

**HISTORICAL CHANNEL ADJUSTMENTS OF THE LOWER BIG BLUE
RIVER BELOW TUTTLE CREEK RESERVOIR, MANHATTAN, KANSAS,
1857 - 1991**

by

JEFFREY JOHN WEATHERLY

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A THESIS

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requirements for the degree

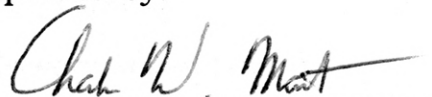
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ABSTRACT



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The complex channel adjustments identified below Tuttle Creek Reservoir along the lower Big Blue River occur as channel degradation, bank erosion, and isolated zones of channel deposition or widening. As a result of the impoundment of the Big Blue River, the regulated clear water discharge from Tuttle Creek Reservoir frequently exceeds the critical-power threshold for stream power. Channel bank erosion and steepening have been the principal changes resulting from river regulation below the Tuttle Creek Dam. The lower Big Blue River is additionally impacted by Rocky Ford Dam. At this spillwater dam, which is located 1.4 miles (2.3 km) downstream of Tuttle Creek Dam, river velocity is increased because of a steeper slope. Excess stream power below Rocky Ford is dispersed through channel bank erosion and channel widening. Channel degradation below Rocky Ford is impeded by extensive channel bed armoring. Channel bed armoring below Rocky Ford has protected a small channel island from scour since 1937. At Casement Road bridge, which is located 2.5 miles (4.0 km) downstream from Tuttle Creek Dam, 12.1 feet (3.69 m) of degradation have occurred in the last 40 years. Sand dredging operations along the lower Big Blue River have severely impacted the channel morphology along the reach of river approximately 6 miles (9.7 km) downstream of Tuttle Creek Reservoir. Channel widening has occurred in both of the channel bends in which sand dredging activities occurred. Significant channel adjustments along the lower Big Blue River are primarily a result of the 1951 flood, the construction of Tuttle Creek Reservoir, and sand dredging activities.

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CHAPTER 1: INTRODUCTION

The U.S. Army Corps of Engineers (COE) reservoir projects protect downstream areas from recurring floods¹, serve as wildlife refuges, and provide recreational opportunities for thousands of patrons each year throughout Kansas (COE 1988). One of the less publicized functions of Tuttle Creek Reservoir near Manhattan, Kansas, is to regulate downstream river discharge in the lower Big Blue, Kansas, Missouri, and Mississippi River systems (Franz 1990). However, through stream impoundment and discharge regulation, reservoirs have historically altered the stream's natural balance between channel degradation and aggradation (Furness et al. 1967; Petts 1979; Andrews 1986, Bull 1991).

This study was undertaken to investigate, characterize, and offer some explanation for significant channel changes that have occurred along the lower Big Blue River between 1857 and 1991. The lower Big Blue River is defined in this study as the 10 mile (16.1 km) stretch of channel between the mouth of the Big Blue River and Tuttle Creek Reservoir. Primary objectives of this thesis are: 1) briefly review the flood history which has impacted the lower Big Blue River between the years 1857 and 1991; 2) map channel position of the lower Big Blue River for the years of 1857, 1886, 1937, 1947, 1952, 1963, 1973, 1982, and 1989; 3) determine channel sinuosity for the years previously noted; 4) evaluate mean monthly flow trends for the Big Blue River in the study area from the years 1927 to 1991; 5) evaluate channel rating curves at a site below the dam for the years of 1951, 1961, 1971, 1981,

¹ Flood being defined as land inundated with water that is not normally covered with water (COE 1972).

and 1991; and 6) identify, characterize, and discuss zones of erosion, deposition or quasi-equilibrium, focusing on the immediate three miles (4.8 km) downstream from the dam. Further detail concerning analyses will be discussed in the Methodology chapter. Through evaluation of historical and current aerial photographs and river flow (discharge) patterns, channel changes in the lower Big Blue River can be graphically and qualitatively described.

This study is unique because: 1) no known work has been completed in the lower Big Blue River study area, which combines all of the study objectives identified above; 2) the lower Big Blue River regime has, potentially, been impacted by both Tuttle Creek Reservoir and Rocky Ford Dam; and 3) it examines the impact of human activity on physical geography (channel morphology).

Adjustment of the Fluvial System

There have been numerous studies conducted on the subject of river channel morphology and the adjustment of rivers to changes due to environmental variables (e.g., Horton 1945; Melton 1959; Leopold et al. 1964; Langbein and Leopold 1966; Morisawa 1968; Cline 1974; Bloom 1978; and Hoppie 1980). Research topics ranged from classification of channel patterns (e.g., Leopold and Wolman 1957; Bagnold 1960; Langbein and Leopold 1966) to discussions of channel streamflow characteristics with respect to channel morphology (e.g., Hedman and Kastner 1977; Hedman and Osterkamp 1982). Much of the work on channel morphology has focused on flood frequency and floodplain development (e.g., McCrae 1954; Wolman and Leopold 1957; Schumm

and Lichty 1963; Kilpatrick and Barnes 1964; Stewart and LaMarche 1967; and Knox 1976).

The classic channel morphology study of Leopold and Maddock (1953) remains the foundation for many stream morphology studies today. Concepts discussed in Leopold and Maddock's work will be the fundamental base from which field observations of the lower Big Blue River will be conducted. Leopold and Maddock found that stream channel characteristics such as channel depth, width, stream velocity and suspended sediment load vary with stream discharge. Specifically they noted that at constant discharge and channel width, an increase in velocity will result in an increase in channel depth, which in turn increases the suspended load and bed load in transport. Leopold and Maddock concluded that channel equilibrium, or grade, is attained relatively early in the development of larger river systems, whereas medium and smaller streams achieve equilibrium at later stages.

Bull (1979, 1991) published work that developed relationships between discharge, specific weight of water, and slope in order to establish stream power. The concept of stream power versus resisting power will be a key concept utilized to distinguish areas along the lower Big Blue River that are at, exceeding, or below the threshold of critical-power. Stream power is the power available to transport sediment load. The concepts of resisting power and the threshold of critical power were also explored by Bull. Resisting power is defined as the power required to transport sediment (Bull 1991). The threshold of critical power is defined as:

$$\text{Threshold of Critical Power} \Rightarrow \frac{\text{stream power}}{\text{resisting power}} = 1.0$$

In cases where stream power exceeds resisting power (Figure 1) for extended periods of time, erosion occurs. In environments where stream power is less than resisting power, deposition occurs. When the stream power equals the resisting power, the stream is in a condition of equilibrium. As Bull (1979, 453) describes it:

"a graded stream is one in which, over a period of years, slope, velocity, depth and width, roughness, pattern and channel morphology delicately and mutually adjust to provide the power and efficiency necessary to transport the load supplied from the drainage basin without net aggradation or degradation of the channel."

Resisting power can be influenced by factors such as size of bedload available to the stream, hydraulic roughness, slope, environmental setting, and human influence (Bull 1991).

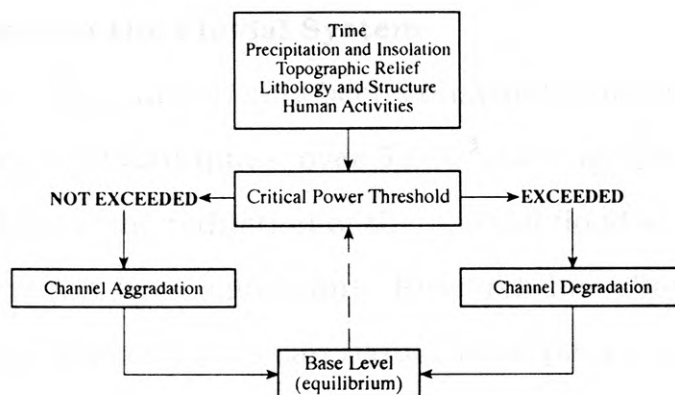


FIGURE 1. Basic elements of a fluvial system as indicated by Bull (1979). Some of the factors influencing critical-power threshold are time, precipitation and insolation, topography, lithology and structure, and increasingly important—human activities. (Adapted from: Bull 1979).

Bull concludes that reaches where the threshold has been exceeded; reaches that are close to or at the threshold; and reaches where the resisting power exceeds stream power can be easily identified in the field. Actively downcutting stream reaches represent zones where stream power exceeds the threshold of critical-power; conversely, actively aggrading reaches are zones where stream power is below the threshold of critical power. Stream regimes close to the critical-power threshold will typically have one or more of the following characteristics: 1) alluvium in amounts greater than that scoured by large discharges; 2) a floodplain that is narrower than the width of the valley floor; 3) dated alluvial deposits that indicate that neither net deposition nor erosion has occurred; 4) parallel fill, or strath terraces, which suggest fluctuating conditions and periodic return to similar threshold conditions; and 5) numerous, small hiatuses of temporary nature in the stratigraphy of a valley fill (Bull 1979, 463).

Impact of Dams on the Fluvial System

Reservoirs have historically been constructed to regulate surface water flow since Egyptian times, over 5,000 years ago (Smith 1971). Through regulation, the reduction of the natural flood stages along controlled rivers has been significant. Research has shown that construction of dams on rivers can reduce flood peaks up to 80% (Lauterbach and Leder 1969; Moore 1969). Tuttle Creek Reservoir, Manhattan, Kansas, has effectively reduced flood crest stage by 76%, as seen in the flood of October, 1973. During this event a maximum mean daily inflow of 98,000 cfs (2,760 cms) into Tuttle Creek Reservoir was

estimated, while a maximum mean daily outflow of 24,000 cfs (676 cms) was released to the lower Big Blue River (COE 1973). Reservoirs effectively act as temporary storage basins by allowing the crest of what normally would be considered a flood to dissipate over a period of time. By regulating discharge, this buffers the collective downstream effect of the flood event (LaCock 1992).

Flood frequency is an important factor in the development of the natural floodplain. If humans continue to utilize property near and on the floodplain, it is important to understand the natural processes which control floodplain development and preservation (Wolman and Leopold 1957). Kilpatrick and Barnes (1964) noted that floods of a given magnitude occur in regular frequencies in river systems. The recurrence interval of bankfull stage is between 1 and 2 years for many small and large rivers (Wolman and Leopold 1957). Wolman and Leopold concluded that floodplains develop through the combination of deposition of point bars in meandering channel systems and overbank flows during flood events. It would be reasonable to believe, then, that the introduction of a reservoir would adversely impact the development of the floodplain.

In addition to altering flood frequency, reservoirs affect river channel sediment loads. In a survey of literature on the impact of dams on fluvial systems, Petts (1979) noted that reservoirs trap and store the entire sediment load. Therefore, discharges from reservoirs are basically sediment-free, or at best contain a fraction of the original sediment load. Sedimentation in the reservoirs reduces the design life of the project in addition to altering the natural morphology of the downstream channel (COE 1973; Andrews 1986). Based on work by Gregory and Park (1974),

and similar findings by Petts and Lewin (1979), long term effects of erosion and sedimentation can be identified in downstream reaches of regulated rivers. Many studies (e.g. Malhotra 1951; Livesey 1963; Gregory and Park 1974; Petts 1979; and Andrews 1986) have discussed fluvial erosion and deposition subsequent to dam closure.

Erosion

Erosion is an important process in any drainage system, regulated or natural, and therefore must be considered in the proper management of that system. Streams meander downslope towards the channel mouth, cutting into unconsolidated deposits, and creating new channels or widening existing channels (Figure 2). Many scientists (e.g. Frye 1945; Leopold and Maddock 1953; Belcher 1975; Hickin and Nansen 1975; and Hooke 1979) have explored the physical cause-and-effect relationship experienced in a stream channel system. Variables such as slope, discharge, sediment load, channel roughness, and channel

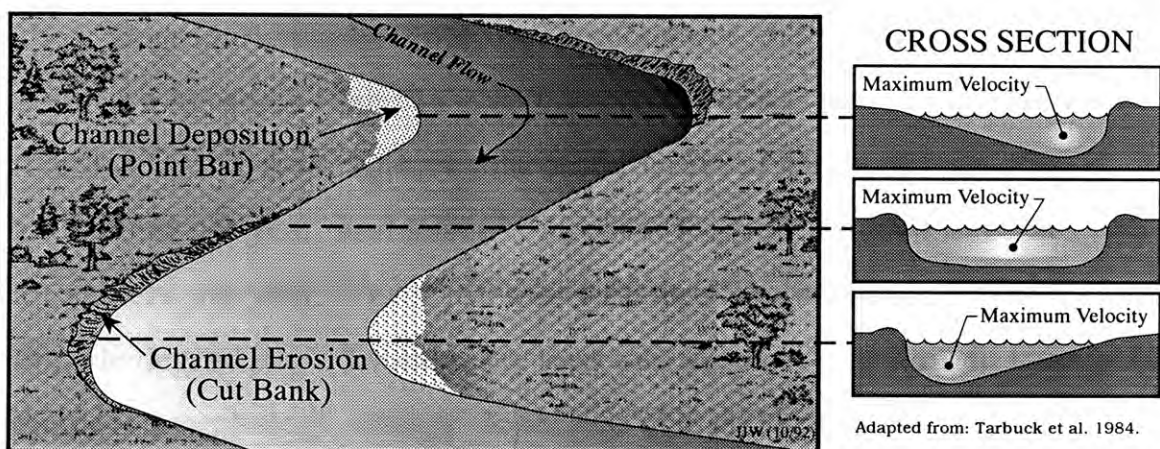


FIGURE 2. Stream channels typically meander laterally by degrading outside channel bends while aggradation occurs on inside bends. Channel maximum velocity shifts with each meander sequence to facilitate the migration.

morphology have been shown to have the most effect on channels. For example, an increase in channel discharge, which increases velocity, would result in greater stream power (Bull 1979, 1991) and cause erosion.

Many of the studies that describe the impacts of reservoirs have focused on the immediate scour or erosion which commonly occurs below the dam outlet works (Petts 1979). It was suggested by Schumm (1969) that channel degradation represented an immediate morphological impact of dam construction on the fluvial system. Typically, the erosional front progresses gradually downstream until the slope of the channel and/or channel bed roughness reduces the velocity of the release below the threshold for sediment transportation (Petts 1979). Over the long term, a complete readjustment in morphology to reach equilibrium will be experienced throughout the length of the river system (Furness et al. 1967, Osterkamp and Hedman 1981). River channels will attempt to reach this new equilibrium through episodes of erosion and deposition (Langbein and Leopold 1964; Knox 1976; Bull 1991).

Degradation subsequent to dam closure has been mentioned in the literature for some time. In extreme cases, Petts (1979) made reference to mountain stream regimes that can migrate at a rate of tens of kilometers per year, and lowland streams that can migrate several kilometers per year. There are many factors that can accelerate or impede degradation, for example type and amount of sediment transport, channel morphology, energy slope, and channel armouring. Most degrading river systems comprise non-compact sands and have a low density of vegetation.

Lawson (1924) identified channel degradation over 93 miles (150 km) downstream from Elephant Butte Reservoir in New Mexico. Field observations indicated that the rate and magnitude of the erosional processes varied significantly between regulated channels and natural channels. Lawson additionally reported reaches of aggradation in the Rio Grande River that appeared to be the result of Elephant Butte Reservoir. The aggradation process is more gradual than is degradation and requires introduction of sediment from tributaries or the remobilization of sediment within the river channel. Lawson concluded that channel change will be directly influenced by the balance between regulated river flow and sediment delivered to the channel.

Harrison (1950) discussed the aspects of channel armouring. Through the differential transportation of sediment, a coarse sediment layer, or armouring, will develop. Armouring effectively acts as a shield that protects the channel perimeter from erosion. Livesey's (1963) work at the Fort Randall Dam, South Dakota, found that a single grain thickness of coarse material, such as a layer of gravel, could effectively shield the underlying channel bed sands from erosion.

Looking at a river in the plan view, meanders or curves in the river path can be identified (Figure 3). Over time, natural channels that continue to meander may eventually and quickly truncate bends. Often truncation occurs during flood events, thus forming an oxbow lake and reducing the channel sinuosity (Plummer and McGeary 1979). The river pathway in a basin, which may consist of meanders, braided, or straight segments, is referred to as the river channel pattern or sinuosity (Leopold and Wolman 1957; Ritter 1978). Sinuosity results from the river

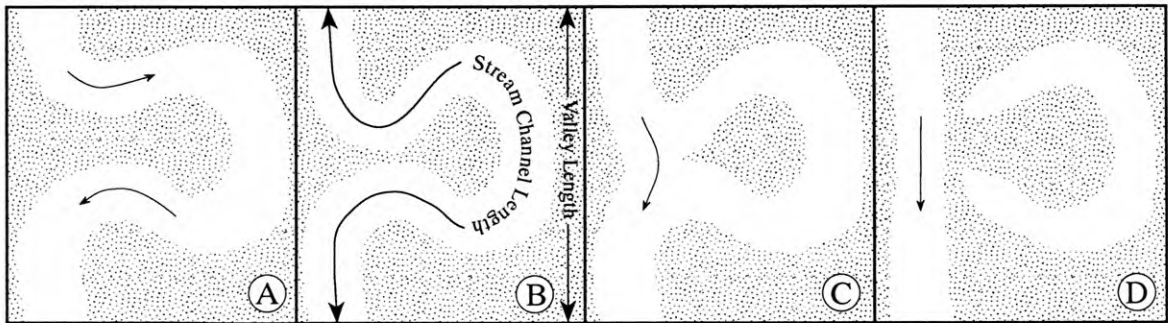


FIGURE 3. A) channel migrates overtime. B) channel sinuosity is the ratio of valley length vs. stream channel length. C) approaching meanders will converge thus altering the main channel path. Such catastrophic events as a flood produce many cut-off channels. D) sediment deposition isolates the truncated meander bend, forming an oxbow lake. *JJW (10/92)*

attempting to minimize energy loss and achieve equilibrium within the channel (Leopold and Maddock 1953). A meandering channel is less energy efficient than a straight channel, therefore increased sinuosity represents increased energy loss (Bagnold 1960). Sinuosity is calculated by dividing the river channel length, measured down the center axis of the channel, by the river valley length (Osterkamp and Hedman 1981). Thus a sinuosity value of 1.0 would indicate a straight channel equal in length to the valley. Values greater than 1.0 reflect increasing channel sinuosity.

Stream channel erosion occurs in all drainage systems. In those systems flowing on bedrock, specifically crystalline rocks, erosion rates are slow; systems developed in alluvium, such as the Big Blue and Kansas Rivers, have greater rates of erosion (Keller 1972; Ritter 1978). Stream velocity is one of the major factors associated with the rate of erosion. Stream velocity is related to stream discharge by the following equation (Leopold and Maddock 1953):

$$Q = wdv$$

where: Q = stream discharge (ft^3/sec)
 w = channel width (ft)
 d = channel depth (ft)
 v = average stream velocity (ft/sec)

Stream power, which best represents the relationship between stream discharge, velocity, and the erosive ability of the stream, can be evaluated with the stream power equation developed by Bull (1979):

$$\omega = \gamma QS/w$$

where: ω = stream power.
 γ = specific weight of water.
 Q = stream discharge.
 S = channel slope.
 w = channel width.

Stream power can be utilized as a quantitative value for potential channel erosion (Medina 1992). The variables used to calculate stream power can be measured and used to calculate stream power values in the fluvial system. Critical-power threshold is the ratio of stream power to resisting power. When the critical-power threshold is equal to 1.0, the river is said to be in a condition of equilibrium; when the threshold is greater than 1.0, the river is degrading; when the threshold is less than 1.0 the river is aggrading. Resisting power is the degree of power that is required to physically transport the sediment load (Bull 1979, 1991).

With the introduction of a reservoir to a natural flowing river system, natural sinuosity trends and discharge patterns are modified. This leads to changes in stream power and resisting power, which in turn alters channel morphology (Gregory 1974; Bull 1979, 1991).

Deposition

A second impact of river regulation on the river regime is aggradation. Petts (1979) reported researchers have historically focused on the degradation effects, however, channel aggradation has also been recognized. Deposition downstream from a reservoir is a much slower process than erosion. Deposition downstream of a reservoir may consist of finer sediment than was deposited prior to construction of the reservoir. Such deposition typically forms berms, which are then covered and stabilized by encroaching vegetation. This ultimately results in channel narrowing (Northrop 1965; Richards and Wood 1972).

Complex Response

The process of degradation and aggradation occurring simultaneously along a regulated river may, in the long term, represent part of a complex single adjustment towards equilibrium (Petts 1979). Work by Wolman and Leopold (1957) suggested that in floodplain development, there are three channel classifications: aggrading, degrading, or stable. Stable represents a condition where neither aggradation or degradation is occurring. Knox (1976) suggested that stable channel morphology is characteristic of a graded stream or one where there is a balance between erosion and deposition. Conversely, an ungraded stream would be undergoing rapid morphologic change. Petts (1979) noted that streams become graded over long time periods (e.g., geologic time scale), although others have argued that the graded condition may be reached over shorter time scales (e.g., Knox 1976; Bull 1979, 1991). Leopold and Maddock (1953), and subsequently Langbein

and Leopold (1964), preferred the term "quasi-equilibrium" to graded. Bull (1991) suggested the term equilibrium, which occurs when the critical-power threshold is equal to 1.0.

It has been suggested by Malhotra (1951) that channel aggradation or degradation seen in downstream reaches is part of a single channel adjustment. Petts (1979) suggested that as a result of complex channel adjustment of a river system, aggradation can be occurring in one reach while degradation can be occurring in another reach.

In the Missouri River basin, work published by Osterkamp and Hedman (1981) found that stream systems with reservoir regulated discharge patterns generally produced narrower channels compared to non-regulated stream systems. The narrowing of river channels was attributed to the impounding and regulation of discharge, which reduced tractive sediment discharge, prevented natural bank development, and eliminated flood stage discharges. Osterkamp and Hedman additionally concluded that an increase in sinuosity occurred in the regulated channels. The increase in sinuosity reduced channel slope.

Gregory and Park (1974) concluded that the reduction of channel capacity is related to the reduction of peak discharges in the regulated channel. The degree of channel capacity decrease depends on the ratio of pre- and post-closure discharges. A direct correspondence between the magnitude of the flow regulation and the degree of channel change does not always occur because the channel may not have been adjusted to discharge frequency prior to closure. It is also possible that channel characteristics may preclude adjustment.

Additional reservoir impact investigations that are relevant to this study of the lower Big Blue River include discussions by Knox (1976) concerning channel equilibrium, Petts (1979) discussion of complex channel responses, and Osterkamp and Hedman's (1981) investigation of regulated stream geometry in the Kansas and the Missouri River Basin.

Knox (1976) discussed graded and ungraded river channel morphology and the condition of quasi-equilibrium. He concluded that development of stream channel morphology (graded condition) takes place rapidly, usually in years. Knox also suggested that quasi-equilibrium is not synonymous with grading. Grading requires morphologic stability over time, which may or may not exist in a state of quasi-equilibrium. Quasi-equilibrium implies the "strong tendency of all streams, graded or ungraded, to undergo an adjustment among the hydraulic variables which reflect inputs of sediment and discharge." (Knox 1976, 194)

Petts (1979) concluded that rivers can aggrade, degrade, or undergo a more complex adjustment characterized by alternating aggradation and degradation. Aggradation can be a response to the reduction of flood magnitudes (Lawson 1924). However, the aggradation process is much slower than degradation. Aggradation requires the introduction of sediment or the redistribution of sediment in the channel. One such sediment source would be non-regulated tributaries that flow into the regulated main channel (Dolan et al. 1974).

