GEOMORPHIC RESPONSE TO CHANNEL MODIFICATIONS OF SKUNA RIVER AT THE STATE HIGHWAY 9 CROSSING AT BRUCE, CALHOUN COUNTY, MISSISSIPPI

by K. Van Wilson, Jr. and D. Phil Turnipseed

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BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY
Robert M. Hirsch, Acting Director

For additional information write to:

District Chief
U.S. Geological Survey
100 W. Capitol St., Suite 710
Jackson, Mississippi 39269

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
feet per year (ft/yr)	0.3048	meter per year
foot (ft)	0.3048	meter
foot per mile (ft/mi)	0.1894	meter per kilometer
foot per second (ft/s)	0.3048	meter per second
inch (in.)	0.0254	meter
mile (mi)	1.609	kilometer
pound per cubic foot (lb/ft^3)	157.1	newton per cubic meter
pound per square foot (lb/ft^2)	47.88	newton per square meter
square mile (mi^2)	2.590	square kilometer

Mississippi Department of Transportation Datum: In this report, elevations are referenced to Mississippi Department of Transportation Datum (MDOTD)--a site-specific datum. At this site, elevations referenced to MDOTD are also to the National Geodetic Vertical Datum of 1929--a datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929 and referred to in this report as sea level.

DEFINITION OF TERMS

Terms used in this report are defined below.

Angle of internal friction -angle of the plane of contact of soil particles with the horizontal at the point of sliding (shearing); angle whose tangent is the coefficient of friction between the soil particles (Cernica, 1982).

Bulk-unit weight -ratio of the weight of the soil to the volume of the soil sample (Das, 1984).

Channel-bed aggradation -filling in of the channel because streamflows are not sufficient to transport the material delivered from upstream channel-bed degradation (Simon and Hupp, 1986a).

Channel-bed degradation -headward erosion of the channel bed, usually caused by increases in downstream channel gradient and cross-sectional area by man (Simon and Hupp, 1986a).

Cohesion -attraction of adsorbed water and soil particles that produce a body which holds together but deforms plastically at varying water contents (Sowers, 1979).

Factor of safety -ratio of the resisting force (shear strength of the soil) to the driving force (weight of the soil). If the resisting force is less than the driving force, the factor of safety is less than 1.0, and therefore, failure occurs (Huang, 1983).

Failure-block width -the measured width of the failure block or the distance between affected stems of woody plants growing in bank material that has failed and fallen down slope and the existing top-bank edge (Hupp, 1987).

Iowa Borehole Shear Test -direct measure of shear strength of fine- to medium-grained soils in situ (from inside a borehole) (Handy, 1981).

Knickpoint -an abrupt change in channel-bed elevation along a reach of channel relative to the upstream or downstream direction.

Moisture content -ratio of the weight of the water present to the weight of the soil solids (Das, 1984).

Planar failure -slides along a surface of rupture whereby the mass progresses down and out along a planar or gently-undulatory surface and has little rotational movement or backward tilting characteristics (Huang, 1983).

Rotational failure -landslide along a surface of rupture that is concave upward. The exposed cracks are concentric in plan and concave toward the direction of movement (Huang, 1983).

Shear strength -capacity of a soil to resist shear; in terms of effective stress, it can be given by the equation:

$$s' = c' + \sigma' \tan \phi'$$

where:

σ' is effective normal stress on plane of shear;

c' is effective cohesion or apparent cohesion of the soil; and

ϕ' is effective angle of internal friction (Das, 1984).

Slough-line angle -angle attained by projecting the slope of failed blocks of soil mass (which represents a temporary angle of stability) to its intersection with the top of channel bank (flood-plain level). It is used to determine short-term (10-20 years) bank widening (Simon and Hupp, 1986b).

Temporary angle of stability -the angle from the horizontal extended from the toe to the top of bank in which that bank at that given height is the most stable. It can be estimated by averaging the existing bank angle with the angle of internal friction of the bank material (Spangler and Handy, 1973).

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ABSTRACT

Skuna River at State Highway 9 at Bruce, Calhoun County, Mississippi, has geomorphically responded to channel modifications by lowering of the channel bed through degradation, which heightened and steepened channel banks and induced widening. Skuna River Canal (Skuna River) has typically degraded about 16.5 feet and widened about 150 feet from 1925 (when constructed) to 1992. Old Skuna River has degraded and widened about 11 feet and 40 feet, respectively, from 1921 to 1991. Skuna River Canal tributary has degraded about 6 feet from 1921 to 1991. Most of the geomorphic response on the Old River and the tributary seems to be a consequence of modifications of the canal. The bankfull discharge of the canal has increased about 1,450 percent, and the channel slope has decreased about 34 percent from 1925 to 1989. The bankfull stream power has been decreasing since 1980. The bankfull channel width-depth ratio has been increasing since 1975, which indicates the canal has been widening more than degrading since 1975. As much as 1 foot of additional degradation and 40 feet of additional widening are projected through 2010 on Skuna River Canal in the vicinity of State Highway 9. About 70 feet of additional widening could occur before the canal reaches quasi-equilibrium, which will likely be reached after 2010. If Old Skuna River and Skuna River Canal tributary degrade as much as the canal, which is doubtful, then about 6 and 11 feet of additional degradation could occur by 2010 on the Old Skuna River and the tributary, respectively, at State Highway 9. Old Skuna River and the tributary could both widen an additional 30 feet in the next 10 to 20 years. The channel low-stage thalweg of Skuna River Canal is beginning to meander around sandbars inducing lateral erosion of the channel banks. The widening projections in this report do not directly account for lateral erosion and are considered to be a minimum for the typical channel reach. Lateral erosion will likely have a significant effect on future widening processes at this site.

INTRODUCTION

The Mississippi Department of Transportation (MDOT) proposes to reconstruct the State Highway 9 crossing of Skuna River at Bruce, Miss. (fig. 1). Because substantial channel-bed degradation and channel-bank widening have occurred, and a bridge at this crossing collapsed in 1955 (see cover photo), the U.S. Geological Survey (USGS), in cooperation with the MDOT, conducted a study during 1988-93 of the geomorphic response to channel modifications of Skuna River.

Background

Many alluvial streams in Mississippi have been modified by engineering practices such as straightening, dredging, clearing, snagging, and dam construction to help alleviate flooding problems. Channel adjustments in response to these types of modifications have been shown to result in channel and bank instability and, in some cases, to contribute to bridge failure. Channel-bed and channel-bank instabilities in Mississippi streams have been documented by Wilson and Turnipseed (1989b), Watson and others (1986), Schumm and others (1984), Thorne and others (1981), and Wilson (1979).

Alluvial channels are dynamic and adjust naturally to altered conditions, such as changes in base level or climate. The rate of energy dissipation is at a minimum for an alluvial channel in dynamic equilibrium for unaltered conditions. If the channel is forced to deviate from its minimum rate of energy dissipation, the channel will adjust velocity and slope through changes in geometry (depth and width) or planform (meandering or sinuosity) so that the rate of energy dissipation will again be minimized. The rate at which these channels adjust is related to magnitude of discharge and channel gradient. The capacity of a stream to transport the sediment resulting from channel adjustment processes was termed "stream power" by Lane (1955), who proposed the following relation for dynamic equilibrium, which can be related to the minimum rate of energy dissipation:

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

where,

Q is channel discharge, in cubic feet per second;
S is channel gradient or slope, in feet per foot;
$\mathbf{Q_s}$ is bed-load discharge, in cubic feet per second; and
$\mathbf{D_{50}}$ is median grain size of bed load, in feet.

Under natural conditions, channel adjustments usually occur slowly. However, when stream conditions are altered by channelization (channel shortening and deepening), both **Q** and **S** can be dramatically increased. This results in increases in $\mathbf{Q_s}$ and the $\mathbf{D_{50}}$ of the transported bed-material, which, in turn, can cause rapid and

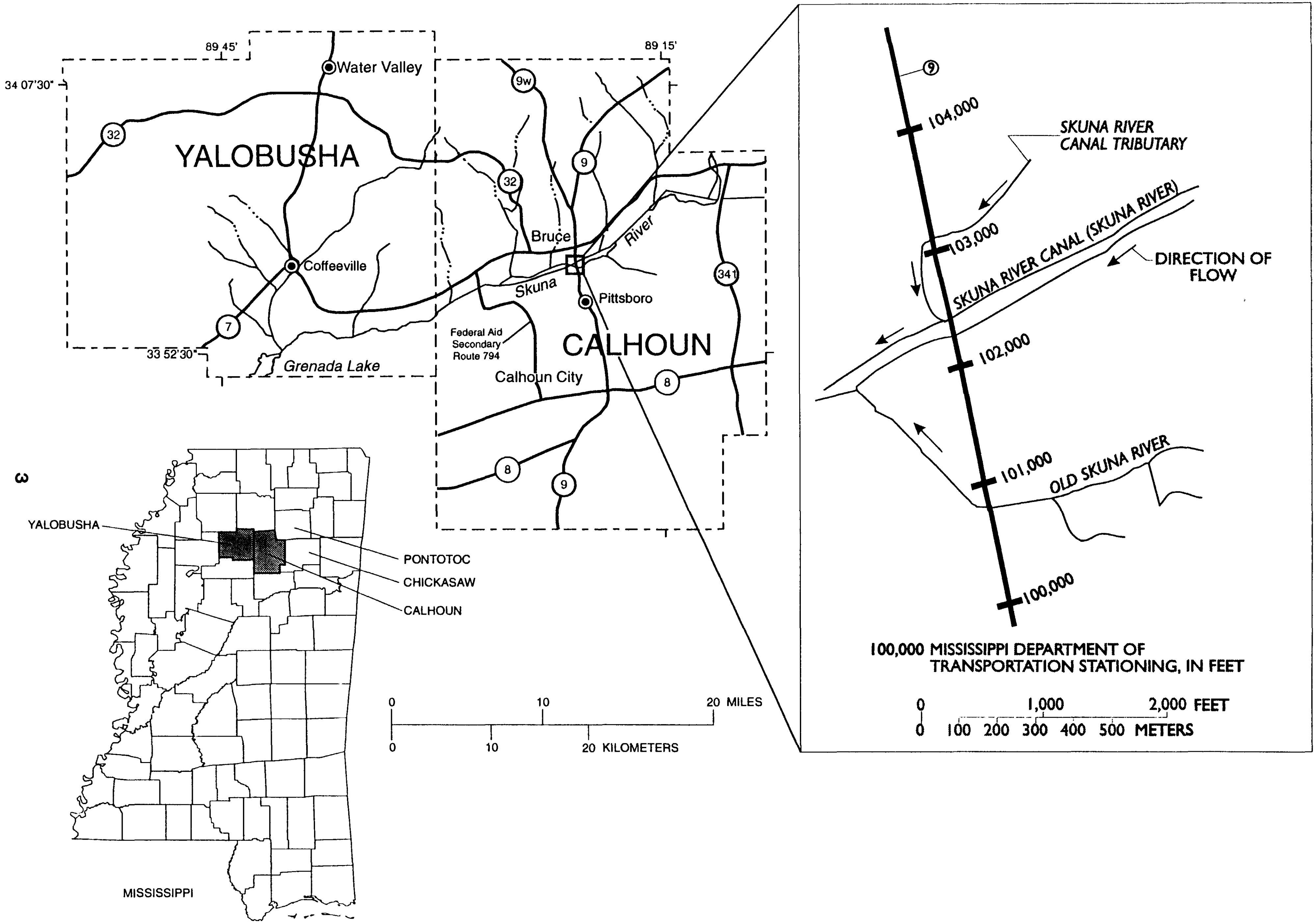

Figure 1.-- Location of Skuna River at State Highway 9 at Bruce, Mississippi.

significant morphologic change both upstream and downstream of the area of disturbance. In time, the channel adjustments tend to progress until the minimum rate of energy dissipation is achieved. Schumm and others (1984) determined that the period of time between the beginning of change and the establishment of a new state of quasi-equilibrium (relaxation time) was between 9 and 15 years for streams they studied in northwestern Mississippi. Simon and Hupp (1986a) determined, for streams in West Tennessee, that degradation migrates upstream and usually continues for 10 to 15 years at a site in response to channel modifications, and after 10 to 15 years of degradation at a site, a period of aggradation follows. Aggradation also progresses upstream with time and can continue for more than 20 years.

Purpose and Scope

This report describes past and present channel conditions of the Skuna River at State Highway 9 at Bruce, Miss., and presents the results of a study to determine the potential for future channel-bed degradation and channel-bank widening at the site. Past and present channel conditions were determined on the basis of field observations of channel-bed elevations, channel-bank failures, ages and types of trees on the channel banks, USGS gaging station records, and bulk-unit weights and shear-strength properties of bank material. This report is the ninth in a series of similar reports for selected stream crossings in Mississippi.

Approach

The potential for future degradation and widening for Skuna River at State Highway 9 at Bruce, Miss., was estimated as follows. The potential for future degradation of Skuna River Canal was estimated by using the trend of annual minimum stages at the State Highway 9 bridge as a log-linear relation with time. The potential for future widening was estimated by using: (1) the trend of channel widths as a log-linear relation with time; (2) a regional relation of bankfull width-depth ratio with drainage area, developed by Schumm and others (1984) for quasi-equilibrium streams; and (3) 1989 channel geometry and bulk-unit weights and shear-strength properties of bank material. Historical aerial photography was used to describe changes in channel pattern.

General Description of Skuna River

Skuna River flows southwestward through the Pontotoc Hills, Flatwoods, and the North Central Hills physiographic regions (Fenneman, 1938). The drainage area of Skuna River at State Highway 9 is 254 mi^2. The present (1993) length of the principal channel upstream of the State Highway 9 crossing is about 31 mi, and the average slope of the channel between points located at 10 and 85 percent of the length upstream of the crossing is about 3.6 ft/mi. The length and slope between points located 10 and 85 percent of the length of the principal channel upstream of the crossing, prior to construction of the canal in 1925, were estimated to be about 36 mi and 2.9 ft/mi, respectively, based on remnants of the Old River channel as shown on topographic maps. Average channel and valley slopes in the vicinity of the crossing are about 1.8 and 2.6 ft/mi, respectively. Skuna River flows into Grenada Lake about 34 mi downstream from the State Highway 9 crossing (fig. 1).

Channel-Bed Material Properties

The channel bed of Skuna River Canal in the vicinity of State Highway 9 is composed of uniform fine- to medium-sized sand with D_{50} of about 0.00101 ft, and the beds of the Old Skuna River and Skuna River Canal tributary are composed of sand and clay. As observed during field surveys conducted in 1989, the bed of the canal was composed mostly of loose sand, and one could push a survey rod as much as 2.5 ft below the existing bed surface. Also, a sand dune, 1.6 ft high with a downstream slope angle of 33 degrees, was present about 450 ft upstream from State Highway 9.

