MEASUREMENT OF BRIDGE SCOUR AT SELECTED SITES IN NEW YORK, EXCLUDING LONG ISLAND

By Gerard K. Butch

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MANUEL LUJAN, JR., Secretary

U.S. GEOLOGICAL SURVEY
Dallas L. Peck, Director

For additional information write to:

U.S. Geological Survey
P.O. Box 1669
Albany, NY 12201

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CONVERSION FACTORS

Multiply	*By*	*To obtain*
	Length	
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
square mile (mi^2)	2.590	square kilometer
	Mass	
pound (lb)	0.4536	kilogram

Other Terms

Kilohertz (kHz)
Megahertz (MHz)

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By Gerard K. Butch

Abstract

In 1988, the U.S. Geological Survey (USGS), in cooperation with the New York State Department of Transportation, collected bridge-scour data at 77 sites throughout New York, excluding Long Island. This report describes the results of the first 2 years of the study to evaluate data-collection methods and predictive equations for local scour at bridges. Methods are similar to the "limited approach" developed by the USGS in cooperative studies with the Federal Highway Administration and are compatible with equipment and procedures used in the USGS streamflow-gaging program.

Local scour holes 1 to 2 feet deep were found at many piers, but not abutments, at the start of the study. At a few sites, the scour has exposed spread footings that were buried during construction. Fifteen measurements during high flows, including two flows with a recurrence interval exceeding 5 years, detected no new scour beyond the previously documented holes. Flows with recurrence intervals greater than 5 years may be necessary to trigger scour in streams with coarse bed material. The scour holes and coarse bed material also indicate that clear-water scour is more common than live-bed scour in the streams studied.

Sonar and other geophysical techniques were evaluated for their effectiveness in bridge-scour investigations. A transducer inside a 100-pound sounding weight suspended from a crane provided an alternative method of measuring water depth, although moving the unit across the bridge was cumbersome. Another method used a transducer, installed on a bridge pier, and a data logger that recorded the distance between the transducer and the streambed automatically at selected time intervals. Geophysical techniques applied to gravel and cobble streambeds did not detect any backfilled scour holes, possibly because (1) holes did not exist, (2) resolution of the equipment (1 to 2 feet) was insufficient to detect a shallow infilled layer, or (3) infilled material was the same as the streambed.

INTRODUCTION

About 500,000 bridges in the United States are built over water and are subject to scour, the most common cause of bridge failure. Accurate estimates of potential scour are needed for the design, construction, and maintenance of bridges. The added cost of making a bridge resistant to scour is generally small in relation to the cost of bridge failure (Federal Highway Administration, 1988).

Scour around bridge piers has been the subject of many investigations (Highway Research Record, 1973; Brice and others, 1978a, b; Wilson, 1979; Davis, 1984). Many equations have been developed to estimate local scour depth at bridges (National Cooperative Highway Research Program, 1970; Anderson, 1974; Norman, 1975; Hopkins and others, 1980; Jones, 1984; Jarrett and Boyle, 1986; Copp and others, 1988; Froehlich, 1988; Richardson and others, 1988). Most of the equations are based on scale-model laboratory measurements because three-dimensional flow patterns near piers during floods make field measurements difficult. Many equations overestimate scour depth along New York streams, partly because they were developed for sand-bed channels, whereas most stream channels in New York are armored with several feet of gravel, cobbles, and(or) boulders over fine-grained sediments or compact till (Raudkivi and Ettema, 1983; Copp and others, 1988; Federal Highway Administration, 1988; and Richardson and others, 1988). Armoring occurs wherever flowing water is sufficient to remove the fine particles but leaves behind the coarse materials, which serve as a protective zone that prevents the movement of subsurface materials (Parker and Klingeman, 1982) during streamflows that do not exceed the shear strength of the armor layer. Yet, despite an armor layer's ability to decrease the rate and depth of scour, stepwise erosion of an armor layer may produce greater scour depth than erosion of a uniform bed (Raudkivi and Ettema, 1985). Failure of equations to account for this armor layer produces results that rarely agree with field measurements, and the widely varying results of these equations for a given set of conditions reduces confidence in their applicability. Uncertainty as to which scour equation to use for a particular set of conditions has increased interest in developing data bases that represent full-scale, prototype field conditions. Field collection of scour data and increased knowledge of scour processes may lead to improved bridge designs (National Cooperative Highway Research Program, 1970; Hopkins and others, 1980, Jones, 1984).

Severe floods in western New York during June 1972 damaged 182 bridges along New York State roads and many bridges on county roads. Scour and debris were the primary causes of damage (Highway Research Record, 1973). Damages from floods throughout southeastern New York in April 1987 ranged from abutment washouts of short, single-span bridges over small streams to the catastrophic collapse of the five-span, multilane New York State Thruway bridge over Schoharie Creek that claimed 10 lives (Zembrzuski and Evans, 1989). Floods in June 1989, in western New York, damaged several bridges.

In 1988, the U.S. Geological Survey (USGS), in cooperation with the New York State Department of Transportation (NYSDOT), began a 6-year study of bridge scour in New York through methods similar to those used in its national bridge-scour program in other States (Jarrett and Boyle, 1986). The objectives were to (1) compile a statewide data base, (2) evaluate data-collection methods and predictive equations for local scour, and (3) identify the types of channels and bridges that are vulnerable to scour.

Purpose and Scope

This report describes the techniques used to collect bridge-scour data at the 77 sites and presents the criteria for site selection, methods of data collection, and types of equipment used. It describes, in general terms, the extent of scour measured during the first 2 years of data collection and discusses the limitations of certain procedures and equipment. It also compares results obtained through conventional methods of data collection with those obtained by sonar and other geophysical techniques.

Acknowledgments

Thanks are extended to NYSDOT for providing bridge plans, inspection and inventory reports, boring logs, particle-size analysis, fathometer mapping, and assistance with the fixed sonar installation, debris removal, and traffic control.

Additional support for data-collection programs was provided by the New York State Department of Environmental Conservation, the U.S. Army Corps of Engineers, the National Weather Service, the Hudson River - Black River Regulating District, New York Power Authority, Niagara Mohawk Power Corporation, New York City Department of Environmental Protection, Cornell University, and several other municipal and county agencies.

