CHANNEL AND BANK STABILITY OF SAND BRANCH TRIBUTARY AT STATE HIGHWAY 342 NEAR PONTOTOC, PONTOTOC COUNTY, MISSISSIPPI

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CONVERSION FACTORS

For readers who may prefer to use the metric (International System) of units rather than the inch-pound units used herein, the conversion factors are listed below:

Multiply inch-pound unit	by	To obtain metric unit
foot per second (ft/s)	0.3048	meter per second (m/s)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m3/s)
foot (ft)	0.3048	meter (m)
foot per mile (ft/mi)	0.018939	meter per kilometer (m/km)
square foot (ft^2)	0.09290	square meter (m^2)
pounds per square foot (lb/ft^2)	47.88	newtons per square meter (N/m^2)
pounds per cubic foot (lb/ft^3)	157.09	newtons per cubic meter (N/m^3)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)

Mississippi State Highway Department Datum: In this report, elevations are referenced to Mississippi State Highway Department Datum (MSHDD). Add 0.76 foot to elevations referenced to MSHDD to convert to the National Geodetic Vertical Datum of 1929 (NGVD 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.

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).

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, 1986b).

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

Critical bank height -height of channel bank above which failure can be expected, produced by an increased height (channel-bed degradation) or bank angle (over steepening through erosion) (Thorne and others, 1981).

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

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 insitu (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 -slide 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' = effective normal stress on plane of shear

c' = cohesion or apparent cohesion of the soil; and

ϕ' = 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, 1986a).

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

The channel of Sand Branch tributary at the site of the proposed reconstruction of the State Highway 342 crossing near Pontotoc, Mississippi, has degraded 3 to 4 feet since the channelization of Chiwapa Creek in 1911. Channel degradation at the mouth of the tributary has totaled 5 to 6 feet. Botanical evidence indicates that several recent bank failures downstream of the crossing occurred during extreme floods in the spring of 1983.

Rates of channel degradation and widening--as determined from channel descriptions, discussions with local residents, and botanical evidence along the banks--were used in conjunction with soil properties to estimate probable future channel degradation and widening through the year 2010. By assuming that channel-bed elevations can be expressed as a power function with time, additional channel degradation through the year 2010 is expected to be about ½ foot at the highway crossing and about 1 foot at the mouth of the tributary. The channel top-bank width could increase about 10 feet just downstream of the highway crossing in the next 10 to 20 years. These projections are based on the assumption that no additional channel modifications and no unusually large and destructive flooding will occur by the year 2010.

INTRODUCTION

The Mississippi State Highway Department proposes to reconstruct the State Highway 342 crossing of Sand Branch tributary near Pontotoc, Mississippi (fig. 1). Because channel degradation and bank sloughing have recently occurred in the lower reach of Sand Branch tributary, the U.S. Geological Survey, in cooperation with the Mississippi State Highway Department, began a study of channel and bank stability at this site. The tributary at the State Highway 342 crossing is unnamed. Inasmuch as this is the only tributary to the main stem of Sand Branch, it is designated Sand Branch tributary for the purpose of this report.

Purpose and Scope

The purpose of this report is to describe the existing channel and bank conditions and present the results of a study to determine the potential for near-future degradation and widening for Sand Branch tributary at the State Highway 342 crossing near Pontotoc, Mississippi. Existing channel and bank conditions are described based on field observations, ages and types of trees on the channel banks, dry bulk-unit weights, and shear-strength properties of bank material used to evaluate the potential for bank failures. The potential for near-future degradation is estimated by using a power function of past channel-bed elevations with time for Sand Branch tributary and Sand Branch at State Highway 342. The potential for widening is estimated by using existing channel geometry and shear-strength properties of the bank material. This report is the second in a series of reports for selected stream crossings in Mississippi.

General Description of Sand Branch Tributary

Sand Branch tributary is located in the Pontotoc Ridge, East Gulf Coastal Plain physiographic region. The drainage area of Sand Branch tributary at State Highway 342 is 0.26 mi^2 (square mile), and the length of the channel upstream of the site is about 1.5 mi (miles). Average channel and valley slopes in the vicinity are about 30 and 15 ft/mi (feet per mile), respectively. A levee about 4 ft (feet) in height, located on the left (east) bank of Sand Branch tributary, extends from the downstream side of the bridge at State Highway 342 to the mouth of the tributary about 0.15 mi downstream. Approximately 0.60 mi downstream from the mouth of the tributary, Sand Branch flows into Chiwapa Creek, which has been channelized (fig. 1). Sand Branch and Sand Branch tributary are crossed by a county road about 0.5 mi and 1.1 mi, respectively, upstream of the State Highway 342 crossings.

The channel of Sand Branch tributary in the vicinity of State Highway 342 is incised into a layer of brownish-gray clay, which is overlain in places by a thin layer of silty sand and pea-size gravel; the channel banks average 4 to 5 ft in height.

Channel Modifications to Sand Branch and Chiwapa Creek

In 1967, the U.S. Soil Conservation Service completed a flood-retarding structure on Sand Branch about a mile upstream of State Highway 342. The structure reduced the contributing drainage area at State Highway 342 from 2.07 to 0.46 mi^2, and thus reduced the chance of intermingling flood flow between Sand Branch and Sand Branch tributary (about 400 ft east of Sand Branch at State Highway 342).

Channelization of Chiwapa Creek was completed by the Chiwapa Drainage District in May 1911 (Ramser, 1930). Additional channelization work was noted at a U.S. Geological Survey gaging station on Chiwapa Creek at Shannon, Mississippi, in 1949. In 1968, the U.S. Soil Conservation Service completed channel modifications (mostly clearing and snagging) and construction of several flood-retarding structures in the basin.

