METHODS FOR ASSESSING CHANNEL CONDITIONS RELATED TO SCOUR-CRITICAL CONDITIONS AT BRIDGES IN TENNESSEE

By Bradley A. Bryan, Andrew Simon, George S. Outlaw, and Randy Thomas

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CONVERSION FACTORS

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
acre	4,047	square meter
acre	0.4047	hectare
square foot (ft^2)	929	square centimeter
square foot (ft^2)	0.0929	square meter
square mile (mi^2)	259.0	hectare
square mile (mi^2)	2.590	square kilometer

Methods for Assessing Channel Conditions Related to Scour-Critical Conditions at Bridges in Tennessee

By Bradley A. Bryan, Andrew Simon, George S. Outlaw, *and* Randy Thomas

Abstract

The ability to assess quickly the potential for scour at a bridge site, to evaluate those bridges with the greatest potential for significant amounts of scour, and to then identify scour-critical structures is important for public protection and bridge maintenance planning. A bridge scour assessment information form was developed for collecting data describing the site; the hydraulic, geomorphic, and vegetation characteristics of the channel and bridge site.

Information from site assessments of 3,964 bridges in Tennessee was used to develop indexes of potential and observed scour. A data base and geographic information system were established for rapid assessment of potential scour characteristics over broad geographic areas, such as counties, regions, or drainage basins.

Channel instability characteristics differ from region to region. In West Tennessee counties, channel instability has progressed from valley bottoms into the uplands through headward degradation. In the middle and east counties of Tennessee, channel widening is a dominant process, but widespread degradation has been prevented by stream beds being lined with erosion-resistant bedrock, boulder, cobble, and gravel, and by the absence of channelization. Neither quantifiable headcutting nor degradation in bedrock channels was noted at any site in the State. However, potential for lateral scour is prevalent in Middle and East Tennessee.

INTRODUCTION

Channel erosion near bridges consists of such processes as degradation, contraction scour, and local scour. These three processes are the result of adjustment of a river to changing land use, past channel modifications, or to localized disturbances, such as piers or abutments. The phenomenon of scour is a major engineering consideration in the design and maintenance of bridges. The term "scour critical" is used to describe a bridge at which abutment and pier foundations are, or have the potential to be, unstable because of erosion of the channel bed or banks (Federal Highway Administration, 1988a). Given the large number of bridges over water in the State, the ability to assess quickly the potential for scour at a given site is important.

Degradation is an adjustment of the bed elevation due to changes in hydrology, hydraulics, or sediment movement and, as defined here, is not caused by the bridge or roadway. Degradation of the stream bed can be induced by changes either upstream or downstream of the bridge. Lane's relation (Lane, 1955),

$$QS \propto Q_s d_{50} \qquad (1)$$

where Q is the water discharge,
S is the channel gradient,
Q_s is the bed-material discharge, and
d_{50} is the median grain size of bed material,

describes this interaction. Changes on either side of the proportionality will affect the stability of the channel.

Contraction scour is the general lowering of the bed across the channel section at the structure due to flow acceleration through a constriction. Although contraction scour is generally considered a short term or cyclic phenomenon, it can be a long lasting problem under special circumstances. Contraction of flow from the flood plain at newly constructed bridges has the potential to induce both bed lowering and bank failure.

Local scour is the erosion that occurs around piers or abutments and is induced by flow acceleration and perturbation. Total scour depth at the site is the sum of degradation, contraction scour, and local scour.

The primary purpose of a State or regional scour assessment is the identification of sites with potential severe scour problems that would require further study. A ranking approach allows for the rapid assessment of a large number of bridges. A more detailed surveying, sampling, and modeling can then be undertaken at those sites that rank high in regard to potential scour. Modeled scour depths and geophysical and structural analyses at sites that rank high can then be used to evaluate potential foundation instability and to identify those bridges that are scour critical.

In 1988, the U.S. Geological Survey (USGS), in cooperation with the Tennessee Department of Transportation (TDOT) and the U.S. Department of Transportation, Federal Highway Administration (FHWA), initiated a 5-year project to describe and assess channel characteristics related to bridge scour at sites throughout Tennessee.

Purpose and Scope

This report describes methods developed and used to generate appraisals of the scour potential of channels at bridges throughout Tennessee. Using these methods, assessments of bridge-site conditions related to high potential for critical scour also are described.

Study Approach

The project was conducted in three phases from 1988-93. Phase 1 included sites throughout the State (TDOT regions 1, 2, 3, and 4) (fig. 1). To increase the density of spatial coverage, phase 2 included additional sites in TDOT region 4 that were not evaluated in phase 1. Phase 3 focused in urban areas and selected counties in regions 1, 2, and 3 with gravelbed channels.

Phase 1 of the project provided an overview of potential scour statewide. The number of sites selected in each county was based on bridge length and a restriction that the bridge be located on a State or Federal route. The limiting structure length, determined by TDOT, was based on upstream drainage area and the ability of the stream to sustain an open channel. This structure length corresponded with a 3-span bridge at least 50 feet long (B.R. Burke, Tennessee Department of Transportation, written commun., 1989). The restriction that bridges be on State or Federal routes further limited the selection to 2,852 sites for phase 1 (table 1). These sites provided adequate coverage of State and Federal routes, but resulted in limited spatial coverage because sites tended to be located closely together.

Phase 2 of the project was initiated in TDOT region 4 (fig. 1) to provide increased site density for determining the extent of scour related to stream network and channel stability as

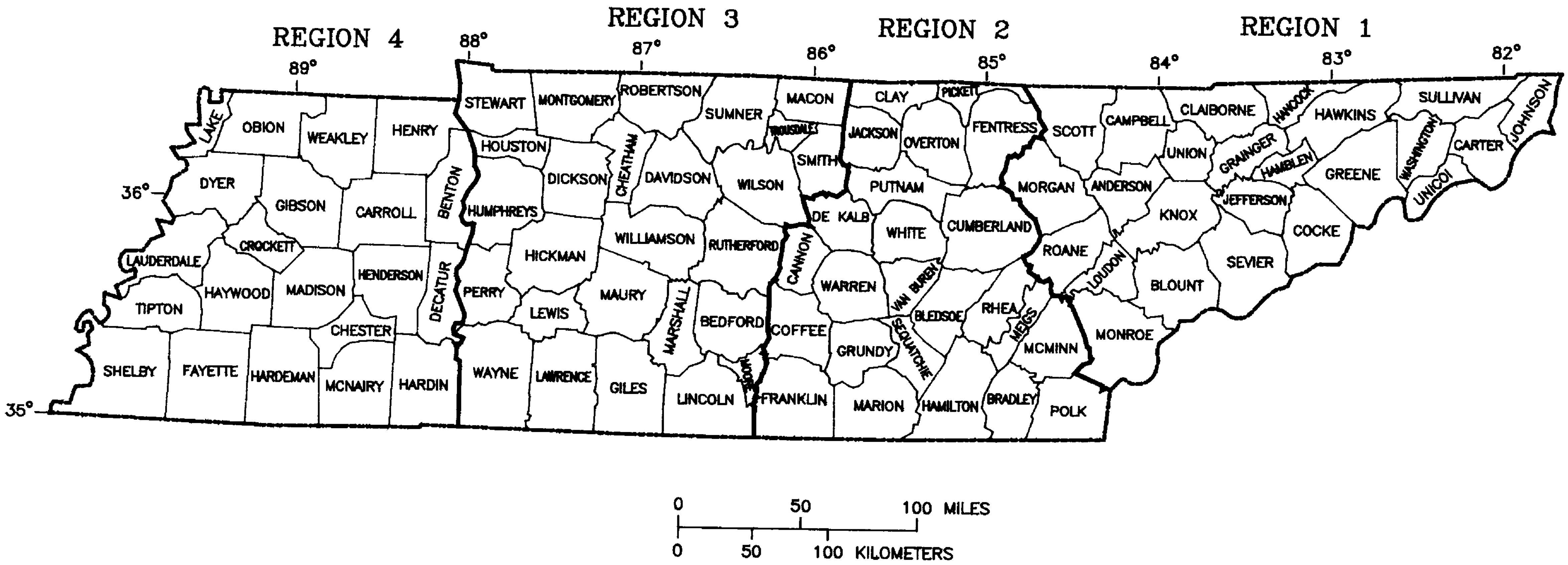


Figure 1. Tennessee Department of Transportation regions and associated counties in Tennessee.

Table 1. *Summary of Tennessee Bridge Scour Data System by Tennessee Department of Transportation region, 1988-93*

[--, No data]

Tennessee Department of Transportation region 1

County (Tennessee Department of Transportation county code)	Number of bridges inspected by study phase			Number of bridges in the Bridge Scour Data System	County area, in square miles	Density of spatial coverage, in square miles per bridge
	1	2	3			
Anderson (1)	32	--	13	45	338	7.51
Blount (5)	20	--	7	27	579	21.44
Campbell (7)	17	--	--	17	447	26.29
Carter (10)	29	--	--	29	355	12.24
Claiborne (13)	12	--	--	12	446	37.17
Cocke (15)	25	--	--	25	434	17.36
Grainger (29)	14	--	--	14	310	22.14
Greene (30)	28	--	--	28	617	22.04
Hamblen (32)	9	--	--	9	174	19.33
Hancock (34)	6	--	--	6	230	38.33
Hawkins (37)	34	--	--	34	494	14.53
Jefferson (45)	18	--	--	18	318	17.67
Johnson (46)	17	--	--	17	299	17.59
Knox (47)	47	--	32	79	511	6.47
Loudon (53)	13	--	--	13	240	18.46
Monroe (62)	20	--	--	20	662	33.10
Morgan (65)	18	--	--	18	539	29.94
Roane (73)	23	--	--	23	354	15.39
Scott (76)	11	--	--	11	549	49.91
Sevier (78)	53	--	--	53	603	11.38
Sullivan (82)	64	--	--	64	425	6.64
Unicoi (86)	19	--	--	19	185	9.74
Union (87)	6	--	--	6	212	35.33
Washington (90)	19	--	--	19	327	17.21
Region total	554	--	52	606	9,648	15.92

Table 1. Summary of Tennessee Bridge Scour Data System by Tennessee Department of Transportation region, 1988-93--Continued

Tennessee Department of Transportation region 2						
County (Tennessee Department of Transportation county code)	Number of bridges inspected by study phase			Number of bridges in the Bridge Scour Data System	County area, in square miles	Density of spatial coverage, in square miles per bridge
	1	2	3			
Bledsoe (4)	9	--	13	22	404	18.36
Bradley (6)	22	--	--	22	338	15.36
Cannon (8)	18	--	6	24	271	11.29
Clay (14)	9	--	--	9	235	26.11
Coffee (16)	39	--	--	39	435	11.15
Cumberland (18)	34	--	--	34	679	19.97
Dekalb (21)	17	--	8	25	276	11.04
Fentress (25)	9	--	--	9	498	55.33
Franklin (26)	21	--	--	21	560	26.67
Grundy (31)	17	--	--	17	358	21.06
Hamilton (33)	57	--	12	69	576	8.35
Jackson (44)	24	--	12	36	327	9.08
McMinn (54)	23	--	--	23	435	18.91
Marion (58)	37	--	6	43	507	11.79
Meigs (61)	8	--	--	8	206	25.75
Overton (67)	15	--	--	15	439	29.27
Pickett (69)	5	--	--	5	157	31.40
Polk (70)	19	--	--	19	436	22.95
Putnam (71)	14	--	9	23	406	17.65
Rhea (72)	20	--	4	24	323	13.46
Sequatchie (77)	9	--	8	17	273	16.06
Van Buren (88)	5	--	--	5	255	51.00
Warren (89)	28	--	--	28	442	15.79
White (93)	7	--	--	7	383	54.71
Region total	466	--	78	544	9,219	16.95

Table 1. Summary of Tennessee Bridge Scour Data System by Tennessee Department of Transportation region, 1988-93--Continued

Tennessee Department of Transportation region 3						
County (Tennessee Department of Transportation county code)	Number of bridges inspected by study phase			Number of bridges in the Bridge Scour Data System	County area, in square miles	Density of spatial coverage, in square miles per bridge
	1	2	3			
Bedford (2)	43	--	--	43	482	11.21
Cheatham (11)	23	--	13	36	301	8.36
Davidson (19)	73	--	12	85	532	6.26
Dickson (22)	25	--	19	44	485	11.02
Giles (28)	40	--	30	70	619	8.84
Hickman (41)	43	--	22	65	613	9.43
Houston (42)	14	--	12	26	207	7.96
Humphreys (43)	31	--	18	49	555	11.33
Lawrence (50)	19	--	14	33	634	19.21
Lewis (51)	11	--	16	27	285	10.56
Lincoln (52)	37	--	15	52	580	11.15
Macon (56)	9	--	23	32	304	9.50
Marshall (59)	42	--	--	42	377	8.98
Maury (60)	47	--	--	47	614	13.06
Montgomery (63)	28	--	20	48	543	11.31
Moore (64)	8	--	--	8	124	15.50
Perry (68)	15	--	23	38	419	11.03
Robertson (74)	23	--	--	23	476	20.70
Rutherford (75)	59	--	18	77	630	8.18
Smith (80)	49	--	--	49	325	6.63
Stewart (81)	23	--	8	31	484	15.61
Sumner (83)	46	--	15	61	538	8.82
Trousdale (85)	9	--	--	9	113	12.56
Wayne (91)	18	--	26	44	741	16.84
Williamson (94)	40	--	22	62	593	9.56
Wilson (95)	55	--	--	55	568	10.33
Region total	830	--	326	1,156	12,142	10.50

Table 1. Summary of Tennessee Bridge Scour Data System by Tennessee Department of Transportation region, 1988-93--Continued

County name (Tennessee Department of Transportation county code)	Number of bridges inspected by study phase			Number of bridges in the Bridge Scour Data System	County area, in square miles	Density of spatial coverage, in square miles per bridge
	1	2	3			
Tennessee Department of Transportation region 4						
Benton (3)	21	13	--	34	392	11.53
Carroll (9)	66	33	--	99	596	6.02
Chester (12)	29	15	--	44	285	6.48
Crockett (17)	23	26	--	49	269	5.49
Decatur (20)	16	16	--	32	337	10.53
Dyer (23)	51	33	--	84	529	6.30
Fayette (24)	61	57	--	118	704	5.97
Gibson (27)	65	52	--	117	607	5.19
Hardeman (35)	56	54	--	110	956	8.69
Hardin (36)	34	29	--	63	587	9.32
Haywood (38)	74	25	--	99	519	5.24
Henderson (39)	44	16	--	60	515	8.58
Henry (40)	34	25	--	59	600	10.17
Lake (48)	11	5	--	16	167	10.44
Lauderdale (49)	53	19	--	72	477	6.62
McNairy (55)	48	22	--	70	569	8.13
Madison (57)	70	49	--	119	560	4.71
Obion (66)	62	43	--	105	556	5.30
Shelby (79)	82	63	--	145	755	5.21
Tipton (84)	34	33	--	67	459	6.85
Weakley (92)	68	28	--	96	576	6.00
Region total	1,002	656	--	1,658	11,015	6.64
Grand total	2,852	656	456	3,964	42,024	10.60

described by Simon (1989) and Simon and Hupp (1986; 1987). The 656 sites chosen for phase 2 (table 1) included sites on and off State and Federal routes.

Phase 3 focused on channels in rapidly urbanizing areas of Tennessee, and on parts of Middle and East Tennessee with gravel-bed streams (TDOT regions 1, 2, and 3, table 1). Increased site density in urban areas and areas with gravel-bed streams allowed more precise evaluation of geographically and physiographically specific channel conditions related to scour potential.

Channels in urban areas may be destabilized by an altered hydrologic regime. Urbanization changes the physical conditions that control hydrographs, generally increasing the number and size of flood peaks. This change in flow characteristics, or regime, provides increased erosion potential resulting in increasing channel dimensions. As Booth (1990) summarized, urbanization can have a drastic affect on area hydrology by altering runoff process and flow paths and can result in channel enlargement through degradation and widening.

Documentation of changing land use and agricultural practices in other regions of the country have shown that gravel-bed streams are susceptible to widening, increased debris export, channel shallowing, or channel migration. For example, in the driftless area of Wisconsin, agricultural practices increased erosion rates sufficiently to exceed the sediment transport capacity of many streams, resulting in channel filling and accelerated sedimentation on flood plains (Trimble, 1981; Trimble and Lund, 1982). Soil conservation measures subsequently reduced erosion rates substantially (Lund, 1976). Trimble (1974) discussed similar conditions, but inferred that the decline in upland erosion and flood-plain accretion was due to abandonment of agriculture in upland areas, rather than to improved agricultural practices. After sediment export from uplands was controlled, either by soil conservation or agricultural abandonment, the infilled channels began to clear (Trimble, 1981). A similar pattern has been observed in Giles County, Tennessee, located in TDOT region 3 (S.W. Trimble, Department of Geography, University of California, oral commun., 1991).

Physical Setting

Bed-material type and supply are closely related to geology, physiography, and topography. The geology in Tennessee ranges from Quaternary sediments in the western part of the State to Precambrian rocks along the eastern border (Miller, 1974). The State has eight major physiographic regions (fig. 2) that reflect the diverse and complex geology of the area.

TDOT region 1 includes parts of the Cumberland Plateau, the Valley and Ridge, and most of the Unaka Mountains in East Tennessee. The Valley and Ridge in Tennessee generally consists of broad valleys with steep valley walls. Like the limestones in the Central Basin, most of the limestone, dolomite, and shale underlying the Valley and Ridge produces little chert or coarse-grained bed material.

Streams originating on the Cumberland Plateau have sources of bed material in sandstone, conglomerate, and shale of Pennsylvanian age. In this area, many streams, both large and small, flow on bedrock, but transport large quantities of sand, gravel, and cobble-sized bed material. These materials have been deposited as alluvial fans at the base of the eastern escarpment of the Cumberland Plateau and in the Sequatchie Valley (fig. 2). The major coal-producing area of Tennessee is in the northern part of the Cumberland Plateau. Surface mining in this area has generated widespread sources of gravel and cobble bed material.

Streams draining from the Unaka Mountains (fig. 2) have steep gradients and an abundant source of gravel derived from weathering of quartzite of Early Cambrian age. Because of the steepness and ruggedness of the terrain, small alluvial fans are common. These fans are of local importance and concern because they constitute dynamic sources of bed material, and

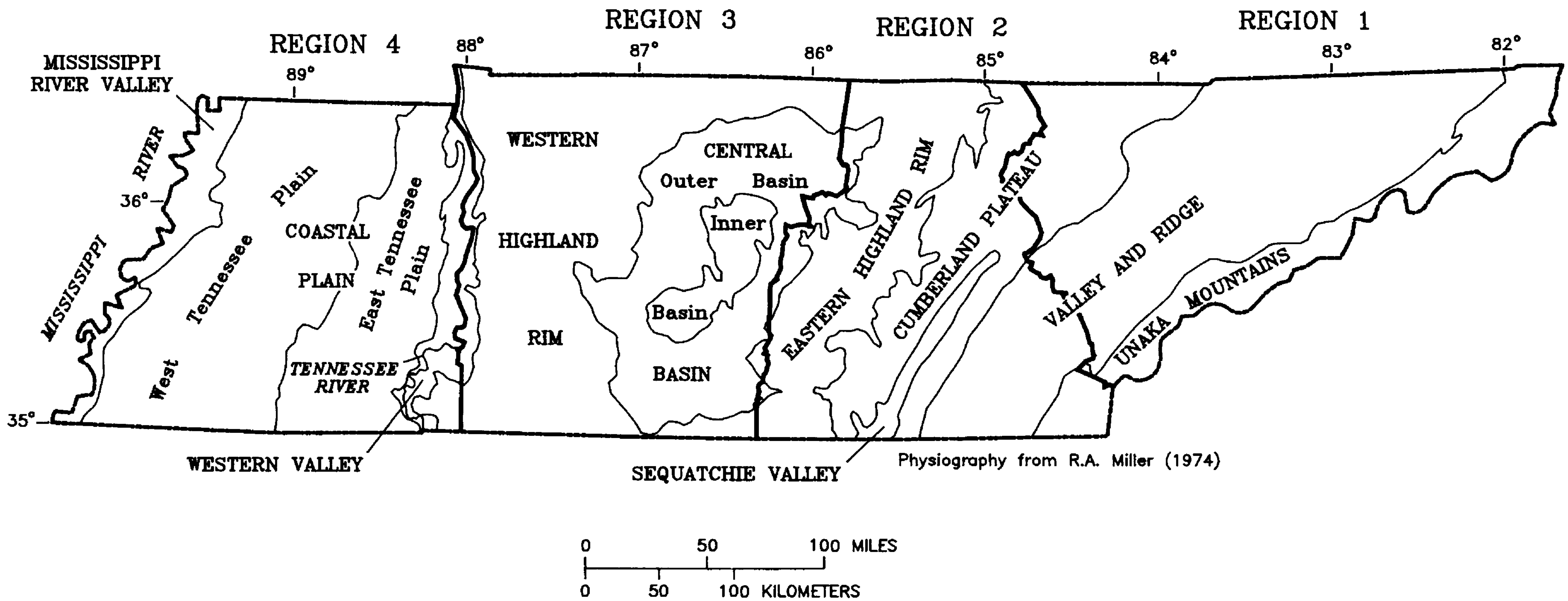


Figure 2. Generalized physiographic map of Tennessee and Tennessee Department of Transportation regions.

any interruption of the downstream movement of the material they contain can result in both upstream and downstream changes in channel morphology.