TYPES OF BRIDGE SCOUR

Scour is the erosive action of flowing water that removes material from the streambed (Federal Highway Administration, 1988), and *scour depth* is the depth to which material is removed below a stated datum. Scour is a natural phenomenon and can occur in any stream that contains erodible bed material.

Three types of scour can occur at a bridge: general scour, constriction or contraction scour, and local scour. *General scour* is the progressive degradation or lowering of the streambed through natural or man-induced processes. Degradation progressing downstream generally results from increased discharge, decreased bedload, or decreased bed-material size. Upstream degradation is generally caused by an increased water-surface slope (Galay, 1983). Lateral erosion caused by a shift in the flow or meander pattern is included with general scour. *Constriction scour* is streambed erosion caused by increased flow velocity near a bridge that results from the decrease in flow area formed by the bridge, approach embankments, or piers. *Local scour* is erosion caused by local disturbances in the flow, such as vortices and eddies in the vicinity of piers. A general practice in bridge design is to estimate the depth of each type of scour separately, then sum the estimated depths to obtain the total scour depth.

The depth and extent of scour is influenced by the following factors, described by Richardson and others (1988); Raudkivi and Ettema (1983, 1985); Klingeman (1973); and Blodgett (1984):

1. Velocity, depth, and angle of approach flow
2. Size and gradation of bed material
3. Bridge geometry
4. Presence of debris or ice
5. Duration of high flow
6. Channel geometry
7. Total number of high flows
8. Channel morphology
9. Bedload supply

Local scour may produce greater scour depths than the other types of scour (Richardson and others, 1988) and is the primary focus of this study. An example of the flow pattern and vortex system induced by a pier is illustrated in figure 1. These vortices result from the obstruction of flow at the upstream face of the pier and subsequent acceleration of the flow around the nose of the pier. The location of a spread footing also has been found to affect scour. Footings that project above the streambed can become the principal cause of local scour. Footings located at or below the streambed tend to reduce pier scour, but the reduction may be negligible unless the footing extends a significant distance away from the pier (Jones, 1989).

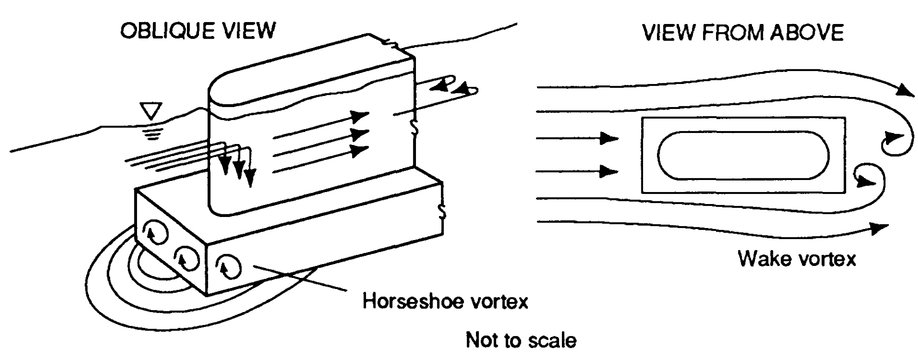

Figure 1.—Flow pattern and vortex system induced by a pier. (Modified from Richardson and others, 1988, fig. 5.5.6)

Two types of local scour are "clear-water" scour and "live-bed" scour. *Clear-water* scour occurs when bed material upstream from the scour hole is motionless and cannot replace material removed from the hole. *Live-bed* scour occurs when bed material upstream of the scour hole is moving, and scour depth increases only if the removal rate of material from the hole exceeds the transport rate of material into the hole.

MEASUREMENT OF BRIDGE SCOUR

The dynamic processes of a stream can cause the streambed to degrade and then aggrade during a flood. Scour holes may develop during floods and fill before the stream returns to normal levels. The interface between the backfilled material and the scour hole can be measured by geophysical techniques if the two layers have differing electrical or seismic-reflection properties (Gorin and Haeni, 1989). If the streambed is composed of fine material, a rod can be used to probe the scour hole and estimate the size or gradation of the armor layer and subsurface material.

Sounding weights are commonly used to measure water depth; however, high velocities and turbulence during floods in New York have been sufficient to cause 150-lb weights to drift downstream, making accurate depth measurement impossible. Although corrections can be applied to compensate for most of this type of error, the exact location of the weight is always uncertain (Rantz and others, 1982; Coon and Futrell, 1986; Beverage, 1987). The use of mobile and fixed sonar instruments to measure scour depth is being studied. The mobile technique used in New York is similar to the method used by the USGS in Arkansas (Southard, 1989), where a graphic recorder plots a cross section of the streambed while a transducer, submerged 1 to 3 ft, is moved across the stream. A fixed sonar installation can be used to automatically record the distance between the transducer and the streambed at the base of a bridge pier.

Site Selection

Selection of potential study sites was based on data from USGS stations. Changes in the stage-to-discharge relation at a streamflow-gaging station may indicate bed-material movement or channel instability near a bridge. Data from crest-stage partial-record stations also were reviewed, and stations in extensive areas of erodible bed material (sand and gravel) were identified (fig. 2). Stations on streams with drainage areas greater than 100 mi^2 and a potential for scour also were identified. Factors to be considered in the evaluation of scour potential included erodible bed material, high stream velocity, and any documented scour nearby. Bridges with a medium or high scour-susceptibility rating[1] in NYSDOT's bridge-inventory file were reviewed, and bridges scheduled for immediate scour countermeasures (such as riprap or concrete-filled bags) were excluded.

Sites identified from the preliminary review were inspected for evidence of scour. Priority was given to sites near USGS stations along streams that contain erodible bed material or that appeared unstable from review of USGS rating curves and NYSDOT files. A checklist developed by the USGS to standardize the selection process is shown in figure 3. If a bridge did not meet the selection criteria, the next two bridges upstream and downstream from the site were inspected. The site-selection criteria were as follows:

a. Site is at or near a USGS station to facilitate data collection and assess channel stability.

b. Drainage basin exceeds 100 mi^2. Bridges in smaller basins generally have single spans (no piers), and the short duration of high flows limits the scour mechanism and the ability to collect flood data.

c. Streambed contains an ample supply of bed material prone to scour. Piers on bedrock or protected by riprap are excluded.

d. Pier nose is square, round, or sharp.