Channel-Bank Material Properties

Bulk-unit weight and shear-strength properties of the channel-bank material (table 1) were determined from borehole tests performed in 1989 on the left (south) bank of Skuna River Canal and on the left (south) bank of Old Skuna River about 70 and 100 ft, respectively, upstream from State Highway 9. An Iowa Borehole Shear Tester[1] (BST) (Handy and Fox, 1967) was used to determine the shear-strength properties of the soils. Shear-strength data obtained using the BST have compared reasonably well with results of triaxial shear-strength tests that have been made by the MDOT.

Channel Modifications of Skuna River

Skuna River has been modified substantially since about 1925 to improve runoff conditions for agriculture. Skuna River Canal was constructed through Calhoun County by Loosascoona River Drainage District No. 1 and Loosascoona River Drainage District No. 2, through Chickasaw County by Schoona Drainage District No. 1, Swamp Land District, and through Pontotoc County by Schoona Drainage District (Mississippi Board of Development, 1940a,b,c). All of the work in each county was completed at about the same time (Mississippi Board of Development, 1940c). From bridge plans (dated 1921) made available by the MDOT, the alignment of the proposed canal was shown, but not indicated as constructed. From additional bridge-maintenance records, the earliest date of the bridge construction was 1925. Therefore, it was assumed that the canal was finished in about 1925 when the State Highway 9 alignment was constructed.

The U.S. Army Corps of Engineers (COE) and the U.S. Soil Conservation Service (SCS) have also been involved in channel modifications of Skuna River. In 1957, the COE cleared and snagged the canal reach from State Highway 9 to about 8.1 mi

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1. The use of trade or product names in this report is for identification purposes only, and does not constitute endorsement by the U.S. Geological Survey.

Table 1.--Bulk-unit weight and shear-strength properties of channel-bank material from borehole tests in 1989 on the left (south) banks of Skuna River Canal and Old Skuna River about 70 and 100 feet, respectively, upstream from State Highway 9 at Bruce, Mississippi

[ft, feet; lb/ft^3, pounds per cubic foot; lb/ft^2, pounds per square foot]

General soil description	Borehole depth (ft)	Bulk-unit weight (lb/ft^3)			Moisture content during testing (percent)	Cohesion (lb/ft^2)	Angle of internal friction (degrees)
		Dry	Wet	Saturated[a]			
Left (south) bank of Skuna River Canal (Ground elevation is 258.7 ft[b])							
Orange-gray clayey silt	0-2.6	81	107	127	24	406	24
Stiff orange-gray clay	2.6-12.7	87	113	130	24	719	16
Gray clayey silt	12.7-15.7	89	114	128	23	0	22
Dense gray sand[c]	15.7-24.7	98	118	130	20	0	34
Loose gray sand[c]	greater than 24.7	102	128	128	26	0	32
Left (south) bank of Old Skuna River (Ground elevation is 257.6 ft[b])							
Orange-gray sand (with clay lenses)	0-15.6	94	116	128	23	82	33
Orange-gray silty clay	greater than 15.6	98	120	131	23	655	18

[a] Estimated

[b] Above Mississippi Department of Transportation Datum

[c] Determined based on information obtained from Mississippi Department of Transportation.

downstream. In 1965, about 11 mi downstream from State Highway 9, the COE shortened a 3.4-mi meandering channel reach to a 1.7-mi straight channel reach. In 1970, the COE cleared and reshaped the 1.7-mi channel reach and extended the channel-modification work upstream about 2.9 mi from the work done in 1965 (from COE records). In 1967-68, the SCS completed channel modifications of Skuna River in Calhoun County and 1.0 mi into Yalobusha County for a total canal reach of 22.8 mi. However, in the canal reach from 2.2 mi upstream to 1.3 mi downstream from the State Highway 9 bridge, SCS records indicate clearing and snagging but no excavation.

From aerial photographs dated Nov. 21, 1958, and August 28, 1969, channel modifications between these dates consisted of straightening of Old Skuna River upstream of State Highway 9 and construction of a diversion ditch, which diverts water from Old Skuna River into the Skuna River Canal about 0.2 mi downstream from the State Highway 9 crossing of the canal. These modifications were probably done in the mid-1960's, because the diversion ditch was already constructed in 1968, according to SCS records. Also, the MDOT realigned the Skuna River Canal tributary downstream of State Highway 9 in 1956, according to MDOT records.

Acknowledgments

The authors thank the members of the Mississippi Department of Transportation, Hydraulics Division, who provided bridge-inspection records and members of the Department's Soil Mechanics Laboratory, who assisted in the analysis of soil samples.

GEOMORPHIC RESPONSE TO CHANNEL MODIFICATIONS

Past, present, and probable geomorphic responses to channel modifications of Skuna River were determined using streamflow-gaging station records, channel cross sections, longitudinal streambed profiles, aerial photography, vegetation, and shear-strength properties of the channel-bank material. Channel cross-sectional evidence and botanical evidence of the past geomorphic response to channel modifications are presented. Geomorphic adjustment processes of channel- bed elevation, channel shape, channel pattern, bankfull discharge, channel slope, and bankfull stream power in the past are analyzed to better understand the probable adjustment processes that occur. The effects of these processes are analyzed by computing factors of safety for bank failures. The use of past geomorphic processes to project future responses (by 2010) could be negated by additional channel modifications or the occurrence of unusually large and destructive flooding, which could alter ongoing geomorphic processes.

Cross Sectional Evidence

Channel cross sections at the State Highway 9 bridges crossing Old Skuna River, Skuna River Canal, and Skuna River Canal tributary indicate these streams have responded to channel modifications by bed lowering (scour and degradation) and bank widening (fig. 2). The 1921, 1925, and 1955 sections in figure 2 were surveyed during low-flow conditions, but the 1973 and 1991 sections were determined from soundings taken during discharge measurements made by the USGS. The discharge for the 1973 and 1991 measurements had recurrence intervals between 5 and 10 years. The canal scoured and degraded as much as 29 ft from 1925 to 1991. Old Skuna River Canal and Skuna River Canal tributary scoured and degraded as much as 11 ft and 6 ft, respectively, from 1921 to 1991. The channels at these bridges widened because of unstable banks caused by scour and degradation.

Botanical Evidence

Botanical evidence of geomorphic response to channel modifications, such as trees or shrubs growing below bankfull level, indicate rates of channel-bed gradation and rates of channel-bank failures. Trees establish a root collar at the ground surface during germination (Simon and Hupp, 1986b). The thickness of sediment burial or the depth of exhumation relative to the root collar defines the degree of aggradation or degradation, respectively. Bank failures along unstable channel reaches may kill, tilt, or scar existing trees, and create fresh surfaces upon which trees may become established. When trees are tilted and not killed and the stem becomes inclined, eccentric growth, resulting in anomalous tree-ring series, and vertical sprouts (tilt sprouts) occur. Eccentric growth is easily determined from tree cross sections in which concentric-ring formation abruptly shifts to the eccentric because ring width is greater in the upslope direction than in the downslope direction. Eccentric ring patterns, tilt sprouts, and scars of tilted trees yield reliable dates (accurate within 1 year, often within one season) of bank failure (Hupp, 1987, 1988; Sigafoos, 1964). Dating of stems or straight trees that have become established on disturbed surfaces yields minimum ages for those surfaces (Simon and Hupp, 1986b).

Botanical data were collected by taking cross sections or increment borings of sprouts of tilted trees and of saplings and mature trees (such as cypress, alder, willow, sycamore, oak, cedar, ash, sweet gum, winged elm, and birch). These data were collected to better understand the degradation and widening processes which have occurred in response to channel modifications.

The amounts of sediment exhumed from the root collar of trees growing below bankfull level and channel-bed conditions were documented on the basis of field observations in 1989 (table 2). Analysis of the data presented in table 2 indicates that as much as 10 ft of degradation occurred by 1989 on Old Skuna River, and as much as 4 ft of degradation has occurred on the tributary in the vicinity of State Highway 9. The magnitude of the depth of exhumation is dependent on the age of the tree and the possibility that the tree has slipped downslope. The estimate of 8 to 10 ft of degradation about 70 ft downstream (table 2) is very interesting because of the discovery of a 2-ft-thick stratum of organic material, which was exposed in the face of the left (south) bank at about 8 to 10 ft above the existing channel bed. This stratum is most likely representative of the bottom of the swamp, which existed prior to the construction of

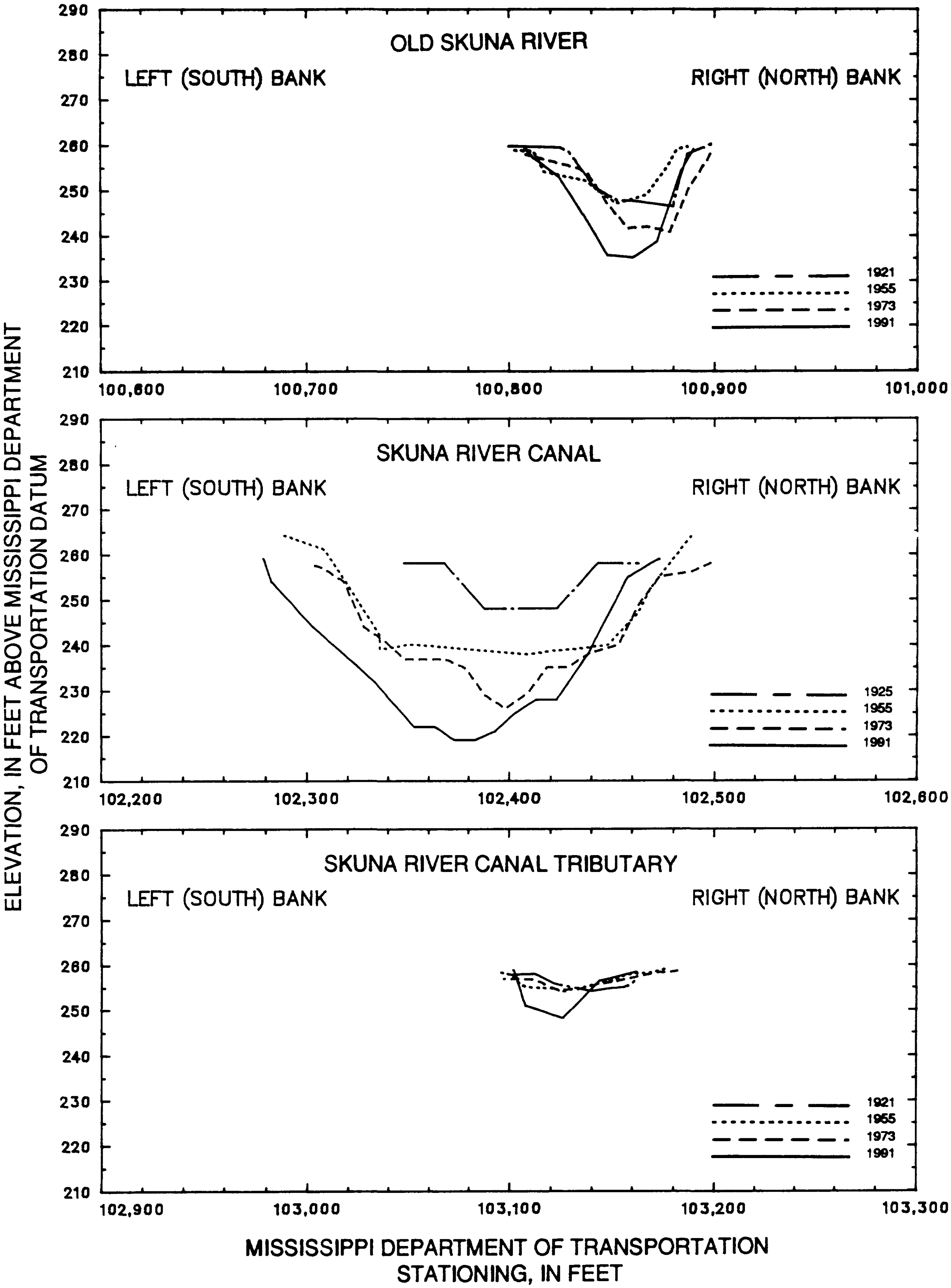

Figure 2.--Channel cross sections at the State Highway 9 bridges crossing Old Skuna River, Skuna River Canal, and Skuna River Canal tributary at Bruce, Mississippi.

Table 2.-- Botanical and geomorphic evidence of channel-bed degradation collected in 1989 on Old Skuna River and Skuna River Canal tributary in the vicinity of State Highway 9 at Bruce, Mississippi
[--, no data]

Distance from State Highway 9 (feet)		Degradation depth (feet)	Description of data
Upstream	Downstream		
		Old Skuna River	
130	--	6	Measured distance from channel bed to root collar of 105- to 110-year old cypress, which has slipped down the right bank.
150	--	2	2-foot-high knickpoint.
--	40	6-8	Measured distance from existing channel bed to top of knickpoints at mouths of ditches flowing into the Old River.
--	70	8-10	Measured distance from channel bed to 2-foot-thick stratum of organics exposed in the face of the left bank.
--	600	10	Measured distance from channel bed to root collar of mature alder.
--	700	6-7	Measured distance from channel bed to the root collar of a willow and sycamore, which slipped down the left bank, dated tilt sprouts 24 to 25 years old.
		Skuna River Canal tributary	
--	80	2	Measured distance from channel bed to root collar of 20-year old alder.
--	200	3-4	Measured distance from channel bed to root collar of mature trees.
--	300	3	Measured distance from channel bed to root collar of 1.5-foot-diameter willow.
--	500	2	2-foot-high knickpoint.
--	600	2	2-foot-high knickpoint.

the canal in about 1925. Swamp conditions were noted on MDOT bridge plans dated 1921. The two 2-ft-high knickpoints (table 2) on the tributary downstream of State Highway 9 and the 2-ft-high knickpoint on Old Skuna River upstream of State Highway 9 are evidence of the upstream progression of degradation. The knickpoints on the tributary are thought to be distorted because of an accumulation of failed bank material in the channel bed.

