# SITE SELECTION AND COLLECTION OF BRIDGE-SCOUR DATA IN DELAWARE, MARYLAND, AND VIRGINIA

By Donald C. Hayes

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 93-4017

Prepared in cooperation with the

DELAWARE DEPARTMENT OF TRANSPORTATION,

MARYLAND DEPARTMENT OF TRANSPORTATION, and

VIRGINIA DEPARTMENT OF TRANSPORTATION

Richmond, Virginia

1993

**U.S. DEPARTMENT OF THE INTERIOR**

**BRUCE BABBITT, Secretary**

U.S. GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information
write to:

Chief, Virginia District
U.S. Geological Survey
3600 West Broad Street, Room 606
Richmond, VA 23230

Copies of this report can be
purchased from:

U.S. Geological Survey
Books and Open-File Reports Section
Box 25425, Denver Federal Center
Denver, CO 80225

## CONTENTS


| | Page |
|---|---|
| Abstract | 1 |
| Introduction | 1 |
| Purpose and scope | 2 |
| Previous studies | 2 |
| Acknowledgments | 3 |
| Site selection and survey | 3 |
| Site-selection criteria | 3 |
| Site reconnaissance | 4 |
| Site survey | 6 |
| Bridges | 6 |
| Cross sections | 9 |
| Bed material | 10 |
| Particle-size distribution | 10 |
| Spatial distribution of samples | 13 |
| Coarse-grained streambeds | 13 |
| Medium-grained and fine-grained streambeds | 13 |
| Bridge-scour-data collection | 15 |
| Equipment | 15 |
| Measurement procedures | 17 |
| Accuracy and limitations | 18 |
| Summary | 20 |
| References cited | 22 |


## ILLUSTRATIONS


| | | Page |
|---|---|---|
| Figures 1-2. | Maps showing location of: | |
| | 1. Bridge-scour study sites in Delaware and Maryland | 7 |
| | 2. Bridge-scour study sites in Virginia | 8 |
| 3. | Diagram of template used to classify gravel-sized streambed particles | 11 |
| 4-5. | Photographs showing bed-material sampler: | |
| | 4. US BMH-60 | 12 |
| | 5. US BMH-53 | 13 |

Page

Figures 6-7. Schematic diagram showing:

6. Bed-material sample locations at a typical bridge site over a course-grained streambed .................................... 14

7. Bed-material sample locations at a typical bridge site over a medium-grained or fine-grained streambed ..................... 16

8-9. Photographs showing:

8. Two-wheeled base and boom with reel, velocity meter, and sounding weight ........................................... 17

9. Fathometer mounted on a two-wheeled handcart with two-wheeled base and boom, sounding weight, and transducer ................. 18

10-11. Graphs showing:

10. Fathometer trace of upstream bed profile at the Nottoway River near Sebrell, Va., January 18, 1991 ........................... 19

11. Upstream bed profile at the Nottoway River near Sebrell, Va., defined by sounding weight and fathometer, January 18, 1991 ............. 21

## TABLES

Page

Table 1. Bridges spanning waterways in the States of Delaware, Maryland, and Virginia ........ 5

2. Location of bridge-scour study sites in Delaware, Maryland, and Virginia............. 6

# SITE SELECTION AND COLLECTION OF BRIDGE-SCOUR DATA IN DELAWARE, MARYLAND, AND VIRGINIA

*By* Donald C. Hayes


## ABSTRACT

Scour in stream channels is the leading cause of bridge failure. Accurate field measurements of scour are difficult to obtain because of the flow conditions at bridges during floods and the inability of existing measuring equipment to function under those conditions. This report describes criteria and methods that were developed by the U.S. Geological Survey to collect base-line data concerning the bridge structure, channel morphology, and bed material; and to collect streambed-profile and stream-velocity data during floods.

Criteria were developed for selecting bridge sites to be monitored for scour during floods. Principal criteria defined for selection of a monitoring site were safety of personnel during measurements, accessibility of the site during floods, and accessibility of possible scour holes at abutments and piers. Fifteen bridge sites were selected for active bridge-scour data collection from more than 13,500 bridges spanning waterways in Delaware, Maryland, and Virginia.

Bed-material characteristics are a principal explanatory variable to scour characteristics at a bridge site. Bed-material sampling procedures were developed to characterize the bed material of the channel near the bridge site. Grid-sample procedures were developed for gravel-bed channels, and bulk-sample procedures were developed for sand-bed channels. Structural information concerning bridge geometry was obtained from bridge plans and verified during the field survey. Channel geometry was surveyed at the approach section, the upstream side of the bridge, the downstream side of the bridge, and at the exit section.

Standard streamflow-gaging equipment and procedures for defining streambed profiles and velocities near abutments and piers during floods were developed. Techniques to define streambed profiles using a fathometer also were developed. Comparison and limitations of the streambed profile defined by a sounding weight and fathometer are discussed.


## INTRODUCTION

Scour can be defined as the lowering of a stream channel by erosion and is of concern, primarily in alluvial channels. Eighty-six percent of the estimated 577,000 bridges in the United States span waterways and, therefore, are subject to damage by scour. Scour in stream channels is the leading cause of bridge damage and failure (U.S. Federal Highway Administration, 1990) and can be described by three primary components–general scour, constriction scour, and local scour.

General scour is the lowering (degradation) of the entire stream channel (normally along a defined length of stream) as a result of changes in channel controls, sediment supply, or stream form. The construction of dams or the mining of gravel in a stream are examples of actions that result in changes in channel controls or sediment supply. The channelization of the stream is an example of a change in stream form. General scour can occur whether a bridge is present or not.

Constriction scour is the lowering of the stream channel because of increased flow velocities caused by a reduced cross-sectional area, primarily during high flows. Constriction scour normally occurs within a short distance; from upstream to downstream of the constriction. Bridges, bridge embankments, and natural constrictions or narrowing of the channel are examples of obstructions that can reduce the cross-sectional area of the stream channel.

Local scour is the erosion of the stream channel because of flow disturbances caused by obstructions in the streamflow. These obstructions create vortices in the flow that remove bed material in the vicinity of the obstruction. Bridge piers, bridge-foundation piles, and debris jams are examples of obstructions.

The primary components of scour are not completely independent; however, separating total scour into these primary components is necessary in studying the causes of scour and in designing scour-resistant bridges. Design engineers can predict the magnitude of each component and combine the results to estimate the total scour at a site (Froehlich, 1991).

Numerous equations have been developed to predict scour depths, but the estimates of scour depths vary over a wide range for the same set of conditions (Highway Research Board, 1970; Melville, 1975; Norman, 1975; Chang, 1980; Hopkins and others, 1980; Jones, 1984; Jarrett and Boyle, 1986; and Froehlich, 1988). Most of these equations are based on theoretical approaches and laboratory measurements and have not been validated by field measurements. Uncertainty as to which equations are applicable for a given set of conditions has emphasized the need for field measurements. Accurate and complete field measurements of scour, however, are difficult to obtain because of streamflow patterns that occur at bridges during floods, inability to get skilled personnel to bridge sites during floods, and problems associated with existing measuring equipment (Davis, 1984). Collection of field-scour data, however, is perhaps the only convincing way to improve bridge-scour predictive equations (Highway Research Board, 1970; Hopkins and others, 1980; and Jones, 1984) and improve the knowledge of the scour processes.

The U.S. Department of Transportation, Federal Highway Administration, has designated bridge scour a High Priority National Program Area (HPNPA). Under this HPNPA, the Federal Highway Administration is monitoring and coordinating research conducted by Federal, State, and other agencies. One aspect of this research is the collection of scour data at bridges before and during floods. In 1988, the U.S. Geological Survey (USGS), in cooperation with the Delaware Department of Transportation, the Maryland Department of Transportation, and the Virginia Department of Transportation, began a study within the boundaries of these three States to improve bridge-scour predictive equations by collection of bridge-scour data.

## Purpose and Scope

This report describes the procedures that were developed to select bridge-scour sites and the procedures used to measure bridge scour and associated characteristics at bridges in Delaware, Maryland, and Virginia, as part of a National program to improve bridge-scour predictive equations. Criteria were developed to select sites where bridge-scour data could be collected under a variety of conditions. In addition, background characteristics necessary for analysis of scour are listed, and procedures for collecting bed-material samples were developed. Equipment and procedures for defining streambed profiles and velocities were developed for measuring bridge scour during floods.

Bridge inventories supplied by each State were used for the initial screening of more than 13,500 bridges in the three-State area. Final site selection was determined from field evaluations. Bridge plans and field surveys were used to collect and verify background geometry data. Bed-material samples were analyzed using sieves and a gravel template. Standard USGS streamflow-gaging equipment was used to collect scour data during floods. In addition to selecting bridges where active-scour measurements could be made, historical discharge measurements were reviewed for possible contributing data.

## Previous Studies

Many investigators have studied scour using empirical and theoretical analyses of fluids over a cohesionless-bed material or in scale-model laboratory measurements. Currently (1992), only a few studies in the United States have contributed significantly to the literature on measurement and analysis of bridge-scour field data. Scour measurements during floods on Alaska streams were documented by Norman (1975). A pilot study to determine methods for measuring bridge scour with existing USGS streamflow-gaging equipment was performed by Jarrett and Boyle (1986). Scour data were collected at four bridge sites in Colorado for the spring runoff during 1984. Through an extensive search of published and unpublished data, Froehlich (1988) obtained 70 field measurements of local scour at bridge piers from which he was able to develop local-scour predictive equations based only on field data. Butch (1991) describes site selection, equipment, and techniques used to collect bridge-scour data at sites in New York.

### Acknowledgments

Personnel from the Departments of Transportation in Delaware, Maryland, and Virginia are gratefully acknowledged for their assistance in providing bridge inventories, site recommendations, bridge plans, technical advice, and for removing debris from bridge sites selected for this study.