Lower Kansas River Studies

The Kansas River, a major tributary to the Missouri River, is supplied and controlled primarily by regulated tributaries such as the Smoky Hill River, Saline River, Solomon River, Republican River, and the Big Blue River (Figure 4). There have been a number of studies that focused on channel degradation and migration of the lower Kansas River (e.g., Furness et al. 1967; U.S. Army Corps of Engineers 1977, 1982, 1990, and Simions et al. 1984). The Corps of Engineers, Kansas City District (1978), inventoried bank erosion along the Kansas River and tributaries. The lower reaches of the Big Blue River were included in this study. There were three areas of severe erosion indicated for the lower Big Blue: the east downstream bank at Rocky Ford Dam, located

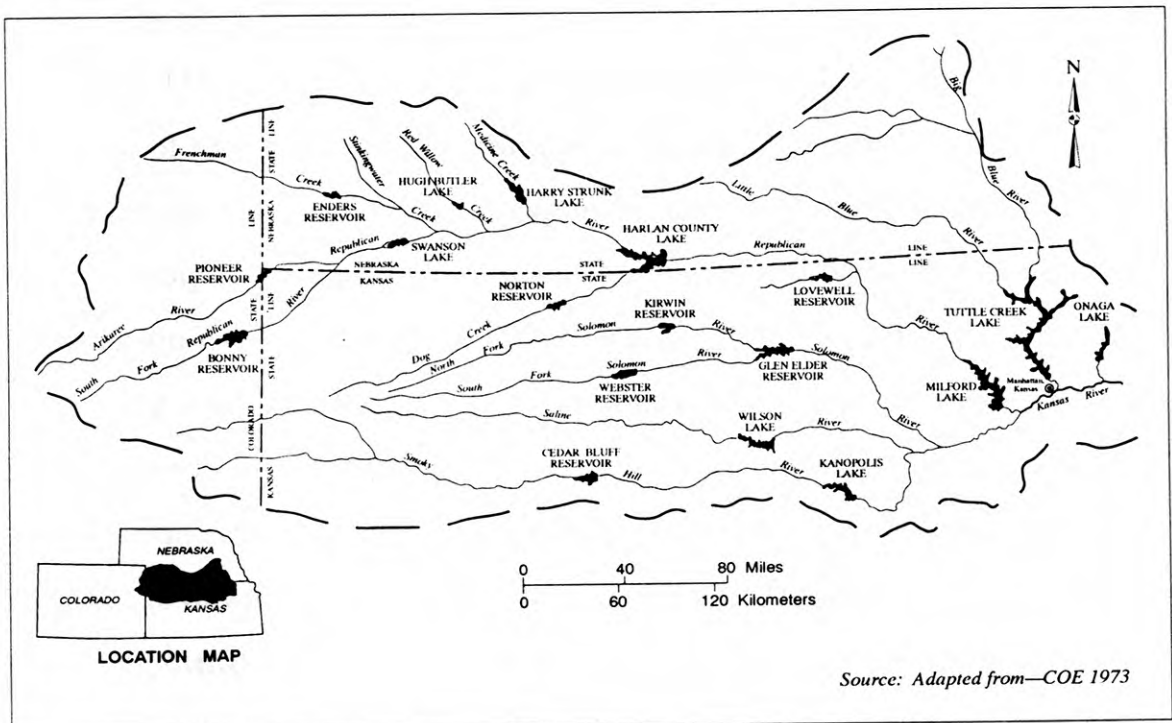


FIGURE 4. A generalized Kansas River watershed above Tuttle Creek Reservoir transverse the northern reaches of Kansas and parts of southern Nebraska and eastern Colorado. The total Kansas River watershed is comprised of approximately 60,060 sq. miles (155,555 km²) (O'Brien et al. 1972).

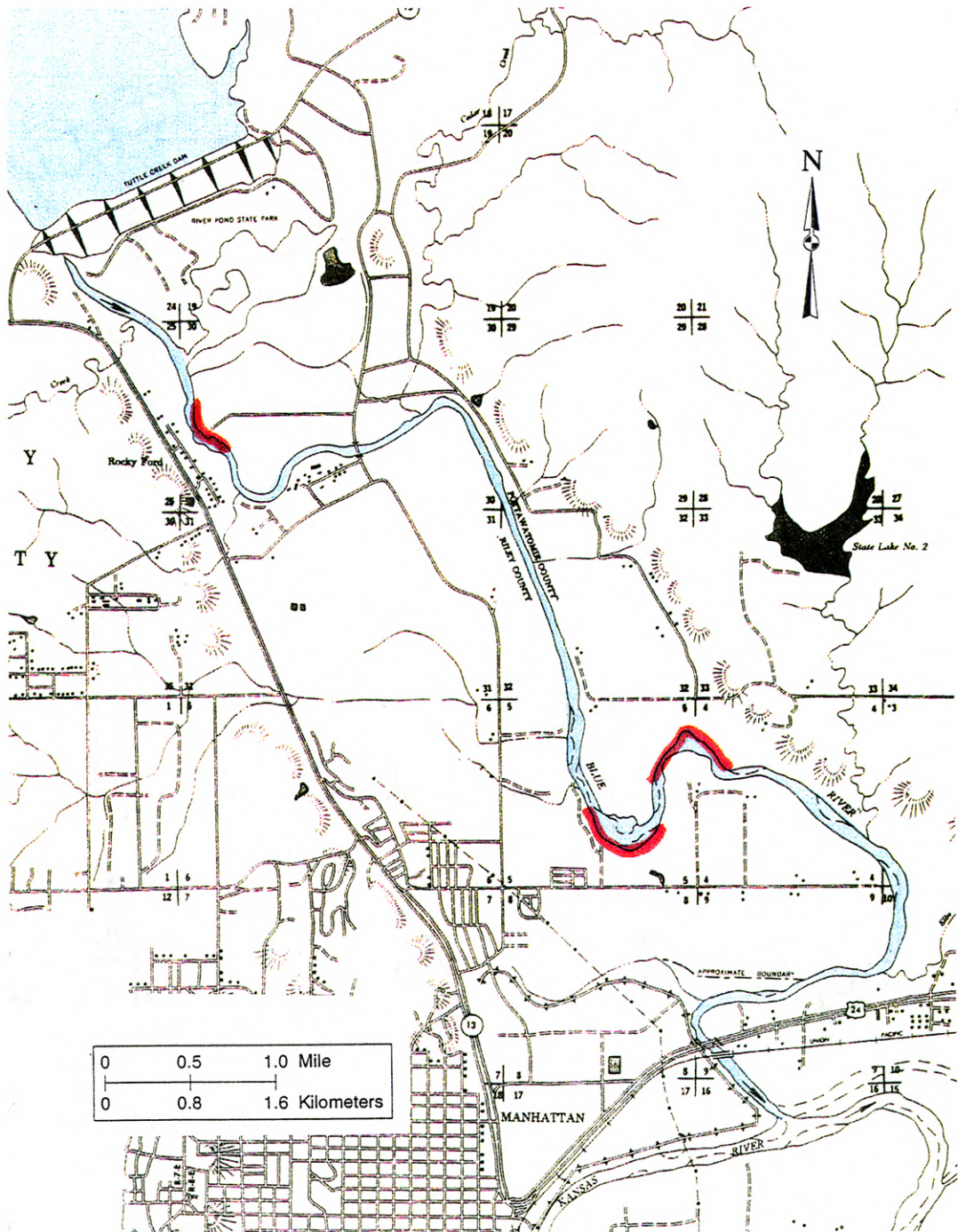
1.4 miles (2.3 km) downstream from Tuttle Creek Reservoir, and the south and north meander banks, located approximately 3 miles (4.8 km) upstream from the mouth of the Big Blue, where dredging once occurred (Figure 5).

The U.S. Army Corps of Engineers, Kansas City District (1979), mapped historical channel migration in the Kansas River basin and its tributaries, a project which closely resembles the mapping efforts of this study. This study, directed by Professor Wakefield Dort, University of Kansas, focused on the bank stabilization of the Kansas River channel and its significant tributaries for the period of 1857-1976. The results are significant to the lower Big Blue study because channel positions of the lower Big Blue were mapped for the years 1909, 1912, 1940, 1950, 1955, and 1976 (Figure 6).

The U.S. Army Corps of Engineers (1989) has outlined the expected response of rivers to the construction of dams. Specifically they have identified the following five key responses that may apply to the study of the lower Big Blue River: 1) degradation will occur below the dam; 2) degradation will start the dam and slowly migrate downstream, decreasing the slope of the river, and thereby reducing the stream power; 3) the river bed surface will become coarser as fine particles are washed downstream over time; 4) sediment is trapped by the impoundment; and 5) the downstream river system is impacted by the changing discharge duration curves controlled by the reservoir.

Potential lower Big Blue River channel degradation could only be found specifically cited in the U.S. Army Corps of Engineers, Lower Kansas River Basin Lake Regulation Manual (1973). Here, emphasis is

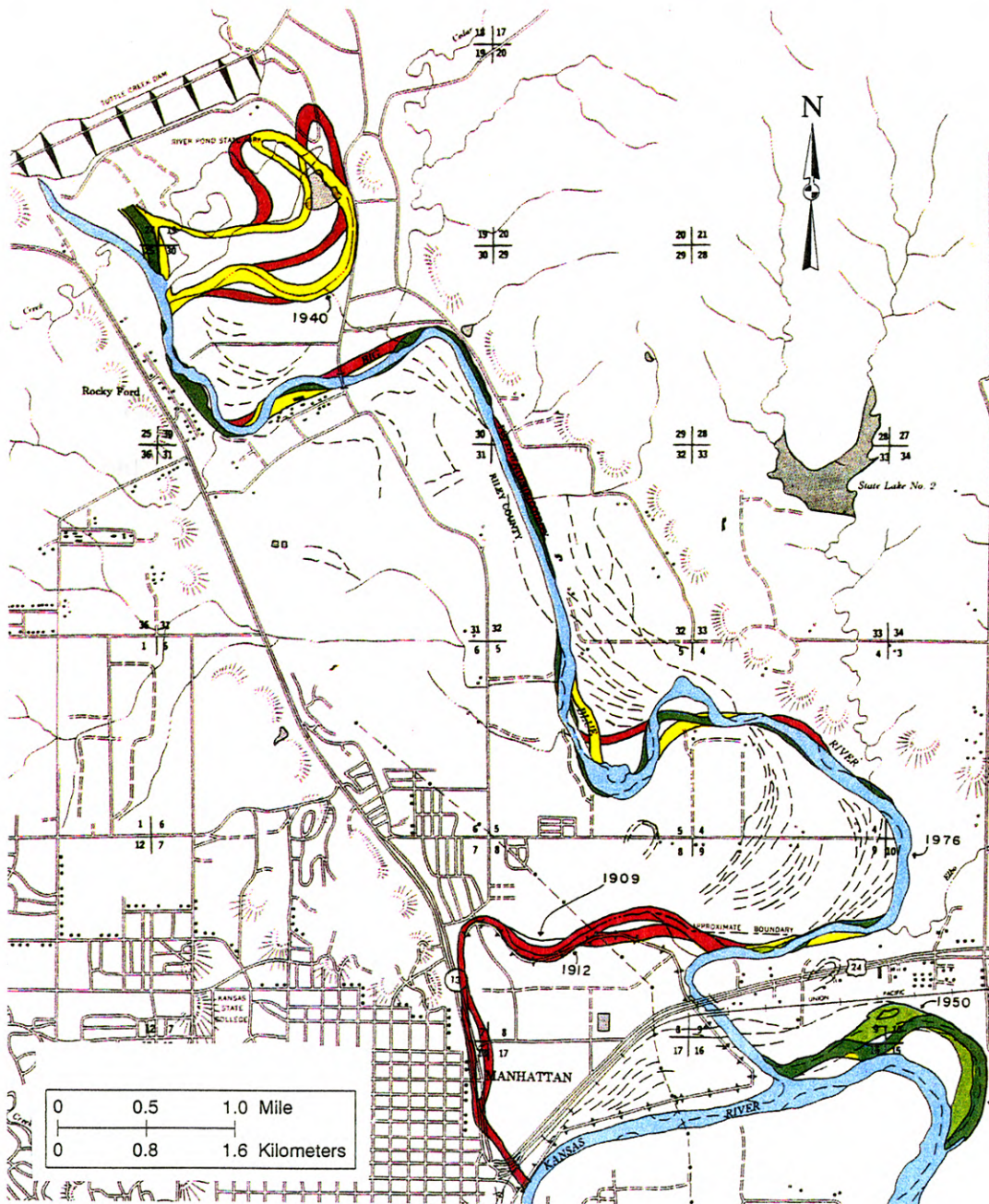
BANK EROSION STUDY



(Source: U.S. Army Corps of Engineers 1978).

FIGURE 5. Army Corps of Engineers channel bank erosion study published in 1978, indicated zones of moderate or severe erosion areas of concern. Areas marked in red indicate "severe erosion" zones.

HISTORICAL CHANNEL MIGRATION STUDY



(Source: U.S. Army Corps of Engineers 1979).

FIGURE 6. Army Corps of Engineers channel bank stabilization study published in 1979, focused on the Kansas River and its tributaries. The Big Blue River channel migration was mapped for the years of: 1909 (red), 1912 (red), 1940 (yellow), 1950 (green), 1955 (dark green), and 1976 (blue).

on Rocky Ford Dam, located 1.4 miles (2.3 km) downstream from Tuttle Creek Reservoir, and how its presence helps prevent upstream degradation. The Corps expected no appreciable degradation between Rocky Ford and Tuttle Creek Reservoir, according to the report. First, Rocky Ford Dam was to act as a stilling basin. Second, the channel below Rocky Ford was well armored and is of a low slope. In the event that Rocky Ford Dam were removed, downcutting would erode sediments collected above the dam. Erosion would eventually reach the level of the bed below Rocky Ford Dam. It was estimated that degradation of more than 10 feet (3 m) would occur between the two dams (COE 1973).

CHAPTER 2: STUDY AREA

Study Area

The area of study will be the 10 miles (16.1 km) of the Big Blue River below Tuttle Creek Reservoir (Figure 7). Attention will be focused on the immediate three miles (4.8 km) downstream from the reservoir due to the high degree of channel change (Figure 8). For the purpose of this study, this reach of the lower Big Blue River will be referred to as the "erosion zone." Brief attention will be focused approximately six miles (9.7 km) downstream from the reservoir (Figure 9) where dredging activities occurred from the early 1940s to 1988 (Kershaw 1992). For the purpose of this study, this reach of the lower Big Blue River will be referred to as the "dredging zone."

Because the focus of this study is the historical changes of the lower Big Blue River, a review of the history of the Big Blue River Valley is provided. There have been a number of researchers (e.g., Reany 1952; Schumacher et al. 1953; Meyer 1962; Webb 1969; Miller 1987) who have detailed the social impact of Tuttle Creek Reservoir on Big Blue River Valley residents. However, few studies (e.g., COE 1973, 1976 and 1978) address potential erosional and discharge impacts of the Tuttle Creek project.

The Big Blue River

The Big Blue River watershed, comprised of the Big Blue and the Little Blue Rivers, covers 9,681 square miles (25,074 km²), including all or portions of twenty Nebraska counties and seven Kansas counties

STUDY AREA

•Lower Big Blue River•



Photo: NASAAM (1989).

FIGURE 7. The lower Big Blue River is the controlled 10 mile (16.1 km) stretch of channel that extends from the release (tubes) of Tuttle Creek Reservoir, southeast to the confluence of the Kansas and Big Blue Rivers.

STUDY AREA

•Erosion Zone•

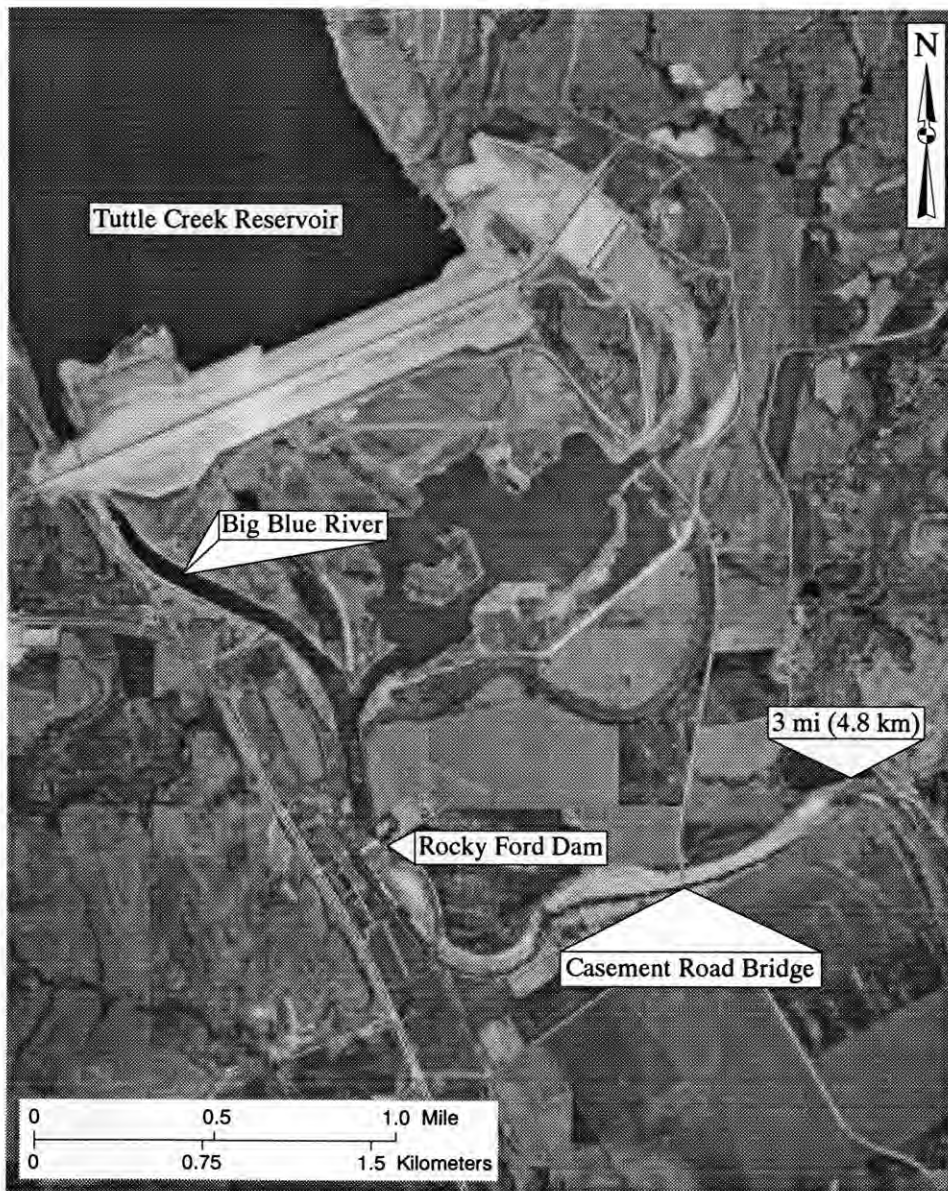


Photo: Kansas Department of Transportation (1962)

FIGURE 8. Immediately below the Tuttle Creek Reservoir, bank erosion can be identified nearly three-miles (4.8 km) downstream from the dam. Rocky Ford Dam is located approximately 1.4 miles (2.2 km) downstream and Casement Road Bridge is approximately 2.5 miles (4.0 km) downstream from Tuttle Creek Reservoir.

STUDY AREA

•Dredging Zone•

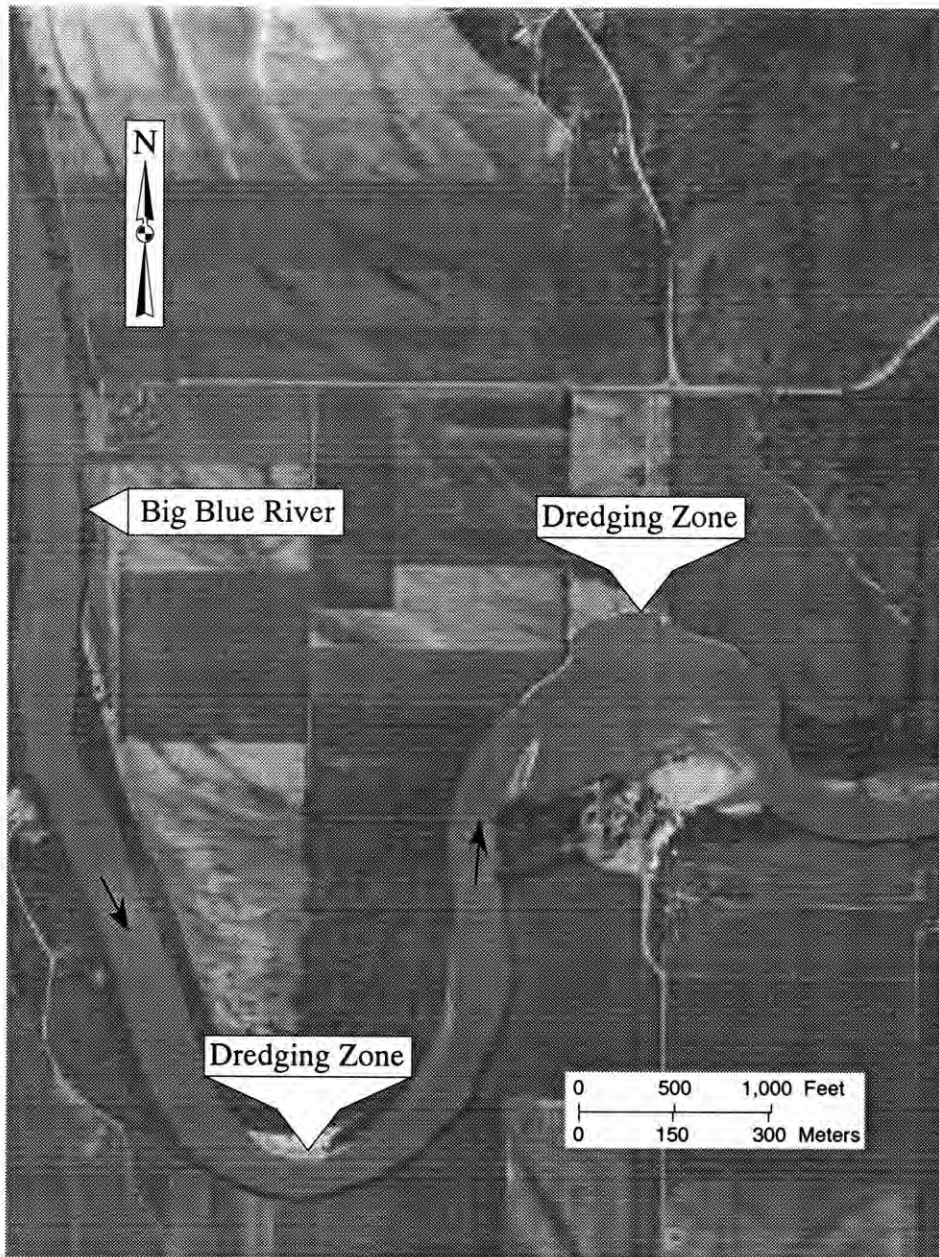


Photo: U.S. Army Corps of Engineers (1967)

FIGURE 9. Sand dredging activities occurred on the Big Blue River between 1940s and 1988 approximately six miles (9.7 km) downstream from Tuttle Creek Reservoir.

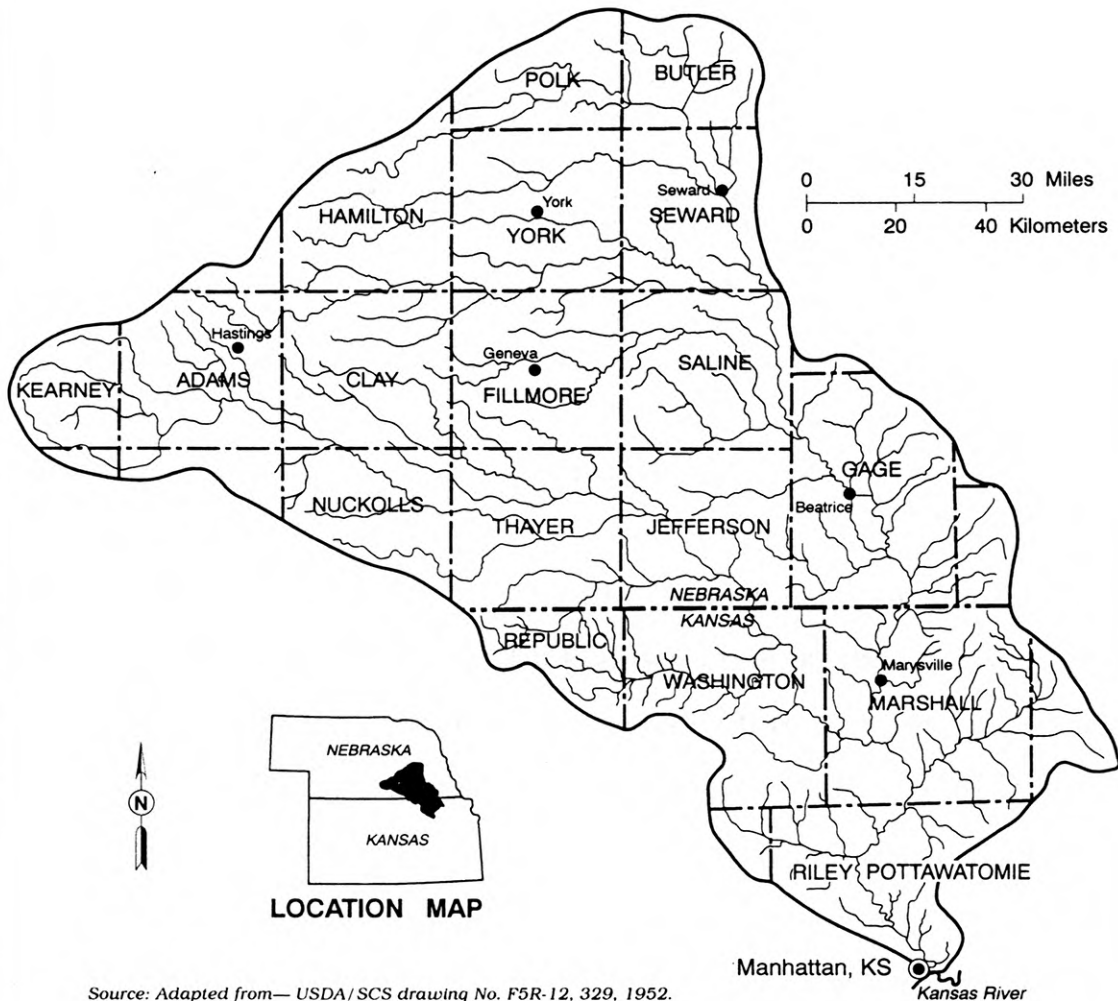
(USDA/SCS 1952; COE 1976). Beginning in southern Nebraska near Grand Island (Figure 10), the Big Blue River flows eastward 50 miles (81 km) to Ulysses, Nebraska, before swinging southeast and flowing nearly 300 river miles (483 km) to the junction with the Kansas River near Manhattan, Kansas (COE 1976). The length of the Big Blue River basin is 150 miles (242 km), with an upper area width of 120 miles (193 km) and a lower area width of 50 miles (81 km). Three-fourths of the watershed is in Nebraska, or 7,200 square miles (18,648 km²). Big Blue River Valley widths vary from 1,320 feet (402 m) to nearly one mile (1.61 km), with an overall valley average of approximately 4,000 feet (1,219 m) spanning from the Tuttle Creek dam northward to Seward, Nebraska. The topography undergoes a gradual transition from gently rolling hills in the upper reaches to the Flint Hill in the lower reaches (COE 1976).

