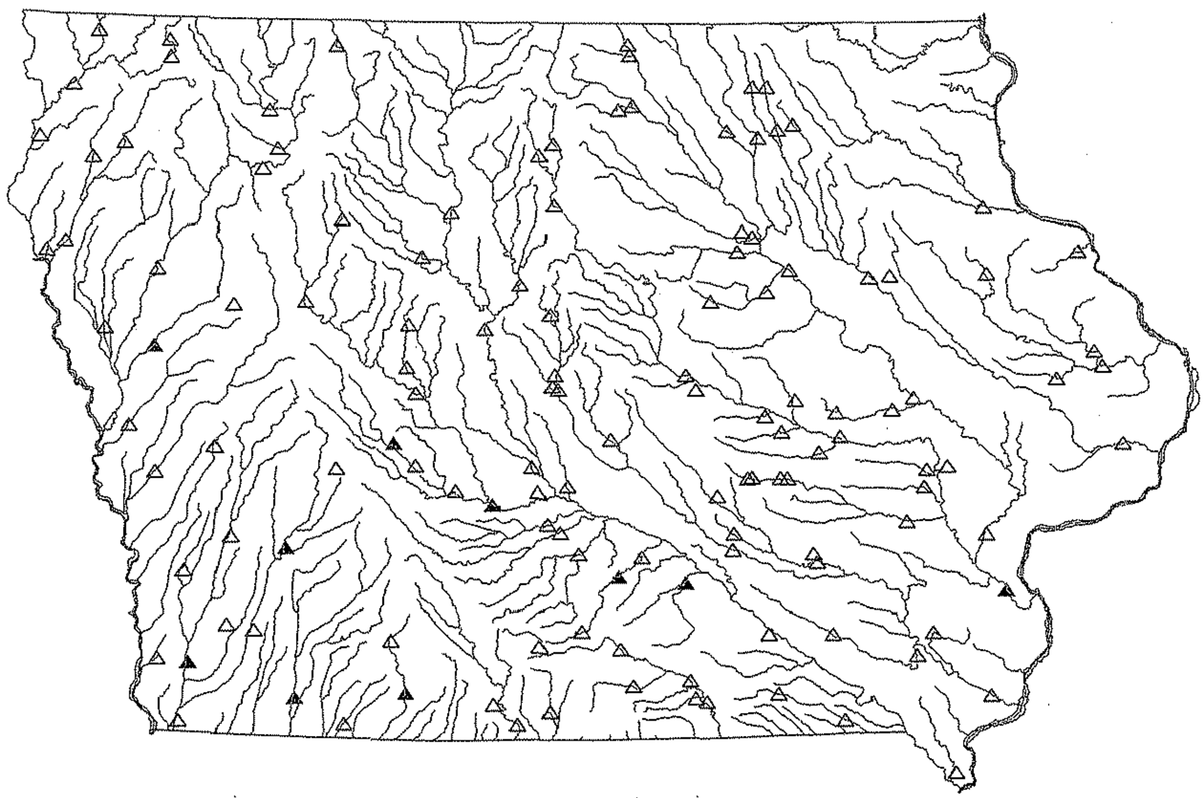
Potential-Scour Assessments and Estimates of Maximum Scour at Selected Bridges in Iowa

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 95-4051



Prepared in cooperation with the
IOWA HIGHWAY RESEARCH BOARD
and the HIGHWAY DIVISION of the
IOWA DEPARTMENT OF TRANSPORTATION
(IOWA DOT Research Project HR-344)

Cover: Map of Iowa showing bridges for which potential-scour assessments were made. Solid symbols show bridges for which maximum scour calculations also were made.

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By EDWARD E. FISCHER

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Iowa City, Iowa
1995

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CONTENTS

FIGURES

FIGURES—Continued

TABLES

CONVERSION FACTORS AND ABBREVIATIONS

Multiply	By	To obtain
foot (ft)	30.48	millimeter
	0.3048	meter
foot per second (ft/s)	0.3048	meter per second
foot per year (ft/yr)	0.3048	meter per year
mile	1.609	kilometer
square foot (ft^2)	0.09290	square meter
square mile (mi^2)	2.590	square kilometer
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
millimeter (mm)	0.032808	foot
meter (m)	3.2808	foot

Potential-Scour Assessments and Estimates of Maximum Scour at Selected Bridges in Iowa

By Edward E. Fischer

Abstract

The results of potential-scour assessments at 130 bridges and estimates of maximum scour at 10 bridges in Iowa are presented. All of the bridges evaluated in the study are constructed bridges (not culverts) that are sites of active or discontinued streamflow-gaging stations and peak-stage measurement sites. The period of the study was from October 1991 to September 1994.

The potential-scour assessments were made using a potential-scour index developed by the U.S. Geological Survey for a study in western Tennessee. Higher values of the index suggest a greater likelihood of scour-related problems occurring at a bridge. For the Iowa assessments, the maximum value of the index was 24.5, the minimum value was 3, and the median value was 11.5. The two components of the potential-scour index that affected the indices the most in this study were the bed-material component, which accounted for 27.1 percent of the overall total of the indices, and bank erosion at the bridge, which accounted for 18.3 percent of the overall total. Because the potential-scour index represents conditions at a single moment in time, the usefulness of potential-scour assessments is dependent upon regular assessments if the index is used to monitor potential-scour conditions; however, few of the components of the index considered in this study are likely to change between assessments.

The estimates of maximum scour were made using scour equations recommended by the Federal Highway Administration. In this study, the long-term aggradation or degradation that occurred during the period of streamflow data collection at each site was evaluated. The streambed appeared to be stable at 6 of the 10 sites, was degrading at 3 sites, and was aggrading at 1 site. The estimates of maximum scour were made at most of the bridges using 100-year and 500-year flood discharges. Other discharges also were evaluated at four of the bridges. With respect to contraction scour, channel cross sections measured during floods show parts of the streambed to be scoured lower than the computed maximum contraction-scour depths at 4 of the 10 sites. The measured discharges at three of the sites were less than the respective 100-year floods used to compute scour.

No pier-scour measurements were obtained in the study except for about 4 feet of local pier scour that was measured at the bridge over the Iowa River at Wapello, Iowa. However, the streambed was below the base of the pier footing, which is supported by piling, at the time the measurement was made. Discharge-measurement cross sections collected at two other bridges, which are not supported by piling, show the streambed between the piers to be lower than the bases of the piers. Additional investigation may be warranted at these sites to determine whether the streambed has been scoured below the bases at the upstream edges of the piers.

Although the abutment-scour equation predicted deep scour holes at many of the sites, the only significant abutment scour that was measured was erosion of the embankment at the left abutment at one bridge after a flood.

INTRODUCTION

Bridge scour is the erosion of soil particles by flowing water from around the piers and abutments that support a bridge. Because of the inherent problem this process poses to bridge stability, bridge scour has been the focus of much international scientific research. Yet, "the most common cause of bridge failures is floods with the scouring of bridge foundations being the most common cause of flood damage to bridges" (Richardson and others, 1993, p. 1). For example, a major bridge in Iowa that failed because of scour was the I-29 bridge over the Big Sioux River in Woodbury County in 1962. Elsewhere in the United States, a scour-related failure that resulted in the loss of life was the collapse of the New York State Thruway bridge over Schoharie Creek in 1987. Because of these and other bridge failures around the Nation, the Federal Highway Administration recommended that "every bridge over a scourable stream, whether existing or under design, should be evaluated as to its vulnerability to floods in order to determine the prudent measures to be taken for its protection" (U.S. Department of Transportation, 1988, p. 2).

Major flooding in south-central Iowa in September 1992 and throughout most of Iowa during the summer of 1993 damaged many bridges in the State. For example, in 1992 the State Highway 2 bridge over the Weldon River in Decatur County was closed because 10 ft of piling at the left abutment were exposed by floodwaters. The peak discharge was about four times the design flood for the bridge, which was built in 1985. The flood and resulting scour damage at this bridge are described by Fischer (1993).

Statewide flooding during the summer of 1993 caused many highways and bridges to be closed. New peak discharges of record occurred at 34 streamflow-gaging stations operated by the U.S. Geological Survey (Southard and others, 1994, p. 7). Even though floodwaters destroyed only two bridges in the State's primary highway system, many bridges were subjected to floodflows that exceeded their 100-year design floods. Of 83 streamflow-gaging stations on unregulated streams in Iowa with 11 or more years of systematic, continuous-record data, 11 stations recorded peak discharges that exceeded the theoretical 100-year flood discharge computed for the respective sites (D.A. Eash, U.S. Geological Survey, written commun., September 1994). The meteorological conditions that caused the flooding during the summer of 1993 are described by Wahl and others (1993), and the flood peaks are described by Parrett and others (1993).

The Iowa Highway Research Board (IHRB) initially addressed bridge scour during the mid-1950s by sponsoring laboratory research at the Iowa Institute of Hydraulic Research at the University of Iowa. Co-sponsors of the research were the Iowa State Highway Commission and the Bureau of Public Roads [currently called the Iowa Department of Transportation (IDOT) and the Federal Highway Administration (FHWA), respectively]. The results of this work were reported in IHRB Bulletin No. 4, "Scour Around Bridge Piers and Abutments" (Laursen and Toch, 1956), and IHRB Bulletin No. 8, "Scour at Bridge Crossings" (Laursen, 1958). According to Vanoni (1975, p. 48), Laursen's studies were influential in the scientific community because his work on the nature of scour (Laursen, 1952) formalized many of the scattered theories of scour at the time into some general principles. The contraction scour equations used in the FHWA manual HEC-18, "Evaluating Scour at Bridges" (Richardson and others, 1993), are based on Laursen's work.

The scour assessments described in this report developed from IDOT's response to FHWA's recommendation concerning bridge scour (U.S. Department of Transportation, 1988). IDOT began a bridge-scour review program that evaluated more than 2,000 bridges in the State's primary highway system. As part of their review, IDOT and the U.S. Geological Survey (USGS) developed a cooperative study that assessed scour at selected bridges in Iowa. The study was comprised of three components: (1) assess potential scour at 130 bridges using a potential-scour index developed by the USGS for a similar study in western Tennessee and evaluate the technique, (2) estimate maximum scour at 10 bridges using 100-year and 500-year (or other) design floods and FHWA scour equations, and (3) obtain scour measurements if possible for comparison with the maximum scour estimates. The study was for the period October 1991 through September 1994.

Purpose and Scope

This report presents the results of potential-scour assessments at 130 bridges in Iowa using a potential-scour index developed by the USGS for a similar study in western Tennessee and the results of maximum-scour estimates at 10 bridges in Iowa using scour equations recommended by the Federal Highway Administration. The potential-scour assessment technique is evaluated, and estimated scour depths are compared to measured scour depths. This information will assist IDOT in making decisions as to whether the potential-scour assessment technique would be of value to the State and whether present bridge-design criteria with respect to scour are adequate.

Acknowledgments

IDOT provided bridge plans showing soil boring information and subsurface structural information for the bridges in the primary highway system that were assessed for scour in this study. County engineers throughout the State provided bridge plans for the county bridges that were assessed.

The streamflow data used in this study were collected in cooperation with IDOT, the Iowa Department of Natural Resources, and the U.S. Army Corps of Engineers. The Federal Highway Administration has supported the USGS National Bridge Scour Project, for which some work was done in this study.

POTENTIAL-SCOUR ASSESSMENTS

A potential-scour assessment is used to help determine whether a bridge may be vulnerable to scour. Although a potential-scour assessment cannot predict actual scour during a flood, it provides a measure of the likelihood of scour-related problems occurring, both during a flood and over time as the channel-evolution processes work on the stream. The assessment is accomplished by an onsite evaluation using a scour-inspection form. The scour susceptibility of the bridge is expressed as a number called the potential-scour index. As used in this study, higher values of the index suggest a greater likelihood of scour-related problems occurring at a bridge. Potential-scour assessments generally are made for approximate bankfull or 1- to 2-year flood event conditions.

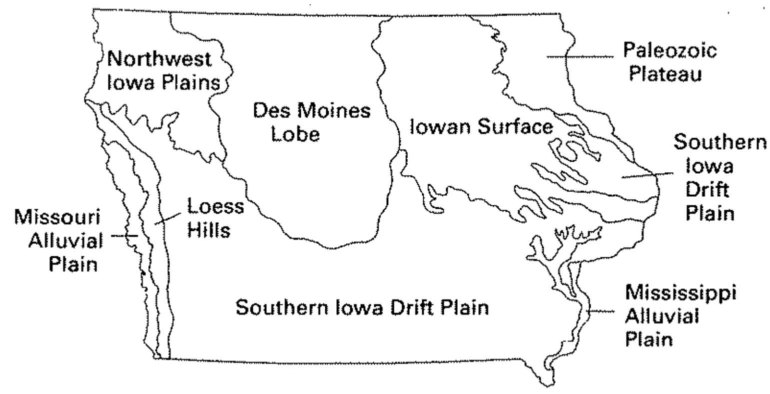
Potential-scour assessments were performed at 130 highway bridges throughout Iowa from November 1991 through May 1992 (fig. 1). All of the bridges are located at sites of active or discontinued USGS streamflow-gaging stations and peak-stage measurement sites. The drainage areas upstream from the bridges range from 23 to 7,785 mi^2. All of the bridges are structures supported by abutments and possibly one or more piers (that is, none of the bridges in this study are culverts). The ages of the bridges range from less than 5 to more than 70 years. The study sites are assumed to be a random selection of bridges in Iowa because the original selection of the bridges at streamflow-gaging stations or peak-flow measurement sites was independent of existing scour conditions at each bridge.

The potential-scour index, the potential-scour data-collection form used for this study, the results of the potential-scour assessments, and an evaluation of the potential-scour assessment technique are described in the following sections. A section on the landform regions of Iowa also is included because the assessment of some of the factors that comprise the potential-scour index were clearly related to some of the regions.

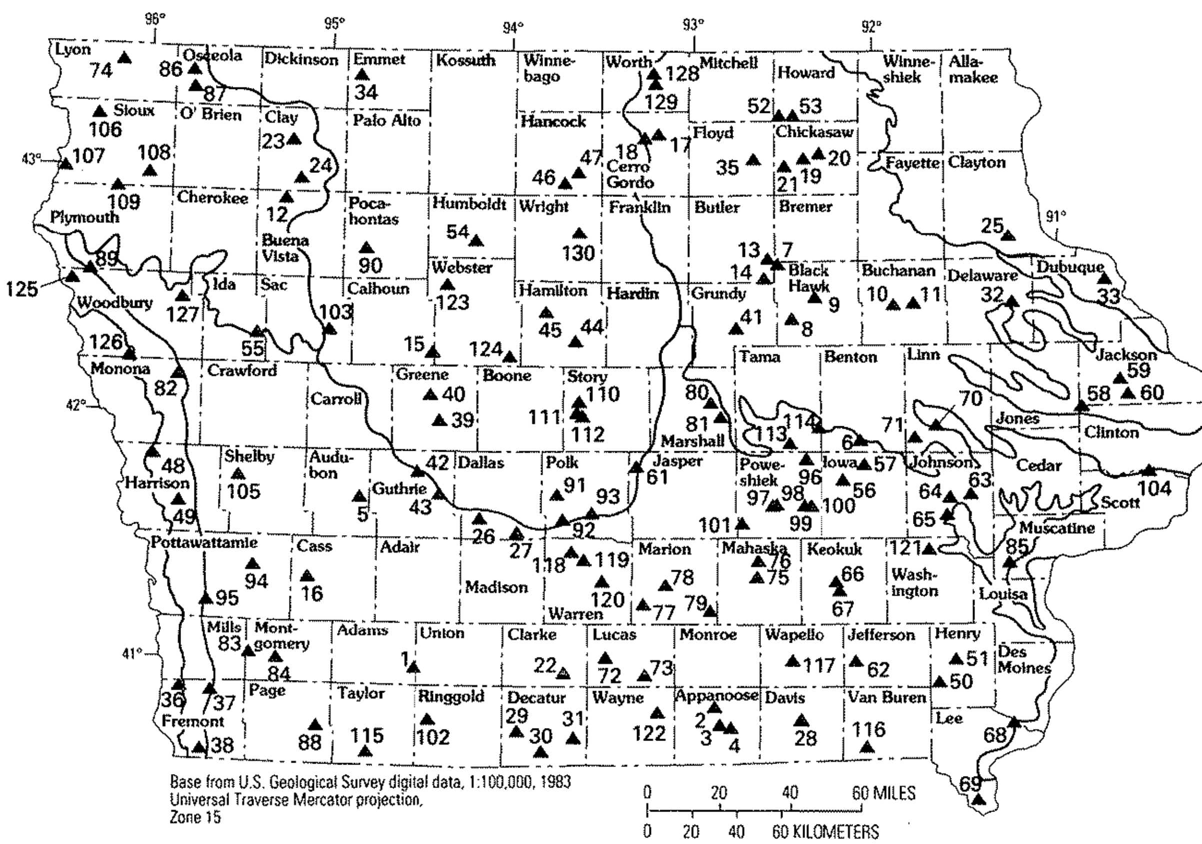
Potential-Scour Index

The potential-scour index used in this study was developed by Simon and Outlaw (1989) for a bridge-scour study by the USGS in western Tennessee. The index is comprised of 11 principal components. A value is assigned to each component according to the results of an onsite evaluation, and the potential-scour index is the sum of the component values. Larger values of the index suggest a greater likelihood for scour-related problems to occur. Evaluation of several of the index components is somewhat subjective and assigned values may vary depending on the inspector's judgment and experience. The effects of variability in the potential-scour index because of differences among persons making scour assessments were not tested in this study. However, no single component dominates the potential-scour index, and variations in the assigned values probably tend to cancel each other out when the components are summed to produce the index. The 11 principal index components are described in the following paragraphs.

Bed material.—The type of bed material determines the relative erodibility of the streambed. Listed in order of increasing erodibility, the values that can be assigned are 0 for bedrock, 1 for boulders/cobbles, 2 for gravel, 3 for sand, and 4 for silt/clay. A value of 3.5 (for alluvium) is assigned if the bed material cannot be determined during the onsite evaluation. No consideration is given to the cohesive properties



Landform regions in Iowa, adapted from Prior (1991)



EXPLANATION

1▲ **Bridge and site identification number**

—— **Boundary of landform region**—Adapted from Prior (1991)

Figure 1. Location of bridges assessed for potential scour and landform regions in Iowa.

of bed materials such as clay. Rather, the basis for evaluating bed material is particle size.

Bed protection.—Riprap may be placed at a bridge site to protect the bed and banks from erosion. A value of 0 is assigned to this component if the bed is protected, and 1 if the bed is not protected. A value of 2 is assigned if the bed is not protected but one bank is protected, and a value of 3 is assigned if the bed is not protected but both banks are protected. The increase in the value because of bank protection is justified on the basis that excess stream energy that cannot be dissipated through lateral erosion will tend to erode the streambed (Simon and Outlaw, 1989, p. 117).

Stage of channel evolution.—This component is based on the channel-evolution model developed by Simon (1989). Each of the stages comprising the model is described in table 1, which is taken directly from Simon and Outlaw (1989, p. 120). Listed in the order presented in table 1, the values and corresponding stages that can be assigned to this component are 0 for Premodified, 1 for Constructed, 2 for Degradation, 4 for Threshold, 3 for Aggradation, and 0 for Restabilization. Evaluation of this component is perhaps the most subjective of any of the index components because it relies on the interpretative skills of the inspector.

Percentage of channel constriction.—This component measures the relative constriction of the main channel by the bridge. The percentage of constriction is calculated by dividing the difference between the widths of the channel upstream of the bridge and at the bridge by the width of the channel upstream and multiplying by 100. Channel width is measured at the top of the banks, and the upstream width is measured sufficiently far upstream to be representative of the natural channel width; for most bridges this is approximately one bridge length from the structure. The values that can be assigned to this component are 0 for 0- to 5-percent constriction, 1 for 6- to 25-percent constriction, 2 for 26- to 50-percent constriction, 3 for 51- to 75-percent constriction, and 4 for greater than 75-percent constriction.

Number of bridge piers in channel.—This component is included because piers represent sites of potential local scour. The values that can be assigned are 0 for no piers in the main channel, 1 for one or two piers in the main channel, and 2 for more than two piers in the main channel. Piers not in the main channel are not considered.

Percentage of blockage by debris.—This component has three subcomponents: percentage of vertical blockage, percentage of horizontal blockage, and percentage of total blockage of bridge opening. The values that can be assigned for each subcomponent are 0 for 0- to 5-percent blockage, 0.33 for 6- to 25-percent blockage, 0.67 for 26- to 50-percent blockage, 1 for 51- to 75-percent blockage, and 1.33 for greater than 75-percent blockage. A fractional value for the subcomponents is used so that the effect of debris blockage on the potential-scour index is not overemphasized (Simon and Outlaw, 1989, p. 118).

Bank erosion.—The values that can be assigned for bank erosion are 0 for no significant erosion, 1 for fluvial erosion (erosion at the base of the banks), and 2 for mass wasting (large sections of the riverbank have fallen into the water). A value is assigned for each bank on the basis of the most severe erosion observed in the vicinity of the bridge.

Proximity of river meander impact point to bridge.—This component is a measure of the likelihood that the outside bend of the river eventually will migrate to the bridge, possibly undermining an abutment. The values that can be assigned are 0 if the impact point is greater than 100 ft from the bridge, 1 if the impact point is between 51 and 100 ft away, 2 if the impact point is between 26 and 50 ft away, and 3 if the impact point is 25 ft or less away.

Pier skew.—Piers that are not aligned with the principal direction of flow through the bridge opening increase the scour potential at a site. The values that can be assigned for this component are 0 if the pier is aligned with the flow and 1 if the pier is not aligned with the flow. A value is determined for each pier in the main channel.

Mass wasting at pier.—A large value is assigned to this component for bridge piers that are at the edge of the bank and mass-wasting processes are occurring in the vicinity of the bridge. The values that can be assigned are 0 for no mass wasting and 3 for mass wasting.

Table 1. Stages of channel evolution (from Simon and Outlaw, 1989, p. 120)

Stage		Dominant processes			
No.	**Name**	**Fluvial**	**Hillslope**	**Characteristic forms**	**Geobotanical evidence**
I	Premodified	Sediment transport—mild aggradation; basal erosion on outside bends; deposition on inside bends.	--	Stable, alternate channel bars; convex top-bank shape; flow line high relative to top bank; channel straight or meandering.	Vegetated banks to flow line.
II	Constructed	--	--	Trapezoidal cross section; linear bank surfaces; flow line lower relative to top.	Removal of vegetation (?).
III	Degradation	Degradation; basal erosion on banks.	Pop-out failures.	Heightening and steepening of banks; alternate bars eroded; flow line lower relative to top bank.	Riparian vegetation high relative to flow line and may lean towards channel.
IV	Threshold	Degradation; basal erosion on banks.	Slab, rotational and pop-out failures.	Large scallops and bank retreat; vertical face and upper-bank surfaces; failure blocks on upper banks; some reduction in bank angles; flow line very low relative to top bank.	Tilted and fallen riparian vegetation.
V	Aggradation	Aggradation; development of meandering thalweg; initial deposition of alternate bars; reworking of failed material on lower banks.	Slab, rotational and pop-out failures; low-angle slides of previously failed material.	Large scallops and bank retreat; vertical face, upper bank, and slough line; flattening of bank angles; flow line low relative to top bank; development of new flood plain (?).	Tilted and fallen riparian vegetation; re-establishing vegetation on slough line; deposition of material above root collars of slough-line vegetation.
VI	Restabilization	Aggradation; further development of meandering thalweg; further deposition of alternate bars; reworking of failed material; some basal erosion on outside bends; deposition on flood plain and bank surfaces.	Low-angle slides; some pop-out failures near flow line.	Stable, alternate channel bars; convex-short vertical face, on top bank; flattening of bank angles; development of new flood plain (?); flow line high relative to top bank.	Re-establishing vegetation extends up slough line and upper bank; deposition of material above root collars of slough line and upper-bank vegetation; some vegetation establishing on bars.

Angle of approach of high flows.—This component accounts for the effect of bridge crossings that are skewed (that is, not perpendicular) to the main direction of floods. The values that can be assigned are 0 for 0 to 10 degrees skew, 1 for 11 to 25 degrees skew, 2 for 26 to 40 degrees skew, 2.5 for 41 to 60 degrees skew, and 3 for greater than 60 degrees skew.

Data Collection for Potential-Scour Assessment

The fundamental data-collection mechanism for the potential-scour assessments was completion of a form adapted from Simon and Outlaw (1989, p. 115–116). The layout of the form was modified several times during the course of the assessments to facilitate the collection of data; however, no data elements were changed. The latest form is in the Appendix. Additional data were collected at many sites to characterize a site for future investigations, including bank heights and angles, bank vegetative cover, bank material, channel-profile description, and type of debris. Some of the elements listed on the form, such as bridge number and sufficiency rating (Appendix), were not determined. These elements were included in the original form for use by the cooperating agencies.

Data were entered into a computer data base, and a computer program was used to calculate the potential-scour index on the basis of the factors described above. The data for each bridge and the calculated potential-scour index are presented in table 4 at the end of this report. The entries in the table are sorted by county and within counties by the USGS station number. The site identification number in the first column of the table is the key to the bridge location in figure 1.

Landform Regions in Iowa

The major landform regions in the State are described here because some components of the potential-scour index were assessed larger values in some regions more frequently than in others. The following introductory description is from *Landforms of Iowa* (Prior, 1991, p. 30); the regions shown in figure 1 are adapted from the same publication (p. 31).

> [The State is comprised of] seven topographic regions: the Des Moines Lobe, the Loess Hills, the Southern Iowa Drift Plain, the Iowan Surface, the Northwest Iowa Plains, the Paleozoic Plateau, and the Alluvial Plains. These regions are distinguished on the basis of physical appearance, and their observable differences result from variations in geologic history * * *. Each region contains distinct landscape patterns and features that resulted from erosional activity at different times, in varying intensity, into variable deposits of loess, drift, alluvium, or bedrock. Some regions contrast sharply, with an obvious topographic boundary separating them. Other boundaries are less clear, and the change from one landscape pattern to another may occur gradually over several miles.