Stem-deformation ages associated with bank failure and the measurement of the distance between the root collar of the affected stems and the present bankfull edge, failure-block width, were documented based on field observations in 1989 (table 3). Also, vertical trees were dated on disturbed surfaces to determine the minimum age of the surface. Past bank failures were as wide as 15 ft on Old Skuna River, 25 ft on Skuna River Canal, and 20 ft on Skuna River Canal tributary (table 3). Established slough lines ranged from at least 6 to 12 years old. Slough-line angles ranged from 12 to 35 degrees and upper-bank angles ranged from 35 to 85 degrees (near vertical). For all three channels, where the fluvial erosion process is undercutting the base of the channel bank, the bank failures are more planar or pop-out type failures instead of rotational. Most typical bank failures appear to have been a mixture of rotational and planar failures. The lower to middle parts of the banks of Old Skuna River, and especially the canal, are experiencing sediment accretion around vegetation, which tends to provide additional support for the upper parts of the channel banks.

Channel-Bed Elevation

The channel bed of Skuna River Canal degraded about 4 ft from 1925 to 1990 at the Federal Aid Secondary Route 794, 16.5 ft from 1925 to 1992 at State Highway 9, and about 20 ft from 1925 to 1989 at State Highway 341 (fig. 3). The degradation was determined from design-bed elevations estimated from Loosascoona River Drainage District No. 2 plans, minimum-stage data from the COE gage at Federal Aid Secondary Route 794 and the USGS gage at State Highway 9, and average bed elevations obtained at State Highway 341.

The available annual minimum daily stages and minimum-bed elevations between 1925 and 1992 at State Highway 9 are shown in figure 4. Minimum channel-bed elevations at State Highway 9 are affected by local and constriction scour. Local and constriction scour are in addition to the ongoing degradation process and, therefore, are not representative of a typical channel reach. Minimum-bed elevations were computed by obtaining maximum flow depths from discharge measurements made at either the upstream or downstream side of the State Highway 9 bridge. The minimum-bed elevations at the bridge give an indication of the total scour occurring at the bridge, but do not sufficiently describe the degradation patterns for a typical channel reach of the canal. Therefore, the minimum-stage data were used for channel-gradation analyses. Generally, specific-gage data (using the water-surface elevation at a selected discharge) are used for channel-gradation analyses instead of minimum-stage data. However, minimum-stage data were used in this report because of the ease of obtaining the information. The minimum stages do not appear to be

Table 3.-- Botanical and geomorphic evidence of channel-bank widening collected in 1989 on Old Skuna River, Skuna River Canal, and Skuna River Canal tributary in the vicinity of State Highway 9 at Bruce, Mississippi

[--, no data]

Distance from State Highway 9 (feet)		Failure-block width (feet)		Description of data
Upstream	Downstream	Left (south) bank	Right (north) bank	
		Old Skuna River		
130	--	--	15	Tilted 105- to 110-year old cypress, eccentric growth indicated it slipped downslope about 20 years ago.
--	40	--	--	7- to 8-year old tilt sprout on willow on right lower bank.
--	200	20	--	15- to 20-year old vertical willow trees, indicating minimum age of failure surface.
--	200	--	--	Mature birch and mimosa, probably at least 30 years old, on mid-to upper right bank.
--	300	--	--	6-year old vertical birch on left bank and 25-year old willow on right bank.
--	500	--	--	Mature willows, at least 50 years old on upper right bank.
--	700	10	--	25-year old tilt sprout on willow and 24-year old tilt sprout on sycamore on left lower bank.
--	700	--	15	23-year old vertical birch, indicating minimum age of failure surface.

Table 3.-- Botanical and geomorphic evidence of channel-bank widening collected in 1989 on Old Skuna River, Skuna River Canal, and Skuna River Canal tributary in the vicinity of State Highway 9 at Bruce, Mississippi--Continued

Distance from State Highway 9 (feet)		Failure-block width (feet)		Description of data
Upstream	Downstream	Left (south) bank	Right (north) bank	
		Skuna River Canal		
700	--	3	--	Pecan tilted on upper left bank, no tilt sprouts. Left bank is being undercut by streamflows.
650	--	--	--	Left bank is being undercut by streamflows; no significant vegetation.
250	--	--	--	Vertical 10-year old sweet gum and 12-year old sycamore on mid-upper right bank.
200	--	--	10-12	Tilted 39- to 40-year old cedar on mid-bank slough line, looks like gradually slipped downslope; sand deposits on lower bank.
150	--	--	--	6-10 year old birch, alder, elm, sweet gum, and oak near base of right bank.
70	--	--	--	16- to 20-year old willows and sweet gums on mid-right bank. On lower-right bank slough line, 1.2 feet of sediment accretion on 11- to 12-year old birch and about 0.8 foot of sediment accretion on 6- to 8-year old alder.
--	100	--	--	On lower-left bank slough line, about 0.3 feet of sediment accretion on small sycamores.

Table 3.-- Botanical and geomorphic evidence of channel-bank widening collected in 1989 on Old Skuna River, Skuna River Canal, and Skuna River Canal tributary in the vicinity of State Highway 9 at Bruce, Mississippi--Continued

Distance from State Highway 9 (feet)		Failure-block width (feet)		Description of data
Upstream	Downstream	Left (south) bank	Right (north) bank	
		Skuna River Canal--Continued		
--	100	2	--	Vertical 6- to 7-year old sycamore and 6-year old willow on lower-left bank slough line; tilted oak on upper bank with no tilt sprouts.
--	400	--	25	6-year old birch and summack indicating minimum age of failure surface. Recent 0.5 foot of sediment accretion on slough line.
--	420	--	25	About 5- to 6-year old summack, birch, and willows growing on right slough line.
-	450	--	--	Vertical 15-year old sweet gum at base of upper right bank.
--	550	--	--	Vertical 5-year old willow growing on right bank slough line, 0.8 foot of sediment accretion above root collar.
--	800	--	8	Tilted oak at mid-right bank with no tilt sprouts. No significant vegetation on this bank, for about 100 feet upstream.
--	900	--	5-6	Tilted tree with no tilt sprouts.
		Skuna River Canal tributary		
--	20	5-6	--	Only grass and weeds on slough line.
--	400	20	--	Bank is mostly covered in kudzu and encroaches the downstream side of the State Highway 9 road embankment.

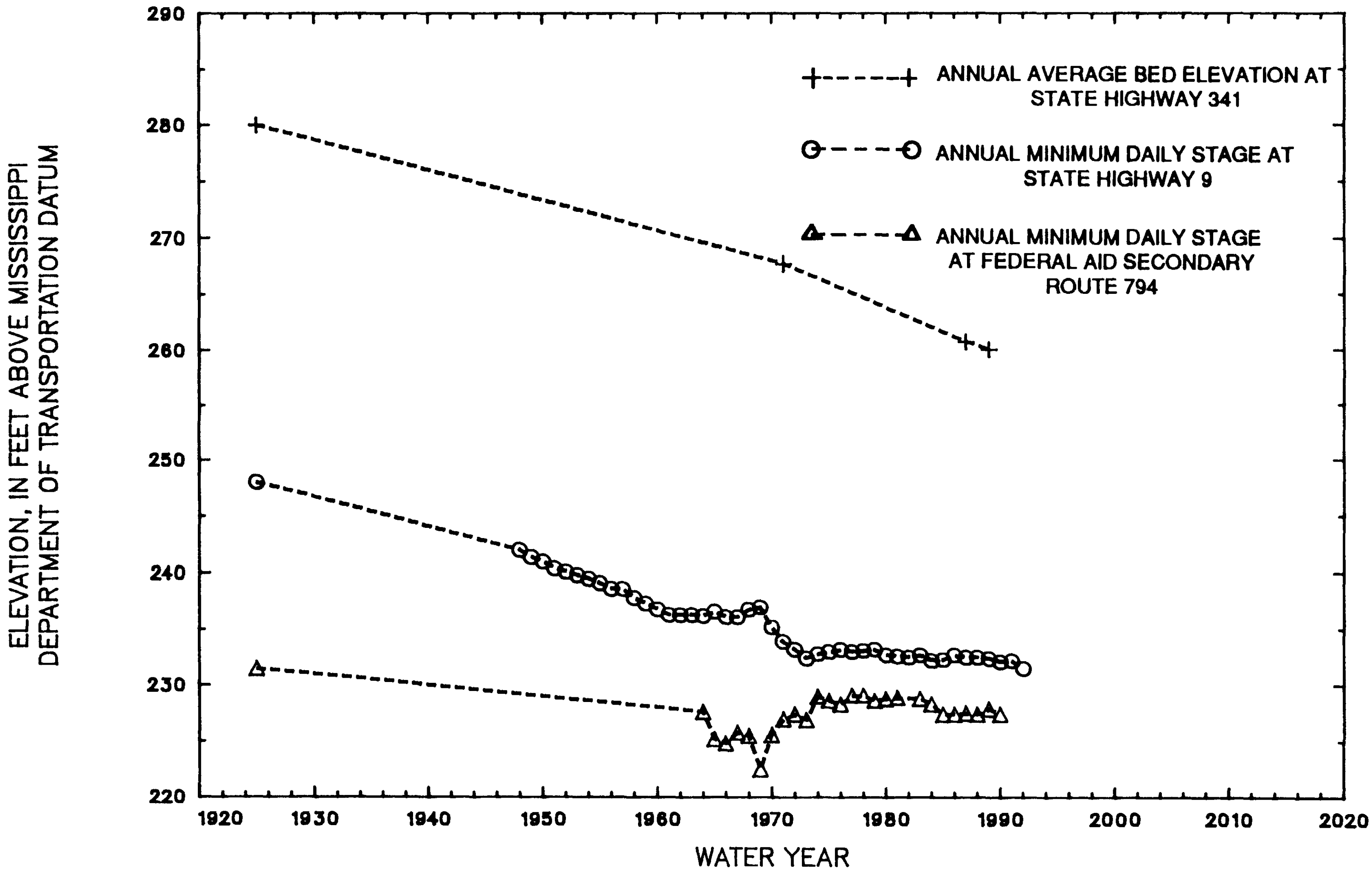

Figure 3.--Channel-bed elevation for Skuna River Canal at Federal Aid Secondary Route 794, State Highway 9, and State Highway 341.

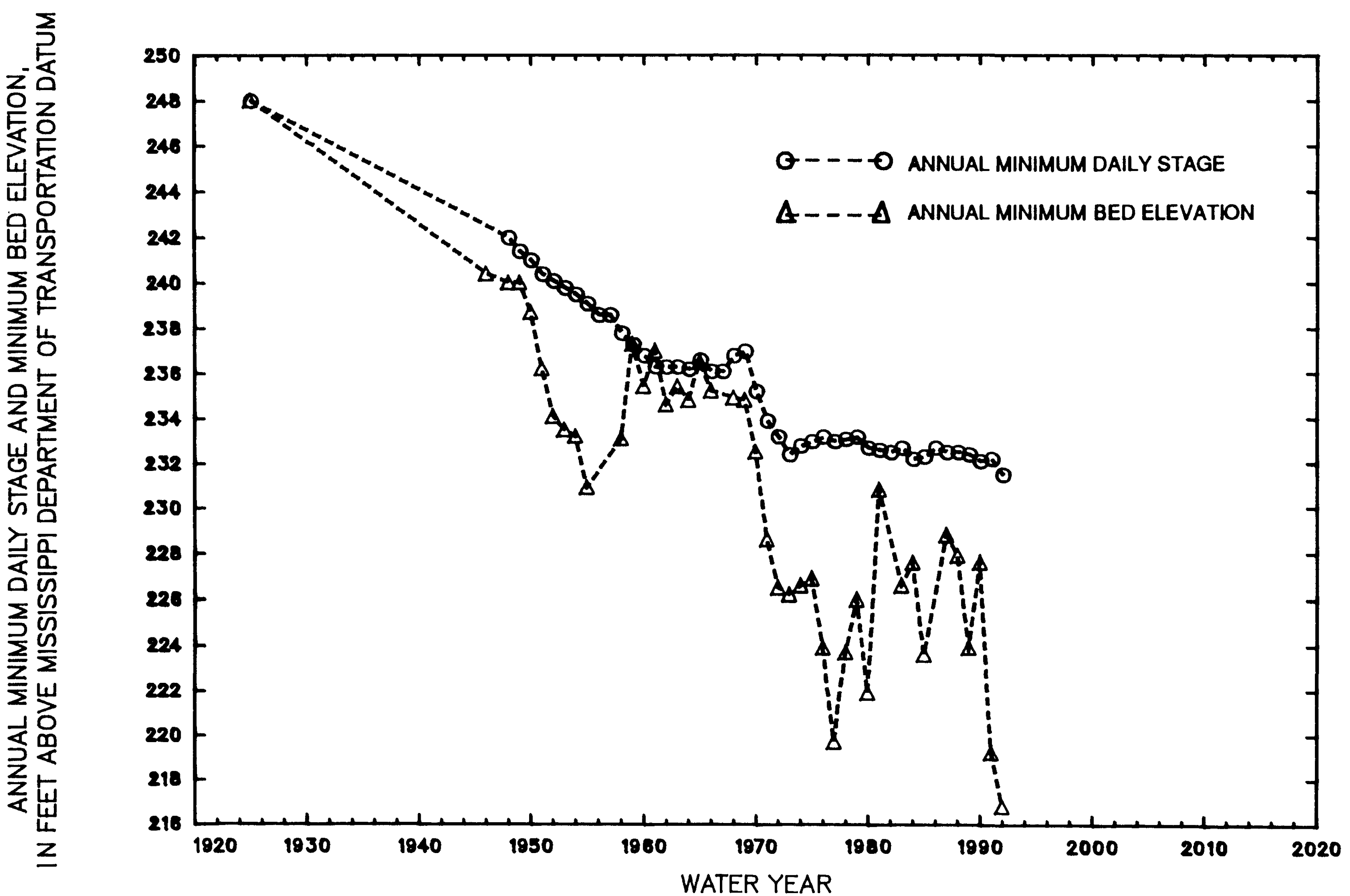

Figure 4.--Annual minimum daily stage and minimum bed elevation for Skuna River Canal at State Highway 9 at Bruce, Mississippi.

distorted by climatology, because minimum discharge did not vary enough to significantly affect the corresponding stage through the years of record (1948-92) as shown in figure 5. From 1925 to 1992, the canal degraded about 16.5 ft in the vicinity of State Highway 9, based on minimum-stage data, but scoured and degraded as much as 31.2 ft at the State Highway 9 bridge, based on minimum-bed data (fig. 4). The difference between 31.2 ft and 16.5 ft is 14.7 ft, which represents the sum of local and constriction scour that occurred at the State Highway 9 bridge.