TDOT region 2 (fig. 2) includes part of the Eastern Highland Rim, much of the Cumberland Plateau, the southeastern third of the Valley and Ridge, Sequatchie Valley, and the southwestern corner of the Unaka Mountains in the eastern part of Middle Tennessee (fig. 2). Streams draining this area transport large quantities of gravel and cobbles.

TDOT region 3 includes part of the Western Highland Rim and most of the Central Basin in the western part of Middle Tennessee (fig. 2). Much of the Western Highland Rim is underlain by the Warsaw, St. Louis, and Ste. Genevieve Limestones of Mississppian age that have weathered to clay and chert gravel (Miller, 1974). Along the western side of the Western Highland Rim, the overlying Tuscaloosa Formation of Cretaceous age also supplies gravel to streams draining counties bordering the Tennessee River (Wade, 1917) (fig. 3). Along the escarpment between the Highland Rim and the Central Basin, weathering of the Mississippian Fort Payne Formation has resulted in gravel supplies made up of shale, chert, and limestone. The Central Basin is underlain by Ordovician limestones that weather mainly to clay (Galloway, 1919), resulting in little chert gravel or coarse bed material.

TDOT region 4 covers primarily the Coastal Plain region in West Tennessee (fig. 2). Bottomlands in this region are composed of alluvium derived from loess. This material is highly erodible, and channels in this region degrade and widen, particularly after channelization (Robbins and Simon, 1983).

In the eastern part of TDOT region 4 (fig. 2), streams drain areas underlain by the Claiborne and Wilcox Formations of Tertiary age and the Cretaceous McNairy Sand (Miller and others, 1966). These geologic units are sources of sand and gravel for bed material. Recovery from channel degradation is more likely for streams that have headwaters in these units because underlying sand and gravel may be exposed and transported, probably arresting downstream degradation, but not channel widening. Degrading channels in this region that begin and end in loess or loess-derived alluvium lack coarse bed material and will probably undergo long-term degradation and channel widening.

METHODS OF CHANNEL AND BRIDGE SITE SCOUR ASSESSMENT

The following sections describe the methods used to conduct site inspections of channels near bridges and itemizes various applications of these data to scour assessment. Initially, site investigators collected the data on bridge scour assessment information forms designed specifically for this project. Data collected described the bridge site and the hydraulic, geomorphic, and vegetation characteristics of the channel, and the bridge structure.

Quality Assurance and Quality Control Procedures

Quality assurance and quality control ensure that where qualitative information forms the basis of decision, that information is generated by using the same decision process, thus resulting in uniform data. Where judgment is warranted, it is used in a consistent manner. Purvis (1991) summarized the origin of quality data when he wrote,

> "The diligence and perserverance necessary to be a good bridge inspector is not present in every individual. Inspection involves looking at hundreds of details before finding a serious problem. Close-up inspection of all critical details is necessary. The work is physically demanding and access is difficult. Bridge inspectors often work at remote locations without senior supervision, and the accuracy of their work cannot be measured directly. How can the unit manager determine if an inspector is maintaining the proper level of intensity***".

Figure 3. Western Highland Rim gravel-bed channel at Tumbling Creek, State Route 230, Humphreys County, Tennessee (photograph by Donald E. League, U.S. Geological Survey, 1993).

While Purvis specifies bridge inspectors, his quote applies fully to scour assessment inspectors. For quality assurance and quality control to be effective, the assessments must be uniformly conducted, and be consistent from site to site.

Quality-Assurance Review and Training

Quality assurance is a term used to describe programs and sets of procedures, including quality-control procedures, that are used to ensure data reliability. Quality assurance procedures were monitored by within-agency reviews, reviews from the TDOT and the FHWA, and a special Scour Project Workgroup composed of scour-project chiefs from outside Tennessee.

Training of project personnel was the first step in ensuring uniformity of data collection and in quality assurance. Each person associated with data collection, review, and editing was familiarized with the data-collection procedures and how to fill out site inspection forms properly. This familiarity with the data-collection procedures and forms ensured that at each step of data processing, the maximum amount of oversight could be achieved.

Initial site-assessment training was provided by the project chief. Classroom instruction was used to familiarize the participants with the data-collection form, the concepts behind the variables, the data-collection procedures and tools, the data base, and how to assess a site.

For field training, project personnel were guided through form completion at training sites.

After the form was completed at each training site, the group reviewed the form and discussed any problems they had encountered in completing the form and any differences in values they had noted on their forms. When project personnel adequately understood the data-collection concepts and were able to follow the procedures, each trainee was allowed to assess the training site as an individual. This practice continued until the trainee had clearly learned all of the concepts. At that time, the trainee was considered fully qualified to make site assessments without on-site supervision.

Office and field technique reviews were made to keep individuals from developing misconceptions about variables. Frequent interaction between field inspectors and the project chief during review of the data form provided the most direct and most positive type of feedback and training. If an inspector had not conducted field data collection for a month or more, the project chief reviewed the inspector's field techniques before certifying that person for field duty. Additionally, review of field techniques by personnel external to the project at least once a year would be beneficial.

Quality Control of Data Collection

Quality control is a term used to describe the routine procedures taken to make measurements and collect data of satisfactory quality. Quality control was monitored within the project by the project chief and inspectors through their review of the data.

Assignment of sites for assessment was made by the project chief to maximize travel efficiency and to utilize inspector experience. Assessment forms were completed on site, sketches were made, and photographs were taken as site documentation and for later use in data review.

Assessment forms were reviewed in the office by project staff other than the original inspector. Problems or unclear data were noted. The project chief or his appointee reviewed all assessment forms to determine if site revisits were needed and to determine whether conceptual discrepancies were developing.

After the data were confirmed through the office review, they were entered into a computer file. Preliminary data were verified through comparison between the original form and the computer file.

Each inspector's techniques were field reviewed as part of the ongoing training process. The best method of cross checking was to independently assess a site before the assigned inspector assessed it. The inspector was not informed that the site was being used for review purposes.

The project chief attended field assessments to observe field technique and to discuss perceptions. The presence of the project chief served as a supplement to the formal review and training, but not as a substitute for independent formal review. The project chief verified that assessment equipment was clean and calibrated.

Scour Assessment Information Form

The Tennessee scour assessment information form is divided into 16 numbered blocks (fig. 4). The word "crossing" as used in this explanation of the form refers to the channel reach from upstream to downstream right-of-way limit. The USGS convention for right or left bank is determined by facing downstream. In some specific instances, right- or left-hand side are used on the form rather than right or left bank.

The stream name in block 1 (fig. 4) was either supplied by TDOT or taken from an appropriate map. Consistent abbreviations (such as Cr for Creek, R for River, Br for Branch, Fk for Fork) were used. Multiple versions of an abbreviation can cause data sorting problems.

"Vicinity" (fig. 4, block 1) refers to the land-mark used for a general site locator. It was usually a town, but may have been designated in

Version 5-92 TENNESSEE SCOUR ASSESSMENT INFORMATION FORM

(1)Introduction: Date______ Stream________________ Vicinity________
Inspector________ Land use____ 1=urban 2=row crop 3=pasture 4=forest

(2)Location:Route______ County______ HighwayLog-mile____ TDOT region____ Bridge Number________
Total bridge length (149)____ Maximum span length (148)____
Channel protection (161)____ Waterway adequacy (171)____ Sufficiency rating (192)____
Number of overflow bridges: Left____ Right____

(3)Flow conditions: Site inspectable? ____ 0=no 1=yes.
Underclearance at thalweg ____ feet or 999 if >35 feet.
Depth of flow at thalweg ____ feet.
High flow angle of approach ____ degrees (+ = toward right bank, - = toward left bank).
Deflected flow ____, 0=no 1=yes; impact point ____ 1=left bank 2=right bank
Cause of deflection and affect on bridge crossing:

Capacity of bridge opening (qualitative), can the bridge handle all flow or is there some restriction for certain flow stages:

Capacity of channel (qualitative):

Observed High Water Marks (HWM) ____ feet above/below ________ (reference point)
Road overflow risk (qualitative):

Abbreviations appearing on form:
TDOT, Tennessee Department of Transportation; (149), Tennessee Department of Transportation code 149; >, greater than; LB, left bank; RB, right bank; Veg., vegetation; %, percent; U/S, upstream; D/S, downstream; B, bent; P, pier; Loc., location; lfp, left flood plain; ltb, left top bank; lb, left bank; mcl, main channel left; mcm, main channel middle; mcr, main channel right; rb, right bank; rtb, right top bank; rfp, right flood plain; N, no exposure; F, footing exposed or moderate amount of driven piling exposed; P, piling exposed or severe amount of driven piling exposed.

(4)Bank condition:

	Height from bed 1 LB	2 RB	Angle 1 LB	2 RB	Veg. cover(%) 1 LB	2 RB	Material 1 LB	2 RB	Erosion 1 LB	2 RB
1 U/S	__	__	__	__	__	__	__	__	__	__
2 D/S	__	__	__	__	__	__	__	__	__	__

Notes: Bank angle sketch with heights and angles. Vegetation type woody only, approximate age, species if recognized.
Material 1=silt/clay 2=sand 3=bedrock 4=gravel/cobble
Erosion 0=none 1=mass wasting 2=fluvial erosion

(5)Bed material characteristics: 1=sand, 2=silt/clay, 3=gravel, 4=cobble/boulder, 5=bedrock, 6= alluvium (if can't tell others)
Bed resistant to scouring flow? 0=no 1=yes
Estimated depth of gravel deposits ____ feet (enter 999 if not observed).

(6)Channel profile: 1 upstream; 1=pool 2=riffle 3=smooth.
2 downstream; 1=pool 2=riffle 3=smooth.

(7)Distance to upstream confluences if any: 0=no 1=yes.
____ feet 1= left bank entry, 2= right bank entry.
____ feet 1= left bank entry, 2= right bank entry.
____ feet 1= left bank entry, 2= right bank entry.

(8)Piers: To be listed from left to right. Stop after first flood plain pier.

				1 2 3 4 5 6 7 8 9 (circle appropriate choice below)	Local scour	Exposure
B__	P__	shape____	skew____	Loc:lfp, ltb, lb, mcl, mcm, mcr, rb, rtb, rfp	0 1 2	N F P
B__	P__	shape____	skew____	Loc:lfp, ltb, lb, mcl, mcm, mcr, rb, rtb, rfp	0 1 2	N F P
B__	P__	shape____	skew____	Loc:lfp, ltb, lb, mcl, mcm, mcr, rb, rtb, rfp	0 1 2	N F P
B__	P__	shape____	skew____	Loc:lfp, ltb, lb, mcl, mcm, mcr, rb, rtb, rfp	0 1 2	N F P
B__	P__	shape____	skew____	Loc:lfp, ltb, lb, mcl, mcm, mcr, rb, rtb, rfp	0 1 2	N F P
B__	P__	shape____	skew____	Loc:lfp, ltb, lb, mcl, mcm, mcr, rb, rtb, rfp	0 1 2	N F P
B__	P__	shape____	skew____	Loc:lfp, ltb, lb, mcl, mcm, mcr, rb, rtb, rfp	0 1 2	N F P
B__	P__	shape____	skew____	Loc:lfp, ltb, lb, mcl, mcm, mcr, rb, rtb, rfp	0 1 2	N F P
B__	P__	shape____	skew____	Loc:lfp, ltb, lb, mcl, mcm, mcr, rb, rtb, rfp	0 1 2	N F P

Notes: B = Bent, P = Pier; check only applicable blank.
Shape is a standard: 1 = squared 2 = rounded 3 = pointed
4 = square piles 5 = round piles 6 = pointed piles
Skew will be based on high flow alignment: + = skew to right, - = skew to left.
Local scour; 0 = none 1 = observed 2 = undefinable, N = no exposure, F = footing exposed or moderate amount of driven piling, P = piling exposed or severe amount of driven piling.

Figure 4. Tennessee scour assessment information form.

1 2 3=exposed piles
(9)Abutment:1= left; skew____ Location: 0, +____feet, -____feet, sloping or vertical. 1=yes 0=no
2=right;skew____ Location: 0, +____feet, -____feet, sloping or vertical. 1=yes 0=no
Notes: Skew will be measured for high flow conditions; + = right skew, - = left skew.
Location: + indicates the abutment is set back from the bank. - indicates the abutment sits out into the stream. 0 indicates the abutment is even with the bank.

(10)Debris accumulation: percentage of opening blocked: horizontal ____ to ____ percent,
vertical ____ to ____percent.
Type and size: ____ 1 = brush 2 = whole trees 3 = trash 4 = all of others.
Potential for debris production (qualitative):

Obstructions (describe):

Note: Left bank to right bank. 0 percent = left bank, 100 percent = right bank.
Bed to top of bank. 0 percent to 100 percent.
Take pictures, make notes.

(11)Channel protection on:
1= upstream right bank; 0=abaent 1=present, 2=good condition, 3=weathered to size smaller, 4=slumped.
2= upstream left bank; 0=absent 1=present, 2=good condition, 3=weathered to size smaller, 4=slumped.
3= At right bank; 0=absent 1=present, 2=good condition, 3=weathered to size smaller, 4=slumped.
4= At left bank; 0=absent 1=present, 2=good condition, 3=weathered to size smaller, 4=slumped.
5= downstream right bank; 0=absent 1=present, 2=good condition, 3=weathered to size smaller, 4=slumped.
6= downstream left bank; 0=absent 1=present, 2=good condition, 3=weathered to size smaller, 4=slumped.
Type and size (qualitative):

If slumped, where and why:

7= bed; 0=absent 1=present, 2=good condition, 3=weathered to size smaller, 4=moved.
Type and size (qualitative):

If moved, to what extent?

8= right abutment; 0=absent 1=present, 2=good condition, 3=weathered to size smaller 4=slumped.
9= left abutment; 0=absent 1=present 2=good condition, 3=weathered to size smaller 4=slumped.
Type and size (qualitative):

If slumped, where and why:

(12)Channel width: upstream____, at____, downstream____;
blowhole ____ 0 = no, 1 = yes, ____ feet downstream (bridge to middle of blowhole)
____ feet wide (top of bank to top of bank), ____ feet long.

(13)Meander characteristic in vicinity of bridge (impact points):

	1 Low flow		2 High flow	
	straight 0=no 1=yes		straight 0=no 1=yes	
	1=left bank	2=right bank	1=left bank	2=right bank
upstream (feet)	____	____	____	____
downstream (feet)	____	____	____	____
Meander wavelength	____ feet		____ feet	

Note: Entry will be left bank or right bank and distance from bridge. 0 = impact at bridge.

(14)Point bar location: ____ 0=absent 1=present, ____ to ____percent (0 percent = left bank, 100 percent = right bank)
Distance to mid-bar upstream (+)____feet or downstream (-)____feet.
Width at mid bar ____ feet.

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

(16)Stage of reach evolution: 1 = undisturbed, 2 = constructed, 3 = degradational,
4 = degradation with channel widening, 5 = aggradation or stable, with channel widening,
6 = restabilized.

Figure 4. Tennessee scour assessment information form.--Continued

other ways. The locator should be shown on readily available county or topographic maps.

"Inspector" (fig. 4, block 1) refers to the person who inspected the site or who was the party leader where more than one person participated in a site assessment. In order that the identity of the inspector be recognizable, initials with full last names were used.

"Land use" (fig. 4, block 1) refers to the general area around the site and was based on the inspector's experience in the area or his observations of the area when approaching the site. When assessing the data base by listing multiple sites on the same stream or within the same drainage network, the data user should be able to form an opinion about how land use varies within a geographic area of interest.

Items in the "Location" block (fig. 4, block 2) allow the interfacing of these data with other systems, either for data merging, manipulation, or mapping. Each Department of Transportation (DOT), State or Federal, has a bridge inventory system that uses a codified bridge identifier. By using the DOT identifier the USGS and DOT data bases will be directly comparable. The items listed in this section with a code I__ (for example, I49) were included at the request of the TDOT.

"Number of overflow bridges" (fig. 4, block 2) addresses the presence of relief openings. Entries in this block indicate that bridges are in place specifically for overflow relief. Small bridges built over a creek are not considered overflow bridges, even though a larger river might use the same bridge at flood flow.

In block 3 (fig. 4), the question is posed, "site inspectable?" This question refers to the ability of the inspector to see enough of the site (banks, vegetation, and so forth) to complete the assessment form with meaningful data. An important notation is whether the stream is in flood stage, whether backwater from a downstream cause is observed, or whether the stream is at some lower stage. Each inspector attempted to obtain the most extensive view of the channel possible. If the inspector could not see the channel banks, effective assessment of the site was not possible. If the channel was bankfull at low-flow conditions, this was the optimum condition and was used. Water level in the channel was noted on the form as a comment.

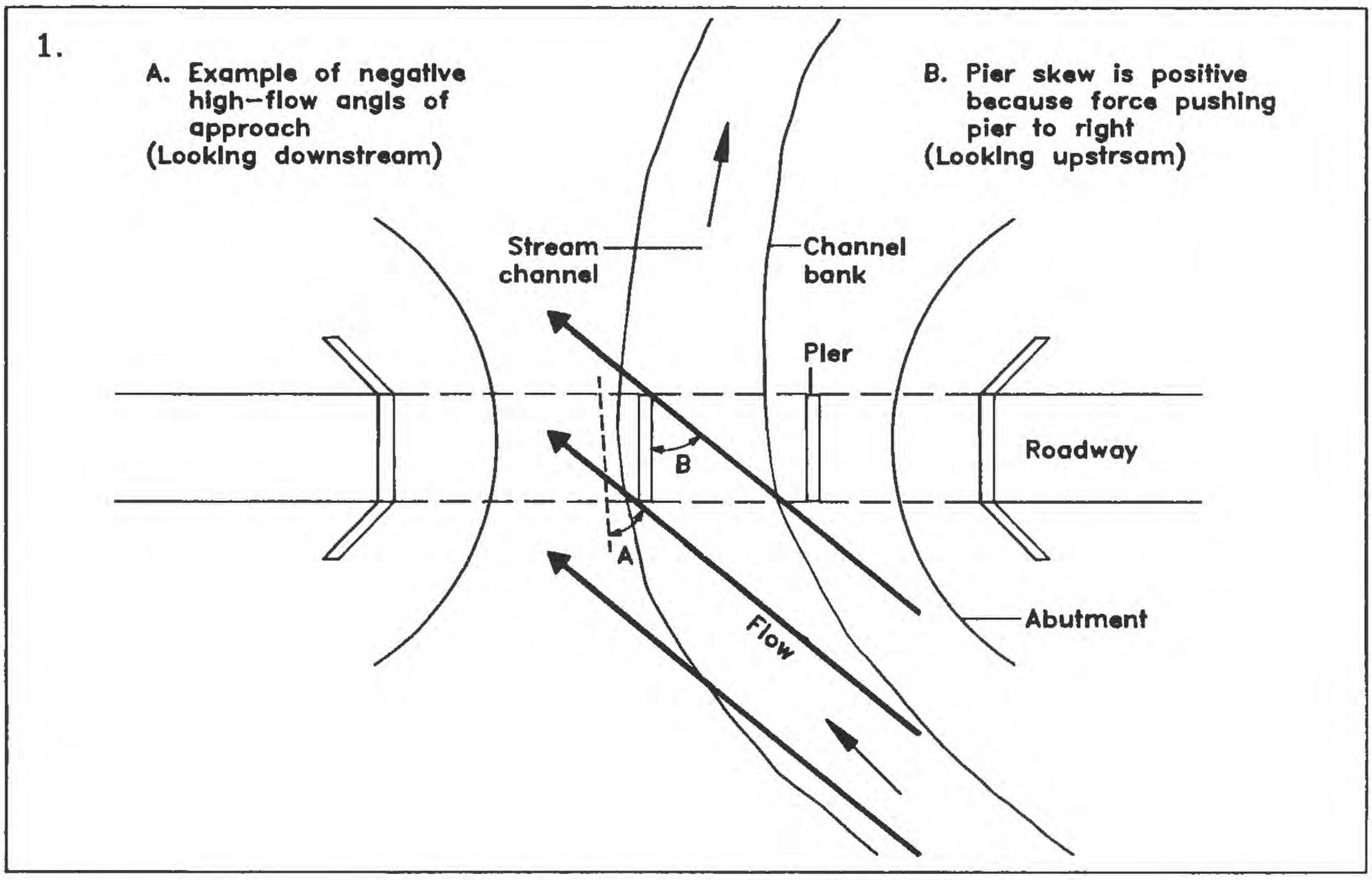
"Underclearance at thalweg" (fig. 4, block 3) refers to the maximum clearance between bridge understructure and water surface. This information gives data users some idea of the probability of pressure flow and concomitant scour. For bridges that are not level or are arched, an additional measurement from water surface to first low beam contact point should be listed on the form as a comment.

"Depth of flow at the thalweg" (fig. 4, block 3) was the depth in the thalweg at time of assessment. For culverts with floors, the depth was measured from the floor of the culvert or any material overlaying the floor, not from the natural bed outside the culvert.

