HISTORIC CHANNEL CHANGE IN THE MEDICINE LODGE RIVER BASIN, KANSAS, 1871-1983

by

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ABSTRACT

Channels in the Medicine Lodge River system of south-central Kansas have narrowed significantly since white European settlement of the area in the 1870s. Remeasurement in 1983 of selected section-line channel crossings from the 1871 original federal land survey demonstrates the narrowing. Further, the riparian vegetative cover in the drainage basin has expanded since 1871. Integration of the channel width data, results from analyses of daily precipitation data for the study area, testimony from local residents, and cores extracted from riparian tree species lead to the development of a model suggesting that a series of wet years in the 1940s initiated the narrowing and allowed vegetation to stabilize mid-channel and point bars. Precipitation during the 1940s was less seasonal than that which occurred in the 1930s, resulting in less variable stream discharge during the 1940s. Under this altered state of stream discharge, vegetation was able to become established in mid-channel and point bar deposits. Land use, because it has not changed significantly in the drainage basin since 1871, is not a crucial factor in explaining recent channel narrowing.

The findings of this thesis suggest that sediment

is alternately stored in and removed from river systems in the Great Plains on a very short time scale. Channel change similar to that reported in this research has apparently occurred throughout the geologic history of the study area and elsewhere in the Great Plains.

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CHAPTER 1: INTRODUCTION

Rivers flowing in alluvium adjust their channel shape and dimensions to the volume of water and the amount and texture of the sediment they transport. Changes in the magnitude and frequency of water and sediment load delivered to a stream may force a stream system into a condition of disequilibrium. To regain a state of equilibrium, there is usually an alteration of the channel width, depth, gradient, or meander wavelength (Leopold and Maddock 1953; Schumm 1960, 1968).

Climatic fluctuations and changes in land use cause variations in surface runoff and sediment yield to a river system. Because subhumid climates support a sparse cover of vegetation, even small climatic fluctuations or minor land-use changes will alter the extent of the vegetative cover and have a significant impact on surface runoff and sediment yields (Langbein and Schumm 1958). Such changes in runoff and sediment yield will, in turn, affect stream channel morphology (Schumm 1968).

This study documents historic channel narrowing and increases in riparian vegetative density that have

occurred since 1871 along the Medicine Lodge River and two of its major tributaries, Elm Creek and Thompson Creek, of south-central Kansas (Plates 1:1, 1:2, and 1:3). The changes are, in turn, correlated with an altered climatic regime. Finally, a model that explains the channel and vegetative changes is presented.

Channel Variables

Leopold and Maddock (1953) first suggested that rivers attempt to develop in such a way as to achieve a condition of equilibrium between channel morphology and the amount of water and the amount and character of the sediment load they transport. They showed that any increase in discharge or a change in the nature of the sediment load at a given point along a river will result in that river widening or deepening its channel. Schumm (1968) later added the variables of channel gradient and meander wavelength to the relationship between discharge and channel morphology to produce the following equation:

$$Qw \propto wdl/s$$

Qw=Flow of Water
w=Width of Channel
d=Depth of Channel
l=Meander Wavelength of River
s=Channel Gradient
An increase in Qw results in an increase in w,d,l,and a decrease in s.

Plate 1:1 Medicine Lodge River

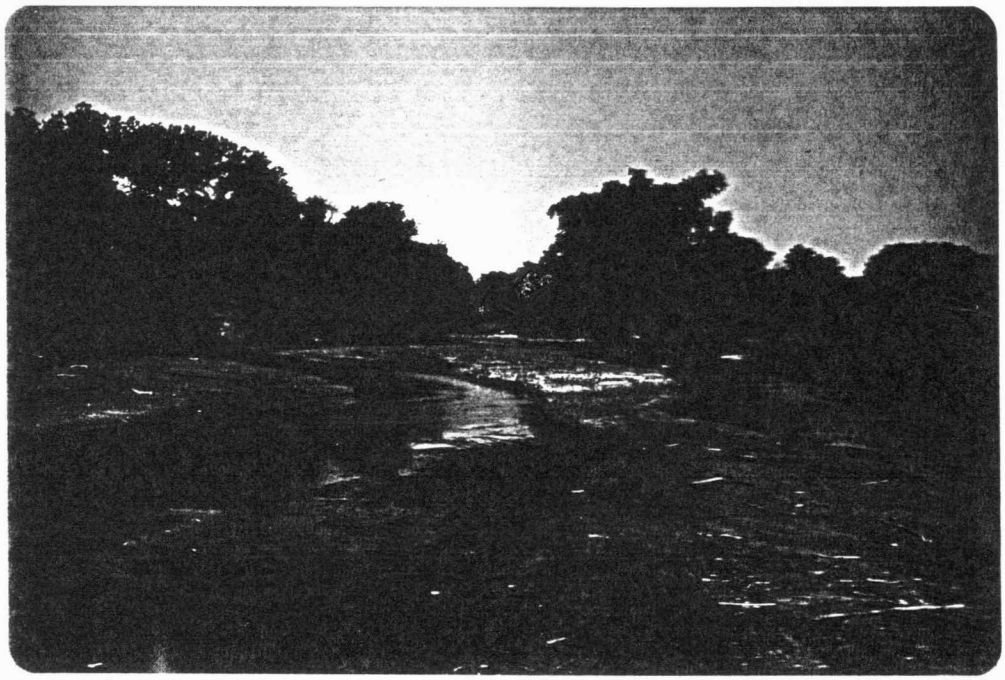


Plate 1:2 Elm Creek

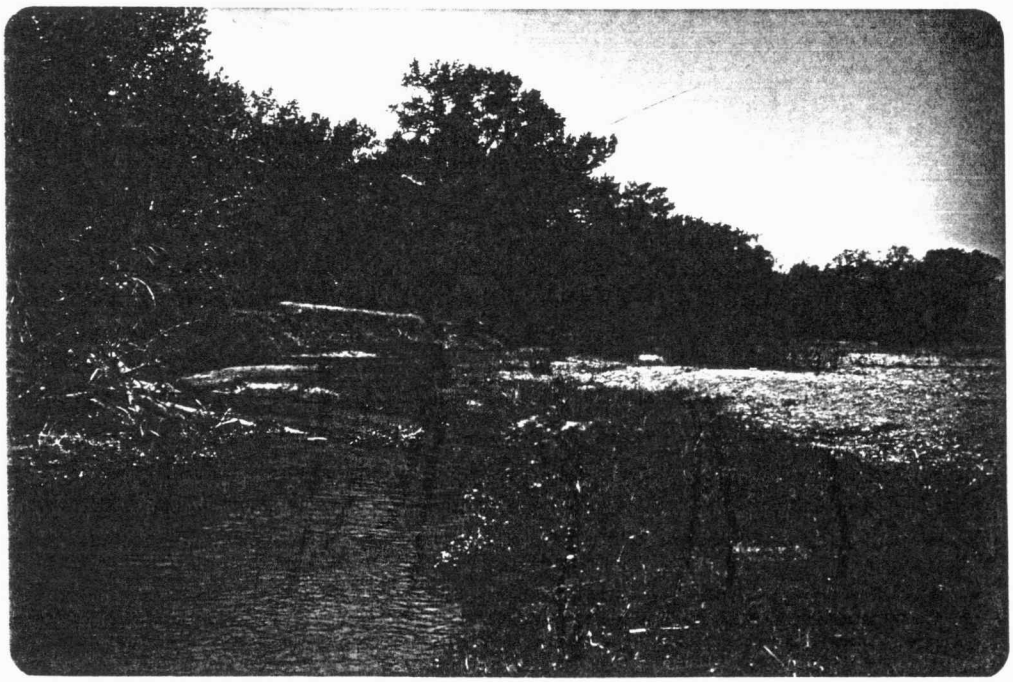
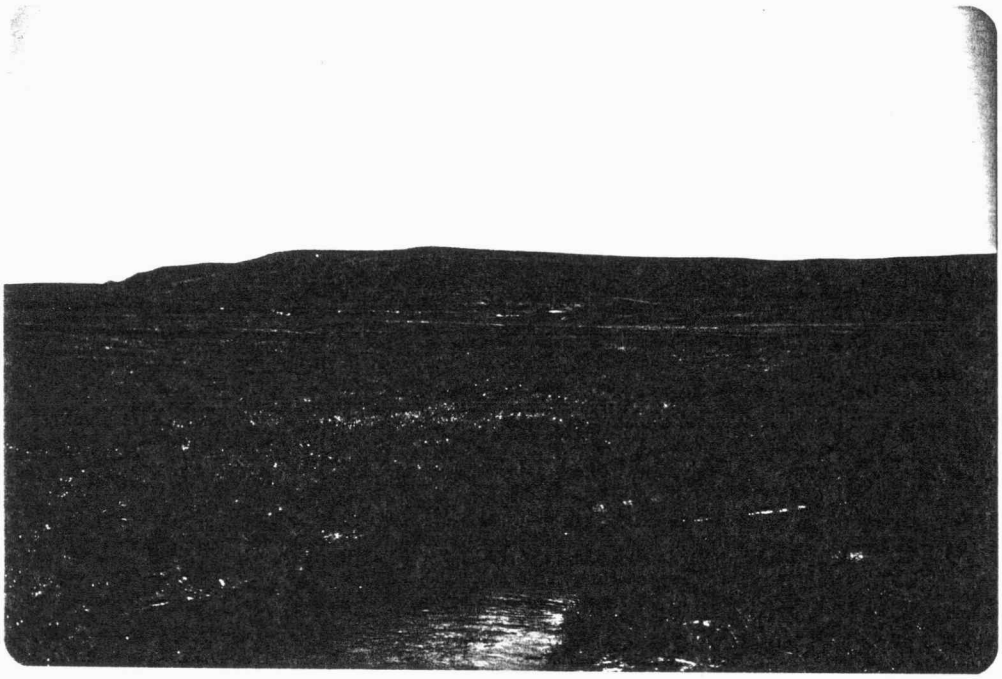


Plate 1:3 Thompson Creek



To explain the relationship between sediment load and channel morphology, he presented the following:

$$Qs \propto wls/dp$$

Qs=Ratio of Bedload to Total Sediment Load
p=River Sinuosity (Ratio of channel length to valley length) In this relationship, an increase in Qs (more bedload,less suspended load) results in an increase in w,l,and s, and a decrease in d and p.

Channels carrying predominantly bedload material tend to develop a larger width-to-depth ratio than those that carry primarily a suspended sediment load. Wide, shallow channels have a steeper velocity gradient and consequently a greater rate of shear near their beds, while narrow, deep channels have a greater rate of shear near their banks; the wide and shallow configuration favors entrainment and transport of coarse material along the bed, the narrow and deep configuration entrainment and transport of fine material in suspension throughout the channel (Lane 1937).

Rivers may alter their widths or their depths in response to changes in discharge or sediment load. Aggradation or narrowing occurs when a high sediment load is introduced to a river, or when peak discharge is reduced. Because it does not have the energy to transport such a large load, the river deposits sediment on its bed or banks or both, reducing channel depth or width. Incision or widening occurs when, because of

increased peak discharge or a reduced sediment load, a river has an excess capacity to transport sediment. In order to obtain sediment, it erodes its bed or banks, deepening or widening its channel. It is important to note that a channel may change its width without undergoing lateral migration. Furthermore, differential erosion or deposition may occur when channel banks and bed are composed of different textures of material.

The type of material in which a river is flowing is an important determinant of the adjustments it makes in response to changes in discharge and sediment load. Channels developed in sandy alluvium, because of the minimal cohesiveness between sand particles, are more unstable than those flowing in silty alluvium. As a consequence, sandy channel banks are less cohesive and rivers flowing in this sandy alluvium tend to adjust to altered environmental conditions by changing their channel width. Conversely, rivers flowing in silty alluvium tend to adjust by altering their depth (Schumm 1960). The Medicine Lodge River, Elm Creek, and Thompson Creek each flow in sandy alluvium, and are, therefore, more likely to modify their widths rather than their depths in response to changed water discharge or sediment load or both.

Rivers flowing in alluvium adjust quickly to

changed water discharges or sediment loads. Leopold and Langbein (1964) stated that the observed form of a channel represents a quasi-equilibrium state, adjusted to prevailing conditions of water discharge and sediment load. Should these conditions change, however, a channel will quickly alter its morphology. The Cimarron River in Kansas, for example, evolved from a channel 15 meters (50 feet) wide in 1916 to one 366 meters (1200 feet) wide in 1941 as a consequence of changes in discharge (Schumm and Lichty 1963). As the result of a flood in 1935, the channel of the Republican River in Kansas was transformed from a narrow river to a wide, sandy one (Smith 1940). The South Platte River in Nebraska was 792 meters (2600 feet) wide in 1897, but by 1959 its width measured 600 meters (1969 feet) (Schumm 1977). All of these relatively rapid changes occurred as a consequence of altered water discharge regimes, changed sediment loads, or a combination thereof.

River Channel Response to Altered Conditions

Two variables, climate and land-use change, have been put forth as the causes of stream channel modifications. Specifically, changes in either of these variables result in new discharge and sediment load

conditions. As discussed previously, these new conditions effect a change in river channel morphology.

Changes in climate, and specifically changes in precipitation, have been linked to periods of historic and pre-historic river metamorphosis. Precipitation, because it determines the amount and type of vegetation that a locality can support, as well as the amount of surface runoff to a river, is a key determinant of channel morphology. Variations in precipitation will, over an undefined period of time, cause a change in the vegetative cover. Changes in the vegetative cover, in turn, result in changed sediment yields to rivers.

Modification of the vegetative cover disrupts the prevailing balance among major stream variables. By affecting soil infiltration capacity, porosity, and permeability, such modification either increases or decreases surface runoff and sediment yield to a river. New conditions of runoff and sediment yield, in turn, alter river discharge and sediment load respectively, and trigger changes in channel morphology as the river strives for a new condition of quasi-equilibrium. The expected relationships between moisture, vegetation, and fluvial processes are summarized in Table 1:1 (Antevs 1955).

Table 1:1 Relationships Among Moisture, Vegetation, and Fluvial Processes

Climate: Phases and Fluctuations	Plant Cover	Process in Upper Reaches of Streams	Process in Middle Reaches
Subhumid	Ample	Streams relatively clear, erosion of stream valleys, soil formation where no erosion	Erosion
Changing from subhumid to semiarid	Good	Filling of stream channels, followed by soil formation on fill	Deposition
Semiarid	Good	Neither appreciable erosion nor deposition; soil formation	Entrenchment; soil formation
Changing from semiarid to arid	Sparse to fair on uplands, fair to good in valleys	Deposition	Deposition; soil formation
Arid upon change from semiarid	Impaired or poor	Accelerated erosion, arroyo-cutting, locally leaving coarse residue; local deposition of fine charco clay	Deposition; main or principal valley alluviation
Changing from arid to semiarid	Sparse to fair on uplands; fair to good in valleys	Arroyo-filling	Deposition; soil formation

Source: Antevs (1955)

This Study

Much has been written about historic channel change in river systems of humid climates, but little about channel change in river systems of subhumid climates, site of the research reported herein. Moreover, most studies, while focusing on the effects of changed land use on river systems, have largely ignored the effect seemingly insignificant climatic fluctuations have had on river systems; indeed, the existing model of historic channel change developed by Knox (1977) and his students after work in Wisconsin is primarily applicable in humid climates where changed land use, not climatic fluctuations, has had the most impact on river systems. Because climatic fluctuations can cause such rapid and substantial changes in channel width, an understanding of them is important.

Inclusion of the study area in the original federal land survey records makes this research unique. Because the study area was not settled until the mid-1870s, the 1871 land-survey records portray essentially pre-European settlement, or pristine, channel and vegetative conditions. By returning to section-line crossings of the Medicine Lodge River, Elm Creek, and Thompson Creek, and noting what changes in width have transpired in the past century, it is possible to assess the effects of

changed land use and climatic fluctuations on channel morphology.

The ultimate result of this study is a model that documents and explains historic channel narrowing along the Medicine Lodge River, Elm Creek, and Thompson Creek. This model is then compared to and contrasted with that which was devised by Schumm and Lichty (1963) in their study of the Cimarron River in southwestern Kansas. Further research may test this model for other drainage basins in the Great Plains to determine whether it depicts a local or widespread trend.

CHAPTER 2: LITERATURE REVIEW

In order to understand how climatic fluctuations affect fluvial processes, a brief review of the previous research on late-Pleistocene and Holocene fluvial change is appropriate.

Late-Pleistocene and Holocene Studies

Studies of late-Pleistocene and Holocene fluvial activity require one to decipher geologic history from alluvial stratigraphies. Using this technique, several geomorphologists have reconstructed fluvial conditions and have then linked them to certain paleoclimatic conditions. Leopold and Miller (1954) attributed periods of degradation in stream valleys of Wyoming to an increase in the ratio of high volume to small volume rains during the relatively dry Altithermal. Humid periods, according to Leopold and Miller's work, were characterized by stream aggradation. Scott (1963), in his work along the Front Range in Colorado, correlated times of maximum wetness during the Quaternary with stream channel cutting, and periods of dryness with stream channel filling and loess deposition. Daniels et al. (1963) attributed three cycles of deposition and erosion on Thompson Creek in Iowa during the late-Holocene to a fluctuating climatic regime. Baker and

Penteado-Orellana (1977), in a study of Pleistocene and Holocene Colorado River alluvial deposits in Texas, linked humid climatic phases to river aggradation, arid climatic phases to floodplain degradation followed by channel aggradation. Knox et al. (1980) delineated three Holocene fluvial deposits in the Driftless Area of Wisconsin and linked them to variations in the magnitude and frequency of floods. Hall (1980) reported a consistent pattern of late-Holocene alluviation, erosion, and soil formation in the alluvial stratigraphy of Oklahoma. Periods of floodplain aggradation were ascribed to moist conditions, periods of floodplain incision to dry conditions. Brakenridge (1981) suggested that periods of river incision along the Pomme de Terre River in south-central Missouri during the past 40,000 years were caused by intensified meridional air flow. Such flow, by increasing precipitation amounts, would have resulted in higher magnitude stream discharges and more frequent flooding. Increased zonal flow, which would have reduced precipitation amounts and thus the frequency and magnitude of floods, would have resulted in stream aggradation and stabilization. In a later study on the Duck River in Tennessee, Brakenridge (1984), using paleosols as stratigraphic markers, divided Holocene alluvial fills into three distinct

units. As in his earlier study, he ascribed periods of floodplain stability and soil formation to reduced flood frequency and intensity caused by a more zonal upper atmospheric circulation. Increased fluvial activity and floodplain accretion were believed to have been caused by an increase in flood frequency and intensity under a period of intensified meridional atmospheric circulation.

Other authors, believing that the connections between paleofluvial activity and specific climatic fluctuations are as yet unknown, have simply attributed late-Pleistocene and Holocene cut and fill episodes to unspecified changes in climate. Cooley (1962) noted at least five stages of fluvial aggradation and degradation prior to recent incision and arroyo cutting in rivers of the Colorado River basin, but he did not attempt to relate the aggradation and degradation to specific climatic regimes. Gooding (1971) divided the post-glacial alluvial stratigraphy of the Whitewater River in Indiana into an entrenchment phase and an alluviation phase, but did not link this fluvial activity to any specific climatic fluctuations. Ritter et al. (1971), in a study along the Delaware River in Pennsylvania, characterized the past 6000 years in that area as a period of overbank alluviation and floodplain

construction, but provided no explanation for such activity. Albanese (1974) noted the presence of four unconformities in Holocene alluvial stratigraphies in Wyoming, but was hesitant about attributing them to a particular type of climatic regime.

Clearly, association of a particular climatic regime with a particular cut or fill episode is a difficult task, especially when data about paleoenvironmental conditions are lacking. The presence of paleosols in an alluvial exposure indicates periods of landscape stability, but there is some question about using them to reconstruct paleoenvironmental conditions. Indeed, it is still uncertain "whether we understand the interaction of soil-forming processes with the site and environmental factors well enough yet to make confident extrapolations [about paleoenvironmental conditions]" (Valentine and Dalyrmple 1976:218). Finally, there is concern that much of the evidence of cutting and filling that we see preserved in late-Pleistocene and Holocene alluvial exposures may not have been the result of individual external events such as climatic fluctuations, but rather the result of a complex response of drainage systems to a single event (Schumm 1977). According to Schumm's model, high sediment production triggered by a single change in climate, land

use, or baselevel results in deposition. Such deposition, in turn, steepens river gradient. As the gradient steepens, the river develops a capacity for transporting sediment, and eventually begins to erode its bed and banks. This newly eroded sediment is deposited downstream, and the process begins again. When repeated along the length of a drainage basin, this series of events results in complex alluvial cut and fill sequences.

In summary, several geomorphologists have attempted to infer climatic conditions from late-Pleistocene and Holocene alluvial chronologies. In light of the few studies completed on this topic, it is difficult to conclude whether we know enough about the linkages between fluvial change and climate to relate an episode of cutting or filling to a particular climatic regime; indeed, some view the complex alluvial stratigraphic record preserved in the Great Plains as evidence of frequent climatic fluctuations in the past, while others (e.g., Schumm 1977) regard it as evidence of the breaching of geomorphic thresholds.

Historic Channel Change

Of primary importance to this study is the research that has been conducted on historic channel change; in this thesis, historic channel change is defined as that

which has taken place since European settlement. Most previous research on such change has utilized historical documents such as old maps, photographs, surveys, and field notes to reconstruct earlier channel and vegetative conditions. Field work has then been conducted to determine what changes have taken place since the original documentation.

Gullying Early work on the subject of historic channel change dealt with the problem of gullying in the American Southwest. Although gullying was first addressed in the late 1920s, its cause, be it climatic fluctuations, overgrazing, catastrophic events, or a combination thereof, is still debated in the literature. Early studies presented the hypothesis that settlement and overgrazing precipitated gullying. Bryan (1927:17) described the gullying in the Southwest as a "deepening and widening of stream channels" that commenced in the 1860s. Bailey (1935) linked it to a new epicycle of erosion in the Colorado Plateau province. Citing the presence of extensive alluvial fills as evidence, he maintained that rivers in the Colorado Plateau had been aggrading, not degrading, their channels prior to settlement of the area. Settlement disturbed the natural vegetative cover, increased

surface runoff, and caused floodplain incision.

Later research on the gullying problem suggested that climatic fluctuations may have initiated entrenchment of alluvial fills. Leopold (1951) and Miller and Wendorf (1958) attributed the accelerated erosion that has occurred since the 1880s in arid and semi-arid portions of the United States to increased magnitudes of precipitation. In two later studies, Tuan (1966) and Denevan (1967) concluded that climatic fluctuations and overgrazing acted in unison to initiate and sustain the gullying cycle. Cooke and Reeves (1976:97) agreed with this view when they concluded that gullying "arose from several interrelated environmental changes." They added that the available data strongly suggested that certain factors, specifically changes in precipitation magnitudes and land use since the 1870s, had initiated and maintained gullying.

Schumm and his associates suggested that episodic gullying in the Southwest may have been the normal sequence of events whereby the region's drainage system responded to change in an external variable. Schumm and Womack (1977) concluded that, although the initial incision of valley floors in the southwest may have been triggered by overgrazing, the subsequent cutting and filling was simply the process whereby sediment was

transported out of the drainage basin. In a later study along the same theme, Patton and Schumm (1981) cited alternating erosional and depositional reaches along river channels in arid and semi-arid regions of the United States as evidence that sediment in those climates is transported episodically out of basins. According to them, multiple episodes of cutting and filling do not necessarily represent a response to a series of changes in an external variable or variables, but may simply represent a response to a single change in one variable.

More recently, Graf (1983) has called for a closer examination of spatial and temporal variables to explain gully development. The concepts of equilibrium, rate laws, thresholds, complex responses, distance decay functions, reversibility, and the balance between force and resistance should be considered in such a study.

In summary, much of the early work on historic channel change focused on the problem of gullying in the southwestern United States. Early research ascribed the gullying that had occurred since the 1860s to overgrazing (e.g., Bryan 1927; Bailey 1935). Later works cited increased precipitation intensity as the probable cause of the erosion (Leopold 1951; Miller and Wendorf 1958). Other geomorphologists argued that overgrazing

and climatic fluctuations, working in tandem, initiated cycles of gully erosion (e.g., Tuan 1966; Denevan 1967; Cooke and Reeves 1976). One recent hypothesis states that alternating periods of cutting and filling in arid and semi-arid climates should be ascribed not to climatic fluctuations, but rather to the natural process whereby sediment is episodically transported through a drainage basin. Examination of temporal and spatial variables may be the most fertile area for future research on gully development.

Studies of Change in Channel Width Several studies on historic channel widening and narrowing have been conducted in the United States. Early studies described changes in channel width, but did not attempt to correlate such changes with climatic fluctuations or land-use changes. Later studies, which had the advantage of a longer record of channel change and more climatic data, have been more integrative, often linking precipitation fluctuations and changed land use to channel change, and then developing a model that explains observed changes. Much of the recent work has focused on river systems in humid and arid climates; indeed, since the 1940s, little has been done on river systems of the sensitive ecotone between subhumid and semi-arid climates, site of the research reported

herein.