Channel gradation processes on alluvial streams undergoing morphologic change in response to channel modifications generally start at an accelerated rate and diminish. Studies of channel-gradation processes on alluvial streams have shown that channel-bed elevation can be expressed as a power function with time (Simon and Hupp, 1986a) in the general form:

$$\mathbf{E = at^b} \tag{2}$$

where

- **E** is elevation of the channel bed, in feet above sea level;
- **a** is regression constant, indicative of channel-bed elevation prior to the onset of the gradation process in response to channel modification, in feet above sea level;
- **t** is time in years since the beginning of the gradation process (t=1 during the first year of channel adjustment); and
- **b** is regression coefficient indicative of the rate of the gradation process (negative for degradation and positive for aggradation).

Datums other than sea level for E in equation 2 may be used for convenience (for example, when sea level datum is not readily available at a site), but this will affect values of **a** and **b**. If elevations above the assumed datum are greater than the elevations obtained when referenced to sea level datum, the value of **a** will increase, but the absolute value of **b** will decrease. Conversely, if elevations above the assumed datum are less than elevations obtained when referenced to sea level datum, the value of **a** will decrease but the absolute value of **b** will increase. Also, by varying the datum, an imposed logarithmic offset for log-linear relation will change; thus, in some cases, improving or worsening the log-linear statistical fit of data points. In previous studies, the effects of channel-bed elevations on gradational trends were analyzed by varying the datum of the study sites; the analysis indicated no significant effects on gradation estimates. Elevations in this report are referenced to MDOT Datum.

Log-linear relations were computed for the periods 1925-48, 1948-57, 1957-67, and 1969-2010 (fig. 6). On the basis of the log-linear relation for 1969-2010, about 1 ft of additional degradation will occur by 2010. Prior to 1948, the channel bed was mostly composed of silt and clay; after about 1948, degradation lowered the bed below an elevation of 243 ft where sand exists, according to the soil borings of bank material (table 1). The relation of available bed elevations and minimum stages with time

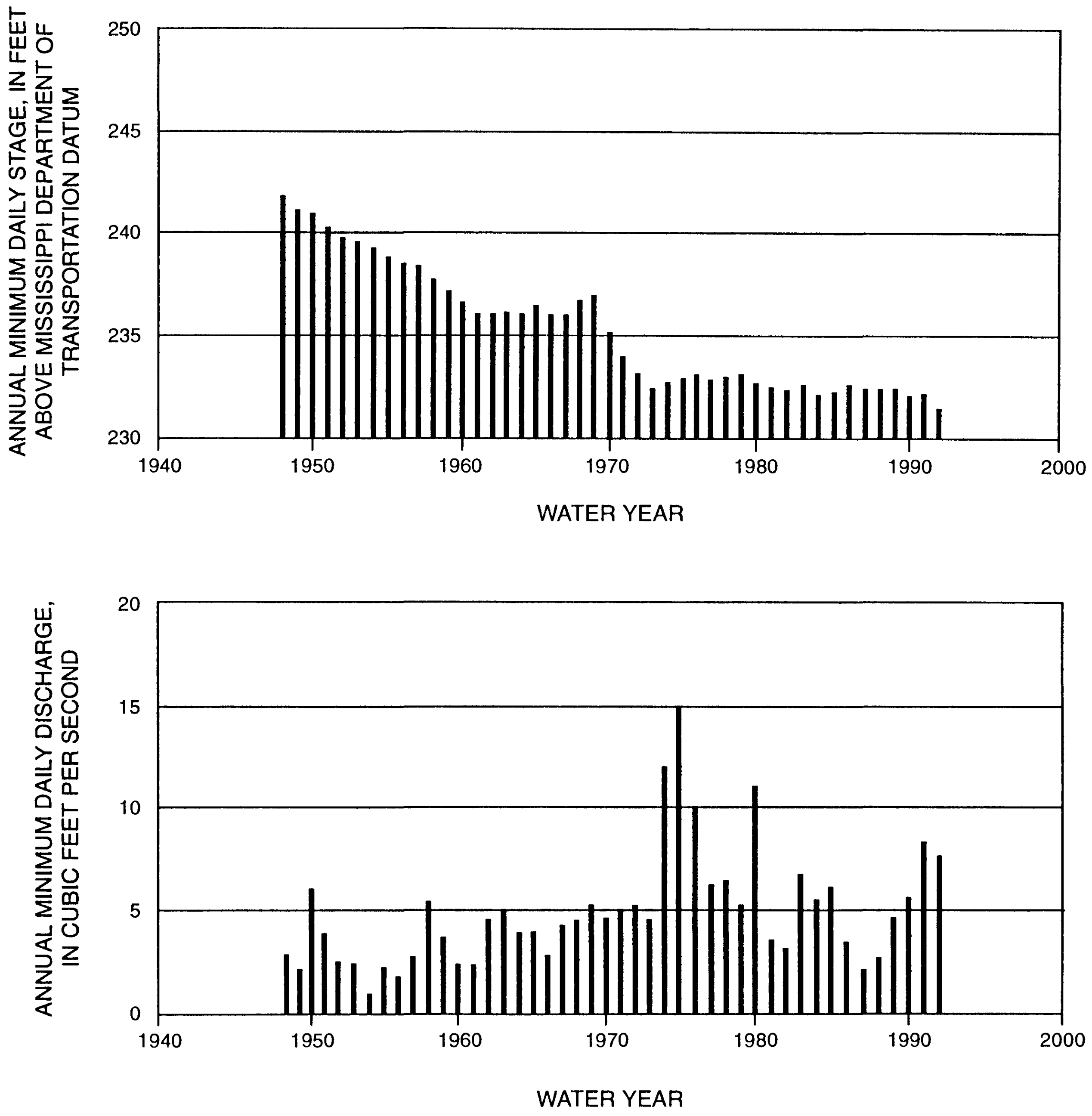

Figure 5.-- Annual minimum daily stage and discharge for Skuna River Canal at State Highway 9 at Bruce, Mississippi.

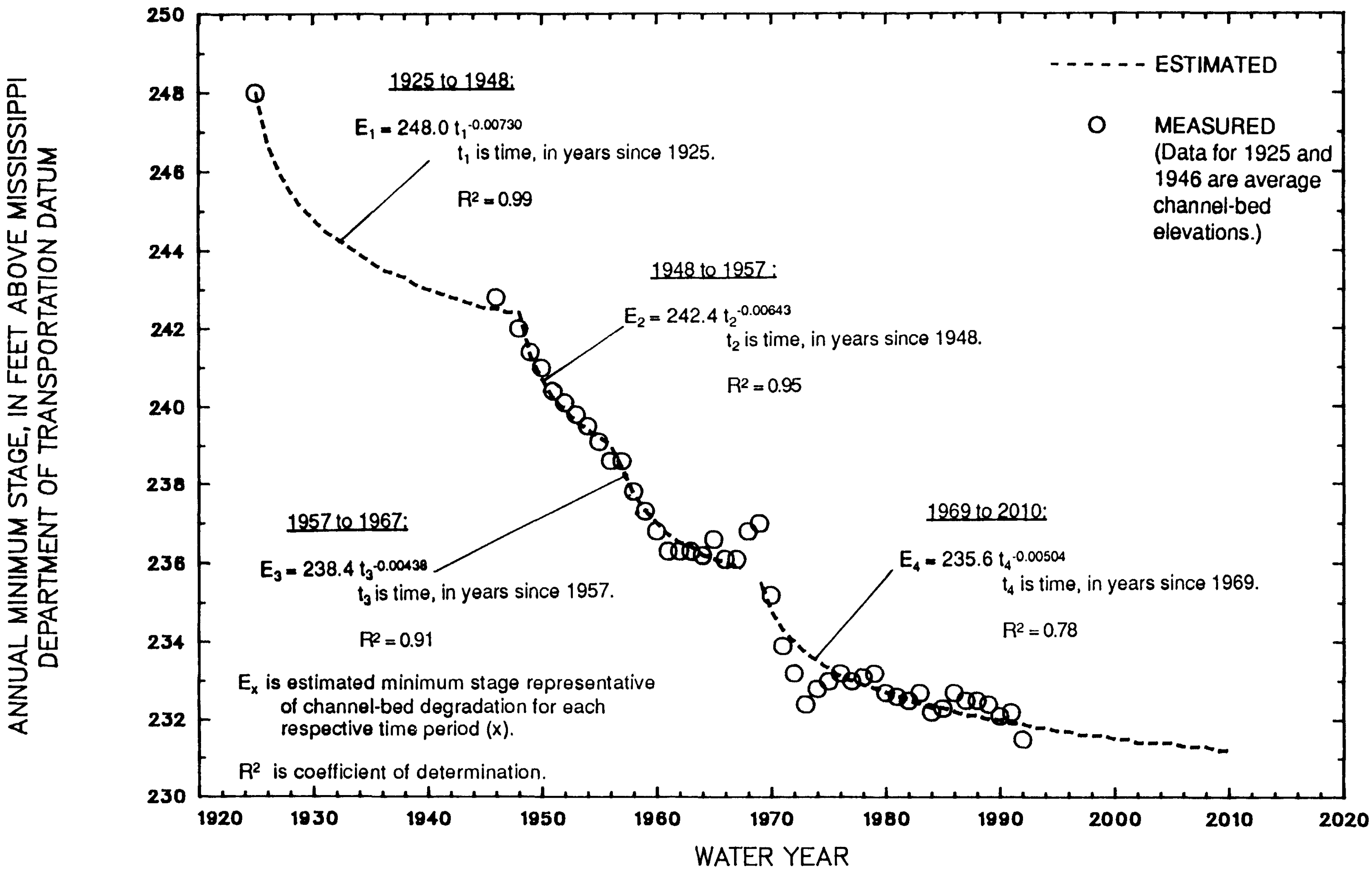

Figure 6.--Estimated patterns of channel-bed degradation on Skuna River Canal at State Highway 9 at Bruce, Mississippi.

indicated a break in the degradation process in 1948, which probably is due to the different channel-bed material. Therefore, the period 1925-57 was subdivided into the sub-periods 1925-48 and 1948-57. The time periods of 1957-67 and 1969-2010 were chosen because of the modifications done in 1957 and 1967-68, respectively.

The limited channel-bed elevations indicate Old Skuna River and Skuna River Canal tributary at State Highway 9 have degraded about 11 ft and 6 ft, respectively, from 1921 to 1991. Both streams have responded to modifications of their channels, but have mostly responded to the canal's geomorphic response to modifications. Limited bed elevations indicate a considerable time lag between the geomorphic response of these two streams and the canal. For instance, when the canal degraded 15.9 ft from 1921 to 1973, Old Skuna River degraded about 4 ft, and the tributary did not significantly degrade. From 1973 to 1991, when the canal did not significantly degrade, Old Skuna River degraded about 7 ft, and the tributary degraded about 7 ft. If Old Skuna River and the tributary degrade as much as the canal degrades, then Old Skuna River and the tributary could degrade an additional 6 ft and 11 ft, respectively. As shown in previous studies by Wilson and Turnipseed (1989a, 1993), it is unlikely these two streams will degrade as much as the canal by 2010.

Channel Shape

Channel shape is described in this report using the bankfull depth (**D**), bankfull width (**W**), and bankfull width-depth ratio (**W/D**) of the channel cross section. The depth of the canal was determined by subtracting the minimum recorded stage elevations from a bankfull elevation of about 258 ft in the vicinity of State Highway 9. The canal widths at the State Highway 9 bridge and for a typical channel reach (excluding State Highway 9) were obtained from the drainage district plans, USGS and MDOT field surveys, and aerial photographs. The canal widths at the State Highway 9 bridge were obtained from cross sections surveyed at the bridge. The typical canal widths were obtained from typical cross sections surveyed away from the bridge or were obtained from aerial photographs for a channel reach extending about 1,000 ft upstream and downstream of the State Highway 9 bridge. Where a decrease in width is indicated, the change in channel width is representative of measurement error and is not indicative of actual decrease in channel width. The relation between channel depth and width indicates that an increase in depth by degradation precedes channel widening as a result of toe undercutting and bank failure (Schumm and others, 1984). As previously described, the channel bed of the canal degraded, which in turn increased the depth, which heightened and steepened the channel banks and induced channel widening through time (figs. 7, 8). The bed-level equations (eq. 2), previously discussed, were used to determine the corresponding channel depth relations with time. Channel-width data for a typical channel reach of Skuna River Canal were used to develop a power function of bankfull channel width with time, a technique used by Wilson and Turnipseed (1989b, 1993), in the general form:

$$\mathbf{W = ct^d} \tag{3}$$

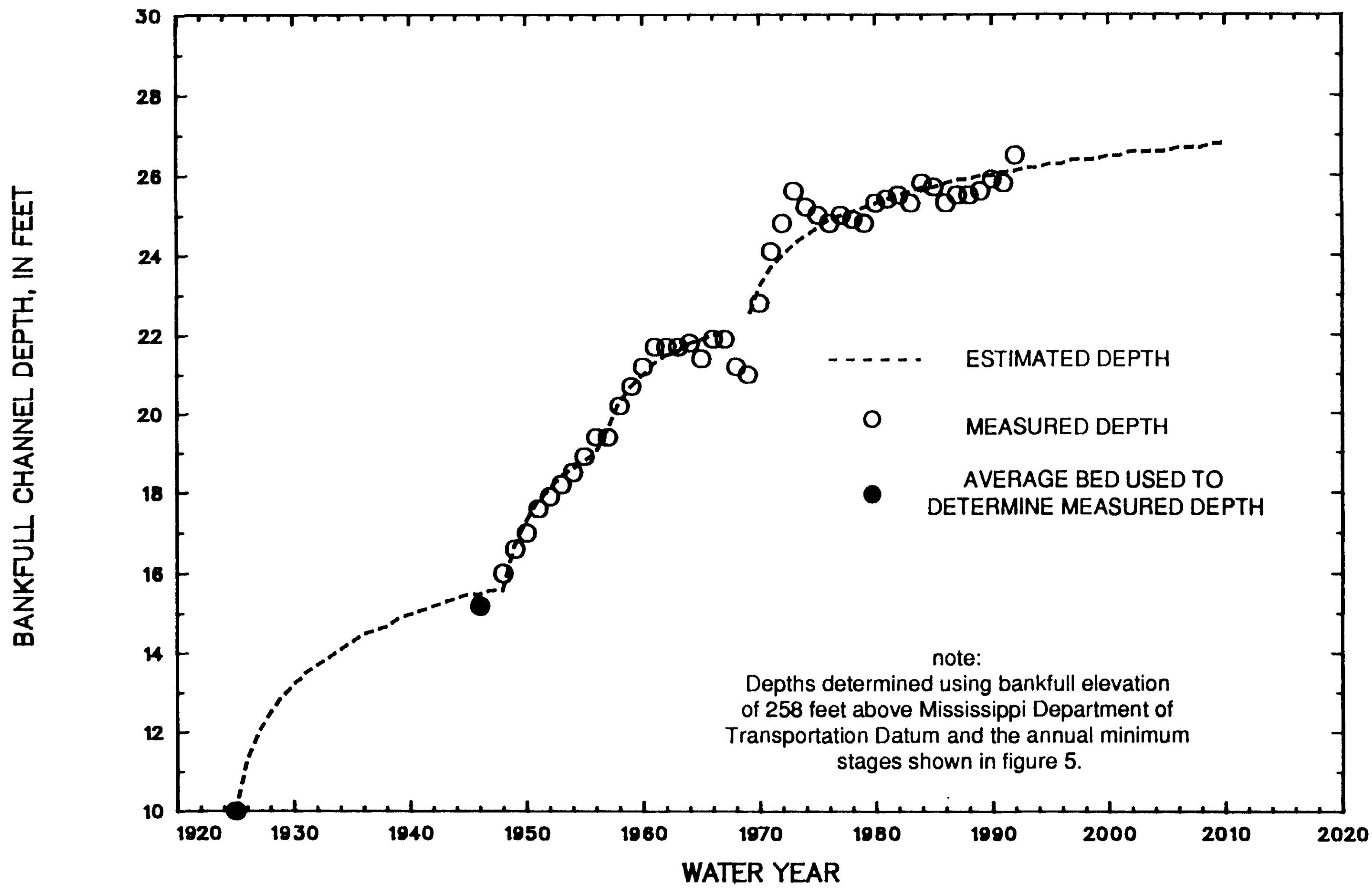

Figure 7.--Estimated patterns of channel deepening on Skuna River Canal at State Highway 9 at Bruce, Mississippi.