"High-flow angle of approach" (fig. 4, block 3) refers to flow and bank alignment (fig. 5), not to flow and bridge alignment. The inspector should imagine the site at approximately bankfull flow. For a swamp-type setting, the inspector should imagine the flow approaching the structure as it would when flowing through the wide area of swamp upstream. Information pertaining to this item may help data users determine how flow may affect the crossing and thereby affect the bridge. Determination of high-flow angle of approach at low-water levels was made based on observation of debris piling, bank scouring, and any other at-site features available (fig. 6). Undercut vegetation (fig. 6) not only provided evidence of high-flow impact, but can be used to date and estimate the rate of bank retreat.

"Deflected flow" (fig. 4, block 3) was included to document any irregular channel obstruction such as cars, pipelines, or large quantities of trash that may be affecting the crossing. Deflected flow is usually upstream, but could possibly be downstream. "Impact point" (fig. 4, block 3) refers to which bank the deflected flow was affecting.

"Capacity of bridge opening" and "capacity of channel" (fig. 4, block 3) are qualitative and



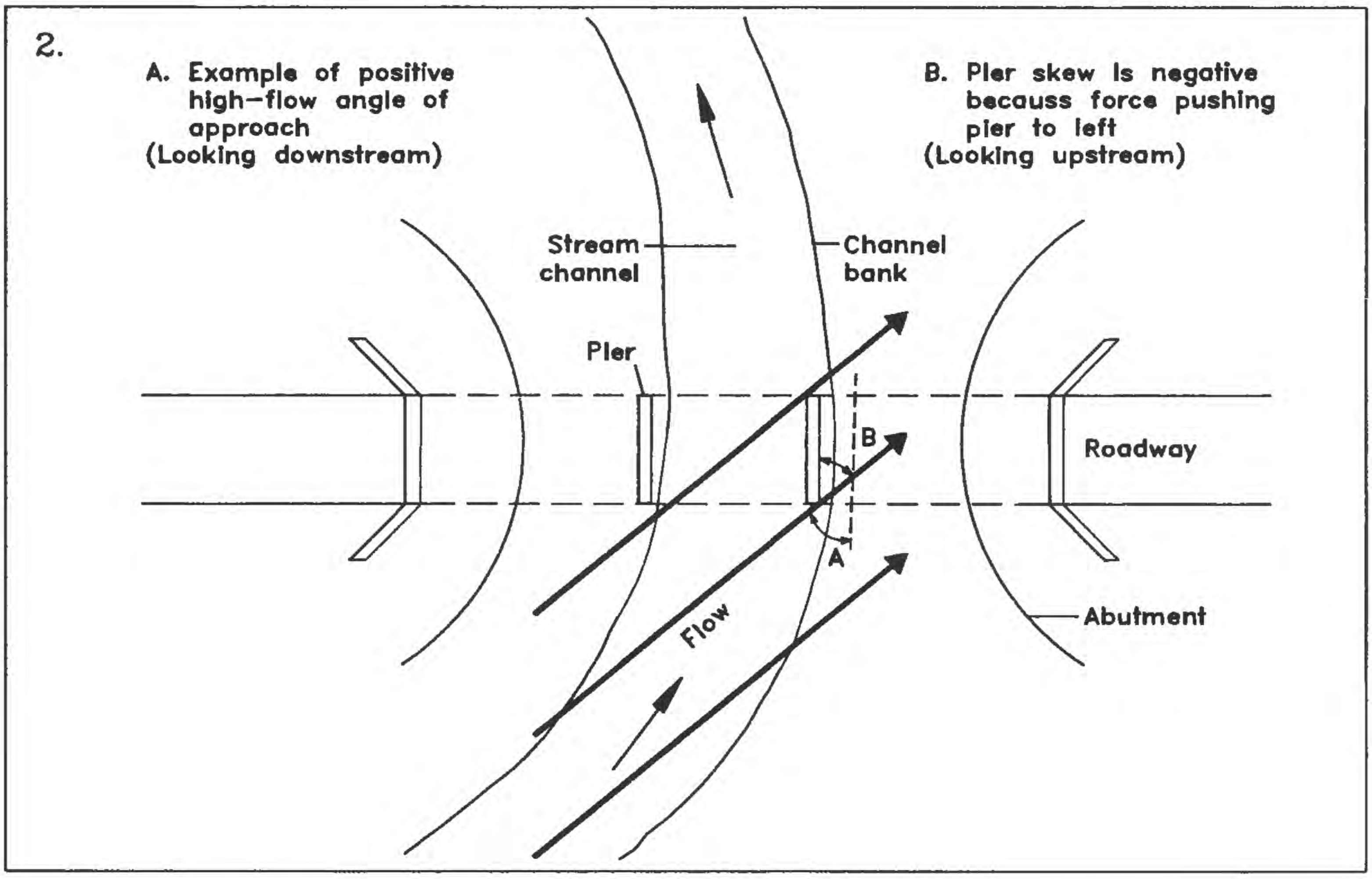


Figure 5. Examples of (1) negative high-flow angle of approach and positive pier and abutment skew, and (2) positive high-flow angle of approach and negative pier and abutment skew.

Figure 6. High-flow impact point at Little Swan Creek, State Route 15 bridge, Lincoln County, Tennessee (photograph by Donald E. League, U.S. Geological Survey, 1993).

were based on the inspector's knowledge of the area hydrology, and on evidence seen in the area. By noting "observed high-water marks" (fig. 4, block 3), the inspector begins to solidify thinking about the hydrology of the area and also about potential storm-event effects on the crossing. High-water marks also may provide data for other TDOT activities, such as bridge replacement design at that site or on the same stream.

"Road overflow risk" (fig. 4, block 3) is qualitative and was included for the benefit of the TDOT. This term referred to road approach, if that was the low spot, or to the bridge, if that was the low spot.

"Bank conditions" (fig. 4, block 4) near a bridge affect the banks and the channel bed under the structure. Stable banks upstream and downstream can indicate that problems at the crossing are site specific, and not related to system-wide response (for example, fig. 7). Certain bank conditions, such as high, steep banks, are more likely to fail by mass wasting and are generally indicative of rapidly occurring bank-forming processes.

"Veg(etation) cover" (fig. 4, block 4) can be an indicator of the overall condition or stability of channel banks. Percent (of vegetation) cover was determined based on the amount of woody plant crown cover. Large numbers of small woody plants may have crown closure, and a high percent of vegetation coverage. Sparser distribution of older trees may have crown closure and also receive a high percent of vegetation coverage. Low amounts of woody plant coverage may indicate mass wasting, frequent

Figure 7. Stable banks along a bedrock channel at Johnson Creek, State Route 48, Dickson County, Tennessee (photograph by Donald E. League, U.S. Geological Survey, 1993).

scouring flows, or that the property owner keeps the stream banks cleared.

"(Bank) Material" (fig. 4, block 4) is important in determining what type of erosion may take place. Silt or clay banks are susceptible to either fluvial erosion or mass wasting. Sand and gravel banks may be susceptible to rapid fluvial erosion. Fluvial erosion is a particle-by-particle action that may result in a lip at bank top composed of plant roots. When the plants are sufficiently undermined, they may fall in a mass. This is not mass wasting. Mass wasting of the bank occurs when the soil strength parameters are exceeded, resulting in a mass of the bank material being detached. Bank failure may appear as a slab, a wedge, a rotated mass, or a composite of types. The observed process is important in determining the overall character of the site and the nature of forces that may come to bear on the bridge unexpectedly.

"Bed material characteristics" (fig. 4, block 5) are basic to scour susceptibility. Sand and gravel beds are highly susceptible to local scour. Bed-rock beds may not scour, but extreme flows in a bedrock channel may cause excessive channel widening that can affect the bridge. Special regional characteristics of bed materials may need to be listed on the assessment form.

The question, "Bed resistant to scouring flow?" is asked in block 5, figure 4. A judgment in regard to resistance to bed-material movement and, therefore, resistance to scour was made by the inspector in order to answer this question. If the bed material was deemed immovable during most flow events, it was considered resistant. If the inspector observed that most flood flows could move the majority of the surficial bed material, it was not considered resistant. Depth, velocity, and turbulence combine to create shear forces that cause bed-material movement.

The "estimated depth of gravel deposits" (fig. 4, block 5) block was completed only when a cohesive bottom was observed underneath non-cohesive deposits. If the deposit (sand or gravel, usually) is deep, scour may proceed vertically. If the deposit is shallow, scour may go to the bottom of the deposit and then act horizontally. If the deposit is shallow over a silt or clay bed, bed degradation may occur.

"Channel profile" (fig. 4, block 6) defines how the energy grade line may be expected to act during flood flow. Pool and riffle profile is a common combination with an energy grade line indicative of scour and deposition. A smooth profile indicates a generally stable energy grade line and, thus, a more uniform bed-material transport capability.

The "distance to upstream confluence" (fig. 4, block 7) documents the possibility of flow or sediment contribution from a tributary near the bridge crossing affecting flow patterns and scour through the structure. Road drains may affect the bridge and, therefore, should be noted.

For this report, the flood-plain support (pier or bent) closest to each side of the main channel and the main channel supports were documented along with their shape, skew, and location. Piers ("P") and bents ("B") (fig. 4, block 8) are differentiated. The methodology and approach assumed that piers have footings and bents do not, because bents are driven piles. "Shape" (fig. 4, block 8) has an effect on turbulence; the less streamlined, the greater the effect. "Skew" refers to pier and flow alignment (fig. 5), not to pier and bridge deck alignment. Skew pertains to creation of turbulence. "Loc" (location) (fig. 4, block 8) indicates the general placement of the pier or bent in the channel (fig. 8).

"Local scour" and "Exposure" (fig. 4, block 8) are used in computing scour indexes. For local scour, if "2 = undefinable" is chosen, an appropriate warning is to be appended to that data. For "Exposure," bents are ranked as 0 = "N" (none), 1 = "F" (some scour), 2 = "P" (apparently serious scour), depending on how much of the piling has been exposed. The inspector cannot know how much of the piling was left exposed at the end of bridge construction, so this entry was dependent on the inspector's experience with channel degradation and bridge construction. If the channel had degraded moderately, an assumption is made that piling exposure (1 = "F," some scour) has occurred, and if the channel has degraded severely, then severe piling exposure (2 = "P," severe or serious exposure) has occurred.

"Abutment" skew (fig. 5; fig. 4, block 9) refers to abutment and flow alignment, not skew to bridge deck. "Loc(ation)" (fig. 4, block 9), in regard to channel bank, provides information on how soon bank erosion may affect the abutment. Distance is measured to the abutment slope toe, unless the abutment makes up the channel bank in which case distance is 0 foot.

"Debris accumulation" (fig. 4, block 10) provides information that may relate to upstream channel stability and also to the trapping efficiency of the specific structure. By specifying percent of horizontal and vertical blockage, the total blockage can be computed and the location of blockage can be specified (fig. 9). The computation programs in use now (1993) do not identify separate debris stacks. The percent of opening blocked is an integration of all debris at the bridge. This value is based on the conveying opening and the low steel of the bridge.

"Type and size" (fig. 4, block 10) of debris were considered indicative of channel-forming processes occurring upstream. Large accumulations of trees or parts thereof may indicate extensive channel widening upstream and also indicate that debris accumulations may be expected to occur during all significant flow events. That is, the normal in-channel debris accumulation and flushing process no longer is in effect.

"Potential for debris production" (fig. 4, block 10) refers to how much debris the bridge site might generate in the near term. The debris in question is composed of brush and tree trunks and is generated by bank erosion and sometimes agricultural practices (clearing, plowing up to the bank, and so forth). The entry is qualitative and

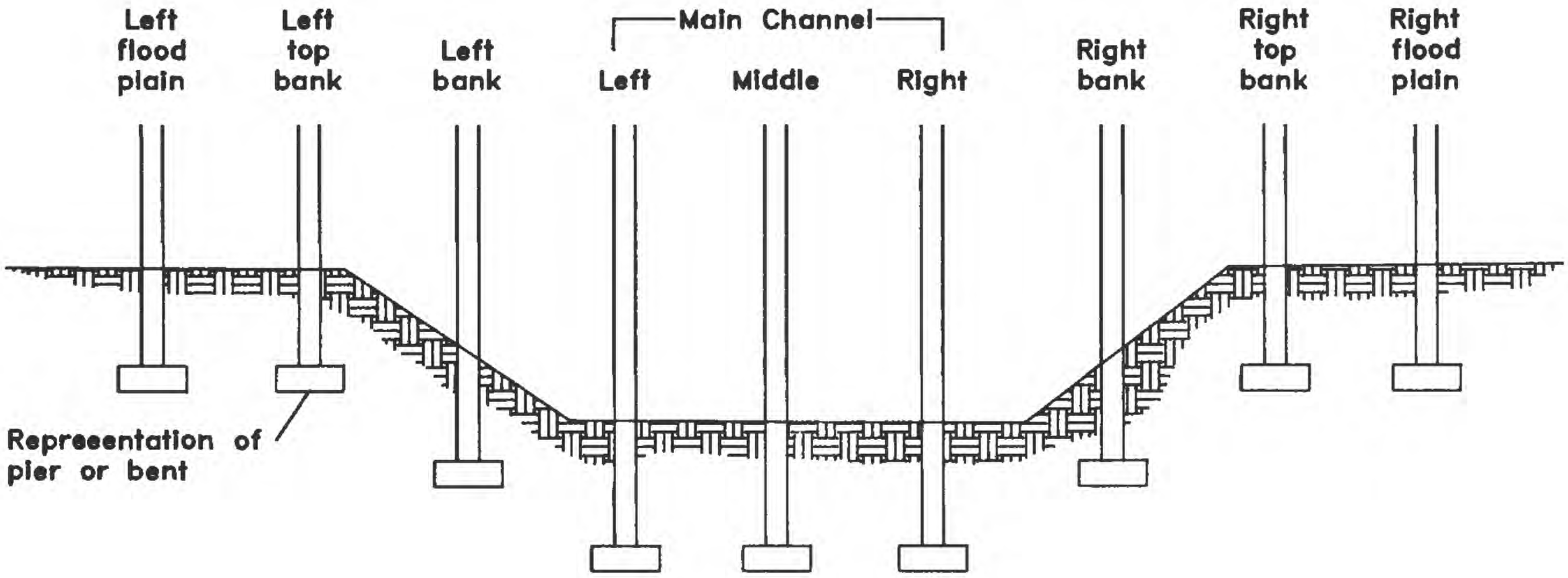


Figure 8. Placement of pier or bent in relation to flood plain and main channel.

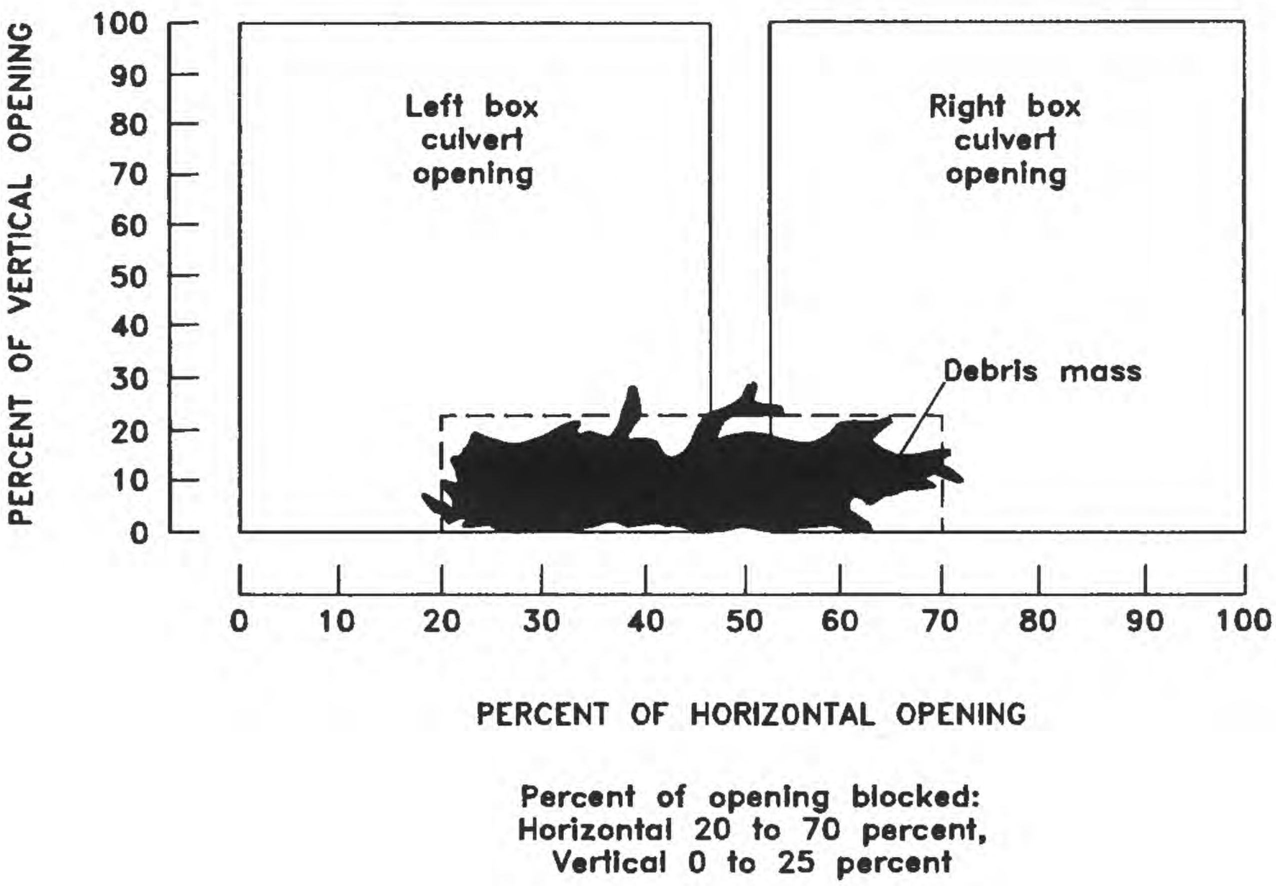


Figure 9. Typical box culvert as seen from directly upstream, showing percent opening blocked by debris.

is based on field experience, an understanding of erosion processes, the normal appearance of vegetation at streamside, and the condition of the banks at the bridge site as described in the assessment form. A rating of high, medium, or low was recorded, along with a short rationale. "Obstructions" (fig. 4, block 10) are objects that may be causing problems at the bridge site. They may be contributing to the reason the flow is deflected. Pipelines, abandoned automobiles, and livestock fencing are common obstructions.

"Channel protection" (fig. 4, block 11), for this report, refers to material that humans have placed in the stream on purpose or by default (old bridge deck left where it fell). Bedrock and boulder bank material are not human placed channel protection. When considering location of the channel protection, the highway right-of-way is a general boundary. If the material goes beyond the highway right-of-way, consider the channel protected upstream or downstream, respectively. "At" (fig. 4, block 11) refers to the bank at the bridge. Material wrapping an abutment is still "At" the bridge. "U/S" (upstream) and "D/S" (downstream) refer to the side of the bridge on which the material is observed, not to distance away from the bridge. Guide banks set back into the flood plain are not channel protection, nor are they abutment protection. The "type and size" of material entry (fig. 4, block 11) is important because that material indicates the scale of flow energy needed to move it.

"Channel width" (fig. 4, block 12) data are used in describing channel constriction at the bridge. Channel crossings with contracted bridge openings can create overwidened sections just downstream of the bridge opening referred to as "blowholes" (fig. 10). A "blowhole" can easily expand upstream to threaten the abutments. "Channel width" upstream and downstream are the normal channel width. "Channel width" at the structure is measured under the structure. For the case of box culverts, the width is the active channel in the culvert or the combined width of the barrels, if all barrels form the channel.

"Meander characteristic in the vicinity of the bridge" (fig. 4, block 13) is a different consideration than "high flow angle of approach" (discussed in block 3). They can correspond, but do not always. Meanders need to be evaluated because they move over time. Notes in this section of the assessment form may indicate that a meander impact point is moving into the crossing or that one is there already. A meander impact point at a crossing can result in bank undercutting and either mass wasting or rapid fluvial erosion and endangerment of the bridge (fig. 11).

"Meander wavelength" (fig. 4, block 13) as used in this report is a local phenomenon, not an overall consideration made after review of an extensive river reach. Meander wavelength is the distance from peak to peak in the wave described by the sinuousity of a channel and will probably be different for high and low flow.

"Point bar location" (fig. 4, block 14) provides data for assessing changing hydraulics near the crossing. As point or in-channel bars build, the thalweg shifts and bank cutting or erosion proceeds. The location of a bar dictates how much affect the bar will have on flow and thereby the crossing and structure.

An "alluvial fan in the vicinity of bridge" (fig. 4, block 15) indicates that an enormous amount of bed material is within transport range of the structure. This ready source of bed material could conceivably be mobilized and redeposited at the bridge. Conversely, if downstream movement of this material is interrupted, downstream bed degradation could occur.

"Stage of reach evolution" (fig. 4, block 16), as developed by Simon and Hupp (1986) for West Tennessee streams, is based on state of stability and thereby stage of evolution (table 2). This entry is based on the information previously listed by the inspector. The inspector should be able to categorize the site with one of the six stages of evolution (table 2).