The principal material comprising the Northwest Iowa Plains, Des Moines Lobe, Iowan Surface, and Southern Iowa Drift Plain landform regions is glacial drift overlying sedimentary bedrock. Drift is the term for deposits of clay, silt, sand, gravel, and boulders left by glaciers or their meltwater streams (Prior, 1991, p. 132). The thickness of the glacial drift is variable throughout the regions, ranging from zero to hundreds of feet. A layer of loess, which is a wind-deposited silt composed predominantly of closely packed grains of quartz (Prior, 1991, p. 49), overlies the glacial drift in the Northwest Iowa Plains, the Southern Iowa Drift Plain, and parts of the Iowan Surface. The thickness of the loess throughout the regions also is variable, but the loess generally is thicker in the western part of the State and in the northern part of the Southern Iowa Drift Plain that is east of the Des Moines Lobe (fig. 1) (Oschwald and others, 1965, p. 6).

The Loess Hills landform region is composed of loess that is generally more than 60 ft thick. Compared to glacial drift, which is somewhat resistive to erosive processes, loess is highly erodible and unstable when wet. "Gully erosion is especially pronounced, and these deep, narrow, steep-sided features are characteristic of the region's smaller drainages. Gullies lengthen headward, deepen, and widen quickly after rainstorms, cutting into cropland, clogging stream channels and drainage ditches, and forcing costly relocations of bridges and pipelines" (Prior, 1991, p. 57).

The Paleozoic Plateau landform region is characterized by shallow sedimentary bedrock and a near absence of glacial deposits. Many deep, narrow valleys have been eroded into the bedrock by the streams of the region (Prior, 1991, p. 84). A layer of loess covers most of the region (Oschwald and others, 1965, p. 6).

The Alluvial Plains constitute the remaining landform region in the State. Although two major plains are shown in figure 1, alluvial plains occur throughout Iowa along the State's major streams and rivers. The plains are formed by sedimentary processes, which are the erosion, entrainment, transportation, deposition, and compaction of sediments (Vanoni, 1975, p. 1). The material comprising the alluvial plains, called alluvium, is made up of sediment that has been transported by water. Bridges over water in Iowa are in alluvial plains and are subject to the effects of the sedimentary processes that created the plains.

Results of Potential-Scour Assessments

A summary of the potential-scour indices and components is provided in table 2. Listed for each component are the minimum, maximum, and median values that were assessed, the sum of the values by component for all of the bridge sites, and the percentage that each component comprises of the overall total of the potential-scour indices (overall total—sum of the 130 potential-scour indices determined in this study). The same summary of values for the potential-scour indices also is listed in the table.

The numerical distribution of the potential-scour indices is summarized graphically by a histogram in figure 2. The median of the 130 indices is 11.5. The interval estimate of the population median at the 95-percent confidence level is 10.5 to 12.5 (Iman and Conover, 1983, p. 202), where population is the set of all bridges over water in Iowa. The histogram shows that the indices are evenly distributed about the median. Five bridges were assessed with indices less than 5, and eight bridges were assessed with indices greater than or equal to 20. The smallest index value of 3 was determined for the State Highway 9 bridge over the Rock River at Rock Rapids in Lyon County (table 4, site 74), and the largest value of 24.5 was determined for the State Highway 191 bridge over Mosquito Creek near Earling in Shelby County (site 105).

The spatial distribution throughout the State of the potential-scour indices grouped by selected ranges of index values is shown in figure 3*A*. The darker symbols denote larger values of the index. The sites with a potential-scour index greater than or equal to 15 are located predominantly in the western part of the State. Five of the eight sites with the index greater than or equal to 20 are in or adjacent to the Loess Hills landform region in the southwest part of the State.

With respect to the components comprising the potential-scour index, bed material had the greatest effect on the index and accounted for 27.1 percent of the overall total of the potential-scour indices (table 2). The bed material component was evaluated as sand, silt/clay, or when it could not be determined as either sand or silt/clay, as alluvium at 123 of the 130 bridge sites. The distribution of the bridges with respect to the values assigned to this component is shown in figure 3*B*. The fairly even distribution about the State attests to the alluvial nature of rivers in Iowa. The rivers have carved the State's valleys and partially filled them with layered deposits of gravel, sand, silt, and clay (Prior, 1991, p. 30, 98). Because of the ubiquitous occurrence of sand, silt, and clay in the State's streambeds, the usefulness of the bed-material component in the potential-scour index is diminished in Iowa. As noted previously, no consideration is given to the cohesive properties of bed material, which affects the erodibility of the stream channel.

The second most effectual component of the potential-scour index was bank erosion at the bridge sites, which accounted for 18.3 percent (sum of left bank erosion and right bank erosion, table 2) of the overall total of the potential-scour indices. The distribution of bridges with respect to this component is shown in figure 3*C*. The symbols in the figure reflect the largest value assigned to either bank at each site. About one-fourth (34) of the bridges had mass wasting occurring at one or both banks. Almost all of the sites in or near the Loess Hills landform region were in this category.

The third most effectual component of the potential-scour index was channel evolution, which accounted for 17.9 percent of the overall total of the potential-scour indices (table 2). The distribution of the bridges with respect to this component is shown in figure 3*D*. The symbols used for each bridge are shown in order of decreasing values of the channel-evolution component. More than one-half (79) of the bridges were assigned a value of 3 (Threshold) or 4 (Aggradation, see table 1). Most of these bridges are in the Southern Iowa Drift Plain and Loess Hills landform regions.

Table 2. Summary of assessed values of the potential-scour index components and potential-scour indices at 130 highway bridges in Iowa

	Index components														
						Percentage of blockage by debris			Bank erosion						
Assigned value	Bed material	Bed protection	Stage of channel evolution	Percentage of channel constriction	Number of piers in channel	Horizontal	Vertical	Total	Left bank	Right bank	Proximity of river-meander impact point	Pier skew	Mass wasting at piers	Angle of approach of high flows	Potential-scour indices
Minimum value assessed	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
Maximum value assessed	4	3	4	3	2	1.33	0.67	0.33	2	2	3	5	6	2.5	24.5
Median of assessed values	3.5	1	3	0	1	0	0	0	1	1	0	0	0	0	11.5
Sum of values by component for all sites	431.5	192	286	37	83	6.33	3.66	0.66	143	149	113	34	60	56	1,595.2
Percentage contribution to overall potential-scour index[1]	27.1	12.0	17.9	2.3	5.2	0.4	0.2	0.0	9.0	9.3	7.1	2.1	3.8	3.5	--
(rank)	(1)	(4)	(3)	(9)	(6)		(11)		(2)		(5)	(10)	(7)	(8)	

[1]Percentages do not sum to 100 because of rounding.

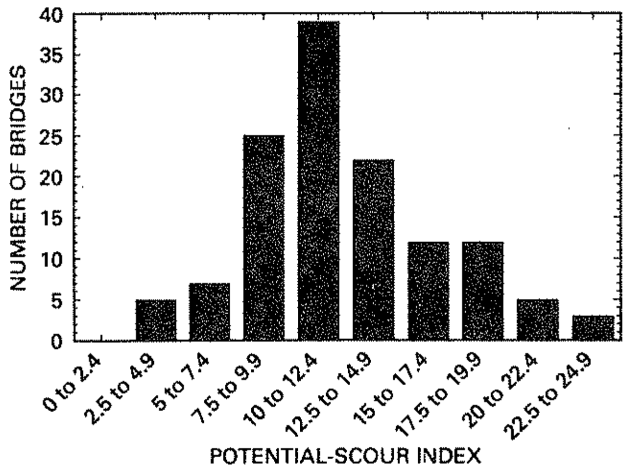


Figure 2. Histogram of potential-scour indices for 130 bridges in Iowa.

The fourth most effectual component of the potential-scour index was bed protection, which accounted for 12 percent of the overall total of the potential-scour indices (table 2). The distribution of the bridges according to the values assigned to this component is relatively uniform (fig. 3*E*). The bed-protection component is a good indication of bridges that have had their banks protected either because of changed conditions after a bridge was built, such as a change in the angle of approaching flows, or because of unusual conditions, such as highly skewed crossings.

The seven remaining index components account for 24.6 percent of the overall total of the potential-scour indices (table 2). They are discussed in decreasing order of effect on the overall total.

Proximity of river meander impact point accounted for 7.1 percent of the overall potential-scour index. With respect to the values assigned to this component, 31 bridges were assigned a value of 3 because impact points are within 25 ft of the bridge, 6 bridges were assigned a value of 2 because impact points are within 50 ft, and 8 bridges were assigned a value of 1 because impact points are within 100 ft.

Number of piers in channel accounted for 5.2 percent of the overall potential-scour index. Ten of the 130 bridges were assigned a value of 2 because of more than two piers in the main channel, and 63 bridges were assigned a value of 1 because they have one or two piers in the main channel. The remaining bridges do not have any piers or do not have piers in the channel during normal flows.

Mass wasting at piers accounted for 3.8 percent of the overall potential-scour index. Five bridges were assigned a value of 6 because of mass-wasting processes near a pier on both banks, and 10 bridges were assigned a value of 3 because of mass-wasting processes near a pier on one bank. The remaining bridges were assigned a value of 0.

Angle of approach of high flows accounted for 3.5 percent of the overall potential-scour index. The highest value of this component was 2.5, which was assigned at eight bridges that were judged to have an angle of approach of high flows of about 45 degrees. Eight other bridges were assigned a value of 2, and 20 bridges were assigned a value of 1 (table 4).

Percentage of channel constriction accounted for 2.3 percent of the overall potential-scour index. The highest value assigned was 3 at one bridge, West Fork Ditch at Hornick in Woodbury County (table 4, site 126). The measured constriction at this bridge was 61 percent. The channel constriction is caused by vertical abutment walls of an old bridge that were left standing just upstream of the current bridge. Six bridges were assigned a value of 2 for this component, and 22 bridges were assigned a value of 1 (table 4).

Pier skew accounted for 2.1 percent of the overall potential-scour index. The bridge with the highest assigned value for this component (5) crosses the Cedar River at Cedar Rapids in Linn County (table 4, site 70). This bridge has five piers in the channel that were assessed as being skewed about 10 degrees from the approach flow.

Very little blockage of the bridge opening by debris was noted during the onsite assessments. As a result, the percentage of blockage-by-debris component affected the overall potential-scour index the least of all the components and accounted for less than 1 percent of the overall total of the indices.

Evaluation of Potential-Scour Assessment Technique

The potential-scour index does not predict scour. Rather, it represents an assessment of the conditions at a bridge that may cause excessive scour. Also, it represents an assessment of conditions at a single moment in time. A single potential-scour assessment may help identify conditions that suggest additional investigation at the site. The usefulness of the index in monitoring potential-scour conditions, however, is dependent on regular assessments and is

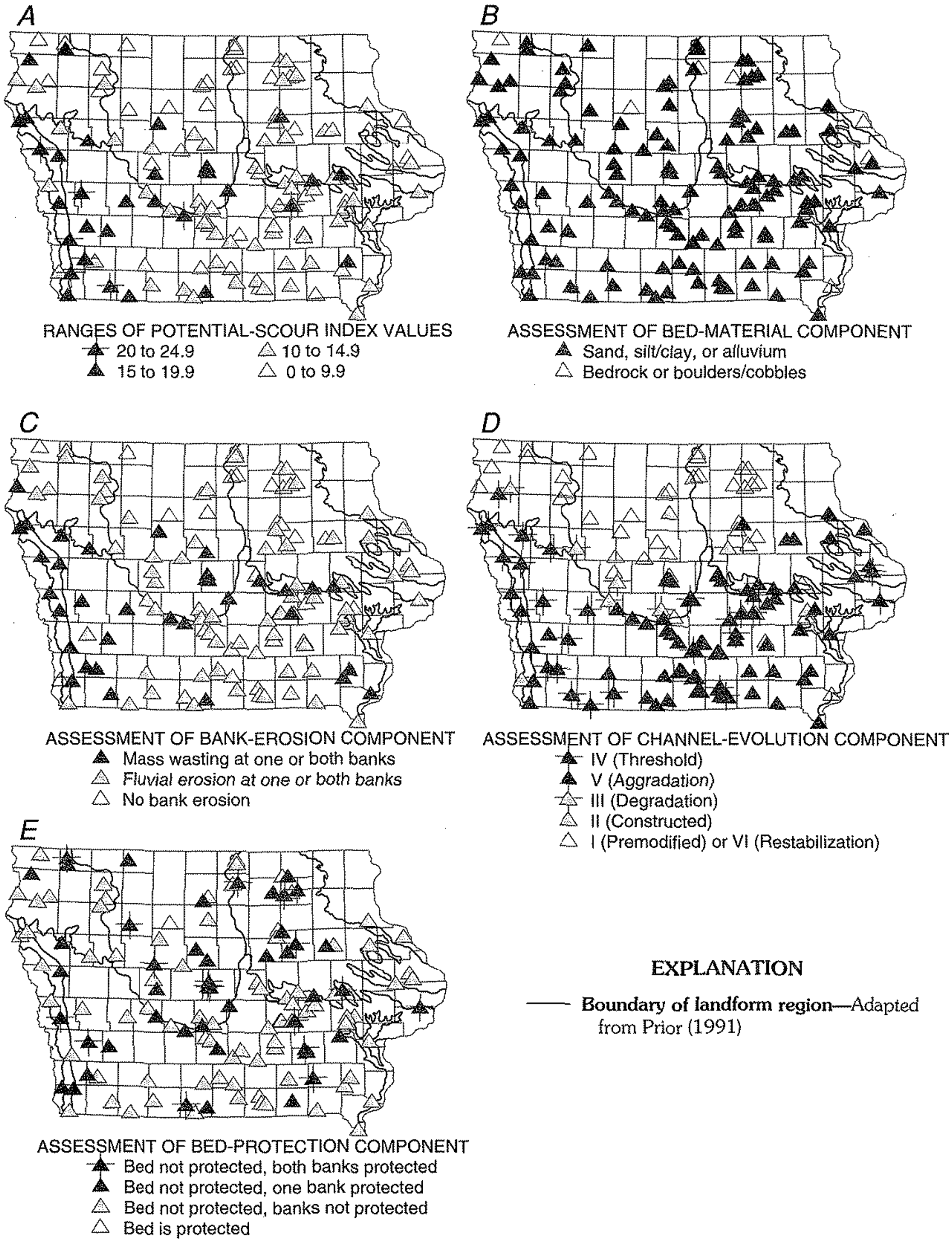


Figure 3. Location of bridges grouped by (*A*) selected ranges of potential-scour index, (*B*) assessment of bed-material component, (*C*) assessment of bank-erosion component, (*D*) assessment of channel-evolution component, and (*E*) assessment of bed-protection component.

limited to those components of the index that may change between assessments. For example, a river meander impact point may move closer to a bridge, suggesting that some protective countermeasures be installed at the bridge before scour problems occur. Also, as will be discussed in the next section, contraction and pier scour may be exacerbated at bridges that trap debris. Several of the components, however, very likely will not change between assessments, such as bed material, bed protection, percentage of channel constriction, and number of piers in channel. The repeated evaluation of these components would not provide new information.

The values of some of the components of the potential-scour index are closely related to the landform region in which the sites are located. For example, the higher valued assessments of channel evolution occurred predominantly in the Southern Iowa Drift Plain and Loess Hills landform regions (fig. 3*D*). The greater likelihood of occurrence of a particular value in a landform region will diminish the value of periodically re-assessing the component because no new information would be gained.

An aspect of potential-scour assessments that may be beneficial to IDOT is that the assessments evaluate some of the geomorphologic processes that affect scour at a bridge. Currently, evaluation of these processes is not part of a typical bridge inspection.

ESTIMATES OF MAXIMUM SCOUR

An estimate of the maximum scour that may occur at a site during an extreme high flow is made by determining the hydraulic properties of the channel and bridge opening for a design flood and using scour equations. Two principal types of scour occur at bridges—contraction scour and local scour at piers and abutments. Included in the estimate of maximum scour is a determination whether long-term aggradation or degradation may be occurring at the bridge.

Estimates of maximum scour were made at 10 highway bridges in this study (fig. 4). The location, drainage area, median bed-material particle size, and flood-frequency data for each of the sites are listed in table 3. The principal criterion for selecting the bridges was that most of the sites have drainage areas greater than about 300 mi^2. In addition, the sites were selected to represent a variety of bridge and channel conditions. The bridge over the Raccoon River at Van Meter in Dallas County (station 05484500, fig. 4) was chosen because it had the second-largest potential-scour index (site 27, table 4). The drainage area of the site with the largest index is 32 mi^2 (site 105, table 4). The bridge over the Iowa River at Wapello (station 05465500, fig. 4) was chosen because of unusual contraction scour that was measured there during the flood of 1993. The flood and resulting scour at this site originally were described by Fischer (1994); additional information is provided in this report.

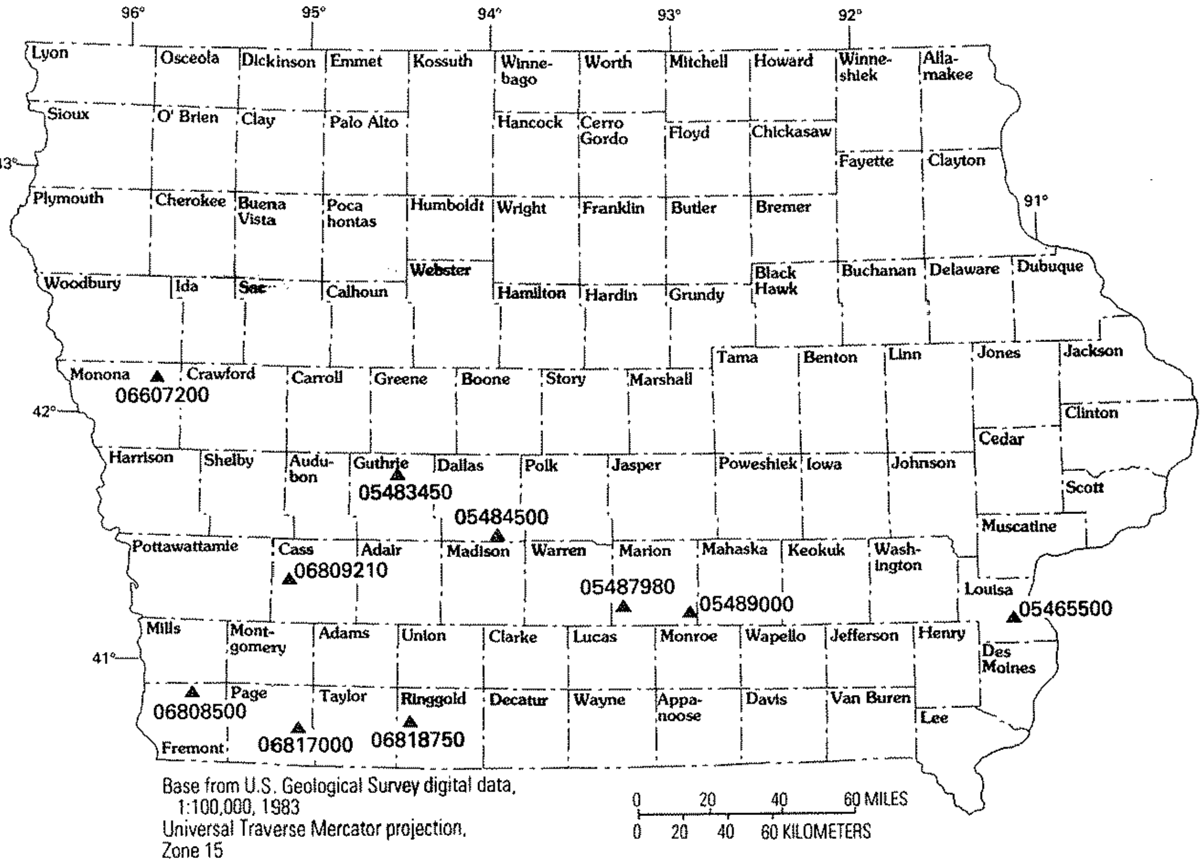
Bridge-Scour Processes and Estimating Maximum Scour

Bridge-scour processes are classified into three components—long-term aggradation or degradation of the stream channel, contraction scour, and local scour at piers and abutments. The total scour that can occur at a bridge is the sum of these components. Also affecting scour is channel stability. Stream channels can migrate laterally, creating flow conditions at a bridge that are significantly different from the flow conditions that existed when the bridge was built. The maximum scour equations used for this study are those presented in the FHWA report "Evaluating Scour at Bridges," second edition, Hydraulic Engineering Circular No. 18 (HEC-18) (Richardson and others, 1993). The report is referred to as HEC-18, and the scour equations are referred to as the HEC-18 equations in the following pages.

Long-Term Aggradation/Degradation of the Streambed

In geologic time, all streams degrade. The process, however, is not evenly distributed; some streams will degrade more quickly or deeper than other streams. Still other streams may aggrade as sediments are deposited. Excessive degradation creates stability problems at a bridge, and excessive aggradation reduces conveyance through a bridge opening that can cause frequent flooding and highway closure.

Human activities can affect degradation or aggradation. Such activities include agricultural practices, urban development, mining operations, and river-control works. For example, construction of a flood-control reservoir on a stream contributes to channel degradation downstream of the dam by trapping much of the sediment and altering the streamflow characteristics. The natural sediment load and flow of the stream were responsible for establish-



EXPLANATION

05465500 ▲ **Bridge site and U.S. Geological Survey streamflow-gaging station number**

Figure 4. Location of bridge sites where maximum scour was estimated.

ing the characteristics of the channel prior to construction of the dam. Clear water (water that is not transporting sediment) released from the reservoir entrains sediment as it moves downstream, eroding the streambed and channel banks until equilibrium with the new flow characteristics is achieved (Vanoni, 1975, p. 2–9).

In this study, the long-term aggradation or degradation of the streambed that has occurred during the period of streamflow data collection at the site is presented. The method of measuring aggradation or degradation is based on changes in the stage corresponding to an index discharge. The index discharge used for this study is the average discharge for the period of streamflow record at each site. The stage of the index discharge is determined from each rating curve that was developed and is assigned the date each curve was developed. A plot of the stage with respect to time shows graphically what has occurred at the site. Generally, changes in the stage corresponding to the index discharge imply a similar change in the elevation of the streambed. Changes in the width of the flow area of the index discharge that are due to changes in the streambed elevation are assumed to be minimal.

Historically, an early variation of the rating-curve method of measuring changes in streambed elevation was the "Specific discharge Gauge" used by Inglis (1949, p. 3, 178–179, 189). According to Inglis, the "Specific discharge Gauge" is the "* * * Gauge reading corresponding to a particular discharge * * * [which] is arrived at by drawing a smoothed—most probable—curve through the Gauge readings observed with discharges approximating to the specific discharges during (R) the rising flood season and (F) the falling flood season" (p. 3). Inglis used several

Table 3. Location, drainage area, median bed-material particle size, and flood-frequency data for bridge sites analyzed for maximum scour

[mi^2, square miles; mm, millimeters; ft^3/s, cubic feet per second]

U.S. Geological Survey streamflow-gaging station number (fig. 4)	Stream name and vicinity, county, highway, date surveyed	Drainage area (mi^2)	Median bed-material particle size, D_{50} (mm)	Flood-frequency data				
				Period of peak-flow record[1]	Number of years of record[2]		Discharge of 100-year flood (Q_{100}) (ft^3/s)	Discharge of 500-year flood (Q_{500}) (ft^3/s)
					Systematic	Historic		
05465500	Iowa River at Wapello, Louisa County, State Highway 99, November 15–18, 1993	12,499	[3]0.60	1903–92	90	0	103,000	121,000
05483450	Middle Raccoon River near Bayard, Guthrie County, State Highway 25, October 25, 1993	375	.34	1973–92	14	20	18,800	26,800
05484500	Raccoon River at Van Meter, Dallas County, County Road R16, November 4–8, 1993	3,441	91	1915–92	78	0	49,100	62,600
05487980	White Breast Creek near Dallas, Marion County, County gravel road, October 19, 1993	342	.45	1962–92	31	48	25,800	35,900
05489000	Cedar Creek near Bussey, Marion County, State Highwy 156, June 15–16, 1993	374	.27	1946–92	46	141	45,900	73,500
06607200	Maple River at Mapleton, Monona County, State Highway 175, October 26, 1993	669	.39	1942–92	51	0	26,200	33,300
06808500	West Nishnabotna River at Randolph, Fremont County, State Highway 184, October 27, 1993	1,326	.41	1949–92	44	45	49,500	59,100

Table 3. Location, drainage area, median bed-material particle size, and flood-frequency data for bridge sites analyzed for maximum scour—Continued

U.S. Geological Survey streamflow-gaging station number (fig. 4)	Stream name and vicinity, county, highway, date surveyed	Drainage area (mi^2)	Median bed-material particle size, D_{50} (mm)	Flood-frequency data				
				Period of peak-flow record[1]	Number of years of record[2]		Discharge of 100-year flood (Q_{100}) (ft^3/s)	Discharge of 500-year flood (Q_{500}) (ft^3/s)
					Systematic	Historic		
06809210	East Nishnabotna River near Atlantic, Cass County, County paved road, May 24–25, October 28, 1993	436	0.34	1948–92	32	45	35,600	45,200
06817000	Nodaway River near Clarinda, Page County, State Highway 2 (business route), June 22–23, 1993	762	.34	1918–25, 1936–92	66	90	42,700	51,800
06818750	Platte River near Diagonal, Ringgold County, County gravel road, May 25, 1993	217	.47	1966–91	24	26	10,000	11,200

[1]Inclusive years of systematic peak-flow data collection; gaps may exist in the interval during which the streamflow-gaging station was discontinued.

[2]Systematic record—period during which streamflow data were collected. Historic record—the period outside the systematic record during which certain peak-discharge information has been determined that enables extension of the peak-flow record.

[3]Average of five sediment-size analyses made during 1992 at Iowa River at Wapello.

reference (index) discharges to show changes in the streambed elevation. More recently, Williams and Wolman (1984, p. 4) used the rating-curve method as one way to determine changes in mean bed elevation downstream of dams on alluvial rivers. They used the discharge that was exceeded 95 percent of the time as the index discharge (p. 5).

Contraction Scour

A highway embankment built across a flood plain reduces the flow area of a flooding river. The embankment contracts the flow, forcing the water from the flood plain through the bridge opening. From the principles of conservation of mass and energy, the flow velocity at the bridge is greater than the flow velocity without the embankment present. The increased flow velocity results in increased bed-shear stress that can scour the streambed at the bridge opening. Contraction scour typically is cyclic; the streambed scours during the rising stage and backfills during the falling stage. Other factors that result in contraction scour include ice, debris, and the growth of vegetation in the channel or flood plain (Richardson and others, 1993, p. 9).