Studies of historic channel change in the Great Plains have dealt primarily with changes that have occurred since settlement of the area by Europeans in the 1870s. Such research has shown that rivers in the Great Plains have been active since the 1870s, frequently widening and narrowing in response to climatic fluctuations and changed land-use conditions. In 1940, Smith reported that the Republican River in Kansas had recently widened. Another major Kansas river, the Cimarron in the southwestern part of the state, also underwent significant changes in channel width during the past century. McLaughlin (1947) and Schumm and Lichty (1963) reported that the Cimarron River changed from a meandering channel 31 m (100 ft) wide in the early 1900s to a wide, straight channel 366 m (1200 ft) wide in the 1940s. Between 1943 and 1954 the river narrowed to a width of 168 m (550 ft). After 1954 it alternately widened and narrowed, but maintained a width of around 152 m (500 ft) in the early 1960s (Schumm and Lichty 1963). In a similar study in Arizona, Burkham (1972) reported that the Gila River widened from less than 91 m (300 ft) in 1903 to 366 m (1200 ft) in 1917. In 1968, however, the channel had narrowed to 122 m (400 ft). In a study in eastern

Kansas, Johnson (1979) reported that the Wakarusa River had widened since European settlement of the area more than a century ago. Johnson et al. (1980) found increases in headwater channel capacity and historic floodplain alluviation on Canadian Sandy Creek, a small stream in central Oklahoma. Other Great Plains rivers have narrowed since European settlement of the area, including the North and South Platte Rivers, the Arkansas River, and the Red River (Schumm 1977).

Research describing historic channel change has also been conducted on rivers of the humid and heavily forested eastern half of the United States. Happ (1944), after surveying the Kickapoo River and comparing his channel width measurements with the pre-settlement measurements obtained from the original federal land-survey, concluded that headwater channels had widened while those downstream had narrowed since the earlier survey had been conducted. Because trunk streams were unable to handle this sudden influx of eroded sediment from headwater channels, sediment accumulated on downstream channel point bars and floodplains. In downstream exposures, Happ reported an old soil surface, which he named the 1850 pre-settlement surface, beneath 0.75 m (2.5 ft) of sandy silt. Historic artifacts found in this sandy alluvium pointed to its recent deposition

(Happ 1944). In a similar study 30 years later on the Platte River watershed of southwestern Wisconsin, Knox (1972, 1977) reported historic widening of headwater channels and narrowing of downstream trunk channels. He, too, located a pre-settlement soil, this one beneath 0.5 to 4 m (1.6 to 13 ft) of historic floodplain alluvium.

In addition to the work of Knox and his students in Wisconsin, studies have been conducted on historic channel change in other regions of the eastern United States. Gooding (1971) reported historic stream channel incison in the Whitewater River basin, Indiana. He further noted that much of the sediment eroded from channels was then deposited on floodplains when floodwaters receded. Leopold (1973) wrote that Watts Branch in Maryland slowly narrowed between 1953 and 1966 as sediment eroded from the surrounding area accumulated in channels. After 1966, with increased land alteration, the pace of this accumulation quickened, resulting in reduced channel capacity and frequent flooding. Eventually, the increased frequency of flooding caused channel erosion and an increase in channel capacity. Brakenridge (1984) concluded that the introduction of row-crop agriculture, grazing, and other intensive human land-use practices to the Duck River

basin, Tennessee, may have produced as much floodplain accretion as any single climatic change that had occurred in the basin during the previous 10,000 years.

Studies in the Piedmont river basins of Maryland, Georgia, the Carolinas, and Virginia by Happ (1945), Trimble (1974), and Costa (1975) suggested that clearing of that region's natural vegetation by settlers in the 1700s increased surface runoff and sediment yields to rivers and resulted in extensive floodplain alluviation. The choking of rivers and streams with sediment reduced channel storage capacities and augmented the frequency and magnitude of overbank floods. Indeed, Costa (1975) estimated that two-thirds of all the sediment eroded from Maryland and Virginia tobacco fields is stored in downstream river floodplains.

In conclusion, the subject of historic channel change has attracted the attention of fluvial geomorphologists for years. Early workers stressed the influence overgrazing had on late-19th century gullying in the southwestern United States. Later, as geomorphologists realized the importance of precipitation fluctuations in initiating gullying, they began to integrate the variables of climatic and land-use change to explain cycles of erosion and deposition in the Southwest. The subject of river channel width

changes has also attracted attention among fluvial geomorphologists. Research has suggested that rivers in the Great Plains have alternately widened and narrowed since the late 1800s. Studies in Wisconsin and in the Piedmont region suggested that headwater channels widened, downstream channels narrowed, after settlement of the two areas in the 1800s and 1700s, respectively. One theme that has been evident through all the research on historic channel change is that rivers respond quickly to changed environmental conditions, often in a few decades or less.

Causes of Channel Change

Geomorphologists have put forth two factors, climatic fluctuations and land-use changes, to explain historic channel change. Changes in either factor force a river system into a state of disequilibrium, requiring modification of stream variables.

Climatic Variation In 1951, Leopold established that fluctuations in the magnitude of precipitation do occur, and determined that such fluctuations may not be evident in gross annual precipitation totals. Prior to Leopold's work, geomorphologists had hypothesized that a link existed between climatic fluctuations and channel changes. For example, Bailey (1935), who studied the

cycle of erosion on the Colorado Plateau, suggested that a change from low- to high-magnitude precipitation events could cause channel erosion, a change in the opposite direction channel aggradation. He also pointed out, as did Leopold, that such changes would not necessarily appear in annual precipitaion totals.

In his study, Leopold examined precipitation data from four stations in New Mexico for the period 1850-1930, and selected three event classes, .25-12.4 mm/day (.01-.49 in/day), 12.5-25 mm/day (.50-.99 in/day), and 25+ mm/day (1.0+ in/day), as measures of precipitation magnitude. The frequency of occurrrence for each class during the study period was then tallied. Tabulations indicated that the frequency of rains smaller than 12.5 mm/day (.50 in/day) increased from 1850 to 1930, but because of opposite trends in the other size classes, the annual precipitation totals did not reflect this increase (Leopold 1951).

Leopold (1951) also concluded that rivers aggrade or degrade their channels depending on the relative number of discharges of a given magnitude that occur; such discharges are controlled by the frequency of various magnitudes of precipitation. Miller and Wendorf (1958) determined that an increased frequency of large rains uproots, and hence weakens, the vegetative cover,

favoring erosion and higher river discharges. Subsequently, Schumm and Lichty (1963) ascribed channel changes along the Cimarron River in Kansas to changes in flood magnitudes brought about by varying precipitation magnitudes. Burkham (1972) reached a similar conclusion as a result of his study of the Gila River in Arizona.

From the above research, it appears that floods can accomplish a significant amount of geomorphic work in subhumid and semi-arid climates, perhaps because such climates support a sparse vegetative cover; in more humid environments, however, most geomorphic work apparently is accomplished by flows of a lower magnitude (Wolman and Miller 1960). Knox et al. (1975) stressed the importance of floods in causing channel bank and bed erosion. Baker (1977) concurred that highly variable flood magnitudes can perform a significant amount of geomorphic work in drainage basins of drier climates.

The most difficult problem facing scholars who study precipitation variation is to relate a certain flood regime to a given type of climatic regime; in other words, they encounter the problem of ascribing a high-or low-magnitude precipitation regime to a humid or dry climatic regime. Patton and Dibble (1982) characterized humid periods during the late-Quaternary as having floods of fairly uniform magnitude, arid

periods as having floods of highly variable magnitude. They concluded that the more extensive vegetative cover of the humid period increased water interception, surface retention, and evapotranspiration, thereby reducing surface runoff and attenuating flood peaks. Schumm and Lichty (1963) noted that periods of above-average precipitation along the Cimarron river were associated with floods of low-to-moderate peak discharge, while periods of below-average precipitation were associated with floods of high peak discharge. Knox (1972) reported that a shift towards greater precipitation would increase the effectiveness of the vegetative cover, thereby reducing the magnitude and frequency of peak flood flows. Conversely, a shift towards a drier climate would reduce the vegetative cover, thereby increasing the frequency and magnitude of peak flood flows.

In summary, the magnitude and frequency of precipitation events do fluctuate, more often in dry than in humid climates. These fluctuations, in turn, affect river discharge. Based on the work of Schumm and Lichty (1963), Knox (1972), and Patton and Dibble (1982), it appears that humid periods are characterized by an increased vegetative cover, more uniform runoff, and low to moderate peak flood discharges. Drier

periods feature a reduced vegetative cover, highly variable runoff, and floods of relatively high peak discharge. According to this model, humid periods result in river stability, aggradation, or channel narrowing, dry periods in river instability, degradation, or widening until such time as a new condition of equilibrium is reached.

Changed Land Use Land use is the second factor that is linked to historic channel change. Numerous studies, from the 1930s to present, isolated replacement of natural vegetation with crops by European settlers as the catalyst for recent fluvial activity. Most concluded that disturbance of the natural vegetative cover increased surface runoff and sediment yields to rivers and streams. The augmented runoff, in turn, lead to larger peak discharges and channel erosion.

Several studies attributed river channel aggradation or degradation or both to disturbance of the natural vegetative cover. In Kansas, Smith (1940) linked accelerated erosion along the Republican River to disturbance of the land cover. In a study along the Kickapoo River in southwestern Wisconsin, Happ (1944) attributed increased soil erosion and fluvial sedimentation in the river to deforestation,

cultivation, and grazing of hillslopes. McLaughlin (1947) ascribed channel widening on the Cimarron River in Kansas to overcultivation of the land and the subsequent abandonment of many acres of bare ground. Gooding (1971) suggested that deforestation and cultivation in the Whitewater River basin, Indiana, increased surface runoff to channels, resulting in larger and more frequent floods. The new flood regime, in turn, initiated channel incision. More recently Knox (1977), after work in Wisconsin, reported that conversion of the natural vegetative cover to cultivated fields caused a 3-fold to 5-fold increase in the magnitude of floods that recur more frequently than once in five years. After comparing present channel widths with those from the original federal land-survey records, he concluded that headwater channels had become wider and shallower to accomodate this increase in discharge. Downstream, however, channels had narrowed as sediment eroded off the disturbed landscape and from the headwater tributaries was stored on floodplain surfaces. He cited the presence of the pre-settlement surface soil buried beneath from 0.46 to 3.6 m (1.5 to 12 ft) of post-settlement alluvium as evidence of this alluviation.

Several studies in the eastern United States have

also addressed the link between changed land use and recent channel change. In a study of the Piedmont region of Maryland, Costa (1975) found that clearing of land in the 1700s increased runoff and sediment yields to rivers. Aggradation in channels, the result of the large influx of sediment, decreased channel storage capacities and resulted in more frequent overbank floods and floodplain alluviation. Trimble (1977) found similar accumulations of eroded sediment in the Piedmont river basins of Georgia, the Carolinas, and Virginia. With the acceptance of conservation practices in the early 20th century, sediment yields were reduced, and streams, now having an excess transporting capacity, entrenched the post-settlement alluvium. It is also possible that entrenchment was simply the next phase in the adjustment of river systems to the altered hydrologic conditions, although this hypothesis has never been examined for river systems in humid climates.

To conclude, studies on the adjustment of river systems to altered natural vegetative cover generally agree that rapid and significant channel metamorphosis has occurred in many river systems. Conversion of the land cover from natural vegetation to crops resulted in increased surface runoff and sediment yields to rivers. In addition, the frequency and magnitude of peak flood

discharges also increased. Headwater channels have been eroded to accomodate these higher discharges. Much of this eroded sediment has been subsequently stored in downstream floodplains and channels, reducing channel storage capacity and giving rise to more frequent overbank flooding. When land-use changes happen to coincide with a climatic fluctuation, as may have been the case in the southwestern United States during the gully cycle of the 1880s, even more visible and damaging erosion and alluviation can occur.

Role of Vegetation

Deferred until now has been a discussion of the role riparian vegetation plays in channel change, and specifically in the process of channel narrowing. Although it does not initiate narrowing, vegetation, once established, does stabilize recently deposited floodplain sediments, thereby preserving the narrowing that has already taken place. Moreover, it may encourage further narrowing by aiding the entrapment of additional sediment.

Floodplains are constructed by one or more of the following processes: 1) development of islands in channels and attachment of them to banks when channels are abandoned; 2) direct deposition of sediment on floodplains; 3) deposition of sediment on stream channel

banks or sides; 4) formation of natural levees; and 5) deposition of sediment on alluvial fans at the mouths of tributary streams (Wolman and Leopold 1970; Burkham 1972; Lewin 1983). Wolman and Leopold (1970) downplayed the importance of vertical accretion relative to lateral accretion in floodplain formation, but several other studies have maintained that vertical accretion, in the form of overbank sedimentation, is the most important mechanism of floodplain construction in rivers of the western United States (Schumm and Lichty 1963; Everitt 1968; Ritter et al. 1973; Stone 1980; Brakenridge 1984). Most likely, floodplain formation in a given river is a complex process that involves several types of sediment accretion (Lewin 1983).

The role of vegetation in stabilizing channel banks and floodplains is not seriously questioned by geomorphologists. As Leopold and Wolman (1957) pointed out:

> The width of a river is subject to constant readjustment if the banks are not well-stabilized by vegetation. The magnitude of the readjustment depends on the nature of the banks and the amount and type of vegetation they support.
>
> (Leopold and Wolman 1957:63-64)

Schumm and Lichty (1963) and Burkham (1972), in

studies of the Cimarron River in Kansas and the Gila River in Arizona respectively, noted the importance of vegetation in floodplain reconstruction following a flood. Schumm and Lichty (1963:79) added that "...the establishment of perennial vegetation was a great aid to floodplain formation.... The trees that border the channel offer considerable protection to the banks, and channel widening may be less easily accomplished under these conditions."

Once established, vegetation often contributes to channel narrowing. Leopold and Wolman (1957) stated that if a channel is wider than that which is needed to maintain a condition of equilibrium, vegetation will begin to grow in unused portions. This vegetation stabilizes sediment and induces further deposition by reducing the velocity of sediment-laden water (Everitt 1968). In his research along the Green River in Utah, Graf (1978) reported an average channel narrowing of 27 percent resulting from an influx of tamarisk to the area; apparently, the trees have trapped and stabilized sediment along the river.

Vegetation is also useful in determining the time when floodplain sediments stabilized. By ascertaining the maximum age of trees along channel banks and floodplains, one can determine the length of time that

the floodplain has been stable. As Sigafoos (1964) emphasized, "...trees can become stabilized on a floodplain only during extended periods of lowflow; yet, once established, they mature and stabilize the banks" (Sigafoos 1964:261). In an effort to map the movement of the Little Missouri River in North Dakota, Everitt (1968) used the ages of cottonwood trees as indicators of the time when the floodplain stabilized; cottonwood, willow, and a number of annuals are the best indicators of stability because they are the first vegetation to take root in stream channel deposits. Using cores to establish tree ages, Everitt found an orderly increase in cottonwood ages as he moved away from the river. With this information, he compiled a contour map of recent channel migration. This mapping technique is especially useful in areas such as the Medicine Lodge drainage basin where sequential aerial photography, which would allow the charting of channel movement and width changes, is unavailable.

In summary, riparian vegetation helps stabilize channel banks and floodplains, induces further sedimentation, and acts as a barrier against extensive channel erosion during floods. Mapping the temporal and spatial distribution of trees along channel banks provides an estimate of the time when floodplain

sediments stabilized. The mapping of tree ages along transects normal to a river produces a chronology of river channel contraction or lateral shifting or both.

Work completed in the field of historic channel change suggests that rivers adjust rapidly and visibly to changed environmental conditions such as human alteration of natural vegetation or shifts in climate. Through their work on the Cimarron River, Schumm and Lichty (1963) demonstrated that rivers in the Great Plains commonly adjust their width without changing the elevation of their channel floor. Width adjustments appear to be caused by changes in precipitation magnitude or frequency or both. Schumm and Lichty's work and this thesis constitute the first steps towards development of a model explaining historic channel change in the Great Plains.

CHAPTER 3: STUDY AREA

Both the physical landscape and historical settlement of it have likely influenced channel narrowing in the Medicine Lodge River basin. For this reason, the following discussion addresses both the physical and cultural aspects of the study area.

Geology

The Medicine Lodge River and its tributaries drain 2520 square km (1565 square miles) of south-central Kansas (Plate 3:1), a physiographic region commonly known as the Red Hills. The name Red Hills originates from the red rocks of Permian Age that stretch across a large portion of the southern Great Plains, and are exposed in the western portion of Barber County and the southeastern corner of Kiowa County (Plate 3:2). Within Kansas, these Red Hills are composed of the very friable and easily eroded reddish-brown, anhydritic silty mudstones, shales, siltstones, and sandstones of the Whitehorse Formation and Nippewalla Group. Several of these formations, most notably the Flower-Pot Shale and the Blaine Formation in the Nippewalla Group, are cemented with gypsum (Latta 1946; Merriam 1963). Geologists believe that the red beds were deposited in

STUDY AREA: HEADWATERS OF MEDICINE LODGE RIVER, ELM CREEK, AND THOMPSON CREEK, KANSAS

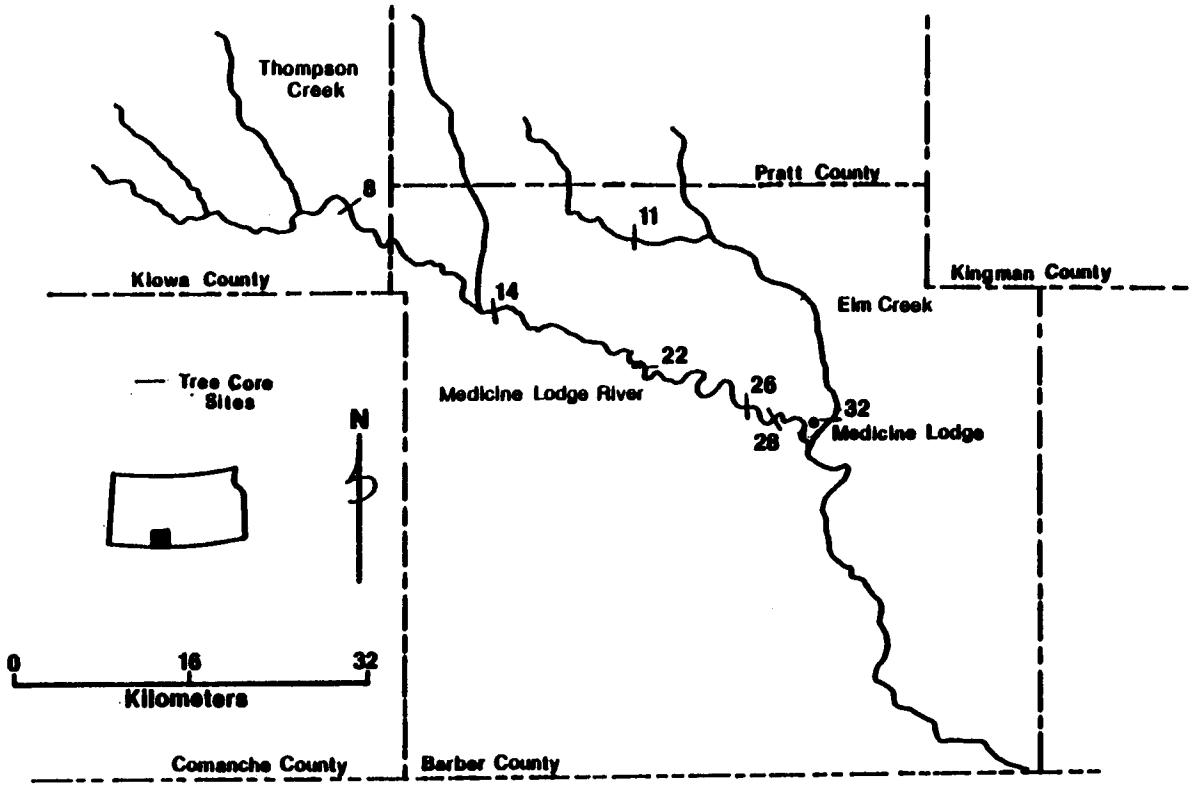
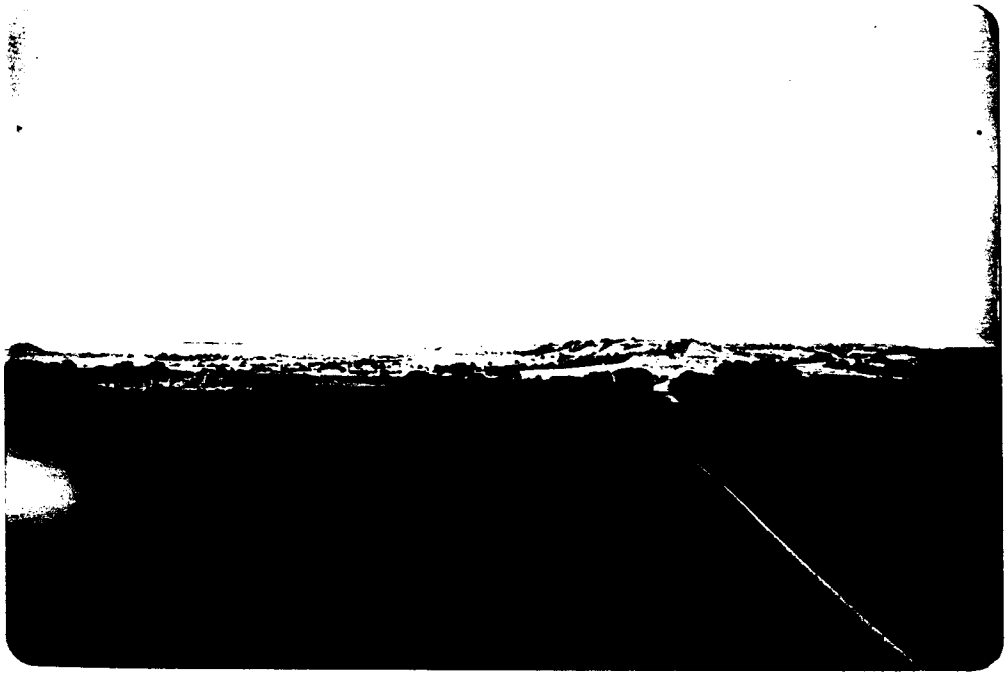


Plate 3:1 Study Area

Plate 3:2 Red Hills Landscape



shallow, brackish-to-saline seas (Holdoway 1978). The ancestral Rockies to the west may have supplied much of the debris that today constitutes these red rocks (Merriam 1963).

An unconformity separates the Permian beds from the overlying Comanchean Series of Cretaceous age. The Comanchean consists of the Cheyenne Sandstone, Kiowa Shale, and Dakota Sandstone. The light colored, fine- to medium-grained, cross-bedded Cheyenne Sandstone overlies the eroded Permian surface. Although weakly cemented, for the most part, the Cheyenne Sandstone does contain some hard layers that have resisted erosion to form the badlands topography found in the northwestern corner of Barber County and the southeastern corner of Kiowa County. The overlying Kiowa Shale is a thin, dark shale that grades upward into clayshale and shell limestone; in some exposures, it also contains lenses of fine-grained sandstone. The youngest rock in the Comanchean, the dark-brown, iron cemented Dakota Sandstone has been removed by erosion in much of the study area (Latta 1946).

Geologists maintain that the Cheyenne Sandstone, which is continental in origin, was deposited by aggrading streams on dry, coastal plains near the advancing strand line of the shallow, brackish

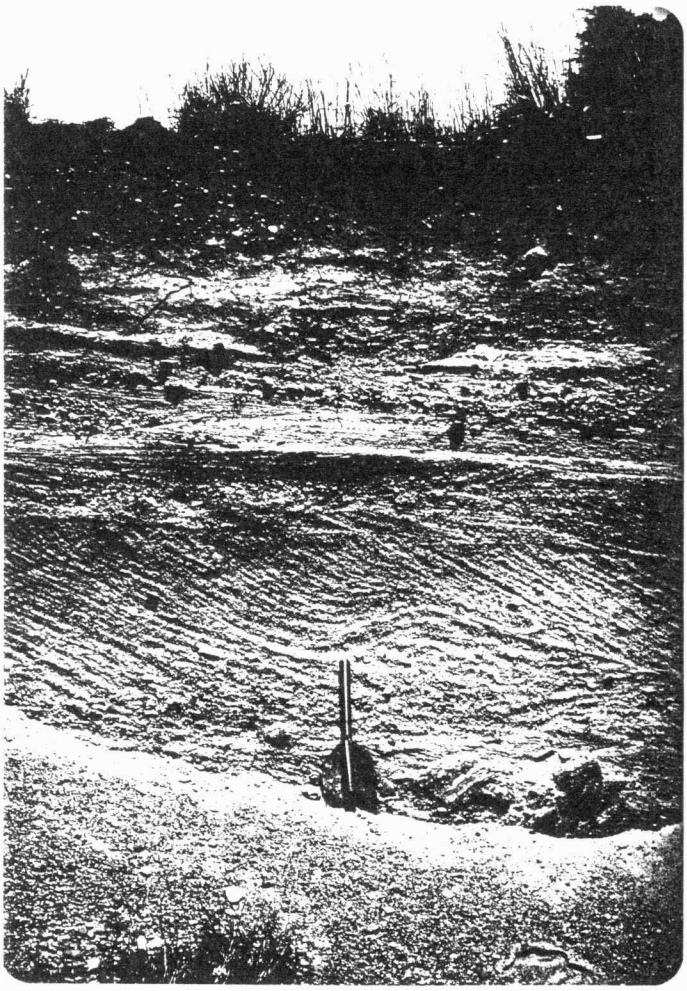
Comanchean Sea (Latta 1946). The Kiowa Shale was then deposited in and along margins of this same sea. Currents and waves created the interlaminated shales, silts, and sand layers so prevalent in this formation. Once the sea began to regress, the coarse sands which constitute the Dakota Sandstone were deposited in stream channels, floodplains, beaches, and lagoons (Latta 1948; Franks 1966). Other shales and sandstones were deposited during subsequent invasions of the sea, but all have been eroded from the study area.