There are two major river systems that contribute to the Big Blue River watershed, the Big Blue and Little Blue Rivers (COE 1960). The Little Blue River is a significant contributor to the Big Blue River discharge. The Little Blue river alone drains 3,538 square miles (9,163 km²), which constitutes approximately 36% of the total watershed. The Little Blue River valley falls from an elevation of 2,230 feet (680 m) in the upper end to 1,080 feet (329 m) at the confluence with the Big Blue River. The Little Blue valley is approximately one mile wide near Hebron, Nebraska, but narrows progressively downstream (COE 1973).

Environmental Setting

Geographically, Tuttle Creek Reservoir is nestled in the Osage Plains division (Figure 11) of the Central Lowlands physiographic

BIG BLUE RIVER WATERSHED



Source: Adapted from— USDA/SCS drawing No. F5R-12, 329, 1952.

FIGURE 10. The Big Blue River watershed covers 9,681 square miles (25,074 km²) above the mouth of the Big Blue River (COE 1976) . The two major contributors to the Big Blue watershed are the Big Blue and Little Blue Rivers. The Little Blue River alone drains 3,538 square miles (9,163 km²), approximately 36%, of the total watershed. (COE 1973).

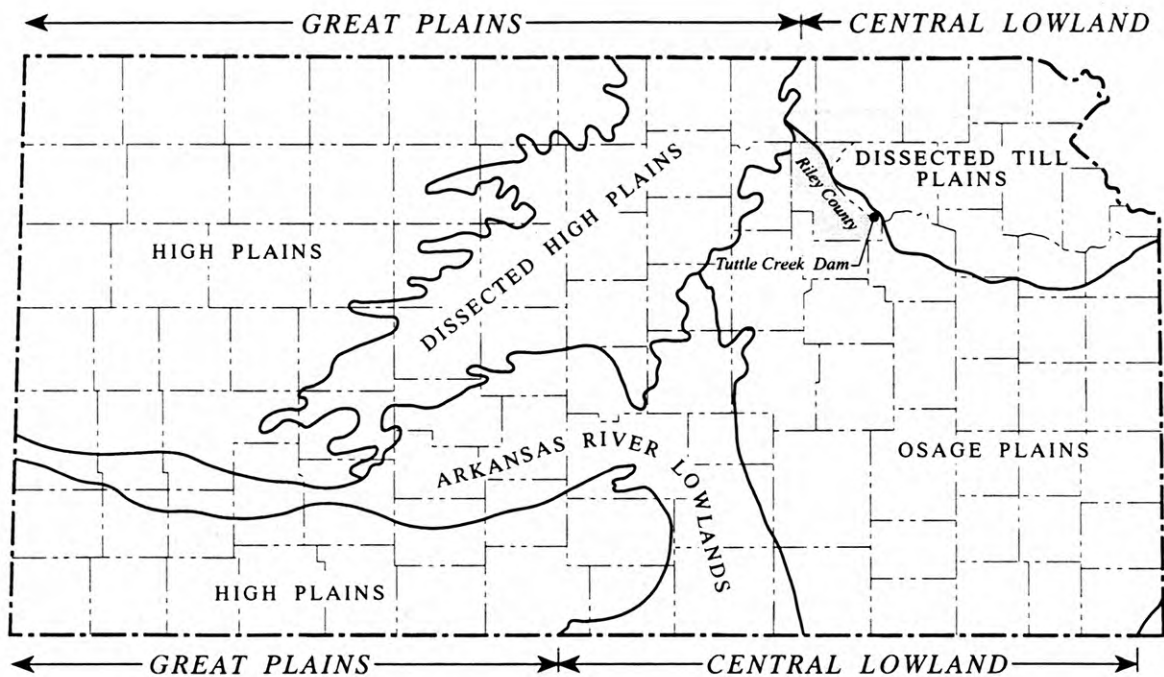


FIGURE 11. Generalized physiographic map of Kansas.
 Source: Adapted from Schoewe 1949.

province (Fenneman 1938). The Big Blue River basin near Randolph, Kansas, is within the Dissected Till Plains section of the Central Lowlands. Pleistocene glacial drift deposits with thicknesses of 300 feet (91.4 m) form a discontinuous mantle over much of the Randolph area (Figure 12) (COE 1976). The stratigraphy underlying Tuttle Creek Dam (Figure 13) is 10 to 50 feet (3.0 to 15.2 m) of alluvial deposits overlying the Foraker Limestone, which in turn overlies the West Branch Shale (Chelikowsky 1976). Exposures in the valley walls are sequences of limestones and shales of Permian Age belonging to the Council Grove group (COE 1976). Beneath the Permian units lie additional sequences of limestone and shales of Pennsylvanian Age extending in thicknesses up to 2,000 feet (610 m). Weathering of bedrock has been described by the Corps of Engineers (1976) as moderate pitting of the limestone and

GENERALIZED GEOLOGIC MAP OF KANSAS

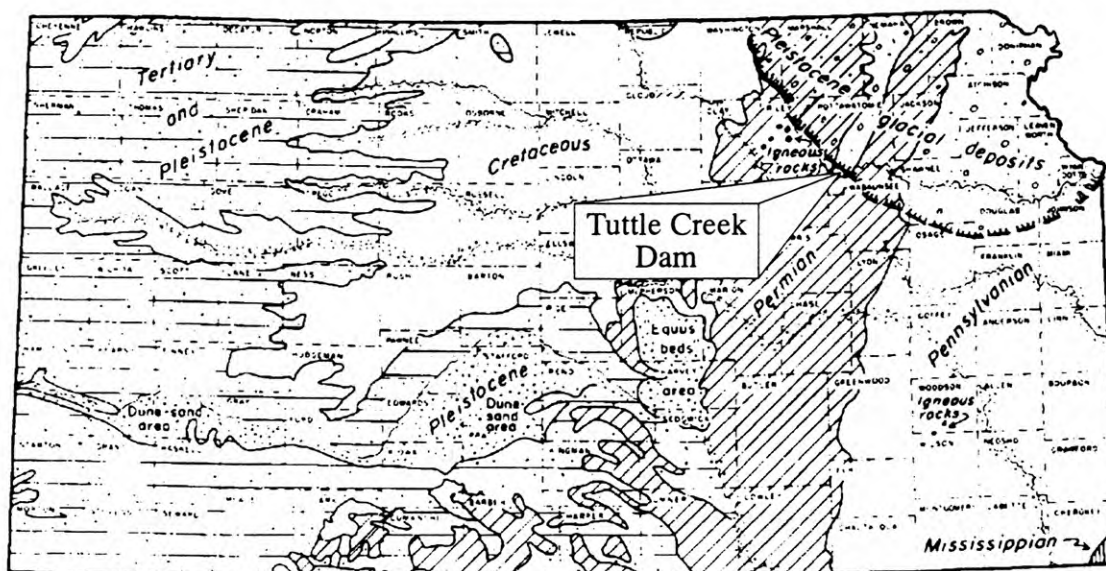


FIGURE 12. Generalized geologic map of Kansas from Chelikowsky (1976). Tuttle Creek Reservoir lies to the west of the boundary between Riley and Pottawatomie Counties.

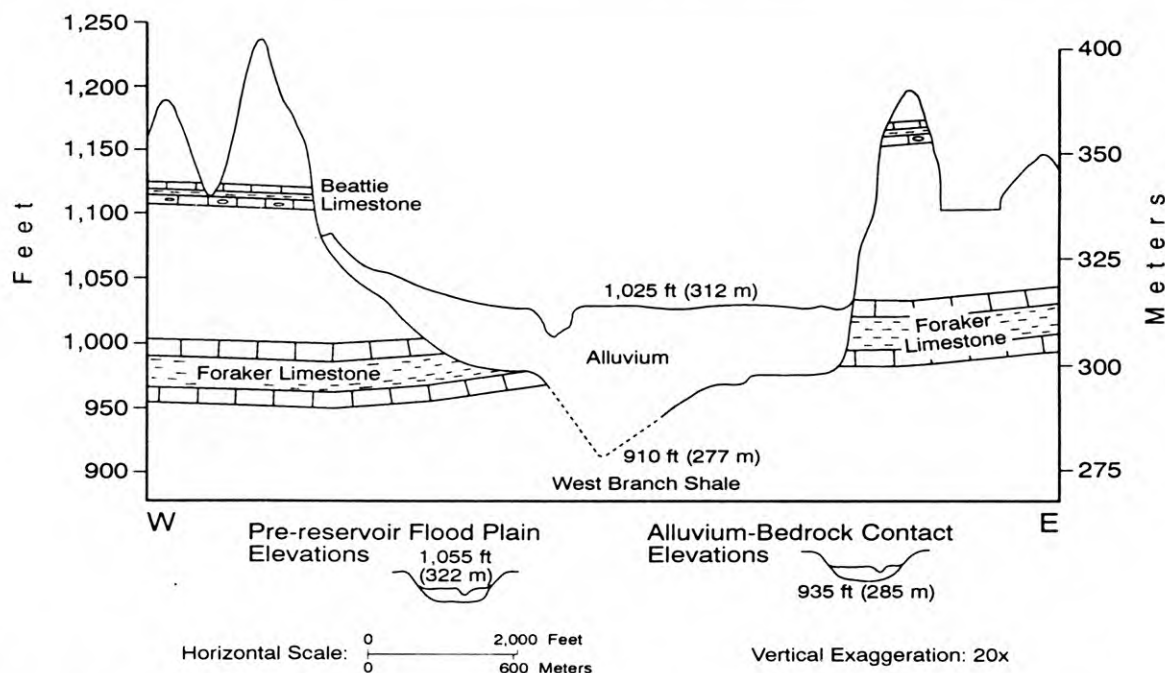


FIGURE 13. Geologic cross section of the Big Blue River Valley at the location of where Tuttle Creek Reservoir now stands. Interbedded limestones and shales dominate the lithology of the area. Principal units are the Beattie Limestone, Foraker Limestone and the West Branch Shale. Source: Adapted from—Chelikowsky 1976

moderate-to-extensive softening of the shales. Tuttle Creek Reservoir geologically lies astride the Abilene Anticline and the Irvine Syncline, according to work published by Chelikowsky (1972).

The soils in the vicinity of Tuttle Creek Reservoir vary according to drainage basin. For example, the Black Vermillion River basin, a minor contributor to the Big Blue River basin, is comprised of silty clay loam soils weathered from glacial till and loess. Conversely, soils encountered in the Little Blue River basin are described as silty loams and silty clay loams developed in loess. The Big Blue River basin contains soils of a silty clay loam nature derived from loess, shale and limestone residuum (COE 1976). Soils below Tuttle Creek dam are classified as the Eudora-Haynie-Sarpy (Figure 14) association consisting of deep, nearly level silt loams with very fine sandy loams on the terraces and flood plains (USDA/SCS 1975).

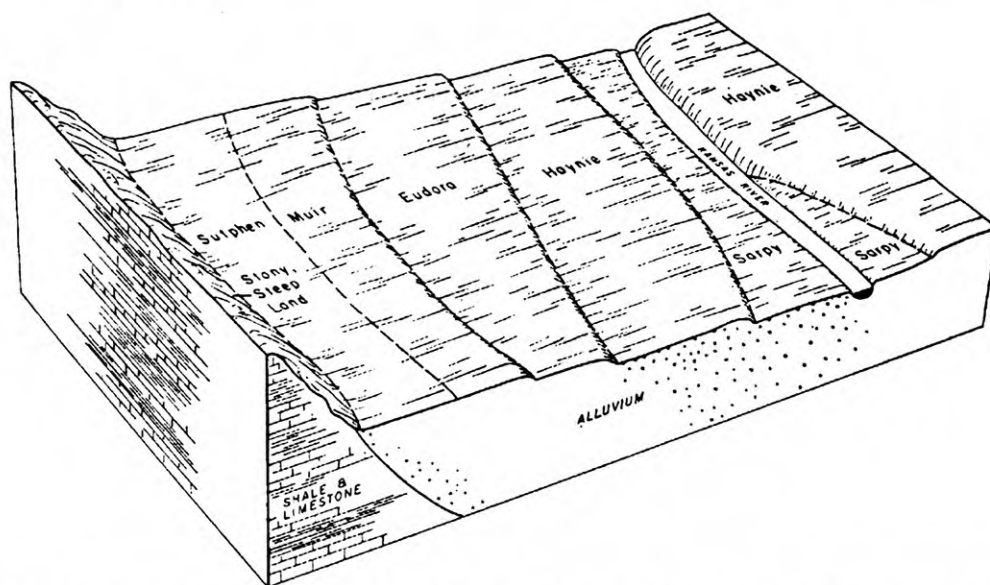


FIGURE 14. Soils common along the river banks of the lower Big Blue River below Tuttle Creek Reservoir, are classified as the Eudora-Haynie-Sarpy association. Soils of this type are primarily losses and loams with more sandy composition near the river channel and higher clay content up on the terraces away from the river channel.

Source: USDA/SCS 1975

Climate of the Big Blue River basin ranges from dry subhumid in the western portion of the basin to moist subhumid in the southeast part of the basin (COE 1973). The Manhattan, Kansas, area is classified as a continental climate that commonly has warm to hot summers, cold winters, abundant sunshine throughout the year, moderate to gusty winds, and low to moderate humidity. The average precipitation is 31.6 inches (803 mm) per year, of which 75% falls between April and September. Annual precipitation in Manhattan has ranged from 15.1 inches (384 mm) in 1860 to 60.4 inches (1,534 mm) during 1951 (USDA/SCS 1975). Maximum annual rainfall recorded for the Big Blue River basin was 40.8 inches (1,036 mm) in 1902, with the minimum annual rainfall being 15.9 inches (404 mm) recorded in 1936 (COE 1973). Snow fall is light with an annual average of 19 inches (48.3 mm) and generally not more than 30 inches (762 mm) during a harsh season. Temperature ranges are relatively large. The average daily maximum for a given year is 67.5°F (19.7°C), while the average daily minimum is 43.1°F (6.2°C). Record temperature extremes range over the period of record (since 1858) from -32°F (-35.6°C) to 116°F (46.7°C). (USDA/SCS 1975). The average annual lake evaporation for Tuttle Creek Reservoir is 51 inches (1,295 mm) , calculated with a pan evaporation value of 0.7. (COE 1973)

Big Blue River Flood History

Flood events are an important factor in a river channel morphology. Each flood event impacts the morphology of the river channel in one way or another; often the channel takes a new course because of a flood event (McCrae 1954; COE 1972, 1973 and 1979; Elks

1979; and Tank 1983). The Big Blue River has a long history of flooding. Many of the early floods experienced in the Big Blue River basin are a matter of legend and folklore rather than of record (COE 1972). Floods in the Big Blue basin were concentrated in the broad flood plains of the main channel and major tributary valleys. Generally, flooding occurs during the spring and summer months, however, floods have occurred in almost all months. Floods on the Big Blue River often contributes to flooding on the Kansas River (COE 1973).

During the 71 year period from 1902 to 1972, floods were recorded in 37 years. However, during the period of 1941-1972, 54 individual flood events occurred in the Big Blue basin (COE 1973).

Flood events from 1973 to 1991 were of low magnitude, according to discharge data collected by the USGS, and were not indicative of the historical flood regime (LaCock 1992). Rains received in 1992 produced significant flood stage levels in the Blue River Basin, however, the statistics for the 1992 events were not compiled for public release as of this writing.

Tuttle Creek Reservoir

Tuttle Creek Reservoir was a key dam in the \$15 billion Pick-Sloan Missouri Basin plan of 1944. This plan was designed to create a network of reservoirs to stabilize surface water flow on the Kansas, Missouri and Mississippi Rivers (Friggens 1953). Although authorized by Congress in the Flood Control Act of 1938 (Public Law 75-761), construction on Tuttle Creek Reservoir did not begin until October, 1952, when \$5 million were appropriated for the project (COE 1973). Construction was

halted in December, 1953, due to a lack of additional appropriations, but resumed in 1955 (Figure 15). During construction in the late 1950's, approximately 2.1 miles (3.4 km) of the Big Blue River channel was rerouted to facilitate the dam construction (Figure 16 and Figure 17). Closure of the dam was completed on July 20, 1959. Operation of Tuttle Creek Reservoir began July 1, 1962. The initial filling of the multipurpose pool, 1,075 feet (327 m) above mean sea level, was reached on April 29, 1963. The total cost of the project was \$80,274,774. (COE 1973) Today, approximately 50% of the Kansas River discharge volume is provided by the Big Blue River (Buehre 1991).

At the normal multipurpose pool level (Figure 18) of 1,075 feet (327 m), Tuttle Creek Reservoir has a mean surface area of 13,350 acres (5,402 ha). During periods of heavy rainfall (Figure 19) in the Big Blue Valley, the flood control pool level could rise to a maximum of 1,136 feet (346 m), with a mean lake surface area of 54,050 acres (21,874 ha) (COE 1988).

The dam is a rockfill and earth embankment 7,487 feet (2,282 m) long, 50 feet (15.2 m) wide at the top and 1,640 feet (500 m) wide at the base. Twenty-one million cubic yards (16,056,600 m³) of fill were needed for the dam. The dam is 134 feet (40 m) above the valley floor, with a maximum height above the streambed of 157 feet (48 m) (COE 1973).

The spillway, located east of the dam, has a width of 1,059 feet (322.8 m) including the piers and bulkheads. The spillway design is a controlled chute, with eighteen Tainter gates, each 40 feet (12.2 m) by 20 feet (6.1 m). The spillway has a maximum flood control pool (1,136 feet / 346.3 m) discharge capacity of 233,500 cfs (26,150 m³) (COE 1973).

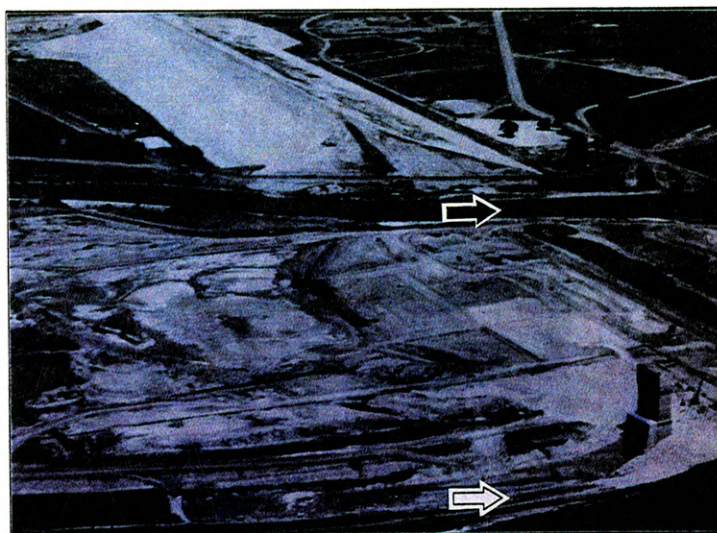


FIGURE 15. An aerial view of the construction of Tuttle Creek Reservoir around 1957, facing east. The original (black arrow) channel and new (white arrow) channel excavation are identified, respectively. Photo courtesy of Riley County Historical Society.

FIGURE 16. During the construction of Tuttle Creek Dam, approximately 2.1 miles (3.4 km) of the Big Blue River channel was rerouted. Source: COE 1973

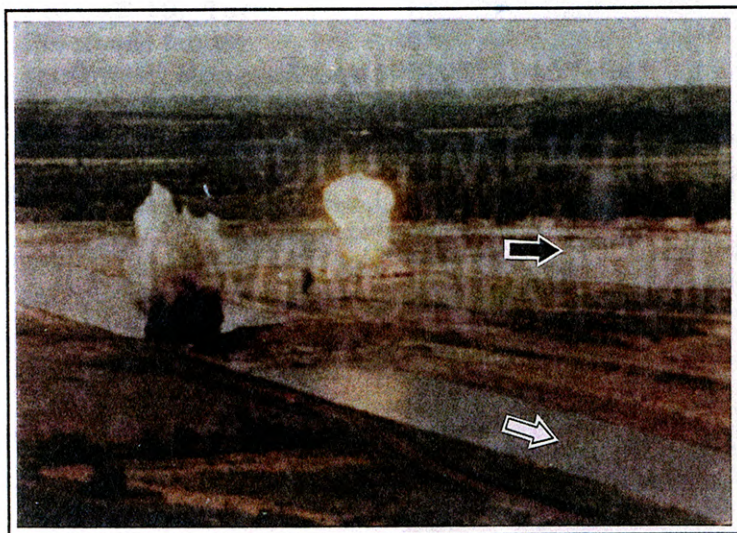
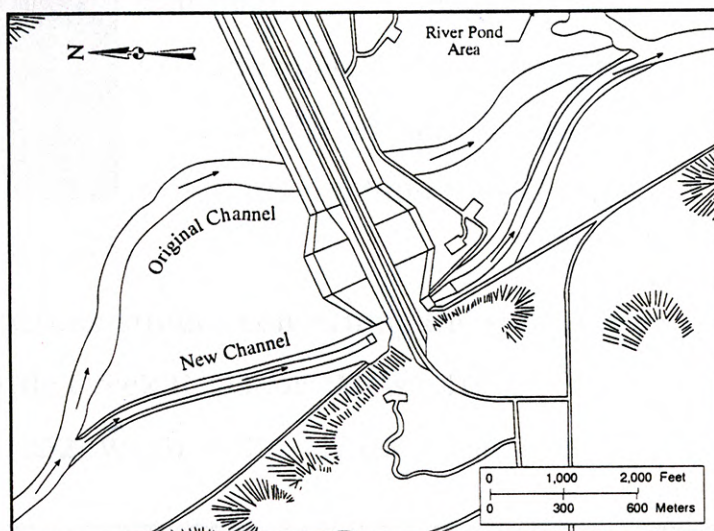


FIGURE 17. The detonation of the explosives to open the new channel of the Big Blue River to the control tower of Tuttle Creek Dam, July 4, 1958, facing north. The original (black arrow) channel and new (white arrow) channel are identified, respectively. Photo courtesy of Riley County Historical Society.



FIGURE 18. The massive intake structure at Tuttle Creek Reservoir photographed around 1959, facing south. During normal operation, control pool elevation (arrow) will be at 1,075 feet (327 m) above mean sea level. Photo courtesy of Riley County Historical Museum.

The outlet works, commonly referred to as the tubes, are a twin horseshoe conduit design, 20 feet (6.1 m) in diameter (Figure 20) operated by four half-inch thick stainless steel hydraulic gates. At flood control capacity, the maximum discharge with both conduits fully open is

45,900 cfs (1,292 cms) (COE 1973).

There have been numerous studies concerning the controversy over the construction of Tuttle Creek Reservoir (Meyer 1962; Schumacher 1953; Reany 1952; Webb 1969). Tuttle Creek project

FIGURE 19. Tuttle Creek Reservoir, facing southwest, along the axis of the dam during operation in June of 1991. During the month of June, 1991, discharge high was 7720 cfs (217 cms), minium discharge was 880 cfs (24.8 cms). The total release from Tuttle Creek Reservoir for this period was 212,200 acre-feet (26,150 m³).

Photo by Author

Statistics: USGS 1992.