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1 Preliminary results of a NYSDOT scour-susceptibility investigation of 3,778 State bridges over water: high susceptibility = 9 percent, medium susceptibility = 38 percent, and low susceptibility = 53 percent. Percentages are based on review of 420 bridges (Georgopoulos, S. G., New York State Department of Transportation, oral commun., 1991).

e. Network represents a wide range of basin characteristics.

f. Pier(s) is in the main channel.

g. Channel is relatively uniform upstream and downstream from bridge.

h. Flow-angle approaching pier is 10 degrees or less.

i. Scour is evident (although having a few sites with no scour is acceptable).

j. Bridge does not constrict main channel.

k. Pier(s) does not reduce cross-sectional flow area by more than 10 percent.

l. Nearest reservoir is at least 10 mi upstream from the site.

m. Quantity of debris or ice is minimal.

n. Water depth at a few piers always exceeds 5 ft.

o. Boat access is available on large streams (to facilitate data collection).

p. Information on site construction, inspection, and maintenance is available.

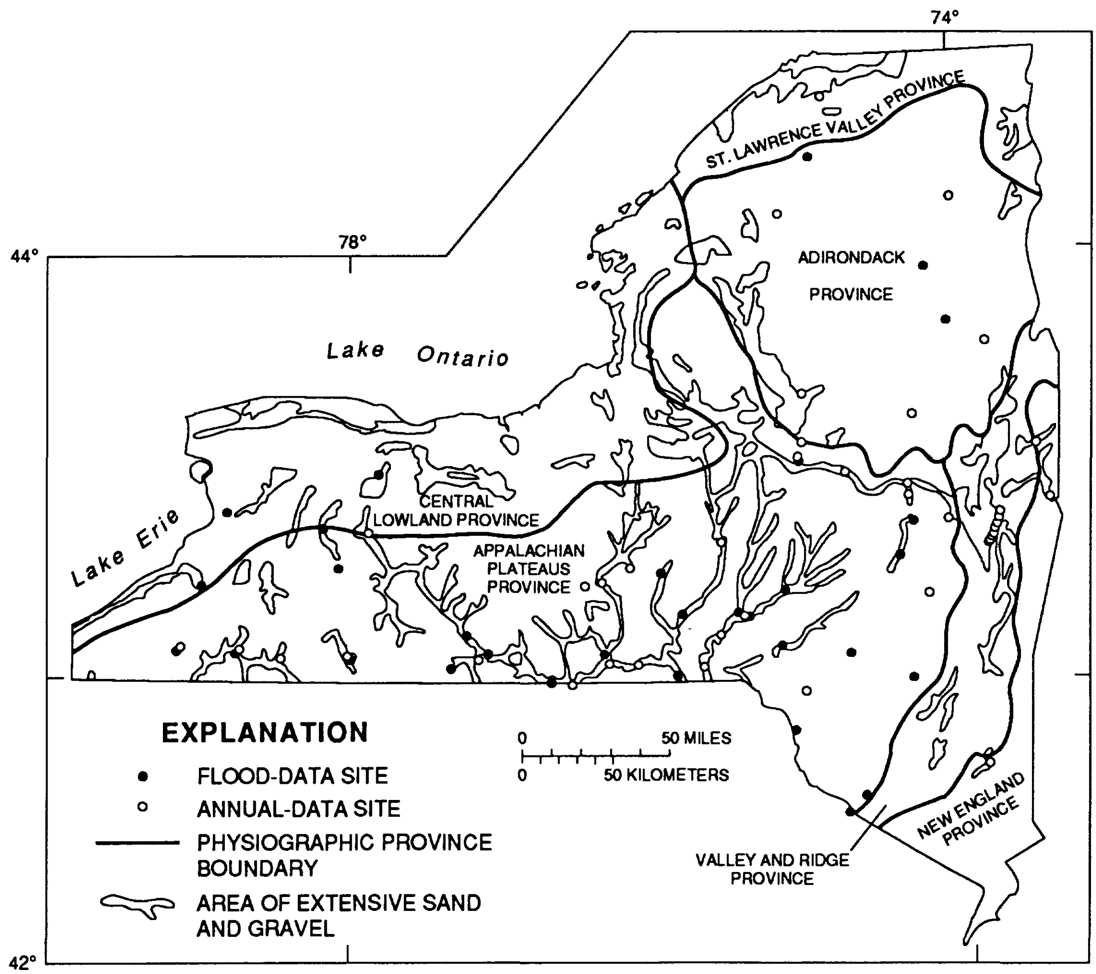

Figure 2.—Locations of study sites, physiographic provinces, and soil associations. (Modified from Cline, 1961, pl. 1.)

Rating Item	+	0	-
Is bridge accessible at high flow? Yes (+); No (-)			
Is streambed composed of bedrock or clay? No (+); Yes (-)			
Distance from bridge deck to streambed (in feet)? Less than 40 (+); 40 to 80 (0); more than 80 (-)			
Is sustained high flow likely during a flood? Yes (+); No (-)			
Can scour be measured safely at this bridge? Yes (+); No(-)			
Are there any other factors that would prevent scour from being measured at this site? No (+); Yes (-)			
Is scour likely to occur at one or more piers? Yes (+); No (0)			/////
Is scour likely to occur at more than one pier? Yes (+); No (0)			/////
Is scour likely to occur at one or more bridge abutments? Yes (+); No (0)			/////
Can pier be reached by a sounding weight lowered from the bridge? Yes (+); No (0)			/////
Does the bridge constrict high flows significantly? Yes (+); No (0)			/////
Shape of pier nose: square or round (+); sharp (0)			/////
Angle at which flow approaches piers (in degrees): 0 to 5 (+); more than 5 (0)			/////
Are pier footings exposed? No (+); Yes or don't know (0)			/////
Has riprap been placed around one or more piers? No (+); Yes or don't know (0)			/////
Is debris lodged on one or more piers? No (+); Yes (0)			/////
Is a gaging station located nearby (within view of the bridge)? Yes (+); No (0)			/////
Is boat access available nearby? Yes (+); No (0)			/////
Does the bridge have trusses? No (+); Yes (0)			/////
Will a traffic lane need to be closed to make measurements? No (+); Yes (0)			/////
Totals (+, 0, and -)			

Figure 3.—Checklist for bridge-site selection. (From U.S. Geological Survey, written commun., 1989).

