CHANGES IN THE PLANFORM OF THE RED RIVER
McCURTAIN COUNTY, OKLAHOMA 1938-1984

By

BRUCE LEE WHITESELL

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Oklahoma State University

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Thesis Approved:

John D. Vitek

Thesis Adviser

David R. Butler

Stephen J. Stadler

Norman N. Durham

Dean of the Graduate College

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CHAPTER I

INTRODUCTION

Overview

Rivers are an integral part of many peoples lives. Since the beginning of human history, people have used rivers as a source of water for drinking, for agriculture, and for transportation. During the last century, geologists, hydrologists, geomorphologists, civil engineers, and others have made numerous studies in an attempt to understand the impact of humans on the mechanics of river systems.

When viewed as systems, rivers are dynamic features on the landscape. Changes in the discharge, sediment load, or course can impact on the people living near the river. If the discharge of water in the river is too high, flooding occurs. If the discharge is too low, the quantity of water may be insufficient to meet the needs of all the people. Increases in the sediment load may choke the channel with sand or gravel while decreases in the load may cause the channel to erode (Knighton, 1984). Changes in the width, depth, or course may result from channel erosion (Morisawa, 1985). Increases in the width or depth of the channel can destroy bridges and other construction projects along a river (Galay, 1983). If the river forms a political boundary, changes in the course may change the boundaries between cities, states, or countries.

Human Impact

Human occupation and use of the earth has had an impact on rivers. Some effects are subtle whereas others are dramatic. Downstream from urban areas an increase in the volume of peak flows occurs, in addition to a decrease in the lag time between rainfall and runoff (Morisawa and Leflure, 1979). Gregory and Brookes (1983) indicate that the shape of river channels is often altered downstream from bridges.

The downstream effects of dams and reservoirs have been examined in recent years. Petts (1980) found that reservoir construction induced changes in the equilibrium of the river. The changes in the fluvial process may bring about problems with flood control, navigation, and irrigation (Chien, 1985). Belt (1975) has attributed a rise in the flood stage of the Mississippi River to the construction of levees, which confine the water to the channel and prevent suspended sediments from being deposited over the floodplain. Deposition within the channel reduces the volume of water that can be accommodated in the channel.

Channel width can be dramatically altered downstream from a dam, either widening or narrowing depending on the relative changes in peak discharge, sediment supply, and vegetation (Howard and Dolan, 1981). The reduction in peak flows and variation in flows from the Fresno Dam, on the Milk River in Montana, have decreased the rate of meander migration by 1.3 m/year (Bradley and Smith, 1984). Harrison and Mellema (1982) found that bank erosion below dams on the Missouri River is concentrated in a few locations which change from year to year. The rates of erosion were also found to increase with distance downstream from the dam. Elimination of highwater discharges on the Colorado River by the Glen Canyon Dam has led to the growth of dense floodplain vegetation in areas of the Grand Canyon which were formerly inundated (Dolan, et al., 1974 and Turner and Karpiscak, 1980). Stream changes initiated by dams also contribute to erosion in downstream valleyside gullies (Olofin, 1984). Erosion of the gullies may add large amounts of sediment to a stream.

Purpose of the Study

The purpose of this study is to determine : (1) whether the meander pattern in the study area is symmetrical or asymmetrical; (2) whether the symmetry or asymmetry has changed through time; (3) the rate of meander migration and changes, if any, overtime; and (4) whether the rate of meander migration has changed since the construction of the Denison Dam. Investigation of the symmetry or asymmetry of the channel was prompted by the on-going debate in the current literature. Interest in the changes in stream dynamics downstream from dams led to the questions concerning changes in the meander migration rate.

River System Mechanics

Modification of the mechanics of the river by human action is reflected in landforms attributed to fluvial processes. The complex interactions of variables in the fluvial system are reviewed here because these interactions are involved in this study.

The concept of dynamic equilibrium is the dominant hypothesis used to explain how channels change with time. According to Williams and Wolman (1984), the concept of dynamic equilibrium implies that the channel size, cross-sectional shape, and the slope are adjusted to the quantities of sediment and water transported so that the streambed neither aggrades nor degrades.

Lane (1955) determined that the product of the sediment discharge, Q_s, and the sediment particle size, D, is directly proportional to the product of the water discharge, Q_w, and the slope of the stream channel, S.

$$Q_s D \quad Q_w S \qquad (1)$$

Using flume models of stream channels, Leopold and Wolman (1957) were able to develop a basic relationship showing the discharge of a stream, Q, is equal to the product of the width, w, the depth, d, and the velocity, v, of a stream .

$$Q=wdv \quad (2)$$

At least thirty variables are now recognized as being involved in the sediment transport process and the interrelationships among these variables are not completely understood (Heede,1980). Because streams can be considered as open systems and all parts are interrelated, changes in one or more of the variables will cause an alteration in some or all of the remaining variables until a new equilibrium state is reached.

Stream flow dynamics determine whether the pattern of the stream channel will be straight, meandering, or braided. The channel pattern is defined as "the plan view of the channel as seen from an airplane" (Leopold and Wolman, 1957, p. 39). Straight and meandering channels are described on the basis of sinuosity, P, which is the ratio of the length of the channel, L_c, to the length of the valley, L_v.

$$P=L_c/L_v \quad (3)$$

Straight channels have a sinuosity of ranging from 1.0 to 1.5 while meandering streams will have a sinuosity value of greater than 1.5. Braided (anastamosing) channels are those with two or more separate channels and relatively stable islands (Ibid, p. 60).

Schumm (1981) schematically related the formation of channel patterns to the sediment size, the amount of sediment carried, sediment load (suspended, mixed, or bed load), and to the velocity of flow. Figure 1 illustrates that changes in the sediment-water relations may cause a change in the plan form of a river.

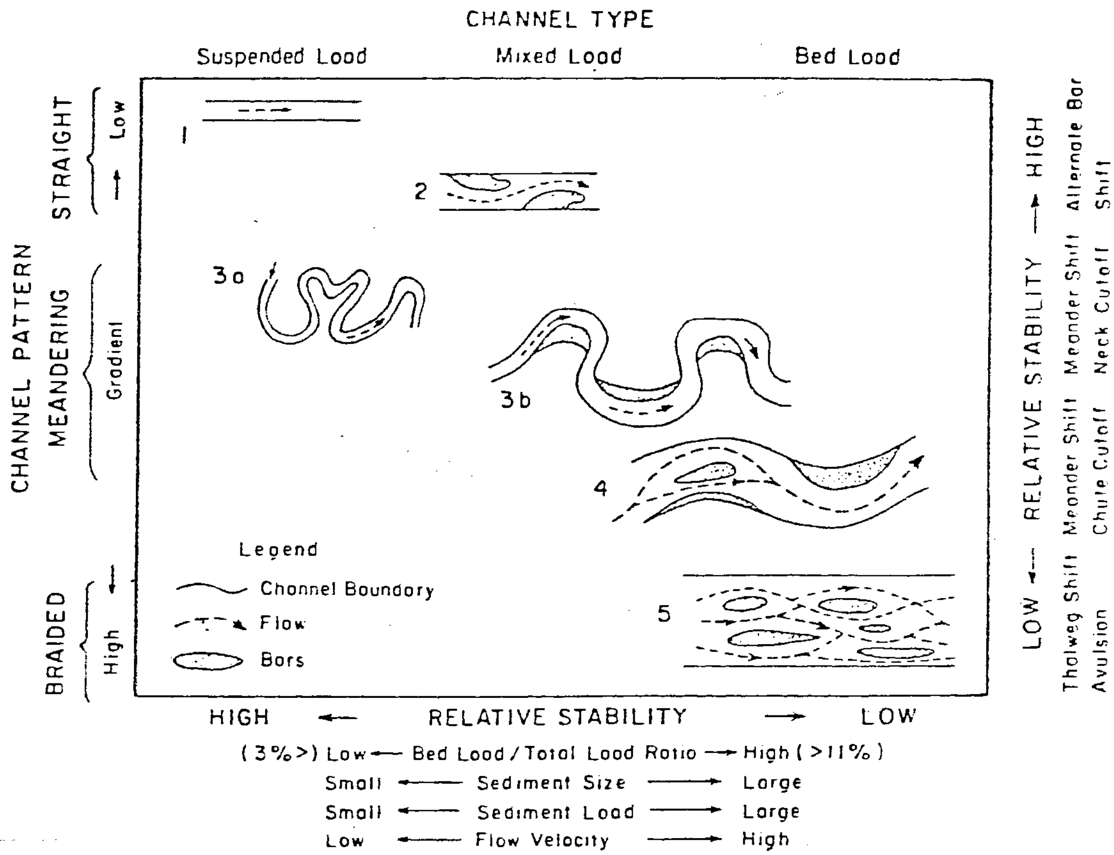
Changes in meander sinuosity, symmetry, and rate of migration of a channel can be used to demonstrate how meanders change through time. The concept of meander symmetry is widely accepted. Langbein and Leopold (1966) found that most of the meanders they studied produced the symmetry of a sine-generated curve. Figure 2 defines the wavelength, L, amplitude, A, and the radius of curvature, r_o, which are commonly used to characterize the symmetry of meanders.

Although the theory of meander symmetry has been used for the last twenty years, Carson and LaPointe (1983) stated that meanders show well defined and consistent asymmetry. The z-value, or asymmetry index, has been defined as the percent of the length of the traverse that is convex down valley. A traverse is the distance between two successive inflection points (Figure 3). The equation used to define the z-value is as follows:

$$z=100(u)/u+d \qquad (4)$$

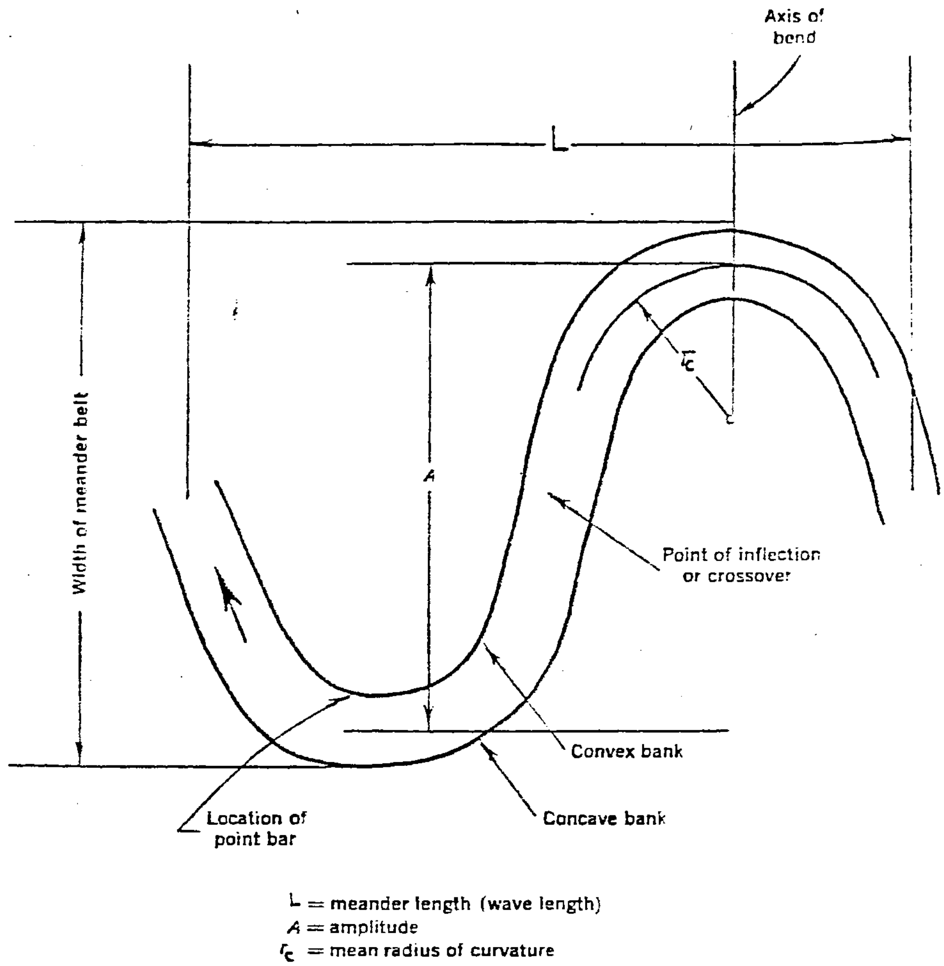
where u is the length of an upstream traverse and d is the length of the subsequent downstream traverse.

Meander migration is the transverse or longitudinal movement of meanders within a stream valley through time. Migration occurs because of flow within a channel. As



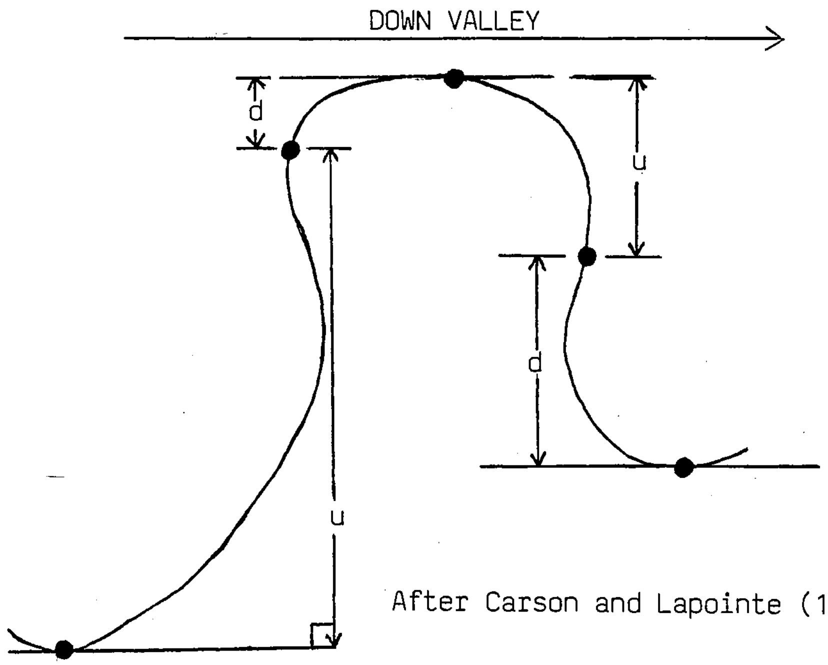
After Schumm (1981)

Figure 1. Channel Pattern vs. Channel Type



After Leopold and Wolman (1960)

Figure 2. Definition Diagram for Meander Geometry



After Carson and Lapointe (1983)

$$\text{ASYMMETRY INDEX} \quad z = \frac{100 \cdot u}{u + d}$$

Traverse A shows delayed inflection asymmetry (Z 50).
Traverse B is symmetric (Z= 50).

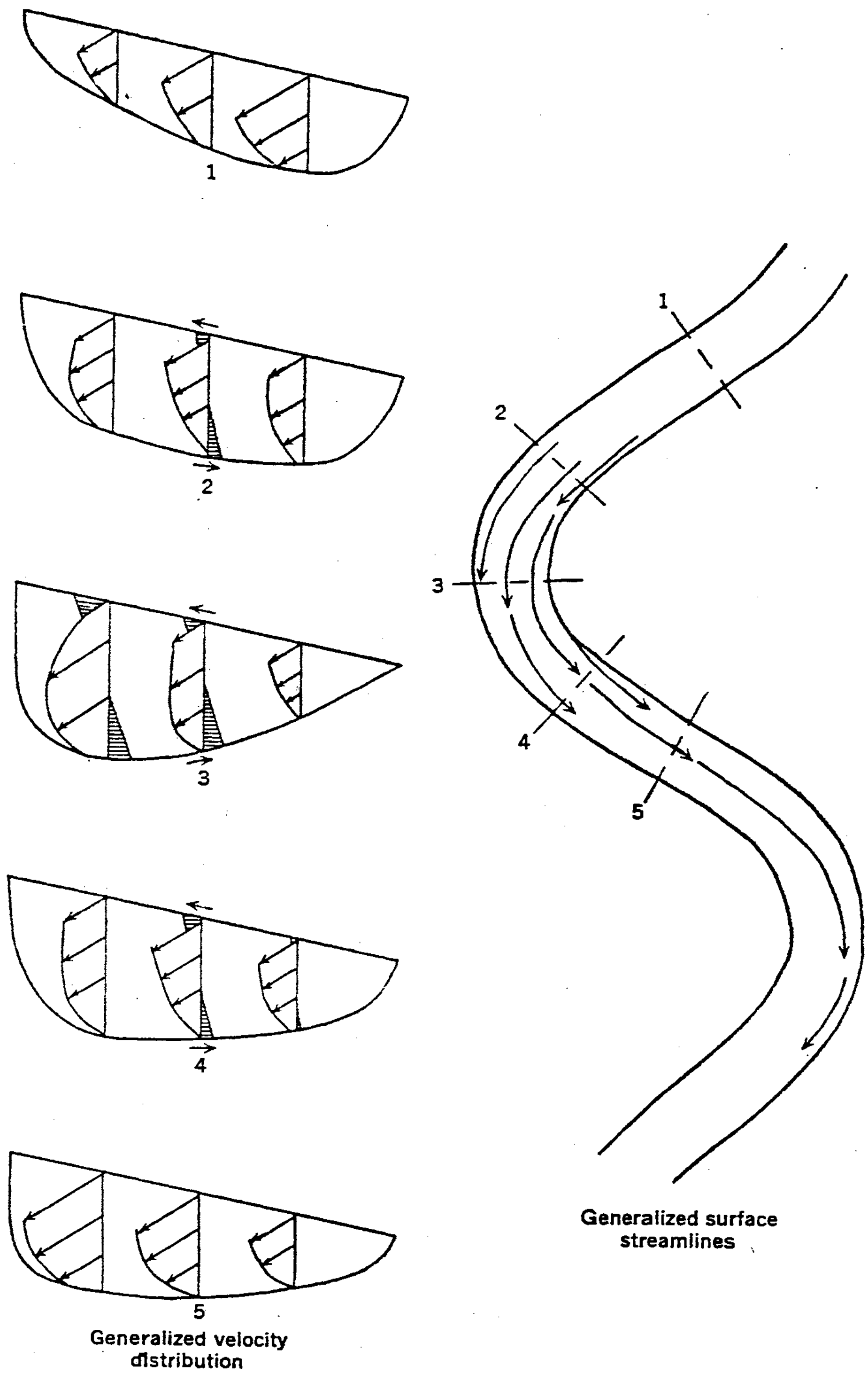
Figure 3. Definition for Asymmetry Index

water flows into a curve the water on the outside of the curve must speed up and the flow near the inside of the curve slows down. The difference in speed forms a helical flow within the channel (Figure 4). Helical flow contributes to the erosion of the outer bank and deposition at the inner bank (Figure 5). Although meanders have been studied for many years, (Bagnold, 1960, Langbein and Leopold, 1966, Lewin, 1976, and Parker and Andrews, 1985), the process is not completely understood.