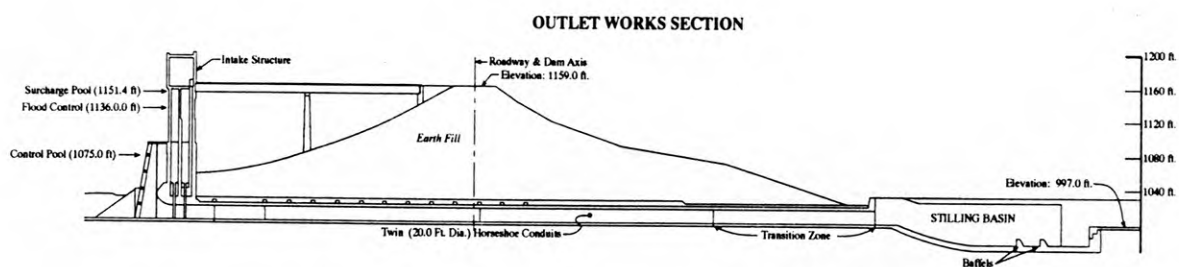


FIGURE 20. Tuttle Creek Reservoir outlet works cross-section. Source: COE 1973

supporters campaigned that the dam would serve as flood protection for downstream communities. After the devastating flood of July 1951, which caused over \$1 billion in damages throughout Kansas and Missouri, Army Engineer General Lewis Pick lobbied to Congress that if there had been reservoirs in place such as Tuttle Creek Dam, the disaster of the 1951 flood could have been averted (Friggens 1953). This statement was challenged by the Kansas Farm Bureau (no date), which argued that Tuttle Creek Dam would have been a negligible factor in controlling the flood of 1951.

Local residents protested that they would suffer acute hardships if the Tuttle Creek Project went forward (Figure 21).

"The Corps of Engineers promised that this lake (Tuttle Creek) will afford wonderful boating and fishing for the residents and vacationers visiting there...

But who wants to sail a boat over the submerged homes of thousands of his fellow-citizens, and who wants to fish where his line may bring up a corpse out of one of the cemeteries of 7 towns? Not to mention the tens of thousands of magnificent trees—elms, oaks, pines, which have shaded the homes in the valley for generations, and which will "Lift their leafy arms to pray" high above the flood, until they die!" —Anonymous— (Morton, no date)

During the Tuttle Creek Project, thirteen churches were removed; seven towns were abandoned, of which only two, Randolph and Blue Rapids, were relocated; eight schools were removed; and twelve

FIGURE 21. This cartoon holds little humor in the eyes of the Blue Valley settlers who would lose millions of dollars in economic revenue every year as a result of the construction of Tuttle Creek Dam. The caricature was thought to be drawn around 1945 by Kenneth McClain. (Graphic courtesy of Riley County Historical Museum).



cemeteries containing 3,212 graves were relocated. No information was available for the number of homesteads that had to be abandoned for the Tuttle Creek Project (Barber 1972). A total of 33,634 acres (13,611 ha) was

acquired for state, public, and corps use, multipurpose pool, fish and wildlife, and recreational purposes (COE 1976).

Rocky Ford Dam

Located 1.4 miles (2.3 km) below Tuttle Creek Dam, Rocky Ford Dam has a long history and significant role in the development of the lower Big Blue River and Manhattan, Kansas.

In 1853 an early settler named Samuel Dyer from Tennessee operated a government-sponsored ferry, which traveled across the Big Blue River at Juniata, about one mile (1.61 km) downstream from the present location of Rocky Ford Dam (Historical Plat 1881). The Ft. Riley military crossing (Figure 22) was also located near the Juniata location

FIGURE 22. Early settlers (1906) are seen here at the old military crossing preparing food. The military crossing was downstream approximately one mile from where Rocky Ford Dam now stands. (Photo courtesy of Riley County Historical Museum).



(Mithen 1992).

In 1860 E. B. Purcell built a wooden dam (Figure 23) to harness the energy of the Big Blue for grinding grain. For nearly ten years Purcell continued to provide milling services for the Riley county residents (Manhattan Mercury 1929).

By 1870 railways had developed in the Big Blue Valley, and farmers

FIGURE 23. Purcell Dam, shown here in an 1870 photograph, was constructed in 1860. The dam was used to mill grain for ten years and then sat idle for 40 years before being developed to generate electricity (Photo courtesy of Riley County Historical Museum).



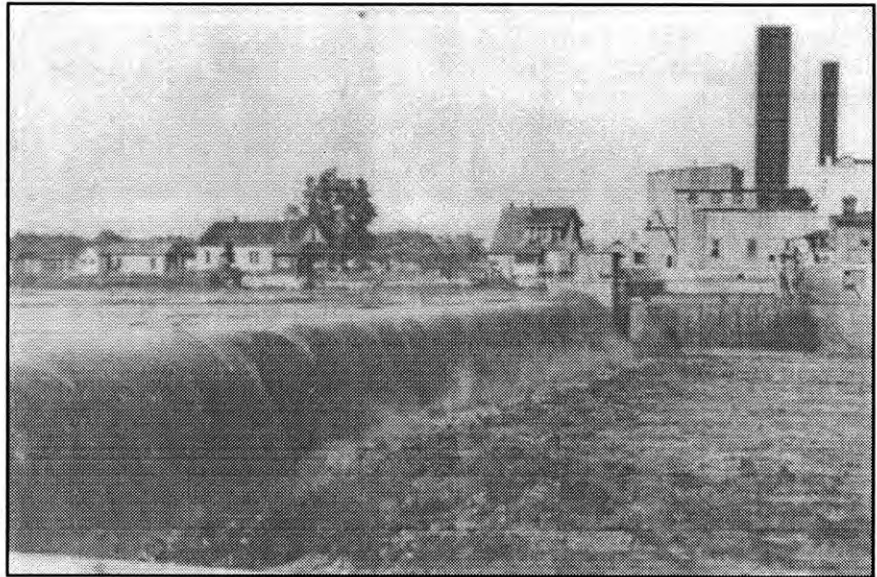
were shipping their wheat out of the valley. This eventually led to the closure of the Purcell Mill. The site remained inactive for 40 years until C.K. Raver and Harry Pierce of Junction City considered the old mill a possible source for generating electricity. After replacing the wooden structure with a 14-foot (4.3 m) high concrete dam and installing efficient water wheels and electric generators, Raver and Pierce began to generate electricity in 1909. Since the power plant site was originally granted for milling purposes, it was necessary to operate a grist mill at the plant for some years. Milling was eventually discontinued due to competition from other millers in the area. By 1910, enough electricity was being produced to service the entire valley (Manhattan Free Press 1991).

Cleyson Brown from Abilene purchased the Rocky Ford Plant in 1917 and installed newer, more efficient machinery to increase the plant's electrical capacity. The Rocky Ford Plant provided service to Manhattan, Ogden, Ft. Riley, Junction City and Abilene, Kansas. In 1919, Rocky Ford Power Plant was destroyed by fire. Brown rebuilt the plant as a two-story building containing new equipment. After the flood of 1920, which washed the original 1908 concrete dam out, a new hollow-core dam was completed in April of 1921. The new dam was designed with a nine-foot (2.7 m) passageway to allow fuel carried by the Blue Valley Railway to be transported from the west bank to the plant on the east bank. The new dam was christened with a dinner served in the passageway for 150 guests (Poresky, No Date).

The demand for electricity grew throughout the 1920s. In 1925-26, the Brown United Company was acquired by the newly formed Kansas Power and Light Company (Figure 24). The Rocky Ford plant

FIGURE 24. Rocky Ford Power Plant, photographed facing north, around the year of 1930, was then under the control of the recently formed Kansas Power & Light Company.

(Photo courtesy of Riley County Historical Museum).



was closed in 1965 in large measure because of the proposal to construct the Jeffrey Energy Center. In 1974 the Kansas Fish and Game Commission announced plans to dismantle the plant, which were later carried out because of public safety concerns (Manhattan Free Press 1991).

Rocky Ford Dam remains today under the control of the Kansas Wildlife and Parks, formerly known as Kansas Fish and Game. Area residents find the Rocky Ford area popular for fishing. The Kansas Wildlife and Parks Commission recently restored the retaining wall, referred to as the “hogback” (Figure 25), to enhance angler access to the river channel area. The new wall stands in approximately the same location as the original retaining wall once did (Beaver 1992).



FIGURE 25. Rocky Ford Dam, photographed facing northwest, in May of 1992, is still a favorite spot for local anglers. The retaining wall was reconstructed in the summer of 1988 to improve angler access to the river. *(Photo by: Author)*

CHAPTER 3: METHODOLOGY

Channel Mapping

Approximate Big Blue River channel migration paths were reconstructed from historical plat surveys, USGS topographic quadrangles, and aerial photographs spanning the study period of 1857 to 1989. Historic channel paths of the Big Blue River were documented in this study for the following years: 1857, 1886, 1937, 1947, 1952, 1963, 1973, 1982, and 1989. The channel path reconstruction dates were selected based upon availability of aerial photographs and maps.

For the purpose of this study, the reconstructed channel paths will be represented from the current location of Tuttle Creek Dam to the confluence of the Big Blue and Kansas Rivers, ten miles (16.1 km) southeast of the dam. The active river channel varies greatly throughout a single year during periods of high and low flow. Therefore, to be consistent for mapping purposes, the "channel" is defined as the river channel at bankfull stage (Figure 26).

The channel was electronically reconstructed in a four stage process (Figure 27): 1) electronically scan the plat map or aerial photograph at 300 dpi resolution, establish reference points; 2) magnify the channel image by 800x and "on-screen digitized" the channel path, export drawing as an Encapsulated Postscript (EPS) image; 3) import the reconstructed channel path into a graphics software package; 4) superimpose the reconstructed channel path (represented in black) on the basemap channel (represented in gray) utilizing known reference points and landmarks to correctly position the digitized channel image.

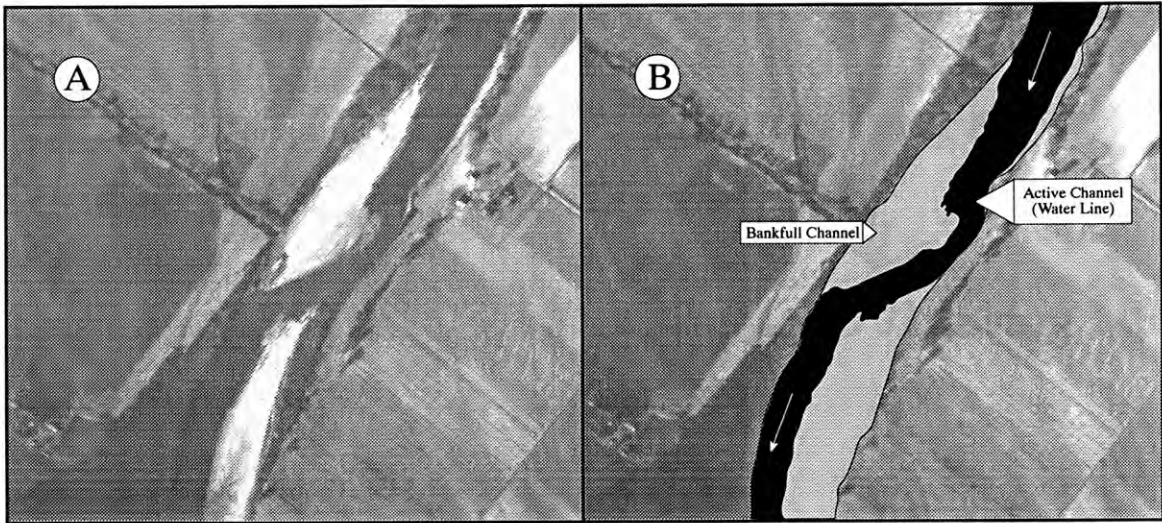


FIGURE 26. A) The active river channel flow may vary throughout the year within the river banks. B) The active river channel (indicated in black), or what is identified on aerial photos as the water line, would not offer a representative annual channel path for a given year. Therefore, the bankfull channel (gray and black portions), which includes sidebar deposits (indicated in gray), is mapped to represent the reconstructed channel for a given year. (Photo source: Corps of Engineers 1952)

Reference points for surveys and USGS topographic quadrangles were the township-range section lines. For example, the channel path years of 1857, 1886, 1947, 1963, and 1982, were positioned by section line reference points. Aerial photographs were referenced to known human-made features present in the study area. For example, features such as Rocky Ford Dam, Casement Road bridge, and the U.S. Highway 24 bridge sites remained constant from 1937 to present. At a minimum, three reference points were utilized to position each reconstructed channel.

It is expected by utilizing the “on-screen digitizing” method of channel reconstruction that there should be little error introduced at this level of the study ($< \pm 1\%$).

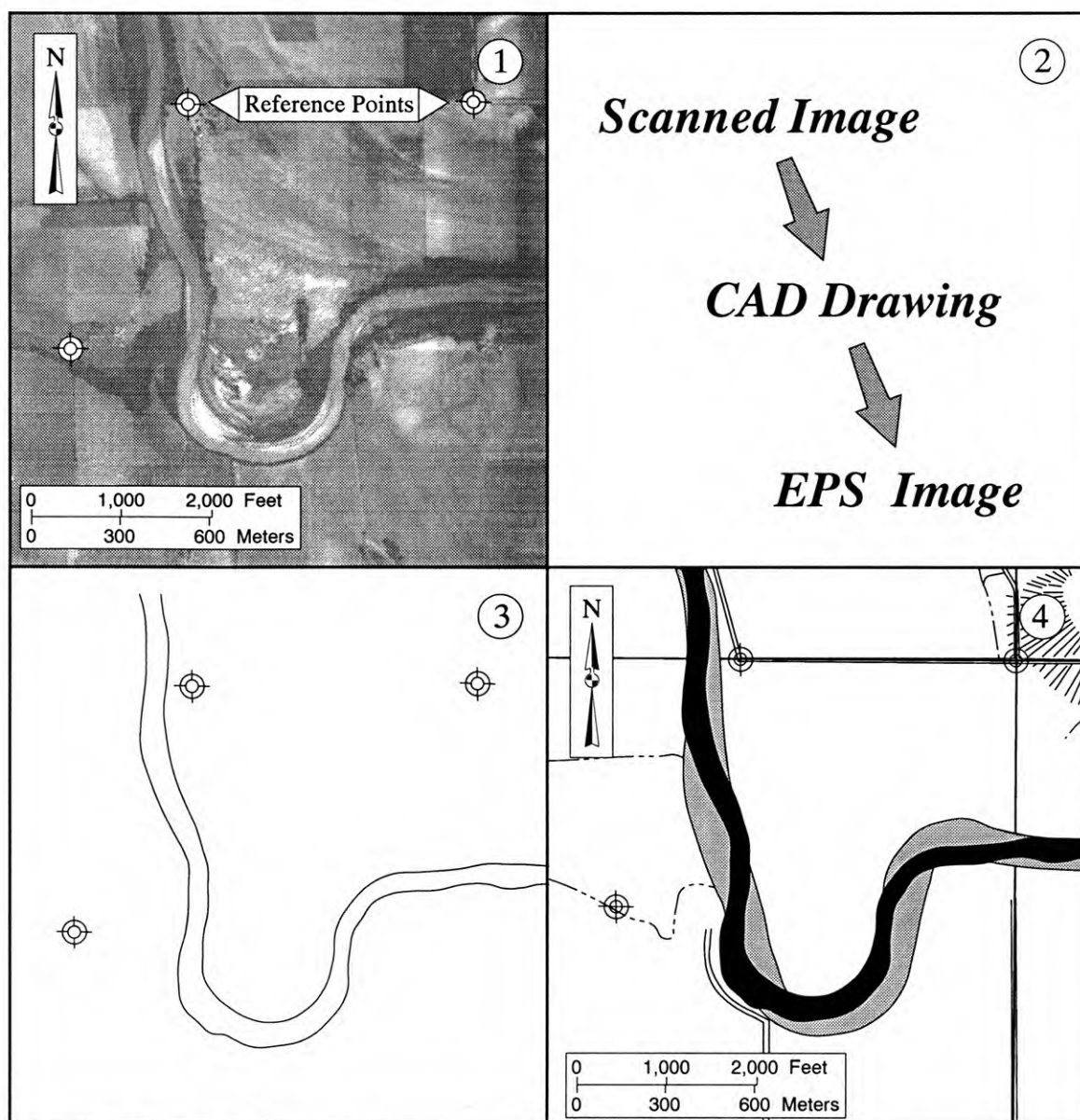


FIGURE 27. 1) Electronically scan the river channel source into the computer, identify reference points. 2) Magnify the channel image and digitally trace the bankfull channel boundary, export tracing as an EPS image. 3) The EPS image is in the form of a line tracing which can be "filled" as a shaded area. 4) Superimpose EPS channel tracing (represented in black) over the basemap channel drawing (represented in gray). (Photo source: National Archives 1937; Basemap: Corps of Engineers 1963)

Aerial Photographs

Aerial photography covering the study area was limited by: coverage availability, extent of coverage, year of the coverage, scale of the coverage, and study funding. The Aerial Photography Summary Record

(1990) supplied from National Cartographic Information Center (NCIC), Rolla, Missouri, listed 77 aerial photography flights between 1937 and 1989 conducted by 10 agencies over the lower Big Blue area. Coverages utilized in this study for the lower Big Blue River ranged from complete, defined as the entire stretch of river being covered, to spotted or partial, indicating only portions of the channel were included in the flight path. Scale of the photography also had to be considered in using images. For example, when aerial photography scale is 1:4,800, as many as 13 individual 9"x9" frames are required to cover the lower Big Blue River. Conversely, if photography has a scale of 1:65,000, one frame completely covers the study area. There were inherent advantages to using larger scaled photographs, including greater detail and increased accuracy with channel reconstruction and sinuosity measurements. The added expense, however, made it too costly to use larger scaled images.

Seventy-eight aerial frames between 1937 and 1989 were evaluated for this study. Aerial photographs utilized in this study are summarized in Table 1.

Low Altitude Aerial Photography

Low altitude (below 2,000 feet) aerial color photography was taken by the author during the month of June, 1991. The flight was chartered from Spicer Aircraft Inc. located in Manhattan, Kansas. The purpose of this photography was to identify areas of concern along the lower Big Blue River representing the period between 1989, the last available aerial photography flight, and 1991, the time of final data collection for this study. The low altitude photography was utilized in this study for

TABLE 1
-Aerial Photography Summary-

DATE	MEDIA	SCALE	COVERAGE	SOURCE
9/18/37	Black & White	1:20,000	Complete	National Archives & Records Washington, D.C.
5/15/42	Black & White	1:20,000	Complete	National Archives & Records Washington, D.C.
8/16/50	Black & White	1:15,840	Partial	Riley County Appraiser's Office Manhattan, Kansas
8/2/51	Black & White	1:24,000	Partial	KSU, Dept. of Agronomy Manhattan, Kansas (ASCS Flight)
8/2/51	Black & White	1:24,000	Complete	Agricultural Stabilization & Conservation Service (ASCS) Salt Lake City, Utah
11/14/52	Black & White	1:12,000	Complete	U.S. Army Corps of Engineers Kansas City, Missouri
8/3/56	Black & White	1:15,840	Complete	Riley County Appraiser's Office Manhattan, Kansas
8/3/56	Black & White	1:20,000	Partial	KSU, Dept. of Agronomy Manhattan, Kansas (ASCS Flight)
8/3/56	Black & White	1:20,000	Partial	KSU, Dept. of Geography Manhattan, Kansas (ASCS Flight)
4/19/62	Black & White	1:24,000	Complete	Kansas Dept. of Transportation Topeka, Kansas
10/12/67	Black & White	1:15,840	Complete	U.S. Army Corps of Engineers Kansas City, Missouri
9/27/69	Black & White	1:20,000	Complete	Agricultural Stabilization & Conservation Service (ASCS) Salt Lake City, Utah
6/20/73	Black & White	1:28,800	Complete	Kansas Dept. of Transportation Topeka, Kansas
6/27/74	Black & White	1:12,000	Complete	U.S. Army Corps of Engineers Kansas City, Missouri
1/23/76	Black & White	1:48,000	Complete	U.S. Army Corps of Engineers Kansas City, Missouri
3/31/77	Color	1:24,000	Complete	U.S. Army Corps of Engineers Kansas City, Missouri
2/?/80	Black & White	1:12,000	Partial	Riley County Appraiser's Office Manhattan, Kansas
3/?/86	Black & White	1:4,800	Complete	Riley County Appraiser's Office Manhattan, Kansas
10/12/89	Color Print	1:65,000	Complete	Earth Science Information Center Rolla, Missouri (NASAAM Flight)

documentation purposes; no channel measurements were collected from this photography. The approximate scale of the photography varied due to focal length, camera angle and flight altitude, therefore photoscale could not be accurately represented.

Map Coverage

In addition to aerial photography, map surveys of the lower Big Blue River channel were utilized to assess historical channel migration. Map accuracy could not be established, however, it was assumed maps provided a reasonable representation of the historical channel path. Map surveys and USGS topographic quadrangles researched for this study are summarized in Table 2.

Sinuosity

Sinuosity was calculated for the lower Big Blue River for the years 1857, 1886, 1937, 1947, 1952, 1963, 1973, 1982, and 1989. Methodology for determination of sinuosity followed procedures discussed by Osterkamp and Hedman (1981). Sinuosity was determined by dividing the lower Big Blue River channel length, measured down the center axis of the channel, by the river valley length. In the event the active river channel had a divided path, such as the case of a divided channel that has yet to be truncated, the longest channel path was calculated.

River channel and valley lengths utilized to determine channel sinuosity were electronically measured from the reconstructed channel figures with the aid of a Macintosh based CAD computer program. Once

TABLE 2
-Map Coverage Summary-

YEAR	SCALE	SOURCE
1857	1:63,360	Cadastral Plat, Riley Co. Engineers Office, Manhattan, KS
1886	1:125,000	Topographic Map, USGS Junction City Quadrangle
1947	1:125,000	Topographic Map, USGS Manhattan Quadrangle
1963	1:30,000	Channel Route Map, Army Corps of Engineers
1978	1:48,000	Historical Channel Migration Map, Army Corps of Engineers
1978	1:24,000	Topographic Map, USGS Manhattan Quadrangle
1979	1:48,000	Bank Stabilization Map, Army Corps of Engineers
1981	1:50,000	Ft. Riley Installation Map, Defense Mapping Agency
1982	1:24,000	Topographic Map, USGS Manhattan Quadrangle
1982	1:4,800	Flood Insurance Maps, City of Manhattan, KS (FEMA)

mapped, the historical channel path was matched against the scale of the original photograph or survey. Utilizing the line dimensioning tool of the Macintosh based Claris CAD software, the channel and valley length for a given year could be determined. The image/drawing scale procedures are discussed further in the Discharge Data Study Parameters section of this chapter.

Sediment Load and Discharge

Many previous studies concerning channel metamorphosis (e.g., Leopold and Maddock 1953; Wolman 1959; Schumm 1960; Hooke 1979) have measured suspended sediment concentrations. Sediment loads are one of many important factors that determine channel morphology. Unfortunately, sediment load cannot be evaluated for the

lower Big Blue River regime because there are no continuous sediment records for the lower Big Blue River.

Another important control of channel morphology is discharge. U.S. Army Corps of Engineers monthly mean discharge data are available from January 1896 to April, 1973 for the lower Big Blue River in the form of a histogram plot. The discharge record, however, does not come from a single location on the Big Blue River. Rather, the data were obtained from the following sources: discharge values for the years 1896 to 1917 are from available records in the vicinity of Manhattan, Kansas or other stations, whereas values from 1918 to 1950 were extended from Randolph, Kansas, on a drainage area ratio basis, (1.05 x Randolph). Records for the Manhattan (Casement Road Bridge) gauge were used from 1951 through 1959, when Tuttle Creek dam was closed. Flow values for the years 1960 through 1971 have been calculated from lake regulation and upstream station records. Values from 1971 to 1973 were compiled from lake regulation records (COE 1973, II-7 , II-9).

A discontinuous discharge record is available from U.S. Geological Survey (USGS) monthly discharge and gauge height records collected since 1895 on the Big Blue River near Manhattan, Kansas. Once again, these data were not collected at a single gauging station. Monthly discharge records, measured near the Tuttle Creek Dam site, were collected from 1895 to 1905. However, it should be noted that records from April 1895 to October 1905 have been found to be unreliable and therefore were not utilized in this study (LaCock 1992) . Monthly discharge and gauge height records collected near Manhattan, Kansas, predating 1905 were sparsely collected and often failed to

document the flow for several months out of a given year. There were no available discharge records for the years 1906 through 1949 for the lower Big Blue River. Monthly discharge measurements collected near the Rocky Ford Dam site from 1950 through 1953 were more reliable with measurements for all twelve months of the year.

The current USGS gauging station (No. 06887000), located 2.5 miles (4.0 km) downstream of Tuttle Creek Reservoir immediately east of Casement Road Bridge on the south bank, has been at this location since April, 1953 (Putnam 1986). Since May, 1953, channel width, area, and mean velocity have also been measured at this station. In November, 1954, a recorder gauge was installed at the Casement Road Bridge station, thus providing a continuous discharge record for the lower Big Blue River (Putnam 1986).

Discharge Data Study Parameters

Discharge information from raw data and that obtained from the histogram will be separately analyzed then compared for the following periods: 1) pre-dam closure, April, 1927, through June, 1959 (387 months); 2) post-dam closure, July, 1959, through September, 1991 (387 months).

The monthly mean discharge information available in the form of a histogram plot provides a reasonable historical record for mean monthly discharge near the Tuttle Creek Dam site. Discharge measurements were calculated for the period January, 1896 to April, 1973 and plotted as a histogram by the COE. All available pre-closure discharge information for the period 1896-1959 (64 years) was nearly twice as

large as the post-closure period, 1959-1991 (33 years). For the purpose of this study, the pre-closure period of record was therefore narrowed to April, 1927 through June, 1959 (387 months). This allows for an equal number of months for pre-closure period analysis as well as post-closure period analysis.

