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Impact of Surface-water and Groundwater withdrawal on Riparian Vegetation and Stream Channel Morphology in the Arkansas River Valley, Western Kansas

A Report of Investigation

by

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for

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PREFACE

This report of investigation provides background and findings of a study of nongame habitat for Kansas Wildlife and Parks. This report is an expansion of masters thesis written by Karen L. Spray, who served as project research assistant. Other individuals who assisted with the research include M. Prante, J. Dunham, and Y. Sidani.

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INTRODUCTION

Dramatic changes have been recorded for river channels and floodplains of the Plains states throughout the historical period. The Platte and Arkansas Rivers have narrowed their channels considerably, while others, such as the Cimarron River, have substantially widened. It is unclear why two rivers such as the Arkansas and Cimarron, which pass as closely as within 30-50 miles (48-80 km) of one another, should evolve in such a dramatically different manner. Several studies have attempted to establish patterns of historical evolution for these and other rivers of the Plains, e.g., the Platte (Eschner et al., 1983), the South Platte and upper Arkansas in Colorado (Nadler, 1978), the Cimarron (McLaughlin, 1947; Schumm and Lichty, 1963), the Kansas River (Dort, 1980) and the Medicine Lodge (Martin and Johnson, 1987). This study concentrates on evolution of the Arkansas in south-western Kansas since settlement of the region in the mid- to late 1800s.

The Arkansas River heads in the Rocky Mountains near Leadville, Colorado. Fed primarily by snow-melt and spring runoff, it passes through the mountain range, entering the High Plains near Pueblo, Colorado. Historically it has been used heavily for irrigation in Colorado and southwestern Kansas. The study area itself is located between Lakin and Dodge City, Kansas (Fig. 1). This reach has exhibited remarkable channel narrowing and major vegetation changes, with some reaches being almost completely

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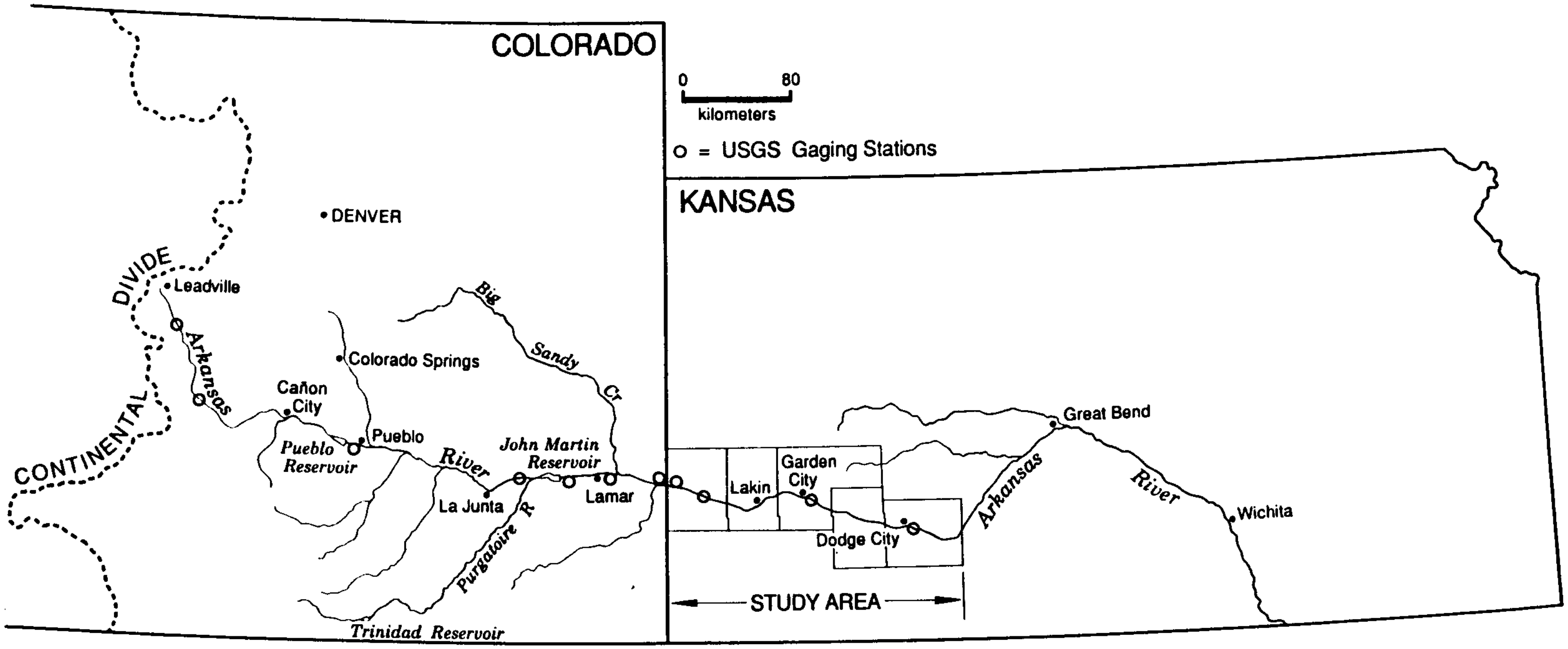


Figure 1. The upper Arkansas River and the study area.

without flow for more than a decade.

Surveyors for the 1872 federal land survey recorded the Arkansas as a wide, shallow, sandy-bottomed river. Today that same river is narrow, mud-bottomed, and deeply incised into its former channel bed and floodplain. Riparian vegetation, while rare in 1872, has locally created dense forests along the river channel. Recently, however, riparian vegetation stands are experiencing a high mortality rate. These events relate to water use, as well as other factors, such as climatic variation and valley geology, which compound water withdrawal problems.

This study attempted to characterize historical changes in channel width and floodplain vegetation (tree cover) along the Arkansas River from the Colorado state line to approximately Dodge City, Kansas. The causes of these changes are discussed with pertinent data. Hopefully this study, in conjunction with others which have addressed this study area, such as Tomelleri (1984) and Sherow (1990), will provide a data base for better management of wildlife and further emphasize the dynamic and deteriorating state of the Arkansas River of western Kansas.

PREVIOUS INVESTIGATIONS

In-depth research regarding changes in rivers of the Great Plains and Western States, their associated vegetation, and relations to water use has only recently become the focus of many studies. Pioneering works were completed in the late 1940s, but prior to this only casual observations were noted.

Rivers

In 1896, Mead (p. 112) observed that "for the past 10 or 15 years we have observed the evolution of a great river [the Arkansas] into a sandy waste or insignificant stream". Others also observed changes, and in 1941 Smith (p. 299) made a "plea for additional data" on changes in the streams of western Kansas. He stated that changes were occurring but they were not consistent from river to river and that "data thus far collected... is fragmentary and incomplete, and is sufficient only to point out the general trends" (Smith, 1941, p. 299). He attributed changes along the Arkansas partially to surface-water diversions in Kansas and Colorado.

The first major study pertaining to historic channel change in the Great Plains concentrated on the Cimarron River in southwestern Kansas (McLaughlin, 1947). In the late 1800s the Cimarron was a narrow, meandering stream, but following a major flood in May of 1914, it destroyed its former banks and became a wide, sandy-bottomed river. This flood removed and replaced much of the surrounding floodplain. McLaughlin attributed this accelerated erosion to overcultivation of land and the subsequent abandonment of many acres of cleared land in 1914.

Schumm and Lichty (1963) also looked at channel widening along the Cimarron River, as well as new floodplain construction. From 1943 to 1954 floodplain construction occurred, and from 1954 to 1963 widening and narrowing alternated in response to climatic fluctuations. They attributed floodplain destruction to a period when major flooding, followed by below-average rainfalls induced bank collapse. Conversely, floodplain development occurred during periods of above-average precipitation, little flooding, and establishment of vegetation. They noted similarities to other rivers in semiarid environments and concluded that channel widening and floodplain construction occur commonly along sandy rivers in semiarid regions in lieu of the degradation and aggradation typical of more humid regions. During this same year (1963), Schumm also wrote about the sinuosity of rivers on the Great Plains. He attributed differences between sinuous and straight channels to differences in bank material and relative amount of bedload, with sinuous streams having a finer sediment size and less bedload.

Burkham (1972) examined at channel changes on the Gila River in Arizona. It, like the Cimarron, was a narrow, meandering stream in the late 1800s. From 1905 to 1917, floodplain destruction occurred in response to frequent large floods carrying little sediment load, while subsequent floodplain reconstruction was dominated by low-intensity floods carrying high sediment load.

Large floods in this region originate in the uplands where little loose sediment is available for runoff and subsequent floodplain construction because of bedrock exposure. It took only 50 years to reconstruct the "pre-flood" floodplain.

Notable historic studies were undertaken along the South Platte and Arkansas Rivers in Colorado (Nadler, 1978) and the Medicine Lodge River basin in Kansas (Martin and Johnson, 1987). Nadler (1978) found that both the South Platte and Arkansas have narrowed and become more sinuous since 1867, although not at the same rates. The Arkansas, unlike the Platte, changed from meandering to multi-thalweg braided to single-thalweg braided in the downstream direction. He attributed morphological change in both rivers to decreases in water and sediment discharge which were, in part, a response to the drought of the early 1900s. An increase in vegetation density was also observed, which he believed to be related to rising water tables from artificial recharge due to irrigation runoff. This also changed the rivers from intermittent to perennial as baseflows increased. When vegetation expanded into the channels, narrowing occurred and river morphology adjusted to the more frequent flow event rather than the extremes. It was Nadler's conclusion that irrigation along the South Platte and Arkansas has permanently changed the morphologic character of the channels, and that they will remain in their new equilibrium state until irrigation ceases in those regions.

In a study of the Cimarron River in the panhandle of Oklahoma, Johnson and Martin (1987) observed changes similar to those noted by McLaughlin (1947) and Schumm and Lichty (1963), yet channel responses were exaggerated and modified by groundwater withdrawals.

The study by Martin and Johnson (1987) of the Medicine Lodge River showed that it has narrowed and exhibited an increase in riparian vegetation density since the 1930s. Like Schumm and Lichty (1963), they found that channels narrowed during periods of above-average precipitation that produced less variation in discharge. High precipitation permitted encroachment of riparian vegetation, which stabilized channel banks. They noted that greater vegetation densities yielded higher transpiration rates and resulted in lower stream discharges. With land use along the Medicine Lodge River remaining essentially unchanged since 1871, changes in morphology and vegetation were primarily attributed to climatic fluctuations.

The United States Geological Survey (USGS) published a series of detailed papers on "Hydrologic and Geomorphic Studies of the Platte River" in which Eschner and others (1983) showed that the Platte River has narrowed during historic time and riparian vegetation has greatly increased. They attributed these changes to several causes such as declining stream discharges, a more perennial flow to the river, elimination of flood peaks by damming, and mining of groundwater systems. Kircher and Karlinger (1983) found that these effects were first noted in the upstream reaches in western Nebraska and propagated downstream. All agreed however that changes along the Platte River have been culturally-induced.

Vegetation

It was readily apparent to early researchers and local residents that the character of vegetation bordering semi-arid/arid rivers was changing as more and more riparian plants became established. Robinson (1952, 1958), in early studies of phreatophytes and their relationship to the groundwater system, found that water use by phreatophytes represents a major source of reclaimable water in arid regions. By removing vegetation or lowering groundwater levels below root depths, up to 25 percent more water would become available in the subsurface for human use. Other studies relating groundwater levels to riparian vegetation were approached by Hendricks and others (1960) and Turner (1974). All came to the same conclusions - that riparian growth has high evapotranspiration rates and these plants have spread extensively along rivers in the western United States since the turn of the century.

Addressing the Arkansas River of western Kansas, Tomelleri (1984) found that decreases in discharge due to irrigation diversions provided excellent conditions for cottonwood establishment. This resulted in vegetative expansion in the early 1900s. The trees thrived due to a shallow water table, but in the early 1970s, groundwater pumping caused water table drawdowns in excess of what root growth could keep up with. As a result, many large riparian trees died. Simultaneously, tamarisk, or salt cedar, has begun to expand from isolated populations, and will continue to expand if unchecked. Although contributing to groundwater depletion, riparian trees of the Arkansas River valley have not been responsible for the dewatering of the channel and alluvial aquifer. The major importance has been one of occupying the channel, bringing about constriction and reduced capacity.

Groundwater and Surface Water Management

Relationships among water management, agriculture, and groundwater supplies were studied by Nace (1960) in a generalized manner which did not specifically address the Great Plains region. It was not until 1974 that intensive studies began in this area. Taylor and Luckey (1974) developed a mathematical model to simulate the stream-aquifer system of the Arkansas River in southeastern Colorado. With water demand greater than supply in this region, researchers became interested in proper management of this and other watersheds. Jordan (1977) discussed losses of streamflow into alluvial sediments and deter mined that seepage caused some western Kansas streams to lose an average of 2 percent of their flow per mile of channel. Similar results were found in central Kansas, but no losses were recognized in eastern Kansas.

In the mid to late 1970s, the USGS, Kansas Geological Survey, Kansas Groundwater Management Districts, and Kansas Department of Agriculture assumed a major role in the investigation of water problems in southwestern Kansas. Pabst and Gutentag (1979) published a summary of water level changes that had occurred in the region since 1940. The USGS began a broad-based, in-depth study of the High Plains aquifer. Many maps of the configuration of the aquifer over time have been published (Gutentag and Weeks, 1980; Pabst, 1982; Pabst and Stullken, 1984; Stullken and Pabst, 1985; Watts and Stullken, 1985; Buddemeier et al., 1991), and stream-aquifer relationships have been modeled along the Arkansas in southwestern Kansas (Barker et al., 1983; Dunlap et al., 1985). Detailed aquifer studies were conducted (Spinazola and Dealy, 1983), irrigation pumpages were determined (Lindgren, 1982), and computer models were developed to postulate long-term effects of groundwater pumping along the Arkansas (Dunlap et al., 1984). The socioeconomic impacts of groundwater depletion in southwestern Kansas were studied by Kromm and White (1981, 1983, 1984, 1992), with data showing that most residents are very aware of current and potential water problems.

GEOLOGIC SETTING

Topography

The study area along the Arkansas River in southwestern Kansas is located in the High Plains physiographic province at elevations ranging from 3000 feet (914 m) at Lakin to 2,464 feet (751 m) at Dodge City. The Arkansas itself is "perched" above neighboring river valleys, with both the Smoky Hill to the north and the Cimarron to the south topographically lower (Latta, 1944). Regional slopes are toward the southeast at about 12.5 feet per mile (2.4 m/km) (Gutentag et al.,1981), while the channel of the Arkansas slopes to the east about seven feet per river mile (1.3 m/km) (Dunlap et al., 1985).

The channel occupies only a small portion of the total valley width, which ranges from .75 to four miles (1-6 km) across, near Hartland and Lakin, respectively. North of the river low bluffs rise to meet the surface of the High Plains, while to the south is a vast expanse of sandhills. Surface drainages are uncommon in the study area, and most runoff either seeps into sandy soils or collects in closed sinkholes (Dunlap et al., 1985; Stramel et al., 1958). The Arkansas River valley within the study area is relatively narrow with no major tributaries. The first tributary of any size in Kansas is the Pawnee River, entering near Learned below the study area. This lack of tributaries and sandy soils dictates that precipitational events in the study area will usually not produce high flows in the Arkansas River.

Stratigraphy

Rocks cropping out in the study area are Cretaceous or younger in age. Cretaceous rocks appearing at the surface include the Greenhorn Limestone, Carlile Shale, and the Niobrara Formation (Latta, 1944). No rocks older than the Greenhorn Limestone crop out in the study area, although Dakota Sandstone is exposed in deep gullies just east of Dodge City (Waite, 1942). The Ogallala of Tertiary age, together with overlying undifferentiated Pleistocene deposits, constitutes the most important aquifer in this region (Latta, 1944; Stramel et al., 1958; and Gutentag et al., 1981). Other Quaternary deposits include loess, dune sand, and alluvial fill (Gutentag et al., 1981; Johnson and Arbogast, 1993) (Table 1).

Aquifers

Some bedrock aquifers occur in Upper Permian, Upper Jurassic-Lower Cretaceous, and Upper Cretaceous rocks. However, these aquifers yield only small amounts of water and it is generally highly mineralized (Gutentag et al., 1981). Of greatest importance is the Ogallala-Pleistocene aquifer, an unconsolidated deposit containing interbedded gravel, sand, silt, and clay. Cemented "mortar" beds are common, with calcium carbonate as the primary cement (Spinazola and Dealy, 1983). The Ogallala and Pleistocene aquifer bodies are lithologically similar and difficult to differentiate from each other; therefore, they are often collectively termed the High Plains aquifer by the USGS. This combination of aquifers ranges from zero to 1200 feet (366 m)

TABLE 1
GENERALIZED STRATIGRAPHY AND WATER-BEARING PROPERTIES
(after Gutentag et al., 1981)

Table 1.--Generalized section of geologic formations and their water-bearing properties*

System	Series	Stratigraphic unit	Thickness, feet	Physical character	Water supply
Quaternary	Pleistocene	Alluvium	0-80	Stream-laid deposits ranging from silt and clay to sand and gravel that occur along principal stream valleys.	Yields to wells range from 500 to more than 1,000 gal/min in the Arkansas River valley; 50 to 500 gal/min in the Pawnee River valley, and 50 to 1,000 gal/min in the Cimarron River valley.
		Dune sand	0-75	Fine to medium quartzose sand with small amounts of clay, silt, and coarse sand formed into mounds and ridges by the wind.	Lies above the water table and does not yield water to wells. The sand has a high infiltration rate and is important as area of ground-water recharge.
		Loess	0-45	Silt with subordinate amounts of very fine sand and clay deposited as windblown dust.	Lies above the water table and does not yield water to wells. Serves as minor area of ground-water recharge.
		Undifferentiated deposits	0-550	Sand, gravel, silt, clay, and caliche overlie Ogallala Formation when both formations are present; composite of stream-lain and windblown deposits.	The sand and gravel of the undifferentiated Pleistocene deposits and the Ogallala Formation are the principal water-bearing deposits in the area. Yields range from 100 to 3,100 gal/min.
Tertiary	Pliocene	Ogallala Formation	0-500	Poorly sorted clay, silt, sand, and gravel generally calcareous; when cemented by calcium carbonate, forms caliche layers or mortar beds.	
Cretaceous	Upper Cretaceous	Niobrara Chalk	0-250	Upper unit (Smoky Hill Chalk Member)--yellow to orange-yellow chalk and light- to dark-gray beds of chalky shale. Lower unit (Fort Hays Limestone Member)--consists of a white to yellow massive chalky limestone; contains thin beds of dark-gray chalky shale.	Initially (1968-72), yielded 500 to 2,500 gal/min to wells in northern Finney and eastern Kearny Counties where the Fort Hays Limestone Member has been honeycombed by fractures and solution openings. Because of increased irrigation development, yields have been reduced by 100 to as much as 2,000 gal/min.
		Carlile Shale	0-330	Upper part consists of a dark-gray to blue-black noncalcareous to slightly calcareous shale that locally is interbedded with calcareous silty very fine-grained sandstone. Lower part consists of very calcareous dark-gray shale and thin gray interbedded limestone layers.	Sandstone in upper part may yield 5 to 10 gal/min to wells.
		Greenhorn Limestone	0-200	Chalky light yellow-brown shale with thin-bedded limestone. Dark-gray calcareous shale and light-gray thin-bedded limestone; contains layers of bentonite.	Not known to yield water to wells in southwestern Kansas.
		Graneros Shale	0-130	Dark-gray calcareous shale interbedded with black calcareous shale; contains thin beds of bentonite. Also contains thin-bedded gray limestone and fine-grained silty sandstone layers.	Not known to yield water to wells in southwestern Kansas.
	Lower Cretaceous	Undifferentiated rocks	0-450	Upper unit (Dakota Formation)--brown to gray fine- to medium-grained sandstone; interbedded with gray sandy shale and varicolored shale; contains lignite lenses (0-160 feet). Middle unit (Kiowa Formation) --dark-gray to black shale; interbedded with light yellow-brown and gray sandstone (0-150 feet). Lower unit (Cheyenne Sandstone)--gray and brown very fine- to medium-grained sandstone; interbedded with dark-gray shale (0-125 feet).	The sandstone units commonly yield from 50 to 500 gal/min to wells. Yields of more than 1,000 gal/min are reported in a few areas. Water may be more mineralized in the lower unit than in the upper unit.
Jurassic	Upper Jurassic	Undifferentiated rocks	0-350	Dark-gray shale; interbedded with grayish-green and bluish-green calcareous shale. Contains very fine- to medium-grained silty sandstone and some thin limestone beds at the base.	In Morton and Stanton Counties, sandstone beds are yielding in combination with the overlying Lower Cretaceous units. In the northernmost counties where the aquifer is deepest, the water may be mineralized.
Permian	Upper Permian	Big Basin Formation	0-160	Brick-red to maroon siltstone and shale; contains very fine-grained sandstone.	Where not highly mineralized, may yield small quantities of usable water for domestic and stock purposes.
		Day Creek Dolomite	0-80	White to pink anhydrite and gypsum; contains interbedded dark-red shale.	Solution cavities have yielded large quantities (300 to 1,000 gal/min) of high sulfate water to wells in Morton County.
		Whitehorse Formation	100-350	Red to maroon fine-grained silty sandstone, siltstone, and shale.	Fresh to highly mineralized water. Not known to yield significant amounts of water to wells in southwestern Kansas.
	Lower Permian	Dog Creek Formation	15-60	Maroon silty shale, siltstone, very fine sandstone, and thin layers of dolomite and gypsum.	Not known to yield significant amounts of water to wells in southwestern Kansas. Water probably highly mineralized.
		Blaine Formation	20-150	Generally consists of four gypsum and anhydrite beds separated by red shale; contains bedded halite at some sites.	

* The classification and nomenclature of the stratigraphic units used in this report are those of the Kansas Geological Survey and differ somewhat from those of the U.S. Geological Survey.

thick, with the Ogallala being the thicker of the units (Gutentag et al., 1984). Vertical boundaries of any individual silt or clay lens are virtually impossible to identify and lateral correlation is difficult because of the irregular pattern of grain deposition (Gutentag et al., 1981).

Many theories regarding accumulation of the Ogallala and Pleistocene aquifers have previously been presented, with common agreement being that aquifer materials were deposited by fluvial action - probably by braided streams on coalescing alluvial fans fronting the Ancestral Rocky Mountains and that later carried this debris farther eastward (Gutentag et al., 1984). Gravel near the base of the Ogallala is primarily composed of locally derived clasts of limestone, sandstone, and chalk, while higher in the formation gravel becomes arkosic, indicating a Rocky Mountain origin (Stramel et al., 1958).

River alluvium, another important aquifer in this region, has a composition similar to that of the Ogallala and Pleistocene aquifers, but has been deposited by Holocene depositional cycles of the Arkansas River (Gutentag et al., 1984). The alluvium, averaging 60 feet (19 m) in thickness within the study area, is hydraulically connected to underlying aquifers, with groundwater moving freely throughout the units and Arkansas river water commonly being lost to the subsurface (Sophocleous, 1991; Johnson and Sophocleous, 1992). Due to the shallow watertable and high permeability of the alluvium, it was the first aquifer to be developed for domestic and early agricultural use. Later development for large-scale irrigation used water from the deeper Ogallala and Pleistocene aquifers (Smith, 1941; Dunlap et al., 1985). Early withdrawals from the alluvium were recharged by deeper aquifer systems, but large-scale production of deeper resources has currently made this impossible (Dunlap et al., 1985). All of the aquifers are predominantly unconfined, with areas of artesian conditions occurring primarily where induced by localized clay and silt lenses (Gutentag et al., 1981; Rosner. 1988; Johnson and Sophocleous, 1992; Johnson, 1991).

Structure

Southwestern Kansas lies between the southeastern flank of the Las Animas Arch and the northern edge of the Hugoton Embayment (Merriam, 1963). The study reach of the Arkansas lies between two large sub-surface faults that have minimal surface expression - the Bear Creek Fault to the west and the Crooked Creek-Fowler Fault to the east (Gutentag et al., 1981) (Fig. 2). These faults are sub-parallel and are believed to have formed in late Tertiary or early Quaternary time by the dissolution of Permian evaporites and subsequent collapse of overlying strata. Each fault has a maximum displacement of about 250 feet (82 m) (Gutentag et al., 1981; McGovern and Long, 1974; Spinazola and Dealy, 1983).

The sub-parallel configuration of the faults, coupled with downward displacement of the Bear Creek Fault on the east and the Crooked Creek Fault on the west, allowed a graben to form (Fig. 2). Development of this graben was contemporaneous with deposition of

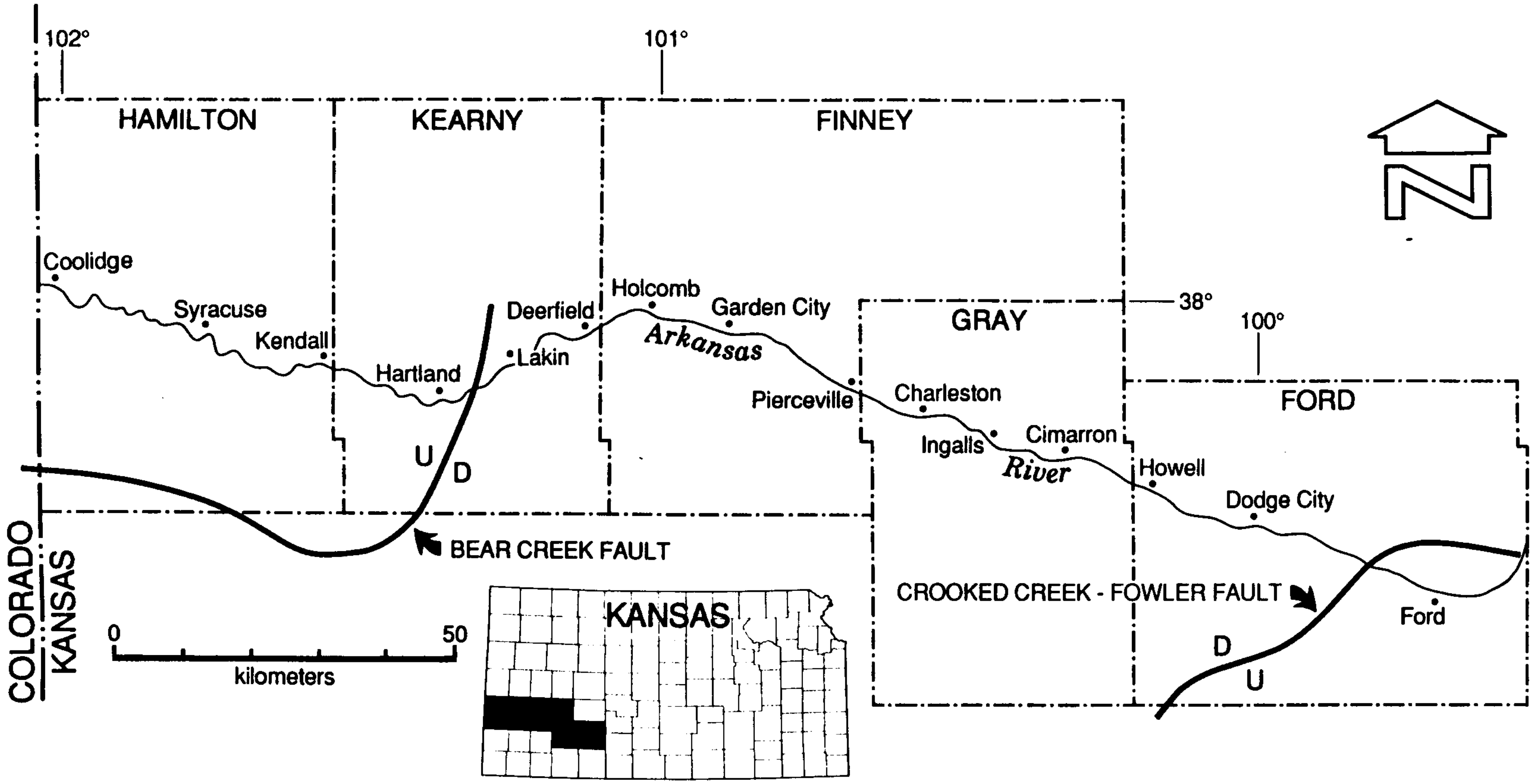


Figure 2. Geography of the study area.

portions of the Ogallala aquifer, a relationship which accounts for the thickness of these, and overlying Pleistocene, deposits in this area. West of the Bear Creek Fault the Arkansas flows in an alluvium-filled trough which is cut into Cretaceous bedrock. The river flows on top of the alluvium and is not hydraulically connected to the Ogallala and Pleistocene aquifers (Barker et al., 1983). East of the Crooked Creek-Fowler Fault the Ogallala and Pleistocene aquifers are much thinner and eventually pinch out. It is the presence of these faults then, that maintains partial control on groundwater saturation levels and groundwater yields within the study area.

HISTORICAL SETTING

Many factors have affected how the Arkansas River evolved during the past 150 years. Some of the resulting changes are direct responses to human settlement (surface- water and groundwater use), while others are less directly related (vegetation densities), or are essentially unrelated (climate). The history of these changes and how they were induced plays an important part in the development of the modern configuration of the Arkansas River in southwestern Kansas.

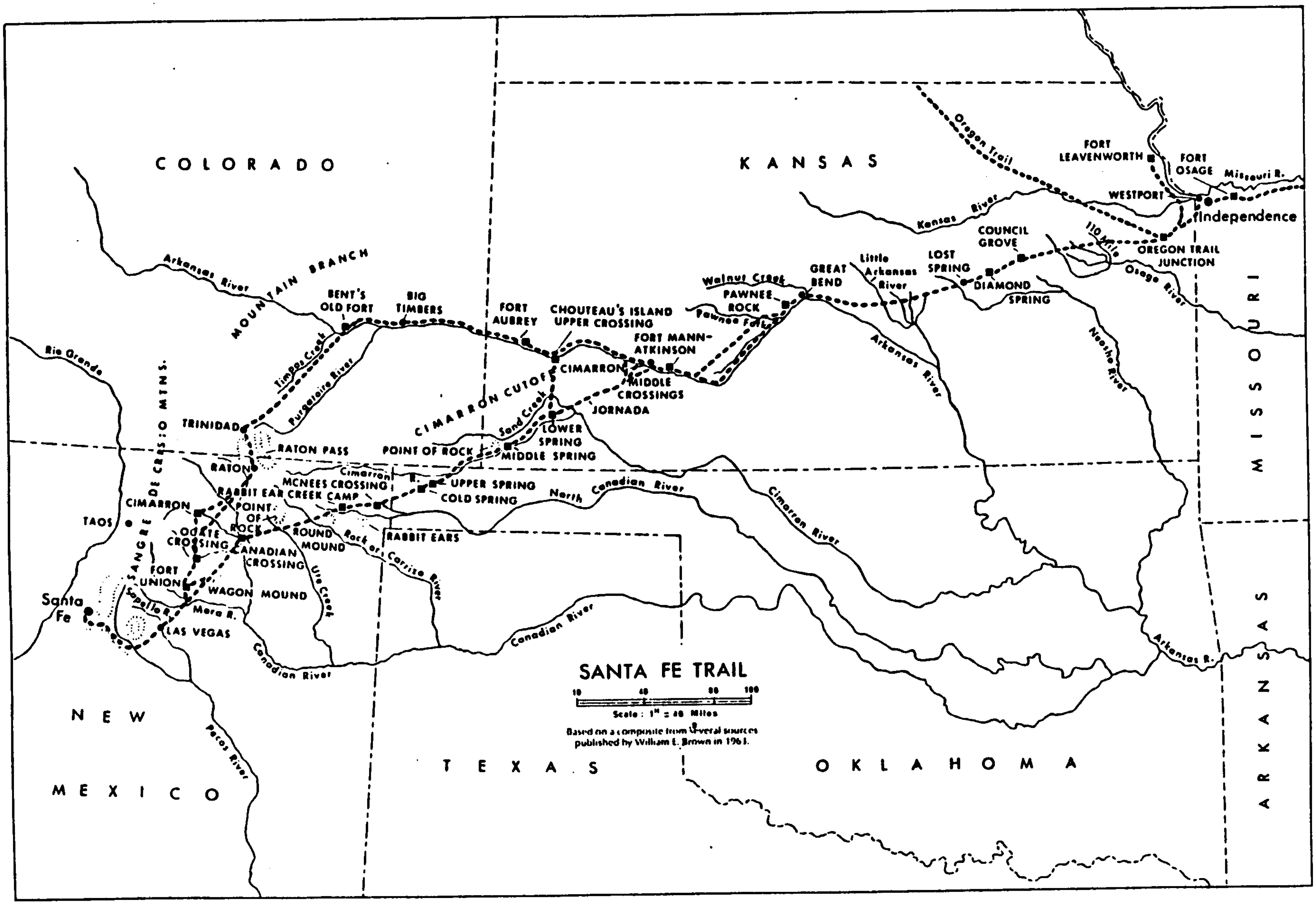
Human Use

Settlement of the Arkansas River Valley began in the late 1800s. The area was previously open rangeland, home to nomadic Indians and large herds of bison (Jackson, 1966). One of the earliest recorded travels along the Arkansas was by Zebulon Pike in 1806 when he led an exploratory party up the river to the Colorado mountains (Jackson, 1966), and certainly the earliest was that of the narratives from the Coronado expedition of 1540-41. Trappers and traders also used the Arkansas as a major route east from the mountains, and as early as 1852, boats carried groups of 15-20 men downriver from Pueblo, Colorado to the Mississippi. Reportedly, the current was swift and the channel ranged from 800 to 1,200 feet (245-366 m) wide with well-defined banks that rose only slightly above the water level (Mead, 1896). Early navigation on the upper Arkansas was carried out in sring and early summer when the channel was full due to the spring freshets. As early as 1852, boats with mountain trappers and traders would float from Pueblo, Colorado (Mead, 1896). During the late 1800s a mivement was underway to make Wichita, Kansas an inland port via the Arkansas River. In spring, 1880, the 500-ton steamboat Tom Ryan steamed upstream to Wichita, and the local newpaper editor dubbed the Arkansas the "Nile of America." Later that same year, the last boat went aground on a sand bar (Miner, 1982).

In the early 1800s, travelers passed the Arkansas River en route far west via the Santa Fe Trail (Fig. 3). This was mainly a commerce route and paralleled the Arkansas for 122 miles (195 km) from Cheyenne Bottoms near Great Bend, Kansas to the Cimarron Crossing near Cimarron, Kansas. Alternate routes took the wagons to the Upper Crossing, near Lakin, or another 143 miles (229 km) along the banks to Bent's Old Fort in Colorado before turning south (Vestal, 1939). Among the landmarks along the trail was Chouteau's Island in Kearny County, near the town site of Hartland about six miles (10 km) southwest of Lakin (Greer, 1973). The island, a natural fortress in the Arkansas River, was named for a party of fur traders led by Auguste Chouteau who was killed on the island during the repulsion of an attack by Pawnee Indians.

Following the arrival of the railroad between 1868 and 1871, and the original federal land survey in 1871-72, settlers began moving into the valley. Among the first were James and William Fulton and their families, who founded Garden City in 1878. It was during this year that the first shade cottonwood tree was planted

Figure 3. Route of the Santa Fe Trail (from Chaput, 1975)



away from the river channel and the first sod was turned in what was later to become Finney County (Blanchard, 1931). Vegetation was very sparse at this time, consisting primarily of short prairie grasses and an occasional cottonwood tree on an island or in draws immediately alongside the channel.

Population grew rapidly initially, but suffered many set-backs due to the harshness of the environment. According to Blanchard (1931), the late 1800s consisted of alternating drought and blizzard; this, coupled with poor farm management, forced many to leave the area in the 1890s. With better farm management and the introduction of surface irrigation, however, fields prospered and, by the turn of the century, the population was once again increasing (Blanchard, 1931). Expansion of agriculture was rapid, with 500,000 acres (202,342 ha) cultivated in 1930 compared to only 3,000 (1340 ha)in 1879. Primary crops at this time were wheat, alfalfa, and sugar beets, with corn and milo secondary. Most grain was shipped east, but the sugar beets were processed in a sugar factory, which was a major industry in Garden City (Blanchard, 1931).

With a rapidly growing population, bridges were needed to cross the Arkansas. As late as 1879, there was no bridge across the Arkansas River between Granada, Colorado and Dodge City, Kansas (Smith, 1964). It appears that the first bridge in the study area was the one at Lakin, built in 1884. A toll bridge at first, objections forced it to free status the following year. In 1885 another bridge was completed at Garden City. It too was a toll bridge, but the following year a "free" bridge was constructed at the foot of Main Street (Fig. 4). In 1886 the first bridges in Ingalls, Pierceville, Hartland, and Holcomb were also completed (Haworth, 1897; Blanchard, 1931; Smith, 1964). The Deerfield bridge was built the following year. The early wooden bridges in Garden City and Holcomb were replaced by steel and concrete bridges in 1919 and 1930, respectively (Blanchard, 1931).

Since the 1930s, the Arkansas River Valley in southwestern Kansas has continued to be a center for agriculture and is gaining as a center for beef production. The Garden City sugar factory has long since ceased operation, and, in the 1960s, cattle-raising became a big business in the region. In Finney County alone there are now 19 feedlots and two major slaughterhouses which are capable of processing a total of 10,000 head of cattle per day. Much of the corn and alfalfa presently raised in the region are used as cattle feed at these feedlots (Branden, pers. comm., 1986).

Water Use

Water use for agricultural purposes began almost immediately after settlement of the area. This was certainly a colorful period for the Arkansas River valley of Kansas, given the speculation and development associated with the construction of irrigation canal systems. Sherow (1990) presented a comprehensive examination of this period. In 1880 the first large-scale diversion ditches were put into operation upstream from Garden City, Kansas (Blanchard, 1931; Sherow, 1990). In 1895, 20 major diversions were located

Figure 4. Garden City bridge about 1890. View north. (courtesy Finney County Historical Society)

between Pueblo, Colorado and the Kansas state line (Nadler, 1978), and by 1903 eight ditch companies had irrigation diversions completed in Kansas (Table 2) (Figs. 5, 6). The diversion system became relatively complex within a short period of time. For example, McKinney Lake, built in 1907 by the Garden City Sugar Company to store irrigation water, was once a 3000 acre (1214 ha) lake, but now is only about one-third that size.