Background of the Study Area

Between 1900 and 1936 three major floods and five lesser ones occurred in the Red River Basin of Oklahoma and Texas. These floods inundated ninety-five percent of Denison, Texas and forty-five percent of Alexandria, Louisiana (Ware, 1979). The U. S. Army Corps of Engineers (1936) determined that the floods affected approximately 6881 square kilometers. Construction of a dam and reservoir near Denison, Texas was initiated in 1938. In addition to regulating the flow of the Red River, the dam provides hydroelectric power, a water supply reservoir, and improved navigation (OWRB, 1984). Construction of the dam, spillway, and outlet works, started in August, 1939, were completed in February, 1944.

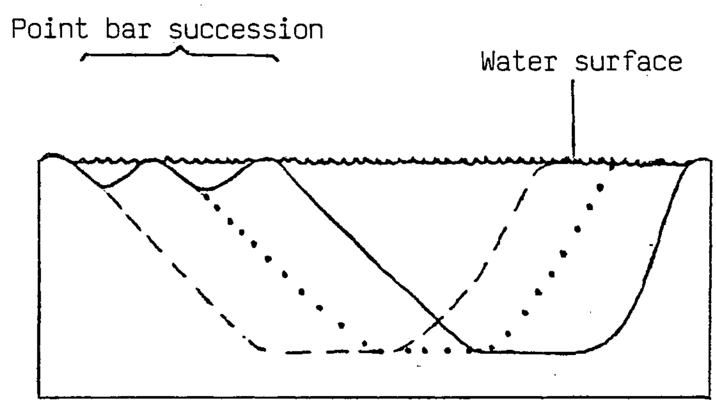
During the period between 1923 and the beginning of flow regulation by the Denison Dam in 1943, the average discharge of the Red River as recorded by a stream gage



• —ISOMETRIC VIEW OF GENERALIZED DIAGRAM OF FLOW DISTRIBUTION IN A MEANDER
Showing downstream (open parabolas with arrows) and lateral (closely lined areas) components of velocity as vectors, and surface stream lines. All sections viewed from a changing position to the left of and above the individual section.

From Leopold and Wolman (1960)

Figure 4. Helical Flow in a Meander



After Ritter (1981)

Channel boundary (period 1)
Channel boundary (period 2)
Present channel boundary

Figure 5. Lateral Migration of Meanders.

near the what is now the site of the Denison Dam was 161 cubic meters per second (m^3/s). From 1943 until 1981, the last year of data examined, the average discharge at the same location was 119 m^3/s (OWRB, 1984). The U. S. Army Corps of Engineers (1981) estimates that the Denison Dam traps about ninety-eight percent of the sediment that the Red River carries into Lake Texoma. The reduction in the discharge and sediment load of the Red River below the Denison Dam should initiate changes in the channel pattern of the river until a new equilibrium is reached.

Study Area

A 29 kilometer segment of the Red River, 192 to 221 kilometers downstream of the Denison Dam, was selected as the study area (Figure 6). The site is bounded by McCurtain County, Oklahoma on the north; Red River County, Texas on the south; the Choctaw,Oklahoma countyline on the west and the Oklahoma state highway 37 bridge on the east. The Oklahoma state highway 37 bridge, currently in use, was constructed in 1954 (OHC, 1955). Prior to bridge construction, the Albion ferry was used at the same location.

Rationale for selecting this site include: (1) the availability of aerial photographs that pre-date construction of the dam, (2) the absence of bedrock and presence of alluvium in the channel, (3) the absence of major tributaries entering the main channel, (4) the

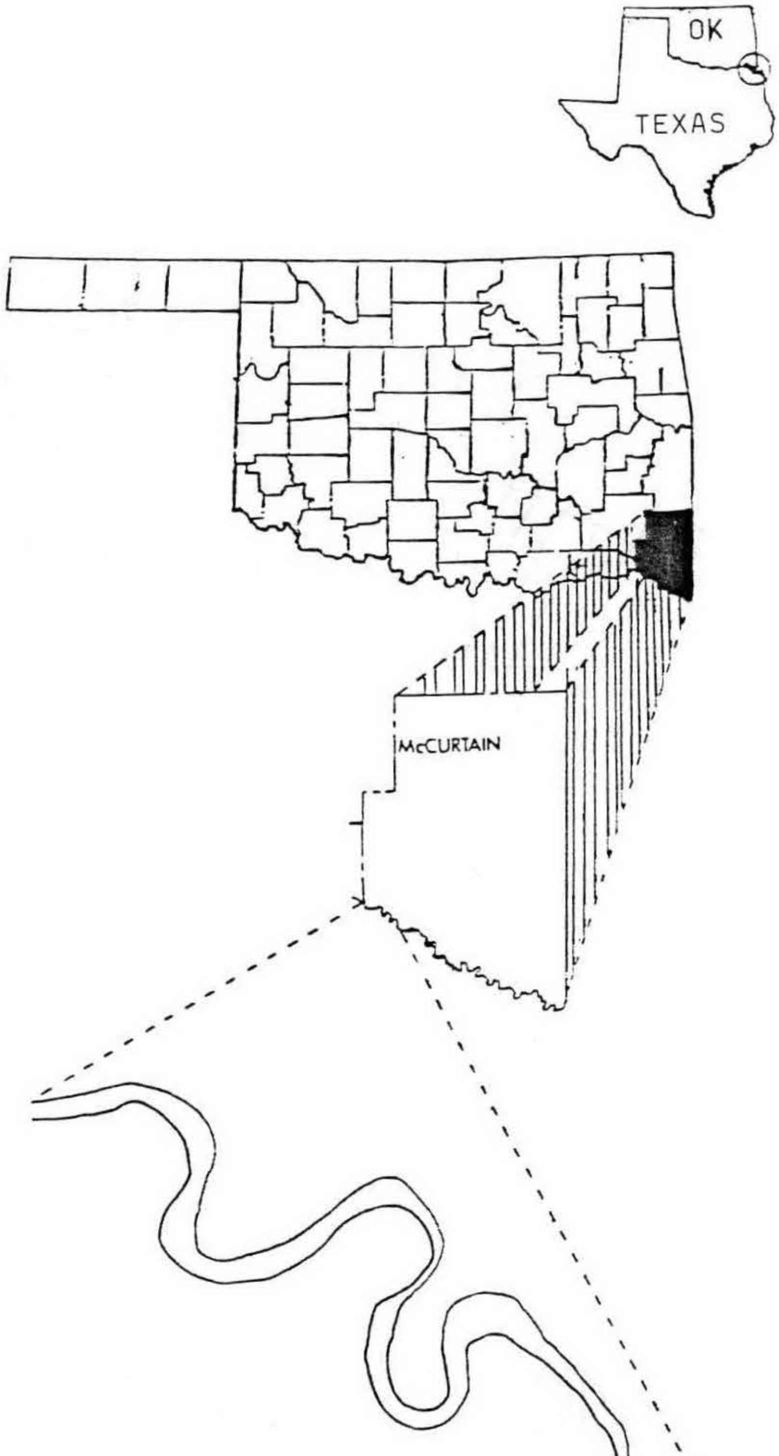


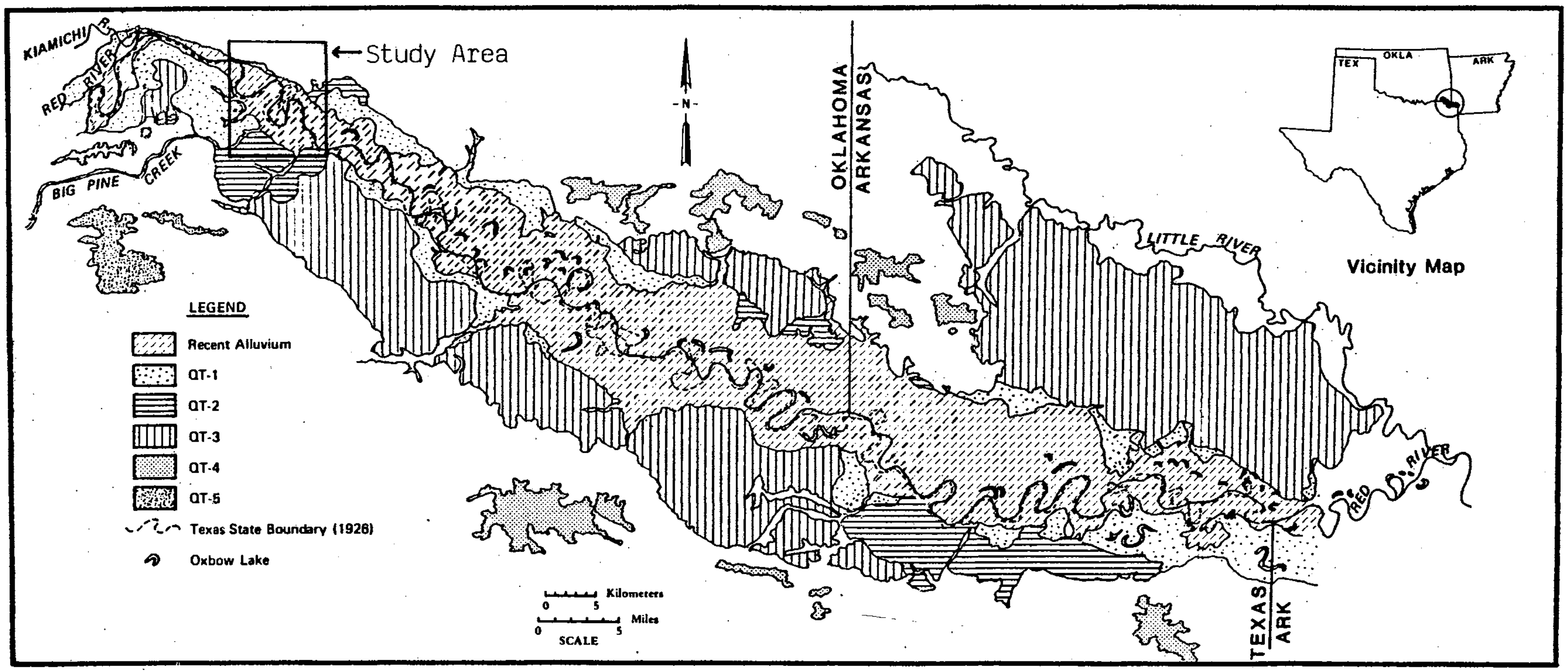
Figure 6. Study Area

meandering planform of the river, and (5) distinctive landmarks, the countyline and the bridge, used for locating the ends of the study reach.

McCurtain County is the only county downstream of the Denison Dam for which aerial photographs pre-date 1939. These pre-dam photos were used as a baseline for determining changes in the channel pattern over time. Aerial photos of the area are also available for 1963, 1969, 1978, and 1984.

The presence of alluvium and the absence of bedrock within the channel allows the river to change its plan form freely in response to changes in the variables that disrupt equilibrium. According to Davis (1959) the study area is underlain by Quaternary age deposits of stream-laid unconsolidated gravel, sand, and clay in intergrading and intertonguing beds up to 33.5 meters thick (Figure 7).

No major tributaries and only five minor perennial streams enter the Red River within the study reach. Examination of aerial photographs and 1:24,000 scale maps reveals the tributaries probably contribute less than two percent of the total flow of the river within the study reach. The discharge and sediment load should not, therefore, be significantly altered by the minor tributaries that enter the river in the study area.



Pleistocene Geology of the Red River Basin Between the Kiamichi and Little River Confluences

After Banks (1983)

Figure 7. Quarternary Geology of Study Area

CHAPTER II

LITERATURE REVIEW

The purpose of this chapter is to provide a survey of the publications currently available on the subject of alluvial rivers. The literature will be grouped into five categories: dynamic equilibrium and thresholds, methods of observation, data collection, analytical techniques, and results and conclusions.

A proliferation in the number of papers published on potamology, the study of rivers, has occurred in recent years. Several authors have written reviews of the literature available on the subject. Gregory (1983, 1984, 1985b) has critiqued most of the papers printed in the last several years dealing with the processes of fluvial geomorphology. Hooke (1984) surveyed the various techniques and results of analyses used to examine river meanders. Brookes (1985) reviewed the morphologic, biologic, and engineering effects of human impacts by channelization on rivers. Studies of hydraulics and hydraulic geometry over the last thirty years are reviewed by Ferguson (1986). In addition to journal articles, a book by Petts (1984) provides an in-depth study of the physical, biological, and hydrologic effects of dams.

The construction of dams has been shown to have numerous impacts on rivers because of reductions in average flow rates. Impacts include alteration of the channel shape, width, and depth (Kennon, 1966); a decrease in the amount of bank erosion downstream of the dam (Schoof, 1980); an increase in bank erosion and the number of downstream boulder rapids (Graf, 1980); and degradation of the river channel for as much as 650 km downstream (Han and Tong, 1982). Gilvear and Petts (1985) examined water released from Llyn Celyn Dam, U.K. and found that at the dam the suspended particles were organic particles with a median size of 20 milli-microns; samples from three km downstream of the dam illustrated that 90% of the suspended particles were mineral sediments finer than ten milli-microns in size. The concept that changes in one or more variables in the river system may cause repercussions throughout the system has been called dynamic equilibrium. The literature suggests every reason to believe this occurs on the Red River.

Dynamic Equilibrium and Thresholds

In a landmark study Leopold and Wolman (1960) found that channel equilibrium is constantly approached, although rarely attained, by a process of continual adjustment. Heede (1981) described equilibrium as a condition permitting rapid adjustment to a new situation. The adjustments are made in the slope, roughness, width, depth, and plan form of the river (Petts, 1980) to the imposed water discharge, sediment yield and size, and the valley gradient (Richards and Greenhalgh, 1984). The impact of humans with dams, mines, and diversions as well as climatic, hydrologic, and tectonic events may induce adjustments in equilibrium (Chang, 1986).

According to Schumm and Lichty (1963) dynamic equilibrium must not be confused with steady state, which can exist on a landscape for only very short periods of time and for only small segments of a river. Schumm (1981) has proposed the use of the term dynamic metastable equilibrium rather than dynamic equilibrium.

Many workers in the field believe that the changes in equilibrium are not continuous, but rather, thresholds are met and exceeded before change occurs in the system. Only small amounts of energy may be needed to initiate changes which may affect the entire system (Coates and Vitek, 1980). Schumm (1979) defined two types of thresholds, intrinsic and extrinsic, depending on whether internal or external factors cause the threshold level to be crossed. River pattern changes can be caused by both types. Both threshold types may affect the Red River. Petts (1979) has shown that a threshold will not be surpassed at the same time throughout a river system; change instead occurs along discrete segments of the channel. Howard (1982) found that the initial stages of adjustment to changes in equilibrium tend to move downstream while later stages of adjustment occur simultaneously throughout a reach.

A fundamental assumption of the threshold/channel concept is that the force required to initiate movement of the bed material is just equaled at the maximum sustained discharge (Andrews, 1984). If the flow within the channel is incompetent, then no bed material is moved and changes in channel morphology will not occur (Petts, 1980). Studies by Carson (1984), showing that the meandering/braided threshold in gravel bed rivers is higher than in sand bed rivers, indicate that hydraulic thresholds are dependent on the sediments in the channel perimeter.

The cross-sectional shape and size of the channel may be influenced by the bankfull discharge (Williams, 1978). Bankfull discharge has been shown to be the threshold level above which erosion of the basal bank material occurs and below which the banks remain stable (Andrews, 1982). Klein (1981) found that bankfull flow is the dominant or threshold flow in drainage basins of more than 2500 km^2 in area. Various methods have been devised to examine the changes in rivers through time.

Methods of Observation

Petts (1977) recognized four techniques which have been used to investigate channel adjustments: (1) comparison of field survey data with values of channel capacity predicted from a regional relationship, (2) comparison of river surveys from various points in time, (3) analysis of sedimentologic data, and (4) dating of deposits. Researchers have used these four methods of investigation for many types of river studies.

Comparison of field data with predicted channel capacity values has been used by Newson (1980) to examine average annual sediment yields into the Upper Rheidol River, U.K. Petts (1984) used Newson's work to estimate what the sediment yield would have been on the River Rheidol if a dam had not been constructed.

Numerous types of river surveys are in use by researchers including maps, aerial photographs, erosion pins, and field surveys of the channel cross section. Laczay (1977) overlaid maps of the Hernad River, Hungary from 1937, 1957, and 1972 to assess changes in the channel planform. Neller (1980) examined channel changes on the Macquarie Rivulet, New South Wales using maps dating from 1833 to 1974. Ovenden and Gregory (1980) used 1:10560 scale maps dating from 1847 through the early 1900s and 1:10000 scale maps from the 1970s to quantify changes in the stream network system of Dove Catchment, Southampton, U.K. In a rebuttal to Ovenden and Gregory (1980), Burt and Gardiner (1982) presented evidence from aerial photographs which questioned the accuracy with which the smallest tributaries were portrayed on the older 1:10560 scale maps.