The locations of bridge sites being studied are shown in figures 2 and 4, and listed in table 1 (at end of report). The network represents six physiographic provinces (fig. 2) in upstate New York[1] and includes a wide range of basin characteristics and bridge designs. Drainage areas range from 30 mi^2 to more than 8,000 mi^2. Some sites with drainage areas less than 100 mi^2 were selected because (1) scour was evident, (2) a USGS station was nearby, or (3) it improved the spatial distribution of the network. Despite these additional considerations, only a few sites met the selection criteria in the Central Lowland, St. Lawrence Valley, and New England physiographic provinces (fig. 2). All bridges were constructed between 1902 and 1989.

Study sites were divided into two categories: flood-data sites and annual-data sites (fig. 4 and table 1). Flood-data sites are locations where data are collected during high flows; data from these sites can be used to identify which types of channels and bridges are vulnerable to scour and to evaluate local scour equations. Annual-data sites provide an inexpensive method of expanding the data base; at these sites the streambed elevation along the upstream side of the bridge is measured annually. A total of 77 bridges were selected—31 for flood-data collection and 46 for annual-data collection.
Additional criteria for selecting flood-data sites were:

a. Streambed adjacent to pier is accessible from upstream side of bridge.

b. Distance from bridge deck to streambed is less than 80 ft, preferably less than 40 ft.

c. Bridge is wide enough to provide safe working space for a two-person crew and measuring equipment and does not interfere with operation of equipment.

d. Telemetry is available or an observer is nearby to provide flood-alert information.

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1 Long Island was excluded from the study area because the drainage basins are small (generally less than 30 mi^2) and channel slopes low, with slow stream velocity.

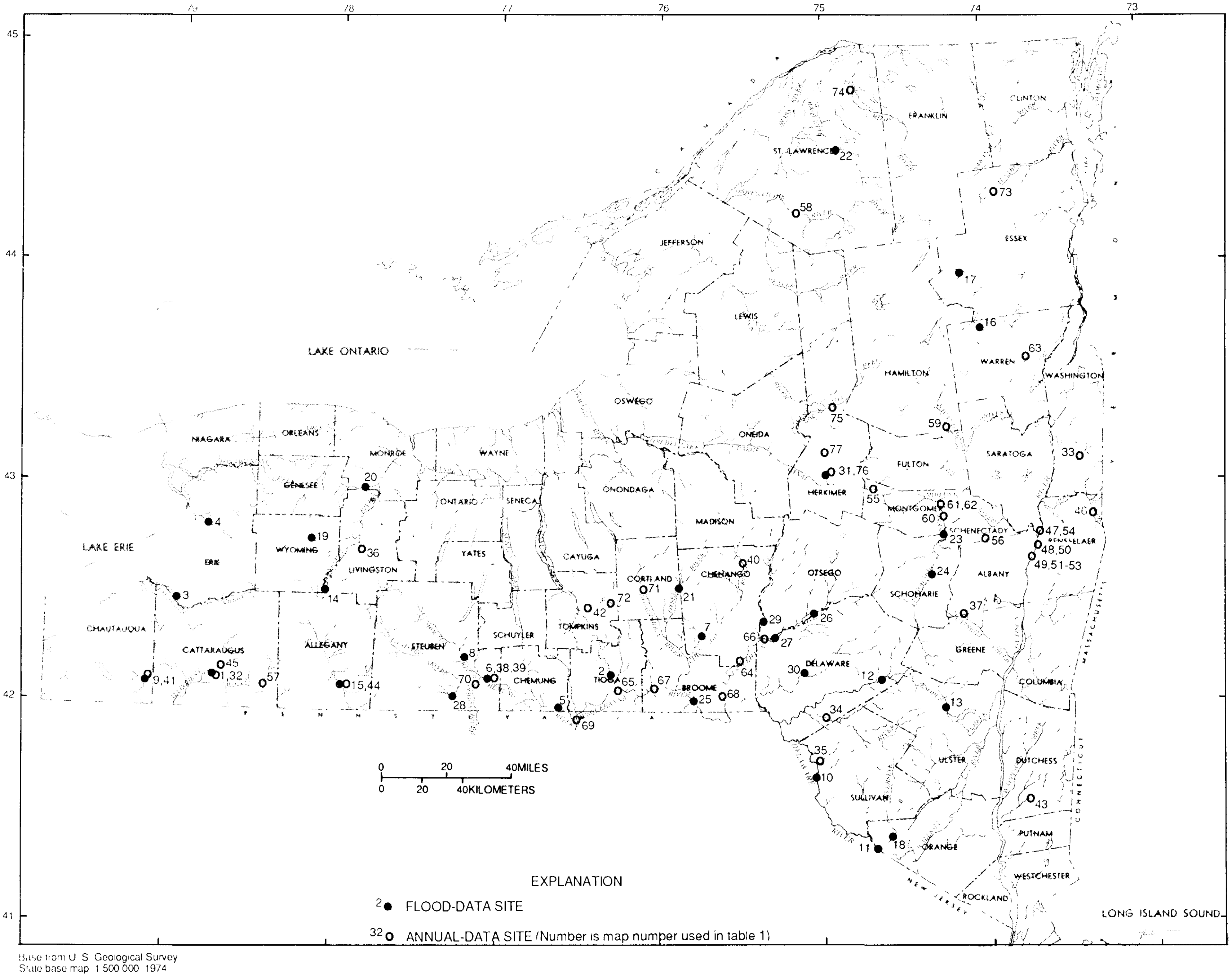

Figure 4.--Locations of study sites.

Data Collection

Data collection at the 77 bridges began in May 1989 (fig. 4). Flood data are being collected at 31 bridges, and annual cross-section data at the remaining 46. Methods are similar to the "limited approach" developed by the USGS in cooperative studies with the Federal Highway Administration, whereby discharge, velocity, streambed elevation, and bed-material data are collected through equipment and procedures compatible with the Survey's stream-gaging program (Jarrett and Boyle, 1986). This approach is being used in the USGS national bridge-scour program and in similar studies in other States; scour data collected in these studies may supplement data collected in New York. Sonar and other geophysical techniques are being used at a few sites to evaluate their usefulness.

Flood Data

Data from high flows are necessary to identify changes in streambed elevation, velocity distribution around piers, and bed-material characteristics. Results are used to determine which types of channels and bridges are vulnerable to scour and to evaluate local scour equations.

