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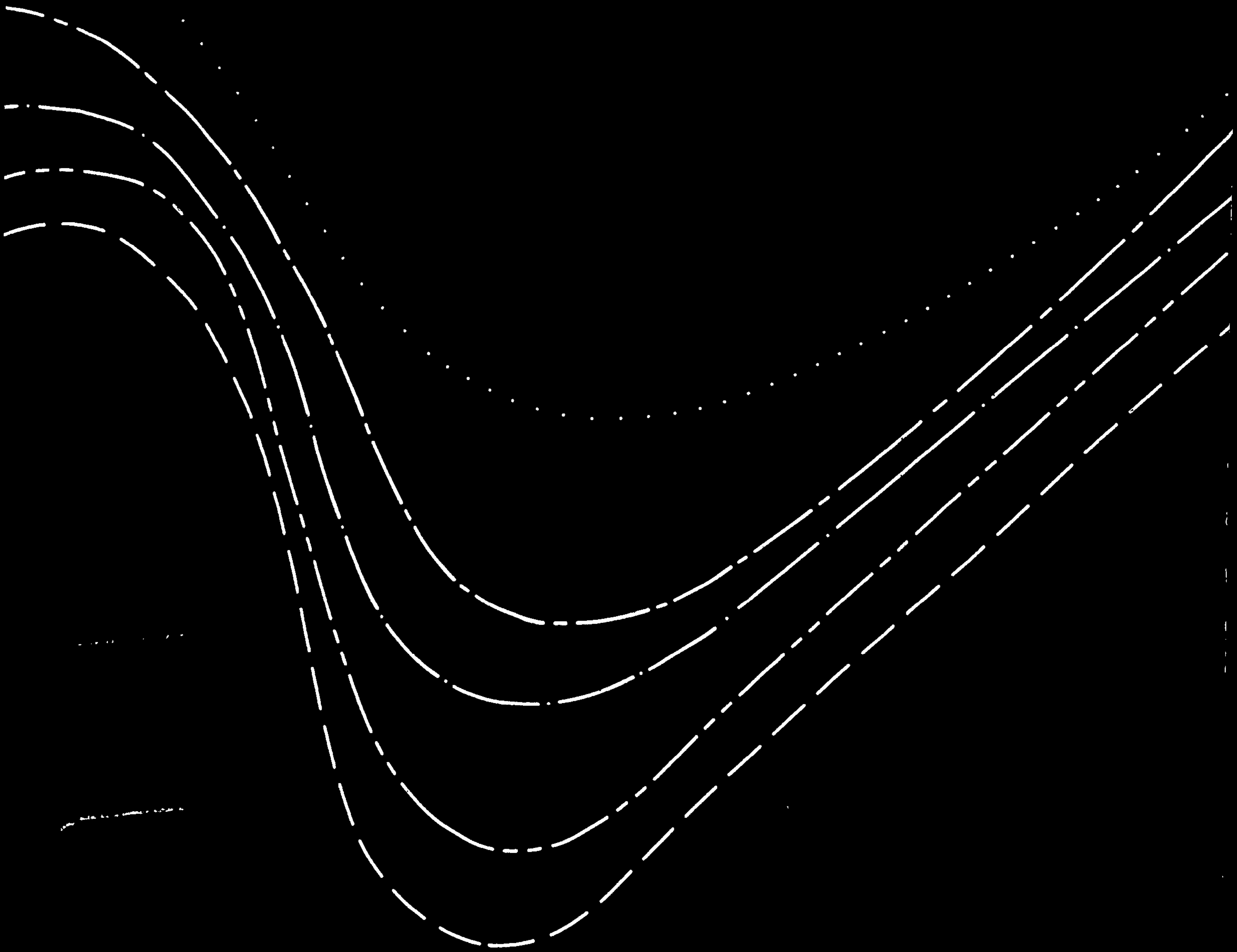
GEOMORPHIC AND VEGETATIVE RECOVERY PROCESSES ALONG MODIFIED STREAM CHANNELS OF WEST TENNESSEE



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U.S. GEOLOGICAL SURVEY

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TENNESSEE DEPARTMENT OF TRANSPORTATION

U.S. DEPARTMENT OF THE INTERIOR
March 3 1849

Cover: Modified profiles of projected channel bed-level lowering over time for North Fork of the Forked Deer River. (See page 52 for detailed illustration.)

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District Chief
U.S. Geological Survey
810 Broadway, Suite 500
Nashville, Tennessee 37203

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CONVERSION FACTORS

Multiply	**By**	**To obtain**
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
foot per year (ft/yr)	0.3048	meter per year
square foot (ft^2)	0.0929	square meter
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
pound (lb)	0.454	kilogram
pound per square inch (lb/in^2)	6.89	kilopascal

GEOMORPHIC AND VEGETATIVE RECOVERY PROCESSES ALONG MODIFIED STREAM CHANNELS OF WEST TENNESSEE

By Andrew Simon and Cliff R. Hupp

ABSTRACT

Hundreds of miles of streams in West Tennessee have been channelized or otherwise modified since the turn of century. After all or parts of a stream are straightened, dredged, or cleared, systematic hydrologic, geomorphic, and ecologic processes collectively begin to reduce energy conditions towards the premodified state. One hundred and five sites along 15 streams were studied in the Obion, Forked Deer, Hatchie, and Wolf River basins. All studied streams, except the Hatchie River, have had major channel modification along all or parts of their courses.