In order to avoid problems with older maps of debatable cartographic accuracy, many investigators have constructed maps of their study area from aerial photographs (Hickin and Nanson, 1975; Nadler and Schumm, 1981; Monsalve and Silva, 1983; and Bradley and Smith, 1984). Martinson (1984) recommends using a stereoplotter with the photographs to remove parallax errors and changes in scale between photographs. Howard and Dolan (1977) found that differences in the river stage between sets of photographs can cause apparent erosion or deposition. Variations in the stage can be overcome by mapping the approximate bankfull discharge (Nanson and Hickin, 1986). Guccione (1983) mapped the bankful discharge as the channel width plus any unvegetated sand bars. Graf (1981, 1984) used historic evidence, maps and aerial photographs, to produce maps showing the probability that a given area will be inundated.

Thorne and Lewin (1979) measured the rate of bank erosion along the Severn River, U.K. by inserting pins into the bank and measuring the amount of the pin which is exposed at some point in time. Murgatroyd and Ternan (1983) used erosion pins to inspect the impact of afforestation on bank erosion and channel form in southwest Dartmoor, U.K.

Field surveys of channel cross sections are commonly used by researchers as a data source. Gregory and Park (1974) surveyed 14 sections downstream and 15 sections upstream of the Clatworthy reservoir in England to examine the down river variation in the channel cross section.

Williams and Wolman (1984) used cross section surveys produced by the U. S. Army Corps of Engineers from 21 rivers to examine the downstream effects of dams.

Sedimentologic data has been used in numerous ways to assess how rivers function. Grain size distributions and sedimentary structures along a 60 mile long (100 km) segment of the Red River of Oklahoma were used by Schwartz (1978) to discriminate channel bars, point bars, flood flats, and flood plains. Wilkin and Hebel (1982) studied sediment movement patterns within a small watershed in the midwestern U.S. and found that most of the eroded sediment either originates on, or is delivered to, the active floodplain and then the stream. An examination of riverbank structure led Thorne and Tovey (1981) to conclude that erosion of alluvial channel banks involves the undercutting of a cohesionless sand/gravel basal layer followed by the cantilever failure of the overlying cohesive silt/clay layer. Pizzuto (1983) corroborated Thorne and Toveys' theory and found that bank erosion, in shallow alluvial channels, is associated with lateral movement of the channel rather than degradation. Parker and Andrews (1985) were able to develop a numerical model which depicts the observed shifting of the locus of coarse sediment from the inside bank to the outside bank near the apex of a bend.

Several techniques have been used to date deposits along rivers. Hereford (1984) used the stratigraphic relationship between deposits exposed in the cut banks and ring samples from cottonwood trees and salt cedars to examine the effects of changes in the climate on the Little Colorado River, Arizona. Alford and Holmes (1985) examined meander scars along the Sabine River, Louisiana and determined that the present day discharge is considerably less than when observed channels were active on their flood plains. Ethridge and Schumm (1978) describe several methods which can be used to reconstruct the morphologic and flow characteristics of ancient rivers.

After the method of study has been determined, data collection can begin, provided the variables required for the study are known and can be measured.

Data Collection

In a review of research Ferguson (1986) shows that hydraulic geometry is composed of two branches, (1) at a point and (2) downstream from a point. Hydraulic geometry at a point examines how variations in discharge within a channel of known size and shape effect water width, depth, and velocity while hydraulic geometry downstream from a point examines the effects of an imposed discharge on the channel size and shape.

Investigations of changes in the channel pattern, or planview, of a river often involve quantification of variables including water discharge, Q, water velocity, v, channel width, w, water depth, d, slope, s, sediment load,

Q_s, bed roughness, f, grain size of the suspended material, D_s, and grain size of the bed material, D_b. Leopold and Wolman (1960) attempted to explain meandering on the basis of the length of the curved channel, the width of the channel, and the radius of curvature. The meander length, L, was defined as the length of one complete sine function and given as having a value of seven to ten times the channel width.

The ratio of curvature of radius to channel width, r_m/w, was shown to be in the range of two to three. Bagnold (1960) examined the flow of water within curved pipes and was able to substantiate Leopold and Wolmans' claim that r_m/w has a range of 2.0 to 3.0. In an analysis of the maximum curvature for which a river does the least work in turning, Chang (1984) found that r_m/w ranges from 2.2 to 4.0 with an average value of 3.0.

Schumm (1963) examined alluvial rivers on the Great Plains and concluded that the sinuosity of a stream is a function of the percentage of silt and clay in the perimeter of the channel and of the width to depth ratio of the channel. Alexander and Nunnaly (1972) indicate that meandering streams have a higher percentage of silt and clay at the channel perimeter than non-meandering streams. The meander wavelength, L, was shown to be dependent on the stream discharge, Q, and the type of sediment of which the channel is composed (Schumm, 1967). Chang (1984/1985) found that streams in alluvial channels which undergo a large reduction in discharge are usually characterized by a meandering pattern. The Red River below the Denison Dam is characterized by these conditions. Examination of the Lower Jordan River, Israel, by Klein (1985) shows that decreasing the mean annual discharge reduces the sinuosity, except where prohibited by local factors like bedrock in the channel.

Analytical Techniques

In a review of techniques for analyzing meanders, Hooke (1984) divided the methods into five categories; bend parameters, curve fitting, spectral analysis, models of change, and graphical analysis. Because the assumption that meanders form sine-generated curves is required to use the bend parameters method, this method was not employed in the current study. The fitting of curves of known radius to the meander bends was not used because of its subjectivity. Spectral analysis uses a heirarchical classification of the digitized centerline of the river to eliminate some of the subjecte bias associated with wavelength measurements (Sinnock and Rao, 1984). A stream reach with heterogenous meander characteristics is required for spectral analysis to be used. The reach selected for the current study does not meet this prerequisite. Modeling of channel change was not employed because of the large number of variables involved requiring extensive in field measurements and the large size of the study area.

Hooke (1984) recommends a graphical analysis of changes in the channel pattern was selected because it allows straightforward inspection of alterations in the planform.

The Bend Differencing Technique of O'neill and Abrahams (1986) is a graphic method for examining bends in a meandering channel. The technique measures changes in direction of the channel at a fixed sampling interval. Two criteria are required: the half-meander tolerance value is used to define bends and half-meanders while the bend tolerance value is used to determine the lengths of the bends. Bend differencing was not used in the current study because values for the bend tolerance and half-meander tolerance are not well defined by the authors at this time.

In this study, changes in the channel will be located graphically and then quantified. Several methods have been used to measure the migration rates of river meanders. According to Ikeda et al. (1981), the best available estimates of erosion are found at a meander loop. Although maximum erosion generally occurs just downstream of the meander apex, Hooke (1980) established that the rates may vary considerably even between sites close to one another on the same alluvial river. Hickin (1974) constructed the orthogonals, or longest erosional pathline across the scroll bars of the point bar along which the maximum amount of erosion takes place. Construction of the orthogonals was not possible for the current study because the scroll bar sequences visible on the available aerial photography were poorly developed. Brice (1983) calculated average rates of erosion by measuring the shortest distance between the sequential banklines of overlaid map pairs from the centerline of the channel and dividing by the number of years between the maps. Measurements were made at two channel width intervals to produce a range of erosion rate values rather than the absolute values formulated with Hickin's orthogonals. Brice's method was employed in the current study to produce estimates of the rates of erosion for each meander bend.

Conclusions

The theory that meandering rivers in equilibrium display sine-generated curves has been dominant for more than thirty years. In recent years the theory has been questioned. Asymmetric meanders on the White River, Indiana were recognized but unquantified by Brice (1973). Thorne and Lewin (1979) give several examples of the formation of loop asymmetry and possible explanations for its occurrence. Parker et al (1982) were able to detect the directions of channel migration and water flow from the asymmetry evident on aerial photographs of bends that were actively migrating downstream. After examining aerial photographs and topographic maps of many meandering rivers, Carson and Lapointe (1983) reached three conclusions: (1) most meander loops show one of two types of well defined and consistent asymmetry; (2) the two forms of asymmetry could be defined as (a) downchannel delay in the inflection point, producing traverses which are convex in the downvalley direction, (b) upvalley skew in the axis of goosenecks (see figure 3); and (3) Asymmetry of meander geometry may be stronger and displayed more prominently in incised meanders and confined floodplains than in broad alluvial floodplains. Laboratory experiments by Davies and Tinkler (1984) utilizing surface tension meanders to examine stream planforms showed that streams tend to meander in regular but asymmetrical planform rather than as sine-generated curves. Howard and Knutson (1984) found while natural meander patterns are irregular, they have a strongly periodic component.

Investigation of the Kansas River, Kansas allowed Burke (1983) to delineate human activities which affect bank erosion including till farming, changes in riparian vegetation, bankstabilization projects, dredging, upland soil conservation practices, and valley land irrigation. Miller (1984) found that clearcutting in the forests of the Ouachita Mountains, Oklahoma produced high sediment losses the first year but reduced rates thereafter. The role of vegetation as an influence on the channel form of larger rivers is less important than on small rivers (Hicken, 1984).

Post-glacial isostatic rebound was proposed as the cause for a regional trend in the meander migration of the Beatton River, Canada by Nanson (1980). While the effects of the Coriolis force were mentioned as a possible cause, no definitive conclusions could be drawn from the data or from the paucity of literature on the subject.

CHAPTER III

Methodology

Overview

The examination of changes in the planform of the Red River was conducted using maps of the study area from five different time periods dating from 1938 to 1984. The maps were constructed from aerial photographs of McCurtain County, Oklahoma, overlaid, and measurements made of the rate of channel movement and the lengths of discrete curved segments.

An average migration rate and asymmetry index value for each meander bend was calculated. The Statistical Program for Social Sciences (SPSS) was employed to perform an analysis of variance (ANOVA) to determine whether variations in the meander migration rate between time periods and between north and south banks were statistically significant.

Map Construction

Aerial photographs of the study area dating from 1938 to 1984 were located and used as the basis for map construction (Table 1). Howard and Dolan (1977) found that

TABLE I

SUMMARY OF AERIAL PHOTOGRAPH SOURCE DATA[1]

Date	Approximate Scale	Source
9/23/1938	1:20,000	ODLA[2]
6/9/1963	1:20;000	OGS[3]
11/1/1969	1:20,000	OSU[4]
12/21/1978	1:12,000	ASCS[5]
9/5/1984	1:7,920	ASCS[5]

[1]All photos are from U.S. Department of Agriculture Agricultural Stabilization and Conservation Service coverage of McCurtain County, Oklahoma.

[2]Oklahoma Department of Libraries, Archives, Oklahoma City, Oklahoma.

[3]Oklahoma Geologic Survey, Norman, Oklahoma.

[4]Oklahoma State University Library, Stillwater, Oklahoma.

[5]U.S. Department of Agriculture, Agricultural Stabilization and Conservation Service, Idabel, Oklahoma.

Mean discharge ranged from approximately 28.1 to 133.7 (cms) cubic meters per second (USGS, 1983).

changes in the discharge as determined from aerial photographs can cause apparent erosion and or deposition. To overcome this problem Martinson (1984) approximated the bankfull discharge by mapping the bankline where the vegetation begins to dominate the ground surface. Bankfull discharge was approximated for the current study in the same manner.

Differences in the formats and scales of the available aerial photographs produced several problems.. The 1938, 1963, and 1969 photographs were available as overlapping nine inch stereo pairs while the 1978 and 1984 photographs were printed as thirty inch plates which joined along the edges. Because all of the photographs did not overlap, stereoscopic viewing was not attempted. In order to reduce image displacement errors only the central portion of each of the 1938, 1963, and 1969 photographs was mapped. The 1978 and 1984 channels were mapped using the entire photo.

The base maps, produced on mylar for scale stability and ease of copying, display river boundaries drafted with a rapidiograph #000 pen. Registration of the maps was accomplished by locating landmarks common to all of the time periods. Section-line road intersections were used on the Oklahoma side of the river, while on the Texas side of the river intersections of the county roads were used. Although the scales of the aerial photographs are identified, the scales are not constant. Small changes in the altitude of the airplane and the landscape can introduce considerable scale variation across a series of photographs. The section-lines on the Oklahoma side of the river aided in maintaining the scale across the length of the maps.

For the purpose of co-registration, it was necessary for all of the maps to be of the same scale. Because the 1963 map had the smallest scale, it was used as a base map. In order to determine the amount of reduction necessary for each map, the distance between two landmarks, "A" and "B", common to all of the maps was measured and compared (Figure 8). Table II shows the percentage of the size of the original map at which each map was reproduced. Because of the large size of the maps, xerographic reduction was utilized. The reduced scale, second generation, maps were printed on vellum stock. The second generation maps were overlaid and registered to the base (1963) map. A Kail projector was used make any minor corrections needed in response to changes in scale across the maps. The scale of the registered maps is approximately 1:20,833.

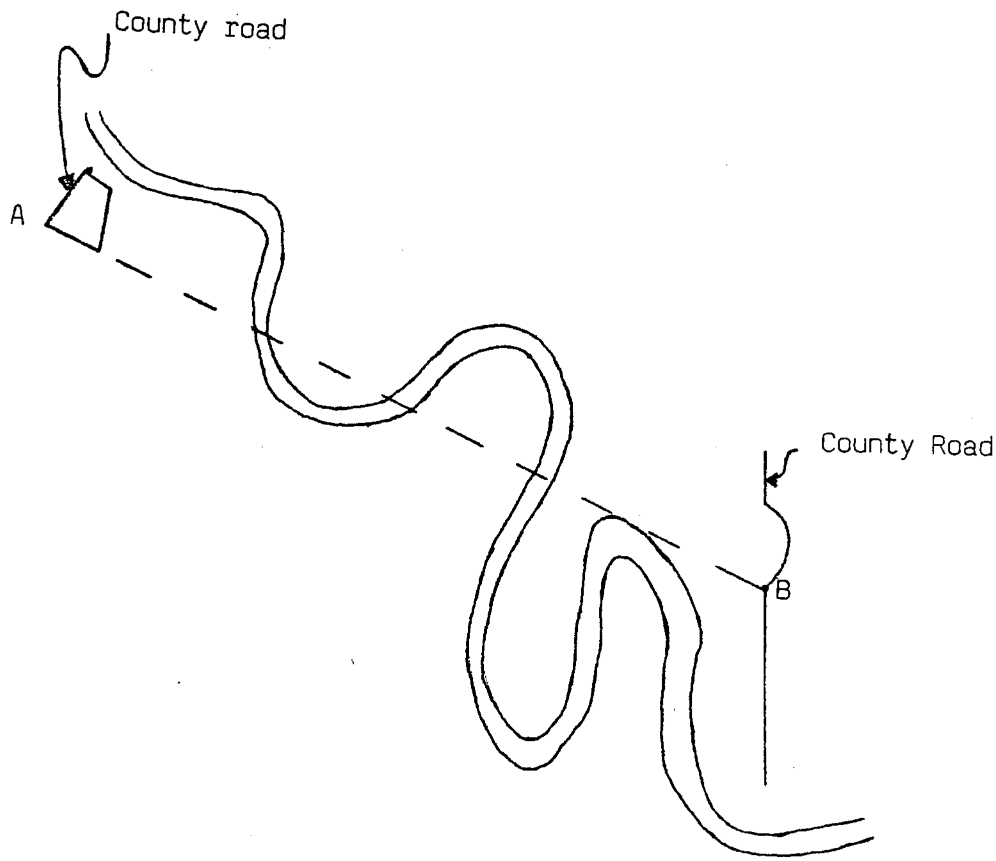


Figure 8. Location of Line A-B

TABLE II

REDUCTION PERCENTAGES FOR ORIGINAL MAPS

YEAR	LENGTH OF A-B[1] (IN CM)	A-B 1963/ LENGTH A-B	PERCENTAGE OF ORIGINAL
1963	64.7	64.7/64.7	100
1938	66.6	64.7/66.6	97.1
1969	68.3	64.7/68.3	94.7
1978	172.0	64.7/172	37.6
1984	113.2	64.7/113.2	57.1

[1] See Figure 8 for location of line A-B.

Data Collection

Random selection of points for data collection introduces a great deal of subjectivity into meander investigations. In order to remove some of the subjectivity from the data collection, Hooke (1984) recommends digitizing the centerline of the channel at about one channel width intervals. Digitizing aids in locating the points of inflection, where changes in the direction of curvature occur within a bend.

Ten measurements of the channel width were made at approximately three kilometer intervals on each map and average width values calculated. The points to be digitized were plotted on each of the maps at one one channel width intervals with the aid of a pen and a ruler.

The digitizing facilities of the Center for Applications of Remote Sensing (CARS) were engaged to produce a data set containing the X and Y coordinates of the channel centerline points for each of the five maps.

A computer program which calculated the angle between each pair of data points and then calculated the difference in the angles was used to locate the inflection points. The inflection points, which were used to divide the meander bends into discrete segments, were found where the difference in angles is zero (Hooke, 1977). A one channel width digitizing interval was found to generate numerous points of inflection for each of the meander bends, the computer program was rerun using every other data point. The use of a digitizing interval of two channel widths produced satisfactory results.

Ten combinations for overlaying the maps two at a time were used and are shown in Table III. Following the methodology of Brice (1983), measurements of the amount and direction of bank movement were made at two channel width intervals along the centerline of the channel for each of the overlaid map pairs. The shortest distance between the sequential banklines of the overlays was measured to the nearest 60th of an inch using an engineering scale. Measurements were converted from inches of map distance to meters of ground distance and recorded. The direction of movement was recorded as either "-", channelward, or "+", bankward.