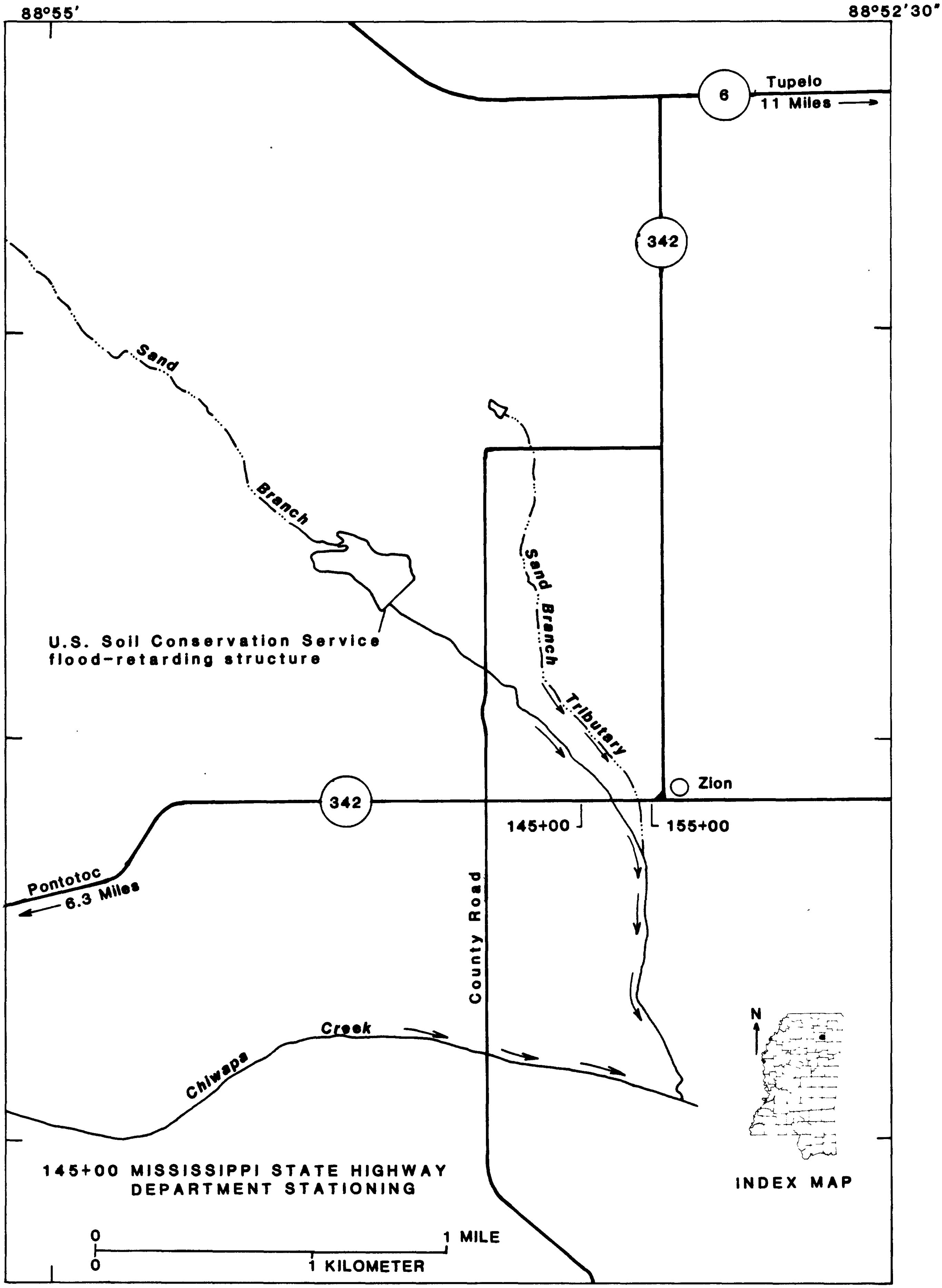

Figure 1.--Location of Sand Branch tributary at State Highway 342 near Pontotoc, Mississippi.

Acknowledgments

The authors are indebted to members of the Mississippi State Highway Department, Hydraulics Division, who provided bridge-inspection records. Gratitude is also extended to the Missississippi State Highway Department, Soil Mechanics Laboratory, which assisted in the analysis of soil samples.

CHANNEL-BED STABILITY

Botanical Evidence of Degradation

Trees growing below tops of banks can indicate rates of aggradation or degradation through measurement of the thickness of sediment burial, or exhumation, from the root collar, which is established at the ground surface during germination (Simon and Hupp, 1986a). Exhumation from the root collar of trees growing below top banks of Sand Branch tributary indicated that the elevation of the channel bed near the highway crossing was about 308 to 309 ft above Mississippi State Highway Department Datum (about 3 to 4 ft above the existing channel bed) prior to substantial degradation. Root-collar botanical evidence also indicated that the channel bed at the mouth of the tributary prior to substantial degradation was about 5 to 6 ft above the existing channel bed (fig. 2). Similar evidence indicated the channel bed at the mouth of Sand Branch, where it flows into Chiwapa Creek, was about 6 to 7 ft above the existing channel bed. This agreed with 7 ft of degradation that was estimated for Chiwapa Creek near the mouth of Sand Branch, using the 1911 channel-design cross section (Ramser, 1930) and a 1988 channel-bed elevation.

Degradation Analysis

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

$$E = a \cdot t^{b} \qquad (1)$$

where:

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

Datums other than sea level for channel-bed elevations (**E**) in equation 1 may be used when the relation to sea level datum has not been established or for convenience, 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 the elevations obtained when referenced to sea level datum, the value of **a** will decrease and the absolute value of **b** will increase. Also, by varying the datum, an imposed logarithmic offset for the log-linear relation will change, thus, in some cases, improving or worsening the log-linear statistical fit of the data points. In previous studies, effects of channel-bed elevations on degradation trends were analyzed by varying the datum of the study sites; the analysis indicated no significant effects on the degradation trends (Andrew Simon, U.S. Geological Survey, oral commun., 1988).