Bridge Scour Data System

The Bridge Scour Data System (BSDS), located on the USGS Tennessee computer

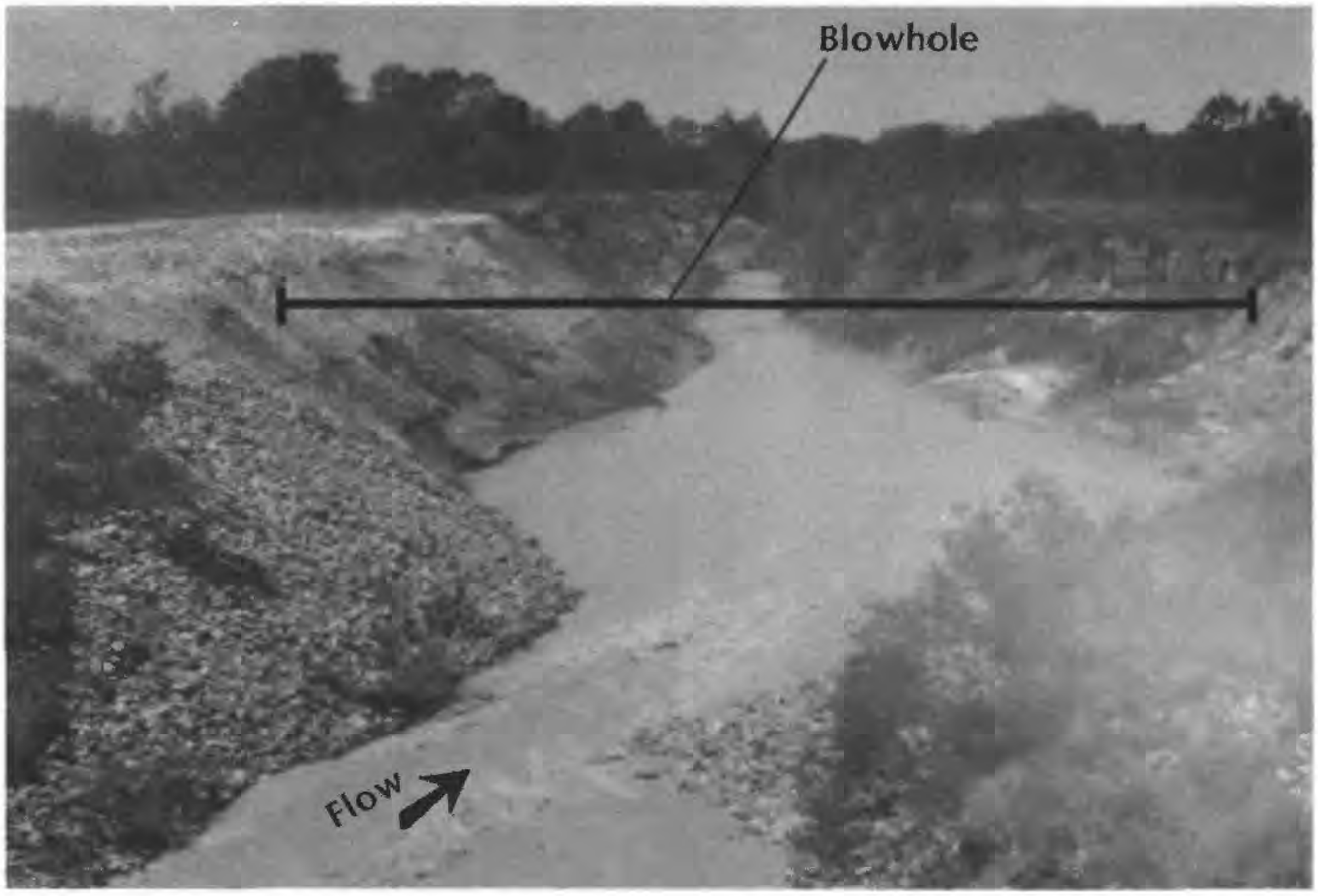


Figure 10. Blowhole formed by flow expansion at Cane Creek, Route A048, Lauderdale County, Tennessee (photograph by Bradley A. Bryan, U.S. Geological Survey, 1992).

A.

B.

Figure 11. Meander impact points: (A) Impact point is moving toward the bridge, and (B) impact point is undercutting a hillside (photographs by Donald E. League, U.S. Geological Survey, 1992).

Table 2. Stages of channel evolution

[No., stage of evolution number; —, not applicable to that dominant process; Modified from Simon and Hupp, 1986]

Stage		Dominant processes		Characteristic forms	Geobotanical evidence
No.	Name	Fluvial	Hillslope		
1	Undisturbed	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
2	Constructed	—	—	Trspezoidal cross section; linear bank surfaces; flow line lower relative to top bank.	Removal of vegetation
3	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.
4	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 bank; some reduction in bank angles; flow line low relative to top bank.	Tilted and fallen riparian vegetation.
5	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.
6	Restabilization	Aggradation; further development of meandering thalweg; further deposition of alternate bars; reworking of failed material; some basal erosion on outaide bends; deposition on flood plain and bank surfaces.	Low-angle slides; some pop-out failures near flow-line.	Stable, alternative 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.

system, was created to store and manipulate the data obtained from field assessments at bridge sites. The data base was designed to have the on-screen data entry form as similar as possible to the field assessment form, for data entry by several personnel simultaneously, for data manipulation for calculations and reports, and for ease of use with a geographic information system (GIS).

Statewide, 3,964 bridge sites have been assessed and included in the BSDS (table 1). This data system includes 2,852 sites from phase 1 (table 1), 656 sites from phase 2, and 456 sites from phase 3.

The BSDS consists of a main data base located in a user file directory, a subdirectory for transfer of data from user input directories to the main data base, and user input data bases located as subdirectories of each user. Input templates were created to allow addition and update of data from a terminal. Once data have been entered and checked at the user input level, they are transferred to a holding directory from which the data base administrator adds the data to the main data base. When the data are entered into the main data base, a program computes and stores potential- and observed-scour indexes for each site. Reports of various types can be produced and GIS maps generated directly from information stored in the data base. Summary reports can be produced for any combination of variables stored in the data base. These reports can be checked and possible data interactions assessed. Data can be sorted by county, stream, State route, region, or by other criteria. This data sorting capability allows for the efficient assessment of a large number of bridge sites or a specific geographic area. TDOT has used the BSDS to choose bridge sites for scheduling scour prevention, maintenance, and repair.

Underwater inspection results were supplied by TDOT as available. Underwater data related to scour were entered into the BSDS and used in the assessment computations.

Observed-Scour Index

The qualitative observations of scour at a bridge site were converted to a quantitative index by summing the ranking values assigned to specific site characteristics (table 3). At some sites documentation of observed pier, bent, or abutment scour was impossible. In such instances, a warning was appended to the data.

When used in conjunction with the potential-scour index (table 4), the observed-scour index is useful for identifying sites where more detailed analysis is needed. A more quantitative evaluation, as explained by Richardson and others (1991), requires inspection of the channel bed (both surface and subsurface) and documentation of changes at the site based on bridge plans.

The observed-scour index is a summation of all values for the following six categories: (1) pier and abutment scour, (2) left and right abutments, (3) slumped bank protection, (4) moved bed protection, (5) blowhole presence, and (6) mass wasting of a bank with a pier or bent. Pier and abutment scour (table 3; fig. 12) can be observed if the water level is sufficiently low or the water is sufficiently clear. Values are summed for each pier or bent, and for left and right abutments. The presence of slumped bank protection or moved bed protection indicates bank undercutting, or excessive velocities (table 3; fig. 12). When present, a blowhole has the capability to expand and damage the bridge (table 3; fig. 10 and 12); for this index, a blowhole has been given a value of 3. Mass wasting of a bank with one or more piers or bents has the potential to destabilize those piers or bents (table 3; fig. 12); for this index, mass wasting has been given a value of 3.

Potential-Scour Index

The potential-scour index value for a particular site is the sum of the ranking values assigned to specified variables from the site

Table 3. Variables, diagnostic characteristics, and assigned values for calculation of observed-scour index for streams in Tennessee

[Observed-scour index equals sum of assigned values]

Pier and abutment scour (local; sum for all)

Scour at each pier:	None	Observed	Footing exposed	Piling exposed
	0	1	2	3

Scour at each bent:	None	Observed	Moderate	Severe
	0	1	2	3

Piling exposed at:	Left abutment	Right abutment
	1	1

Slumped bank rip-rap at bridge (sum of both values)

Left bank		Right bank	
yes	no	yes	no
1	0	1	0

Bed rip-rap moved?		Blowhole observed?	
yes	no	yes	no
1	0	3	0

Mass wasting at bank with pier (calculated for each pier)

yes	no
3	0

(table 4). Variables were chosen based on reoccurring observed effect at channel crossings.

In the potential scour index, the assigned value for the first variable, bed material (table 4), is a function of relative erodibility and bed recoverability following high flow. Bedrock as bed material generally will not scour, nor is it generally susceptible to channel degradation. Therefore, it is assigned a low index value. Exceptions do occur in weakly consolidated or highly weathered rock, but the rate that head-cutting progresses in bedrock is usually slow and, therefore, easily detected before dangerous or destabilizing conditions develop.

Transport or scouring of bed material made up of individual grains is a factor of particle size

Table 4. Variables, diagnostic characteristics, and assigned values for calculation of potential-scour index for streams in Tennessee

[>, greater than; potential-scour index equals sum of assigned values]

Bed material

Bedrock	Boulder/ cobble	Gravel	Sand	Unknown alluvium	Silt/ clay
0	1	2	3	3.5	4

Bed Protection

Yes	No	(with)	1 bank	2 banks protected
0	1		2	3

Stage of channel evolution

Stage	1	2	3	4	5	6
Index value	0	1	2	4	3	0

Percent of channel constriction

Constriction	0-5	6-25	26-50	51-75	76-100
Index value	0	1	2	3	4

Number of piers in channel

Number of piers	0	1-2	>2
Index value	0	1	2

Percent of blockage: Horizontal (6), Vertical (7), total (8)

Blockage, in percent	0-5	6-25	26-50	51-75	76-100
Index value	0	1	2	3	4

(Values to be divided by 3 to compensate for inclusion of three items on same topic)

Bank erosion for each bank

Erosion type:	None	Fluvial	Mass-wasting
Index value	0	1	2

Meander impact point, distance from bridge (in feet)

Distance	0-25	26-50	51-100	>100
Index value	3	2	1	0

Presence of pier skew (sum for all piers in channel)

Yes	No
1	0

Mass wasting of bank with pier (calculated for each bank)

Yes	No
3	0

High-flow angle of approach (in degrees)

Angle	0-10	11-25	26-40	41-60	61-90
Index value	0	1	2	2.5	3

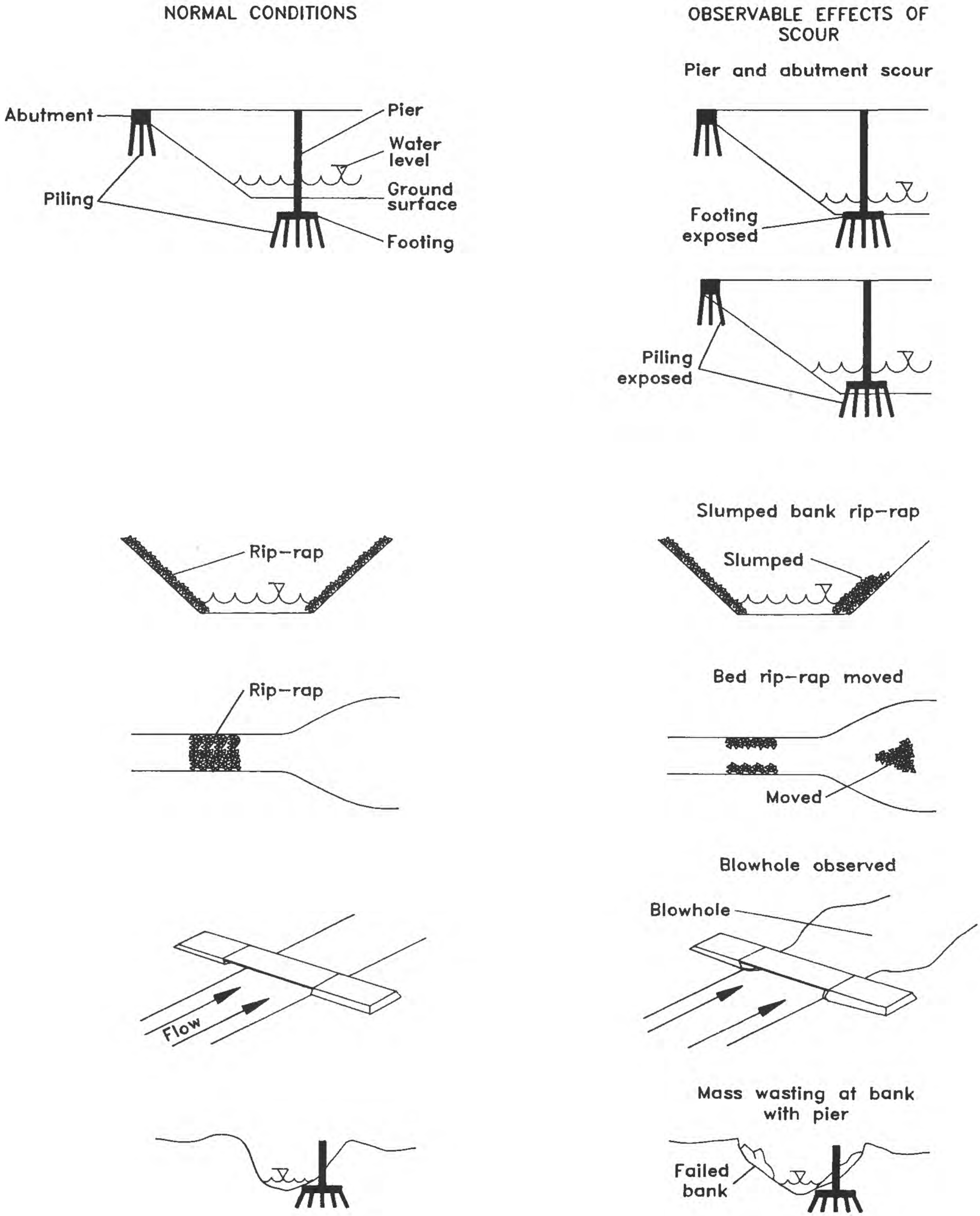


Figure 12. Observable effects of scour at bridges used in the observed-scour index.

and shape. Boulder and cobble type bed material (table 4) is subject to transport under high gradient or high boundary shear conditions, but much less so than smaller particle-size materials. Gravel and sand bed material (table 4) is highly susceptible to scouring flow, even when the shape allows for tight packing. Material removed by contraction or local scour is often replaced as the flood flow receeds. However, the newly placed material does not provide support; it provides a cushion or buffer between footings and pilings and the next scouring flow.

If bed material type cannot be specifically determined, the bed material is labeled "unknown alluvium" (table 4) and is given a high value to be conservative on the side of safety. This category describes locations where the channel bed is unreachable during inspection.

Silt and clay beds (table 4) are highly susceptible to channel degradation, a major component of scour assessment and evaluation. Silt and clay beds are given the highest scour susceptibility ranking because no transportable material is available with which to refill the scour hole or excavation.

Bed protection location (table 4) deters scour and is ranked accordingly . Ranking values for this category increase for no bed protection, and increase further for no bed protection when bank protection is present (fig. 13). This increase in ranking is justified on the basis that excess stream energy that cannot be dissipated through lateral erosion tends to erode the channel bed.

Assigned values for stage of channel evolution (table 4) reflect the shifting dominance of channel-forming processes. Stage 4 (table 2; fig. 14) is assigned the highest value because both bed degradation and channel widening are dominant channel-forming processes.

Percent of channel constriction (table 4) refers to differnces in channel width, and therefore conveyance, upstream and at the bridge. Contraction scour occurs as a result of flow acceleration caused by the channel constriction; therefore, as constriction increases, the assigned value increases. Scour resulting from channel constriction at floored culverts often exposes the downstream sill and undermines the abutment wall or wing wall (fig. 15).

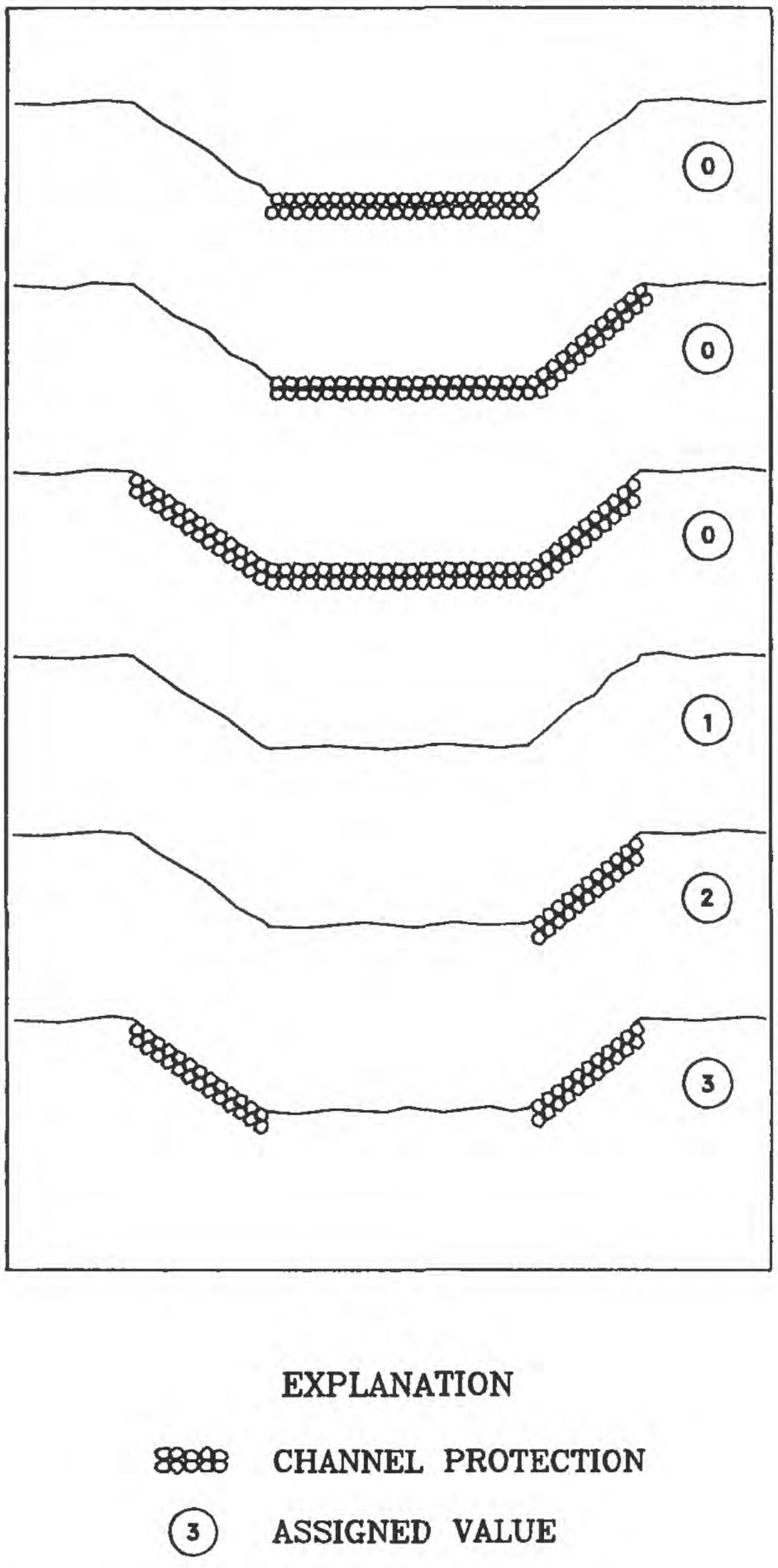
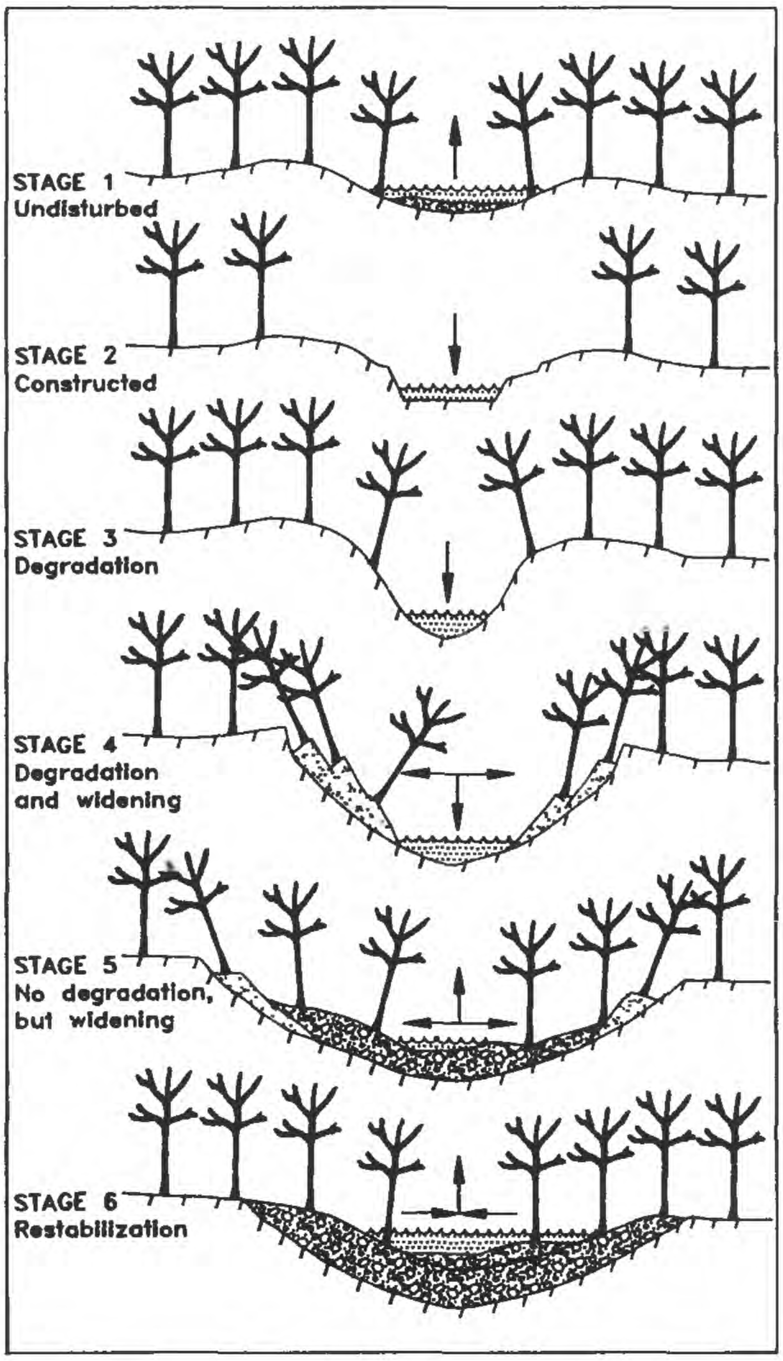


Figure 13. Cross sections of a hypothetical channel showing several combinations of bed and bank protection and the corresponding assigned values for calculation of potential-scour index.