Capping the Cretaceous bedrock is a complex series of late-Tertiary and Quaternary sands, silts, and gravels, most of which have been inadequately classified and correlated. In fact, the only Tertiary unit that has been widely identified in the study area is the Ogallala Formation. Following erosion of the underlying Cretaceous materials during the early Tertiary, rivers began to aggrade their beds, depositing the silts, sands, and gravels that constitute this formation. Subsequent erosion during the early Pleistocene removed some of the Ogallala, but along the Medicine Lodge River and its tributaries, this calcareous, calcium cemented, yellow, brown and gray sand and gravel formation can still be seen. (Latta 1948).

More work has been done with the extensive

exposures of later Pleistocene gravels found in river and stream valleys streams and on uplands (Plate 3:3). The oldest of the Pleistocene formations is the Meade Formation. Tan, brown, and reddish-brown fluvially deposited clays, silts, sands, and gravels intermixed with a few isolated beds of volcanic ash constitute the Meade Formation, which reaches thicknesses of up to 91 m (300 ft) at some localities. The tan-to-brown-colored, eolian and fluvial silts and sand/silts of the Kingsdown Silt Formation are unconformable on the Meade (Latta 1948). Several cycles of fluvial erosion and deposition, most likely related to glacial activity during the late-Pleistocene, produced the 9 to 60 m thick (30 to 196 ft) continuous, upland blanket of fine to coarse sands and gravels classified as the Grand Island Formation, and the sandy, silty Sappa Formation (Layton and Berry 1973). Unfortunately, little research has been undertaken on the Holocene alluvial and colluvial deposits and terraces along the Medicine Lodge River and its tributaries. For this reason, little is known about the basin's fluvial history over the past 10,000 years.

Plate 3:3 Pleistocene Upland Gravels



During the course of field work, however, three paleosols were noted along Elm Creek, one paleosol along Thompson Creek, and one paleosol with a cut and fill sequence along the Medicine Lodge River. Because this thesis addresses historic channel activity, there was no attempt to determine the significance of these paleosols to the Holocene fluvial environment of the basin. Nevertheless, their presence demonstrates that fluvial cutting and filling has been separated by periods of stability during the past several thousand years.

Today, the headwaters channels of the Medicine Lodge River and Elm Creek have incised into their old floodplains, and appear to be cutting headward towards the northwest and north respectively. Downstream, the Medicine Lodge River and Elm Creek are flowing in well-defined channels about 1.5 to 3 m (5 to 10 ft) below the level of the surrounding landscape. Both rivers have a high width-to-depth ratio, and both appear to be transporting predominantly a load of fine to coarse sands.

Soils

Soils within the Medicine Lodge River basin are classified as mollisols, entisols, or inceptisols, and have been divided into upland, lowland, or floodplain soils. Upland soils are classified as argiustolls,

which are mollisols containing an illuvial clay horizon, lowland soils as ustochrepts, which are inceptisols with a light colored surface, and floodplain soils as either ustifluvents, which are entisols that developed in floodplain alluvium, or as ustipsamments, which are entisols of a sandy texture. (Dodge 1977).

The following divisions have been made on the basis of soil position in the landscape. Upland soils have formed in the sands and gravels of old alluvium. Being primarily loamy and sandy loam soils, they are well-drained and have slow to medium runoff. Subsurface horizons commonly contain clay illuviated from the A horizon. Loamy soils found on steep slopes are the Albion-Shellabarger soils, while those loamy soils found on nearly level and gently sloping topography are the Blanket-Farnum soils. Sandy and loamy soils developed on nearly level to gently rolling topography are the Pratt-Attica-Farnum soils, while those soils of a loamy texture developed on nearly level and gently sloping topography are the Farnum-Naron-Ost soils. All of these upland soils are found mainly to the north of the Medicine Lodge River in Barber, Pratt, and Kiowa Counties (Dodge 1977).

Lowland soils are shallow soils that formed in material weathered from soft sandstone, siltstone, and

shale. The Vernon-Kingfisher soils, formed in material weathered from siltstone and shales, have a clay loam texture, poor permeability, and rapid surface runoff. The Quinlan-Woodward-Grant soils, formed in material derived from sandstone, have a silt loam to loam texture, slow runoff, and rapid permeability. These two types of soil are found mainly on lowlands, but also appear on some uplands south of the Medicine Lodge River (Dodge 1977).

Floodplain soils formed in floodplain and stream terrace alluvial deposits. The Lincoln-Yahola soils, which are found immediately adjacent to the Medicine Lodge River, Elm Creek, and other major tributaries of the basin, developed in recently deposited sandy alluvium. They have a sandy to loamy texture, are excessively drained and very permeable. The Port-Canadian-Minco soils formed in silty and clayey alluvium on stream terraces. They feature a surface horizon with a silt loam texture and subsurface horizons with a heavy silt loam or silty clay loam texture. They are well-drained and moderately permeable (Dodge 1977).

Soil texture varies markedly across the study area, and especially across the headwaters of the Medicine Lodge River and its tributaries. For example, the texture of the material in which the Medicine Lodge

River and Elm Creek have their headwaters differs. Elm Creek, at its headwaters in southern Pratt County and northern Barber County, flows through the loamy Blanket-Farnum and Albion-Shellabarger soils. As a result, it carries a substantial load of loamy and sandy material. In contrast, the Medicine Lodge River, with its headwaters in southeastern Kiowa County, flows in the finer textured Quinlan-Woodward and Vernon-Kingfisher soils. Consequently, the Medicine Lodge River transports a finer sediment load in its headwaters than does Elm Creek. As will be shown, these differences have affected the changes in channel width that occurred in the headwaters of these two systems.

Climate

The area drained by the Medicine Lodge River receives about 640 mm (25 in) of precipitation each year, classifying it as a subhumid climate (Dodge 1977). The three stations closest to the Medicine Lodge drainage basin (Medicine Lodge, Pratt, and Greensburg) have maintained precipitation records since the early 1900s. Medicine Lodge, which is located within the drainage basin, received an annual average of 644 mm (25 in) of precipitation over a 79 year record. Pratt, which is located just north of the drainage basin, received an

annual average of 620 mm (24 in) of precipitation over a 73 year record, while Greensburg, which is located northwest of the drainage basin, received an annual average of 579 mm (23 in) of precipitation over a 71 year record. At all three stations, most precipitation comes from frequent convective storms in the late-spring and early summer. Table 3:1 summarizes monthly temperature and precipitation values for the Medicine Lodge station.

Table 3:1 Medicine Lodge Temperature and Precipitation

	Temperature (C°)		Precipitation
	Mean Daily Max.	Mean Daily Min.	(mm)
J	7.9	-6.3	12.8
F	11.0	-4.3	22.3
M	16.2	.1	34.6
A	22.1	6.6	58.4
M	26.6	12.3	102.6
J	31.9	17.5	92.4
J	35.1	19.8	72.9
A	34.8	19.1	73.5
S	30.2	14.6	69.4
O	23.8	7.7	54.8
N	15.7	.2	29.4
D	9.1	-4.8	19.9

Source: Dodge 1977:71.

Analysis of precipitation data reveals that annual precipitation totals in the Medicine Lodge River basin display significant year-to-year variation. For example, at Medicine Lodge the wettest year on record was 1923, when 1080 mm (42 in) of precipitation were

recorded, while the driest year was 1954, when only 286 mm (11 in) of precipitation fell. Such annual variation has likely had a substantial impact on the vegetative cover of the drainage basin.

Vegetation

Vegetation in the Medicine Lodge River drainage basin can be separated into that which is natural to the area and that which has been imported by European settlers. Land-use data for Barber County serve as an estimate of this divison between natural and cultivated vegetation. In 1980, 90,960 hectares (224,670 acres), or 31 percent of the land in Barber County, was under cultivation. 185,829 hectares (459,000 acres), or 62 percent of the total land area in Barber County, was in pasture; the remaining 7 percent of the land was paved or regarded as unuseable for human purposes (Kansas State Board of Agriculture Annual Bulletin 1980). Pasture is generally located on the more rugged valley sideslopes and along rivers and streams, while cultivated land is found on the more level uplands.

Grassland is the predominant natural vegetation of the study area, although there are scattered riparian forest stands along rivers and streams. Tall grass prairies are found on the few upland pastures and along rivers, mid- and short grass prairies on valley sides.

Common prairie grasses include little bluestem (Andropgon scoparius), big bluestem (A. gerardi), switchgrass (Pancium virgatum), indiangrass (Sorghastrum nutans), Scribner's panic grass (P. scribnerianum), sand dropseed (Sporobolus crytndrus), blue grama (Bouteloua gracilis), hairy grama (B. hirsuta), eastern gramagrass (Tripsacum dactyloides), prairie cordgrass (Spartina pectinata), Canada wild-rye (Elymus canadensis), Maximilian's sunflower (Helianthus maximiliani), western wheatgrass (Agropyron smithii), sideoats grama (B. curtipendula), Baldwin's ironweed (Vernonia baldwini), sand sagebrush (Artemesia filifolia), buffalo grass (Poa pratensis) and foxtail barley (Hordeum jubatum) (Weaver 1954; Dodge 1977). Along rivers and streams, eastern cottonwood (Populus deltoides), American elm (Ulmus americana), white ash (Fraxinus americana), northern catalpa (Catalpa speciosa), redcedar (Juniperus virginiana), black willow (Salix nigra), hackberry (Celtis occidentalis) and black walnut (Juglans nigra) commonly grow. As will be shown later in the discussion of pre-settlement vegetative conditions, it does not appear that today's vegetative cover differs significantly from that which existed prior to settlement of the area, except that tree cover increased along river and stream banks.

Cultural History

The Medicine Lodge River basin was settled during the large westward migration from Illinois, Missouri, Iowa, Indiana, and Ohio in the late-1860s and early 1870s. Conditions in the United States at that time favored this general movement west: the railroad had begun to move westward, the Indians were being herded onto reservations, credit and easy loans were widely available, and plentiful rainfall in the Great Plains during the 1870s was taken as an indication that the climate would support crops (Sheridan 1956).

In 1871, the first settlers arrived in what today is the town of Medicine Lodge. In 1873, Barber County, then supporting 100 settlers, was organized by the state legislature. Attracted by the prospects for cattle ranching and farming, people continued to settle there, and, by 1880, approximately 2000 people resided in Barber County (Barber County Historical Committee 1980).

The next ten years, from 1880 to 1890, were a period of great growth and transition in Barber County. Between 1881 and 1885 Barber County's population more than tripled from 2282 in 1881 to 7800 in 1885 (Barber County Historical Committee 1980). To be sure, much of this increase was fueled by rising farm and cattle

prices, a rainy period that persisted throughout the 1870s and the first half of the 1880s, and the availability of cheap land. But perhaps more importantly, the Kansas railroad expansion, second only to that of Texas during the 1880s, and the rumor of the impending arrival of the Santa Fe Railroad in Medicine Lodge, precipitated movement to and settlement in Barber County (Sheridan 1956; Barber County Historical Committee 1980).

The importance of the railroad to Barber County, and especially to its agricultural economy, should not be underestimated. Arrival of the railroad opened eastern contacts to settlers, permitting them to obtain goods and much needed capital. In short, it brought a change from a subsistence agricultural economy to a commercial agricultural economy as farmers suddenly gained access to markets for any surplus crops they might produce (Sheridan 1956). With new markets, farmers increased the amount of land in crops from 971 hectares (2400 acres) in 1876 to 3643 hectares (9000 acres) in 1880 to 42,834 hectares (105,800 acres) in 1890 (Kansas State Board of Agriculture Annual Report 1876,1880,1890). The railroad also facilitated the importation of new and improved cattle breeds from the east (Barber County Historical Committee 1980). As a

result, the number of cattle in the county increased from 3200 in 1876 to 11,000 in 1880 to 28,000 in 1890 (Kansas State Board of Agriculture Annual Report 1876,1880,1890).

To townspeople, the railroad symbolized the difference between a "primitive and civilized manner of living" (Sheridan 1956:154). By providing access to Barber County from the east, the railroad precipitated battles between an increasing number of homesteading farmers and townspeople on the one side, and the large cattle pools such as the Comanche Livestock Pool on the other, over the herding and fencing of cattle. As a result of these battles, herd laws were passed in the mid-1880s and large cattle pools were divided into smaller, enclosed ranching operations (Barber County Historical Committee 1980). This did nothing to diminish the role of ranching in the county's economy, however, as its continued dominance today attests.

Unfortunately, the arrival of the railroad and its attendant economic boom were offset somewhat by a period of drought, crop failure, and widely fluctuating agricultural prices from 1887 to 1896. Forced liquidation, absentee ownership, and a rise in tenantry were common on farms and ranches of Barber and surrounding counties. Towns such as Medicine Lodge,

which were economically dependent on their agricultural neighbors, also felt the shock of economic depression. As reflected in population totals from Barber County during that period, people began to leave the area. In 1885, 7868 people lived in the county. By 1890, despite the arrival of the railroad, the county's population had fallen to 7521, and by 1895 only 5145 people resided in Barber County. With the return of plentiful rains and better economic times in the late 1890s, the population once again increased, finally reaching its peak of 9700 on the eve of the dust bowl in 1930. The flight to urban areas and the consolidation of small farms has steadily eroded the county's population since it reached that peak. Today, only 7800 people live in Barber County. (Kansas State Board of Agriculture Annual Report 1890, 1895, 1930, 1983).

Neighboring Kiowa County, where the Medicine Lodge River has its headwaters, has experienced a more tumultuous cultural history than has Barber County. The state legislature organized Kiowa County in 1867, but later dissolved it when they discovered that fewer than the 600 people required to form a county actually lived there; not coincidentally, this dissolution benefitted the giant Comanche Livestock Pool by keeping out settlers and smaller landowners. Nevertheless, settlers

soon began to push into the area once again, and in 1886 the legislature reestablished Kiowa County. Arrival of both the Rock Island Railroad at Greensburg and the Santa Fe Railroad at Belvidere in 1887 linked Kiowa County to counties in the east, encouraging further settlement of the area (Kiowa County Libraries 1979).

Agriculture has been the dominant economic function in both Barber and Kiowa Counties. The majority of land in the Medicine Lodge River basin is used for pasture to support cattle ranching, the key component of this agricultural economy. Small parcels of floodplain land and some uplands are used for the cultivation of crops, but the farmer is less important to the agricultural ecomony than is the rancher. The sole industry in the Medicine Lodge River drainage basin is the National Gypsum Company's wall board plant in Medicine Lodge. Gypsum has been mined from land within the basin since 1889, most recently from a site opened south of Sun City in 1920.

CHAPTER 4: METHODOLOGY

This methodology section is divided into the following three parts, each detailing procedures used during a different facet of this thesis:

1.) methods used to study changes in channel width;
2.) methods used to establish pre-setlement vegetative conditions;
3.) methods used to analyze climatic data.

Channel Width Change

Federal Land Survey The Medicine Lodge River basin was surveyed between January and May of 1871 as part of the original federal land-survey of new territories. In addition to laying out Township and Range lines, the surveyors were instructed to record the widths of all rivers and stream channels their section lines crossed and to note the type and extent of the vegetation along these lines. For example, the following surveying manual, titled Instructions to the Surveyors General of Public Lands of the United States, For those Surveying Districts established in and since the Year 1850; Containing, Also, A Manual of Instructions to Regulate the Field Operations of Deputy Surveyors, Illustrated by Diagrams charged surveyors to measure "... all rivers, creeks, and smaller streams of water which the [section]

line crosses; the distances on line at the points of intersection, and their widths on line" (White 1982:466). Furthermore, they were directed to record the "...timber - the several kinds of timber and undergrowth, in the order in which they predominate" (White 1982:466).

The records from the Kansas survey, consisting of a series of township plat maps and field notes, are kept in the state capitol building in Topeka. Channel widths and vegetative descriptions that pertain to the Medicine Lodge River, Elm Creek, and Thompson Creek were recorded from these maps and field notes. During the summer of 1983, section-line crossings of these three water courses were located and channel widths remeasured. Vegetative type and density along section lines were also noted.

While the survey does provide a detailed picture of pre-settlement river and vegetative conditions, there are some inherent problems in using the 1871 data. First, it is unclear whether surveyors measured water widths or bankfull channel widths; inspection of their surveying manuals does not clarify this point. In a study using federal land-survey records, Knox concluded that surveyors probably recorded water widths and not bankfull widths (Knox 1977). In light of this

uncertainty, I measured both lowflow and bankfull widths.

Second, it is unclear whether the survey data represent right-angle channel widths, or measurements taken on section lines. If measurements were made on section lines, then recorded widths may not represent the actual channel width because section lines do not always intersect a river at a right angle. The set of instructions quoted earlier, which stated that width measurements should be made "on line", suggests that the surveyors did not measure right-angle channel widths. Two surveying manuals written prior to 1850, however, specifically state that measurements were to be taken at right angles to the water course. From the manual General Instructions, Office of the Surveyor General of Wisconsin and Iowa, Dubuque, May 28, 1846 comes the following instructions to include in field notes:

> All rivers, creeks, and smaller streams of water, with their actual or right angled widths, course, banks, current, and bed, at the point where your lines cross.
> (White 1982:345)

The General Instructions to His Deputies; By the Surveyor General of the United States, For the States of Ohio, Indiana, and Michigan 1850 tells surveyors to record in their field notes:

> All rivers, creeks, and smaller streams of water, with their right-angled width, and the course they run when the lines of your survey intersect or cross them, and whether the current be rapid, sluggish or otherwise.
>
> (White 1982:370).

Both of the previously mentioned manuals were written for surveyors working in areas other than Kansas, and both were written in the mid-1800s, more than 20 years before the Kansas survey. Moreover, the surveying manual used after 1850 for the entire country (see White 1980:466) instructs surveyors to measure channel widths on section lines, and not at an angle normal to the river. For these reasons, it is likely that channel width measurements were taken along section lines. The net result is that, compared to their 1983 counterparts, which were measured at a right-angle to the river, some 1871 channel width measurements may be slightly inflated because not all of them were made at a right-angle to the river.

Channel Width Measurements Between May and August 1983, several trips were made to the Medicine Lodge River basin to measure present-day channel widths and note riparian vegetative type and density. Because of time and fiscal constraints, the study was restricted to the Medicine Lodge River above the town of Medicine Lodge and to Elm Creek and Thompson Creek, two of the

Medicine Lodge's major tributaries. With the aid of 1:24,000-scale U.S. Geological Survey topographic maps, section-line fences, and directions from local residents, section lines established by the federal land surveyors in 1871 were located. These section lines were then followed to their intersection with the Medicine Lodge River, Elm Creek, or Thompson Creek, and right-angled bankfull and lowflow channel widths were measured using a surveyor's tape and chaining pins. In this manner, all section lines that intersected Elm Creek (35 measurements) and Thompson Creek (8 measurements), and every third section line that intersected the Medicine Lodge River (29 measurements) were measured; Appendix I contains these measurements. In addition to the measurements, the type and extent of vegetation along section lines was also noted.

These section-line, channel-width measurements constitute a systematic sample of all section-line channel widths in the Medicine Lodge River basin north of the town of Medicine Lodge. As such, they may not be representative of all channel widths in the drainage basin north of Medicine Lodge. Also, the drainage basin north of Medicine Lodge is only a sample of the entire Medicine Lodge drainage basin. Nevertheless, the three channels selected for measurement represent the major

trunk stream, a major tributary, and a smaller tributary of the drainage system.

Aerial Photography and Interviews Aerial photography of the study area is available, but only for the years 1956 and 1979; unfortunately, photographs taken in the 1930s have been lost. Measured section-line crossings pictured on the 1956 and 1979 photographs were compared and contrasted to see how the riparian vegetative cover had changed. Copies of the 1956 and 1979 aerial photographs depicting sites where tree cores were collected have been placed in the discussion section of this thesis. Unfortunately, a search through various public and private collections failed to uncover any old photographs depicting earlier channel or riparian vegetative conditions. Because the extent of photographic documentation is limited, I have depended heavily on personal interviews with long-term residents, many of whom have spent their entire lives in the area and were able to recall channel and vegetative conditions from as early as the 1910s, for information about channel and vegetative changes.

Statistical Analyses Several statistical tests were performed on the channel width data to determine whether the 1871 and 1983 channel widths differed significantly.

All tests were run on the Kansas University Honeywell Computer using the Statistical Package for the Social Sciences (SPSSx).

A bivariate regression analysis of drainage area against channel width was done to see whether the relationship between these two variables had changed since 1871. The logarithms of the 1871 channel widths, the 1983 bankfull channel widths, and the 1983 lowflow channel widths were combined and regressed against the logarithm of the drainage area. Three separate bivariate regressions were then carried out for the logarithm of 1871 widths, 1983 lowflow widths, and 1983 bankfull widths against the logarithm of the drainage area. Bivariate regression lines were fitted, and regression equations and coefficients determined, using the least squares method.

Although channels appear to be narrower today than they were in 1871, the observed difference in channel widths needed to be tested to determine whether it was statistically significant. To this end, the 1871 channel and 1983 channel widths for all streams combined were compared using a Wilcoxon Test. The same test was then performed on each stream separately to determine whether one had undergone more change than the others. By convention, the probability level for all tests was

set at the .05 level. Appendix II contains a discussion of the tests used as well as the test hypotheses.

Dendrochronology One method used to determine the date when channel narrowing began is to establish the ages of the oldest trees adjacent to the channel bank. This technique is valid because trees do not establish themselves on a floodplain surface until that surface is no longer being reworked by the river. Thus, the ages of the sampled trees provide an estimate of the date when floodplains became stable enough to support permanent vegetation (see Sigafoos 1964 and Everitt 1968). To this end, a Swedish increment borer was used to collect 32 tree cores from along seven section-line transects that crossed the Medicine Lodge River and Elm Creek. Crossings were selected for this sampling on the basis of the following two factors: 1) those crossings where floodplains supported enough trees to make coring feasible; and 2) those that had narrowed substantially since the 1871 survey. Tree core sites are marked on Plate 3:1, and more detailed maps of the sites are found on Plate 5:5.

After extraction, the cores were stored in labeled, plastic straws, and the straw ends sealed with masking tape to reduce moisture loss and facilitate core site

identification. Once in the laboratory, they were affixed in grooved, soft wooden mounts to prevent breakage and permit sanding of the core. Some cores, twisted during extraction from the tree, were steamed prior to mounting in order to realign trachieds. Cores were sanded, first with coarse grit sandpaper, and subsequently with finer grit papers, to accentuate rings. Using a low-power stereomicroscope (7-30 x), the number of rings on each core were counted to determine the approximate date when that tree began to grow; because cores were extracted from a level 1.2 m (4 ft) above the tree's root crown, the first five or so years of growth were not represented in the core.

Pre-Settlement Vegetative Conditions

A key conclusion of this thesis is that riparian vegetative density has increased since the original federal land-survey of 1871. To reconstruct pre-settlement conditions, several primary historical sources that described, in varying detail, the extent of riparian vegetation in the nineteenth century were consulted.

The most important source of information on pre-settlement conditions were the field notes kept by the federal land surveyors. They noted, in admittedly qualitative terms such as "scattered" or "dense", the

density and type of vegetation encountered along section lines. Because a thick vegetative cover would have obscured their sight, the surveying parties were probably accurate in noting the amount of vegetation they came across during their work. Relevant excerpts from the 1871 field notes along with my 1983 observations are contained in Appendix III.

As a supplement to the field notes, reporters' accounts of the Medicine Lodge Peace Treaty held on the Medicine Lodge River in October 1867 were read, and sketches of the treaty site made by an artist who attended the gathering were examined. In addition, journal accounts from the Stephen H. Long Expedition of 1820 which passed just north of the Medicine Lodge River on its journey to the Rocky Mountains were read. Unfortunately, the descriptions contained in many of the journals are too general to provide a portrait of 19th century vegetative conditions in and around the study area. Finally, local residents were interviewed about the vegetative changes that had taken place during their lifetimes.

Analyses of Climatic Data

Daily precipitation measurements have been collected at Medicine Lodge, Pratt, and Greensburg since

1900 (See Plate 3:1 for town locations). These data were subjected to time-series analyses to chart precipitation trends over the past 80 years. Five- and ten-year running means from each station's annual precipitation data were calculated and curves drawn to accentuate wet and dry periods.

The availability of daily precipitation data for the past 80 years also permitted study of the changes in precipitation magnitude, frequency and seasonality that had occurred between 1930 and 1959. Only that 30-year period was examined because, based on interviews and tree cores, it appears that channel narrowing began during that time. To measure changes in precipitation magnitude and frequency, all precipitation events during those 30 years were grouped into four size classes [.25-12.4 mm/day (.01-.49 in/day), 12.5-25 mm/day (.50-.99 in/day), 25-37.5 mm/day (1.0-1.49 in/day), and 37.5+ mm/day (1.5+ in/day)] and the number of events in each class counted for each year between 1930 and 1959; Leopold's 1951 paper on precipitation variability served as the model for the selection of classes. In addition, the number of events in each size class were counted by season for the years 1930 to 1959. Next, the number of events in each size class were plotted for each year during the 30-year record. To measure seasonality of

precipitation, each year's winter, spring, summer and fall precipitation were summed, and the resulting values plotted across the years 1930 to 1959; winter was delineated as the months of January-March, spring as April-June, summer as July-September and fall as October-December. The mean precipitation values were subjected to Wilcoxon tests to ascertain whether observed differences were significant. In addition, the percentage of a given year's precipitation that fell in a season was calculated to study changes in the contribution of each season to the annual total.