It is assumed that the general form of equation 1 is applicable for estimating channel-bed degradation in the near future (to the year 2010) on Sand Branch and Sand Branch tributary. The estimated near-future channel-bed degradation is based on the assumption that no additional channel modifications and no unusually large

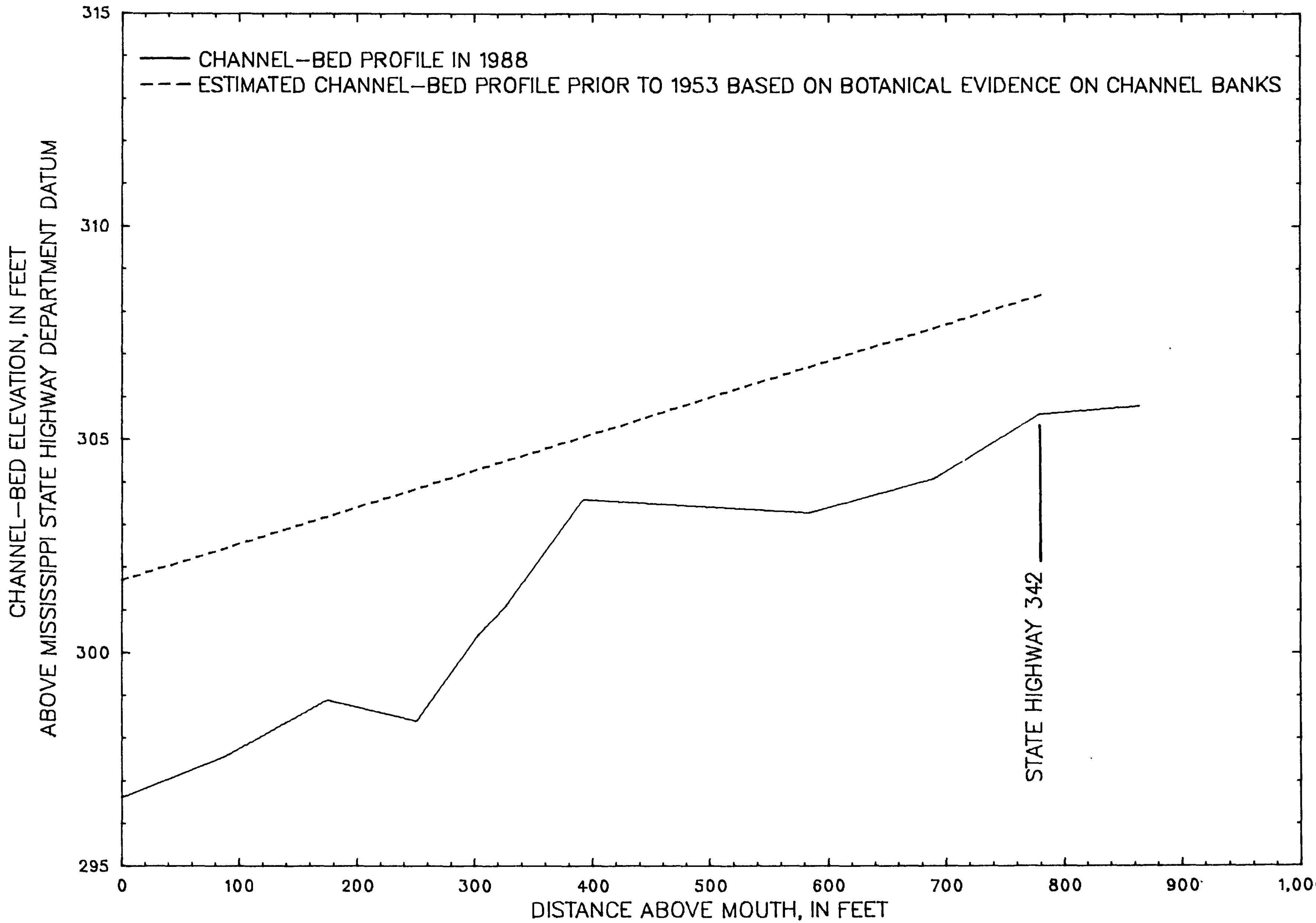

Figure 2.––Channel–bed profiles for Sand Branch tributary in the vicinity of State Highway 342 near Pontotoc, Mississippi.

destructive flooding will occur by the year 2010.

The channel-bed elevations used in these analyses were obtained from surveys and inspections made by the Mississippi State Highway Department and the U.S. Geological Survey. Some differences in channel-bed elevations may not be indicative of actual change, but rather of error involved in comparing survey measurements. The channel-bed elevations used to analyze degradation were obtained at bridges; no significant evidence of localized scour was observed. Localized scour occurs when flow velocities are increased for a short distance upstream and downstream from a bridge. Increased velocities are caused by the cross sectional area being substantially reduced by bridge-approach embankments, piers, and other obstructions. The effect of localized scour would be an addition to the ongoing degradation process and, therefore, would not be representative of the selected reaches of channels studied.

Elevations in these analyses were referenced to Mississippi State Highway Department Datum, which was 0.76 ft below sea level datum. The differences in datums did not significantly affect degradation trends as determined by equation 1.