EXPLANATION

WATER

SLUMPED MATERIAL

ACCRETED MATERIAL

DIRECTION OF BANK
OR BED MOVEMENT

Figure 14. Representative conditions for the six stages of channel evolution. (Modified from Simon and Hupp, 1987.)

The number of piers in the channel (table 4) represents the number of sites of potential local scour. As the number of piers in the flow zone increases, the potential for local scour increases, as does the potential for structural problems.

Channel blockage caused by debris accumulation on the upstream side of bridge openings may cause flow constriction or flow deflection. Like percent of channel constriction (table 4), assigned values of channel blockage increase with the percent of blockage (table 4; fig. 9). In order that horizontal, vertical, and total blockage caused by debris accumulation are not over emphasized, each assigned value is divided by 3.

Bank erosion may undermine bridge substructures not meant to be exposed to flow. The rate of bank erosion determines how quickly bridge substructures will be affected. The variable, bank erosion for each bank (table 4) is assigned a value according to degree of severity.

The proximity of a meander impact point to a pier or abutment can also result in undermining of the bridge structure. Assigned values for meander impact point (table 4), therefore, increase with decreasing distance from the bridge. Meander impact causes channel shifting. Upstream flow patterns, well out of the bridge zone, can affect the establishment of meander impact points (fig. 11). Therefore, if an upstream flow impact pattern is observable, it is documented.

Pier skew-to-flow has long been recognized as a cause of local scour. The presence of pier skew (table 4; fig. 5), not the skewness itself, is included in the calculation and the value is summed for each pier in the main channel that is skewed to the flow. Skew also is linked to debris trapping potential, and is probably more serious for multiple column piers or pile bents. Multiple column piers and bents create a greater potential to trap long debris, such as tree trunks, providing not only a starting point for further debris accumulation, but also increasing the potential for local scour due to flow diving under the debris mass.

Mass wasting of the banks near a pier (table 3 and 4; fig. 12) can lead to failure of the pier.

Figure 15. Example of downstream sill exposure due to flow expansion on downstream side of a floored culvert at Indian Creek, Route 1779, Humphreys County, Tennessee (photograph by Donald E. League, U.S. Geological Survey, 1992).

Mass wasting of banks is assigned a high index value (3).

The high-flow angle of approach (table 4, fig. 5) to the bank may indicate potential for scour on a particular side of the channel, potential for in-channel bar formation, or an increased likelihood of the undermining of the channel bank or abutments. For these reasons, assigned index values increase with increasing angles of approach.

Disagreement between observed- and potential-scour index values does not imply that the assessment and ranking procedures are conceptually inadequate. Relatively large differences between observed- and potential-scour indexes can easily occur. For example, a low observed-scour ranking and a high potential-scour ranking for the same site could mean that the interaction of destabilizing channel-forming processes has not yet affected the bridge structure.

Potential-scour index values were examined in order to better understand the component contributions in the four TDOT regions (table 5). Bed-material type contributes a high percent to the mean index in all four TDOT regions, but only in region 4 does it approach the maximum possible contribution. Stage of channel evolution and bank erosion also follow this pattern of contribution, indicating that the channel-forming processes are more integral to bridge structure stability in TDOT region 4 than in the other three regions. This type analysis, when done by county or specified geographic region, such as TDOT region, could aid maintenance, repair, and design engineers in identifying scour components pertinent to the unit of consideration.

Limitations on Methodology

Site inspection procedures and data collection forms were developed with the intent of collecting meaningful data during a short site visit. The inspector's observations and measurements were to be used by offsite personnel to review

Table 5. Mean values for the contribution of each variable in the potential-scour index and percent contribution to the mean potential-scour index, by Tennessee Department of Transportation region

Variables	Tennessee Department of Transportation region 1 Mean	1 Percent	2 Mean	2 Percent	3 Mean	3 Percent	4 Mean	4 Percent	Maximum possible contribution
Bed material	1.69	17.0	1.49	17.6	1.16	11.0	3.42	25.2	4
Stage of evolution	1.19	12.0	.97	11.5	1.70	16.2	2.15	15.9	4
Bank erosion	1.77	17.8	1.56	18.4	1.85	17.6	2.71	20.0	4
Meander impact	1.06	10.7	.90	10.6	1.13	10.7	.80	5.9	3
High-flow angle	.37	3.7	.42	5.0	.57	5.4	.37	2.7	3
Bed protection	1.85	18.6	1.44	17.0	1.87	17.8	1.30	9.6	3
Channel constriction	.28	2.8	.31	3.7	.28	2.7	.46	3.4	4
Main-channel piers	1.01	10.3	.75	8.9	.95	9.0	.71	5.2	2
Skewed piers	.51	5.2	.42	4.9	.65	6.2	.24	1.8	9
Debris blockage	.19	1.9	.19	2.2	.33	3.1	.28	2.1	4
Mass wasting with pier	0	0	.02	.2	.03	.3	1.12	8.2	6
Potential scour index	9.93		8.47		10.55		13.56		46

and assess a site quickly. Although the inspections were done during periods of relatively low discharge, data were collected from the perspective of bankfull flow conditions. These conditions can be envisioned without benefit of hydraulic or hydrologic analysis; however, these conditions do not describe site characteristics or scour potential for all flows.

Site assessment methods are largely qualitative and do not reflect scour potential from sources that require quantitative analysis. Indexes developed from assessment data cannot be relied upon by themselves. For example, a site may be nearly scour critical due to only one or two characteristics, but have fairly stable conditions otherwise, so that the site would not rank as having a scour problem. The data user is expected to look for high values in individual characteristics and not just high ranks. The bridge scour data base developed during this project does not contain bridge foundation information, so evaluations cannot be done solely from the data base. Lastly, rivers are not static entities. They are constantly in flux due to land-use changes, climate changes, changes in agricultural practices, and the manipulation of humans. Periodic updating and verification of the data base will help to retain its utility.

ASSESSMENT OF CHANNEL AND BRIDGE-SITE SCOUR CONDITIONS

The sites were assessed after being inspected and entered into the data base. The relations among the methods of site assessments were investigated using exploratory data analysis and geographic information system mapping and are described in the following sections.

Data System Output

Summary reports can be obtained from the BSDS as (1) a data printout in the format of the assessment form, (2) a listing of the potential-scour and observed-scour indexes at any or all sites (table 6), and (3) a more detailed listing displaying the actual values assigned for each variable that constitute the calculation of the potential-scour or the observed-scour index (table 7). Data tables or computer files for any combination of variables also can be generated from the BSDS. These types of summary reports have been used by the USGS and TDOT to identify sites with similar characteristics for further study, and also as part of the TDOT maintenance planning activities (table 8).

Even though the potential-scour index provides a ranking of scour susceptibility, the observed-scour index and parameters also should be reviewed for each site. Comparison of observed and potential scour at a site will more fully describe scour susceptibility. The site used as an example in table 7 has a high potential-scour value and a moderate observed-scour value. The potential-scour and observed-scour reports indicate that channel degradation is ongoing.

In TDOT region 4 and TDOT regions 1, 2, and 3, different ranges of potential-scour index were related to potential for a site to be classified as scour critical. Based on field experience and discussions with TDOT personnel, sites in TDOT region 4 with a potential-scour index of 20 or greater (221 of the 1,658 region 4 sites) can be considered as having substantial potential to be classified as scour critical (fig. 16). Examination of the potential-scour index for sites in TDOT regions 1, 2, and 3 indicate that a ranking of about 14 is well above normal (fig. 16; table 5). For example, State Route 347 over North Fork Creek near New Hope, Hawkins County (fig. 17), in TDOT region 1, has a potential-scour index of 17.3 generated by a significant high-flow angle of approach that has resulted in a

Table 6. Example output of potential-scour and observed-scour index values for selected sites in Tennessee

[A426, county road designation; SR, state route]

Bridge number	Stream	County	Route	Highway log-mile	Potential-scour index value	Observed-scour index value
230A4260005	Pond Creek	Dyer	A426	1.78	28.66	11.00
360A0040001	Beason Creek	Hardin	A004	1.60	28.00	8.00
66S81650007	Paw Paw Creek	Obion	1433	7.65	27.00	7.00
35S81170001	Short Creek	Hardeman	867	2.63	26.50	17.00
81SR0760015	Dyer Creek	Stewart	SR 76	16.36	20.67	0.00
44SR0850005	Indian Creek	Jackson	SR 85	4.77	20.50	0.00
73S25530003	Paint Rock Creek	Roane	SR 322	2.98	20.17	1.00
54SR0300015	Oostanaula Creek	McMinn	SR 30	12.13	20.00	3.00
19003620001	Stoners Creek	Davidson	SR 45	16.54	19.67	1.00
37S23670003	Holston River	Hawkins	SR 347	4.26	19.50	0.00
73SR0610004	Caney Creek	Roane	SR 61	3.99	19.00	2.00
90S23820007	Clear Fork Creek	Washington	SR 75	6.81	19.00	0.00
19SR0240011	Brown Creek	Davidson	SR 24	14.74	19.00	10.00
83S61260005	Madison Creek Branch	Sumner	SR 174	1.86	19.00	0.00
06SR0740005	Mill Creek	Bradley	SR 74	0.98	18.67	3.00
66SR0030029	Obion River	Obion	SR 3	2.38	18.33	7.00

Table 7. Output of detailed report of potential-scour and observed-scour calculation for Pond Creek, Dyer County, Tennessee

Potential Scour

Bridge-number: 230A4260005 Stream: Pond Creek
County: Dyer Highway Log Mile 1.78 Route: A426

Bed material condition:	4.00
Bed protection:	3.00
Stage of channel evolution:	4.00
Constriction:	2.00
Number of piers:	0.00
Horizontal blockage:	.33
Vertical blockage:	1.00
Total blockage:	.33
Erosion for left bank:	2.00
Erosion for right bank:	2.00
Meander impact point:	3.00
Pier skew:	.00
Mass wasting at left bank pier:	3.00
Mass wasting at right bank pier:	3.00
High flow angle of approach:	1.00
Total:	28.66

Observed Scour

Pier 1:	2.00
Pier 2:	2.00
Pier 3:	.00
Pier 4:	.00
Pier 5:	.00
Pier 6:	.00
Pier 6:	.00
Pier 7:	.00
Pier 8:	.00
Pier 9:	.00
Left abutment exposed piles:	.00
Right abutment exposed piles:	.00
At left bank rip rap:	.00
At right bank rip rap:	1.00
Bed rip rap:	.00
Blowhole:	.00
Mass wasting at left bank pier:	3.00
Mass wasting at right bank pier:	3.00
Total:	11.00

high-flow meander impact point and skewed piers; the reach is considered as widening. Debris accumulation is exacerbated by the multiple column piers skewed to high flow.

Bedrock controls vertical scour at the site, but lateral erosion or scour is ongoing.

Geographic Information and Mapping System

The geographic information system (GIS) mapping component of the BSDS has been used to extrapolate site characteristics to areas or streams with no data, but which are located in similar geologic and physiographic settings. This extrapolation is done by plotting the characteristic or variable of interest and following the trend in characteristics upstream.

As an example, a plot of bed material at sites in Fayette County (fig. 18) shows a majority of sites as having sand or silt and clay channel beds. Many streams in the county have a linear configuration indicating they have been channelized. Streams with headwaters in the eastern third of the county drain from the Claiborne and Wilcox Formations, a source of sand and gravel bed material. These streams supply sand to many of the sites in the western part of the county. Streams with headwaters in the western part of the county may have sand or silt and clay channel beds due to transport from upstream or to stratigraphy of the flood plain near the site.

A map of stage of channel evolution for Fayette County (fig. 19) shows that channel widening (stages of evolution 4 or 5) is ongoing at the majority of sites. This GIS map is particularly informative when a stream of interest is followed upstream. By comparing upstream and downstream sites, processes controlling channel evolution and affecting scour become more apparent and an estimate of the future condition at a site can be more easily made.

Interpretation techniques applicable for Fayette county are directly transferrable to a watershed or basin, such as the Loosahatchie River basin of West Tennessee (fig. 20). The Loosahatchie River has had extensive, repeated channel modification. Bed material in the Loosahatchie River basin has been categorized as

Table 8. Example of data requests made by Tennessee Department of Transportation from the Bridge Scour Data System for selected sites

[no., number; I__, Interstate highway __; SR__, State route; NUM, number; HWY, Highway]

Request number	Date, variables, rationale for data request, and example of requested data
1	No date: Region, county, route, bridge number, stream, bed-material type. TDOT used these data to begin characterizing bed material across the State for screening bridge sites with potential for scour.

Region	County	Route	Bridge no.	Stream	Bed material
1	Anderson	I75	01I00750005	Hinds Creek	Alluvium
2	Bledsoe	SR28	04SR0280013	Cannon Creek	Gravel
3	Bedford	SR64	02SR0640011	Davis Creek Branch	Bedrock
4	Benton	SR192	03SR0690007	Overflow-Birdsong Creek	Silt/clay

Request number	Date, variables, rationale for data request, and example of requested data
2	11-14-90: Region, county, route, bridge number, stream, gravel bed present, bedrock bed present, exposed footings or pilings present, channel widening occurring, blowhole present. TDOT was attempting to isolate sites with significant problems requiring channel protection. Exposed footings or piling on bedrock in region 1, 2, or 3 generally indicates the pier was built with shallow foundations. Exposed footing or piling in a gravel bed might indicate degradation or local scour. Channel widening might indicate potential abutment scour or destabilization. Sites with blowholes in place have a potentially unstable situation in effect.

Region	County	Route	Bridge no.	Stream	Bed material	Footing or piling exposed	Stage of evolution	Blowhole present
1	Hawkins	SR1	37SR0010037	North Fork Holston River	Bedrock	yes	5	no
2	DeKalb	SR53	21SR0530005	Smith Fork Creek	Bedrock	yes	1	no
3	Davidson	I40	19I00400007	Harpeth River	Gravel	yes	1	no
4	Shelby	SR3	79SR0030007	Nonconnah Creek	Gravel	yes	5	no

Table 8. Example of data requests made by Tennessee Department of Transportation from the Bridge Scour Data System for selected sites--Continued

Request	Data, variables, rationale for data request, and example of requested data
3	1-17-90: Potential Scour Index long report for all TDOT region 4 sites. TDOT supplied this data to the TDOT region 4 bridge engineer for determination of site characteristics which caused high index values at specific sites. This was part of a scour-protection planning effort.

BRIDGE NUM. : 20SR0690001 STREAM : STEWMANS CREEK
COUNTY : DECATUR HWY LOG MILE : 4.90 ROUTE : SR69

BED MATERIAL CONDITION :	3.50
BED PROTECTION :	3.00
STAGE OF EVOLUTION CONDITION :	0.00
CONSTRICTION :	0.00
NUMBER OF PIERS :	0.00
HORIZONTAL BLOCKING :	0.00
VERTICAL BLOCKING :	0.00
TOTAL BLOCKING :	0.00
EROSION FOR LEFT BANK :	1.00
EROSION FOR RIGHT BANK :	1.00
MEANDER IMPACT POINT :	1.00
PIER SKEW :	0.00
MASS WASTING ON LEFT BANK PIER	0.00
MASS WASTING ON RIGHT BANK PIER	0.00
HIGH FLOW ANGLE	0.00
TOTAL :	9.50

Request	Data, variables, rationale for data request, and example of requested data
4	4-90: Data were retrieved for all Interstate bridges in region 4, all State Route bridges in the Loosahatchie River and Wolf River basins. The retrieval demonstrated site isolation by highway system importance and river system. The data were used by TDOT to rank the sites for scour-protection planning and evaluation.

County	Route	Bridge number	Highway log-mile	Stream	Potential-scour index	Observed-scour index
Shelby	I40	79I00400134	29.03	Hall Creek	23.17	12.00
Haywood	I40	38I00400009	2.41	Big Muddy Creek	24.99	12.00
Shelby	SR1	79SR0010039	30.34	Loosahatchie River	18.00	12.00
Shelby	SR205	79S80740025	19.14	Loosahatchie River	20.00	17.00
Shelby	SR3	79SR0030025	75.25	Wolf River	22.66	26.00
Fayette	SR76	24SR0760011	5.51	Watkins Branch	25.50	16.00

Table 8. Example of data requests made by Tennessee Department of Transportation from the Bridge Scour Data System for selected sites--Continued

5 4-90: Geographic information system maps of the Loosahatchie River basin were compiled showing stage of channel evolution and bed material. The maps were intended as demonstrations of how mapped data could be used to understand the interrelated nature of problems at sites on the same river.

6 1-91: Data were retrieved for regions 2 and 3 gravel-bed channel sites. This data retrieval demonstrated the ability to geographically locate sites with potential-scour problems.

Region	County	Bridge number	Route	Highway log-mile	Stream	Bed material
2	Fentress	25SR0280001	SR28	27.85	Dry Branch	Gravel
3	Stewart	81SR0760015	SR76	16.36	Dyer Creek	Gravel

7 5-90 to 9-90: Geographic information system maps of region 4 counties were supplied to TDOT. The maps showed stage of channel evolution at all sites. These maps were used by TDOT for evaluation of the overall drainage network conditon within the counties.

8 4-1-91: Region, county, route, bridge number, stream, sand bed present, gravel bed present, cobble or boulder bed present. TDOT and USGS used this data output as part of the effort to locate suitable channel-evolution modeling sites.

Region	County	Route	Bridge number	Stream	Bed material
1	Anderson	SR9	01SR0090011	Clinch River Branch	Gravel
2	Cannon	SR53	08SR0530003	Duke Creek	Cobble/boulder
2	Cumberland	SR1	18SR0010003	Bean Creek	Sand
4	Benton	SR192	03SR0690003	Sycamore Creek	Sand

9 10-3-91: Region, county, route, bridge number, stream, bedrock bed present, bed rip-rap present, footing or piling exposure present. TDOT and USGS used this request for a screening guide for selection of channel-evolution modeling sites in TDOT regions 1, 2, and 3. Bedrock bed and bed rip-rap caused sites to be rejected from consideration. Footing or piling exposure in a main channel with bed material other than bedrock allowed the site to be considered for modeling.