The seasonality of precipitation was studied because it should affect stream discharge. For example, if a given year's precipitation events are clustered in a few months, river discharge should fluctuate widely during that year. Conversely, if a given year's events are spread through all 12 months, discharge should remain fairly constant. Widely fluctuating discharge regimes, as past research has suggested, generally result in periods of channel erosion, while steady discharge results in channel stability or narrowing (e.g., Schumm and Lichty 1963; Burkham 1972; Brakenridge 1981).

River Discharge Data

Unfortunately, daily discharge data for the

Medicine Lodge River, which could serve as a surrogate indicator of climatic conditions, have only been recorded at Kiowa, Kansas, a town about 50-river km (31-river miles) south of the southern boundary of my study area, and only for the years 1939-1950, 1954-1955 and 1959 to present. Because data are unavailable for the drought years of the 1930s and 1950s, it was not possible to establish what, if any, changes in discharge magnitude and frequency occurred between 1930 and 1959, the period when channel narrowing took place. Moreover, I question how representative these figures are of conditions in the study area in light of the distance between Kiowa and the measured cross sections. For these reasons, river discharge data have not been considered further in this thesis.

CHAPTER 5: RESULTS AND DISCUSSION

The results and discussion section of this thesis is separated into three parts. The first part describes the channel narrowing and the increase in riparian vegetative density that have occurred along the Medicine Lodge River, Elm Creek, and Thompson Creek since 1871. The second part links this channel narrowing and the increase in riparian vegetative cover to climatic fluctuations that have taken place in the study area during the past 50 years. The final part presents a model that describes historic channel narrowing throughout the Great Plains.

Channel Narrowing and Riparian Vegetative Change

The Medicine Lodge River, Elm Creek, and Thompson Creek are all narrower today than they were at the time of the original federal land-survey measurements in 1871. Table 5:1 lists the mean channel widths for all streams as a group and for each stream individually. Plates 5:1 and 5:2 illustrate two section-line crossings where channels were narrower in 1983 than in 1871. Medicine Lodge River section-line crossing #28 was 60.4 m wide in 1871; by 1983, as Plate 5:1 displays, the Medicine Lodge River had narrowed to a width of 20.4 m.

Similarly, Medicine Lodge River section-line crossing #14 was 80.5 m wide in 1871, but by 1983 (Plate 5:2) the river had narrowed to 18.3 m. Channel width measurements can be found in Appendix I of this thesis. Since 1871, channels narrowed at all 29 measured section-line crossings along the Medicine Lodge River, at 29 of the 33 measured section-line crossings along Elm Creek, and at 5 of the 8 measured section-line crossings along Thompson Creek.

Table 5:1 Mean Channel Width and Standard Deviation (m)
(Standard Deviations Shown in Parentheses)

	1871	1983 Bankfull	1983 Lowflow
All Streams	41.8 (39.1)	15.1 (8.5)	8.0 (4.6)
Medicine Lodge River	66.3 (46.5)	18.1 (9.5)	10.7 (4.9)
Elm Creek	28.5 (18.9)	14.9 (6.2)	6.6 (3.2)

As a group, the 70 section-line measurements from 1871 are not normally distributed at the .05 level according to a Kolmogorov-Smirnov Test (K-S z=1.70). Moreover, the variances of the 1871 data and the 1983 data are not equal at the .05 level; the variance for the 1871 data is 1527, while for the 1983 data it is 21 at lowflow stage and 72 at bankfull stage. For these reasons, the nonparametric Wilcoxon Test was used to determine whether the 1871 and 1983 mean channel widths are significantly different. This test was performed on

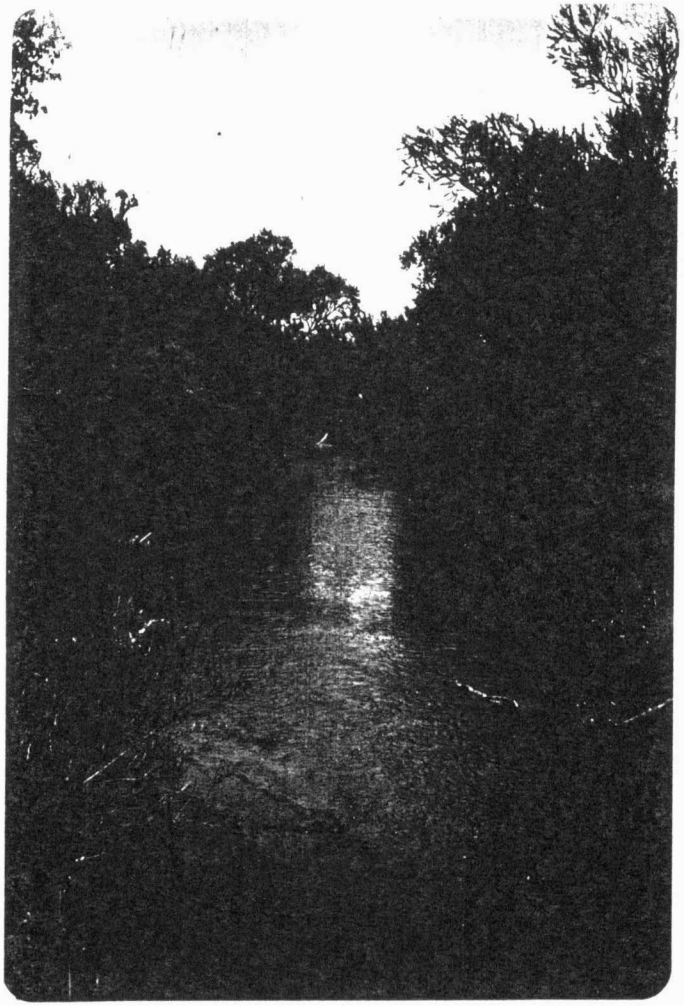


Plate 5;2 Medicine Lodge River Section-Line Crossing #14, 1983.

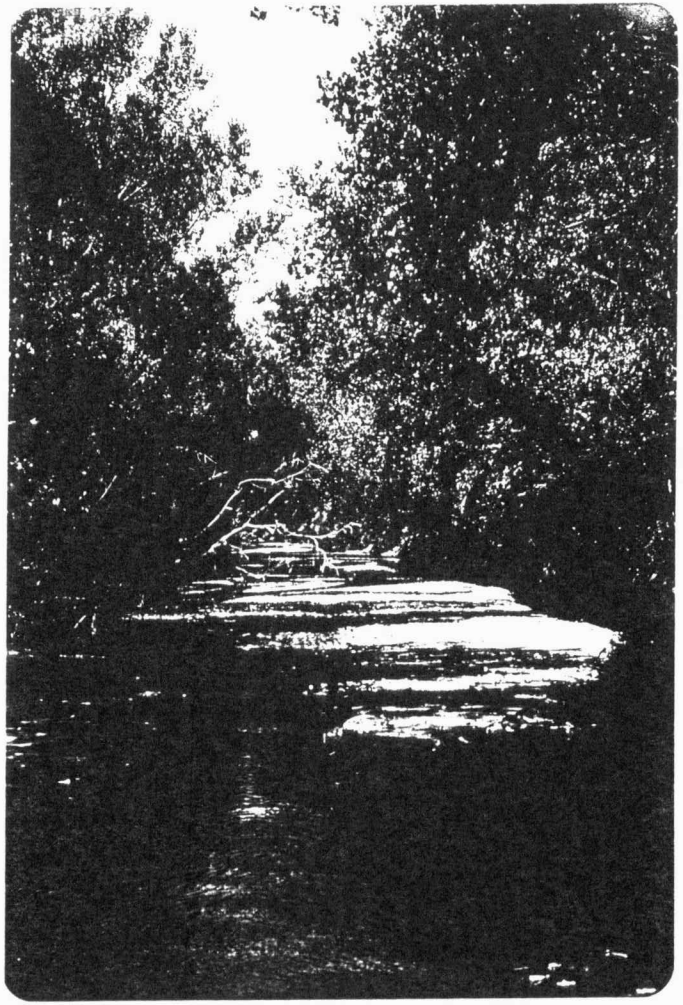


Plate 5:1 Medicine Lodge River Section-Line Crossing #28, 1983.

the rivers as a group and on each individually. For the test hypotheses, levels of significance, and a discussion of the test, see Appendix II. Table 5:2 presents the z-values and probabilities for the Wilcoxon Tests. In all tests, the calculated probability is less than the critical probability of .05, indicating that as a group and as individuals the channels were significantly narrower in 1983 than in 1871.

Table 5:2 Mean Channel Widths, Wilcoxon Test

Variables	Z-Values	Probability	N
All Streams			
1983 Bankfull vs. 1871 Widths	-6.51	0.0	62
1983 Lowflow vs. 1871 Widths	-6.84	0.0	62
Medicine Lodge River			
1983 Bankfull vs. 1871 Widths	-4.66	0.0	29
1983 Lowflow vs. 1871 Widths	-4.70	0.0	29
Elm Creek			
1983 Bankfull vs. 1871 Widths	-4.42	0.0	33
1983 Lowflow vs. 1871 Widths	-5.01	0.0	33

This conclusion is further supported by the regression plots of channel width against drainage area for the three rivers. Figure 5:1 shows that river channels in the Medicine Lodge River system were wider in 1871 than in 1983 for drainage areas greater than 20 km^2. Examination of the regression plots for the Medicine Lodge River and Elm Creek reveals that both rivers have narrowed along much of their length since 1871 (Figures 5:2 and 5:3). Along Elm Creek, however, 1871 channel widths were less than 1983 bankfull widths for drainage areas less than 30 km^2. The widening since 1871 may be the result of cultivation within the headwaters of Elm Creek; in addition, the headwater channels of Elm Creek flow in sandy material which would be readily eroded.

The absence of any pre-1956 aerial photographs hindered accurate determination of the timing of channel narrowing. Photographs taken in the 1930s have been misplaced or destroyed, and were not available for this study. Information obtained from interviews and tree cores, however, suggests that channel narrowing and increases in vegetative density began in the early 1940s. Residents of the Medicine Lodge River basin agree that, prior to the 1930s, rivers in the Medicine Lodge drainage area were approximately twice as wide as they

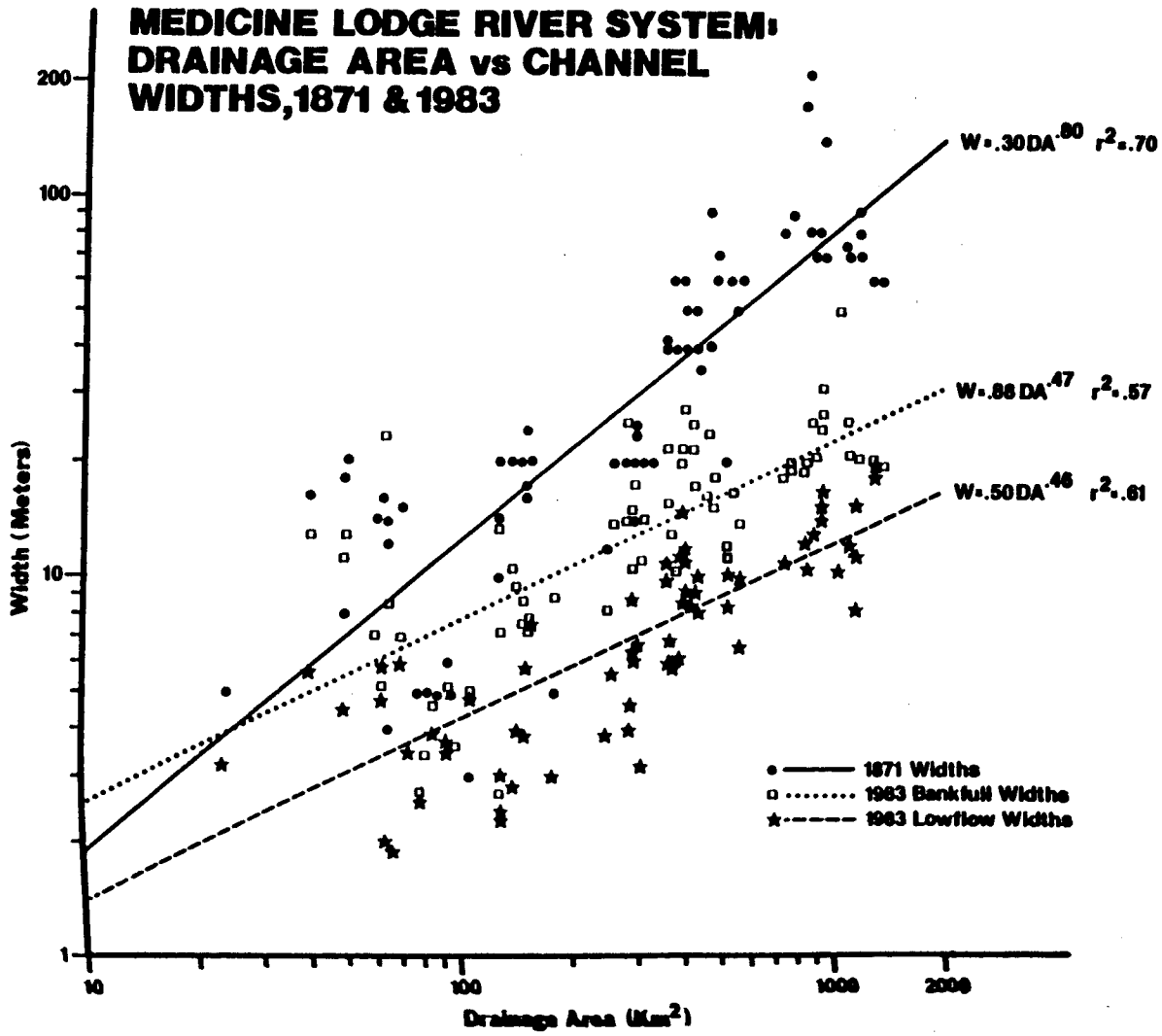


Figure 5:1 Regression Lines Medicine Lodge River System

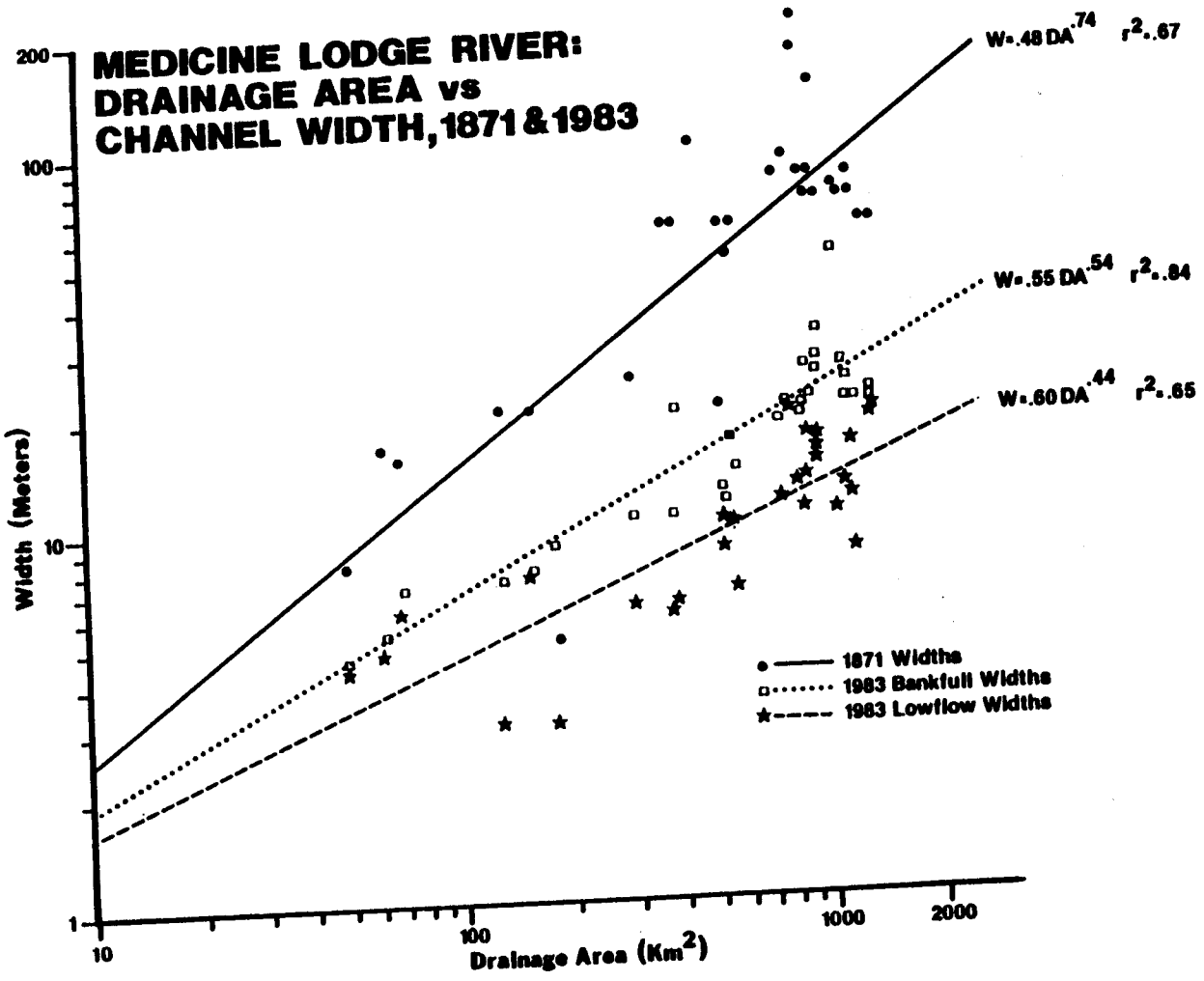


Figure 5:2 Regression Lines Medicine Lodge River

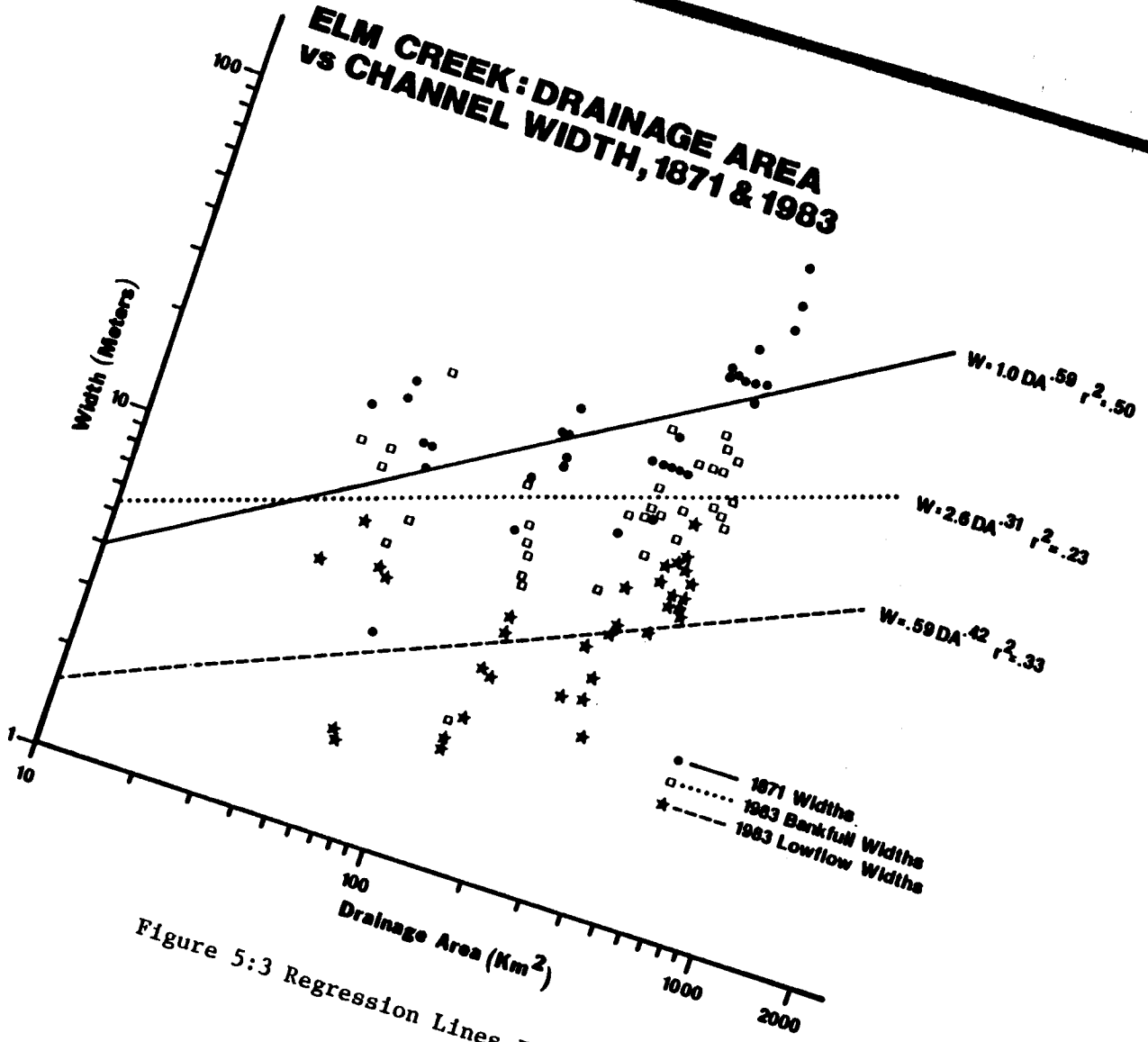


Figure 5:3 Regression Lines Elm Creek

are today. In the 1930s, only scattered stands of cottonwood and elm grew along channel banks. Starting in the 1940s, and continuing to present, channels began to narrow. At the same time, riparian vegetation began to grow along channel banks and in channel beds.

Comparison of summaries extracted from the original federal land-survey field notes and my 1983 field notes illustrates the riparian vegetation change that has occurred between 1871 and 1983; both sets of field notes are contained in Appendix III. Note that surveyors recorded "scattered" vegetation at many section-line crossings during their surveys in May 1871. In the summer of 1983, however, the vegetative cover at these same section-line crossings was significantly thicker - so thick, in places, that visibility along section lines was obscured. For example, Medicine Lodge River section-line crossings #12 and #9, which are pictured in Plates 5:3 and 5:4, respectively, were described by the 1871 survey as having only "scattered vegetation" along the river banks. Had the vegetative cover in 1871 been as thick as that present today, it surely would have been described as "thick" or "dense" by the surveyors.