Because the raw data values utilized to generate the histogram were not available, discharge values had to be estimated from the histogram. Estimated discharge values were obtained in a six step computer recreation process (Figure 28) : 1) electronically scan the histogram into a Tag Image File Format (TIFF); 2) import the TIFF file into a Macintosh Computer Assisted Drafting (CAD) computer program, Claris CAD; 3) match the drawing scale (i.e., 1 unit = 1,000 units) to that represented in the histogram; 4) magnify the CAD image (800x) to add in the measure of histogram height (i.e., 452 units) with the line dimensioning function tool, adjust for the change in scale identified in the histogram where needed; 5) measure monthly magnitude with the computer five times from the TIFF image, omitting high and low values, then calculating an average value for the remaining middle three values, then rounding to the nearest 5 cfs; and 6) enter the estimated unit value (equivalent to discharge in cfs) into a spreadsheet program for analysis. With the estimated discharge values, a duplicate discharge histogram could be produced. Estimated error for the estimated discharge values was calculated to be $\pm 3.5\%$. Error was calculated by a ratio comparison of known monthly mean discharge values identified in the COE (1973) histogram plot with discharge values measured by the USGS during the period where the two data sets overlapped (1950-1973).

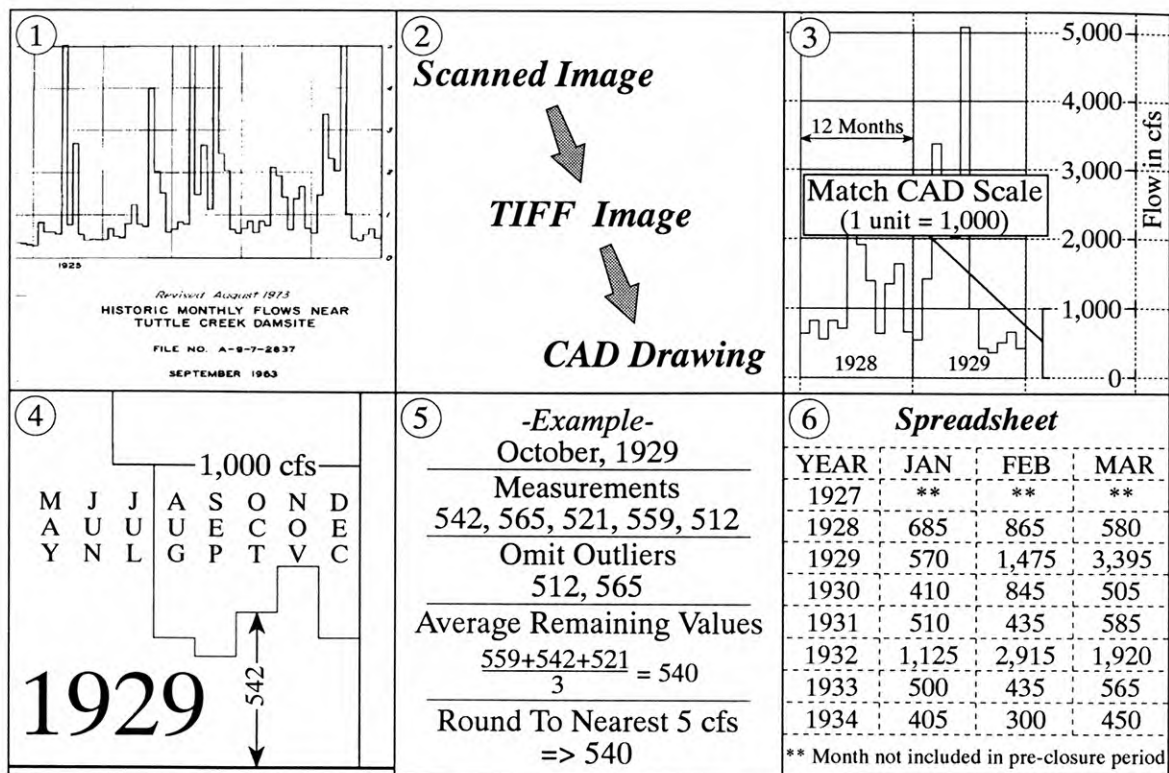


FIGURE 28. 1) Electronically scan the discharge histogram plot into the computer. 2) Convert scanned image into a CAD drawing file. 3) Match the CAD drawing scale to the histogram scale (e.g., 1: 1,000). 4) Measure the magnitude of the plot for each month utilizing the line dimensioning tool. 5) Each month is measured five times, outliers omitted, average remaining values, round to the nearest 5 cfs 6) Enter monthly mean values (cfs) into a spreadsheet software package for analysis . (JJW 8/93)

USGS discharge data collected at gauging station No. 06887000 (located at Casement Road Bridge) were available as raw measured values. Mean daily, mean monthly, mean monthly high discharge, and mean monthly low discharge values were available for the lower Big Blue River from the USGS for October, 1951 to present. For the purpose of this study, the post-closure period was established as July, 1959, through September, 1991. Because mean daily discharge, mean monthly high discharge, and mean monthly low discharge values are not available from the histogram data, I was able to compare only mean monthly discharge data. Raw USGS data values (monthly discharge

means) were directly entered into a spreadsheet software program for statistical analysis.

Discharge Data Analysis

Mean monthly discharge values were compiled and statistically summarized by month, year and period for mean, median, mode, maximum mean value, minimum mean value, and standard deviation. A nonparametric Wilcoxon signed-rank test was calculated utilizing pre-dam closure and post-dam closure mean monthly discharge values. Discharge variances were calculated and statistically compared with the analysis of variance (ANOVA) F-test. All statistical analyses were completed with the use of Microsoft Excel spreadsheet and Statview SE + statistical analysis computer software programs. Principal equations for which the computations are based on are as follows:

Mean discharge values were calculated from recorded mean monthly discharge values utilizing...

$$\bar{x} = \frac{\sum x}{n}$$

where...

$\bar{x}$ = mean discharge

x = monthly mean discharge values

n = total number of months

Median discharge values (middle value of a set) were calculated from recorded mean monthly discharge values by arranging the set of measurements in increasing magnitude, thus the sample median is the

value of y in the $0.5 (n + 1)$ st position (Devore 1987).

$$\{y_1, y_2, \dots, y_n\} \Rightarrow y = 0.5 (n + 1)$$

where...

y = median value

n = total number of values

Mode discharge values, most frequently occurring values in a given data set, were directly identified from the monthly, yearly, and period data sets.

Maximum and minimum values return the largest mean and smallest mean value in the sample sets, respectively.

Standard deviation is a measure of how widely values are dispersed from the mean value for a given set of arguments. The “nonbiased” or “ $n-1$ ” method was used to calculate standard deviation (Devore 1987).

$$s = \sqrt{\frac{n \sum x^2 - (\sum x)^2}{n(n-1)}}$$

where...

s = standard deviation

x = discharge value

n = number of values evaluated

Discharge trends, as discussed previously, were graphically compared to illustrate similarities and/or differences and are summarized in Chapter 4.

The Wilcoxon signed-rank test determines whether two samples are likely to have come from the same two underlying populations that have the same mean. In this case, the test determines whether the pre-dam closure and post-dam closure sample mean discharge trends are

equal. The Wilcoxon test makes no assumptions as to whether the two data sets have a normal distribution (Devore 1987; McGrew and Monroe 1993). Thus...

Null hypothesis: $H_0: \mu_1 = \mu_2, \mu_1 - \mu_2 = 0$
 $H_a: \mu_1 \neq \mu_2, \mu_1 - \mu_2 \neq 0$

where...

H_0 = null hypothesis

H_a = alternative hypothesis

μ_1 = true mean of data set 1

μ_2 = true mean of data set 2

Test Statistic:

$$Z_{w_i} = \frac{W_i - \bar{W}_i}{s_w}$$

where...

W_i = sum of ranks of sample i

$\bar{W}_i$ = mean of W_i

$$= n_i \left(\frac{n_1 + n_2 + 1}{2} \right)$$

s_w = standard deviation of W

$$= \sqrt{n_1 n_2 \left(\frac{n_1 + n_2 + 1}{12} \right)}$$

n_1 = number of observations in data set 1

n_2 = number of observation in data set 2

Assuming a 90% confidence level, do not reject H_0 if the Z-value is within the acceptance zone (p-value greater than 0.1) as derived for the null distribution of the Wilcoxon signed-rank statistic table (McGrew and Monroe 1993).

The ANOVA F-test returns the one-tailed probability that the variances in data set 1 and data set 2 are not significantly different. In this case, the variances seen in the pre-dam closure and post-dam closure values are equal (Devore 1987). Thus...

Null hypothesis: $H_0: \sigma^2_1 = \sigma^2_2, \sigma^2_1 - \sigma^2_2 = 0$
 $H_a: \sigma^2_1 \neq \sigma^2_2, \sigma^2_1 - \sigma^2_2 \neq 0$

where...

H_0 = null hypothesis

H_a = alternative hypothesis

σ^2_1 = true variance of data set 1

σ^2_2 = true variance of data set 2

Test Statistic:

$$F \text{ ratio} = \frac{\text{between sample variance}}{\text{within samples variance}} \text{ or } F = \frac{\hat{\sigma}_B^2}{\hat{\sigma}_W^2}$$

where...

$$\hat{\sigma}_W^2 = \frac{\sum_{k=1}^K \sum_{n=1}^n (x - \bar{x})^2}{N - k}$$

k = number of samples

n = number of observations per sample

N = total number of observations for all samples

$\bar{x}$ = mean of each sample

$$\hat{\sigma}_B^2 = \frac{\sum_{k=1}^K n (\bar{x} - \bar{x}_G)^2}{k - 1}$$

k = number of samples

n = number of observations per sample

$\bar{x}$ = mean of each sample

$\bar{x}_G$ = grand mean for all samples

Assuming a 90% confidence level, do not reject H_0 if the F-value is within the acceptable zone (p-value greater than 0.1) as derived for the null distribution of the F-test critical value statistic table (McGrew and Monroe 1993).

Rating Curves

Channel rating curves were included in this study to provide quantitative evidence for an aggradating or degrading environment occurring within the lower Big Blue River. Rating curve coverage for the lower Big Blue river was available from the USGS the period December, 1950 to September, 1991. Rating curves including the years 1951, 1961, 1971, 1981, and 1991 were electronically reproduced, following the same procedures described for the channel path reconstruction, and evaluated for the lower Big Blue River.

Field Observations

Observations in the form of site visits and low altitude aerial photography were concentrated in the first three miles (4.83 km) downstream from the dam because this was the area most visibly affected by erosion. Additional field work was conducted at the zone of former sand dredging activity approximately six miles (9.7 km) downstream from the dam. Field observations were conducted during

the months of April and June, 1991. Additional site visits were conducted in May, 1992.

Objectives of the field observations were to: 1) identify areas of excessive erosion or deposition within the lower Big Blue River; 2) identify areas of stream power change; and 3) photograph areas of significant erosion or deposition. Field observations were combined with results of the previously noted study methodologies to characterize the channel changes which have occurred on the lower Big Blue River.

CHAPTER 4: RESULTS

Flood Frequency

Floods are an important factor in the natural development in any fluvial system. Often during flood events the entire channel path may be straightened, thereby creating a more energy efficient regime. A detailed flood history analysis of the lower Big Blue River is outside the scope of this study, however, a brief overview is provided.

Floods affecting the Manhattan, Kansas, area occurred in 1785, 1826, 1844, 1845, 1855, 1858, 1870, 1881, and 1886 (COE 1972; Historical Plat 1881), however, there are no further records detailing these events. Of the earliest floods on record, the flood of 1897 recorded a flood stage of 25.4 feet (7.7 m) on the Big Blue River² (COE 1972).

Some of the most historically severe floods, in chronological order, were as follows: 1903 Flood was the second largest flood event within the study period, with reliable stage records, occurred in the later part of May and the first of June of 1903. The peak flood stage measured at Manhattan, Kansas, was 36.5 feet (11.1 m) with a discharge of 98,000 cfs (2,760 cms). The Big Blue was a major contributor to the disastrous flooding occurring on the main stem of the Kansas River (COE 1972 and 1973)

1908 Flood nearly matched the peak flood stage of the 1903 flood with a flood stage of 35 feet (10.7 m). This event was produced with

²Flood stage occurs when a river overflows the natural banks and begins to cause damage in the reach where flood measurements are made (Tank 1983).

widespread precipitation throughout the Kansas River basin. The volume of runoff measured at the present location of Tuttle Creek Dam was 1,372,000 acre-feet (1,692,335,000 m³) (COE, 1973).

During 1935 there were a series of flood stages that occurred through the months of May to June. The Big Blue River had a peak discharge of 34,600 cfs (975 cms) measured near the Tuttle Creek Dam site (COE 1972 and 1973).

During the month of June, 1943, the Big Blue River basin received an average rainfall of 6.5 inches (165.1 mm). Discharge for the Big Blue river was measured at 46,000 cfs (1,295 cms) at Manhattan, Kansas. Damages were estimated to be in excess of \$4 million (COE 1973).

A series of rainfall events produced the runoff surplus for the June, 1947 flood event. Based on the volume of inflow, this event was the second largest since 1930. The Big Blue had a peak discharge of 51,100 cfs (1,439 cms) measured near the Tuttle Creek Dam site. Damages assessed on the Kansas and lower Missouri Rivers were estimated to be in excess of \$56 million (COE 1973).

The 1951 flood was, without question, the most significant flood on record with impacts that can still be remembered throughout Kansas (Figure 29). The Big Blue River reached a peak discharge of 93,400 cfs (2,630 cms) during the July 9-13 rains of 1951. The volume of runoff measured near the Tuttle Creek Dam site was 3,285,000 acre-feet (4,051,980,000 m³). Damages suffered in the 1951 flood were in excess of \$1 billion (Figure 30) for Kansas and Missouri river properties (COE 1972 and 1973).

The flood experienced in March of 1960 was unique in that it was

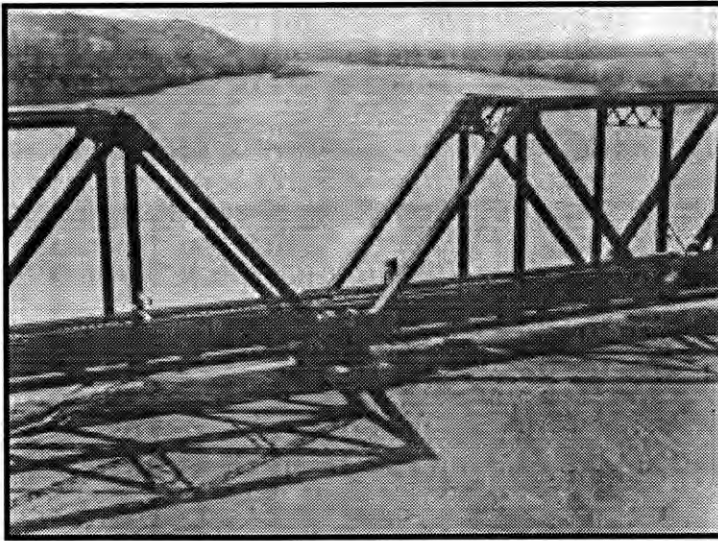


FIGURE 29: The former Chicago, Rock Island and Pacific railroad bridge once located adjacent to the Highway 177 bridge. High water pictured here looking upstream on the Kansas River to the south. Surviving the 1951 flood, the railroad bridge was later dismantled in the late 1980's, however the concrete pillars can still be seen protruding from the river bed. Photo: COE 1972.

FIGURE 30: Damages attributed to the 1951 flood were in excess of \$1 billion in the Kansas and Missouri River Basins. The flood affected 183 towns, caused the evacuation of 87,366 people, destroyed 2,533 homes, 354 businesses, flooded another 24,893 homes and 3,889 businesses. 18 lives were lost in the flood.

Photo: COE 1972; Statistics: COE 1951.



caused primarily by snow melt. Tuttle Creek Dam stored 366,000 acre-feet (451,454,000 m³) up to an elevation of 1,071 feet (327 m). Because this flood was held to non-damaging proportions, Tuttle Creek Reservoir was credited with preventing an estimated \$15.25 million in potential property losses (COE 1973).

The weather patterns experienced during the June, 1967, flood were similar to those that caused the record flood of 1951. Damages

upstream in the Big Blue River basin exceeded \$2.4 million and 29,430 acres (11,910 ha) of cropland were flooded. Tuttle Creek Reservoir was credited with preventing downstream damages to the Kansas and Missouri Rivers in excess of \$17.4 million (COE 1973). Since the closure of Tuttle Creek Dam in 1959, the maximum discharge measured on the lower Big Blue River was 31,500 cfs (887 cms) in June of 1967 (Putnam 1986).

The 1969 Flood was a result of snow melt episode. The inflow into Tuttle Creek Reservoir was estimated as 693,000 acre-feet (854,802,000 m³) during the period of February 24 through March 31 of 1969. The maximum mean inflow into Tuttle Creek was 33,000 cfs (929 cms), while the maximum mean release from Tuttle Creek was 24,000 cfs (676 cms). Tuttle Creek Reservoir was credited with preventing an estimated \$6 million in damages along the Kansas and Missouri Rivers (COE 1973).

In 1973, heavy precipitation occurring throughout the Kansas River Basin caused flooding in October. Records detailing this event are not fully available. Inflow to Tuttle Creek had to be estimated since the gauging stations closest to the dam were in backwater (LaCock 1992). For example, the gauging station at Barns, Kansas, recorded a peak discharge of 53,700 cfs (1,512 cms) with a flood stage of 27.7 feet (8.4 m) for the Little Blue River. The Black Vermillion River recorded a peak discharge of 36,400 cfs (1,025 cms) with a flood stage of 30 feet (9.1 m). Both the Barns and Black Vermillion stations were in backwater during this event. Tuttle Creek Reservoir reached a maximum pool elevation of 1,127.9 feet (343.8 m) during this event.

Between 1973 and 1991 there were no historically significant flood

events recorded by the USGS. Recent rains received in 1992 resulted in significant flood stage levels in the Blue River Basin, however, the statistics for the 1992 events were not compiled for public release as of the writing of this study (LaCock 1992).

Channel Mapping

Channel positions of the lower Big Blue River were mapped for the years of 1857, 1886, 1937, 1947, 1952, 1963, 1973, 1982, 1989, and then compared to the lower Big Blue River channel of 1963. The 1963 channel was selected as a basemap for two reasons: 1) deriving a basemap from aerial photograph (1937, 1952, 1973, 1989) was outside the scope of this study, therefore only surveys and USGS topographic quadrangles were candidates for a basemap (1857, 1886, 1947, 1963, 1982). Photographs and maps from pre-closure years were not sufficiently detailed to permit identification of the position of Tuttle Creek dam, thus leaving the 1963 COE survey (1:29,400) and the 1982 USGS Manhattan quadrangle (1:24,000). 2) Each of the two remaining basemap candidates had comparable scales, however, the COE survey was featured on one 11"x17" (27.9 cm x 43.2 cm) highly detailed plate, which offered an ideal source to be electronically scanned into the computer. Channel positions were derived from sources and procedures as detailed in the Methodology chapter. Results of the historical channel positions for the noted years are presented in Figures 31 through Figure 39. The 1963 active channel will be represented in gray, which also identifies channel sidebars with a sandy texture. The pre- and post-1963 channels are represented in black.

LOWER BIG BLUE RIVER CHANNEL - 1857

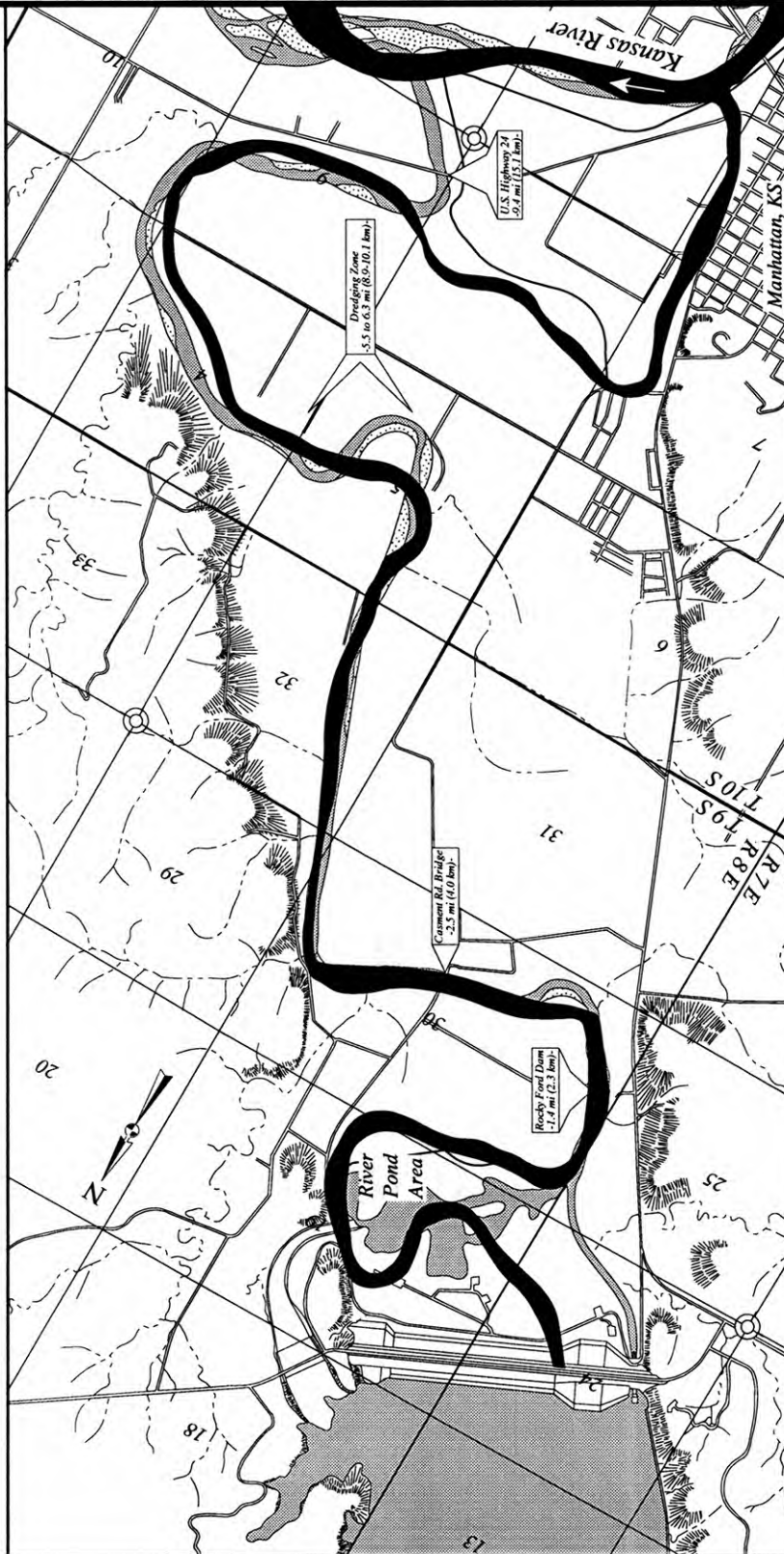


FIGURE 31. 1857 channel position (black) in reference to the 1963 channel position (gray).

Sources: 1857 channel - Cadastral Survey Map; 1963 basemap/channel - Corps of Engineers.

