Riparian-Vegetation Controls on the Spatial Pattern of Stream-Channel Instability, Little Piney Creek, Missouri

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By ROBERT B. JACOBSON and AARON L. PUGH

Prepared in cooperation with the
Missouri Department of Conservation

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CONTENTS

PLATE

[Plate is in pocket]

FIGURES

FIGURES—Continued

TABLES

CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
	Length	
millimeter (mm)	0 03937	inch
meter (m)	3 281	foot
kilometer (km)	0 6214	mile
	Area	
square meter (m^2)	10 76	square foot
square kilometer (km^2)	0 3861	square mile
	Flow rate	
cubic meter per second (m^3/s)	35 31	cubic foot per second
	Hydraulic gradient	
meter per kilometer (m/km)	5 27983	foot per mile

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows

$$°F = (1\ 8 \times °C) + 32$$

Sea level In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic 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

Riparian-Vegetation Controls on the Spatial Pattern of Stream-Channel Instability, Little Piney Creek, Missouri

By Robert B Jacobson *and* Aaron L Pugh

ABSTRACT

Post-settlement land-use changes in the Ozark Plateaus, Missouri, have been considered responsible for creating widespread channel instability and degradation of aquatic habitat A review of land-use history indicates that the most potential for creating instability has been from farming and grazing practices that have destroyed woody riparian vegetation or prevented the re-establishment of woody vegetation on gravel bars The role of riparian vegetation has been assessed quantitatively by using a 50-year record of valley-bottom vegetation and channel dynamics developed from historical aerial photography A 12-kilometer segment of Little Piney Creek, a typical Ozark Plateaus, spring-fed, fifth-order stream, has been mapped with a stereoplotter Digital maps from 1938, 1948, 1955, 1965, 1976, and 1989 then were analyzed using a geographic information system Polygon identities of each pair of subsequent maps provide transition frequencies for estimating the relative areal rates at which riparian cropland, grassland, and woodland have been eroded or subjected to gravel aggradation

Results indicate that nonwooded land (cropland plus grassland) has been no more likely to erode than woodland, and that nonwooded land has been slightly more susceptible to gravel deposition than woodland These results may be explained by several factors, including physiographic controls on channel migration and deposition of noncohesive sediment in discrete disturbance reaches along the valley, the ineffectiveness of woody vegetation in contributing to bank stabilization where bank heights are greater than typical rooting depths, and possible changes in sediment, runoff, or flood peaks because of land-use changes upstream

INTRODUCTION

Channel form results from interactions among shear stresses exerted by moving water, sediment loads carried by the water, and the resistance of streambed and banks to erosion Woody vegetation in and along streams can contribute to flow resistance and energy dissipation, thus ultimately decreasing total shear stresses transmitted to the streambed and banks Furthermore, in many stream channels, vegetation contributes to the strength of streambed and bank, thereby imparting greater resistance to erosion and, consequently, greater channel stability These vegetational effects have been widely recognized by fluvial geomorphologists (for example, Petryk and Bosmajian, 1975, Smith, 1976, Graf, 1978, Murgatroyd and Ternan, 1983, Andrews, 1984, Shields and Nunnally, 1984, Fukuoka and Fujita, 1990, Thorne, 1990, Watts and Watts, 1990, Hupp and Simon, 1991, Hupp, 1992, Trimble, 1994, McKenney and others, 1995), but quantification has been difficult, partly because of the diverse ways in which vegetation interacts with fluvial processes

Because of the evident contributions of woody vegetation to bank strength and energy dissipation, many researchers have concluded that vegetation in and along streams has a net stabilizing effect on channels As a result, land and stream management decisions are frequently made that assume increased widths and densities of streamside vegetation would decrease bank erosion Some onsite data support these conclusions (Smith, 1976, Andrews, 1984), but other studies indicate that net effects of vegetation are a complex function of channel morphology, flow patterns, spatial density, and size of the vegetation communities (Thorne, 1990; Trimble, 1994). Therefore, the U.S. Geological Survey, in cooperation with the Missouri Department of Conservation, has begun studies to help provide a more complete understanding of interactions between riparian[1] vegetation and fluvial processes that is needed to improve channel and riparian management techniques.

[1]The term *riparian* is used in this report to include woody vegetation growing on banks, bars, and on the valley bottom for an arbitrary distance from the channel. This definition is used to include a strict definition of riparian (that is, limited only to streambank area) and the operational definition used by many land and stream managers (that is, alluvial bottomland, frequently including the entire valley bottom).

Purpose and Scope

The purpose of this report is to present an analysis of the spatial controls on stream instability exerted by woody riparian vegetation on Little Piney Creek, Missouri. Results from this study of Little Piney Creek are applicable to other streams of the Ozark Plateaus Physiographic Province (known locally and hereinafter referred to as the Ozarks).

The report focuses on a 12-km (kilometer) segment[2] of Little Piney Creek (fig. 1). The bedrock geology, soils, land-use, valley slope, and channel-network

[2]The term *segment* is used in this report to indicate longitudinal parts of a stream system between substantial tributaries and with relatively uniform properties of bedrock and valley physiography (Frissell and others, 1986). In Ozarks streams, segments are typically on the order of several to tens of kilometers long.

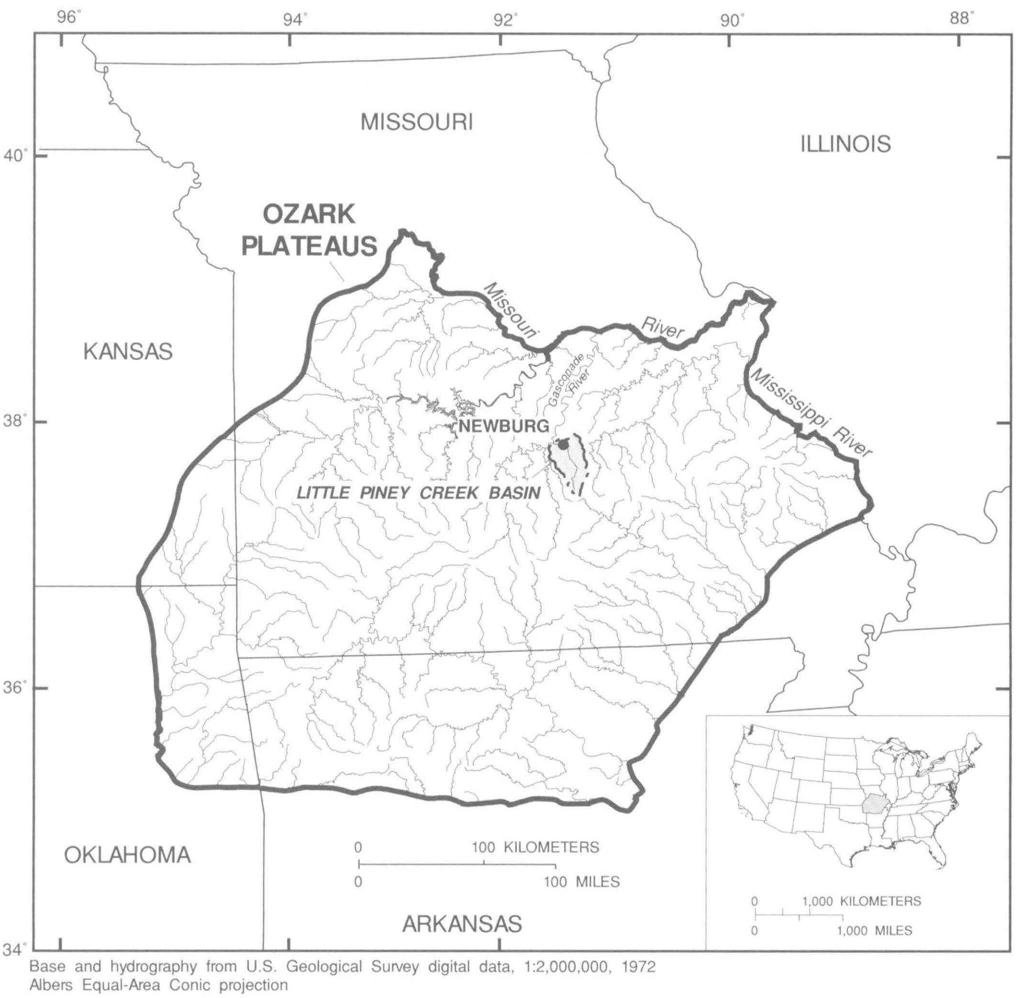

Figure 1. Location of Little Piney Creek and the Ozarks of Missouri.

characteristics of Little Piney Creek are representative of many fourth- to sixth-order streams of the Ozarks (Jacobson, 1995). Therefore, the results of the study should be applicable to other streams in the Ozarks and to other alluvial streams in drainage basins with rural land use and a humid-temperate climate, where the channel is free to migrate between confining bedrock walls.

Historical aerial photography was used to evaluate where and how much channel migration has occurred during a 50-year (1938–89) interval and to determine the association of channel migration locations with adjacent riparian land use. The 50-year interval and 12-km length of the study segment provide temporal and spatial coverage that cannot be replicated in conventional onsite-based monitoring studies. The scope and scale of this retrospective study are controlled in part by the scale of available aerial photography. Using photogrammetric techniques and photography that ranges from 1:8,000 to 1:24,000 negative scale, linear resolution of spatial changes during the 50 years considered in this report is approximately 5 m (meters). Hence, the study assesses effects of land use averaged over areas of land of hundreds of square meters rather than considering the scale of individual trees.

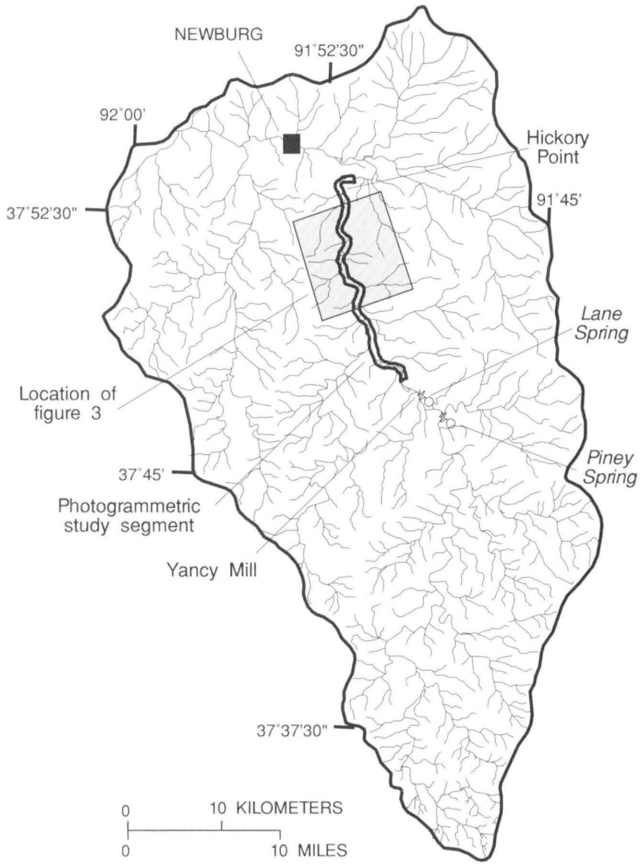

Figure 2. Location of the study segment of Little Piney Creek, Missouri.

Physical Setting

Little Piney Creek is located in the north-central Ozarks (figs. 1, 2). It has been gaged from 1928 to the present (1995) at Newburg, Missouri (fig. 2), where the drainage area is 512 km^2 (square kilometers). The 12-km segment used for photogrammetric study is a fifth-order stream with a drainage area ranging from 247 to 380 km^2.

The basin is underlain mainly by interbedded cherty dolomite and sandstone of the Roubidoux Formation (Ordovician age) and cherty dolomite of the Gasconade Dolomite (Ordovician age; Pratt and others, 1985). A small area of the uplands is underlain by dolomite and argillaceous dolomite of the Jefferson City Dolomite (Ordovician age; Pratt and others, 1985). The geologic structure is dominated by a regional dip of approximately 2 m/km (meters per kilometer) to the northwest (McCracken, 1971). The regional dip has gentle northwest trending folds superimposed on it. The anticlinal axis of one of these folds is west of and parallels the trend of the Little Piney Creek photogrammetric segment; bedrock dip along this limb of the fold is approximately 11 m/km to the northeast (Lee, 1913). Jointing in the area is nonsystematic and is unrelated to bedrock structure in any clear way (Lee, 1913). The Newburg Fault Zone crosses Little Piney Creek near Hickory Point (fig. 2). The fault displacement ranges from 5 to 30 m.

From the highest point in the basin to the junction of Little Piney Creek with the Gasconade River, the relief is approximately 215 m. Most of the upland area in the Little Piney Creek Basin is underlain by the Roubidoux Formation, whereas most stream valleys of third order and greater are incised into the Gasconade Dolomite. Typical valley-bottom to upland relief is 50 to 100 m, and steep bedrock bluffs are common (fig. 3). Residual and colluvial soils are as thick as 12 m on uplands but can be absent on steep slopes along the main valley (Pratt and others, 1985). A blanket of wind-blown loess no more than 0.30 m thick is preserved in patches on upland divides.

