Chasing Floods and Measuring Scour

ROY E. TRENT AND MARK LANDERS

ABSTRACT

Field measurements of local scour at bridges during floods, and measurement of sedimentation processes in general, has been a frustrating and unrewarding activity in the past. Surprisingly, little scour data has been collected in that time and only a small portion of the data have been taken during floods at bridges crossing natural streams. Recent efforts of U.S. Geological Survey (USGS) field crews to measure scour during floods for the Federal Highway Administration and several State highway agencies, however, demonstrate that it can be done. This paper outlines procedures used, insights and experiences gained, and some preliminary results obtained while chasing floods and measuring scour during the May 1990 floods in the Southwest.

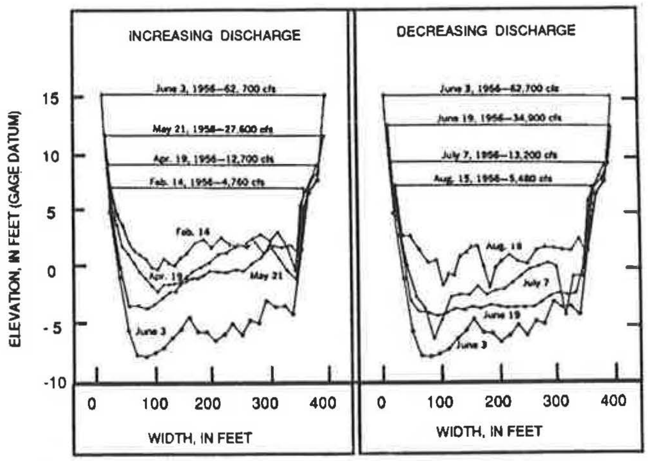

Figure 1. Scour and deposition with flood flow for Colorado River at Lees Ferry, Arizona.

BACKGROUND

Scour data collected during flood conditions reinforces our knowledge that fluvial processes are dynamic. The high flow velocities and turbulence that occurs during a flood causes increased shear stress on the streambed and results in scour, erosion, and increased sediment transport capacity of streams. As flood flows recede, the bed load is redeposited and streambed elevations typically increase and scour holes in the streambed and near structures refill. Figure 1 shows an example of bed scour and fill for a 1956 flood on the Colorado River at Lees Ferry, Arizona. Figure 2 shows another example of this process for the May 1990 flood on the Red River at the U.S. Highway 71 bridge in Arkansas. This process is characteristic of alluvial streams having noncohesive sand or silt bed materials. This process is less typical of rivers with cobbles or boulders or cohesive clay bed materials; however, if finer materials are also present, they will fill local scour holes in the cohesive or large grain size material during the flow recession. The process of channel scour and fill is not linear with hydraulic factors because of the effects of bed load and other deterministic factors on scour. Bed load is itself a temporally and spatially dynamic process, so that generalizations of the relation between scour and hydraulic factors must be applied with care. The relation of bed load to discharge will generally follow a clockwise, hysteretic curve for a given flow event. For live bed streams, this may mean initial filling of the general (and thus local scour) sections for a flow event. This is illustrated in figure 3 for data collected on the South Altamaha River at I-95 near Brunswick, Georgia, and in figure 4 for San Juan River near Bluff, Utah. These and other data emphasize the importance of measuring scour near the peak of the flood to improve our understanding of these processes. This is particularly important when conducting scour inspections of bridges.

Obviously, it cannot be safely concluded that a depression or deep hole measured around a pier after the flood represents the maximum scour experienced in recent time. **Accordingly, inspection of bridges for scour, even shortly after a flood, may result in misleading and even dangerous conclusions.** Perhaps, coring or using geophysical subbottom profiling techniques, and looking for undisturbed sediments, marles, or other parent materials, may provide conclusions about the scour history of a particular pier. Every pier, however, requires separate evaluation because every pier has different scour potential and scour resistance. Scour potential also varies laterally across the channel as a function of channel curvature, flow concentration due to contraction or flow redirection, and many other site specific parameters. Many variables affect the rate and depth of scour. The actual scour performance of a bridge during any given flood event is best determined by real time measurements by field crews.