## SITE SELECTION AND SURVEY

Criteria were developed for selection of bridge-scour sites because of the many physical characteristics associated with scour at bridges and the difficulty of accurately measuring these characteristics during floods. These criteria were chosen to maximize the probability of obtaining useful data and were applied to the selection of bridge sites in the three-State area.

### Site-Selection Criteria

Many physical and logistic factors are considered in determining the suitability of an individual site for collection of bridge-scour data during floods. The following is a list of criteria used in this study for selection and ranking of bridge-scour sites. The list is not necessarily comprehensive.

1. The site is accessible during high flows.
2. The bridge is wide enough to provide sufficient safe working space for personnel and scour-measuring equipment. Sites requiring extensive traffic-control measures are undesirable because of the increased manpower and time required for measurements.
3. The streambed is composed of erodible material, not bedrock and preferably not clay. For pier or abutment foundations set on bedrock, an ample supply of alluvial material exists above the bedrock so that there is no physical restraint on probable scour depths.
4. The location of the bridge piers relative to the upstream edge of the bridge permits measurement of the scour hole. Bridges with piers that extend to the edge of the bridge deck, or are recessed less than 1 ft are preferred. Bridges with piers that are recessed more than 1 ft or extend beyond the bridge deck are undesirable. Many bridges in Maryland have sharp-nosed piers that extend several feet beyond the bridge deck. These bridges were acceptable because scour holes on a sharp-nosed pier do not develop at the nose of the pier, but along the side of the pier downstream from the nose.
5. The flow duration at flood stages, distance from the office assigned to collect the data, and flood-monitoring equipment combine to allow time to reach the site to collect discharge and scour measurements during a flood. Telemetry located at or near the site is very useful for monitoring streamflow conditions in the area. The number of sites located at or near streamflow-gaging stations are maximized. Historical streamflow records can be analyzed for the frequency and duration of floods. Historical discharge measurements can be analyzed for existence of general scour and variations of the streambed elevation over time.
6. Sites on stream reaches where the sediment supply can be affected by dams or gravel mining are undesirable. Dams located upstream from a bridge site disrupt the natural migration of bed material down the stream and can cause extensive general scour of the streambed. Gravel and sand mining in the streambed upstream from the bridge, can cause similar disruptions in the sediment supply. If the mine is located downstream from a bridge site, the

mine can cause a locally steepened streambed slope or head cut. Head cuts typically migrate upstream, causing significant general scour, until a stable, equilibrium streambed slope is achieved.

7. Flow at flood stages is essentially parallel to the bridge piers. Flows should approach the piers at angles of 5 degrees or less. If the flow is not parallel to the piers, the deepest point of the scour hole will not be at the nose of the pier, and the location and maximum depth of the scour hole will be difficult to locate.
8. The distance from the bridge deck to the stream bottom is within a range permitting measurement during floods, preferably less than 40 ft and not greater than 80 ft. Errors in measuring the depth of flow increase as the distance increases because of the drag on the weight and suspension cable.
9. The pier has a simple shape. Square-nosed and round-nosed piers are preferable to sharp-nosed piers. Square-nosed and round-nosed piers typically produce larger maximum scour depth than sharp-nosed piers (Richardson, and others, 1990), and the scour hole is consistently located at the nose of the pier. The scour hole for sharp-nosed piers can be located downstream from the nose of the pier at a distance that primarily depends on the approach angle of the flow.
10. Sites with exposed pier footings are undesirable. Scour mechanics are complicated by such exposure.
11. Piers or abutments are not protected by riprap. Riprap is placed to protect structures against scour.
12. The amount of debris at a site is minimal. Bridges with a history of collecting debris are undesirable because stream depths and velocities cannot be measured around debris. Scour mechanics also are complicated by debris.
13. A high probability exists that local scour will occur at one or more piers and abutments at a bridge. Local scour at each pier and abutment is considered separately in the data analysis.
14. Boat access is desirable at bridge sites crossing large streams. Boat access simplifies collection of background data, such as channel soundings and bed-material sampling.
15. Bridges with trusses are undesirable because the trusses significantly increase the time required to complete the measurement.
16. The channel is relatively uniform upstream and downstream from the bridge. Sites on stream reaches where the flows can be affected by joining streams are undesirable. The bridge should constrict the natural channel slightly.

**Site Reconnaissance**

In 1989, a total of 13,564 bridges spanned waterways in Delaware, Maryland, and Virginia. The number of bridges of different sizes (defined by span length) are listed in table 1 for each State in the study area. Because of the vast number of bridges to be evaluated, initial screening of the sites was accomplished by use of bridge inventories supplied by the States.

Inventories of multispan bridges over waterways with bridge lengths greater than 150 ft were requested from the highway department in each State. Because of the limited number of bridges in Delaware, single-span and multispan bridges with lengths greater than 100 ft were reviewed. Abutment-scour data and constriction-scour data could be collected at any single-span bridge selected for the study. Further screening of the sites was accomplished by use of the following information from the bridge inventories:

1. Year built.
2. Length.
3. Number of spans.
4. Type of superstructure.
5. Type of substructure.
6. Type of foundation (if available).
7. Bridge condition (if available).

Bridges constructed with multiple piers, with foundations not set on bedrock, and without trusses or drawbridges were selected from the inventories for further evaluation. These sites were plotted on available State and county maps and were reviewed for proximity to reservoirs, gravel min-

**Table 1.**–Bridges spanning waterways in the States of Delaware, Maryland, and Virginia

[>, indicates greater than]

| State | Total number of bridges spanning waterways | Number of bridges spanning waterways having span length, in feet | | | Sites field evaluated | Sites selected for active-scour measurements |
|---|---|---|---|---|---|---|
| | | 20-50 | 50-200 | >200 | | |
| Delaware | 530 | 325 | 143 | 62 | 63 | 2 |
| Maryland | 2,870 | 1,330 | 1,107 | 433 | 217 | 3 |
| Virginia | 10,164 | 6,332 | 2,865 | 967 | 568 | 10 |
| Total | 13,564 | 7,987 | 4,115 | 1,462 | 848 | 15 |

ing, joining streams, and other factors that could affect sediment transport or alter the flow beneath the bridge.

Bridges of special interest to the Department of Transportation of each State were specifically evaluated. Often, these bridges had scour problems previously documented by each State. In most cases, these bridges were flagged for special consideration during the office-screening process and the bridges were evaluated in the field.

Bridges located at streamflow-gaging stations also were given special consideration. Availability of telemetry and the number of historical discharge measurements made from the bridge were included in the evaluation. Several bridges that were not suitable for active-scour measurements but were located at streamflow-gaging stations were included in the study. At these bridges, data from historical discharge measurements were used for the constriction-scour analysis.

Between 6 and 12 percent of the total number of bridges spanning waterways in each State were evaluated in the field (table 1). Each bridge site was evaluated by use of the criteria discussed in the section "Criteria." A field evaluation form was completed for each site documenting why the site was retained or eliminated. If any of the first five criteria could not be met at a given site, the site was not considered. Any condition that would prevent measuring scour safely at a site during high flows excluded the site from selection. The more criteria satisfied at a site, the higher the site ranked on the final selection list.

Bridge-scour sites were difficult to locate in Delaware and Maryland. In Delaware, many of the bridges are either single span with no piers or span large estuaries. In Maryland, many bridge foundations are set on bedrock, have recessed piers, or have piers and abutments protected by riprap. In both States, many bridges that did not pass the initial screening were reevaluated in the field in an attempt to increase the number of bridge-scour sites in those States. Problems with site selection in Virginia were similar to those in Maryland; however, the large number of bridges in Virginia allowed more sites to be selected.

Only a small percentage of the bridges in the three-State area met enough of the criteria to become bridge-scour sites. The primary reasons bridges were not selected for the study are as follows:

1. The bridge had no sidewalks or shoulders from which to work. Traffic would require at least one lane to be closed for safety.
2. The bridge was set on single-column recessed piers. Any scour holes caused by the piers could not be measured with available equipment during high flows.
3. Bridge foundations were set on bedrock with insufficient alluvial material above the bedrock; therefore, a physical restraint on scour depths existed.
4. Piers and abutments were protected by riprap.
5. The flood-hydrograph duration was too short with flood peaks passing through the bridge too rapidly to allow sufficient time for accurate measurements.