Table III

MAP COMBINATIONS USED FOR DATA COLLECTION

BASE YEAR	YEARS OVERLAID
1938	1963, 1969, 1978, 1984
1963	1969, 1978, 1984
1969	1978, 1984
1978	1984

Measurements of the variables required to calculate Carson and Lapointes'(1983) asymmetry index include the lengths of the bend segments that are concave in the downvalley direction, d, and the lengths of segments concave downvalley, u, (see Figure 3).

Analysis

The data sets for channel migration were analyzed with the Statistical Program for the Social Sciences (SPSS) which calculated the maximum, minimum, and average amounts of channel movement for each bend segment during each of the ten time periods. Average migration rates were calculated by dividing the average movement value by the number of years in the time period observed. An Analysis of Variance (ANOVA) was applied to the ten migration rates to determine if the overall rate has been constant or varies significantly through time.

Asymmetry indices were calculated for each bend traverse during each of the time periods to determine whether the channels were asymmetrical. An ANOVA was utilized to determine whether the differences in asymmetry values changed significantly through time.

The meander wavelength was measured in average channel widths and recorded for each of the five individual maps. The wavelength values were examined using an ANOVA to determine whether changes were significant.

CHAPTER IV

DATA ANALYSIS

Overview

The purpose of this chapter is to examine the data collected with respect to answering the four questions raised in the "Purpose of the Study" section of this investigation. Questions concerning meander geometry will be examined in the first section of the chapter while the second section will deal with the migration of the channel. The channel planform during 1938, 1963, 1969, 1978, and 1984 is shown in Figures 9 through 13 respectively.

Meander Geometry

Sine-generated curves have been used to describe meander patterns for more than 30 years. By measuring the wavelength, symmetrical meander wave-forms can be quantified. Because the symmetric wave-form model does not always work well, some researchers have characterized meanders as asymmetric in planform. Carson and Lapointe (1983) developed the z-value to quantify planform asymmetry.