DATA REQUIREMENTS

Different levels of data are required for different purposes. Currently, a primary concern of bridge owners and major purpose

[1] Office of Research and Development, Federal Highway Administration, 6300 Georgetown Pike, McLean, VA 22101-2296 and United States Geological Survey, Water Resources Division MS 415, 12201 Sunrise Valley Drive, Reston, VA 22092

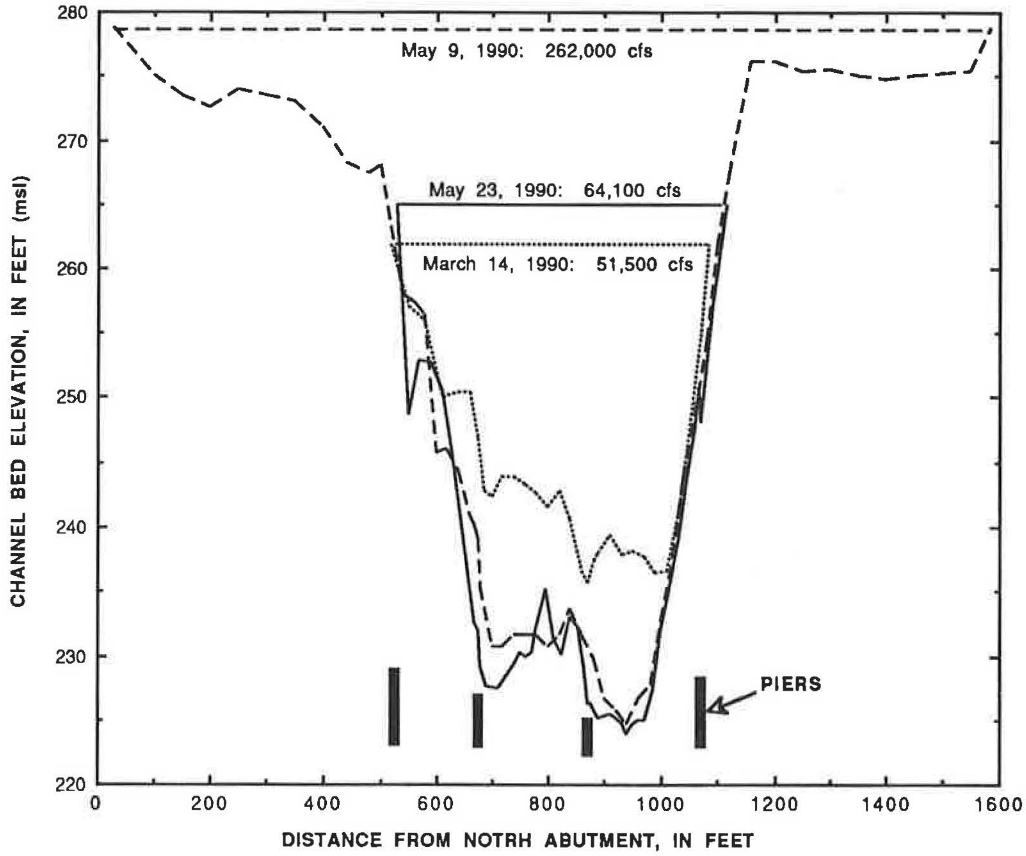

Figure 2. Changes in channel geometry with flood discharge for the Red River at U. S. Highway 71 near Ibex, Arkansas.

for measuring bridge scour is to verify local scour formulas or to put practical constraints on the resulting scour estimates. A **limited data set** is required for these objectives. This paper discusses procedures for obtaining the limited data set. Such data includes and is an extension of data (stage, velocities, depths) obtained from standard flood discharge measurement procedures used by USGS. An important distinction exists between flood discharge measurements and scour measurements: **the limited data set focuses measurements on and around the bridge features that are typically avoided in standard discharge measurements.** Scour measurement adds details on geometry of the river bottom near the bridge piers and abutments, including cross sections on both sides of the bridge, photographs and observations of flow conditions, and a judgement about the status of bedload movement. USGS scour survey teams use a checklist as a reminder of items to be included in a limited data set (figure 5). Other critical data are site records on foundations, bed material, channel and floodplain characteristics, and bridge hydraulics. These data are preferably obtained prior to measured flood events, but at many sites they can also be collected afterwards.

Another reason to collect data is to develop, calibrate, and verify sediment transport models and methods in order to simulate fluvial processes--a ***detailed data set*** is required. Data required for this purpose would include flow, sediment, and bedload data in addition to scour depths and velocity data. This data must be measured at the bridge and at sections well upstream and downstream several times over the flood hydrograph. In addition to collecting real time data during the flood, surveys of section bedforms and channel conditions before (during preliminary field surveys of study sites) and soon after the flood should be made. Uses for this level of data includes modeling the fluvial processes for long-term performance of a river system, as well as the response of the channel to a single flow event. Simulation of channel response to measures like channelization, dredging, aggregate mining, channel shortening, flow control, flood proofing, and width constrictions are now possible. These data will support improved technology and simulation models that are easier to use and more reliable. Ultimately this and even more detailed data are needed to establish cause and effect relationships, for example, to relate the flow event to the sedimentation processes and relate that to river responses.