Region	County	Route	Bridge number	Stream	Bed material	Bed protection present	Footing or piling exposure
1	Carter	SR159	10SR1590005	Elk River	Cobble/boulder	no	yes
2	Hamilton	SR17	33SR0580013	South Chickamauga Creek	Cobble/boulder	no	yes
3	Hickman	SR50	41SR0500019	Swan Creek	Gravel	no	yes

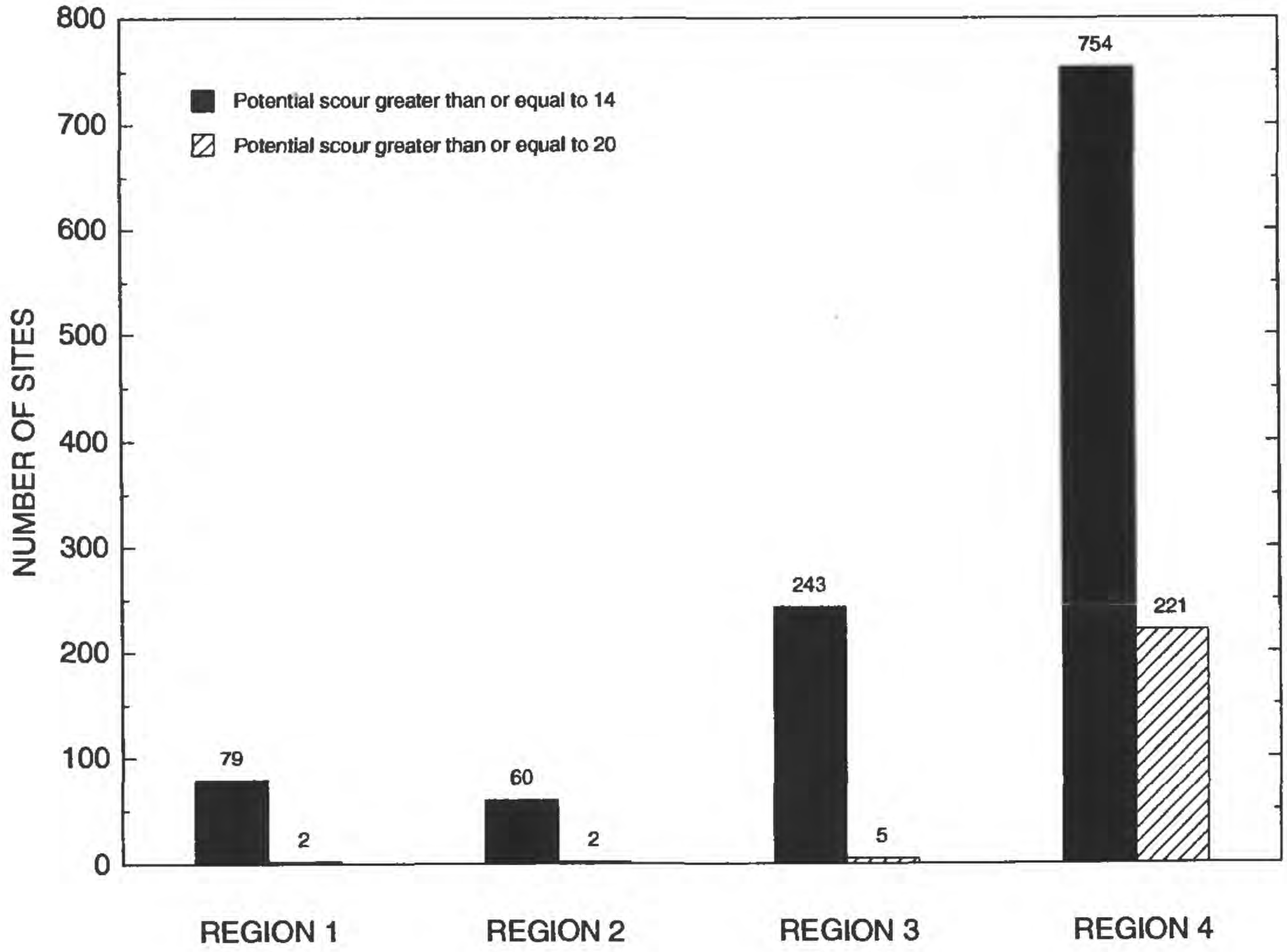
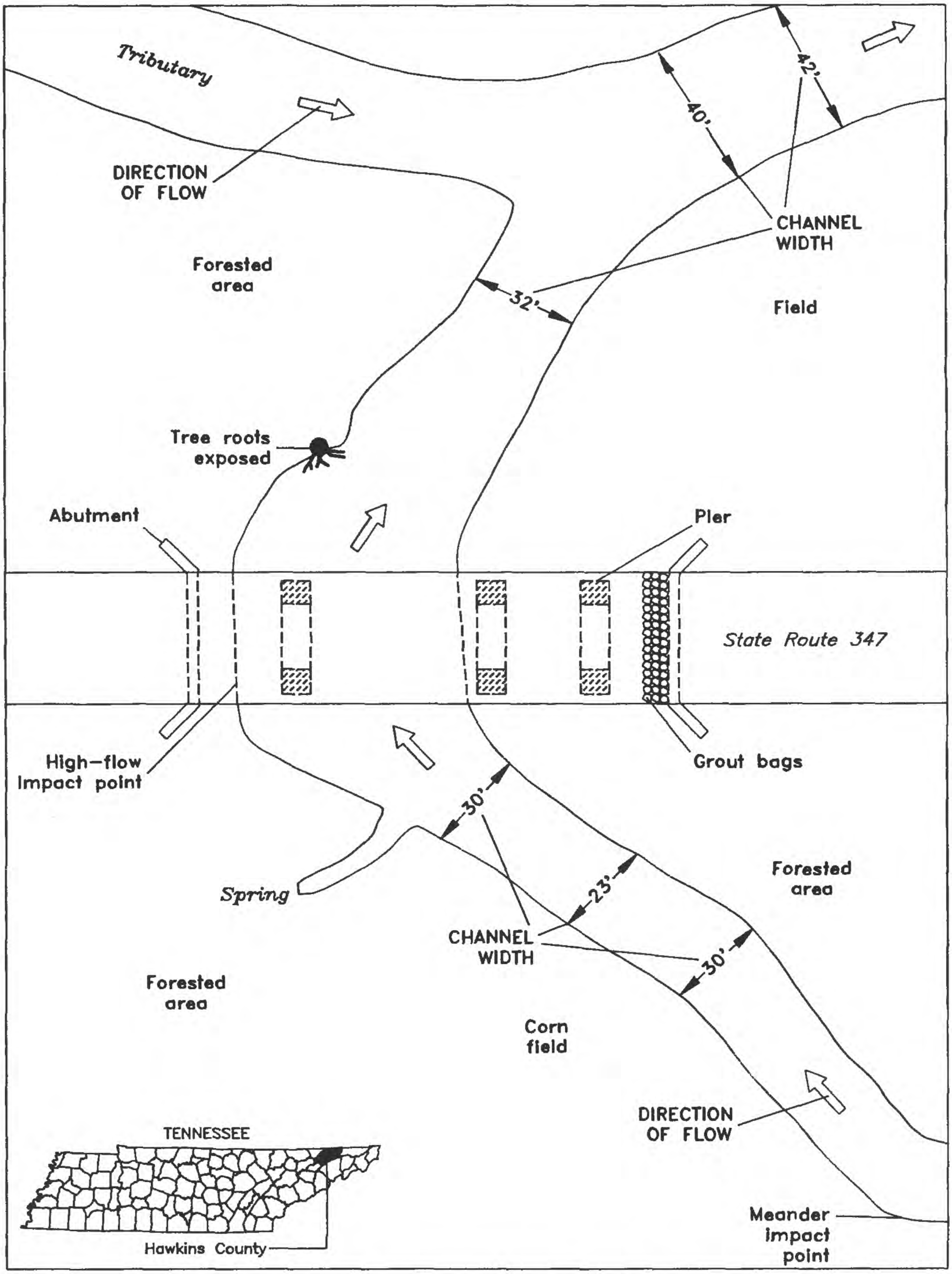


Figure 16. Numbers of sites in the Tennessee Bridge Scour Data System with potential-scour index values greater than or equal to 14 and greater than or equal to 20 for Tennessee Department of Transportation regions 1,2, 3, and 4.

sand, silt/clay, gravel, and unknown alluvium (fig. 20). Main-channel bed material is sand, except for one location where silt/clay was exposed and two sites that were designated unknown alluvium. Exposure of silt/clay in the channel is controlled by flood-plain stratigraphy and the extent of response to past channel modification. Future channel modifications have the potential to alter the current main-channel bed material characterization.

Smaller headwater tributaries on the north side of the main channel of the Loosahatchie River generally have silt/clay or unknown alluvium bed material (fig. 20). This bed-material type indicates that headward degradation and channel widening either is a current problem, or will be a problem in the future. Smaller headwater tributaries to the south of the main channel generally have sand bed material (fig. 20). The presence of sand bed material does not preclude problems associated with channel degradation, but does indicate that bed-level recovery is possible. In the silt/clay bed material area north of the main channel, bed-level recovery should be much slower due to a lack of coarse bed material.

Examination of the stage of channel evolution distribution for the Loosahatchie River basin (fig. 21) takes this limited interpretation technique one step further. The main channel generally has been characterized as having a stable or accreting bed with channel widening (stage of channel evolution 5). In Fayette and Hardeman Counties, stages of evolution 3 and 4 (fig. 14) were identified in several locations. These reaches are interspersed with the more stable stage 5 reaches. However, flood-plain stratigraphy and sand transport from the uplands will play an important role in determining if these site reaches become more or less unstable.



NOT TO SCALE

Figure 17. Site sketch for the State Route 347 crossing of North Fork Creek near New Hope, Hawkins County, Tennessee.

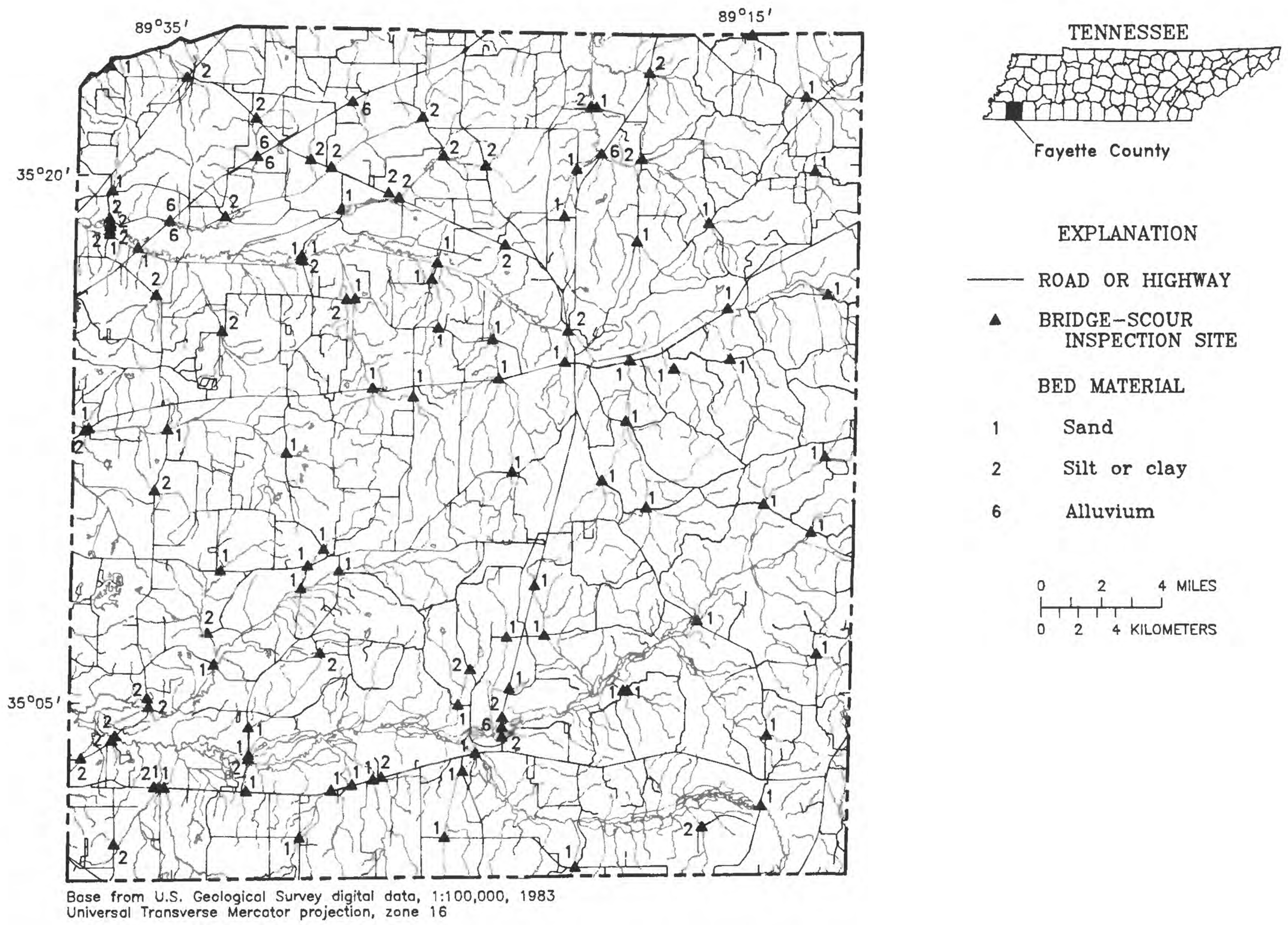


Figure 18. Example geographic information system map of Fayette County, Tennessee, showing bed-material distribution.

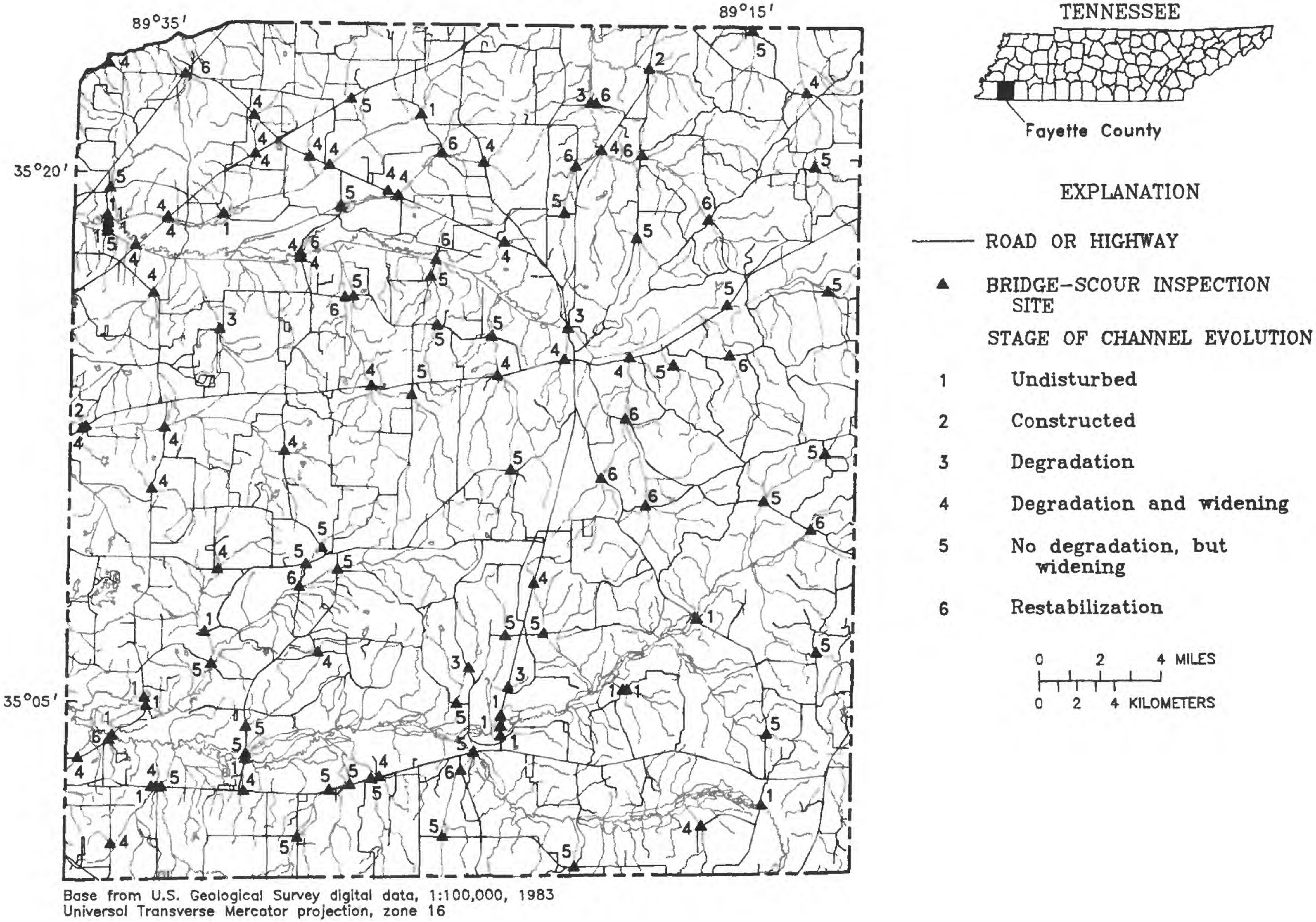


Figure 19. Example geographic information system map of Fayette County, Tennessee, showing stage of channel evolution distribution.

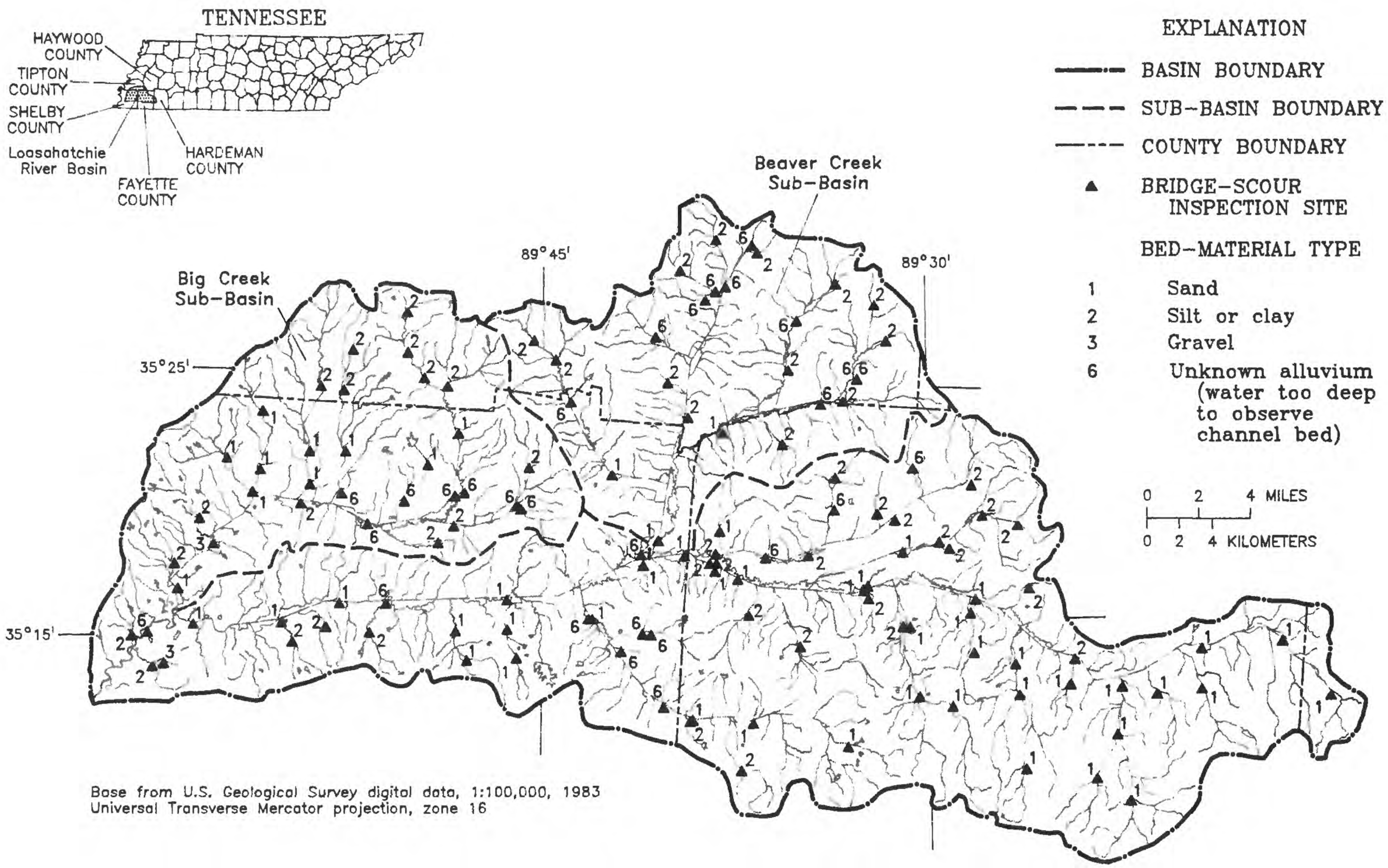


Figure 20. Example geographic information system map of bed-material distribution at bridge-scour sites in the Loosahatchie River basin in Tennessee.