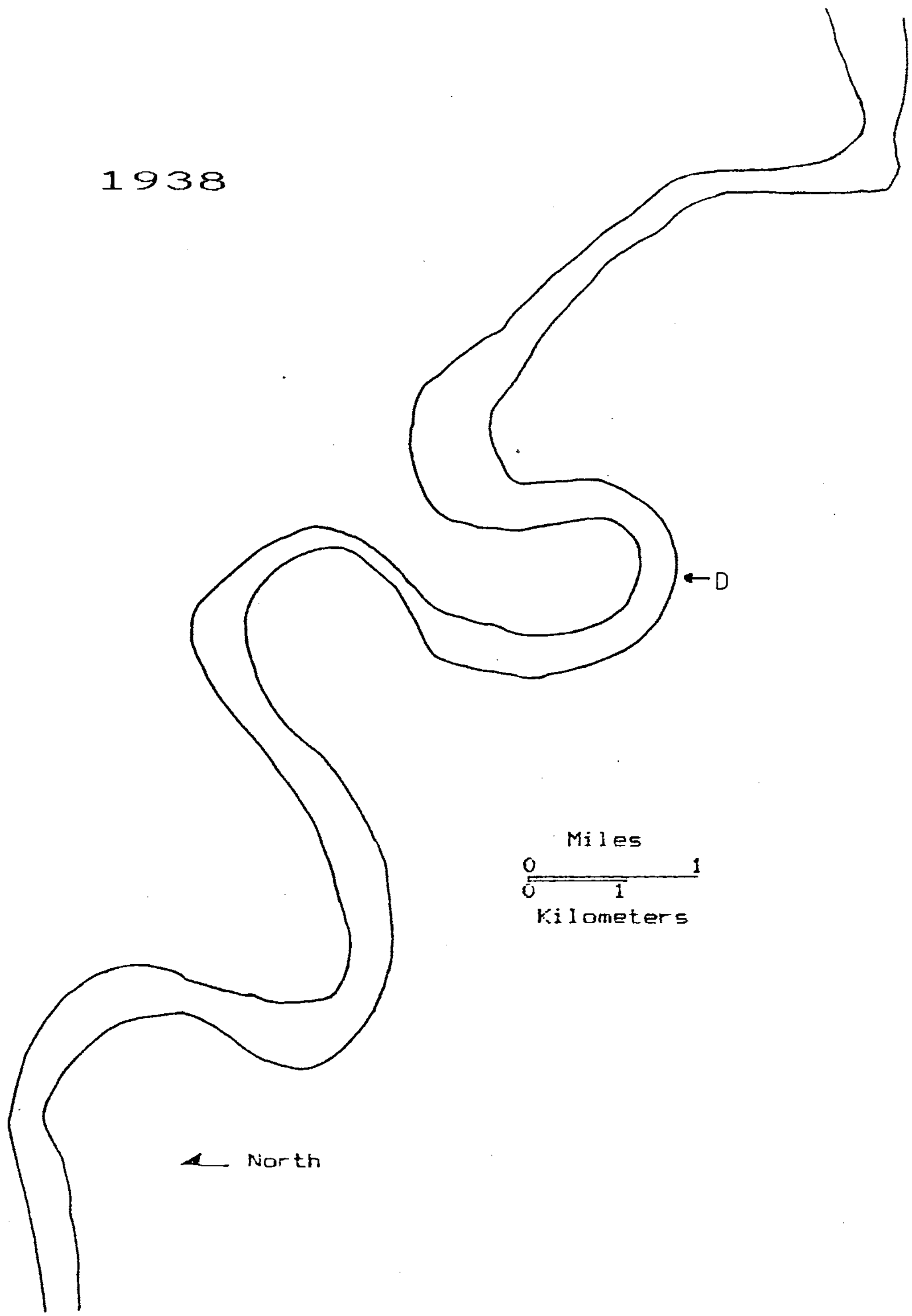


Figure 9. 1938 Channel

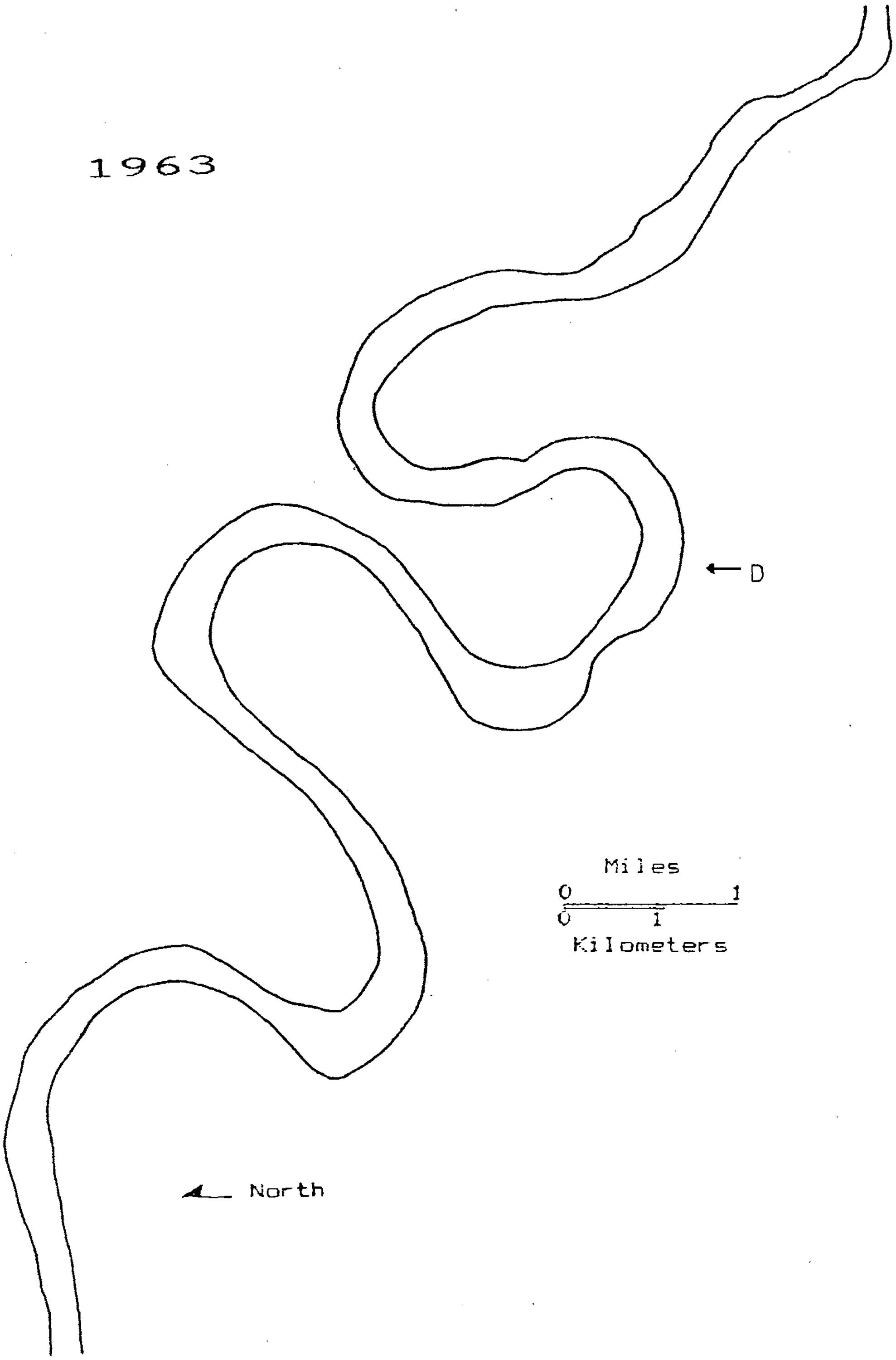


Figure 10 . 1963 Channel

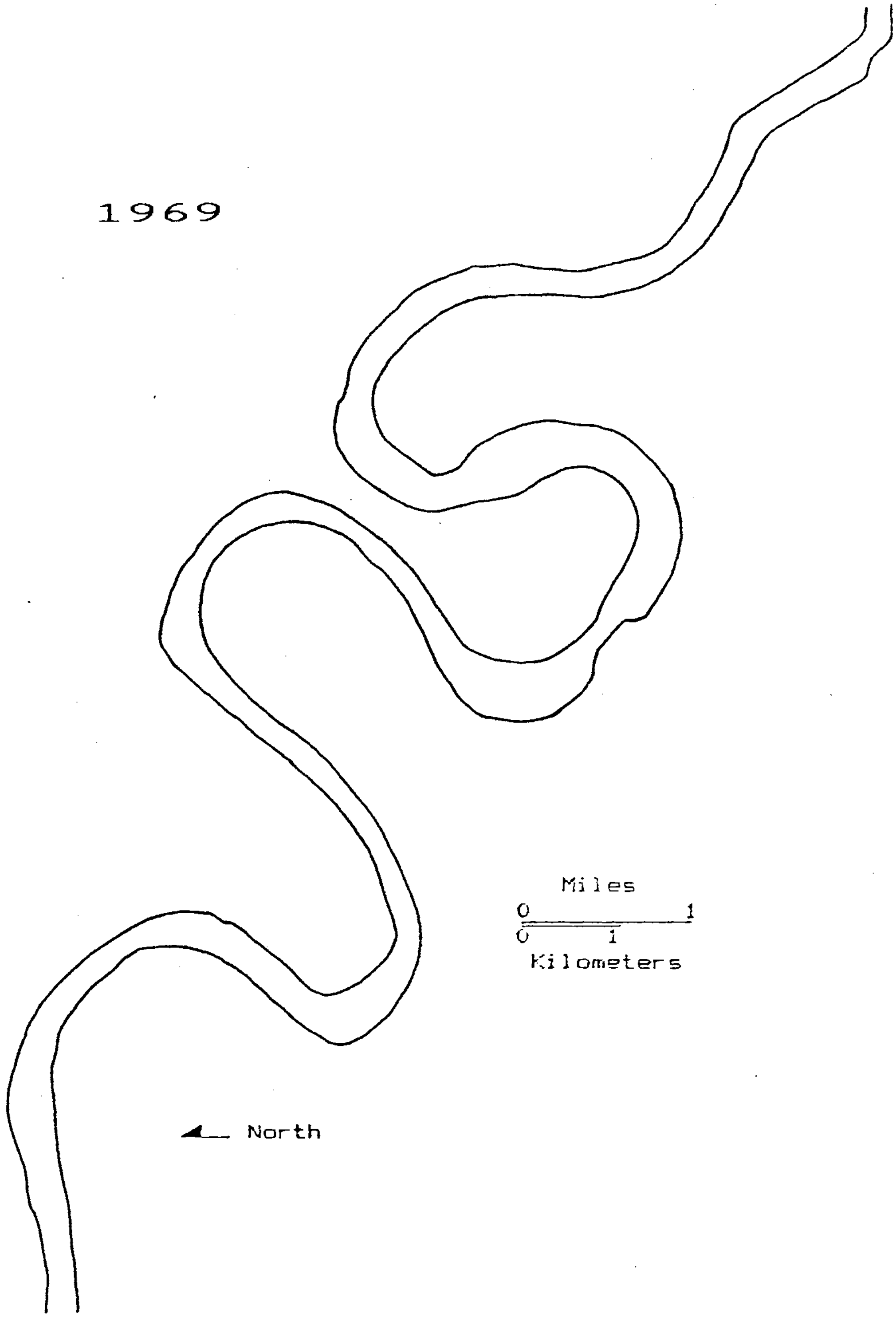


Figure 11. 1969 Channel

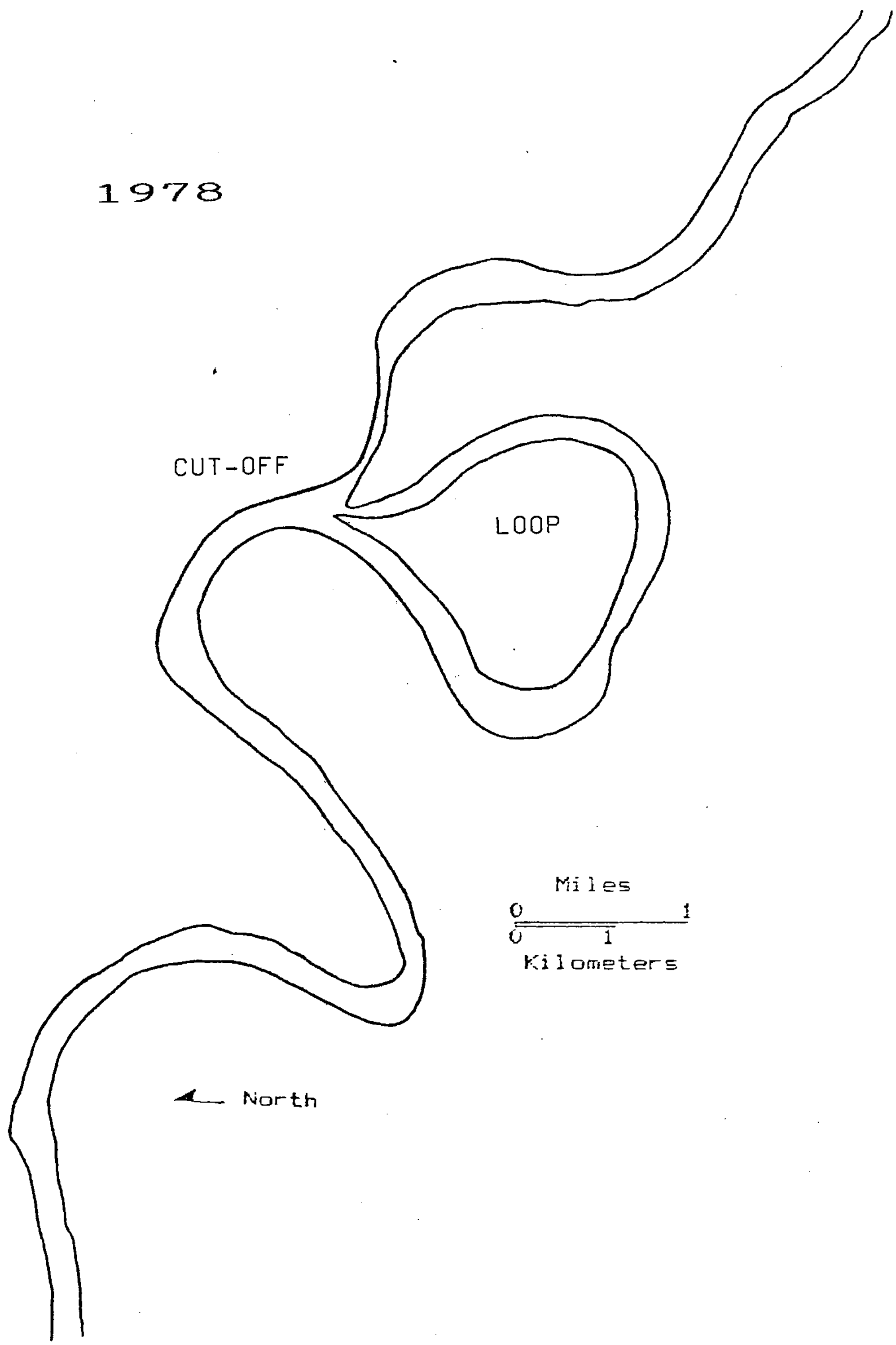


Figure 12. 1978 Channel

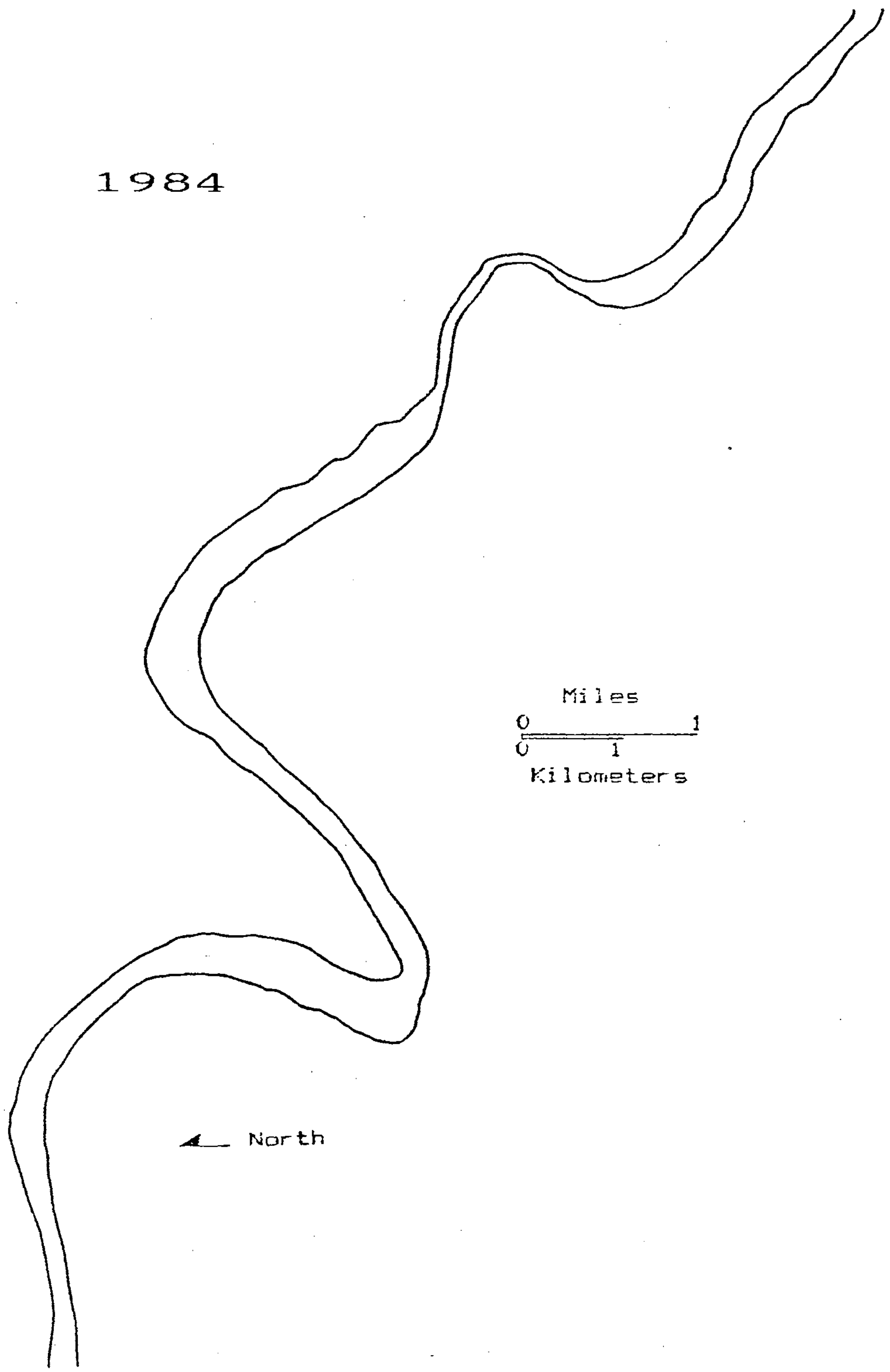


Figure 13. 1984 Channel

Table IV displays all the meander wavelengths and z-values by year. 1978 is split into two parts, 1978a and 1978b, in the table because of the formation of a meander cut-off. Part of the discharge within the channel was able to flow through the meander loop and part through the cut-off (Figure 12). Morphometry of the meander loop is recorded as 1978a while 1978b shows values for the cut-off channel.

Table V shows the results of a one-way analysis of variance, ANOVA, test performed on the wavelengths. The mean wavelength values are recorded in the dimensionless units of number of average channel widths. The null hypothesis tested states no significant changes in the wavelengths have occurred while the alternative hypothesis states significant changes in the wavelength have occurred. With the exception of 1978b, the standard deviations are small, indicating that the means are a good representation of the wavelengths in the sample. The 1978b route has a high standard deviation because only two wavelengths could be measured, one of which is small while the second is very large. The F-ratio value, 2.23, is considered to be significant at the 0.11 level calculated by the ANOVA program. The calculated F-value is much smaller than the value of 2.96 expected at the 0.05 significance level, therefore no significant differences between the mean wavelengths are observed.

TABLE IV

Wavelength, (L)[1], and Z-Score Values by Year

Year	L	Z
1938	15	50
	15	59
	14	36
	20	39
		70
1963	22	60
	13	80
	13	56
	14	11
		41
1969	16	63
	14	72
	13	24
	13	50
		27
1978a	16	56
	13	80
	15	43
	13	88
1978b	16	56
	25	31
1984	18	63
	24	46
		9

[1] Wavelengths are measured in average channel widths

TABLE V

ANALYSIS OF VARIANCE ON WAVELENGTHS

ANALYSIS OF VARIANCE

SOURCE	D.F.	SUM OF SQUARES	MEAN SQUARES	F RATIO	F PROB.
BETWEEN GROUPS	5	119.5500	23.9100	2.2279	.1092
WITHIN GROUPS	14	150.2500	10.7321		
TOTAL	19	269.8000			

GROUP	COUNT	MEAN	STANDARD DEVIATION	STANDARD ERROR	MINIMUM	MAXIMUM	95 PCT CONF INT FOR MEAN		
1938	4	16.0000	2.7080	1.3540	14.0000	20.0000	11.6910	TO	20.3090
1963	4	15.5000	4.3589	2.1794	13.0000	22.0000	8.5641	TO	22.4359
1969	4	14.0000	1.4142	.7071	13.0000	16.0000	11.7497	TO	16.2503
1978A	4	14.2500	1.5000	.7500	13.0000	16.0000	11.8632	TO	16.6368
1978B	2	20.5000	6.3640	4.5000	16.0000	25.0000	-36.6779	TO	77.6779
1984	2	21.0000	4.2426	3.0000	18.0000	24.0000	-17.1186	TO	59.1186
TOTAL	20	16.1000	3.7683	.8426	13.0000	25.0000	14.3364	TO	17.8636
FIXED EFFECTS MODEL			3.2760	.7325			14.5289	TO	17.6711

Because the wavelengths can be measured, it might be assumed that the channel is symmetrical. The wave-form model, however, does not fit well to the channel segment under study. The river as it appeared in 1938 is shown in Figure 9. By 1963, Figure 10, loop D had expanded upstream forming what Brice (1974) labeled as compound loops. The sine-curve model can not account for compound loop formation, therefore the asymmetric channel model may provide a better fit.

The z-values shown in Table IV are used to examine the possible asymmetry of the channel. According to Carson and Lapointe (1983) an asymmetry index value of 45 to 55 indicates a symmetrical traverse while values less than 45 or greater than 55 indicate asymmetry of the channel planform. A one-way analysis of variance was used to test the null hypothesis which states: no significant differences exist between z-scores. The results of the ANOVA performed on the z-values are shown in Table VI. Because the value for the within groups mean squares, 466.37, is larger than the between groups mean squares, 317.42, the F-test result is declared nonsignificant and the null hypothesis can not be rejected (Steele and Torre, 1980). Therefore, the mean z-values are not significantly different and the channel appears to be symmetric in planform.

The mean z-values for 1938, 1963, and 1969 fall within the range for symmetrical traverses but this is misleading.

TABLE VI

ANALYSIS OF VARIANCE ON ASYMMETRY INDEX

ANALYSIS OF VARIANCE

SOURCE	D.F.	SUM OF SQUARES	MEAN SQUARES	F RATIO	F PROB.
BETWEEN GROUPS	5	1587.1167	317.4233	.6806	.6439
WITHIN GROUPS	18	8394.7167	466.3731		
TOTAL	23	9981.8333			

GROUP	COUNT	MEAN	STANDARD DEVIATION	STANDARD ERROR	MINIMUM	MAXIMUM	95 PCT CONF INT FOR MEAN
1938	5	50.8000	14.0961	6.3040	36.0000	70.0000	33.2977 TO 68.3023
1963	5	49.6000	25.6768	11.4830	11.0000	80.0000	17.7185 TO 81.4815
1969	5	47.2000	21.3237	9.5362	24.0000	72.0000	20.7236 TO 73.6764
1978A	4	66.7500	20.8706	10.4353	43.0000	88.0000	33.5407 TO 99.9593
1978B	2	43.5000	17.6777	12.5000	31.0000	56.0000	-115.3275 TO 202.3275
1984	3	39.3333	27.6104	15.9409	9.0000	63.0000	-29.2554 TO 107.9221
TOTAL	24	50.4167	20.8325	4.2524	9.0000	88.0000	41.6199 TO 59.2135
FIXED EFFECTS MODEL			21.5957	4.4082			41.1554 TO 59.6779

The high values for the standard deviation indicate that mean z-values are not good estimates of the sample population. Examination of the data in Table IV, used to calculate the mean z-values, reveals that only four of the 24 values fall within the symmetry range. Because the remaining 20 values are dispersed both above and below the symmetry range, 45 > z < 55, the mean values indicate symmetry. Therefore, although the means indicate channel symmetry, the planform is asymmetric.

Possible changes in the symmetry or asymmetry of the channel geometry overtime is the second area to be examined in this study. The analysis of variance tests conducted on the wavelengths, Table V, reveals that the average wavelength values show no significant change through time. A slight decline in the mean wavelength is shown for the period from 1938 until the formation of the cut-off, 1978b, at which time the wavelengths increase in size. The mean wavelengths for all years except 1978b and 1984 fall within the 95 percent confidence interval formulated by the fixed effects model. The change can be accounted for by the formation of the cut-off of the large meander loop which increases the wavelength value.

Examination of changes in asymmetry during the period of study reveals no significant differences between the mean z-values through time but the small sample population is not adequately represented by mean z-scores. More than two-thirds of the sample values fall outside the 95 percent confidence interval generated by the fixed effects model. More acceptable results might be achieved if the sample sizes were larger and data contributed to a smaller standard deviation.

Channel Migration

Changes in the planform of the river are evident from examination of figures in the appendix . The tables on the figures provide quantification of the meander migrations in the form of average amounts of migration, in meters, and average rates of migration, in meters per year, for each of the bend segments. The method used to determine the magnitudes and rates of channel migration provides a measure of both the direction of movement and the amount of change of the banks for each of the ten possible time intervals. The direction of change is noted with a "+" for bankward and a "-" for channelward movement. The direction is relative to the most recent channel on the map. The tick marks along the channel delineate the areas of migration. The first migration magnitude and rate values listed on each figure correspond to the eastern most portion of the study reach while the last values are for the western most portion. Figure 15, in the appendix , for example, shows a "-" change for the south bank and a "+" change for the north bank at the western most segment of the study area. As the channels begin to migrate towards the south the signs change and the south bank shows a "+"

movement while the north bank shows a "-" movement.

The final question under consideration in this study involved changes in the rate of migration through time. The null hypothesis tested is: there are no significant differences between the rates of migration through time. An analysis of variance was performed on the average erosion rate data from each of the ten time periods. Two problems were encountered in this analysis: (1) negative values can not be included in the calculations of the mean migration rates, therefore, most of the sample sizes are reduced; and (2) the overlap of time periods i.e., 1938-1984 and 1938-1978. The overlapping intervals produce such high within-groups error values that the null hypothesis must be accepted for migration rates on both the north and south banks.

These problems were alleviated by examining the values for the direction of change (positive or negative) separately from the absolute amount and by looking at only four time periods; 1938-1963, 1963-1969, 1969-1978, and 1978-1984. The use of four time periods allows hypothesis testing for the south bank to be based on the F-ratio values. Tables VII and VIII display results of the ANOVA tests performed on the rate of migration for the north and south banks respectively.

The channelward or accretionary migration, negative direction of movement, and the bankward or erosive migration, positive movement, of the north bank, show no

Table VII

Analysis of Variance on North Bank Migration

Variable RATECHG
By Variable TIMESPAN

ACCRETION

ANALYSIS OF VARIANCE

SOURCE	D.F.	SUM OF SQUARES	MEAN SQUARES	F RATIO	F PROB.
BETWEEN GROUPS	3	127.3322	42.4441	.8872	.4631
WITHIN GROUPS	22	1052.5132	47.8415		
TOTAL	25	1179.8454			

GROUP	COUNT	MEAN	STANDARD DEVIATION	STANDARD ERROR	MINIMUM	MAXIMUM	95 PCT CONF INT FOR MEAN
38-63	5	5.8945	4.6776	2.0919	.0000	11.2883	.0866 TO 11.7024
63-69	5	10.0765	5.7089	2.5531	2.9397	18.3729	2.9881 TO 17.1649
69-78	7	10.3367	9.0511	3.4210	1.9598	25.9671	1.9658 TO 18.7075
78-84	9	5.7381	6.5488	2.1829	.0000	18.1629	.7042 TO 10.7719
TOTAL	26	7.8405	6.8698	1.3473	.0000	25.9671	5.0658 TO 10.6153
FIXED EFFECTS MODEL			6.9168	1.3565			5.0274 TO 10.6537

Variable RATECHG
By Variable TIMESPAN

EROSION

ANALYSIS OF VARIANCE

SOURCE	D.F.	SUM OF SQUARES	MEAN SQUARES	F RATIO	F PROB.
BETWEEN GROUPS	3	133.6949	44.5650	.1284	.9422
WITHIN GROUPS	21	7289.7061	347.1289		
TOTAL	24	7423.4010			

GROUP	COUNT	MEAN	STANDARD DEVIATION	STANDARD ERROR	MINIMUM	MAXIMUM	95 PCT CONF INT FOR MEAN
38-63	4	12.0862	4.4445	2.2222	8.0631	15.9918	5.0142 TO 19.1582
63-69	5	19.6223	32.7075	14.6272	1.4698	77.9012	-20.9888 TO 60.2333
69-78	8	15.0148	15.0942	5.3366	3.6746	41.1553	2.3957 TO 27.6338
78-84	8	16.0610	13.9206	4.9217	2.9397	39.6855	4.4231 TO 27.6989
TOTAL	25	15.8025	17.5872	3.5174	1.4698	77.9012	8.5429 TO 23.0621
FIXED EFFECTS MODEL			18.6314	3.7263			8.0533 TO 23.5517

TABLE VIII

Analysis of Variance on South Bank Migration

Variable RATECHG
By Variable TIMESPAN

ACCRETION

ANALYSIS OF VARIANCE

SOURCE	D.F.	SUM OF SQUARES	MEAN SQUARES	F RATIO	F PROB.
BETWEEN GROUPS	3	735.7351	245.2450	.5223	.6709
WITHIN GROUPS	25	11737.6709	469.5068		
TOTAL	28	12473.4060			

GROUP	COUNT	MEAN	STANDARD DEVIATION	STANDARD ERROR	MINIMUM	MAXIMUM	95 PCT CONF INT FOR MEAN	
38-63	6	9.4989	9.7782	3.9919	.0000	24.1641	-.7626 TO	19.7603
63-69	5	19.0196	28.4837	12.7383	2.2047	69.5721	-16.3470 TO	54.3862
69-78	8	16.1977	33.3271	11.7829	.0000	97.9889	-11.6644 TO	44.0598
78-84	10	6.4232	5.1582	1.6312	.0000	14.6983	2.7332 TO	10.1131
TOTAL	29	11.9277	21.1064	3.9194	.0000	97.9889	3.8993 TO	19.9562
FIXED EFFECTS MODEL			21.6681	4.0237			3.6409 TO	20.2146

Variable RATECHG
By Variable TIMESPAN

EROSION

ANALYSIS OF VARIANCE

SOURCE	D.F.	SUM OF SQUARES	MEAN SQUARES	F RATIO	F PROB.
BETWEEN GROUPS	3	312.8598	104.2866	1.2095	.3245
WITHIN GROUPS	28	2414.2515	86.2233		
TOTAL	31	2727.1113			

GROUP	COUNT	MEAN	STANDARD DEVIATION	STANDARD ERROR	MINIMUM	MAXIMUM	95 PCT CONF INT FOR MEAN	
38-63	7	7.5711	5.3400	2.0183	1.4110	14.9335	2.6325 TO	12.5098
63-69	6	15.1883	13.6201	5.5604	1.4698	33.8062	.8951 TO	29.4815
69-78	8	6.2815	6.0267	2.1308	.9799	19.9897	1.2430 TO	11.3199
78-84	11	10.4937	10.3023	3.1063	1.4698	36.7458	3.5726 TO	17.4149
TOTAL	32	9.6816	9.3793	1.6580	.9799	36.7458	6.3000 TO	13.0632
FIXED EFFECTS MODEL			9.2856	1.6415			6.3191 TO	13.0440

significant differences between time periods (Table VII). Because of the large within-groups error value, the null hypothesis can not be rejected. Therefore, the mean accretion and erosion rates are considered to be equivalent through time. The high within-groups error values probably reflect that the mean values used in the ANOVA are calculated from average values for each bend segment.

Erosion and accretion rates for the south bank, Table VIII, are also considered to be equivalent through the period of study. While the equivalence of the bankward erosion rates, positive movement, is forced due to large within groups error, the channelward accretion rates have an F-ratio value of 1.2 which is not significant at the 0.05 significance level. The south bank erosion and accretionary migration values show no significant differences between time periods.

CHAPTER V

CONCLUSIONS

Overview

The objective of this chapter is to draw conclusions from the results of the analyses performed in order to determine: (1) whether the meander pattern in the study area is symmetrical or asymmetrical; (2) whether the symmetry or asymmetry has changed through time; (3) the rate of meander migration and changes, if any, over time; and (4) whether the rate of meander migration has changed since construction of the Denison Dam. The conclusions will be followed by recommendations for future studies.