A log-linear regression computed from the 1953, 1965, and 1985 channel-bed elevations of Sand Branch at the State Highway 342 crossing was used to develop a channel-bed degradation equation (**$E' = 303.8t'^{-0.00529}$**, where t' is time, in years since 1953). The previously determined and the projected channel-bed elevations through the year 2010 are presented in table 1. A channel-bed degradation equation (**$E = 308.4t^{-0.00253}$**, where **t** is time, in years since 1953) was also developed for Sand Branch tributary at State Highway 342 and channel-bed elevations through 2010 were projected (table 2). It is uncertain when degradation began at either site at State Highway 342. Channel-bed elevations prior to 1953 were not available; therefore, the beginning of the channel-adjustment process is unknown. Relations of channel-bed elevations with time were developed by varying the beginning year. The best statistical fit was with time beginning in 1953, which indicates that the effects of degradation on Chiwapa Creek could have taken as long as 43 years to progress upstream to the State Highway 342 crossings. This report is based on the assumption that most of the channel degradation that has occurred at both crossings is a result of the original channelization of Chiwapa Creek in 1911. The resulting difference in channel-bed elevation from 1953 to 1985 at Sand Branch and 1953 to 1988 at Sand Branch tributary agreed closely with field estimates of channel-bed degradation by use of botanical evidence.

Table 1.--*Channel-bed degradation on Sand Branch at State Highway 342 near Pontotoc, Mississippi*

Year	Time, t' (years)	Channel-bed elevation, E' (feet)	Total degradation since 1953 (feet)
1953	1	303.8	0.0
1965	13	299.8	4.0
1985	33	298.2	5.6
1990	38	[1]298.0	5.8
1995	43	[1]297.8	6.0
2000	48	[1]297.6	6.2
2005	53	[1]297.5	6.3
2010	58	[1]297.3	6.5

[1] Estimated using Regression Equation $E'=303.8t'^{-0.00529}$, number of observations = 3, coefficient of determination = 1.00

Table 2.--*Channel-bed degradation on Sand Branch tributary at State Highway 342 near Pontotoc, Mississippi*

Year	Time, t (years)	Channel-bed elevation, E (feet)	Total degradation since 1953 (feet)
1953	1	308.4	0.0
1985	33	305.7	2.7
1988	36	305.6	2.8
1990	38	[1] 305.6	2.8
1995	43	[1] 305.5	2.9
2000	48	[1] 305.4	3.0
2005	53	[1] 305.3	3.1
2010	58	[1] 305.2	3.2

[1] Estimated using Regression Equation $E=308.4t^{-0.00253}$, number of observations = 3, coefficient of determination = 1.00

A plot of the measured and regression-estimated channel-bed elevations as a function of time (fig. 3) indicates that near-maximum degradation has occurred on Sand Branch and Sand Branch tributary at State Highway 342. About 5½ ft of degradation has occurred on Sand Branch and about 3 ft of degradation has occurred on Sand Branch tributary. Further degradation through the year 2010 could reasonably be expected to be about 1 ft on Sand Branch and about ½ ft on Sand Branch tributary.

CHANNEL-BANK STABILITY

Botanical Evidence of Widening

Bank failures along unstable reaches may kill, tilt, or scar existing woody plants, and create fresh surfaces upon which plants may become established. Scars and sprouts from parental stems of tilted plants yield accurate (within 1 year, often within one season) dates of bank failures (Sigafoos, 1964).

Eccentric growth, resulting in anomalous tree-ring series, occurs when the stem is inclined. This type of growth is determined easily from cross sections where concentric-ring formation abruptly shifts to the eccentric because ring width is greater in the upslope direction. Eccentric-ring patterns also yield highly accurate dates, usually accurate within one season, of tilting. Dating of stems that have established on disturbed surfaces yields minimum ages for the surfaces (Simon and Hupp, 1986a).

Trees growing on unstable bank surfaces along Sand Branch tributary near State Highway 342 show the effects of recent bank sloughing in their stem morphology, anatomy, and ages. Channel banks on both sides of the stream downstream appear to have sloughed recently in a combination of planar and rotational failures. Botanical data were collected by taking cross sections of sprouts from tilted trees and also saplings (such as water oak, sweetgum, sycamore, and willow) to determine the ages of the sprouts and saplings, by increment borings of mature trees to determine their ages, and by measuring bank failure-block widths. These data indicate 3- to 5-ft-wide bank failures occurred on the downstream left (east) bank in 1983. On the downstream right (west) bank, 2- to 4-ft-wide bank failures occurred in 1983 and about a 6-ft-wide bank failure occurred in 1973. These bank failures indicate that the critical bank height has