Contraction scour is affected by the sediment transport characteristics of a river. Therefore, two sets of equations in HEC-18 are used to compute maximum contraction scour, one for live-bed sediment transport conditions and the other for clear-water sediment transport conditions. Live-bed sediment transport conditions occur when the flow is transporting sediment along the bottom of the channel. The contraction scour depth increases at the bridge opening, decreasing the bed-shear stress until the sediment transport rate out of the opening is equal to the sediment transport rate into the opening. Clear-water scour occurs when no upstream bed material is transported into the opening. The contraction scour depth increases until the shear velocities in the enlarged bridge opening are less than the threshold of sediment motion. An equation is presented in HEC-18 to help determine whether to use the live-bed equations or the clear-water equations to estimate contraction scour. The equation is based on the critical flow velocity that will transport the D_{50} bed material. D_{50} is the median diameter of the streambed material such that 50 percent by weight of the streambed particles have diameters less than D_{50}. Live-bed sediment transport conditions are common in most Iowa rivers, and clear-water conditions occur on most flood plains.

Pier Scour

Erosion of the streambed around bridge piers is caused by redirection of the flow as water is deflected downward and accelerated around the pier. The redirected flow increases the shear stress that can transport bed material away. Like live-bed contraction scour, the maximum live-bed local scour occurs when the rate of sediment transported out of the scour hole exceeds the rate of sediment transported into the hole. For clear-water conditions, the scour hole will deepen until the shear velocity in the scour hole cannot transport additional material. The HEC-18 pier-scour equation is recommended to be used for both live-bed and clear-water sediment transport conditions (Richardson and others, 1993, p. 39).

Many factors affect local pier scour. They include pier width, pier shape, flow velocity, flow depth, and alignment of the pier with respect to the approaching flow. Debris piles can increase the effective width of piers, resulting in deep scour holes (Laursen and Toch, 1956, p. 28; Richardson and others, 1993, p. 46).

Abutment Scour

Erosion of the streambed at abutments is caused by the rapid change in flow direction as water enters the bridge opening from the flood plain. Abutment scour is affected by the type of abutment (vertical-wall abutments, spill-through abutments), the type of wing walls, and guide banks. According to Richardson and others (1993, p. 47), all of the abutment-scour equations in the literature include the approach highway embankment length as one of the variables, which results in excessively conservative (very deep) estimates of scour. Richardson and others (1993, p. 50) also present an alternative abutment scour equation that may be used where conditions at a bridge are similar to the field conditions from which the equation was developed (scour at the end of a spur dike extending into a river). In this study, however, calculations of abutment scour using the alternative equation generally estimated deeper scour.

Channel Stability

The tendency of river channels to migrate or shift laterally as the banks erode on the outside edges of bends and fill in on the inside edges affects scour at bridges. A migrating stream will change the hydraulic conditions at a bridge. A bridge designed for one type of hydraulic condition may not be appropriate for a new condition. For example, piers that were aligned with the flow when the bridge was built but are no longer aligned because of a change in the angle of the approaching flow are subject to greater scour because of the increase in the obstructive area the pier presents to the flow. Also, a migrating stream eventually may cause streamflows to be directed towards an abutment, undermining it.

Total Scour

The total scour that can occur is the sum of the components described above. If the streambed is likely to degrade during the life of the bridge, the maximum contraction scour, pier scour, and abutment scour depths are measured from the expected elevation of the degraded bed. If a pier or abutment is located in an area where contraction scour also may occur, the maximum pier scour and abutment scour are measured from the computed elevation of maximum contraction scour.

Data Collection and Method of Analysis for Estimating Maximum Scour

The scour equations in HEC-18 require quantification of variables that can be obtained from a hydraulic analysis of the bridge site. Therefore, the estimates of maximum scour in this study were made using the following methodology: (1) determine the 100-year flood (Q_{100}) and 500-year flood (Q_{500}) discharges for a site, (2) determine the corresponding hydraulic properties of the channel and bridge, (3) compute the water-surface profiles for the flood discharges, and (4) calculate the maximum scour.

Flood Discharges

The Q_{100} and Q_{500} flood discharges used to compute the water-surface profiles were determined from flood-frequency analyses of the streamflow records at each bridge site. The flood frequencies were determined according to procedures outlined in Bulletin 17B of the U.S. Interagency Advisory Committee on Water Data (1982). The analyses were computed using streamflow records collected through water year 1992, except one site that was discontinued at the end of water year 1991. The 1993 flood peaks were not used to compute flood frequencies because they were not available at the time of the scour analyses. The peak-flow record, the number of years of systematic and historic record used in the frequency analyses, and the Q_{100} and Q_{500} flood discharges are listed for each site in table 3. In the subsequent hydraulic analyses, flood discharges other than Q_{100} and Q_{500} were used at four sites for reasons that are explained in the respective analyses.

Hydraulic Properties

Channel cross-section and bridge-geometry data were collected using an electronic surveying instrument and entered into a step-backwater computer model so that the hydraulic properties at a bridge could be determined. Cross-section properties were computed for the exit section, the full-valley section, the bridge-opening section, and the approach section. If a cross section could not be surveyed, that cross section was estimated from another cross section using the template option of the step-backwater model (Shearman, 1990, p. 123). All elevations were referenced to gage datum.

Water-Surface Profiles

Water-surface profiles were calculated using the WSPRO step-backwater model (Shearman, 1990; Shearman and others, 1986). WSPRO is a water-surface profile computation model for one-dimensional, gradually varied, steady flow in open channels. The model can estimate hydraulic properties through bridges and in flood plains. The model was calibrated at each site by adjusting channel roughness values to match the estimated water-surface elevation at the bridge section for the Q_{100} flood discharge with the stage-discharge rating curve in effect at each site. Rating curves that did not include the Q_{100} flood discharge were extended.

Maximum Scour Equations

The HEC-18 scour equations were used to estimate scour. Input variables to the equations, such as channel widths, discharges, flow depths, and flow velocities, were obtained or derived from WSPRO. The median diameter of the streambed material, D_{50}, was obtained from unpublished data collected by Eash (1993). The values used for each site are listed in table 3.

Results of Estimates of Maximum Scour

The results of the estimates of maximum scour are presented for each site in the following format: (1) the channel and bridge at a site are described, (2) the water-surface profiles are discussed, (3) the calculated scour depths are tabulated, and (4) the results are discussed. The long-term aggradation or degradation that has occurred is shown in a graph of the river stage corresponding to the average streamflow plotted as a function of time. The channel cross section at the downstream side of the bridge is shown in an elevation view. The scour depths calculated for the Q_{100} flood discharge (or other discharge as noted) are superimposed on the cross section. The contraction-scour depth is referenced to the streambed at the time the bridge site was surveyed. The local scour depths for the piers and abutments are referenced to the elevation of the calculated contraction scour (Richardson and others, 1993, p. 69), and the abutment-scour depths are shown at the toe of the abutment embankment. The cross-section data (dashed line in the figures) were obtained from discharge measurements made at the bridge. The vertical scale of the elevation view is exaggerated to facilitate rendition of the calculated scour depths. The dimensions of the pier footings and pilings were determined from bridge plans provided by IDOT.

The bridge sites are presented in downstream order by USGS streamflow-gaging station number except Iowa River at Wapello, which is presented last because of the unusual contraction scour that occurred there.

Middle Raccoon River near Bayard (05483450)

This bridge is located on State Highway 25 in Guthrie County. It crosses the main channel of the river at a 20-degree angle; upstream of the bridge, the main channel bends to about a 45-degree angle to the bridge and highway. The river valley is relatively narrow and extends about 500 ft from side to side in the vicinity of the bridge. Upstream of the bridge, the channel is near the right edge of the valley, and the left flood plain is a pasture. Downstream, the channel is near the left side of the valley, and the right flood plain is a cultivated field. Trees cover the narrow flood plain on each side of the bridge, and thin bands of trees line the opposite side of the channel. The bridge is a 245-ft by 36-ft, concrete-beam structure resting on abutments and two concrete piers, which are skewed 15 degrees from perpendicular to the axis of the bridge. The abutment and pier footings are supported by steel piling. The bridge was built in 1980 (Iowa Department of Transportation, 1979).

The water-surface profile computations show pressure-flow conditions at the bridge for the Q_{500} flood discharge. Contraction-scour depths were not determined because negative values were computed. The negative values are due to the channel being wider at the bridge than upstream (W_2 greater than W_1 in equation 16, Richardson and others, 1993, p. 33). The scour depths calculated for the bridge at Middle Raccoon River near Bayard are summarized in the table below.

Figure 5*A* shows that the stage corresponding to the average streamflow at the site is 1.4 ft higher in 1993 than in 1978, which indicates that the streambed is aggrading. Whether the streambed will continue aggrading cannot be estimated from the data because of the short (15 years) period of record.

Figure 5*B* shows the cross section surveyed at the downstream side of the bridge on October 25, 1993, with the pier- and abutment-scour depths calculated for the Q_{100} flood superimposed. Also shown in figure 5*B* is the cross section obtained from a discharge measurement made on July 9, 1993. The measured discharge was 23,200 ft^3/s, which is greater than the Q_{100} flood. The discharge-measurement cross section shows clear evidence of scour in the middle of the channel and no evidence of scour at either abutment. The measured scour was about to the elevation of the base of the piers.

	100-year flood (Q_{100})	500-year flood (Q_{500})	Remarks
Discharge (ft^3/s)	18,800	26,800	No road overflow; pressure flow for Q_{500}.
River stage at bridge (ft above gage datum)	26.75	28.84	--
Contraction-scour depth (ft)	--	--	Live-bed conditions; negative values computed.
Pier-scour depth (ft)	10.5	11.5	--
Abutment-scour depth (ft)			
Left abutment	11.9	13.9	--
Right abutment	14.1	18.5	--

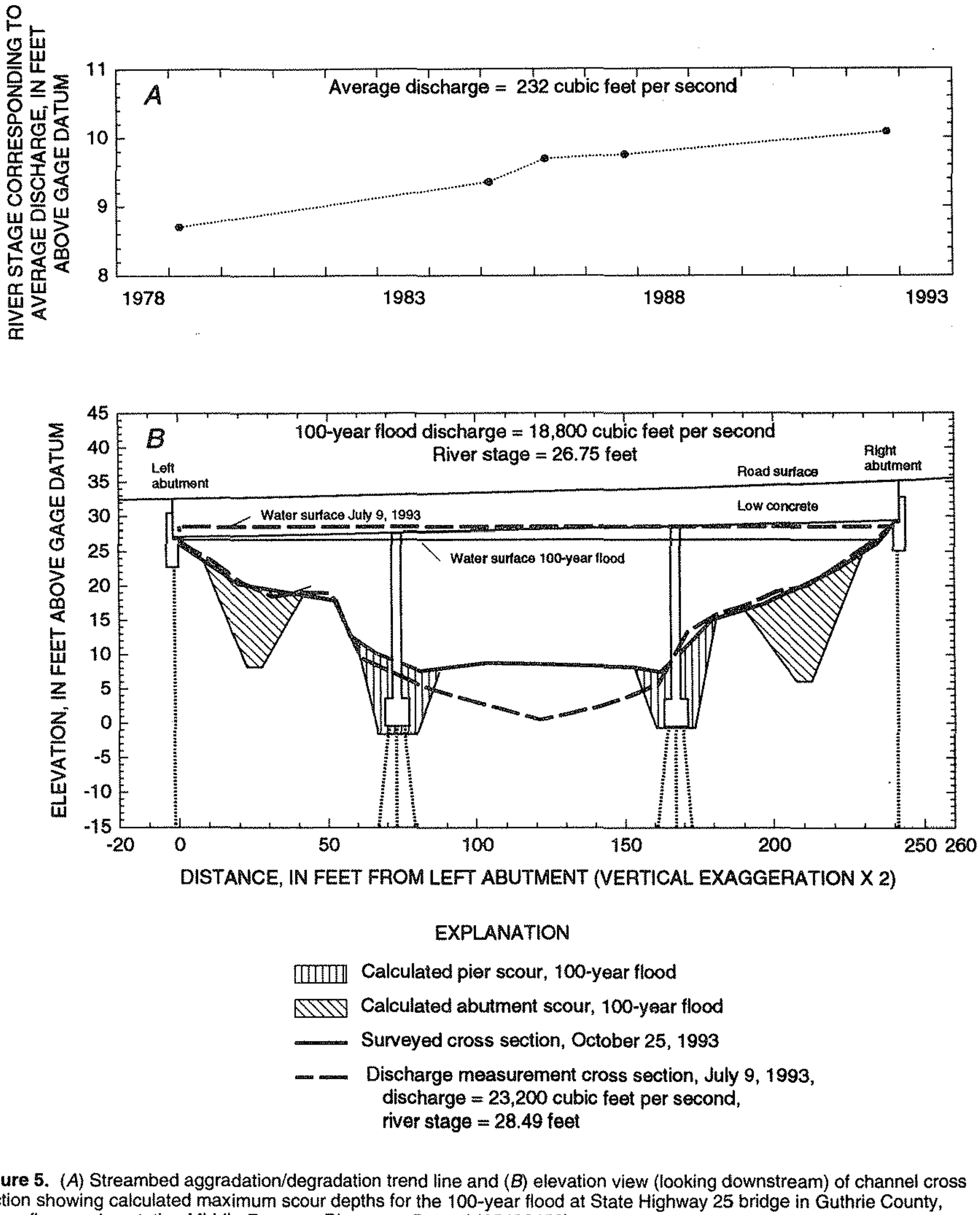


Figure 5. (*A*) Streambed aggradation/degradation trend line and (*B*) elevation view (looking downstream) of channel cross section showing calculated maximum scour depths for the 100-year flood at State Highway 25 bridge in Guthrie County, streamflow-gaging station Middle Raccoon River near Bayard (05483450).

Raccoon River at Van Meter (05484500)

This bridge site is located on County Road R16 in Dallas County. The bridge is near the right edge of the river valley and crosses the river at a wide bend in the river. The alignment of the piers is perpendicular to the axis of the bridge; however, the angle of approach of floodflows is about 15 degrees. The flood plain is about 2,000 ft wide at the bridge. Upstream, the left flood plain is cultivated, and the right flood plain is covered with trees and marshland, the area of which, according to the bridge plans, was formerly a gravel pit. Downstream, the left flood plain is cultivated between the edge of the plain to about 300 ft from the edge of the river; between this point and the river the flood plain is covered with trees. The right flood plain is cultivated. The bridge is a 445-ft by 24-ft, continuous I-beam structure resting on abutments and four piers. The abutments and pier footings are supported by steel piling. The two right piers are in the main channel, and the right abutment is protected with riprap. The bridge was built in 1957 (Iowa Department of Transportation, 1956).

The water-surface profile computations indicated submerged pressure-flow conditions for the Q_{500} flood discharge. Contraction-scour depths in the main channel were not determined because the scour equations produced negative values. The scour depths calculated for the bridge over the Raccoon River at Van Meter are summarized in the table below.

Figure 6*A* shows that the streambed has been stable at this site since the gaging station was installed. Figure 6*B* shows the cross section surveyed at the downstream side of the bridge on November 14, 1993, with the contraction-, pier-, and abutment-scour depths calculated for the Q_{100} flood superimposed. Contraction scour is shown only for the overbank (flood-plain) portion of the cross section because the contraction-scour equations produced a negative value for the main channel. The surveyed cross section shows the streambed between the first and second piers from the right abutment to be about at the elevation of the base of the piers.

Two discharge-measurement cross sections also are shown in figure 6*B*. The discharge measured on July 1, 1986, was 38,300 ft^3/s with a corresponding river stage of 22.25 ft. The other cross section is from the first discharge measurement made at the site after the flood peak, which occurred July 10, 1993 (date of cross section = July 19, 1993, discharge = 13,600 ft^3/s, river stage = 14.01 ft). Unsafe conditions prevented measurement of the flood peak at the bridge because water was flowing against the side of the bridge beams. Discharge measurements were made at another bridge about 5 mi downstream during the extreme high flows. The peak discharge at the study bridge was determined to be 70,100 ft^3/s; the corresponding river stage was 26.34 ft (Southard and others, 1994, p. 164). This peak discharge was greater than the theoretical Q_{500} flood (table 3).

Because the streambed was nearly at the same elevation in November when the site was surveyed as it was when measured on July 19, it was assumed that the channel did not fill in between the flood peak and the discharge measurement 9 days later. The similar bed elevations of these two cross sections and of the cross section measured in 1986 suggest that contraction and abutment scour at the bridge is much less than the scour predicted by the scour equations. That contraction scour in the main channel is minimal and is likely a consequence of the large size (D_{50} = 91 mm) of the bed material (table 3).

	100-year flood (Q_{100})	500-year flood (Q_{500})	Remarks
Discharge (ft^3/s)	49,100	62,600	Road overflow.
Discharge through bridge opening (ft^3/s)	46,600	49,500	Pressure flow for Q_{500}.
River stage at bridge (ft above gage datum)	23.95	25.64	--
Contraction-scour depth (ft)			
Main channel	--	--	Clear-water conditions; negative values computed.
Overbank	8.7	10.2	Clear-water conditions.
Pier-scour depth (ft)	19.4	20.1	--
Abutment-scour depth (ft)			
Left abutment	26.4	24.5	--
Right abutment	22.1	18.6	--

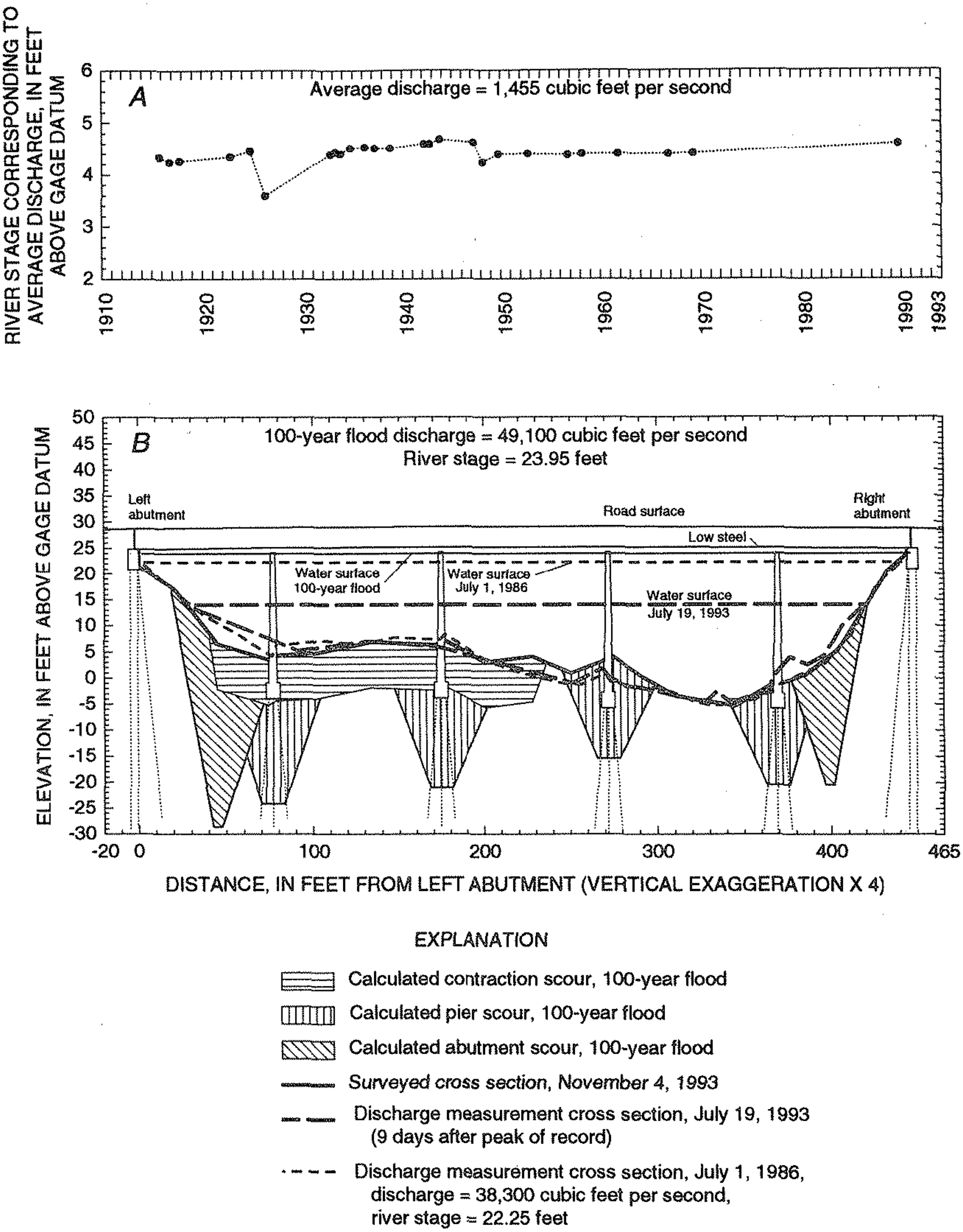


Figure 6. (*A*) Streambed aggradation/degradation trend line and (*B*) elevation view (looking downstream) of channel cross section showing calculated maximum scour depths for the 100-year flood at County Road R16 bridge in Dallas County, streamflow-gaging station Raccoon River at Van Meter (05484500).

White Breast Creek near Dallas (05487980)

This bridge site is located on a gravel road in western Marion County. The bridge crosses the stream at about a 30-degree angle and is downstream about 350 ft from a bend in the stream. The road in the left flood plain curves 90 degrees to the bridge in the upstream direction. Upstream of the bridge, the right flood plain is a pasture, and the left flood plain is cultivated. There is a large clump of trees on the left bank near the bridge. Downstream, the flood plain is cultivated on both sides of the stream, and trees line the banks. The bridge is a 250-ft by 20-ft, continuous I-beam structure supported by abutments and two concrete piers that are skewed 30 degrees to the axis of the bridge to be parallel to the flow. The abutments and piers are supported by wood piling. The bridge was built in 1955 (Iowa Department of Transportation, 1954a). The site is marked by active erosion at the right bank and abutment. Streamflow occasionally is affected by backwater from a reservoir about 15 mi downstream.

The water-surface profile computations indicated that the higher velocities through the bridge opening occur at the stage of the stream when flow begins to go over the road on the left flood plain rather than at the stage of the Q_{100} flood (Q_{100} = 25,800 ft^3/s). Therefore, scour calculations were made for a discharge of 17,700 ft^3/s, denoted Q_{pro} (point-of-road overflow), rather than for Q_{100}. The maximum scour depths calculated for the bridge over White Breast Creek near Dallas are summarized in the table below.

Figure 7*A* shows that the streambed has been stable since 1962. Figure 7*B* shows the cross section surveyed at the downstream side of the bridge on October 19, 1993, with scour depths calculated for the point-of-road-overflow flood (Q_{pro}) superimposed. The extent of the erosion at the right abutment is shown by the outline of a discharge-measurement cross section made July 5, 1981. The area of the bridge opening (computed parallel to the axis of the bridge) has enlarged approximately 400 ft^2 since 1981. The primary cause of the erosion is a river-meander impact point occurring at the bridge during normal flows (see table 4, site 77).

	Discharge, point-of-road overflow (Q_{pro})	500-year flood (Q_{500})	Remarks
Discharge (ft^3/s)	17,700	35,900	Road overflow for Q_{500}.
Discharge through bridge opening (ft^3/s)	17,700	25,100	--
Stream stage at bridge (ft above gage datum)	27.50	33.00	--
Contraction-scour depth (ft)	1.4	1.7	Live-bed conditions.
Pier-scour depth (ft)	8.5	8.7	--
Abutment-scour depth (ft)			
Left abutment	11.9	17.4	--
Right abutment	10.3	18.0	--

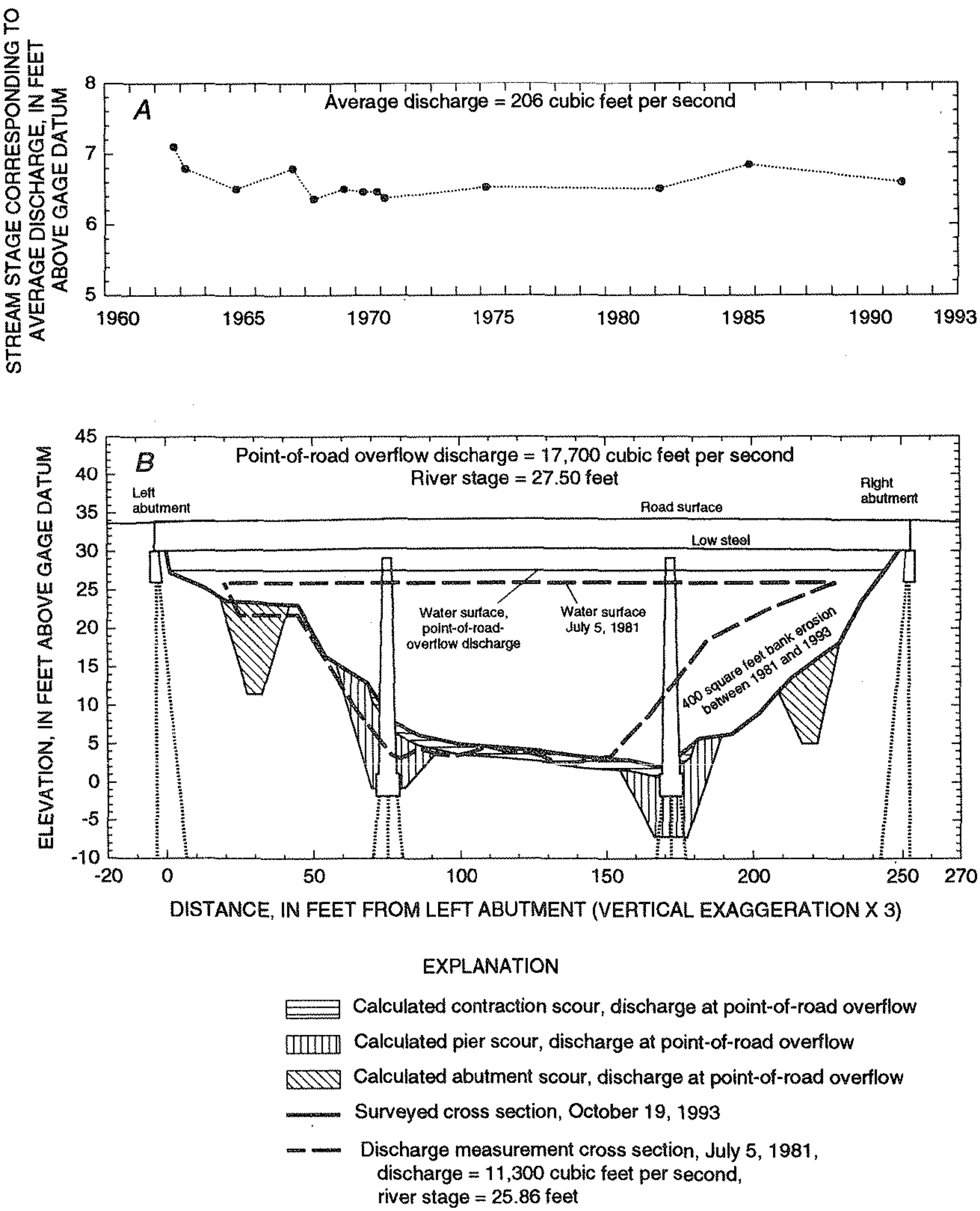


Figure 7. (*A*) Streambed aggradation/degradation trend line and (*B*) elevation view (looking downstream) of channel cross section showing calculated maximum scour depths for the point-of-road-overflow flood at county road bridge in Marion County, streamflow-gaging station White Breast Creek near Dallas (05487980).