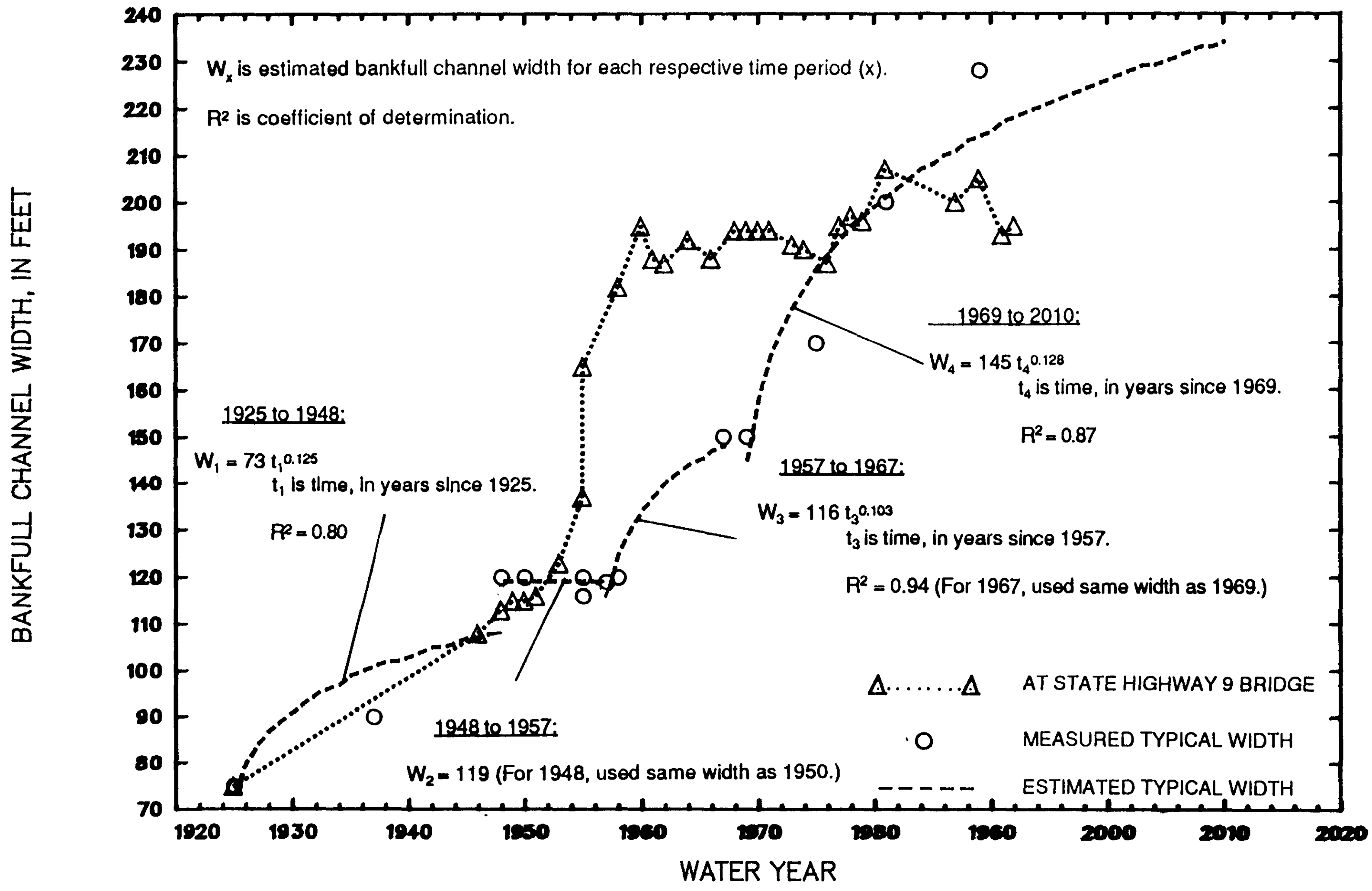

Figure 8.--Estimated patterns of channel-widening on Skuna River Canal at State Highway 9 at Bruce, Mississippi.

where

- **W** is bankfull channel width, in feet;
- **c** is regression constant indicative of bankfull width prior to the onset of widening processes in response to channel modification, in feet;
- **t** is time, in years since beginning of the widening process ($t=1$ during the first year of channel adjustment); and
- **d** is regression coefficient indicative of the rate of widening.

The canal widening relations were approximated using the same time periods as used for the bed-level and depth relations. Bankfull channel width typically has increased from about 75 ft in 1925 to 228 ft in 1989 for a total widening of about 150 ft (rounded to nearest 10 ft). The average channel width in the vicinity of State Highway 9 increased about 45 ft from 1925 to 1948, did not significantly increase from 1948 to 1957, increased about 30 ft from 1957 to 1967, and increased about 78 ft from 1969 to 1989 (reasonably representative of 1993 width). For the State Highway 9 bridge, the channel width increase of about 50 ft (fig. 8) was induced during the March 1955 flood, when debris caught on the bridge and the bridge collapsed. The bridge collapsed due to past degradation and widening and the additional local and constriction scour caused by the debris within the bridge opening. As shown in figure 8, there has not been a significant increase in width at the bridge since about 1960. The MDOT placed riprap and old car bodies on the left (south) bank at the bridge in about 1980, and the bank seems to have held in place fairly well (fig. 9). The log-linear relation of channel width with time for 1969 to 2010 indicates about 6 ft of additional widening will occur on the average by 2010 (fig. 8). The relation of width with time from 1969 to 1989 appears to be linear with an average widening rate of 4.0 ft/yr (fig. 8). On this basis, as much as 90 ft of additional widening could occur by 2010. This estimate is likely conservative because widening processes have been shown to decrease with time.

The channel widths and depths were used to compute **W/D** for the typical channel reach of Skuna River Canal in the vicinity of State Highway 9 (fig. 10). A trend reversal of **W/D** can indicate a change in the channel adjustment process. Simon and Hupp (1986a, 1991), in a study of West Tennessee streams, and Schumm and others (1984), in a study of northwestern Mississippi streams, used **W/D** to analyze channel adjustment processes. The measured **W/D** for the canal typically decreased from 7.5 to 5.9 from 1925 to 1958, increased to 7.1 in 1969, decreased from 7.1 to 6.8 in 1975 and increased to 8.9 in 1989 (fig. 10). From 1969 to 1975, width and depth increased 20 ft and 4 ft, respectively; from 1975 to 1989, width increased 58 ft, but depth only increased 0.6 ft. The widening process from 1975 to 1989 apparently did not depend as much on depth as it did prior to 1969. The bankfull channel width-depth ratio has been increasing since 1975, which indicates the canal has been widening more than degrading since 1975. Although the channel is not degrading significantly, the channel is widening due to bank failures caused by steep high banks and by lateral erosion undercutting the banks. Using the degradation and widening log-linear relations for the time period 1969-2010,

June 15, 1989 (Stage is 249.4 feet above Mississippi Department of Transportation Datum.)

March 23, 1989 (Stage is 234.6 feet above Mississippi Department of Transportation Datum.)

Figure 9.--Old car bodies on the upstream left (south) bank of Skuna River Canal at State Highway 9 at Bruce, Mississippi.

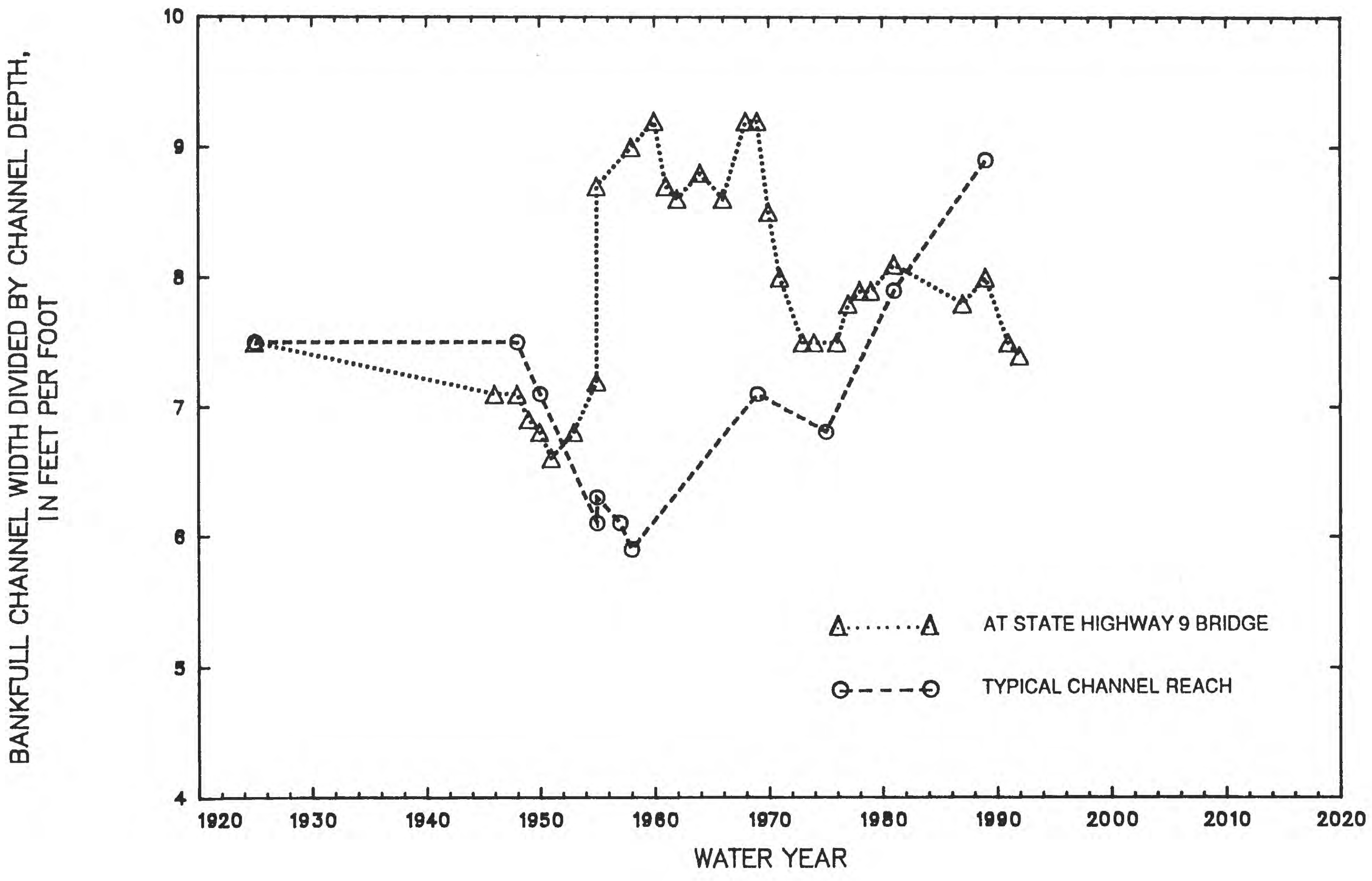

Figure 10.--Bankfull channel width divided by channel depth for Skuna River Canal at State Highway 9 at Bruce, Mississippi.

the projected **W/D** for 2010 is about 8.7. Schumm and others (1984) developed a regional relation of **W/D** with drainage area for quasi-equilibrium channel reaches of northwestern Mississippi streams. Using the regional relation (Schumm and others, 1984) at the canal (drainage area of 254 mi^2), the **W/D** for quasi-equilibrium channel conditions is about 11.0. The projected depth of 26.8 ft for 2010 multiplied by 11.0 results in a width of about 295 ft, which suggests about 70 ft (rounded to nearest 10 ft) of additional widening will occur before the canal width reaches quasi-equilibrium. Quasi-equilibrium will probably be attained after 2010 if the widening processes follow the normal pattern of diminishing with time.

The limited channel cross sections were used to estimate channel widening that has occurred since 1921 on Old Skuna River and Skuna River Canal tributary. Old Skuna River has widened about 40 ft since 1921, but total widening that has occurred since 1921 on Skuna River Canal tributary could not reasonably be determined because of a poorly defined channel.