Mean annual temperature for the Little Piney Creek Basin is approximately 16 °C (degrees Celsius)

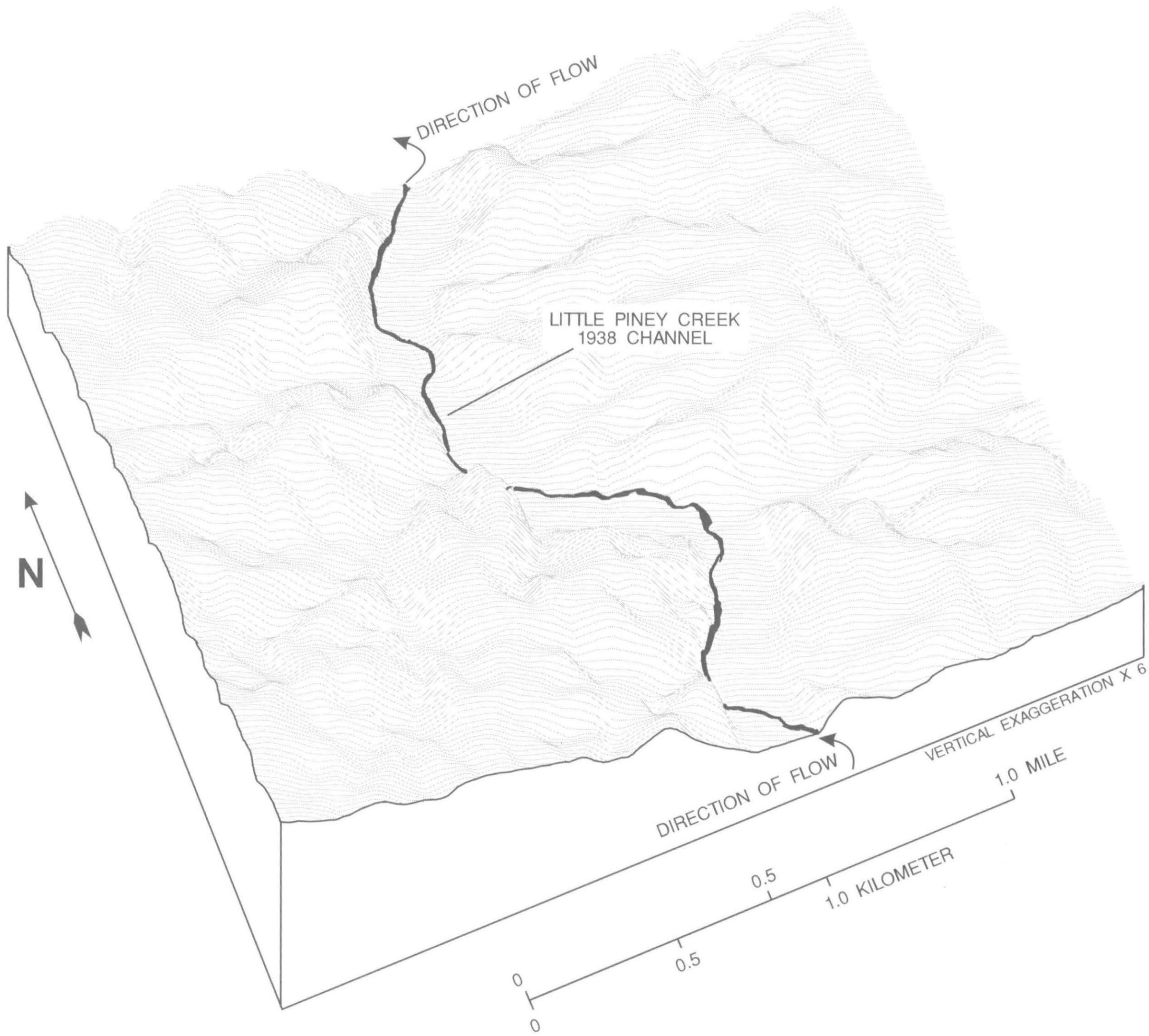

Figure 3. Three-dimensional map of a section of the Little Piney Creek Valley showing the wide, bedrock-confined valley bottom, underlain by floodplain sediments and alluvium of Holocene age (Albertson and others, 1995).

and mean annual precipitation is 1,050 mm (millimeters; Jacobson and Pugh, 1992). Typically, May and June have the greatest monthly average precipitation, but during the decades of the 1940's and the 1980's, secondary peaks in the monthly distribution occurred during autumn months (Jacobson and Pugh, 1992).

Streams of the Ozarks typically occupy winding valleys. The valley bends have been termed ingrown, incised meanders (Dury, 1964). Although these streams are not manifestly underfit as defined by Dury (1964), the stream widths are small as compared to the valley width, and stream and valley bends do not correspond in every case. As a result, the stream channel alternates between long straight reaches[3] adjacent and parallel to the valley wall and shorter, sinuous reaches where the stream impinges on the valley wall at a high angle or crosses from one side of the valley to the other. The sinuous and straight reaches have been

[3]The term *reach* is used in this report to indicate longitudinal subdivisions of stream segments between breaks in channel slope and characterized by channel patterns that contrast with those upstream and downstream. This definition differs somewhat from Frissell and others (1986) because it does not use riparian vegetation or valley floor width. Reaches in Ozarks streams typically include multiple riffle/pool sequences and are tens to thousands of meters long.

termed disturbance and stable reaches (Jacobson, 1995) Although the origins of the alternating disturbance and stable reaches are poorly understood, flow patterns and the resulting spatial distribution of erosion and deposition differ substantially in these two types of reaches (pl 1) Like most Ozarks streams, Little Piney Creek has a gravel-cobble bed and carries a mixed sediment load

Much of the Ozarks is cavernous and has a karst drainage system The karst drainage system has resulted in some streams that are dry most of the time, whereas other streams with similar surface drainage areas have springs that provide substantial, relatively constant base flow Because much of the residual soil of the region is thin or relatively impermeable, or both, intense rainstorms can produce runoff that bypasses the underlying karst drainage system, resulting in fast-rising floods Approximately one-third of the upstream drainage area of Little Piney Creek Basin has intermittent, losing streams Substantial flows enter Little Piney Creek from Lane Spring and Piney Spring, immediately upstream of the 12-km study segment (fig 2) Discharge statistics for Little Piney Creek at Newburg are given in table 1

Table 1 Discharge statistics for Little Piney Creek at Newburg, Missouri, 1928–93

[Data from Reed and others, 1994]

Discharge statistic	Discharge, in cubic meters per second
Annual mean discharge	4 5
Highest annual mean	11 1
Lowest annual mean	1 3
Highest daily mean	554
Lowest daily mean	7
Instantaneous peak flow	920

PHOTOGRAMMETRIC DATA ACQUISITION AND ANALYSIS

Maps of channel features and valley-bottom[4] vegetation were compiled for the Little Piney study segment from historical aerial photography (table 2) Stereo pairs of photographs were used to create three-dimensional stereomodels for the study segment Each model was oriented in absolute space to a common set of control points digitized from existing 1 24,000 topographic maps The most reliable and consistent controls points were road intersections and sharply defined topographic peaks Because the control points come from a source with absolute horizontal precision of plus or minus 12 m and vertical precision of plus or minus 1 5 m (U S Geological Survey, 1987), absolute locations are no more accurate than the control source However, this study is concerned with changes over time, and the replicability between dates is limited more by the resolution and scale of the highest altitude photography rather than the precision of control points The mapping accuracy in relative space among all dates of photography is estimated to be, at most, 5 m for sharp-edged features such as channel margins and cutbanks For fuzzy-edged features, like woodland boundaries, accuracy is degraded further by subjective determination of the edge and differences in leafing conditions The three-dimensional properties of the stereomodels were used in absolute orientation of the models and to aid in geomorphic interpretation Elevation data, however, were not used to calculate thicknesses of the valley-bottom deposits or heights of cutbanks because of the low relief and relative lack of precision in the vertical dimension

Data from the stereomodels were compiled using an analog stereoplotter with digital encoders that transferred dimensional information to a computer operating a photogrammetric mapping software package (Kork Digital Mapping System[5]) Data from each adjacent stereomodel for a given date were oriented and edgematched using the photogrammetric software Map data were then exported to a digital geographic information system (GIS) where they were assembled, edited, and analyzed

Because of variability among the available sets of photography, the map units that were defined to depict land-use types had to be simplified to match the least-detailed photography Land-use types were simplified and mapped as cropland, grassland, woodland, gravel, and channel (table 3) Other data presented in this report were developed in three previous reports

[4]Valley-bottom refers to the relatively flat surfaces between steep valley walls These surfaces are underlain alluvial sediments of Holocene age (Albertson and others, 1995)

[5]Use of trade names in this report is for identification purposes only and does not constitute endorsement by the U S Geological Survey

Table 2 Sources and characteristics of aerial photography, Little Piney Creek, Missouri
[USDA, U S Department of Agriculture, USGS, U S Geological Survey]

Date of photography	Source	Negative scale	Remarks	Daily mean discharge, in cubic meters per second
Oct 24, 1938	USDA, Agricultural Stabilization and Conservation Service, through Aerial Photography Field Office	1 20,000	Black and white photographs, leaves partially off	1 8
Jan 17, 1948	U S Department of the Army, through USGS, Earth Science Information Center	1 30,000	Black and white photographs, leaves off	3 0
Oct 19, 1955	USDA, Agricultural Stabilization and Conservation Service, through Aerial Photography Field Office	1 20,000	Black and white photographs, leaves partially off	9
Sept 28, 1964	USDA, Agricultural Stabilization and Conservation Service, through Aerial Photography Field Office	1 20,000	Black and white photographs, leaves on	1 1
Mar 13, 1976	USGS, Earth Science Information Center	1 24,000	Black and white photographs, leaves off	2 8
Apr 19, 1989	USGS, Rolla, Missouri	1 8,000	Black and white photographs, leaves off	3 9

Table 3 Map units used in photogrammetric mapping

Map unit	Description
Cropland	Area of plowed crops, identified by furrowed ground, row crops, or corn shocks
Grassland	Area occupied by pasture, hay crops, or herbaceous cover It includes some areas of brushy vegetation
Woodland	Area occupied by trees that would have a closed canopy under leaves-on conditions It includes some areas of brushy vegetation and barnyards
Gravel	Area occupied by gravel and sand, identified by highly reflective tones and lack of vegetated cover
Channel	Area occupied by water at the time of the photography

Methods for collection and analysis of the stratigraphic data are given in Jacobson and Pugh (1992), methods for collection of hydrologic and land-use data are given in Jacobson and Primm (1994), and methods for collection and analysis of streambed-elevation data are given in Jacobson (1995)

CHANGES IN OZARKS STREAMS AND LAND-USE HISTORY

Stratigraphic information from valleys of Little Piney Creek and other streams in the Ozarks of Missouri corroborate that substantial changes in channel form and processes occurred after European settlement beginning in the 1830's Prior to settlement, the late Holocene history of Ozarks streams indicates episodic deposition of fining-upward sequences of cobbles to clay (Jacobson and Pugh, 1992, Jacobson and others, 1992, Albertson and others, 1995, data on file at the U S Geological Survey, Rolla, Missouri) At or near the time of settlement, streams started depositing somewhat more gravel and much less silt and clay Decreased sedimentation of fine sediments probably indicates decreased energy dissipation in the valley bottom because of less riparian vegetation on banks and bars Jacobson and Primm (1994) hypothesized that some gravel has been added to streams of third and higher orders by headward extension of the intermittent-channel network into previously unchanneled valleys

Abundant historical and anecdotal evidence indicates that Ozarks streams have decreased stability and degraded aquatic habitat as compared to conditions that existed at the turn of the 20th century (Hall, 1958, Love, 1990, Jacobson and Primm, 1994) Commonly, long-term residents of the Ozarks have observed that pools have filled up with gravel Jacobson and Primm (1994) hypothesized that vegetation clearing and open-range grazing in the riparian zone were the key land-use changes that led to stream instability and habitat degradation

From a study of regional changes in streambed elevations at U S Geological Survey streamflow-gaging stations, Jacobson (1995) determined that at gages with a drainage area less than approximately 1,400 km^2 (including Little Piney Creek) a passage of a wave of land-use-related sediment or channel degradation had occurred by the late 1940's (fig 4) Because the earliest stream gages in the Ozarks were not installed until the early 1920's, nearly a century after the first Europeans settled in the Ozarks, the streambed-elevation data show only the receding limb of the hypothesized wave of sediment Since the 1940's, streambed elevations at gages of these small drainage basins have stabilized In basins with larger drainage areas, some stations showed multiple, high-amplitude waves of gravel moving past the gage, whereas others showed low-amplitude changes Jacobson (1995) interpreted these data to indicate that streams with drainage areas of less than 1,400 km^2 were relatively depleted of gravel, and gravel was accumulating in streams with larger drainage areas, although the effect of gravel accumulation in larger river segments was variable because of variations in routing and storage of sediment For small drainage basins like Little Piney Creek, the streambed-elevation data also indicate that, since the 1940's, large floods typically do not have persistent effects on the streambed elevation For example, the largest daily mean flood on record (December 3, 1982) had no persistent effect on streambed elevation (fig 4)

Because streamflow-gaging records did not begin until the 1920's, it is impossible to determine if a wave of sediment has moved past the gage or if degradation of the streambed has occurred at the gage In either case, streambed-elevation data support the idea that smaller basins have recovered or, at least, stream instability is getting no worse

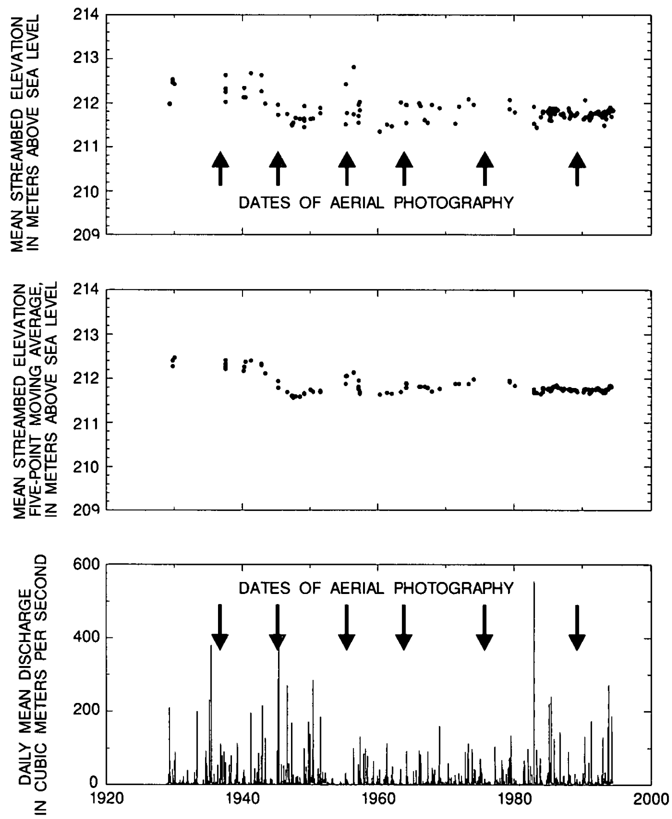

Figure 4 Mean streambed elevation and daily mean discharge, Little Piney Creek at Newburg, Missouri, 1927–93

Drainage-Basin-Wide Land-Use Changes

Like most Ozarks counties, Phelps County (location of the Little Piney Creek study segment) experienced an increase in human population from the 1830's to the turn of the century (Jacobson and Primm, 1994, fig 5, table 4) Simultaneously, the number of acres of improved land (consisting of cultivated and fenced land) increased, along with cattle and hog populations Timber resources in Phelps County were not subjected to the large, corporate logging operations that existed in the southern part of the State (Jacobson and Primm, 1994) Hence, the statewide timber production figures shown in figure 5 may overemphasize the relative magnitude of timber cutting for the Little Piney Creek Basin, where timber production was predominantly from smaller companies and individual