For selected high risk bridges, where scour potential is known to be a serious threat, scour measurements taken during major flood events could become a part of the standard bridge inspection reports. Only a very ***restricted inspection data set*** (local geometry near piers and abutments) would usually be required for safety inspections of bridges during floods. The methods prescribed here would be suitable for adoption and adaptation by bridge inspection teams or highway maintenance crews for making scour inspections during floods. The primary use for such data would be to document conditions of foundation support rather than to quantify or describe scour processes.

PROCEDURES

Procedures for collecting scour data are governed by the requirements for the data set being collected, be that an inspection, limited, or detailed data set. The procedures

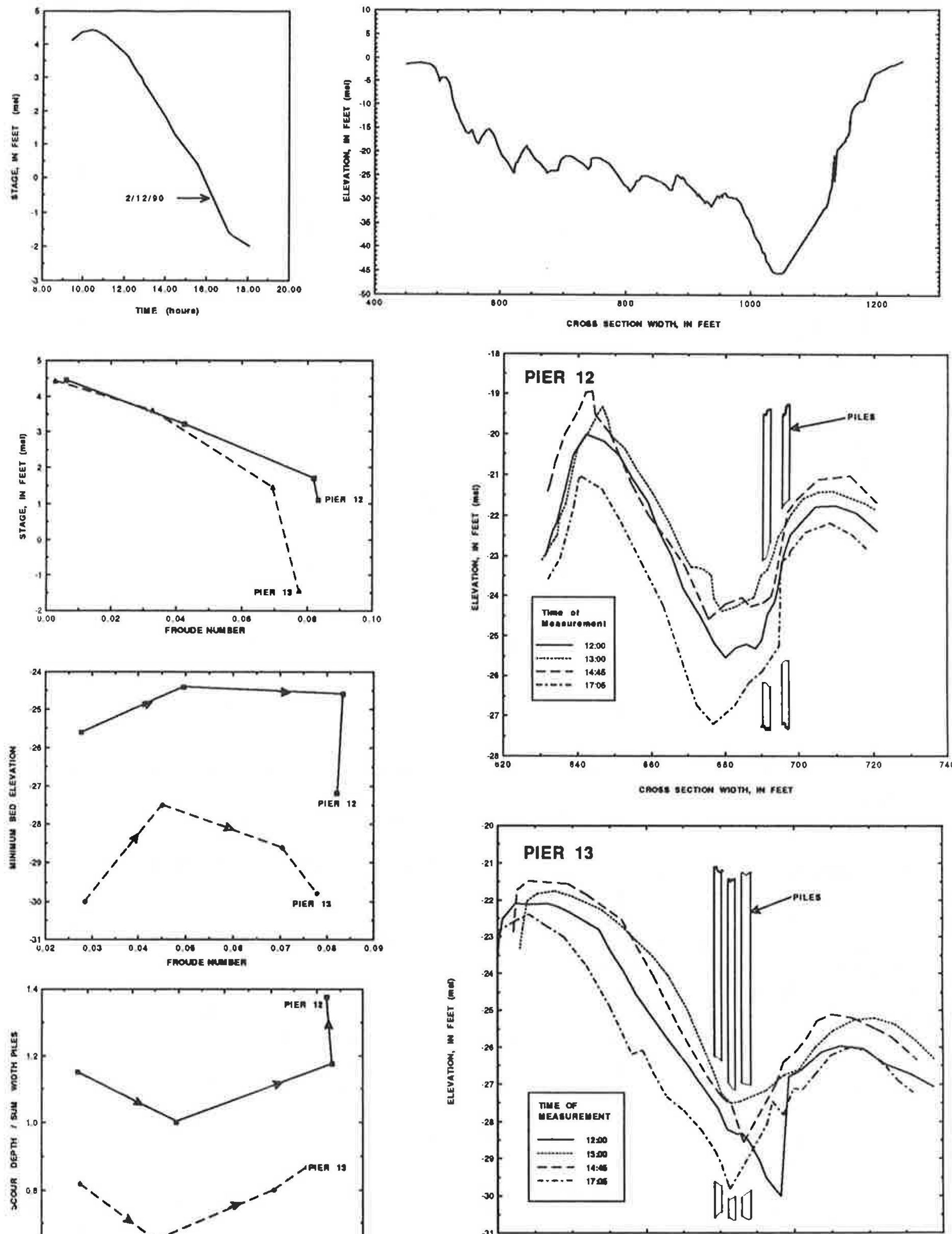

Figure 3. Relation between kinetic energy (Froude number) of the approach flow, channel geometry, and local scour depth, for South Althamaha River at the upstream side of I-95, near Darien, Georgia, on February 12, 1990.