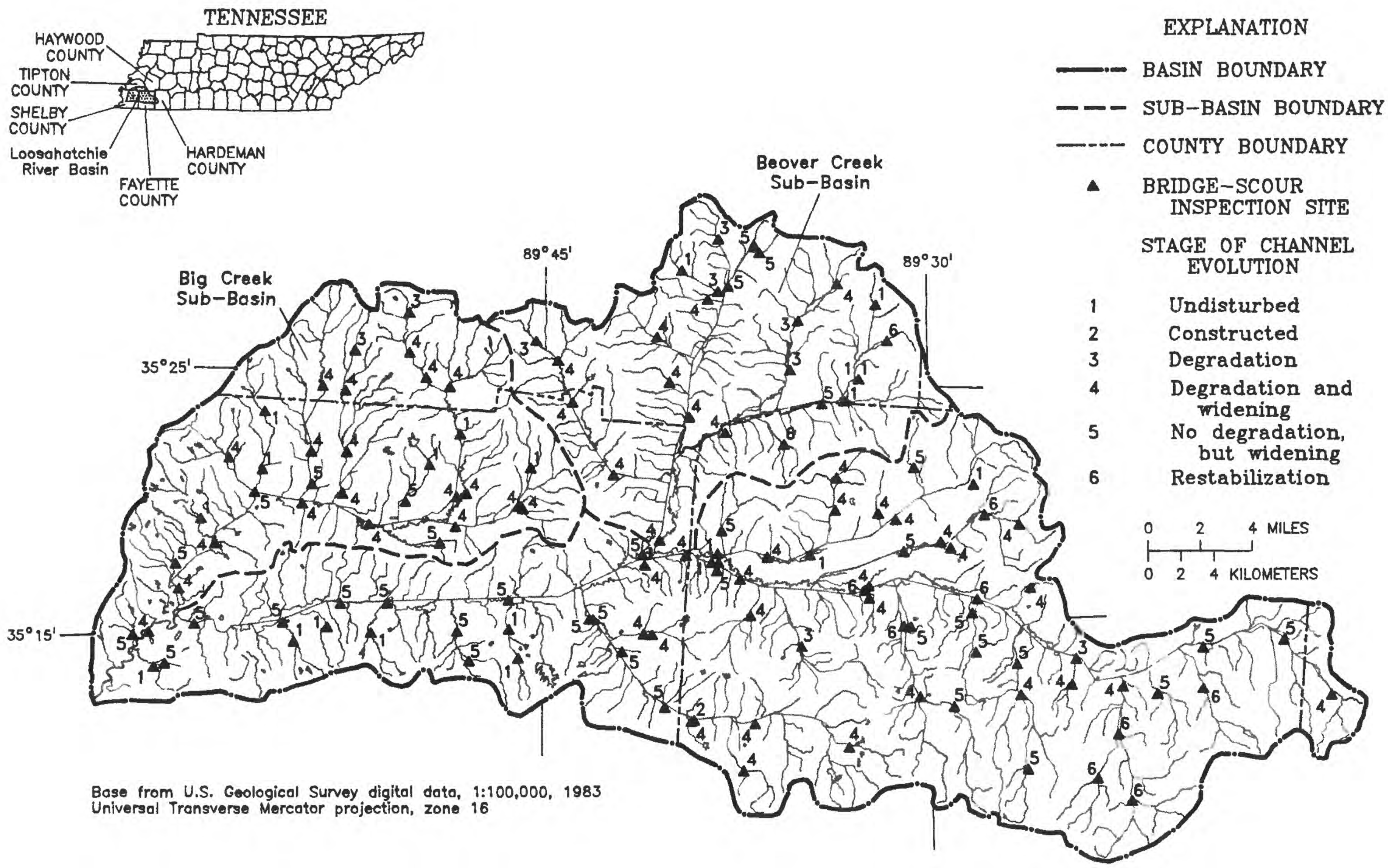


Figure 21. Example geographic information system map of channel evolution at bridge-scour sites in the Loosahatchie River basin in Tennessee.

Sites north of the Loosahatchie River main channel (fig. 21), where silt/clay bed material predominates (fig. 20), have been principally categorized as stages 3 and 4, with some stage 1, 5, and 6 sites (fig. 14). The large number of stage 3 and 4 sites corresponds with previous experience in channelized West Tennessee streams. When degradation is initiated in channels on deep loess, such as at sites north of the Loosahathcie River main channel, the ramifications will be far reaching and long lasting.

Sites south of the Loosahatchie River main channel (fig. 21), where sand bed material predominates (fig. 20), show a mix of ongoing degradation and widening (stage of evolution 3 and 4, fig. 14), and aggradation and recovery (stage of evolution 5 and 6, fig. 14). Again, this pattern is affected strongly by the availability of coarse bed material that is necessary for bed-level recovery.

This type of limited analysis provides basic information for scour evaluation and remediation plans. The northern and southern parts of a basin may require different types and intensities of scour remediation.

Regional Conditions

Based on data from phases 1, 2, and 3, channel stability characteristics differ among the four TDOT regions. The majority of sites in TDOT regions 1 and 2 have stable channels (stage of evolution 1 and 6, fig. 22). Region 3 has a high percentage of sites characterized as widening (stage 5; fig. 22) and the majority of sites in region 4 have unstable channels (stages 3, 4, and 5, fig. 22). Channel instability may be related to predominant bed material in the specific regions (fig. 23). In region 4, channel instability also is strongly related to past channel modifications (Robbins and Simon, 1983; Simon and Hupp, 1986).

While a high proportion of channels in each region is fluvially eroding (fig. 24), only region 4 has a high percentage of banks failing through mass wasting. Again, this channel instability is related to the unstable nature of channels in region 4 (fig. 22) and to the bed and bank material types (fig. 23 and 25).

Mass wasting of banks and fluvial erosion are present in all TDOT regions. Mass wasting of banks is prevalent in TDOT region 4 (fig. 24), but is rare in TDOT regions 1, 2, and 3 due to the lack of channel degradation and resultant excessive bank heights and bank angles. Fluvial erosion, however, is prevalent in regions 1, 2, and 3. The hypothesized causes of these conditions are altered hydrology in urban areas and agricultural practices. Because bed material is more resistant in TDOT regions 1, 2, and 3, excess energy during high flows can be expended through bank and abutment erosion. For example, flooding in South Carolina caused by tropical storms Klaus and Marco in 1990 caused 80 bridge failures. Of these bridge failures, 79 were due to abutment failure brought on by fluvial erosion (N.M. Hurley, Jr., U.S. Geological Survey, written commun., 1992).

Channel widening in regions 1, 2, and 3 was analyzed through a subsample of urbanizing counties, counties with gravel-removal permits, and counties in locales known for gravel or cobble bed-material transport (table 9). Urban counties with large populations, such as Davidson, Williamson, Knox, Hamilton, and Shelby, have high numbers of channel widening sites (tables 9, 10, and 11). Shelby County has the highest number of widening sites, but it also is located in region 4, which is known for channel instability. The other counties in the urban analysis in regions 1, 2, and 3 show a mix in regard to channel widening and bed-material type (table 9).

Soils and geology may play as large a part in urban hydrologic response as does urban development (Wibben, 1976). In the Nashville (Davidson County) area, for instance, Wibben (1976) found no difference between floodflow characteristics from small urban and rural basins,

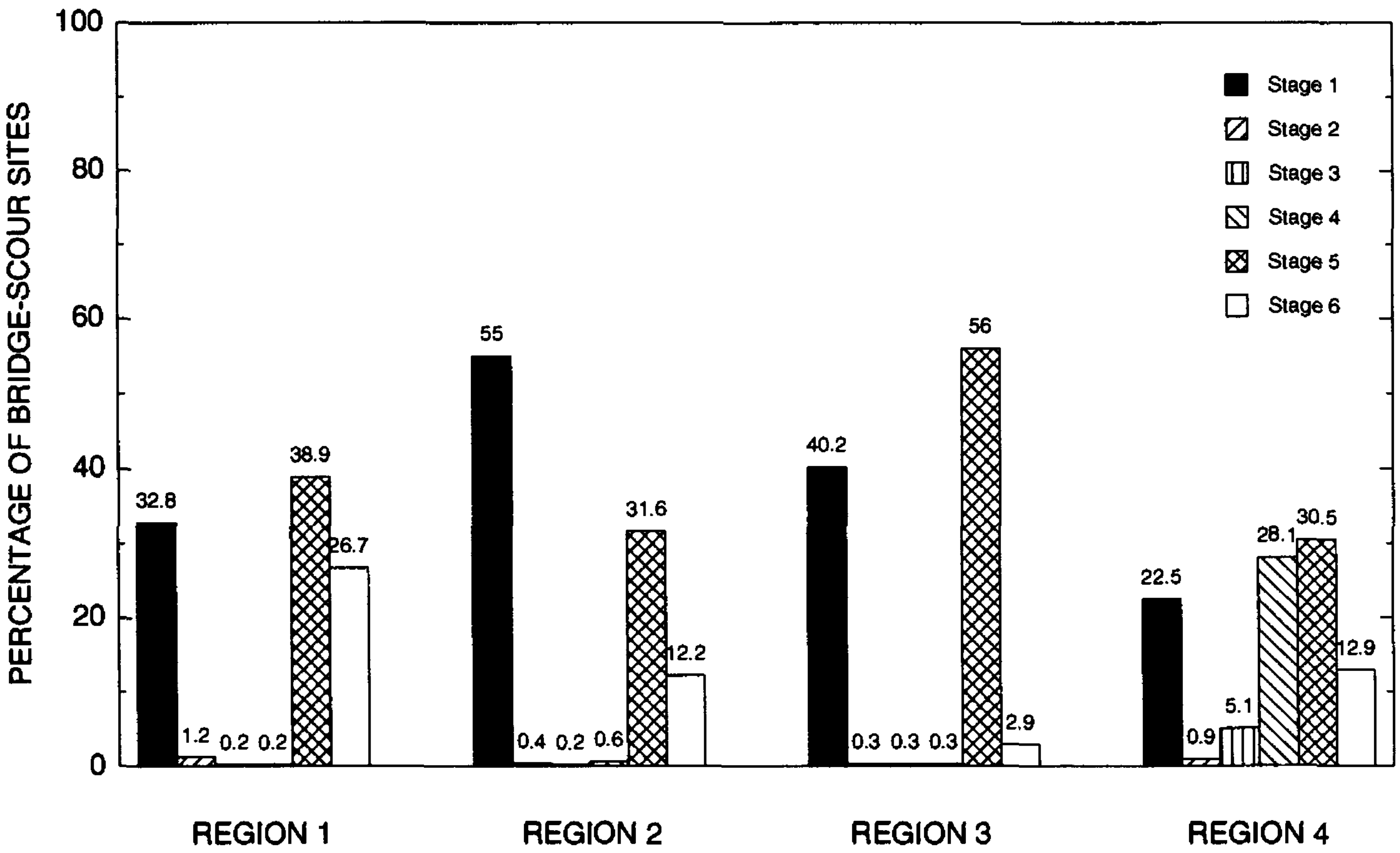


Figure 22. Percentage of bridge-scour sites in Tennessee Department of Transportation regions 1, 2, 3, and 4, by stage of channel evolution.

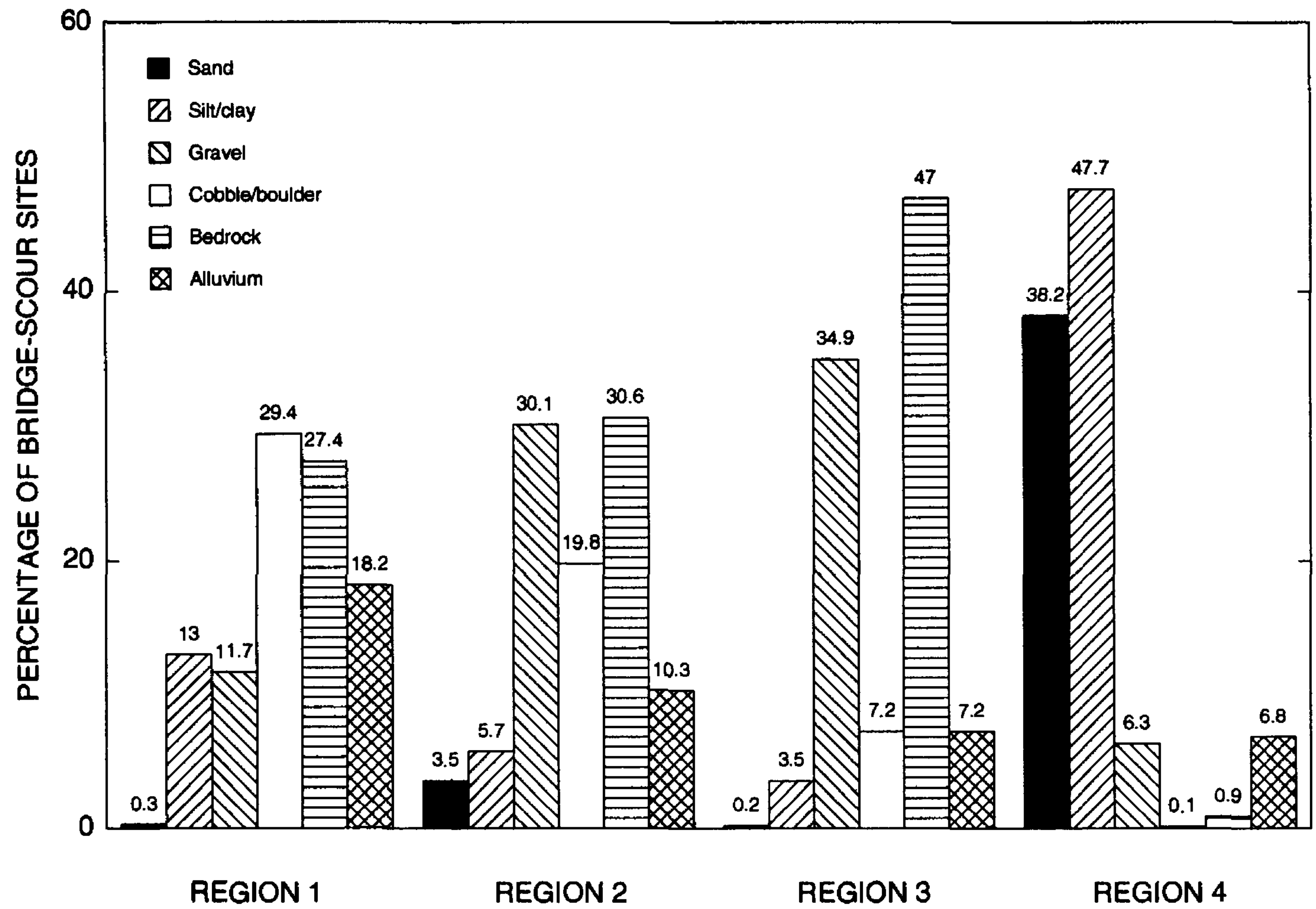


Figure 23. Percentage of bridge-scour sites with given bed-material characteristics in Tennessee Department of Transportation regions 1, 2, 3, and 4.

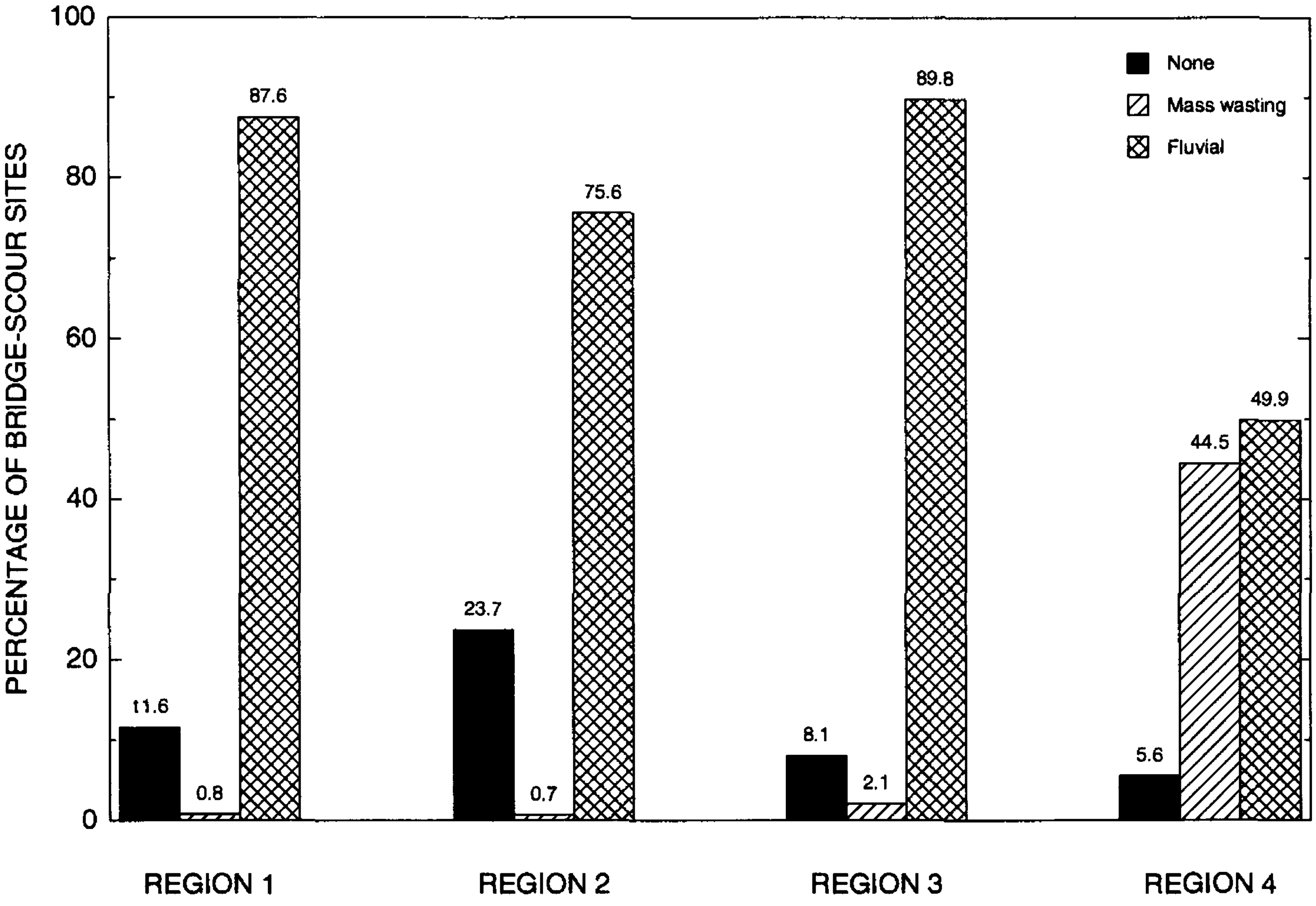


Figure 24. Percentage of bridge-scour sites and type of bank erosion in Tennessee Department of Transportation regions 1, 2, 3, and 4.

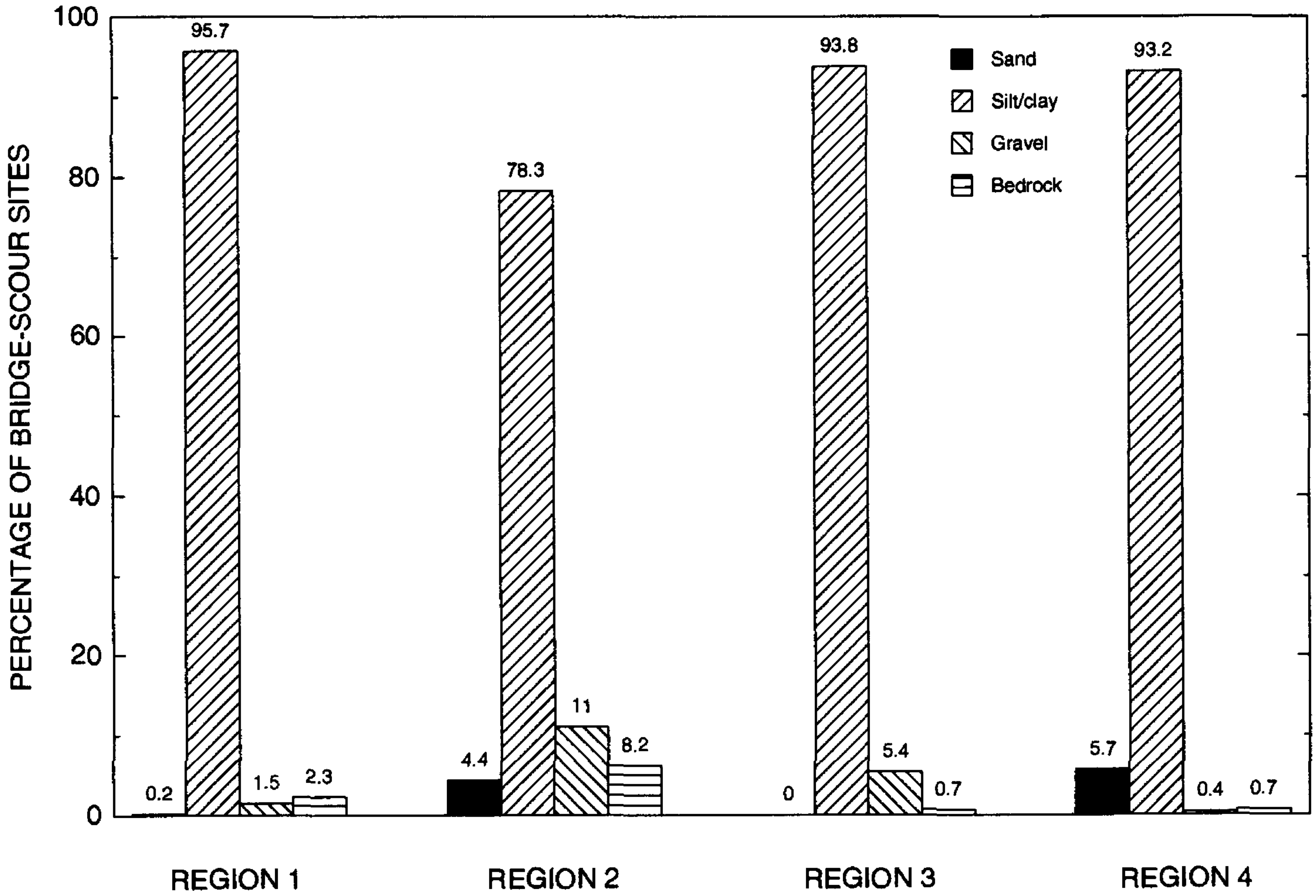


Figure 25. Percentage of bridge-scour sites with given bank-material characteristics in Tennessee Department of Transportation regions 1, 2, 3, and 4.

and he attributed this finding to the shallow soils and frequent rock outcropping. However, Robbins (1984) reported significant differences in hydrologic response between small urban and rural basins in East Tennessee.