Pattern Symmetry/Asymmetry

Because meander wavelengths can be defined and measured, evidence for symmetry of the channel pattern exists. Evidence has also been presented, in the form of z-values, which points toward asymmetry of the planform. The U.S. Army Corps of Engineers (1968) refers to the meanders below the Denison Dam as a "series of reverse irregular curves (p. 58)", alluding to asymmetry of the channel. Because 83 percent, 20 out of 24, z-values indicate asymmetric meander traverses, the findings of this study support Carson and Lapointes' (1983) theory, and provide an example of an asymmetrical broad alluvial channel.

Changes in Symmetry/Asymmetry

Results of an analysis of variance test on the mean z-values, indicate that no significant differences are observed between the asymmetry index values through the four time periods, 1938-1963, 1963-1969, 1969-1978, and 1978-1984, therefore, construction of the Denison Dam did not significantly affect the asymmetry of the river planform. Although the use of all ten possible time intervals produced similar results, the within-groups error values were larger than the between groups error values, therefore, the null hypothesis could not be rejected. Use of only four time periods allowed the hypothesis testing to be based on the F-ratio values for part of the sample.

Magnitudes and Rates of Migration

During 1960 and 1969 the U.S. Army Corps of Engineers (1981) surveyed 37 cross-section of the Red River downstream of the Denison Dam. One of the cross-sections, DR-28, is located within the current study area (Figure 19). The surveyed migration values of approximately 10 meters for the north bank and 30 meters for the south bank compare favorably with the average measurements of 26 meters for the north bank and 32 meters for the south bank computed in this study.

Examination of the individual bends reveals that average rates of migration within a time period are easily calculated. The average values are shown for each bend segment on the maps in the appendix. The values in the appendix are not considered to be absolutes, merely estimates of the directions, magnitudes, and rates of migration. Errors made during map construction, reproduction, registration and measurement of migration rates are believed to be compensating and produce an overall error value of plus or minus 27 meters.

Because of changes in the location of the bend segments through time, the average rates of migration between time intervals are difficult to compare. Several analyses of variance were performed in an attempt to compare the migration rates through time. The method of analysis used in this study does not permit the calculation of just one overall rate of migration. The total mean migration rate computed for channelward accretion, "-", movement and bankward erosion, "+", movement of the north and south banks provide the best overall estimates of the migration along the channel through time. Total mean migration of: 9.6 m/year channelward accretion and 11.9 m/year bankward erosion for the north bank and 15.8 m/year channelward accretion and 7.8 m/year bankward erosion for the south bank were computed. F-tests on the mean erosion rates for the north and south banks show no significant changes through time, consequently, no significant changes in the rates of migration have occurred since the construction of the Denison Dam.

Extrinsic Factors

Visual inspection of the figures in the appendixes indicates that the channel pattern has been substantially altered during the last 46 years. No human activities in or near the study area have been found to explain the changes in bank erosion. William Bookout, McCurtain County Soil Scientist with the USDA Agricultural Stabilization and Conservation Service, indicated that no major irrigation, dredging, or bank stabilization projects have been undertaken in the study area during the period under investigation (personal communication). Close examination of the aerial photographs used for map construction shows only minor changes in landuse.

Changes in the flow of the river are difficult to ascertain. Discharge and sediment load records for the study area are sporadic, at best, and in many cases unavailable, making it difficult to obtain a good representation of the actual discharge on, or near, the dates of the photographs used in this study. The period of record for the gaging station at Arthur City, Texas, approximately 20 kilometers upstream of the study area, is from 1946 through 1977. The 39 discharge samples for 1946 produce a mean annual discharge approximately 1360 cms while the 22 samples for 1977 produce a mean annual discharge of 477 cms (Blumer, 1983). The period of record for the Index, Arkansas gage, 76 kilometers downstream, extends from 1918 through 1975. The mean discharge for 1938 was approximately 240 cms while the mean discharge for 1969 was 1961 cms. The irregular nature of the records and the large distance between the gages and the study area provide little information about the discharge through the study reach.

Because of the interactions of the variables involved in channel migration, it is difficult to identify all of the sources of variation in the system. Other factors which must be accounted for include changes in the climate and tectonic activities.

Idabel, Oklahoma, approximately 21 km east of the study area, is representative of the climate of the area. Precipitation data for Idabel from 1941-1984 are shown in Figure 14. Increased rainfall within the study area would increase the discharge of the river and could have an affect on the channel pattern. Each of the four time periods has more years of below average rainfall than above average rainfall, but the minimum amount of rainfall increases following the drought of 1956.

In a study of a reach of the Red River approximately 160 kilometers downstream of the current investigation, Guccione (1983) found that tectonism was not a significant

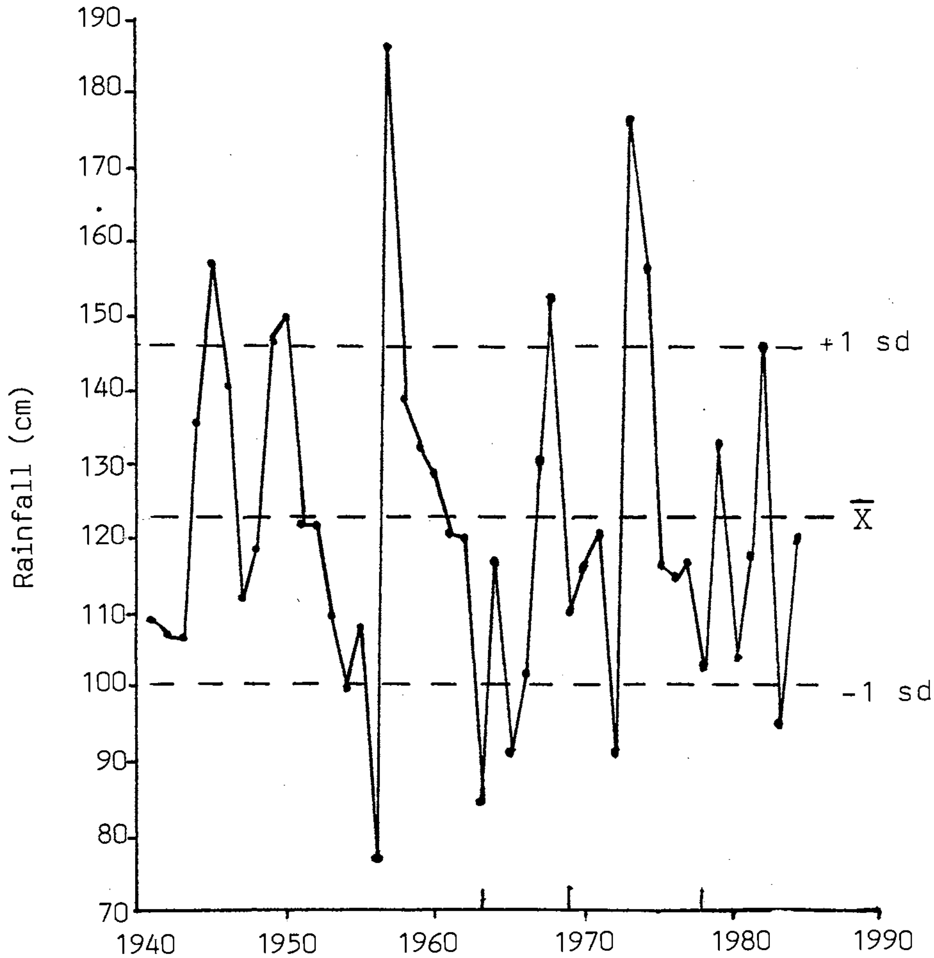


Figure 14. Total Rainfall (cm) vs. Year for Idabel, Oklahoma.

force in the area during periods less than 10^{2-3} years in length. The 46 year period of this study is sufficiently small therefore, to disregard tectonic effects.

The effects of the Denison Dam can not be ruled out as causing the changes nor can the dam be seen as the only factor involved in the changes. Differences in the discharge through the area may be significant and the increase in the average precipitation through time undoubtedly contribute to the changes in the planform of the river channel.

Recommendations

The current study could be improved in several ways. The level of accuracy obtained with the methods of map construction, reproduction, and data collection used in this study could be substantially increased with the use of photographic negatives of the area which can be overlaid with the aid of a projector. Because fewer transformations would be necessary, the amount of error introduced should be lower. A second improvement would involve increasing the length of the reach under investigation. A larger study area would increase the sample sizes for the asymmetry index values and migration rates which might reduce the standard deviations and the within groups error values.

Further studies of the occurrence of asymmetry in broad alluvial channels are needed to determine whether the asymmetry model should replace the currently accepted theory that meanders form sine-generated curves. Many studies will be necessary to provide evidence sufficient to reject the wave-form model.

Examinations of the the impact of humans on rivers must continue until the thresholds within the systems are understood and can be quantified. By understanding how dams, bank stabilization works, land use changes, etc. affect the river, engineers can alleviate problems rather than create new ones. Knowledge of the conditions necessary to produce maximum and minimum amounts of erosion along an undammed river may aid land-use planners in determining the discharge from a dam required to produce minimal erosion of the banks downstream. As the maps in this study show, the effects of channel migration can be dramatic over time. As geomorphplogists gain a better understanding of river systems, better methods may be developed which will end or at least slow such changes.

Gaging stations along rivers need to be constructed and maintained in order to provide necessary information for river studies. Measurements of the discharge and sediment load can aid in the quantification of erosion thresholds. Potamological studies need to continue until the river is completely understood as a system.

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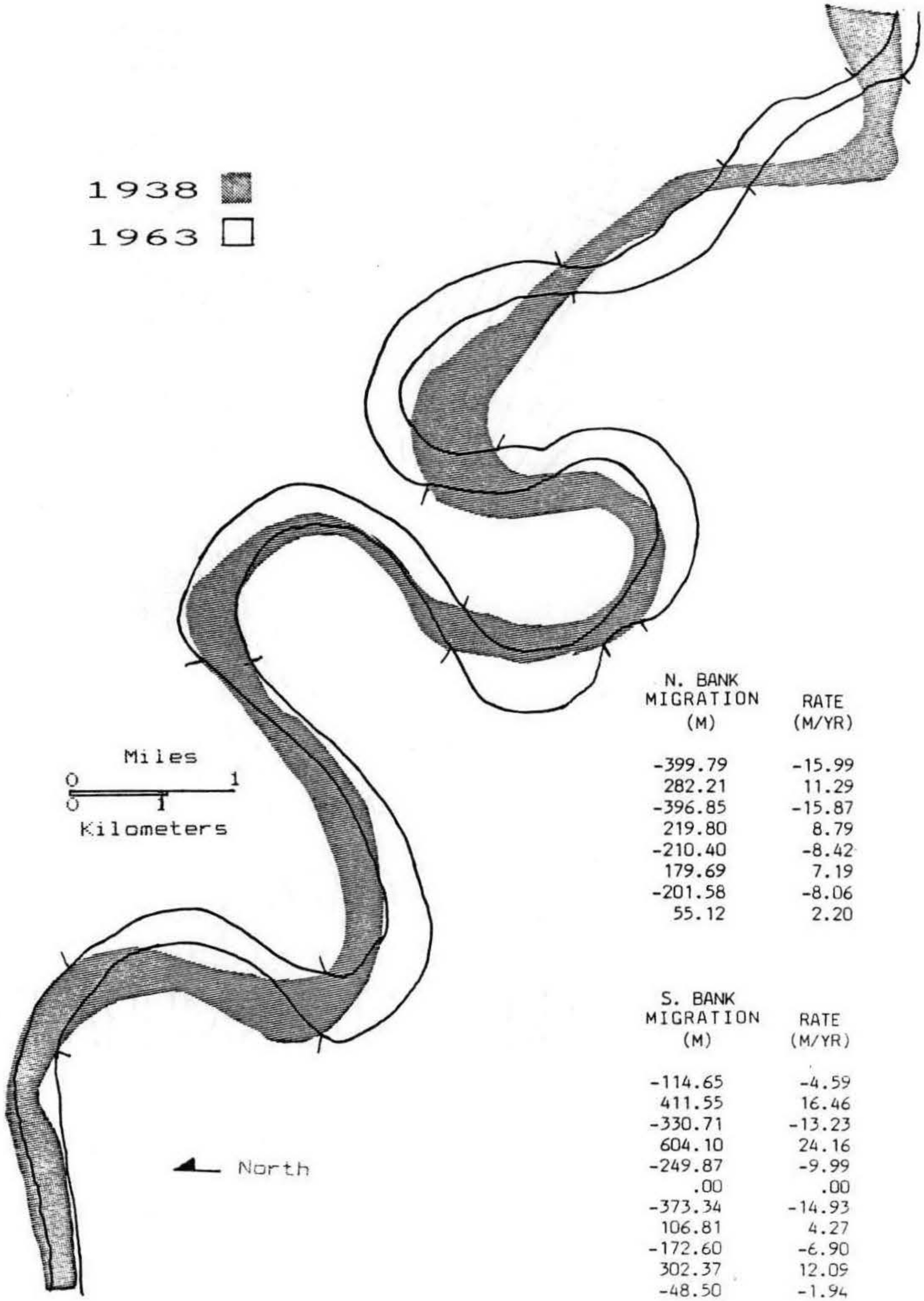
APPENDIX

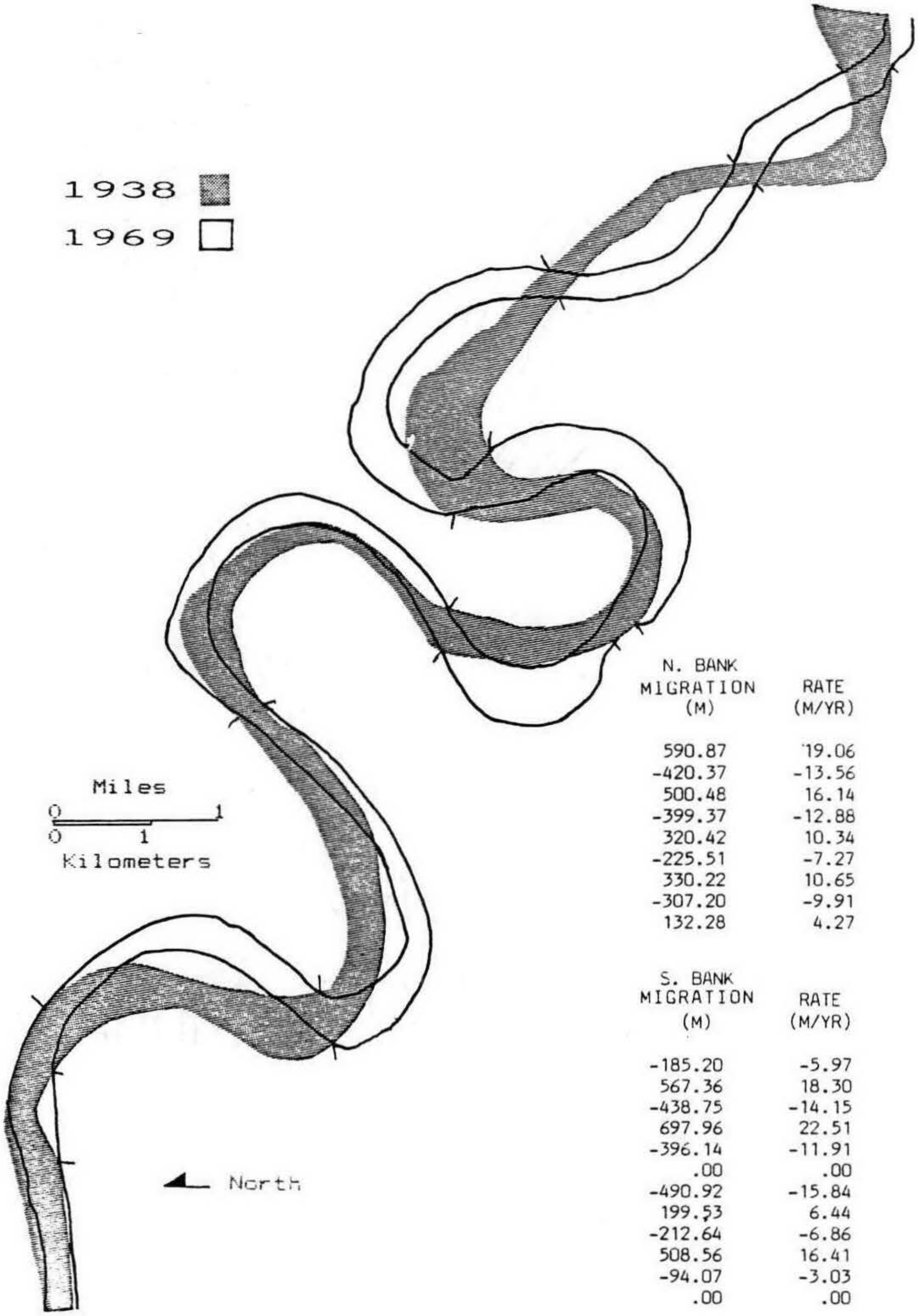
CHANNEL MIGRATION FIGURES AND DATA



N. BANK MIGRATION (M)	RATE (M/YR)
-399.79	-15.99
282.21	11.29
-396.85	-15.87
219.80	8.79
-210.40	-8.42
179.69	7.19
-201.58	-8.06
55.12	2.20

S. BANK MIGRATION (M)	RATE (M/YR)
-114.65	-4.59
411.55	16.46
-330.71	-13.23
604.10	24.16
-249.87	-9.99
.00	.00
-373.34	-14.93
106.81	4.27
-172.60	-6.90
302.37	12.09
-48.50	-1.94