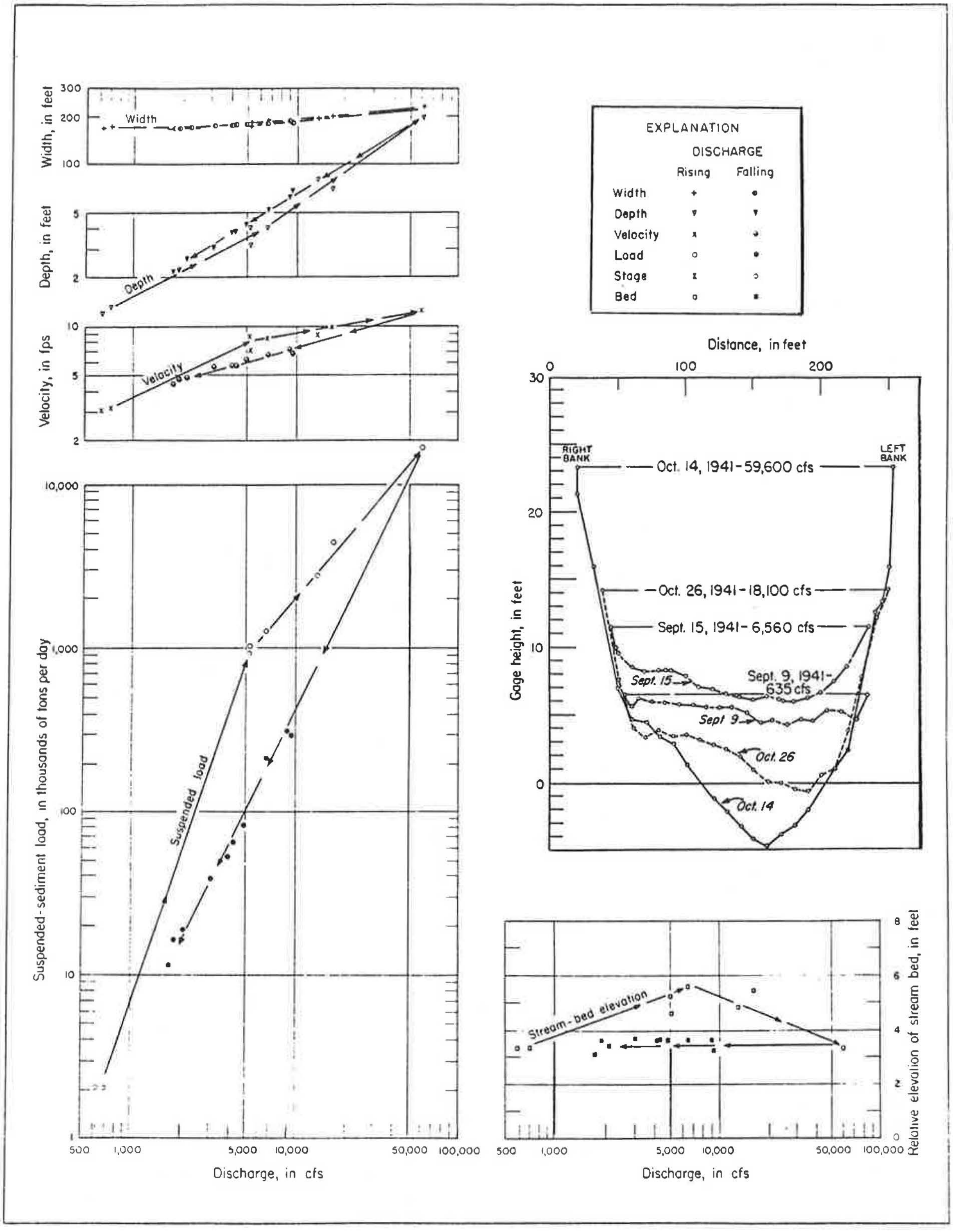

Figure 4. Changes in channel geometry, velocity, and sediment load during the flood of September-December 1941, San Juan river near Bluff, Utah (from Leopold and Maddock, Jr., 1953).

prescribed here apply to the limited data set used to collect local scour data. An adaptation of these procedures may be particularly useful for bridge owners to use as a standard inspection procedure for bridges suspected to have the potential for scour.

Preparation

Preparation for collection of scour data may be broken down into three phases: reconnaissance, site selection, and site establishment. Note that the field methods described may also be used where sites have not been reconnoitered or established; however, it is very useful to have advanced knowledge of bridge and hydraulic conditions.