Cores extracted from the oldest trees along the Medicine Lodge River and Elm Creek also suggest an increase in riparian vegetation over the past 40 years

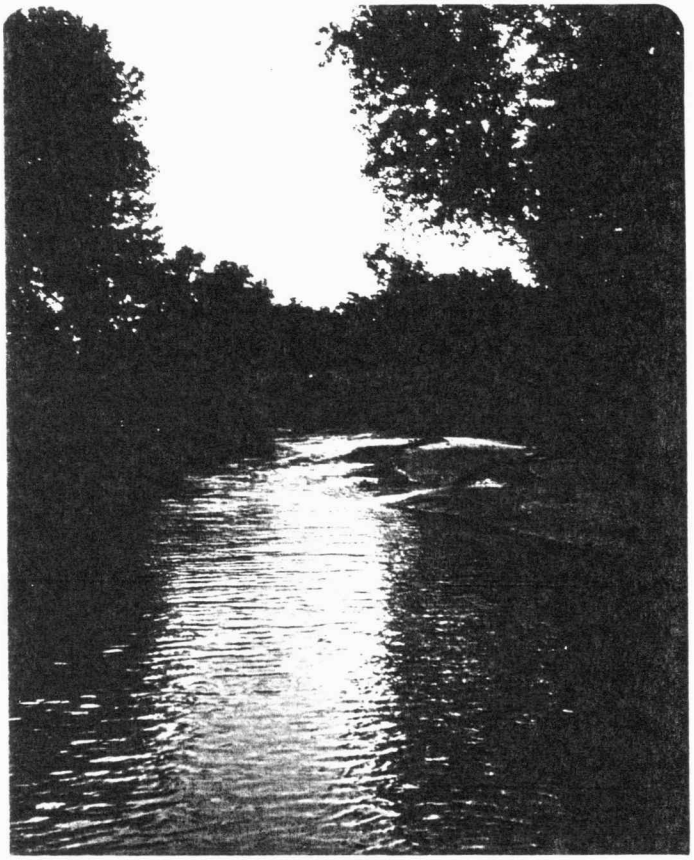


Plate 5:3 Medicine Lodge River Section-Line Crossing #12, Vegetation Change

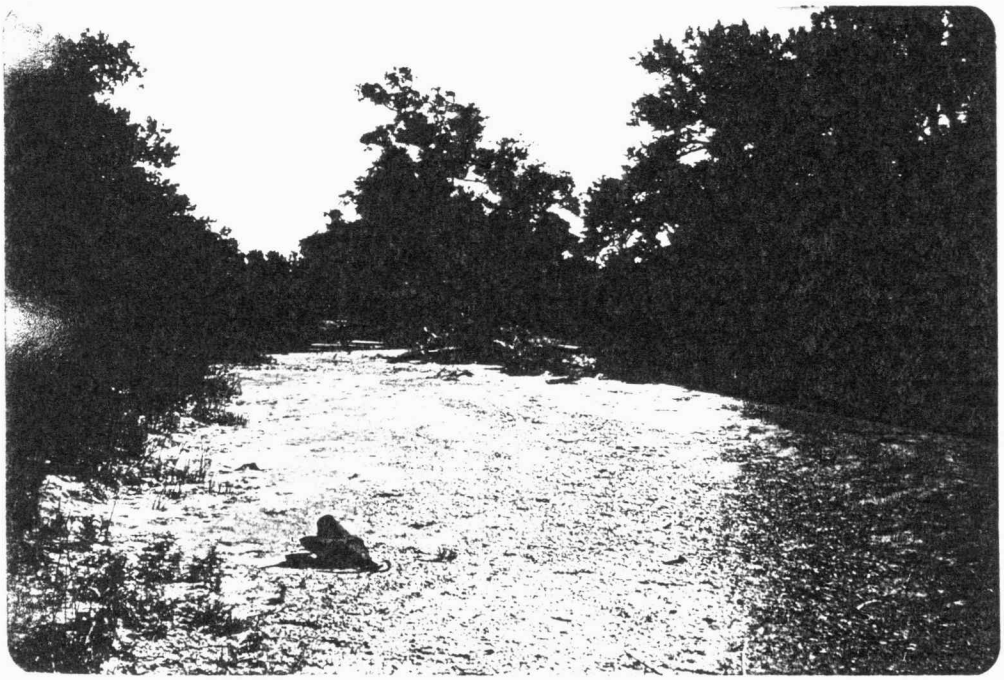
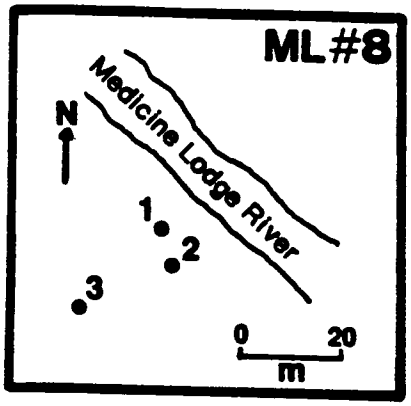


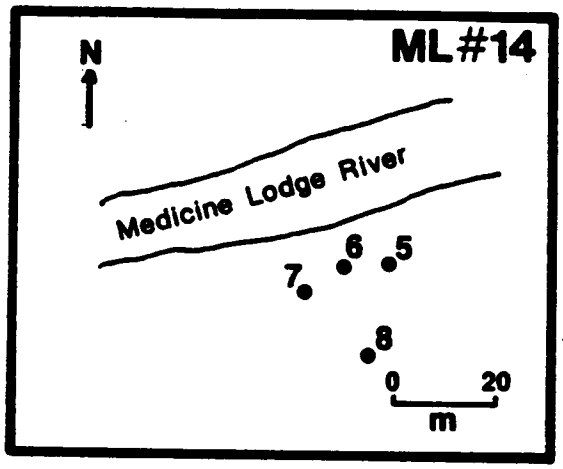
Plate 5:4 Medicine Lodge River Section-Line Crossing #9, Vegetation Change

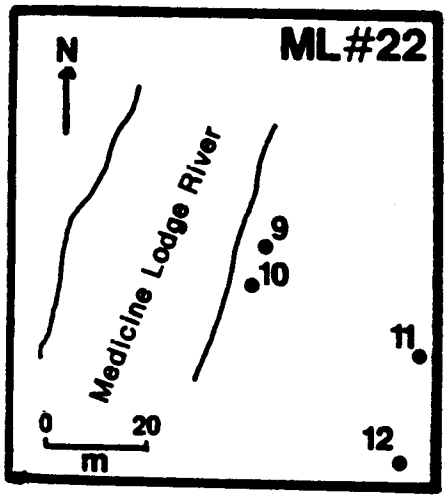
Plate 5:5, which shows the location of sampled trees along the Medicine Lodge River and Elm Creek channel section-line crossings, should be used in conjunction with Plate 3:1 to ascertain the sites where cores were extracted. These cores, collected along transects normal to Elm Creek and the Medicine Lodge River, reveal that, with a few exceptions, the oldest trees germinated in the early 1940s (Table 5:3). Trees are progressively younger as one moves away from channel banks. Pairs of 1956 and 1979 photographs portraying areas from which core samples were taken display some of the change in riparian vegetative density (Plate 5:6).

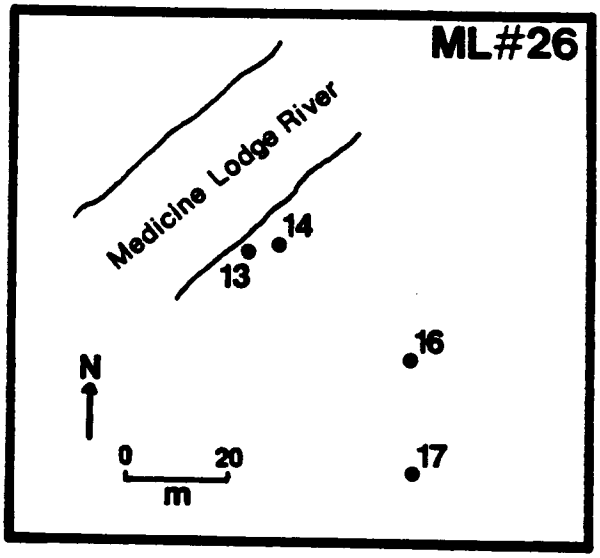
Previous research has shown that riparian vegetation has increased elsewhere on the Great Plains during this century. In a study by Phillips (1963), pairs of photographs taken at identical locations in the Dakotas in the early 1900s and late-1950s illustrate increases during that interval in the amount of riparian vegetation along streams and creeks. Clouser (1974) concluded that woodlands advanced over the Great Plains during the past 100 years as a consequence of man's control of prairie fires. Williams (1972), in a study along Walnut Creek in west-central Kansas, reported that there was more riparian vegetation along the creek in 1972 than there had been in 1938.

Plate 5:5 Tree Core Sites









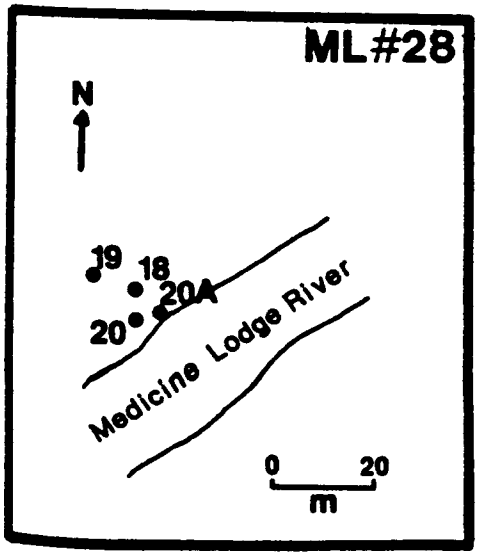
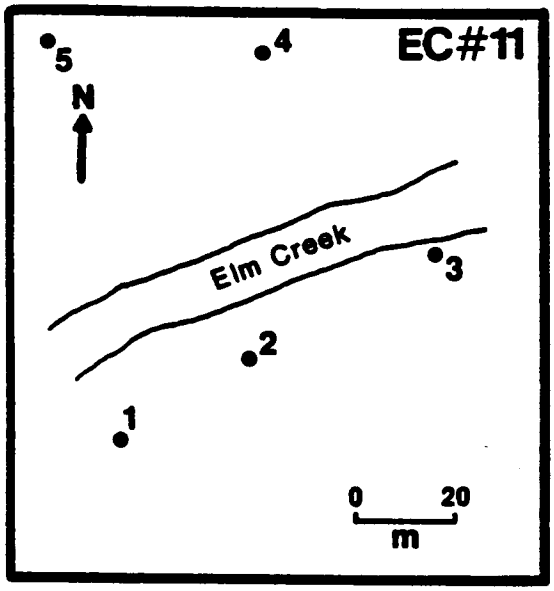


Plate 5:5 Tree Core Sites



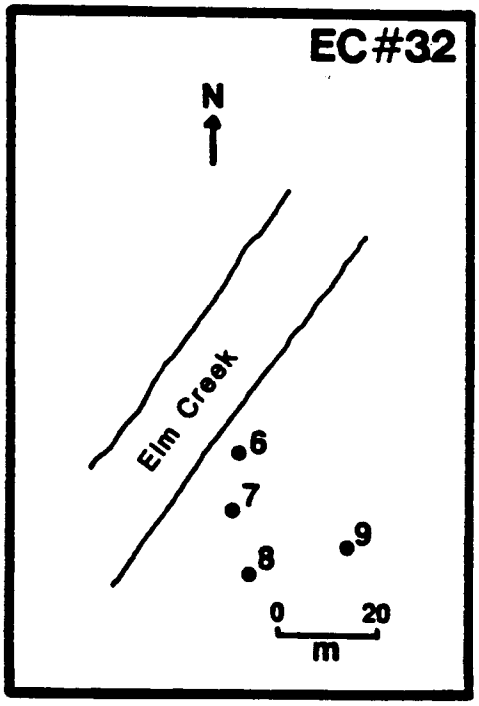
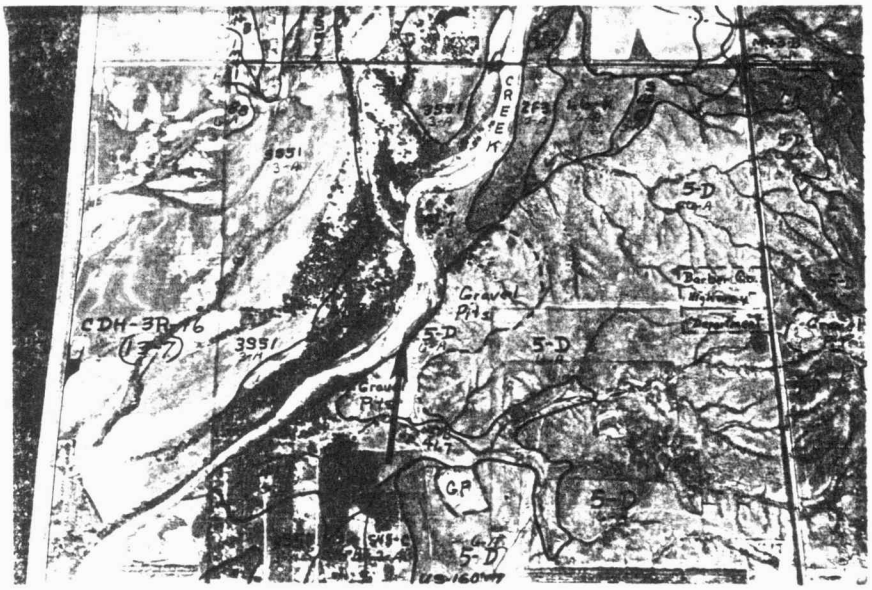


Table 5:3 Channel Cross-Section Sites, Tree Core Ages

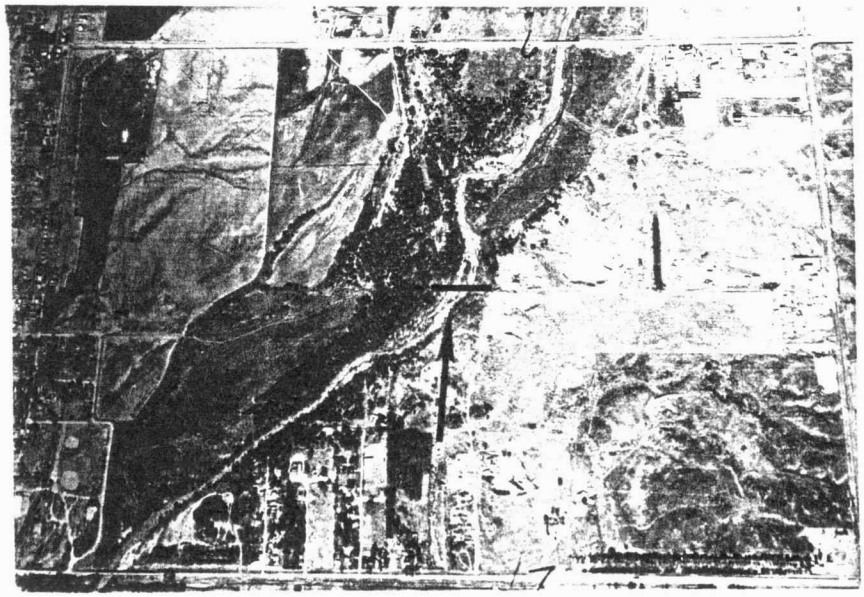
Sample	Age
ML #8	
1	54*
2	51*
3	30
4	Irretrievable
ML #14	
5	22
6	22*
7	17
8	25
ML #22	
9	18
10	26
11	39
12	89
ML #26	
13	25
14	27*
15	Irretrievable
16	57
17	23*
ML #28	
18	44
19	57
20	28
20A	28
EC #11	
1	30
2	29
3	70
4	32
5	60
EC #32	
6	23
7	27
8	30
9	27

ML = Medicine Lodge River
EC = Elm Creek
* = Age underestimated, cores damaged or tree center not reached.

Plate 5:6 1956 and 1979 Aerial Photographs

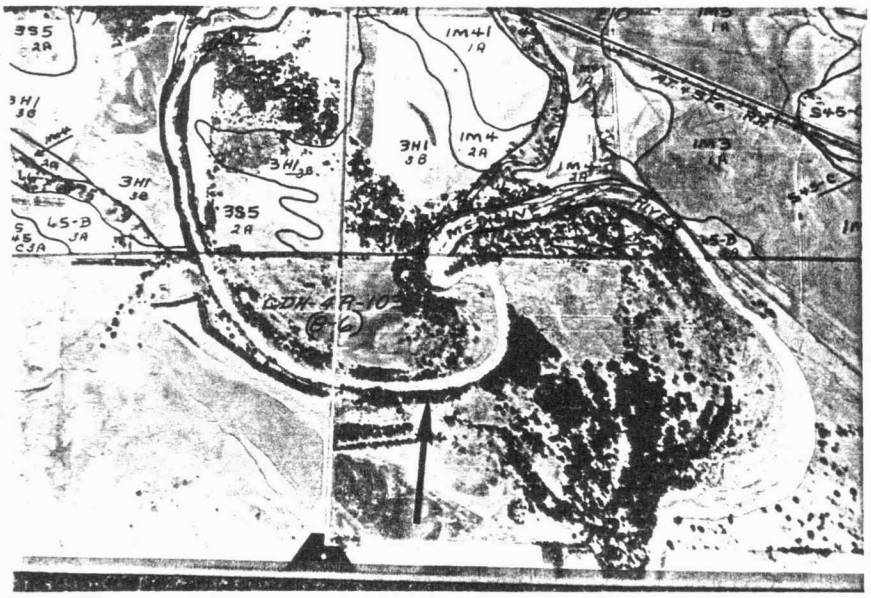


Elm Creek #32, 1956

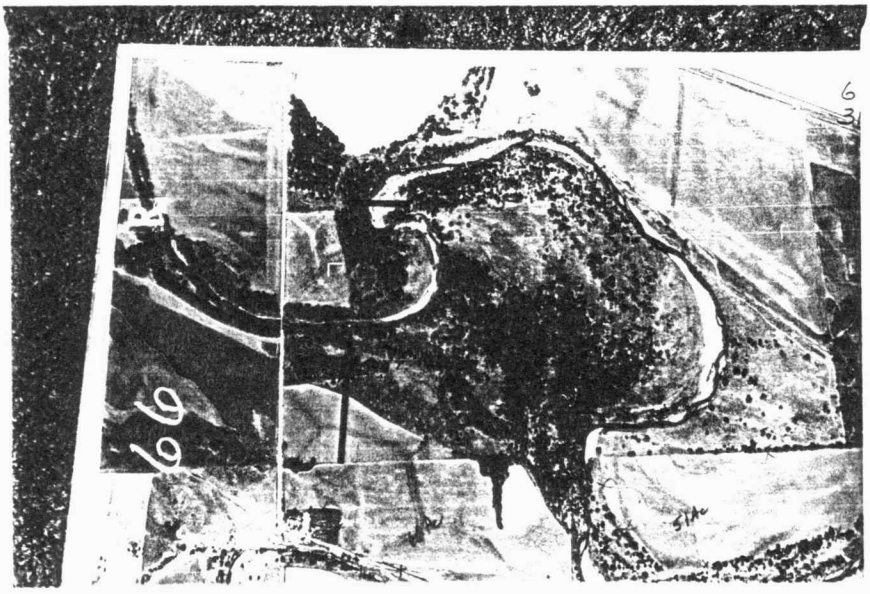


Elm Creek #32, 1979
Note increase in vegetation on mid-channel bars from 1956 to 1979 (arrows).
Section-line crossings indicated by dash marks.

Plate 5:6 1956 and 1979 Aerial Photographs

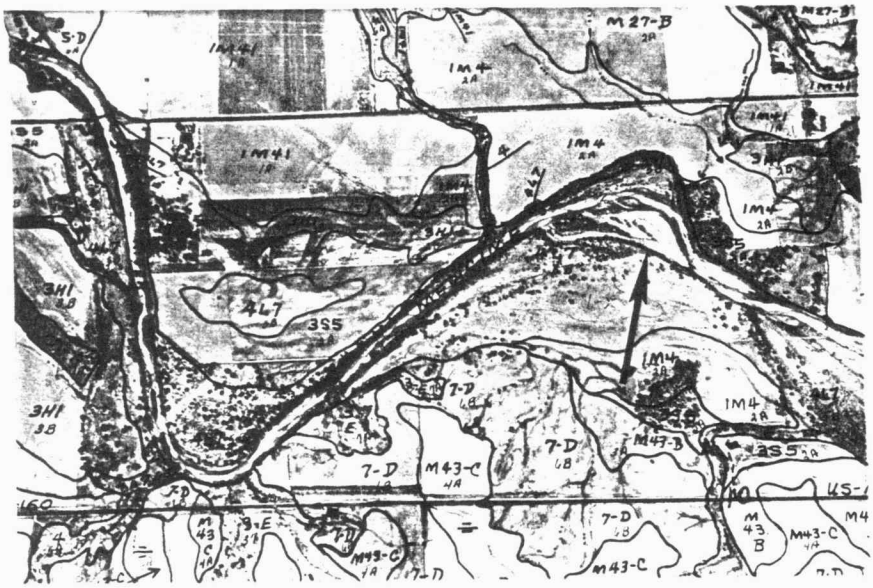


Medicine Lodge River #22, 1956

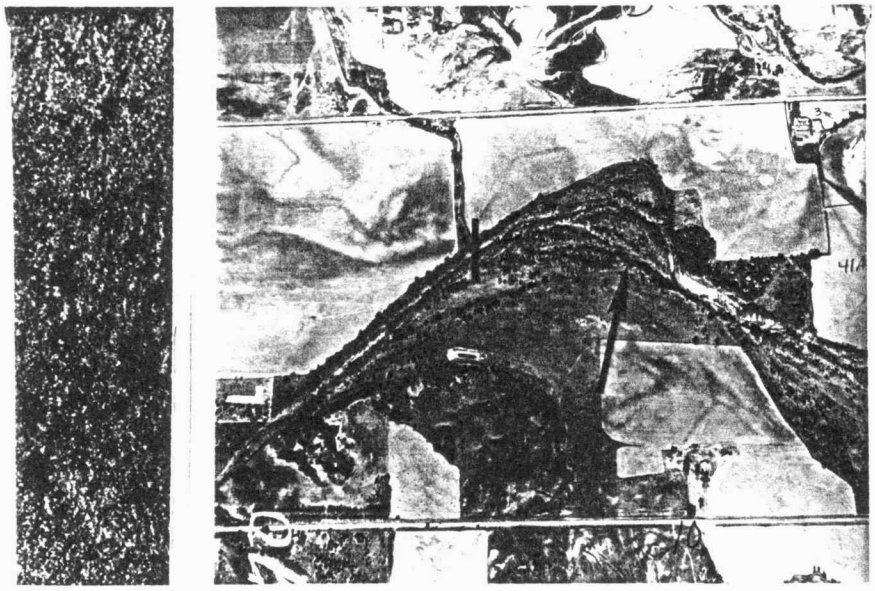


Medicine Lodge River #22, 1979
Note narrowing of channel and increases in vegetation on channel banks from 1956 to 1979 (arrows). Section-line crossings indicated by dash marks.

Plate 5:6 1956 and 1979 Aerial Photographs



Medicine Lodge River #28, 1956



Medicine Lodge River #28, 1979

Note narrowing of channel and increases in vegetation on point bars from 1956 to 1979 (arrows). Section-line crossings indicated by dash marks.

It is inappropriate to conclude, however, that the channels of the Medicine Lodge drainage basin were void of vegetation in the 1800s. Surveyor's field notes and traveler's journals from that time report that scattered stands of timber were present along channel banks. In October of 1867 a reporter who accompanied the Medicine Lodge Peace Treaty Commission to the area described the meeting site as "... a beautiful grove on Medicine Lodge Creek" (N.Y. World Herald 1867:3). Accounts from the Stephen H. Long Expedition in 1820 suggest that there was riparian vegetation along the Arkansas and Walnut Rivers, two drainage basins adjacent to the Medicine Lodge River (Thwaites 1905:240). Finally, the name Elm Creek, which appears on the original federal land survey plat maps, implies the presence of elm trees within the tributary basin.

Integration of information obtained from interviews, historic sources, tree cores, and channel measurements yielded the following sequence of vegetative and channel changes along channels of the Medicine Lodge River Basin. In 1871, channels were much wider than they are today, and scattered stands of cottonwood, elm, hackberry, and willow grew along their banks. During the 1930s and early 1940s, channels began to narrow and riparian vegetative density began to

increase. Both the channel narrowing and the increase in vegetative density continued between 1956 and 1979 as a comparison of aerial photographs from those two dates indicates. The presence today of willow and cottonwood seedlings in channel bottoms suggests that riparian vegetative cover is still expanding.

Causes of Channel Narrowing and Increases in Vegetation

Two factors, climatic fluctuations and land-use changes, are commonly cited as the causes of most historic channel change. These two factors are examined separately for the sake of clarity and because the degree to which they have interacted in the study area is unclear. It will be demonstrated, however, that land use does not appear to have changed greatly since settlement of the Medicine Lodge area in 1871. For this reason, its effect on channel narrowing is discussed in less detail than is that of climatic fluctuations.

Role of Climate Precipitation, because it determines the amount and type of vegetation that an area can support, as well as the quantity of surface runoff to a river, is a key determinant of channel morphology. Variations in precipitation cause changes in the vegetative cover and affect sediment yield and water discharge to a drainage basin. Previous research has

shown that channels in semi-arid climates may rapidly adjust their width in response to fluctuations in precipitation (e.g., McLaughlin 1947; Schumm and Lichty 1963; Burkham 1972; Schumm 1977).

In the study area, annual precipitation totals have varied greatly since the early 1900s (Figures 5:4 and 5:5). Of note are the drought of the 1930s and the wet years of the early 1940s, periods when, according to local residents, channels in the Medicine Lodge drainage basin began to narrow and riparian vegetative density began to increase.