LOWER BIG BLUE RIVER CHANNEL - 1886

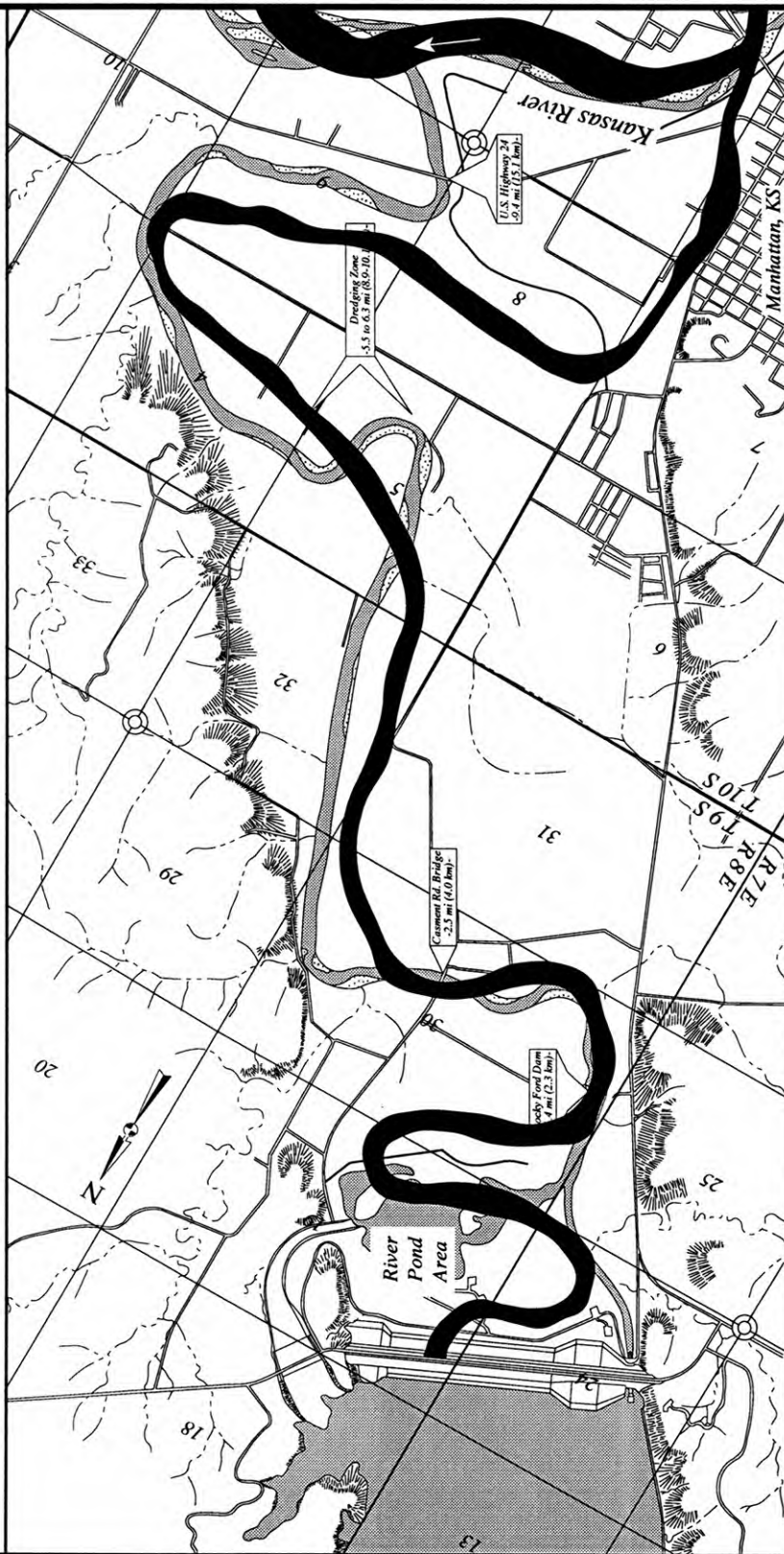


FIGURE 32. 1886 channel position (black) in reference to the 1963 channel position (gray).

Sources: 1886 channel - USGS Junction City Topographic Quadrangle;
1963 basemap/channel - Corps of Engineers.

LOWER BIG BLUE RIVER CHANNEL - 1937

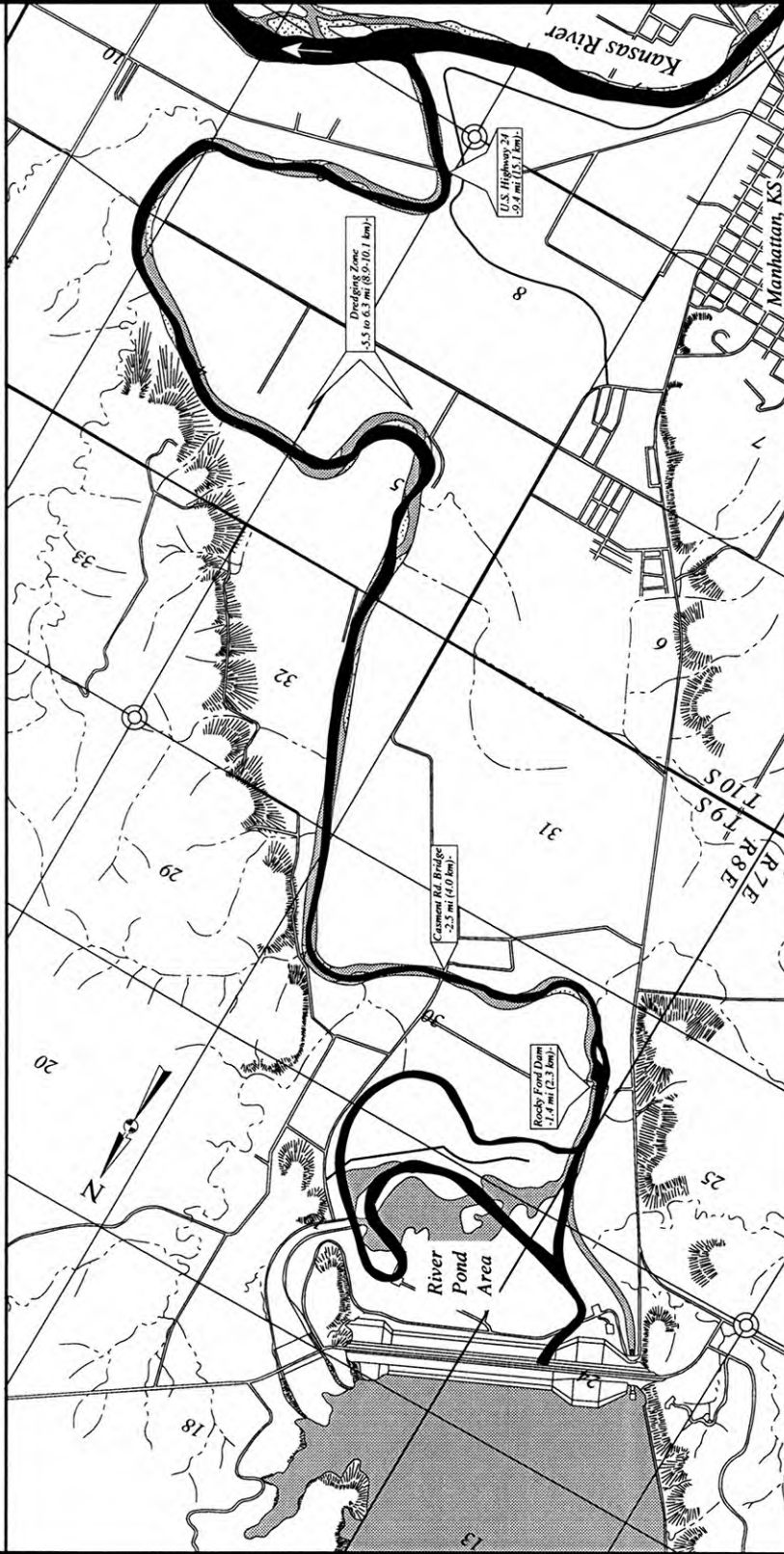


FIGURE 33. 1937 channel position (black) in reference to the 1963 channel position (gray).

Sources: 1937 channel - National Archives Aerial Photography;
1963 basemap/channel - Corps of Engineers.

LOWER BIG BLUE RIVER CHANNEL - 1947

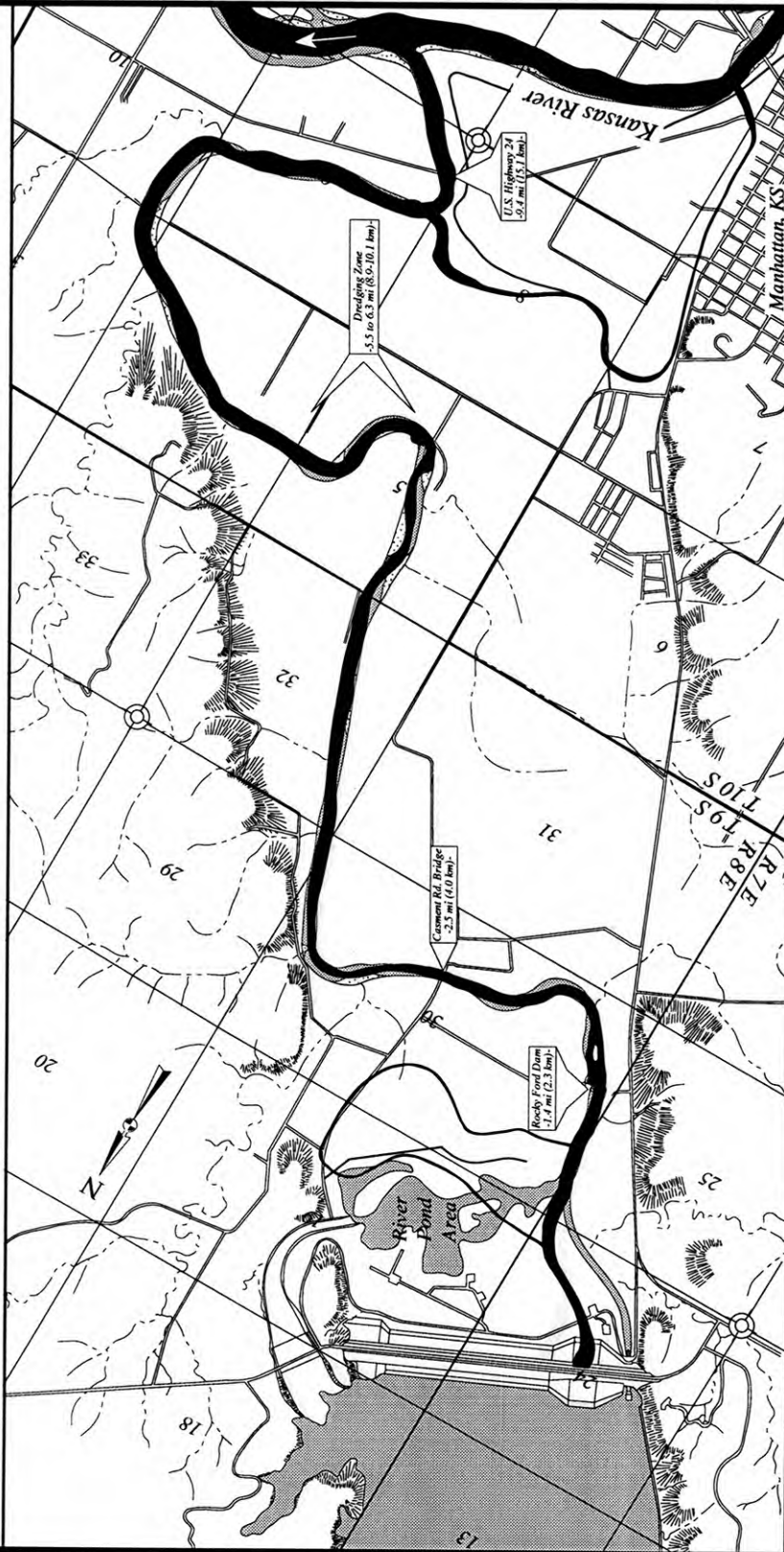


FIGURE 34. 1947 channel position (black) in reference to the 1963 channel position (gray).

Sources: 1947 channel - USGS Manhattan Topographic Quadrangle;
1963 basemap/channel - Corps of Engineers.

LOWER BIG BLUE RIVER CHANNEL - 1952

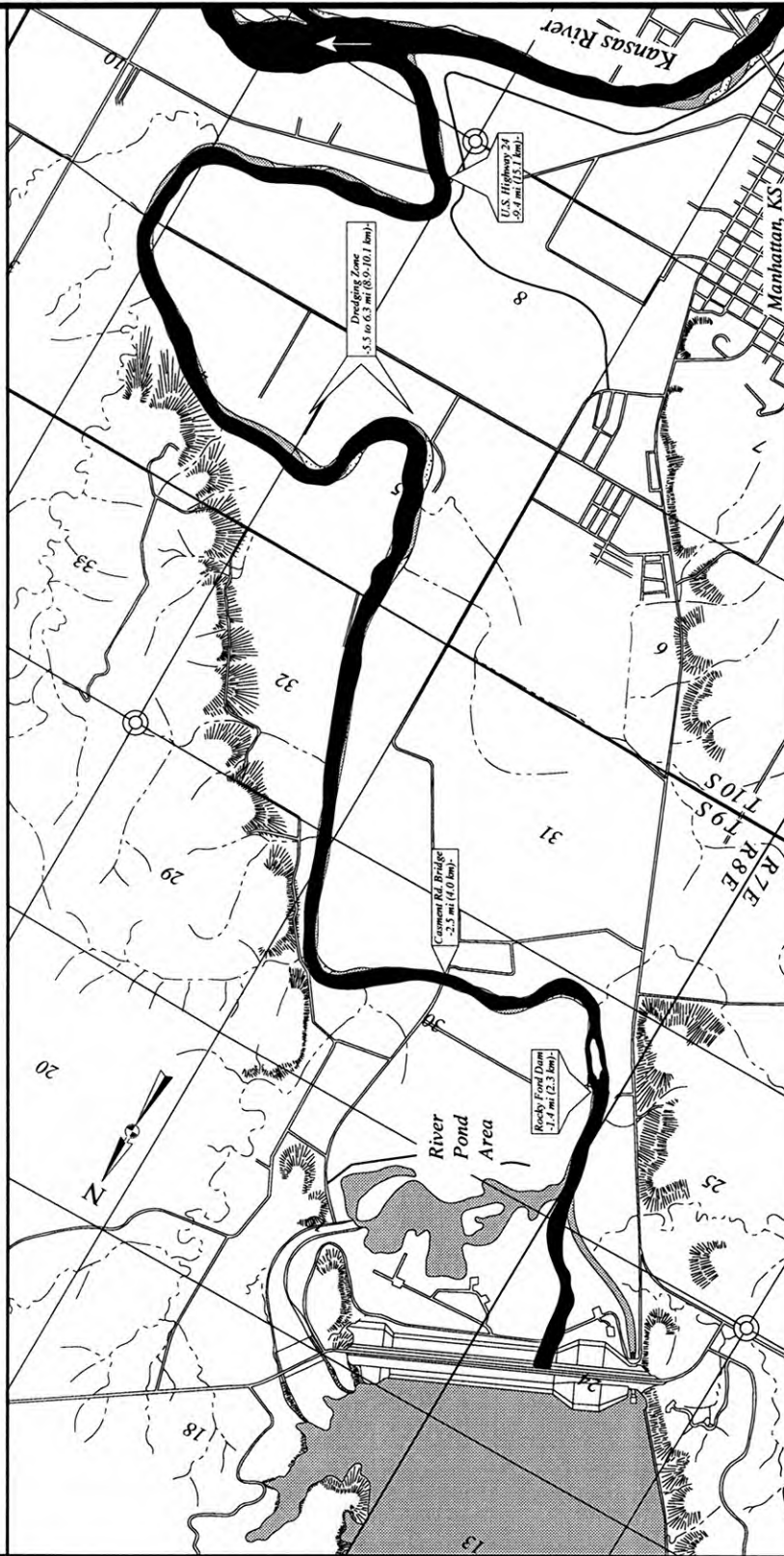


FIGURE 35. 1952 channel position (black) in reference to the 1963 channel position (gray).

Sources: 1952 channel - Corps of Engineers Aerial Photography;
1963 basemap/channel - Corps of Engineers.

LOWER BIG BLUE RIVER CHANNEL - 1963

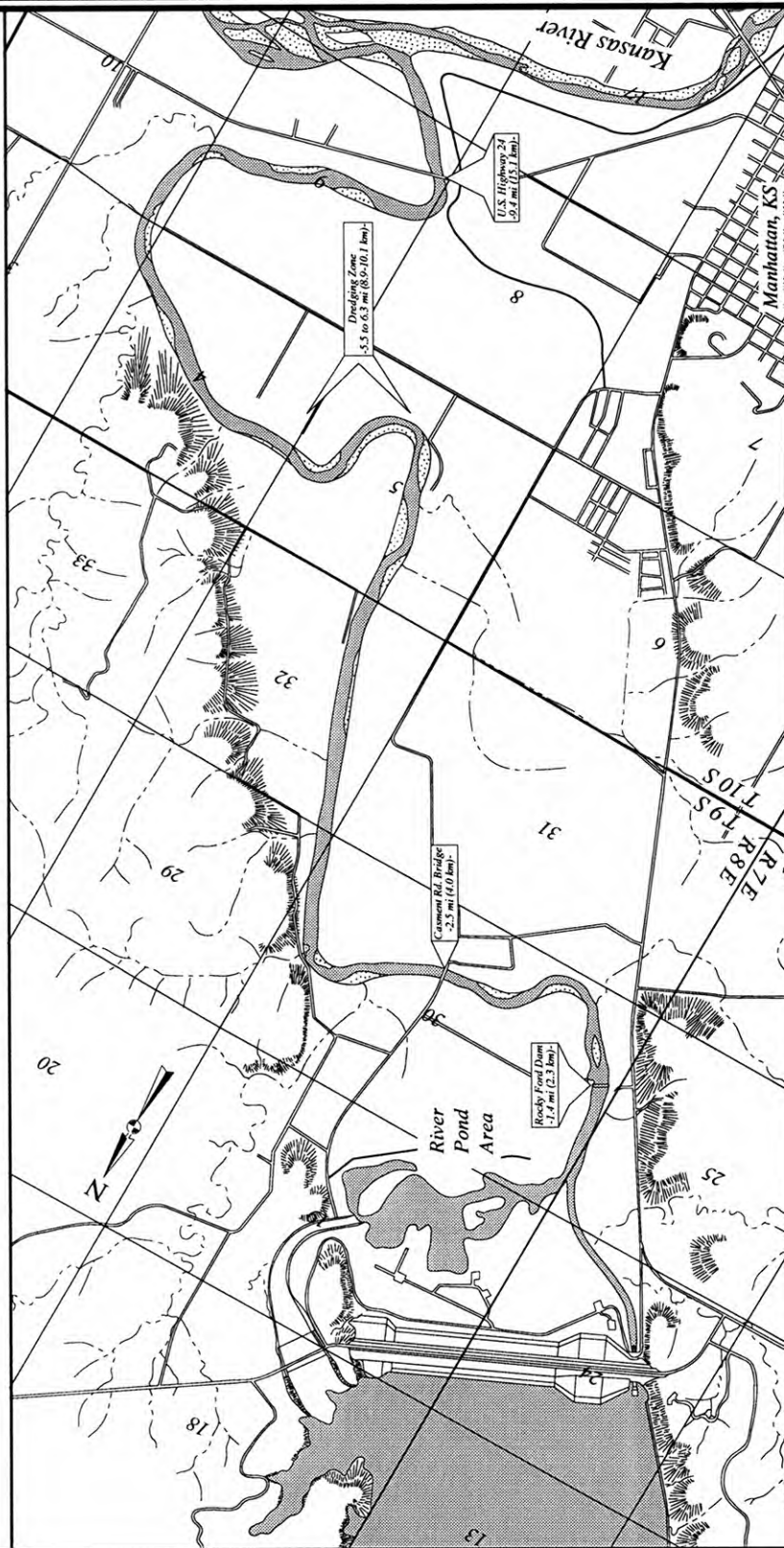


FIGURE 36. 1963 channel position with respect to the current location of Tuttle Creek Reservoir. The 1963 channel was used as the basemap for this study.

Sources: 1963 basemap/channel - Corps of Engineers.

LOWER BIG BLUE RIVER CHANNEL - 1973

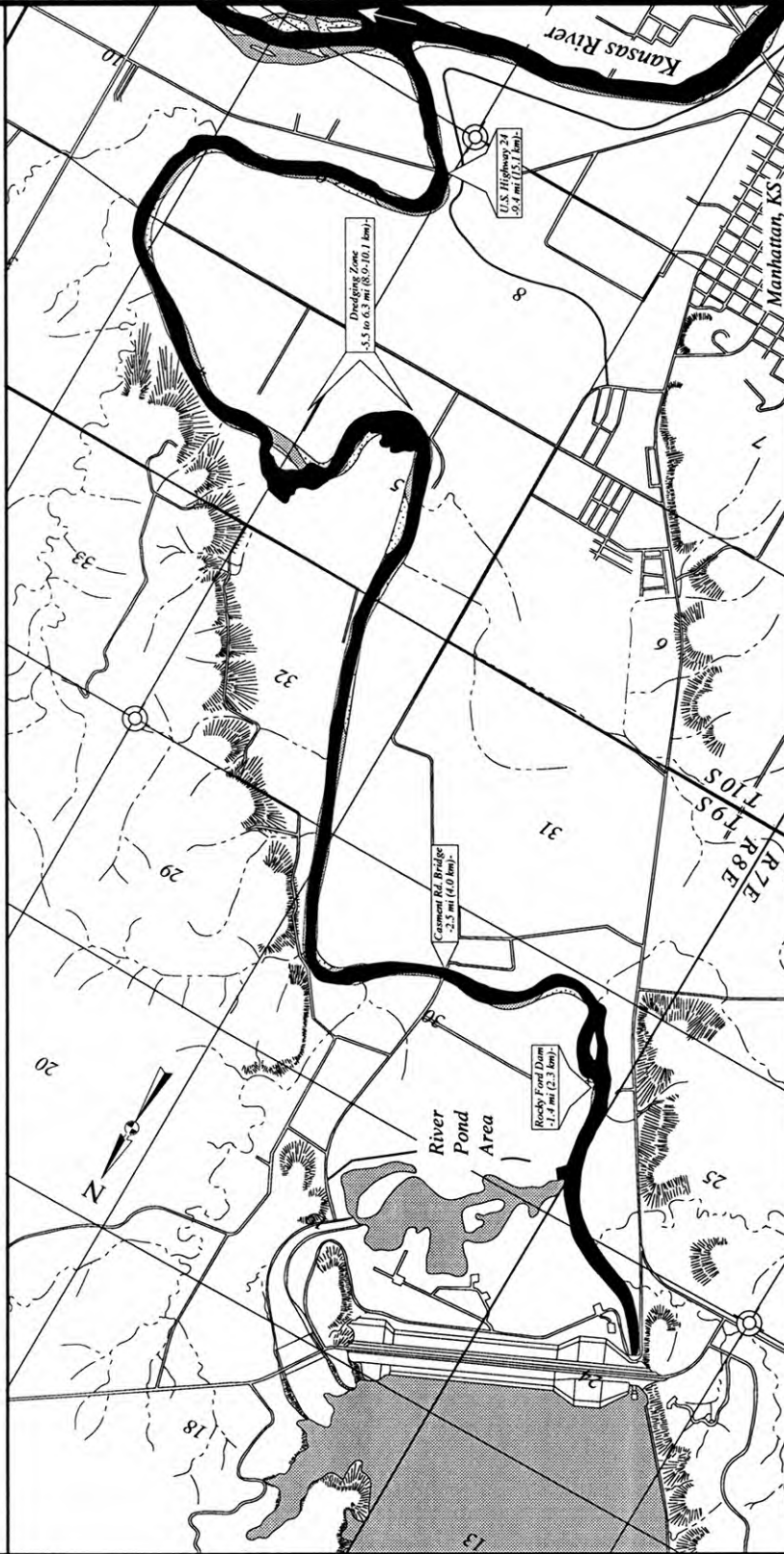


FIGURE 37. 1973 channel position (black) in reference to the 1963 channel position (gray). The backwaters of the River Pond Area are not included for 1973.

Sources: 1973 channel - Kansas Dept. of Transportation Aerial Photography;
1963 basemap/channel - Corps of Engineers.

LOWER BIG BLUE RIVER CHANNEL - 1982

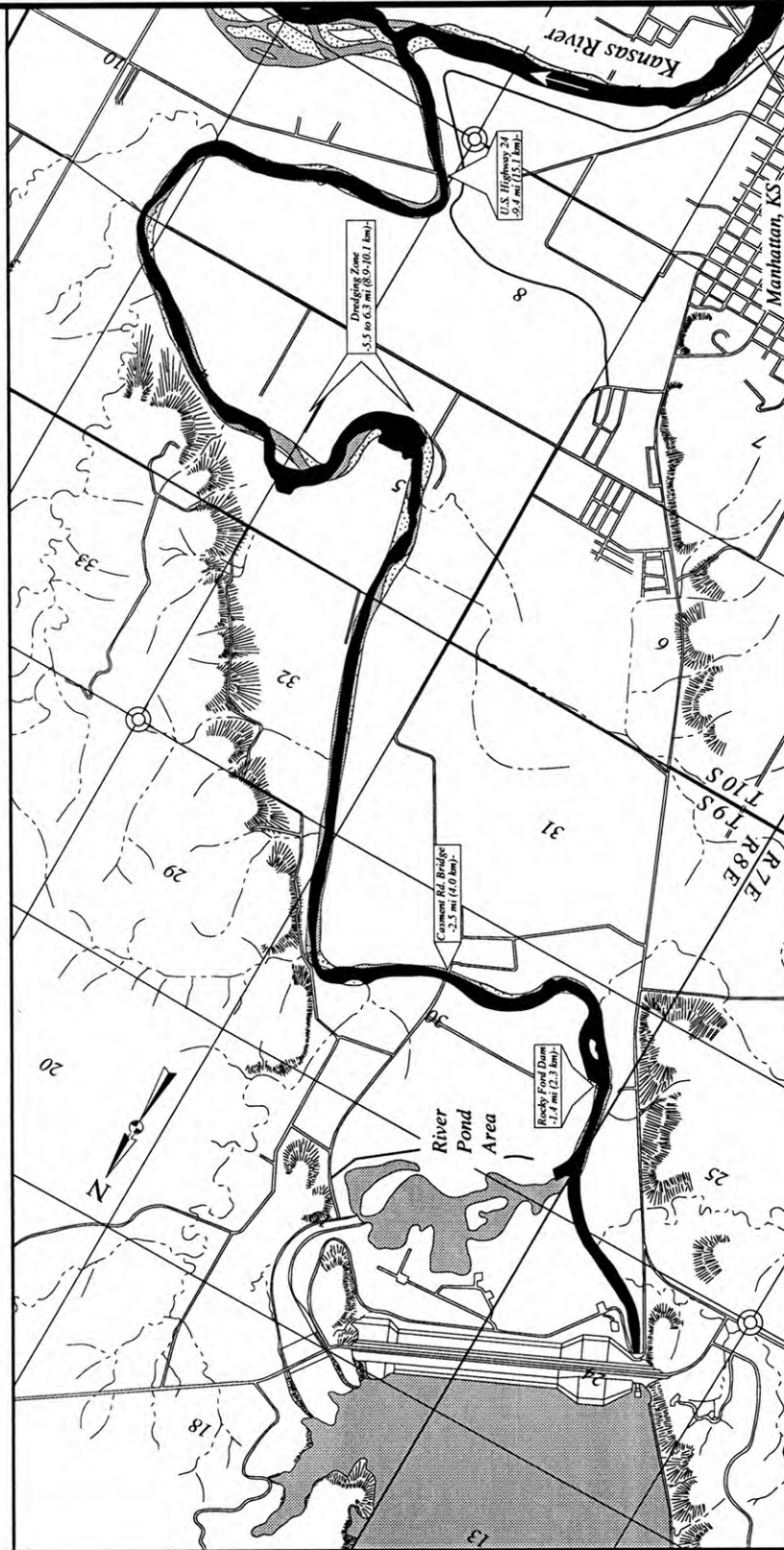


FIGURE 38. 1982 channel position (black) in reference to the 1963 channel position (gray). The backwaters of the River Pond Area are not included for 1982.

