediment, or entrained air.

The research has focused on development and testing of bridge scour-measuring devices to meet specific criteria established by the NCHRP project panel. These devices were developed so that maximum scour could be measured at bridge piers and abutments to provide a better understanding of the scour process. These devices could also function as monitors, providing early warnings at potentially unsafe bridges.

Thus, the ability to measure scour in the field would allow scour-critical bridges to be monitored so that countermeasures can be taken before problems become severe, or to provide possible long-term alternate countermeasures in some circumstances. These actions would increase the safety of the traveling public and would reduce the costs of bridge inspection, operation, and maintenance. The results of this research, therefore, would be of immediate value to state highway departments, authorities, county and city roadway and street departments, and private bridge owners.

FINAL REPORT

The overall objective, research approach, findings, and recommendations are presented in the main body of the agency Phase I final report, Project 21-3, titled, "Instrumentation for Measuring Scour at Bridge Piers and Abutments." Detailed descriptions of the test program, facilities, equipment, and findings are presented in the Appendices. Appendix A presents the literature review and correspondence; Appendix B, the bibliography; and Appendix C, the supporting laboratory and test data. In volume II of the appendixes, Appendix D details the small-scale laboratory investigations; Appendix E, the near-prototype; and Appendix F the laboratory data and results. Appendix G lists a set of slide photographs of laboratory and field testing.

The agency final report for Phase I will not be published in the regular NCHRP report series. However, loan copies of the agency report are available by contacting: Transportation Research Board, National Cooperative Highway Research Programs, 2101 Constitution Avenue, N.W., Washington, D.C. 20418.

ACKNOWLEDGEMENTS

The research project summarized herein was performed under NCHRP Project 21-3, Phase I, by Resource Consultants, Inc. (RCI), Fort Collins, Colorado, with laboratory testing conducted by the Engineering Research Center, Colorado State University, Fort Collins, Colorado. Dr. Everett V. Richardson, Senior Associate, served as Principal Investigator and Dr. Peter F. Lagasse, President, served as Co-Principal Investigator. They were assisted by Drs. James D. Schall and Jerry R. Richardson, Senior Engineers, and Drs. George V. Sabol and Carl F. Nordin, Consultants. Mr. Gerry Price, Electronics Engineer, ETI Instrument Systems, Fort Collins, Colorado, supported RCI for instrumentation and development of scour-measuring devices.

Devices were tested in the Engineering Research Center laboratory facilities of Colorado State University (CSU) under the direction of Dr. Steven R. Abt, Professor of Civil Engineering. Dr. Pierre Y. Julien, Associate Professor of Civil Engineering, and Dr. Thomas J. Siller, Assistant Professor of Civil Engineering, Colorado State University, assisted Dr. Abt in the areas of hydraulics laboratory testing and evaluation, and geotechnical engineering, respectively.

A special acknowledgement is made to the manufacturers or developers of scour-measuring devices who supplied prototype devices for testing.

TRANSPORTATION RESEARCH BOARD
National Research Council
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

00002105 2C 1A 9512 001
Robert M Smith
Research & Asst Matls Supvr
Idaho Transportation Dept
P O Box 7129
Boise ID 83707-1129

TABLE 4. Applicability of scour-measuring devices for new bridges

	SPREAD FOOTING, PILE CAP OR SLOPING PIER			VERTICAL PIERS			ABUTMENTS	
DEVICE TYPE	SAND	COBBLE/ BOULDER	SILT/ CLAY	SAND	COBBLE/ BOULDER	SILT/ CLAY	VERTICAL WALL	SPILL/ THROUGH
FALLING ROD (BRISCO) EPHEMERAL	NO	NO	NO	YES	YES	YES	YES	NO
PERENNIAL	NO	NO	NO	YES	YES	YES	YES	NO
SONIC DEVICE EPHEMERAL	*YES	*YES	*YES	YES	YES	YES	YES	NO
PERENNIAL	*YES	*YES	*YES	YES	YES	YES	YES	NO
BURIED ROD EPHEMERAL	YES	**MAYBE	YES	YES	**MAYBE	YES	YES	YES
PERENNIAL	YES	**MAYBE	YES	NO	YES	YES	YES	YES
OTHER BURIED DEVICES TETHERED EPHEMERAL	YES	**MAYBE	YES	YES	**MAYBE	YES	YES	YES
PERENNIAL	YES	**MAYBE	YES	YES	**MAYBE	YES	YES	YES

* IF MOUNTING ANGLE < 15°
** LARGE BED MATERIAL MAY INHIBIT INSTALLATION

TABLE 5. Applicability of scour-measuring devices for existing bridges

	SPREAD FOOTING, PILE CAP OR SLOPING PIER			VERTICAL PIERS			ABUTMENTS	
DEVICE TYPE	SAND	COBBLE/ BOULDER	SILT/ CLAY	SAND	COBBLE/ BOULDER	SILT/ CLAY	VERTICAL WALL	SPILL/ THROUGH
FALLING ROD (BRISCO) EPHEMERAL	NO	NO	NO	YES	YES	YES	YES	NO
PERENNIAL	NO	NO	NO	YES	YES	YES	YES	NO
SONIC DEVICE EPHEMERAL	*YES	*YES	*YES	YES	YES	YES	YES	NO
PERENNIAL	*YES	*YES	*YES	YES	YES	YES	YES	NO
BURIED ROD EPHEMERAL	YES	**MAYBE	YES	YES	**MAYBE	YES	YES	YES
*** PERENNIAL	NO	NO	NO	NO	NO	NO	NO	NO
OTHER BURIED DEVICES TETHERED EPHEMERAL	YES	**MAYBE	YES	YES	**MAYBE	YES	YES	YES
PERENNIAL	NO	NO	NO	NO	NO	NO	NO	NO

* IF MOUNTING ANGLE < 15°
** LARGE BED MATERIAL MAY INHIBIT INSTALLATION
*** INSTALLATION IN CHANNELS ON PERENNIAL STREAMS IS DIFFICULT