As early as 1905, legal problems arose between Colorado and Kansas regarding priority of water rights along the Arkansas, and in 1907 the United States Supreme Court ruled that the river was overappropriated (Sherow, 1990). Numerous other lawsuits followed and, with the construction of John Martin Dam near Caddoa, Colorado, in the 1940s, the Arkansas River Compact was drawn up between the states. This agreement allows Kansas 40 percent of all annual inflow to John Martin Reservoir (Madson, 1982; Anton, 1986). Old animosities have arisen, however, and in early 1986 Kansas once again filed suit against Colorado over the water issue, claiming that excessive water is being stored in upstream reservoirs in order to prevent Kansas from getting its appropriate share (Anton, 1986).

To supplement flow in the Arkansas River, water has been diverted over the continental divide from the Colorado River basin since 1880. Nine trans-mountain diversions were in use by 1977, adding an average of 94,000 acre-feet of water to the Arkansas River basin per year (Table 3). Other attempts to supplement surface-water supplies included a federal government-run

TABLE 2
SURFACE-WATER DIVERSIONS
KANSAS

Name	Commenced	Abandoned
Hamilton County System		
Frontier Ditch Company	1895	--
Alamo Ditch Company	1902	1966
Fort Aubrey Ditch Company	1903	1969
Associated Ditch Systems		
Kearny County Farmers Irrigation Association	1888	--
South Side Ditch Association	1882	--
Great Eastern Irrigation Association	1881	--
Finney County Water Users Association	1880	--
Garden City Ditch Company	1880	--

-- Still in operation

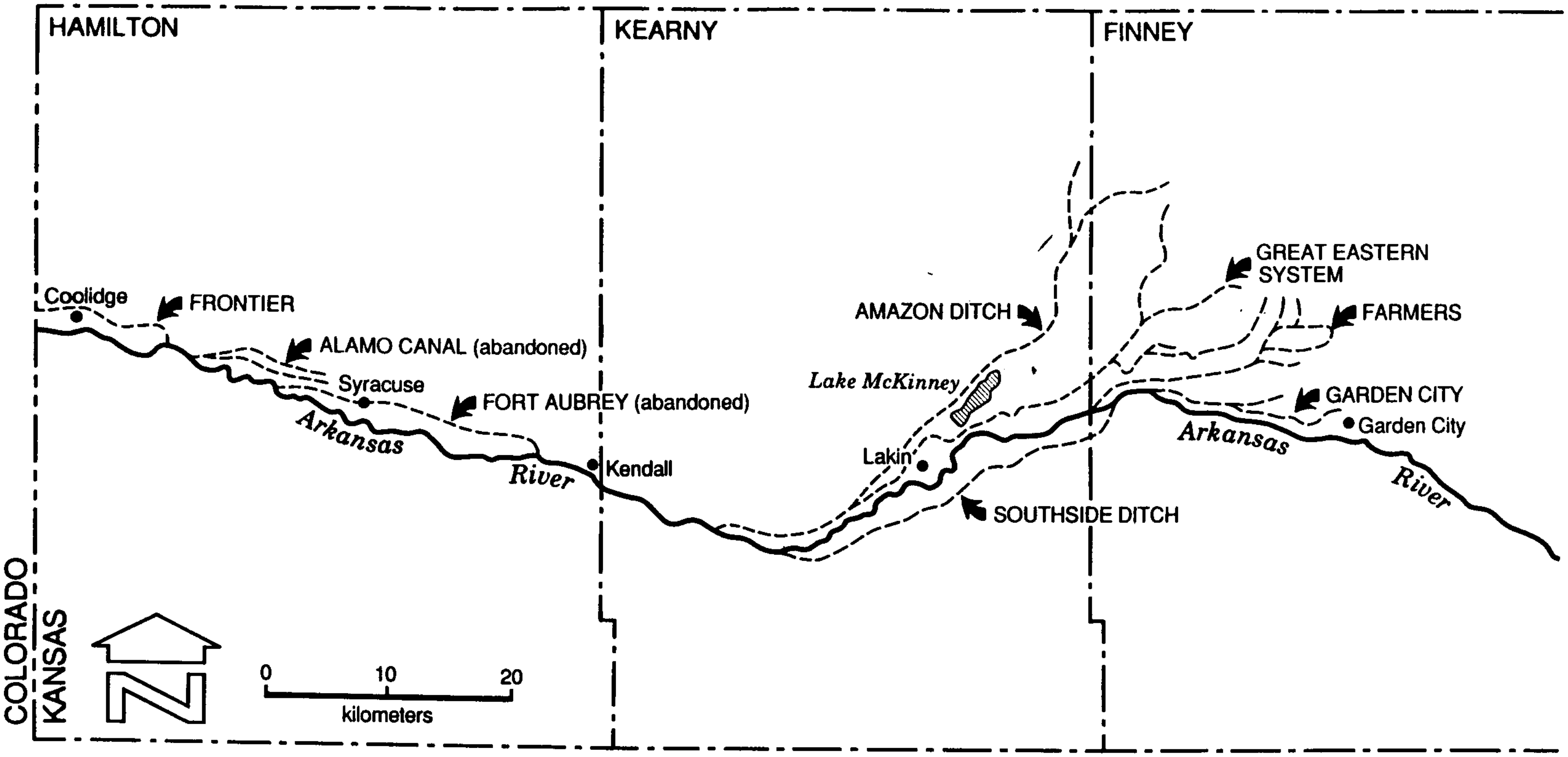


Figure 5. Location of Arkansas River diversion ditches in southwestern Kansas.

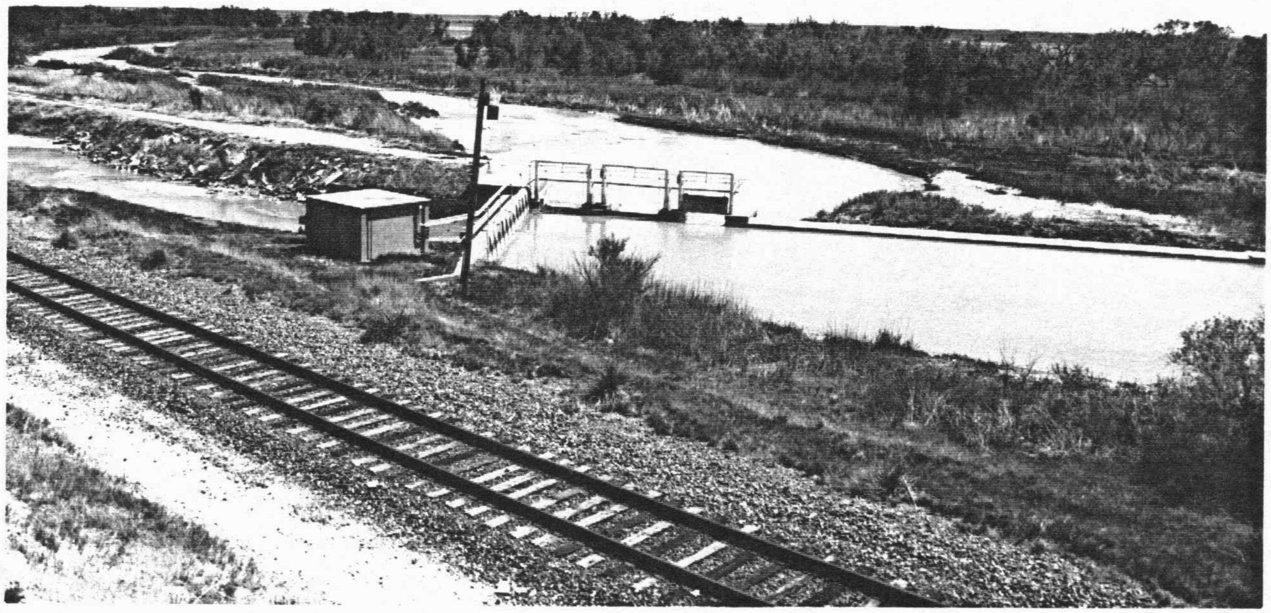


Figure 6. The headgate for the Amazon Ditch, western Kearny County. View to the southeast.

TABLE 3
TRANSMOUNTAIN DIVERSIONS INTO ARKANSAS RIVER BASIN

Diversion	Year Completed	Average Annual Diversion (Ac-Ft)
Fremont(a)	1929(b)	1,230
Columbine	1931(b)	1,004
Ewing	1880	1,207
Wurtz	1932(b)	2,115
Busk-Ivanhoe	1925	4,383
Twin Lakes	1935	35,121
Larkspur	1935(b)	142
Hoosier Pass	1952	6,307
Homestake	1967	
Boustead	1972	
Total Average Annual Diversion in 1960		51,510 ac-ft

a = Fremont Ditch Defunct 1969

b = indicated date of earliest records

-from Nadler (1978)

groundwater pumping experiment near Deerfield, Kansas in 1905. The government placed a line of pumps across the Arkansas River valley and pumped water into the Farmers' Ditch to be sold to irrigators. The expense was high, and the project was abandoned due to the cheaper cost of Arkansas River water obtained via surface diversions (Blanchard, 1931; Darton, 1916).

In 1948 the Army Corps of Engineers completed John Martin Dam in southeastern Colorado (Nadler, 1978). This was the first dam on the upper Arkansas River, and its main functions were flood control and storage of water for irrigation. Prior to 1978, the gates of the dam were opened in late spring each year, and the reservoir was allowed to run "dry" (Madson, 1982). More recently, however, a permanent conservation, or recreation, pool has been maintained, with water releases in the spring and summer as downstream irrigators request them. Due to above-average snowpacks from 1979 to thelate 1980s, the reservoir has remained at or near capacity, and in spring of 1985 dam gates were frequently open. With downstream ditches already full to overflowing, water bypassed the headgates and continued downriver. This was the first time in nearly a decade that water flowed in the Arkansas River past Garden City, Pierceville, and as far downstream as Howell. It is generally considered a waste of water to irrigators in this region when water flows, untapped, past Garden City (Craig, pers. comm., 1986).

The 1950s witnessed the introduction of center-pivot irrigation to the Great Plains through introduction of the Valley system produced by Valmont Indistries of Valley, Nebraska (Green, 1992). Each center-pivot unit consists of a central pumped groundwater well that is connected to an overhead sprinkler system which revolves around the center point, irrigating a circular area unique to this method of irrigation (Fig. 7). A system typically makes one revolution each 24-hours, and common spacing is one unit per quarter section (four units/section)(Madson, 1982). Pumpage rates range from 100 gpm to 2,500 gpm, with an average of 1,000 gpm (Stramel et al., 1958). Pumps in this region generally run on natural gas, while earlier pumps were powered by electricity (Blanchard, 1931; Branden, pers. comm., 1986).

Center-pivot systems rapidly expanded from the late 1950s to the early 1970s. In 1940 there were 520 irrigation wells in southwestern Kansas pumping 90,000 acre-feet of water annually, and in 1978, 8,250 wells were withdrawing an estimated 3,500,000 acre-feet annually (Pabst and Gutentag, 1979). Due to uncontrolled expansion of center-pivot systems in the early 1970s, Groundwater Management Districts were set up, and in 1977 a moratorium was declared on applications for permits to withdraw groundwater within, and bordering, the Arkansas River Valley (Dunlap et al., 1984). This moratorium was declared because little was known about the relationship between decreasing stream-flows and lowering groundwater levels, and what long-term effects might result. Since then very little new center-pivot development has occurred. Ongoing research is attempting to decipher the groundwater-surface water connection (Sophocleous, 1991; Johnson and Sophocleous, 1992).

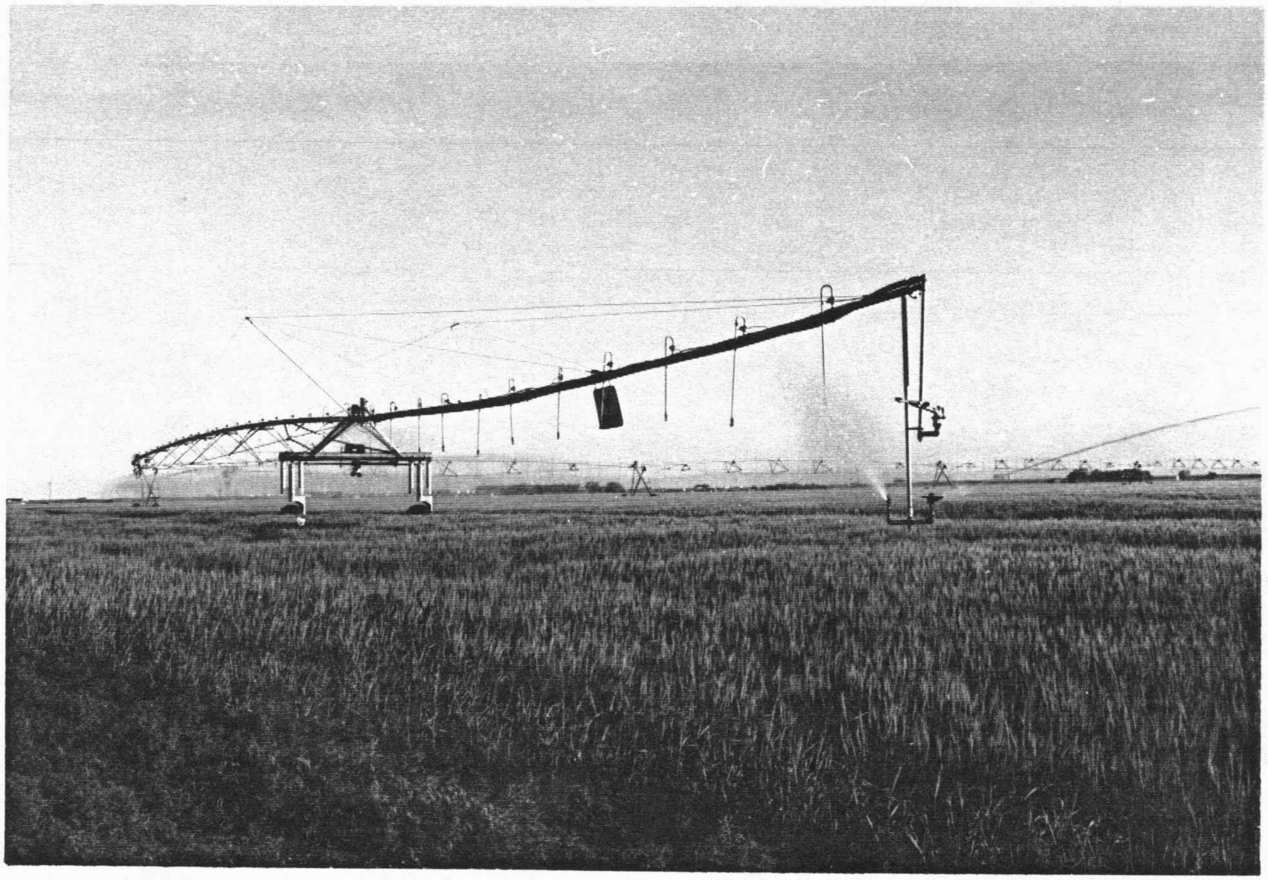


Figure 7. A center-pivot irrigation system located immediately west of Garden City. View north, northwest.

Climatic History

Southwestern Kansas is a semi-arid region where precipitation is low and evaporation high. Precipitation is lowest near the Colorado state line, with Syracuse averaging only 16.21 inches (41 cm) of precipitation per year. Eastern stations such as Cimarron and Dodge City, average 21.05 inches (53 cm) and 20.10 inches (51 cm) per year, respectively. Although some climatic fluctuations have been occurring, they seem to be on a scale of 20 years or more (Appendix A). Long-term resident Blanchard (1931, p. 129) wrote:

> "The prevailing climate is pleasant without extremes. The weather records do not show any fundamental change in climate in the half century since settlement began in this region. There is no more rainfall, no less wind and it is neither hotter or colder, on the average, than it was fifty years ago."

She went on to state that the breaking up of the prairie for agriculture had lessened the "hot winds" which apparently were common. Instead, the planting of crops and trees helped cool and break the winds. She only briefly mentioned the drought of the 1890s, although climatic records for southeastern Colorado indicate that it was as severe as the drought of the 1930s. A study by Borchert (1971) documents this drought, as well as those of the 1910s, 1930s, and 1950s. Variability does in fact describe the climate of the study area (Rosenberg, 1987).

In the early 1900s precipitation amounts displayed very little variation from year to year (Appendix A). A major drought occurred in the 1930s, however, which was followed by a decade of above average rainfall and flooding. The early 1950s also produced a serious drought, but it was of shorter duration than that of the 1930s (5 years versus 7 - 10 years). A wet period did not follow this drought; instead two short droughts occurred (1966-1968 and 1974-1976), which were neither as severe nor as long as earlier dry periods. The last case of extreme flooding recorded along the Arkansas occurred during 1965, when storm systems produced excessive quantities of rain in a short period of time over southeastern Colorado and southwestern Kansas (Snipes et al., 1974).

Seasonality of precipitation has shown moderate fluctuations during the period of record. According to Blanchard (1931), from 1908 to 1925 76 percent of all yearly rainfall occurred from April to October. Stramel and others (1958) reported that 75 percent of yearly rainfall occurred from April to September. Currently, 76 percent of yearly rainfall occurs from April to September in the western towns of Syracuse and Lakin, but only 67-68 percent occurs during this period in Garden City and Cimarron. In Dodge City only 63 percent of yearly rainfall occurs from April to September. This compares to early 1900s values of 81-82 percent in Syracuse and Lakin and 76 percent in Garden City, Cimarron, and Dodge City. Differences in the seasonality of rainfall from station to station results from the more arid climate at the western stations. At all stations, however, it seems that the seasonality of precipitation has diminished slightly and precipitation events may be trending toward a more even distribution throughout the year.

In general, the extremes of wet and dry periods seem to be moderating towards more average yearly precipitation amounts. The shift in seasonality of events reflects this, as the percentage of moisture occurring during the spring and summer months has lessened, the years of 1980 and 1988 being good examples.

The climatic variability of the central Great Plains and montane headwaters region of the Arkansas River has resulted in a number of major floods. The flood of 1867 was the first recorded for the study area (Mead, 1896). Several others to follow are well relatively documented by the Kearny County Historical Society (1964, 1973). The years of major floods include 1881 (February), 1914 (May), 1921 (June), 1927 (August), 1935 (August), 1942 (?), 1949 (June), 1957 (June), and 1965 (June). The flood of 1914 was noted as the first major flood due to its magnitude and the fact that is washed out all the bridges from LaJunta, Colorado to Dodge City. The 1965 flood, however, was considered the "grand daddy" of all floods; John Martin Dam was ineffective because the rains fell below the dam.

Vegetative History

Early travelers to the Arkansas River Valley noted a bleakness to the land. Few trees were to be found and those were on river islands and in small clusters near the banks (Blanchard, 1931). Emory, in 1846, noted that "The only tree of any magnitude found on its (the Arkansas) course is the cotton-wood,... and it frequently happens that not one of these is seen in a whole day's journey..."(Calvin, 1951, p. 29). Most of the trees were cottonwood or willow and the surrounding prairie was covered with short prairie grasses. Often settlers would have to burn buffalo chips for fuel (Blanchard, 1931, p. 63).

The late 1800s brought permanent settlers, however, and with them came many types of trees and bushes. By the early 1900s, woody vegetation was becoming established in the area, occupying positions on both banks of the channel as well as on islands. Rapid growth and encroachment of these trees stabilized the Arkansas channel, and by the 1950s large forests of cottonwood, box elder, willow, and salt cedar were considered normal, paralleling the valley floor of the Arkansas River.

In the 1970s, however, many of the larger trees began dying and now most of the large riparian trees are dead in certain reaches. Some are victims of rapidly dropping water tables, while others are dying due to senescence, i.e., many tree are 80-90 years old. In many areas, landowners have removed the dead and dying trees and are now cultivating and irrigating alongside and within the river channel. The appearance and spread of salt cedar is presently posing a new threat to groundwater levels and riparian habitat.

Current trends suggest a return to the treeless landscape of the 1800s unless groundwater depletion is restrained. Only that vegetation which does not require large quantities of water and the salt cedar will survive in this region, because rainfall alone is not adequate to sustain large riparian trees such as cottonwood and willow. Without flood events, the salt cedar will grow only on sand bars and near-shore areas of the channel. With flood events it is rejuvenated on the floodplain as well.

From an analysis of the riparian vegetation in the study area, Tomelleri (1984) noted four distinct periods of vegetation dynamics. In the presettlement era, prior to 1880, no continuous corridor of riparian vegetation existed, and the trees which were present (cottonwood and willow) were mainly on the south side of the river due to the fire break afforded by the sandhills and to the lack of traffic from travellers. During the second period, 1880-1942, diversion to cnals reduced flow, therby permitting invasion of the channel by cottonwood and willow. From 1943 to 1973, decline of the water table due to uncontrolled groundwater mining of the Ogallala and Arkansas River alluvium reduced the flow of the river (drying out an 48 mi/80 km reach) and fatally stressed woody vegetation. The fourth period, 1974-1983(+?), experienced pronounced woody vegetation mortality in the middle of the study area, and salt cedar became the dominant woody species west of Garden City.

METHODOLOGY

Many sources of research data (e.g., aerial photography, discharge records, climatic records, historical journals, and personal communications) were used in conjunction with field data in order to provide the foundation for this study. Using 1872 federal land survey maps and aerial photography for the years 1939, 1952, 1973, and 1980/81, maps showing changes in vegetation density and channel width were constructed. Other years of photography were available, but due to budgetary constraints, photographs of only representative or contrasting reaches were obtained. Notes and maps from the 1872-73 survey were obtained from the Office of the Secretary of State in Topeka, Kansas, and aerial photographs were from the Soil Conservation Service in Salt Lake City, Utah, and the National Archives in Washington D.C.

Each set of maps was constructed by tracing channel banks, or vegetation stands, from aerial photographs. Minor scale adjustments became necessary on channel-change maps in order to trace each year's channel onto a single map for each reach. Only recent photographs were available in 1" = 660′ enlargements, so an optical enlarger was used to transform older aerial photographs (1" = 681′ and 1′ = 704′) and 1872 survey maps (1" = 2,640′) to this scale. Scale adjustments were not needed on vegetation-density maps, because separate maps were constructed for each set of photographs used. Blocks of vegetation were delineated by tracing those areas having highly visible and dense stands of trees and shrubs. It was not possible to construct a vegetation-density map for 1872 due to lack of data.

Both channel-change maps and vegetation-density maps yielded important quantitative data regarding channel width and vegetation density changes along the Arkansas River since the late 1800s. Width measurements were made for each year of map coverage and comparisons of these widths yielded information on the rates and timing of channel narrowing. By planimetering vegetation stands on the vegetation density maps, changes in vegetation acreage over time were obtained. Acreage changes were then compared to determine rates of vegetation expansion and degradation within the study area.

Discharge records of the Arkansas River were obtained from the USGS in Lawrence, Kansas. These are recorded in the October-to-September water-year format. Records from 11 separate stations were gathered - two within the immediate study reach and nine upstream. Neither station within the study reach had extensive periods of complete records, so it was necessary to use nearby upstream stations to provide some stability to the data. Distant upstream stations were used to help determine effects of damming and large-scale climatic variability on discharge. Graphs of discharge versus time were generated for each station and used to compare discharge changes at the various locations. These changes were then related to possible causes. Downstream changes were evaluated using longitudinal plots of discharge versus station, from Granite, Colorado, to Dodge City, Kansas.

Climatic factors were evaluated using precipitation data obtained from the National Oceanic and Atmospheric Administration (NOAA). Four stations within the study reach were used, with seven upstream stations for comparison. For each station, a time series of mean yearly precipitation was filtered using 10-year running means to search for any long-term climatic variations along the Arkansas.

The Garden City District of the Kansas State Department of Agriculture - Division of Water Resources provided data on diversions of Arkansas River water west of Garden City. These data included names and locations of diversion ditches, dates of completion, times of abandonment, and yearly water diversion amounts from 1951 to present. Unfortunately, the early 1950s also marked the introduction of center-pivot irrigation to the region, so surface water diversion was probably tapering off and earlier diversion levels are speculative, at best. Groundwater withdrawal data was unavailable due to the prohibitive cost of retrieving the information from computer files, but changes in water levels in southwestern Kansas since 1940 were obtained from Kansas Geologic Survey publications.

Field work was first undertaken beginning May 1985, and continued through June 1987, with occasional field work through September 1991. Width measurements and visual observations of vegetation and channel variations were made. Channel widths were measured using measuring tapes and chaining pins, with all measurements being made at right angles to channel banks. Basic channel shape, widths, landmarks, and other relevant information were then plotted on USGS 7.5-minute (1:24000) topographic maps and recorded in a field journal. Trips were also made to diversion ditch headgates and John Martin Reservoir in order to fully appreciate their relationships to river flow.

Much of this project was dependent upon historical and oral information. Resources at the University of Kansas Libraries were used to compile a thorough history of the river and its use. Early writings of explorers such as Zebulon Pike provide a good picture of what the Arkansas River and its valley appeared prior to European settlement. Writings by early settlers, such as Blanchard and Mead, describe how the river appeared at the turn of the century. Old photographs and early maps of the river obtained from both the libraries and the Garden City Historical Society were used to provide visual impressions and make comparisons with the present-day landscape. Personal communications with several individuals from the Garden City area also provided invaluable insight into river characteristics.

RESULTS AND DISCUSSION

Discharge has decreased dramatically along most reaches of the Arkansas River in Kansas during the past century (Table 4). However, the river is currently a gaining stream from its headwaters downstream to Pueblo, Colorado, below which it has both gaining and losing reaches (Fig. 8). The large increase in mean annual discharge below John Martin Reservoir is primarily due to regulation of flow by dam management and is not evident in pre-impoundment data. Within the study area it is a losing stream, not gaining discharge again until past Dodge City.

Stream discharges are influenced by many different factors - both natural and cultural. Discharge fluctuations result in other changes to a river system such as shifts in width, depth, and channel character. These in turn may disturb prevailing discharge patterns and result in a further evolution of the river.

Causes of Change in Discharge

Diversion of Surface Water. Diversion of surface water via ditches for irrigation is the most obvious cause of decreasing discharge along the Arkansas. This is especially true within the study reach. Between the Kansas-Colorado state line and the westernmost boundary of the study area, eight major ditch systems have diverted Arkansas River water for agricultural use (Fig. 5). The Alamo and Fort Aubrey ditches upstream from Syracuse were abandoned in 1966 and 1969, respectively, so currently there are only six major

TABLE 4
MEAN DISCHARGES - 10 YEAR GROUPINGS (CFS)

Station	1900-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-84
Granite	—	352	353	308	360	374	389	451	543
Salida	—	668	674	532	618	644	660	636	—
Pueblo	756	773	783	529	742	590	634	694	—
L.Animas	—	—	—	—	362	151	130	112	320
JMR	—	—	—	—	519	269	245	165	335
Lamar	—	278	418	114	302	*81	117	51	142
Holly/Cool.	—	—	473	191	404	200	265	88	133
Syracuse	—	—	475	222	465	216	267	93	121
Garden City	—	—	276	84	330	131	163	—	—
Dodge City	—	—	—	—	*232	168	179	#49	#.54

* = incomplete record - one or more years missing
# = channelization in 1977 altered flow

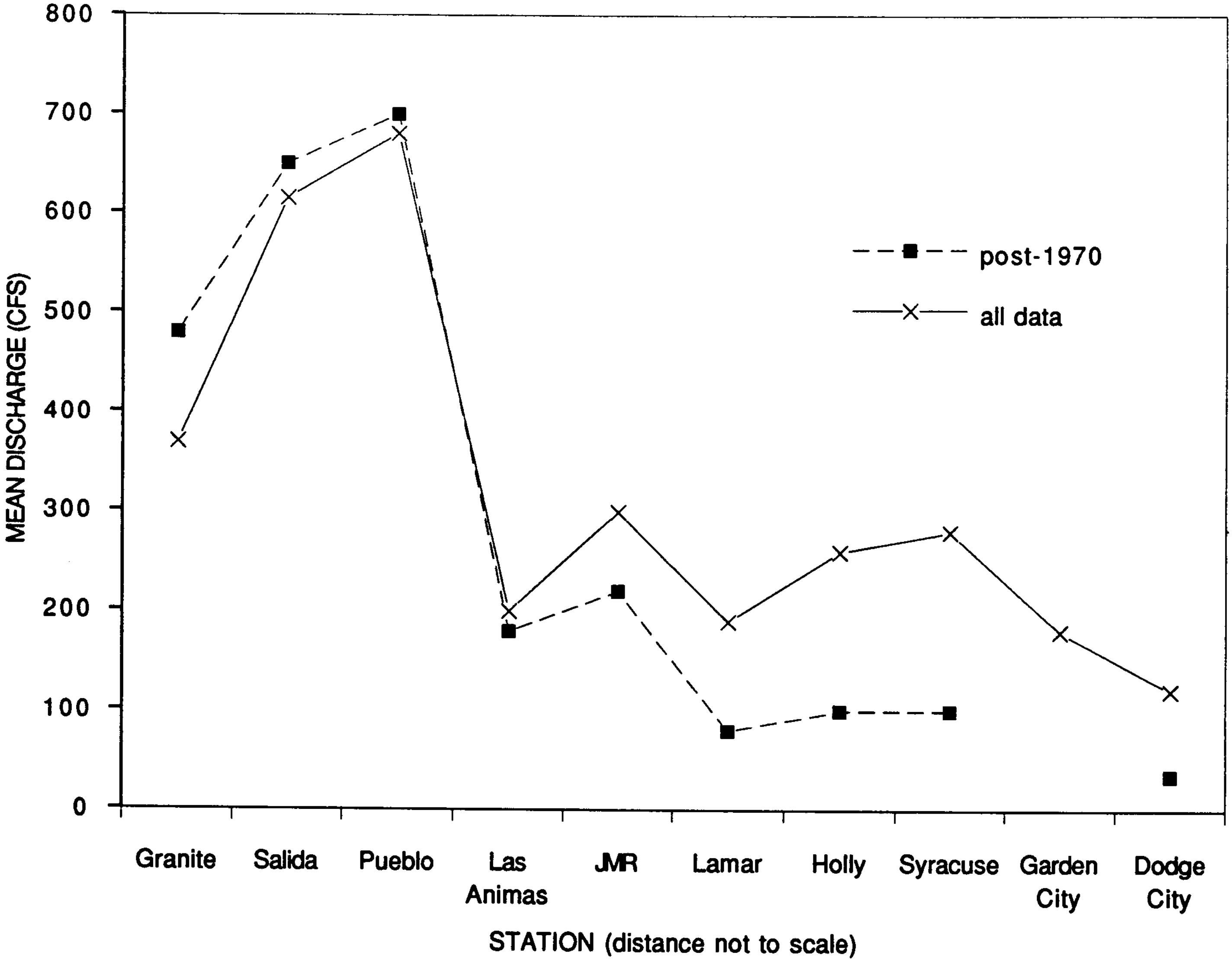


Figure 8. Plot of mean annual discharge versus station (west to east), from Granite, Colorado to Dodge City, Kansas.(JMR = John Martin Reservoir)

diversions within this reach. From 1951 to 1969 an average of 20 percent of total river discharge (including diversion returns) was diverted into these ditches between the state line and Syracuse. Between the state line and Garden City, located 70 miles (112 km) downstream from Syracuse, diversion was very heavy, totaling approximately 86 percent of total river discharge for the same time period. Although diversion data were not obtained for Colorado, Taylor and Luckey (1974) stated that between 1959 and 1968, 80 percent of the annual demand for Colorado irrigation waters was furnished by canal diversions. Currently, some Kansas ditch diversions are being used less since groundwater pumping systems have become the dominant source of irrigation waters.

Upstream damming. In the late 1940s the Army Corps of Engineers closed John Martin Dam, located just west of Lamar, Colorado. Downstream Kansas irrigators expressed extreme concern over potential losses of flow by the damming. Because of this, the Arkansas River Compact was drawn up in 1948. Effects of the dam and dam management have altered minimum, maximum, and mean flow, as well as channel width, depth, and riparian vegetation in downstream reaches.

In a plot of station versus average minimum discharge (Fig. 9), it is seen that pre-impoundment flow generally decreased downstream - a common occurrence in losing stream systems. However, the post-impoundment plot shows a cross-over of values immediately downstream from John Martin Reservoir, and

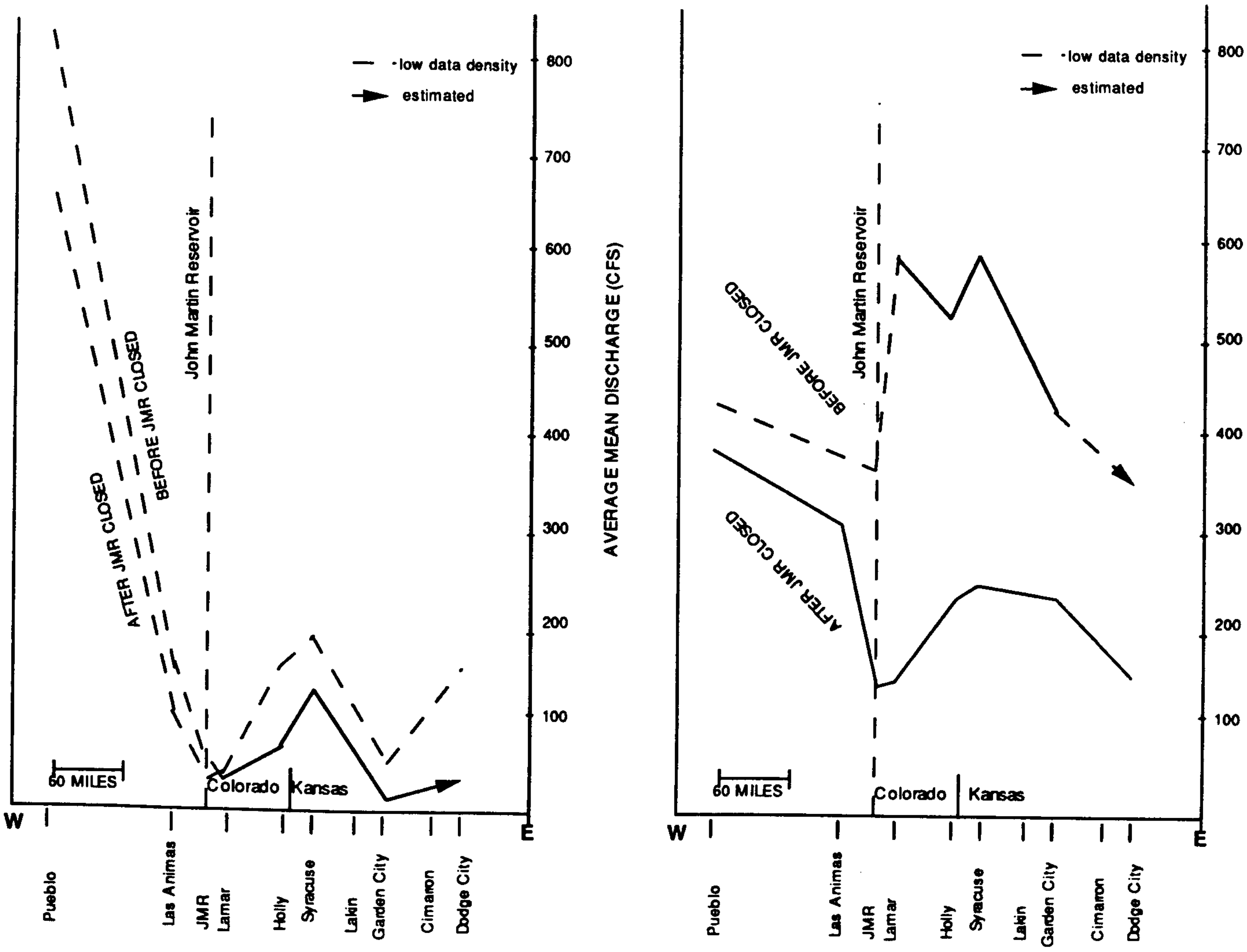


Figure 9 & 10. Effect of John Martin Reservoir on minimum discharge(left) and maximum discharge (right).

post-impoundment minimum flow in these reaches is actually greater than pre-impoundment values. The increase in flow between Lamar and Syracuse on both pre- and post-impoundment plots is probably the result of returns from the Fort Lyon canal (Colorado's largest canal), seepage returns from storage lakes north of Lamar, and the entrance of many small, unmonitored tributaries in this area (Cooper, pers. comm., 1986). Also in this reach, the channel of the Arkansas flows on Cretaceous shales, into which little streamflow seeps. Upstream, it flows on the Cretaceous Dakota Sandstone that is in hydraulic contact with the Arkansas, potentially capturing streamflow.

Average maximum flow has been curtailed greatly since 1948. This is partially attributable to the emplacement of John Martin Dam which was built for flood control and agricultural purposes. Figure 10 shows both pre- and post-impoundment plots of station versus average annual maximum discharge (flows greater than 20,000 cfs were ignored on this graph due to the strongly skewed mean values they gave). Of major interest is the divergence of pre- and post-impoundment plots immediately downstream from the dam. This indicates a sharp decrease in maximum flows after dam completion. Although the strongest influence is just downstream from the dam, divergence is not completely compensated by the time flow reaches Dodge City, and the differences between pre- and post-impoundment values remain substantially greater in Dodge City than in Pueblo.