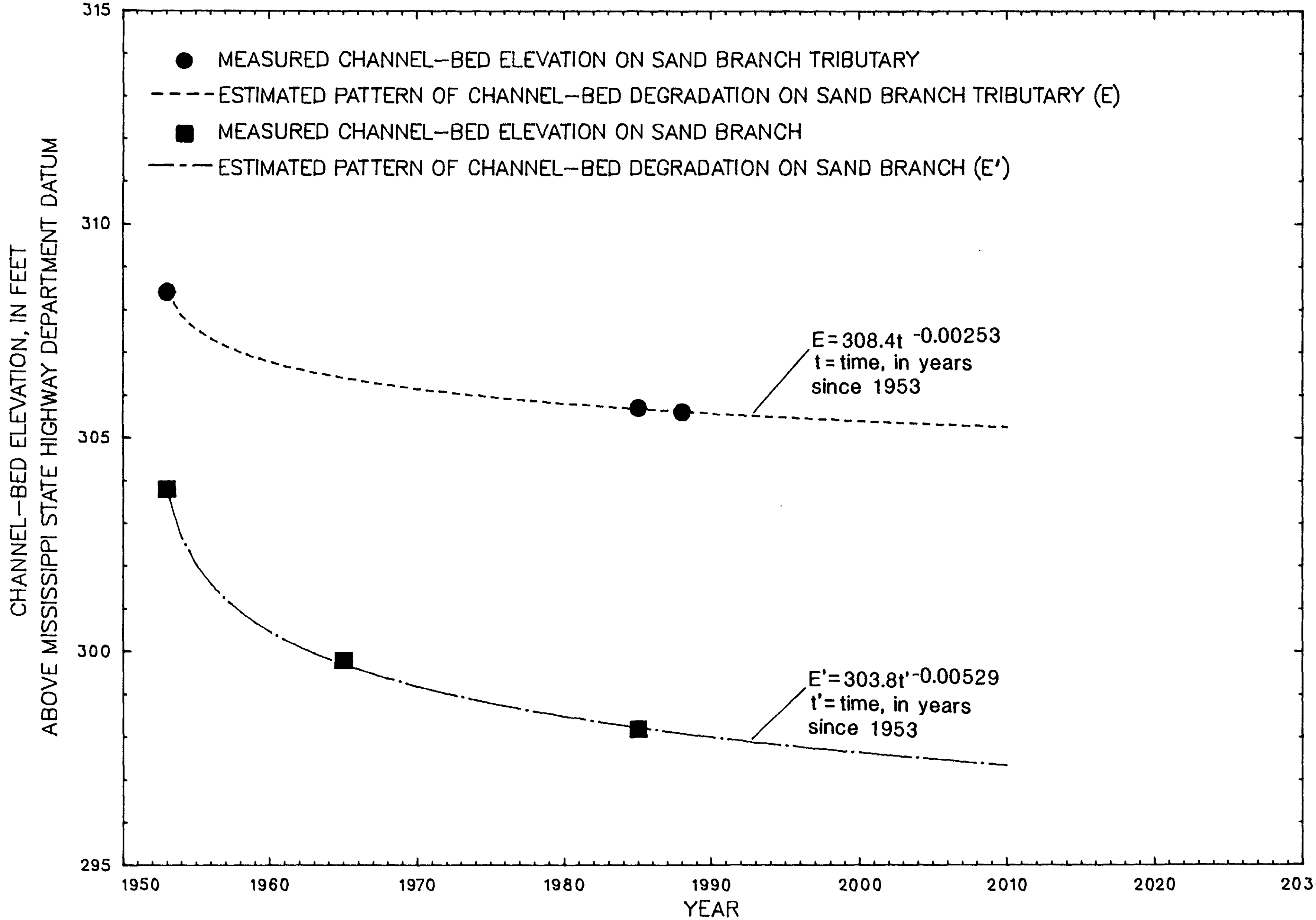

Figure 3.—Estimated patterns of degradation on Sand Branch tributary and Sand Branch at State Highway 342 near Pontotoc, Mississippi.

been exceeded in recent years in this reach downstream from the bridge. It should be noted that botanical evidence of previous bank failures may have been obscured with time and (or) by succeeding large floods (Simon and Hupp, 1986a).

Knickpoints of about 2½ and 2 ft are located in the channel of Sand Branch tributary about 350 and 450 ft, respectively, downstream from the State Highway 342 bridge. These knickpoints appear to represent an accumulation of failed bank material in the channel bed, rather than a headward-progressing degradation process. The channel-bed profile just downstream and upstream of the failed material (extending from about 300 to 500 ft upstream from the mouth) nearly parallels the estimated channel-bed profile prior to degradation (fig. 2).

Stability Analysis

Shear-strength properties of the channel banks were determined on the right (west) bank of Sand Branch tributary about 80 ft downstream from State Highway 342 with the Iowa Borehole Shear Tester[1] (BST), (Handy and Fox, 1967). Dry bulk-unit weights and shear-strength properties of soils obtained at the site are given in table 3. The average moisture content of the soils when tested was about 21 percent.

Shear-strength data obtained using the BST have compared reasonably well with the results of other standard laboratory procedures for the determination of soil strength (Wilson and Turnipseed, 1989; Thorne and others, 1981). BST results for individual soil strata were used in stability analyses.

Factors of safety for bank failures for various degrees of bank saturation were determined by using shear-strength properties and bulk-unit weights of the bank material at a typical cross section just downstream from the State Highway 342 crossing. An iterative search to obtain the minimum factor of safety for each degree of bank saturation analyzed was done using the computer programs REAME (Rotational Equilibrium Analysis of Multilayered Embankments) and SWASE (Sliding Wedge Analysis of Sidehill Embankments) developed by Huang (1983). The factor of safety 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, when the factor of safety is less than 1.0, failure occurs; conversely, when it is greater than 1.0, failure does not occur. This is based on the assumption that all the forces are known. A factor of safety of at least 1.5 generally is used in design.

Planar and rotational bank failures were observed in the field. Analysis of both failure types showed rotational bank failures to be more critical. Therefore, results are presented only for rotational bank failures. Factors of safety ranged from 1.29 to 2.47 at all levels of saturation tested, indicating that the banks of the tributary just downstream of State Highway 342 are fairly stable. The critical-failure surfaces with the respective factors of safety for 100-percent bank-saturation conditions are shown in figure 4. The right bank becomes susceptible to failure (factor of safety less than 1.5) when the channel bank is more than 50-percent saturated. The left (east) bank appears stable, with a factor of safety greater than 1.5 even at 100-percent bank-saturation conditions. On the right (west) bank, the failure-block width is about 2½ ft; on the left (east) bank, the failure-block width is about 5½ ft (fig. 4). Similar failure-block widths were observed in the field.

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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.