Cedar Creek near Bussey (05489000)

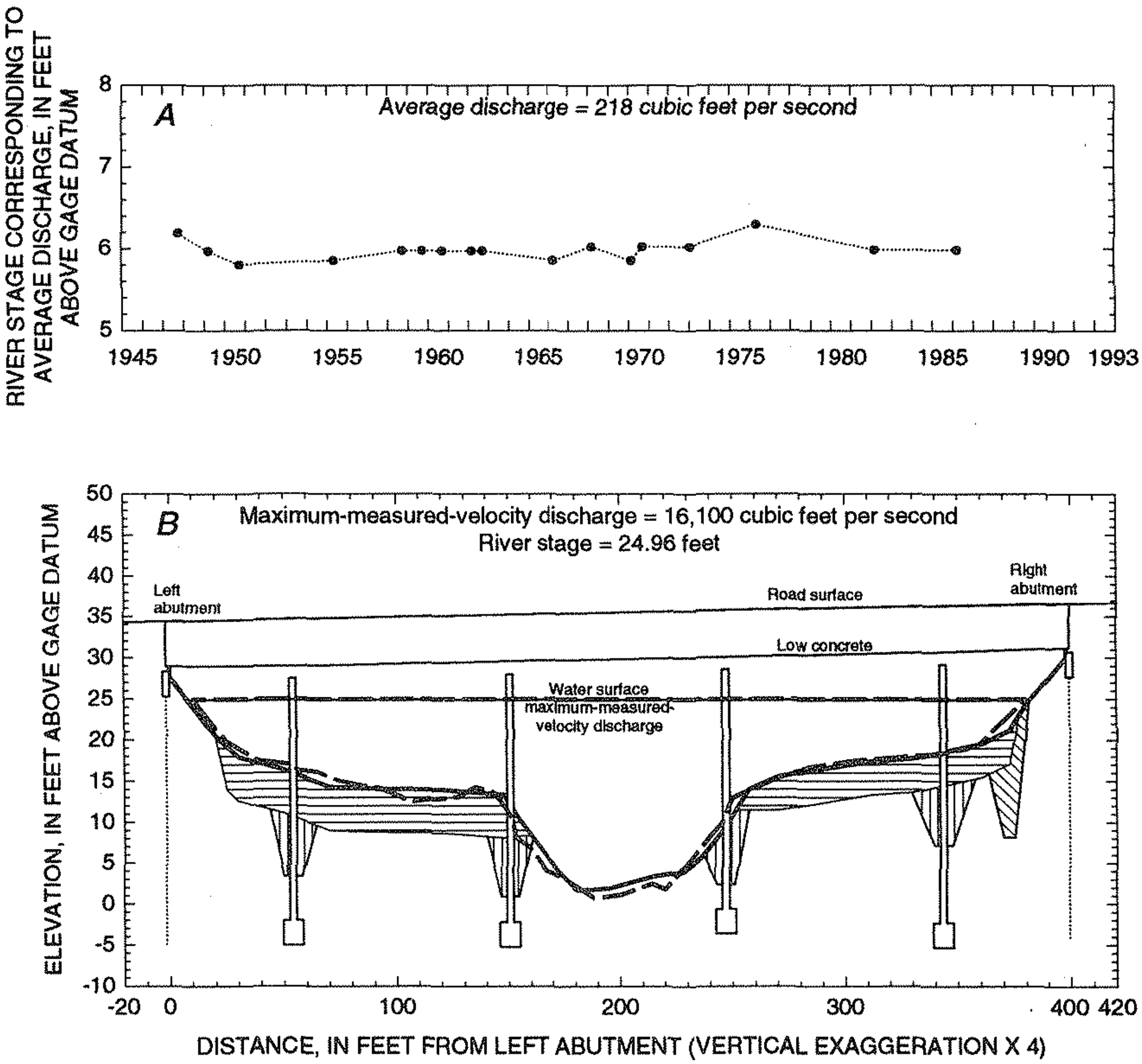
The bridge at this site is located on State Highway 156 in eastern Marion County. The highway crosses the river at an angle of about 15 degrees near the right edge of the river valley and continues across the flood plain for about 0.5 mi before leaving the valley. Upstream of the bridge, the stream is approximately parallel to the highway for about 0.5 mi. The left flood plain on both sides of the highway is cultivated; narrow bands of trees line the riverbank. The right flood plain on both sides of the bridge is covered by trees. The bridge is a 401-ft by 36-ft, pretensioned, prestressed, concrete-beam bridge supported on abutments and four concrete piers that are skewed 15 degrees from perpendicular to the axis of the bridge to be parallel to the flow. The abutments are supported by steel piling, and the piers are supported by spread footings on shale and limestone. An earthen guide bank extends upstream from the left abutment. The bridge was built in 1989 (Iowa Department of Transportation, 1989).

Road overflow begins at discharges greater than approximately 16,000 ft^3/s, which is about one-third the theoretical Q_{100} flood of 45,900 ft^3/s. The point of road overflow is not in the same hydraulic section as the bridge but is about 2,500 ft upstream. Therefore, it was necessary to divide and route streamflows over the road and through the bridge. The water-surface profile computations indicated that the bridge section is not a contracted opening for discharges greater than about 20,000 ft^3/s. This indication is supported by flood profiles made in the Cedar Creek drainage basin in 1981 and 1982 (Heinitz, 1986, fig. 22, p. 32). The flood profiles show a fall of 0.3 ft at the site (old bridge) for the peak discharge of 26,600 ft^3/s in 1981, and no fall for the peak discharge of 96,000 ft^3/s in 1982.

Because maximum scour conditions are not likely to occur when the bridge is not acting as a contracted opening, it was decided to calculate scour using the discharge with the maximum measured velocities at the current bridge and compare the results with the measurement. The discharge measurement was made July 6, 1993, and was 16,100 ft^3/s; the average velocity was 3.82 ft/s. There was no road overflow. The scour depths calculated for the bridge over Cedar Creek near Bussey using this discharge are summarized in the table below.

Figure 8*A* shows that the streambed has been stable for the period of record (1947–93). Figure 8*B* shows the cross section surveyed at the downstream side of the bridge June 15, 1993, with the calculated scour depths superimposed on the cross section. The calculated contraction scour for the main channel is 0.1 ft and is not discernible in figure 8*B*. Abutment scour was not calculated for the left abutment because of the presence of the guide bank. The cross section from the discharge measurement, measured at the upstream side of the bridge, also is shown in figure 8*B*. The actual scour is much less than the calculated scour except for about 1 ft of contraction scour in the main channel. Although pier scour was not measured during the flood, a post-flood inspection showed minor scour at the piers. An inspection after the flood of September 15-16, 1992 (maximum discharge = 20,900 ft^3/s, discharge through bridge opening = 15,900 ft^3/s, river stage = 28.28 ft), also showed that minor scour occurred at the site. The inspection in 1992 revealed that the toe of the upstream end of the guide bank had eroded an estimated 5 ft and that the erosion was lateral into the guide bank rather than into the ground.

	Discharge measured July 6, 1993	Remarks
Discharge (ft^3/s)	16,100	Discharge with maximum measured flow velocities, no road overflow.
River stage at bridge (ft above gage datum)	24.96	--
Contraction-scour depth (ft)		
Main channel	0.1	Live-bed conditions.
Left overbank	5.3	Clear-water conditions.
Right overbank	4.1	Clear-water conditions.
Pier-scour depth (ft)	7.3	--
Abutment-scour depth (ft)		
Left abutment	--	Not calculated because of guide bank.
Right abutment	8.9	--



EXPLANATION

Calculated contraction scour, maximum-measured-velocity discharge

Calculated pier scour, maximum-measured-velocity discharge

Calculated abutment scour, maximum-measured-velocity discharge

Surveyed cross section, June 15, 1993

Discharge measurement cross section, July 6, 1993
(upstream side of bridge),
discharge = 16,100 cubic feet per second,
river stage = 24.96 feet

Figure 8. (*A*) Streambed aggradation/degradation trend line and (*B*) elevation view (looking downstream) of channel cross section showing calculated scour for the discharge with maximum measured velocities at State Highway 156 bridge in Marion County, streamflow-gaging station Cedar Creek near Bussey (05489000).

Maple River at Mapleton (06607200)

This bridge is on State Highway 175 over the Maple River about 1 mi southwest of Mapleton in Monona County. The highway crosses the river at an angle of about 30 degrees near the left side of the river valley. The highway is parallel to the axis of the valley away from the bridge, and the flood plain is about 3,500 ft wide. Small trees and brush cover the left flood plain on both sides of the highway in the immediate vicinity of the bridge. A low levee extends downstream from the highway about 250 ft from the riverbank on the right flood plain. The right flood plain is cultivated on the upstream side of the highway, and it is cultivated beyond the levee on the downstream side. The bridge is a 240-ft by 26-ft, continuous I-beam structure supported by concrete abutments and two concrete piers, which are skewed 30 degrees from perpendicular to the axis of the bridge to be parallel to the flow. The abutment and pier footings are supported by wood piling. The bridge was built in 1955, replacing a bridge that was washed out in 1954 (Iowa Department of Transportation, 1954b).

The bridge site is characterized by degradation of the streambed by more than 6 ft since systematic collection of streamflow records began in 1942. The water-surface profile analyses indicated that the Q_{100} and Q_{500} flood discharges will pass through the bridge opening. The maximum scour depths calculated for the bridge at Maple River at Mapleton are summarized in the table below.

Figure 9*A* shows that the stage corresponding to the average discharge decreased 6.7 ft between 1941 and 1987, which indicates that the streambed degraded approximately the same amount. The rate of degradation decreased about 1971; between 1971 and 1987 the streambed degraded about 0.5 ft. The rate of degradation for the period of rating-curve changes is 0.146 ft/yr (6.7 ft in 46 years); the rate of degradation since 1971 is 0.031 ft/yr (0.5 ft in 16 years). The most likely explanation for the streambed degradation at this site is the response of the river to channel straightening in the 1930's. The site is located in the Loess Hills landform region (site 82, fig. 1).

Figure 9*B* shows the cross section surveyed at the downstream side of the bridge October 26, 1993, with the calculated scour depths superimposed on the cross section. The cross section of the largest recently measured discharge also is shown in figure 9*B*. The measurement, made at the downstream side of the bridge June 15, 1991, shows that the streambed scoured in the middle of the channel and that the depth of scour is below the elevation of the bases of the piers. This scour, however, is not the result of flood-plain flow returning to the main channel because the streamflow was approximately bankfull. Rather, the streambed lowered during the flood as the result of a general entrainment of bed material caused by the rapidly flowing water. The scoured streambed backfilled as the flow returned to the base discharge.

	100-year flood (Q_{100})	500-year flood (Q_{500})	Remarks
Discharge (ft^3/s)	26,200	33,300	No road overflow.
River stage at bridge (ft above gage datum)	18.72	20.34	--
Contraction-scour depth (ft)	5.4	7.4	Live-bed conditions.
Pier-scour depth (ft)	8.8	9.4	--
Abutment-scour depth (ft)			
Left abutment	14.0	11.8	Q_{100} depth greater because of large difference in highway embankment length for Q_{500}.
Right abutment	15.8	20.3	--

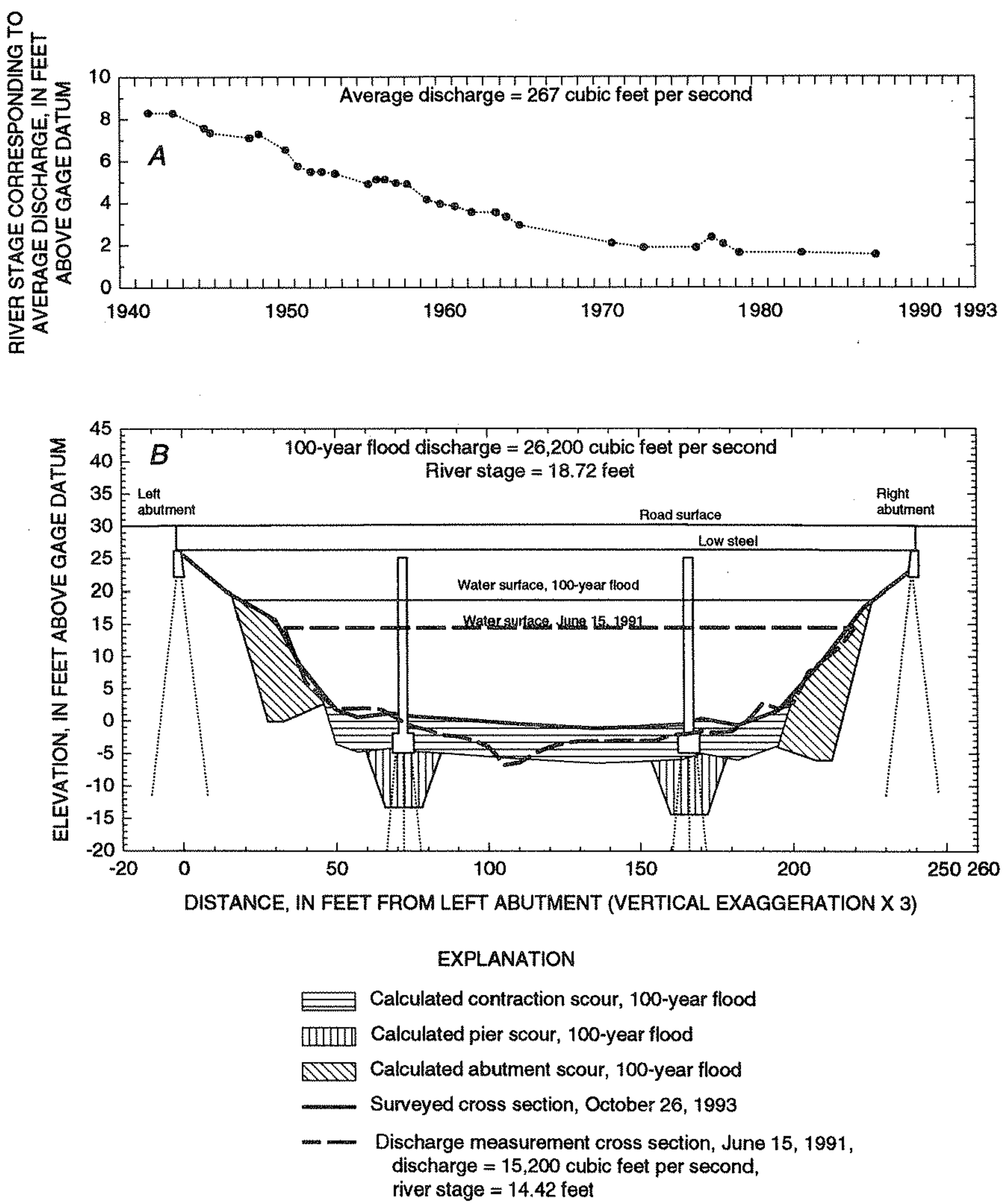


Figure 9. (*A*) Streambed aggradation/degradation trend line and (*B*) elevation view (looking downstream) of channel cross section showing calculated scour for the 100-year flood at State Highway 175 bridge in Monona County, streamflow-gaging station Maple River at Mapleton (06607200).

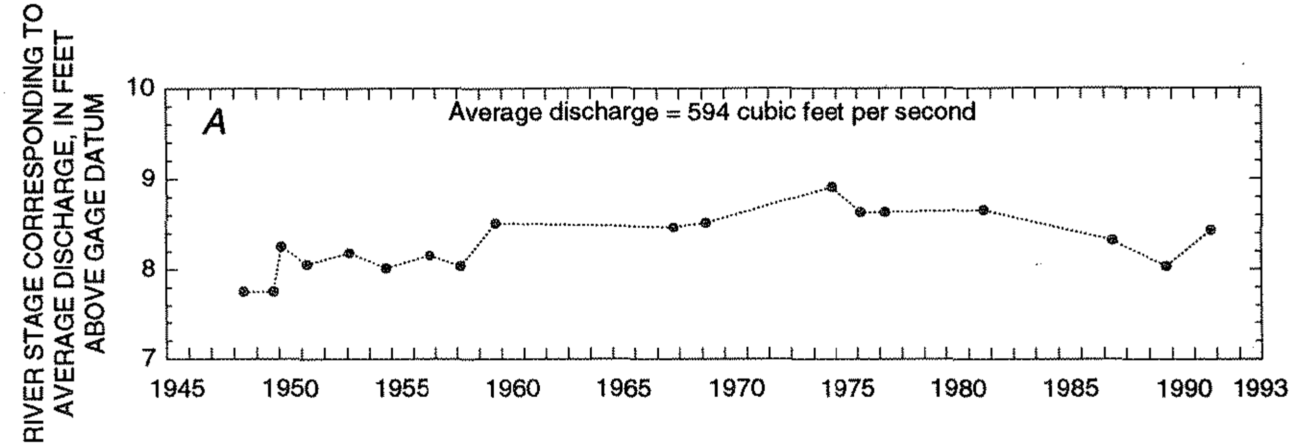
West Nishnabotna River at Randolph (06808500)

This bridge is located on State Highway 184 in Fremont County. The highway crosses the river valley and river at nearly right angles. The flood plain is about 3,500 ft wide at the bridge. Tree-covered levees line the banks on both sides of the highway, and the left and right flood plains are cultivated. The bridge is a 384.5-ft by 32-ft, pretensioned, prestressed, concrete-beam structure supported by abutments and three concrete piers, which are supported by steel piling. The bridge was built in 1974 (Iowa Department of Transportation, 1973).

The water-surface profile calculations show that road overflow occurs on the left flood plain for the Q_{100} and Q_{500} flood discharges. Water in the right flood plain is ponded at flood stages and therefore does not contribute to the conveyance of flow; the Q_{100} flood stage is about level with the top of the levee, and the Q_{500} flood stage is less than 1 ft higher. The levee on the left flood plain is about 2 ft lower than the levee on the right flood plain. During the calibration of the WSPRO model, it became apparent that adjusting the channel roughness values alone would not be sufficient to accomplish the calibration, nor would it be possible to set the end of the approach cross section in the left flood plain at the top of the levee because that would have affected the road overflow computations. The final calibration was accomplished by increasing the bridge discharge coefficient to 0.98 (from the automatically calculated value of 0.85). This fact suggests that the contribution of flow to the bridge opening from the left flood plain is minimal, even though the flood plain is connected hydraulically. The scour depths calculated for the bridge at West Nishnabotna River at Randolph are summarized in the table below.

Figure 10*A* shows that the streambed at this site has been relatively stable for the period of record (1948–93). Figure 10*B* shows the cross section surveyed at the downstream side of the bridge October 27, 1993, with the calculated pier-scour depths superimposed on the cross section. Also shown in figure 10*B* is the cross section of a flood measured May 26, 1987. The peak discharge of the flood was 35,800 ft^3/s, of which 3,100 ft^3/s was road overflow on the left flood plain. The cross section shows that the streambed near the downstream side of the bridge scoured about 6 ft between the left and center piers and that it scoured about 5 ft between the center and right piers. The scour is attributable to a general lowering of the streambed during the flood and to possible debris caught on the piers. A debris pile was noted on the center pier at the time of the potential-scour assessment in March 1992 (see table 4, site 37).

	100-year flood (Q_{100})	500-year flood (Q_{500})	Remarks
Discharge (ft^3/s)	49,500	59,100	Road overflow.
Discharge through bridge opening (ft^3/s)	32,600	37,400	--
River stage at bridge (ft above gage datum)	24.97	25.72	--
Contraction-scour depth (ft)	--	--	Live-bed conditions; negative values computed.
Pier-scour depth (ft)	8.5	8.4	--
Abutment-scour depth (ft)	--	--	Not calculated because the levees affect the approach flow like guide banks.



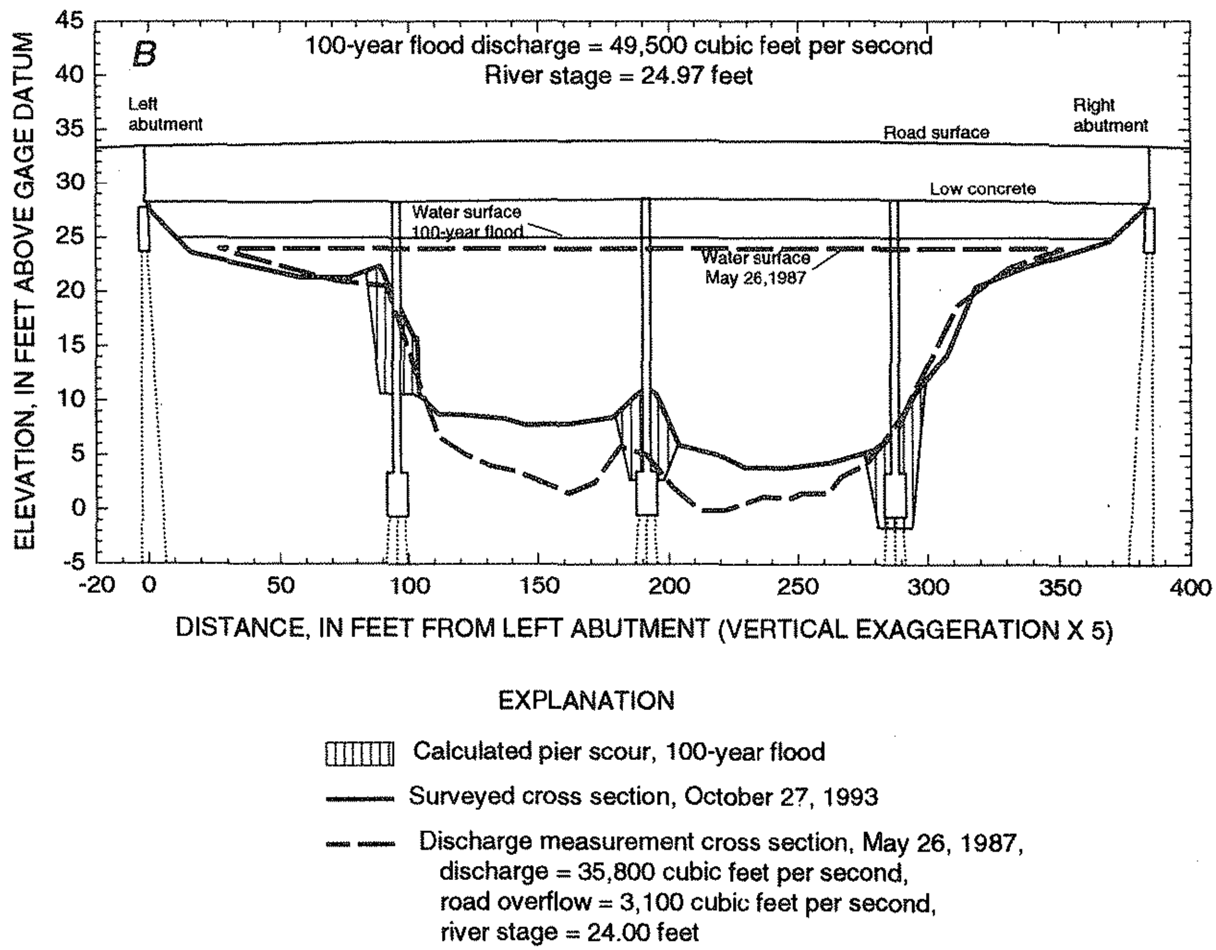


Figure 10. (*A*) Streambed aggradation/degradation trend line and (*B*) elevation view (looking downstream) of channel cross section showing calculated scour for the 100-year flood at the State Highway 184 bridge in Fremont County, streamflow-gaging station West Nishnabotna River at Randolph (06808500).

East Nishnabotna River near Atlantic (06809210)

The bridge is on a paved county road in Cass County. The highway is perpendicular to the axis of the river valley; it crosses the river at an angle of about 12 degrees. The river is near the right edge of the valley; during flooding, road overflow occurs in the left flood plain. The right flood plain is cultivated on the upstream side of the highway, and the left flood plain is a pasture. The flood plain is cultivated on both sides of the river downstream of the highway. Narrow bands of trees line the banks along the cultivated portions of the flood plain. The bridge is a 240-ft by 20-ft, continuous I-beam structure supported by abutments and two concrete piers that are skewed 15 degrees from perpendicular to the axis of the bridge to be parallel to the flow. The abutments are supported by wood piling, and the piers are supported by spread footings on shale and limestone. The bridge was built in 1951 (Iowa Department of Transportation, 1950).

Considerable erosion of the bank has occurred at the left abutment. During the potential-scour assessments, the site had mass wasting on the left bank, which is caused by a river meander impact point at the bridge (table 4, site 16). Sheetpiling has been driven into the channel at the base of the abutment, and riprap has been installed on the embankment.

The water-surface profile analyses indicated that the bridge section is not a contracted opening at the Q_{100} and Q_{500} flood discharges. It was necessary to composite the bridge and road sections to create a regular (non-bridge) channel cross section to compute the water-surface profiles (Shearman, 1990, p. 90–91; Shearman and others, 1986, p. 40). The analyses also indicated that the conveyance-tube flow velocities at the bridge were less for the Q_{500} flood than for the Q_{100} flood. Therefore, rather than use the Q_{500} flood, it was decided to compute scour using the discharge occurring at the point-of-road overflow, Q_{pro}, which was determined to be about 22,000 ft^3/s. The scour depths calculated for the bridge over the East Nishnabotna River near Atlantic are summarized in the table below.

Figure 11*A* shows that the streambed at this site has degraded about 1 ft between 1970 and 1989. The rate of degradation for the period is 0.053 ft/yr (1 ft in 19 years). The points in figure 11*A* are for the period of record at the current site; before 1970, the gaging station was located 2.2 mi upstream.