Average annual mean flow does not show the marked fluctuations that minimum and maximum flows do. Figure 11 shows

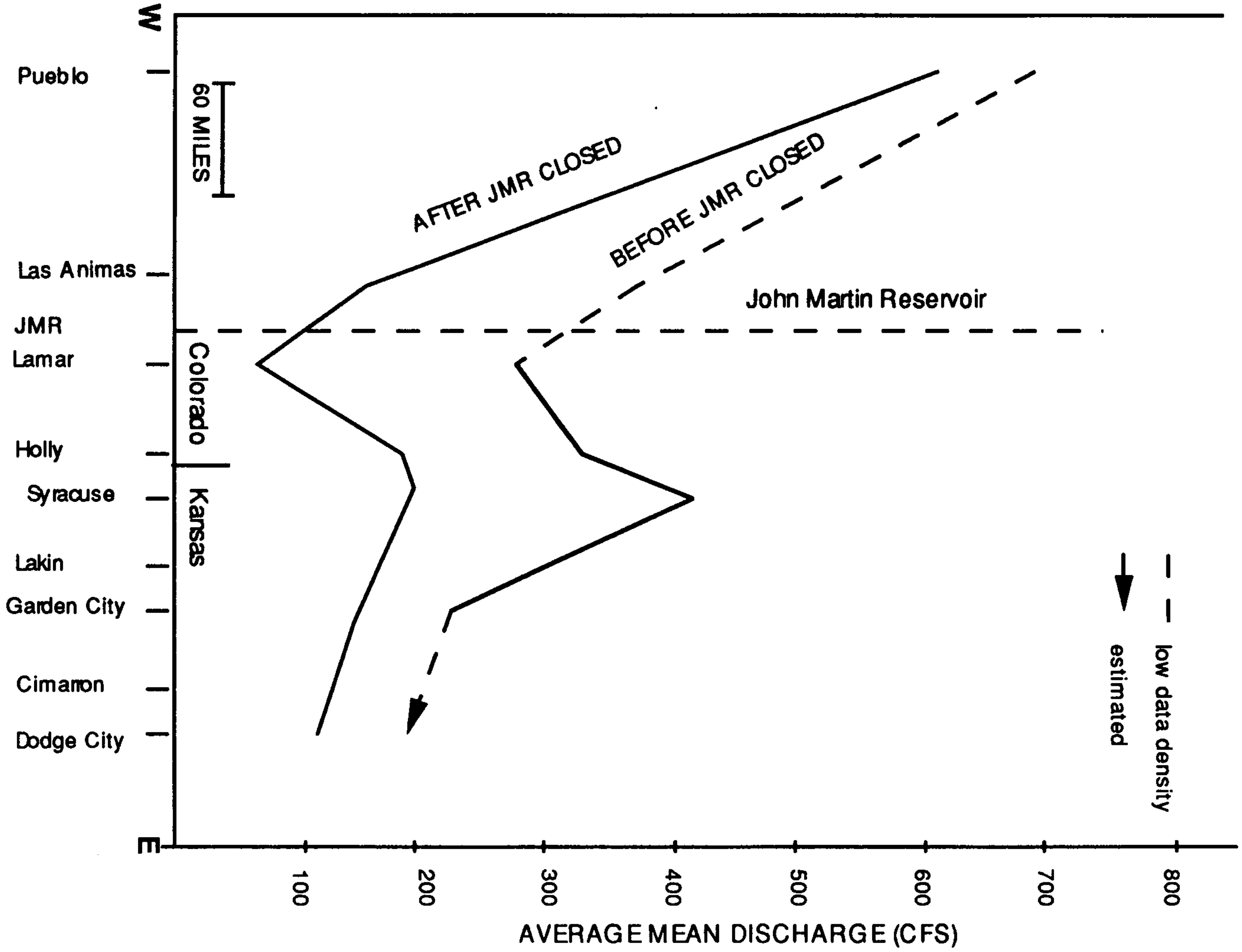
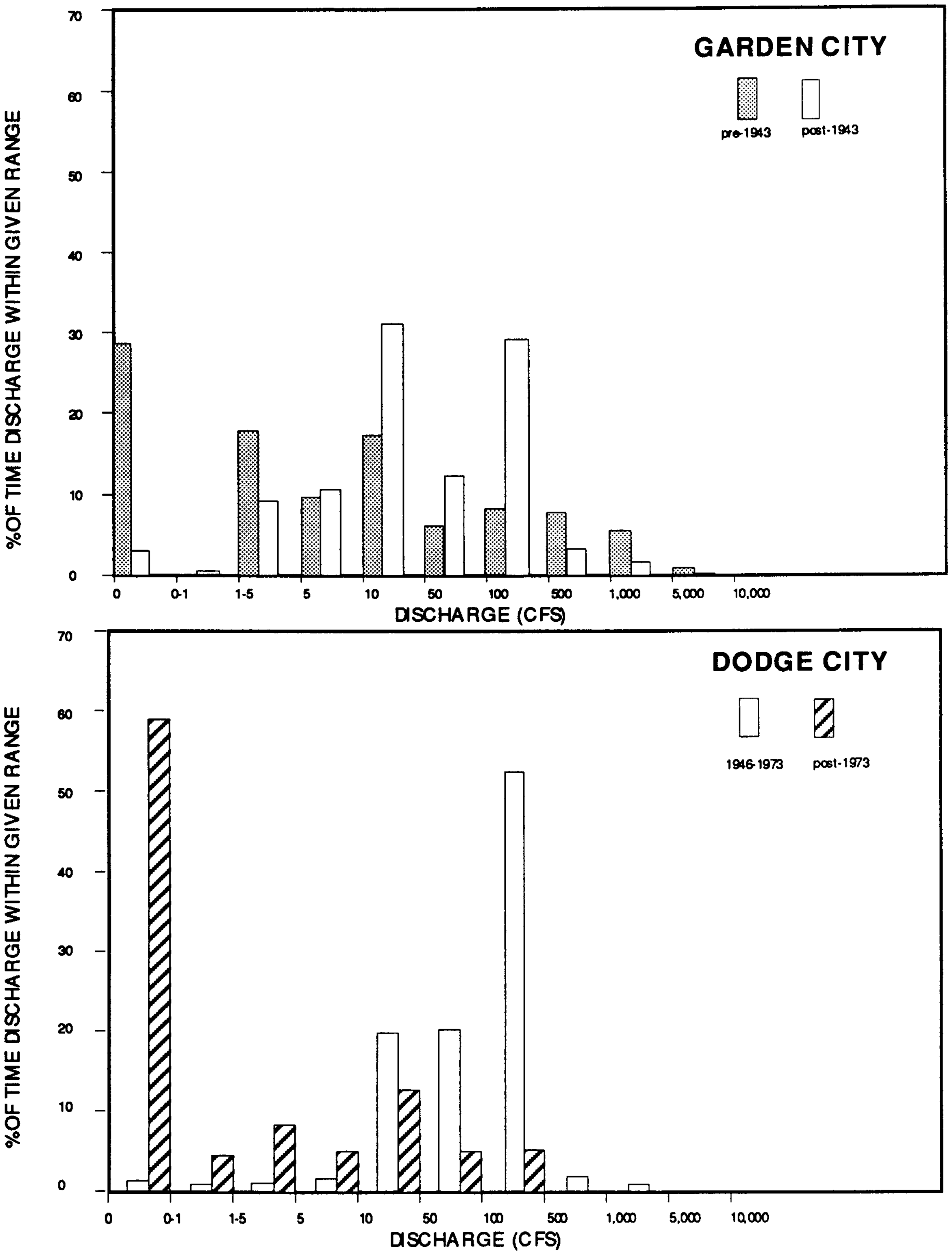


Figure 11. Effect of John Martin Reservoir on mean discharge.

that between 1948 and 1983 mean annual discharge decreased about 200 cfs at both Las Animas, above John Martin Dam, and at Lamar, below John Martin Dam. This shows that decreases at Lamar were not caused by the operation of the dam. Instead, these changes were probably induced by water-use in upstream reaches of the Arkansas and along its tributaries and some climatic variability.

Those stations within the study area historically subject to zero flow days, such as Garden City and Dodge City, have benefited from effects of John Martin Dam. In histograms (Figs. 12, 13) of percentage of time flow is equaled versus discharges it is seen that impoundment, and subsequent management, of the reservoir all but eliminated zero flow days and made each distribution more closely represent a "normal" type of curve. Unfortunately, the Garden City station ceased operation in 1969 and the Dodge City station did not commence operation until 1946, so a 100 percent overlap of data is not possible. Discharge trends at the stations parallel each other, however, and similar curves can be transferred from one diagram to the other to help make long-term comparisons. The return to zero-flow days after 1973 is attributed to groundwater withdrawals and surface-water diversions exceeding reservoir releases. A plot from Pueblo represents stations located upstream from John Martin Dam (Fig. 14), and a plot from Syracuse represents stations downstream from the dam yet not historically subject to zero flow days (Fig. 15).

Damming of the Arkansas River at John Martin Reservoir, therefore, has had effects upon overall river flow. Minimum flows



Figures 12 & 13. Percentage of time discharge within given range versus discharge for Garden City and Dodge City.

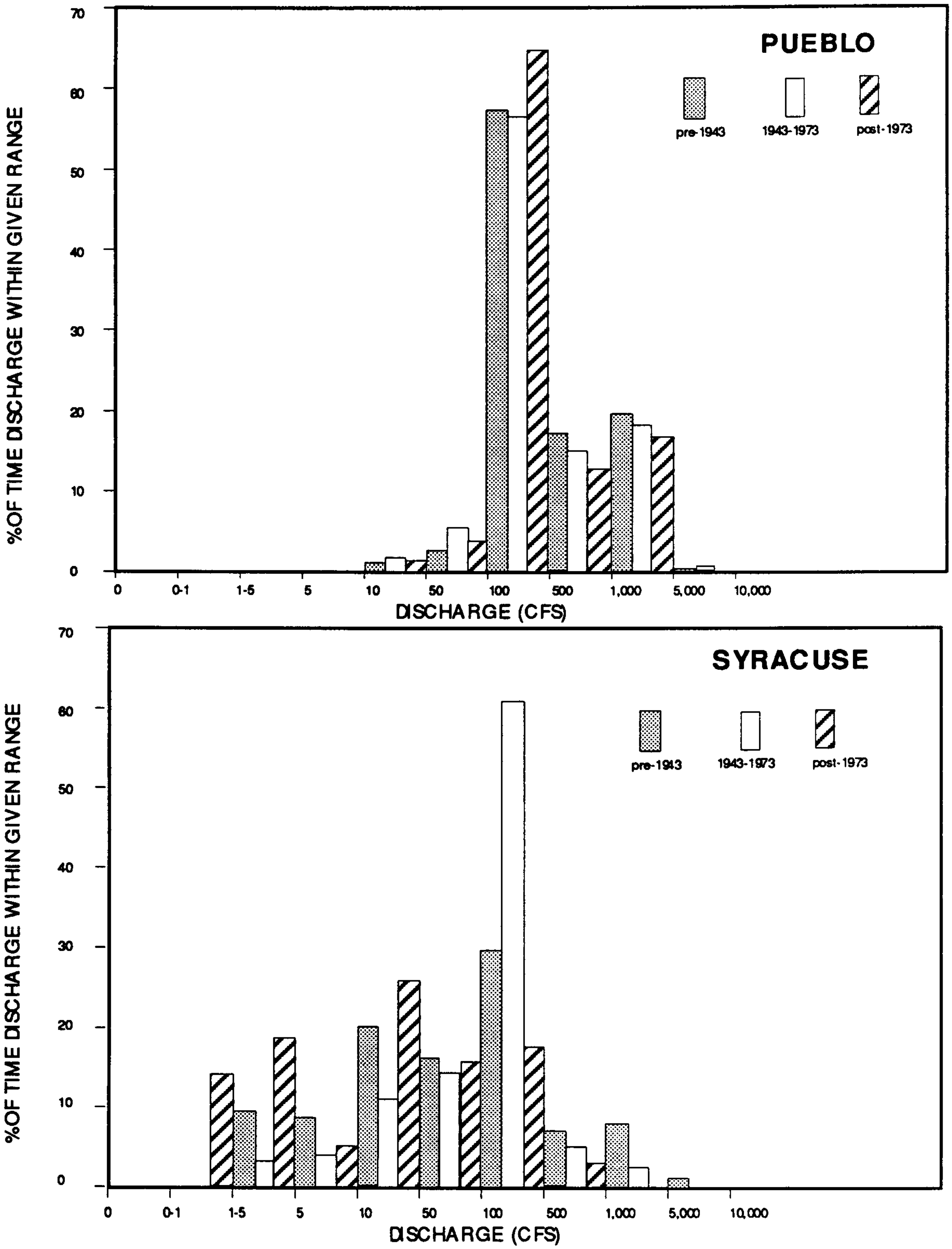


Figure 14 & 15. percentage of time discharge within given range versus discharge for Pueblo, Colorado and Syracuse, Kansas.

have increased and maximum flows have decreased, creating a more regular pattern of flow. By losing days of zero flow and large-scale floods, the Arkansas has become more perennial - losing its earlier intermittent character. This metamorphosis has had a direct impact on other historically changing variables, such as vegetation and channel character, which is discussed subsequently.

Groundwater Use. Groundwater use did not play an important role in discharge changes until after widespread expansion of center-pivot irrigation systems in the 1950s through the 1970s, because few large-capacity irrigation wells were in operation until this time. Within the study reach, the Arkansas River is hydraulically connected to underlying alluvial aquifers and the deeper Ogallala-Pleistocene aquifer. This means that water levels in the Arkansas generally represent the water table, especially within the alluvium. When groundwater levels rise, the river tends to rise. Conversely, when groundwater levels drop, the river also drops, potentially causing the river to go dry (Fig. 16).

Early wells were screened in the shallow alluvial aquifer, but during the 1960s and early 1970s, high capacity irrigation wells were screened in the lower, Ogallala-Pleistocene aquifer. When water levels in the lower aquifer declined substantially, the Ogallala- Pleistocene aquifer recharged through dewatering of overlying alluvium, and hence the Arkansas River. It is in this manner that discharge has been decreased by excessive groundwater pumping.

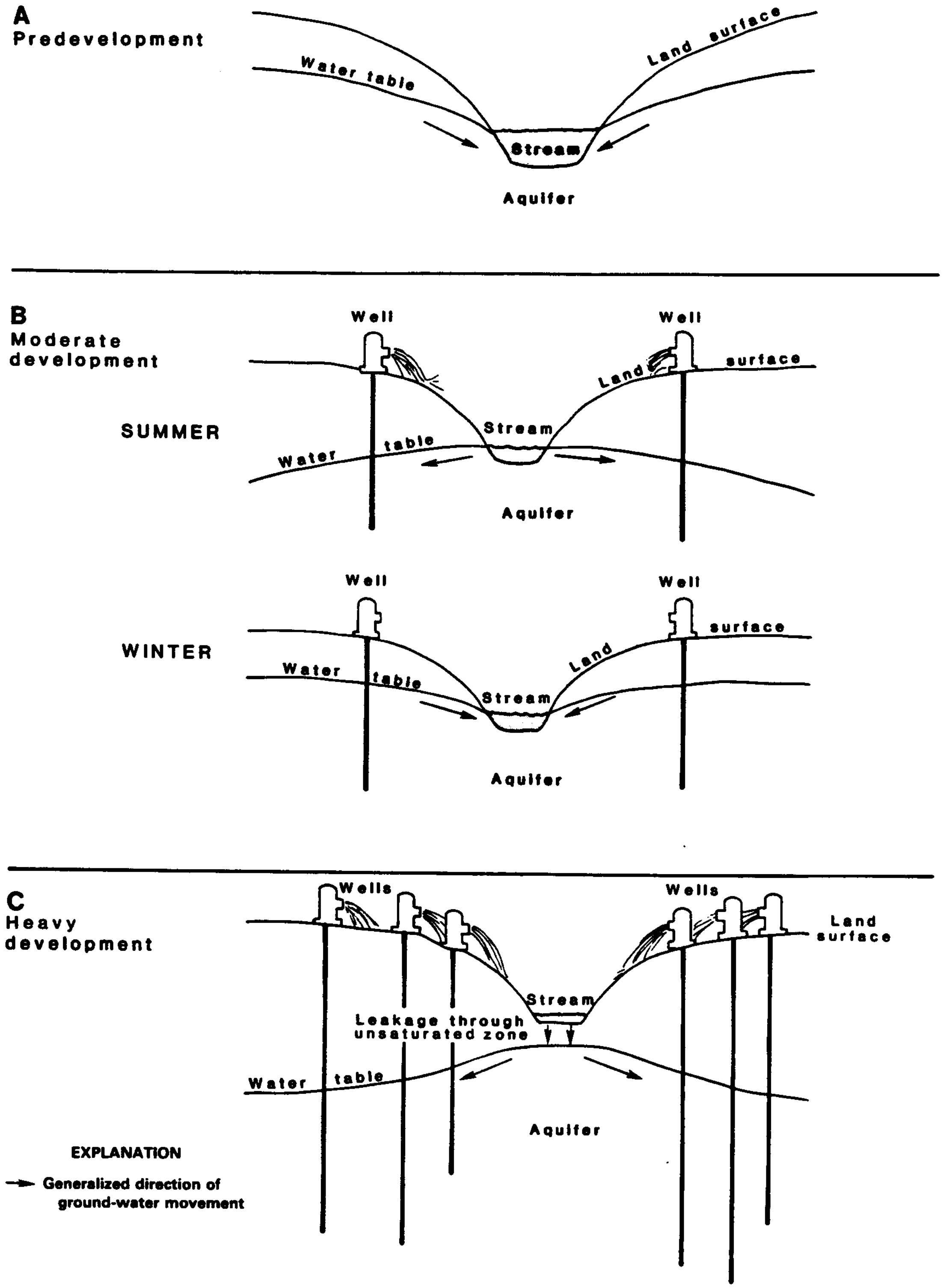


Figure 16. Stream-aquifer relationships (from Barker et al., 1980).

Groundwater pumpage from the Ogallala-Pleistocene aquifer, or the High Plains aquifer, in Kansas has increased from less than four million acre-feet in 1949 to about 20 million acre-feet in 1978 (Gutentag et al., 1984). In southwestern Kansas, the number of irrigation wells mushroomed from 520 in 1940 to 8,250 in early 1978, with corresponding groundwater withdrawals increasing from 90,000 acre-feet per year to 3,500,000 acre-feet per year - an order of magnitude greater than the annual recharge of about 348,000 acre-feet per year (Pabst and Gutentag, 1979). The density of wells increased rapidly to 1980 (Fig. 17). This has resulted in an overall drop of ground water levels within the study area (Table 5) and a decade without flow in the Arkansas between Garden City and Dodge City. Buddemeier and others (1991) doumented, on a regional basis, substantial declines in groundwater levels since predevelopment conditions in southwestern Kansas. The decline for a well in Finney County provides a graphic example (Fig. 18). The regional decline, as of 1991, for southwestern Kansas has been manifested as a 10-50 foot (3-16 m) drop in water table since predevelopment. and up to a 50 percent reduction in saturated thickness (Fig. 19).

Climatic Variability. Climatic influences are very difficult to identify as a potential factor causing changes in discharge. Precipitation should have the most obvious effect on discharge and it is this variable that was studied. When visually comparing graphs of mean discharge versus time and mean precipitation versus

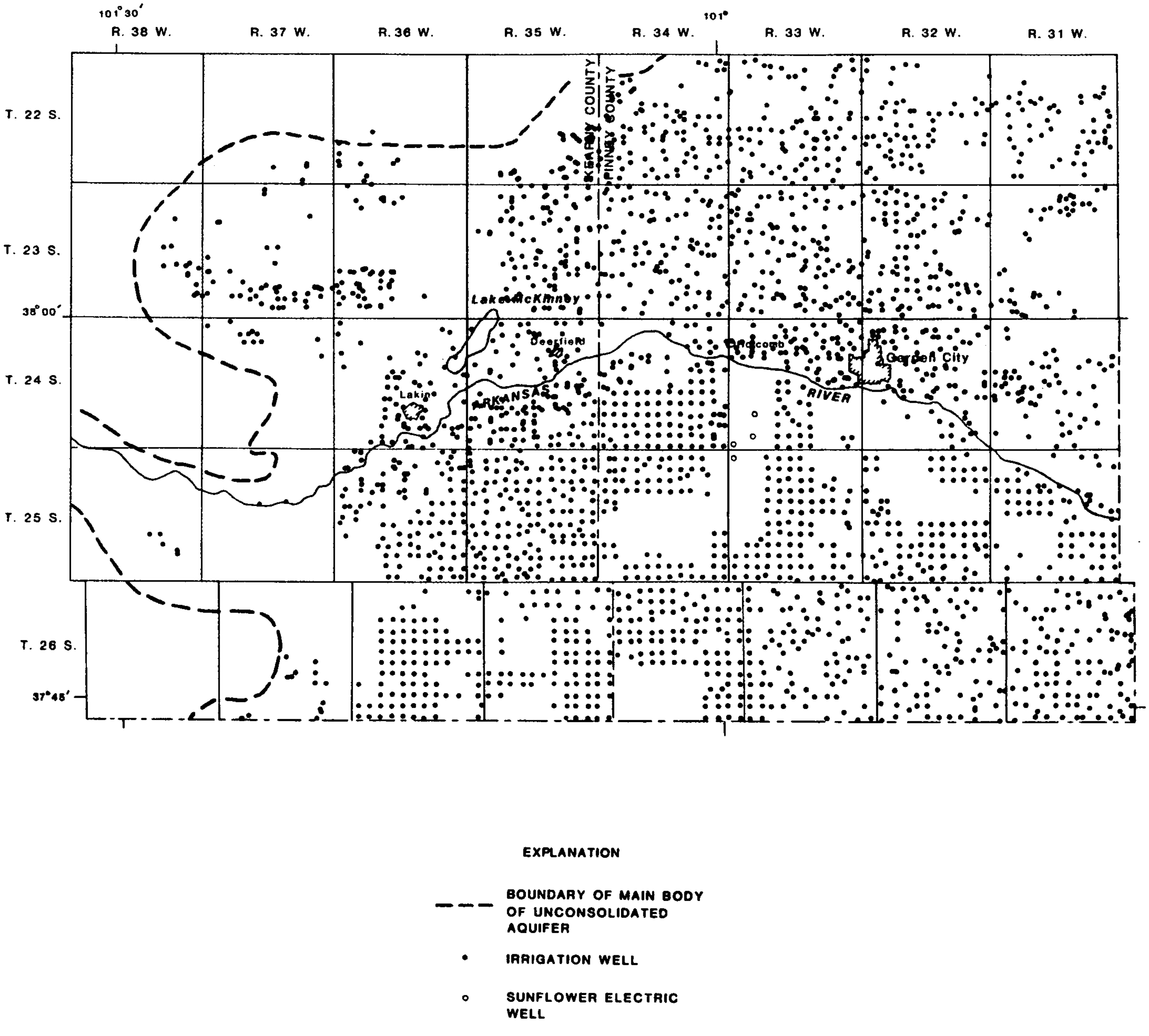


Figure 17. Locations of irrigation wells and Sunflower Electric wells in eastern Kearny and western Finney Counties (from Dunlap et al., 1985).

TABLE 5
GROUNDWATER DECLINES BY COUNTIES FOR THE EARLY PERIOD OF DEVELOPMENT (pre-1980)

County	Ave.Decl. 1948-78 Ft.	Max.Decl. 1940-78 Ft.	Min.Decl. 1940-78 Ft.	Max.Decl. 1977-78 Ft.	Min. Decl. 1977-78 Ft.	Wellden. 1975 #/SEC
Kearny	-9	-18	0	-4.98	-0.66	1.0
Finney	-22	-47	-2	-7.71	+0.25	1.7
Gray	-8	-20	-2	-3.96	+0.86	1.4
Ford*	-4.5	-5	-4	---	---	---

* = low data density

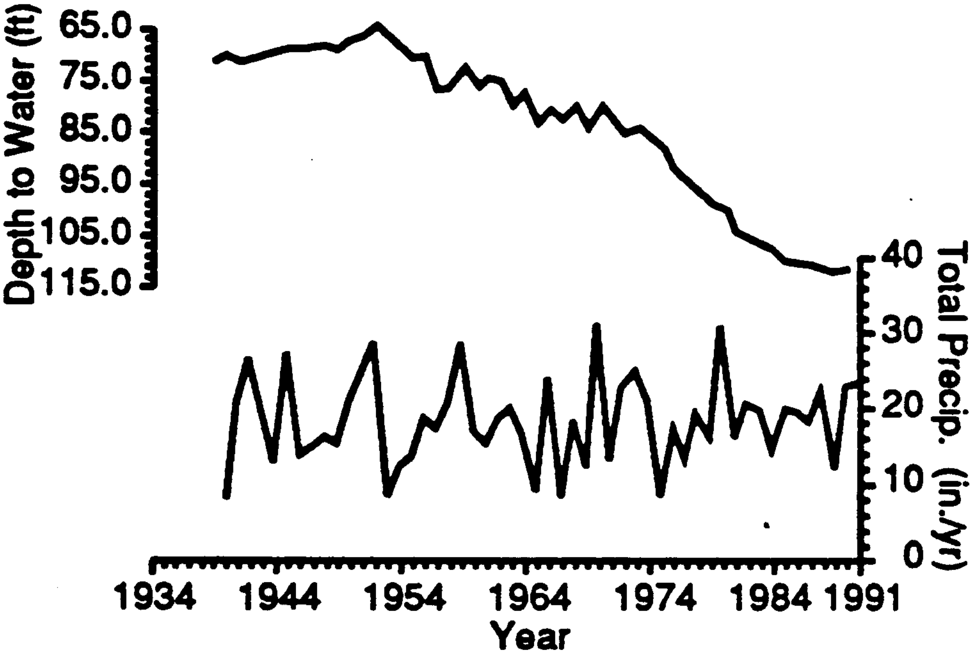


Figure 18. Water levels in Finney County well 24S-32W-03DAC. Precipitation data are from the Garden City Experimental Station. (from Buddemeier et al., 1991)

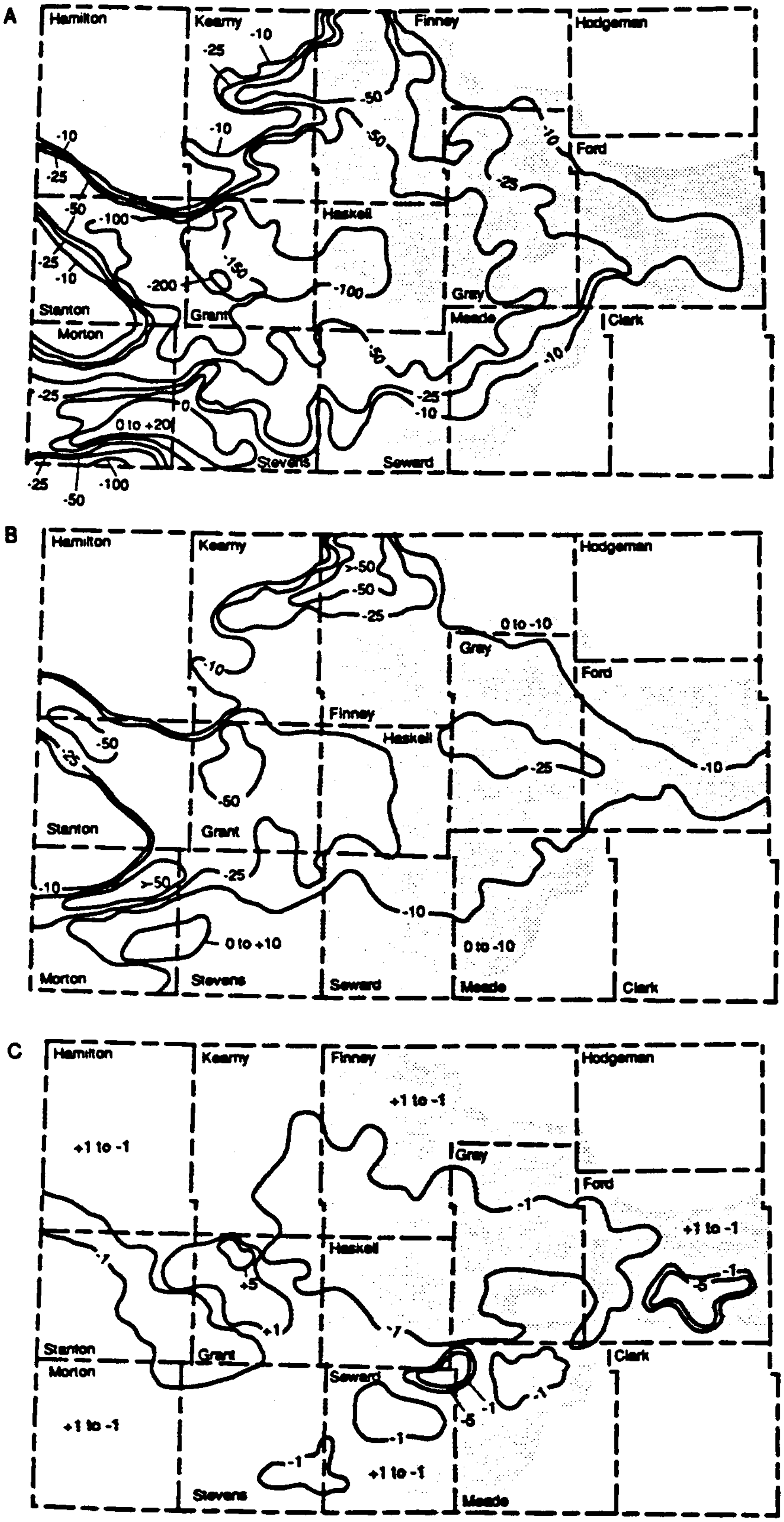


Figure 19. Groundwater in Southwestern Kansas: (A) water table change (in feet) predevelopment to 1991; (B) change (%) in saturated thickness; (C) water-level change (feet) 1990-91.

time it can be seen that discharge responds strongly to precipitation events (Appendix A). Major peaks and troughs are echoed in the plots and long-term patterns (sequences of 20 to 25 years or greater) show similarities. Correlation is not absolute, however, and in plots of mean discharge versus mean precipitation a scatter pattern emerges (Fig. 20). A relationship between the two is evident in this plot, yet values from data collected after dam completion and center-pivot expansion tend to cluster in the lower mean discharge range.

A linear regression was performed using yearly precipitation and discharge data from stations within the study reach and upstream. Three time periods were chosen as representative in order to first eliminate, and then highlight, the influences of damming (1948) and massive groundwater pumping (1973) (Table 6). Overall correlations in Colorado were best before the river was dammed and heavily used for agriculture. The period between damming and extreme groundwater use shows a decrease in correlation in Colorado, while Syracuse actually shows a better precipitation-to-discharge relationship, possibly a result of local climatic change or influences of dam management. Once heavy groundwater pumping began, however, no correlation existed in Colorado or Kansas and in some cases negative correlations were induced. Correlations over the entire time period show strong precipitation-to-discharge relationships in Colorado and far western Kansas. However, at stations where the Arkansas channel is hydraulically connected with underlying aquifers, such as Garden

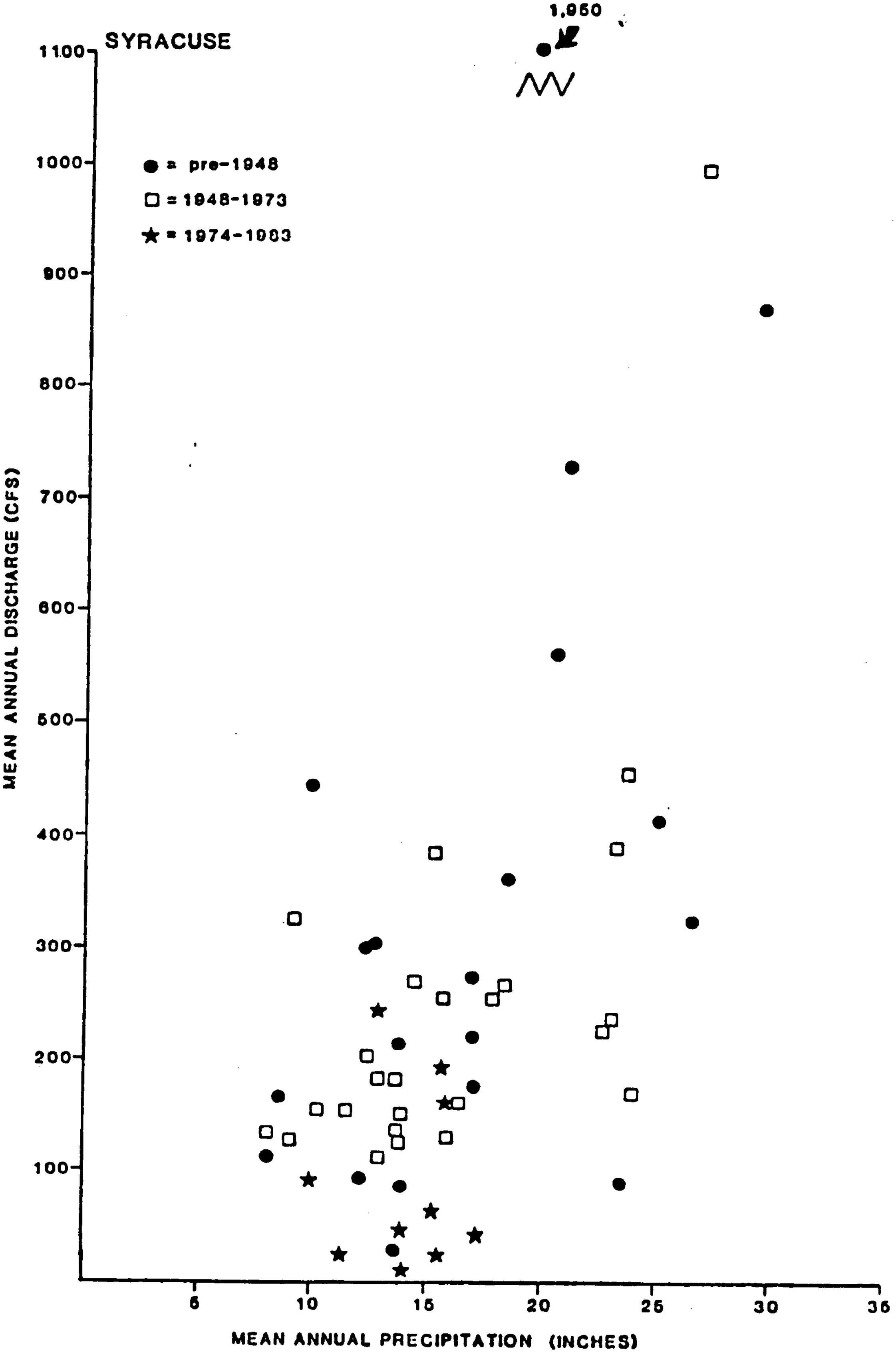


Figure 20. Scatter-plot diagram of mean annual discharge versus mean annual precipitation for Syracuse, Kansas.

TABLE 6
CORRELATIONS BETWEEN PRECIPITATION AND DISCHARGE
X = precipitation (inches); Y = discharge (cfs)

	PRE-1948	1948-1973	POST-1973	TOTAL
Pueblo, Colorado				
X =	11.72	11.20		11.54
Y =	712.50	652.40		691.40
Corr. =	0.58**	0.48*		0.54**
Lamar, Colorado				
X =	15.44	14.45	14.59	14.95
Y =	287.50	97.80	86.50	192.30
Corr. =	0.42*	0.34	-0.15	0.38**
Syracuse, Kansas				
X =	16.79	16.07	13.99	16.04
Y =	399.00	236.60	72.80	264.90
Corr. =	0.36	0.62**	0.02	0.44**
Garden City, Kansas				
X =	17.38	18.84		18.08
Y =	224.60	152.10		189.90
Corr. =	0.36	0.38		0.19
Dodge City, Kansas				
X =		21.12	21.08	21.11
Y =		173.00	7.00	125.60
Corr. =		0.27	-0.34	0.22

** = maximum association
* = moderate association
= no association

Correlations tested using Rohlf and Sokal (1981), Statistical Tables, Table 25 - Critical values for correlation coefficients.

City and Dodge City, no correlations were found.

The data suggest that climatic variables such as precipitation exert a strong influence on discharge changes, but can be overridden by other, man-made, factors. Rapidity and severity of discharge changes along the Arkansas during historic time do not appear to be attributable solely to climatic change. Instead, these "short-term" (on a year-to-year basis) fluctuations seem to be more related to other variables such as the use of river water by humans and the ability of the river and channel to buffer influxes of water. The latter is readily apparent in the Garden City to Dodge City reach where surface-subsurface water interactions exert a major control on discharge volumes. Climate is exerting a much less obvious influence on discharge along the Arkansas as more and more human factors intervene. Long-term climatic influences, however, are still very important, with major droughts compounding pumped withdrawals and wet periods lessening them by decreasing and increasing discharges, respectively.

The Nature of Channel Change

The channel of the Arkansas River has narrowed considerably within the study reach since it was first charted by early explorers. The earliest accounts of the Arkansas River record a channel 1/4 mile (.4 km) wide with little tree growth (Jackson, 1966). A military expedition observed in 1820 that the river was 400 to 600 yards (366-549 m) wide (Fuller and Hafen, 1957). Shortly thereafter, a government survey recorded an average width of 350 to

500 yard (320-457 m) (Gregg, 1952). The original federal land survey indicated that the average width was about 1200 feet (366 m), with a maximum of 1800 feet (549 m) in the study area. In addition to a great width, the shallow depth, sandy bottom (sand bars), and low discharge were frequently recorded. Mead (1896) and Haworth (1897) first observed that the channel width was shrinking in response to diversions to irrigation canals.

The change in width from the turn of the century to the present is evident when comparing recent photographs of the river at Garden City, Kansas with those from the early 1900s (Figs. 21). These photographs were taken from approximately the same location, looking north towards Garden City, yet the only thing they have in common is the location of the bridge. Pilings from an earlier bridge are yet visible on the downstream side of the present bridge (Fig. 22).

The dramatic narrowing of the channel and changes in channel character that have occurred since the original federal land survey have been represented on maps of the Lakin and Charleston areas (Appendix B). Further, width data obtained from these sources and field observations are presented in Appendix C, as tables of channel widths. The channel of the Arkansas lost 80 percent of its 1872 width prior to 1939. Rapid early narrowing of the channel, followed by less dramatic changes and minor widening during 1985, are seen in a plot of percentage of 1872 width (all stations) versus year (Fig. 23).

The original survey-era channel banks are still evident at

Figure 21. Arkansas River at Garden City in 1903 (top) and 1989 (bottom). View is north, northwest.

Figure 22. Remains of the pilings from an earlier bridge, but not the original 1880's bridge, at Garden City. Note evidence of recent channel bed degradation on the supports of the present bridge. View is north, northwest.