Bank material shear-strength properties were determined through drained borehole-shear testing (168 tests) and used to interpret present critical bank conditions and factors of safety, and to estimate future channel-bank stability. Mean values of cohesive strength and angle of internal friction were 1.26 pounds per square inch and 30.1 degrees, respectively. Dendrogeomorphic analyses were made using botanical evidence of channel-bank failures to determine rates of channel widening; buried riparian stems were analyzed to determine rates of bank accretion. Channel bed-level changes through time and space were represented by a power equation. Plant ecological analyses were made to infer relative bank stability, to identify indicator species of the stage of bank recovery, and to determine patterns of vegetation development through the course of channel evolution. Quantitative data on morphologic changes were used with previously developed six-stage models of channel evolution and bank-slope development to estimate trends of geomorphic and ecologic processes and forms through time.

Immediately after channel modifications, a 10- to 15-year period of channel-bed degradation ensues at and upstream from the most recent modifications (area of maximum disturbance). Channel-bed lowering by degradation was as much as 20 feet along some stream reaches. Downstream from the area of maximum disturbance, the bed was aggraded by the deposition of sediment supplied by knickpoint migration upstream; aggradation also occurred in initially degraded sites with time. Additionally, if degradation caused an increase in bank height beyond the critical limits of the bank material, a period of channel widening by mass wasting followed. Degradation knickpoints migrated upstream at rates greater than 1 mile per year; the rates attenuated with distance above the area of maximum disturbance. Channel widening rates of up to 16 feet per year were documented along some severely degraded *reaches. Planar failures were generally more frequent but rotational failures dominated the most rapidly widening reaches. Total volumes of bank erosion may represent 75 percent or more of the total material eroded from the channel, but this material generally exits the drainage basin. Mean factors of safety vary with the stage of channel evolution with the lowest values for planar and rotational failures occurring during the threshold stage (stage IV) 1.00 and 1.15, respectively. As channel gradients decrease, degradation ceases and then a period of "secondary aggradation" (at lesser rates than degradation) and bank accretion begins that may fill the channel to near flood-plain level. This shift in process represents an oscillation in channel bed-level adjustment. Streams in basins underlain by loess may require an order of magnitude more time than sand-bed streams to stabilize due to a lack of coarse-grained material (sand) for aggradation.*

A systematic progression of riparian species that reflects the six-stage model of channel evolution has been identified. This progression can be used to infer ambient channel stability and hydrogeomorphic conditions. Woody vegetation establishes on low- and mid-bank surfaces (the slough line, initially) at about the same time that bank accretion begins. This slough line forms at a mean temporary stability angle of 24 degrees and expands upslope with time by the accretion of sediments. Species involved in this initial revegetation are hardy, fast growing, and can tolerate moderate amounts of slope instability and sedimentation; these species include river birch, black willow, boxelder, and silver maple. Vegetation appears to enhance bank stability, and with increasing stability, species such as bald cypress, tupelo gum, and various hydric oaks, which are more characteristic of stable, premodified riparian settings, begin to establish. Detrended-correspondence analysis indicated species assemblages associated with the six stages of channel evolution and bank-slope development. Ordination of site variables based on species data such as channel widening, bank accretion, and woody vegetative cover also reflects the temporal changes identified by the models.

Long-term channel geometry was estimated from a quantitative model of bed-level change, and from documented trends in channel widening. An idealized stable channel of a major sand-bed stream may have a width/depth ratio near 10 and bank slopes of about 24 degrees. This stable channel will ultimately undergo the development of point-bars and incipient meanders, characteristic of unmodified streams.

INTRODUCTION

Alluvial channels are dynamic geomorphic features that naturally adjust to altered environmental conditions. This ability to adjust indicates that a natural or man-induced change imposed on a fluvial system will cause channel adjustments that offset the change for some distance upstream and downstream.

Lane (1955) describes this general balance in terms of the stream power proportionality:

$$QS \propto Q_S d_{50}, \tag{1}$$

where Q = water discharge,
S = channel gradient,
Q_S = bed-material discharge, and
d_{50} = median particle size of channel-bed material.

Natural channel adjustments can be exceedingly slow and progressive, practically imperceptible by human standards. When natural stream channels are altered by dredging or straightening (shortening), both bankfull discharge (Q) and channel gradient (S) can be increased. Equation 1 indicates that such channel modifications will result in an increase in bed-material discharge (Q_S) and (or) median grain size of the channel-bed material (d_{50}), such that rapid and observable morphologic changes occur.