Figure 11*B* shows the cross section surveyed at the downstream side of the bridge May 24, 1993, with the calculated scour depths for the Q_{100} flood superimposed on the cross section. Also shown in figure 11*B* is the cross section of a flood measured June 14, 1991. The peak discharge of the flood was 21,000 ft^3/s, and the river stage was 18.29 ft. There was no road overflow. The discharge-measurement cross section shows that the streambed was scoured below the elevation of the base of the footing of the left pier. The measured scour was about 9 ft, which is more than twice the calculated Q_{100} contraction scour depth (3.3 ft). A possible cause for the scour in addition to the contraction caused by the highway embankment is debris on the piers. A debris pile was noted on the left pier at the time of the potential-scour assessment in March 1992 (table 4, site 16). Given the facts that the measured scour depth is below the elevation of the base of one pier, that the pier is not supported by piling, and that debris piles can cause deeper scour holes (see, for example, Laursen and Toch, 1956, p. 30), additional investigation of local scour at the pier may be warranted.

	Discharge, point-of-road overflow (Q_{pro})	100-year flood (Q_{100})	Remarks
Discharge (ft^3/s)	22,000	35,600	Road overflow for Q_{100}.
Discharge through bridge opening (ft^3/s)	22,000	31,600	--
Stream stage at bridge (ft above gage datum)	18.94	22.64	--
Contraction-scour depth (ft)	2.4	3.3	Live-bed conditions.
Pier-scour depth (ft)	11.9	12.8	--
Abutment-scour depth (ft)			
Left abutment	17.4	21.7	--
Right abutment	13.0	16.2	--

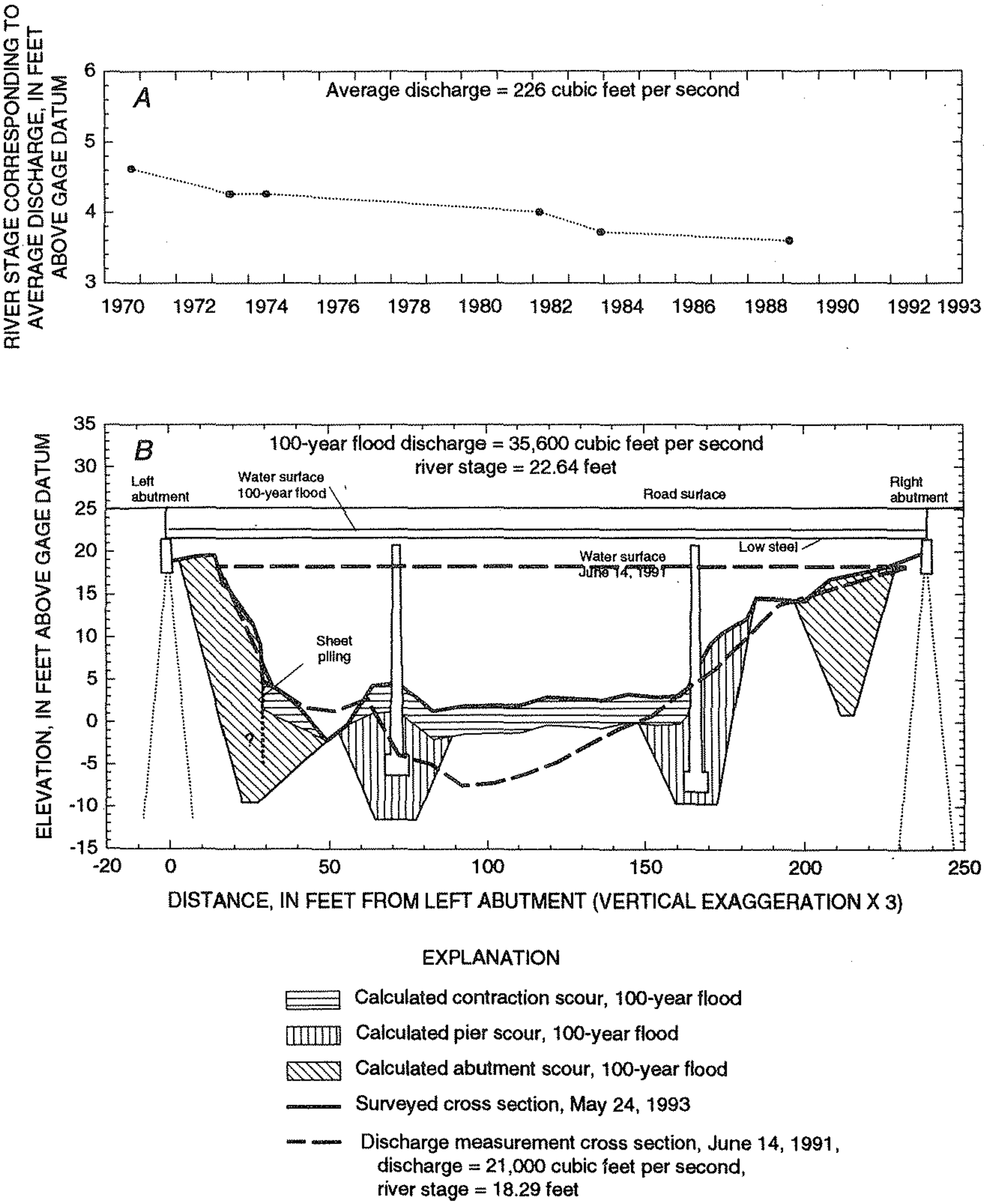


Figure 11. (*A*) Streambed aggradation/degradation trend line and (*B*) elevation view (looking downstream) of channel cross section showing calculated scour depths for the point-of-road-overflow flood at county road bridge in Cass County, streamflow-gaging station East Nishnabotna River at Atlantic (06809210).

Nodaway River at Clarinda (06817000)

The bridge at this site is located on State Highway 2 (business route) in Page County. The highway crosses the river at an angle of about 17 degrees near the center of the river valley. The flood plain is cultivated on both sides of the river. Very few trees are standing in the vicinity of the bridge. The bridge is a 314-ft by 26-ft, continuous I-beam structure supported by concrete abutments and three concrete piers, which are perpendicular to the axis of the bridge. According to the bridge plans, the piers and right abutment previously supported the old bridge, which was built in 1917. The current left pier was formerly the left abutment. The present left abutment is supported by wood pilings, and the right abutment and three piers are apparently spread footings on "hardpan." The right abutment and the piers are sharp-nosed and angle outward on the upstream side of the bridge. The present bridge was built in 1949 after one of the spans of the previous structure collapsed because of an overloaded truck (Iowa Department of Transportation, 1949).

The water-surface profile analyses indicate that road overflow will not occur for the Q_{100} and Q_{500} flood discharges. The scour depths calculated for the bridge over the Nodaway River at Clarinda are summarized in the table below.

Figure 12*A* shows that the streambed at this site has degraded, aggraded, and again degraded during the period of record (1918–93). The data points show a decrease in the elevation of the streambed of about 1.2 ft between 1918 and 1953, an increase of about 1.5 ft between 1953 and 1960, and a decrease of about 2.5 ft between 1960 and 1987. (The gaging station was discontinued from 1925 to 1936; hence, there are no data during that interval.) The rate of degradation between 1960 and 1987 is 0.093 ft/yr (2.5 ft in 27 years). The rating curve has not been changed since 1987, which suggests that the rate of degradation has decreased.

Figure 12*B* shows the cross section surveyed at the downstream side of the bridge June 22, 1993, with the calculated scour depths for the Q_{100} flood superimposed on the cross section. Also shown in figure 12*B* is the cross section of a discharge measurement made September 15, 1992. The measured discharge was 24,500 ft^3/s, and the river stage was 18.43 ft. The cross section shows that the streambed was scoured below the base of the footings between the center and right piers. Because the maximum stage was only 1 to 2 ft above bankfull stage, the scoured streambed is likely the result of general entrainment of bed material caused by the rapidly flowing water and contraction of flow area caused by debris on the bridge piers. Debris was noted at this site at the time of the potential-scour assessment (table 4, site 88). Given the facts that the measured scour depth is below the elevation of the base of the piers, that the piers are not supported by pilings, and that debris piles can cause deeper scour holes (Laursen and Toch, 1956, p. 30), additional investigation of local scour at the piers may be warranted.

	100-year flood (Q_{100})	500-year flood (Q_{500})	Remarks
Discharge (ft^3/s)	42,700	51,800	No road overflow.
River stage at bridge (ft above gage datum)	26.22	27.58	--
Contraction-scour depth (ft)	4.1	6.7	Live-bed conditions.
Pier-scour depth (ft)	22.6	23.8	--
Abutment-scour depth (ft)			
Left abutment	12.5	17.6	--
Right abutment	15.5	19.7	--

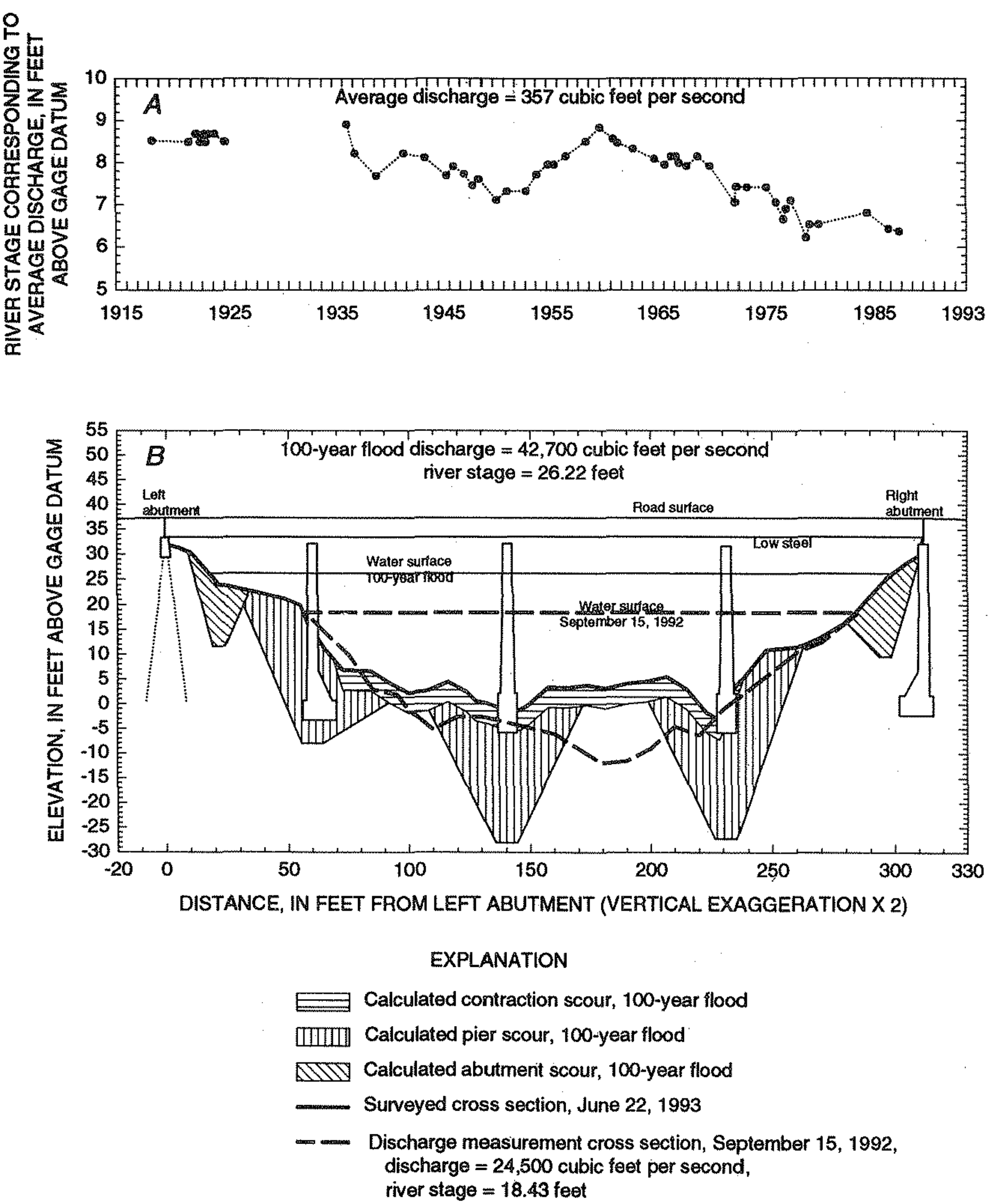


Figure 12. (*A*) Streambed aggradation/degradation trend line and (*B*) elevation view (looking downstream) of channel cross section showing calculated scour for the 100-year flood at the State Highway 2 (business route) bridge in Page County, streamflow-gaging station Nodaway River at Clarinda (06817000).

Platte River near Diagonal (06818750)

The bridge is located on a gravel county road in Ringgold County. The river is a straight channel upstream and downstream of the bridge, and the banks are lined with narrow bands of trees. The flood plain is flat, about 3,500 ft wide, and cultivated on both sides of the river upstream and downstream of the road. The road crosses the river valley and river at a nearly 90-degree angle. The road embankment is raised about 4 ft above the surrounding fields except at the bridge where it is about 7 ft higher. Two culverts cross under the road on the right flood plain, but they were not considered in the hydraulic analysis. The bridge is a 180-ft by 20-ft, prestressed concrete-beam structure supported on concrete abutments and two pile bents. Low concrete on the bridge is approximately 3 ft above the lowest crown elevation surveyed on the road. The bridge was built in 1962 (Iowa Department of Transportation, 1961).

This site was chosen for analysis because there were no apparent factors to affect application of the scour equations. It is also the only bridge with pile bents that was analyzed for scour in this study. The scour depths calculated for the bridge over the Platte River near Diagonal are summarized in the table below.

Figure 13*A* shows that the streambed at this site has been relatively stable. The data points show degradation of about 0.7 ft between 1968 and 1980 and aggradation of about 0.5 ft between 1980 and 1987.

Figure 13*B* shows the cross section surveyed at the downstream side of the bridge May 25, 1993, with the calculated scour depths for the Q_{100} flood superimposed on the cross section. Also shown in figure 13*B* is the cross section of a discharge measurement made July 5, 1993. The measured discharge was 9,650 ft^3/s, which is within 3.5 percent of the Q_{100} discharge. The river stage was 23.60 ft. Because the gaging station at this site was not active in 1993, it is not known when the peak occurred. The measurement notes indicate that there was no road overflow at the time. The cross section shows that part of the embankment near the left abutment eroded and that the erosion is lateral into the embankment.

	100-year flood (Q_{100})	500-year flood (Q_{500})	Remarks
Discharge (ft^3/s)	10,000	11,200	Road overflow.
Discharge through bridge opening (ft^3/s)	9,800	10,400	--
River stage at bridge (ft above gage datum)	24.20	24.50	--
Contraction-scour depth (ft)	6.5	7.8	Live-bed conditions.
Pier-scour depth (ft)	4.2	4.3	--
Abutment-scour depth (ft)			
Left abutment	8.6	8.8	--
Right abutment	15.0	16.4	--

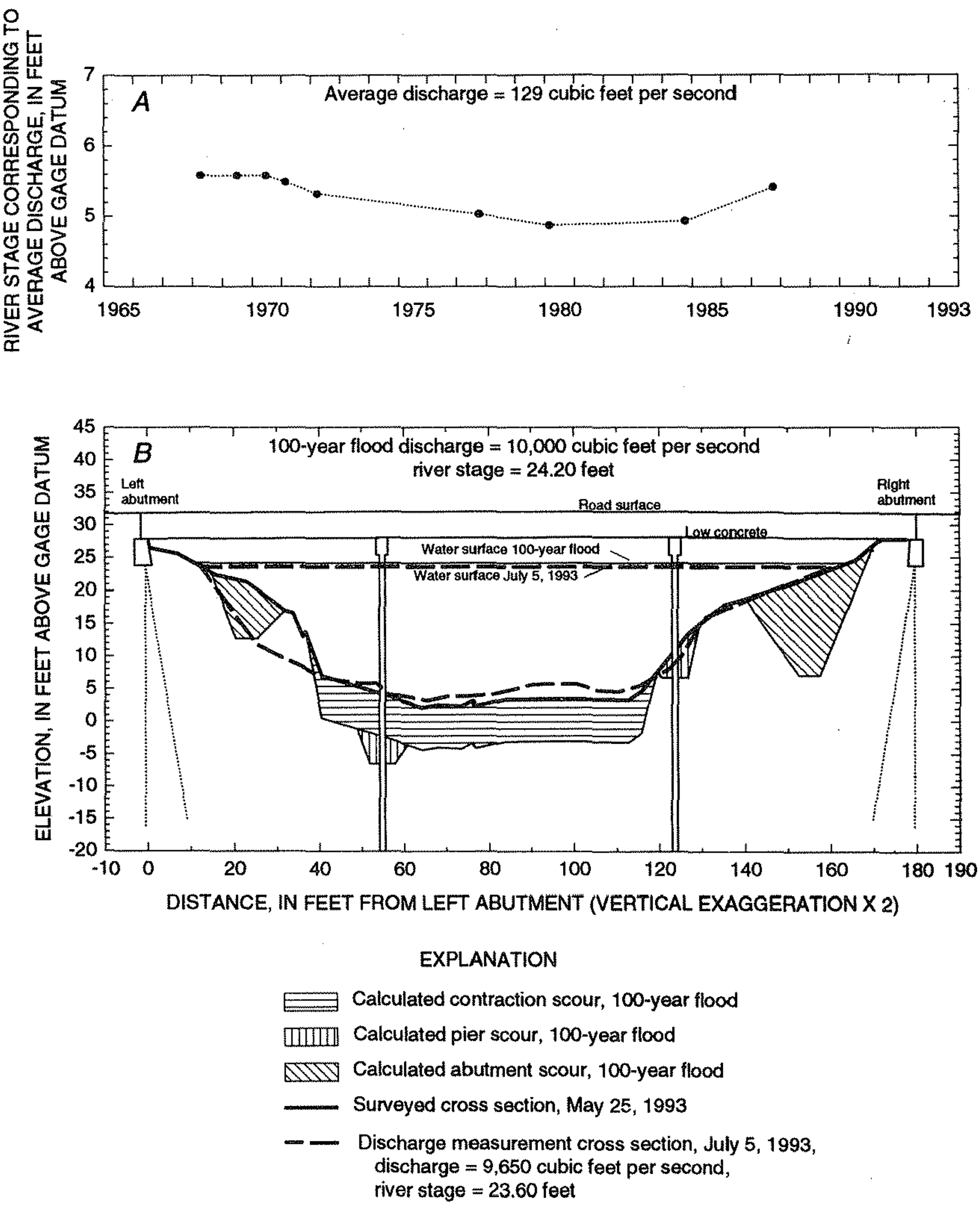


Figure 13. (*A*) Streambed aggradation/degradation trend line and (*B*) elevation view (looking downstream) of channel cross section showing calculated scour for the 100-year flood at county road bridge in Ringgold County, streamflow-gaging station Platte River near Diagonal (06818750).

Iowa River at Wapello (05465500)

This bridge is located on State Highway 99 at the eastern edge of the City of Wapello in Louisa County. The bridge crosses the river at an angle of about 5 degrees. The river valley at the bridge is about 1.3 mi wide with the main channel at the right edge of the valley. The effective left edge of the flood plain, however, is defined by a levee at the end of the bridge. The levee was built parallel to the river at the bridge, but about 600 ft upstream it was built to the left edge of the valley at a nearly 90-degree angle to the axis of the valley. The effect of this configuration of the levee is a large hydraulic contraction of floodflows. Upstream of the bridge, the right bank is protected by concrete-filled fabric erosion-protection mats. Downstream the right bank is generally unprotected, although some areas are protected by broken concrete pieces. The left flood plain between the main channel and levee on both sides of the bridge is covered with trees. The bridge is a 1,217-ft by 30-ft, multiple-span structure consisting of a 639-ft five-span, continuous-deck girder section over the main channel and a 576-ft eleven-span, continuous I-beam section over the flood plain. It is supported by concrete abutments and 15 concrete piers. The abutments and piers are supported by wood piling. The right abutment and rightmost pier were protected with riprap in 1988 (Brad Barrett, IDOT, oral commun., February 1994). The bridge was built in 1946 (Iowa Department of Transportation, 1945). Planimetric views of the river, flood plain, and bridge are given in Fischer (1994).

Computed scour depths were compared to scour depths measured during the flood of 1993. There was evidence of extensive contraction scour in the main channel at the bridge, and about 10 ft of piling were exposed below the second pier from the right bank. Scour depths were computed using the maximum discharge measured at the site during the flooding. Because the hydraulic contraction is upstream of the bridge, the channel section at the bridge was not coded as a bridge section for the purposes of computing the water-surface profile. The values for the upstream variables used in the contraction scour equations were derived from the channel section upstream of the levee. Abutment scour was not calculated because the abutments do not extend significantly into the flow path and because the right abutment is protected with riprap. The scour depths calculated for the bridge over the Iowa River at Wapello are summarized in the table below.

Figure 14*A* shows that the streambed at this site has been relatively stable for the period of record (1914–93). Figure 14*B* shows the cross section surveyed at the downstream side of the bridge November 15, 1993, with the calculated scour depths for the maximum measured discharge superimposed on the cross section. Also shown in figure 14*B* is the cross section of the maximum discharge measurement, which was made July 8, 1993. The measured discharge was 106,500 ft^3/s, which is greater than the theoretical Q_{100} discharge. The river stage was 28.07 ft. At the time of the measurement, the streambed between the second and third piers from the right abutment was higher than when the cross section was surveyed in November 1993.

The discharge measurement cross section, which was made at the downstream side of the bridge, shows that the streambed was scoured to the base of

	Discharge measured July 8, 1993	Remarks
Discharge (ft^3/s)	106,500	Maximum measured discharge; discharge greater than Q_{100}.
River stage at bridge (ft above gage datum)	28.07	--
Contraction-scour depth (ft)		
Main channel:	19.2	Live-bed conditions.
Left overbank:	--	Clear-water conditions; negative value computed.
Pier-scour depth (ft)	23.3	Calculated for piers in main channel only.
Abutment-scour depth (ft)	--	Not calculated.

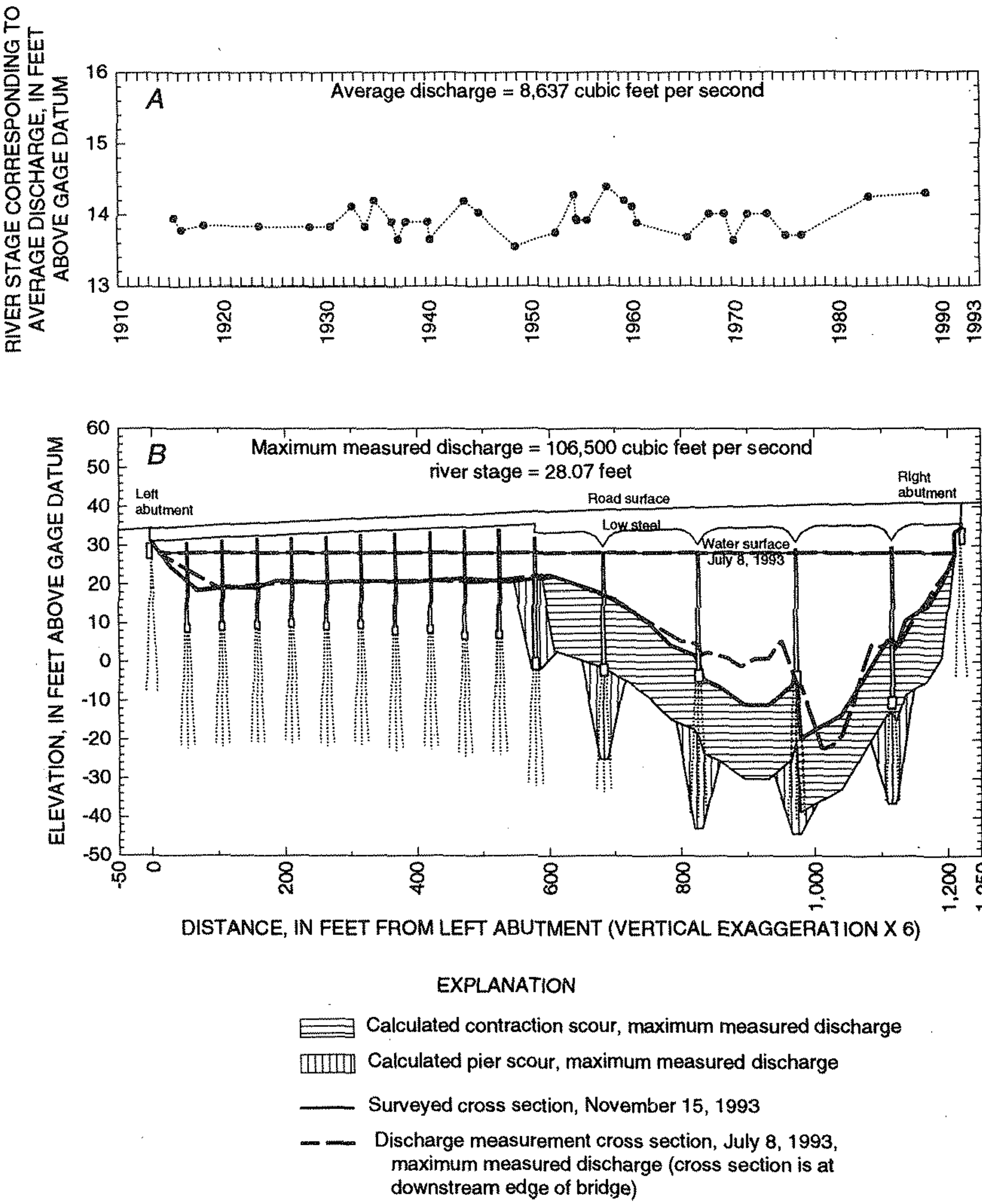


Figure 14. (*A*) Streambed aggradation/degradation trend line and (*B*) elevation view (looking downstream) of channel cross section showing calculated scour for the maximum measured discharge at State Highway 99 bridge in Louisa County, streamflow-gaging station Iowa River at Wapello (05465500).

the second pier. Depth measurements made along the upstream side of the bridge in the main channel, however, show that streambed was scoured below the base of the pier (fig. 15). The cross sections shown in figure 15 were measured between July 9 and November 17, 1993. The soil layers shown in the figure are from soil-boring information shown on the bridge plans (Iowa Department of Transportation, 1945). An unusual characteristic of the flood of 1993 was the long duration of high water. The river was above flood stage from June 8 to September 22, 1993, a period of 106 days (R.E. Southard, U.S. Geological Survey, written commun., February 1994), and the cross sections show a steady decrease in the elevation of the streambed in the main channel. Figure 15*A* shows that the bed was already scoured below the base of the second pier. Figure 15*A* also shows about 4 ft of local pier scour using the ambient bed as a reference; the total scour measured below the base on July 9 was 8 ft. Figures 15*B* and 15*C* show additional scour of the streambed; however, local pier scour at the second pier is no longer apparent. The maximum measured scour below the base was 11 ft on August 18, 1993 (fig. 15*C*). No scour was observed at the rightmost pier because it is protected with riprap.