Sources: 1982 channel - USGS Manhattan Topographic Quadrangle;
1963 basemap/channel - Corps of Engineers.

LOWER BIG BLUE RIVER CHANNEL - 1989

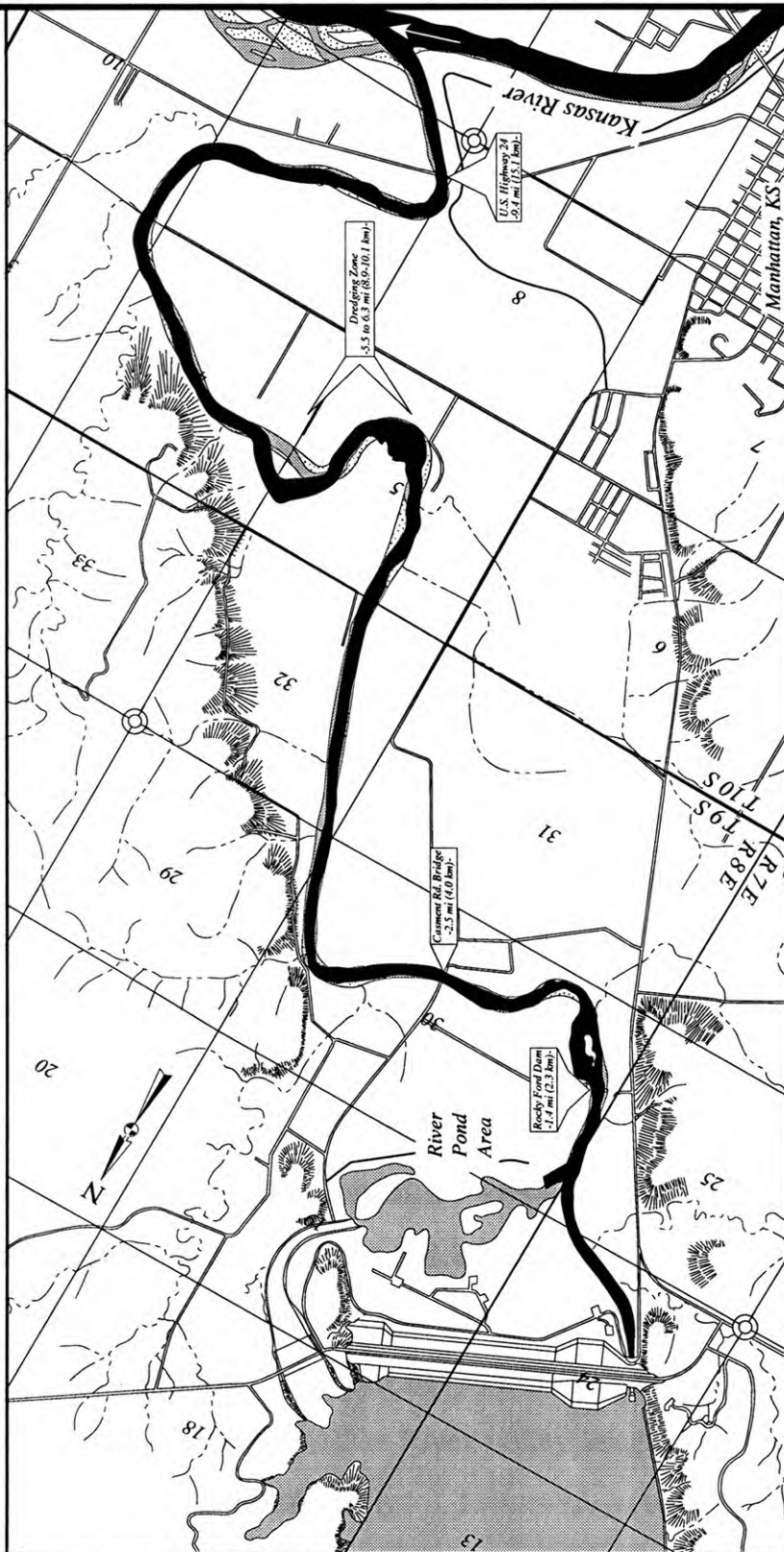


FIGURE 39. 1989 channel position (black) in reference to the 1963 channel position (gray). . The backwaters of the River Pond Area are not included for 1989.

Sources: 1989 channel - NASAAM Color Aerial Photography;
1963 basemap/channel - Corps of Engineers.

Channel Sinuosity

Researchers have noted (Bagnold 1960; Osterkamp and Hedman 1981) that sinuosity can be used as a measure of the energy efficiency of a fluvial system. As the fluvial system makes adjustments to become more energy efficient, for example a meandering channel becoming straighter, a change in sinuosity can be seen. Sinuosity is determined by dividing the river channel length by the river valley length. Sinuosity was determined for the mapped channels. A brief summary of the components of sinuosity, channel length and valley length, will be included in the following sinuosity discussion of the lower Big Blue River.

For the purpose of this study, channel length will be the distance from the center axis of Tuttle Creek Dam to the confluence of the Big Blue and Kansas Rivers. Channel lengths for the study period ranged from a minimum of 9.81 miles (15.80 km) seen in 1952 to a maximum of 14.65 miles (23.58 km) in 1947 (Table 3). Pre-dam closure years were found to have channel lengths from 13.54 miles (21.80 km) in 1857 to 9.81 miles (15.80 km) in 1952. The maximum channel length for the pre-dam closure period was in 1947, the minimum channel length was in 1952. Following closure of the dam channel lengths were found to be more closely grouped; the minimum was 9.89 miles (15.62 km) in 1963, the maximum was 10.15 miles (16.34 km) in 1973.

Valley length, as defined for this study, began at the center axis of Tuttle Creek Dam and ended at the confluence of the Big Blue and Kansas Rivers. Lower Big Blue River valley lengths identified in this study did not differ significantly. However, actual valley lengths differed due to: 1) Tuttle Creek Dam not being perpendicular to the river

TABLE 3
Lower Big Blue River
-Sinuosity Summary-

YEAR	CHANNEL LENGTH		VALLEY LENGTH		SINUOSITY
	Miles	Kilometers	Miles	Kilometers	
1857	13.54	21.80	5.83	9.39	2.32
1886	12.41	19.98	5.85	9.42	2.12
1937	12.96	20.86	5.99	9.65	2.16
1947	14.65	23.58	6.15	9.90	2.38
1952	9.81	15.80	6.02	9.70	1.63
1963	9.89	15.62	6.12	9.85	1.62
1973	10.15	16.34	6.15	9.90	1.65
1982	10.10	16.26	6.16	9.91	1.64
1989	10.06	16.19	6.15	9.91	1.64

valley; and 2) influences of the Kansas River migrating in and out of the Big Blue River valley throughout the study period. The valley lengths ranged from a minimum of 5.83 miles (9.39 km) in 1857 to a maximum of 6.16 miles (9.91 km) in 1982. Pre-dam closure years were found to have valley lengths of 5.83 miles (9.39 km) in 1857 and 6.02 miles (9.70 km) in 1952. The minimum valley length for the pre-closure period was in 1857. The maximum valley length was 9.90 miles (2.38 km) in 1947 for this same period.

Valley lengths found in the post-closure period were 6.12 miles (9.85 km) in 1963 to 6.15 miles (9.91 km) in 1989. The minimum valley

length in the post-closure period was in 1963. The maximum valley length was 6.16 miles (9.91 km) in 1982 for the same period.

The measurable range for sinuosity is 1.0 and greater, with 1.0 representing a perfectly straight channel (e.g., channel length equals valley length). The range of sinuosity identified in the lower Big Blue River for the study period was a minimum of 1.62 in 1963 to a maximum of 2.38 in 1947.

A minimum sinuosity of 1.63 was found to be in 1952 for the pre-closure period. The 1951 flood may have had the single largest impact on the lower Big Blue River channel. Channel morphology seen in 1947 reflects two divided channels which were effectively truncated meanders during the 1951 flood, thus shortening the river channel length seen in 1952. There was an additional reduction in sinuosity in 1958 when approximately 2.1 miles (3.4 km) of river channel were rerouted as a part of Tuttle Creek Dam construction, resulting in straightening of the channel.

The maximum sinuosity identified in this study for the lower Big River channel occurred in 1947 (2.38). The high sinuosity is a result of the divided channel resulting from the 1935 and 1943 floods. Sinuosity was high in 1857 (2.32) when the active channel followed a similar path as represented in 1947.

The channel position and sinuosity began to become stabilized after the 1951 flood. The closure of Tuttle Creek Dam in July, 1959, would continue to stabilize channel position by minimizing peak flood discharge events. Sinuosity identified in the post-closure period of 1963 to 1989 were all within the 1.62 to 1.65 range. The minimum sinuosity

(1.62) found in the post-closure period was in 1963. Impacts of the channel straightening associated with the construction of Tuttle Creek Dam would be the single most dominant factor in the sinuosity value for 1963.

The maximum sinuosity (1.65) for the post-closure period was in 1973. The minor increase in sinuosity here appears to have resulted from channel adjustment associated with the downstream sand dredging operations. Approximately 5.5 to 6.3 miles (8.9 to 10.1 km) downstream from Tuttle Creek Dam sand dredging activities have altered the channel width within this zone, which ultimately increased channel length. Impacts of dredging activities on the lower Big Blue River will be further discussed in the Field Observations section of this chapter.

Conclusions which can be drawn from sinuosity adjustment in the lower Big Blue River indicate a change of channel energy from pre- to post-closure periods. Sinuosity found in the pre-closure period reflects higher energy loss than the sinuosities found in the post-closure period. This shift in sinuosity is primarily due to the 1951 flood followed by the construction of Tuttle Creek Dam. The 1951 flood effectively straightened the channel, thus reducing sinuosity, while the construction of Tuttle Creek Dam preserved the lower sinuosity through peak flood discharge reduction. It is suspected that lateral migration would have continued along the lower Big Blue River without the introduction of Tuttle Creek Reservoir.

Discharge Analysis

Mean monthly discharge values for the lower Big Blue River were divided into pre-closure (April, 1927 through June, 1959), and post-closure (July, 1959 through September, 1991) periods. Each discharge analysis period comprises 387 months. All statistically derived values were based on mean monthly discharge values. Statistical comparison of mean, median, mode, standard deviation, minimum discharge values and maximum discharge values for the pre-closure, post-closure, and study periods are summarized in Table 4. Statistical values are estimated to be within an error range of $\pm 3.5\%$, based on discharge extrapolation techniques discussed in the Methodology chapter.

TABLE 4
Lower Big Blue River
-Monthly Discharge Summary-

Statistic	Pre-closure Period (1927 - 1959)		Post-closure Period (1959 - 1991)		Study Period (1927 - 1991)	
	cfs	cms	cfs	cms	cfs	cms
Mean	1,888	53	2,295	65	2,092	59
Median	815	23	1,216	34	975	27
Mode	260	7	**	**	260	7
Std. Dev.	2,964	83	2,994	84	2,984	84
Min. Value	85	2	21	<1	21	<1
Max. Value	27,820	784	20,110	566	27,820	784

** No Value Returned

For the purpose of this discussion, reference to "mean monthly" discharge values will represent monthly discharge values comprised of reported monthly mean values, essentially the mean of monthly mean discharge.

Mean monthly discharge showed a significant increase of 21.6% ($\pm 3.5\%$) from pre-closure (1,888 cfs/53 cms) to post-closure (2,295 cfs/65 cms) periods. Typically, there is a reduction in the mean discharge seen in post-closure periods (Howard and Dolan 1981). This increase can be attributed to the influence of flood control discharge which is released to the lower Big River. In order to effectively reduce the peak discharge likely to be experienced in a flood event, the total volume of flood event water must be released over a longer period. The direct result of flood peak prevention is increased mean discharge, which is seen in the post-closure period.

A graphical comparison of pre-closure and post-closure mean monthly discharge values with respect to the pre-closure median (815 cfs/23 cms) and the post-closure median (1,216 cfs/34 cms) discharges is summarized in Figure 40. A peak monthly mean discharge reduction can be identified above 20,110 cfs (566.5 cms) in the post-closure period. However, it should be noted that in the 387 months of the pre-closure period, a mean monthly discharge of 20,110 cfs (566.5 cms) was only exceeded twice, during June and July of the 1951 flood. The second highest mean discharge peak of the post-closure period is in July, 1984 (15,510 cfs/436.9 cms). Graphically, the post-closure discharge pattern does not appear to be significantly different than the pre-closure pattern. There appear to be "cyclic" periods of high and low discharges,

Mean Monthly Discharge -Lower Big Blue River-

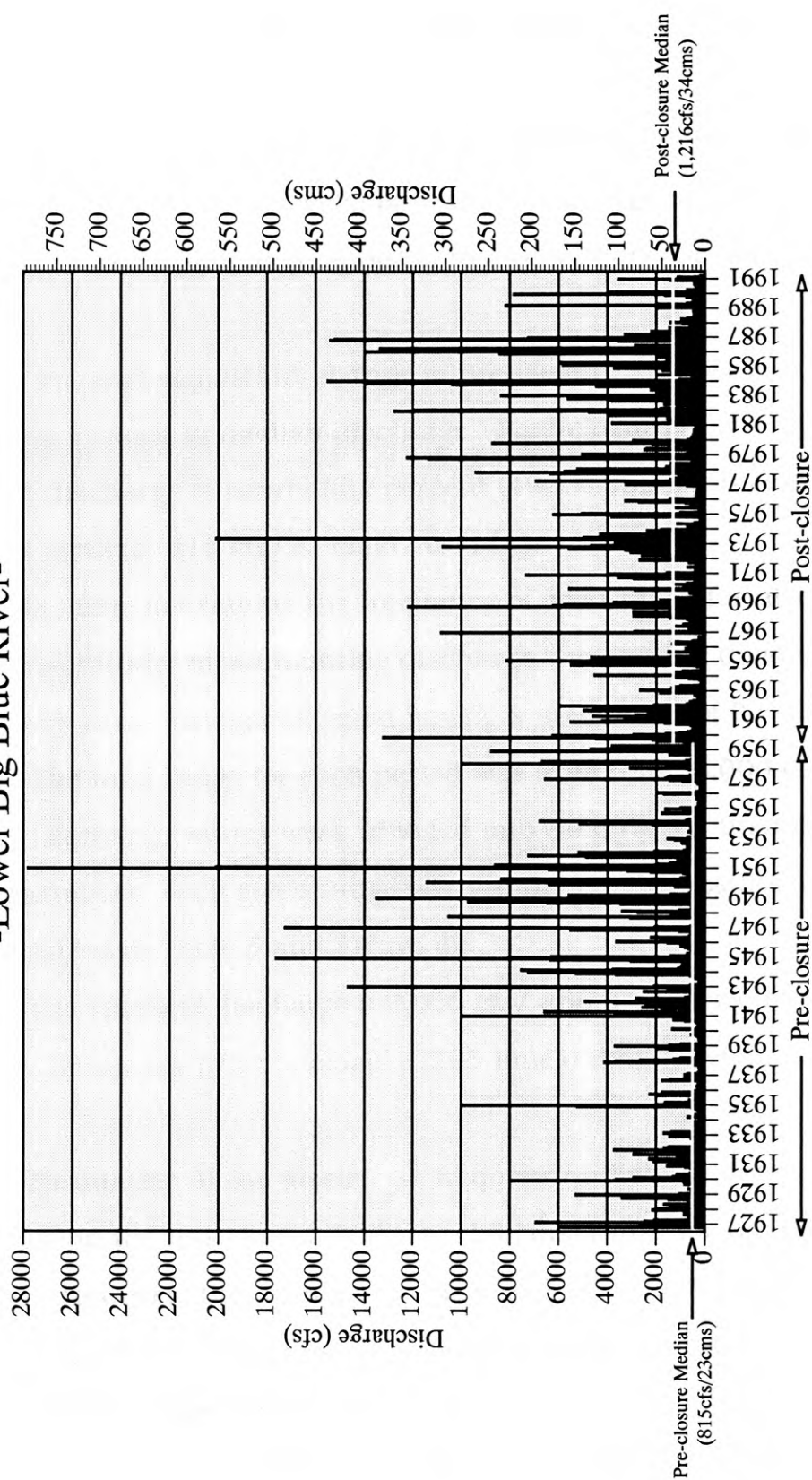


FIGURE 40. Mean monthly discharge of the lower Big Blue River, 1927-1991.

representing wet and drier periods, present in both the pre- and post-closure periods.

In comparison, a plot of the mean annual discharge values (Figure 41) further supports the cyclic pattern of discharge means for the pre- and post-closure periods in addition to a reduction in peak discharge means.

The most significant change in pre-closure vs. post-closure discharge is seen in median discharge. Post-closure (1,216 cfs/34 cms) median discharge is nearly fifty percent ($49.2\% \pm 3.5\%$) higher than pre-closure median (815 cfs/23 cms) discharge.

In order to examine the frequency of occurrence for discharges of a given magnitude, mean monthly discharge values were divided into 14 frequency range categories, each having a magnitude of 2,000 cfs (56.3 cms). The total range for each period was from 0 to 28,000 cfs (789 cms). Discharge values were divided into each range, then the number of occurrences each given range were counted. The results are summarized in Table 5 and Figure 42.

The smallest discharge (<2,000 cfs/ <56.3 cms) occurred with a greater frequency prior to closure (295 times) than following closure (261 times).

Evaluation of the discharge frequency reflects a minor $8.8\% \pm 3.5\%$ decrease in the less than 2,000 cfs (<56 cms) range for the post-closure period. However, the decrease in the 0 to 2,000 cfs (56 cms) range is essentially offset with a post-closure increase in the 2,001 to 6,000 cfs (56-169 cms) ranges ($8.6\% \pm 3.5\%$).

In the post-closure period, high mean monthly discharges above

Mean Annual Discharge -Lower Big Blue River-

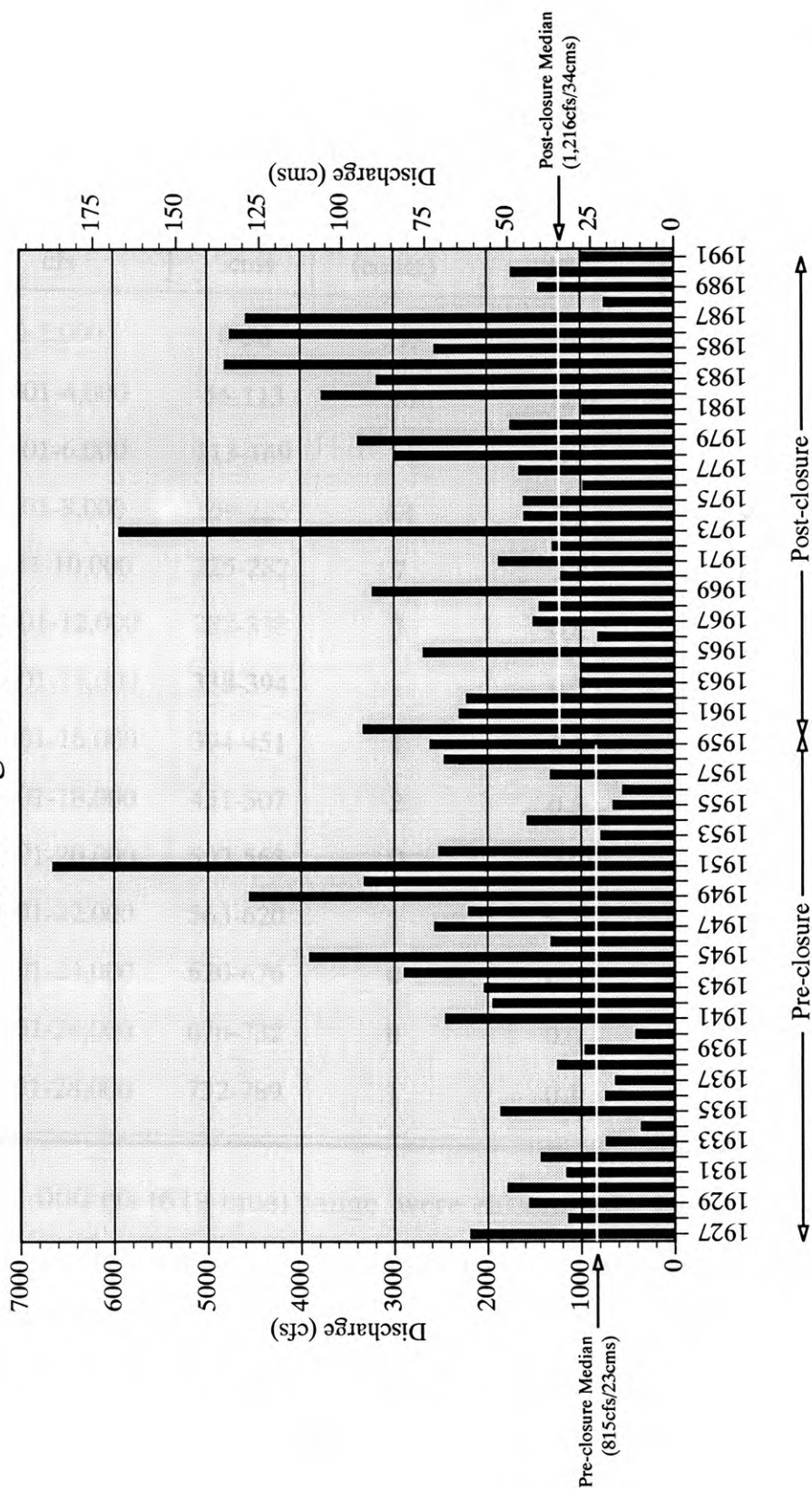


FIGURE 41. Mean annual discharge of the lower Big Blue River, 1927-1991.

TABLE 5
Lower Big Blue River
-Mean Monthly Discharge Range Frequency-

Range		Pre-closure		Post-closure	
cfs	cms	(count)	(%)	(count)	(%)
0-2,000	0-56	295	76.2	261	67.4
2,001-4,000	56-113	48	12.4	63	16.3
4,001-6,000	113-169	14	3.6	32	8.3
6,001-8,000	169-225	14	3.6	8	2.0
8,001-10,000	225-282	7	1.8	6	1.6
10,001-12,000	282-338	3	0.8	6	1.6
12,001-14,000	338-394	1	0.3	6	1.6
14,001-16,000	394-451	1	0.3	4	1.0
16,001-18,000	451-507	2	0.5	0	0.0
18,001-20,000	507-563	0	0.0	0	0.0
20,001-22,000	563-620	1	0.3	1	0.3
22,001-24,000	620-676	0	0.0	0	0.0
24,001-26,000	676-732	0	0.0	0	0.0
26,001-28,000	732-789	1	0.3	0	0.0

the 22,000 cfs (619 cms) range were eliminated. The reduction of peak discharge frequencies are a direct result of flood control through river regulation.

Conclusions drawn from analysis of the discharge frequency distribution reflect an insignificant difference of occurrence in small mean monthly discharges prior to closure versus subsequent to closure.