Man-induced changes often involve shortened timeframes relative to naturally induced adjustments. This temporal difference presents an opportunity to examine successive process-response mechanisms through the course of fluvial adjustment over a short period of time. Channelization is a common and controversial engineering practice aimed at controlling flooding or draining wetlands. Channel modifications from 1959 to 1978 throughout most of West Tennessee have created a natural laboratory for the study of channel adjustments and evolution in modified fluvial networks. Quantification of channel responses can be of substantial value in efforts to mitigate the effects of channelization on river-crossing structures and on lands adjacent to, and upstream and downstream from affected channels.

This study was undertaken by the U.S. Geological Survey in cooperation with the Tennessee Department of Transportation to obtain a more complete understanding of the potential effects of alluvial channel changes on West Tennessee bridges and highways. The report is a comprehensive summary of four previous studies of modified streams in West Tennessee and builds on this earlier work.

Historical Background

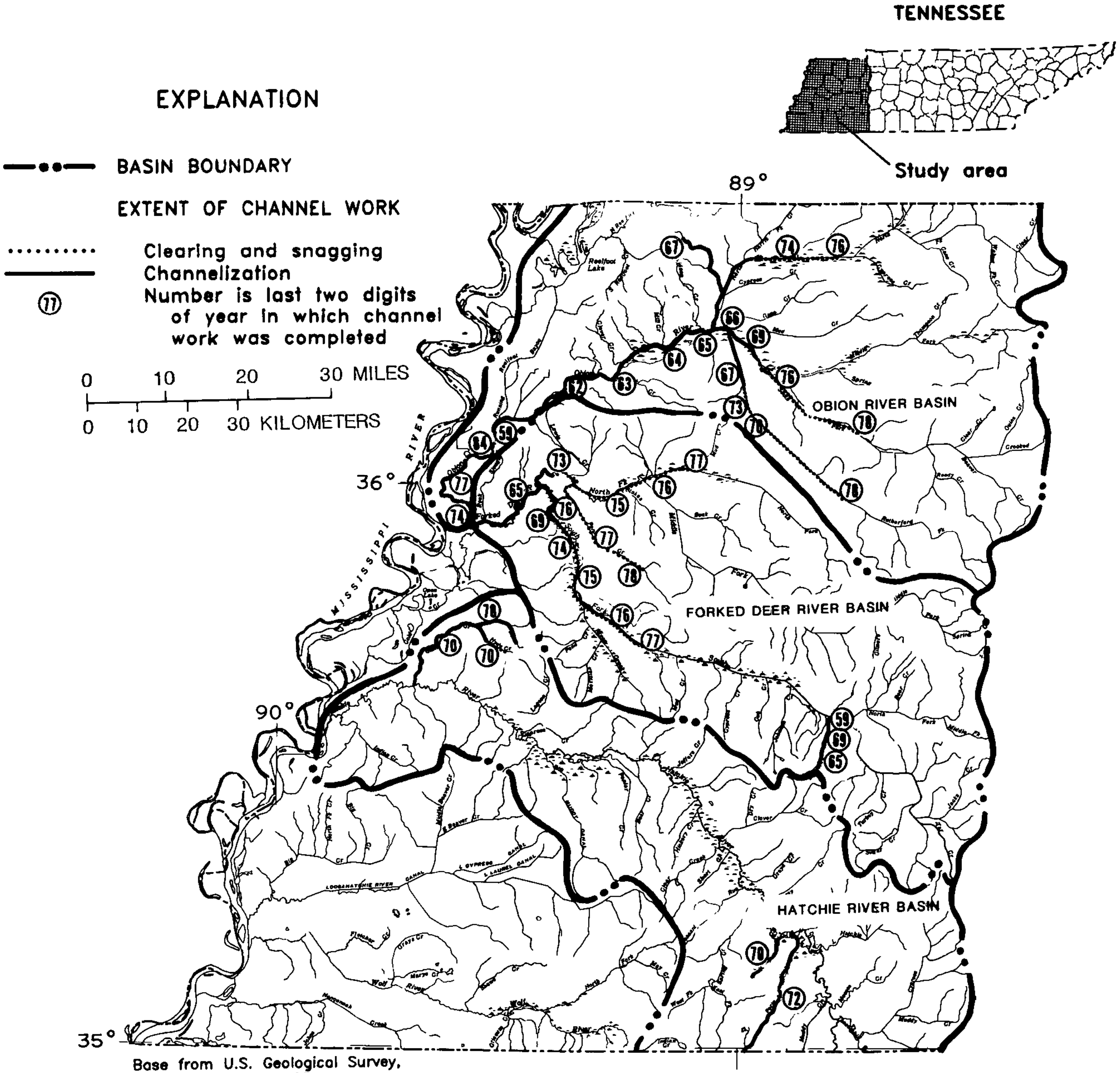
Prior to major deforestation in the West Tennessee region after the Civil War, rivers "flowed with good depths year round" (Ashley, 1910). Clearing of large tracts of land led to intense erosion of the uplands and to gullying in fields. The eroded material was deposited on the flood plains (Maddox, 1915) and in the stream channels; this resulted in a general loss of channel capacity (Ashley, 1910). Channels became extremely sinuous, choked with sediment and debris, and were subject to frequent and prolonged flooding (Morgan and McCrory, 1910). Early (circa 1910) surveys of the Obion and South

Fork Forked Deer Rivers indicated mild channel gradients of approximately 0.000114 foot per foot (ft/ft) and broad flood plains 1 to 3 miles wide (U.S. Army Corps of Engineers, 1907; Hidinger and Morgan, 1912). Hidinger and Morgan (1912) advocated enlargement of West Tennessee channels and the construction of levees to convey and contain flood waters. Conservation measures were proposed to protect and reclaim the gullied landscape (Maddox, 1915).