Figure 15*D* shows the elevation of the bed at the upstream edge of the bridge on November 17, 1993, 2 months after the river receded below flood stage. Because the channel did not appear to be backfilling, the channel was sounded upstream and downstream to determine the extent of the scoured bed. Soundings made November 17 showed that the streambed had scoured about 1,600 ft upstream of the bridge (fig. 16*A*). Soundings made July 15, 1994, show that the streambed is filling again (fig. 16*B*). The lines of equal streambed elevation in figure 16*B* show a depression in the streambed downstream of the bridge that is not present in figure 16*A*. The depression may have been present in November 1993 but was not detected because the cross-section spacing was farther apart in 1993 than in 1994.

SUMMARY AND CONCLUSIONS

Potential-scour assessments were made at 130 bridges in Iowa. A potential-scour value was assigned to each bridge using an index developed for a potential-scour assessment study in western Tennessee. Higher values of the index suggest a greater likelihood of scour-related problems occurring at a bridge. The maximum value of the potential-scour index that was assigned during the Iowa assessments was 24.5, and the minimum value was 3. The median of the indices was 11.5; the interval estimate of the median index for all bridges in Iowa at the 95-percent confidence level was 10.5 to 12.5. Most of the bridges assigned an index value of 15 or more are in the western part of the State where loess soil deposits generally are thicker.

The component of the potential-scour index that contributed most to the overall total of the 130 indices was bed material, which accounted for 27.1 percent of the overall total. This component was identified as sand, silt/clay, or alluvium at 123 sites. The cohesive properties of the bed material were not considered in the assessment of this component. The component with the second greatest contribution to the overall total of the indices was bank erosion at the bridge, which accounted for 18.3 percent of the overall total. Most of the sites that have mass wasting at one or both banks are located in the parts of the State where the loess deposits are thicker. Listed in order of decreasing contribution to the overall total of the potential-scour indices, the remaining components are stage of channel evolution (17.9 percent), bed protection (12.0 percent), proximity of river meander impact point (7.1 percent), number of piers in channel (5.2 percent), mass wasting at piers (3.8 percent), angle of approach of high flows (3.5 percent), percentage of channel constriction (2.3 percent), pier skew (2.1 percent), and percentage of blockage by debris (0.6 percent).

The potential-scour index represents conditions at a bridge at a single moment in time. A single potential-scour assessment may help identify conditions that suggest the need for additional investigation at a site. The usefulness of potential-scour assessments is dependent upon regular assessments if the index is used to monitor potential-scour susceptibility, although few of the components of the index considered in this study are likely to change between assessments. Because bridges already are inspected at regular intervals by IDOT, it would be possible to include a potential-scour assessment for one or more of the components described in this study in the bridge-inspection report.

Maximum scour was estimated at 10 bridges. The aggradation or degradation of the streambed that has occurred during the period of streamflow data collection at each site was determined using a method

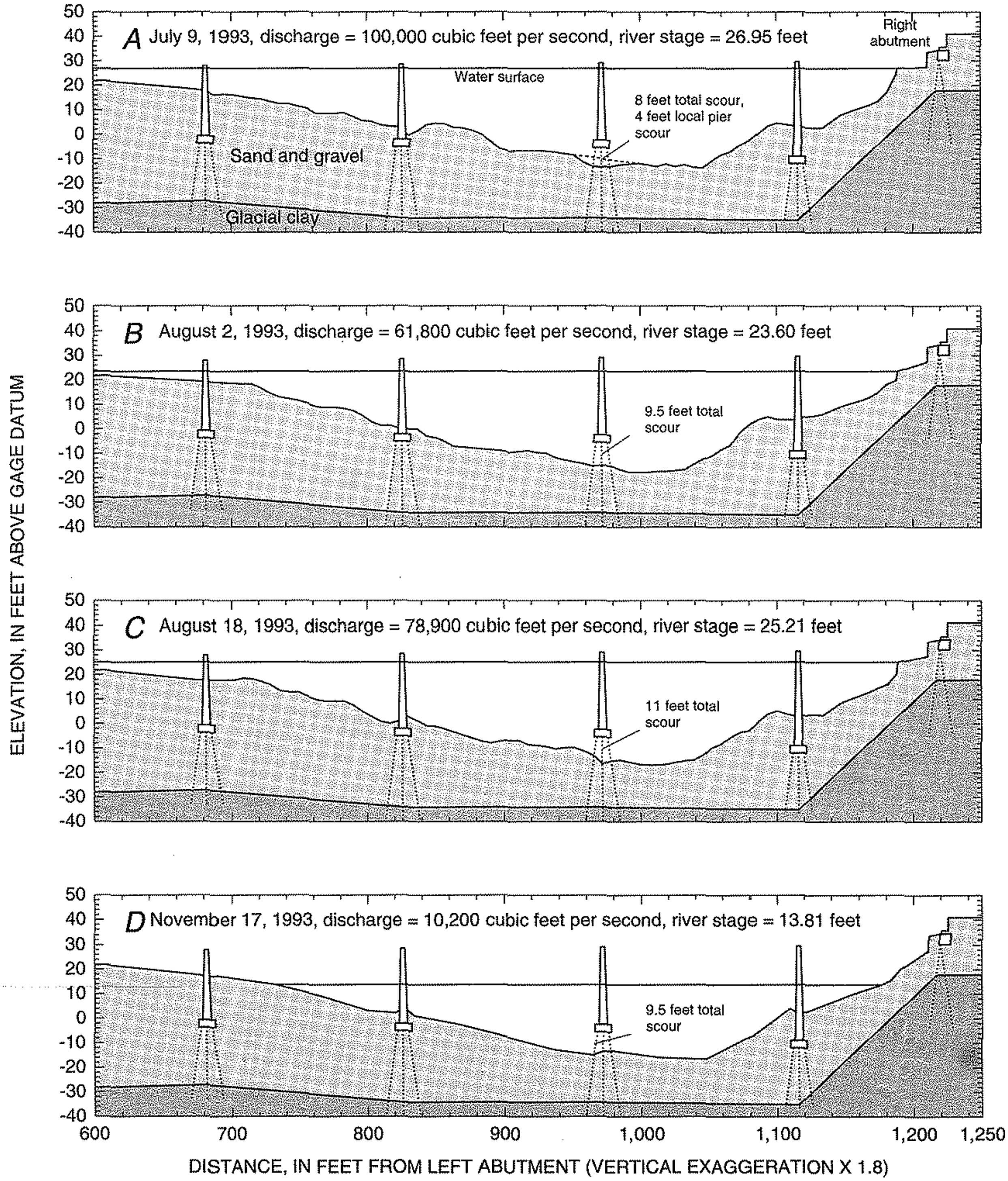


Figure 15. Streambed elevations in main channel at upstream edge of the State Highway 99 bridge over Iowa River at Wapello (streamflow-gaging station 05465500), July–November 1993 (modified from Fischer, 1994).

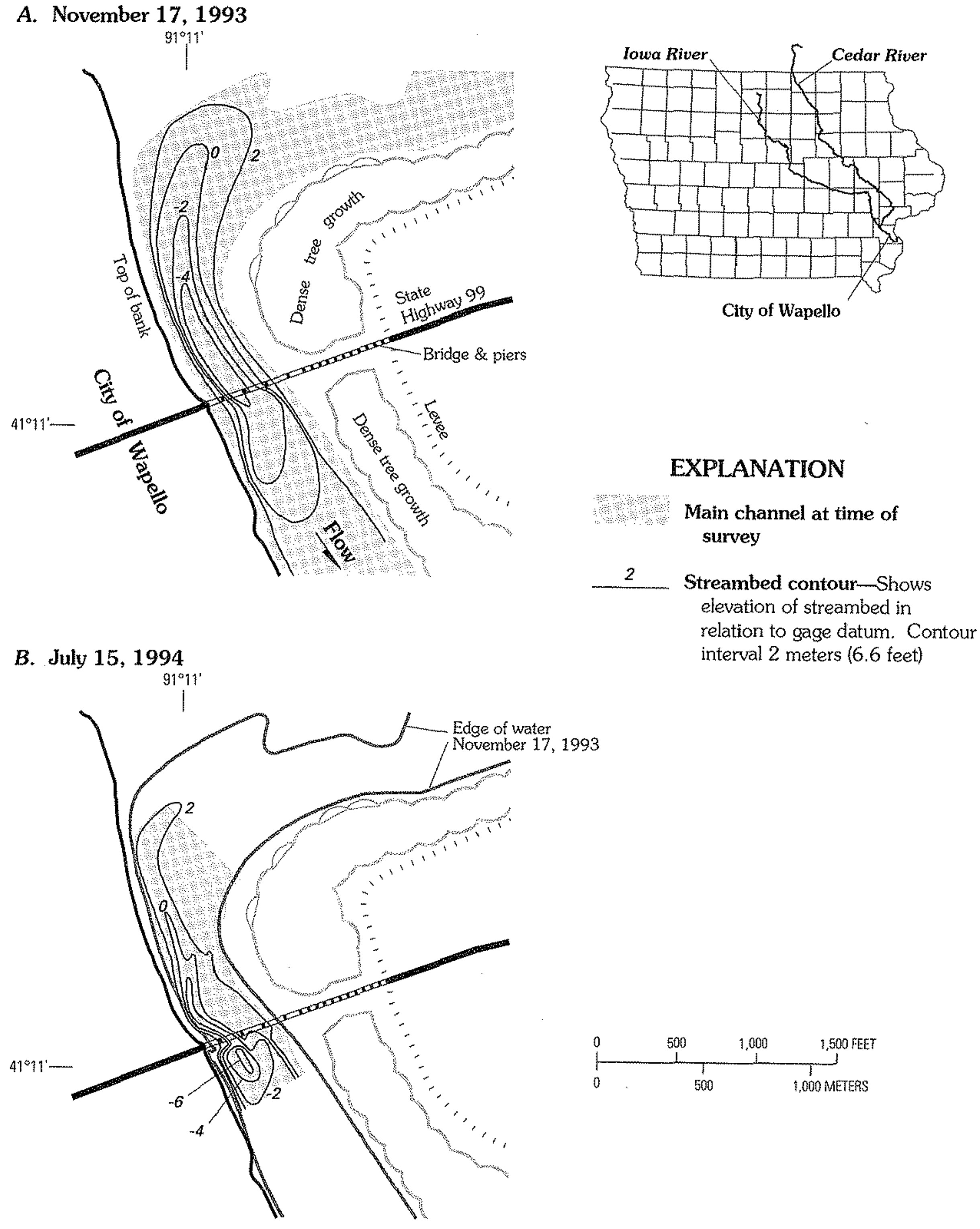


Figure 16. Streambed elevations in the Iowa River at State Highway 99 bridge, Wapello, Iowa, (*A*) November 17, 1993 (from Fischer, 1994), and (*B*) July 15, 1994.

that considers changes in the river stage corresponding to an index discharge. The streambed appears to be stable at six sites; has degraded at three sites, and has aggraded at one site. The greatest degradation observed in this study was 6.7 ft at the bridge over the Maple River at Mapleton. The rate of degradation was 0.146 ft/yr for the period 1941–87, although the rate of degradation since 1971 was 0.031 ft/yr.

Maximum scour was estimated using Federal Highway Administration scour equations. The principle discharges used to estimate scour were the 100-year (Q_{100}) and 500-year (Q_{500}) floods. Other discharges also were used at four bridges, generally because it was determined that the Q_{100} and (or) Q_{500} floods did not represent the conditions that would cause maximum scour.

Channel cross sections obtained from discharge measurements at four of the study bridges show greater scour than the contraction scour predicted using the scour equations. In three of the cases, the measured discharge was less than the respective Q_{100} flood used to estimate maximum scour (West Nishnabotna River at Randolph, East Nishnabotna River near Atlantic, and Nodaway River at Clarinda). In the fourth case, the measured discharge was greater than the Q_{100} flood, but a negative value was computed for contraction scour (Middle Raccoon River near Bayard). The measured scour at two of the sites was at or below the base of the piers, although not in the vicinity of the piers (East Nishnabotna River near Atlantic and Nodaway River at Clarinda).

No pier-scour measurements were obtained in this study except at the bridge over the Iowa River at Wapello. The total scour measured below the base of the second pier at this bridge during the flood of 1993 was 11 ft. Most of the scour at this pier was caused by contraction scour. About 4 ft of local pier scour was measured during the early part of the flood, although the ambient (reference) bed was already below the base of the pier. Because discharge-measurement cross sections at two other sites (East Nishnabotna River near Atlantic and Nodaway River at Clarinda) show the streambeds to be at or below the elevation of the base of the piers, additional investigation may be warranted at these sites to determine whether the streambed has been scoured below the upstream edge of the bases of the piers.

The abutments of the 10 bridges analyzed in this study were designed as spill-through abutments with sloped-earth embankments. The only significant abutment scour that was measured was erosion of the embankment at the left abutment at the bridge over the Platte River near Diagonal. Erosion at the right abutment at White Breast Creek near Dallas is the result of a river meander impact point occurring at the bridge during normal flows that has undermined the embankment.

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Table 4. *Potential-scour index at selected highway bridges in Iowa*

[The index is the sum of the component values and is applicable at the time each site was evaluated. Listed below each component value is the assessment description (in parentheses) made during the onsite visit (see pages 3–7 in this report). Sites are listed by county. USGS, U.S. Geological Survey; mi^2, square miles; ft, feet; >, greater than; est., estimated]

Site identification number (fig. 1)	Stream name and vicinity (USGS station number), drainage area, highway, date visited	Index components														Potential scour index
		Bed material	Bed protection	Stage of channel evolution	Percentage of channel constriction	Number of piers in channel	Percentage of blockage by debris: Horizontal	Percentage of blockage by debris: Vertical	Percentage of blockage by debris: Total	Bank erosion (type): Left bank	Bank erosion (type): Right bank	Proximity of river meander impact point (ft)	Pier skew (number of piers)	Mass wasting at pier (number of piers)	Angle of approach of high flows (degrees)	
	Adams County															
1	Platte River near Stringtown (06818598), 51.7 mi^2, U.S. Highway 34, March 23, 1992	4 (silt/clay)	1 (bed not protected)	3 (V Aggradation)	0 (0)	1 (1)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	1 (85)	1 (1)	0 (0)	0 (0)	13.0
	Appanoose County															
2	Chariton River near Rathbun (06903900) (site from 1960 to 1969, which is downstream from current site), 549 mi^2, County road, February 4, 1992	4 (silt/clay)	1 (bed not protected)	4 (IV Threshold)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	0 (>100)	0 (0)	0 (0)	0 (0)	11.0
3	Cooper Creek at Centerville (06903990) 47.8 mi^2, State Highway 5, February 4, 1992	3.5 (alluvium)	1 (bed not protected)	3 (V Aggradation)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	0 (>100)	0 (0)	0 (0)	0 (0)	9.5
4	Chariton River near Centerville (06904000), 708 mi^2, State Highway 2, February 4, 1992	3.5 (alluvium)	1 (bed not protected)	4 (IV Threshold)	2 (38)	0 (0)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	0 (>100)	0 (0)	0 (0)	0 (0)	12.5

Table 4. Potential-scour index at selected highway bridges in Iowa—Continued

Site identification number (fig. 1)	Stream name and vicinity (USGS station number), drainage area, highway, date visited	Index components														Potential scour index
		Bed material	Bed protection	Stage of channel evolution	Percentage of channel constriction	Number of piers in channel	Percentage of blockage by debris			Bank erosion (type)		Proximity of river meander impact point (ft)	Pier skew (number of piers)	Mass wasting at pier (number of piers)	Angle of approach of high flows (degrees)	
							Horizontal	Vertical	Total	Left bank	Right bank					
						Audubon County										
5	Davids Creek near Hamlin (06809000), 26.0 mi^2, State Highway 44, April 6, 1992	3.5 (alluvium)	1 (bed not protected)	4 (IV Threshold)	1 (8)	0 (0)	0 (0)	0 (0)	0 (0)	2 (mass, wasting)	2 (mass, wasting)	0 (>100)	0 (0)	6 (2)	0 (0)	19.5
						Benton County										
6	Prairie Creek at Blairstown (05464560), 87.0 mi^2, State Highway 82, January 14, 1992	3.5 (alluvium)	2 (bed not protected, right bank protected)	3 (V Aggradation)	0 (0)	1 (1)	0 (0)	0 (0)	0 (0)	2 (mass, wasting)	2 (mass, wasting)	0 (>100)	0 (0)	3 (1)	0 (0)	16.5
						Black Hawk County										
7	West Fork Cedar River at Finchford (05458900), 846 mi^2 County Road C55 April 13, 1992	3.5 (alluvium)	2 (bed not protected, right bank protected)	3 (V Aggradation)	1 (9)	2 (3)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	2 (50)	0 (0)	0 (0)	0 (0)	15.5
8	Black Hawk Creek at Hudson (05463500), 303 mi^2, State Highway 58, April 14, 1992	3.5 (alluvium)	2 (bed not protected, right bank protected)	0 (VI Restabilization)	0 (2)	1 (1)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	3 (0)	1 (1)	0 (0)	1 (20)	13.5
9	Cedar River at Waterloo (05464000), 5,146 mi^2, 6th Street, April 13, 1992	3.5 (alluvium)	3 (bed not protected, both banks protected)	0 (I Premodified)	0 (0)	2 (6)	0 (5)	0 (5)	0 (0)	0 (none)	0 (none)	0 (>100)	0 (0)	0 (0)	0 (0)	8.5

Table 4. Potential-scour index at selected highway bridges in Iowa—Continued

Site identification number (fig. 1)	Stream name and vicinity (USGS station number), drainage area, highway, date visited	Index components: Bed material	Bed protection	Stage of channel evolution	Percentage of channel constriction	Number of piers in channel	Percentage of blockage by debris: Horizontal	Vertical	Total	Bank erosion (type): Left bank	Right bank	Proximity of river meander impact point (ft)	Pier skew (number of piers)	Mass wasting at pier (number of piers)	Angle of approach of high flows (degrees)	Potential scour index
	Buchanan County															
10	Wapsipinicon River at Independence (05421000), 1,048 mi², Buchanan County, State Highway 150, March 20, 1992	3.5 (alluvium)	2 (bed not protected, right bank protected)	3 (V Aggradation)	0 (0)	2 (3)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	1 (0*)	0 (0)	0 (0)	1 (20)	14.5
11	Pine Creek near Winthrop (05421200), 28.3 mi², State Highway 939, March 20, 1992	3 (sand)	1 (bed not protected)	3 (V Aggradation)	0 (0)	1 (1)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	0 (>100)	1 (1)	0 (0)	1 (15)	12.0
	Buena Vista County															
12	Little Sioux River at Linn Grove (06605850), 1,548 mi², State Highway 264, April 28, 1992	3.5 (alluvium)	1 (bed not protected)	0 (VI Restabilization)	0 (0)	1 (2)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	0 (>100)	0 (0)	0 (0)	0 (0)	7.5
	Butler County															
13	Shell Rock River at Shell Rock (05462000), 1,746 mi², County Road C45, April 14, 1992	3.5 (alluvium)	0 (protected bed)	0 (VI Restabilization)	0 (3)	1 (2)	0 (0)	0 (0)	0 (0)	0 (none)	0 (none)	0 (>100)	0 (0)	0 (0)	0 (0)	4.5
14	Beaver Creek at New Hartford (05463000), 347 mi², County Road T55, April 13, 1992	3.5 (alluvium)	1 (bed not protected)	0 (I Premodified)	0 (0)	2 (3)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	0 (>100)	0 (0)	0 (0)	0 (0)	8.5

Table 4. Potential-scour index at selected highway bridges in Iowa—Continued

Site identification number (fig. 1)	Stream name and vicinity (USGS station number), drainage area, highway, date visited	Index components: Bed material	Bed protection	Stage of channel evolution	Percentage of channel constriction	Number of piers in channel	Percentage of blockage by debris: Horizontal	Vertical	Total	Bank erosion (type): Left bank	Right bank	Proximity of river meander impact point (ft)	Pier skew (number of piers)	Mass wasting at pier (number of piers)	Angle of approach of high flows (degrees)	Potential scour index
							Calhoun County									
15	Hardin Creek near Farnhamville (05482600), 43.7 mi^2, State Highway 175, April 9, 1992	4 (silt/clay)	3 (bed not protected, both banks protected)	0 (VI Restabilization)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	1 (75)	0 (0)	0 (0)	0 (0)	10.0
							Cass County									
16	East Nishnabotna River near Atlantic (06809210), 436 mi^2, County road, March 25, 1992	4 (silt/clay)	2 (bed not protected, left bank protected)	4 (IV Threshold)	0 (0)	1 (1)	0.33 (10)	0.67 (45)	0 (5)	2 (mass wasting)	1 (fluvial)	3 (0)	0 (0)	0 (0)	0 (0)	18.0
							Cerro Gordo County									
17	Winnebago River at Mason City (05459500), 526 mi^2, Thirteenth Street, May 14, 1992	1 (cobbles)	3 (bed not protected, both banks protected)	0 (I Premodified)	1 (8)	0 (0)	0 (0)	0 (0)	0 (0)	0 (none)	0 (none)	0 (>100)	0 (0)	0 (0)	1 (15)	6.0
18	Willow Creek near Mason City (05460100), 78.6 mi^2, U.S. Highway 18, May 14, 1992	3 (sand)	1 (bed not protected)	0 (I Premodified)	0 (0)	1 (1)	0 (0)	0 (0)	0 (0)	0 (none)	0 (none)	0 (>100)	0 (0)	0 (0)	0 (0)	5.0

Table 4. Potential-scour index at selected highway bridges in Iowa—Continued

Site identification number (fig. 1)	Stream name and vicinity (USGS station number), drainage area, highway, date visited	Index components: Bed material	Bed protection	Stage of channel evolution	Percentage of channel constriction	Number of piers in channel	Percentage of blockage by debris: Horizontal	Vertical	Total	Bank erosion (type): Left bank	Right bank	Proximity of river meander impact point (ft)	Pier skew (number of piers)	Mass wasting at pier (number of piers)	Angle of approach of high flows (degrees)	Potential scour index
	Chickasaw County															
19	Little Wapsipinicon River near New Hampton (05420650), 95.0 mi², U.S. Highway 18, May 12, 1992	3 (sand)	1 (bed not protected)	0 (VI Restabilization)	1 (8)	1 (1)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	0 (>100)	0 (0)	0 (0)	0 (0)	8.0
20	East Fork Wapsipinicon River near New Hampton (05420690), 30.3 mi², U.S. Highway 63, May 12, 1992	3 (sand)	3 (bed not protected, both banks protected)	0 (VI Restabilization)	0 (0)	1 (2)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	3 (10)	0 (0)	0 (0)	0 (0)	12.0
21	Little Cedar River near Ionia (05458000), 306 mi², County Road B57, May 12, 1992	3 (sand)	3 (bed not protected, both banks protected)	0 (VI Restabilization)	0 (0)	1 (2)	0.67 (40)	0 (5)	0 (2)	0 (none)	0 (none)	3 (0)	2 (2)	0 (0)	2 (35)	14.7
	Clarke County															
22	South White Breast Creek near Osceola (05487600), 28.0 mi², County Road R53, February 27, 1992	3 (sand)	1 (bed not protected)	3 (V Aggradation)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	0 (>100)	0 (0)	0 (0)	0 (0)	9.0
	Clay County															
23	Ocheyedan River near Spencer (06605000), 426 mi², County Road M38, April 28, 1992	3.5 (alluvium)	1 (bed not protected)	0 (VI Restabilization)	0 (0)	1 (1)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	0 (>100)	1 (1)	0 (0)	0 (10)	8.5

Table 4. Potential-scour index at selected highway bridges in Iowa—Continued

Site identification number (fig. 1)	Stream name and vicinity (USGS station number), drainage area, highway, date visited	Index components: Bed material	Bed protection	Stage of channel evolution	Percentage of channel constriction	Number of piers in channel	Percentage of blockage by debris: Horizontal	Vertical	Total	Bank erosion (type): Left bank	Right bank	Proximity of river meander impact point (ft)	Pier skew (number of piers)	Mass wasting at pier (number of piers)	Angle of approach of high flows (degrees)	Potential scour index
	Clay County—Continued															
24	Willow Creek near Cornell (06605750), 78.6 mi^2, U.S. Highway 71, April 28, 1992	3.5 (alluvium)	1 (bed not protected)	0 (VI Restabilization)	0 (0)	1 (1)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	3 (0)	1 (1)	0 (0)	1 (15)	12.5
	Clayton County															
25	Turkey River at Garber (05412500), 1,545 mi^2, County Road C43, February 6, 1992	3.5 (alluvium)	1 (bed not protected)	3 (V Aggradation)	0 (0)	2 (3)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	0 (>100)	0 (0)	0 (0)	0 (0)	11.5
	Dallas County															
26	South Raccoon River at Redfield (05484000), 994 mi^2, County road, April 15, 1992	3.5 (alluvium)	1 (bed not protected)	3 (V Aggradation)	0 (0)	1 (1)	0 (1)	0 (5)	0 (0)	1 (fluvial)	2 (mass wasting)	0 (>100)	0 (0)	0 (0)	0 (0)	11.5
27	Raccoon River at Van Meter (05484500), 3,441 mi^2, County Road R16, April 16, 1992	3.5 (alluvium)	2 (bed not protected, right bank protected)	3 (V Aggradation)	2 (35)	1 (2)	0.67 (40)	0.67 (40)	0.33 (16)	2 (mass wasting)	2 (mass wasting)	3 (0)	2 (2)	0 (0)	2 (30)	24.2
	Davis County															
28	Fox River at Bloomfield (05494300), 87.7 mi^2, County road, February 3, 1992	3 (sand)	2 (bed not protected, right bank protected)	3 (V Aggradation)	1 (10 est.)	0 (0)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	0 (>100)	0 (0)	0 (0)	0 (0)	11.0