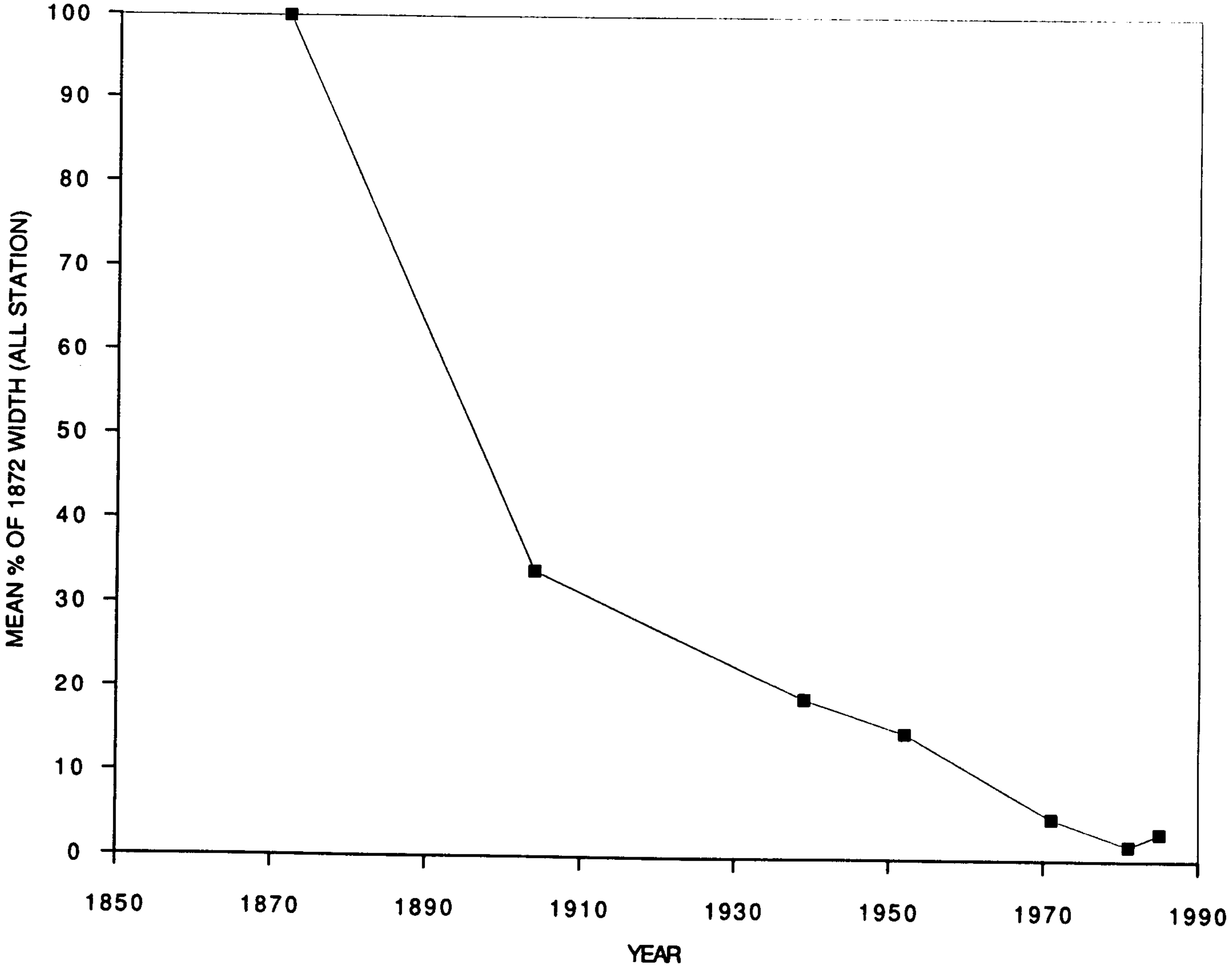


Figure 23. Mean percentage of 1872-73 width (all stations) by year.

many locations in the study area. In aerial photography and on the ground the former location of the bank is revealed by the limit of cottonwood trees, i.e., the trees grow in the former channel bed. These banks have an average height of about six feet (2 m) (Fig. 24). The pre- and early settlement banks were apparently sufficient, given the immense channel width, to contain the flow during the high spring discharges (Monahan, 1873; Mead, 1896; Fuller and Hafen, 1957).

There has also been a vertical component to the channel change in the study area. Depth data were obtained from channel migration patterns, length of shadows in aerial photographs, surface photographs, and modern observation. Photographs of the dry river channel in 1903 (Fig. 25) show the channel to be a maximum of four feet (1.2 m) deep. This was calculated by assuming the woman in the photograph to be of average height (5'4" to 5'5", 1.65 m) and making a scale comparison with bridge supports. However, Haworth (1897, p. 28) stated that bridges in this region were usually built high enough that a man on horseback could ride under while sitting erect. It seems that the Arkansas was building up, or aggrading, its bed as well as narrowing its channel - a common occurrence in areas where land had been cultivated and then abandoned, allowing excess sediment to enter the river. This occurred in southwestern Kansas in the late 1890s during the first historically recorded great drought. Notes by Smith (1941, p. 299) state that "it has not been ascertained whether or not this process of filling has continued down to the present...". Had major deepening occurred by

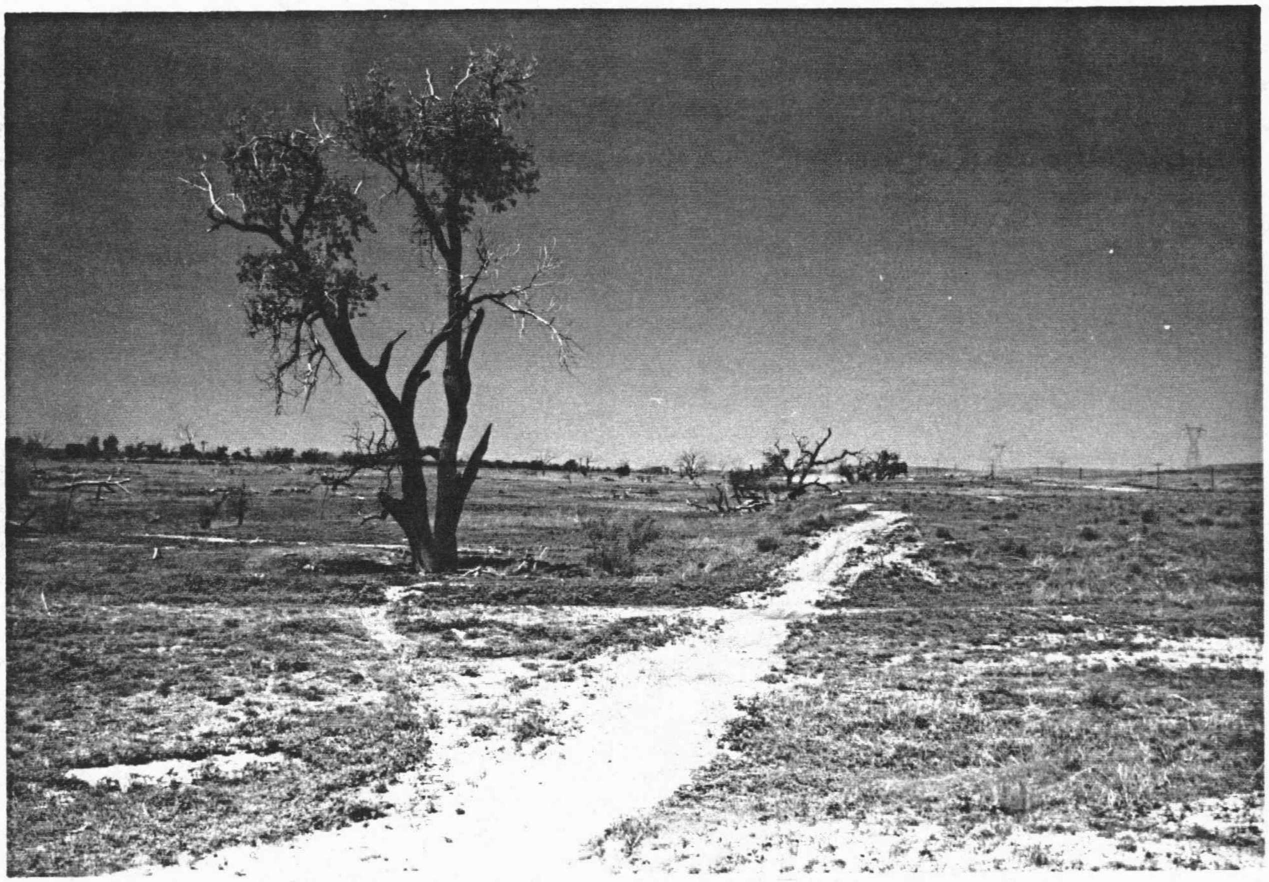


Figure 24. The 1872-73 channel bank rising to the north (right) of an aging cottonwood. View west, northwest near Pierceville, Finney County.

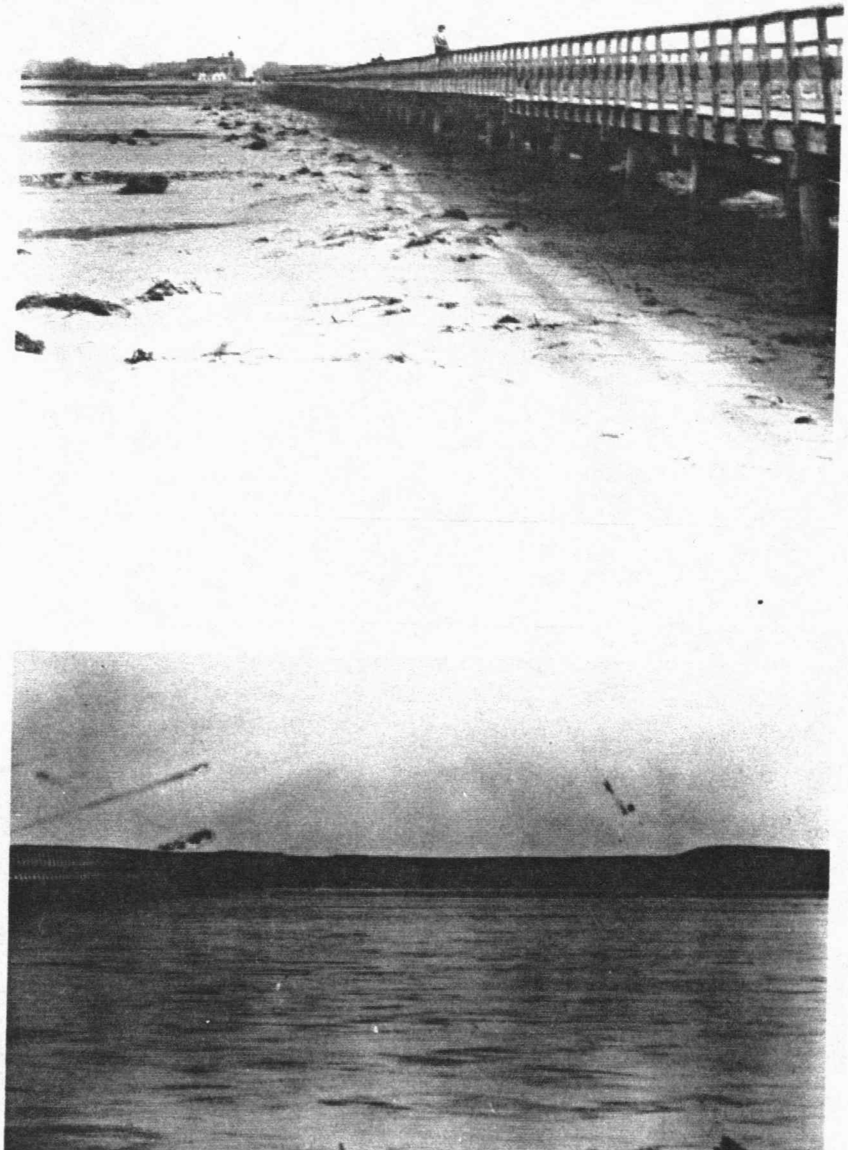


Figure 25. Dry bed of the Arkansas River in 1903 at Garden City (top); Arkansas River at same location, same year, at high stage (bottom).

this time it probably would have been noticed.

Channel migration patterns and shadows on aerial photographs show little to no channel deepening before 1952. At this time minor deepening was evident and by 1973 depths had increased substantially. The channel bottom was probably near its modern level by this time. A schematic diagram of depth changes and associated width changes is presented in Figure 26.

It appears that channel deepening occurred after the great drought of the 1930s, and probably was not a direct result of long-term climatic fluctuation. Instead, other factors such as rapid scouring during major floods, like those in 1965, removal of sediment from the stream by upstream damming, and channel width constriction by vegetation may have had more direct influences. Studies on the Gila and Cimarron Rivers show that a single large flood event can trigger channel changes and major floodplain destruction (Burkham, 1972; Schumm and Lichty, 1963). It is also thought that flood histories control the form of many rivers over short spans of time (Stevens et al., 1975).

Causes of Channel Change

Surface Water Diversion. By 1903 all eight major Kansas diversion ditches upstream from Garden City were in operation. Early diversion quantities were minor, increasing as more and more acreage went into cultivation. In Finney County alone, the area under cultivation, much of which was irrigated, jumped from 2,905 acres (1,175 ha) in 1879 (pre-ditch) to 500,000 acres (202,342 ha)

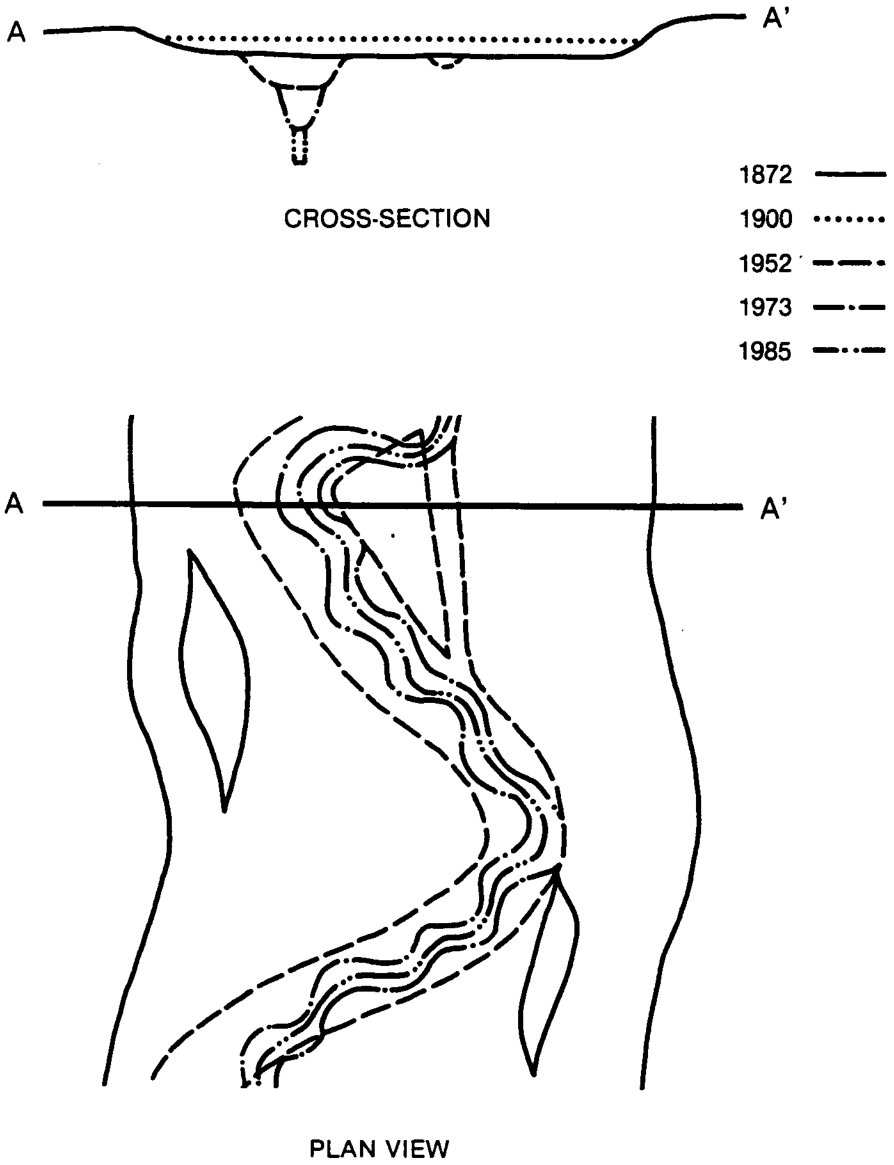


Figure 26. Schematic diagram of historical changes in depth and width for the Arkansas River of the study area.

in 1930 (Blanchard, 1931). The demand for river water rose proportionally, since it was the source of irrigation water at this time.

Early withdrawal rates are not available, so an exact relationship between channel width change and water diversion cannot be made for the period of maximum narrowing. The continuity equation, $Q = w \times d \times v$ (where Q = discharge, w = width, d = depth, and v = velocity) dictates that changes in width, depth, velocity, or some combination thereof had to occur given the large amounts of water diverted, e.g., 86 percent of river flow was diverted by ditches upstream from Garden City after 1951. Prior to 1939 ditch diversions were less than in the 1950s, but overall discharge did decrease during irrigating months, inducing channel changes. The Arkansas primarily compensated for this decrease in discharge by decreasing its channel width, since this was the variable of least resistance at the time.

With massive ditch irrigation upstream in Colorado as well as in Kansas, the Arkansas often "ran dry" during peak irrigation periods (Slichter, 1906; Blanchard, 1931). Historically, the Arkansas would frequently dry up during winter months and begin peaking in flow about April. Photographs (Fig. 25) of the river taken around 1903 show both the dry, winter stage, and the high, spring stage. No evidence of narrowing since the federal survey is evident in the photographs. Aerial photographs from 1939, however, show permanent channel narrowing, even when viewed during the April rise (Fig. 27). Irrigation diversions during most peak flow periods

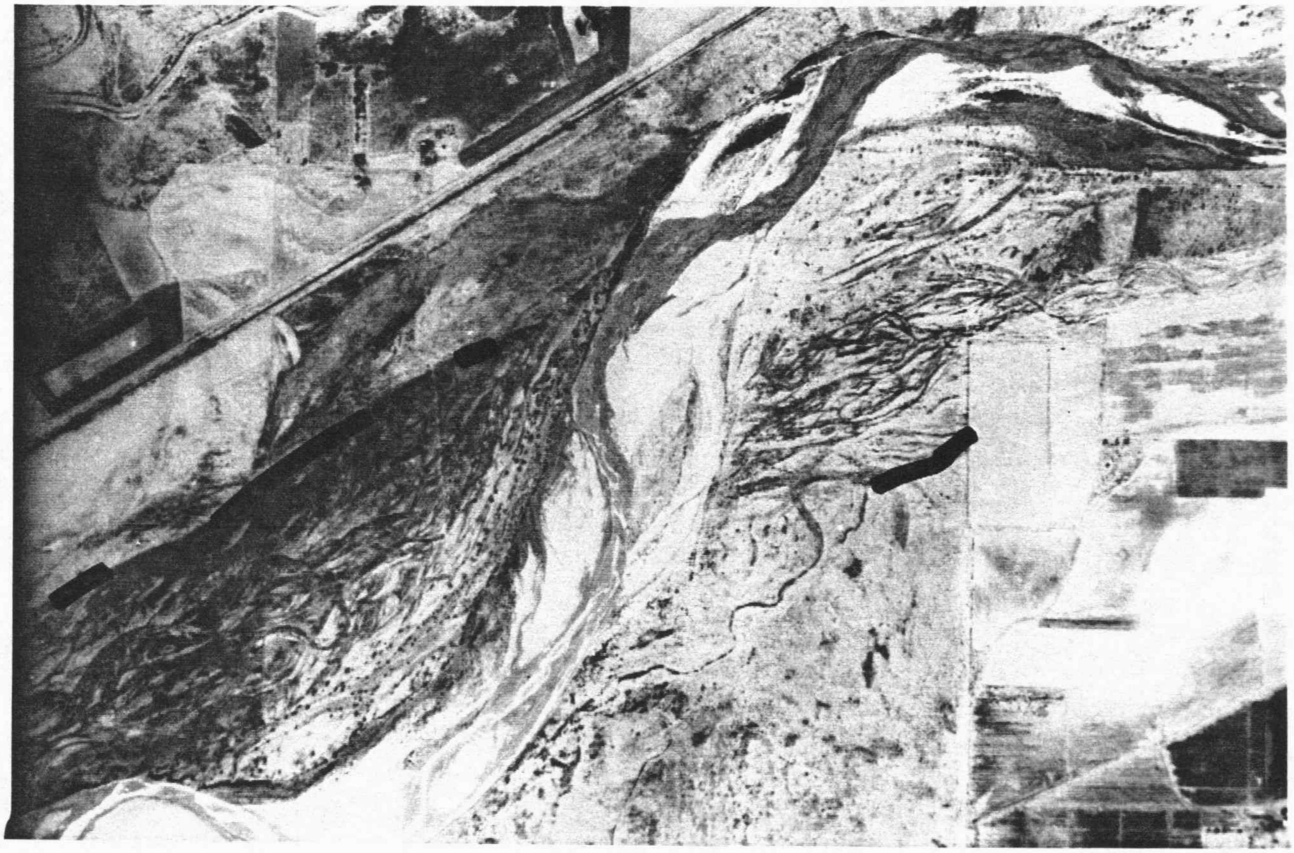


Figure 27. Aerial photography showing channel narrowing by 1939. The limits of the 1872-73 channel are represented by the black line.

from 1903 to 1939 appear to be one of the major causes of channel width changes along the Arkansas since the outer channel areas no longer carried continuous flow. Climate undoubtedly also played a role, since 1939 marked the culmination of a great drought in the Great Plains (Appendix A).

Climate. Climate has played a role in the decrease in channel width along the Arkansas River, but primarily on a long-term scale. Studies by Borchert (1950, 1971) and precipitation data reveal that the end of the period of major channel narrowing in 1939 coincided with the end of a great drought. It has been suggested that the loss of discharge due to drought caused the channels to narrow. This is not completely true, however, as human influences were very important.

Precipitation records for the study area only date back to 1920. This year is at the end of a wet period and beginning of the drought that is partially concurrent with channel metamorphism. Precipitation records for the Las Animas station, however, date back to 1867. A time series of precipitation shows that a drought of similar extent and magnitude as the 1930s drought occurred in the 1890s (Fig. 28). Large-scale events such as droughts and wet periods follow similar patterns in both southeastern Colorado and southwestern Kansas (Fig. 29). Therefore, if channel narrowing was purely caused by climate, major width decreases should have been evident in 1903. This was not the case. In 1906, Slichter mapped four short reaches of the Arkansas from Hartland to Garden City.

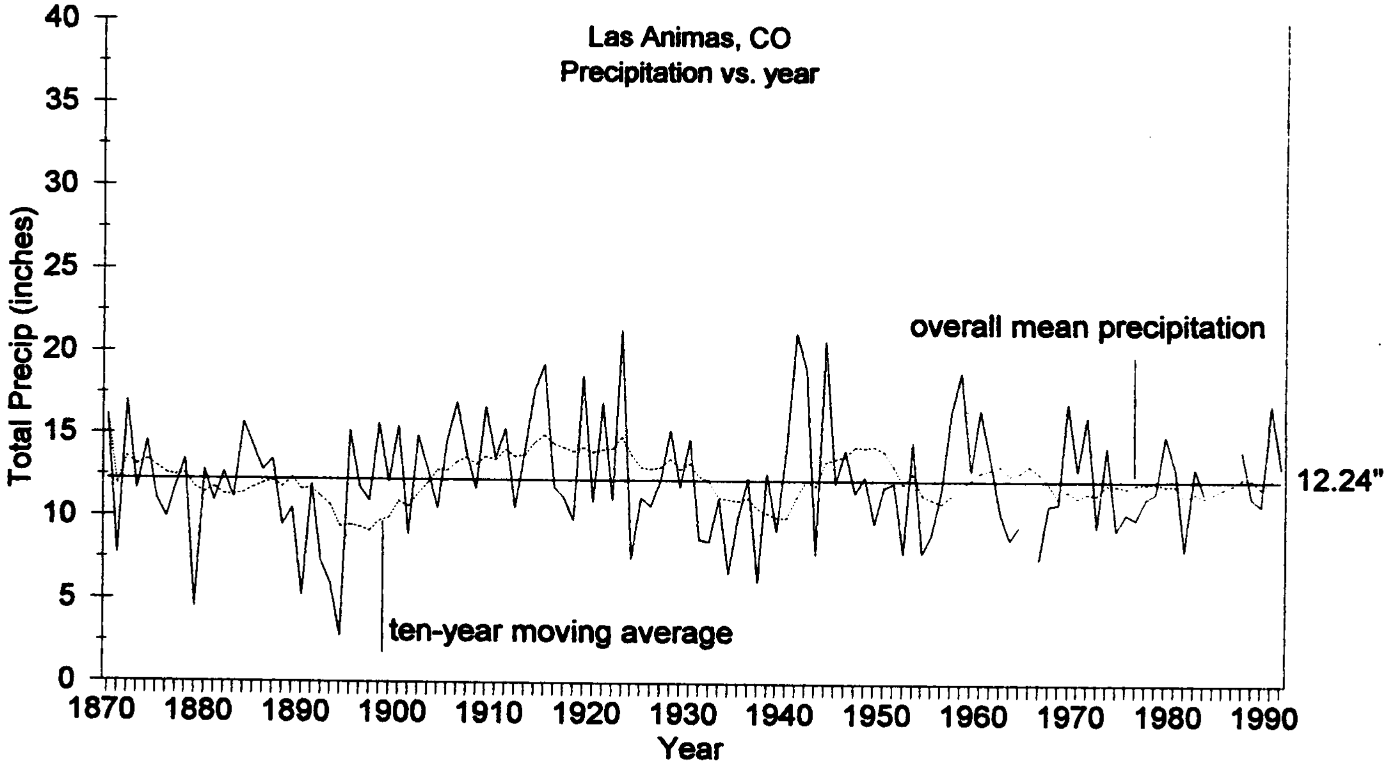
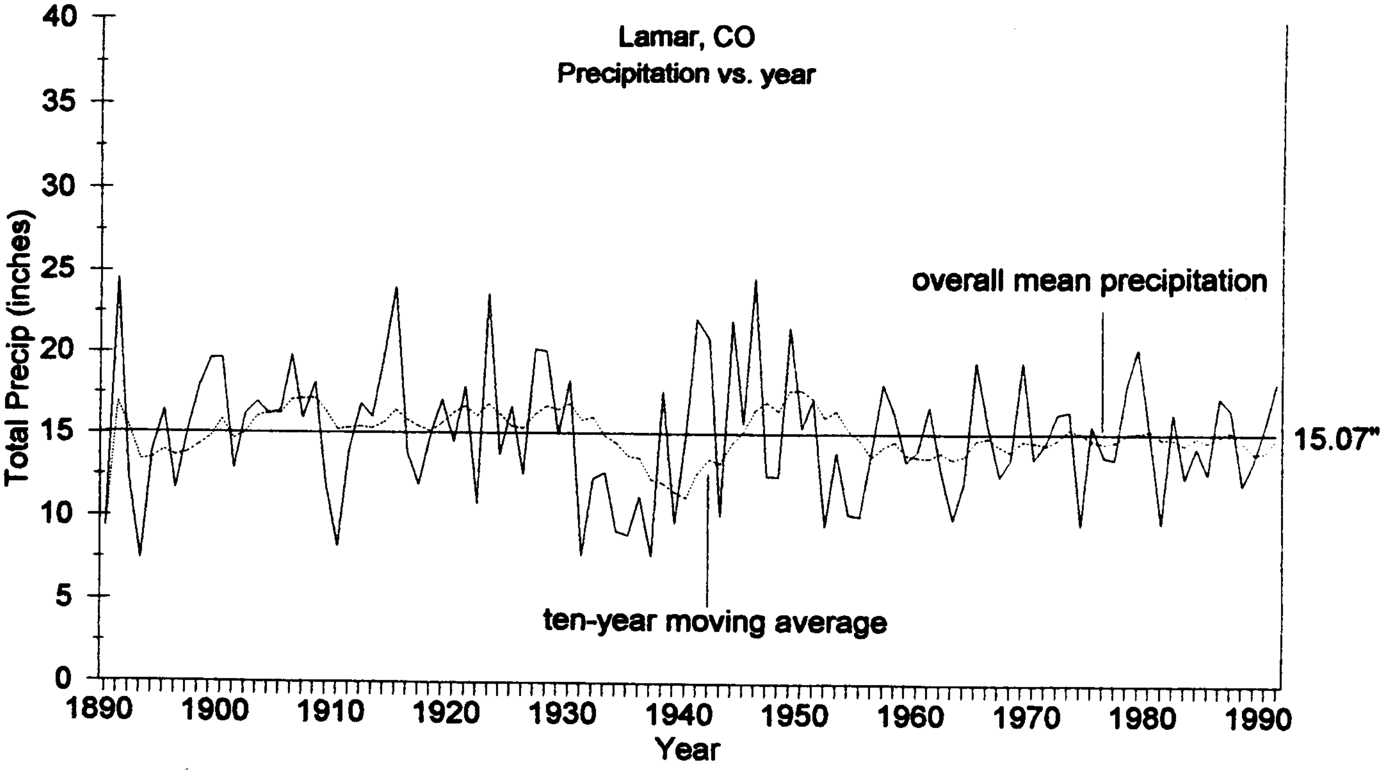


Figure 28. Time series of annual precipitation at La Aminas, Colorado.



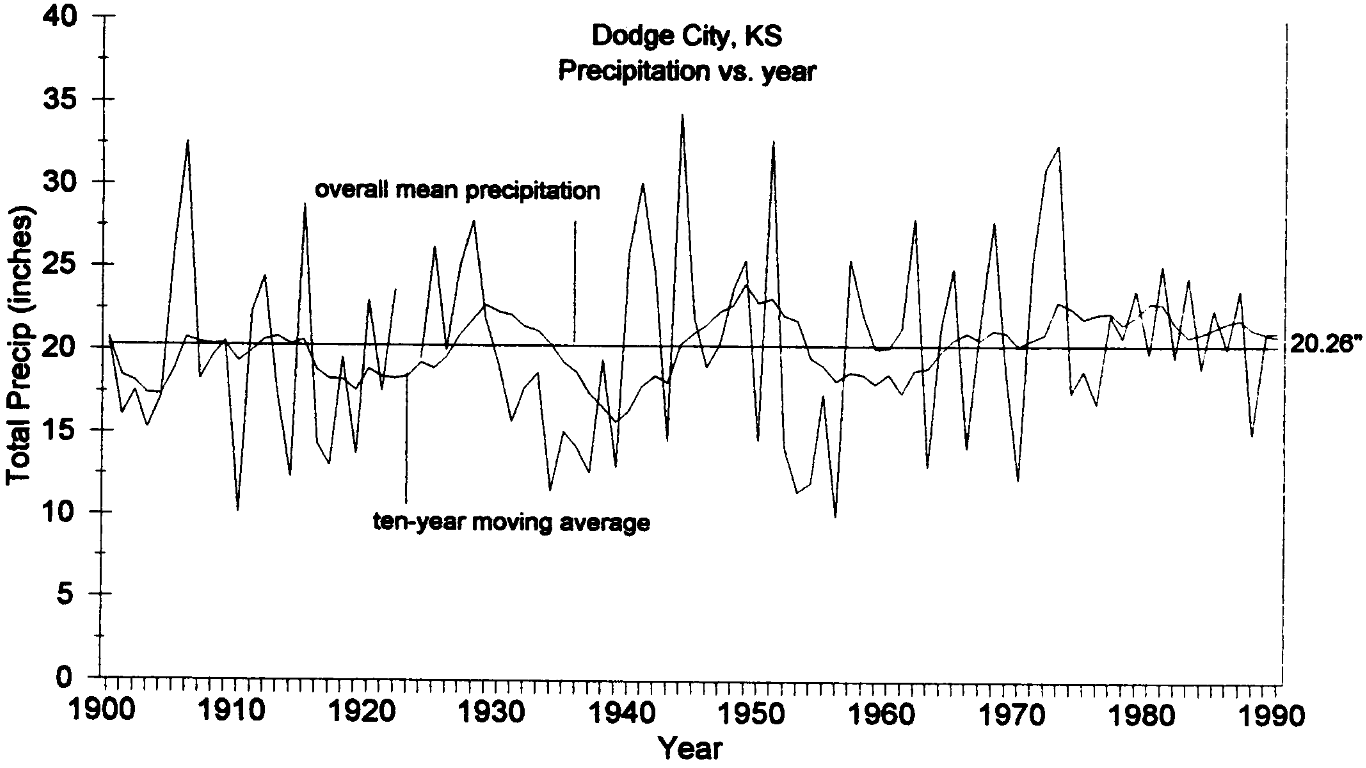


Figure 29. Time series of annual precipitation at Lamar, Colorado and Dodge City, Kansas.

These maps show the channel to range from 800 to 1000 feet (244-305 m) in width - a maximum decrease of only 25 percent from 1872 to 1906, leaving up to a 55 percent loss of width to be accounted for between 1906 and 1939. It appears that increasing reliance on diverted river water by settlers before and during the drought of the 1930s resulted in permanent changes in river width.

Upstream Damming and Groundwater Use. Upstream damming is known to reduce the amount of sediment load in a stream, thereby causing degradation of the stream bed immediately downstream from the dam. At John Martin Reservoir, in 1951, average degradation per year was 0.041 feet - substantially less than at other dam-sites in semi-arid and arid climates (Leopold et al., 1964). It is unknown how far downstream degradation effects can propagate or how much this has affected the depth of the Arkansas within the study reach. Due to the long distance from the dam and the minimal amount of water that has been flowing through these reaches, it is doubtful that dam closure has had a measurable impact on channel depth.

Damming has contributed to channel width changes, however. By regulating flow at John Martin Dam, most high flood peaks are attenuated. It was these floods that would periodically scour the channel of debris and vegetation, keeping it open for flow. While channel width changes were once the easiest variable to shift in channel cross-sectional area (w x d) due to a lack of lateral restraints, vegetation now stabilizes much of the channel banks, possibly indirectly inducing depth increases during high flow.

Changes in groundwater use has had an important impact on recent stream morphology. The Arkansas has virtually ceased to flow within the study reach due to increasing groundwater withdrawals for irrigation. Initially, this resulted in the expansion of riparian vegetation by providing germination locations with a shallow water source due to the anomalously high water table created by irrigation practices. When riparian vegetation stabilized the banks of the Arkansas, channel deepening occurred. The rate of deepening was not proportional to the rate of channel narrowing, however, so channel capacity diminished and flood potential rose. Since 1940, maximum water-level decreases of close to 50 feet (15 m) have been common north of Garden City, with smaller decreases elsewhere in the study area. Full-scale removal of riparian vegetation would lessen the chance of flooding by allowing channels to remain clear and open to flow. This would also increase the possibility that the channel will widen, should the river ever flow again. Minor widening was apparent during 1985 when the Arkansas flowed for the first time in more than a decade in many reaches within the study area.

Riparian Vegetation Change

Riparian vegetative changes have been very noticable along the Arkansas during historic time. During his 1806 expedition, Pike noted only a "few" cottonwood trees bordering the banks (Jackson, 1966), and surveyors for the 1872-73 federal land survey recorded "scatterings" of small cottonwood and willow timber on islands and river banks (General Land Survey, 1871-73). Photographs from the late 1800s and early 1900s also show a marked absence of large trees and shrub growth (Fig. 25). Aerial photographs from the 1960s and early 1970s, however, show the banks of the Arkansas to be locally supporting dense riparian forests - primarily cottonwood, with minor willow, salt cedar and other varieties. In the mid- to late 1970s these large riparian trees began experiencing a high mortality rate, and recent visits to the area show that many reaches within the study area are now devoid of their earlier growth.

Imported in the early 1800s, salt cedar has since spread along channel beds in many arid and semi-arid westerns states (Robinson, 1952, 1958, 1965). In the Study area, salt cedar was used as in wind breaks (Kellog, 1909). The first occurrences in the Arkansas River valley were reported after the flood of 1921 (Gesink et al., 1970). Gesink and others (1970) surveyed the riparian vegetation of this study area via a series of transects. They found that salt cedar was most abundant near the Colorado-Kansas line and declined eastward. Tomelleri (1984) repeated the Gesink and others study and found that salt cedar populations had significantly increased west of Finney County, while populations east of Finney County remained low.

Maps of changes in vegetation densities were drafted for the years 1939, 1952, 1973, and 1980/81 for selected reaches. Large shrubs and riparian tree stands that were easily seen on aerial photographs were used to represent vegetation density changes both qualitatively and quantitatively (Appendix D). The first map series indicate areas of continuous tree cover for the Lakin and Charleston areas. The former is an area of minor cultivation in the west-central part of the study area, and the latter a heavily cultivated area in the east-central part of the study area. The two locations also represent the ends of a reach of relatively poor tree vigor extending from central Kearny to central Gray County as observed in the field and mapped by Tomelleri (1984). Table 7 shows the results of planimetering areas of vegetation and provides vegetation density comparisons for each reach. Both mapped areas show maximum vegetation expansion between 1952 and 1973 (7% and 9%) and between 1939 to 1952 (~5%), with depletion from 1973 to 1981 (-13% and -19%). The other series of maps in Appendix D provides a quantitative representation of tree crown density in selected reaches for selected years. The maps (Kearny, Finney, and Gray Counties) convey an impression of change and recent (1980/81) status. In 1939 Kearny County had low crown densities, typically less than 40 percent. By 1950, the area of tree cover had expanded and increased in density. The density in 1980 for the reaches in the central and eastern part of the county exhibits a decrease in crown density (implying high tree mortality) and the appearance of center-pivot units. Finney County, in 1939, had a low tree density similar to that of Kearny County. The 1980 map portrays the decline in crown density from the height reached during the mid and late 1960s. A high mortality rate and poor vigor were clearly evident on the ground as well as on the aerial photography. The low density of

TABLE 7
VEGETATION DENSITIES

Lakin - Total area - 560 acres
Reach - 1.75 miles x 0.5 miles

1939 = 15 acres veg. = 2.7% total area
(2.3 acres/yr)
1952 = 45 acres veg. = 8.0% total area
(2.5 acres/yr)
1973 = 98 acres veg. = 17.5% total area
(-11.1 acres/yr)
1980 = 20 acres veg. = 3.6% total area

Charleston - Total area - 960 acres
Reach - 3 miles x 0.5 miles

1939 = 50 acres veg. = 5.2% total area
(4 acres/yr)
1952 = 103 acres veg. = 10.7% total area
(3.6 acres/yr)
1973 = 179 acres veg. = 18.6% total area
(*)
1981*= 0 acres veg. = 0.0% total area

* = vegetation removed for installation of irrigation systems between 1973 and 1981.