The magnitude and frequency of precipitation events and the seasonality of precipitation are the two factors that seem to most influence stream channel width. From previous research, we know that the magnitude and frequency of precipitation events fluctuate; this study demonstrates that the seasonality of precipitation varies, as well. In his study of preciptation in New Mexico, Leopold (1951) concluded that precipitation magnitude and frequency vary. In a later study, Schumm and Lichty (1963) found that periods of below-average precipitation are characterized by infrequent storms of a large magnitude, while wet periods are characterized by frequent storms of a lesser magnitude. The former condition favors channel

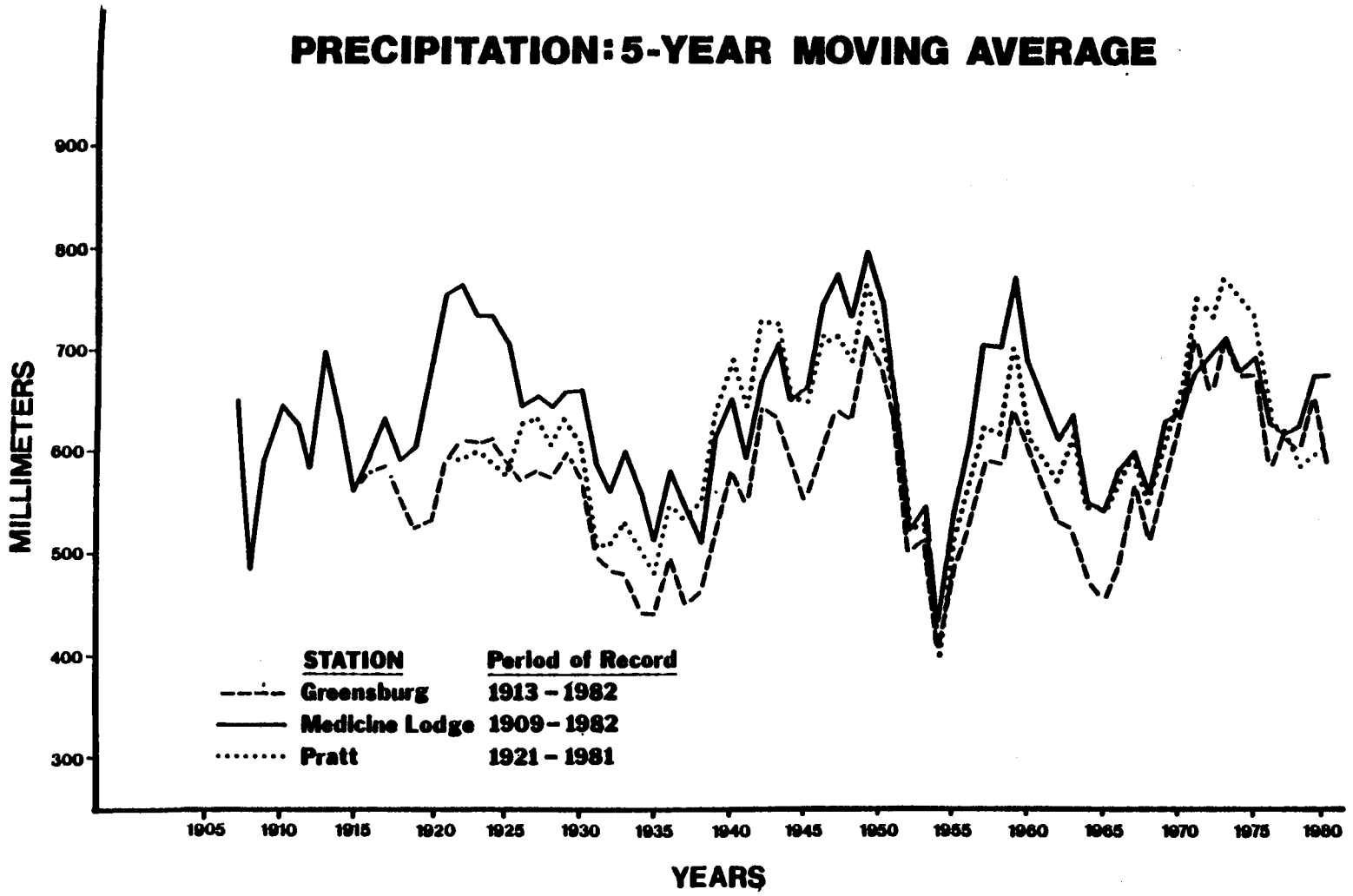


Figure 5:4 Precipitation, 5 Year Moving Average

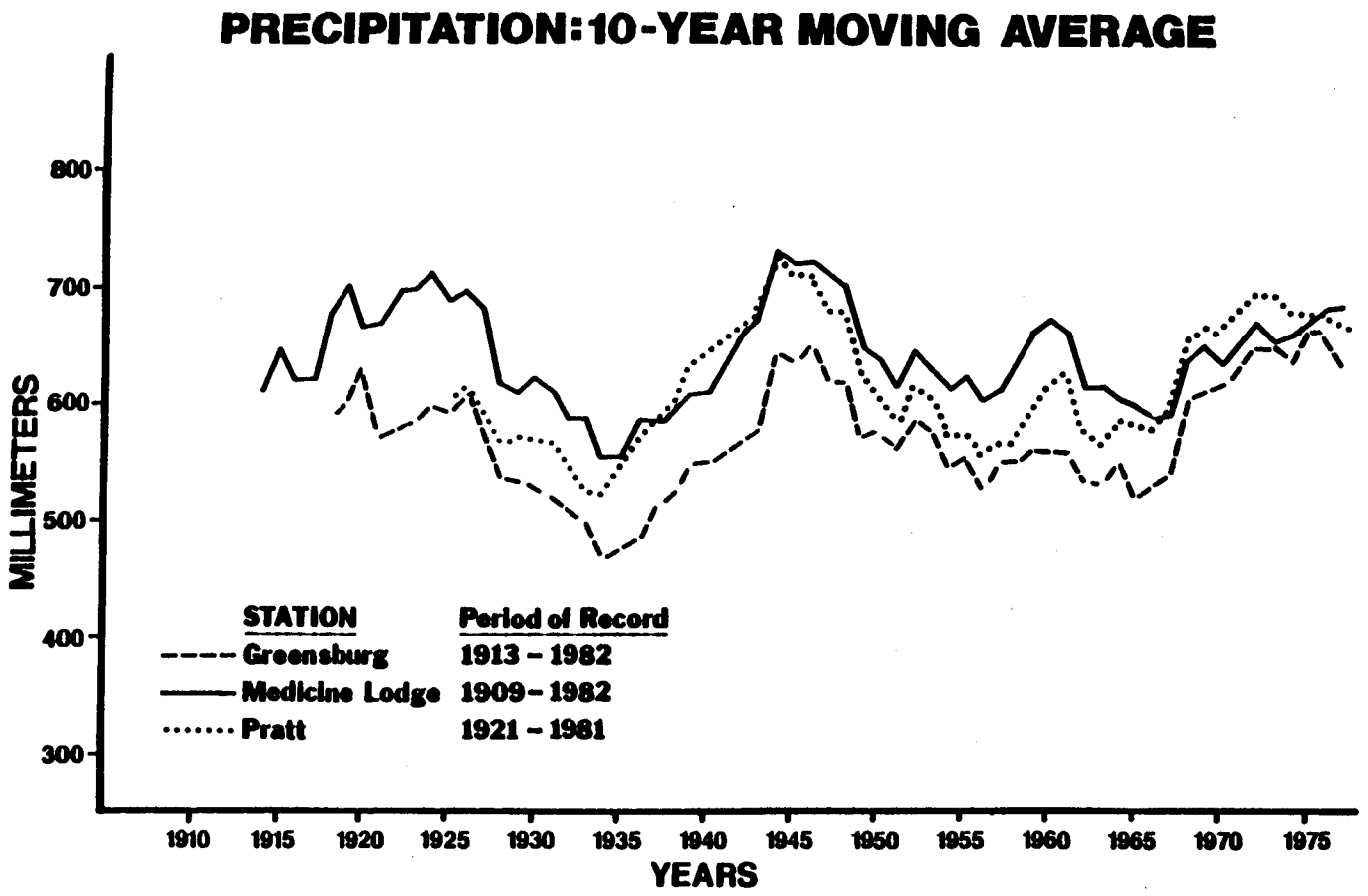


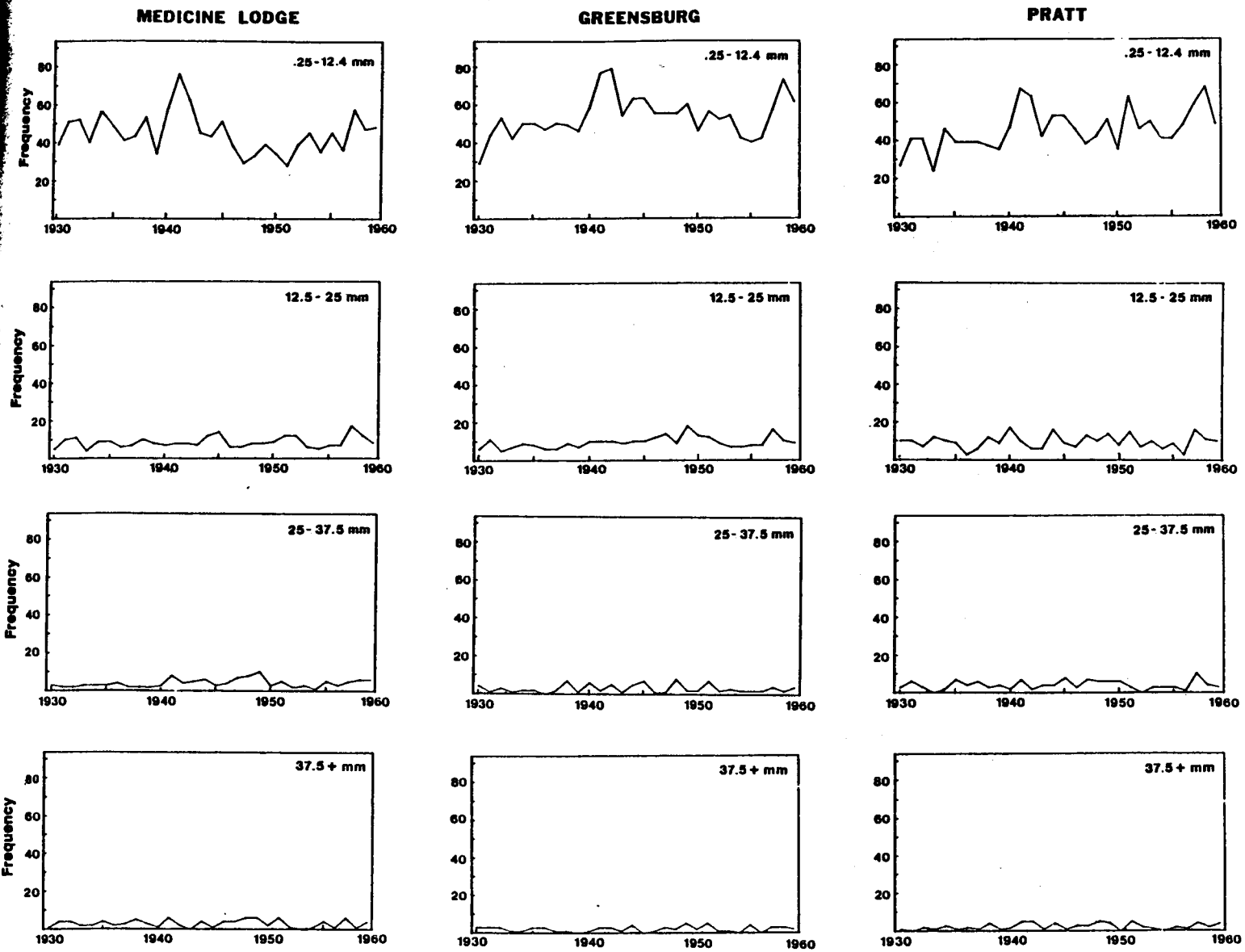
Figure 5:5 Precipitation, 10 Year Moving Average

widening, the latter favors channel narrowing.

Seasonality of precipitation should also influence channel width. If a year's precipitation is clustered in only a few months, stream discharge should display wide fluctuations over the course of that year. Conversely, if a year's precipitation is evenly distributed across all 12 months, stream discharge should remain at a fairly constant level throughout that year. Previous research has shown that climatic regimes featuring widely fluctuating water discharge tend to promote channel widening, while regimes that feature steady discharge result in channel narrowing (e.g., Schumm and Lichty 1963; Burkham 1972; Brakenridge 1981).

Precipitation Fluctuations Analyses of the frequency and magnitude of precipitation events reveal that the frequency of occurrence for the three largest classes of precipitation events (12.5-25 mm/day, 25-37.5 mm/day, and 37.5+ mm/day) varied little between 1930 and 1959 (Figure 5:6). Based on these graphs, it does not appear that the drought of the 1930s was characterized by infrequent, high magnitude precipitation events as was suggested by Schumm and Lichty (1963) in their study area. The number of small precipitation events (.25-12.4 mm/day), however, did increase between 1930 and 1959, finally reaching a peak in the early 1940s. This trend

igure 5:6 Frequency of Occurrence of Various Precipitation
agnitudes, 1930-1959



is evidence that, in contrast to the dry 1930s and 1950s, the wet period of the 1940s was characterized by an increased proportion of small precipitation events. More frequent, smaller events, by augmenting baseflow, may have reduced variability in perennial river and stream discharges, and provided the adequate water supplies required by young riparian vegetation.

The seasonality of precipitation also varied between 1930 and 1959. Table 5:4 lists the differences in seasonal precipitation for Medicine Lodge, Greensburg, and Pratt. Graphs illustrating the seasonality of precipitation reveal some interesting trends for the period 1930 to 1959. Figures 5:7 and 5:8 indicate that winter, summer, and autumn precipitation was higher during the 1940s than during the dry 1930s and 1950s. Spring precipitation also increased during the 1940s, but the increase was smaller than that registered by winter, summer, and autumn precipitation.

Figures 5:7 and 5:8 suggest that precipitation is distributed through all four seasons more evenly during wet years than during dry years. Autumn and summer precipitation constituted a greater percentage of the total annual precipitation in the wet 1940s than they did in the dry 1930s and 1950s. To test this hypothesis, the percentage of a given year's precipitation

Table 5:4 Mean Seasonal Precipitation, 1930-1959 (mm)
(Standard Deviations in Parentheses)

	Winter	Spring	Summer	Autumn
Pratt				
1930-39	58 (31)	240 (80)	156 (40)	72 (44)
1940-49	96 (43)	277 (87)	217 (76)	133 (73)
1950-59	73 (44)	246 (146)	190 (86)	71 (52)
Greensburg				
1930-39	52 (32)	214 (77)	143 (48)	61 (44)
1940-49	87 (49)	251 (107)	195 (69)	12 (51)
1950-59	63 (36)	235 (116)	186 (90)	65 (44)
Medicine Lodge				
1930-39	64 (37)	247 (90)	169 (67)	76 (49)
1940-49	94 (43)	261 (64)	221 (77)	150 (71)
1950-59	71 (40)	267 (151)	204 (88)	77 (61)

Figure 5:7 Seasonal Precipitation, 5 Year Moving Average, 1930-1959

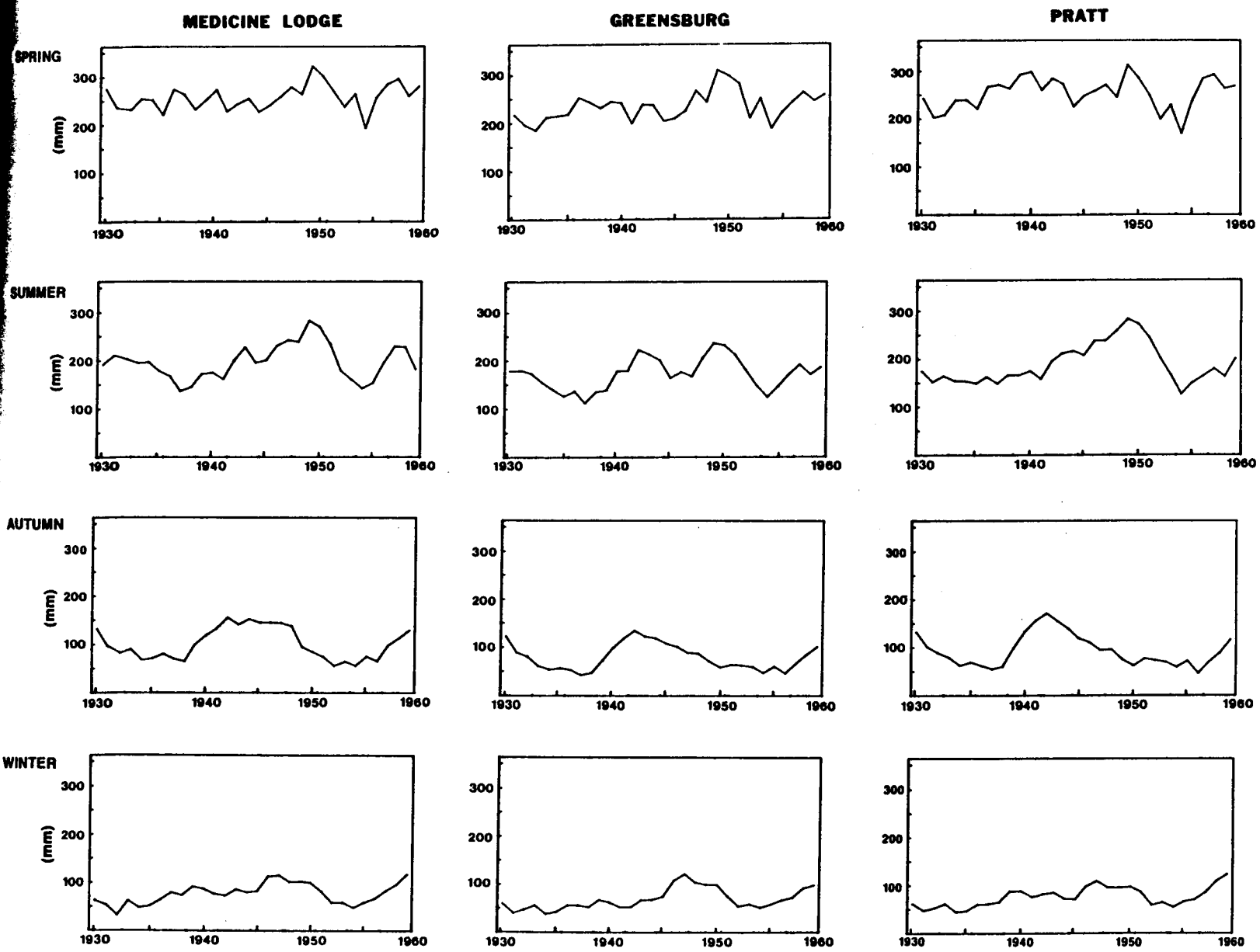
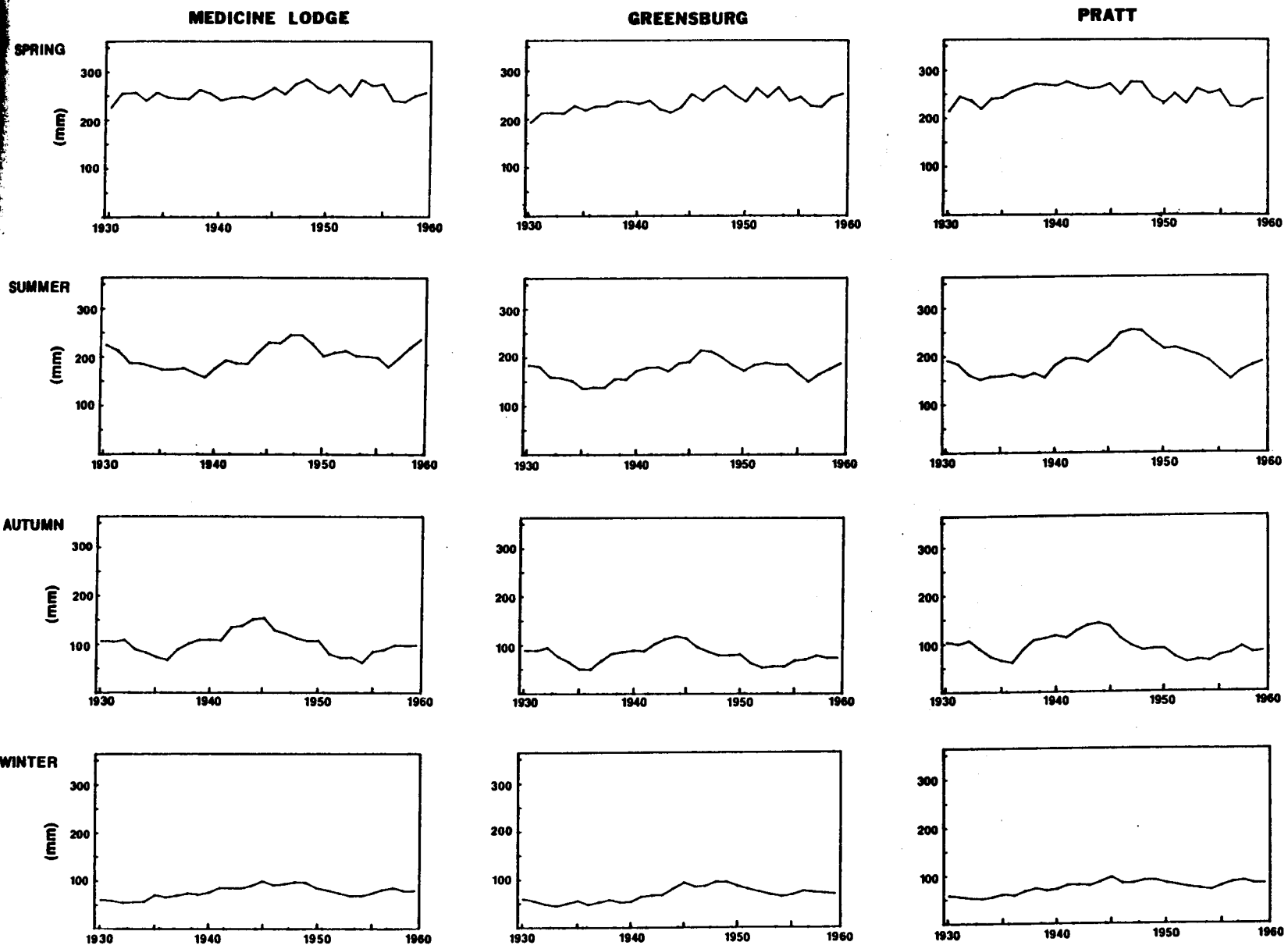


Figure 5:8 Seasonal Precipitation, 9 Year Moving Average, 1930-1959



contributed by each of the four seasons was calculated (Table 5:5). Graphs illustrate the trends between 1930 and 1959 (Figures 5:9 and 5:10). Autumn and, to a lesser extent, summer precipitation contributed more to the annual total in the moist 1940s than it did in the dry 1930s and 1950s. Spring precipitation constituted a smaller proportion of the total precipitation during the wet 1940s than during the dry 1930s and 1950s. In the 1930s, 42%-47% of the annual precipitation fell in the spring. During the 1940s, however, only 35%-40% of the annual total fell in the spring; during this same period, autumn and summer contributions increased. The decline in the relative contribution of spring precipitation during the 1940s is especially striking, and suggests that the above-average precipitation during those years was the result of more summer and autumn precipitation rather than the result of increased spring precipitation.

The frequency of occurrence for the four size classes of precipitation events was also examined on a seasonal basis for the years 1930-1959; Appendix IV contains the results of this analysis. The results show that during the 1930s at the Medicine Lodge station, 61% of the 37.5+ mm/day precipitation events occurred in the spring. In the 1940s, however, only 37% of the 37.5+

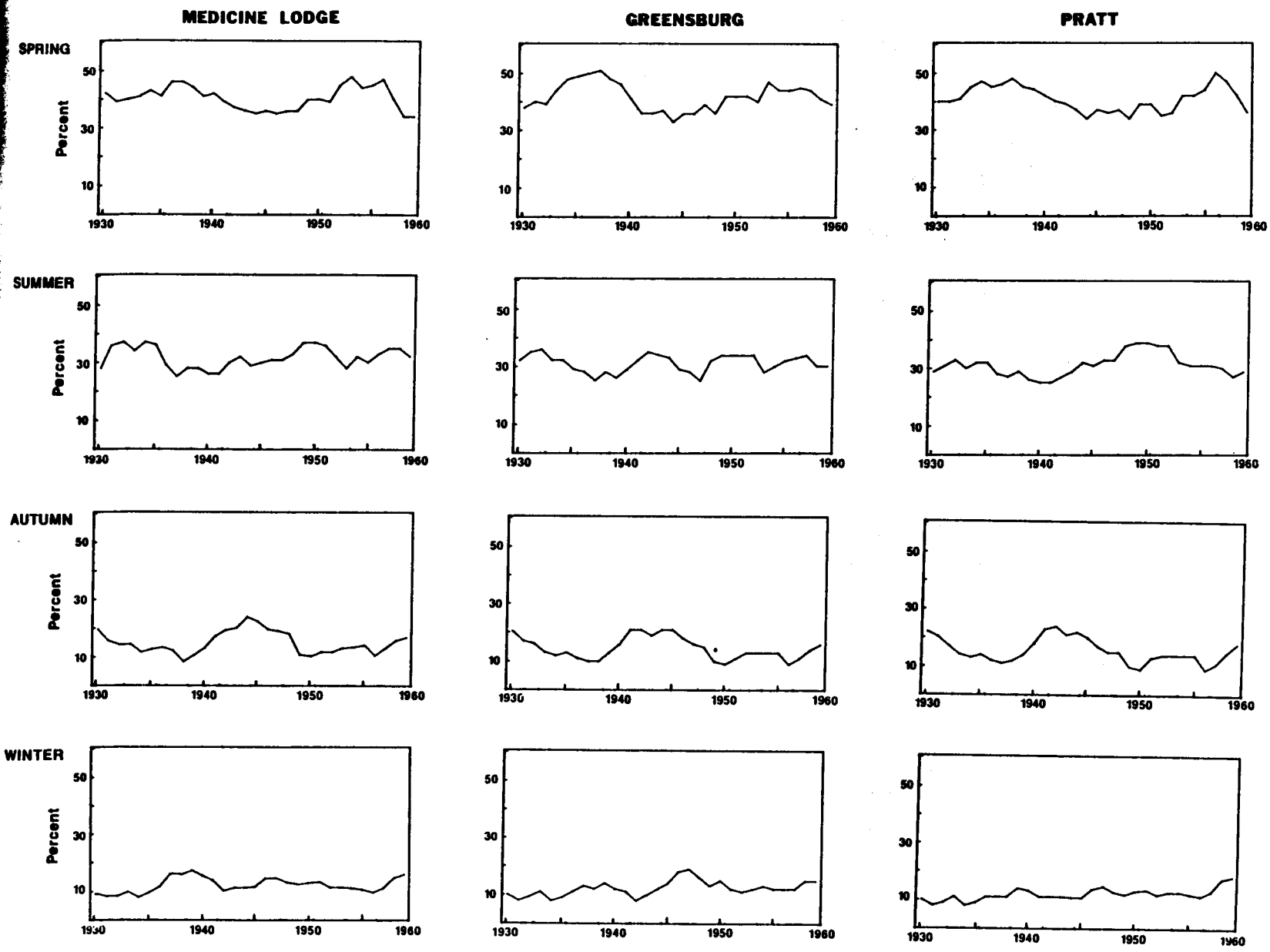
mm/day precipitation events took place in the spring. These results further support the conclusion that precipitation was less seasonal in the 1940s than in the 1930s.