Estimates of near-future (10 to 20 years) bank widening were obtained by projecting the streambank slough-line angle on a plotted streambank profile, a technique developed by Simon and Hupp (1986b), or by projecting a temporary angle of stability, a technique developed by Spangler and Handy (1973). Projection of this slough-line angle on the banks was used where conditions were fairly stable and vegetation was well established. On banks where a slough line has not developed, a temporary angle of stability was estimated by averaging the angle of internal friction of the bank material and the existing bank angle. The angles were extended at surveyed channel cross sections and individual streambank profiles (table 4). Channel cross sections of the canal located about 500 ft upstream, 250 ft upstream, 60 ft downstream, and 850 ft downstream from State Highway 9 were surveyed by the USGS and the MDOT in 1989 and were considered to be representative of conditions in 1993, except for some minor failures. Photographs of Skuna River Canal upstream and downstream of State Highway 9 are shown in figure 11. By extending the slough-line angle or temporary angle of stability, the bankfull channel width could increase as much as 36 ft on Skuna River Canal and 31 ft on both Old Skuna River and Skuna River Canal tributary (table 4). Rounding to the nearest 10 ft, Skuna River Canal could widen an additional 40 ft, and Old Skuna River and Skuna River Canal tributary could both widen an additional 30 ft in the next 10 to 20 years (by 2010). Bankfull channel width for Skuna River Canal could increase a total of about 23 ft, 25 ft, 21 ft, and 2 ft at the cross sections surveyed about 500 ft upstream, 250 ft upstream, 60 ft downstream, and 850 ft downstream from State Highway 9, respectively. For Old Skuna River, the bankfull channel width could increase a total of about 31 ft at the cross section surveyed about 130 ft upstream from State Highway 9 (table 4). These widening projections are considered minimums because lateral erosion is undercutting the base of the channel banks, and projections of the amount of lateral erosion were not determined in this report.

Table 4.-- Estimates of near-future (10 to 20 years) channel-bank widening for Old Skuna River, Skuna River Canal, and Skuna River Canal tributary in the vicinity of State Highway 9 at Bruce, Mississippi

[--, no data; S, slough-line angle extended; T, temporary stability angle extended]

Distance from State Highway 9 (feet)		Projected near-future widening				
		Left (south) bank		Right (north) bank		Total
Upstream	Downstream	Angle (degrees)	Distance (feet)	Angle (degrees)	Distance (feet)	distance (feet)
		Old Skuna River				
130	--	16 (S)	26	27 (S)	5	31
		Skuna River Canal				
650	--	27 (T)	18	--	--	--
500	--	22 (S)	12	21 (S)	11	23
250	--	52 (T)	10	18 (S)	15	25
200	--	--	--	22 (S)	5	--
--	60	22 (S)	16	18 (S)	5	21
--	400	--	--	12 (S)	36	--
--	420	--	--	23 (S)	10	--
--	450	--	--	30 (S)	2	--
--	500	--	--	30 (S)	9	--
--	800	--	--	32 (T)	15	--
--	850	17 (T)	0	44 (T)	2	2
		Skuna River Canal tributary				
--	20	22 (S)	12	--	--	--
--	400	18 (S)	31	--	--	--

View upstream of State Highway 9

View downstream of State Highway 9
(Stage is 233.0 feet above Mississippi
Department of Transportation Datum.)

Figure 11.--Views upstream and downstream of the State Highway 9 crossing of Skuna River Canal at Bruce, Mississippi, February 20, 1992.

Channel Pattern

Channel pattern is used in this report to describe the plan view of a reach of river as seen from above, and includes meandering, braiding, or relatively straight channels. The changes of channel pattern through time for Skuna River Canal were determined using a technique used by Turnipseed and Smith (1992) in their study of the Pearl River in Mississippi. Tops of the canal's banks were delineated on historical black-and-white aerial photographs and transferred with an Aus Jena Sketchmaster to scale-stable material overlain on acetate-film positives of USGS 7.5-minute quadrangle maps. A geographic information system (GIS) provided a means of storing, referencing, and displaying the tops of channel banks through time and, therefore, displaying the changes of channel pattern through time. Skuna River Canal at bankfull stage presently (1993) remains relatively straight (small sinuosity) in the vicinity of the State Highway 9 bridge. However, the low-stage channel is developing alternate sandbars and the low-stage thalweg, defined by field surveys in 1989, meanders around the sandbars in a sinuous fashion (fig. 12). The meandering of the channel thalweg causes lateral erosion of the base of outside banks, which steepens and causes localized bank instability. According to Osman and Thorne (1988), the relative amount of lateral erosion is a function of bank material properties, bank geometry, type of bed material, and streamflow characteristics. As with other geomorphic responses to channel modifications, channel patterns will adjust to the changes in stream power.

Bankfull Discharge

The geomorphic response to channel modification has a significant effect on the bankfull discharge capacity, which, in turn, affects overbank flooding. The bankfull discharge of the Skuna River Canal was determined for each year of gage record by using a stage of 258 ft (about bankfull stage near State Highway 9) with the stage-discharge relation for each year. As illustrated in figure 13, the capacity of the canal has substantially changed since its construction in about 1925. From 1925 to 1992, bankfull discharge increased about 1,450 percent. Bankfull discharge increased from about 1,900 to 5,000 ft^3/s from 1925 to 1948, about 5,000 to 6,370 ft^3/s from 1948 to 1957, and about 6,370 to 13,000 ft^3/s from 1957 to 1969. However, for the period of record 1969-92, the bankfull discharge increased from 13,000 to 38,600 ft^3/s from 1969 to 1980, remained at about 38,600 ft^3/s from 1980 to 1988, and based on recent measurements, decreased from 38,600 to 29,400 ft^3/s from 1988 to 1992. During the period 1980-88, no discharge measurements were obtained at stages above 250 ft to determine a revision of bankfull discharge; therefore, the bankfull discharge was assumed constant. The bankfull discharge probably was decreasing from 1980 to 1988. The combination of change in cross-sectional area, velocity, hydraulic radius, slope, and roughness has affected the discharge capacity of the channel. Through the years, the occurrence of overbank flooding on Skuna River has been reduced (fig. 14). For the period 1949-68, the annual peak stage exceeded bankfull stage of 258 ft for 15 of 20 years; however, for the period 1969-92, the annual peak stage exceeded bankfull stage

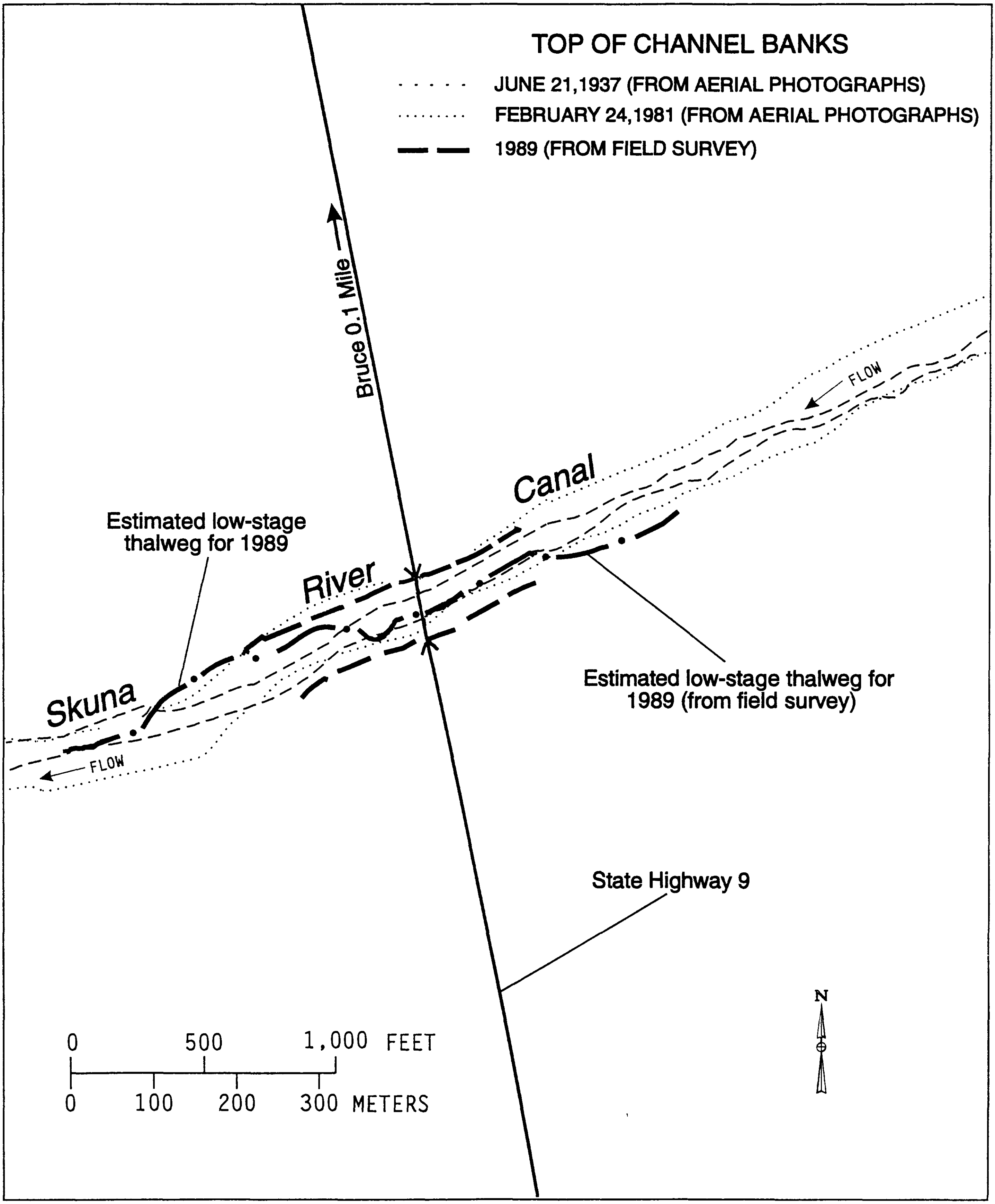

Figure 12. --Historical changes in channel pattern of Skuna River Canal in the vicinity of State Highway 9 at Bruce, Mississippi.

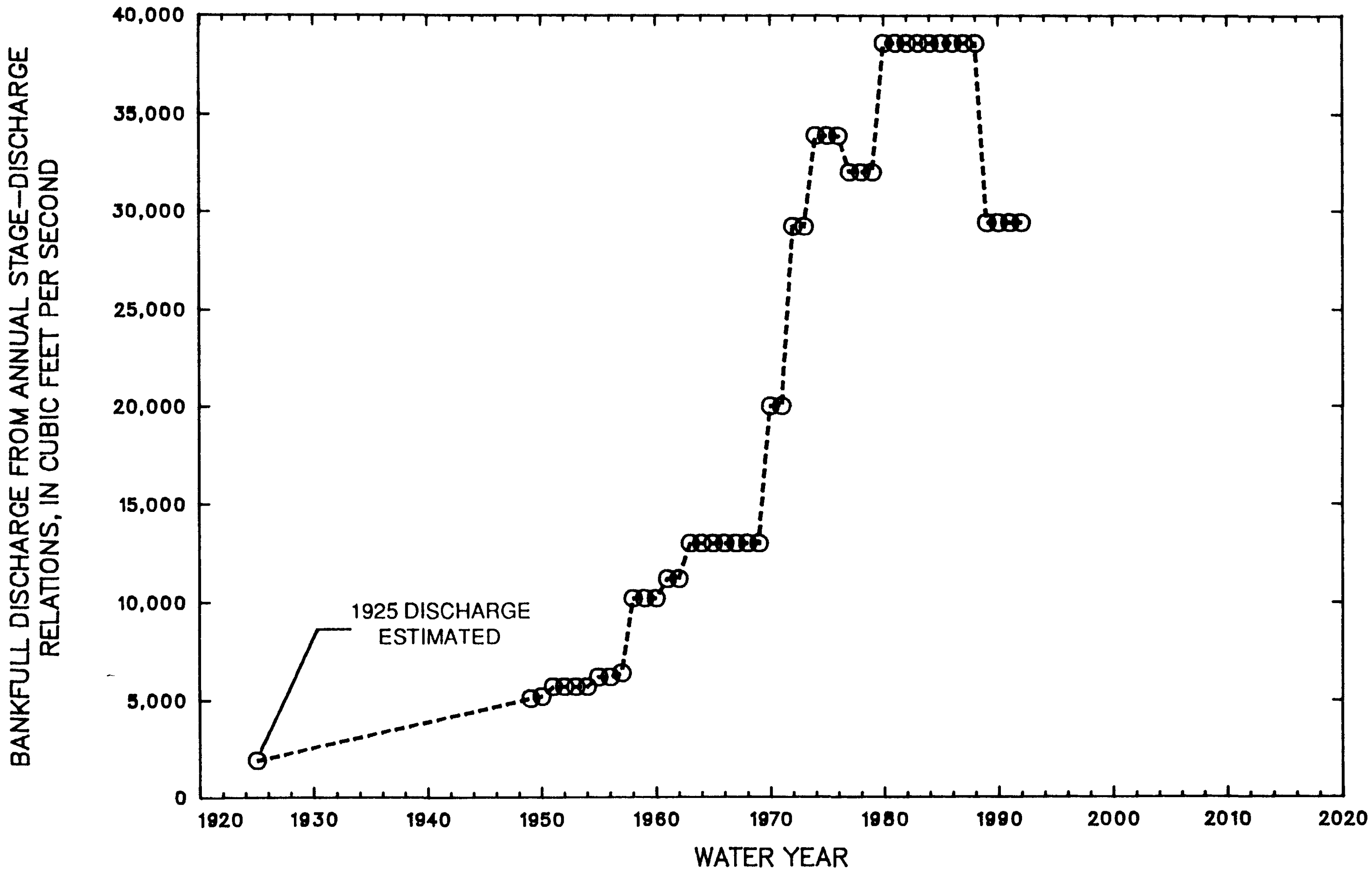

Figure 13.--Bankfull discharge from annual stage-discharge relations for Skuna River Canal at State Highway 9 at Bruce, Mississippi.