**Table 2.**–Location of bridge-scour study sites in Delaware, Maryland, and Virginia

[DE, indicates Delaware State Highway; MD, indicates Maryland State Highway; VA, indicates Virginia State Highway; US, indicates Federal Highway; A, indicates active bridge-scour measurements; H, indicates historical discharge measurements; and latitude and longitude are reported in degrees (° ), minutes ('), seconds (")]

| Station number | Name | Latitude | Longitude | Bridge number | Road | Data type |
|---|---|---|---|---|---|---|
| 01483530 | Leipsic River at Leipsic, Del. | 391444 | 0753105 | 2-12B | DE 9 | A |
| 01484702 | Assawoman Bay near Fenwick Island, Del. | 382720 | 0750400 | 437 | DE 54 | A |
| 01490750 | Choptank River near Goldsboro, Md. | 390200 | 0754500 | 5002 | MD 287 | A |
| 01581700 | Winters Run near Benson, Md. | 393112 | 0762224 | 12065 | US 1 | H |
| 01625880 | South River at Lyndhurst, Va. | 380245 | 0785635 | 6071 | VA 664 | A |
| 01633050 | North Fork Shenandoah River near Mount Jackson, Va. | 384656 | 0783603 | 6312 | VA 7 | A |
| 01639500 | Big Pipe Creek at Bruceville, Md. | 393645 | 0771410 | 6035 | MD 194 | A,H |
| 01649500 | Northeast Branch Anacostia River at Riverdale, Md. | 385737 | 0765534 | 16069 | MD 410 | H |
| 01673000 | Pamunkey River near Hanover, Va. | 374603 | 0771957 | 6918 | VA 614 | A,H |
| 02027000 | Tye River near Lovingston, Va. | 374255 | 0785855 | 1017 | VA 56 | A |
| 02039550 | Bush River near Rice, Va. | 371642 | 0782104 | 1031 | US 460 | A |
| 02044280 | Little Nottoway River near Blackstone, Va. | 370516 | 0780323 | 6171 | VA 603 | A |
| 02047000 | Nottoway River near Sebrell, Va. | 364613 | 0770959 | 6111 | VA 653 | A,H |
| 02076000 | Dan River at South Boston, Va. | 364137 | 0785409 | 1900 | US 501 | A |
| 03076500 | Youghiogheny River at Friendsville, Md. | 393913 | 0792431 | 11011 | MD 42 | A,H |
| 03164000 | New River near Galax, Va. | 363850 | 0805845 | 1007 | VA 94 | H |
| 03166700 | Reed Creek near Wytheville, Va. | 365647 | 0810132 | 6189 | VA 649 | A |
| 03167500 | Big Reed Island Creek near Allisonia, Va. | 365320 | 0804340 | N80A | VA 693 | H |
| 03208500 | Russell Fork at Haysi, Va. | 371225 | 0821745 | 1042 | VA 63 | H |
| 03487990 | North Fork Holston River near North Holston, Va. | 365429 | 0814208 | 6042 | VA 633 | A |

Sites were selected in separate physiographic provinces in the three-State area so that different streambed materials and pier types could be sampled. An attempt was made to select sites so that each USGS field office had three potential sites to sample during a flood. Preferably, the sites were in separate basins and far enough apart so that the probability was greater of a local storm event causing flooding at one of the bridge sites. Selecting sites in separate basins increased the opportunity to measure scour in the field.

The sites that were selected for this study for active-scour measurements and the sites where historical discharge measurements were available are listed in table 2. The locations of selected bridge-scour sites in Delaware and Maryland are shown in figure 1. The locations of selected bridge-scour sites in Virginia are shown in figure 2.

## Site Survey

Once a site was selected for collection of active bridge-scour data, base-line data about the bridge, channel, and bed material were collected in preparation for scour measurements. Base-line data also were collected at sites where historical discharge measurements were available.

### Bridges

Bridge plans were obtained from the State highway departments, when available. Structural information obtained from the bridge plans include

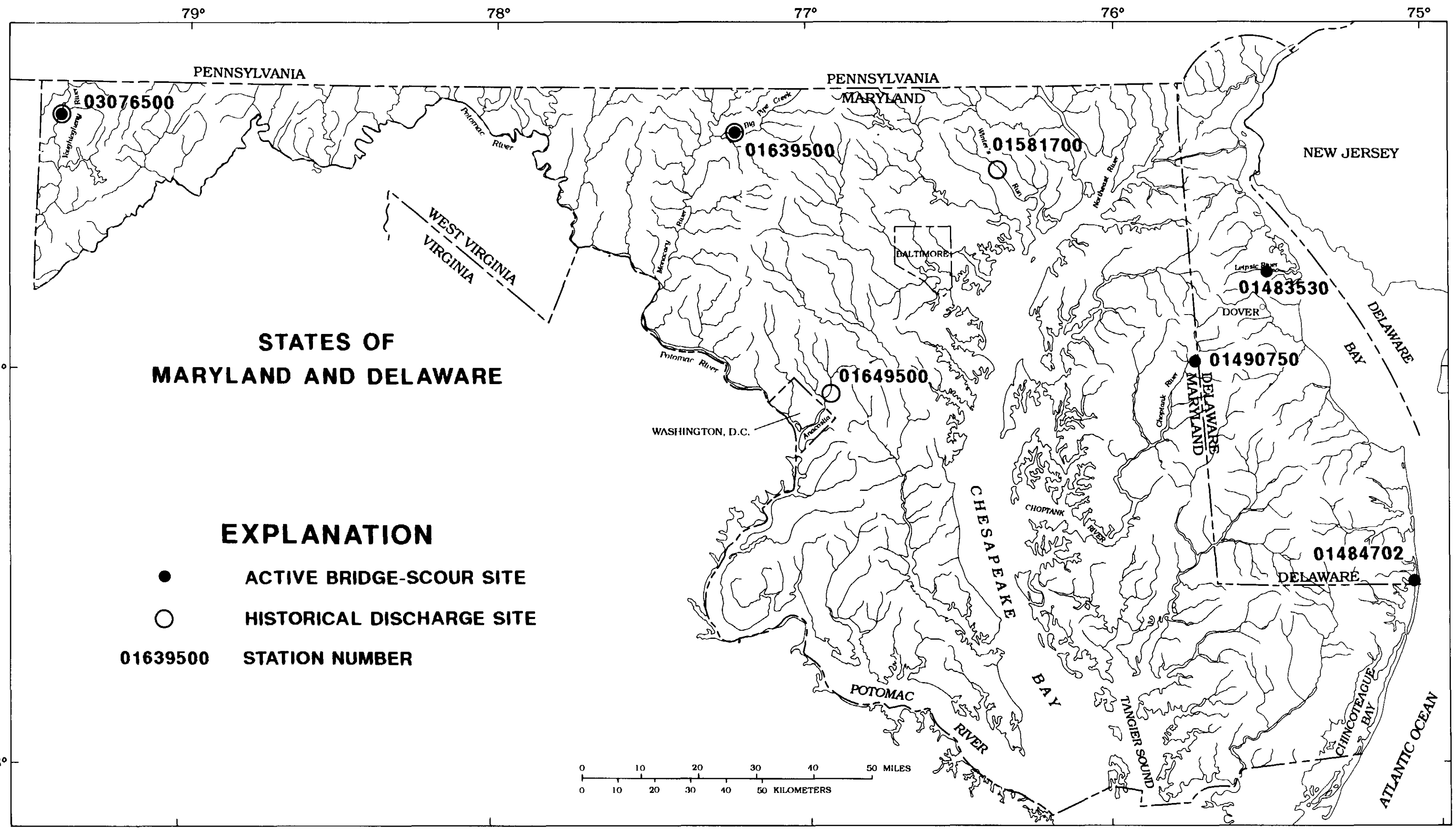


Figure 1.–Location of bridge-scour study sites in Delaware and Maryland.

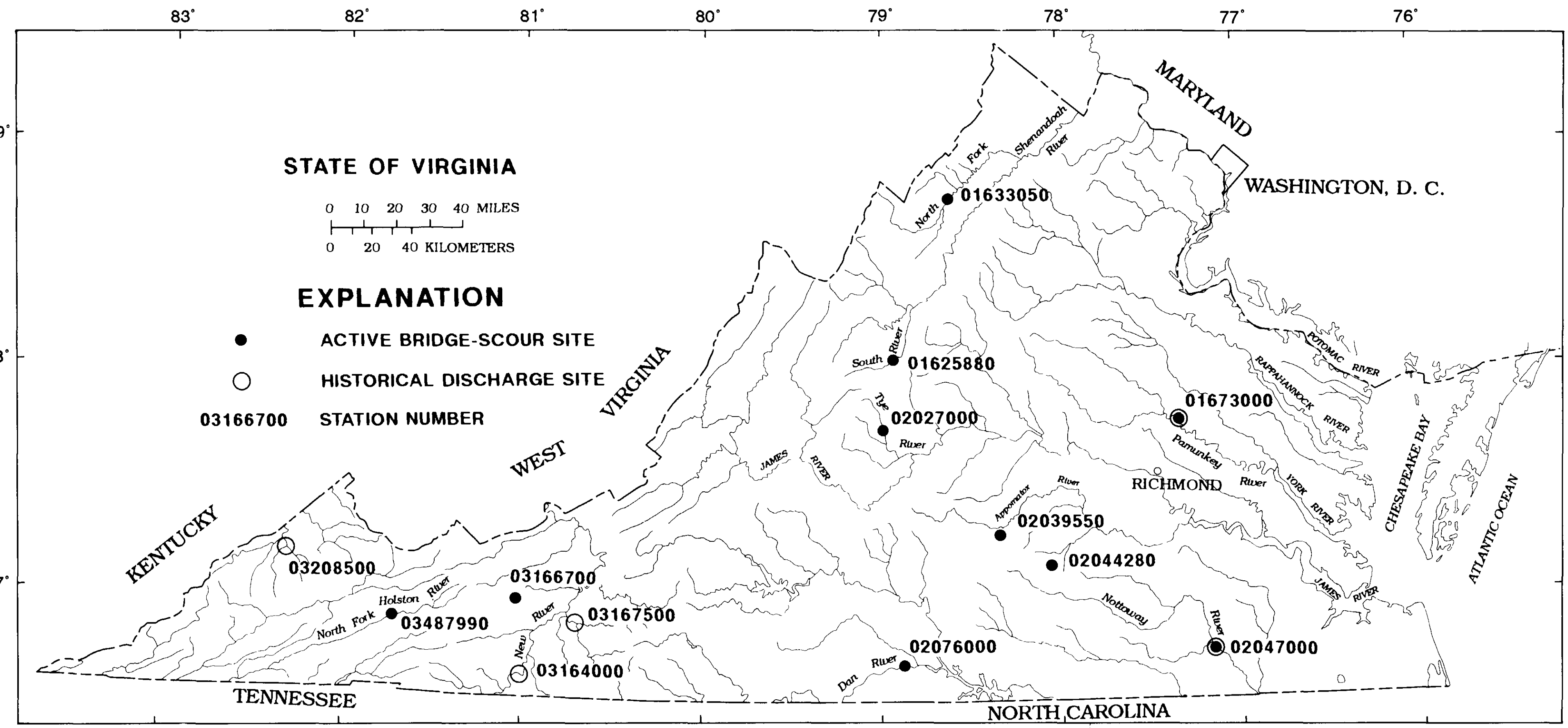


**Figure 2.**–Location of bridge-scour study sites in Virginia.

(1) the number, size, and location of piers, (2) abutment type and construction, (3) elevation of low-steel on the bridge structure, (4) type of foundation (spread footer or piles), and (5) the size and elevation of footers or pile caps. In addition, channel cross sections surveyed before bridge construction and borehole data were obtained from the bridge plans.