All data from aerial-photographs.

1939 is also displayed on the Gray County map, whereas the 1973 map shows a continuous and generally dense crown. The map for 1981, however, indicates a vastly reduced crown density and a large number of center-pivot units. Poor vigor and high mortality are clearly evident as well.

Causes of Vegetation Change

Surface-Water Diversion. Diversion of river water into irrigation ditches occurs primarily during the spring and summer, times when the Arkansas usually peaks in flow. With most high flows being diverted into irrigation ditches, many of the outer channels were abandoned, with flow restricted to a narrow inner channel. These dry channel sections were prime germination areas for riparian vegetation. The river alluvium was rich and underlying aquifers provided an extensive source of shallow water. This was especially true as irrigation practices initially expanded. Whereas virgin prairie soils were hard-packed and induced much surface runoff, cultivation broke up the soils and allowed irrigation waters to percolate downward to the water table (Mead, 1896; Eschner et al., 1983; Tomellari, 1984). It is estimated that as much as 20 percent of surficially applied irrigation waters may percolate downward to the water-table (Stramel et al., 1958). Experimental figures from Meyers and others (1970) show this to be valid in Finney County, near the center of the study area. Downward percolation also created an unnaturally high water level during early stages of irrigating in this region, a condition that helped lead to the initial expansion of riparian growth. The effect was, however, somewhat localized and short-lived. Perennial flow encourages dense growth of woody vegetation but is not necessary to initiate adventive growth into the channel, i.e., most of the early channel shrinkage occurred downstream of the diversions in the eastern part of the study area. Little channel flow typically made it eastward; the easternmost canal (Soule) often was without water. Nonetheless, riparian tree growth did occur downstream of the diversions. Near-surface water in the channel alluvium was still available for riparian growth, i.e., a lack of flow did not preclude saturated alluvium or standing pools in the channel.

Upstream Damming. In 1948 John Martin Dam was closed, affecting the nature of flow of the Arkansas in downstream reaches. The river lost its intermittant character and became more perennial as dam management regulated flow (Figs. 11-14). Both extremely low and high flows were moderated and became much less common. Dam management also inhibited periodic flood flows that previously had scoured the channel of debris and vegetation, adding to the stabilization of abandoned outer channels.

Cottonwood, willow, and salt cedar need surface water to begin growth (Tomellari, 1984). By making the river more continuous in flow, excellent conditions were established for growth of seedlings. This is shown by the expansion of vegetative cover in the 1952 to 1973 post-impoundment period, when the two mapped reaches showed approximately 18% and 19% of respective total acreages covered by riparian vegetation. Notably, cottonwood seeds are viable for only a few weeks after release in May or June (R.Brooks, pers. comm., 1990), and high water occurred historically in May to August. Consequently, water was usually available during the germination period, so the reduction in extremes of flow may have been most important for this species.

Groundwater Use. The apparent maximum extent of riparian growth is visible in 1973 aerial photographs. Visual inspection of aerial photographs reveals that even at this time some large riparian trees were beginning to display signs of stress, such as the bleaching of bark and lessened foliage, from decreasing amounts of available water. The 1950s through early 1970s was a period of expansion of groundwater systems for irrigation purposes. Introduction of center-pivot sprinkler irrigation systems made it more economical, and more reliable to use groundwater as the main source of irrigation water as opposed to conventional irrigation and natural rainfall. The use of these systems also made it profitable to cultivate many regions south of the river, an area once considered a wasteland as its sandy soils could not retain enough precipitation to grow crops. Large-scale pumping of water necessary for crop growth in this region has had detrimental effects on riparian vegetation.

Groundwater levels bordering the river dropped an average of 22 feet (6.7 m) in Finney County and eight feet (2.4 m) in Gray County since the early 1940s (Pabst and Gutentag, 1979), causing dewatering of shallow alluvial aquifers and the Arkansas River. This has had a serious effect on riparian vegetation as root growth was unable to keep up with the rapidly dropping water table, resulting in the death of much of the forests paralleling the river. This is particularily true in areas where irrigation is most developed. Another detrimental effect on riparian vegetation is the encroachment of center-pivot sprinklers on the river channel itself. Aerial photographs from 1973 show live, dying, and dead trees bordering the channel near Charleston, but by 1981 landowners removed these in order to place more land into cultivation. In some cases, this included farming through the actual river channel (Fig. 30). Some reaches have escaped the removal of vegetation for cultivation purposes, but not the high mortality rates. Many areas bordering the river are graveyards of dead and dying riparian growth.

Futrue Trends

The future does not look promising for the Arkansas River in southwestern Kansas. Although surface diversion quantities have decreased, analysis of all available data shows this to be primarily due to lessened river flow and an increased dependence on groundwater pumping.

As demand for water increased all along the Arkansas, people turned more and more to groundwater as a major water source. Now that groundwater resources are becoming strained, some are looking towards methods with which to "import" water from water-rich

Figure 30. Aerial photography of a center-pivot irrigation system partially occupying the channel of the Arkansas River near Charleston, western Gray County.

regions. These include several plans to divert water from the Missouri River to irrigate the dry lands in western Kansas (Bittinger and Green, 1980). New upstream sources are essentially unavailable. With the population of Colorado expanding rapidly, more and more Arkansas River water is being used before the river even enters the Great Plains. Water from tributaries, and even the Arkansas itself, is potentially earmarked as water sources for expanding suburbs of large cities such as Colorado Springs and Denver (Anton, 1986). Diversions of this magnitude would seriously affect both flow in the river and irrigation bordering the river.

Riparian vegetation is dying alongside the Arkansas River throughout the study area. This effect of ground water pumping seems to be working its way upstream towards Colorado, with riparian vegetation beginning to show signs of stress near Syracuse. Groundwater levels have dropped too low and surface water is too rare within most of the study area to allow old, dormant riparian seeds to germinate. Some small cottonwood have emerged from old roots near Charleston during the past few years, but it is highly unlikely that any will reach maturity. Ash, locust, and cedar are relatively drought resistant and may persist. Inspection of precipitation records indicates the potential for an extended period of dry years, or drought, in the next decade or so. Therefore, it appears as though the riparian forests of the past century may die out, permitting the landscape to return to the treeless prairie described by explorers in the early 1800s.

Prehistoric Perspective

Although the channel of the Arkansas River was wide, shallow and braided when first encountered by traders and settlers, a prehistoric, or ancestral form of the river was relatively narrow, deep, and tightly meandering. Ancient channels (paleochannels) are visible throughout much of the study area, but particularly so up to three miles (5 km) south of the present channel near Deerfield (Fig. 31). Recent photogrammetric, ground, and subsurface surveys of these paleochannels has revealed an average width of 66 m (216 ft), depth of 10 m (33 ft), meander wave length of 767 m (2,515 ft), radius of meander curvature of 185 m (606 ft), and a high channel sinuosity (2.8) (Johnson and Dort, 1988). A comparison of widths (Table 8) indicates that the paleochannel was intermediate to the 1872 and present (1987) channels. Coring of the relict channels revealed their size and the silty and clayey nature of the material they were flowing within and transporting (Fig. 32). The fine sediment load is in contrast to the sand and gravel load of the present stream regime. The ancient system probably represent the cooler and more moist environment of the late Pleistocene. The remains of extinct megafauna (e.g., mastodon, bison) are common within the fill, and radiocarbon ages of 19,340 and 16,420 years before present have been obtained on similar features in the Arkansas River valley upstream from Wichita, Kansas. Striking differences in discharge are also evidence of a time of greater runoff. Using the reconstructed channel parameters, mean annual discharge of the ancestral system would have been 900-1200

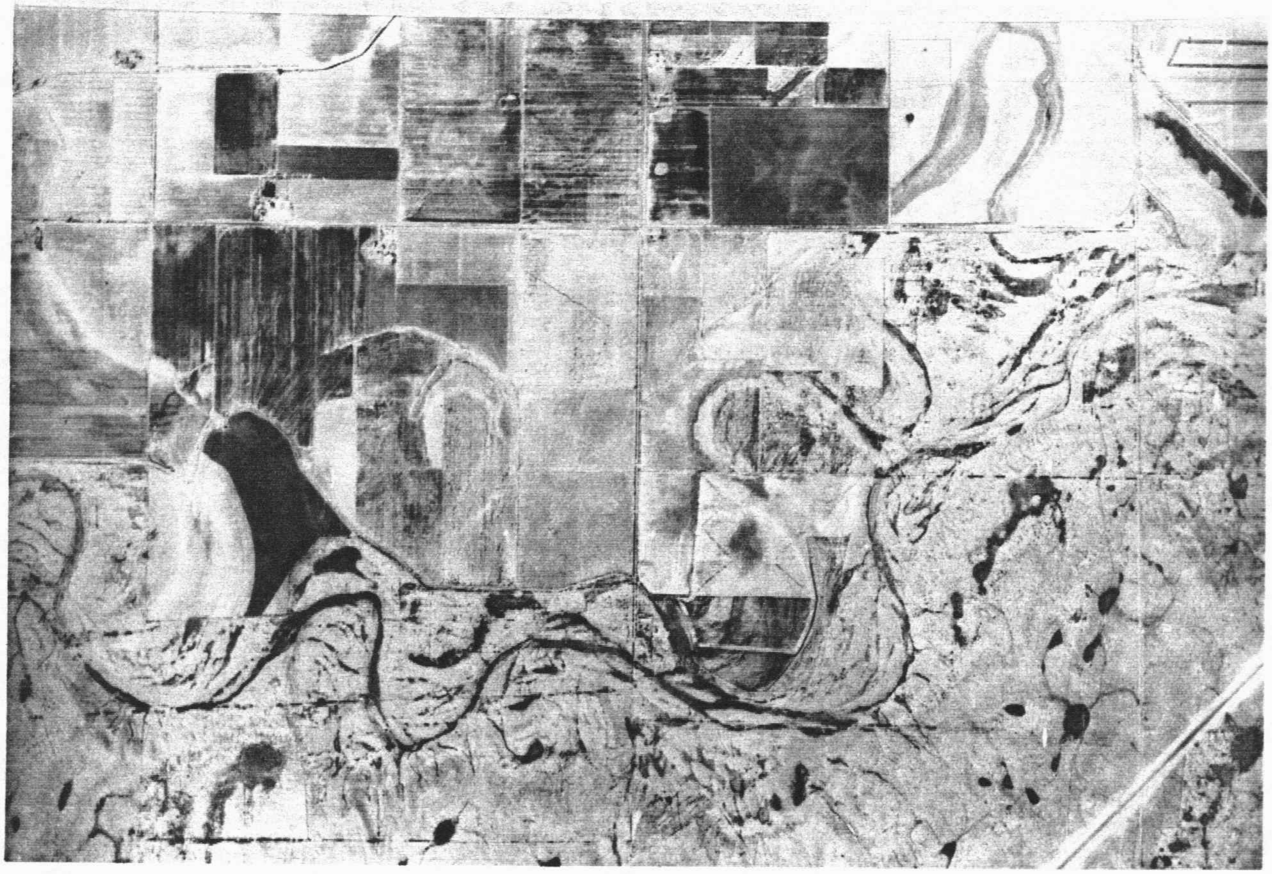


Figure 31. Aerial photography of paleochannels south of the modern Arkansas River channel near Lakin in eastern Kearny County.

TABLE 8
CHANNEL GEOMETRY
ARKANSAS RIVER NEAR LAKIN, KS

	Late Pleistocene	1872	1987
W_{mean} (mean width)	66m	305m	13m
D_{mean} (mean depth)	10m	2m	2m
R_c (radius of curvature)	185m	-	-
L_m (meander wave length)	767m	-	-
P (sinuosity)	2.8	1.1	1.3
F (W/D)	6.6	153	6.5

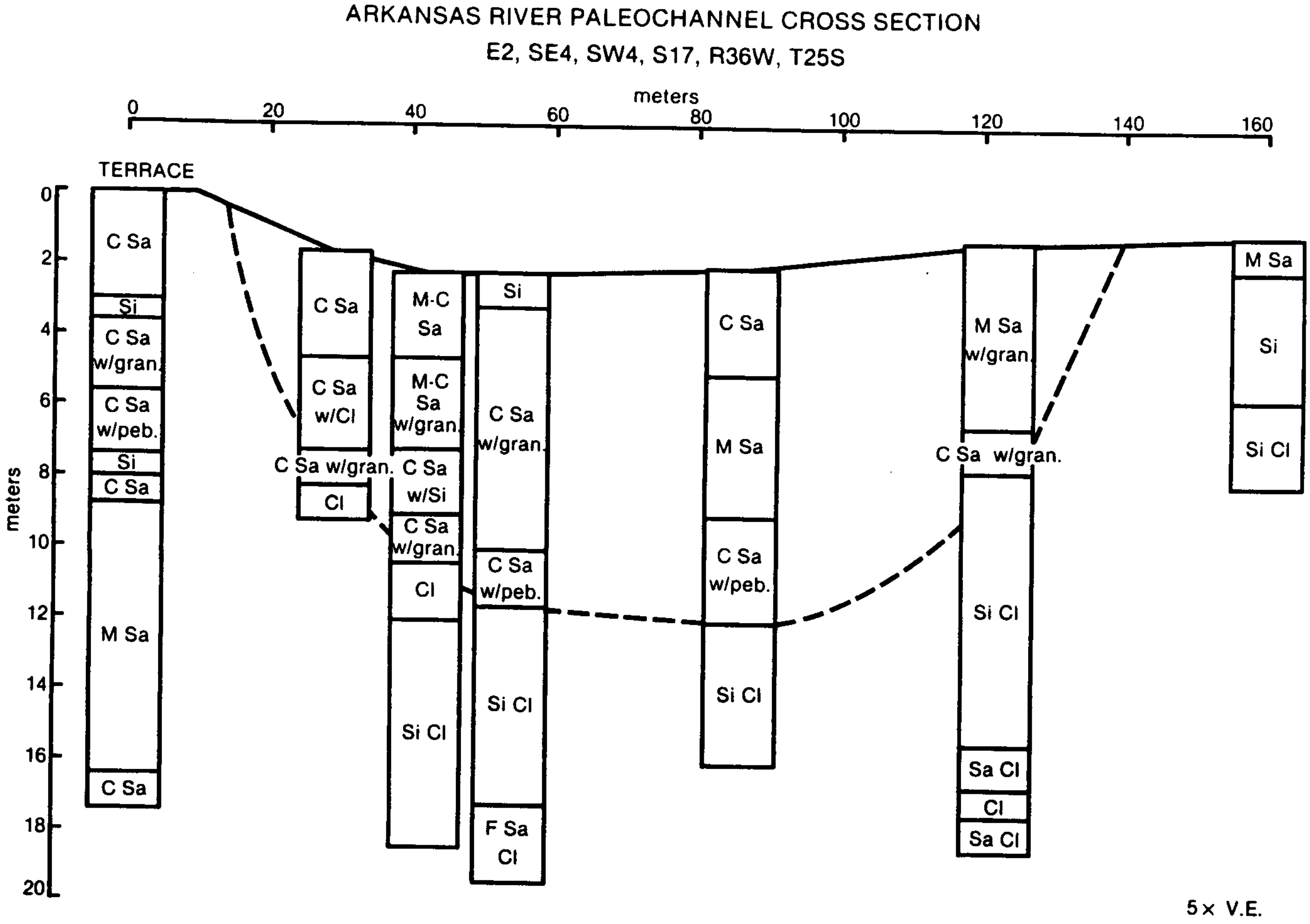


Figure 32. Core data from a paleochannel cross section near Lakin. Channel outline is represented by the dashed line, where the sediment size changes abruptly. (size designations refer to clay, silt, granuales, sand, medium, coarse).

ft^3/second (26-34 m^3/s) 10-20,000 years ago versus 309 ft^3/second (8.75 m^3/s) at Syracuse for the period of record. A comparison of the historic river regime with that of the prehistoric period permits us to keep the present dynamics (with or without human intervention) in perspective.

CONCLUSIONS

Major changes in discharge and channel morphology along the Arkansas River during the past century are directly related to withdrawal of surface water and groundwater, primarily for agricultural use.

Decreases in discharge began with widespread expansion of irrigation ditches in southeastern Colorado and southwestern Kansas in the late 1800s and early 1900s. These early decreases, coupled with large-scale droughts in the 1890s and 1930s, resulted in permanent channel narrowing, from 800 to 1,200 feet (244-366 m) in 1872 to less than 40 feet (12 m) in 1985. Groundwater levels rose in response to percolation of irrigation waters in irrigated fields. This yielded a supply of moisture for riparian tree growth. Moisture available from irrigation riparian vegetation to gain a foothold.

Narrowing was initially most pronounced in the eastern part of the study area due to the diversions to the west. More recent wholesale narrowing has been attributable to a reduction in the magnitude and frequency of discharge events and to the encroachment of salt cedar. When John Martin Reservoir was completed in 1948, maximum flows decreased and minimum flows increased, giving the Arkansas more continuous flow. This lessened the ability of the river to scour its channel of debris and vegetation through periodic flooding.

With vegetation stabilizing the banks of the river, channel depth began increasing from a minimum of three to four feet (.9-1.2 m) in 1872 to greater than 20 feet (6 m) in 1985. This was probably because heavy vegetation stands caused channel width to decrease more rapidly than discharge decreased, making depth increases necessary to compensate for quantity of flow. Another possible cause for rapid changes in channel depth was the occurrence of large, infrequent floods, such as the 1965 flood, that have the ability to scour the inner channel intensely and rapidly. This was shown to be possible by Burkham (1972) and Schumm and Lichty (1963) on the Gila and Cimarron Rivers.

Recent decreases in discharge reflect the large-scale "mining" of groundwater resources in the region. This occurs when groundwater withdrawal exceeds recharge quantities. Groundwater levels have dropped as much as 47 feet (14 m) within the study area as a result of a shift from ditch irrigation methods to center-pivot sprinkler irrigation. This change extended from the late 1950s to the early 1970s and, when coupled with surface-water removals, resulted in complete loss of flow for more than a decade between Garden City and Dodge City.

Vegetation has suffered greatly due to dropping water levels. The rapidly dropping water table has stranded most riparian root systems far above a continuous water supply which is necessary for their growth. With little or no water available, the mortality rate is high and many reaches are now completely devoid of riparian growth.

What does the future hold for the Arkansas River in southwestern Kansas? Vegetation mortality is expanding and groundwater pumpage rates and surface-water diversion rates remain high, with more than 2,000,000 acre-feet of water withdrawn annually from wells alone in southwestern Kansas (Gutentag et al., 1981). Unless water-table levels rise in the near future, riparian vegetation will continue to die and cease to expand. With agriculture a vital part of the economy in southwestern Kansas, however, it is unlikely that discharge, water table levels and other favorable habitat conditions required to support extensive riparian forests will return. Instead, this region will probably regain its treeless visage of the past. The river itself is subject to become narrow (gully-like in some reaches), carrying water only during unusually wet periods and flash floods. Regulation of flow by diversions, upstream damming, and groundwater pumping has all but eliminated the potential for surface-water to scour, widen, or even flow within the Arkansas River.

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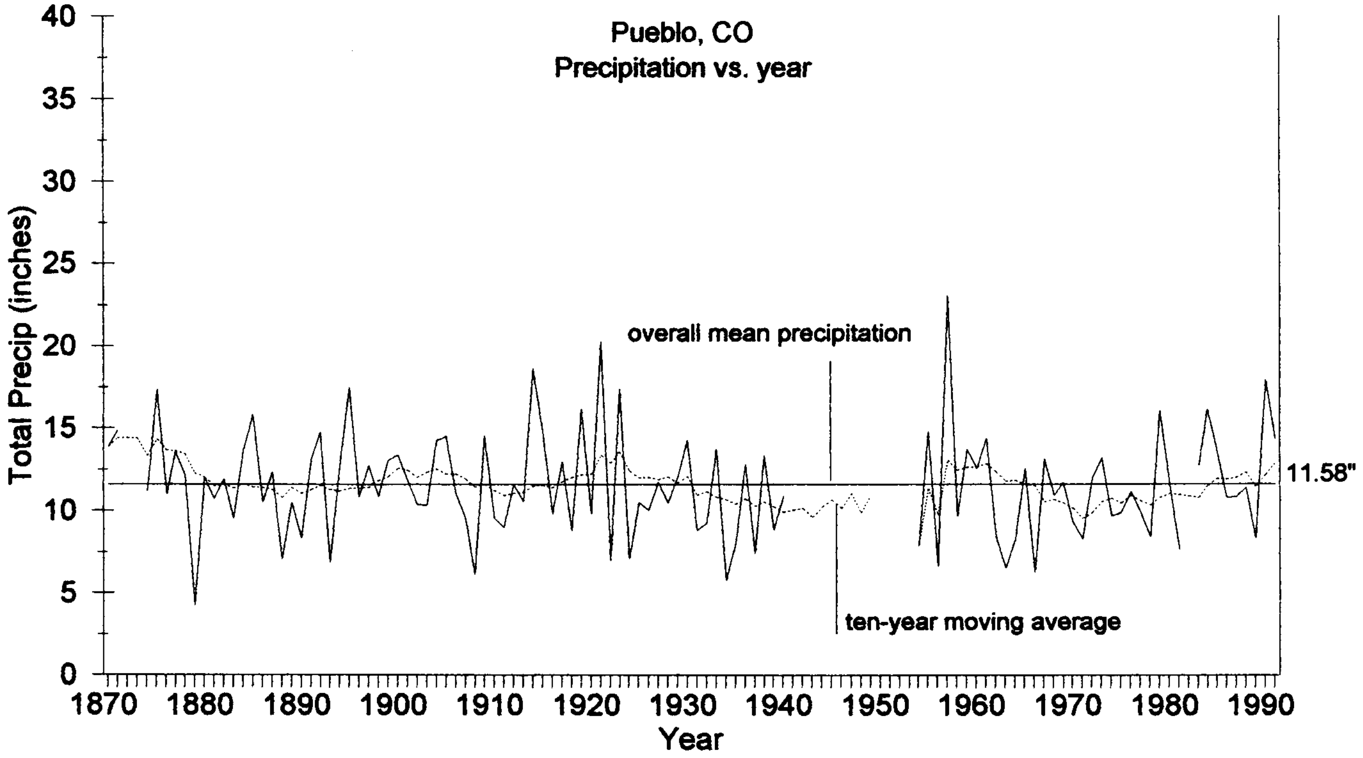
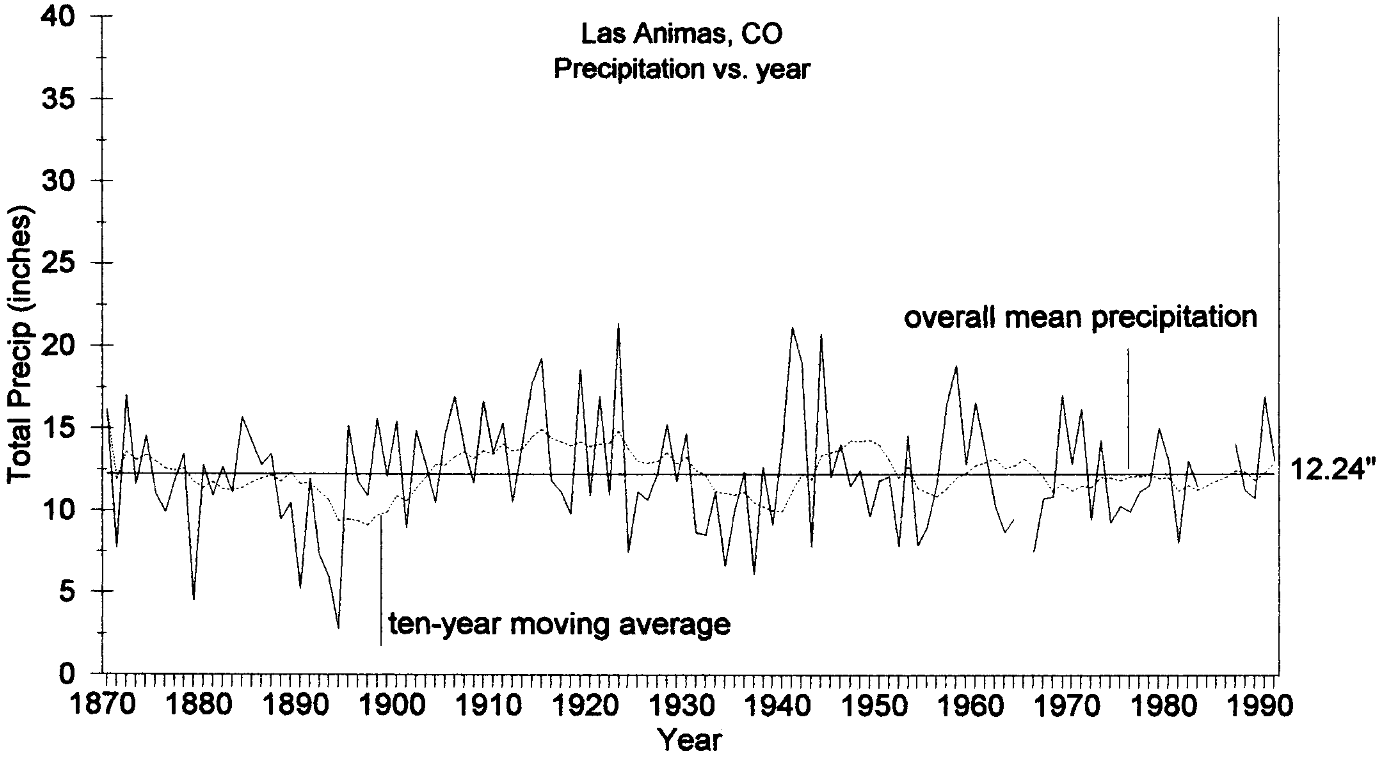
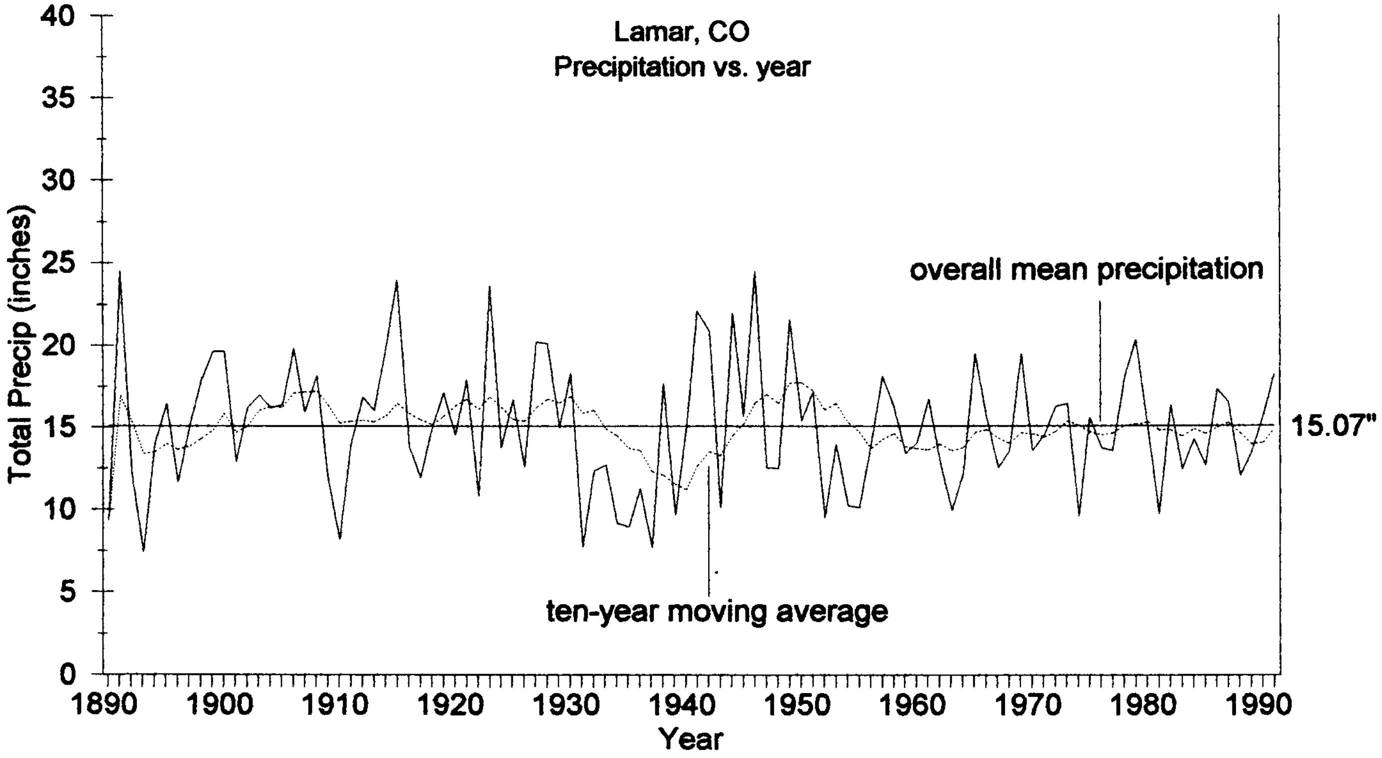
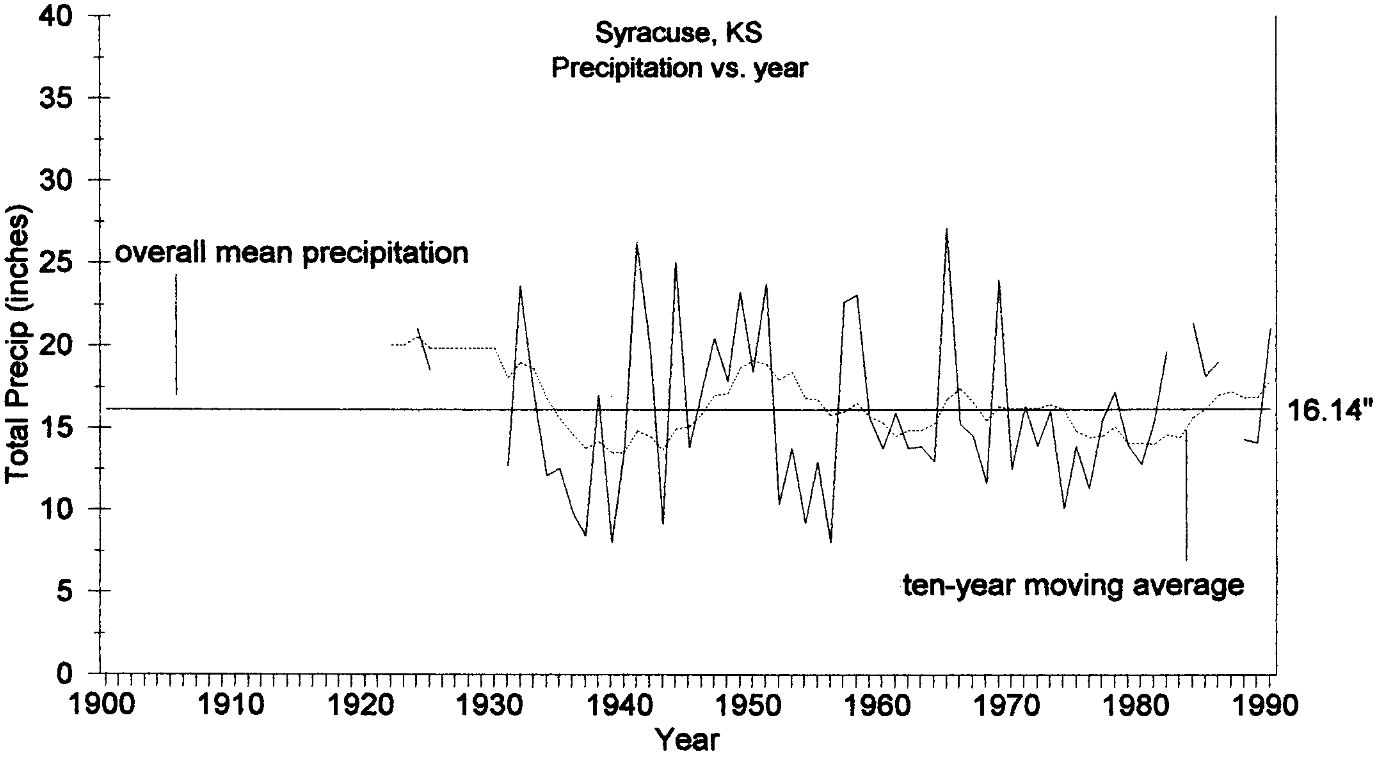
APPENDIX A

Time series of mean annual discharge and annual precipitation, eastern Colorado and western Kansas

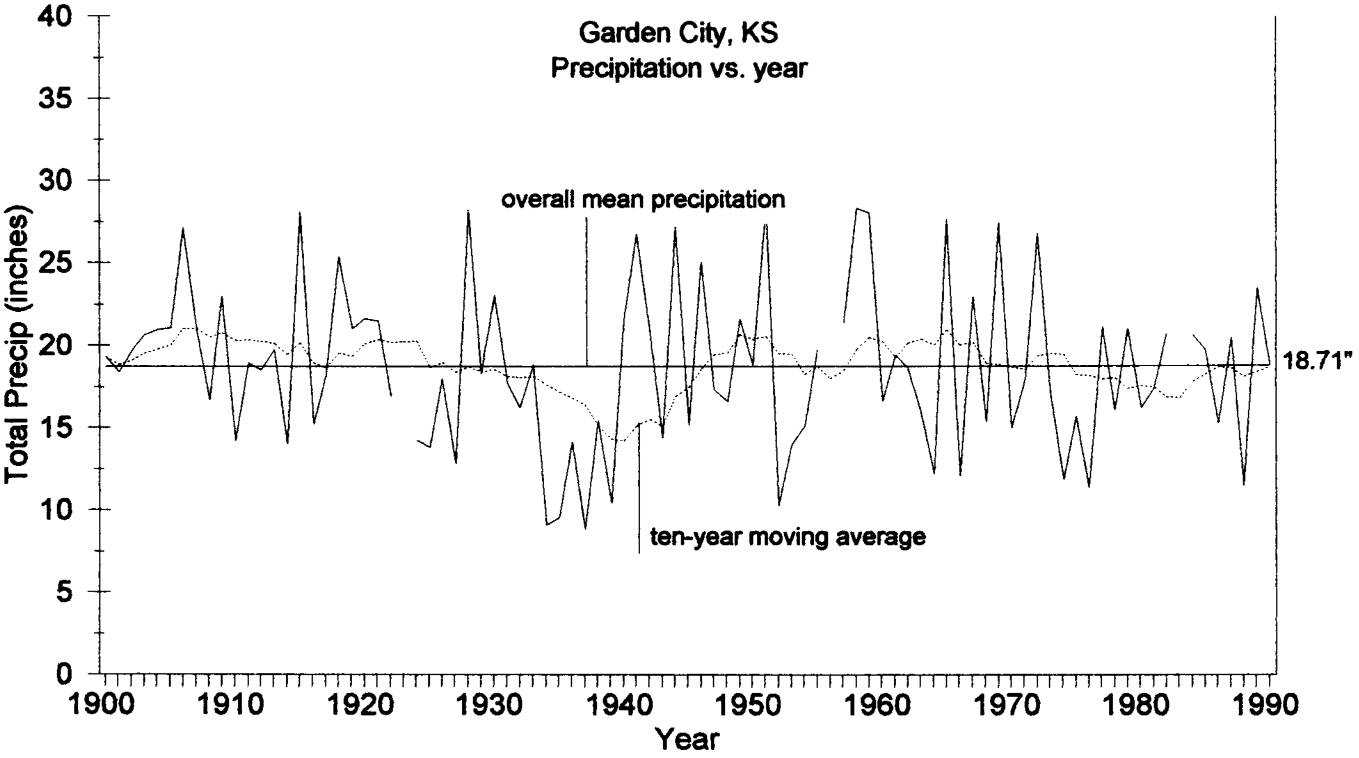

Pueblo, CO
Precipitation vs. year
overall mean precipitation
ten-year moving average
11.58"
Total Precip (inches)
0
5
10
15
20
25
30
35
40
1870
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
Year