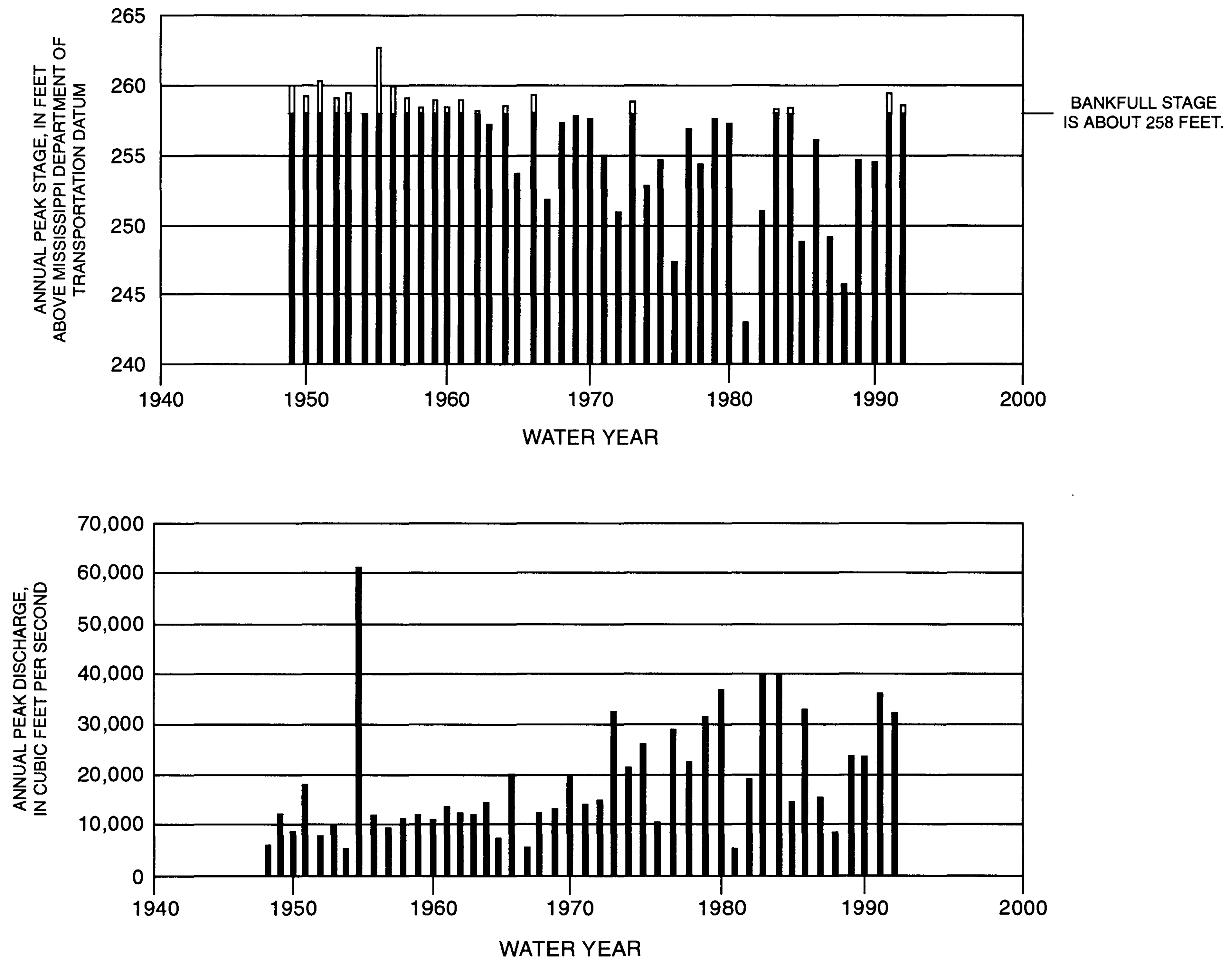

Figure 14.-- Annual peak stage and discharge for Skuna River at State Highway 9 at Bruce, Mississippi.

only 5 of 24 years. The corresponding peak discharges for the annual peak stages that exceeded bankfull stage ranged from 8,050 to 61,400 ft^3/s for the period 1949-68 and ranged from 31,800 to 39,300 ft^3/s for the period 1969-92.

The increase of the discharge capacity of the channel has altered the rainfall-runoff relation due to the reduction of basin storage within the flood plain because more discharge is contained within the channel. Changes in land use also affect the rainfall-runoff relation for a stream basin, but are not addressed in this report. The average of the annual peak discharges for the period 1948-68 is 13,200 ft^3/s and for the period 1969-92, is 23,000 ft^3/s. The average daily discharge for the period 1948-68 is 354 ft^3/s and for the period 1969-92 is 375 ft^3/s. The average of the peak discharges for the period 1969-92 is 74 percent higher than the average of the peak discharges for the period 1948-68, but the average of the daily discharges is only 6 percent higher, when comparing the respective time periods. Watson and others (1986) used the gage record at Skuna River for a simulation in a geomorphic study of a nearby ungaged stream, and they determined the relationship between mean flow and peak flow was significantly different for the record before 1970 compared to the record after 1970. They attributed this difference to channelization.

Using the present (1993) stage-discharge relation at the site, the present bankfull discharge is about 29,400 ft^3/s with a recurrence interval of about 5 years, according to the flood-frequency relation for present conditions determined by Landers and Wilson (1991). Using the estimated length and slope for natural channel conditions prior to 1925 (when the canal was constructed) in the flood-frequency regression equations developed by Landers and Wilson (1991), the present bankfull discharge of 29,400 ft^3/s would have had a recurrence interval of about 33 years.

Channel Slope

The channel slope provides information on a channel reach rather than just at a specific point or cross section. Slope is a controlling variable on river adjustment and is the primary dependent variable (Mackin, 1948). The fluctuations in other variables, such as sediment and water discharge, bedload sediment size, as well as other geologic, hydrologic, and geometric properties and characteristics, are accounted for by changes in channel slope (Robbins and Simon, 1982). The average water-surface slope used in the vicinity of State Highway 9 was based on the channel reach between Federal Aid Secondary Route 794 and State Highway 341. Available channel-bed profiles from field surveys and topographic maps and surveyed water-surface profiles for streamflows contained within the canal were used to estimate a representative channel slope in the vicinity of State Highway 9. In natural alluvial channels that are not being stressed, slope is independent of time, and a statistical relation of slope with time does not exist. However, in significantly modified alluvial channels, slope is significantly related to time, and although the relation between slope and time is not linear, it can be defined by exponential or log-normal regression (Robbins and Simon, 1982). According to equation 1, a reduction in $\mathbf{Q_s}$ or an increase in $\mathbf{Q}$ will result in a reduction of $\mathbf{S}$. Due to degradation and widening in response to channel modifications, the bankfull discharge has significantly increased (fig. 13), and the channel slope has been reduced (fig. 15). In this report, adjustments of channel slope are described using a power function in the general form:

$$S = ft^d \tag{4}$$

where

- **S** is channel slope, in feet per foot;
- **f** is regression constant indicative of channel slope prior to the onset of slope adjustment processes in response to channel modification, in feet per foot;
- **t** is time, in years since beginning of slope adjustment process (**t**=1 during first year of adjustment); and
- **d** is regression coefficient indicative of the rate of change in channel slope.

The channel slope decreased about 34 percent from 1925 to 1989. The channel slope decreased about 18 percent from 0.0005368 ft/ft in 1925 to 0.0004408 ft/ft in 1967. The channel modifications in 1967 and 1968 increased the slope about 16 percent from 0.0004408 ft/ft to 0.0005108 ft/ft, which initiated another phase of channel evolution for Skuna River. From 1969 to 1989, the slope decreased about 31 percent from 0.0005108 ft/ft to 0.0003549 ft/ft.

Bankfull Stream Power

As previously described, bankfull stream power is dependent on the bankfull discharge and slope, which have changed significantly since 1925 (fig. 16). Due to degradation and widening in response to channel modifications, the bankfull stream power has increased about 880 percent from 1925 to 1992, when bankfull discharge increased about 1,450 percent and channel slope decreased about 34 percent. Stream power increased about 126 percent from 1925 to 1949, increased about 24 percent from 1949 to 1957, and increased about 132 percent from 1957 to 1969. For the period 1969-92, stream power reached a maximum of 14.4 ft^3/s in 1980, but since 1980, the stream power has decreased about 31 percent to 10.0 ft^3/s, possibly indicating channel adjustment processes have progressed upstream.

Channel-Bank Stability

Bulk unit-weight and shear-strength properties of the channel-bank material (table 1) used in the stability analyses were determined from borehole tests done in 1989 on the left (south) bank of Skuna River and the left bank of Old Skuna River about 70 ft and 100 ft, respectively, upstream from State Highway 9. The BST results for the individual soil strata were used in the stability analyses. The factor of safety used to describe channel-bank stability is the ratio of the resisting force (shear-strength of the bank material) to the driving force (weight of the bank material). Therefore, if the resisting force is equal to the driving force, then the factor of safety is 1.0. Theoretically,

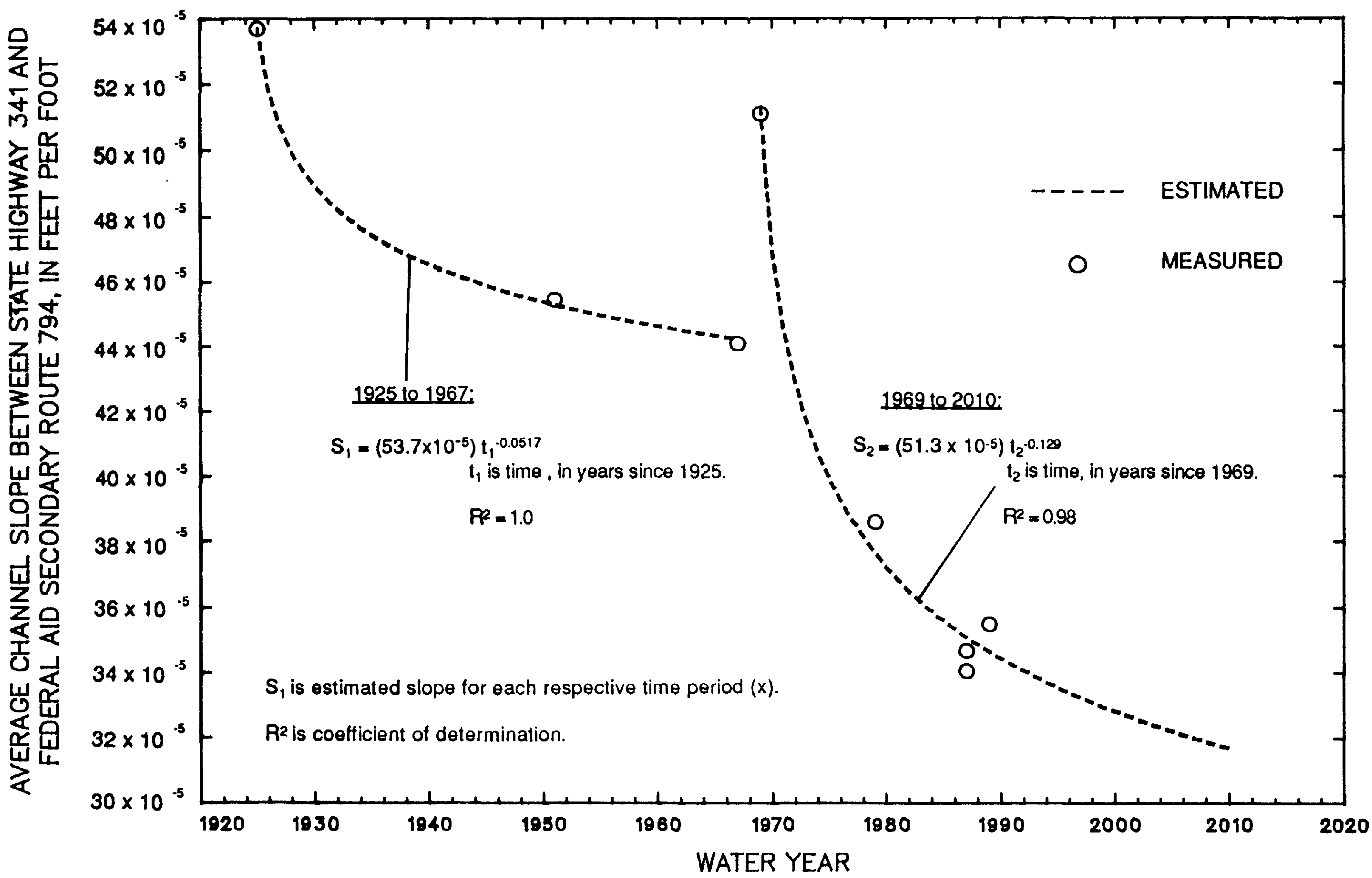

Figure 15.--Average channel slope of Skuna River Canal between State Highway 341 and Federal Aid Secondary Route 794.

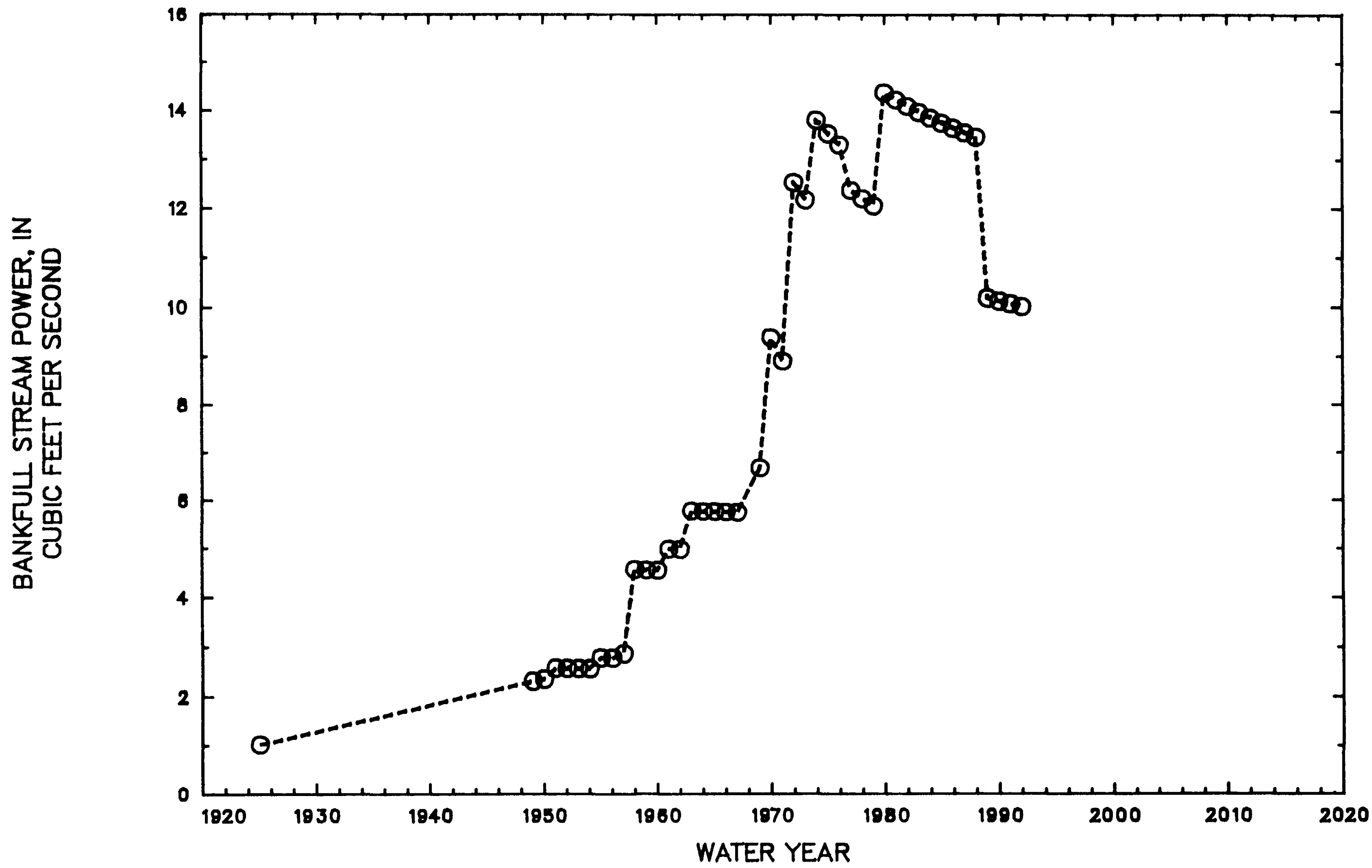

Figure 16.--Bankfull stream power for Skuna River Canal at State Highway 9 at Bruce, Mississippi.

when the factor of safety is less than 1.0, failure occurs, and when it is greater than 1.0, failure does not occur. This theory is based on the assumption that all the forces are considered. A factor of safety of at least 1.5 generally is used in design. Factors of safety for bank failures were determined by using wet and saturated bulk-unit weights and shear-strength properties of the bank material at cross sections surveyed by the USGS and MDOT in 1989. The cross sections for Skuna River Canal were located about 500 ft upstream, 60 ft downstream, and 850 ft downstream from State Highway 9. The cross section for Old Skuna River was located about 130 ft upstream from State Highway 9. The computer program UTEXAS2 (University of Texas Analysis of Slopes-Version 2) developed by Wright (1986) was used in the bank-stability analyses. An iterative search was made by the program to determine the minimum factor of safety for each selected soil condition.