- Reconnaissance: A thorough review of local, university, State, and Federal agency data files should be examined for previous records (like past discharge measurements made from bridges or similar records) that can be used to evaluate constriction scour and/or local scour. Figures 1, 4, and 6 are based on the results of past discharge measurement or bridge inspection reports. Research papers, journal articles, and other technical publications related to bridge scour may contain additional information on the past scour performance of bridges. A major source of information on scour problems and bridge performance is available from the bridge owner, particularly the bridge inspection, hydraulics, and maintenance organizations. Types of information to gather include repair and maintenance reports, soils data, and design plans.

- Site selection: This is a very critical step toward a successful program. Sites should be selected to support the purpose of the program and to obtain the required data. There are many criteria to consider for targeting a potential site for inclusion in a data collection effort. Obviously, bridge sites must be accessible during floods. Physically, the bridge must be safe and effective for survey work. Foundation geometry and bridge configuration should be simple and typical. The channel, floodplain, and river system should be uncomplicated and representative. The river bed should have potential to scour and be free of scour limitations like a shallow hardpan layer that will not erode or even a protective layer of riprap around the pier or abutment. In brief, sites should be representative of the primary concerns and reasons for collecting scour data--including geographical distribution, bridge and foundation type and size, hydrology and watershed factors, fluvial geomorphology and sediment types--and of course for special problem resolution. Finding suitable, representative sites may at first seem impossible--ideal conditions can only be found in the laboratory. Consider that the goal of site selection is to **maximize the opportunity and potential** to collect data types required to support established program purposes.

- Site establishment: Activities required to properly establish a site include gathering more thorough information on a site as an extension to the reconnaissance performed earlier, and preparation of the sites and also survey teams for easy and effective field work. Initial preparation would include: equip and train teams, establish procedures to "watch" the sites for measurable events, assigning sites to each team to watch, and possibly hire local

BRIDGE SCOUR MEASUREMENT CHECKLIST

Sta. no:________ Name:________________
Date:________ Party:________________

Get all the information once. If the peak is long enough, measure it all again. **Detail of scour hole geometry (~1 ft. intervals) is critical.** Try to sound directly at face and sides of piers.

__ Photographs and notes of observations of turbulence around piers, flow conditions in channel, overbank, and at abutments, constriction of floodplain flow at bridge, debris, angels, etc.

__ Determine whether bed is moving.

__ Cross section measurements on upstream side of bridge, including detailed soundings around and as close as possible to piers, abutments. and other scour holes.

__ Cross section measurements on downstream side of bridge including detailed soundings around and as close as possiblo to to piers, abutments. and other scour holes.

__ Standard flood discharge measurement, also if not at gage, regular tapedowns over duration of measurement.

__ Water temperature.

NOTE: If the high-stage rating is fairly well defined, measure the cross section and scour hole data first, before the discharge measurement.

Figure 5. Checklist form used by USGS scour survey teams.

flood observers who give an alert at a predetermined stage or precipitation amount. Site preparations would include preliminary surveys and soundings, scouting boat launch sites when applicable, marking the bridge for measurement stations, taking field notes and documenting potential problems, and preparing advanced data entry forms and summary sheets.

Methods

Methods for collecting scour data are not unlike those used in typical discharge measurements, except for the method of sounding to collect channel geometry. The traditional method for gathering scour and bedform data has been to sound the depth with a Columbus-type lead sounding weight (figure 7). For scour data collection, a 100- to 300-pound weight is generally used. Sounding with the weight may be the best method to collect channel geometry data where velocities are high, average channel depths are less than about 15 feet, and the channel bed is relatively hard. For example, on May 10, 1990, flooding on the Red River at I-30 resulted in flow for the first time through a relief opening which also serves as an overpass for a local paved road. This bridge nearly failed during that flood because of contraction and abutment scour. Large fill material was dumped at the upstream abutments almost constantly over a 24-hour period in an attempt to arrest local scour. USGS personnel measured a velocity of 14.8 feet per second in the opening. The fathometer could not obtain a depth reading due to excessive turbulence and entrained air, so the transducer was stripped from the weight. The 200-pound weight was allowed to free-fall to make a single contact sounding of the bottom before being swept downstream. The average depth was about 8 feet and the maximum was about 9 feet. These conditions might also prevail in mountainous regions with steep sloped streams.