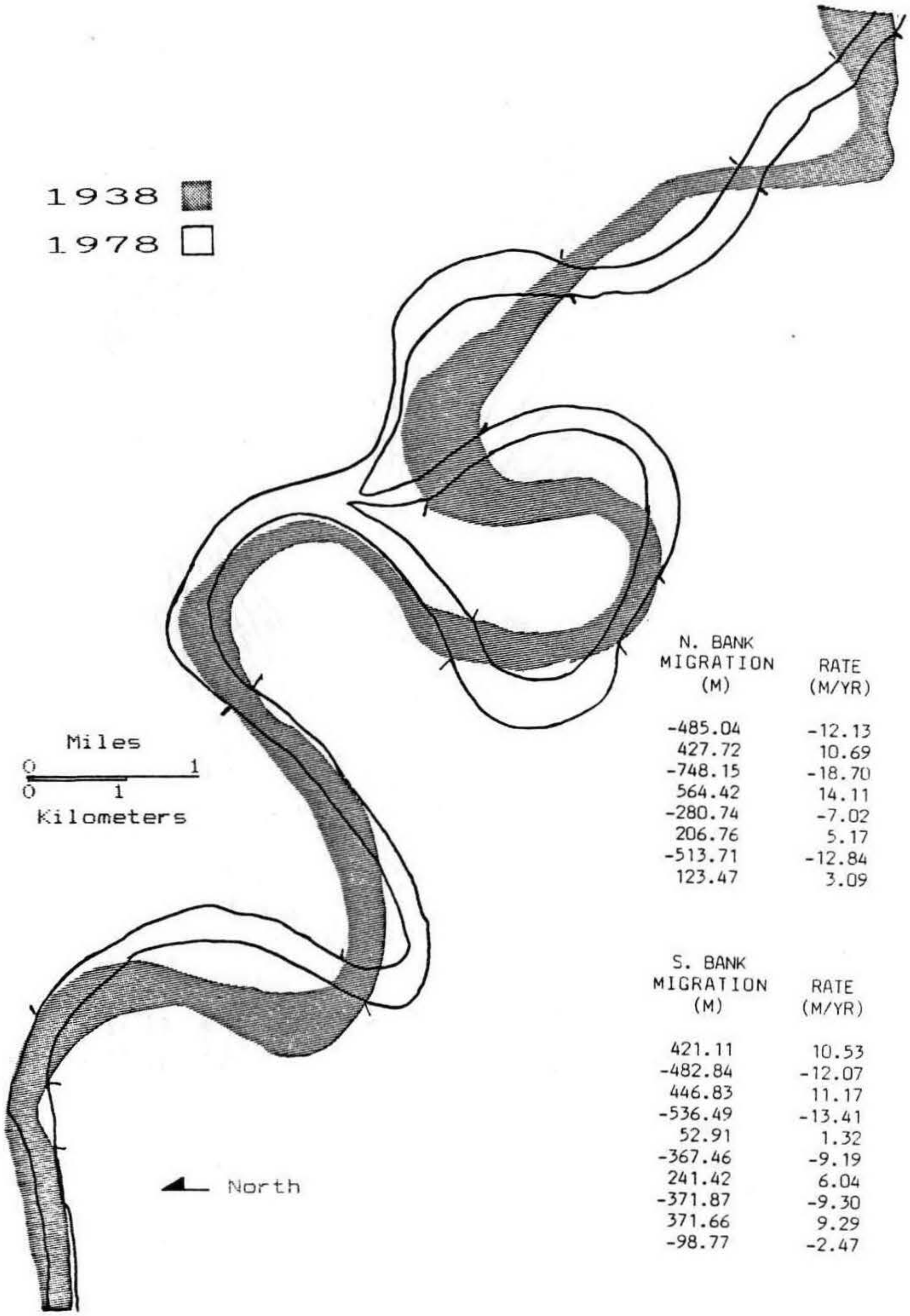
Figure 15. Channel Migration 1938-1963



N. BANK MIGRATION (M)	RATE (M/YR)
590.87	19.06
-420.37	-13.56
500.48	16.14
-399.37	-12.88
320.42	10.34
-225.51	-7.27
330.22	10.65
-307.20	-9.91
132.28	4.27

S. BANK MIGRATION (M)	RATE (M/YR)
-185.20	-5.97
567.36	18.30
-438.75	-14.15
697.96	22.51
-396.14	-11.91
.00	.00
-490.92	-15.84
199.53	6.44
-212.64	-6.86
508.56	16.41
-94.07	-3.03
.00	.00

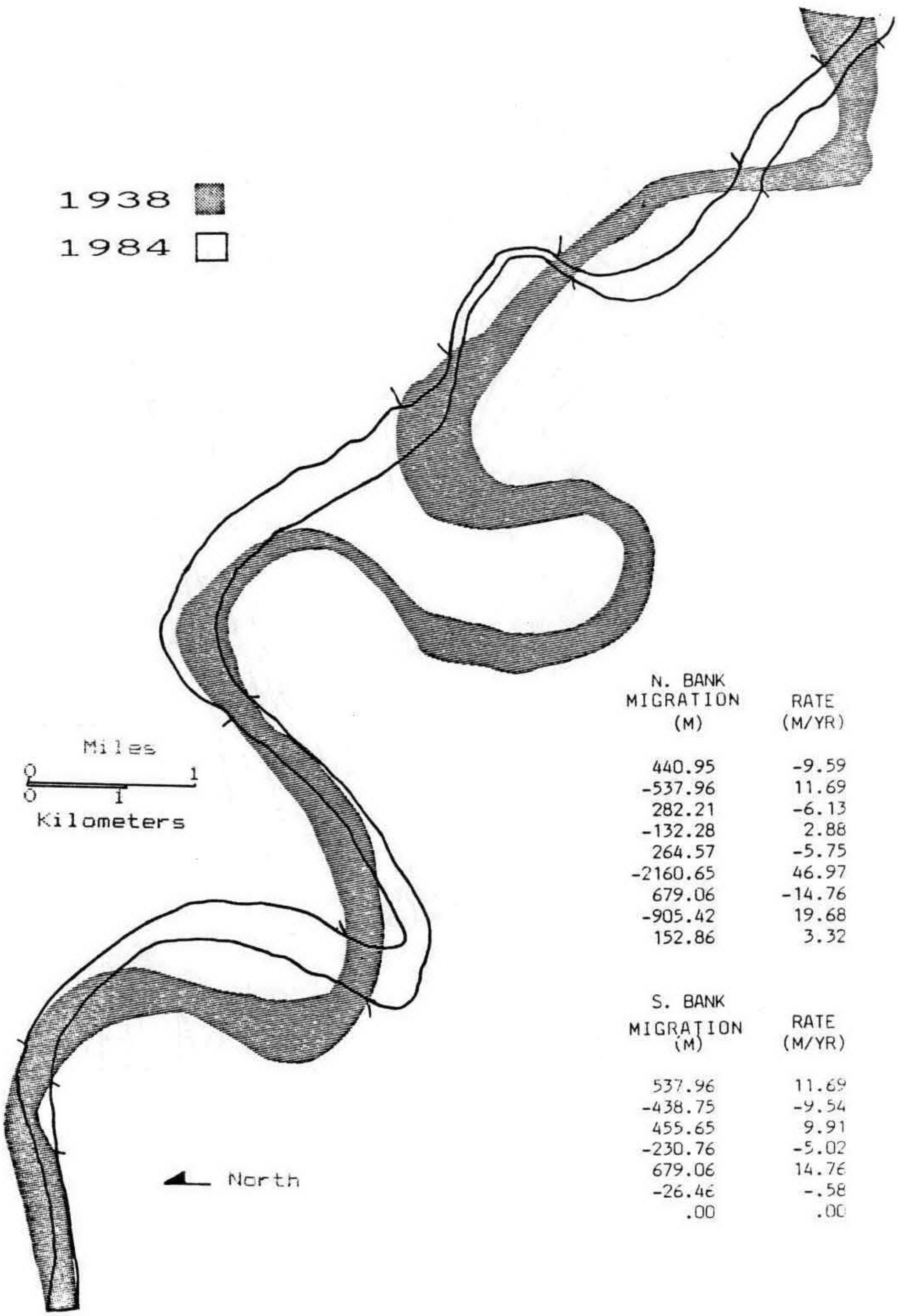
Figure 16. Channel Migration 1938-1969



N. BANK MIGRATION (M)	RATE (M/YR)
-485.04	-12.13
427.72	10.69
-748.15	-18.70
564.42	14.11
-280.74	-7.02
206.76	5.17
-513.71	-12.84
123.47	3.09

S. BANK MIGRATION (M)	RATE (M/YR)
421.11	10.53
-482.84	-12.07
446.83	11.17
-536.49	-13.41
52.91	1.32
-367.46	-9.19
241.42	6.04
-371.87	-9.30
371.66	9.29
-98.77	-2.47

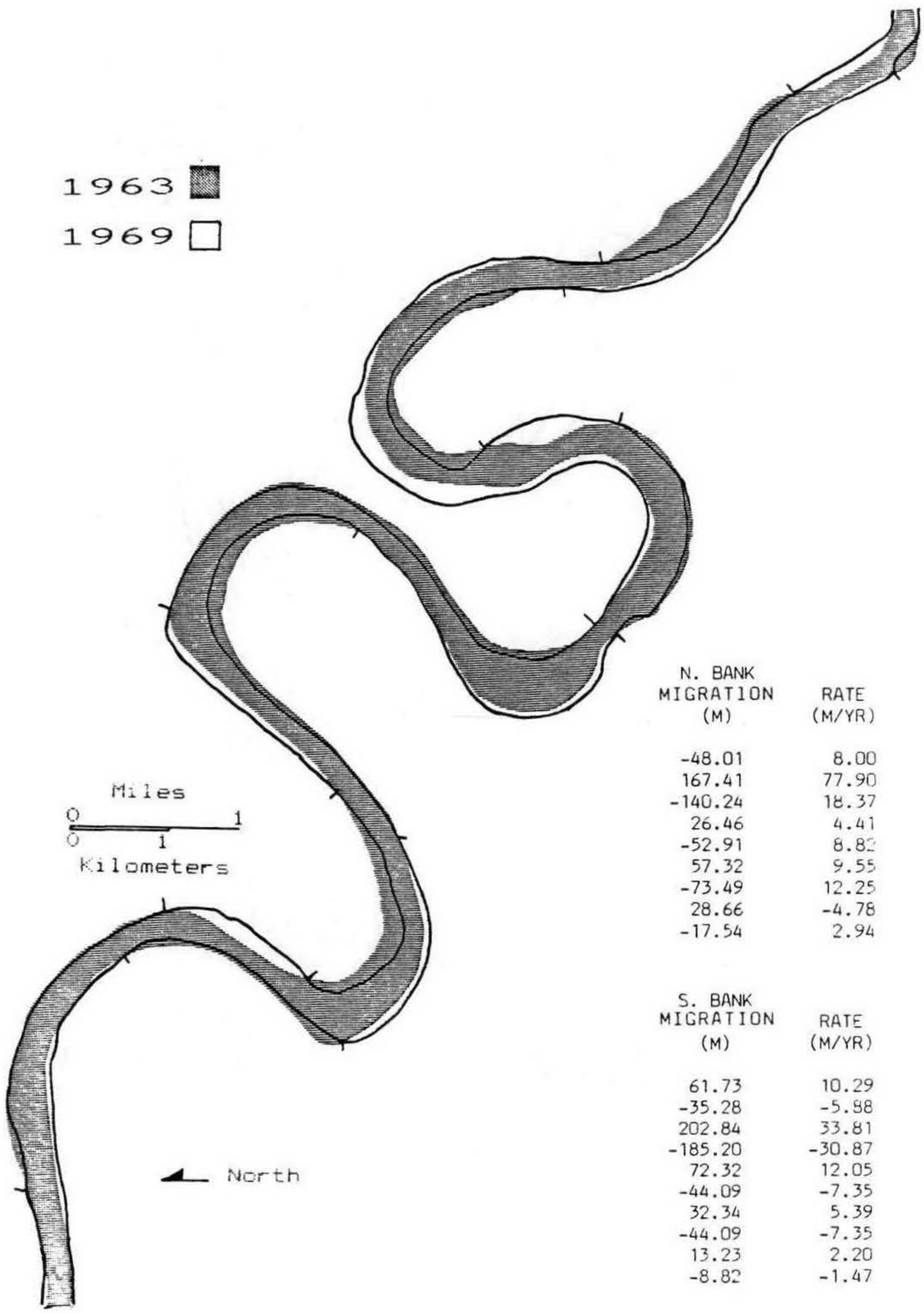
Figure 17. Channel Migration 1938-1978



N. BANK MIGRATION (M)	RATE (M/YR)
440.95	-9.59
-537.96	11.69
282.21	-6.13
-132.28	2.88
264.57	-5.75
-2160.65	46.97
679.06	-14.76
-905.42	19.68
152.86	3.32

S. BANK MIGRATION (M)	RATE (M/YR)
537.96	11.69
-438.75	-9.54
455.65	9.91
-230.76	-5.02
679.06	14.76
-26.46	-.58
.00	.00

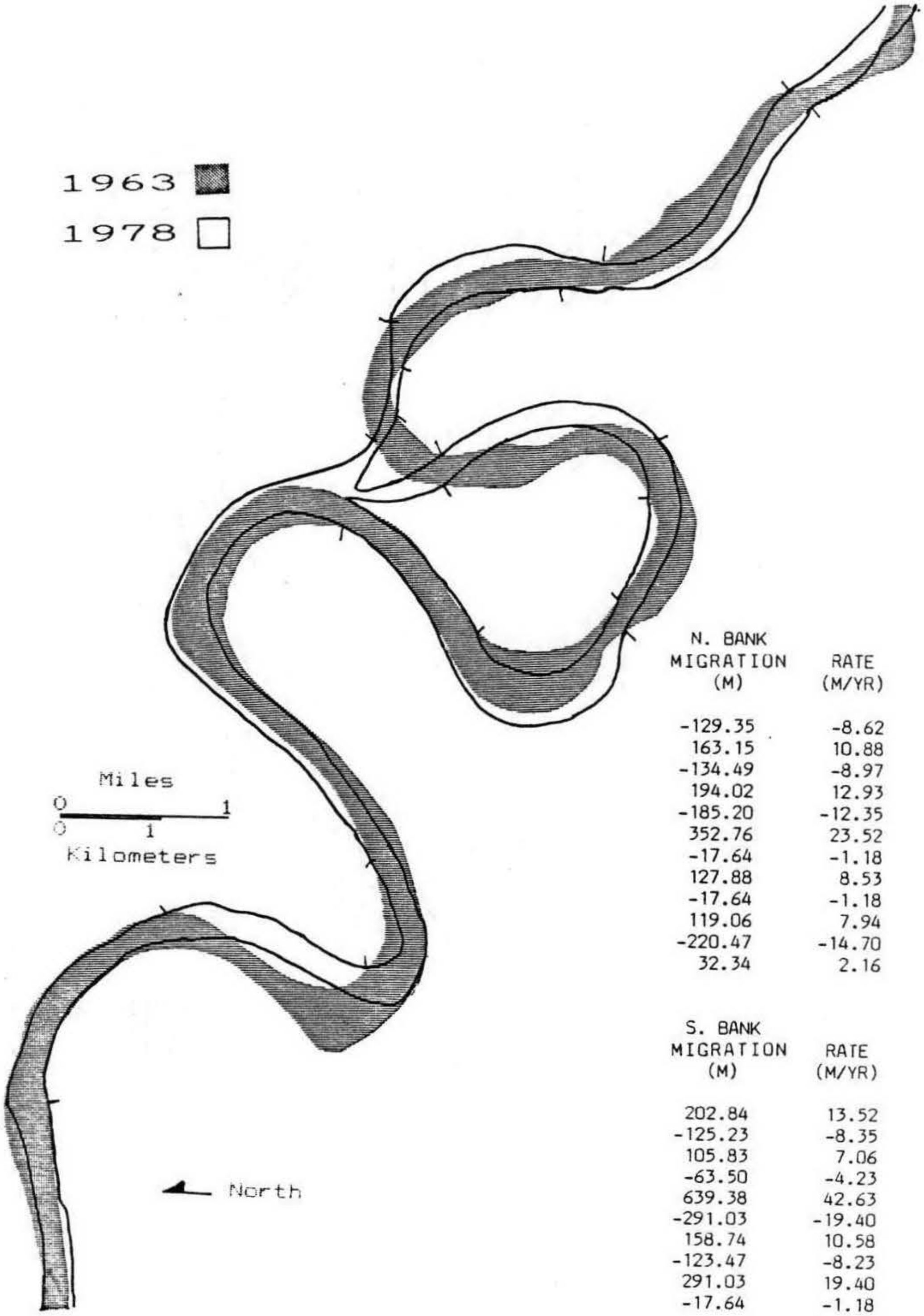
Figure 18. Channel Migration 1938-1984



N. BANK MIGRATION (M)	RATE (M/YR)
-48.01	8.00
167.41	77.90
-140.24	18.37
26.46	4.41
-52.91	8.82
57.32	9.55
-73.49	12.25
28.66	-4.78
-17.54	2.94

S. BANK MIGRATION (M)	RATE (M/YR)
61.73	10.29
-35.28	-5.88
202.84	33.81
-185.20	-30.87
72.32	12.05
-44.09	-7.35
32.34	5.39
-44.09	-7.35
13.23	2.20
-8.82	-1.47