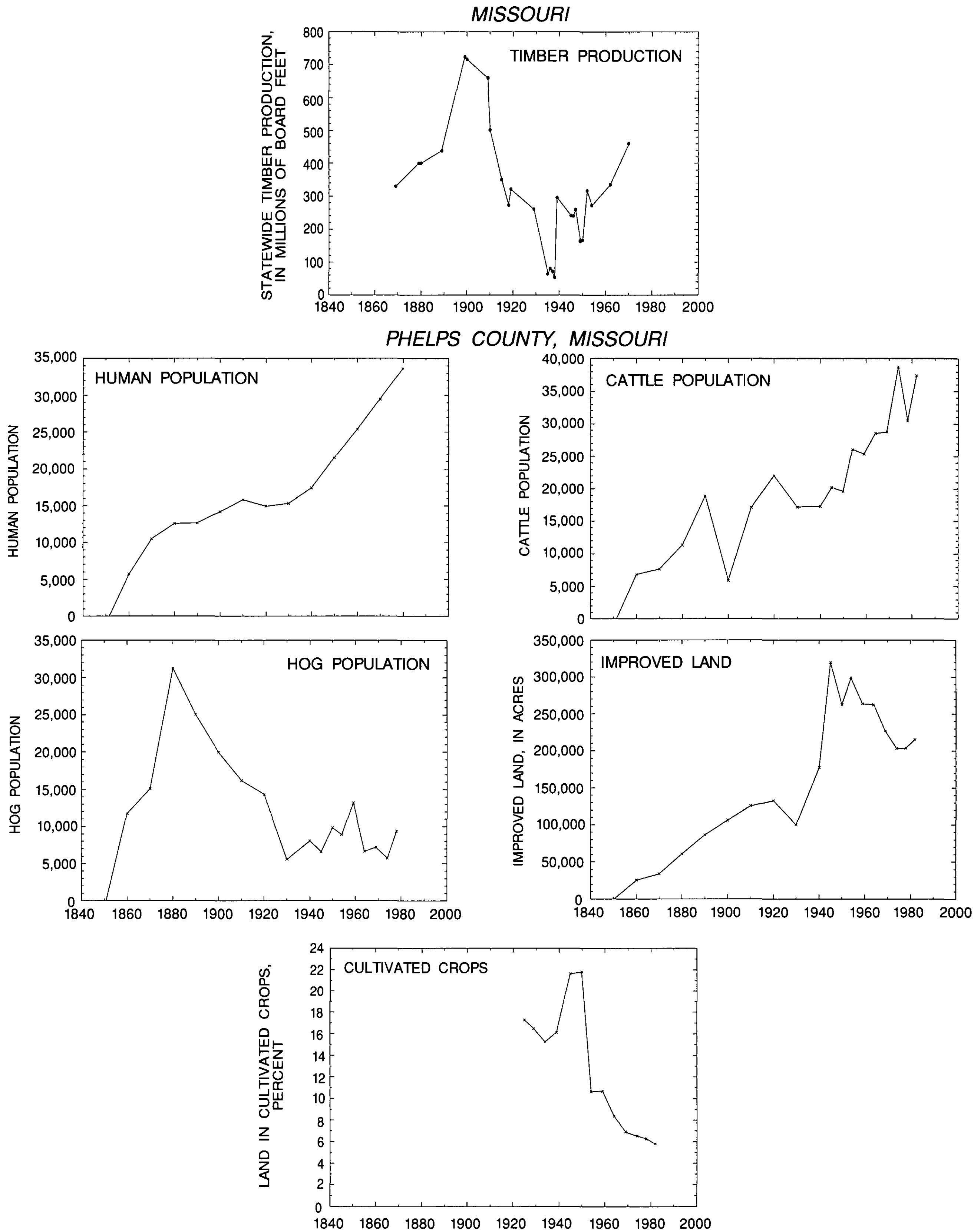

Figure 5. Selected statistics associated with land use, 1850–1982 (data from U S Bureau of the Census, 1850–1982)

landowners However, Lıttle Pıney Creek was used for some tie drives—transportation of floating rafts of railroad ties—from Yancy Mill to Newburg during the 1930's and 1940's

Table 4 Land use in Little Piney Creek Basin, as determined from high-altitude photography, 1973

Land-use category	Percentage of Little Piney Creek Basin
Urbanized	1 3
Pasture and row crops	29 9
Deciduous forest	68 0
Evergreen forest	6
Mixed forests	1
Ponds and lakes	1

Jacobson and Primm (1994) concluded that the land-use changes with the greatest potential for destabilizing stream channels in the Ozarks were the cutting of riparian timber and the continuous disturbance of riparian vegetation as a result of open-range grazing These land-use changes continued from early settlement in the 1830's until the end of open-range grazing laws in the 1940's through 1950's The conclusion that riparian land-use changes had the greatest potential to affect stream-channel stability was based on the lack of evidence that upland land-use practices were severe enough to change hydrologic and sediment budgets sufficiently to cause regional stream disturbance In addition, because of settlement patterns that favored valley-bottom sites, riparian land-use changes had been in effect for a longer period of time than those in uplands Jacobson and Primm (1994) also identified a period of intense row-crop agriculture in the 1940's when steep, marginally fertile land was cropped and might have produced additional runoff and sediment that contributed to stream instability

Analysis of seasonal rainfall and runoff relations for Little Piney Creek Basin, however, does not show anomalously high runoff during the period of intense row-crop agriculture, nor does it indicate a trend of decreasing runoff since the 1950's Precipitation measured at Rolla, Missouri, and runoff in Little Piney Creek Basin measured at Newburg from 1929 to 1994 are shown in figures 6A and 6B Precipitation and runoff were classified into growing season (March–August) and winter season (September–February) to indicate effects of vegetation Plots of seasonal runoff as a function of precipitation show general increases of runoff with increasing precipitation (figs 6C, 6D), winter-season runoff is generally somewhat higher for a given precipitation value (fig 6C) Linear regression models of runoff as a function of precipitation provide a prediction of runoff for actual precipitation values for the average conditions for 1928 through 1992 Residuals of the models (actual minus predicted runoff) plotted by year (fig 6D) do not show the hypothesized peak for 1940 through 1950, nor is there a trend of decreasing runoff discernible within the variation

Riparian Land-Use Changes

The U S Bureau of the Census aggregates land-use data at the county level and does not specify where on the landscape particular land-use types exist To evaluate the effect of land-use change on hydrologic and sediment budgets, specific land-use information is critical For this study, valley-bottom land-use was determined for the 12-km study segment for 1938, 1948, 1955, 1964, 1976, and 1989 by mapping from aerial photography (fig 7) This information is shown by photogrammetric maps (pl 1) and is summarized in figure 8

These data indicate progressive increase of wooded land, at the expense of cropland and grassland, from 1948 to 1989 Land use in 1938 consisted of nearly equal areas of grassland, cropland, and woodland Cropland was absent in this segment of the valley in 1948 Oral-historical accounts described flooding and gravel sedimentation in the late 1940's that were so severe that farmers quit planting in the Little Piney Creek Valley bottom (Jacobson and Primm, 1994) Historical accounts are supported by the fact that the total area of gravel mapped in 1948 was much larger than that for other years

From 1948 to 1989, woodland increased substantially, and gravel and grassland decreased in area After an increase in cropland in 1955, cropland area decreased until 1989 The association of decreases in gravel area with increases in woodland area could indicate that increased riparian woodland has increased channel stability This hypothesis is consistent with the observation that after the 1940's the mean streambed elevation stabilized at Newburg (approximately 8 km downstream of the Little Piney Creek study segment) An alternate hypothesis that recovery

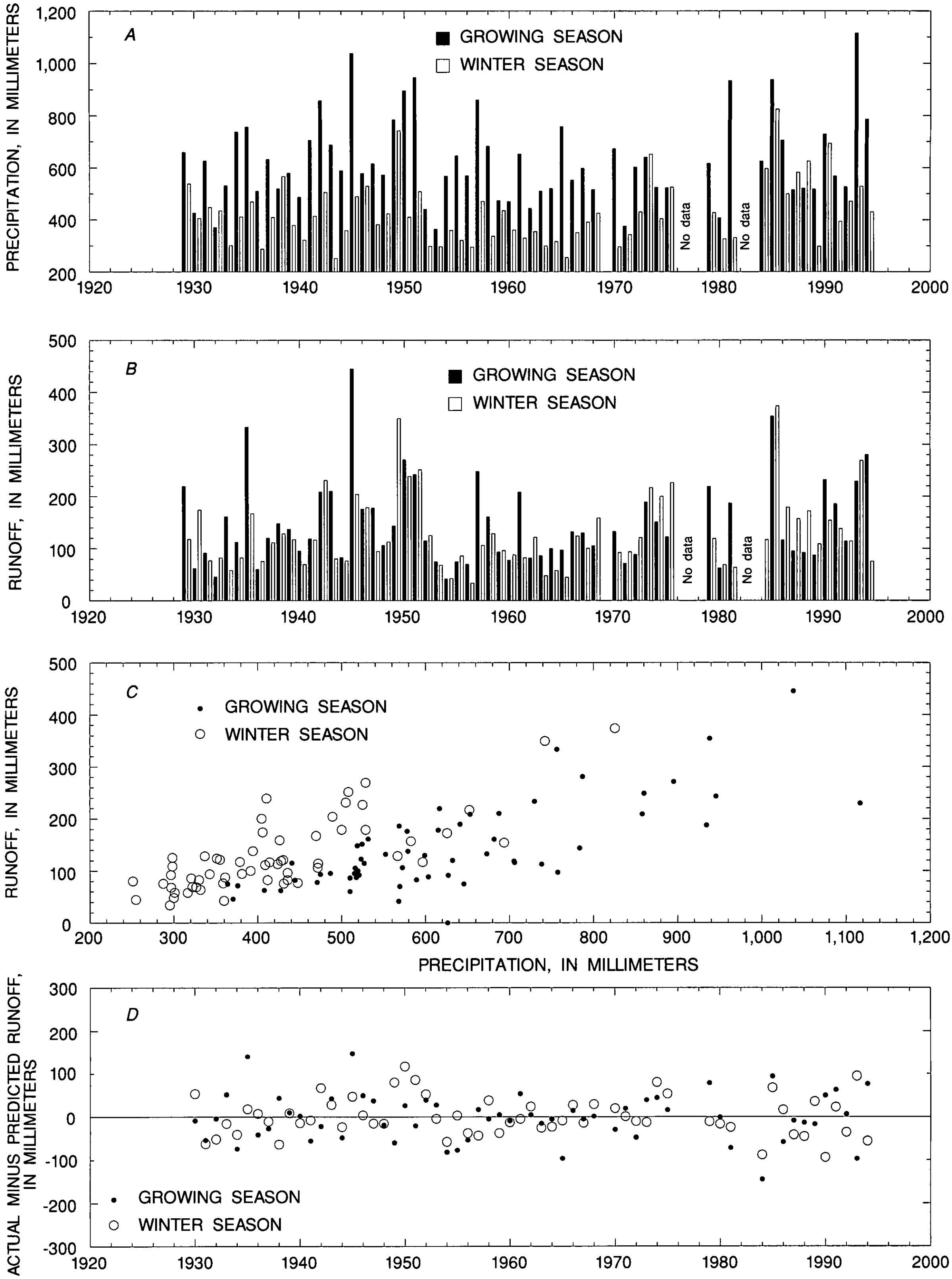

Figure 6. Seasonal precipitation and runoff for Little Piney Creek Basin, Missouri, 1928–94 *A,* growing season and winter season precipitation, *B,* growing season and winter season runoff, *C,* scatter plots of runoff by precipitation, growing season and winter season, *D,* residuals of linear regression models of runoff as a function of precipitation plotted by year, growing season and winter season

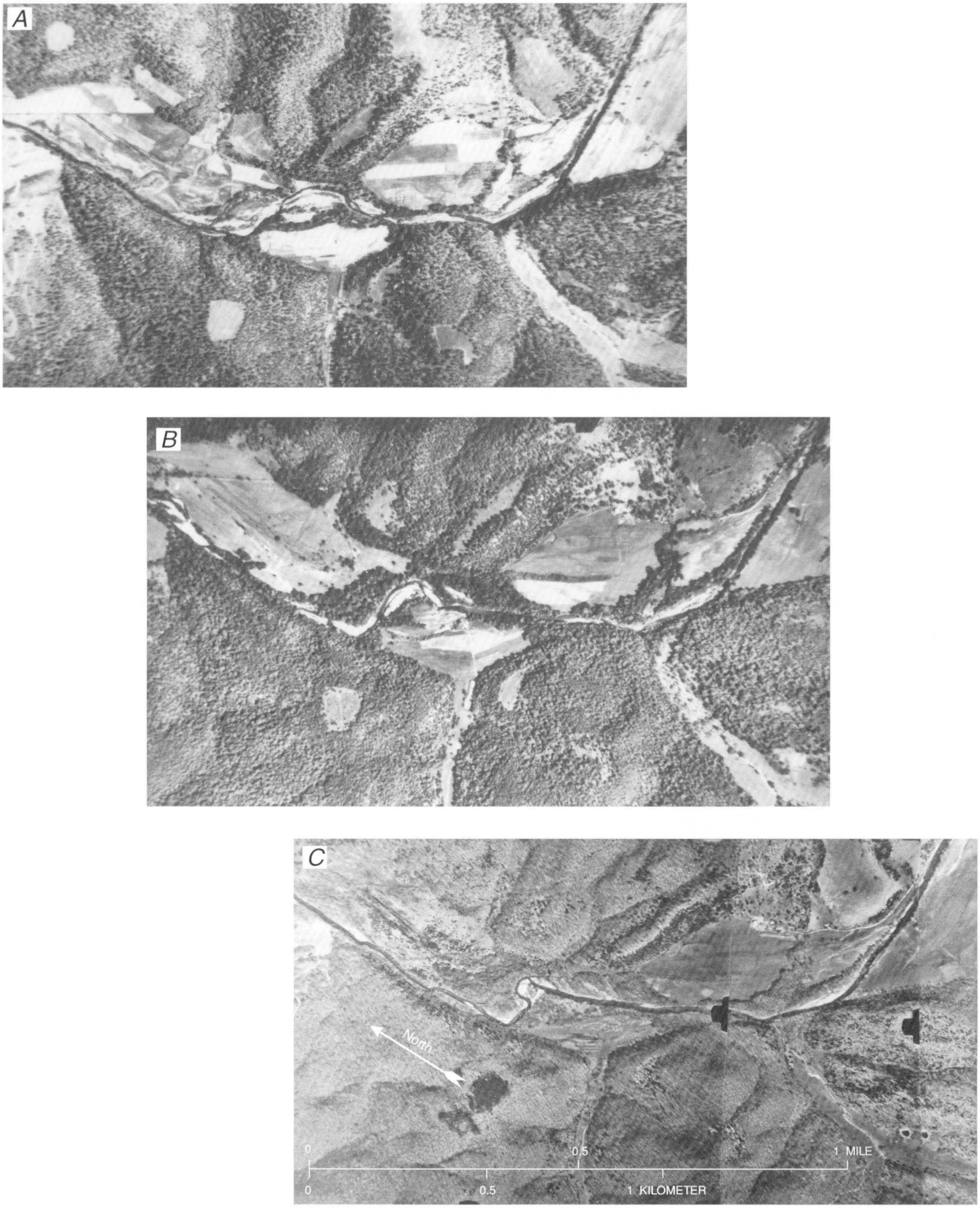

Figure 7. Aerial photographs of a part of the study segment of Little Piney Creek Valley, Missouri. *A,* 1938; *B,* 1955; *C,* 1989. Note: Flow is from right to left.