In counties selected for analysis between bed material and channel widening, a relation between widening and occurrence of gravel-removal permits appears to exist (table 9). Both gravel and bedrock bed material are related to widening, when banks are composed of erodible material. While channel widening may not cause pier or abutment instability, the widening does have an effect on supply of large woody debris through bank erosion (Diehl and Bryan, 1993). Even though channel widening caused by bank erosion may introduce large amounts of woody debris into the channel, the channel shape, width, and depth must be such as to allow downstream movement of debris before the debris will have the opportunity to interact with piers in the flow path, and thereby create the opportunity for scour.

Analysis of channel widening for the entire BSDS shows that 51 percent of all channels near bridge sites are widening (table 10). The highest percentage of channel widening was recorded in region 4. The extent of channel widening in region 3 is high and of concern, but the rate at which channel widening occurs in region 3 appears to be much less than in region 4. Floodflow deflected by large woody debris that is generated by channel widening increases the possibility for pier or abutment scour in regions 1, 2, or 3.

Widening differs between urban and gravel-supplying counties. An analysis of sites studied in phase 3 of the investigation shows that channel widening in urban counties is widespread and occurs in all bed-material categories (tables 9 and 10). In gravel-supplying counties (tables 9 and 10), sites with gravel, bedrock, and alluvium bed materials are more likely to be widening.

Gravel infilling of channels causes flow to adjust conveyance where banks are erodible. This infilling has become a problem in Humphreys County and other counties of that area (Louis Bordinave, Tennessee Department of Environment and Conservation, oral commun., 1991). When channel conveyance has adjusted to the gravel infilling adequately, the banks should regain a stable appearance, unless acted upon by other channel-forming processes. The duration of this adjustment is unknown.

Regression analysis was used to investigate relations between land-use characteristics (table 11) and potential-scour indexes of the counties studied in phase 3. No single land-use characteristic, group of characteristics, or changes in characteristics over time resulted in a relation accounting for more than 25 percent of the total variation. However, when placed in geographic context (fig. 26), channel instability expressed through channel widening is highlighted throughout region 4 and along the southern and western boundaries of region 3. Channel widening in other regions appears to be geologically or possibly demographically controlled.

SUMMARY AND CONCLUSIONS

The ability to quickly assess the potential for scour at a given bridge, to evaluate those bridges with the greatest potential for significant amounts of scour, and then to identify scour-critical structures is important for public protection and bridge maintenance planning. A bridge site assessment form was developed by the U.S. Geological Survey (USGS) and the Tennessee Department of Transportation (TDOT) for collecting data that describe the bridge site and the hydraulic, geomorphic, and vegetation characteristics of the channel. Site assessments of channels at 3,964 bridges were used to describe both potential for scour and actual scour problems statewide. A data base was created with capability for mapping using a geographic information system. Mapping is used to assess rapidly potential-scour characteristics over broad geographic areas, such as counties, regions, or drainage basins. The current data base contains inspections done between 1988 and 1993.

Table 9. Number of sites with channel widening, type of bed material, and number of gravel removal permits in phase 3 counties in Tennessee

[TDOT, Tennessee Department of Transportation]

County and TDOT county code	Channel widening at site	Total sites per county	Bed Material						Urban or gravel supplier	Gravel removal permits as of 1991	Number streams permitted
			Sand	Silt/ clay	Gravel	Cobble/ boulder	Bedrock	Alluvium			
Anderson (1)	20	45	0	0	8	5	7	0	Urban	0	0
Blount (5)	6	27	0	4	0	1	1	0	Urban	0	0
Davidson (19)	46	85	0	2	11	6	18	9	Urban	4	3
Hamilton (33)	34	69	0	1	18	7	6	2	Urban	0	0
Knox (47)	34	79	0	6	6	3	13	6	Urban	0	0
Montgomery (63)	22	48	0	1	13	0	7	1	Urban	6	3
Rutherford (75)	28	77	0	4	3	12	9	0	Urban	4	2
Shelby (79)	114	145	35	16	19	0	0	44	Urban	0	0
Williamson (94)	38	62	0	2	9	6	19	2	Urban	12	6
Bledsoe (4)	13	22	0	0	2	2	7	2	Gravel	0	0
Cannon (8)	4	24	0	0	0	0	4	0	Gravel	30	11
Cheatham (11)	23	36	0	0	9	1	12	1	Gravel	45	9
DeKalb (21)	5	25	0	0	2	0	3	0	Gravel	56	5
Dickson (22)	24	44	0	0	12	3	9	0	Gravel	15	7
Giles (28)	53	70	0	0	17	0	29	7	Gravel	86	25
Hickman (41)	37	65	0	0	25	2	9	1	Gravel	32	15
Houston (42)	22	26	0	0	20	0	2	0	Gravel	15	6
Humphreys (43)	33	49	0	0	29	0	3	1	Gravel	56	12
Jackson (44)	15	36	0	0	8	0	7	0	Gravel	32	12
Lawrence (50)	23	33	0	0	6	0	17	0	Gravel	58	24
Lewis (51)	20	27	0	0	15	0	5	0	Gravel	11	6
Lincoln (52)	33	52	1	0	17	0	13	2	Gravel	14	8
Macon (56)	24	32	0	0	12	0	12	0	Gravel	70	15
Marion (58)	14	43	1	1	3	5	1	3	Gravel	3	2
Perry (68)	22	38	0	0	19	0	2	1	Gravel	0	0
Putnam (71)	9	23	0	0	6	1	2	0	Gravel	15	2
Rhea (72)	8	24	0	1	0	1	6	0	Gravel	0	0
Sequatchie (77)	10	17	0	0	2	4	1	3	Gravel	0	0
Stewart (81)	15	31	0	0	15	0	0	0	Gravel	69	17
Sumner (83)	41	61	0	1	6	0	34	0	Gravel	78	21
Wayne (91)	34	44	0	0	28	0	6	0	Gravel	2	2
TOTAL	824	1,459	37	39	340	59	264	85			

Table 10. Categorization of sites with channel widening by Tennessee Department of Transportation region and for sites from phase 3 counties

Tennessee Department of Transportation region	Sand	Silt/ clay	Gravel	Cobble/ boulder	Bedrock	Alluvium	Total number sites	Number widening sites	Percent of total sites
	Number of widening sites for complete data base								
1	1	33	28	58	100	17	606	237	39
2	6	11	69	33	41	14	544	174	32
3	1	14	296	43	267	29	1,156	650	56
4	438	384	70	0	0	78	1,658	970	58
	Number of widening sites for phase 3 counties/possible sites per category								
Urban	35/44	36/68	87/132	40/74	80/192	64/126	637	342	52
Gravel supplier.	2/8	3/29	253/370	19/63	184/304	21/ 49	822	482	59
	Number of widening sites for phase 3 counties (excluding Shelby County)/possible sites per category								
Urban	0/1	20/37	68/112	40/74	80/187	20/81	492	228	46
Gravel supplier.	2/8	3/29	253/370	19/63	184/304	21/49	822	482	59

In West Tennessee counties, channel instability has extended from valley bottoms into the uplands through headward degradation. The potential for both vertical and lateral scour is serious. In TDOT regions 1, 2, and 3, channel widening is a dominant process, but widespread degradation has been prevented by erosion-resistant bedrock, boulder, cobble, and gravel bed material, and by the absence of channelization. However, potential for lateral scour is prevalent in the eastern part of the State and appears to be generating considerable quantities of large woody debris.

Neither changes in population nor changes in the land-use categories of cropland, pasture, or timberland were statistically related to potential-scour indexes. Geographic setting, and possibly degree of urbanization as reflected by population, did appear to be connected to channel widening.

This study established an assessment procedure useful in delineating those bridge locations undergoing scour or with a potential for scour. Using the computed scour indexes along with GIS plots of site characteristics, planners and managers can develop a broad view of potential problems and identify specific sites on which to focus immediate attention. Timely identification of actual or potential-scour problems can improve the effectiveness and reduce the cost of solutions. The present (1993) data base provides only an overview of current conditions. Site data collected by the State during biannual structure inspections will provide a mechanism to update the existing data base.

Table 11. Land use characteristics, number of bridge-scour sites with channel widening, and the total number of bridge-scour sites for phase 3 counties in Tennessee

[mi², square mile]

County	Area, in mi² [1]	Population			Cropland, in acres			Pasture, in acres			Timber, in acres			Bridge-scour sites per county	
		1880 [2]	1890 [1]	Change	1978 [3]	1987 [4]	Change as percent of county area	1978 [3]	1987 [4]	Change as percent of county area	1980 [5]	1889 [6]	Change as percent of county area	Widening	Total
Urban Counties															
Anderson	337.5	67,346	68,250	904	20,078	20,371	0.1	21,311	18,644	-1.2	134,200	124,000	-4.7	20	45
Blount	558.6	77,770	85,969	8,199	68,109	68,991	.2	51,448	47,008	-1.2	126,000	69,900	-15.7	6	27
Davidson	502.3	477,811	510,784	32,973	41,678	27,131	-4.5	45,149	31,075	-4.4	98,000	108,100	3.1	46	85
Hamilton	542.5	287,643	285,536	-2,107	33,921	29,639	-1.2	29,590	27,243	- .7	203,000	210,700	2.2	34	69
Knox	508.5	319,694	335,749	16,055	61,967	58,601	-1.0	54,274	49,434	-1.5	102,000	127,000	7.7	34	79
Montgomery	539.2	95,290	100,498	5,208	123,894	119,490	-1.3	81,646	73,301	-2.4	103,400	136,900	9.7	22	48
Rutherford	619.0	95,948	118,570	22,622	147,504	127,135	-5.1	152,842	127,373	-6.4	156,000	155,700	- .1	28	77
Shelby	754.9	777,113	826,330	49,217	150,824	98,833	-10.8	35,046	32,367	- .6	93,600	111,600	3.7	114	145
Williamson	582.7	58,108	81,021	22,913	138,626	116,929	-5.8	137,889	121,342	-4.4	126,000	142,000	4.3	38	62
Gravel Supply Counties															
Bledsoe	406.3	9,478	9,669	191	56,145	49,276	-2.6	44,069	35,836	-3.2	171,000	186,300	5.9	13	22
Cannon	265.7	10,234	10,467	233	49,637	49,003	- .4	58,642	56,928	-1.0	34,000	88,500	32.0	4	24
Cheatham	302.7	25,412	27,140	1,728	36,704	35,483	- .6	33,811	28,506	-2.7	104,000	118,200	7.3	23	36
DeKalb	304.6	13,589	14,360	771	59,241	54,598	-2.4	52,245	52,190	- .0	74,000	114,200	20.6	5	25
Dickson	489.9	30,037	35,061	5,024	76,177	76,151	- .0	83,192	75,847	-2.3	151,200	174,300	7.4	24	44
Giles	611.0	24,625	25,741	1,116	156,699	142,684	-3.6	174,883	171,805	- .8	121,800	171,800	12.8	53	70
Hickman	612.7	15,151	16,754	1,603	59,523	59,309	- .1	5,5935	54,533	- .4	275,000	297,200	5.7	37	65
Houston	200.2	6,871	7,018	147	20,184	19,798	- .3	24,363	23,754	- .5	81,900	94,200	9.6	22	26
Humphreys	532.2	15,957	15,795	-162	52,028	49,549	- .7	47,784	43,670	-1.2	223,200	241,200	5.3	33	49
Jackson	308.9	9,398	9,297	-101	39,432	34,459	-2.5	55,559	53,371	-1.1	112,200	135,900	12.0	15	36
Lawrence	617.2	34,110	35,303	1,193	138,222	119,287	-4.8	88,225	91,521	.8	153,900	199,800	11.6	23	33
Lewis	282.1	9,700	9,247	-453	16,252	13,049	-1.8	16,225	13,106	-1.7	131,100	158,000	14.9	20	27
Lincoln	570.3	26,483	28,157	1,674	180,553	162,617	-4.9	169,412	162,432	-1.9	105,000	136,700	8.7	33	52
Macon	307.1	15,700	15,906	206	69,000	68,249	- .4	64,135	59,065	-2.6	59,400	77,000	9.0	24	32
Marion	499.8	24,416	24,860	444	30,370	31,233	.3	19,714	21,004	.4	240,800	251,700	3.4	14	43
Perry	414.9	6,111	6,612	501	24,677	21,904	-1.0	16,977	20,858	1.5	218,300	223,600	2.0	22	38
Putnam	401.0	47,690	51,373	3,683	59,705	52,758	-2.7	57,244	52,279	-1.9	136,400	152,300	6.2	9	23
Rhea	315.9	24,235	24,344	109	26,758	33,260	3.2	22,427	23,388	.5	124,200	126,400	1.1	8	24
Sequatchie	265.9	8,605	8,863	258	13,909	12,456	- .9	9,692	10,449	.4	134,400	137,300	1.7	10	17
Stewart	457.7	8,665	9,479	814	30,058	23,231	-2.3	27,790	22,225	-1.9	198,400	219,700	7.3	15	31
Sumner	529.4	85,790	103,281	17,491	37,955	135,838	- .6	106,127	96,853	-2.7	73,500	88,200	4.3	41	61
Wayne	734.0	13,946	13,935-	11	52,440	51,322	- .2	48,789	56,116	1.6	372,000	372,600	.1	34	44

[1] U.S. Bureau of the Census, 1991
[2] Tennessee Department of State, 1991
[3] U.S. Bureau of the Census, 1981
[4] U.S. Bureau of the Census, 1989
[5] U.S. Forest Service, 1982
[6] U.S. Forest Service, 1990

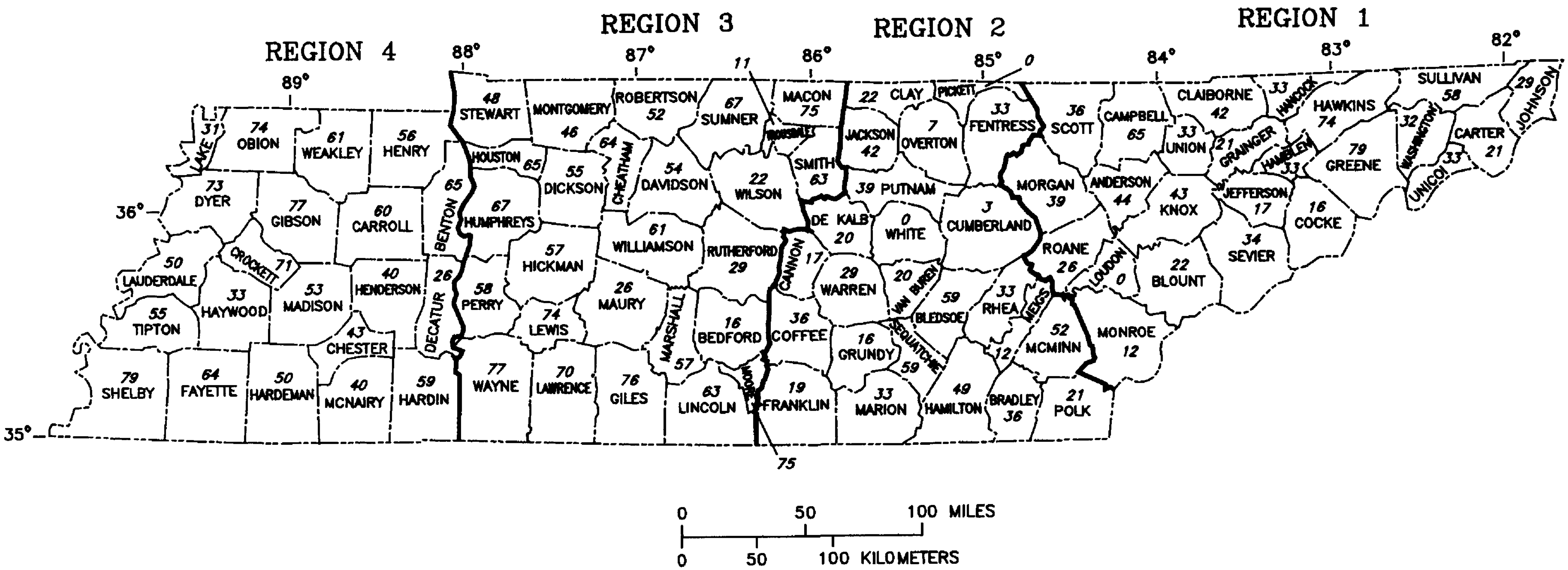


Figure 26. Ratio of number of channel-widening sites to total number of sites per county, expressed as a percentage, for counties in Tennessee Department of Transportation regions 1, 2, 3, and 4.

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GLOSSARY

Abutment. The end support or substructure for girder-span bridges.

Accretion. Accumulation of material on a surface, such as caused by sediment settling from a water column onto a channel bank or flood plain.

Aggradation (bed). A progressive buildup or raising of the channel bed due to sediment deposition.

Alluvium. Sediment deposited by a stream. "Unknown alluvium" in the Bridge Scour Data Base refers to the fact that the inspector was unable to determine the specific bed material at a site.

Blowhole. An overwidened and deepened section of the channel directly downstream of a bridge-related contraction of the channel.

Channelization. Straightening or deepening of a channel by engineering methods.

Channel gradient. Fall per unit length along the center line of a channel.

Channel instability. Changes in channel dimension, such as deepening, widening, or filling.

Channel morphology. The physical characteristics of a channel cross section, a river reach, or the drainage network of a given basin.

Confluence. The junction of two or more streams.

Contraction scour. Scour of the bed of a channel due to the acceleration of flow caused by channel constriction.

Crown closure. The overlapping of foliage of neighboring woody plants.

Crown cover. The surface area of the site covered by foliage of woody plants, such as trees and bushes.

Degradation (bed). A progressive lowering of the channel bed due to a change in the stream-discharge and sediment-load characteristics.

Energy grade line. An inclined line representing the total energy of a stream flowing from a higher elevation to a lower elevation.

Escarpment. A steep slope or cliff formed by erosion or faulting.

Fluvial erosion. Displacement of soil particles on the land surface due to water action.

Geomorphology. The systematic description and analysis of landscapes and the processes that change them.

Geophysical techniques. Methods that apply physical properties of the earth to geological problems.

Guide banks. A dike extending upstream, and in some cases downstream, to direct flow through the bridge opening.

Hectare. A unit of surface measure in the metric system, equal to 10,000 square meters.

Highway log mile. The distance from the beginning of a highway. As used in this report, highway log mile is the distance from the beginning of the highway moving in a northerly or westerly direction.

Hydrology. The science concerned with the occurrence, distribution, and circulation of water.

Kilometer squared. A unit of area measure with a total area representative of a square having sides of 1 kilometer in length.

Local scour. Scour that is localized at a pier, abutment, or other obstruction to flow.

Loess. Deposits of silt-size, previously wind-borne material.

Loess derived alluvium. Alluvial deposits having loess as a source.

Lower Cambrian quartzite. A hard, metamorphosed sandstone so firmly cemented that breakage occurs through the grains rather than between them and that occurs in stratigraphy of Early Cambrian period between 500 and 600 million years before present.

Mass wasting. Failure of a slope due to exceedance of material strength, resulting in movement of masses of material rather than a particle-by-particle detachment.

Meander. Windings or convolutions within a stream reach.

Observed scour. Scour at a bridge describable with data.

Ordovician limestones. Limestones laid down during the Ordovician period 430 to 500 million years before present.

Perturbation. Disorder caused by the interaction of objects, such as flowing water and bridge pier.

Potential scour. Scour that may occur due to the interaction of specified hydraulic and geomorphic variables.

Physiographic map. A map showing the exterior physical features of a specific geographic area.

Profile. The graphical description of the change in elevation of a channel bed progressing from the upstream to the downstream.

Quaternary sediments. Sediments deposited during the Quaternary period, from about 1.6 million years ago to the present.

Schematic cross section. A cross section having annotation identifying specific components of interest.

Scour. Erosion due to flowing water, usually considered to be localized as opposed to general bed degradation.

Spatial coverage. The extent or concentration of sites within an area of interest.

Stabilization. Elimination of or protecting against a destabilizing influence.

Stratigraphy. Arrangement in layers of rocks as to position and order of sequence.

Thalweg. A line extending down a channel that follows the lowest elevation of the bed.