Reference points surveyed to a common datum were established at four cross sections at each site—the upstream and downstream bridge railings, the approach section (one bridge-width upstream), and the exit section (one bridge-width downstream). The water-surface and streambed-elevations at each cross section were also calculated.

Copies of bridge plans, boring logs, maintenance and inspection sheets, and fathometer surveys were obtained from NYSDOT. Dimensions of the piers and footings were recorded from bridge plans or site inspections. Channel-roughness coefficients at each cross section were estimated (Barnes, 1977).

Discharges of the 2-year and 5-year floods[1] were estimated from guidelines outlined by the Interagency Advisory Committee on Water Data (1982) or multiple regression analyses (Zembrzuski and Dunn, 1979). Flood data are collected whenever streamflow exceeds the mean-annual flood, and postflood data are collected when the flow exceeds a 5-year recurrence interval. The selected recurrence intervals were based on studies of sand, gravel, and cobble streambeds in which thresholds for particle motion were exceeded during flows of these magnitudes (Culbertson and others, 1967; Norman, 1975; Andrews, 1979, 1984; and Sidle, 1988).

A bed-material sample was collected in a shallow area of the channel or at water's edge near each bridge. A variation of the grid-sampling technique (International Organization for Standardization, 1989) was used because the streambeds are armored. The physical size of a particle, especially gravel or larger, can be expressed in terms of the three diameters (axes) of the particle that are mutally perpendicular (longest, intermediate, and shortest). In this study, the intermediate axis of each particle or rock was measured with calipers every 0.5 ft along a 50-ft tape. The frequency of each size interval is the percentage, by number, of the 100 rocks or particles in the original sample that fall in the interval. A USGS bedload sampler is to be used at streams that may have live-bed scour at high flow to determine the size of the bed material in motion (Helley and Smith, 1971).

The size distribution of the subsurface material is estimated from a 5- to 10-lb bulk sample collected after removal of the armor layer. The bulk sample was collected in the same area as the grid sample. The frequency of each size interval is expressed as the percentage, by mass, of the total sample that falls within the interval. The relations among different methods of sampling that have been established for densely packed cubes in random arrangement indicate that the grid sample (by number) frequency is equivalent to the bulk sample (by mass) frequency (Kellerhals and Bray, 1971). Core samples from borings are to be collected at selected sites for particle-size analysis.

Baseline cross sections were measured from each reference point at the beginning of the study to determine the extent of scour. Streambed elevations at the sections are compared with (1) those shown

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1 The 2-year flood (approximate mean annual) has a 50-percent chance of occurring in any 1-year period, and the 5-year flood has a 20-percent chance of occurring in any 1-year period.

on bridge plans, (2) previous measurements at the site, and (3) data collected during the study. About 20 soundings were used to define each cross section, and additional soundings within one pier width of each pier were used to provide detail at the upstream and downstream sides of the pier. The cross sections at the approach and exit sections are used to measure general scour; those at the bridge are used to measure constriction scour; and soundings near the pier are used to determine local scour.

Whenever discharge at a site exceeds the mean-annual flood, the following procedures are used:

1. Make a standard discharge measurement at the upstream side of the bridge.
2. Measure water-surface elevations at the approach section, upstream and downstream sides of the bridge, and exit section before and after the discharge measurement.
3. Make additional depth soundings across the downstream side of the bridge and at the upstream and downstream ends of the pier(s) with a sounding weight or by the mobile-sonar technique. If the sounding weight is used, make the soundings about 1 ft apart within one pier width of the pier, and remove the velocity meter to reduce drag.
4. Photograph the stream and bridge (during high flow and after flow recedes) to document the hydraulic conditions, particularly the state of flow, the direction (angle) of flow approaching the bridge, the presence of debris or ice, eddies, water-surface profile near piers, drawdown, and any evidence of scour at piers.
5. Evaluate bedload-transport conditions with a bedload sampler or by listening for the sound of rocks striking the bridge or other rocks.
6. Measure water temperature.
7. If the recurrence interval of the flood exceeds 5 years, make depth soundings and measure gage height at both sides of the bridge after the flow recedes to determine whether changes in streambed elevation have occurred.

Annual Data

Data are collected annually at 46 sites to expand the data base. The streambed elevation is measured in relation to a reference point established on the upstream side of each bridge. About 20 soundings are used to define a cross section, and additional soundings are made within one pier width of each pier. Dimensions of the piers and footings are determined from bridge plans or site inspections. An annual-data site can become a flood-data site if significant scour is measured.

Supplemental Data

Since 1984, NYSDOT bridge-inspection procedures require scour-depth measurements every 2 years, and diving inspections at bridges in deep water every 5 years. This information, along with data from bridge plans and USGS measurements, is to be analyzed to determine long-term changes in streambed elevation.

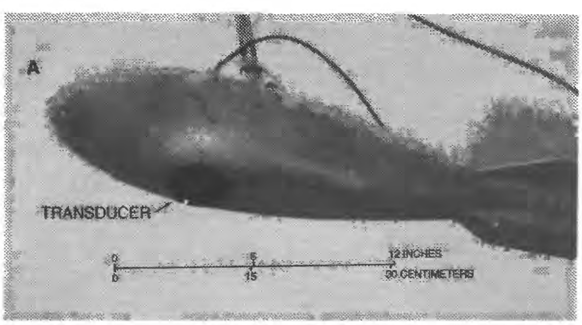
Equipment

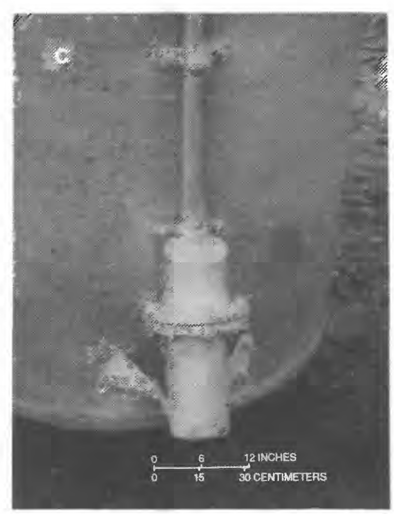
Standard USGS streamflow-measuring equipment is used to collect most of the scour data. This equipment includes a four-wheel base and crane, velocity meter, and sounding weight (50 to 100 lb); descriptions are given in Rantz and others (1982). Transducers mounted on boats, floats, and piers have been used to measure scour depth (Norman, 1975; Hopkins and others, 1980; and Skinner, 1986). In this study, sonar and other geophysical equipment are being tested for accuracy, safety, and ease of operation. The equipment must be reliable, simple, and practical.