For more commonly occurring alluvial channels, the lead weight sounding method has several potential problems. As channels get deeper and or velocities get higher, the weight is swept much farther downstream from the point of suspension. Vertical angle corrections may be applied in this case; however the depth measured may not be very close to the desired cross section location on the upstream or downstream sides of the bridge. At velocities above about 10 feet per second, it may not be possible to sound depths at all with a weight on deeper streams. Debris near the bottom, and especially around piers, can easily hang up a weight, break a cable, and create a hazard to the field crew.

Sonic depth finders have been used as an alternative to sounding with weights. The systems used at most of the sites on the spring 1990 floods are graphical chart-recording fathometers with narrow (8-degree) beam transducers to improve accuracy close to piers. These units were tuned by the manufacturer for 100 feet of transducer cable. The transducer is mounted on the bottom of a weight (figure 7) and suspended from an instrument crane mounted on a truck or dolly device mounted on a bridge (figure 8). Accurate soundings can usually be obtained running the transducer 2 or more feet below the surface of the water, and moving slowly across the bridge at a fixed rate. The elevation of the transducer is referenced to the measured stage of the water surface. The depth of the transducer below the water surface must be checked often to provide an accurate record of depth to the channel bottom. Where piers are inset from the edge of a bridge, the sounding weight may be lowered further to increase the drag allowing the flow of water to carry the sounding weight closer to the pier. Another successful method has been to attach flotation devices to the weight, which can increase drag. The flotation device shown in figure 9 worked reasonably well in velocities up to about 6 feet per second. Depth to the transducer varies with velocity and was measured using tags to the suspension cable. More streamlined floats are being tested.

Use of this equipment under flood conditions by USGS hydrologists has not required special training. Bridge maintenance or inspection teams would be able to take valid soundings during floods after some initial training and experience in deployment methods. Table 1 provides a list of equipment typically used be the USGS for a detailed data set survey. Prices are approximate and less expensive components are available.

TABLE 1. LIST OF EQUIPMENT USED IN SCOUR DATA COLLECTION SURVEYS.

Crane, truck mounted	$2,000
Power wench for crane	2,500
Sounding weight, 600 pounds	600
Fathometer, recording	700
Floats for sounding weight	150
Velocity meter	2,000

USGS scour teams typically contact State highway agencies during large floods to assist in checking bridges of particular concern. Problem bridges, however, do not often provide useful data for the limited data set. Also large regional floods, such as those of May 1990 in the southwest, endanger many bridges and USGS teams or personnel for this activity are limited. Flood scour inspection teams need to make repeated checks at bridges where a relatively small change in scour depths would endanger the bridge and where flood hydrographs may last for several days. This was the case for two bridges on the Red River in the May 1990 flood. Because a crew could not stay at these sites and make repeated measurements over the hydrograph, it was assumed that data collected was the maximum scour. On major bridges or where the streambed is not alluvial, this assumption could result in misleading information or dangerous conclusions.

The use of a boat and recording fathometer can dramatically increase the information on channel geometry and bedform under

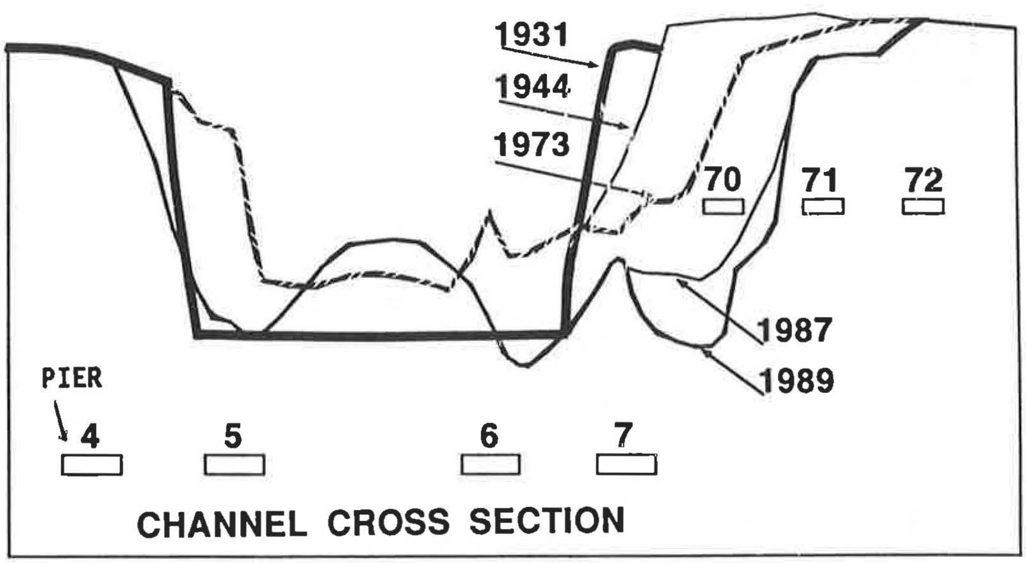

Figure 6. Bridge inspection records document the history of channel migration and bedform changes over several years.