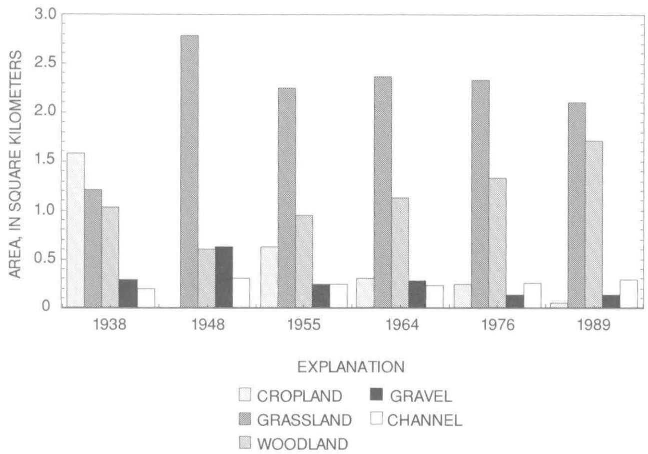

Figure 8. Land use in the study segment of Little Piney Creek Valley, Missouri, for selected years from 1938–89.

of the stream channel has resulted from basin-wide changes in hydrologic or sediment budgets is not supported definitively by the precipitation and runoff data (fig. 6). Sediment yield from the uplands and channel instability would be expected to vary directly with runoff, but the amount of runoff produced by a given amount of precipitation shows no clear trend over an interval when human population, cattle population, and area in improved land all increased substantially.

EROSION AND DEPOSITION BY LITTLE PINEY CREEK

Planimetric erosion and deposition rates for Little Piney Creek were determined by comparing areas of map units that became different map units between sequential dates of photography. The calculations were performed in a digital GIS by creating a polygon identity map from each pair of successive maps (1938–48, 1948–55, 1955–64, 1964–76, and 1976–89). An identity map is a geometric intersection of the two maps. The identity map contains all features of the two input maps, and each resulting intersected polygon has attributes of both parent polygons (fig. 9). Once created, the identity map can be queried for total area that changed according to each of the possible transitions between map units. Of interest to this study were transition frequencies from cropland, grassland, and woodland to gravel and channel map units.

Spatial biases of map units also need to be considered. Frequently, cropland and grassland are preferentially sited away from stream channels, and woodland is adjacent to stream channels. Because of this bias, woodland has a greater chance of being eroded or subjected to gravel deposition. To assess this bias, buffers were created for each channel at 7.5, 15, 30, and 60 m away from the channel. A minimum buffer distance of 7.5 m was used because it is greater than the worse-case estimated accuracy between successive photos of 5 m. In addition, the area of the entire valley bottom was assessed and assigned a buffer width of 120 m, a value approximately one half of the valley width. Hence, for each polygon in the identity map for two dates, the distance of that polygon from the channel at the time of the first date also is known (fig. 10).

The effects of riparian vegetation on lateral channel erosion and gravel deposition can be evaluated by comparing the polygon areas of different map units that change to channel or gravel areas in each transition period. The relative susceptibility of different land-use types to geomorphic change can then be calculated by comparing the types using ratios, termed susceptibility ratios. To simplify the analysis, the small area of cropland was combined with grassland into a single category, cropland plus grassland. This combination is based on the general similarities in hydraulic properties and erosion resistance of grassland and cropland relative to woodland. For example, the susceptibility ratio for erosion for a particular transition period and for a particular buffer distance is the sum of the areas of all cropland polygons that became channel polygons plus all grassland polygons that became channel polygons, divided by the sum of the areas of all woodland polygons that became channel polygons. Hence, the susceptibility ratios are ratios of areal rates of change.

Discrete dates of photography and the inability to measure thicknesses of deposits using the planimetric maps constrain the analysis of these data. The total area of erosion calculated as the area of cropland, grassland, woodland, and gravel polygons that became channel polygons during a transition period is a minimum measure of erosion. In areas of substantial lateral channel migration, the channel commonly migrated several channel widths between photography dates (pl. 1). It is impossible to determine if migration occurred by nearly instantaneous avulsion or by incremental lateral movement. If the latter is true, more area was eroded during the transition period than would be indicated only by those polygons that had changed to channel polygons by the end of the transition period.

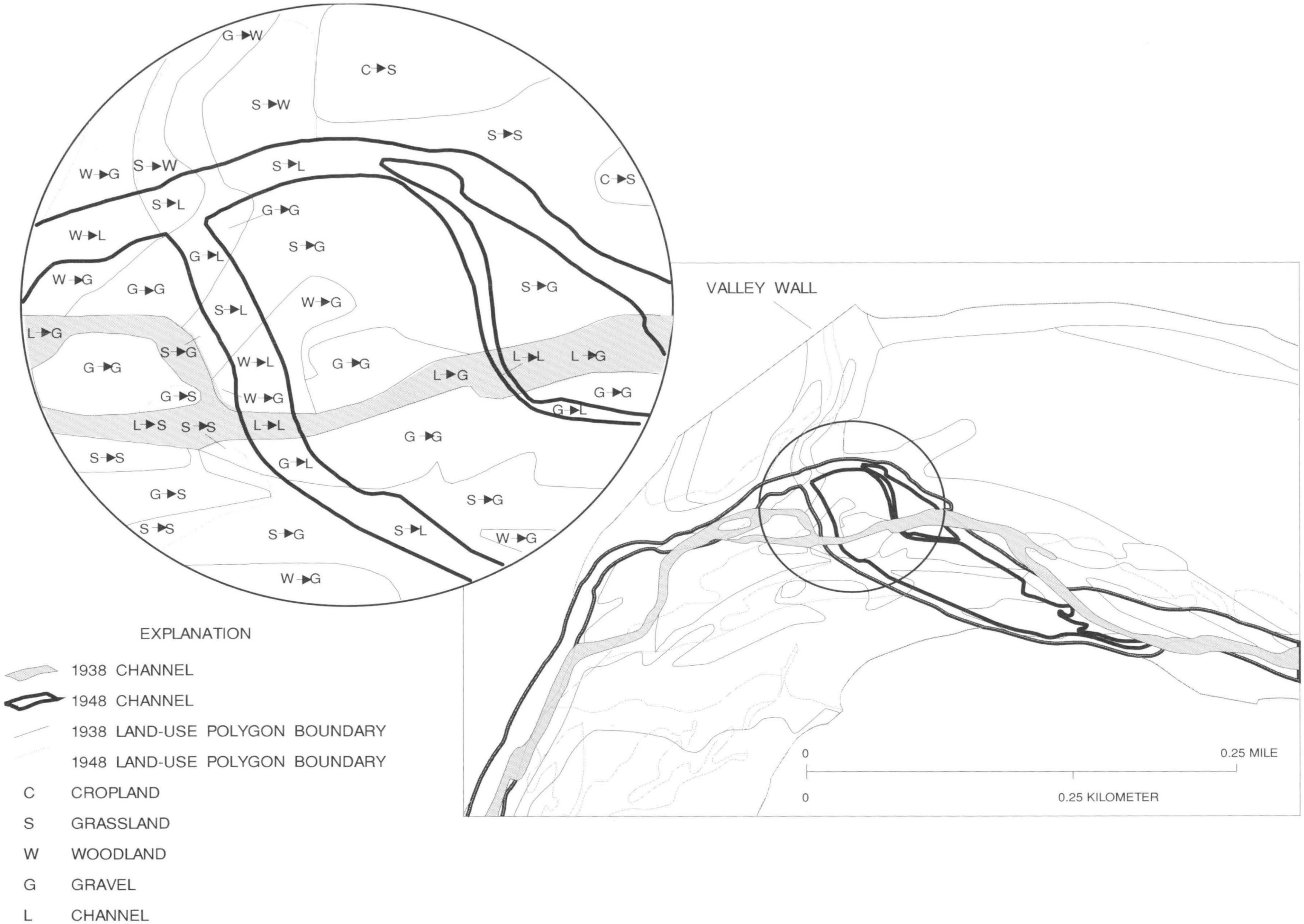

Figure 9. A small part of the study segment of Little Piney Creek Valley, Missouri, showing identity polygons and attribute transitions for 1938 and 1948.

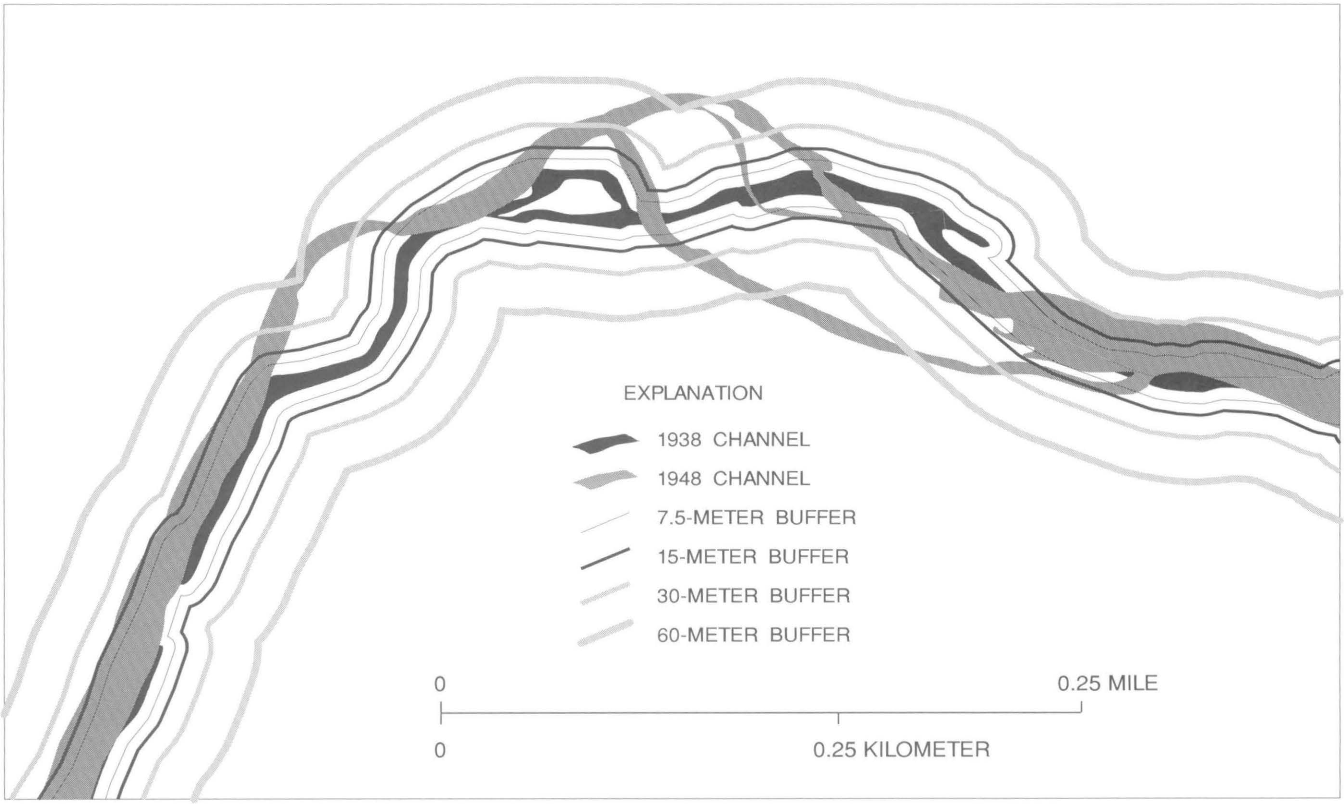

Figure 10. A small part of the study segment of Little Piney Creek Valley, Missouri, showing the 1948 channel and buffers designated around the 1938 channel.

Areas of new deposition include those areas that were eroded by lateral channel migration and were subsequently filled plus those areas of pre-existing floodplain that had gravel and sand deposited over them. In general, deposits would be thick (several to tens of meters) in the former case and thin (a meter or less) in the latter case. Planimetric mapping cannot distinguish these different cases, so inferences about erosional and depositional volumes are tenuous. Additionally, because only bare sediment surfaces were mapped as gravel deposits, areas of gravel deposition that were substantially colonized by vegetation during the transition period would be mapped as grassland or woodland. This would tend to underestimate areas affected by gravel deposition. In addition to separate calculations of erosion and deposition, total geomorphic change was calculated as the sum of areas that were eroded or had deposition.

Variations in stream discharge among dates of photography could affect calculations of eroded areas. This effect is minimal because all aerial photographs were taken at discharges less than the annual mean discharge (tables 1, 2). At these low discharges, discharge-related differences in channel area probably are within the mapping precision.

Areas and areal rates of change calculated from the identity maps of sequential dates of photography are presented in table 5, and susceptibility ratios are summarized in table 6. Total geomorphic change rate was calculated as the percent area per year of cropland plus grassland plus woodland that changed to channel or gravel. This total change rate varied substantially by transition period as well as by buffer width (distance from channel; fig. 11, table 5). The 1938–48 transition period had the greatest total geomorphic change, and total geomorphic change decreased systematically with time. This variation in planimetric change over time is consistent with the mean streambed-elevation data from Newburg, which indicate that vertical changes in the streambed have decreased over time (fig. 12).