The mobile sonar system used in this study is a transducer mounted in a 100-lb sounding weight (fig. 5A). The system is portable and can be used to collect data at several locations.The design of the sounding weight enables the transducer to remain horizontal in the water. The transducer is deployed from a four-wheel base and crane, but a truck mount can be used if no obstruction such as guardrails interfere with equipment operation. Output is plotted by a graphic recorder.

A sonar unit (fig. 5B) attached to a bridge pier is being evaluated. This unit was chosen because the analog output can be transmitted to a data logger as far as 300 ft away; other systems with digital or graphic output must be within 100 ft of the transducer and were not compatible with the data logger. The force of waterborne ice and debris can severely damage or destroy this equipment; therefore a shield was designed to protect the transducer and sonar unit (fig. 5C). Newer models allow the sonar unit to be positioned out of water. The data logger activates the unit at preselected time intervals, records the distance between the transducer and streambed, and transmits the data by satellite telemetry.

Four types of geophysical equipment are being used to calculate the depth of backfilled material in a scour hole: ground-penetrating radar, a tuned transducer, a color fathometer, and a black-and-white fathometer; descriptions are given in Gorin and Haeni (1989). The radar system, with dual 80-MHz antennae, is floated in water. The output is recorded on magnetic tape and a graphic recorder. The tuned transducer is operated from a boat at a frequency of 3 to 14 kHz. The output is recorded with equipment similar to the radar system. The color fathometer, operating at 20 to 100 kHz, digitizes reflected seismic signals and assigns a color for every 6-decibel change in the acoustic impedance of the reflected signals. The output is recorded on cassette tape and displayed on a color monitor. A black-and-white fathometer, operating at a frequency of 200 kHz, can distinguish only between a hard and soft streambed. This system provides a rapid and accurate depth measurement and is used with the other geophysical equipment to verify the water depth. Output from the fathometer is plotted by a graphic recorder.





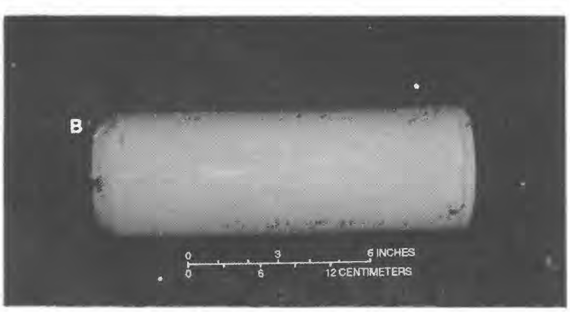


Figure 5.—Sonar equipment.

A. Transducer in 100-pound weight.
B. Sonar unit used at fixed installation.
C. Protective shield for sonar unit, mounted onto bridge pier.

Observed Scour at Selected Sites

Local scour holes 1 to 2 ft deep were found at many piers, but not abutments, at the start of the study. At a few sites, the scour has exposed spread footings that bridge plans show to have been buried during construction. Many of these holes may have been created by clear-water scour during a previous flood or floods. Fifteen high-flow measurements, including two flows with a recurrence interval between 5 and 10 years, show no additional scour since the initial observation. These results agree with those from Sidle (1988) that show scouring of coarse material to be triggered only by flows with recurrence intervals greater than 5 years.

LIMITATIONS OF PROCEDURES AND EQUIPMENT

One objective of the study is to evaluate the accuracy, safety, and ease of operation of the procedures and equipment. Stream velocity and depth are difficult to measure near piers in deep, swift streams, especially when debris is present, and heavy weights (100 to 150 lb) are not always adequate to stabilize the equipment. When mobile- and fixed-sonar installations are used to measure water depth, air or sediment entrained in the flow may interfere with the signal. Also, even though the mobile equipment can be brought to a site rather than installed permanently, moving it across the bridge and recording data is cumbersome. Mobile equipment deployed from a truck may be an alternative if no obstructions (such as guardrails) interfere with the operation of equipment. Fixed installations, by contrast, can record the distance between the transducer and the streambed automatically at selected time intervals but must be extremely durable. A sample of the output from the data logger is shown in figure 6. Signal scatter caused by wide reflections from cobbles increases as the signal ground loses contact with water (gage height 4.0 ft), and spikes or "lost signals" occur when the transducer is exposed to air (gage height 3.0 ft). This equipment has been tested for over 1 year, in which the recurrence interval of the peak flow was less than the mean-annual flood, and no scour was observed.

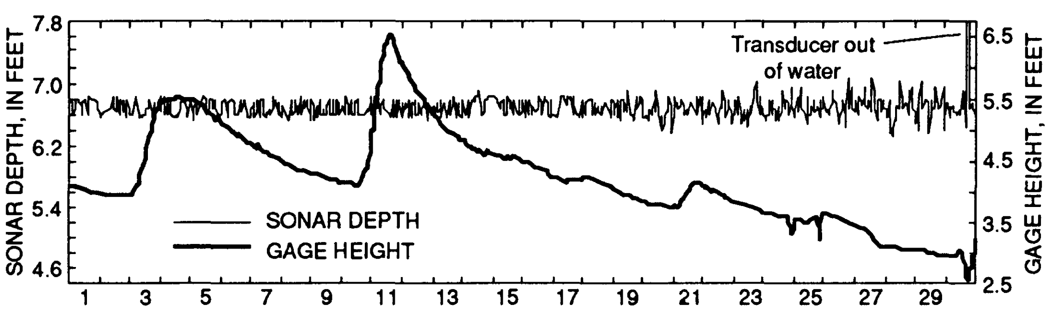


Figure 6.—Sample sonar and gage-height output from data logger.

Geophysical techniques were applied to gravel and cobble streambeds but did not reveal any back-filled scour holes. Among possible reasons are that: (1) holes were not present, (2) resolution of equipment (1 to 2 ft) did not permit detection of a shallow infilled layer, or (3) the infilled material was the same as the streambed. The usefulness of geophysical techniques depends on the characteristics of the site. The equipment is sophisticated and requires a high degree of skill for effective operation and interpretation. Many objects can interfere with the signal; for example, buried pipes, rocks, backfill from construction, and side echoes. The most useful results are likely to be from streams that undergo live-bed scour and have clear differences between backfilled and undisturbed material in the scour hole.