Bridge geometry also was collected during the field survey. Some structural components, such as size and elevation of footers, often were not visible during the field survey. Data collected in the field survey were compared with the bridge plans; information found to be different was annotated on the bridge plans.

Additional tasks completed at each bridge site are as follows:

1. Reference marks and reference points were established. At least one reference mark was established away from the bridge. The reference marks were set in locations that were expected to be safe during major floods. Reference points were established on the upstream and downstream bridge railings over the main channel. If reference marks or reference points were already established on the bridge, new ones were not set. If a bridge had a wire-weight gage, no reference point was established on that side. All elevations were leveled to the same datum (gage datum) until levels could be run to tie the elevations to sea level.
2. The upstream and downstream railings were marked for horizontal stationing. The stationing was set such that the center of each pier was the same station number on the upstream and downstream sides of the bridge.
3. Debris was cleared from the upstream side of the bridge. If the debris was too large for the USGS to remove, local highway maintenance departments removed the debris. Each bridge site was checked quarterly for debris accumulation.

### Cross Sections

Stream cross-sections were surveyed at the approach section, the upstream side of the bridge, the downstream side of the bridge, and at the exit section. Cross sections were tied to the same datum as the reference mark and reference point (gage datum or sea level). Collection of cross-section data followed guidelines established by Benson and Dalrymple (1968). The approach and exit cross sections are available if numerical modeling is needed for discharge computations. The cross sections at the upstream and downstream side of the bridge are available for reference in comparison with cross sections measured during floods.

1. Approach section.–The stream cross-section profile at the approach section was run approximately one bridge opening upstream from the bridge. The ends of the cross-section were extended into the flood plain one bridge width or to the elevation of low-steel on the bridge, whichever was lower. Stakes were set on each stream bank at the cross section for future reference to the section.
2. Upstream side of the bridge.–Readings at 15 to 25 points were used to define the section with additional soundings made at 1-ft increments on each side of the pier for a distance of two-pier diameters. Preferably, the soundings were upstream of the pier and footing (if visible). If an existing scour hole extended beyond two-pier diameters, the soundings were extended at 1-ft intervals until clear of the scour hole. The ends of the cross section were extended to low-steel.
3. Downstream side of the bridge.–Readings at 15 to 25 points were used as needed to define the section. Additional measurements were not collected near the piers. The ends of the cross section were extended to low-steel.
4. Exit section.–The cross section at the exit section was run approximately one bridge opening downstream from the bridge. The ends of the exit section were extended into the flood plain one bridge width or to the elevation of low-steel on the bridge, whichever was lower. Stakes were set on each stream bank at the cross section for future reference to the section.

Profiles of the channel water surface were run to determine the natural slope of the streambed. Elevations of water surface were obtained every 50 to 100 ft upstream and downstream from the bridge for a distance of 300 to 400 ft. Water-surface elevations were used to better define the channel slope near the bridge.

Manning's roughness coefficients (n values) were selected for the approach section, the bridge sections, and the exit section. Roughness coefficients were estimated assuming bankfull flood elevations using guidelines established by Barnes (1967), Jarrett (1985), and Arcement and Schneider (1989).

### Bed Material

Bed-material characteristics are a principal explanatory variable to scour characteristics at a bridge site (M.N. Landers, U.S. Geological Survey, written commun., 1990). Particle-size distribution is the primary method used to characterize bed material. The particle-size distribution is determined by dividing a representative sample into size classes, and determining the amount of material in each class by use of the number of particles or weight of material in each size class.

Bridge-scour data were collected for a wide range of types of bed material across the three-State area; gravel in the steep channels of central and western Maryland and Virginia; sand in gently sloping channels of central and eastern Maryland and Virginia; and clay and silt in the tidal channels of eastern Delaware. Gravel-bed streams can consist of two distinct components–(1) a coarse, surface material, and (2) a finer, subsurface material (International Organization for Standardization, 1989). For this study, both components were sampled in gravel-bed streams. Sand-bed streams and clay-bed or silt-bed streams can be layered, but the components are less distinct. Only the surface material was sampled in these streams. Methods and procedures for collection of bed-material samples, as described in this report, are modifications of methods and procedures described in Guy (1969), International Organization for Standardization (1977 and 1989), Yuzyk (1986), and Ashmore and others (1988).

#### Particle-Size Distribution

The particle-size distribution is measured to characterize the streambed material. The distribution is determined by dividing a representative sample of bed material into size classes from which a cumulative distribution can be calculated. Size classes were defined by use of a gravel template for coarse-grained material (gravel), sieves for medium-grained material (sand), and a sedimentation cylinder for the fine-grained material (silt-clay).

Determination of the particle-size distribution begins with collection of the sample. A grid-sample procedure was used for collection of coarse-grained material. A bulk-sample procedure was used for collection of medium-grained material and fine-grained material. Particle size of the surface layer was the determining factor in selection of the sampling procedure. The grid-sample procedure was used if the median grain size (D50) of the surface-layer material was larger than 4 mm or if the grain size of which 84 percent of the surface-layer material is smaller (D84) was larger than 8 mm. Bulk-sample procedures were used if the D50 of the surface-layer material was less than 4 mm and the D84 of the surface-layer material was less than 8 mm. Bulk-sample procedures also were used for collection of subsurface material in gravel-bed streams. Two sample procedures had to be used because standard equipment for bulk sampling of coarse-grained material is not defined (Guy and Norman, 1970).

The grid-sample procedure consisted of establishing an equally spaced grid across an exposed bar or wadeable section of a stream. The grid spacing was on the order of two times the diameter of the largest visible particle. Spacing larger than two times the diameter of the largest visible particle often simplified establishing the grid (for example, use of a 1-ft grid where the diameter of the largest visible particle is 4 in.). The grid section extended across as much of the low-water channel as was wadeable. A sample of 100 particles was collected from a single line. If the grid size and wadeable stream width would not allow collection of all the particles from a single line, additional parallel lines 10 ft apart were added until the sample of 100 particles were collected. Only particles larger than 8 mm (0.31 in.) were collected to characterize the surface material. Each particle was removed from the streambed at the designated points on the grid and classified by use of the gravel template (fig. 3).