The 1938–48 transition period shows an increase in percent area changed per year with decreasing buffer width, except for small buffer

Table 5 Map unit changes by transition period and channel buffer width

[Sum of areas of channel buffers vary by transition period because of small changes in channel length, numbers of islands, and differences in discharge, NA, rate calculation is not applicable]

Channel buffer width, in meters	Map unit category	Area changed during transition period, in square meters						Rate of change during transition period, in square meters per year						Rate of change during transition period, in percent area per year					
		Crop-land	Grass-land	Wood-land	Gravel	Channel	Sum	Crop-land	Grass-land	Wood-land	Gravel	Channel	Cropland plus grassland	Crop-land	Grass-land	Wood-land	Gravel	Channel	Cropland plus grassland
								Transition period 1938–48											
7.5	Cropland	0	0	0	0	0	0	NA	0	0	0	0	NA	NA	0.0	0.0	0.0	0.0	NA
	Grassland	1,592	3,135	13,325	6,384	12,304	36,740	159	NA	1,332	638	1,230	NA	3.1	NA	1.1	8	6	NA
	Woodland	468	2,698	28,928	12,627	24,563	69,284	47	270	NA	1,263	2,456	317	9	1.4	NA	1.6	1.3	1.3
	Gravel	1,867	5,621	31,594	33,582	54,756	127,421	187	562	3,159	NA	5,476	749	3.6	3.0	2.5	NA	2.8	3.1
	Channel	1,220	7,246	50,297	25,458	103,805	188,026	122	725	5,030	2,546	NA	847	2.4	3.9	4.1	3.3	NA	3.5
	Sum	**5,146**	**18,700**	**124,143**	**78,051**	**195,429**	**421,470**												
15	Cropland	0	0	0	0	0	0	NA	0	0	0	0	NA	NA	0	0	0	0	NA
	Grassland	7,089	8,790	33,184	11,546	12,304	72,913	709	NA	3,318	1,155	1,230	NA	4.0	NA	1.4	9	6	NA
	Woodland	1,624	7,482	70,211	23,682	24,563	127,562	162	748	NA	2,368	2,456	911	9	1.9	NA	1.8	1.3	1.6
	Gravel	5,284	11,210	62,796	60,643	54,756	194,689	528	1,121	6,280	NA	5,476	1,649	3.0	2.8	2.6	NA	2.8	2.9
	Channel	3,525	12,259	78,325	37,977	103,805	235,892	352	1,226	7,832	3,798	NA	1,578	2.0	3.1	3.2	2.8	NA	2.8
	Sum	**17,521**	**39,742**	**244,515**	**133,848**	**195,429**	**631,056**												
30	Cropland	0	0	0	0	0	0	NA	0	0	0	0	NA	NA	0	0	0	0	NA
	Grassland	37,886	34,880	72,701	18,417	12,304	176,188	3,789	NA	7,270	1,842	1,230	NA	5.8	NA	1.6	9	6	NA
	Woodland	5,972	22,420	154,581	38,191	24,563	245,727	597	2,242	NA	3,819	2,456	2,839	9	2.3	NA	1.9	1.3	1.7
	Gravel	15,351	22,788	116,458	102,043	54,756	311,397	1,535	2,279	11,646	NA	5,476	3,814	2.3	2.3	2.6	NA	2.8	2.3
	Channel	6,530	18,442	102,069	45,707	103,805	276,554	653	1,844	10,207	4,571	NA	2,497	1.0	1.9	2.3	2.2	NA	1.5
	Sum	**65,739**	**98,530**	**445,810**	**204,358**	**195,429**	**1,009,866**												
60	Cropland	0	0	0	0	0	0	NA	0	0	0	0	NA	NA	0	0	0	0	NA
	Grassland	174,087	144,109	140,871	32,075	12,304	503,446	17,409	NA	14,087	3,208	1,230	NA	7.3	NA	2.0	1.2	6	NA
	Woodland	15,434	45,088	289,108	47,984	24,563	422,178	1,543	4,509	NA	4,798	2,456	6,052	6	1.7	NA	1.8	1.3	1.2
	Gravel	41,311	53,698	175,457	137,029	54,756	462,251	4,131	5,370	17,546	NA	5,476	9,501	1.7	2.0	2.4	NA	2.8	1.9
	Channel	7,704	21,879	115,397	49,210	103,805	297,995	770	2,188	11,540	4,921	NA	2,958	3	8	1.6	1.8	NA	6
	Sum	**238,536**	**264,773**	**720,833**	**266,299**	**195,429**	**1,685,870**												
120	Cropland	0	0	0	0	0	0	NA	0	0	0	0	NA	NA	0	0	0	0	NA
	Grassland	1,431,181	988,291	307,577	41,427	12,304	2,780,780	143,118	NA	30,758	4,143	1,230	NA	9.1	NA	3.0	1.4	6	NA
	Woodland	30,901	91,495	402,810	55,471	24,563	605,240	3,090	9,149	NA	5,547	2,456	12,240	2	8	NA	1.9	1.3	4
	Gravel	111,374	105,021	203,833	146,448	54,756	621,432	11,137	10,502	20,383	NA	5,476	21,640	7	9	2.0	NA	2.8	8
	Channel	7,704	22,130	118,727	49,652	103,805	302,019	770	2,213	11,873	4,965	NA	2,983	0	2	1.1	1.7	NA	1
	Sum	**1,581,161**	**1,206,937**	**1,032,947**	**292,997**	**195,429**	**4,309,472**												

Table 5. Map unit changes by transition period and channel buffer width—Continued

Channel buffer width, in meters	Map unit category	Area changed during transition period, in square meters						Rate of change during transition period, in square meters per year						Rate of change during transition period, in percent area per year					
		Crop-land	Grass-land	Wood-land	Gravel	Channel	Sum	Crop-land	Grass-land	Wood-land	Gravel	Channel	Cropland plus grassland	Crop-land	Grass-land	Wood-land	Gravel	Channel	Cropland plus grassland
								Transition period 1948–55											
7 5	Cropland	0	457	35	1	5	498	NA	65	5	0	1	NA	NA	0 2	0 0	0 0	0 0	NA
	Grassland	0	7,968	8,202	20,674	38,314	75,158	0	NA	1,172	2,953	5,473	NA	NA	NA	1 6	2 3	1 8	NA
	Woodland	0	17,831	46,045	43,322	69,477	176,675	0	2,547	NA	6,189	9,925	2,547	NA	6 4	NA	4 8	3 2	6 4
	Gravel	0	3,677	3,984	39,241	38,648	85,551	0	525	569	NA	5,521	525	NA	1 3	8	NA	1 8	1 3
	Channel	0	9,689	14,885	25,333	161,107	211,014	0	1,384	2,126	3,619	NA	1,384	NA	3 5	2 9	2 8	NA	3 5
	Sum	**0**	**39,623**	**73,150**	**128,571**	**307,552**	**548,896**												
15	Cropland	0	2,664	222	434	2,886	6,205	NA	381	32	62	412	NA	NA	4	0	0	1	NA
	Grassland	0	28,470	16,732	35,201	45,201	125,603	0	NA	2,390	5,029	6,457	NA	NA	NA	1 6	2 5	1 8	NA
	Woodland	0	38,192	100,943	74,320	139,135	352,591	0	5,456	NA	10,617	19,876	5,456	NA	6 1	NA	5 2	5 5	6 1
	Gravel	0	5,752	8,134	63,603	13,886	91,376	0	822	1,162	NA	1,984	822	NA	9	8	NA	5	9
	Channel	0	13,646	19,502	31,235	161,107	225,489	0	1,949	2,786	4,462	NA	1,949	NA	2 2	1 9	2 2	NA	2 2
	Sum	**0**	**88,723**	**145,533**	**204,793**	**362,215**	**801,264**												
30	Cropland	0	11,035	1,071	2,767	5	14,878	NA	1,576	153	395	1	NA	NA	7	1	1	0	NA
	Grassland	0	101,677	34,803	61,710	38,314	236,505	0	NA	4,972	8,816	5,473	NA	NA	NA	1 8	2 8	1 8	NA
	Woodland	0	77,595	200,532	112,756	69,477	460,360	0	11,085	NA	16,108	9,925	11,085	NA	5 1	NA	5 2	3 2	5 1
	Gravel	0	9,257	14,012	97,807	38,648	159,724	0	1,322	2,002	NA	5,521	1,322	NA	6	7	NA	1 8	6
	Channel	0	18,156	24,682	35,963	161,107	239,908	0	2,594	3,526	5,138	NA	2,594	NA	1 2	1 3	1 7	NA	1 2
	Sum	**0**	**217,719**	**275,101**	**311,002**	**307,552**	**1,111,374**												
60	Cropland	0	46,947	2,521	8,742	5	58,215	NA	6,707	360	1,249	1	NA	NA	1 2	1	3	0	NA
	Grassland	0	338,766	66,440	115,984	38,314	559,504	0	NA	9,491	16,569	5,473	NA	NA	NA	2 2	3 7	1 8	NA
	Woodland	0	153,385	321,126	153,373	69,477	697,361	0	21,912	NA	21,910	9,925	21,912	NA	3 8	NA	4 8	3 2	3 8
	Gravel	0	15,911	16,966	134,389	38,648	205,914	0	2,273	2,424	NA	5,521	2,273	NA	4	6	NA	1 8	4
	Channel	0	19,230	26,271	39,284	161,107	245,893	0	2,747	3,753	5,612	NA	2,747	NA	5	9	1 2	NA	5
	Sum	**0**	**574,239**	**433,323**	**451,773**	**307,552**	**1,766,887**												
120	Cropland	0	590,220	7,689	26,996	5	624,911	NA	84,317	1,098	3,857	1	NA	NA	3 0	2	6	0	NA
	Grassland	0	1,865,667	124,390	216,626	38,314	2,244,998	0	NA	17,770	30,947	5,473	NA	NA	NA	2 9	5 0	1 8	NA
	Woodland	0	271,396	428,648	177,651	69,477	947,172	0	38,771	NA	25,379	9,925	38,771	NA	1 4	NA	4 1	3 2	1 4
	Gravel	0	34,187	18,168	155,032	38,648	246,036	0	4,884	2,595	NA	5,521	4,884	NA	2	4	NA	1 8	2
	Channel	0	19,299	26,316	39,580	161,107	246,302	0	2,757	3,759	5,654	NA	2,757	NA	1	6	9	NA	1
	Sum	**0**	**2,780,771**	**605,212**	**615,885**	**307,552**	**4,309,420**												

Table 5. Map unit changes by transition period and channel buffer width—Continued

Channel buffer width, in meters	Map unit category	Area changed during transition period, in square meters						Rate of change during transition period, in square meters per year						Rate of change during transition period, in percent area per year					
		Cropland	Grassland	Woodland	Gravel	Channel	Sum	Cropland	Grassland	Woodland	Gravel	Channel	Cropland plus grassland	Cropland	Grassland	Woodland	Gravel	Channel	Cropland plus grassland
								Transition period 1955–64											
7.5	Cropland	166	1	53	0	21	241	NA	0	6	0	2	NA	NA	0.0	0.0	0.0	0.0	NA
	Grassland	261	8,426	7,800	2,922	11,570	30,979	29	NA	867	325	1,286	NA	6.5	NA	.6	.6	.5	NA
	Woodland	10	20,511	70,337	14,988	52,036	157,882	1	2,279	NA	1,665	5,782	2,280	.2	3.6	NA	3.1	2.3	3.6
	Gravel	10	16,602	18,490	23,023	58,585	116,710	1	1,845	2,054	NA	6,509	1,846	.3	2.9	1.5	NA	2.6	2.9
	Channel	0	17,256	38,702	13,635	124,001	193,594	0	1,917	4,300	1,515	NA	1,917	0	3.1	3.2	2.8	NA	3.0
	Sum	**447**	**62,795**	**135,383**	**54,568**	**246,214**	**499,406**												
15	Cropland	436	1	75	15	21	548	NA	0	8	2	2	NA	NA	0	0	0	0	NA
	Grassland	726	29,313	17,853	5,994	11,570	65,457	81	NA	1,984	666	1,286	NA	5.6	NA	.8	.8	.5	NA
	Woodland	259	39,112	149,979	27,072	52,036	268,458	29	4,346	NA	3,008	5,782	4,375	2.0	3.7	NA	3.4	2.3	3.7
	Gravel	17	24,480	29,367	37,592	58,585	150,042	2	2,720	3,263	NA	6,509	2,722	.1	2.3	1.3	NA	2.6	2.3
	Channel	0	23,279	51,829	17,853	124,001	216,961	0	2,587	5,759	1,984	NA	2,587	0	2.2	2.3	2.2	NA	2.2
	Sum	**1,438**	**116,185**	**249,104**	**88,526**	**246,214**	**701,466**												
30	Cropland	1,350	905	156	267	21	2,698	NA	101	17	30	2	NA	NA	0	0	0	0	NA
	Grassland	6,249	110,132	35,269	14,361	11,570	177,581	694	NA	3,919	1,596	1,286	NA	6.8	NA	.9	1.1	.5	NA
	Woodland	2,575	68,501	297,035	44,324	52,036	464,472	286	7,611	NA	4,925	5,782	7,897	2.8	3.2	NA	3.4	2.3	3.2
	Gravel	23	31,412	42,868	63,814	58,585	196,702	3	3,490	4,763	NA	6,509	3,493	0	1.5	1.1	NA	2.6	1.4
	Channel	0	27,914	57,415	20,420	124,001	229,748	0	3,102	6,379	2,269	NA	3,102	0	1.3	1.5	1.6	NA	1.2
	Sum	**10,197**	**238,864**	**432,743**	**143,185**	**246,214**	**1,071,202**												
60	Cropland	6,833	12,078	2,303	602	21	21,838	NA	1,342	256	67	2	NA	NA	.2	0	0	0	NA
	Grassland	35,303	341,716	76,392	28,822	11,586	493,818	3,923	NA	8,488	3,202	1,287	NA	8.2	NA	1.2	1.6	.5	NA
	Woodland	5,623	127,473	488,455	57,090	52,119	730,760	625	14,164	NA	6,343	5,791	14,788	1.3	2.6	NA	3.2	2.4	2.5
	Gravel	244	41,142	52,780	91,689	58,585	244,440	27	4,571	5,864	NA	6,509	4,598	.1	.8	.9	NA	2.6	.8
	Channel	0	29,177	59,332	22,424	124,001	234,934	0	3,242	6,592	2,492	NA	3,242	0	.6	1.0	1.2	NA	.5
	Sum	**48,003**	**551,587**	**679,262**	**200,627**	**246,312**	**1,725,791**												
120	Cropland	145,335	154,671	4,526	1,440	21	305,994	NA	17,186	503	160	2	NA	NA	.8	.1	.1	0	NA
	Grassland	451,301	1,723,109	124,959	53,507	11,586	2,364,461	50,145	NA	13,884	5,945	1,287	NA	8.0	NA	1.5	2.4	.5	NA
	Woodland	27,789	279,334	702,131	63,407	52,119	1,124,781	3,088	31,037	NA	7,045	5,791	34,125	.5	1.4	NA	2.9	2.4	1.2
	Gravel	487	58,039	55,712	105,031	58,585	277,854	54	6,449	6,190	NA	6,509	6,503	0	.3	.7	NA	2.6	.2
	Channel	0	29,931	59,968	22,654	124,001	236,553	0	3,326	6,663	2,517	NA	3,326	0	.1	.7	1.0	NA	.1
	Sum	**624,913**	**2,245,083**	**947,295**	**246,040**	**246,312**	**4,309,644**												