The number of years of data and hydrologic conditions during the sampling period may determine the amount of information available in some basins. If scour countermeasures are installed at some sites by NYSDOT before the project is completed, results will be affected.

SUGGESTIONS FOR FURTHER STUDY

Long-term data collection at scour-prone sites is needed to document the sensitivity of the scour process to high flows, and research and development of scour-sensing equipment is needed to monitor the evolution of a scour hole. The Massachusetts Department of Public Works found side-scan sonar to be an effective method of inspecting bridges and setting priorities for detailed inspections (Bedingfield and Murphy, 1987). This technique also may be useful in deep water or in determining the extent of tidal scour. Further study also is needed to (1) identify the most effective types of scour arrestors, and (2) determine the proper weight, particle size, and placement of riprap.

SUMMARY

Scour data are being collected at 77 bridges in New York, excluding Long Island. Bridges near USGS stations on streams with erodible bed material were selected in six physiographic provinces. High-flow data are being collected at 31 bridges, and annual data at the remaining 46 bridges. The conventional method of data collection with a sounding weight is being compared with sonar and other geophysical techniques for accuracy, safety, and ease of operation. Streambed cross sections measured at the beginning of the study are to be compared with bridge plans, previous measurements, and data collected during the remaining years of the project to determine the extent of scour at the selected sites.

Local scour holes 1 to 2 ft deep were found at many piers, but not the abutments, at the start of the study. At a few sites, the scour has exposed spread footings that bridge plans show to have been buried during construction. Fifteen high-flow measurements, including two flows with a recurrence interval exceeding 5 years, did not show any new scour. Present scour holes and the coarse bed material may indicate that clear-water scour is more common than live-bed scour in these streams. At abutments, general or constriction scour may be more significant than local scour, depending on channel geometry, flow pattern, and channel migration.

Geophysical techniques were applied to gravel and cobble streambeds but did not reveal any backfilled scour holes. The effectiveness of these techniques depends on local conditions, and the methods and equipment require a high degree of skill for effective operation and interpretation. Streams with live-bed scour that have clear differences between backfilled and undisturbed material probably provide more useful results than those with clear-water scour.

A fathometer provided quick and accurate depth measurements. The mobile method that uses a four-wheel base and crane was cumbersome. Deployment of the equipment from a truck may be an alternative if no obstructions (such as guardrails) interfere with the operation of equipment. A fixed installation designed to record the distance between the transducer and the streambed automatically at selected time intervals required extensive protection but is expected to provide useful information during floods. Further study is needed to determine how well these units operate amid flood turbulence, debris, sediment, and ice.

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Table 1.--Bridge sites, locations, and selected characteristics.

[Locations are shown in fig. 4]

A. FLOOD-DATA SITES

No. in Fig. 4	Site Name	Site number[1] USGS	Site number[1] NYSDOT	Drainage Area (mi^2)	Year Built	Pier Nose	Roadway and County
1	Allegheny River at Salamanca	03011020	6600050	1608	1989	Sharp	Main street, Cattaraugus
2	Catatonk Creek near Owego	01514801	3335120	151	1967	Round	County road 23, Tioga
3	Cattaraugus Creek at Gowanda	04213500	3328300	436	1959	Round	Aldrich street, Cattaraugus/Erie
4	Cazenovia Creek at Ebenezer	04215500	3326930	135	1955	Sharp	Ridge road, Erie
5	Chemung River at Chemung	01531000	1061330	2506	1967	Round	Rt.427, Chemung
6	Chemung River at Corning	01529952	1218080	2006e	1979	Round	Rt.414, Steuben
7	Chenango River at Greene	01507000	1024810	593	1934	Sharp	Rt.206, Chenango
8	Cohocton River near Campbell	01529552	1046090	494	1983	Round	Rt.333, Steuben
9	Conewango Creek near Waterboro	03013007	3027950	297	1950	Sharp	Rt.62, Chautauqua
10	Delaware River at Callicoon	01427510	1091670	1820	1961	Round	Interstate bridge #7, Sullivan
11	Delaware River at Port Jervis	01434000	5223060	3070	1939	Round	Rt.209/6, Orange
12	East Branch Delaware River near Margaretville	0141385004	1053400	173	1969	Round	Rt.28, Delaware
13	Esopus Creek at Coldbrook	01362500	2020380	192	1911	Sharp	Rt.28A, Ulster
14	Genesee River at Portageville	04222998	3319860	984e	1973	Sharp	Bailey road, Wyoming
15	Genesee River at Wellsville	04221000	2215520	288	1974	Round	Veterans Memorial bridge, Allegany
16	Hudson River at North Creek	01315500	1053660	792	1930	Sharp	Rt.28N, Warren
17	Hudson River near Newcomb	01312000	1020480	192	1959	Round	Rt.28N, Essex
18	Neversink River at Godeffroy	01437500	3364830	307	1975	Sharp	Graham road, Orange
19	Oatka Creek at Warsaw	04230380	3320280	39	1940	Square	Court street, Wyoming
20	Oatka Creek near Scotsville	04230520	3359090	203	1948	Round	Bowerman road, Monroe
21	Otselic River at Cincinnatus	01510200	3312170	153	1981	Round	Rt.23, Cortland
22	Raquette River at South Colton	04267500	1027250	937	1937	Sharp	Rt.56S, St. Lawrence
23	Schoharie Creek at Esperance	01351500	1054370	883e	1929	Sharp	Rt.20, Schoharie
24	Schoharie Creek at Middleburg	01350500	1021010	534	1958	Round	Rt.30/145, Schoharie
25	Susquehanna River at Conklin	01503000	3349250	2232	1966	Round	County road 314, Broome
26	Susquehanna River at Oneonta	01498620	3358280	678	1973	Round	County road 48A, Otsego
27	Susquehanna River at Unadilla	01500501	1094170	982	1973	Round	RT. 991H, Delaware/Otsego
28	Tuscarora Creek above South Addison	01525981	1012640	102	1966	Round	Rt. 417, Steuben
29	Unadilla River at Rockdale	01502500	3353660	520	1989	Sharp	County road 40, Chenango
30	West Branch Delaware River at Walton	01423000	1040430	332	1957	Round	Rt.206, Delaware
31	West Canada Creek near Herkimer	01346040	2204620	563	1988	Sharp	Shellsbush road, Herkimer

1 USGS = U. S. Geological Survey site number
NYSDOT = New York State Department of Transportation bridge-identification number
e Estimated

Table 1.--Bridge sites, locations, and selected characteristics (continued).