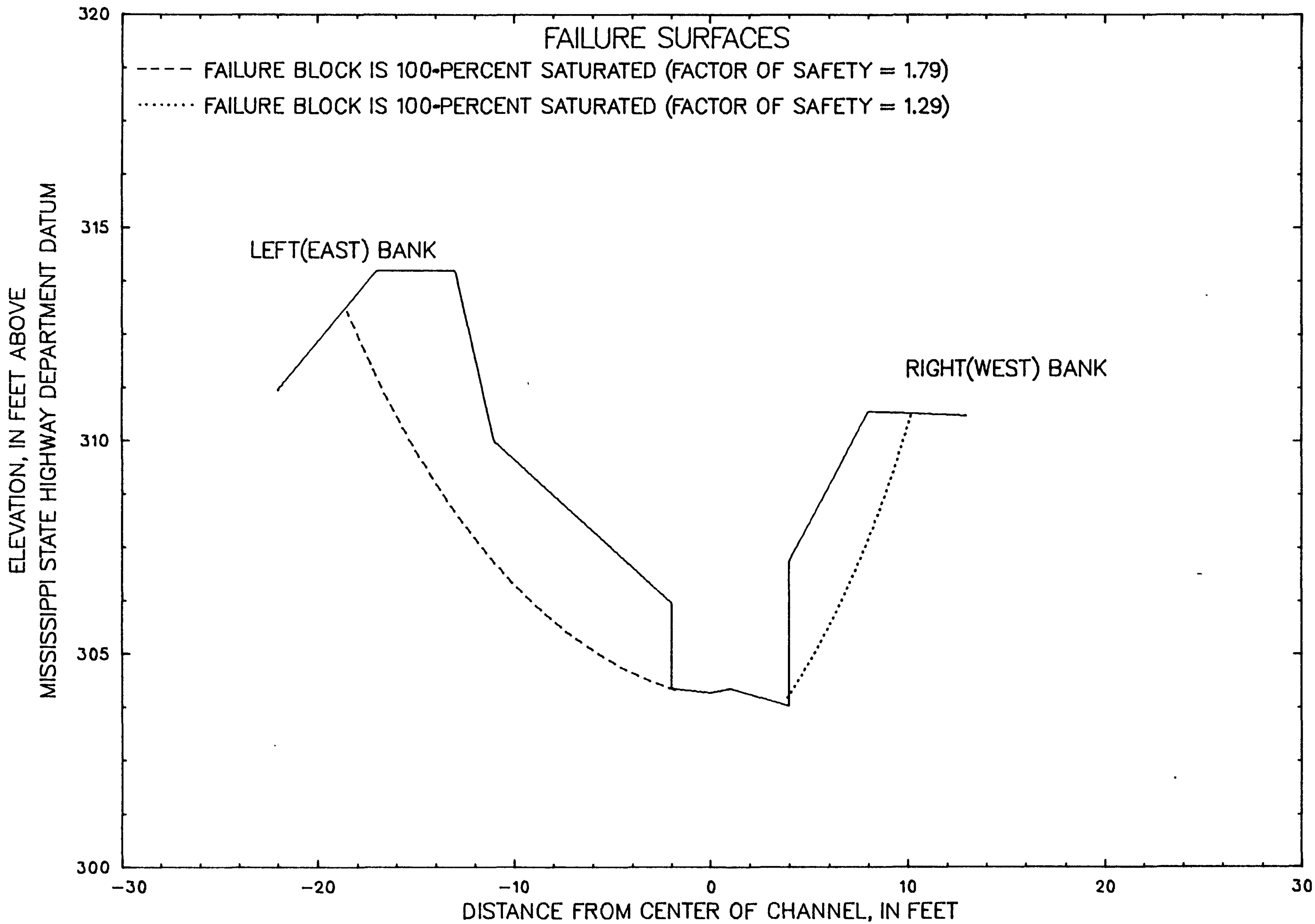

Figure 4.—Cross section showing critical failure surfaces for channel banks on Sand Branch tributary 80 feet downstream of State Highway 342 near Pontotoc, Mississippi.

Table 3.--*Dry bulk-unit weight and shear-strength properties of soil as determined from borehole tests about 80 feet downstream from State Highway 342 near Pontotoc, Mississippi*

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

General soil description	Borehole depth (ft)	Dry bulk-unit weight (lb/ft^3)	Cohesion (lb/ft^2)	Angle of internal friction (degrees)
Grayish-brown, silty-sandy clay	0-4.5	100	151	32.5
Brownish-gray, silty clay	4.5-9.5	103	210	20.5

Widening Analysis

Estimates of near-future (10 to 20 years) bank widening can be obtained by projecting the streambank slough-line angle on a plotted cross section (Simon and Hupp, 1986b). Projection of this slough-line angle on the banks was used where conditions were stable and vegetation was well established. On banks where a slough line had 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, a technique developed by Spangler and Handy (1973). Estimates of near-future bank widening upstream of the bridge were made by extending the temporary angle of stability (fig. 5). Extensions of the slough-line angle and the temporary angle of stability were used to estimate near-future bank widening downstream of the bridge (figs. 6, 7). In the next 10 to 20 years, top-bank width could increase about 2 ft at the cross section located 80 ft upstream of State Highway 342, about 10 ft at the cross section 80 ft downstream of the highway crossing, and about 12 ft at the cross section 650 ft downstream of the highway crossing. Destructive flooding can affect these projections.

CONCLUSIONS

The channel of Sand Branch tributary at State Highway 342 near Pontotoc, Mississippi, has degraded about 3 ft since 1953 and continues to respond to the degradation of Chiwapa Creek which was channelized in 1911. About 1 ft of further degradation through the year 2010 could reasonably be expected on Sand Branch at the mouth of the tributary, and about ½ ft could be expected on the tributary downstream of State Highway 342. The channel top-bank width of the tributary in the vicinity of State Highway 342 is expected to increase about 10 ft in the next 10 to 20 years. These projections are based on the assumption that no additional channel modifications and no unusually large and destructive flooding will occur by the year 2010.