Table 5 Map unit changes by transition period and channel buffer width—Continued

Channel buffer width, in meters	Map unit category	Area changed during transition period, in square meters						Rate of change during transition period, in square meters per year						Rate of change during transition period, in percent area per year					
		Crop-land	Grass-land	Wood-land	Gravel	Channel	Sum	Crop-land	Grass-land	Wood-land	Gravel	Channel	Cropland plus grassland	Crop-land	Grass-land	Wood-land	Gravel	Channel	Cropland plus grassland
								Transition period 1964–76											
7 5	Cropland	0	205	46	0	0	251	NA	17	4	0	0	NA	NA	0 1	0 0	0 0	0 0	NA
	Grassland	16	8,367	15,564	14,241	24,689	62,876	1	NA	1,297	1,187	2,057	NA	1 9	NA	1 1	1 4	1 0	NA
	Woodland	34	7,108	59,032	30,997	71,737	168,908	3	592	NA	2,583	5,978	595	4 2	2 5	NA	3 1	2 9	2 5
	Gravel	3	1,367	9,359	14,209	711	25,649	0	114	780	NA	59	114	3	5	6	NA	0	5
	Channel	15	6,616	37,406	24,268	112,339	180,644	1	551	3,117	2,022	NA	553	1 8	2 3	2 6	2 4	NA	2 3
	Sum	**67**	**23,663**	**121,407**	**83,715**	**209,476**	**438,328**												
15	Cropland	184	928	199	44	0	1,356	NA	77	17	4	0	NA	NA	1	0	0	0	NA
	Grassland	30	24,317	30,046	23,071	24,689	102,153	2	NA	2,504	1,923	2,057	NA	9	NA	1 0	1 5	9	NA
	Woodland	34	20,051	138,331	51,264	71,737	281,417	3	1,671	NA	4,272	5,978	1,674	1 1	2 9	NA	3 3	2 5	2 8
	Gravel	3	2,389	18,561	23,413	27,009	71,375	0	199	1,547	NA	2,251	199	1	3	6	NA	1 0	3
	Channel	15	10,799	57,374	33,354	112,339	213,881	1	900	4,781	2,780	NA	901	5	1 5	2 0	2 1	NA	1 5
	Sum	**265**	**58,485**	**244,511**	**131,146**	**235,774**	**670,181**												
30	Cropland	2,140	6,818	958	108	0	10,024	NA	568	80	9	0	NA	NA	3	0	0	0	NA
	Grassland	667	82,783	50,655	34,031	24,691	192,826	56	NA	4,221	2,836	2,058	NA	1 9	NA	9	1 5	9	NA
	Woodland	85	59,641	297,638	79,114	71,809	508,287	7	4,970	NA	6,593	5,984	4,977	2	3 0	NA	3 5	2 5	2 9
	Gravel	3	3,720	32,695	34,523	27,009	97,949	0	310	2,725	NA	2,251	310	0	2	6	NA	1 0	2
	Channel	15	14,642	74,580	38,629	112,339	240,205	1	1,220	6,215	3,219	NA	1,221	0	7	1 4	1 7	NA	7
	Sum	**2,910**	**167,603**	**456,526**	**186,405**	**235,848**	**1,049,291**												
60	Cropland	15,320	23,955	2,777	365	0	42,417	NA	1,996	231	30	0	NA	NA	4	0	0	0	NA
	Grassland	10,073	275,580	82,912	47,799	24,689	441,052	839	NA	6,909	3,983	2,057	NA	3 1	NA	1 0	1 7	9	NA
	Woodland	2,046	140,181	511,429	105,772	71,737	831,166	171	11,682	NA	8,814	5,978	11,852	6	2 5	NA	3 7	2 5	2 4
	Gravel	3	4,920	47,855	41,189	27,009	120,976	0	410	3,988	NA	2,251	410	0	1	6	NA	1 0	1
	Channel	15	16,757	79,929	40,582	112,339	249,622	1	1,396	6,661	3,382	NA	1,398	0	3	9	1 4	NA	3
	Sum	**27,457**	**461,392**	**724,902**	**235,707**	**235,774**	**1,685,232**												
120	Cropland	99,453	119,961	24,033	606	0	244,054	NA	9,997	2,003	51	0	NA	NA	4	2	0	0	NA
	Grassland	172,172	1,868,813	195,550	67,143	24,691	2,328,368	14,348	NA	16,296	5,595	2,058	NA	4 7	NA	1 5	2 0	9	NA
	Woodland	34,325	339,980	761,533	121,747	71,809	1,329,394	2,860	28,332	NA	10,146	5,984	31,192	9	1 2	NA	3 7	2 5	1 2
	Gravel	7	8,332	61,178	45,903	27,009	142,428	1	694	5,098	NA	2,251	695	0	0	5	NA	1 0	0
	Channel	15	26,168	81,309	41,219	112,339	261,050	1	2,181	6,776	3,435	NA	2,182	0	1	6	1 2	NA	1
	Sum	**305,972**	**2,363,254**	**1,123,603**	**276,618**	**235,848**	**4,305,294**												

Table 5. Map unit changes by transition period and channel buffer width—Continued

Channel buffer width, in meters	Map unit category	Area changed during transition period, in square meters						Rate of change during transition period, in square meters per year						Rate of change during transition period, in percent area per year					
		Cropland	Grassland	Woodland	Gravel	Channel	Sum	Cropland	Grassland	Woodland	Gravel	Channel	Cropland plus grassland	Cropland	Grassland	Woodland	Gravel	Channel	Cropland plus grassland
								Transition period 1976–89											
7.5	Cropland	0	82	0	20	215	317	NA	6	0	2	17	NA	NA	0.0	0.0	0.0	0.0	NA
	Grassland	0	6,227	6,805	1,479	6,482	20,993	0	NA	523	114	499	NA	NA	NA	4	2	2	NA
	Woodland	0	15,545	67,498	12,071	66,306	161,420	0	1,196	NA	929	5,100	1,196	NA	2.7	NA	1.8	2.0	2.7
	Gravel	0	9,710	15,990	14,435	41,136	81,272	0	747	1,230	NA	3,164	747	NA	1.7	9	NA	1.3	1.7
	Channel	0	12,783	50,843	22,412	137,159	223,197	0	983	3,911	1,724	NA	983	NA	2.2	2.8	3.4	NA	2.2
	Sum	**0**	**44,348**	**141,136**	**50,417**	**251,297**	**487,198**												
15	Cropland	0	82	0	20	215	317	NA	6	0	2	17	NA	NA	0	0	0	0	NA
	Grassland	341	21,739	15,765	3,370	6,482	47,697	26	NA	1,213	259	499	NA	7.7	NA	4	3	2	NA
	Woodland	0	33,234	161,486	22,869	66,371	283,961	0	2,556	NA	1,759	5,105	2,556	0	2.9	NA	2.3	2.0	2.9
	Gravel	0	14,584	26,076	20,098	41,136	101,894	0	1,122	2,006	NA	3,164	1,122	0	1.3	7	NA	1.3	1.3
	Channel	0	19,270	76,261	28,941	137,159	261,631	0	1,482	5,866	2,226	NA	1,482	0	1.7	2.1	3.0	NA	1.7
	Sum	**341**	**88,909**	**279,589**	**75,299**	**251,363**	**695,500**												
30	Cropland	0	82	0	20	215	317	NA	6	0	2	17	NA	NA	0	0	0	0	NA
	Grassland	3,349	85,339	34,634	5,734	6,513	135,569	258	NA	2,664	441	501	NA	5.8	NA	5	4	2	NA
	Woodland	1,088	64,920	364,156	41,955	66,698	538,818	84	4,994	NA	3,227	5,131	5,078	1.9	2.6	NA	3.1	2.0	2.5
	Gravel	0	19,725	34,257	25,395	41,247	120,624	0	1,517	2,635	NA	3,173	1,517	0	8	5	NA	1.3	8
	Channel	0	25,085	89,173	30,889	137,561	282,708	0	1,930	6,859	2,376	NA	1,930	0	1.0	1.3	2.3	NA	1.0
	Sum	**4,437**	**195,152**	**522,220**	**103,993**	**252,234**	**1,078,035**												
60	Cropland	0	85	120	20	215	440	NA	7	9	2	17	NA	NA	0	0	0	0	NA
	Grassland	25,288	269,002	61,348	12,044	6,786	374,467	1,945	NA	4,719	926	522	NA	6.7	NA	6	7	2	NA
	Woodland	3,628	148,200	655,953	57,134	68,140	933,055	279	11,400	NA	4,395	5,242	11,679	1.0	2.4	NA	3.4	2.1	2.4
	Gravel	0	22,971	38,594	30,775	41,247	133,587	0	1,767	2,969	NA	3,173	1,767	0	4	4	NA	1.2	4
	Channel	0	26,142	89,918	31,132	137,732	284,923	0	2,011	6,917	2,395	NA	2,011	0	4	8	1.8	NA	4
	Sum	**28,916**	**466,399**	**845,932**	**131,104**	**254,120**	**1,726,472**												
120	Cropland	0	51,742	3,429	20	215	55,406	NA	3,980	264	2	17	NA	NA	2	0	0	0	NA
	Grassland	233,181	1,732,973	108,963	15,381	12,783	2,103,280	17,937	NA	8,382	1,183	983	NA	7.3	NA	6	8	4	NA
	Woodland	10,873	485,573	1,085,704	62,973	68,992	1,714,115	836	37,352	NA	4,844	5,307	38,188	3	1.6	NA	3.4	2.0	1.5
	Gravel	0	26,327	40,816	32,919	41,247	141,310	0	2,025	3,140	NA	3,173	2,025	0	1	2	NA	1.2	1
	Channel	0	31,416	90,344	31,132	137,732	290,624	0	2,417	6,950	2,395	NA	2,417	0	1	5	1.7	NA	1
	Sum	**244,054**	**2,328,031**	**1,329,256**	**142,425**	**260,969**	**4,304,735**												

Table 6. Susceptibility ratios measuring relative susceptibility of cropland plus grassland and woodland to erosion, deposition, and total change

Transition period	Channel buffer width, in meters	Erosion susceptibility ratio, calculated as area of cropland plus grassland that became channel divided by area of woodland that became channel	Deposition susceptibility ratio, calculated as area of cropland plus grassland that became gravel divided by area of woodland that became gravel	Erosion plus deposition susceptibility ratio, calculated as area of cropland plus grassland that became channel or gravel divided by area of woodland that became channel or gravel
1938–48	7 5	0 88	1 23	1 01
	15	86	1 12	98
	30	66	89	78
	60	37	78	61
	120	09	39	28
1948–55	7 5	1 20	1 70	1 31
	15	1 15	1 16	1 15
	30	93	83	90
	60	55	71	61
	120	16	41	26
1955–64	7 5	95	1 92	1 27
	15	95	1 77	1 25
	30	84	1 27	1 03
	60	56	89	71
	120	16	35	25
1964–76	7 5	91	75	88
	15	78	54	72
	30	53	30	46
	60	31	15	25
	120	14	06	10
1976–89	7 5	80	1 93	1 07
	15	79	1 75	1 04
	30	74	1 51	95
	60	50	1 02	65
	120	18	33	23

widths at 7 5 and 15 m (fig 11A) This relation is typical of all transition periods and indicates that a greater percentage of the area within the buffer is susceptible to reworking with decreasing distance from the channel The decrease in percent area of geomorphic change at the small buffer widths may result in part from the limits of mapping accuracy compared to these small buffer widths, but most of the decrease probably results from channel erosion and deposition that extend outside the buffer At locations where the channel has been extremely active, much of the change recorded in a given transition period can occur outside the buffer designated around the channel that existed at the first date in that period

The erosion susceptibility ratio—which measures the area of cropland plus grassland polygons that became channel polygons relative to the area of woodland polygons that became channel polygons—increases systematically with decreasing buffer width (fig 11B) At large buffer widths the ratio is substantially less than unity, indicating that cropland plus grassland are much less likely to be eroded As the buffer width decreases, the ratio increases, which results in part from decreasing spatial bias as the analysis focuses on areas closer to the channel The susceptibility ratios can be projected to a value of about 1 0 at zero buffer width (fig 11B) A susceptibility ratio of 1 0 would indicate no difference in the areal

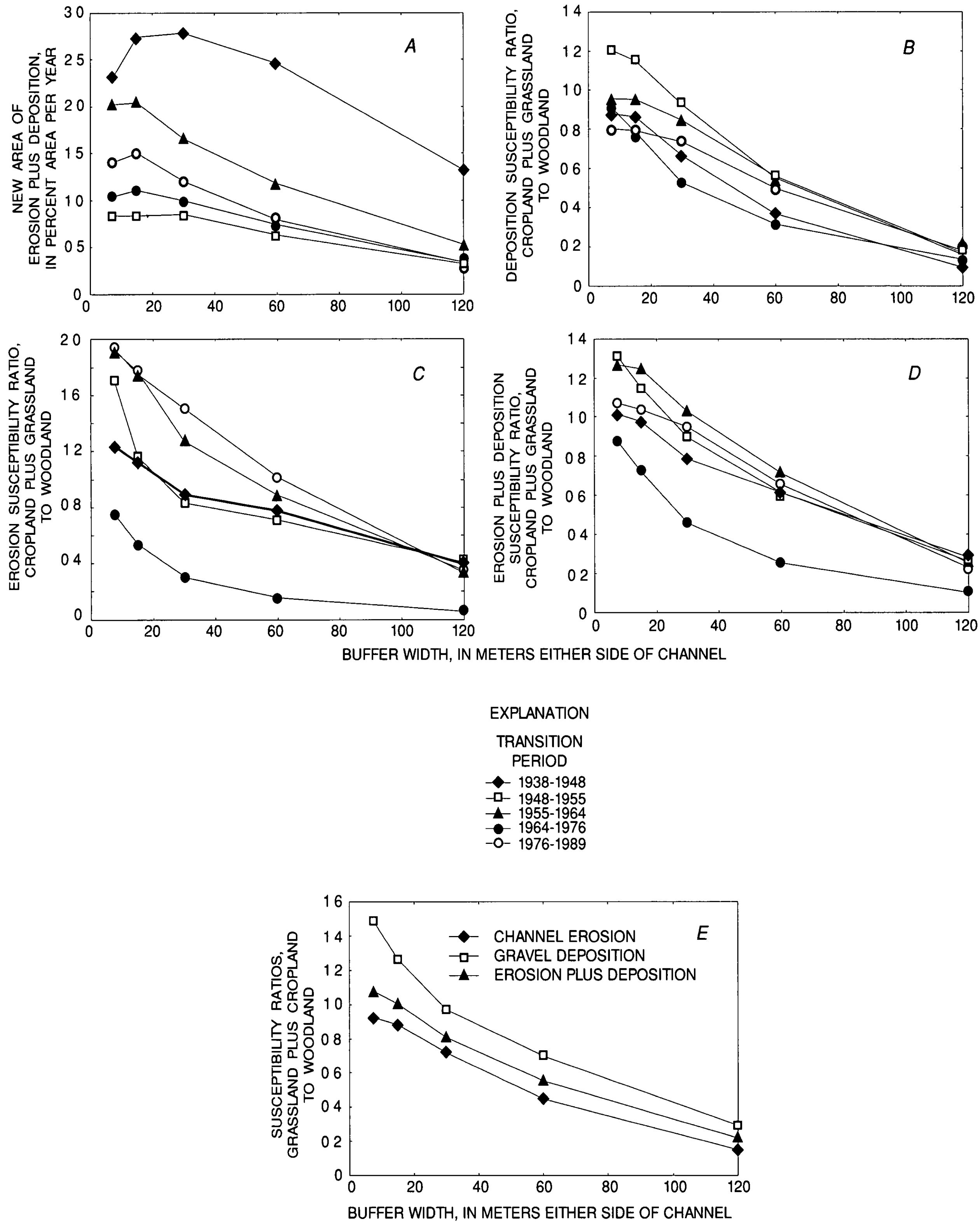

Figure 11 Erosion and deposition, Little Piney Creek Valley, Missouri, for 1938–89, by channel buffer width *A*, percentage of area in buffer changed per year by buffer width for all transitions, *B*, erosion susceptibility ratio by buffer width for all transition periods, *C*, deposition susceptibility ratio by buffer width for all transition periods, *D*, erosion plus deposition susceptibility ratio by buffer width for all transition periods, *E*, deposition, erosion, and erosion plus deposition susceptibility ratio by buffer widths, averaged over all transition periods