B. ANNUAL-DATA SITES

No. in Fig. 4	Site Name	Site number[1] USGS	Site number[1] NYSDOT	Drainage Area (mi²)	Year Built	Pier Nose	Roadway and County
32	Allegheny River at Salamanca	03011019	6012240	1608e	1957	Round	Rt.417, Cattaraugus
33	Batten Kill at Center Falls	01329530	3306710	399	1949	Sharp	Center Falls Road, Washington
34	Beaver Kill at Cooks Falls	01420498	1054971	237	1966	Round	Rt 17, upstream lane, Delaware
35	Callicoon Creek at Callicoon	01427501	7359700	110e	1934	Sharp	Railroad bridge, Sullivan
36	Canaseraga Creek at Shakers Crossing	04227000	1071740	335	1982	Round	Rt.408, Livingston
37	Catskill Creek at Oak Hill	01361500	3303120	98	1982	Sharp	County road 22, Greene
38	Chemung River at Corning	01529950	2218090	2006	1937	Sharp	Bridge Street, Steuben
39	Chemung River at Corning	01529951	....	2006e	1921	Sharp	Pedestrian bridge, Steuben
40	Chenango River at Sherburne	01505000	1030730	263	1954	Round	Rt.80, Chenango
41	Conewango Creek at Waterboro	03013000	1012150	290	1938	Sharp	Rt.394, Chautauqua
42	Fall Creek near Etna	04233760	1010400	122	1964	Round	Rt.13, Tompkins
43	Fishkill Creek at Hopewell Junction	01372800	1046980	57	1947	Round	Rt.376, Dutchess
44	Genesee River at Wellsville	04221002	1012450	289	1988	Sharp	Rt.417, Allegany
45	Great Valley Creek near Salamanca	03011000	1041470	137	1960	Round	Rt.219, Cattaraugus
46	Hoosic River near Hoosic	01333700	1004310	327	1932	Sharp	Rt 7, Rensselaer
47	Hudson River at 112th street	01357999	4093220	8000e	1924	Sharp	112th street/Rt.470, Albany
48	Hudson River at Congress street	01358100	1004279	8090e	1969	Sharp	Congress Street/Rt.2, Albany
49	Hudson River at Conrail RR	01359136	7092890	8290	1902	Sharp	Railroad bridge, Albany
50	Hudson River at Green Island	01358000	1095910	8090	1982	Sharp	Green Island bridge, Albany
51	Hudson River at I-90	01359130	1092839	8290e	1968	Sharp	I-90, Albany
52	Hudson River at Menands	01359105	1062850	8290e	1932	Sharp	Menands bridge/Rt.378, Albany
53	Hudson River at Rt.9/20	01359140	1093029	8290	1969	Sharp	Rt.9/20, Albany
54	Hudson River at Waterford	01335770	4000950	4620	1909	Sharp	Rt.4, Albany
55	Mohawk River at St.Johnsville	01348065	4309630	1687	1954	Sharp	Bridge street, Montgomery
56	Normanskill at Rt.406	01359200	1047730	41	1946	none	Rt.406, Schenectady
57	Olean Creek near Hinsdale	03010798	3322850	194	1988	Round	Lockwood road, Cattaraugus
58	Oswegatchie River near Oswegatchie	04262000	3340910	259	1930	Round	County road 122, St. Lawrence
59	Sacandaga River at Benson	01321030	1021170	523	1960	Round	Rt.30, Hamilton
60	Schoharie Creek at Rt.161	01353900	1038820	919	1928	Sharp	Rt.161, Montgomery
61	Schoharie Creek at I-90	01353990	5515869	927	1988	Round	I-90, Montgomery
62	Schoharie Creek at Rt.5S	01353995	1002940	928	1929	Sharp	Rt. 5S, Montgomery
63	Schroon River at Riverbank	01317050	1033581	535	1965	Round	I-87, Warren
64	Susquehanna River at Afton	01502701	1024760	1716	1948	Sharp	Rt.41, Chenango

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e Estimated

Table 1.--Bridge sites, locations, and selected characteristics (continued).

B. ANNUAL-DATA SITES (continued)

No. in Fig. 4	Site Name	Site number[1] USGS	Site number[1] NYSDOT	Drainage Area (mi^2)	Year Built	Pier Nose	Roadway and County
65	Susquehanna River at Owego	01513831	1060150	4216	1933	Sharp	Rt.96, Tioga
66	Susquehanna River at Sidney	01500810	1004470	1024	1936	Sharp	Main street, Delaware/Otsego
67	Susquehanna River at Vestal	01513500	3349850	3941	1935	Sharp	County road 316, Broome
68	Susquehanna River at Windsor	01502731	3349960	1820	1935	Sharp	County Road 315, Broome
69	Susquehanna River at Sayre	0151601010	....	4913	1987	Round	East Lockhart street, PA.
70	Tioga River near Erwins	01526500	2216900	1377	1930	Sharp	Mulholland road, Steuben
71	Tioughnioga River at Blodgett Mills	01509030	3312520	344	1965	Round	Blodgett Mills road, Cortland
72	Virgil Creek at Dryden	0423368620	1010410	30	1924	Sharp	Rt.13, Tompkins
73	West Branch Ausable River near Lake Placid	04274000	1032730	116	1973	Round	Rt.86E, Essex
74	West Branch St.Regis River at Winthrop	0426896505	3341930	269	1949	Sharp	Rt 420, St. Lawrence
75	West Canada Creek near Wilmurt	01343060	1004750	238	1931	Sharp	Rt.8, Herkimer
76	West Canada Creek at Kast Bridge	01346000	3307700	560	1931	Sharp	County road 7, Herkimer
77	West Canada Creek at Middleville	01345500	1020110	512	1936	Sharp	Rt. 28, Herkimer

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e Estimated