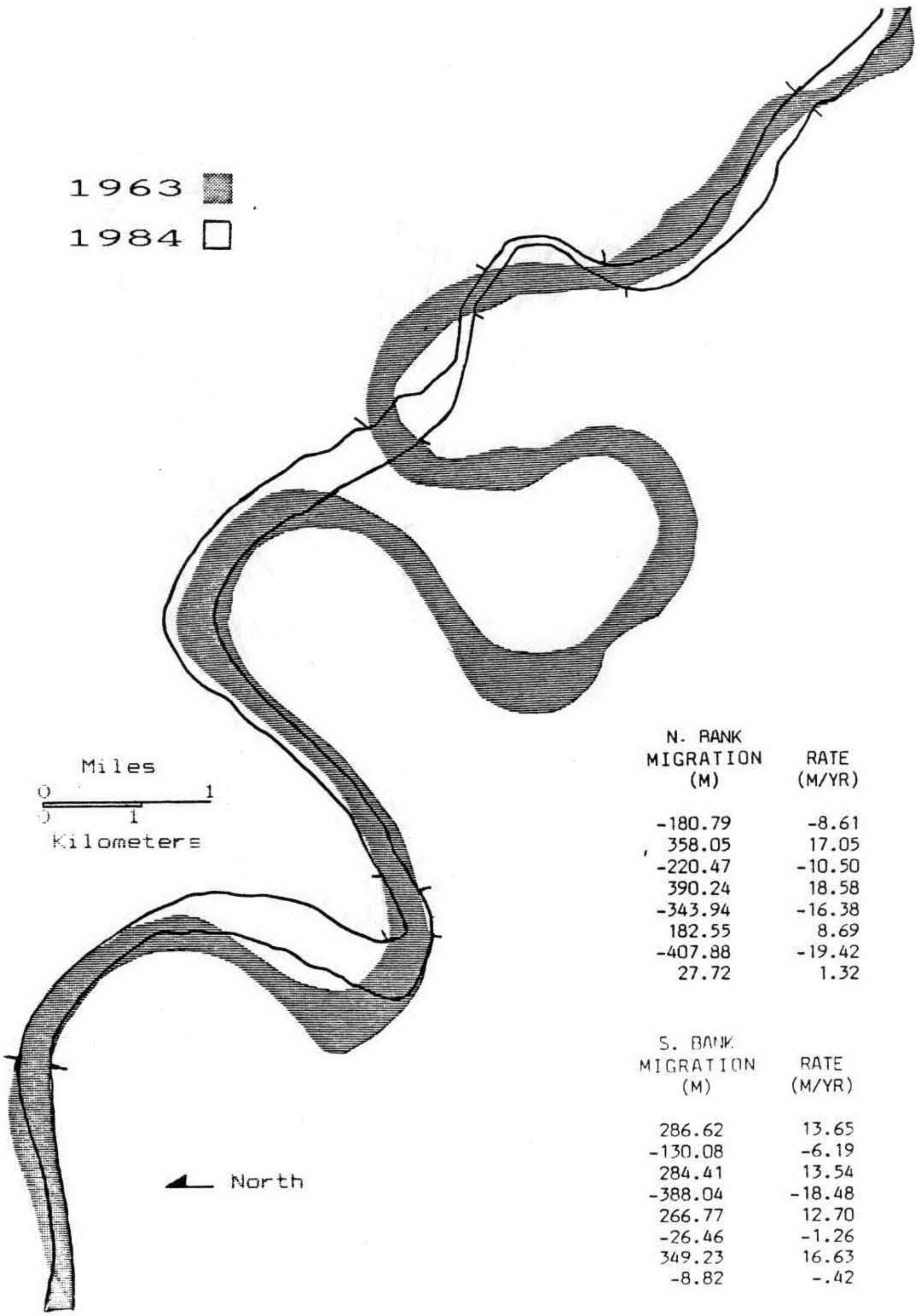
Figure 19. Channel Migration 1963-1969



N. BANK MIGRATION (M)	RATE (M/YR)
-129.35	-8.62
163.15	10.88
-134.49	-8.97
194.02	12.93
-185.20	-12.35
352.76	23.52
-17.64	-1.18
127.88	8.53
-17.64	-1.18
119.06	7.94
-220.47	-14.70
32.34	2.16

S. BANK MIGRATION (M)	RATE (M/YR)
202.84	13.52
-125.23	-8.35
105.83	7.06
-63.50	-4.23
639.38	42.63
-291.03	-19.40
158.74	10.58
-123.47	-8.23
291.03	19.40
-17.64	-1.18

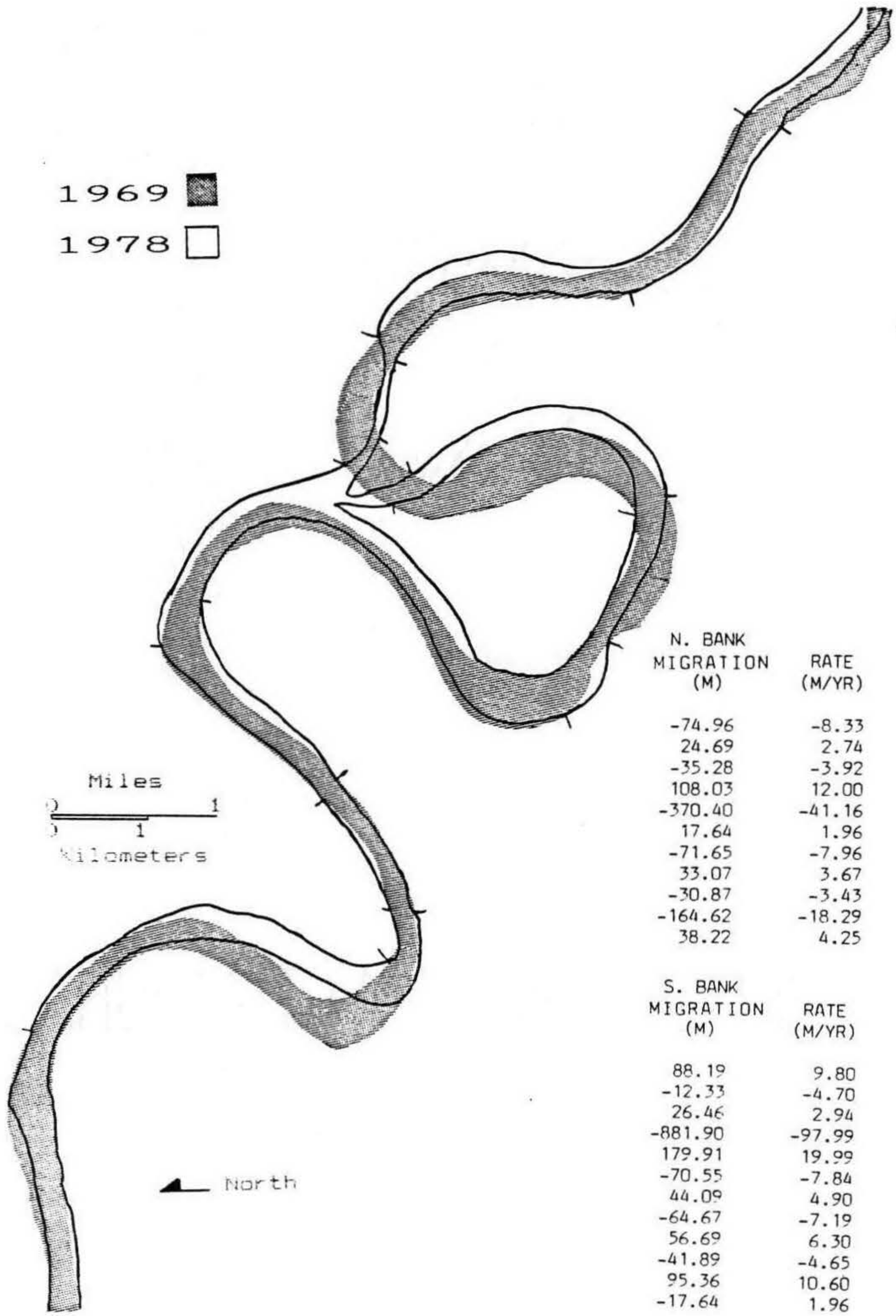
Figure 20. Channel Migration 1963-1978



N. BANK MIGRATION (M)	RATE (M/YR)
-180.79	-8.61
358.05	17.05
-220.47	-10.50
390.24	18.58
-343.94	-16.38
182.55	8.69
-407.88	-19.42
27.72	1.32

S. BANK MIGRATION (M)	RATE (M/YR)
286.62	13.65
-130.08	-6.19
284.41	13.54
-388.04	-18.48
266.77	12.70
-26.46	-1.26
349.23	16.63
-8.82	-.42

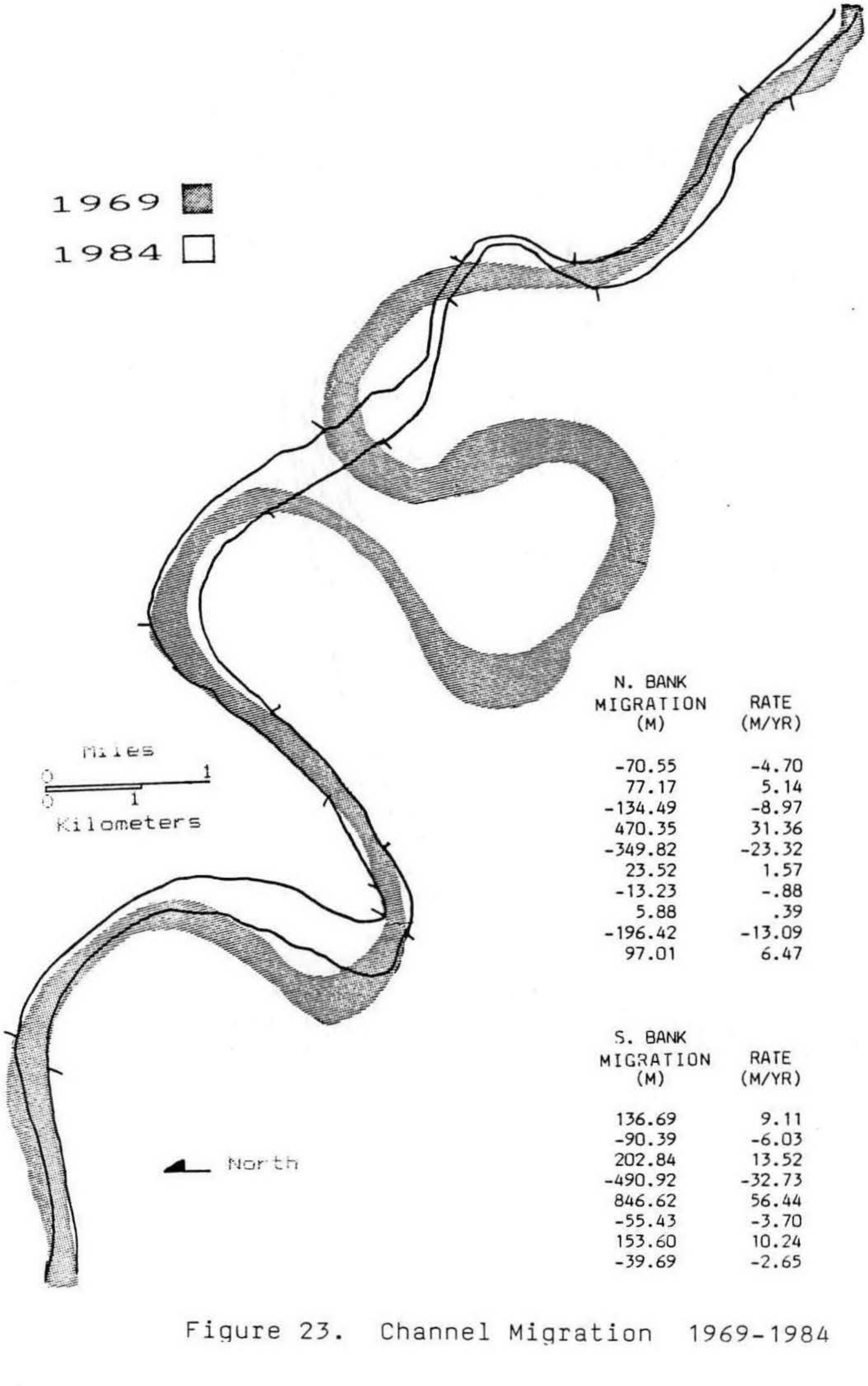
Figure 21. Channel Migration 1963-1984



N. BANK MIGRATION (M)	RATE (M/YR)
-74.96	-8.33
24.69	2.74
-35.28	-3.92
108.03	12.00
-370.40	-41.16
17.64	1.96
-71.65	-7.96
33.07	3.67
-30.87	-3.43
-164.62	-18.29
38.22	4.25

S. BANK MIGRATION (M)	RATE (M/YR)
88.19	9.80
-12.33	-4.70
26.46	2.94
-881.90	-97.99
179.91	19.99
-70.55	-7.84
44.09	4.90
-64.67	-7.19
56.69	6.30
-41.89	-4.65
95.36	10.60
-17.64	1.96

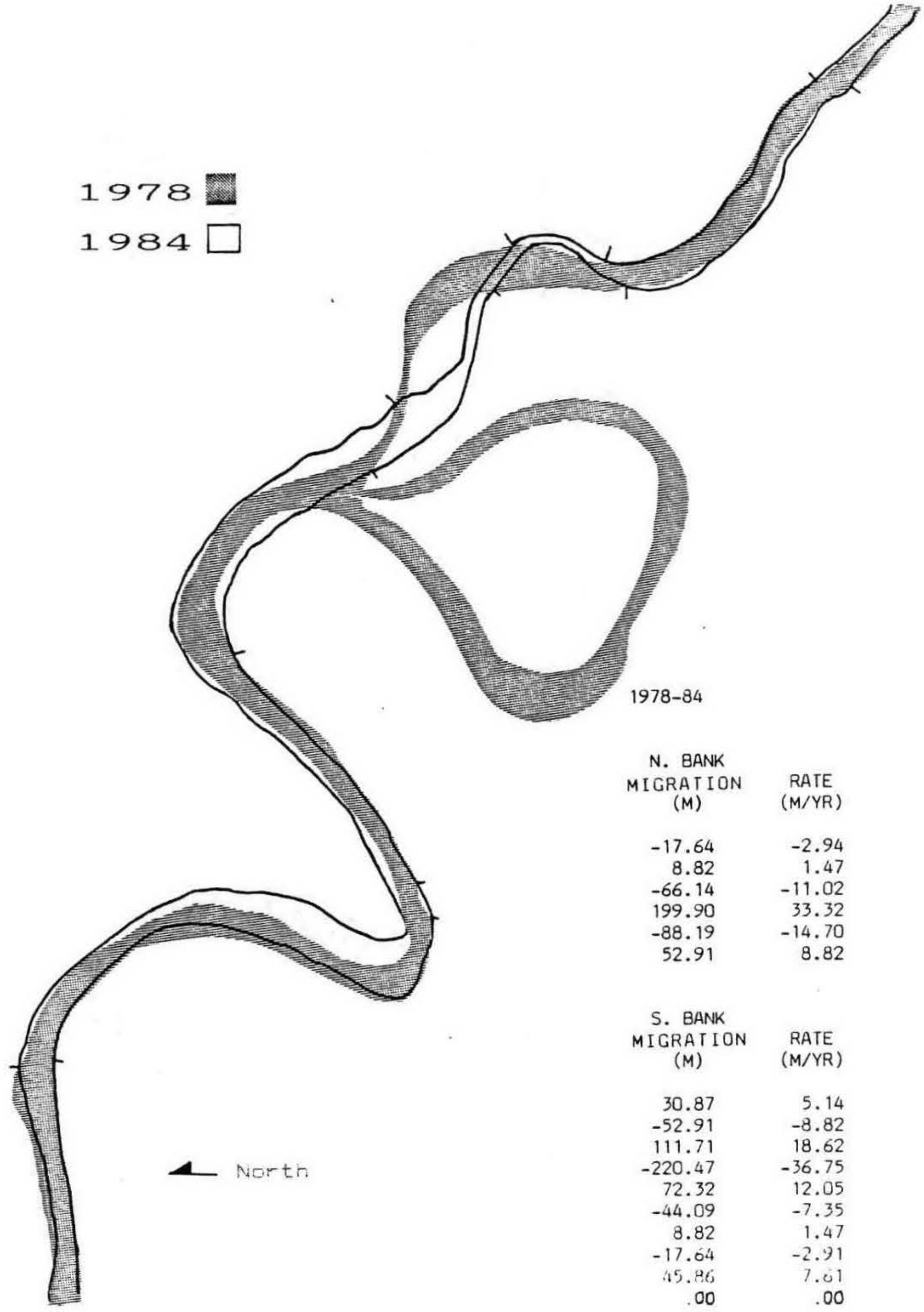
Figure 22. Channel Migration 1969-1978



N. BANK MIGRATION (M)	RATE (M/YR)
-70.55	-4.70
77.17	5.14
-134.49	-8.97
470.35	31.36
-349.82	-23.32
23.52	1.57
-13.23	-.88
5.88	.39
-196.42	-13.09
97.01	6.47

S. BANK MIGRATION (M)	RATE (M/YR)
136.69	9.11
-90.39	-6.03
202.84	13.52
-490.92	-32.73
846.62	56.44
-55.43	-3.70
153.60	10.24
-39.69	-2.65

Figure 23. Channel Migration 1969-1984



N. BANK MIGRATION (M)	RATE (M/YR)
-17.64	-2.94
8.82	1.47
-66.14	-11.02
199.90	33.32
-88.19	-14.70
52.91	8.82

S. BANK MIGRATION (M)	RATE (M/YR)
30.87	5.14
-52.91	-8.82
111.71	18.62
-220.47	-36.75
72.32	12.05
-44.09	-7.35
8.82	1.47
-17.64	-2.91
45.86	7.61
.00	.00

Figure 24. Channel Migration 1978-1984

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VITA

Bruce Lee Whitesell

Candidate for the Degree of

Master of Science

Thesis: CHANGES IN THE PLANFORM OF THE RED RIVER McCURTAIN COUNTY, OKLAHOMA 1938-1984

Major Field: Geography

Biographical:

Personal Data: Born Bartlesville, Oklahoma, November 21, 1959, the son of Louis B. and Janet Whitesell.

Education: Graduated from Putnam City High School, Oklahoma City, Oklahoma, in May 1978; received Bachelor of Science Degree in Geology from Oklahoma State University in December, 1983; completed requirements for the Master of Science degree at Oklahoma State University in July, 1986.

Professional Experience: Teaching Assistant, Department of Geography, Oklahoma State University, January 1985, to June 1986.