Most stream channels in West Tennessee, with the exception of Hatchie River main stem, had been dredged and straightened by 1926 in an effort to decrease the magnitude and frequency of out-of-bank flows (Speer and others, 1965). Further enlargement of the channels occurred in response to the modifications (Ramser, 1930). Subsequent accumulation of debris (trees and stumps) from failed banks caused backwater and sedimentation at the downstream ends of the forks of the Obion and Forked Deer Rivers (Speer and others, 1965). Continued aggradation and debris accumulation through the 1930's necessitated bank clearing and channel snagging (removal of trees and stumps) of about 170 miles of main stem, forks, and tributaries of the Obion River system in the late 1930's and 1940's. After this work was completed, the cycle began again and channel filling occurred through the 1940's and 1950's (Robbins and Simon, 1983). This resulted in the formulation of a regional program to further channelize or rechannelize many of the drainage systems in West Tennessee. Channel work on the Hatchie River during the period 1938-52 was limited to channel snagging, which preserved its meandering course.

From the late 1950's through the 1970's, various types of channelization projects were undertaken in West Tennessee in basins ranging in size from 10.7 to 2,440 mi^2; these projects resulted in the adjustment of entire fluvial networks (fig. 1). A short reach of the lower Obion River was modified in 1984 but was not included in this study. The West Tennessee Tributaries Project, which provided for the enlargement and straightening of 118 miles in the Obion River system and 105 miles in the Forked Deer River system, was temporarily halted by court order in 1970 when it was about one-third complete (Robbins and Simon, 1983). At that time, channelization in the Obion River system had extended into the lower reaches of its three forks (fig. 1).

Most downstream reaches of the constructed channels typically began to fill with accumulated sediment and debris emanating from eroding reaches farther upstream (Robbins and Simon, 1983). The entire length of the Obion River main stem has become a depository for material eroded from the North, South and Rutherford Forks. Rates of aggradation along this river range from 0.1 foot per year (ft/yr) at the confluence of the forks, to 0.4 ft/yr, 8.5 miles downstream. At the most downstream study site on the South Fork Forked Deer River, 7.2 feet of infilling took place over a 12-year period after channelization.



Base from U.S. Geological Survey,
State base map, 1967,
revised 1973

Figure 1.--Extent of recent channel work in West Tennessee.

About 51 miles of channels in the Forked Deer River system and 67 miles of channels in the Obion River system were cleared from 1973 to 1978. Additional dredging and straightening activities on the lower Obion main stem were done in the late 1970's and early 1980's.

Channelization projects of lesser geographic extent than the West Tennessee Tributaries Project also were included in this study (fig. 1). The affected streams were shortened as much as 44 percent, steepened as much as 600 percent, and lowered by as much as 170 percent (Simon, in press). The Hatchie River reflects largely "natural" fluvial development, because the only direct alterations involved snagging and clearing between 1938 and 1952 with no alteration to pattern or profile. It is one of the few sinuous channels remaining in West Tennessee and has shown relative stability in profile (Robbins and Simon, 1983). Therefore, it was excluded from the quantitative analysis of adjustment trends. The Hatchie River, however, cannot be interpreted as representing presettlement conditions because of post-Civil War deforestation, and because its tributary basins are intensely farmed and channelized.

Purpose and Scope

The overall objective of this study was to quantify changes in alluvial-channel morphology after channel modifications, and to provide information regarding expected future changes as a result of those modifications. The purpose of this report is to present the results of a 3-year study, which builds on four previous studies of channelized streams in West Tennessee (Robbins and Simon, 1983; Simon and Hupp, 1986a; Simon and Hupp, 1986b; Simon and Robbins, 1987; Simon and Hupp, 1987; Simon, 1989). These previous studies are discussed in greater detail later in this report. The work described in this report emphasizes interdisciplinary approaches to analysis of fluvial adjustment. Specific objectives of this report are:

1. Quantification of channel-bed and bank adjustments caused by channelization over time and space;

2. Estimation of the amounts of channel-bed degradation, aggradation, channel widening, and bank accretion in order to attain a stable channel cross section;

3. Determination of the relative role of shear-strength and mass-wasting processes in affecting channel morphology over the course of fluvial adjustment;

4. Determination of the reliability of riparian (streambank) vegetation as a major diagnostic criterion for denoting channel processes;

5. Estimating the time required to attain a stable-channel geometry by "natural" adjustment processes;

6. Testing of previously developed six-stage conceptual models of bank-slope development and channel evolution with quantitative data;

7. Incorporation of a previously developed quantitative model of bed adjustment, with quantitative data on channel-width adjustment, into an empirical model of channel evolution;

8. Determination of the ecological response of woody riparian species and their relation to the six-stage models of bank-slope development and channel evolution; and

9. Description of the interdisciplinary methods needed to estimate potential morphologic changes and long-term channel geometry in other unstable alluvial-stream systems.