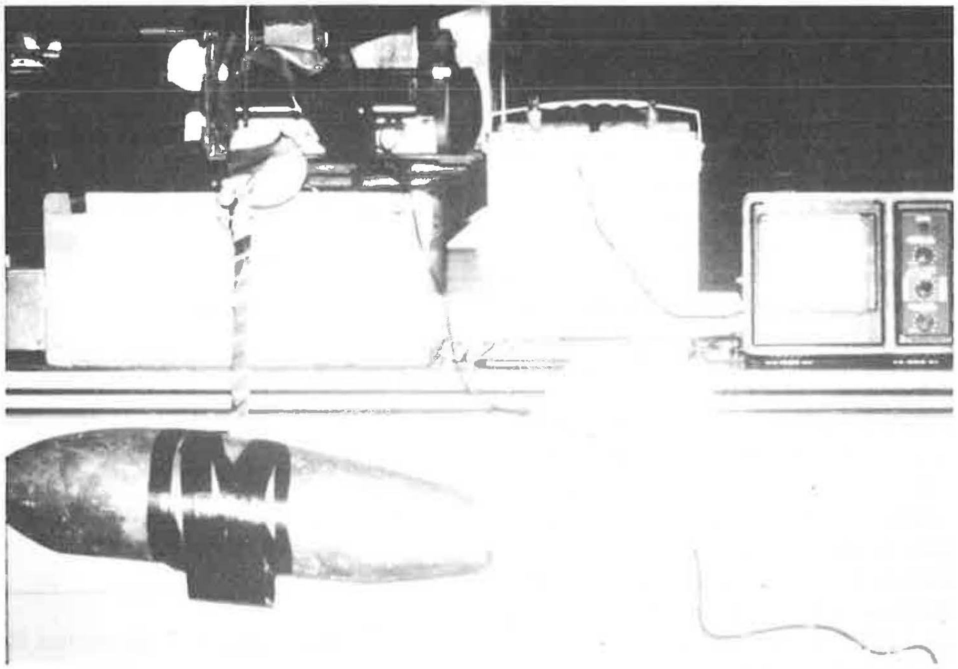

Figure 7. Columbus-type sounding weight, used by USGS with a fathometer transducer attached to the bottom.

the bridge and at approach and exit cross sections. It is not always possible nor safe, however, to launch and operate a boat during a measurable flow event, and less likely during a large flood. Where detailed data sets are the goal, boats provide invaluable data on channel movement at considerable distances from the bridge. Management of information becomes a considerable problem because large quantities of data can be generated in a very short time. Use of a graphic recording fathometer will help control bed elevation records. Position of the bridge and bank with regard to all observations and records must be estimated and carefully logged. Automatic positioning systems are now available. When these records are tied to fathometer records and other location dependent data, more accurate and easier to interpret information results. A simple range finder, hand compass, stop watch, and clinometer or hand level, when combined with encoded notes that can be deciphered later, work together to document fathometer and sounding records taken from a boat.

Figure 8. Truck-mounted crane used to suspend and manipulate the weight over the side of the bridge.