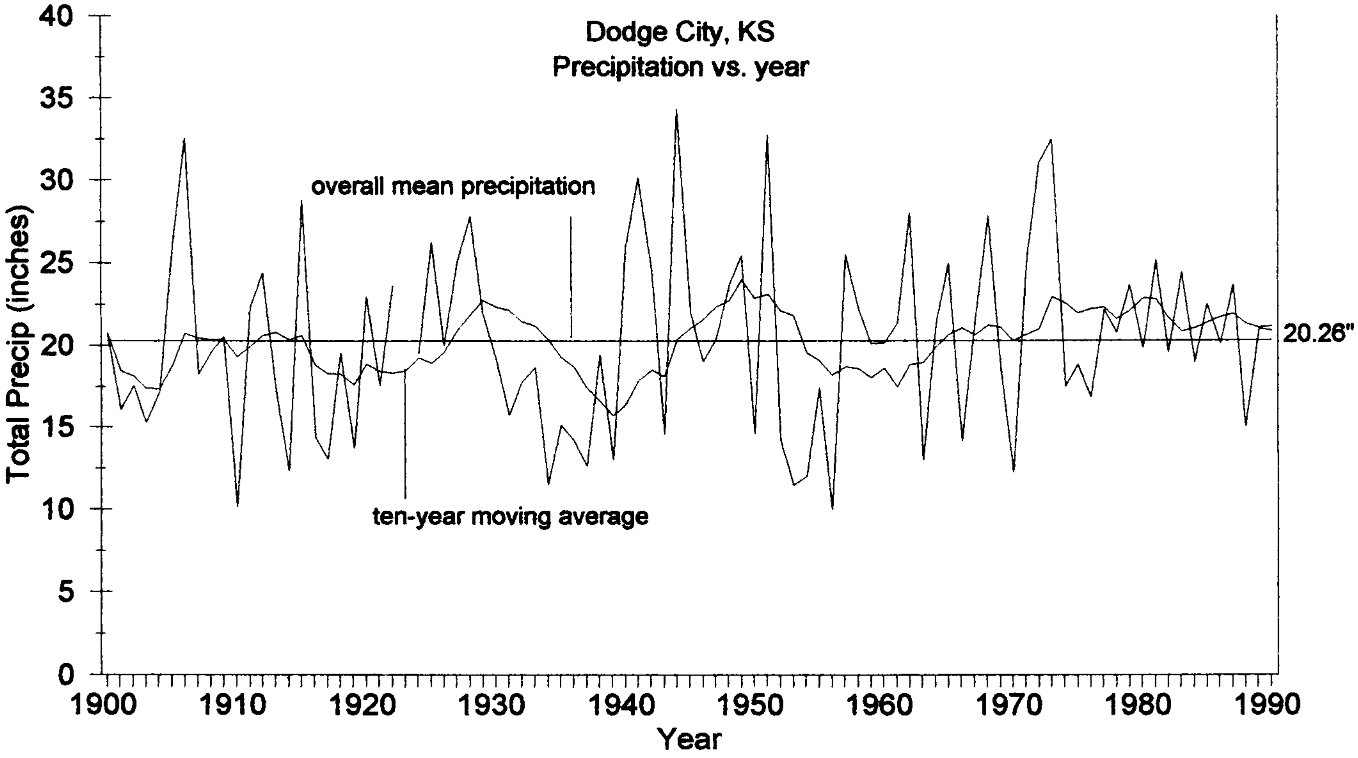

Las Animas, CO
Precipitation vs. year
Total Precip (inches)
40
35
30
25
20
15
10
5
0
overall mean precipitation
12.24"
ten-year moving average
1870
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
Year

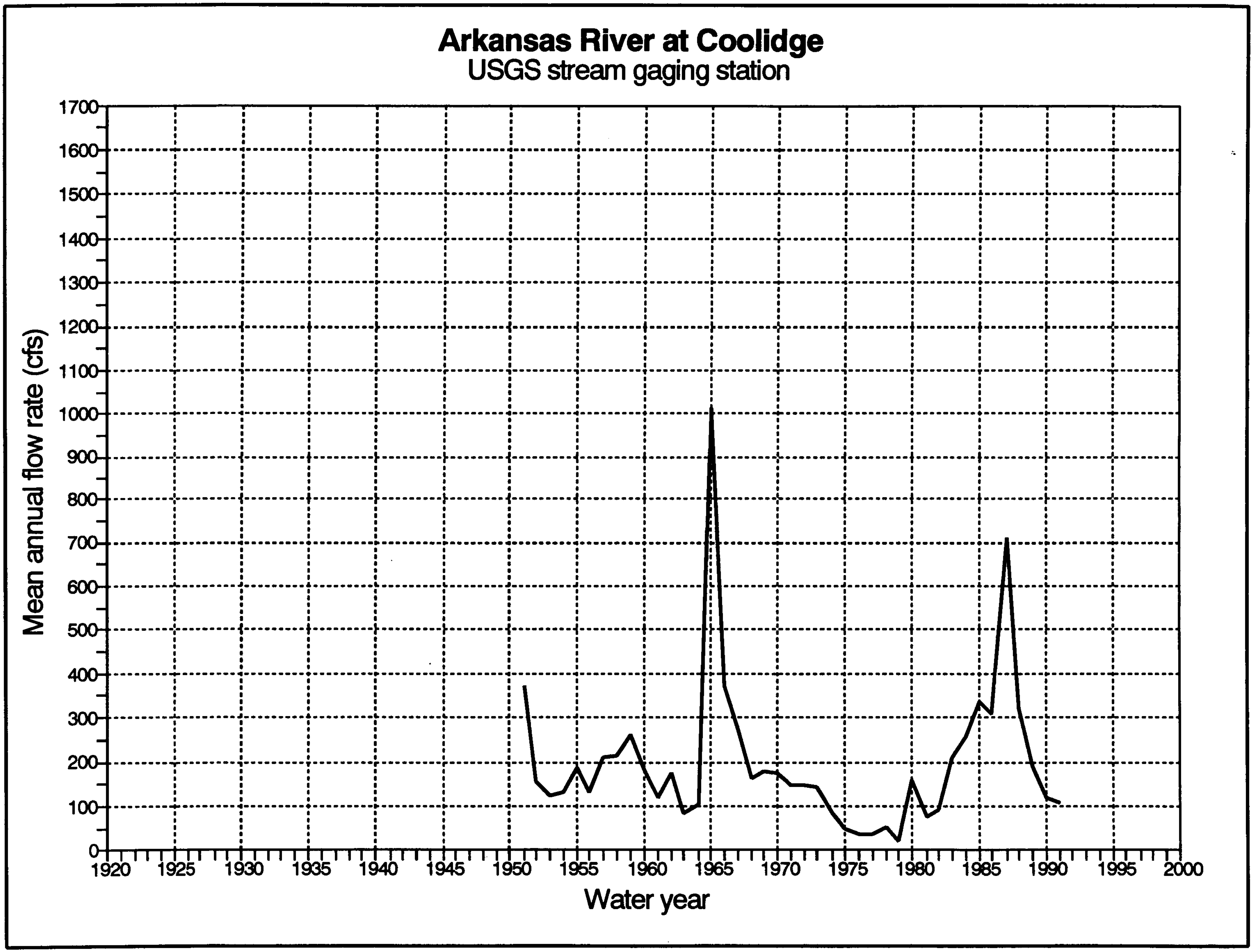

Lamar, CO
Precipitation vs. year
Total Precip (inches)
0
5
10
15
20
25
30
35
40
Year
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
overall mean precipitation
15.07"
ten-year moving average

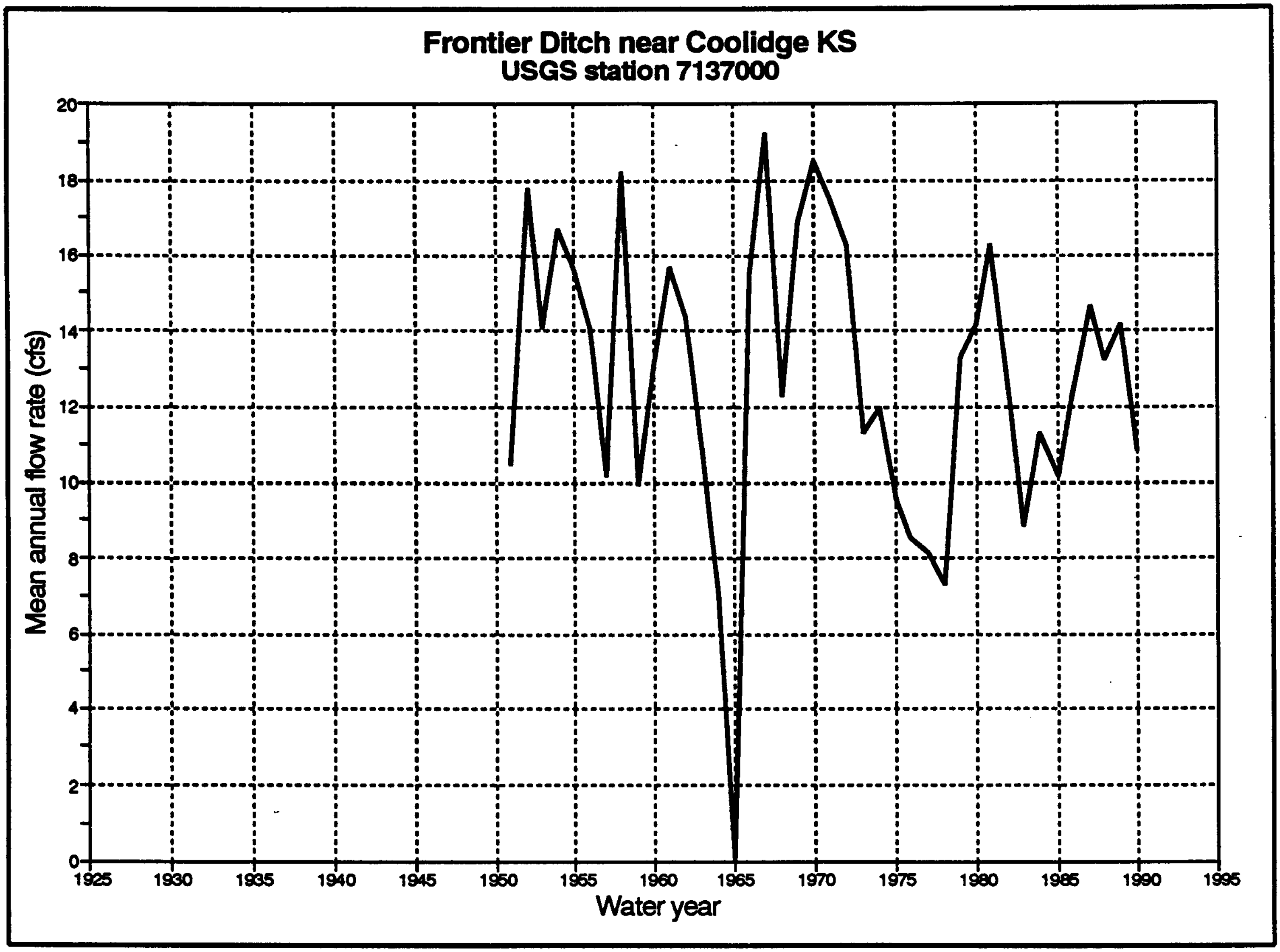


Syracuse, KS
Precipitation vs. year
overall mean precipitation
ten-year moving average
16.14"
Total Precip (inches)
0
5
10
15
20
25
30
35
40
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
Year


Garden City, KS
Precipitation vs. year
overall mean precipitation
ten-year moving average
18.71"
Total Precip (inches)
40
35
30
25
20
15
10
5
0
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
Year

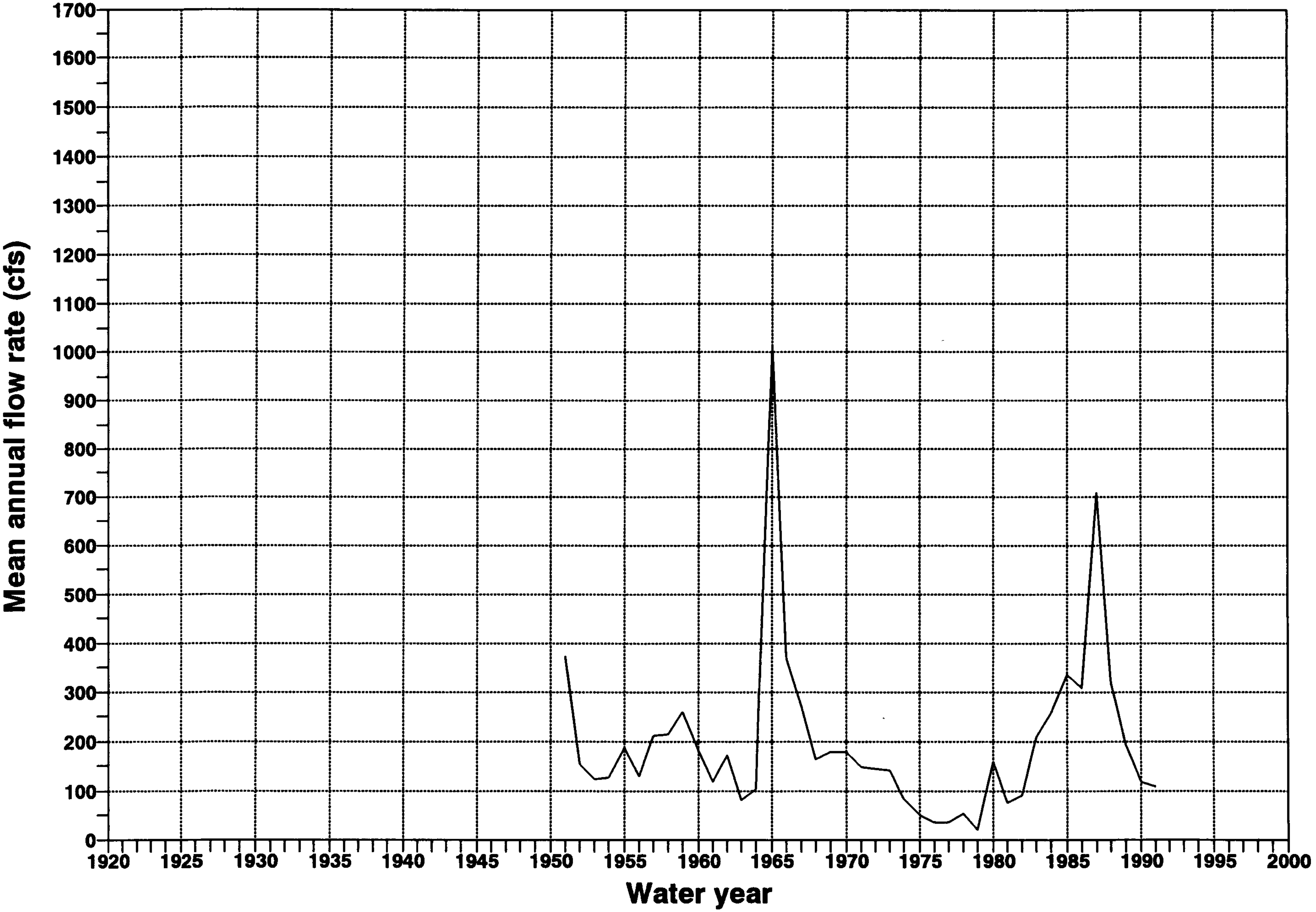

Dodge City, KS
Precipitation vs. year
overall mean precipitation
ten-year moving average
20.26"
Total Precip (inches)
40
35
30
25
20
15
10
5
0
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
Year

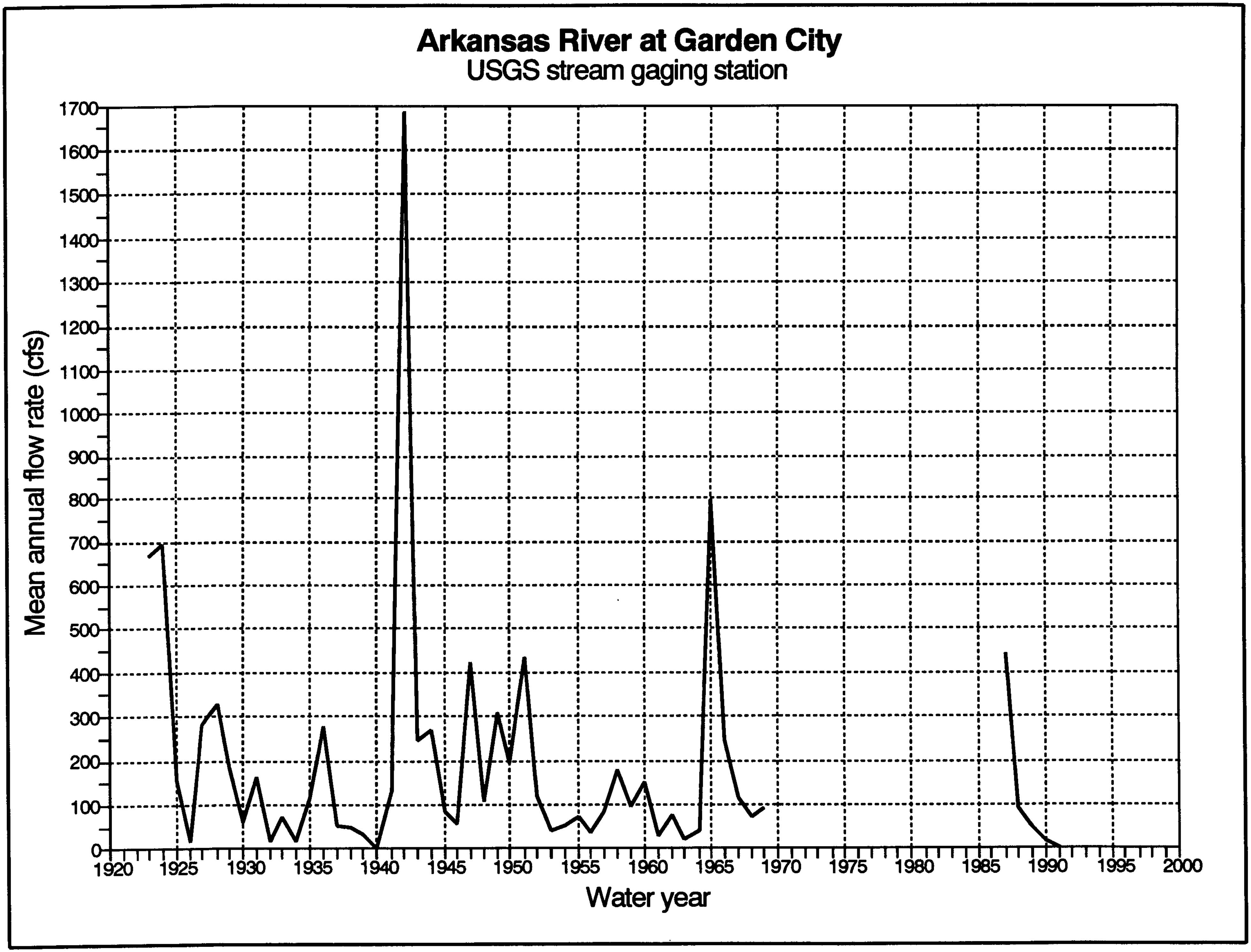

Arkansas River at Coolidge
USGS stream gaging station
Mean annual flow rate (cfs)
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
1920
1925
1930
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
Water year


Frontier Ditch near Coolidge KS
USGS station 7137000
Mean annual flow rate (cfs)
Water year
0
2
4
6
8
10
12
14
16
18
20
1925
1930
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995

Arkansas River at Syracuse

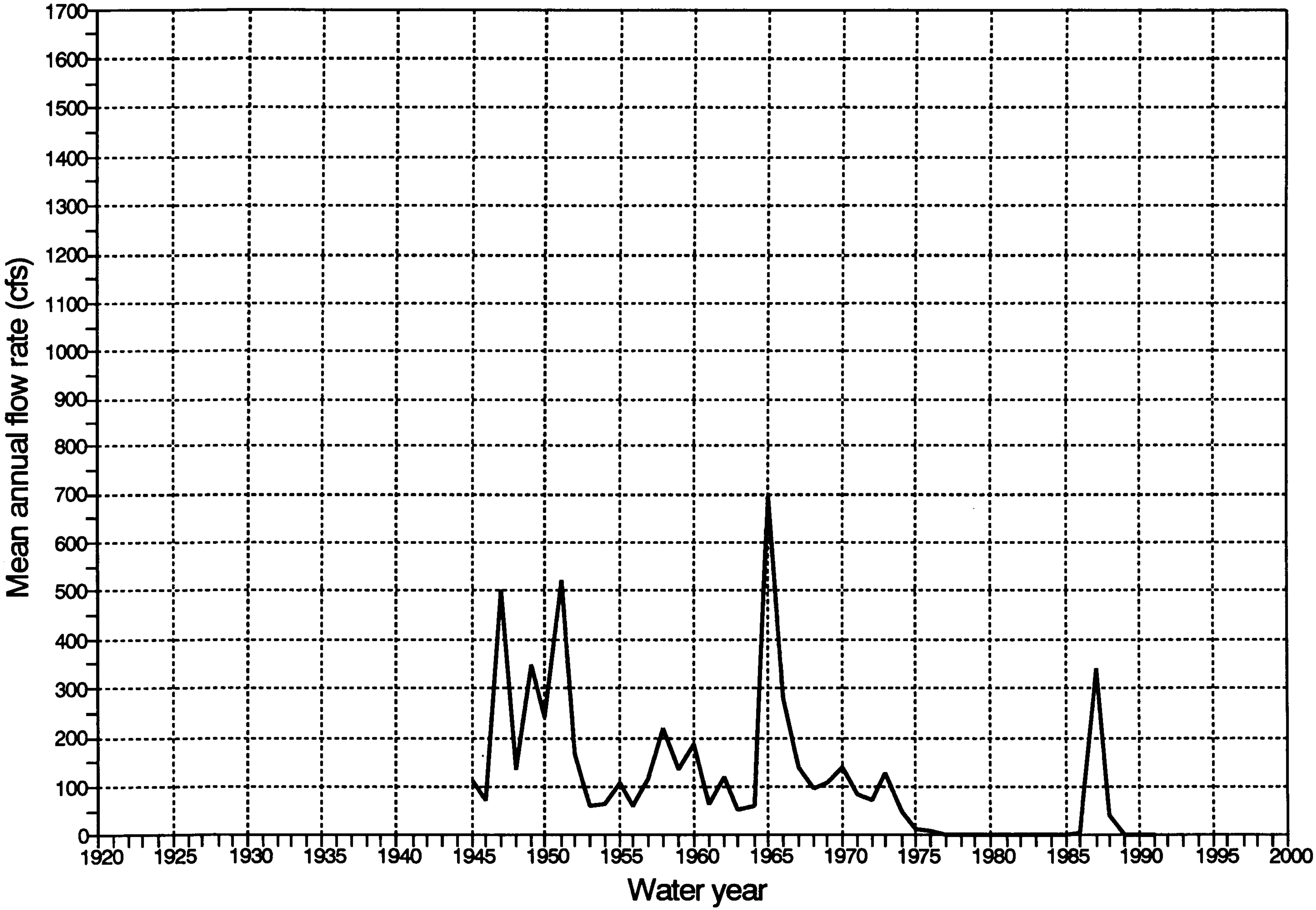
USGS stream gaging station



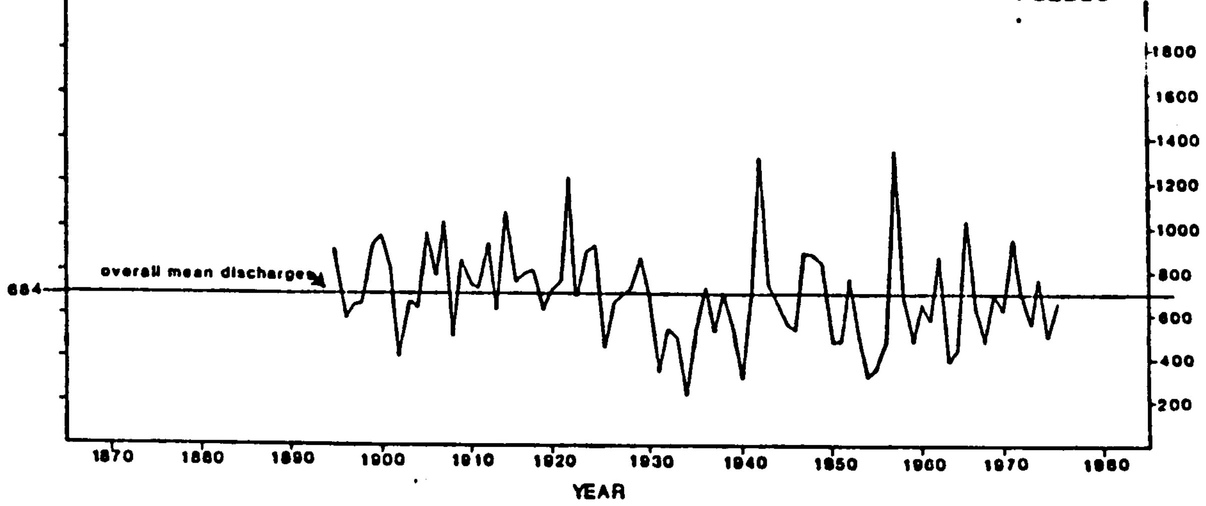

Arkansas River at Garden City
USGS stream gaging station
Mean annual flow rate (cfs)
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
1920
1925
1930
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
Water year

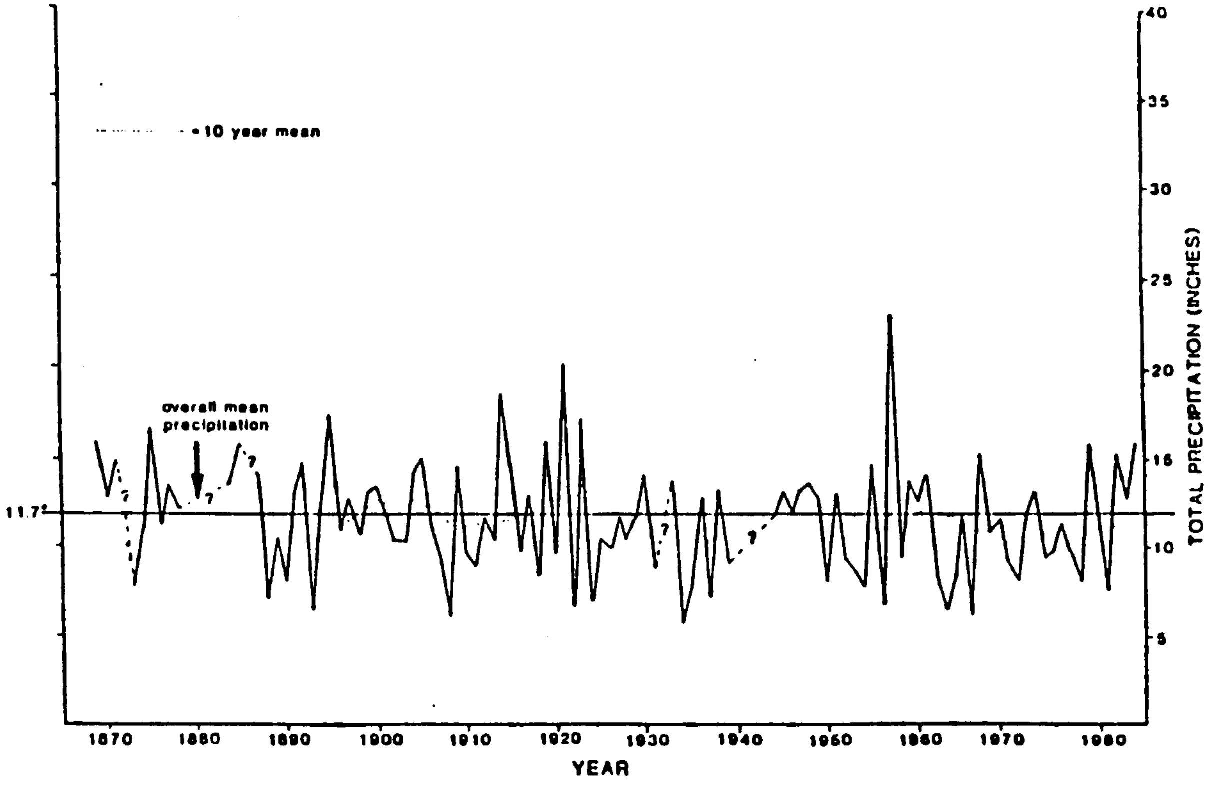
Arkansas River at Dodge City

USGS stream gaging station

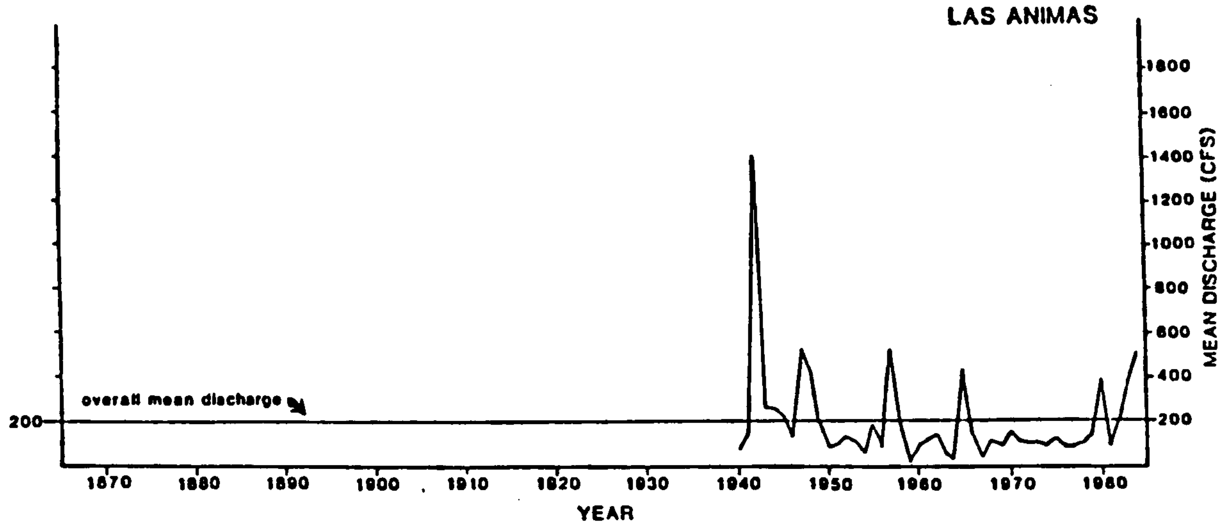


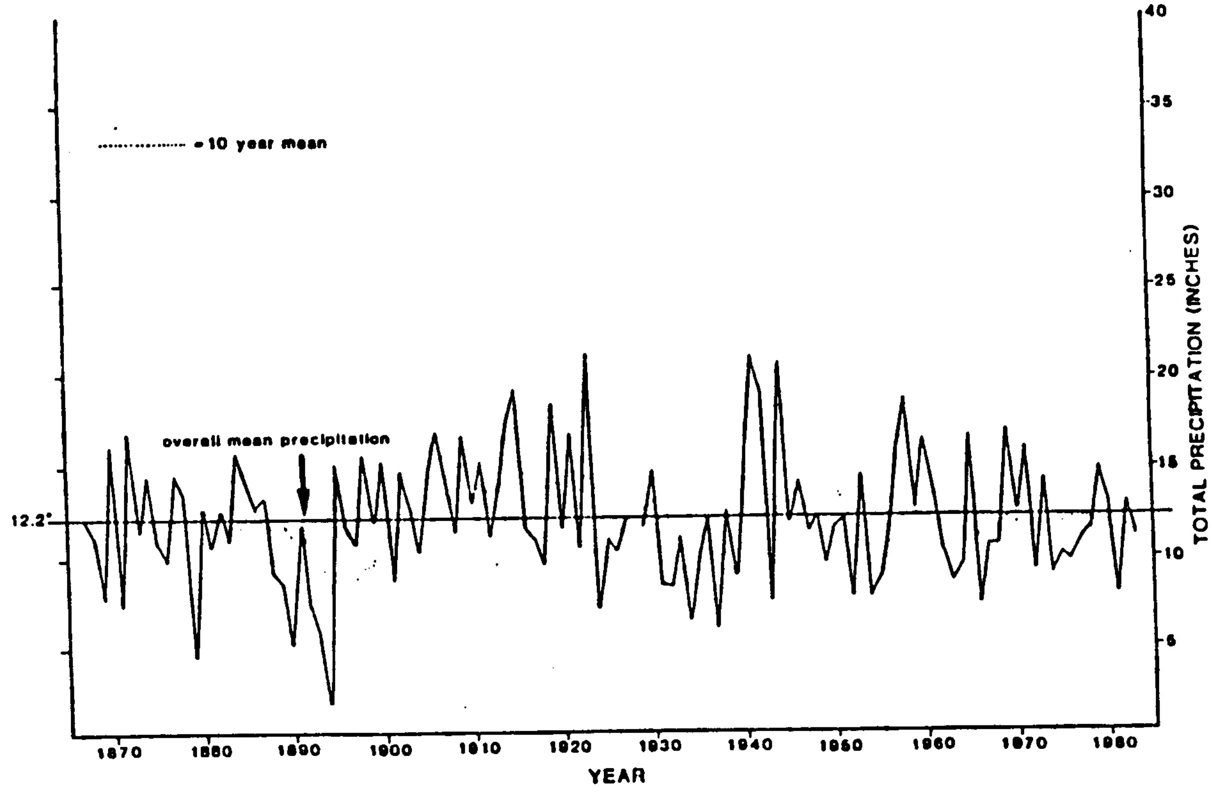
PUEBLO

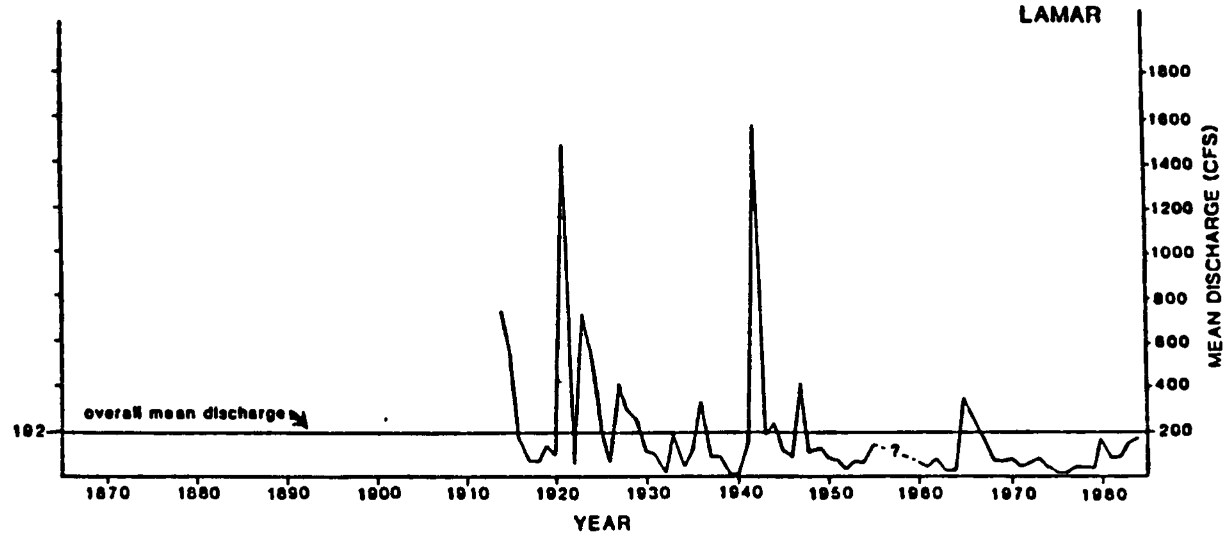


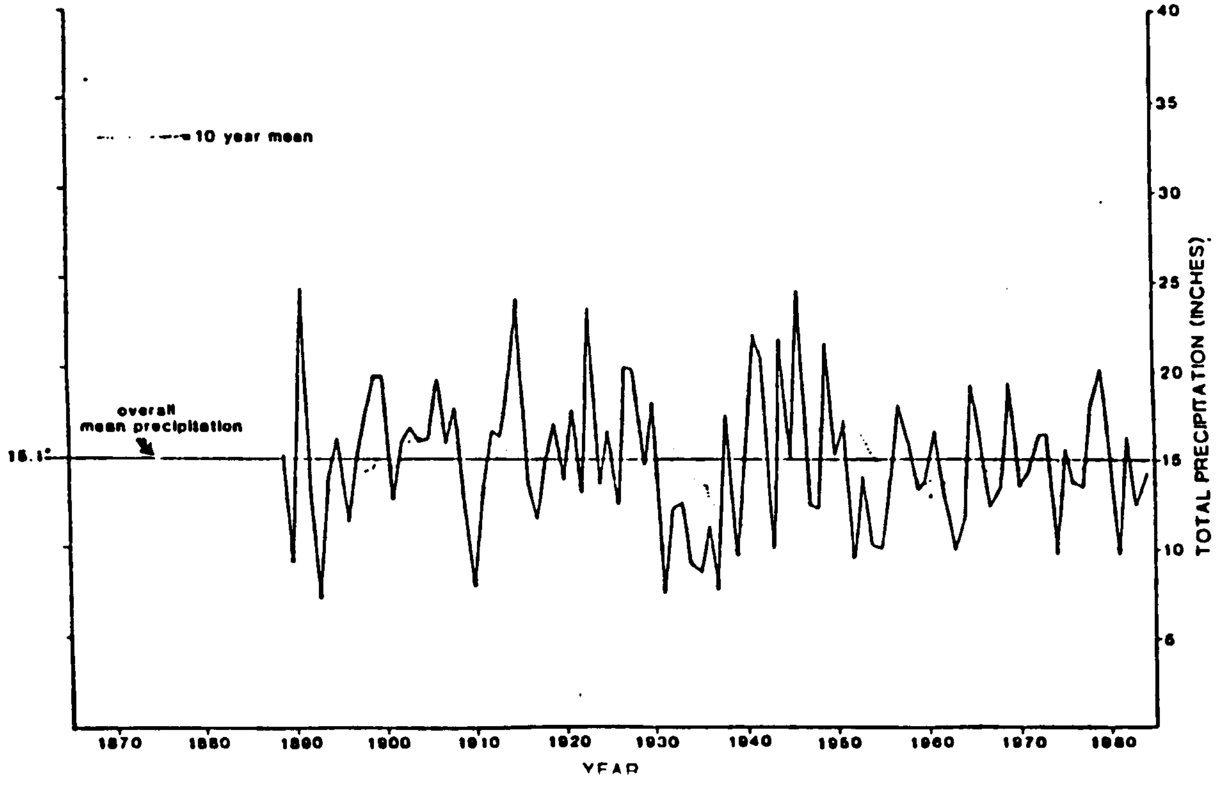


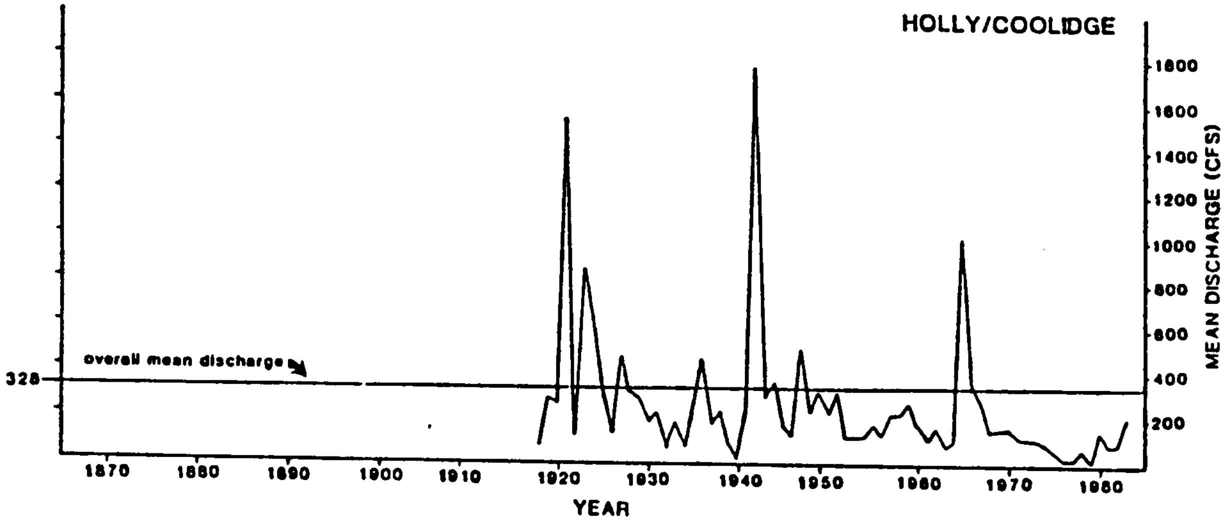
Note: All 10 year means plotted at end of period