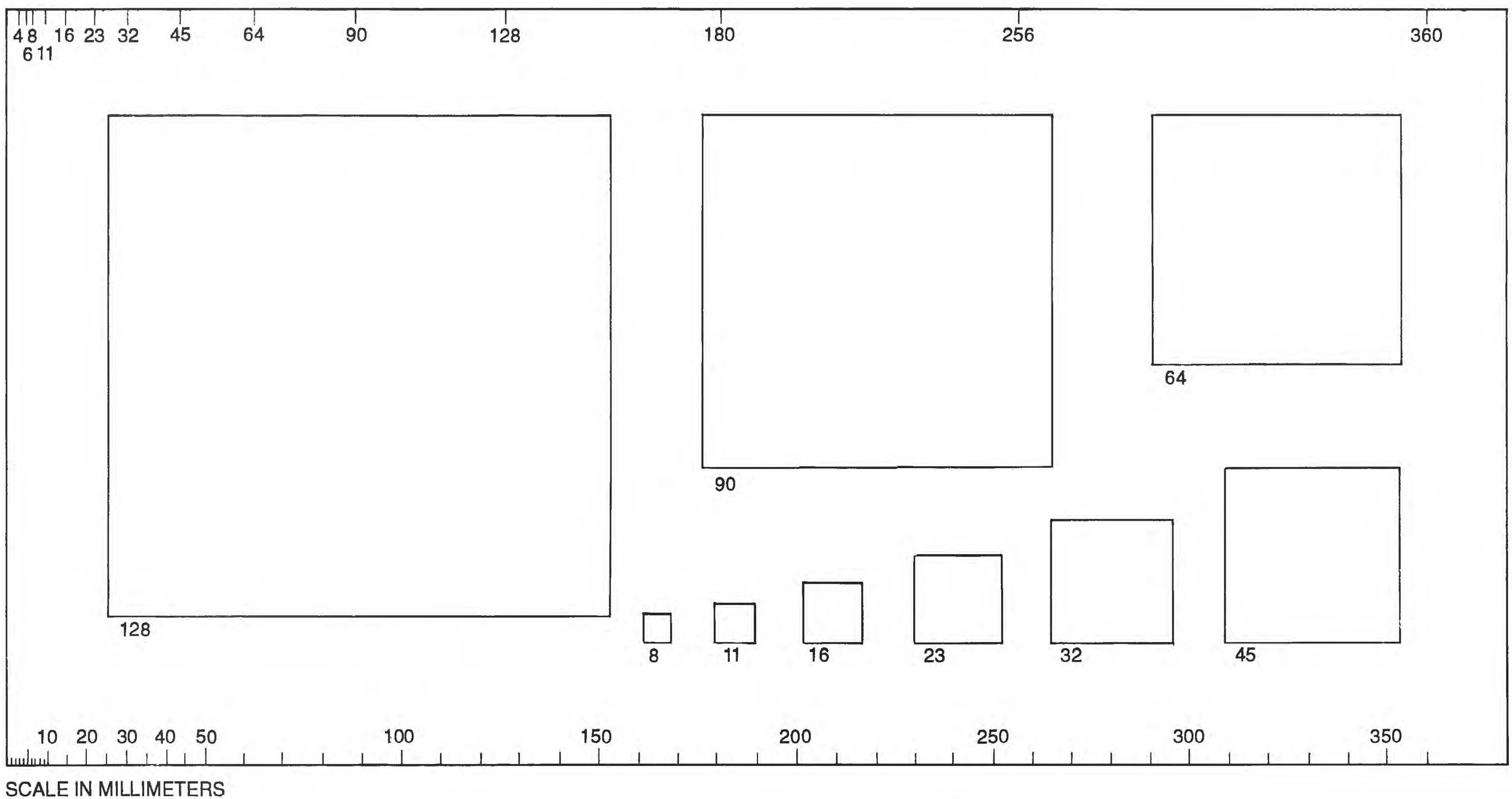


**Figure 3.**–Template used to classify gravel-sized streambed particles.

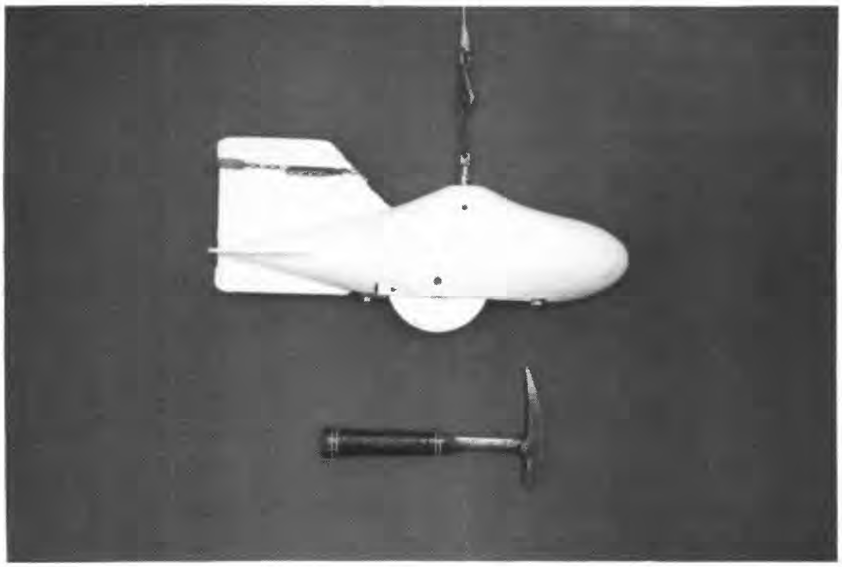

**Figure 4.**–Bed-material sampler, US BMH-60.

The particle-size classes were recorded so that a frequency-by-number distribution could be computed when the sample was complete.

The particle-size distribution of the gravel material was determined from the gravel template with square openings 128, 90, 64, 45, 32, 23, 16, 11, and 8 mm on a side. The 100 particles selected in the grid-sample procedure were classified by determining the largest opening through which the particle would not pass. The particle-size distribution was determined from the number of particles in each size class. This grid-by-number approach has been shown to produce frequency distributions equivalent to those produced by bulk sampling for the same population (Yuzyk, 1986).

Bulk samples were collected using either a digging-type sampler or a vertical-type sampler. The type of sampler used depended on the bed-material characteristics; access to the sample location; and depth of water, if any, at the sample location.

Digging-type samplers consist of a bucket or scoop that is built into the body of the sampler. The digging-type sampler used in this study was the US BMH-60 (fig. 4). Once the sampler is lowered to the streambed, a release triggers a drive spring, and the sample bucket is rotated approximately 180 degrees through the bed material until it strikes a stop plate. As the sampler is raised, the bucket and plate retain the sample material until the bucket is manually rotated. The bucket penetrates the bed about 1.7 in. and captures approximately 0.006 ft of material.

Vertical-type samplers consist of a cylinder that is forced into the bed material. As the sampler is raised, a partial vacuum or a bottom plate retains the material in the container. Two types of vertical samplers were used in this study. The first vertical-type sampler, the US BMH-53, is piston operated (fig. 5). This sampler is approximately 2 in. in diameter and can collect a sample 8 in. long. The piston was marked so that only the top 2 in. of bed material was sampled. Depth and volume are consistent with the depth and volume of samples collected with the US BMH-60.

The second vertical-type sampler was used where the bed material would not remain in the BMH-53, as in the case of loose sand. The top 2 in. of a 16-oz, plastic sample bottle and a flat-bottomed scoop were used to collect the sample material. The sample-bottle section was pushed into the

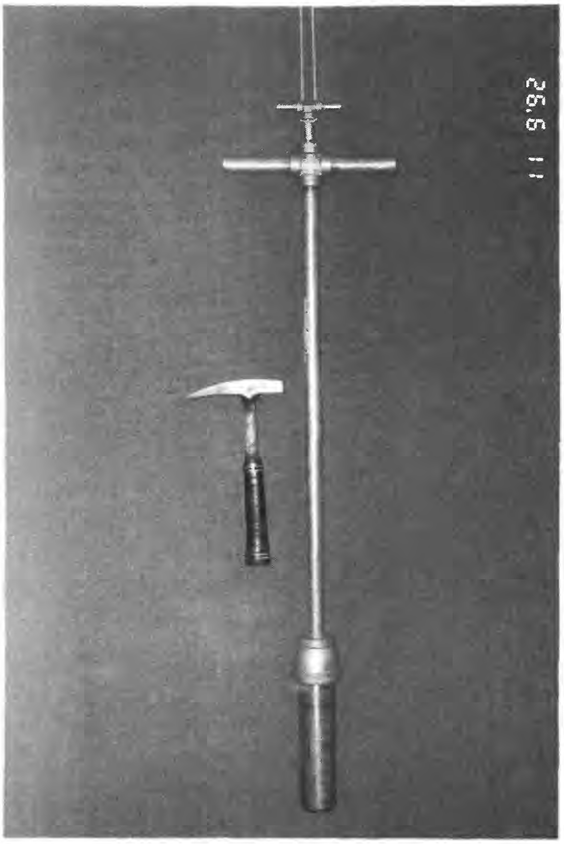

**Figure 5.**–Bed-material sampler, US BMH-53.

bed material, and the scoop was slid underneath to retain the sample material. The bottle and scoop were removed together and then inverted to eliminate any excess material on the scoop. Depth and volume are consistent with the depth and volume of samples collected by the other samplers discussed.

The particle-size distribution of the sand material was determined from a nest of sieves with square openings 32.0, 16.0, 8.0, 4.0, 2.0, 1.0, 0.50, 0.250, 0.125, and 0.063 mm on a side. A splitter was used to obtain a part of the sample weighing 50 to 100 g. The material was placed in a sieving machine and was sieved for 10 minutes. The particle-size distribution was determined from the weight of material retained in each sieve.

Few bed-material samples for this study contained large amounts of silt-clay. In those samples that contained 50 percent or more silt-clay, the silt-clay fraction was determined by use of a sedimentation cylinder. Further refinement of the silt-clay into more detailed class limits (separates) was not accomplished.

## Spatial Distribution of Samples

Spatial variability of bed-material size in a stream reach can be quite large; therefore, the particle-size distribution of a single-point sample cannot adequately represent the bed material of a stream reach. Yuzyk (1986) discusses the high spatial variability exhibited in fluvial gravels, but the report does not determine the coefficient of variation for a stream reach. Ashmore, and others (1988) determined the coefficient of variation of approximately 30 percent for the sand-bed channel sampled in their study. Variability in the size of bed material in a sample reach can, in part, be attributed to channel morphology (Ashmore, and others 1988). Because of the variability of bed material in a stream reach, bed-material characteristics were measured at the bridge site and at the approach cross section.

*Coarse-grained streambeds.*–Samples of bed material were collected from coarse-grained streambeds near the approach cross section. Three parallel transects were set one stream width to a maximum of 50 ft apart, with the center transect located in the vicinity of the approach cross section (fig. 6). Sample points were located at each transect by defining the grid spacing (a minimum of two times the diameter of the largest visible particle). The bed material at each transect was collected and analyzed separately according to the grid-sample procedures described earlier. Grid samples were collected only at the approach section on coarse-grained streambeds because of the greater depth of flow typically found at the bridge.

A single-bulk sample of the subsurface layer was collected at each transect at a representative location. The top, coarser layer was removed to the depth of the deepest lying surface particle and a composite sample consisting of five replicate samples was collected by use of a digging-type sampler or vertical-type sampler.