Analysis of the adjustment of West Tennessee alluvial channels in this report is limited to consideration of the effects of channelization work that was done from the late 1950's through the 1970's (tables 1 and 2). This includes documentation of the trends of geomorphic and vegetative response and the estimation of future, stable-channel geometries over the course of channel evolution. The timeframe involved for these adjustments are in the order of 50 to 100 years (Simon, in press).

Study Area

The study area includes approximately 10,600 mi^2 in West Tennessee bounded by the Mississippi River on the west and the Tennessee River divide on the east (fig. 1). This area is entirely within the Mississippi embayment and is part of the Gulf Coastal Plain province (Fenneman, 1938). All stream systems studied drain to the Mississippi River and are in the Obion, Forked Deer, Wolf, and Hatchie River basins (fig. 1, table 1). These rivers flow through unconsolidated and highly erosive sediments (U.S. Department of Agriculture, 1980), predominantly of Quaternary age. The Obion and Forked Deer Rivers flow through Mississippi River alluvial deposits in their most downstream reaches, and loess-derived alluvium farther upstream, and in their forks (fig. 2). Most tributary streams flow across deposits of loess that thin eastward from 100 feet along the bluffs of the Mississippi River, to less than 5 feet near the outcrop of the Claiborne and Wilcox Groups of Tertiary age (Miller and others, 1966; fig. 2). These groups, composed predominantly of sand, are the source of sand for the major drainages of the region, as well as for the eastern tributaries (fig. 2). There is a complete lack of bedrock control of local base level, assuring unrestricted channel adjustment. During the course of this study, none of the studied reaches in the Obion-Forked Deer or Wolf River basins were affected by grade-control structures. Grade-control structures on Cane Creek (upstream of the study sites) and on Cub and Porters Creeks did not influence data analysis.

Table 1.--*Drainage basins, drainage areas, and dominant surficial geology of the study area*

Basin	Drainage area (square miles)	Dominant surficial geologic units
Obion River[1,2]	2,445	Loess
North Fork Obion River	578	Loess
Hoosier Creek	34.3	Loess
South Fork Obion River	426	Loess
Rutherford Fork Obion River.	277	Loess
Forked Deer River[1]	2,080	Holocene alluvium
North Fork Forked[1] Deer River.	952	Loess
Pond Creek	69.6	Loess
South Fork Forked[1] Deer River	1,061	Loess, Claiborne and Wilcox Groups.
Wolf River[1]	816	Loess, Claiborne and Wilcox Groups.
Hatchie River[1]	2,609	Loess, Claiborne, and Wilcox Groups.
Cane Creek	86.6	Loess
Hyde Creek	10.7	Loess
Cub Creek	16.7	Midway Group
Porters Creek	63.7	Midway Group