Table 5:5 Mean Percent of Precipitation in a Season
1930-1959
(Standard Deviations in Parentheses)

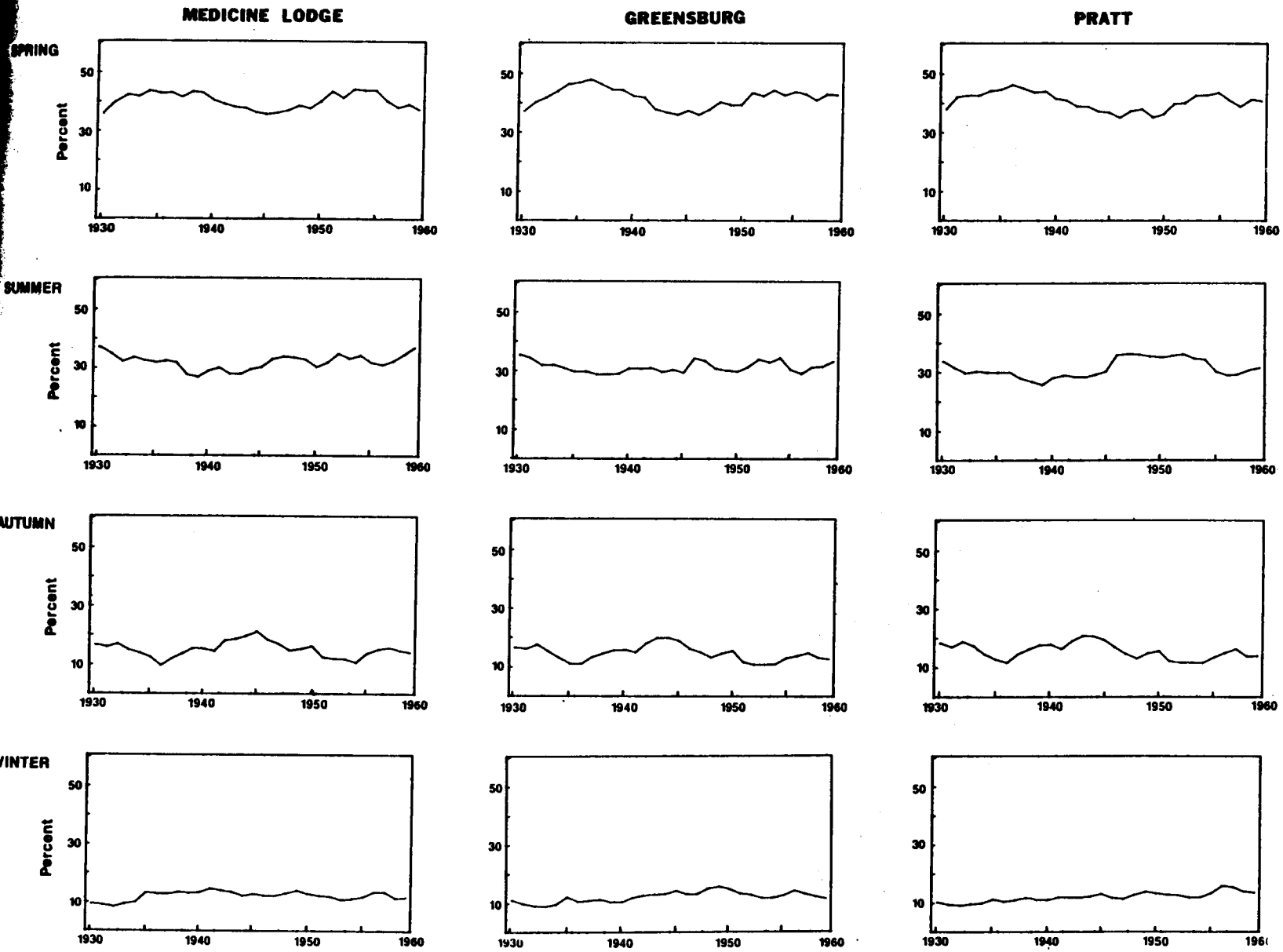
Pratt	Winter	Spring	Summer	Autumn
1930-39	10.4 (5.0)	45.1 (8.0)	30.2 (7.8)	14.2 (7.9)
1940-49	12.7 (4.2)	37.8 (8.1)	29.9 (7.3)	19.3 (10.9)
1950-59	12.2 (5.9)	41.5 (13.8)	33.6 (11.9)	12.7 (8.9)
Greensburg				
1930-39	11.2 (7.5)	45.5 (11.8)	30.3 (6.9)	12.9 (7.2)
1940-49	13.5 (7.1)	37.8 (10.0)	29.9 (8.4)	18.6 (10.0)
1950-59	11.6 (5.2)	42.1 (10.2)	34.0 (13.7)	12.2 (7.7)
Medicine Lodge				
1930-39	12.3 (8.5)	43.3 (8.9)	31.1 (13.6)	13.2 (7.3)
1940-49	12.4 (4.0)	36.2 (6.3)	30.1 (6.6)	21.2 (12.0)
1950-59	11.3 (5.8)	42.4 (13.4)	33.8 (12.7)	12.5 (8.2)

The tables show increases in autumn, winter, and summer precipitation, and a decrease in spring precipitation, during the wet period of the 1940s. In order to determine whether the observed differences in seasonal precipitation were significant, the means of the seasonal percentages of annual precipitation were compared using a Mann-Whitney U Test; this nonparametric test was selected because each sample contains only 10 values. Table 5:6 lists the results for each of the

Figure 5:9 Percent Seasonal Precipitation, 5 Year Moving Average, 1930-1959



igure 5:10 Percent Seasonal Precipitation, 9 Year Moving Average, 1930-1959



three climatic stations. The test hypotheses, levels of significance, and a discussion of the test are listed in Appendix II. The values of "U" that are significant at the 0.05 level are marked with an asterisk.

Table 5:6 Percent of Precipitation, Mann-Whitney Test

	1930s vs. 1940s		1940s vs. 1950s	
	U-Calculated	U-Critical	U-Calculated	U-Critical
Pratt				
Winter	37	27	44.5	27
Spring	28	27	31.5	27
Summer	47.5	27	47	27
Autumn	34	27	32	27
Greensburg				
Winter	39	27	45	27
Spring	30.5	27	38.5	27
Summer	49	27	44	27
Autumn	33	27	29.5	27
Medicine Lodge				
Winter	41.5	27	40.5	27
Spring	25.5*	27	37.5	27
Summer	48.5	27	44	27
Autumn	33	27	30.5	27

At the Pratt and Medicine Lodge stations, the contributions of spring precipitation to the annual totals were less in the 1940s than in the 1930s. In all other tests, the means of the seasonal percentage of precipitation did not differ significantly at the 0.05 level.

Another examination of the graphs of 5- and 10-year

running means for annual precipitation (Figures 5:4 and 5:5) reveals that the period 1932 to 1938 was the driest of the 1930s drought, while the period 1942 to 1948 was the wettest of the 1940s. When the years 1939-41 are removed from the analysis, and only the years 1932-38 and 1942-48 examined, precipitation contrasts are heightened (Table 5:7).

Table 5:7 Mean Seasonal Precipitation(mm)
1932-38 vs. 1942-48
(Standard Deviations in Parentheses)

	Winter	Spring	Summer	Autumn
Pratt				
1932-38	54 (26)	252 (94)	164 (47)	54 (30)
1942-48	83 (41)	243 (80)	219 (73)	129 (62)
Greensburg				
1932-38	48 (26)	240 (75)	135 (35)	47 (24)
1942-48	87 (52)	215 (76)	190 (79)	113 (47)
Medicine Lodge				
1932-38	59 (29)	258 (104)	193 (64)	66 (39)
1942-48	93 (46)	247 (63)	210 (72)	144 (77)

At all three stations, winter, summer, and autumn precipitation was greater and spring precipitation less during the period 1942-48 than during the period 1932-38. Precipitation appears to be much more seasonal during the period 1932-38 than during the period 1942-48. To demonstrate this, the seasonal precipitation

data were converted to seasonal percentages of annual precipitation (Table 5:8).

Table 5:8 Mean Percent of Precipitation in a Season 1932-38 vs. 1942-48
(Standard Deviations in Parentheses)

	Winter	Spring	Summer	Autumn
Pratt				
1932-38	9.8 (3.9)	47.2 (8.4)	32.0 (9.1)	11.0 (5.7)
1942-48	12.2 (4.6)	35.6 (8.6)	31.9 (5.6)	20.2 (11.1)
Greensburg				
1932-38	9.4 (4.8)	50.6 (10.0)	29.4 (7.5)	10.5 (5.1)
1942-48	14.4 (7.9)	34.9 (9.8)	30.8 (9.3)	19.8 (10.3)
Medicine Lodge				
1932-38	10.4 (5.2)	43.4 (10.3)	35.1 (14.5)	11.1 (5.4)
1942-48	12.7 (4.7)	35.7 (7.2)	30.1 (7.7)	21.4 (12.4)

At all three stations, winter and autumn contributions to annual precipitation increased, summer contributions remained nearly the same, and spring contributions decreased from the period 1932-38 to 1942-48. To determine whether these observed differences were significant, mean values were compared using a Mann-Whitney U Test (Table 5:9). Hypotheses and levels of significance are listed in Appendix II. Values of "U" that are significant at the 0.05 level are marked with an asterisk.

Table 5:9 Percentage of Precipitation, Mann-Whitney Test 1932-38 vs. 1942-48

	U-Calculated	U-Critical
Pratt		
Winter	18	11
Spring	8*	11
Summer	24	11
Autumn	12	11
Greensburg		
Winter	15	11
Spring	5*	11
Summer	21	11
Autumn	10*	11
Medicine Lodge		
Winter	16.5	11
Spring	13	11
Summer	18.5	11
Autumn	9*	11

The preceeding tables demonstrate that in Pratt and Greensburg, spring precipitation contributed less to the annual total during the period 1942-48 than during the period 1932-38, while at Greensburg and Medicine Lodge, autumn precipitation contributed less to the annual total during the period 1932-38 than during the period 1942-48. In short, precipitation appears to have been more seasonal during the period 1932-38 than during the period 1942-48.

Based on information contained in the aforementioned statistical analyses, graphs, and tables, the following conclusions about precipitation variation

are put forth. First, graphs of the number of large precipitation events (12.5-25 mm/day, 25-37.5 mm/day, and 37.5+ mm/day) do not display any trends for the period 1930-1959. A similar graph depicting the number of small precipitation events (.25-12.4 mm/day) does show an increase in events of this size during the late 1930s and early 1940s; after a peak in 1942, however, the curve again declines to its 1930's level (Fig. 5:6). In sum, it appears that there was a slight increase in the number of small precipitation events between 1930 and 1941. Such an increase may have lessened the variability of stream discharge fluctuations. According to previous research, less variable stream discharges tend to favor channel narrowing and floodplain construction (e.g., Schumm and Lichty 1963; Burkham 1972).

Second, spring precipitation as a percentage of total annual precipitation was less in the 1940s than in the 1930s (Figures 5:7, 5:8, 5:9, and 5:10). The decrease in spring precipitation was offset by an increase in autumn precipitation and, to a lesser extent, by an increase in winter precipitation. In addition, at the Medicine Lodge station, and at the Greensburg and Pratt stations to a lesser extent, during the 1930s, the 37.5+ mm/day precipitation events were

clustered in the spring; in the 1940s, however, these large precipitation events were distributed more evenly throughout the year. During the 1940s, then, precipitation was less seasonal than it had been during the 1930s. The precipitation regime of the 1940s likely resulted in less variable stream discharges and less channel erosion during the 1940s than had occurred during the 1930s.

Finally, the 1930s was a period of drought, the 1940s a period of above-average precipitation in the study area. The early 1940s, years when riparian vegetative density began to increase and channels began to narrow, was characterized by a climatic regime of above-average precipitation, a slightly increased number of small precipitation events, and a decrease in the seasonality of precipitation. These conditions likely favored more uniform stream discharges and resulted in channel stability, and, finally, channel narrowing.

Land Use Although maps showing present-day land use in the Medicine Lodge drainage basin are unavailable, data detailing the number of acres of land in pasture and under cultivation are available. Much of the land along rivers and streams and on valley slopes of the Medicine Lodge drainage basin is grazed by cattle. Most

of the cultivated land is located on the flatter uplands outside of the drainage basin. Table 5:10 lists changes in land-use that have occurred in Barber County since 1875.

Table 5:10 Barber County Land Use, 1875-1980

Year	Land Cultivated (Hectares)	%	Land Grazed (Hectares)	%
1875	571	.2	NA	NA
1880	3643	1	NA	NA
1885	17,157	5	NA	NA
1890	27,859	9	NA	NA
1895	61,222	21	NA	NA
1900	48,720	16	NA	NA
1905	58,470	20	NA	NA
1910	70,607	24	NA	NA
1915	89,173	30	153,808	52
1920	88,794	30	135,633	46
1925	88,243	30	136,220	46
1930	93,042	31	150,743	51
1935	83,679	28	150,844	51
1940	73,241	25	165,520	56
1945	89,305	30	157,214	53
1950	83,558	28	172,804	58
1955	57,521	19	181,203	61
1960	76,100	26	193,443	65
1965	71,106	24	193,443	65
1970	63,132	21	175,783	59
1975	81,080	27	193,039	65
1980	90,902	31	185,754	62

Source: Kansas State Board of Agriculture, Annual Reports

Grazing has certainly altered the natural vegetative cover of the drainage basin. The intensity of grazing, however, is nearly impossible to ascertain because residents are hesitant to admit that land has been overgrazed. Field mapping the condition of

rangeland would be a long process, and furthermore, such a map would not depict changes in land use that have taken place over the past century.

The only sources for information about land use are the local soil conservation offices in Greensburg and Medicine Lodge. Conservationists at these offices maintain that rangeland is in as good a shape today as it was a century ago. They estimate, based on accounts from long-term residents, that both the species of grass and density of the grass cover are much the same today as they were at the beginning of the 20th century. Their testimony, coupled with my observations of the extent of rangeland, leads to the conclusion that the natural vegetative cover has not been significantly disturbed by white European settlement of the area. As a result, water and sediment yield to streams and rivers has not increased significantly in most of the study area.

The above conclusion differs from that reached by Knox and his students after their research in Wisconsin. They concluded that disturbance of the vegetative cover brought about by European settlement of the region resulted in increased surface runoff and a widening of stream channels. The key difference between their studies and this one is that land in most of the drainage basins they examined had been cleared of

forests and cultivated, while land in the Medicine Lodge drainage basin remains essentially in its natural state. Consequently, surface runoff to the Medicine Lodge River and its tributaries has not increased significantly as a result of land-use change and channels have not widened.

Model of Channel and Vegetative Changes

In order to integrate the findings of this thesis into a concise summary, a working model detailing and explaining both the channel narrowing and the increase in vegetative density that have occurred in the Medicine Lodge River basin has been developed. This model traces channel narrowing back to the early 1940s, and links it to an increase in annual precipitation and a decrease in precipitation seasonality. The moister climate of the 1940s favored an increase in riparian vegetation. Increased vegetative density and less variable stream discharge, in turn, initiated channel narrowing.

Pre-1940 Conditions The original federal land-survey stream measurements from 1871 indicate that the Medicine Lodge River and Elm Creek were more than twice as wide in 1871 as they are today. Apparently, the wider channels persisted into the 1900s. Indeed, local residents maintain that the Medicine Lodge River and Elm Creek were approximately twice as wide in the 1920s as

at present. Within the wide high-water channel, there likely existed a meandering low-water channel.

The 1871 field notes mention only scattered stands of timber along the same stream and river channels that support dense riparian vegetation today. Riparian vegetation was unable to establish itself within the high-water channel because floods periodically covered the area, reworking channel deposits. Local residents report that visibility along the Medicine Lodge River and Elm Creek was greater in the 1920s than it is today. Today's reduced visibility is likely the result of an expanded riparian vegetative cover. Cores extracted from the oldest trees on the floodplain of the Medicine Lodge River and Elm Creek revealed that few trees germinated prior to about 1940. Two conclusions can be drawn from this finding. First, the vegetated floodplain present today may, in 1940, have been an unstable surface that, because of frequent inundation by floods, supported few trees. Second, because the river was much wider in 1871 than it is today, the vegetated floodplain found today did not exist at that earlier time. Testimony from local residents regarding channel narrowing suggests that the latter conclusion is likely the correct one.

The 1930s, years of below average and more seasonal precipitation, was a period of variable stream

discharges and a slowly contracting vegetative cover. As a consequence of the reduced vegetative cover, surface runoff, and hence stream discharge, probably increased during precipitation events. Higher discharges, by flushing out sediments previously stored in channel banks, widened river channels.

Post-1940 Conditions During the late-1930s, and into the 1940s, annual precipitation began to increase. The number of small precipitation events also increased, and annual precipitation became less seasonal. With precipitation distributed more evenly throughout a given year, stream discharge became less variable. The combination of relatively unfluctuating stream discharges and an increase in annual precipitation induced vegetative growth on floodplains, mid-channel bars, point bars, and areas adjacent to low-water channels. Plates 5:7 and 5:8 depict vegetation growth on point bars and areas adjacent to the low-water channel of Elm Creek. The expanded vegetative cover, in turn, resulted in more sediment deposition and further channel narrowing. The absence of any paleosols in the alluvial stratigraphy downstream from the headwaters of the Medicine Lodge River basin suggests that lateral rather than vertical accretion was the main component of

Plate 5:7 Vegetation Stabilization of Channel Deposits, Elm Creek

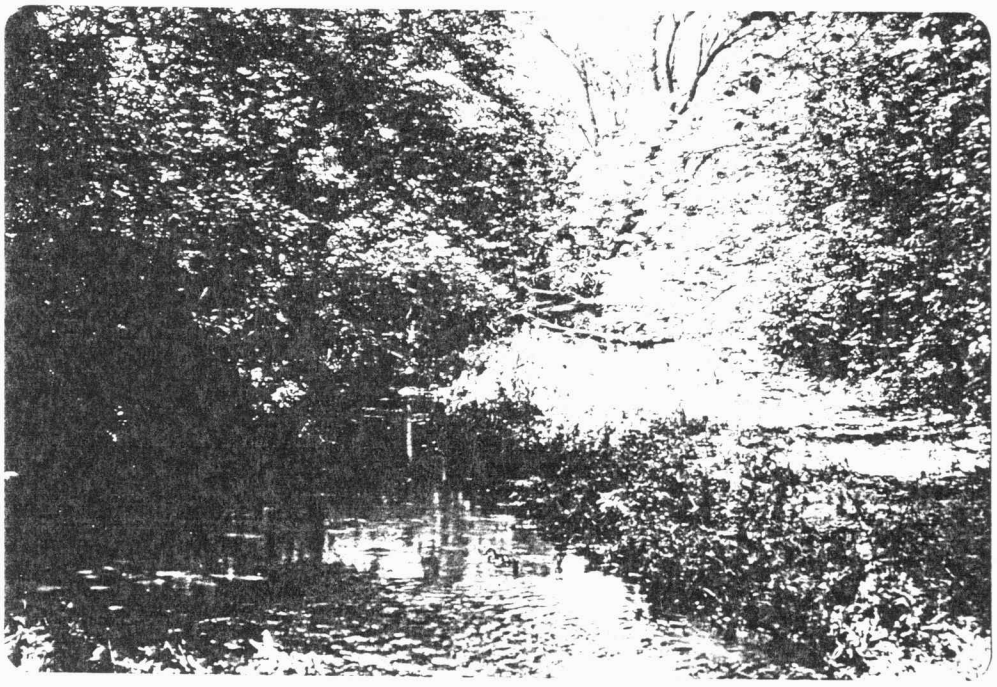
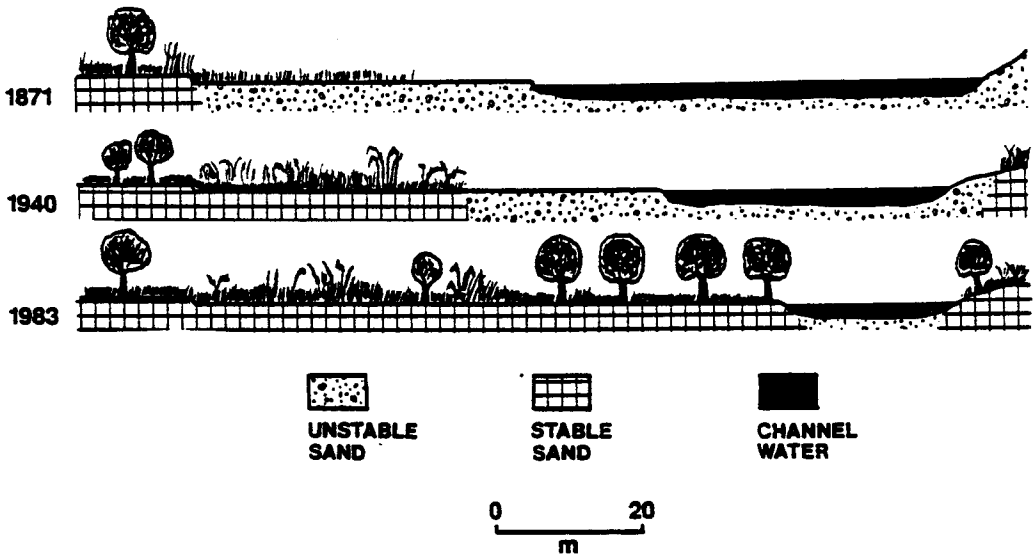


Plate 5:8 Vegetation Stabilization of Channel Deposits, Elm Creek

floodplain construction in the study area. This conclusion is further supported by the presence of young seedlings and older saplings on what appear to be former point or mid-channel bar deposits. As a result of this lateral accretion, channels began to narrow. Increased transpiration by the expanded vegetative cover resulted in more water being withdrawn from river channels; this process reduced water levels and accelerated the narrowing. Figure 5:11, modified from a diagram by Graf (1978), portrays the process of channel narrowing and vegetative growth that likely occurred in the Medicine Lodge River basin between 1871 and 1983.

Figure 5:11 Channel Narrowing (After Graf 1978)



Today the Medicine Lodge River and Elm Creek are narrow, tree-lined streams. The absence of any large floods during the past 10 years has permitted young willow and cottonwood seedlings to take root in channel bottoms. Because channels have narrowed, the potential for a large flood is greater today than it was 50 years ago when channels were wider; when such a flood occurs, however, the expanded vegetative cover may retard overbank stream-flow velocity, thereby reducing significantly the potential for channel widening (see Leopold and Wolman 1957; Schumm and Lichty 1963; Sigafoos 1964; Everitt 1968; Burkham 1972).

A final note in the discussion of the model of channel change is the presence of Simpson Gully. According to local testimony, this gully, located about 3.2 km (2 miles) west of the town of Medicine Lodge, was excavated during the 20th century. A sample of wood from a burnt, upright, in situ Juniper (Juniperus sp.) within the gully yielded a radiocarbon date of Modern (DIC-2784). Sediment within the Juniper stump, however, suggested that the tree had, at one time, been buried. It appears, then, that Simpson Gully is an old feature that was filled during the last 250 years and subsequently reexcavated during the 20th century. Such rapid change demonstrates the speed with which alluvial

cutting and filling can occur in the Great Plains.

CHAPTER 6: CONCLUSIONS AND IMPLICATIONS OF THIS STUDY

A description of the historic channel and riparian vegetative changes that have occurred along the Medicine Lodge River in south-central Kansas has been presented and a model explaining these changes developed. The findings of this study are important because much research has been conducted on river systems in humid climates, but little has been done on river systems in the subhumid and semi-arid Great Plains, site of the Medicine Lodge River.

Conclusions

Stream channels in the Medicine Lodge River basin have narrowed and riparian vegetative density has increased since the original federal land-survey was conducted there in 1871. Remeasurement of channel widths at section-line crossings along the Medicine Lodge River, Elm Creek, and Thompson Creek revealed that, at most crossings, channels are narrower today than they were in 1871. Interviews with long-term residents of the area suggest that the channel narrowing and the increase in riparian vegetation began in the late-1930s and early 1940s. Tree cores demonstrating that many of the oldest trees along several reaches of the Medicine Lodge River and Elm Creek germinated in the

late-1930s and early 1940s support their testimony. Comparison of 1956 and 1979 aerial photographs that depict selected channel measurement sites further indicates that the channel narrowing and increases in riparian vegetation are continuing to present.

The channel narrowing appears to have occurred during periods of above-average precipitation; such periods appear to be characterized by less seasonal precipitation, while drier periods seem to be characterized by more seasonal precipitation. As a result, stream discharge is less variable during wet periods than during dry periods. Past research has related variable stream discharge to channel widening, less variable discharge to channel narrowing or stability (e.g., Schumm and Lichty 1963; Burkham 1972; Stevens et al. 1975; and Brakenridge 1981). Periods of above-average precipitation also increase vegetative density. The increased transpiration from this expanded vegetative cover results in increasingly larger volumes of water being withdrawn from streams, reducing stream discharge and inducing channel bank stability. The vegetative cover, should it become extensive enough, may anchor channel banks during floods, thereby preventing channel widening.

The model presented in this thesis is both similar

to and different from those developed for river systems in humid climates. In humid climates, most historic channel change has been attributed to changed land-use conditions. In this study, it was impossible to assess the impact of changed land-use on the Medicine Lodge River system because that variable does not appear to have changed substantially since the original federal land-survey in 1871. In that respect, this study cannot be directly compared to those done by Knox and his students. Nevertheless, it demonstrates that river systems in subhumid climates are sensitive to changes in the seasonality and amount of precipitation. Research in humid climates suggests that such river systems are less responsive to fluctuations in precipitation than those in drier climates. Perhaps the more extensive vegetative cover found in humid climates is less sensitive to precipitation fluctuations, the magnitude of these fluctuations is smaller, or fluctuations do not occur regularly. In subhumid climates, it appears that precipitation fluctuations, which do occur frequently, are an important cause of channel change.

Implications of the Study

In addition to describing and explaining the channel narrowing and riparian vegetative changes that have occurred in a single river system, the Medicine

Lodge River basin, and then developing a model for channel change in the central Great Plains, this research has more wide ranging implications in the field of fluvial geomorphology. Specifically, the widening of channels in the 1800s, and their subsequent narrowing in the 1940s, suggests that sediment was alternately stored in and then removed from the river system. Perhaps such alternation is typical of river systems located in subhumid climates where climatic fluctuations occur frequently. Furthermore, the channel narrowing and expansion of the riparian vegetative cover suggest a possible model for floodplain construction along rivers in the Great Plains.