*Medium-grained and fine-grained streambeds.*–Samples of bulk material were collected on medium-grained and fine-grained streambeds near the abutments and piers, and near the approach

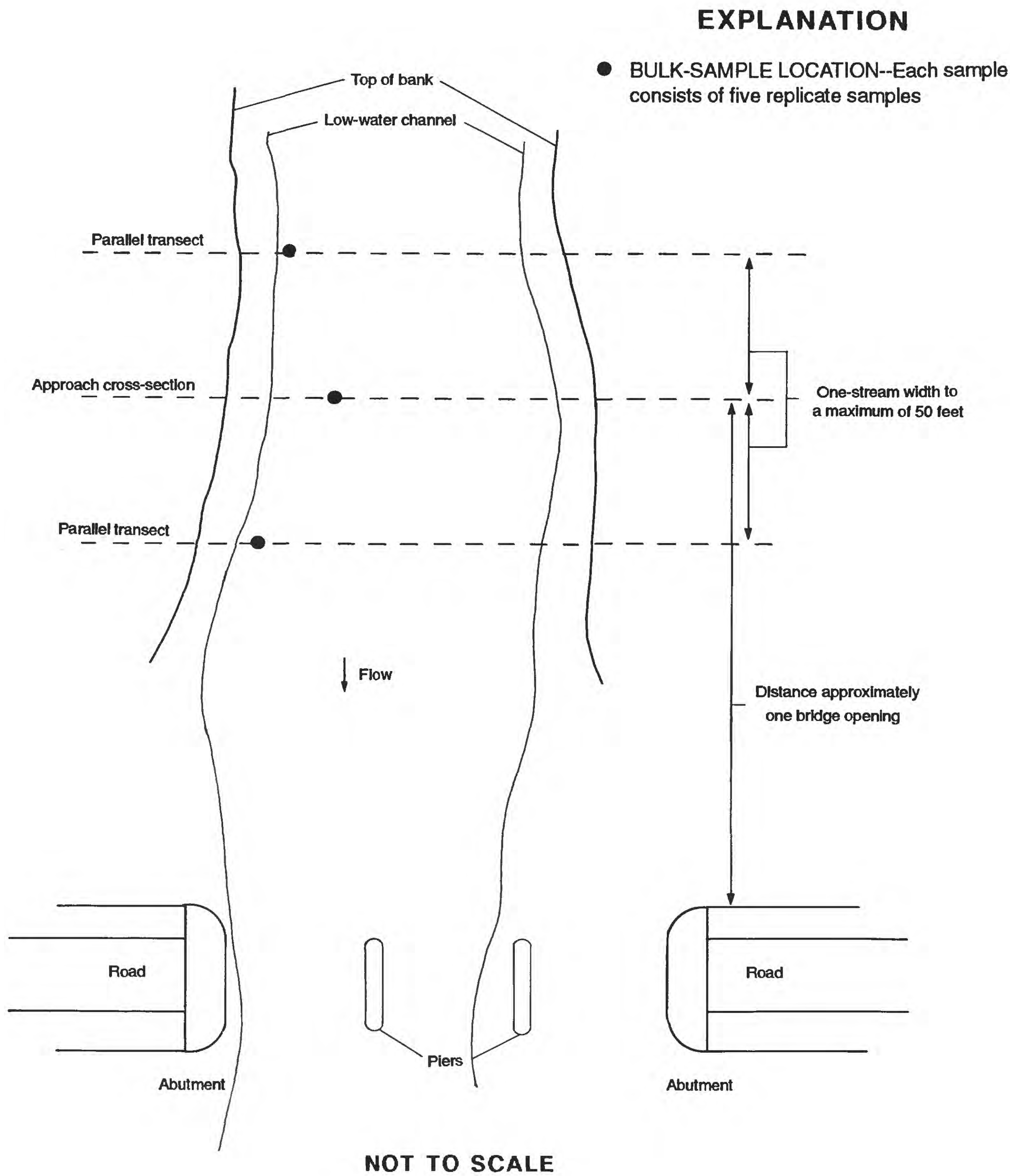


**Figure 6.**–Schematic diagram showing bed-material sample locations at a typical bridge site over a coarse-grained streambed.

cross section (fig. 7). A composite sample, consisting of five replicate samples, was obtained at each sampling vertical. Replicate samples were collected at different points in the vicinity of the sample vertical with the result that each replicate sample collected undisturbed material. Sample material was collected at one vertical located at the upstream side of the abutments, outside of any existing scour holes. Two samples were collected on the upstream side of each pier, approximately two-pier diameters from the pier, and outside of any existing scour holes. The composite samples collected at each vertical were analyzed separately.

Samples were obtained at three parallel transects, one stream width to a maximum of 50 ft apart. The center transect was located in the vicinity of the approach cross section. A total of five composite samples were collected, one composite sample from each of the following stream locations: the right bank, the right side of the channel, the center of the channel, the left side of the channel, and the left bank. A composite sample consisted of the three verticals (one from the same stream location at each transect) with five replicate samples each. Bulk samples were not collected from the approach cross sections at Assawoman Bay near Fenwick Island, Del., due to limited access and boat traffic.

## BRIDGE-SCOUR-DATA COLLECTION

Problems associated with measuring streambed profiles and velocities around bridge piers and abutments during floods, and the interaction of complex streamflow patterns with alluvial streambed materials, make accurate field data difficult to obtain. Because of the complexity of the problem, equipment and procedures for collecting bridge-scour data need to be simple to achieve the desired results. This section describes the equipment and methods used for collection of bridge-scour data in the three-State area of Delaware, Maryland, and Virginia.

### Equipment

Standard streamflow-gaging equipment (except the fathometer) was used to define the streambed profile and flow conditions during the collection of discharge measurements. Measurements of the water-surface elevation, the depth of the river, the velocity of the flow, and the water temperature were collected. The equipment is discussed in detail in Rantz and others (1982).

Water-surface elevations were measured by use of standard surveying equipment. Permanent reference points were established at each bridge and leveled to sea level or gage datum. Steel tapes, wire-weight gages, or automatic-stage recorders connected to floats were used to record the water-surface elevations. Horizontal control was referenced to either the left or right abutment and was laid out parallel to the upstream side of the bridge deck. Reference distances were marked with paint at 10-ft increments on both the upstream and downstream sides of the bridges. Additional reference locations were marked on the upstream side of the bridge at 1-ft increments on each side of the piers for a distance of 2.5-pier diameters. A tag line or steel tape was used to determine the locations of the reference distances.

Depth of the river was measured either by a sounding weight suspended from a reel by a cable, or by a fathometer with the transducer suspended by a rope. The Price-type AA meter was used to measure the velocity of the flow. Columbus sounding weights of 30 to 100 lb were used to keep the cable and velocity meter vertical and stationary in the flow at any desired depth. Counters were mounted on the reels to indicate depth. The reel, sounding weight, and meter were mounted on a bridgeboard, a two-wheeled base and boom, or a four-wheeled base and boom. The two-wheeled base and boom (fig. 8) was used only in Virginia and lifted a maximum weight of 50 lb. The fathometer was either mounted on a two-wheeled handtruck or carried with a strap (fig. 9). The transducer was mounted 0.8 ft below a 15-lb Columbus sounding weight and extended from the bridge by use of the two-wheeled base and boom. A bridgeboard was mounted on the boom when the transducer needed to be extended farther away from the bridge to clear bridge piers or footers.

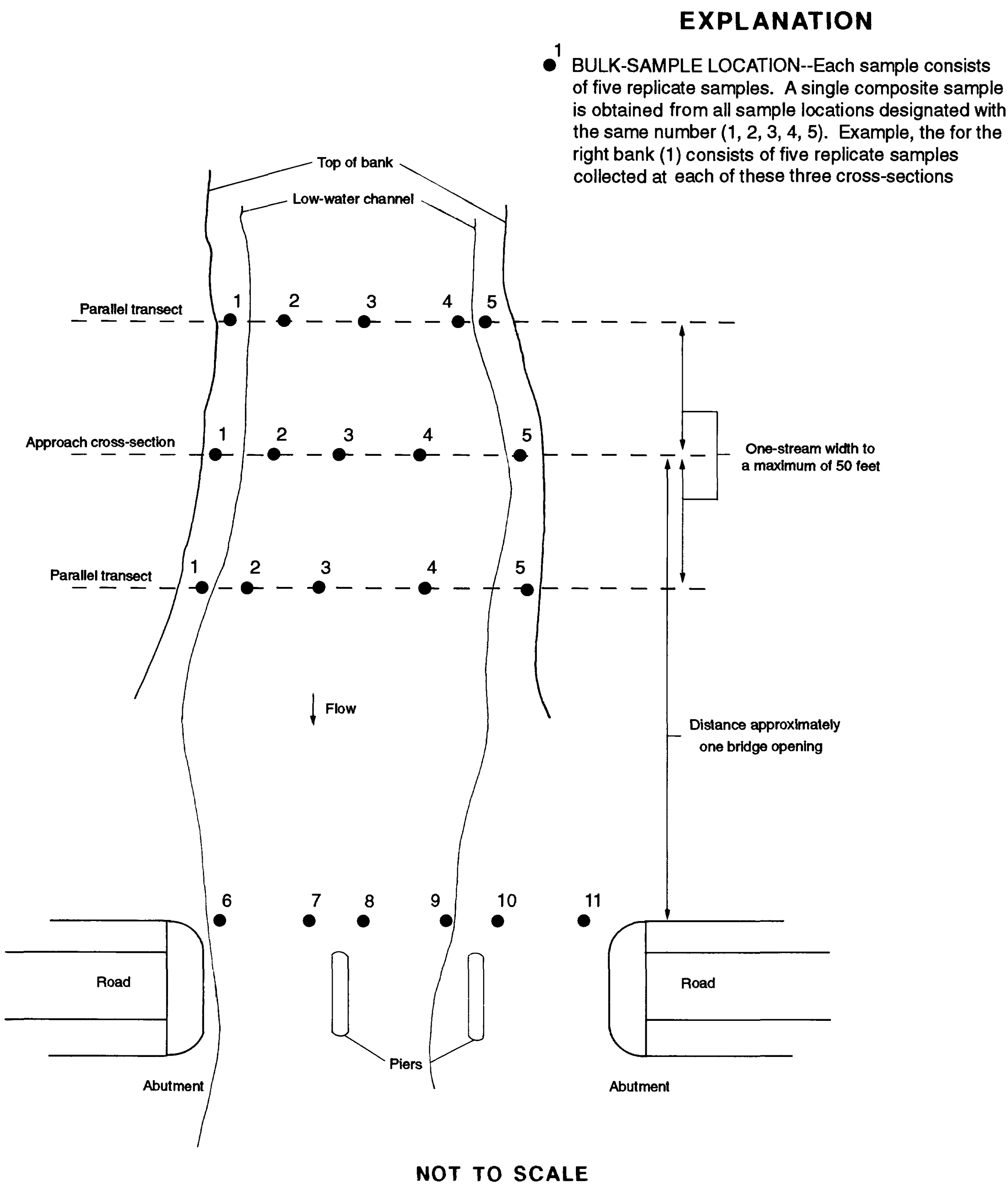


**Figure 7.**–Schematic diagram showing bed-material sample locations at a typical bridge site over a medium-grained or fine-grained streambed.