Analyses of both planar and rotational bank failures indicated that rotational bank failures were more likely to occur. Using streambank classification schemes of Taylor (1948) and Lohnes and Handy (1968), bank angles greater than 60 degrees are considered steep banks and angles less than or equal to 60 degrees are considered gently sloping banks. According to Osman and Thorne (1988) and Simon and Hupp (1991), steep bank slopes generally fail along a more planar surface; whereas, gently sloping banks generally fail along a curvilinear or rotational failure surface. Factors of safety and bank-failure block widths are presented in table 5. For saturated conditions (soil condition 2, table 5), failure block widths were as much as 11 ft for Skuna River Canal (fig. 17) and as much as 4 ft for Old Skuna River (fig. 18), and factors of safety ranged from 1.1 to 2.9 for Skuna River Canal and 1.0 to 1.5 for Old Skuna River. The computed failure-block widths compared reasonably well with failure-block widths observed in the field. For Skuna River Canal, the analyses indicate the left (south) bank 850 ft downstream from State Highway 9 is the most stable, and the right bank 850 ft downstream is the most unstable. For Old Skuna River, the right (north) bank is more stable than the left bank at 130 ft upstream from State Highway 9.

The results from the UTEXAS2 computer program indicate possible tension cracks forming in the upper part of all banks analyzed, except for the left bank of the canal 850 ft downstream from State Highway 9. When tension cracks occur at the top of cohesive banks, the shear strength of the bank material is reduced, which causes the bank to be more susceptible to failure. No tension cracks have recently been observed at this site; however, to estimate the effects of possible tension cracks, a tension crack depth of 5 ft was used (soil condition 3, table 5). The factors of safety for Skuna River Canal were decreased to 1.3, 1.1, and 0.8 for the cross sections located 500 ft upstream, 60 ft downstream, and 850 ft downstream, respectively. The factor of safety for Old Skuna River was decreased to 0.5 for the cross section located 130 ft upstream. The most significant reduction of the factor of safety was from 2.1 to 1.1 at the left bank located 60 ft downstream from State Highway 9. The possible formation of tension cracks in the upper part of the streambank greatly affects the stability of the streambank. Thorne and others (1981) determined tension cracks play an important role in controlling the stability, critical mode of failure, and limiting height of steep streambanks in northwestern Mississippi.

Table 5.-- Factor of safety and failure-block width for critical channel-bank failures on Skuna River Canal and Old Skuna River in the vicinity of State Highway 9 at Bruce, Mississippi

[ft, feet; soil condition: 1, wet bulk-unit weight; 2, estimated saturated bulk-unit weight and pore pressures in clay 3, saturated conditions with 5-foot-deep tension crack on upper bank; *, failure does not intersect top of channel bank; --, not applicable]

Selected soil condition	Left bank: Factor of safety	Left bank: Failure-block width (ft)	Right bank: Factor of safety	Right bank: Failure-block width (ft)
		Skuna River Canal		
		500 ft upstream from State Highway 9		
1	2.0	11	2.1	11
2	1.7	11	1.9	11
3	1.3	9	1.7	12
		60 ft downstream from State Highway 9		
1	2.9	11	2.9	8
2	2.1	11	2.3	11
3	1.1	11	1.6	9
		850 ft downstream from State Highway 9		
1	3.1	*	1.7	*
2	2.9	*	1.1	*
3	--	--	0.8	*
		Old Skuna River		
		130 ft upstream from State Highway 9		
1	1.3	7	1.8	3
2	1.0	4	1.5	3
3	0.5	15	1.5	3

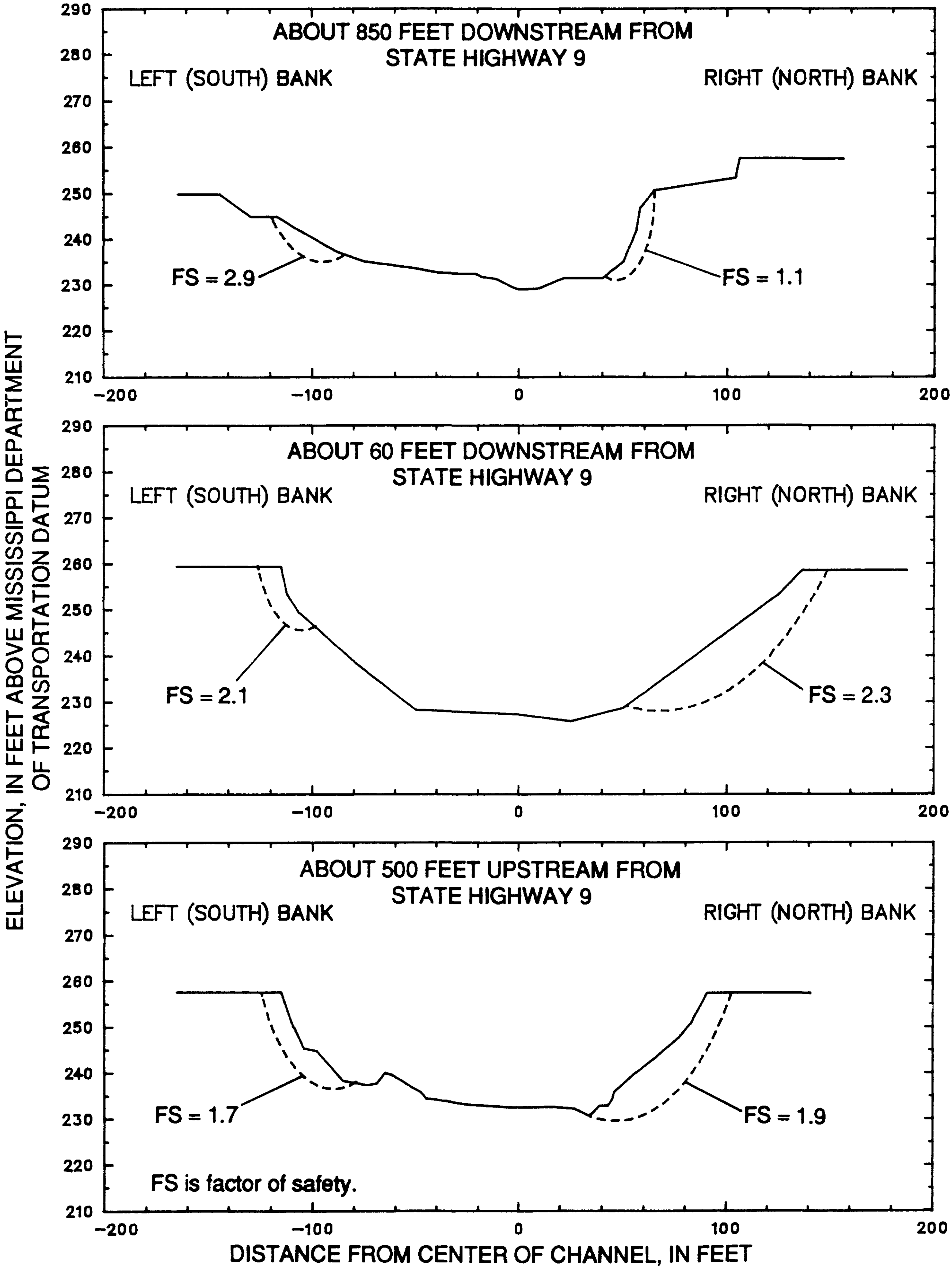

Figure 17.--Cross sections showing critical failure surfaces for saturated channel banks on Skuna River Canal in the vicinity of State Highway 9 at Bruce, Mississippi, 1989.

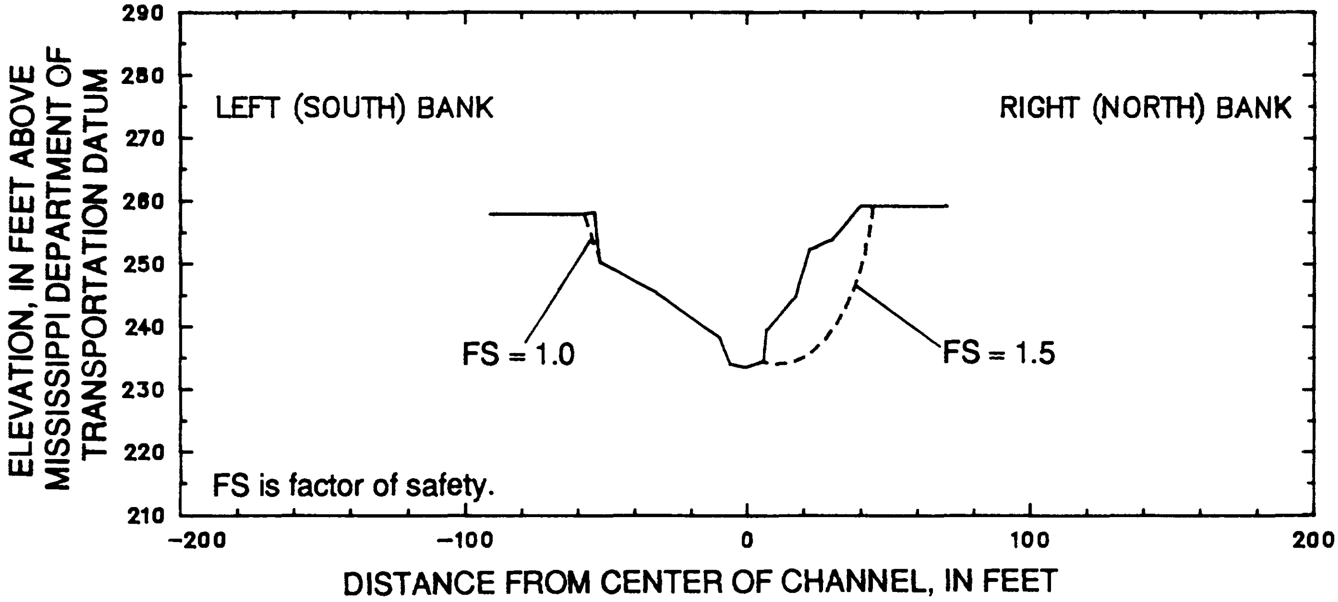

Figure 18.--Cross section showing critical failure surfaces for saturated channel banks on Old Skuna River about 130 feet upstream from State Highway 9 at Bruce, Mississippi, 1989.

SUMMARY AND CONCLUSIONS

Skuna River at State Highway 9 at Bruce, Calhoun County, Miss., has responded to channel modifications by lowering of the channel bed through degradation, which heightened and steepened channel banks and induced widening. Skuna River Canal (Skuna River) degraded about 16.5 ft and widened about 150 ft from 1925 (when constructed) to 1992. Old Skuna River and Skuna River Canal tributary have responded to modifications of their channels, but have mostly responded to modifications of the canal. Old Skuna River degraded and widened about 11 ft and 40 ft, respectively, from 1921 to 1991. Skuna River Canal tributary degraded about 6 ft from 1921 to 1991. No estimates of total widening since 1921 for the tributary were determined because of a poorly defined channel, as indicated by available cross sections. The bankfull discharge of the canal increased about 1,450 percent, and the channel slope decreased about 34 percent from 1925 to 1989. The bankfull stream power has been decreasing since 1980, when it was a maximum of 14.4 ft^3/s. The bankfull channel width-depth ratio has been increasing since 1975, which indicates the canal has been widening more than degrading since 1975. Additional channel-bed and channel-bank widening on Skuna River Canal through 2010 in the vicinity of State Highway 9 are projected to be 1 and 40 ft, respectively. Using a regional relation of bankfull channel width-depth ratio with drainage area, about 70 ft of additional widening could occur before the canal reaches quasi-equilibrium, which will most likely be reached after 2010. If Old Skuna River and Skuna River Canal tributary degrade as much as the canal, then about 6 and 11 ft of additional degradation could occur by 2010 on the Old Skuna River and the tributary, respectively, at State Highway 9. Old Skuna River and the tributary could both widen an additional 30 ft in the next 10 to 20 years. It is doubtful these streams will degrade as much as the canal by 2010, because a considerable time lag exists between the geomorphic response of these two streams and the canal. All projections are based on the assumption that no additional channel modifications and no unusually large and destructive flooding will occur by 2010.

The channel low-stage thalweg is beginning to meander around sandbars, inducing lateral erosion of the base of outside banks. The widening projections in this report do not directly account for lateral erosion and are considered to be a minimum for the typical channel reach. Lateral erosion will likely have a significant effect on future widening processes at this site. Future studies might include additional field surveys, analyses of new aerial photographs as they become available, and streamflow modeling to improve the understanding of the meandering process and to provide a means of projecting probable instabilities that could effect the proposed bridge.

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