Table 4. Potential-scour index at selected highway bridges in Iowa—Continued

Site identification number (fig. 1)	Stream name and vicinity (USGS station number), drainage area, highway, date visited	Index components: Bed material	Bed protection	Stage of channel evolution	Percentage of channel constriction	Number of piers in channel	Percentage of blockage by debris: Horizontal	Vertical	Total	Bank erosion (type): Left bank	Right bank	Proximity of river meander impact point (ft)	Pier skew (number of piers)	Mass wasting at pier (number of piers)	Angle of approach of high flows (degrees)	Potential scour index
Decatur County																
29	Elk Creek near Decatur City (06897950), 52.5 mi^2, County road, February 28, 1992	3 (sand)	3 (bed not protected, both banks protected)	3 (V Aggradation)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	0 (>100)	0 (0)	0 (0)	0 (0)	11.0
30	Thompson River at Davis City (06898000), 701 mi^2, U.S. Highway 69, February 28, 1992	3.5 (alluvium)	1 (bed not protected)	3 (V Aggradation)	0 (0 est.)	1 (1)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	0 (>100)	1 (1)	0 (0)	2.5 (45)	14.0
31	Weldon River near Leon (06898400), 104 mi^2, County Road J48, February 28, 1992	3 (sand)	2 (bed not protected, left bank protected)	3 (V Aggradation)	0 (0)	1 (1)	0 (0)	0 (0)	0 (0)	2 (mass wasting)	1 (fluvial)	0 (>100)	1 (1)	0 (0)	2.5 (45)	15.5
Delaware County																
32	Plum Creek at Earlville (05417530), 41.1 mi^2, U.S. Highway 20, February 6, 1992	3 (sand)	1 (bed not protected)	3 (V Aggradation)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	0 (>100)	0 (0)	0 (0)	0 (0)	9.0
Dubuque County																
33	Little Maquoketa River near Durango (05414500), 130 mi^2, County road, February 6, 1992	0 (bedrock)	1 (bed not protected)	3 (V Aggradation)	1 (19)	0 (0)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	0 (>100)	0 (0)	0 (0)	0 (0)	7.0

Table 4. Potential-scour index at selected highway bridges in Iowa—Continued

Site identification number (fig. 1)	Stream name and vicinity (USGS station number), drainage area, highway, date visited	Index components: Bed material	Bed protection	Stage of channel evolution	Percentage of channel constriction	Number of piers in channel	Percentage of blockage by debris: Horizontal	Percentage of blockage by debris: Vertical	Percentage of blockage by debris: Total	Bank erosion (type): Left bank	Bank erosion (type): Right bank	Proximity of river meander impact point (ft)	Pier skew (number of piers)	Mass wasting at pier (number of piers)	Angle of approach of high flows (degrees)	Potential scour index
	Emmet County															
34	Des Moines River at Estherville (05476500), 1,372 mi^2, State Highway 9, April 30, 1992	3.5 (alluvium)	2 (bed not protected, right bank protected)	0 (VI Restabilization)	0 (0)	1 (2)	0.33 (10)	0 (2)	0 (0)	0 (none)	0 (none)	0 (>100)	0 (0)	0 (0)	0 (0)	6.8
	Floyd County															
35	Cedar River at Charles City (05457700), 1,054 mi^2, U.S. Highway 18, May 13, 1992	1 (cobbles)	2 (bed not protected, left bank protected)	0 (VI Restabilization)	0 (0)	1 (2)	0 (0)	0 (0)	0 (0)	0 (none)	0 (none)	0 (>100)	0 (0)	0 (0)	0 (0)	4.0
	Fremont County															
36	Waubonsie Creek near Bartlett (06806000), 30.4 mi^2, County Road J10, March 24, 1992	4 (silt/clay)	2 (bed not protected, right bank protected)	1 (II Constructed)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (none)	0 (none)	3 (0)	0 (0)	0 (0)	1 (20)	11.0
37	West Nishnabotna River at Randolph (06808500), 1,326 mi^2, State Highway 184, March 24, 1992	3.5 (alluvium)	2 (bed not protected, right bank protected)	3 (V Aggradation)	0 (0)	1 (1)	0 (5)	0.67 (50)	0 (3)	2 (mass wasting)	2 (mass wasting)	3 (0)	1 (1)	3 (1)	0 (10)	21.2
38	Nishnabotna River above Hamburg (06810000), 2,806 mi^2, US Highway 275, March 24, 1992	3.5 (alluvium)	1 (bed not protected)	3 (V Aggradation)	0 (0)	1 (1)	0 (5)	0.33 (10)	0 (1)	1 (fluvial)	1 (fluvial)	3 (0)	1 (1)	0 (0)	1 (15)	15.8

Table 4. Potential-scour index at selected highway bridges in Iowa—Continued

Site identification number (fig. 1)	Stream name and vicinity (USGS station number), drainage area, highway, date visited	Index components: Bed *material*	Bed *protection*	Stage of channel *evolution*	*Percentage of channel constriction*	Number of *piers in channel*	Percentage of blockage by debris: Horizontal	Vertical	Total	Bank erosion (type): Left bank	Right bank	Proximity of *river* meander impact point (ft)	Pier skew (number of piers)	Mass wasting at pier (number of piers)	Angle of approach of high flows (degrees)	Potential scour index
	Greene County															
39	*North Raccoon River near* Jefferson (05482500), 1,619 mi^2, State Highway 4, *April* 9, 1992	3.5 (alluvium)	2 (bed not protected, right bank protected)	2 (III Degradation)	1 (18)	1 (2)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	3 (0)	2 (2)	0 (0)	1 (20)	17.5
40	Hardin Creek near Farlin (05482900), 101 mi^2, County road, April 4, 1992	3.5 (alluvium)	1 (bed not protected)	0 (VI Restabilization)	0 (0)	1 (1)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	1 (70)	0 (0)	0 (0)	0 (0)	8.5
	Grundy County															
41	Black Hawk Creek at Grundy Center (05463090), *56.9 mi*^{2}, State Highway 14, April 14, 1992	3.5 (alluvium)	2 (bed not protected, *right bank* protected)	2 (III Degradation)	0 (0)	1 (1)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	0 (>100)	0 (0)	0 (0)	0 (0)	10.5
	Guthrie County															
42	Middle Raccoon River near Bayard (05483450), 375 mi^2, State Highway 25, April 6, 1992	3.5 (alluvium)	1 (bed not protected)	2 (III Degradation)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	3 (0)	0 (0)	0 (0)	1 (15)	12.5
43	Middle Raccoon River at Panora (05483600), 440 mi^2, County road, April 6, 1992	3.5 (alluvium)	2 (bed not protected, left bank *protected*)	3 (V Aggradation)	0 (0)	1 (2)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	3 (0)	2 (2)	0 (0)	2.5 (45)	19.0

Table 4. Potential-scour index at selected highway bridges in Iowa—Continued

Site identification number (fig. 1)	Stream name and vicinity (USGS station number), drainage area, highway, date visited	Index components														Potential scour index
		Bed material	Bed protection	Stage of channel evolution	Percentage of channel constriction	Number of piers in channel	Percentage of blockage by debris			Bank erosion (type)		Proximity of river meander impact point (ft)	Pier skew (number of piers)	Mass wasting at pier (number of piers)	Angle of approach of high flows (degrees)	
							Horizontal	Vertical	Total	Left bank	Right bank					
	Hamilton County															
44	Mud Lake Drainage Ditch 71 at Jewell (05469860), 65.4 mi^2, U.S. Highway 69, April 15, 1992	3.5 (alluvium)	2 (bed not protected, right bank protected)	0 (VI Restabilization)	1 (11)	1 (1)	0 (0)	0 (0)	0 (0)	0 (none)	2 (mass wasting)	1 (60)	0 (0)	0 (0)	0 (0)	10.5
45	Boone River near Webster City (05481000), 844 mi^2, State Highway 17, April 27, 1992	3.5 (alluvium)	2 (bed not protected, left bank protected)	0 (VI Restabilization)	0 (0)	1 (1)	0 (1)	0 (3)	0 (0)	1 (fluvial)	1 (fluvial)	2 (40)	1 (1)	0 (0)	0 (5)	11.5
	Hancock County															
46	West Branch Iowa River near Klemme (05448500), 112 mi^2, County road, May 14, 1992	3.5 (alluvium)	2 (bed not protected, left bank protected)	0 (VI Restabilization)	1 (18)	1 (1)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	0 (>100)	0 (0)	0 (0)	0 (0)	9.5
47	East Branch Iowa River near Klemme (05449000), 133 mi^2, County Road B55, May 14, 1992	3.5 (alluvium)	1 (bed not protected)	0 (I Premodified)	1 (16)	1 (2)	0 (0)	0 (0)	0 (0)	1 (fluvial)	0 (none)	1 (75)	0 (0)	0 (0)	0 (0)	8.5

Table 4. Potential-scour index at selected highway bridges in Iowa—Continued

Site identification number (fig. 1)	Stream name and vicinity (USGS station number), drainage area, highway, date visited	Index components: Bed material	Bed protection	Stage of channel evolution	Percentage of channel constriction	Number of piers in channel	Percentage of blockage by debris: Horizontal	Vertical	Total	Bank erosion (type): Left bank	Right bank	Proximity of river meander *impact* point (ft)	Pier skew *(number of piers)*	Mass wasting *at pier* (number of piers)	Angle of approach *of high* flows (degrees)	Potential scour index
	Harrison County															
48	Soldier River at Pisgah (06608500), 407 mi^2, County Road F20, April 7, 1992	3.5 (alluvium)	1 (bed not protected)	4 (IV Threshold)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (fluvial)	2 (mass wasting)	0 (>100)	0 (0)	0 (0)	0 (5)	11.5
49	Boyer River at Logan (06609500), 871 mi^2, U.S. Highway 30, April 7, 1992	3.5 (alluvium)	3 (bed not protected, both banks protected)	4 (IV Threshold)	1 (9)	1 (1)	0 (3)	0 (4)	0 (0)	2 (mass wasting)	2 (mass wasting)	0 (>100)	0 (0)	3 (1)	0 (0)	19.5
	Henry County															
50	Cedar Creek near Oakland Mills (05473400), 530 mi^2, County Road H46, December 11, 1992	3.5 (alluvium)	1 (bed not protected)	3 (V Aggradation)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	2 (mass wasting)	2 (mass wasting)	0 (>100)	0 (0)	0 (0)	0 (0)	11.5
51	Big Creek near Mount Pleasant (05473500), 106 mi^2, County road, December 11, 1992	3.5 (alluvium)	1 (bed not protected)	3 (V Aggradation)	0 (0 est.)	0 (0)	0 (0)	0 (0)	0 (0)	2 (mass wasting)	2 (mass wasting)	0 (>100)	0 (0)	6 (2)	0 (0)	17.5
	Howard County															
52	Wapsipinicon River near Elma (05420560), 95.2 mi^2, County Road B17, May 13, 1992	3 (sand)	1 (bed not protected)	0 (VI Restabilization)	0 (5)	0 (0)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	0 (>100)	0 (0)	0 (0)	0 (0)	6.0

Table 4. Potential-scour index at selected highway bridges in Iowa—Continued

Site identification number (fig. 1)	Stream name and vicinity (USGS station number), drainage area, highway, date visited	Index components: Bed material	Bed protection	Stage of channel evolution	Percentage of channel constriction	Number of piers in channel	Percentage of blockage by debris: Horizontal	Vertical	Total	Bank erosion (type): Left bank	Right bank	Proximity of river meander impact point (ft)	Pier skew (number of piers)	Mass wasting at pier (number of piers)	Angle of approach of high flows (degrees)	Potential scour index
	Howard County—Continued															
53	Little Wapsipinicon River near Elma (05420640), 37.3 mi^2, County Road B17, May 13, 1992	3 (sand)	2 (bed not protected, left bank protected)	0 (VI Restabilization)	1 (13)	0 (0)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	3 (20)	0 (0)	0 (0)	2.5 (45)	13.5
	Humboldt County															
54	East Fork Des Moines River at Dakota City (05479000), 1,308 mi^2, County Road P56, April 30, 1992	0 (bedrock)	0 (protected bed)	0 (VI Restabilization)	0 (0)	2 (3)	0 (5)	0 (5)	0 (0)	0 (none)	0 (none)	2 (30)	0 (0)	0 (0)	0 (0)	4.0
	Ida County															
55	Odebolt Creek near Arthur (06607000), 39.3 mi^2, County Road M27, April 8, 1992	3.5 (alluvium)	1 (bed not protected)	4 (IV Threshold)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	2 (mass wasting)	2 (mass wasting)	0 (>100)	0 (0)	3 (1)	0 (5)	15.5
	Iowa County															
56	Big Bear Creek at Ladora (05453000), 189 mi^2, County Road V52, December 16, 1991	3.5 (alluvium)	1 (bed not protected)	3 (V Aggradation)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	0 (>100)	0 (0)	0 (0)	0 (0)	9.5
57	Iowa River at Marengo (05453100), 2,794 mi^2, County Road V66, December 16, 1991	3.5 (alluvium)	1 (bed not protected)	3 (V Aggradation)	0 (0)	1 (2)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	0 (>100)	0 (0)	0 (0)	0 (0)	10.5

Table 4. Potential-scour index at selected highway bridges in Iowa—Continued

Site identification number (fig. 1)	Stream name and vicinity (USGS station number), drainage area, highway, date visited	Index components: Bed material	Bed protection	Stage of channel evolution	Percentage of channel constriction	Number of piers in channel	Percentage of blockage by debris: Horizontal	Vertical	Total	Bank erosion (type): Left bank	Right bank	Proximity of river meander *impact* point (ft)	Pier skew *(number of piers)*	Mass wasting *at pier* (number of piers)	Angle of approach *of high* flows (degrees)	Potential scour index
	Jackson County															
58	Bear Creek near Monmouth (05417700), 61.3 mi^2, County road, January 6, 1992	3.5 (alluvium)	1 (bed not protected)	3 (V Aggradation)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	0 (>100)	0 (0)	0 (0)	0 (0)	9.5
59	North Fork Maquoketa River at Fulton (05418450), 516 mi^2, U.S. Highway 61, January 6, 1992	0 (bedrock)	1 (bed not protected)	4 (IV Threshold)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	0 (>100)	0 (0)	0 (0)	0 (0)	7.0
60	Maquoketa River near Maquoketa (05418500), 1,553 mi^2, State Highway 92, January 6, 1992	3 (sand)	1 (bed not protected)	4 (IV Threshold)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	0 (>100)	0 (0)	0 (0)	0 (0)	10.0
	Jasper County															
61	Indian Creek near Mingo (05471200), 276 mi^2, State Highway 117, April 14, 1992	3 (sand)	2 (bed not protected, right bank protected)	4 (IV Threshold)	0 (0)	1 (1)	0 (0)	0 (0)	0 (0)	2 (mass wasting)	2 (mass wasting)	0 (>100)	0 (0)	3 (1)	0 (0)	17.0
	Jefferson County															
62	Cedar Creek near Batavia (05473300), 252 mi^2, U.S. Highway 34, January 31, 1992	3.5 (alluvium)	3 (bed not protected, both banks protected)	3 (V Aggradation)	1 (20)	0 (0)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	0 (>100)	0 (0)	0 (0)	0 (0)	12.5

Table 4. Potential-scour index at selected highway bridges in Iowa—Continued

Site identification number (fig. 1)	Stream name and vicinity (USGS station number), drainage area, highway, date visited	Index components: Bed material	Bed protection	Stage of channel evolution	Percentage of channel constriction	Number of piers in channel	Percentage of blockage by debris: Horizontal	Vertical	Total	Bank erosion (type): Left bank	Right bank	Proximity of river meander impact point (ft)	Pier skew (number of piers)	Mass wasting at pier (number of piers)	Angle of approach of high flows (degrees)	Potential scour index
	Johnson County															
63	Rapid Creek near Iowa City (05454000), 25.3 mi², State Highway 1, November 11, 1991	3.5 (alluvium)	1 (bed not protected)	3 (V Aggradation)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	0 (>100)	0 (0)	0 (0)	2 (30)	11.5
64	Clear Creek near Coralville (05454300), 98.1 mi², County road, November 20, 1991	3.5 (alluvium)	1 (bed not protected)	1 (II Constructed)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	0 (>100)	0 (0)	0 (0)	0 (0)	7.5
65	Old Man's Creek near Iowa City (05455100), 201 mi², County Road W65, November 20, 1991	3.5 (alluvium)	1 (bed not protected)	0 (I Premodified)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (none)	0 (none)	0 (>100)	0 (0)	0 (0)	0 (0)	4.5
	Keokuk County															
66	Rock Creek at Sigourney (05472445) 26.3 mi², State Highway 92, January 31, 1992	3.5 (alluvium)	3 (bed not protected, both banks protected)	0 (VI Restabilization)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	0 (>100)	0 (0)	0 (0)	1 (15)	9.5
67	North Skunk River near Sigourney (05472500), 730 mi², State Highway 149, January 31, 1992	4 (silt/clay)	2 (bed not protected, right bank protected)	3 (V Aggradation)	0 (0 est.)	1 (1)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	0 (>100)	0 (0)	0 (0)	2 (30)	14.0

Table 4. Potential-scour index at selected highway bridges in Iowa—Continued

Site identification number (fig. 1)	Stream name and vicinity (USGS station number), drainage area, highway, date visited	Index components: Bed material	Bed protection	Stage of channel evolution	Percentage of channel constriction	Number of piers in channel	Percentage of blockage by debris: Horizontal	Vertical	Total	Bank erosion (type): Left bank	Right bank	Proximity of river meander impact point (ft)	Pier skew (number of piers)	Mass wasting at pier (number of piers)	Angle of approach of high flows (degrees)	Potential scour index
	Lee County															
68	Skunk River at Augusta (05474000), 4,303 mi^2, State Highway 394, December 21, 1991	0 (bedrock)	1 (bed not protected)	0 (VI Restabilization)	0 (0)	1 (1)	0 (5)	0.33 (20)	0 (1)	2 (mass wasting)	2 (mass wasting)	0 (>100)	0 (0)	6 (2)	1 (18)	13.3
69	Sugar Creek near Keokuk (05491000), 105 mi^2, County Road W62, December 11, 1991	4 (silt/clay)	1 (bed not protected)	3 (V Aggradation)	0 (0 est.)	0 (0)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	0 (>100)	0 (0)	0 (0)	0 (0)	10.0
	Linn County															
70	Cedar River at Cedar Rapids (05464500), 6,510 mi^2, Eighth Avenue, March 20, 1992	3.5 (alluvium)	3 (bed not protected, both banks protected)	0 (VI Restabilization)	0 (0)	2 (5)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	0 (>100)	5 (5)	0 (0)	0 (10)	15.5
71	Prairie Creek at Fairfax (05464640), 178 mi^2, U.S. Highway 151, December 9, 1991	3.5 (alluvium)	1 (bed not protected)	3 (V Aggradation)	0 (0)	1 (2)	0 (0)	0 (0)	0 (0)	1 (fluvial)	2 (mass wasting)	0 (>100)	0 (0)	0 (0)	0 (0)	11.5
	Lucas County															
72	White Breast Creek at Lucas (05487800), 128 mi^2, U.S. Highway 65, February 27, 1992	3.5 (alluvium)	1 (bed not protected)	3 (V Aggradation)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	0 (>100)	0 (0)	0 (0)	1 (15)	10.5

Table 4. Potential-scour index at selected highway bridges in Iowa—Continued

Site identification number (fig. 1)	Stream name and vicinity (USGS station number), drainage area, highway, date visited	Index components: Bed material	Bed protection	Stage of channel evolution	Percentage of channel constriction	Number of piers in channel	Percentage of blockage by debris: Horizontal	Vertical	Total	Bank erosion (type): Left bank	Right bank	Proximity of river meander impact point (ft)	Pier skew (number of piers)	Mass wasting at pier (number of piers)	Angle of approach of high flows (degrees)	Potential scour index
	Lucas County—Continued															
73	Chariton River near Chariton (06903400), 182 mi^2, County Road S43, February 27, 1992	3.5 (alluvium)	1 (bed not protected)	3 (V Aggradation)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	0 (>100)	0 (0)	0 (0)	0 (0)	9.5
	Lyon County															
74	Rock River at Rock Rapids (06483270), 788 mi^2, State Highway 9, April 29, 1992	1 (cobbles)	1 (bed not protected)	0 (VI Restabilization)	0 (0)	1 (1)	0 (0)	0 (0)	0 (0)	0 (none)	0 (none)	0 (>100)	0 (0)	0 (0)	0 (0)	3.0
	Mahaska County															
75	South Skunk River near Oskaloosa (05471500), 1,635 mi^2, U.S. Highway 63, December 18, 1991	3.5 (alluvium)	1 (bed not protected)	3 (V Aggradation)	0 (0)	1 (1)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	0 (>100)	0 (0)	0 (0)	0 (0)	10.5
76	Middle Creek near Lacey (05472390), 23.0 mi^2, U.S. Highway 63, December 18, 1991	3.5 (alluvium)	1 (bed not protected)	4 (IV Threshold)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	0 (>100)	0 (0)	0 (0)	0 (0)	10.5
	Marion County															
77	White Breast Creek near Dallas (05487980), 342 mi^2, County road, February 20, 1992	3.5 (alluvium)	1 (bed not protected)	4 (IV Threshold)	0 (0 est.)	1 (1)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	3 (0)	0 (0)	0 (0)	0 (0)	14.5

Table 4. Potential-scour index at selected highway bridges in Iowa—Continued

Site identification number (fig. 1)	Stream name and vicinity (USGS station number), drainage area, highway, date visited	Index components														Potential scour index
							Percentage of blockage by debris			Bank erosion (type)						
		Bed material	Bed protection	Stage of channel evolution	Percentage of channel constriction	Number of piers in channel	Horizontal	Vertical	Total	*Left* bank	*Right* bank	Proximity of *river* meander impact *point* (ft)	*Pier* skew (*number of* piers)	*Mass* wasting at pier (*number* of piers)	*Angle of* approach of high *flows* (degrees)	
	Marion County—Continued															
78	White Breast Creek near Knoxville (05488000), 380 mi², State Highway 92, February 20, 1992	3.5 (alluvium)	1 (bed not protected)	3 (V Aggradation)	0 (*0 est.*)	0 (0)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	0 (>100)	0 (0)	0 (0)	0 (0)	9.5
79	Cedar Creek near Bussey (05489000), 374 mi², State Highway 156, February 4, 1992	4 (silt/clay)	1 (bed not protected)	3 (V Aggradation)	2 (38)	0 (0)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	0 (>100)	0 (0)	0 (0)	0 (0)	12.0
	Marshall County															
80	Iowa River at Marshalltown (05451500), 1,564 mi², State Highway 14, April 3, 1992	3 (sand)	1 (bed not protected)	3 (V Aggradation)	0 (0)	1 (2)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	0 (>100)	0 (0)	0 (0)	0 (0)	10.0
81	Timber Creek near Marshalltown (05451700), 118 mi², U.S. Highway 30, April 3, 1992	4 (silt/clay)	1 (bed not protected)	3 (V Aggradation)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	2 (mass wasting)	2 (mass wasting)	0 (>100)	0 (0)	0 (0)	0 (0)	12.0
	Monona County															
82	Maple River at Mapleton (06607200), 669 mi², State Highway 175, April 7, 1992	3.5 (alluvium)	2 (bed not protected, right bank protected)	4 (IV Threshold)	1 (16)	1 (2)	0 (0)	0 (0)	0 (0)	2 (mass wasting)	2 (mass wasting)	3 (0)	0 (0)	0 (0)	0 (0)	18.5

Table 4. Potential-scour index at selected highway bridges in Iowa—Continued

Site identification number (fig. 1)	Stream name and vicinity (USGS station number), drainage area, highway, date visited	Index components														Potential scour index
		Bed material	Bed protection	Stage of channel evolution	Percentage of channel constriction	Number of piers in channel	Percentage of blockage by debris: Horizontal	Percentage of blockage by debris: Vertical	Percentage of blockage by debris: Total	Bank erosion (type): Left bank	Bank erosion (type): Right bank	Proximity of river meander impact point (ft)	Pier skew (number of piers)	Mass wasting at pier (number of piers)	Angle of approach of high flows (degrees)	
						Montgomery County										
83	Indian Creek near Emerson (06807470), 37.3 mi^2, U.S. Highway 34, March 24, 1992	4 (silt/clay)	2 (bed not protected, right bank protected)	4 (IV Threshold)	1 (12)	0 (0)	0 (0)	0 (0)	0 (0)	2 (mass wasting)	2 (mass wasting)	3 (0)	0 (0)	3 (1)	1 (15)	22.0
84	East Nishnabotna River near Red Oak (06809500), 894 mi^2, Coolbaugh Street, March 24, 1992	4 (silt/clay)	1 (bed not protected)	4 (IV Threshold)	0 (0)	1 (1)	0.33 (25)	0 (2)	0 (1)	2 (mass wasting)	2 (mass wasting)	0 (>100)	0 (0)	0 (0)	0 (0)	14.3
						Muscatine County										
85	Cedar River near Conesville (05465000), 7,785 mi^2, County Road G28, December 27, 1991	3.5 (alluvium)	1 (bed not protected)	4 (IV Threshold)	0 (0)	2 (4)	0 (1)	0 (1)	0 (0)	1 (fluvial)	1 (fluvial)	0 (>100)	0 (0)	0 (0)	0 (0)	12.5
						Osceola County										
86	Otter Creek at Sibley (06483430), 29.9 mi^2, County Road A22, April 30, 1992	3.5 (alluvium)	3 (bed not protected, both banks protected)	0 (VI Restabilization)	0 (0)	1 (2)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	3 (0)	0 (0)	0 (0)	0 (0)	12.5
87	Otter Creek near Ashton (06483460), 88.0 mi^2, County Road A34, April 30, 1992	3.5 (alluvium)	2 (bed not protected, right bank protected)	0 (VI Restabilization)	0 (0)	1 (1)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	3 (10)	1 (1)	0 (0)	2.5 (45)	15.0