**Figure 8.**–Two-wheeled base and boom with reel, velocity meter, and sounding weight.

Water temperature was measured at the riverbank using a standard thermometer.

### Measurement Procedures

Standard streamflow-gaging procedures (Rantz and others, 1982) were used to collect depth and velocity data; however, the procedures were modified to define the bed profile near abutments and piers, and to estimate the approach velocity in front of the abutments and piers. Guidelines used for measuring bridge scour follow:

1. When a flood was imminent, sites to be measured were evaluated. The decision on which site or sites to be measured was based on location of the rainfall, distance to the sites, estimated time to peak, manpower available and manpower needed, and number of measurements previously made at each site. All available information, such as telemetry of gage height from nearby streamflow gages or weather predictions by the National Weather Service were used to help estimate the time and magnitude of the peaks.
2. An attempt was made to make at least three bridge-scour measurements at the selected sites during the flood. If possible, one measurement was made on the rising limb of the hydrograph, one near the peak of the hydrograph, and one on the falling limb of the hydrograph. Multiple measurements were needed to determine whether the streambed was actively scouring and filling. Without knowledge of the streambed movement, scour depths from historical scour holes could be incorrectly associated with current flow depths and velocities. Measurement information was useful even if only one or two measurements were made during the flood.
3. The upstream side of the bridge was measured first, except when using the fathometer. Standard measurement procedures were followed unless the flood peak traveled rapidly through the bridge site as indicated by rapidly rising or falling stages. Under such conditions, the number of sections (verticals) was reduced from 25 to 30 sections (the number collected during a normal discharge measurement) to 15 to 20 sections. Velocity measurements at each vertical were made at 0.6 times the stream depth except for the verticals near the piers and abutments. Velocity measurements were made at 0.2 and 0.8 times the stream depth at the abutments and on each side of the piers. These velocities were measured at a vertical close to the abutment or pier, but far enough away so that the vortices produced because of the presence of the abutment or pier did not affect the flow. In most instances, the location of the velocity measurements was 1 to 2 ft from the abutment, or 2 to 2.5 times the diameter of the pier on each side of the pier. The approach velocity in front of the abutment or pier was estimated from the average of the velocities next to the abutment or on each side of the piers. Additional soundings were collected at 1-ft increments on each side of the pier for a distance of 2.5 times the pier diameter. If a

**Figure 9.**–Fathometer mounted on a two-wheeled handcart with two-wheeled base and boom, sounding weight, and transducer.

scour hole existed at the pier, the soundings were continued away from the pier at 1-ft increments, until the scour hole was well defined.

4. The streambed profile on the downstream side of the bridge was defined using 10 to 15 soundings. Additional soundings were not collected near the piers or abutments.
5. Water-surface elevations were measured every 30 minutes at the upstream side of the bridge and before and after the measurement on the downstream side of the bridge. Water temperature was measured after the discharge measurement was completed.
6. When a fathometer was used to define the streambed profile, the downstream side of the bridge was defined first. Next, the streambed profile on the upstream side of the bridge was defined with the fathometer. Finally, a discharge measurement was made from the upstream side of the bridge by use of standard sounding weights and velocity meters. To define the streambed profile, the transducer was maintained at a depth of 0.8 ft below the water surface and moved across the section at a slow pace. One hydrographer controlled the elevation of the transducer and the speed at which the bridge was traversed, while another hydrographer operated the fathometer. A mark was placed on the fathometer trace when the transducer passed the location marks previously painted on the bridge (fig. 10). After both profiles were defined, the discharge measurement was made using procedures previously described; however, few soundings were made near the bridge piers. Soundings were made as close to the side of the pier or footer as possible so that stream depths measured by the sounding weights could be compared to the stream depths measured by the fathometer.

## Accuracy and Limitations

The reduced number of verticals and velocity measurements decrease the accuracy of the discharge computation. Tests performed by Carter and Anderson (1963) have shown that standard discharge measurements with 30 verticals and the velocity measured at 0.2 and 0.8 times the flow depth have a standard error of estimate of 2.2 percent, and measurements with 16 verticals and the velocity measured at 0.6 times the flow depth have

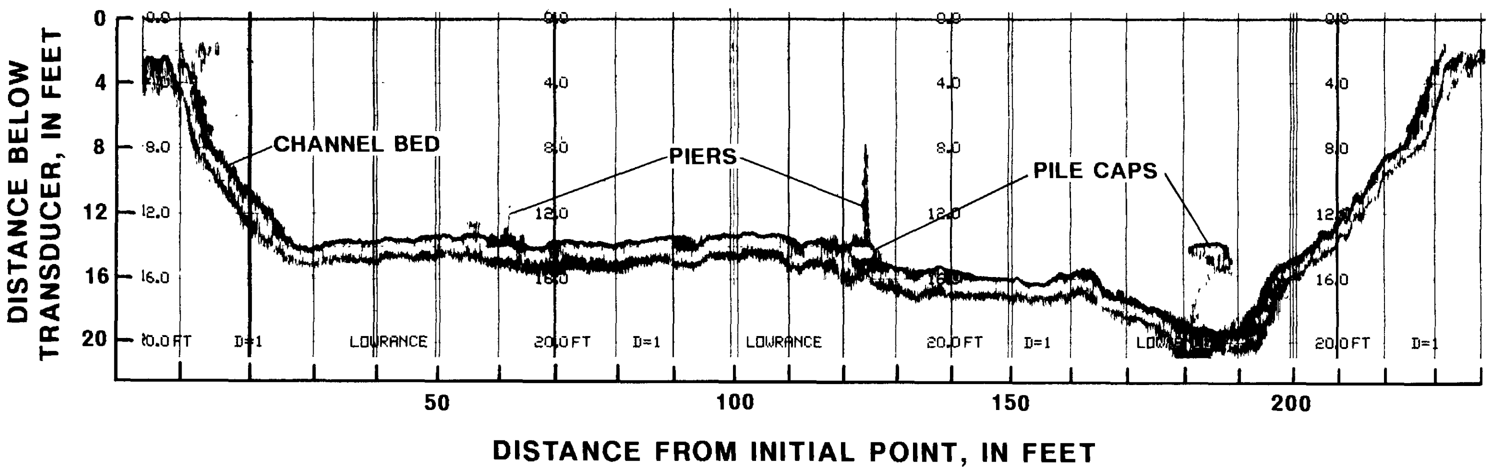


**Figure 10.**–Fathometer trace of upstream bed profile at the Nottoway River near Sebrell, Va., January 18, 1991.

a standard error of estimate of 4.2 percent. Errors associated with the reduced number of verticals and velocity measurements, however, generally are less than the errors expected as the result of changing flow patterns because of a rapidly changing stage (Rantz and others, 1982). Procedures for measuring discharge when the stage is changing rapidly are described in the section "Measurement Procedures" and follow the guidelines in Rantz and others (1982).

Accuracy of the streambed profile using sounding weights or a fathometer are not specifically addressed in this report. Comparison of the streambed profiles defined by each piece of equipment and limitations of the equipment are discussed. Inaccuracies in measuring depths by use of sounding weights are greatest in deep sections or high velocity sections where the sounding weight is swept further downstream. Larger weights could reduce potential errors; however, the increased size and weight can cause other errors, and the larger weights are more difficult to handle. The inability of the fathometer to determine the precise location of the streambed is greatest when working near piers or debris, or in high velocity sections. The center pier and pile cap can be seen in the center of the trace shown in figure 10. The outline of a possible scour hole can also be seen below the pile cap but the exact position of the streambed is difficult to determine because of the multiple returns and poor definition of the bottom. The transducer and sounding weight combination described in the Equipment section worked best in surface velocities of less than 5.0 ft/s. At greater velocities, the transducer would not remain vertical. Increasing the size of the weight located above the transducer was not practical because of the suspension equipment used in this investigation.

Streambed profiles defined using a 50-lb Columbus weight and a fathometer for the Nottoway River near Sebrell, Va., are shown in figure 11. The difference in measured streambed elevations was less than 0.5 ft, except around the piers and pile caps where the difference was greater. These differences could be because of difficulties in accurately measuring streambed elevations in front of the pile cap with the sounding weight, the weight resting on or sliding off debris, or the inability to determine the exact streambed location on the fathometer trace. The best method to determine the streambed profile was the combination of soundings by the weight and the fathometer trace

Errors introduced by estimation of the approach velocity in front of the abutment or pier from averaging the velocities beside the abutment or pier cannot be determined because the approach velocity cannot be measured with the available equipment. Visual observations of the surface velocities in front of the abutments and piers, and at the verticals beside the abutments and piers, indicate that the averaged velocities were similar to the approach velocities.

## SUMMARY

Accurate field measurements of scour are difficult to obtain because of the flow conditions at bridges during floods, and the inability of existing measuring equipment to function under those conditions. Criteria were developed for selection of bridge sites to be monitored for scour during floods. Principal criteria defined for selection of a bridge site were safety of personnel during measurements, accessibility of the site during floods, and accessibility of possible scour holes at abutments and piers. Fifteen bridge sites were selected for active bridge-scour data collection from more than 13,500 bridges spanning waterways in Delaware, Maryland, and Virginia. Initial screening of the sites was accomplished using bridge inventories supplied by the States. Field evaluations were used for the final evaluation. Five bridge sites that were not suitable for active-scour measurements and that were collocated with streamflow-gaging stations were included in the study. At these bridges, data from historical streamflow measurements were used for the scour analysis.