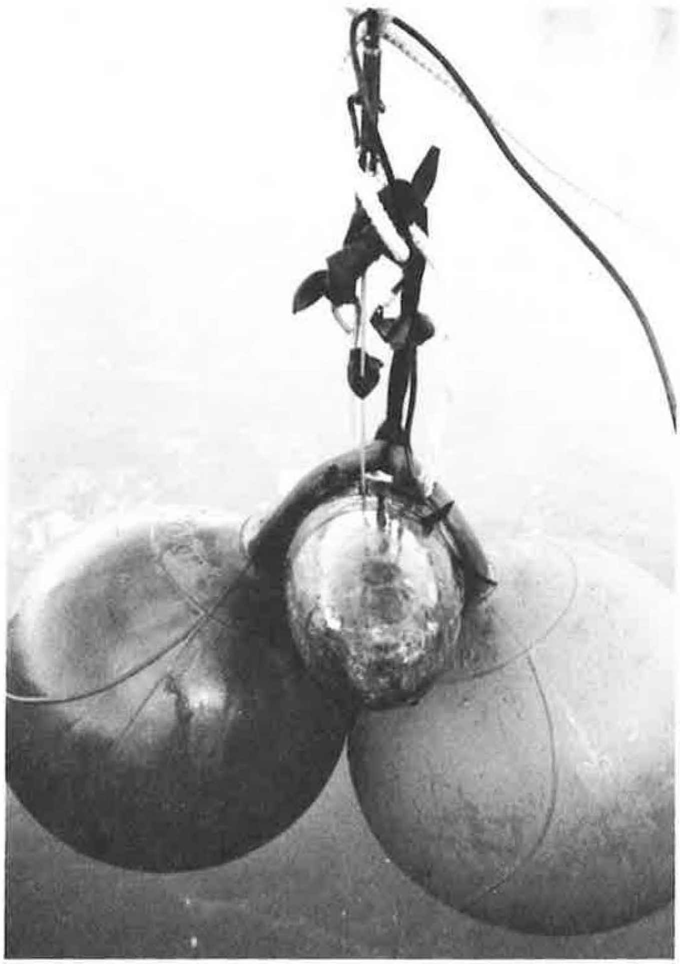

Figure 9. Balloons are added to a sounding weight to float it under the bridge deck for data collection near the pier.

Manpower

The key ingredient to successful collection of scour data during a flood lies with the motivation, and to a lesser extent, the training and experience of the field crew. Chasing floods to collect scour data requires a willingness, if not eagerness, to work weekends, holidays, long hours and usually in adverse weather, and sometimes with uncertain opportunities to sleep and eat. Besides, it might not be entirely safe to work on a bridge with a scourable river bottom--and sometimes a known scour problem. And yet, hydrologists are uncommonly willing to work in such conditions if they have the full support of management and are provided proper equipment, resources, and preparation.

A minimum of two qualified crew members are required to collect the limited detail scour data at a site during a flood. A procedural element, which may be more important than the number of people, is an advanced agreement to assign personnel and equipment to collect scour data during a flood event. This requires special consideration because there can be no advanced schedule to collect scour data. It takes a lot of coordination and planning to put a fast response team in the field in time to take records at critical times during the flood. It may not be logistically possible for a headquarters based team to survey remote sites or to arrive in time to take measurements where the time to flood peak is quick or where the flood duration is short. Teams need the freedom and authority to respond to rapidly changing conditions, requirements, and opportunities for these procedures to work. Under even the most favorable circumstances, this activity needs high administrative priority and managerial support.

LIMITATIONS AND PROBLEMS

Scour data collection is limited by a variety of factors, including the logistics of assembling a team with field equipment and getting to a site in time to measure the actual event. Other adverse working conditions are and will continue to limit collecting scour data while its occurring. Accurately locating and recording horizontal and vertical transducer or sounding weight positions is the principal limitation to accuracy using this technique.

Bridges themselves pose one of the greatest problems--they come in all sizes and shapes. Trying to use the procedures outlined here on a through-truss bridge consumes much more time than a deck structure (truss or girder) supported entirely from the bottom. Bridges with walkways, pedestrian barriers, fences, or other obstructions to the upstream edge will not allow access with the crane currently being used.

Bridges and entire road systems may not be accessible due to high water or road failures. Sanitation, safe drinking water, adequate rest, and fit food for the field crew, though usually accounted for, cannot be overlooked. Traffic control of course can be a problem and an added hazard. Debris around a pier can block fathometer readings and other sounding devices. Moving debris can also rip the sounding weight and transducer away or damage the rig and crane transport. Experienced teams actually have few problems with debris or other obstacles.

CONCLUSIONS

Local scour, contraction scour, and degradation and aggradation of alluvial streambeds are dynamic processes that occur during floods or high flow conditions. The data collected in the Spring of 1990 show that these various forms of scour are difficult to separate, except in the laboratory or an ideal case. Chasing floods provides the best chance of collecting data for proper interpretation and separation of the different contributing scour processes.

Maximum scour occurs during floods and high flow events. Scour holes usually start to infill or refill and bedload starts to redeposit after the flood passes or before the flood fully recedes. Accordingly, remnant scour holes (ones that remain after the flood peak has passed or high flow recedes) can be a misleading and dangerous indication of the actual scour performance of a bridge during the flood.

Key ingredients to a successful program to collect scour data during floods includes:

- Properly prepared and motivated survey teams.
- Management support of the scour data collection program.
- Practical and flexible operating procedures.
- Innovative approach to instrumentation and its use.

One dependable method of measuring scour is to use fast response field crews to mobilize when floods are in progress and take real time scour and flow measurements at bridges using the procedures prescribed in this paper. Other candidate methods to measure scour have limitations that make portable instrumentation, mobile teams, and chasing floods attractive for certain classes of problems and sites.

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