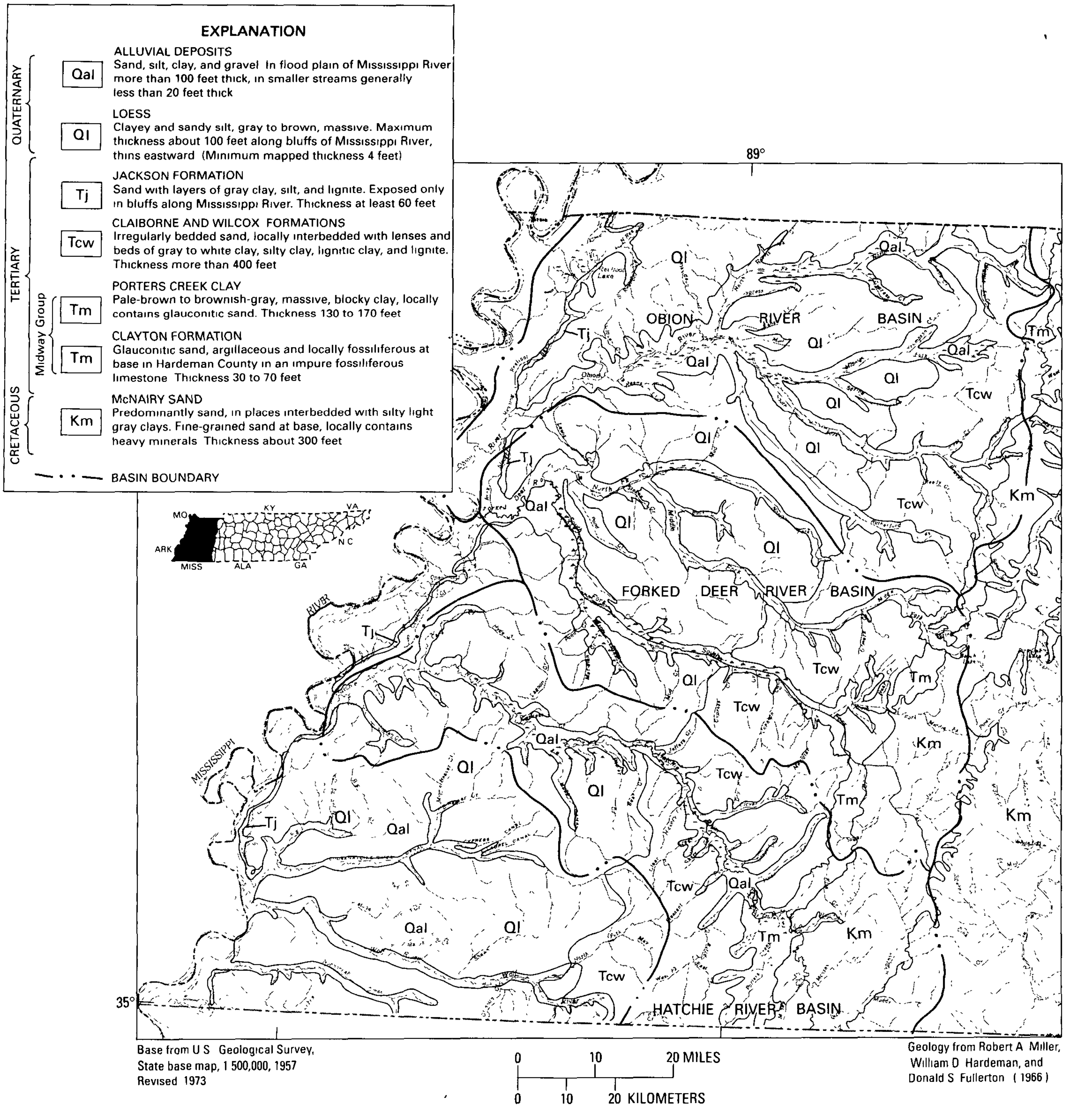
[1] Larger streams also flow through substantial alluvial deposits of Holocene age.
[2] Upstream from mouth of Forked Deer River.

The native vegetation growing along channelized streams in many West Tennessee bottomlands has been affected either directly or indirectly by channel modifications (Miller, 1985; Hupp and Simon, 1986). However, a few large tracts of bottomland forest along the Hatchie River main stem remain relatively unaffected by channel work; these tracts function as control areas for this study. The bottomlands are characterized by low gradient, meandering streams with scattered stands of bald cypress (*Taxodium distichum*) and water tupelo (*Nyssa aquatica*). Southern bottomland forests, are on slightly higher elevations, and are composed of green ash (*Fraxinus pennsylvanica*), soft maples (*Acer rubrum*, *A. saccarhinum*), and various hydric oaks (*Quercus*). Cottonwood (*Populus deltoides*), sycamore (*Platanus occidentalis*), black willow (*Salix nigra*), and river birch (*Betula nigra*) also grow in disturbed areas of the bottomland, particularly along the channels.

Table 2.--*Periods and extents of recent channel modifications on studied streams (1959-78)*

[Data from Corps of Engineers, Soil Conservation Service, and Obion-Forked Deer Basin Authority construction plans]

Stream	Modification type	Distance (miles)	Dates
Obion	Enlarging and straightening	46.6	1959-66
	Clearing and snagging	4.2	1976
	Enlarging and straightening	--	1974-77
North Fork Obion River.	Enlarging and straightening	10.9	1967
	Clearing and snagging	10.8	1974-76
Hoosier Creek	Enlarging and straightening	7.4	1967
Rutherford Fork Obion River.	Enlarging	7.4	1967
	Clearing and snagging	17.9	1973-78
South Fork Obion River.	Enlarging	6.0	1967,69
	Clearing and snagging	17.1	1976-78
North Fork Forked Deer River.	Enlarging and straightening	4.3	1973
	Clearing and snagging	19.6	1974-77
Pond Creek	Clearing and snagging	13.1	1976-78
South Fork Forked Deer River.	Enlarging and straightening	4.4	1969
Meridian Creek	Enlarging and straightening	1.6	1959?
	Enlarging and straightening	5.2	1969
	Enlarging	1.6	1969
Cane Creek	Enlarging and straightening	32.3	1970
	Enlarging and straightening	13.0	1978
Hyde Creek	Enlarging and straightening	0.8	1970
Cub Creek	Enlarging and straightening	9.7	1970
Porters Creek	Enlarging and straightening	21.4	1972
Wolf River	Enlarging and straightening	21.8	1964



EXPLANATION

QUATERNARY

Qal ALLUVIAL DEPOSITS
Sand, silt, clay, and gravel In flood plain of Mississippi River more than 100 feet thick, in smaller streams generally less than 20 feet thick