LAS ANIMAS
overall mean discharge
200
1800
1600
1400
1200
1000
800
600
400
200
MEAN DISCHARGE (CFS)
1870
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
YEAR

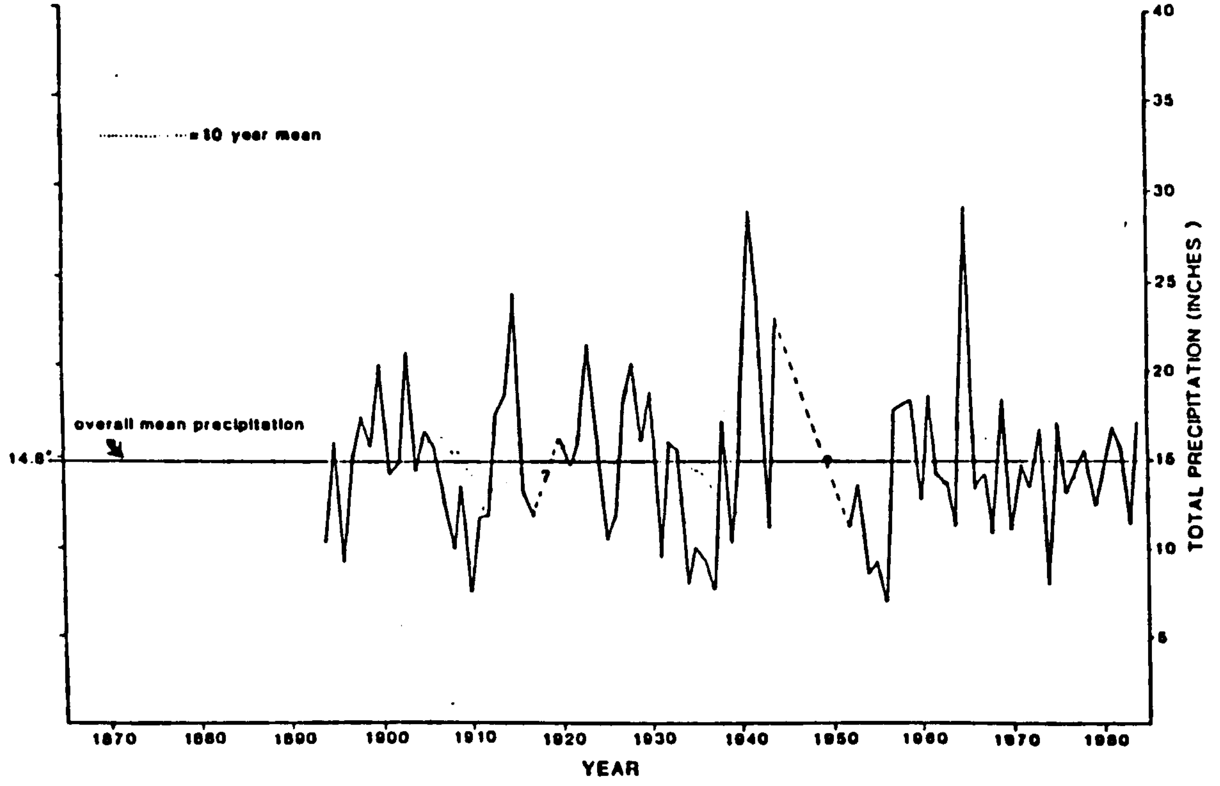

= 10 year mean
overall mean precipitation
12.2"
40
35
30
25
20
15
10
5
TOTAL PRECIPITATION (INCHES)
1870
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
YEAR


LAMAR
1800
1600
1400
1200
1000
800
600
400
200
MEAN DISCHARGE (CFS)
overall mean discharge
192
?
1870
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
YEAR

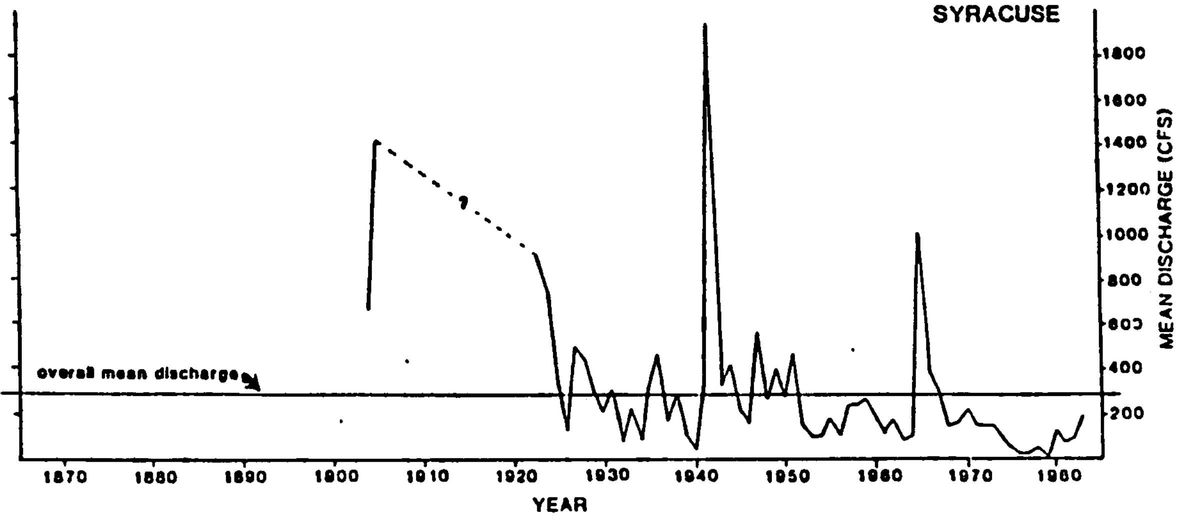

10 year mean
overall
mean precipitation
15.1
40
35
30
25
20
15
10
5
TOTAL PRECIPITATION (INCHES)
1870
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
YEAR

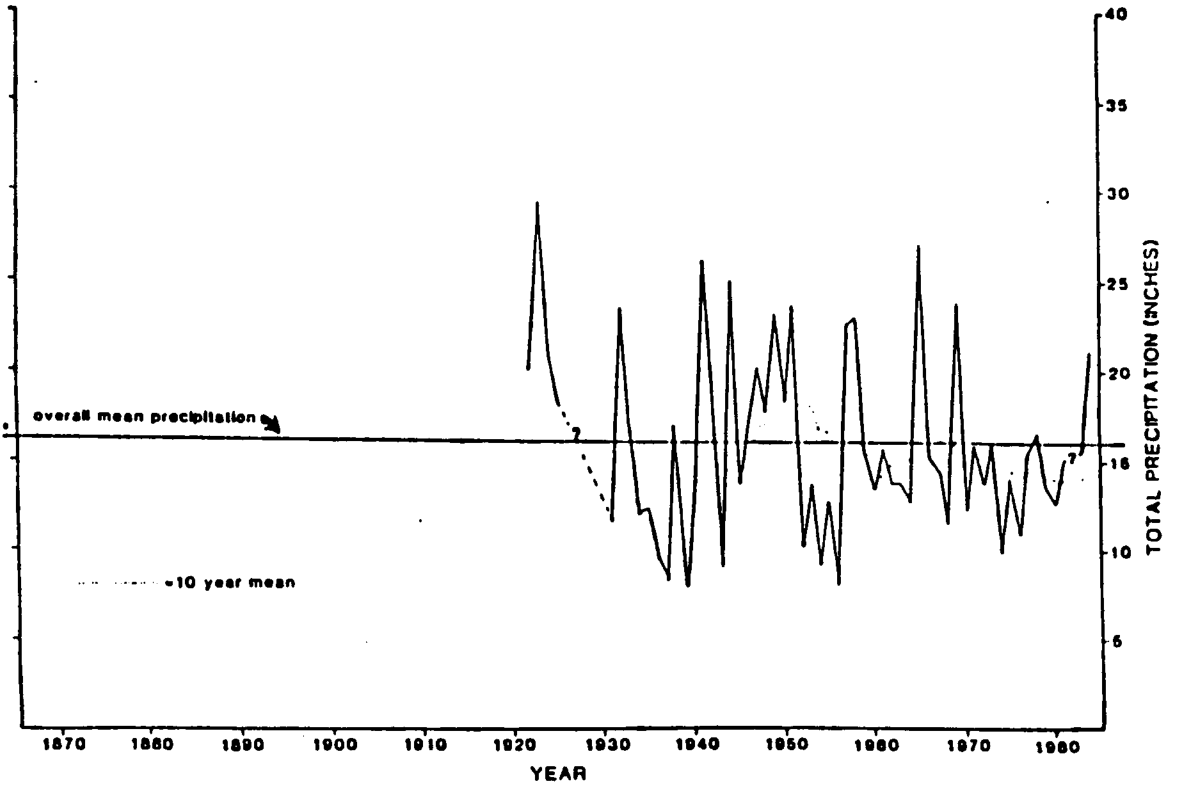


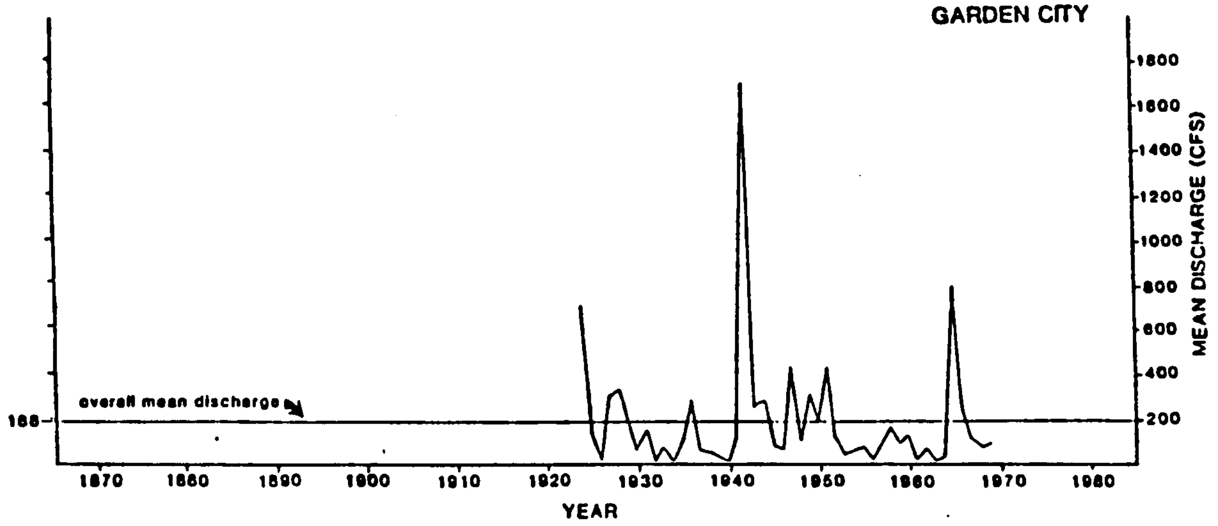
HOLLY/COOLIDGE
overall mean discharge
328
1800
1600
1400
1200
1000
800
600
400
200
MEAN DISCHARGE (CFS)
1870
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
YEAR

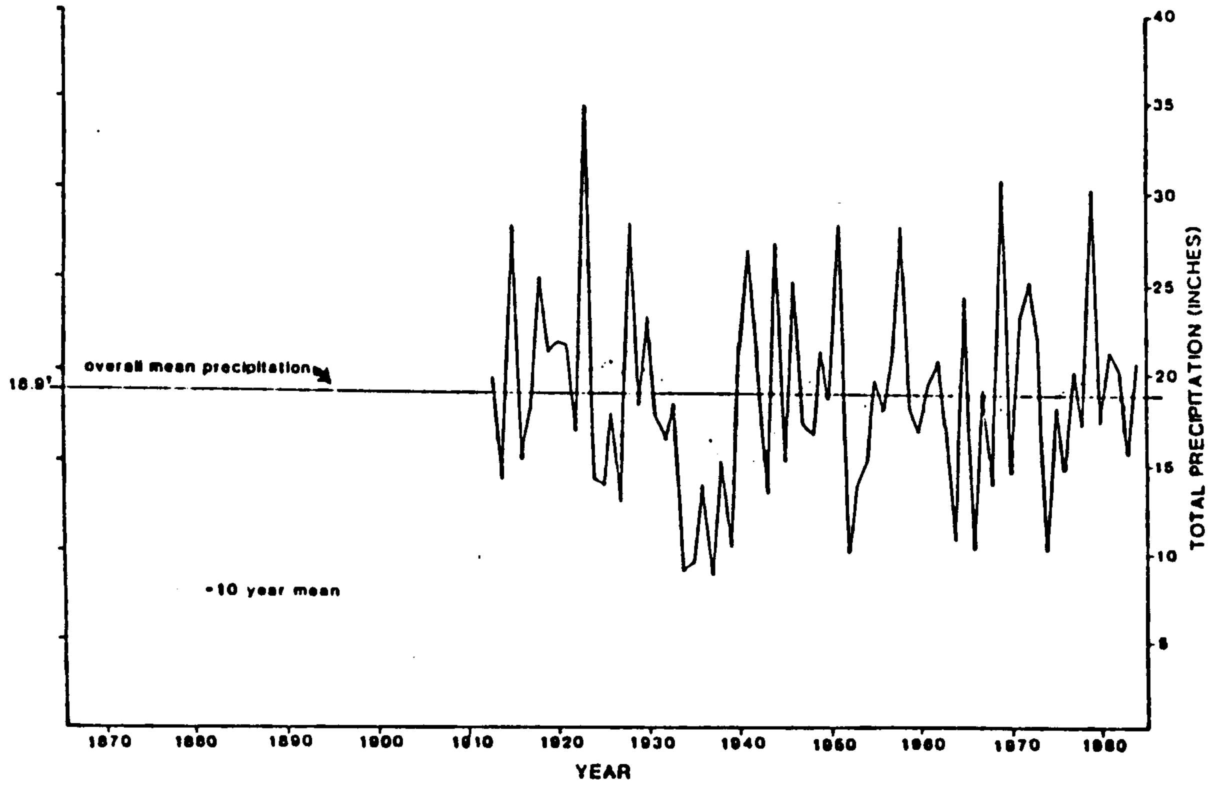


= 10 year mean
overall mean precipitation
14.8"
?
40
35
30
25
20
15
10
5
TOTAL PRECIPITATION (INCHES)
1870
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
YEAR


SYRACUSE
1800
1600
1400
1200
1000
800
600
400
200
MEAN DISCHARGE (CFS)
overall mean discharge
270
?
1870
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
YEAR

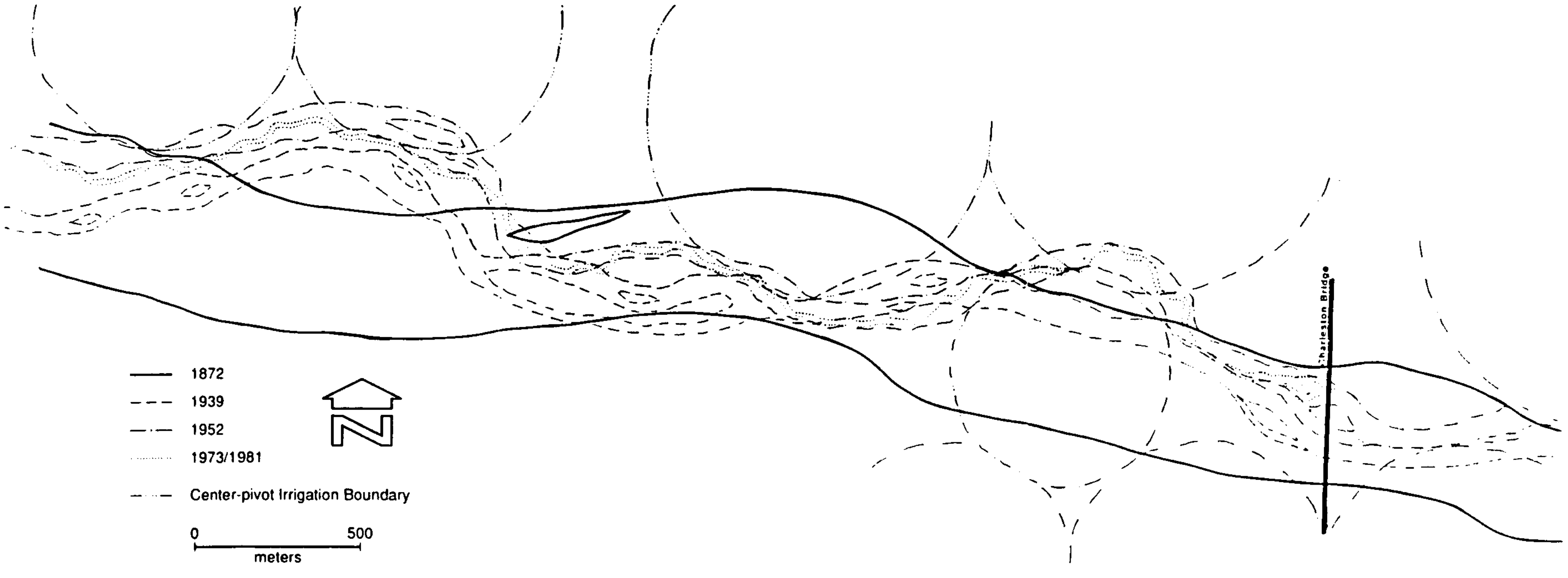

40
35
30
25
20
15
10
5
TOTAL PRECIPITATION (INCHES)
overall mean precipitation
16.2"
?
?
?
10 year mean
1870
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
YEAR

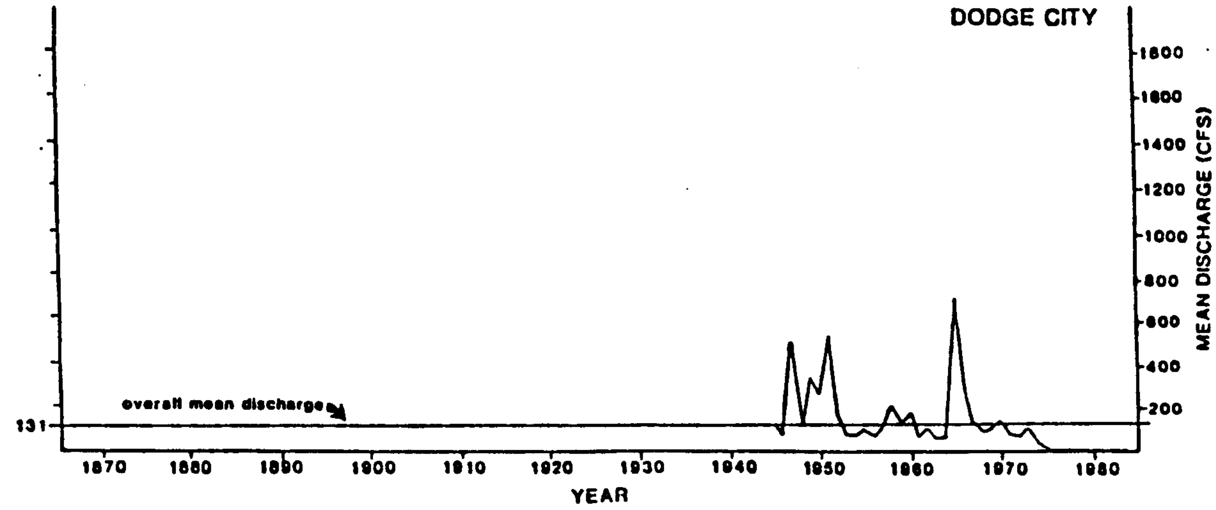

GARDEN CITY
1800
1600
1400
1200
1000
800
600
400
200
MEAN DISCHARGE (CFS)
overall mean discharge
188
1870
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
YEAR

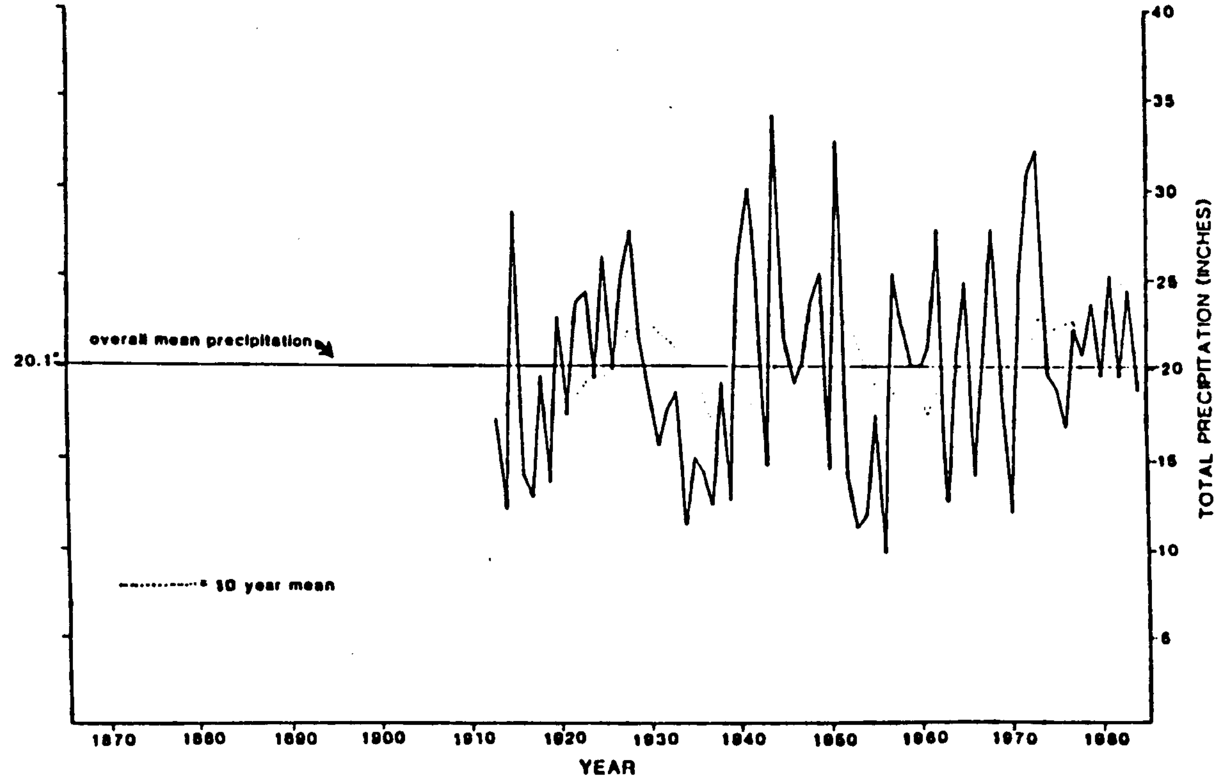

overall mean precipitation
18.9'
-10 year mean
40
35
30
25
20
15
10
5
TOTAL PRECIPITATION (INCHES)
1870
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
YEAR

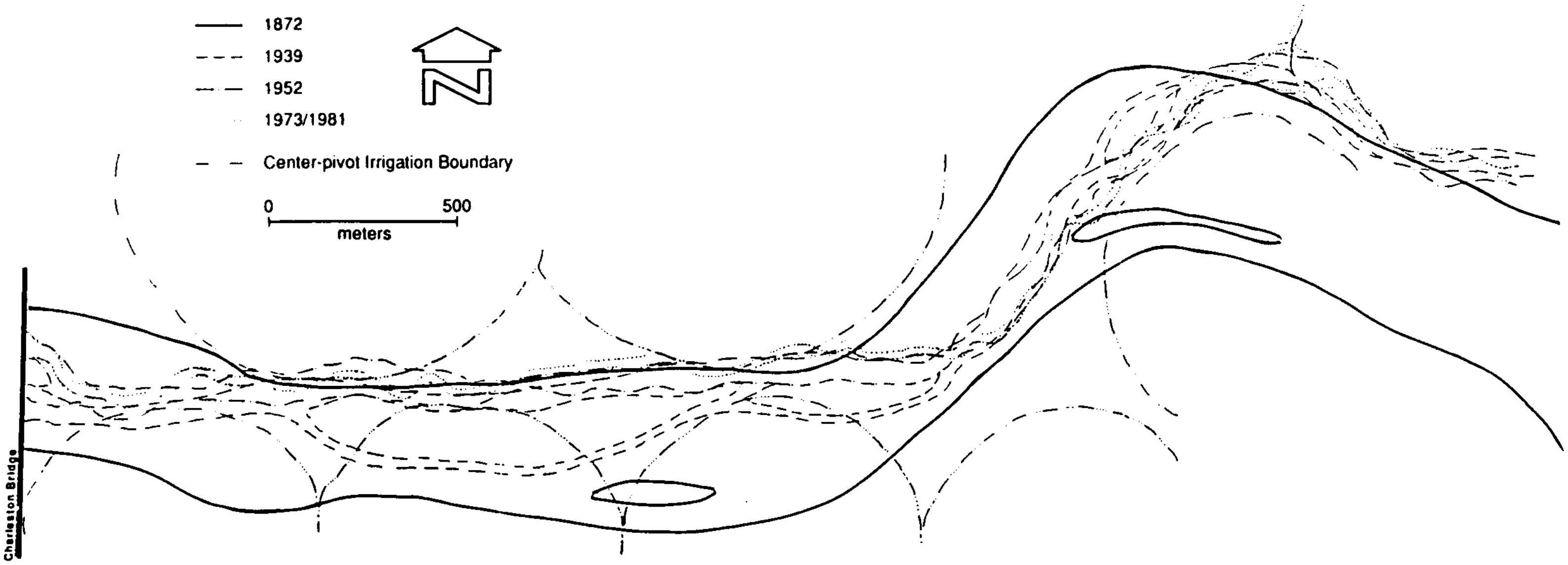
APPENDIX B

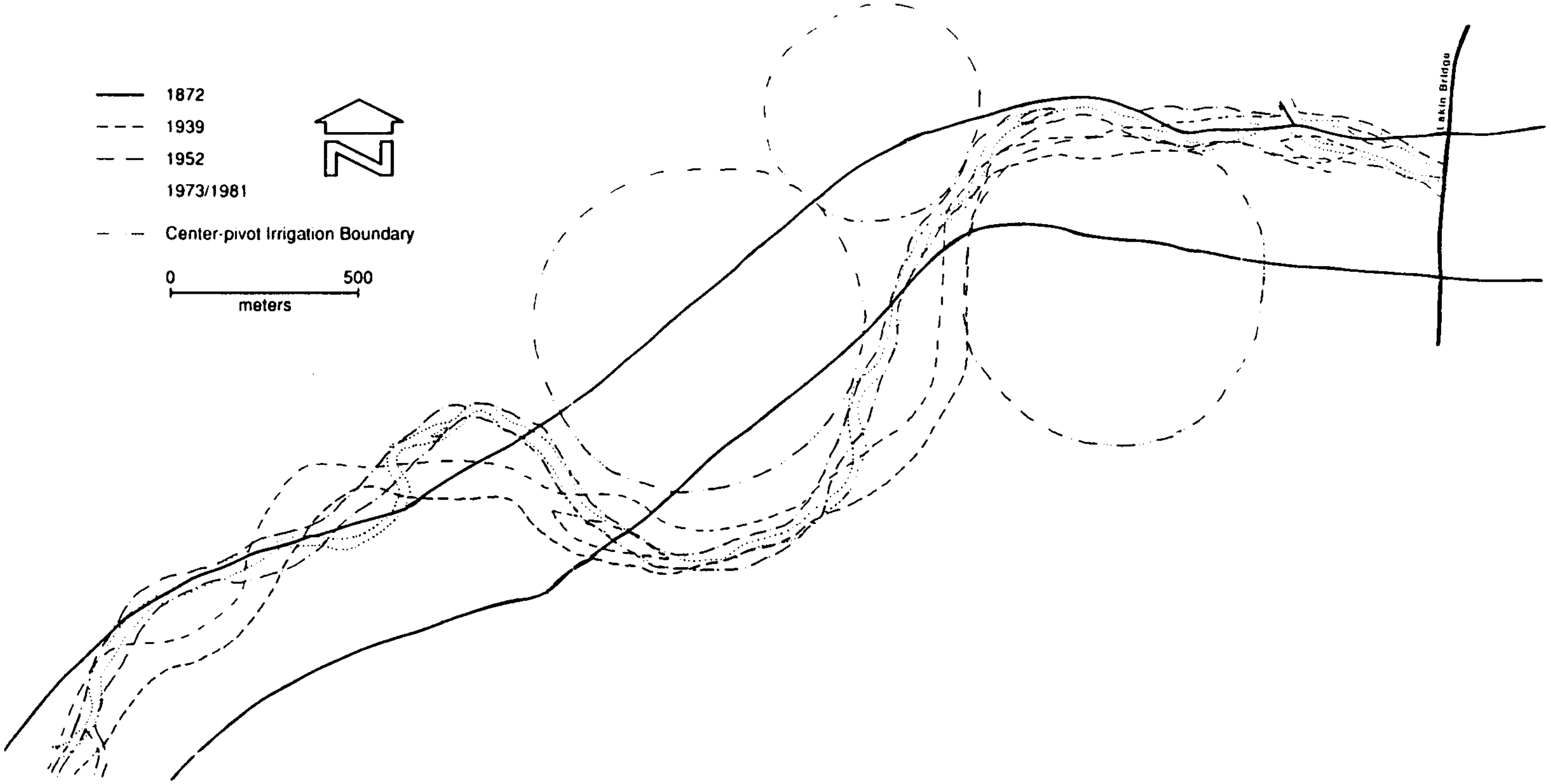
Maps of historical channel shrinkage near Lakin and Charleston


Charleston Bridge
1872
1939
1952
1973/1981
Center-pivot Irrigation Boundary
N
0
500
meters


DODGE CITY
overall mean discharge
131
1800
1600
1400
1200
1000
800
600
400
200
MEAN DISCHARGE (CFS)
1870
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
YEAR


overall mean precipitation
20.1"
10 year mean
40
35
30
25
20
15
10
5
TOTAL PRECIPITATION (INCHES)
1870
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
YEAR


1872
1939
1952
1973/1981
Center-pivot Irrigation Boundary
0
500
meters
N
Charleston Bridge


1872
1939
1952
1973/1981
Center-pivot Irrigation Boundary
0
500
meters
Lakin Bridge

APPENDIX C

Historical channel width measurements

APPENDIX C
CHANNEL WIDTHS

Location	Year	Channel (ft)	Floodplain (ft)
2 miles W.	1872	1056	---
Hartland	1904	850	---
T25S R37W S17	1939	477	---
Hartland, KS	1872	990	---
	1882	528	---
	1887	875	---
	1892	1050	---
	1939	193	795
	1952	182	458
	1959	130	---
	1966	80	---
	1971	66	182
	1980	22	33
	1986	40	---
	1992	48	---
Lakin, KS	1872	1408	---
	1939	264	562
	1952	231	282
	1971	66	66
	1980	44	50
	1985	41	---
	1987	44	---
East of Lakin	1872	1221	---
(near cars)	1939	252	763
	1952	141	465
	1971	66	93
	1980	53	~55
N-S			
Section Line	1872	1518	---
T24S R35W	1939	264	650
16/15	1952	157	422
21/22	1971	missing photo	---
	1980	33	50
Deerfield	1872	1188	---
	1904	~825	---
	1939	363	---
Sherlock	1872	1100	---
(Holcomb)	1904	~800	---
	1939	363	---

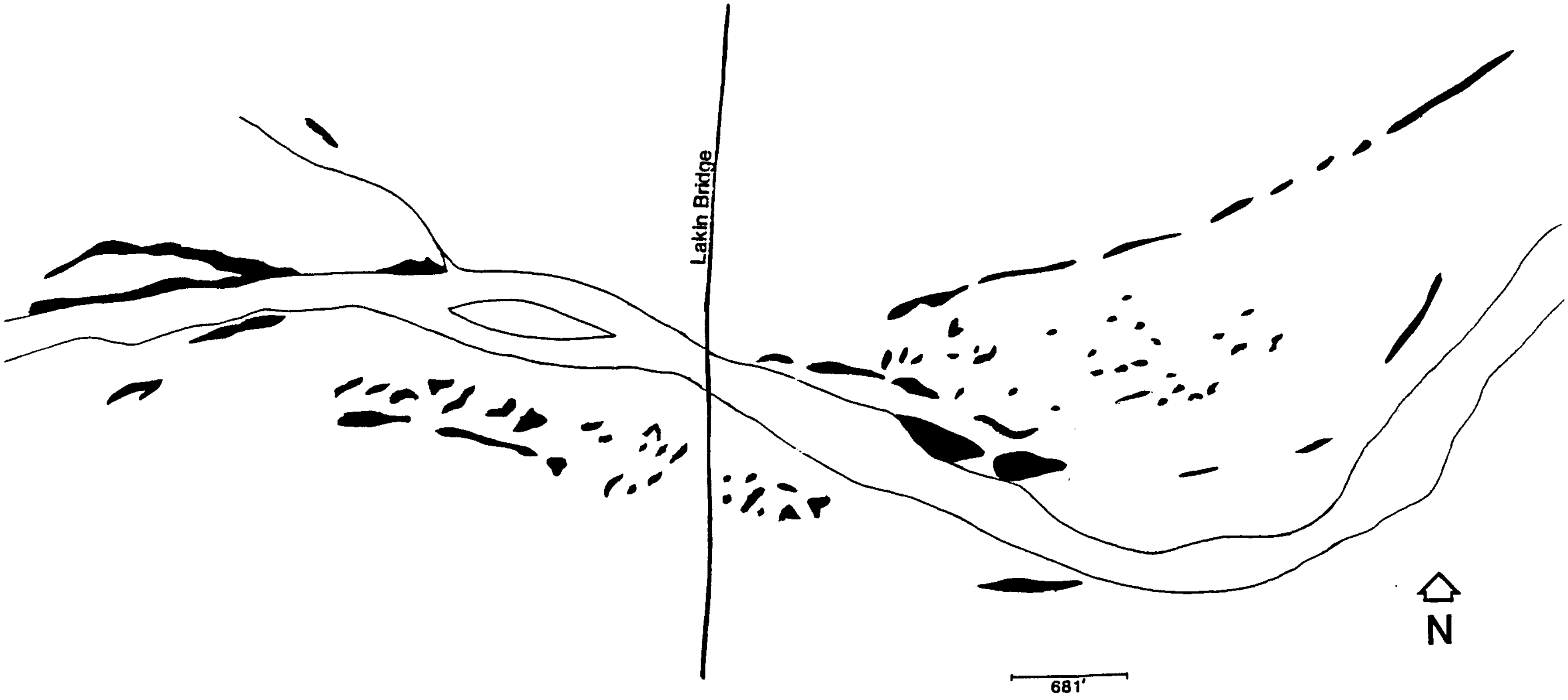
Location	Year	Channel	Floodplain
2 miles W.	1872	1177	---
Garden City	1904	1000	---
T24S R33W	1939	511	---
Sec.22-23			
Pierceville	1872	1144	---
	1939	224	---
	1952	198 (est)	---
	1971	50 (est)	---
	1980	22 (est)	---
	1985	25	---
N-S	1872	1320	---
Section Line	1939	170	443
T25S R30W	1952	158	528
21/22	1971	33	58
28/27	1980	17	25
	1985		
Charleston	1872	1109	---
	1939	317	757
	1952	275 (v.braid)	581
	1971	55	149
	1980	22	33
	1985	35	---
N-S			
Section Line	1872	1485	---
T25S R29W	1939	221	315
20/21	1952	141	315
29/28	1971	50	66
	1981	17	33

Scales

1872 -- 1" = 40 chains : 66 feet/chain
1939 -- 1" = 681'
1952 -- 1" = 704'
1971 -- 1" = 660'
1981 -- 1" = 660'