The relatively wider channels found in the study area in 1871 indicate that the 1800s were a period of sediment removal by the process of channel widening. It would be interesting to examine the records of rivers downstream, such as the North and South Canadian Rivers in Oklahoma, to determine whether they also underwent a period of widening during the 1800s. One would suspect that the increased sediment discharge from tributary streams such as the Medicine Lodge River caused trunk rivers to undergo a period of floodplain aggradation and sediment storage. Conversely, the 1900s, which were a period of sediment storage and channel narrowing in

tributary streams, might have been a period of channel widening in trunk streams as the latter experienced an excess capacity to transport sediment. The linkage between tributary and trunk streams merits further study.

From a geologic perspective, it appears that the type of channel change addressed in this thesis has not been restricted to historic time, but has occurred frequently throughout the Holocene. The presence of three stacked paleosols separated by sand and gravel deposits along Elm Creek suggests that, in the study area, the Holocene has been characterized by alternating periods of stability and fluvial activity. In the Great Plains, paleosols found in alluvial cut-bank exposures along streams such as Wolf Creek, Deer Creek, and the Kansas River have commonly radiocarbon dated to ca. 400, 1000, and 2000 years BP (Johnson, Dort, and Sorenson 1980).

The channel narrowing of the 1900s also provides insight into the process of floodplain construction along rivers of the Great Plains. Previous research has implied that floodplain construction proceeds through a combination of lateral and vertical accretion (e.g., Schumm and Lichty 1963; Wolman and Leopold 1970; and Lewin 1983). Lateral accretion begins with mid-channel

bars becoming vegetated during an extended period of low magnitude stream discharges. Once vegetated, these bars become a permanent fixture in the channel, and subsequently divert stream flow, creating two channels. The channel having the higher discharge becomes the main channel while that with the lower discharge becomes a branch channel. In time, the branch channel, which transports the largest proportion of bedload, begins to aggrade and eventually is abandoned. Once the channel is abandoned, vegetation will move in and stabilize the recently deposited sediment.

Vertical accretion proceeds by the growth of vegetation adjacent to the low-water channel under a climatic regime characterized by low-magnitude floods. Under such a flood regime, the material in which this vegetation is rooted is rarely inundated by floodwaters, hence the vegetation is able to mature. At the same time, vegetation may begin to grow on point bar deposits. The presence of this new riparian vegetation initiates sediment deposition when floodwaters overtop the low-water channel. Once these areas of the channel are sheltered by vegetation, they, in turn, shield other parts of the channel from the destructive force of large floods, allowing them to become stable. The process of floodplain construction, then, is one of positive

feedback whereby low-magnitude flows allow expansion of the vegetative cover. The expanded vegetative cover, in turn, aids in the entrapment and deposition of sediment and narrowing of channels. The absence of paleosols downstream from the headwaters of the Medicine Lodge River, Elm Creek, and Thompson Creek suggests that lateral accretion may be the most important mechanism of floodplain construction in the study area.

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APPENDIX I

1871 and 1983 Channel Width Measurements (m)

MEDICINE LODGE RIVER

MLR#	1871	1983 Bankfull	1983 Lowflow	DA (km^2)
1	8.0	4.5	4.5	50
2	16.1	5.2	4.8	63
3	15.1	6.9	6.1	71
4	20.1	7.2	3.1	132
5	20.1	7.6	7.5	159
6	5.0	8.8	3.0	184
7	24.1	10.5	6.1	300
8	60.4	10.4	5.8	381
9	60.4	20.0	6.2	394
10	20.1	12.2	8.5	523
11	60.4	11.6	10.1	536
12	50.3	16.9	9.9	557
13	60.4	13.9	6.7	578
14	80.5	18.3	11.2	751
15	90.5	20.1	19.9	795
16	171.0	18.9	12.5	850
17	211.2	20.9	10.7	862
18	80.5	25.2	12.8	888
19	80.5	21.2	16.9	909
20	140.8	24.5	16.9	948
21	70.4	26.8	14.3	956
22	70.4	31.3	15.9	956
23	75.4	50.2	10.5	1070
24	70.4	25.9	12.3	1110
25	90.5	20.9	15.8	1160
26	80.5	23.9	11.7	1170
27	70.4	20.4	8.2	1200
28	60.4	20.4	18.6	1310
29	60.4	21.5	19.2	1340

MLR = Medicine Lodge River site.
DA = Drainage Area, Measured in Square Kilometers.

1871 and 1983 Channel Width Measurements (m)

ELM CREEK

EC #	1871	1983 Bankfull	1983 Lowflow	DA (km^2)
1	16.1	12.8	5.7	41
2	18.1	11.1	7.8	50
3	20.1	12.9	NA	51
4	NA	15.2	NA	51
5	14.1	7.1	6.1	61
6	14.1	23.3	5.8	64
7	12.1	NA	2.0	65
8	4.0	8.6	1.9	66
9	10.0	13.6	2.4	131
10	14.1	2.7	2.3	131
11	20.1	10.6	2.8	143
12	20.1	9.3	3.9	148
13	17.1	8.7	3.9	151
14	16.1	7.3	4.6	155
15	24.1	7.6	5.4	155
16	12.1	8.2	3.9	251
17	20.1	13.9	5.6	264
18	20.1	25.3	3.9	290
19	14.1	14.0	4.7	293
20	24.1	14.8	8.8	298
21	20.1	17.4	6.4	300
22	20.1	14.2	6.6	311
23	20.1	11.1	3.2	313
24	40.2	15.8	9.9	365
25	40.2	21.8	11.0	365
26	40.2	12.9	6.9	376
27	40.2	21.3	15.0	401
28	50.3	27.9	11.1	404
29	50.3	25.5	8.7	414
30	40.2	21.6	12.0	417
31	35.2	17.1	9.2	420
32	90.5	16.3	9.2	432
33	40.2	23.8	8.5	432
34	70.4	15.2	10.1	448
35	60.4	18.0	8.2	448

EC = Elm Creek site.
DA = Drainage Area, Measured in Square Kilometers.
NA = Data Not Available.

1871 and 1983 Channel Width Measurements (m)

THOMPSON CREEK

TC #	1871	1983 Bankfull	1983 Lowflow	DA (km^2)
1	4.0	8.8	8.0	19
2	5.0	3.8	3.2	24
3	5.0	2.7	2.6	80
4	5.0	3.3	3.3	83
5	5.0	4.6	3.9	87
6	5.0	5.1	3.7	96
7	6.0	3.6	3.6	96
8	3.0	4.9	4.9	110

TC = Thompson Creek site.
DA = Drainage Area, Measured in Square Kilometers.

APPENDIX II

Statistical Tests and Hypotheses

Wilcoxon Test: Mean Channel Widths 1871 vs. 1983

Table 5:2 Test Hypotheses

H_o = There is no significant difference between mean channel width in 1871 and 1983.

H_1 = The channels in 1983 are significantly narrower than those in 1871.

Level of Significance = .05

The Wilcoxon Test for paired samples tests observed differences in two means to determine whether they are the result of chance or consistent differences in the data. Because it is a non-parametric test, the data need not have a normal distribution and variances need not be equal. The test has a 95% power-efficiency (see Hammond and McCullagh 1978:207-213).

Mann-Whitney U Test: Percent of Seasonal Precipitation

Table 5:6 Test Hypotheses

H_o = The mean percents of seasonal precipitation are not significantly different.

1930s vs. 1940s

H_1 = The mean percent of seasonal precipitation for winter, summer, or fall was greater in the 1940s than in the 1930s.

H_1 = The mean percent of seasonal precipitation for spring was less in the 1940s than in the 1930s.

1940s vs. 1950s

H_1 = The mean percent of seasonal precipitation for winter, summer, or fall was greater in the 1940s than in the 1950s.

H_1 = The mean percent of seasonal precipitation for spring was less in the 1940s than in the 1950s.

Level of Significance = .05

Mann-Whitney U Test: Percent of Seasonal Precipitation

Table 5:9 Test Hypotheses

H_o = The mean percents of seasonal precipitation are not significantly different.

H_1 = The mean percents of seasonal precipitation for winter, summer, or fall were greater during the period 1942-48 than 1932-38.

H_1 = The mean percent of seasonal precipitation for spring was less during the period 1942-48 than 1932-38.

Level of Significance = .05

The Mann-Whitney U Test determines whether the observed differences in two independent means are the result of chance or consistent differences in the data. If U-calculated is less than U-critical, then the null hypothesis is rejected. Because it is a non-parametric test, the data need not be normally distributed or have equal variances. Like the Wilcoxon Test, the Mann-Whitney U Test is 95% efficient (see Hammond and McCullagh 1978:199-207). One-tailed U-critical values obtained from Taylor (1977:344).

APPENDIX III

Field Notes 1871 and 1983

MEDICINE LODGE RIVER MEASUREMENTS

#1 T30S R18W Sec. 2 to 11

1871: "Creek 40 links bearing southeast."
1983: Tall grasses, widely scattered willow and cottonwood on banks.

#2 T30S R18W Sec. 12 to 13

1871: "Creek 80 links wide bearing southeast. Cottonwood and elm."
1983: Elm, cottonwood, catalpa, and grasses along banks.

#3 T30S R17W Sec. 7 to 8

1871: "Enter timber (cottonwood and elm). Creek 75 links wide bearing east."
1983: Scattered willow and cottonwood on banks.

#4 T30S R17W Sec. 16 to 17

1871: "Creek 100 links runs east. Scattered cottonwood and elm."
1983: Very scattered cottonwood and elm.

#5 T30S R17W Sec. 14 to 13

1871: "Creek 100 links wide runs east. Scattered elm."
1983: Tall grasses along stream, elms and willow on banks.

#6 T30S R16W Sec. 18 to 7

1871: "Creek 25 links runs northeast."
1983: Cottonwoods and elms on banks.

#7 T30S R16W Sec. 8 to 9

1871: No field notes.
1983: Cottonwood, elm, willow on banks.

#8 T30S R16W Sec. 3 to 10

1871: "Creek 4 chains wide, timber (no species).
1983: Scattered willow, cottonwood, and elm.

#9 T30S R16W Sec. 15 to 14

1871: "Creek 3 chains wide, runs southeast. Scattered cedar and cottonwood."
1983: Cottonwood, willow, and cedar on banks.

#10 T30S R16W to R15W Sec. 13 to 18

1871: "Creek 100 links wide runs east."
1983: Cottonwood, willow, elm, and dense underbrush.

#11 T30S R15W Sec. 30 to 29

1871: "Creek 300 links wide runs southeast. Scattered cottonwoods on banks."
1983: Willow, cottonwood, cedar, and shrubs on banks.

#12 T30S R15W Sec. 27 to 34

1871: "Creek 250 links wide runs northeast."
1983: Willow, cedar, and cottonwoods on banks.

#13 T30S R15W Sec. 34 to 35

1871: "Creek 30 links wide runs southeast."
1983: Willow, elm, and cottonwood with scattered cedar.

#14 T31S R15W Sec. 11 to 12

1871: "Creek 200 links wide runs northeast."
1983: Willow and cottonwood on banks.

#15 T31S R14W Sec. 6 to 7

1871: "Medicine Lodge Creek 4.5 chains wide comes from west, runs southeast."
1983: Elm, scattered willow and cottonwood.

#16 T31S R14W Sec. 8 to 17

1871: "Medicine Lodge Creek 3.25 chains wide running water; bed of creek 8.00 chains wide, runs from northwest to east. Leave creek and enter timber (cottonwood and elm)."
1983: Willow, elm, catalpa, ash, and scattered cottonwood.

#17 T31S R14W Sec. 17 to 16

1871: "Medicine Lodge creek 10.50 chains wide runs from west to southeast."
1983: Willow and elms along banks, large cottonwoods about 17 to 25 meters back from river.

#18 T31S R14W Sec. 16 to 15

1871: "Medicine Lodge Creek 400 links wide runs southeast. Ash, elm, cottonwood, walnut, mulberry, and hackberry along banks."
1983: Catalpa, willow, cottonwood, ash, and hickory in dense tree cover along banks.

#19 T31S R14W Sec. 15 to 14

1871: "Medicine Lodge Creek 400 links wide runs east. timber of cottonwood, elm, ash, hackberry, and walnut.
1983: Elm, walnut, hackberry, catalpa, and cottonwood along banks.

#20 T31S R14W to R13W Sec. 24 to 19

1871: "Medicine Lodge Creek 7.0 chains wide runs east. After crossing enter timber (cottonwood, elm, ash, hackberry, mulberry, and wild china)."
1983: Willow, elm, cedar, and cottonwood on banks.

#21 T31S R13W Sec. 30 to 29

1871: "Creek 350 links wide runs east. Scattered timber of cottonwood, ash, elm, hackberry, and vines."
1983: Banks lined with catalpa, willow, cottonwood, walnut, and elm.

#22 T31S R13W Sec. 29 to 20

1871: "Medicine Lodge Creek 350 links runs northeast. Timber of cottonwood, ash, elm, and vines."
1983: Elm, walnut, cedar, cottonwood, catalpa, and willow trees. Younger trees along channels, line of older trees back from channel.

#23 T31S R13W Sec. 28 to 27

1871: "Medicine Lodge Creek 375 links runs east. timber of cottonwood and elm."
1983: Cottonwood, willow, and elm on one channel bank. Other void of vegetation.

#24 T31S R13W Sec. 26 to 35

1871: "Medicine Lodge Creek 350 links runs south. Timber of elm, ash, cottonwood, hackberry, and undergrowth of vines east of channel."
1983: Thick cedar, cottonwood, and walnut on banks.

#25 T31S R13W to R12W Sec. 36 to 31

1871: "Medicine Lodge Creek 4.50 chains wide runs northeast. Scattered cottonwood and elm on banks."
1983: Elm, cottonwood, cedar, and willow on banks. Area was cleared of trees about two decades ago.

#26 T32S R12W Sec. 6 to 5

1871: "Medicine Lodge Creek, 4 chains wide."
1983: Elm, cottonwood, and willow on banks. Small trees on banks, large trees back from banks.

#27 T32S R12W Sec. 4 to 9

1871: "Medicine Lodge creek 3.50 chains wide, runs south. Timber of cottonwood, elm, ash, hackberry, walnut, and mulberry."
1983: Cottonwood, cedar, and walnut on banks. Young trees close to bank, old trees back from bank.

#28 T32S R12W Sec. 9 to 10

1871: "Medicine Lodge Creek 3 chains runs southeast."
1983: Cottonwoods dominate, willow, and a few elm. Younger trees closer to bank, older trees back from bank.

#29 T32S R12W Sec. 11 to 14

1871: "Medicine Lodge Creek 3 chains wide, comes from east flows south. Timber cottonwood and elm east of creek."
1983: Thick cover of willow, cottonwood, elm, and cedar.

ELM CREEK MEASUREMENTS

#1 T30S R14W Sec. 10 to 11

1871: "Dry creek, 80 links wide bearing S.E."
1983: Widely scattered cottonwood, short grass prairie

#2 T30S R14W Sec. 11 to 14

1871: "Dry creek 90 links bears S.E."
1983: Widely scattered elm and cottonwood. Short grass prairie above banks.

#3 T30S R14W Sec. 14 to 13

1871: "Dry creek 100 links wide runs east".
1983: No vegetation along stream.

#4 T30S R14W Sec. 12 to 13

1871: "Enter dry creek bears southwest and east. Leave same dry creek bears west and southeast".
1983: Willow growing in bed.

#5 T30S R14W Sec. 13 to 18

1871: "Creek 70 links wide runs southeast."
1983: Grass in bed, cottonwood, elm, and willow on banks.

#6 T30S R13W Sec. 18-19

1871: "Creek 70 links runs southeast."
1983: Scattered cottonwood on banks.

#7 T30S R13W Sec. 19 to 20

1871: "Creek 60 links runs east."
1983: Scattered cottonwoods on banks.

#8 T30S R13W Sec. 20 to 17

1871: "Creek 20 links runs northeast, scattered timber on banks.
1983: Cottonwood, willow, elm, cedar along banks.

#9 T30S R13W Sec. 17 to 20

1871: "Creek 50 links wide runs southeast, scattered timber on banks."
1983: Scattered willow on banks.

#10 T30S R13W Sec. 20 to 21

1871: "Creek 70 links wide runs southeast."
1983: Grass, elms, and willow along banks.

#11 T30S R13W Sec. 21 to 22

1871: "Creek 100 links wide runs east. Scattered cottonwood, hackberry, and elm on banks."
1983: Point bar deposits stabilized by vegetation. Willow, cottonwood, and elm on banks. Small cedar on flodplain.

#12 T30S R13W Sec. 22 to 23

1871: "Enter timber east-west. Elm, cottonwood, and hackberry. Creek 100 links wide runs east."
1983: Vegetated point bars 1.5 meters above current stream level. Cottonwood and some willow on banks.

#13 T30S R13W sec. 23 to 14

1871: "Enter timber (cottonwood, elm, hackberry, and ash). Creek 85 links wide runs southeast.
1983: Willows, elm, and cedar along banks.

#14 T30S R13W Sec. 14 to 23

1871: "Creek 80 links wide runs southeast."
1983: Scattered cottonwood, elm, hickory, and walnut along banks.

#15 T30S R13W Sec. 23 to 24

1871: "Enter timber (cottonwood, elm, hackberry, ash, and willow) bears east-west. Creek 120 links wide runs east."
1983: Scattered cottonwood, elm, hickory, and walnut along banks.

#16 T30S R13W to R12W Sec. 24 to 19

1871: "Creek 60 links wide runs southeast. Timber of cottonwood, elm, ash, hackberry, and vines."
1983: Cottonwood, willow, elm, and weeds along bank.

#17 T30S R12W Sec. 19 to 20

1871: "Enter timber (cottonwood, elm, willow, and hackberry) running northwest-southeast. Creek 100 links wide.
1983: Cottonwood, willow, and brush on banks.

#18 T30S R12W Sec 20 to 29

1871: "Enter scattered timber (cottonwood, elm, hackberry) trending northwest-southeast. Creek 100 links wide."
1983: Willow and cottonwood on banks.

#19 T30S R12W Sec 29 to 28

1871: "Scattered timber (cottonwood, elm) bears northwest-southeast. Creek 70 links wide runs southeast."
1983: Scattered cottonwoods and willow.

#20 T30S R12W Sec 28 to 33

1871: "Enter timber (cottonwood, elm, and hackberry) bearing northwest-southeast. creek 120 links runs southeast."
1983: Cottonwood, willow, and hickory on banks.

#21 T30S R12W Sec. 33 to 34

1871: "Creek 100 links wide bearing southeast. Scattered timber (cottonwood and elm) on banks."
1983: Cottonwood, willow, hickory on banks.

#22 T30S R13W Sec. 34 to 35

1871: "Enter timber (cottonwood, elm, and hackberry) bearing northwest-southeast. creek 100 links bearing southeast."
1983: Cottonwood and willow on banks.

#23 T30S to T31S R12W Sec. 35 to 2

1871: No field notes.
1983: Cottonwood, willow, elm, and catalpa.

#24 T31S R12W Sec. 2 to 1

1871: "Creek 2 chains wide runs southeast. Scattered cottonwood on banks."
1983: Cottonwood, willow, and catalpa on banks.

#25 T31S R12W Sec. 1 to 12

1871: "Creek 2 chains wide bearing southeast. Cottonwood and elm scattered along banks."
1983: Cottonwood, willow, elm, and catalpa along banks.

#26 T31S R12W Sec. 12 to 13

1871: "Creek 2 chains wide runs southwest. Elm and cottonwood on banks."
1983: Cottonwood, willow, elm, and catalpa along banks.

#27 T31S R12W Sec. 13 to 24

1871: "Creek 2 chains wide runs south."
1983: Cottonwood, willow, and catalpa along banks.

#28 T31S R12W Sec. 24 to 25

1871: "Creek 250 links runs south. Timber (cottonwood and elm) on banks."
1983: Willow, cottonwood, elm, and catalpa along banks.

#29 T31S R12W Sec. 25 to 30

1871: "Creek 250 links wide runs east and southeast. Scattered timber (cottonwood, willow, and elm) on banks."
1983: Cottonwood, elm, willow, and catalpa on banks.

#30 T31S R11W Sec. 30 to 31

1871: "Creek 2 chains wide runs south. Scattered cottonwood, willow, and elm on banks."
1983: Catalpa, willow, and elm on banks.

#31 T31S to T32S R11W Sec. 31 to 6

1871: "Creek 175 links bearing south."
1983: Grass on banks with widely scattered cottonwood and willow.

#32 T32S R11W Sec. 6 to 7

1871: "Creek 450 links wide runs southwest."
1983: Heavy underbrush, willow, cottonwood, catalpa, and elm on banks.

#33 T32S R11W to R12W Sec. 7 to 12

1871: "Creek 200 links wide bearing southwest. Scattered cottonwood and elm on banks."
1983: Sandy creek bed, heavy undergrowth. Cottonwood, elm, and willow.

#34 T32S R12W Sec. 12 to 11

1871: "Creek 2 chains wide. Scattered timber cottonwood, ash, and elm) on banks."
1983: Elm, catalpa, and cottonwood on banks.

#35 T32S R12W Sec. 11 to 14

1871: "Creek 2 chains wide. Cottonwood and elm on banks."
1983: Elm, cottonwood, and willow on banks.

THOMPSON CREEK MEASUREMENTS

There are no field notes for Thompson Creek because, in 1871, that area was part of an Indian Reservation. Channel width measurements were obtained from the 1871 survey plat maps.

APPENDIX IV

Frequency of Occurrence for Precipitation Magnitudes by Season
(Percentages of Given Size Event in Parentheses)

MEDICINE LODGE

Precipitation Event	Winter	Spring	Summer	Autumn
1930s				
0.25-12.4 mm	70 (15.6)	158 (35.3)	122 (27.2)	98 (21.9)
12.5-25 mm	15 (18.9)	28 (35.4)	23 (29.1)	13 (16.4)
25-37.5 mm	1 (4.0)	8 (32.0)	12 (48.0)	4 (16.0)
37.5+ mm	1 (3.2)	19 (61.2)	10 (32.2)	1 (3.21)
1940s				
0.25-12.4 mm	106 (22.4)	144 (30.4)	121 (25.5)	103 (21.7)
12.5-25 mm	10 (11.9)	31 (36.9)	28 (33.3)	15 (17.8)
25-37.5 mm	5 (8.3)	23 (38.3)	21 (35.0)	11 (18.3)
37.5+ mm	4 (11.4)	13 (37.1)	10 (28.5)	8 (22.8)
1950				
0.25-12.4 mm	82 (20.0)	151 (37.0)	122 (29.9)	53 (12.9)
12.5-25 mm	14 (15.2)	41 (44.6)	22 (23.9)	15 (16.3)
25-37.5 mm	4 (10.5)	13 (34.2)	17 (44.7)	4 (10.5)
37.5+ mm	0 (0.0)	16 (66.6)	5 (20.8)	3 (12.5)

GREENSBURG

Precipitation Event	Winter	Spring	Summer	Autumn
1930s				
0.25-12.4 mm	84 (19.0)	146 (33.1)	117 (21.3)	94 (21.3)
12.5-25 mm	12 (16.0)	29 (38.7)	24 (32.0)	10 (13.3)
25-37.5 mm	0 (0.0)	10 (45.4)	10 (45.4)	2 (9.0)
37.5+ mm	1 (5.2)	11 (57.9)	5 (26.3)	2 (10.5)
1940s				
0.25-12.4 mm	146 (23.6)	187 (30.2)	152 (24.5)	134 (21.6)
12.5-25 mm	15 (13.1)	46 (40.3)	35 (30.7)	18 (15.8)
25-37.5 mm	1 (2.6)	17 (44.7)	14 (36.8)	6 (15.8)
37.5+ mm	3 (13.0)	10 (43.5)	7 (30.4)	3 (13.0)
1950s				
0.25-12.4 mm	106 (20.6)	194 (37.7)	138 (26.8)	77 (14.9)
12.5-25 mm	14 (14.1)	38 (38.4)	29 (29.3)	18 (18.2)
25-37.5 mm	3 (10.0)	17 (56.6)	8 (26.7)	2 (6.6)
37.5+ mm	0 (0.0)	7 (33.3)	14 (66.6)	0 (0.0)

PRATT

Precipitation Event	Winter	Spring	Summer	Autumn
1930s				
0.25-12.4 mm	64 (18.6)	119 (34.7)	82 (23.9)	78 (22.7)
12.5-25 mm	9 (10.8)	31 (37.3)	28 (33.7)	15 (18.1)
25-37.5 mm	1 (2.7)	17 (47.2)	14 (38.9)	4 (11.1)
37.5+ mm	0 (0.0)	9 (60.0)	6 (40.0)	0 (0.0)
1940s				
0.25-12.4 mm	109 (21.7)	151 (30.0)	145 (28.9)	97 (19.3)
12.5-25 mm	14 (12.9)	47 (43.5)	26 (24.1)	21 (19.4)
25-37.5 mm	5 (10.2)	15 (30.6)	19 (38.8)	10 (20.4)
37.5+ mm	3 (9.3)	16 (50.0)	9 (28.1)	4 (12.5)
1950s				
0.25-12.4 mm	110 (22.3)	154 (31.2)	146 (29.6)	83 (16.8)
12.5-25 mm	16 (17.4)	31 (33.7)	34 (36.9)	11 (11.9)
25-37.5 mm	4 (11.8)	14 (41.2)	12 (35.3)	4 (11.8)
37.5+ mm	1 (4.8)	13 (61.9)	6 (28.6)	1 (4.8)