Bed-material characteristics are a principal explanatory variable to scour characteristics at a bridge site. Bed-material sampling procedures were developed to characterize the bed material of the channel near the bridge site. Grid-sample procedures were used in gravel-bed channels to collect bed material for size-distribution analysis at three transects near the approach section. Bulk-sample procedures were used in sand-bed channels to collect bed material for size-distribution analysis near

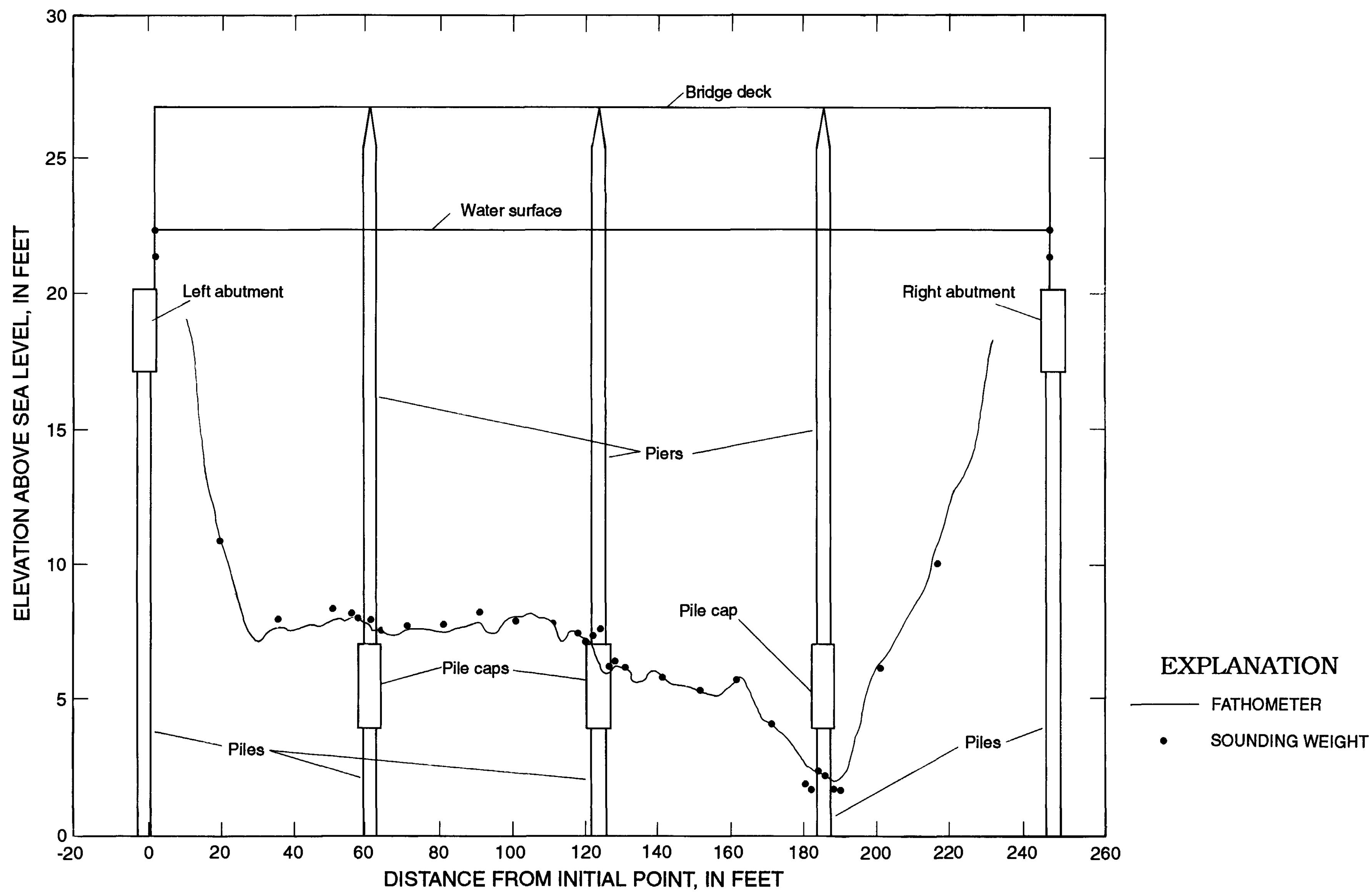


**Figure 11.**–Upstream bed profile at the Nottoway River near Sebrell, Va., defined by sounding weight and fathometer, January 18, 1991.

the abutment and piers, and at three transects near the approach section. Structural information concerning bridge geometry was collected from bridge plans and verified in the field survey. Channel geometry also was surveyed at the approach section, the upstream side of the bridge, the downstream side of the bridge, and at the exit section.

Streamflow-gaging equipment (sounding weight and Price-type AA meter) was used and procedures for defining streambed profiles and velocities near abutments and piers were developed for measuring bridge scour during floods. Techniques to define streambed profiles using a fathometer also were tested. The standard error of estimate is increased from 2.2 to 4.2 percent by modifying the standard discharge-measurement procedures for a bridge-scour measurement. The difference in the streambed profile defined by a sounding weight and fathometer averaged less than 0.5 ft except near piers where the difference was greater. A method combining the use of sounding weights and a fathometer was best in determining the streambed profile for the measuring conditions encountered.

## REFERENCES CITED

Arcement, G.J., Jr., and Schneider, V.R., 1989, Guide for selecting Manning's roughness coefficients for natural channels and flood plains: U.S. Geological Survey Water-Supply Paper 2339, 38 p.

Ashmore, P.E., Yuzyk, T.R., and Herrington, R., 1988, Bed-material sampling in sand-bed streams: Sediment Survey Section, Water Resources Branch, Inland Waters Directorate, Environment Canada, Report IWD-HQ-WRB-SS-88-4, 83 p.

Barnes, H.H., Jr., 1967, Roughness characteristics of natural channels: U.S. Geological Survey Water-Supply Paper 1849, 213 p.

Benson, M.A., Dalrymple, Tate, 1968, General field and office procedures for indirect discharge measurements: U.S. Geological Survey Techniques of Water-Resources Investigations, book 3, chap. A1, 30 p.

Butch, G.K., 1991, Measurement of bridge scour at selected sites in New York, excluding Long Island: U.S. Geological Survey Water-Resources Investigations Report 91-4083, 17 p.

Carter, R.W., and Anderson, I.E., 1963, Accuracy of current-meter measurements: American Society of Civil Engineers Journal, v. 89, no. HY4, p. 105-115.

Chang, F.M., 1980, Scour at bridge piers–field data from Louisiana files: Federal Highway Administration, Report No. FHWA-RD-79-105, 32 p.

Davis, S.R., 1984, Case histories of scour problems at bridges: Transportation Research Record 950, p. 149-155.

Froehlich, D.C., 1988, Analysis of onsite measurements of scour at piers: Proceedings of the 1988 National Conference, Hydraulic Engineering, American Society of Civil Engineers, Colorado Springs, Colo., August 8-12, 1988, p. 534-539.

_____1991, Upper confidence limit of local pier-scour predictions, in Third Bridge Engineering Conference Proceedings: U.S. Transportation Research Board, Washington, D.C., Research Record 1290, v. 2, 12 p.

Guy, H.P., 1969, Laboratory theory and methods for sediment analysis: U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chap. C1, 58 p.

Guy, H.P., and Norman, V.W., 1970, Field methods for measurement of fluvial sediment: U.S. Geological Survey Techniques of Water-Resources Investigations, book 3, chap. C2, 59 p.

Highway Research Board, 1970, Scour at bridge waterways: National Cooperative Highway Research Program Synthesis of Highway Practice Washington D.C., no. 5, 37 p.

Hopkins, G.R., Vance, R.W., and Kasraie, B., 1980, Scour around bridge piers: U.S. Federal Highway Administration, Washington, D.C., FHWA-RD-79-103, 141 p.

International Organization for Standardization, 1977, Liquid flow measurement in open channels–Bed material sampling: International Organization for Standardization-4364-1977 (E), 13 p.

_____1989, Liquid flow measurement in open channels–Sampling and analysis of gravel-bed material: International Organization for Standardization Draft International Standard 9195, 9 p.

Jarrett, R.D., 1985, Determination of roughness coefficients for streams in Colorado: U.S. Geological Survey Water-Resources Investigations Report 85-4004, 54 p.

Jarrett, R.D., and Boyle, J.M., 1986, Pilot study for collection of bridge-scour data: U.S. Geological Survey Water-Resources Investigations Report 86-4030, 46 p.

Jones, J.S., 1984, Comparison of prediction equations for bridge pier and abutment scour: Transportation Research Record 950, Second Bridge Engineering Conference, v. 2, p. 202-209.

Melville, B.W., 1975, Local scour at bridge sites: University of Auckland, School of Engineering, Auckland, New Zealand, Report No. 117.

Norman, V.W., 1975, Scour at selected bridge sites in Alaska: U.S. Geological Survey Water-Resources Investigations 32-75, 171 p.

Rantz, S.E., and others, 1982, Measurement of stage and discharge, volume 1 of Measurement and Computation of Streamflow: U.S. Geological Survey Water-Supply Paper 2175, 284 p.

Richardson, E.V., Simons, D.B., and Julien, P.Y., 1990, Highways in the river environment, participant notebook–Fort Collins, Colo.: U.S. Federal Highway Administration FHWA-HI-90-016, 718 p.

U.S. Federal Highway Administration, 1990, High priority National program area–McLean, Va.: Federal Highway Administration Report No. FHWA-RD-90-054, 8 p.

Yuzyk, T.R., 1986, Bed material sampling in gravel-bed streams: Sediment Survey Section, Water Resources Branch, Inland Waters Directorate, Environment Canada, Report IWD-WRB-HQ-SS-86-7, 74 p.