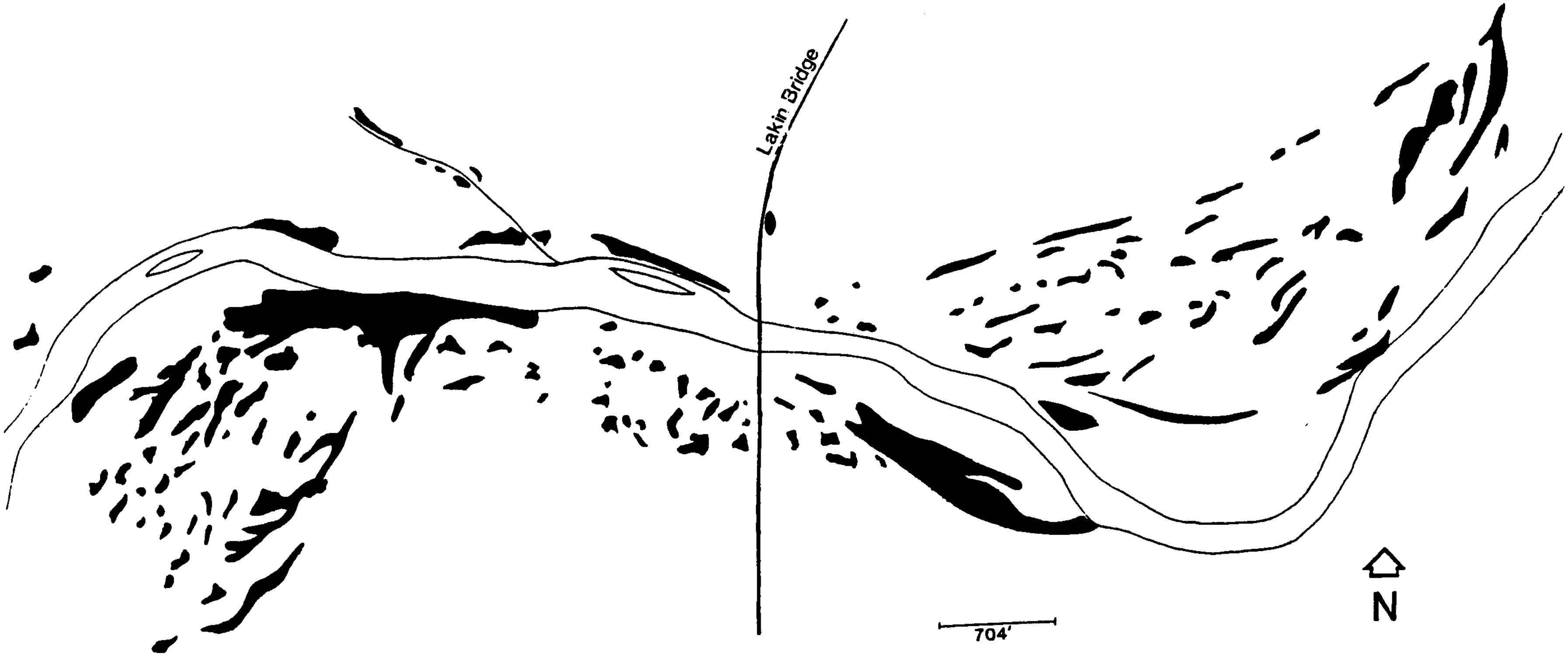
APPENDIX D

Qualitative and quantitative representation of tree cover for selected periods and reaches

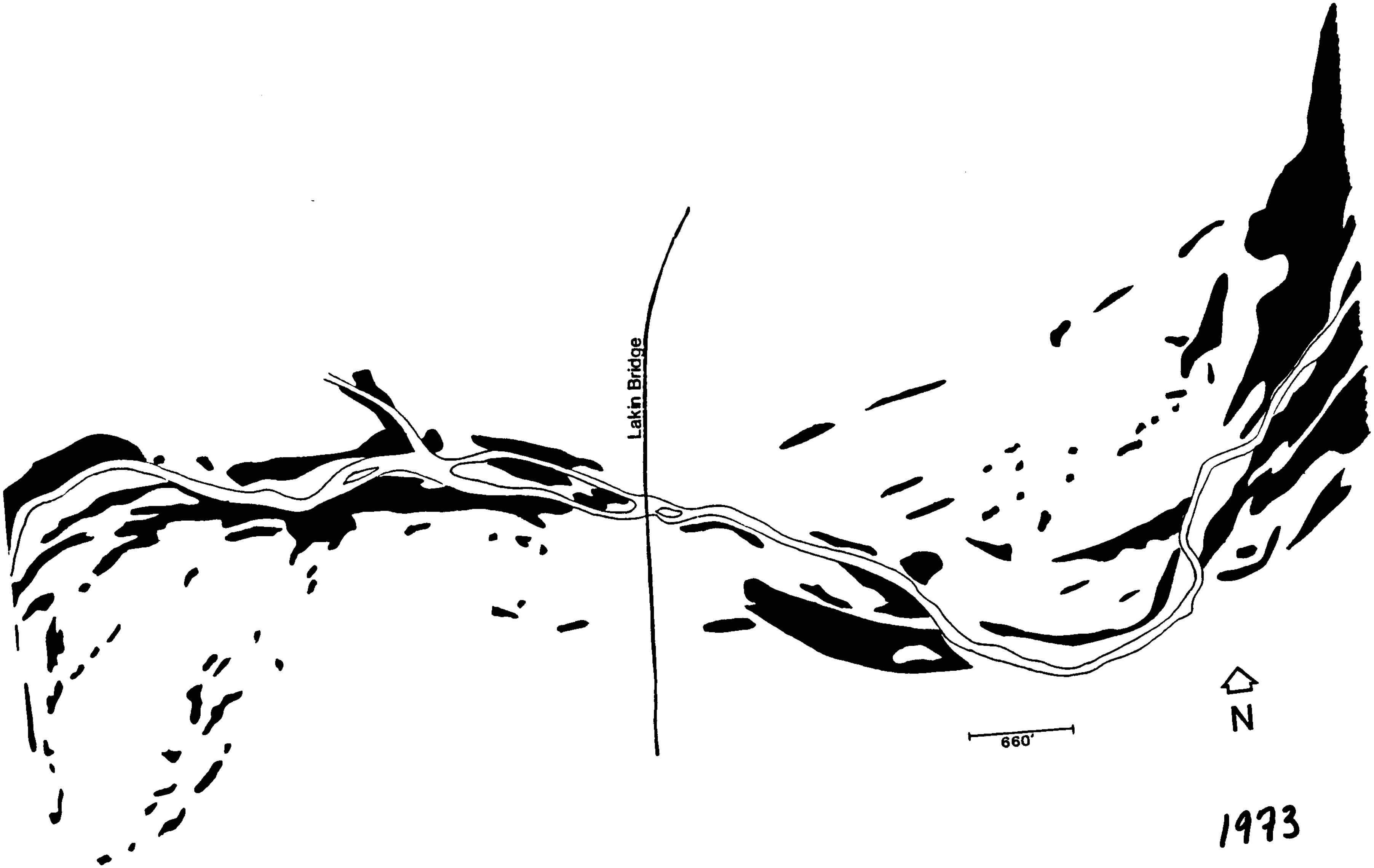


1939

[redacted]

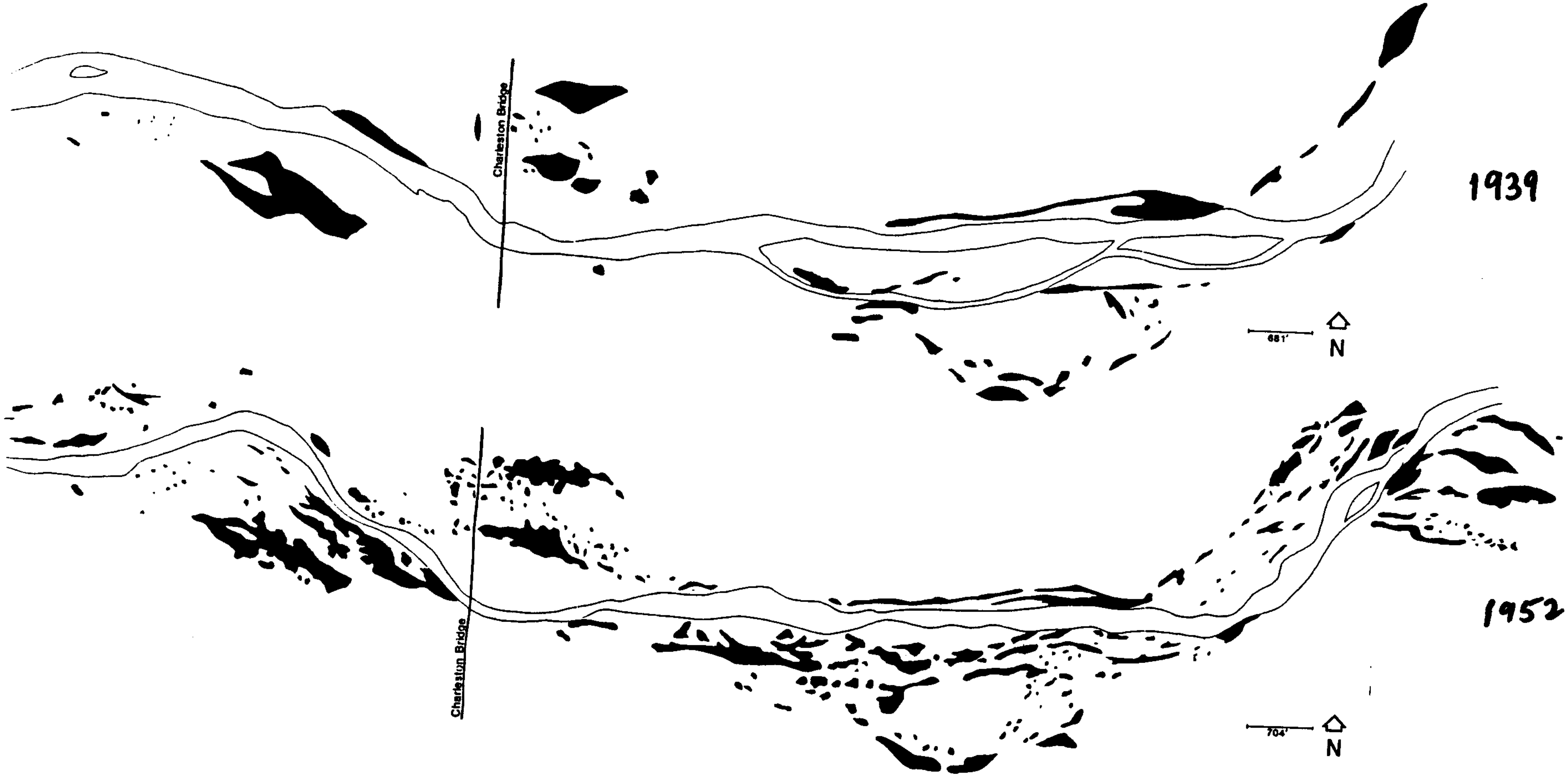


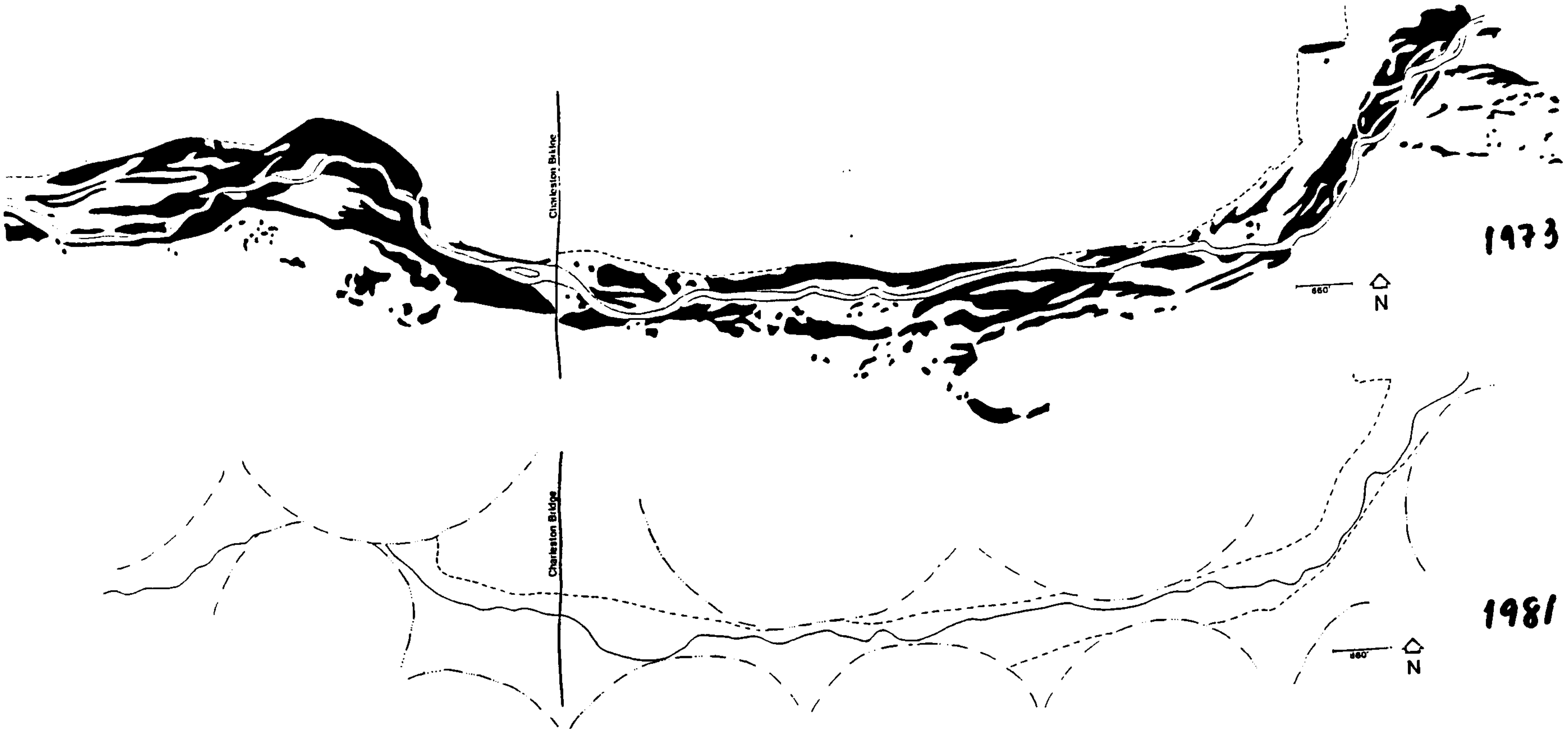
1952



1973

1980


Charleston Bridge
1939
681'
N
Charleston Bridge
1952
704'
N


Charleston Bridge
1973
660'
N
Charleston Bridge
1981
660'
N

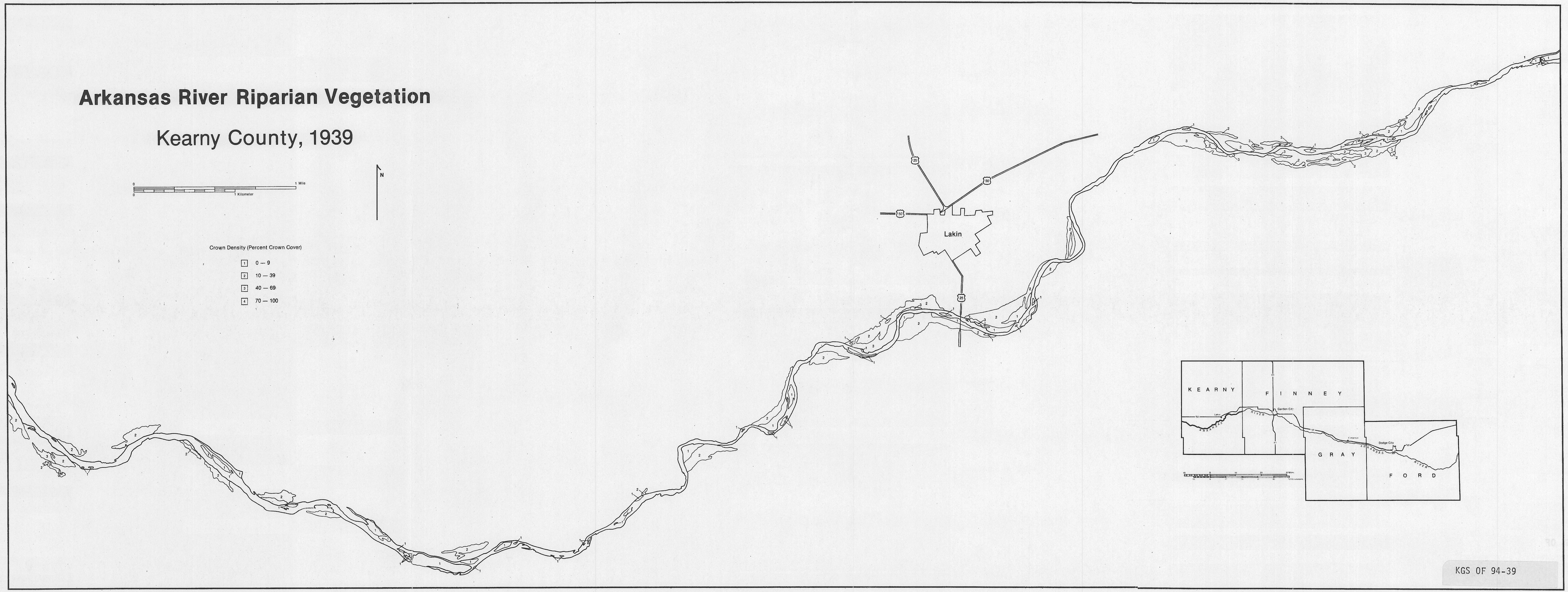
Arkansas River Riparian Vegetation

Gray County, 1973

KGS OF 94-39

Arkansas River Riparian Vegetation

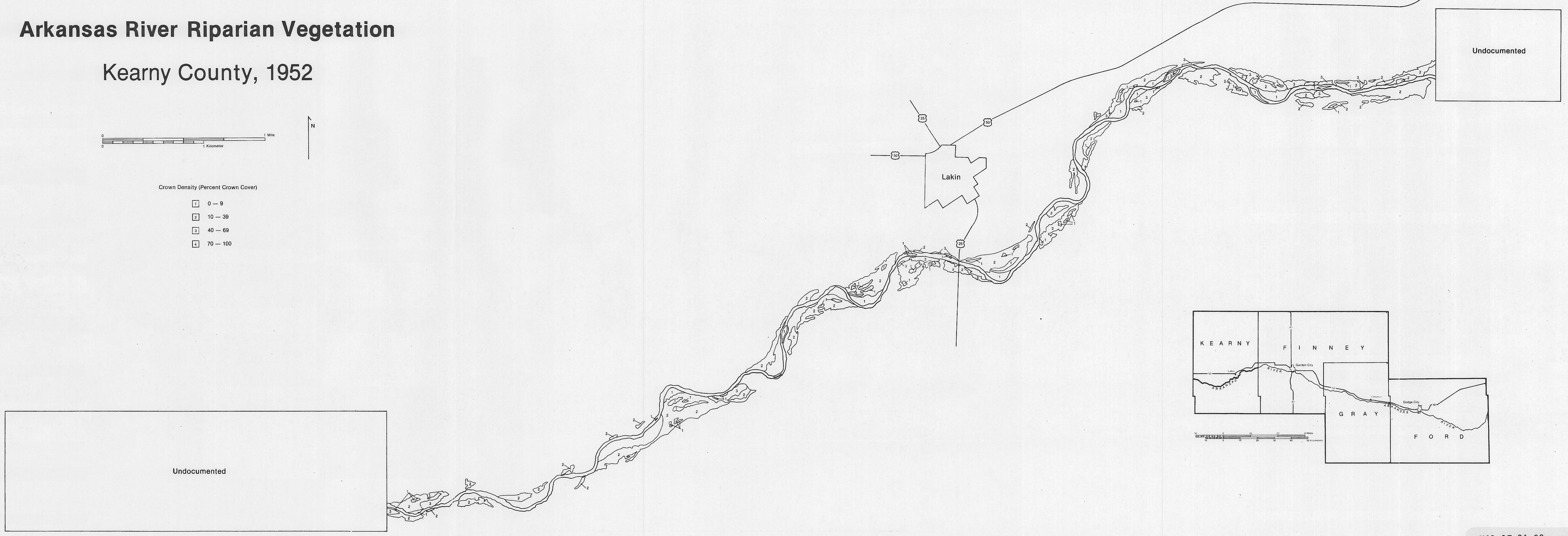
Kearny County, 1939



KGS OF 94-39

Arkansas River Riparian Vegetation

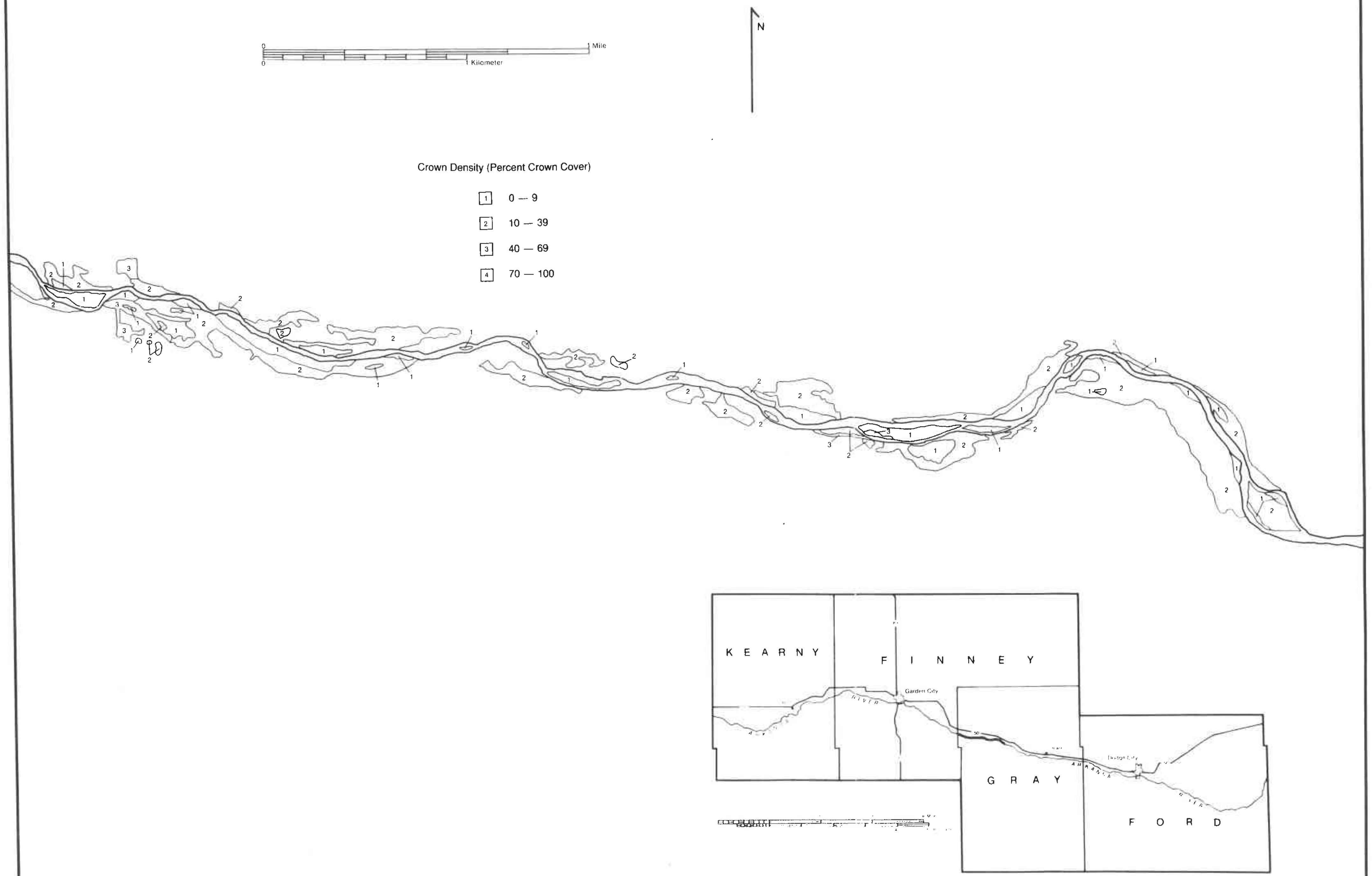
Kearny County, 1952



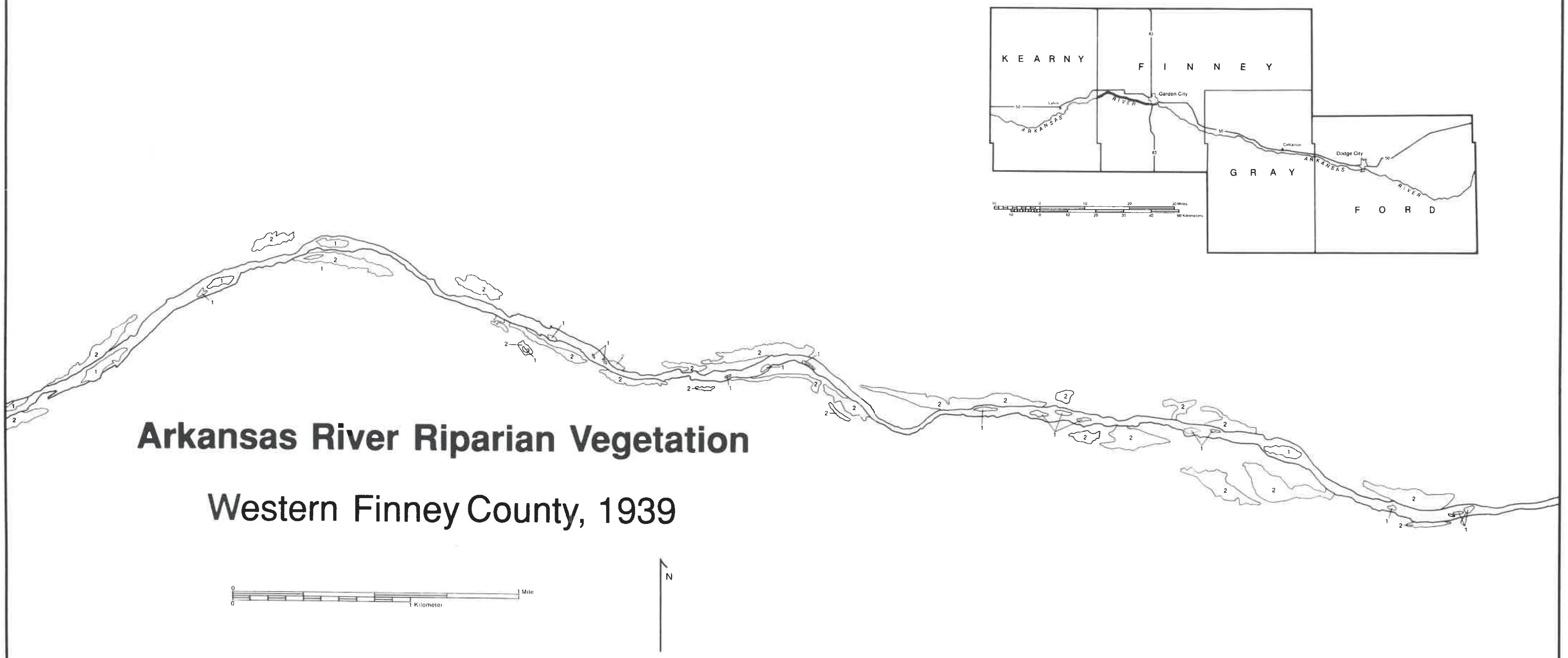
KGS OF 94-39

Arkansas River Riparian Vegetation

Western Gray County, 1939



KGS OF 94-39



Arkansas River Riparian Vegetation

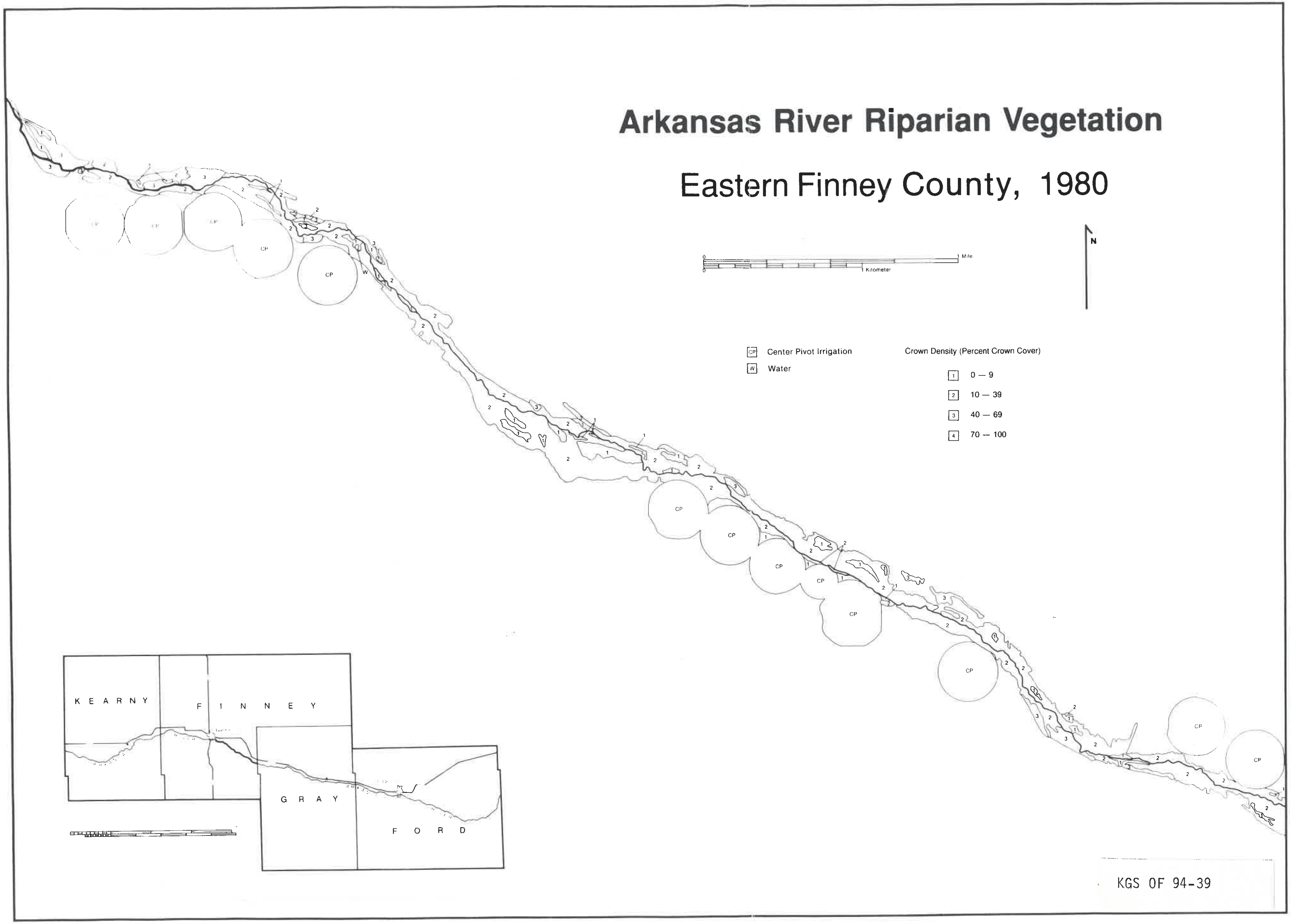
Western Finney County, 1939

Crown Density (Percent Crown Cover)

1	0 — 9
2	10 — 39
3	40 — 69
4	70 — 100

Arkansas River Riparian Vegetation

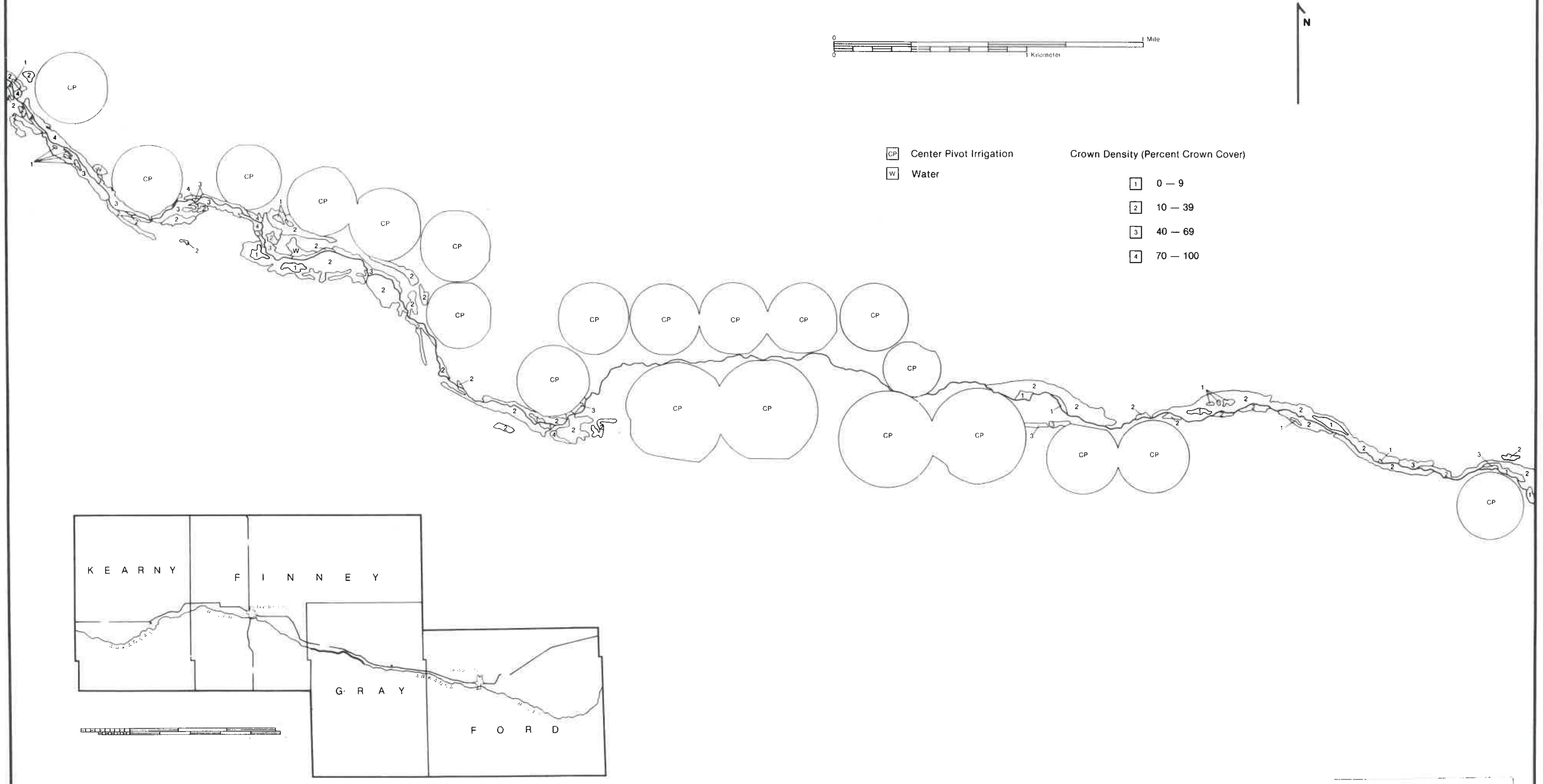
Eastern Finney County, 1980



KGS OF 94-39

Arkansas River Riparian Vegetation

Western Gray County, 1981



KGS OF 94-39

Arkansas River Riparian Vegetation

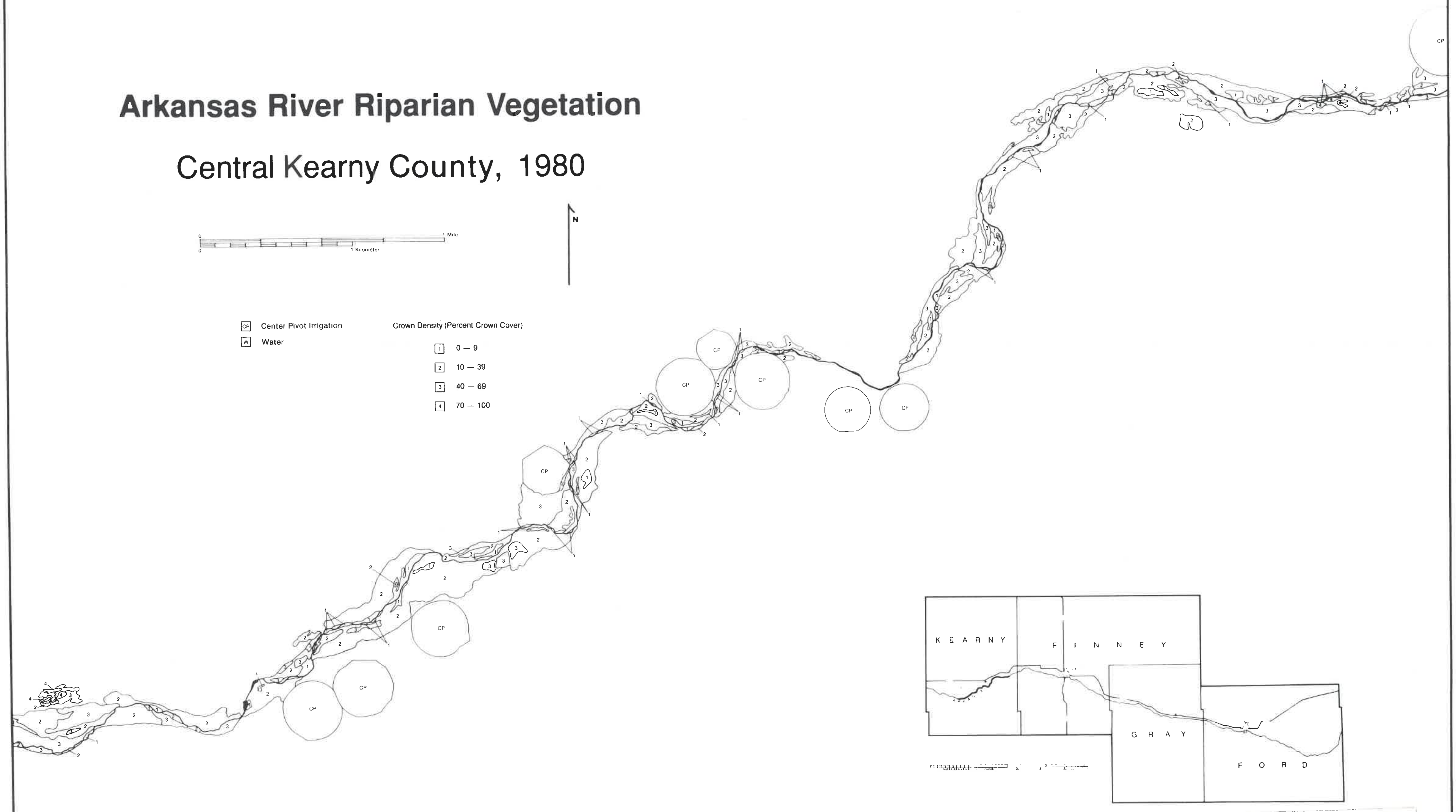
Central Kearny County, 1980

CP Center Pivot Irrigation

W Water

Crown Density (Percent Crown Cover)

- 1 0 — 9
- 2 10 — 39
- 3 40 — 69
- 4 70 — 100



KGS OF 94-39