Table 4. *Potential-scour index at selected highway bridges in Iowa—Continued*

Site identification number (*fig. 1*)	Stream name and vicinity (USGS station number), drainage area, highway, date visited	Index components														Potential scour index
		Bed material	Bed protection	Stage of channel evolution	Percentage of channel constriction	Number of piers in channel	Percentage of blockage by debris			Bank erosion (type)		Proximity of river meander impact point (ft)	Pier skew (number of piers)	Mass wasting at pier (number of piers)	Angle of approach of high flows (degrees)	
							Horizontal	Vertical	Total	Left bank	Right bank					
	Page County															
88	Nodaway River at Clarinda (06817000), 762 mi^2, *State Highway 2*, March 23, 1992	4 (silt/ clay)	1 (bed not protected)	4 (IV Threshold)	0 (0)	1 (2)	1.00 (75)	0.33 (10)	0.33 (8)	1 (fluvial)	2 (mass wasting)	3 (0)	2 (2)	0 (0)	1 (15)	20.7
	Plymouth County															
89	Floyd River at James (06600500), 886 mi^2, County Road C70, April 8, 1992	3.5 (alluvium)	1 (bed not protected)	4 (IV Threshold)	0 (0)	1 (1)	0 (0)	0 (0)	0 (0)	2 (mass wasting)	2 (mass wasting)	0 (>100)	0 (0)	3 (1)	0 (0)	16.5
	Pocahontas County															
90	Big Cedar Creek near Varina (05482170), 80.0 mi^2, County Road N33, April 28, 1992	3.5 (alluvium)	3 (bed not protected, both banks protected)	0 (VI Restabilization)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	0 (>100)	0 (0)	0 (0)	0 (0)	8.5
	Polk County															
91	Beaver Creek near Grimes (05481950), 358 mi^2, County Road F42, April 16, 1992	3.5 (alluvium)	1 (bed not protected)	2 (III Degradation)	0 (0)	1 (1)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	3 (0)	0 (0)	0 (0)	0 (0)	12.5
92	Walnut Creek at Des Moines (05484800), 78.4 mi^2, State Highway 28, May 15, 1992	3.5 (alluvium)	2 (bed not protected, left bank protected)	3 (V Aggradation)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	3 (10)	0 (0)	0 (0)	1 (25)	14.5

Table 4. Potential-scour index at selected highway bridges in Iowa—Continued

Site identification number (fig. 1)	Stream name and vicinity (USGS station number), drainage area, highway, date visited	Index components					Percentage of blockage by debris			Bank erosion (type)		Proximity of river meander impact point (ft)	Pier skew (number of piers)	Mass wasting at pier (number of piers)	Angle of approach of high flows (degrees)	Potential scour index
		Bed material	Bed protection	Stage of channel evolution	Percentage of channel constriction	Number of piers in channel	Horizontal	Vertical	Total	Left bank	Right bank					
						Polk County—Continued										
93	Fourmile Creek at Des Moines (05485640), 92.7 mi^2, Easton Boulevard, April 16, 1992	3.5 (alluvium)	1 (bed not protected)	0 (VI Restabilization)	1 (6)	0 (0)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	2 (30)	0 (0)	0 (0)	1 (25)	10.5
						Pottawattamie County										
94	West Nishnabotna River at Hancock (06807410), 609 mi^2, County Road G30, March 25, 1992	4 (silt/clay)	3 (bed not protected, both banks protected)	3 (V Aggradation)	0 (0)	1 (1)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	3 (0)	1 (1)	0 (0)	1 (15)	18.0
95	Middle Silver Creek near Treynor (06807780), 42.7 mi^2, County Road L55, March 25, 1992	4 (silt/clay)	1 (bed not protected)	4 (IV Threshold)	1 (14)	0 (0)	0 (0)	0 (0)	0 (0)	2 (mass wasting)	2 (mass wasting)	3 (0)	0 (0)	3 (1)	0 (10)	20.0
						Poweshiek County										
96	Walnut Creek near Hartwick (05452200), 70.9 mi^2, County Road V21, December 17, 1991	4 (silt/clay)	1 (bed not protected)	4 (IV Threshold)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	0 (>100)	0 (0)	0 (0)	0 (0)	11.0
97	North English River near Montezuma (05455140), 31.0 mi^2, County road, May 1, 1992	3.5 (alluvium)	1 (bed not protected)	4 (IV Threshold)	1 (23)	0 (0)	0.33 (10)	0.33 (10)	0 (1)	1 (fluvial)	1 (fluvial)	0 (>100)	0 (0)	0 (0)	0 (0)	12.2

Table 4. Potential-scour index at selected highway bridges in Iowa—Continued

Site identification number (fig. 1)	Stream name and vicinity (USGS station number), drainage area, highway, date visited	*Index components*														Potential scour index
		Bed material	Bed protection	Stage of channel evolution	Percentage of channel constriction	Number of piers in channel	Percentage of blockage by debris			Bank erosion (type)		Proximity of river meander impact point (ft)	Pier skew (number of piers)	Mass wasting at pier (number of piers)	Angle of approach of high flows (degrees)	
							Horizontal	Vertical	Total	Left bank	Right bank					
					Poweshiek County—Continued											
98	North English River near Montezuma (05455150), 34.0 mi^2, U.S. Highway 63, May 1, 1992	3.5 (alluvium)	1 (bed not protected)	0 (VI Restabilization)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	2 (40)	0 (0)	0 (0)	0 (0)	8.5
99	North English River near Guernsey (05455200), 68.7 mi^2, County Road V21, May 15, 1992	3.5 (alluvium)	1 (bed not protected)	4 (IV Threshold)	2 (35)	1 (1)	0 (0)	0 (0)	0 (0)	2 (mass wasting)	2 (mass wasting)	2 (30)	1 (1)	3 (1)	1 (15)	22.5
100	North English River near Guernsey (05455210), 81.5 mi^2, State Highway 21, May 15, 1992	3.5 (alluvium)	3 (bed not protected, both banks protected)	1 (II Constructed)	2 (26)	0 (0)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	0 (>100)	0 (0)	0 (0)	0 (0)	11.5
101	Sugar Creek near Searsboro (05472290), 52.7 mi^2, State Highway 225, December 18, 1991	3 (sand)	1 (bed not protected)	4 (IV Threshold)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	0 (>100)	0 (0)	0 (0)	0 (0)	10.0
					Ringgold County											
102	Platte River near Diagonal (06818750), 217 mi^2, County road, March 23, 1992	4 (silt/clay)	1 (bed not protected)	4 (IV Threshold)	0 (0)	1 (1)	0 (5)	0 (5)	0 (0)	1 (fluvial)	1 (fluvial)	0 (>100)	0 (0)	0 (0)	0 (0)	12.0

Table 4. Potential-scour index at selected highway bridges in Iowa—Continued

Site identification number (fig. 1)	Stream name and vicinity (USGS station number), drainage area, highway, date visited	Index components: Bed material	Bed protection	Stage of channel evolution	Percentage of channel constriction	Number of piers in channel	Percentage of blockage by debris: Horizontal	Vertical	Total	Bank erosion (type): Left bank	Right bank	Proximity of river meander impact point (ft)	Pier skew (number of piers)	Mass wasting at pier (number of piers)	Angle of approach of high flows (degrees)	Potential scour index
	Sac County															
103	North Raccoon River near Sac City (05482300), 700 mi², County road, April 8, 1992	4 (silt/ clay)	1 (bed not protected)	2 (III Degradation)	0 (0)	1 (2)	0 (5)	0 (5)	0 (0)	1 (fluvial)	1 (fluvial)	0 (>100)	0 (0)	0 (0)	0 (0)	10.0
	Scott County															
104	Wapsipinicon River near Dewitt (05422000), 2,330 mi², U.S. Highway 61, January 6, 1992	3 (sand)	3 (bed not protected, both banks protected)	4 (IV Threshold)	0 (0 est.)	1 (2)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	0 (>100)	0 (0)	0 (0)	0 (10)	13.0
	Shelby County															
105	Mosquito Creek near Earling (06610520), 32.0 mi², State Highway 191, April 7, 1992	3.5 (alluvium)	1 (bed not protected)	4 (IV Threshold)	1 (12)	0 (0)	0 (0)	0 (0)	0 (0)	2 (mass wasting)	2 (mass wasting)	3 (0)	0 (0)	6 (2)	2 (30)	24.5
	Sioux County															
106	Rock River near Rock Valley (06483500), 1,592 mi², Highway K30, April 29, 1992	3.5 (alluvium)	2 (bed not protected, left bank protected)	0 (VI Restabilization)	0 (0)	2 (3)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	3 (0)	3 (3)	0 (0)	2.5 (45)	18.0

Table 4. Potential-scour index at selected highway bridges in Iowa—Continued

Site identification number (fig. 1)	Stream name and vicinity (USGS station number), drainage area, highway, date visited	Index components: Bed material	Bed protection	Stage of channel evolution	Percentage of channel constriction	Number of piers in channel	Percentage of blockage by debris: Horizontal	Vertical	Total	Bank erosion (type): Left bank	Right bank	Proximity of river meander impact point (ft)	Pier skew (number of piers)	Mass wasting at pier (number of piers)	Angle of approach of high flows (degrees)	Potential scour index
								Sioux County—Continued								
107	Dry Creek at Hawarden (06484000), 48.4 mi^2, State Highway 10, April 29, 1992	3.5 (alluvium)	1 (bed not protected)	0 (VI Restabilization)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (fluvial)	2 (mass wasting)	3 (0)	0 (0)	0 (0)	0 (5)	10.5
108	Floyd River at Alton (06600100), 268 mi^2, County road, April 29, 1992	3.5 (alluvium)	1 (bed not protected)	2 (III Degradation)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	0 (>100)	0 (0)	0 (0)	0 (0)	8.5
109	West Branch Floyd River near Struble (06600300), 180 mi^2, County Road B62, April 29, 1992	3.5 (alluvium)	1 (bed not protected)	4 (IV Threshold)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	1 (60)	0 (0)	0 (0)	2.5 (45)	14.0
								Story County								
110	South Skunk River near Ames (05470000), 315 mi^2, County road, April 15, 1992	3 (sand)	3 (bed not protected, both banks protected)	0 (VI Restabilization)	0 (0)	1 (2)	0 (0)	0 (0)	0 (0)	2 (mass wasting)	2 (mass wasting)	3 (0)	0 (0)	0 (0)	2 (30)	16.0
111	Squaw Creek at Ames (05470500), 204 mi^2, Lincoln Way, April 15, 1992	3 (sand)	3 (bed not protected, both banks protected)	3 (V Aggradation)	0 (5)	1 (1)	0 (2)	0 (2)	0 (0)	2 (mass wasting)	2 (mass wasting)	1 (75)	1 (1)	0 (0)	1 (25)	17.0

Table 4. Potential-scour index at selected highway bridges in Iowa—Continued

Site identification number (fig. 1)	Stream name and vicinity (USGS station number), drainage area, highway, date visited	Index components: Bed material	Bed protection	Stage of channel evolution	Percentage of channel constriction	Number of piers in channel	Percentage of blockage by debris: Horizontal	Vertical	Total	Bank erosion (type): Left bank	Right bank	Proximity of river meander impact point (ft)	Pier skew (number of piers)	Mass wasting at pier (number of piers)	Angle of approach of high flows (degrees)	Potential scour index
	Story County—Continued															
112	South Skunk River below Squaw Creek near Ames (05471000), 556 mi^2, U.S. Highway 30, April 15, 1992	3 (sand)	3 (bed not protected, both banks protected)	0 (VI Restabilization)	0 (0)	1 (2)	0 (0)	0 (0)	0 (0)	2 (mass wasting)	2 (mass wasting)	3 (10)	0 (0)	3 (1)	2 (30)	19.0
	Tama County															
113	Richland Creek near Haven (05451900), 56.1 mi^2, County road, December 17, 1991	4 (silt/clay)	1 (bed not protected)	4 (IV Threshold)	0 (0)	1 (1)	0 (0)	0 (0)	0 (0)	2 (mass wasting)	2 (mass wasting)	0 (>100)	0 (0)	0 (0)	0 (0)	14.0
114	Salt Creek near Elberon (05452000), 201 mi^2, U.S. Highway 30, December 17, 1991	3.5 (alluvium)	1 (bed not protected)	4 (IV Threshold)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	0 (>100)	0 (0)	0 (0)	0 (0)	10.5
	Taylor County															
115	East Fork 102 River near Bedford (06819190), 92.1 mi^2, County Road J55, March 23, 1992	4 (silt/clay)	1 (bed not protected)	4 (IV Threshold)	1 (12)	1 (1)	0.67 (30)	0.33 (15)	0 (5)	1 (fluvial)	1 (fluvial)	3 (0)	1 (1)	0 (0)	1 (20)	19.0

Table 4. Potential-scour index at selected highway bridges in Iowa—Continued

Site identification number (fig. 1)	Stream name and vicinity (USGS station number), drainage area, highway, date visited	Index components: Bed material	Bed protection	Stage of channel evolution	Percentage of channel constriction	Number of piers in channel	Percentage of blockage by debris: Horizontal	Vertical	Total	Bank erosion (type): Left bank	Right bank	Proximity of river meander impact point (ft)	Pier skew (number of piers)	Mass wasting at pier (number of piers)	Angle of approach of high flows (degrees)	Potential scour index
	Van Buren County															
116	Fox River at Cantril (05494500), 161 mi^2, State Highway 2, February 3, 1992	3 (sand)	1 (bed not protected)	3 (V Aggradation)	0 (0 est.)	0 (0)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	0 (>100)	0 (0)	0 (0)	0 (0)	9.0
	Wapello County															
117	Bear Creek at Ottumwa (05489490), 24.0 mi^2, U.S. Highway 34, February 3, 1992	3 (sand)	1 (bed not protected)	3 (V Aggradation)	1 (13)	0 (0)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	0 (>100)	0 (0)	0 (0)	0 (0)	10.0
	Warren County															
118	North River near Norwalk (05486000), 349 mi^2, County Road R57, February 21, 1992	3.5 (alluvium)	1 (bed not protected)	3 (V Aggradation)	0 (0)	0 (0)	1.33 (90)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	0 (>100)	0 (0)	0 (0)	0 (0)	10.8
119	Middle River near Indianola (05486490), 503 mi^2, County road, February 21, 1992	3.5 (alluvium)	1 (bed not protected)	3 (V Aggradation)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	0 (>100)	0 (0)	0 (0)	0 (0)	9.5
120	South River near Ackworth (05487470), 460 mi^2, County road, February 20, 1992	3.5 (alluvium)	2 (bed not protected, right bank protected)	3 (V Aggradation)	0 (0)	1 (1)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	0 (>100)	0 (0)	0 (0)	0 (0)	11.5

Table 4. Potential-scour index at selected highway bridges in Iowa—Continued

Site identification number (fig. 1)	Stream name and vicinity (USGS station number), drainage area, highway, date visited	Index components: Bed material	Bed protection	Stage of channel evolution	Percentage of channel constriction	Number of piers in channel	Percentage of blockage by debris: Horizontal	Vertical	Total	Bank erosion (type): Left bank	Right bank	Proximity of river meander impact point (ft)	Pier skew (number of piers)	Mass wasting at pier (number of piers)	Angle of approach of high flows (degrees)	Potential scour index
	Washington County															
121	English River at Kalona (05455500), 573 mi^2, State Highway 1, November 21, 1992	3.5 (alluvium)	2 (bed not protected, right bank protected)	3 (V Aggradation)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	0 (>100)	0 (0)	0 (0)	0 (0)	10.5
	Wayne County															
122	South Fork Chariton River near Promise City (06903700), 168 mi^2, County Road S50, February 27, 1992	3.5 (alluvium)	1 (bed not protected)	3 (V Aggradation)	0 (0)	1 (1)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	0 (>100)	0 (0)	0 (0)	0 (0)	10.5
	Webster County															
123	Lizard Creek near Clare (05480000), 257 mi^2, County road, April 28, 1992	3.5 (alluvium)	1 (bed not protected)	0 (VI Restabilization)	0 (0)	1 (1)	0.67 (30)	0 (5)	0 (2)	1 (fluvial)	2 (mass wasting)	3 (0)	1 (1)	0 (0)	2.5 (45)	15.7
124	Des Moines River near Stratford (05481300), 5,452 mi^2, State Highway 175, April 27, 1992	3 (sand)	1 (bed not protected)	0 (VI Restabilization)	0 (0)	2 (3)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	0 (>100)	0 (0)	0 (0)	0 (0)	8.0

Table 4. *Potential-scour index at selected highway bridges in Iowa*—Continued

Site identification number (fig. 1)	Stream name and vicinity (*USGS station* number), drainage area, highway, date visited	Index components: Bed *material*	Bed *protection*	Stage of *channel* evolution	Percentage of channel constriction	Number of piers in channel	Percentage of blockage by debris: Horizontal	Vertical	Total	Bank erosion (type): Left bank	Right bank	Proximity of river meander impact point (ft)	Pier skew (number of piers)	Mass wasting at pier (number of piers)	Angle of approach of high flows (degrees)	Potential scour index
	Woodbury County															
125	Perry Creek at 38th Street, Sioux City (06600000), 65.1 mi^2, 38th Street, April 8, 1992	3.5 (alluvium)	0 (protected bed)	4 (IV Threshold)	2 (41 est.)	0 (0)	0 (0)	0 (0)	0 (0)	2 (mass wasting)	2 (mass wasting)	3 (0)	0 (0)	0 (0)	2 (30)	18.5
126	West Fork Ditch at Hornick (06602020), 403 mi^2, State Highway 141, April 7, 1992	3.5 (alluvium)	1 (bed not protected)	4 (IV Threshold)	3 (61)	0 (0)	0 (0)	0 (0)	0 (0)	2 (mass wasting)	2 (mass wasting)	0 (>100)	0 (0)	6 (2)	0 (0)	21.5
127	Little Sioux River at Correctionville (06606600), 2,500 mi^2, State Highway 31, April 8, 1992	3.5 (alluvium)	2 (bed not protected, right bank protected)	4 (IV Threshold)	0 (5)	1 (1)	0 (0)	0 (0)	0 (0)	1 (fluvial)	2 (mass wasting)	0 (>100)	0 (0)	0 (0)	0 (0)	13.5
	Worth County															
128	Shell Rock River near Northwood (05459000), 300 mi^2, County Road A27, May 13, 1992	3.5 (alluvium)	1 (bed not protected)	0 (I Premodified)	1 (8)	1 (2)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	0 (>100)	0 (0)	0 (0)	0 (0)	8.5
129	Elk Creek at Kensett (05459010), 58.1 mi^2, U.S. Highway 65, May 13, 1992	3.5 (alluvium)	1 (bed not protected)	0 (VI Restabilization)	0 (0)	1 (2)	0 (0)	0 (0)	0 (0)	1 (fluvial)	1 (fluvial)	0 (>100)	0 (0)	0 (0)	0 (0)	7.5

Table 4. Potential-scour index at selected highway bridges in Iowa—Continued

Site identification number (fig. 1)	Stream name and vicinity (USGS station number), drainage area, highway, date visited	Index components														Potential scour index
							Percentage of blockage by debris			Bank erosion (type)						
		Bed material	Bed protection	Stage of channel evolution	Percentage of channel constriction	Number of piers in channel	Horizontal	Vertical	Total	Left bank	Right bank	Proximity of river meander impact point (ft)	Pier skew (number of piers)	Mass wasting at pier (number of piers)	Angle of approach of high flows (degrees)	
Wright County																
130	Iowa River near Rowan (05449500), 429 mi^2, County Road C38, May 14, 1992	3.5 (alluvium)	1 (bed not protected)	1 (II Constructed)	0 (0)	1 (2)	0 (0)	0 (0)	0 (0)	0 (none)	0 (none)	0 (>100)	0 (0)	0 (0)	0 (0)	6.5

APPENDIX

The data-collection form used to collect information for the assessment of potential scour in this study is shown in this appendix. The form is adapted from Simon and Outlaw (1989, p. 115–116).

(4/10/92) BRIDGE SCOUR ASSESSMENT FORM

Date ____________________

(1) Stream________________________ Vicinity______________________ Party ____________________

Land Use 1 = urban, 2 = row crop, 3 = pasture, 4 = forest, 7 = range land

(2 Route_______ County___________ Hwy. Log mile____________ IDOT Bridge No.___________

Lat.__________ Long___________ Total Bridge Length______________ IDOT Region___________

Max span length __________ Channel protection___________ Waterway adequacy _____________

Sufficiency rating_______________ Number of overflow ridges: left________ right________

Flood-Characteristic Region_______

(3) Nearest gaging station____ Station ID_______________________

Flow regulated: 0=no 1=yes Baseflow at inspection: 0=no 1=yes 2=unknown

Depth of flow_______ ft. at____(describe)

WS slope ____

High-flow angle of approach _________ degrees (+ =toward right bank, - =toward left bank)

Observed High-Water Marks (HWM) __________ ft. above/below reference point.

Describe reference point ____

Describe HWM's____

Deflected flow __________, 0=no 1=yes Impact point: LB RB _________ ft US DS

Cause of deflection and effect on bridge crossing (describe):

Capacity of bridge opening (qualitative): can bridge handle flow at all stages or is there some restriction at certain stages?

Capacity of channel (qualitative): describe any side or overflow channels upstream and downstream of bridge:

Road overflow risk (qualitative): none possible likely ?

(4) Bank condition:

	Height 1 LB	Height 2 RB	Angle 1 LB	Angle 2 RB	Veg. Cover (%) 1 LB	Veg. Cover (%) 2 RB	Material 1 LB	Material 2 RB	Erosion 1 LB	Erosion 2 RB
1 U/S	____	____	____	____	____	____	____	____	____	____
2 D/S	____	____	____	____	____	____	____	____	____	____
3 At bridge									____	____

NOTE: Include bank angle sketch with heights and angles, vegetation type (woody or herbaceous), approx. age, and species if recognized. Measure bank height in ft from the channel bed.

Material: 1=ml/cl 2=sand 3=becrock 4=gravel/cobble 5=artificial (describe)
Erosion: 0=none, 1=mass wasting, 2=fluvial erosion

Is site a good candidate for measuring scour? y n

(5) Bed material characteristics: 1=sand 2=ml/cl 3=gravel 4=cobble/boulder
5=bedrock 6=alluvium (if can't tell others)

Material size________ Armored: 0=no 1=yes
Est. depth of gravel deposits________ft (enter 999 if not observed)

(6) Channel profile: 1 U/S 1=pool 2=riffle 3=smooth/continous
2 D/S 1=pool 2=riffle 3=smooth/continuous

(7) Distance to U/S confluence or diversion: 0=no 1=yes
_____ft 1=LB entry 2=RB entry
_____ft 1=LB entry 2=RB entry

(8) Piers: List from left to right. Start/stop at first flood plain pier.

	1 2 3 4 5 6 7 8 9 (circle appropriate choice below)	0 1 2 Local scour	width
#___shape___skew___	loc:1fp,1tb,1b,mcl,mcm,mcr,rb,rtb,rfp	0 1 2 F P N	___
#___shape___skew___	loc:1fp,1tb,1b,mcl,mcm,mcr,rb,rtb,rfp	0 1 2 F P N	___
#___shape___skew___	loc:1fp,1tb,1b,mcl,mcm,mcr,rb,rtb,rfp	0 1 2 F P N	___
#___shape___skew___	loc:1fp,1tb,1b,mcl,mcm,mcr,rb,rtb,rfp	0 1 2 F P N	___
#___shape___skew___	loc:1fp,1tb,1b,mcl,mcm,mcr,rb,rtb,rfp	0 1 2 F P N	___

Shape:	Skew:	Local scour:
1=squared	looking d/s toward bridge	0=none
2=rounded	during high-flow alignment	1=observed
3=pointed	+ skew to the right	2=undefinable
4=square-pile	- skew to the left	F=footing exposed
5=round-pile		P=piling exposed
6=pointed pile		N=no exposure

Use 'B' for pier number if it is a bent

		1	2	abutment pilings exposed
(9) Abutment:	1=left,skew___ loc:0,+___ft,-___ft,	sloping	or vertical.	0=no 1=yes
	2=right,skew___ loc:0,+___ft,-___ft,	sloping	or vertical.	0=no 1=yes

Wingwalls:		Length	Angle (from road)	0=no 1=yes
	USLB_____	_____	_____	
	USRB_____	_____	_____	
	DSLB_____	_____	_____	
	DSRB_____	_____	_____	

NOTE: Skew measured for high flow conditions as difference between normal flow and abutment. + =right skew, - =left skew
Location (loc.): + indicated abutment is set back from the bank,
- indicates the abutment sits out into the stream, 0 indicates the abutment is even with the bank. Compare to bankfull width upstream.

(10) Debris accumulation (% of opening blocked): horizontal_____to_____ %
vertical_____to_____ %

Type and size:____ 1=brush, 2=whole trees, 3=trash, 4=rock/sediment, 5=all

Potential for debris (qualitative - include ice): high moderate low

Obstructions (describe)- TAKE PICTURES, MAKE NOTES:

(11) Riprap:

1=US rt bank	0=absent	1=present	2=good cond	3=weathered smaller	4=slumped
2=US lf bank	0=absent	1=present	2=good cond	3=weathered smaller	4=slumped
3=At rt bank	0=absent	1=present	2=good cond	3=weathered smaller	4=slumped
4=At lf bank	0=absent	1=present	2=good cond	3=weathered smaller	4=slumped
5=DS rt bank	0=absent	1=present	2=good cond	3=weathered smaller	4=slumped
6=DS lf bank	0=absent	1=present	2=good cond	3=weathered smaller	4=slumped

Type and size (qualitative):

If slumped, where and why:

7=Bed: 0=absent 1=present 2=good cond 3=weathered smaller 4=moved
If moved, to what extent:

Type and size (qualitative):

8=At rt abut.	0=absent	1=present	2=good cond	3=weathered smaller	4=slumped
9=At lf abut.	0=absent	1=present	2=good cond	3=weathered smaller	4=slumped

Type and size (qualitative):

If slumped, where and why:

(12) Channel width: US____, at bridge____, DS____. Blowhole____ 0=no 1=yes
Size and location of blowhole: ____ft DS, ____ft wide, ____ft long.

(13) Braided (=0) or meandering (=1)
Meandering characteristics in vicinity of bridge (impact points):

	1 Low flow		2 High flow	
straight	0=no	1=yes	straight 0=no	1=yes
	1=LB	2=RB	1=LB	2=RB
US (ft)	____	____	____	____
DS (ft)	____	____	____	____

Meander wavelength ____ft ____ft
NOTE: Entry will be LB or RB and distance from bridge, 0=impact at bridge.

(14) Point bar location: ____ 0=absent 1=present, ____to____ % (0%=LB, 100%=RB)
Distance US (+)____ft or DS (-)____ft. Width at mid bar ____ft.
Vegetated ____ 0=no 1=yes

(15) Alluvial fan in vicinity of bridge: 0=no 1=yes 2=questionable
If questionable, then describe:

(16) Stage of channel evolution: 1=undisturbed 2=new construction 3=degrading
4=degrading and bank failure 5=aggrading or stable, with bank failure
6=fully recovered