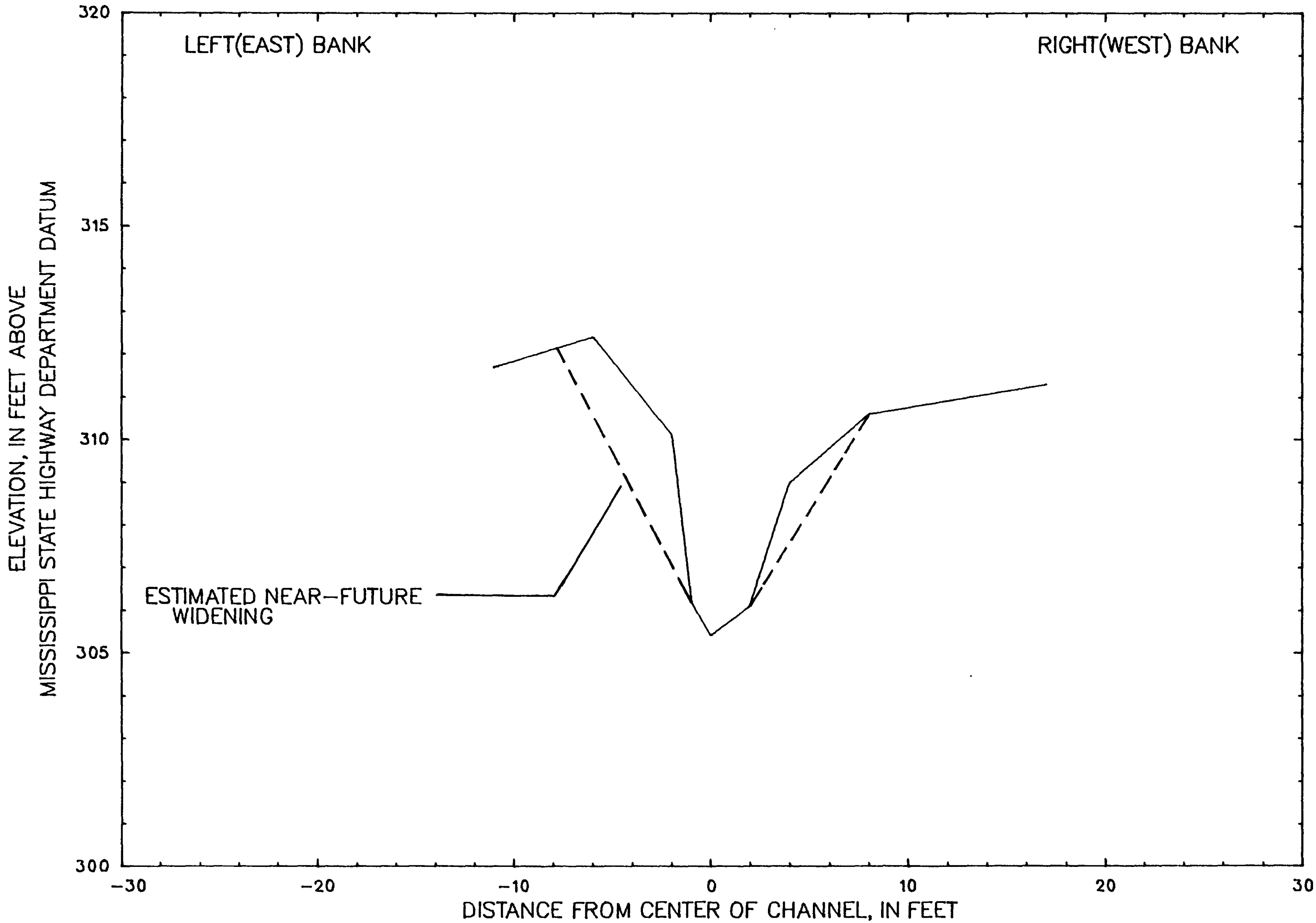

Figure 5.——Existing channel cross section showing near—future widening for Sand Branch tributary 80 feet upstream of State Highway 342 near Pontotoc, Mississippi.