Ql LOESS
Clayey and sandy silt, gray to brown, massive. Maximum thickness about 100 feet along bluffs of Mississippi River, thins eastward (Minimum mapped thickness 4 feet)

TERTIARY

Tj JACKSON FORMATION
Sand with layers of gray clay, silt, and lignite. Exposed only in bluffs along Mississippi River. Thickness at least 60 feet

Tcw CLAIBORNE AND WILCOX FORMATIONS
Irregularly bedded sand, locally interbedded with lenses and beds of gray to white clay, silty clay, lignitic clay, and lignite. Thickness more than 400 feet

Midway Group

Tm PORTERS CREEK CLAY
Pale-brown to brownish-gray, massive, blocky clay, locally contains glauconitic sand. Thickness 130 to 170 feet

Tm CLAYTON FORMATION
Glauconitic sand, argillaceous and locally fossiliferous at base in Hardeman County in an impure fossiliferous limestone Thickness 30 to 70 feet

CRETACEOUS

Km McNAIRY SAND
Predominantly sand, in places interbedded with silty light gray clays. Fine-grained sand at base, locally contains heavy minerals Thickness about 300 feet

— • • — BASIN BOUNDARY

Base from U S Geological Survey,
State base map, 1 500,000, 1957
Revised 1973

Geology from Robert A Miller,
William D Hardeman, and
Donald S Fullerton (1966)

Figure 2.—Surficial geology of West Tennessee.

Acknowledgments

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CONSEQUENCES OF CHANNEL MODIFICATIONS

Upstream-progressing degradation and downstream aggradation are common attributes of channelized streams, and are caused by increases in channel gradient and capacity. Additional consequences of degradation are bank failures (from overheightening and oversteepening) and undermining of hydraulic structures, such as bridges.

Daniels (1960) reports that straightening of the Willow River in southwestern Iowa, led to approximately 30 feet of degradation in some reaches. Canyon-type gullies formed and extended into the surrounding countryside, damaging agricultural land and forcing the repair and reconstruction of roads and bridges (Ruhe, 1970). Channelization projects between 1938 and 1940 on the lower reaches of the Homochitto River in southwestern Mississippi caused up to 19 feet of degradation, accelerated bank caving, and led to the collapse of several bridges (Wilson, 1979). After channelization of the Blackwater River in Missouri, degradation and channel widening increased channel cross-sectional area by as much as 1,000 percent, which also caused several bridge failures (Emerson, 1971). The channel-bed elevation was lowered about 17 feet in 10 years along some reaches of Cane Creek, West Tennessee, in response to channelization activities (Simon and Hupp, 1986b).

Sediment that eroded from upstream degrading reaches and tributary streams generally is deposited along the low gradient downstream reaches. Such aggradation leads to a loss of channel capacity, increased frequency of flooding, and increased magnitudes of peak flows; this counters the purpose of the channelization (Parker and Andres, 1976). The downstream reaches of Cub and Porters Creeks, Hardeman County, Tenn., became filled with sediments within 2 years after these streams were channelized.

The lowering of channel-bed levels can create an unstable, overheightened and oversteepened bank profile. Continual basal erosion undercuts and removes support for the top part of the bank which ultimately results in "slab failure" (Thorne and others, 1981). High, low-angle slopes may fail along a circular arc as "deep-seated rotational slides" as a result of prolonged wetting and (or) incision (Bradford and Piest, 1980). Fluvial erosion of bank material does not contribute substantially to bank retreat in the loess-derived materials that characterize streams of the West Tennessee study area (Simon, 1989). Channel widening in these materials takes place primarily by mass-wasting processes that occurs when critical conditions (bank height and angle) are exceeded (Lohnes and Handy, 1968). The critical bank height (H_c) is a function of the amount of material at the slope base, the slope angle, and moisture and soil conditions. A complete discussion of bank-stability analyses is given in Lohnes and Handy (1968) and Thorne and others (1981).

Bank-stability analyses have been used to assess bank stability in typical loess and loess-derived materials of Iowa and West Tennessee (Lohnes and Handy, 1968; Bradford and Piest, 1980; and Simon and Hupp, 1986b) and northern Mississippi (Thorne and others, 1981; and Little and others, 1982).

Tension cracking and piping are common in loess soils. Tension cracking which develops at the ground surface and proceeds downward (Thorne and others, 1981) serves to destabilize the bank internally. Piping, an erosion process started by the percolation of water through a soil mass, further weakens banks composed of loess-derived alluvium (Simon and Hupp, 1986b).

Channel widening after degradation also is well documented in the literature. Increases in channel width (between tops of banks) and channel capacity as a result of channelization are reported by Hidinger and Morgan (1912), Ramser (1930), Daniels (1960), Parker and Andres (1976), Wilson (1979), Thorne and others (1981), Harvey and others (1983), and Robbins and Simon (1983). Simon and Hupp (1986b) report 150 feet of widening by rotational failures between 1970 and 1980 along some parts of Cane Creek, West Tennessee, after channelization.