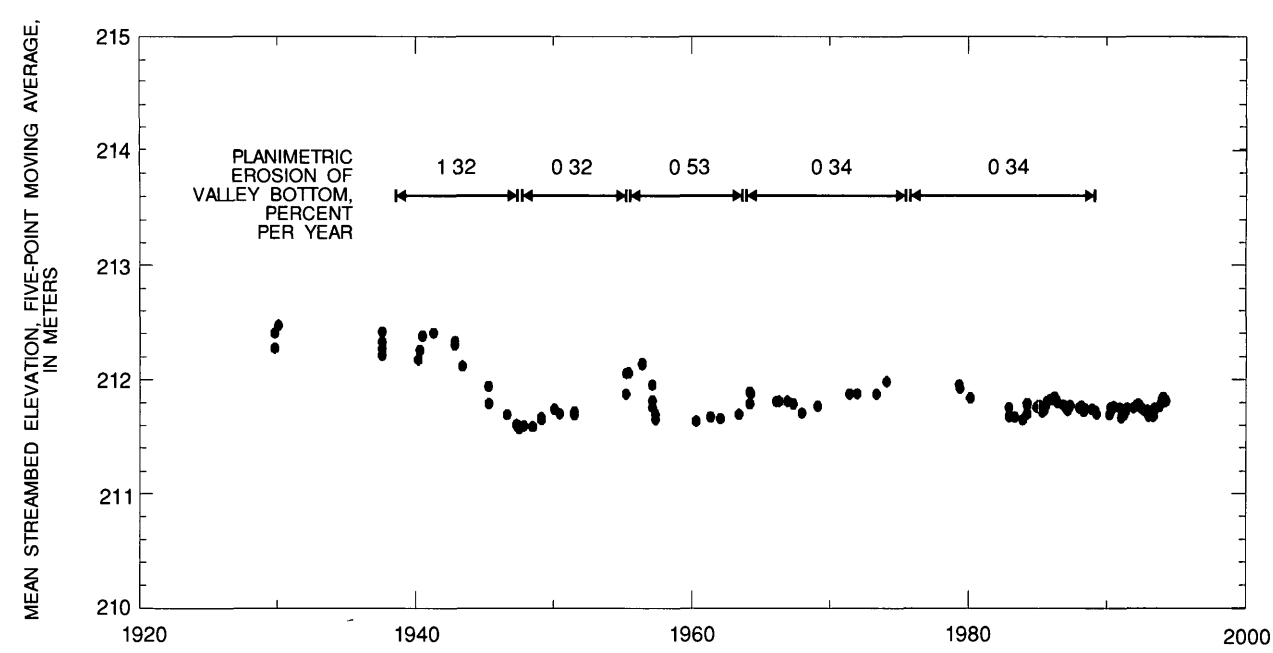

Figure 12 Streambed elevation changes, Little Piney Creek at Newburg, Missouri, and planimetric valley-bottom erosion rates calculated for the study segment, 1938–89

rates at which cropland plus grassland erode relative to the areal rates at which woodland erodes There is no apparent systematic change of the erosion susceptibility ratios over time

The deposition susceptibility ratio—which measures the area of cropland plus grassland polygons that became gravel polygons relative to the area of woodland polygons that became gravel polygons—also increases with decreasing buffer width (fig 11C) The range in deposition susceptibility ratio values for all transition periods and all buffer widths is greater than the range in values for the erosion susceptibility ratios This larger range may result from enhanced spatial variations in gravel deposition controlled by vegetation, channel geometry, and interactions of channel flow with the valley wall (pl 1)

Four of the five transition periods would project to deposition susceptibility ratio values of 1 2 and greater at zero buffer width Ratio values greater than 1 0 indicate that cropland plus grassland are more susceptible than woodland to deposition of gravel These ratios do not take into account the thickness of gravel deposition, however Onsite observations indicate that gravel deposition in wooded areas generally is thicker than in open cropland or grassland In open cropland and grassland, gravel and sand tend to be deposited in laterally extensive splays that cover large areas Hence, if it were possible to calculate the deposition susceptibility ratio in terms of gravel volume rather than area, the ratios might be lower

The susceptibility ratios for erosion plus deposition project to a value of 1 0 to 1 4 at zero buffer width (fig 11D), indicating that cropland plus grassland is only slightly more susceptible than woodland to total planimetric geomorphic change As with the separate erosion and deposition susceptibility ratios, there is no apparent trend over time However, for the erosion plus deposition and deposition susceptibility ratios, the transition period 1964–76 consistently has the lowest values for each buffer width These values indicate that woodland had greater susceptibility to deposition and erosion than cropland and grassland during this period The period also is at the end of a 25-year period of relatively few large floods (figs 4, 6)

Susceptibility ratios for deposition, erosion, and erosion plus deposition averaged over the five transition periods are shown in figure 11E The average erosion susceptibility ratio projects to about 1 0, indicating little difference in erodibility between nonwooded and wooded riparian land The average deposition susceptibility ratio projects to about 1 4, indicating that nonwooded land is more susceptible to measurable deposition than wooded land The average erosion plus deposition susceptibility ratio projects to about 1 2, indicating that nonwooded land is slightly more susceptible to total geomorphic change than nonwooded land

RIPARIAN VEGETATION AND STREAM-CHANNEL INSTABILITY

Streambed-elevation data from the Newburg streamflow-gaging station indicate a trend toward recovery of Little Piney Creek from post-settlement, human-induced, land-use disturbance (fig 4) Total geomorphic change rates (calculated from the photogrammetric/GIS data as a percentage of total valley bottom that changed to gravel or channel divided by the number of years in the transition period) also declined and stabilized (fig 12), despite large floods in the 1980's Runoff/rainfall relations (fig 6) from 1929 through 1994 do not indicate trends in basin-wide runoff on a seasonal scale, therefore, changes in runoff and sediment delivery probably are not responsible for increased channel stability Furthermore, historical analysis of land-use changes supports the model that streams were initially destabilized and maintained in an unstable condition because of riparian land-use practices that decreased riparian vegetation (Jacobson and Primm, 1994)

These lines of evidence support the idea that increased woodland vegetation in the Little Piney Creek Valley bottom from 1938 to 1989 could have been the direct cause for increased channel stability However, the results of photogrammetric/GIS analysis of locations of erosion and deposition indicate that the susceptibility of riparian land to erosion or deposition is insensitive to riparian land use Four factors described in the following four sections, alone or in combination, may reconcile these apparently inconsistent interpretations

Relation to Valley Physiography and Channel Pattern

Probably the single most important factor affecting channel instability is channel pattern as controlled by local valley physiography Lateral channel migration of Little Piney Creek is not uniformly distributed along the valley (pl 1) Instead, lateral migration is preferentially located in discrete disturbance reaches separated by stable reaches in which lateral migration is relatively limited The dichotomy of disturbance and stable reaches is a common feature of Ozarks streams (Jacobson, 1995, Miller and Jacobson, 1995) As an operational definition, disturbance reaches have lateral migration rates of several channel widths or more per decade, whereas stable reaches have lateral migration rates of a fraction of a channel width or less per decade

The origins of disturbance and stable reaches are poorly understood (Miller and Jacobson, 1995) Many—but not all—of the stable reaches occur along straight valley walls Many—but not all—of the disturbance reaches occur where the valley orientation changes These observations indicate that during overbank floods straight valley walls parallel to the flow may impart stability to the flow patterns by providing low hydraulic roughness as compared to the valley flat Decreased roughness along the valley wall may increase downstream components of velocity sufficiently to damp out cross-stream components that would otherwise cause flow divergence and lateral channel migration

Hypothetically, transition downstream to a disturbance reach could occur because of several mechanisms In one case, if the valley wall bends away from the direction of the straight reach, there is an effective flow expansion, and diverging flow may cause enough perturbation to create lateral channel instability In another case, a perturbation in flow may occur because current velocities have increased sufficiently downstream to trigger vertical scour of the streambed Sediment scoured from the bed would be transported in the down-valley direction and accumulate on a floodplain surface or pointbar Accumulation on the bar would add to topographic steering of the flow away from the valley wall, thus perturbing the flow sufficiently to create a disturbance reach This mechanism might occur with or without a change in valley orientation Another possible mechanism may be upstream backwater effects from where the flow impinges at a high angle on the valley wall Sediment deposited in the backwater area could lead to lateral channel instability and creation of the disturbance reach

Although these hypothetical mechanisms remain to be demonstrated, the effect of the dichotomy of stable and disturbance reaches on channel morphology is profound Instead of the "textbook" case wherein flow resistance and energy dissipation is uniformly distributed along a meandering channel, Ozarks streams like Little Piney Creek apparently expend erosional energy nonuniformly Because most of the lateral channel migration measured in the 12-km study segment occurred in disturbance reaches, the conclusion that susceptibility to channel erosion is insensitive to riparian land use pertains mostly to disturbance reaches Possibly, no matter what riparian vegetation grows in and along disturbance reaches, the erosional energy focussed in the reach will overcome the stabilizing effects of vegetation Moreover, channel instability has probably caused landowners to abandon farming adjacent to the channel in disturbance reaches, thereby preferentially siting wooded land in zones of high erosion rates

Relation to Erosional Processes

Although many studies have concluded that riparian vegetation aids in channel stability by contributing flow resistance and erosional resistance (Smith, 1976, Graf, 1978, Shields and Nunnally, 1984, Beschta and Platts, 1986, Hupp, 1992, McKenney and others, 1995), other studies have noted exceptions related to specific properties of vegetation, sediment, and erosion processes In Ozarks streams, vegetation has different potential effects on channel stability depending on size of the channel and whether vegetation is growing on an accreting, gravel point bar or on an eroding cutbank (Thorne, 1990, McKenney and others, 1995)

McKenney and others (1995) noted that efficacy of riparian vegetation in stabilizing banks decreased with increasing drainage area of Ozarks streams In reaches where the banks were no higher than the typical rooting depth of woody riparian vegetation, interlocking roots were seen to provide substantial barriers to particle-by-particle erosion and provided buttresses and root strength to inhibit slumping, sliding, and toppling failures In downstream reaches where banks were higher than typical rooting depths, roots were less effective because banks could be oversteepened by basal erosion

On accreting point bars, woody vegetation has been shown to increase sedimentation of sand and gravel in Ozarks streams (McKenney and others, 1995) In this same study, however, the effectiveness of riparian vegetation communities to increase flow resistance was shown to decrease systematically with age of the vegetation community, primarily because of rapid decreases in stem density Thus, woody vegetation on gravel bars can contribute to stability during initial stages of colonization when stems are very dense, but the effect seems to decrease to near background levels by the time the community is 40 years old Areas of bars or floodplains with older vegetation communities then become potential sites of erosion and avulsion because of lowered hydraulic roughness

On cutbanks, coarse sediments can erode particle by particle from in between the roots of even well-established trees (fig 13) In contrast, cohesive cutbank sediments generally erode by slumping, sliding, or toppling of large blocks (fig 14) Root networks in cohesive sediment can add as much as 100 percent of the total shear strength to resist these gravitational failure processes (Waldron, 1977) In a fifth-order stream segment like the Little Piney Creek study segment, cutbank heights typically are greater than rooting depths (fig 15), so roots are minimally effective in preventing lateral bank erosion, even in cohesive sediment Additionally, in reaches with extensive lateral channel migration, the channel frequently cuts back into newly deposited, noncohesive sediments Roots can be expected to contribute minimal strength to noncohesive sediment

Relation to Upstream Riparian Land-Use Changes

Geomorphic changes in the Little Piney Creek study segment may be affected in part by changes in riparian land use in the extensive tributary area Jacobson and Primm (1994) related sparse historical evidence to support a hypothesis that headward extension of the channel network contributed gravel to downstream reaches They also discussed the potential for changes in riparian vegetation along tributary streams to alter the timing of flood peaks by increasing or decreasing the cumulative energy dissipation of floodwaters Hence, increased growth of riparian vegetation in tributary channels from 1938 through 1989 may have decreased gravel delivery to downstream channel sections or decreased flood peak heights, or both These sediment budget and hydraulic factors may be responsible for the recovery of the Little Piney Creek study segment, independent of riparian vegetation in the study segment However, evaluation of these factors is outside of the scope of this report

Relation to Disturbance History

Recovery of the Little Piney Creek channel from land-use changes involves continuing effects from processes that occurred in the past The initial

Figure 13. Erosion of gravel, particle by particle, from below and around sycamore tree roots on a gravel bar, Little Piney Creek, Missouri.