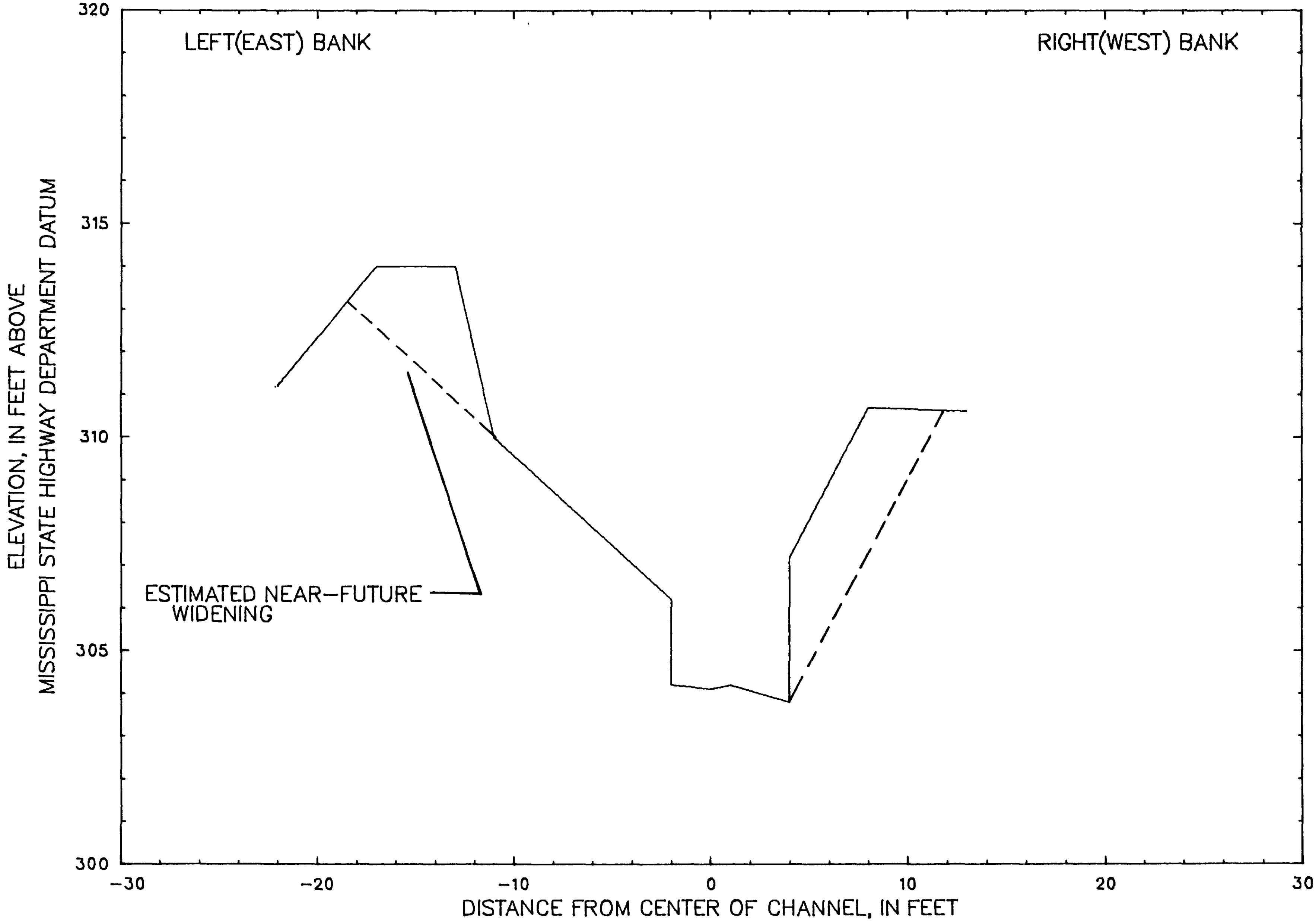

Figure 6.——Existing channel cross section showing near—future widening for Sand Branch tributary 80 feet downstream of State Highway 342 near Pontotoc, Mississippi.

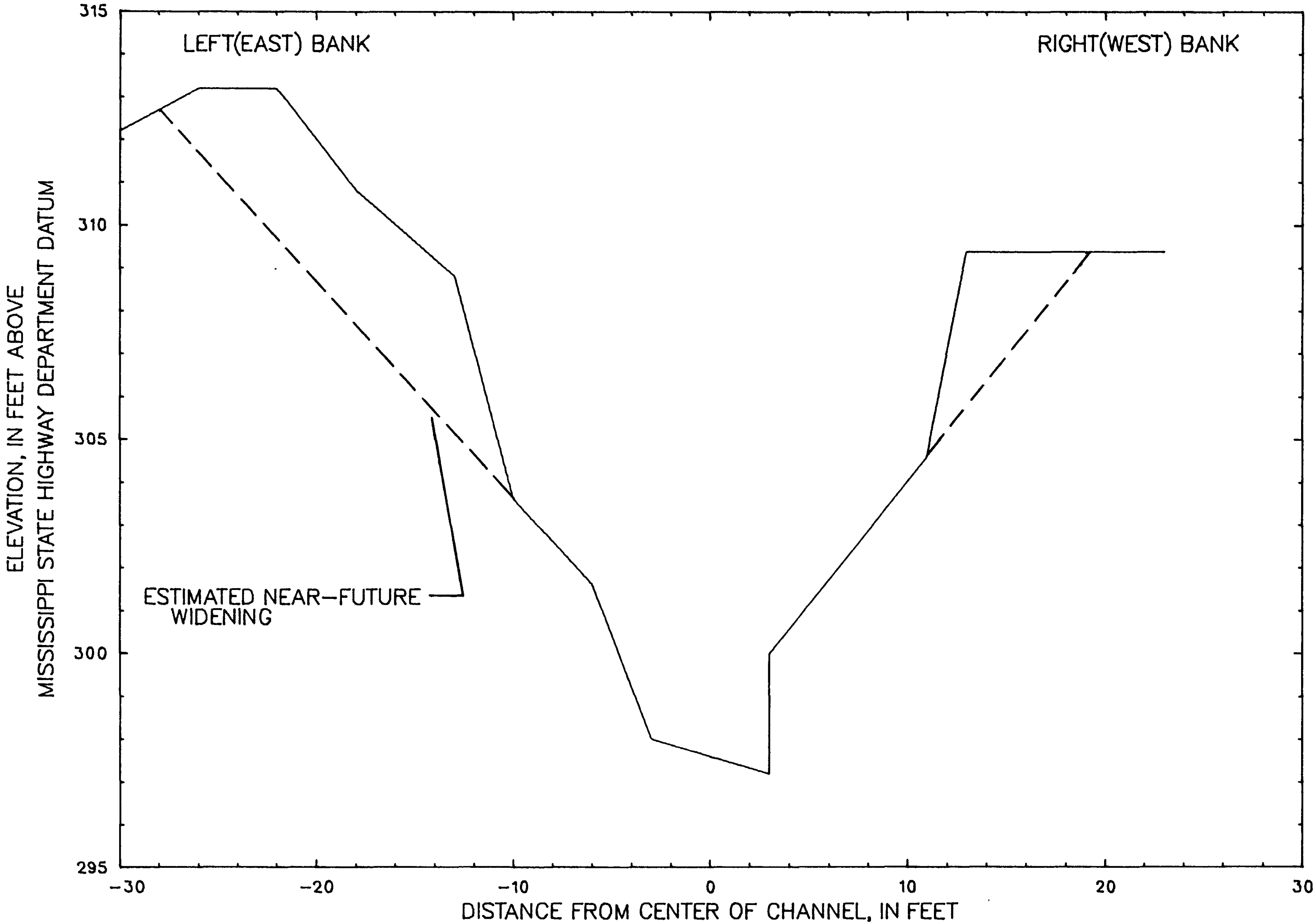

Figure 7.——Existing channel cross section showing near—future widening for Sand Branch tributary 650 feet downstream of State Highway 342 near Pontotoc, Mississippi.

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