Channel Adjustment--General

Channel-bed adjustments through time are best described by nonlinear functions which approach a condition of apparent or quasi-equilibrium. The description of channel adjustment and evolution by nonlinear decay functions is well documented (Schumm and Lichty, 1965; Graf, 1977; Bull, 1979, Hey, 1979, Robbins and Simon, 1983). There seems to be considerable disagreement however as to the mathematical form of the function. Graf (1977) used exponential functions to describe the "relaxation time" necessary to achieve equilibrium after a disturbance. Simon and Robbins (1987) used similar equations to model gradient adjustment through time. Williams and Wolman (1984) found that hyperbolic functions were appropriate for describing channel-bed degradation downstream from dams.

Detailed analytical studies of channel response to channelization are not common in the literature. Most studies of channel response are relatively descriptive; Others deal with network rejuvenation derived from experimental-flume studies (Schumm and Parker, 1973; Begin and others, 1981), and with theoretical models (Schumm, 1973; Graf, 1977; Bull, 1979; and Hey, 1979). Notable exceptions are studies done in northern Mississippi (Schumm and others, 1984), and in West Tennessee. The Tennessee studies are based on field data and attempt to quantify adjustment trends after channelization.

Five studies (including this one) were conducted on the unstable stream channels of West Tennessee between the mid-1970's and the mid-1980's. The first study was designed to investigate channel stability problems near bridges that were initially attributed to localized bridge scour. It was during the course of this investigation that it was realized that scour was of secondary importance, and that entire fluvial net-works were adjusting to man-induced disturbances (Robbins and Simon, 1983; Simon and Robbins, 1987).

The second study was designed specifically to address the problem of channel bed-level changes through time and to associate these changes with the magnitude and extent of the imposed disturbances (dredging and channelization). As a result of this study, a bed-level model was developed (Simon and Hupp, 1986a); comparison of observed and predicted values were provided (Simon, in press); and the conceptual models of bank-slope development and channel evolution were advanced (Simon, 1989; Simon, in press). It was also during this study that the importance of channel widening by mass-wasting processes was first realized.

A third study concentrated on channel adjustments after channelization along a reach of Cane Creek, Lauderdale County, and resulted in the development of a method to estimate future channel widening (Simon and Hupp, 1986b). A fourth study was conducted in cooperation with the Soil Conservation Service along the length of Cane Creek. This work was comprehensive in scope and investigated channel adjustments along a disturbed channel that had no appreciable sand load for downstream aggradation.

Results of the fifth West Tennessee study are given in this report and provide a comprehensive summary of previous work. This report couples detailed analyses of channel-bank processes and forms, and plant ecology, with previously documented models of bank-slope development and channel evolution. Preliminary results of this study were reported in Simon and Hupp (1987).

The northern Mississippi studies concentrate on developing quantitative relations that can be used to recognize channels that would be the most receptive to mitigation measures. An area-gradient index and space-for-time substitutions were used to predict changes in channel morphology (Schumm and others, 1984). The West Tennessee studies have resulted in a quantitative model of bed-level adjustment, and in conceptual models of bank-slope development and channel evolution (Simon and

Hupp, 1986a; Simon, 1989). Because the approach of this study was dictated to some extent by the results of previous work in West Tennessee, a fairly detailed review of those studies will follow in a later section.

Vegetation Response

Vegetation analyses (dendrochronological and plant ecological) are an integral part of the present study. The use of vegetation analyses in the interpretation of geomorphic disturbances, is a relatively recent activity (Graf, 1977; White, 1979: Cairns, 1980; Hupp, 1988). Only a few analyses of riparian vegetation along channelized streams have been conducted (McCall and Knox, 1978; Shields and Nunnally, 1985; Simon and Hupp, 1986a; 1986b; Hupp, 1987).

All of the above-mentioned studies of vegetative response rely on certain basic dendrochronologic concepts that are based on the annual-growth increment of woody plants--the tree ring. Hydrogeomorphic events such as floods and bank failures usually affect the growth rate of woody plants such that datable anomalies can be detected in wood tissue. These anomalies include corrasion scars, tilt sprouts, eccentric growth rings, and suppression or release sequences. Thus, by coring or taking cross-sections of affected stems and counting the number of growth rings since the plant was affected, the number of years since the event occurred can be determined. These techniques have been used in West Tennessee to obtain rates of channel widening and bank accretion (Hupp and Simon, 1986; Hupp, 1987) and to determine the date of initial bank stability.

The magnitude and timing of geomorphic processes are reflected in the presence and character of riparian plants along modified channels or along channels upstream from modifications. Vegetation can be virtually absent along unstable reaches, whereas dense thickets of black willow, river birch, or silver maple can dominate in stable reaches (Hupp and Simon, 1986). The degree of revegetation on the channels banks has been used as an indicator of the general stage of bank-slope development (Simon and Hupp, 1986a, and Simon, 1989).

Examples From West Tennessee Studies

System-wide channel adjustments along streams in West Tennessee have been studied since 1983 by the U.S. Geological Survey. These adjustments involve drastic changes to both the channel bed and banks.