Figure 14. Bank erosion by slumping, Little Piney Creek, Missouri.

instability of the stream channel possibly resulted from modification of riparian vegetation, but once the channel was disturbed, regrowth of woody riparian vegetation was not sufficient to re-establish stability. This would be the case if most streambanks were initially convex-upward and covered with woody vegetation. In this situation, roots of woody vegetation protect the entire bank (fig. 16A). If woody vegetation is removed from a convex bank, accelerated lateral channel erosion could form a concave-upward or vertical cutbank greater than the rooting depth and for which roots would provide little protection against

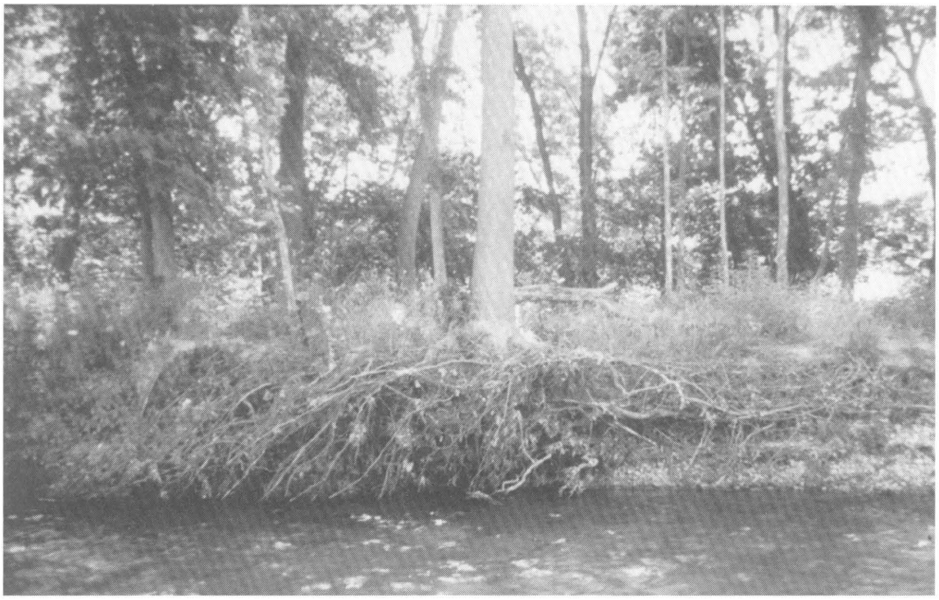

Figure 15. Cutbank showing limitation of rooting depth in bank protection, Little Piney Creek, Missouri.

erosion (fig. 16B). Creation of concave-upward banks would be a threshold event, after which bank vegetation would be less capable of stabilizing banks.

Another historical effect may be the relative decrease of large woody debris (LWD) in Little Piney Creek. Oral-historical accounts describe greater LWD concentrations in the Ozarks during the early 1900's; many LWD concentrations were removed recreationally or to improve downstream passage of railroad tie rafts (Jacobson and Primm, 1994). Concentrations of LWD in channel bends may have been sufficient to protect some cutbanks from erosion (fig. 17).

Also, the cumulative effect of land-use changes in the Little Piney Creek Basin has resulted in recent deposition of greater thicknesses of sand and gravel substratum at the expense of silt and clay top stratum (Jacobson and Pugh, 1992). This deposition has been interpreted as the result of increased delivery of gravel to streams and decreased retention of fine sediment due to decreased riparian vegetation density and associated decreases in flow resistance. As the stream migrated across the valley in disturbance reaches, gravel and sand have replaced the pre-existing fining-upward sequence of cobbles to clay. This change has

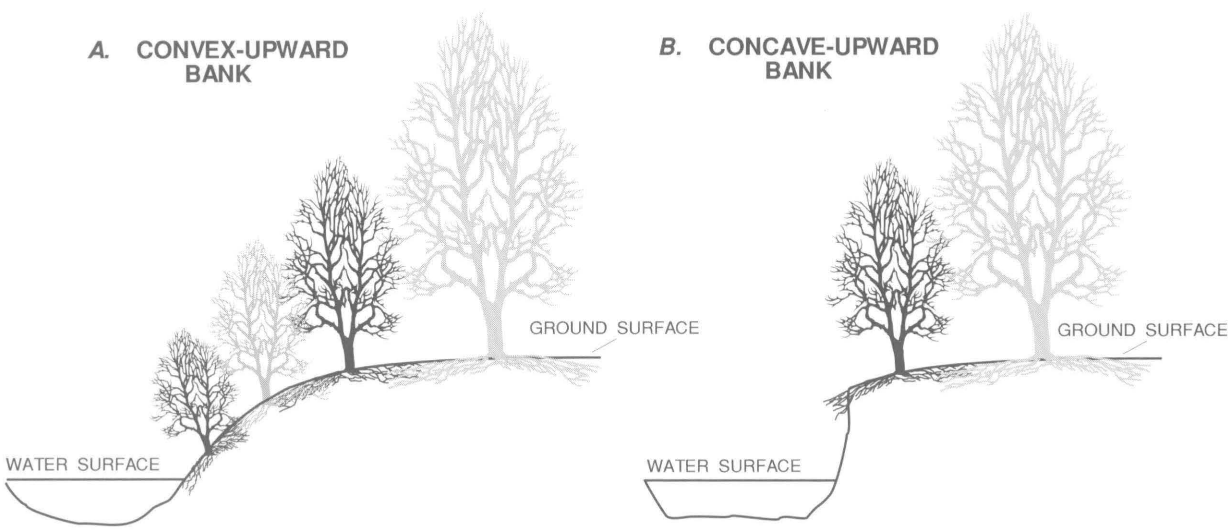

Figure 16. Differing role of roots on a convex-upward bank *(A)* and concave-upward bank *(B)*.

Figure 17. Extensive concentration of large woody debris along channel bend on Little Piney Creek, Missouri (the woody debris protects the cutbank from erosion).

affected the boundary conditions that determine channel cross-sectional morphology and may have decreased the effectiveness of vegetation to increase erosional resistance.

As noted by Schumm (1960), channel cross-sectional morphology is controlled in part by the particle-size characteristics of the streambed and bank materials. Banks that are constructed of fine sediment (silt plus clay) can attain substantial cohesive strength and, therefore, maintain steep bank angles. Banks that are composed of noncohesive gravel and sand support lower bank angles. Hence, as the pre-settlement fining-upward alluvium of the Little Piney Creek Valley has been replaced by noncohesive sand and gravel, channels would be expected to become shallower and wider. In some disturbance reaches, gravel has been deposited on one side of the channel, but the stream is still migrating laterally into pre-settlement cohesive alluvium (fig. 18). In this situation, the channel is asymmetrical and the bank is steeper on the side bordered by cohesive sediment. In other disturbance reaches, the channel has migrated into a previous position so it is now bordered by coarse, noncohesive sediment on both sides of the channel (fig. 19). In these reaches, a well-defined thalweg typically is absent, and pool habitats are limited to scour around LWD.

In addition to affecting channel morphology, the change in sediment may have a substantial effect on growth of riparian vegetation communities and, consequently, on the stability of newly deposited gravel bars. Because of low-nutrient concentrations and low water-holding capacity, coarse sediments are poorer substrates for establishment and growth of vegetation than are fine sediments, especially where thickness is so great that roots cannot penetrate to the water table. Therefore, if all other factors are equal, vegetation growing on gravel bars can be expected to be less vigorous and inherently less effective in resisting erosion than vegetation growing on fine sediment.

The replacement of fine, cohesive sediment with coarse, noncohesive sediment will have a long-term effect on channel morphology. Once the delivery of coarse sediment stops, decades would still be required to remobilize the coarse sediment now in the valley bottom, even at the high rates of lateral migration occurring in disturbance reaches (pl. 1). Additionally, long-term recovery of the channel to pre-settlement conditions will require deposition of fine sediment. Because deposition of fine sediment is directly related to vegetation density and because density and growth of the riparian vegetation community probably are adversely affected by the coarse particle-size of the sediment, recovery to pre-settlement conditions possibly will take more time, or special conditions, as compared to the processes that destabilized the streams initially. This conceptual model describes a system in

Figure 18. Low-altitude, oblique aerial photograph showing gravel and sand deposits replacing cohesive top stratum (to left), Little Piney Creek, Missouri (view is upstream; channel width is approximately 9 meters).

which an internal threshold has been crossed (deposition of coarse sediment), thereby making it difficult for the system to return to its former state because of a positive feedback (poor conditions for growth of riparian vegetation and ineffectiveness in stabilizing gravel). The implication of such a conceptual model for this study is that the 50 years of photographic record used to document recovery of Little Piney Creek may have documented a system in which recovery processes have been inhibited because of the lack of fine sediment. The positive feedback would have been concentrated in the disturbance reaches because that is where deposition and erosion occur concurrent with lateral channel migration.

Recovery of Little Piney Creek and Management Implications

The results of this study illustrate some of the complex processes that can modify the effectiveness of woody riparian vegetation in controlling the spatial pattern of stream instability. Recognition of these complexities may have some implications for riparian land management for streams in the Ozarks and other similar regions.

Woody riparian vegetation, of course, has many other ecological benefits in addition to potentially adding to channel stability. Vegetation also contributes substrate, cover, shading, rainfall-energy dissipation, and filtering of nutrients to aquatic ecosystems (Welsch, 1991). When woody vegetation falls into a river because of bank erosion, it continues to provide important habitat elements (fig. 20). In typical Ozarks streams, rootwads and log complexes provide critical habitat for rock bass and smallmouth bass (Probst and others, 1984). Hence, the ecological importance of riparian woody vegetation should not be underestimated, even when it does not contribute substantially to channel stability.

For applications to channel stability, limitations of riparian vegetation should be understood. In stream reaches characterized by vertical or concave-upward banks with heights greater than the typical rooting depth of trees and where channel migration is concentrated, riparian vegetation can be expected to have

Figure 19. Low-altitude, oblique aerial photograph of Little Piney Creek, Missouri, showing gravel and sand deposits on both banks, and resulting wide and flat-bottomed channel (the view is downstream; channel width is approximately 5 meters).

minimal bank stabilization effect. Shields and others (1995, p. 486) concluded from results of an experimental study of bank stabilization "...if bank heights become great enough, even the best vegetation will prove inadequate." The greatest benefits of riparian vegetation to channel stability will accrue at sites of incipient channel instability in stable reaches, where banks can be graded to low angles or convex slopes. The least benefits toward channel stability will accrue at actively eroding sites in disturbance reaches. Whether a stream site is in a disturbance or stable reach can be determined from qualitative evaluation of historical aerial photographs. This context can help stream managers determine the sites where riparian

Figure 20. Scour pool formed around a rootwad, Little Piney Creek, Missouri (darker water around the rootwad indicates greater depth of water; the field of view is approximately 10 meters).

vegetation likely would be most effective in channel stabilization.

Some characteristics of stream reaches and segments are controlled by processes in the upstream channel network and drainage area. Because sites of erosion in the study segment have been insensitive to riparian vegetation type, recovery of Little Piney Creek since approximately 1950 (fig. 12) probably is attributable to changes in upstream processes, either changes in runoff or sediment budgets. Because runoff data from 1929 to 1994 do not show trends indicative of hydrologic recovery (fig. 6), decreases in sediment supply can be inferred. Sparse historical data indicate that excess gravel probably was introduced into Ozarks streams by headward extension of the channel network, possibly associated with widening or incision of low-order, ephemeral channels. Instability of low-order channels probably resulted from clearing of riparian vegetation and the effects of free-range grazing (Jacobson and Primm, 1994). Conversely, recovery of riparian vegetation along these low-order channels probably has been responsible in part for relative stabilization of downstream reaches of Little Piney Creek since 1950. Corroboration of this inferential model could indicate the importance of low-order channels to overall stability of Ozarks streams and might serve to focus management concerns on these sensitive reaches.

The spatial and historical context of the study segment of Little Piney Creek also indicates that recovery of the segment to pre-settlement conditions may take a longer path and involve different processes than initial destabilization. This is because the stream likely has crossed two vegetation-related, geomorphic thresholds as it adjusted to increased coarse sediment load. Concerning the first threshold, steepening of initially convex banks to vertical or concave-upward may have markedly decreased the efficacy of woody vegetation to stabilize the banks. Once steepened, banks are more susceptible to erosion because discharges necessary to remove sediment from the toe of the bank, maintain steepness, and induce bank slumping recur with greater frequency than the discharge that would have been necessary to erode a vegetated, convex bank. Recovery of banks to the hypothesized, pre-settlement conditions would require either of two conditions. The first is a sufficient time interval between discharges capable of eroding the oversteepened cutbank. During this interval, small to moderate discharges could deposit sediments to form convex-upward banks inset along the cutbank, and woody vegetation could be established on the new surface. Such a period of small to moderate discharges is unlikely because floods less than bankfull have been observed to cause slumping of substantial parts of vertical banks, however, regional, multi-year droughts occur in the Ozarks (for example, 1950–80, fig 4) and may be sufficient to promote recovery of some steepened banks The second condition is for the channel to reverse lateral migration direction and move back across the valley If vegetation has become established on the opposite point bar, the channel would encounter a stable, convex-upward bank

For a pointbar to become well-vegetated, however, requires overcoming the second vegetation-related, geomorphic threshold Vegetation must become sufficiently dense so that it is capable of trapping fine sediment and thereby increase sediment cohesion and water-holding capacity Growth of vegetation on the pointbar and its effectiveness in trapping sediment are dependent on seed dispersal mechanisms, growth rates, growth habits, and the sequence of stream discharges (McKenney and others, 1995) Periods of low discharge may not provide sufficient moisture for vegetation to germinate or grow, whereas large floods may damage, erode, or bury pointbar vegetation

Assuming that pointbar vegetation can become established so it is effective in trapping fine sediment and that no additional sources of disturbance occur in the Little Piney Creek Basin, lateral channel erosion rates can give an indication of how long it would take channels to migrate across the valley, reverse, and begin migrating against stable, convex-upward banks For an average valley width of 300 m and a representative disturbance reach migration rate of approximately 3 2 m per year, as much as 100 years might be necessary, depending on down-valley and cross-valley components of migration This calculation gives an indication of the possible time scale required for complete recovery of Little Piney Creek

SUMMARY AND CONCLUSIONS

The photogrammetric/GIS analysis presented in this report indicates that spatial patterns of erosion and deposition on Little Piney Creek are relatively insensitive to riparian vegetation type These results are applicable to streams in the Ozark Plateaus Physiographic Province and elsewhere which have similar physiographic controls and have undergone similar land-use histories

Results from this analysis indicated that wooded and nonwooded land bordering Little Piney Creek have about the same susceptibility to erosion Nonwooded land is slightly more susceptible to gravel deposition than wooded land When the spatial and historical context of channel processes is taken into account, a variety of reasons can be identified to explain the inefficacy of riparian vegetation in channel stability for moderate-size Ozarks streams (fourth to sixth order)

- Valley-wall geometry exerts a strong control on where channel instability occurs Lateral channel instability in disturbance reaches may exist independent of stabilizing potential of riparian vegetation
- In the study segment, banks are sufficiently high that tree roots do not contribute substantially to bank stability Lateral erosion of initially convex-upward banks may have created a greater proportion of near-vertical cutbanks than was originally present
- Erosion and deposition in the study segment depend in part on changes in the drainage basin or riparian zones upstream Thus, recovery of the study segment may have resulted from upstream changes in tributary riparian zones that decreased sediment supply, runoff, or flood peaks
- Because of a history of land-use changes and landscape response, Ozarks streams are now (1995) depositing greater quantities of gravel and sand and lesser quantities of fine sediment than they did in pre-settlement time Woody vegetation is less effective in stabilizing banks and bars composed of coarse sediment than those composed of fine sediment

The results of this study show that the efficacy of riparian vegetation in channel recovery depends on basin-wide factors and the spatial and historical context of individual reaches Recovery of a stream segment may take a longer time and involve different processes than the initial destabilization Recognition of spatial variations along a stream and the history of channel changes should indicate where woody riparian vegetation will be most successful in promoting channel stability

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