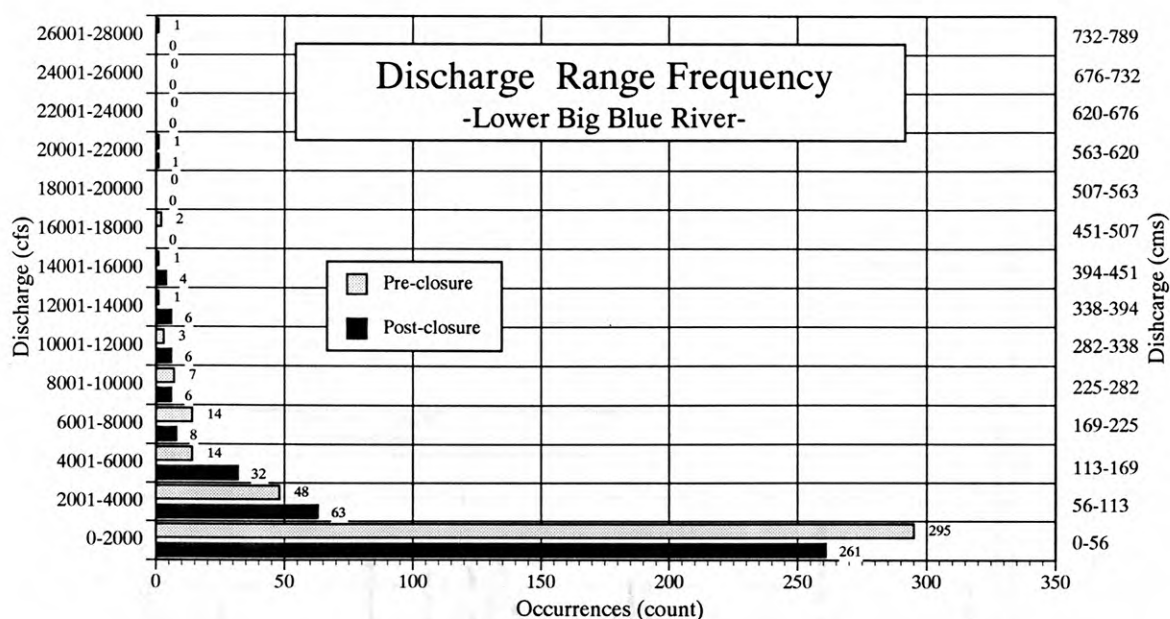


FIGURE 42. Mean monthly discharge values are plotted in frequency ranges in magnitudes of 2,000 cfs (56.3 cms). Occurrences or counts indicate the number of reported values that fall into a specific discharge frequency range.

The mid-sized discharge frequencies and smaller have not significantly changed based on the available discharge record.

Standard deviation of discharge from the mean values of both pre- and post-closure periods were negligible. Pre-closure standard deviation, (2,964 cfs, 83.5 cms) increased only slightly following closure (2,994 cfs/ 84.3 cms).

By comparing the lowest mean monthly discharge for a given year, an annual minimum discharge value can be assessed. A reduction in the annual minimum discharge can be seen in the post-closure period (Figure 43) with respect to the pre-closure minimums. Pre-closure minimum discharge of 85 cfs (2.4 cms) was reduced by 405% $\pm$ 3.5% to 21 cfs (0.6 cms) in the post-closure period. However, this reduction is of little significance since the value represents a single monthly mean

Minimum Mean Monthly Discharge -Lower Big Blue River-

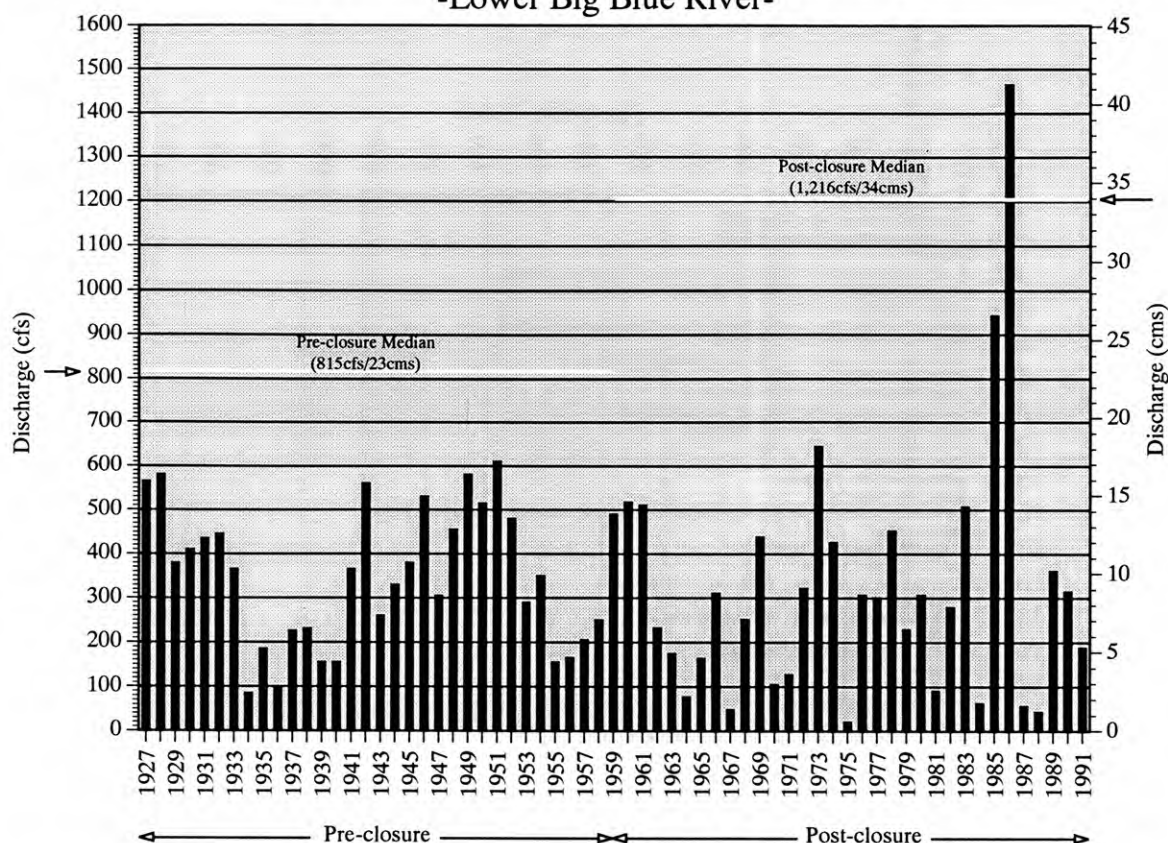


FIGURE 43. Minimum mean monthly discharge of the lower Big Blue River, 1927-1991

minium within the period. The key analysis factor here is seen in the occurrence reductions of minimum discharges below 200 cfs (5.6 cms). There was a significant increase of occurrences below 200 cfs (5.6 cms) following closure of the Tuttle Creek dam.

The maximum mean monthly discharge values have been affected by the closure of Tuttle Creek Dam as well (Figure 44). Typically, closure of a dam results in significant reduction in peak discharge values. The highest mean monthly discharge recorded during the post-closure period (20,110 cfs / 566.5 cms) is $38.3 \pm 3.5\%$ lower than the highest mean monthly discharge recorded during the pre-closure period. Excluding

Maximum Mean Monthly Discharge -Lower Big Blue River-

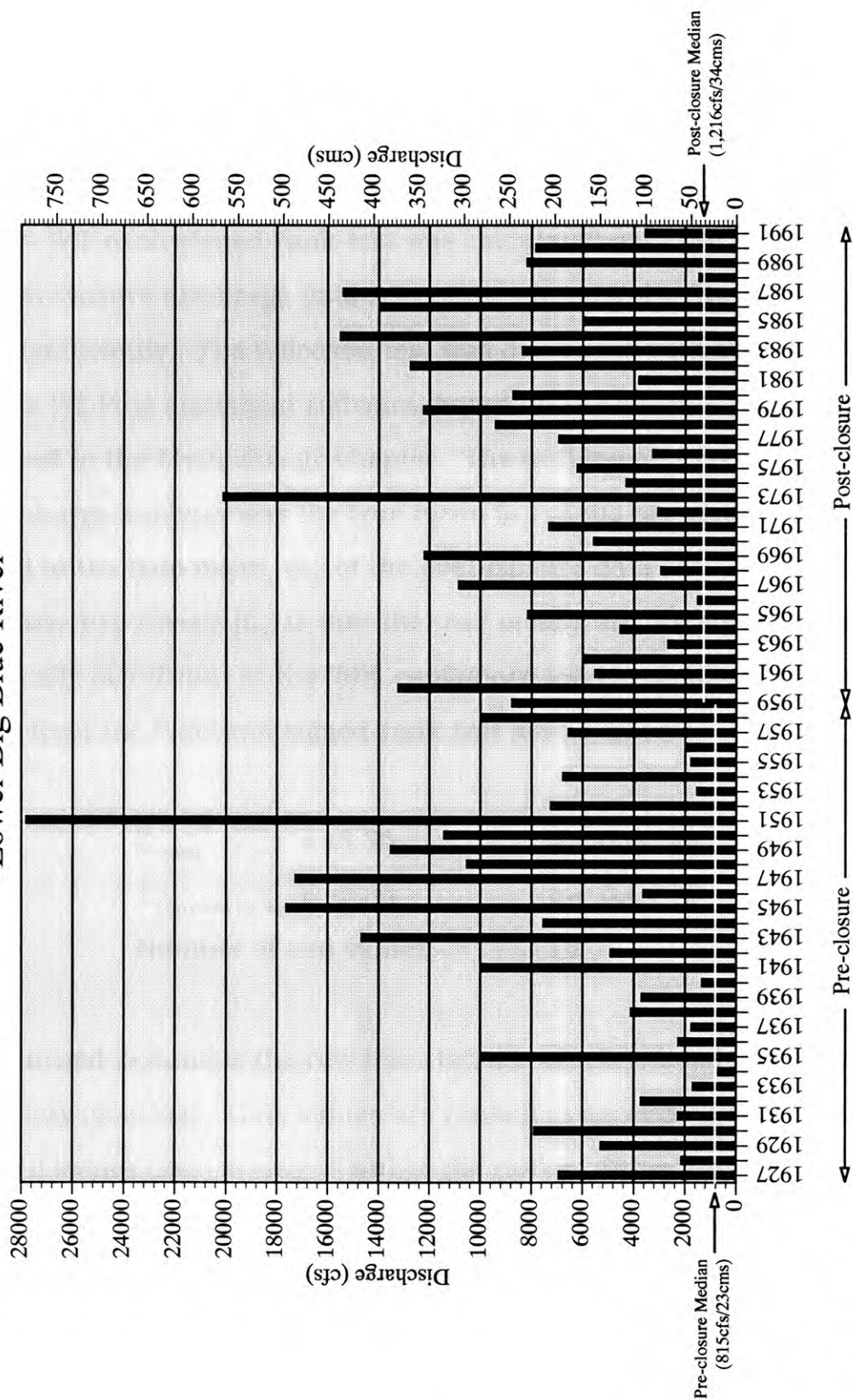


FIGURE 44. Maximum mean monthly discharge of the lower Big Blue River, 1927-1991.

1973, the maximum mean monthly discharge was effectively reduced to below 15,510 cfs (436.9 cms) for the post-closure period. However, discharge maximums below 14,000 cfs (394.4 cms) were not significantly different between pre-closure and post-closure periods.

A Wilcoxon signed-rank test was calculated with the pre-closure and post-closure discharge data sets to determine if the discharge means differ significantly. The Wilcoxon test was calculated with the use of Statview SE Plus statistical software, based on the formula principles as discussed in the Methodology chapter. The null hypothesis (h_0) tested for the discharge analysis was the true mean (μ_1) of the pre-closure data set is equal to the true mean (μ_2) of the post-closure data set. The alternative hypothesis (h_a) is that the true means are not equal, thus statistically significant at the 90% confidence level ($p < 0.10$). Statistical results from the Wilcoxon signed-rank test are as follows:

Z_{value}	= -3.35	$p = 0.0008$
$Z_{\text{corrected for ties}}$	= -3.35	$p = 0.0008$
Number of tied values:		14

The returned Z-value is the raw test statistic which is used to identify the probability (p-value). Data values are ranked in ascending order with identical values (ties) averaged within the ranks. There were 14 tied values associated with the pre-closure and post-closure analysis. The difference between the Z-value and the corrected Z-value for rank ties was negligible due to the large number of data points (387 months per period). The test statistic probability ($p = 0.0008$) is highly significant at

the 90% confidence level. Therefore, the null hypothesis was rejected and the alternative hypothesis was accepted that the discharge means of pre-closure and post-closure are significantly different.

A second test statistic approach was calculated with the pre-closure and post-closure discharge data. An ANOVA F-test of variance was calculated to see if the pre-closure and post-closure discharge variances statistically differ. The F-test was calculated with the use of Statview SE Plus statistical software, based on the formula principles as discussed in the Methodology chapter. The null hypothesis (h_0) tested for the discharge analysis was the true variance (σ^2_1) of the pre-closure data set is equal to the true variance (σ^2_2) of the post-closure data set. In this case the alternative hypothesis (h_a) would be that the true variances are not equal, thus statistically significant at the 90% confidence level ($p < 0.10$). Statistical results from the F-test are as follows:

$$F_{\text{value}} = 1.6 \qquad p = 0.0001$$

The F-value is the raw test statistic which is used to determine the probability (p-value). The test statistic probability ($p = 0.0001$) is highly significant at the 90% confidence level. Therefore, reject the null hypothesis and accept the alternative hypothesis that the discharge variances of pre-closure and post-closure are significantly different.

Channel Rating Curves

A method to determine whether aggradation or degradation have taken place in a channel by comparing historical channel rating curves

for the lower Big Blue River. By plotting stream gage height against discharge in the logarithmic scale, a nearly linear curve effectively identifies if degradation or aggradation has occurred recently. Degradation is occurring if the plot slope decreases over time (Figure 45), which lowers gage height. Conversely, aggradation is occurring if the slope of the curve steepens, therefore raising gage height (LaCock 1992, 1994). A detailed analysis of channel rating curves is outside the scope of this study, however, a brief historical review will indicate whether the lower Big Blue River has been in a phase of degradation, aggradation, or quasi-equilibrium for the years 1951, 1961, 1971, 1981, and 1991 (Figure 46 through Figure 50). As a comparison benchmark, mean sea level is calculated by adding the gage height at a given discharge to the National Geodetic Vertical Datum (NGVD) of 1929. The NGVD was at 991.86 feet (302.32 m) through September 30, 1974 then lowered three feet (0.91 m)

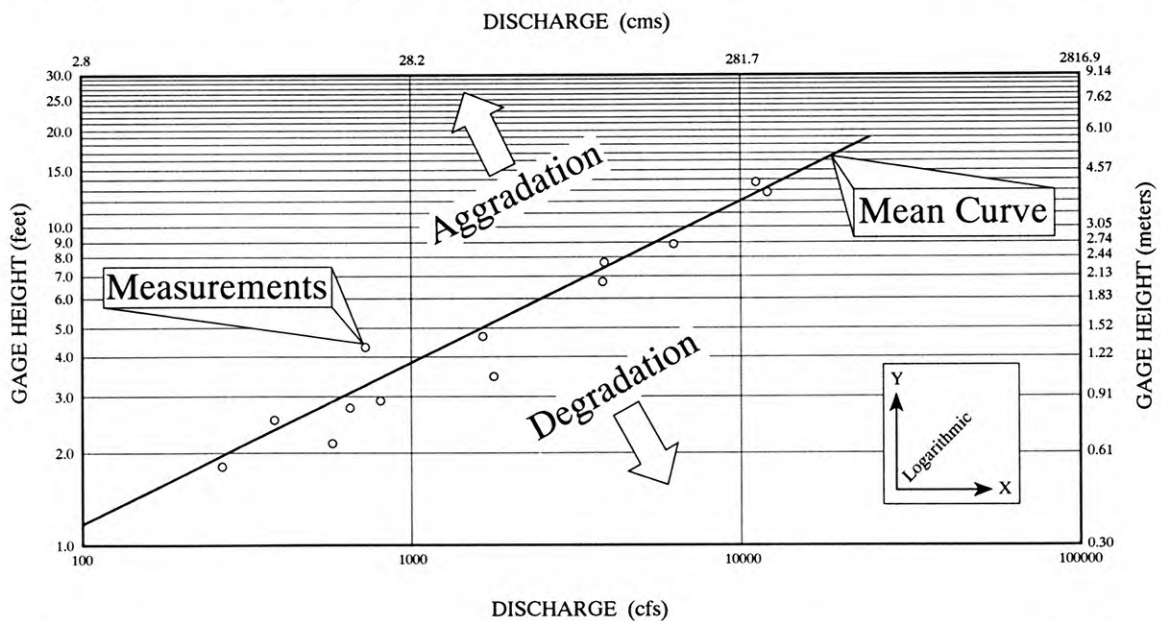


FIGURE 45. Channel rating curves will identify periods of degradation or aggradation as measured at the gage location. (JJW-3/94)

Lower Big Blue River Channel Rating Curve - 1951

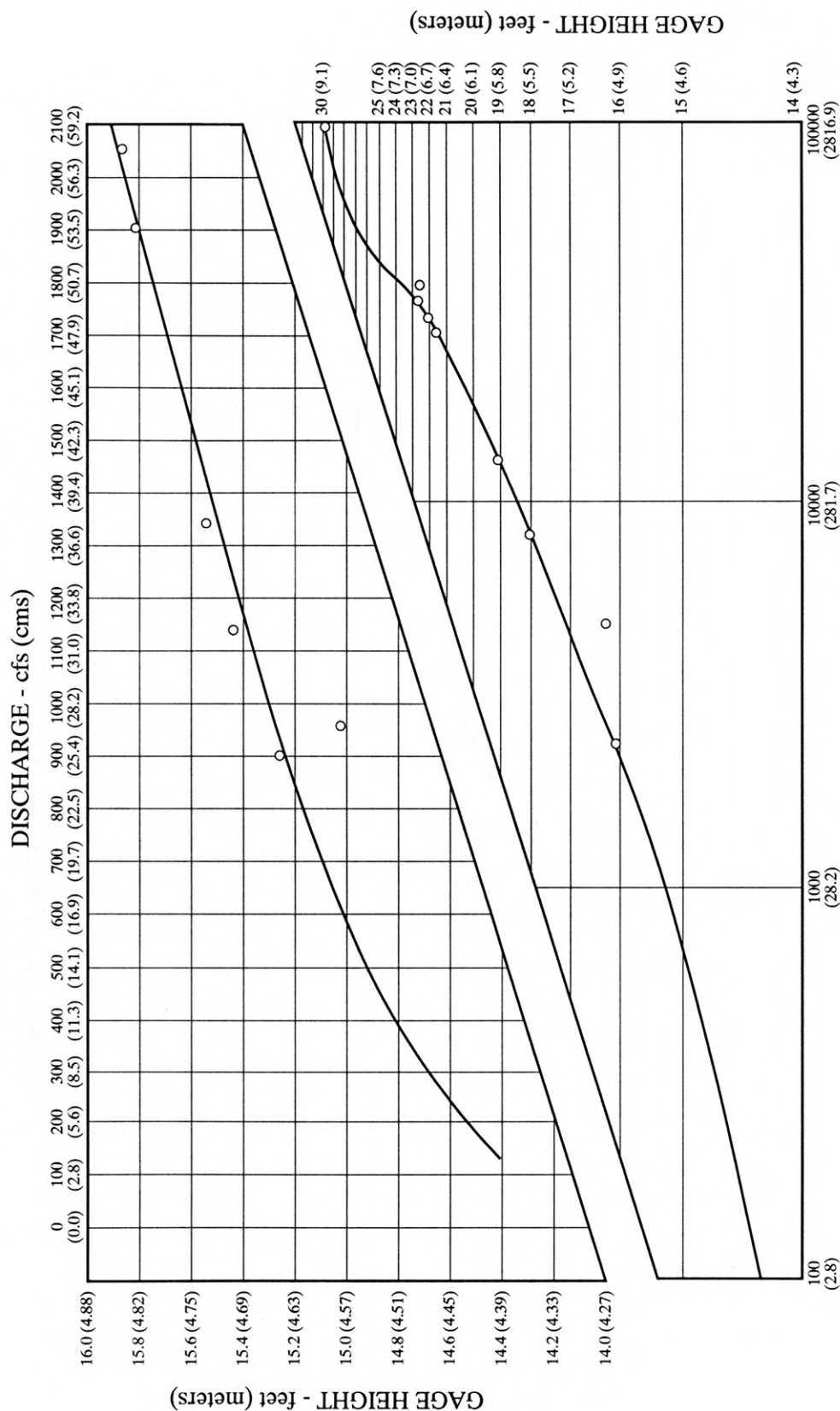


FIGURE 46. Channel rating curve, logarithmic scale for discharges over 2,100 cfs (59.2 cms), arithmetic scale for discharges below 2,100 cfs (59.2 cms). Gage height for 1951 at 1,000 cfs (28.2 cms) was 15.3 feet (4.6 m) Source: USGS 1992

Lower Big Blue River Channel Rating Curve - 1961

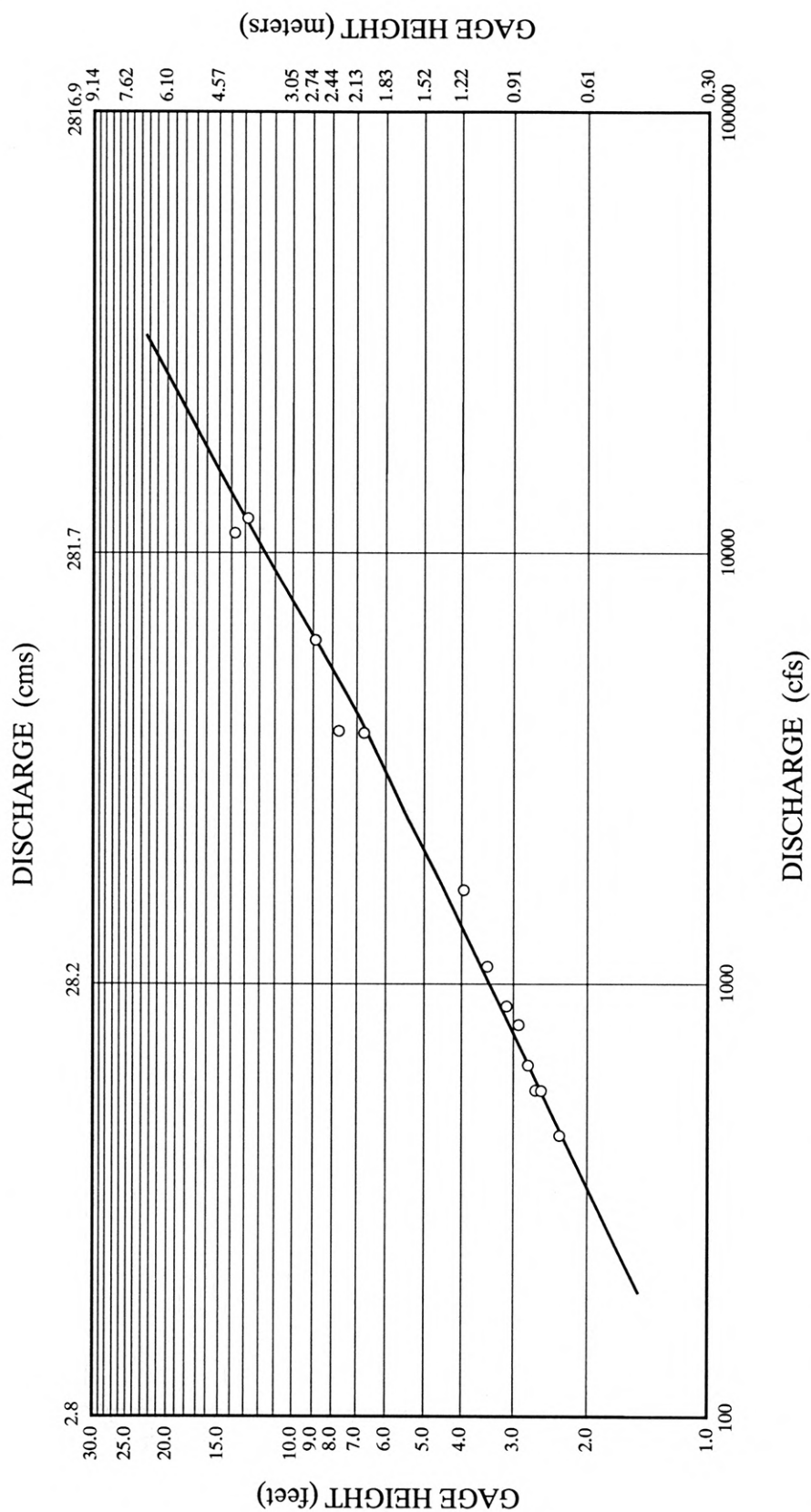


FIGURE 47. Due to degradation of the river channel in previous years, 3.0 feet (2.74 m) must be mathematically added onto the plotted gage height to accurately determine the mean sea level represented in this curve. Source: USGS 1992

Lower Big Blue River Channel Rating Curve - 1971

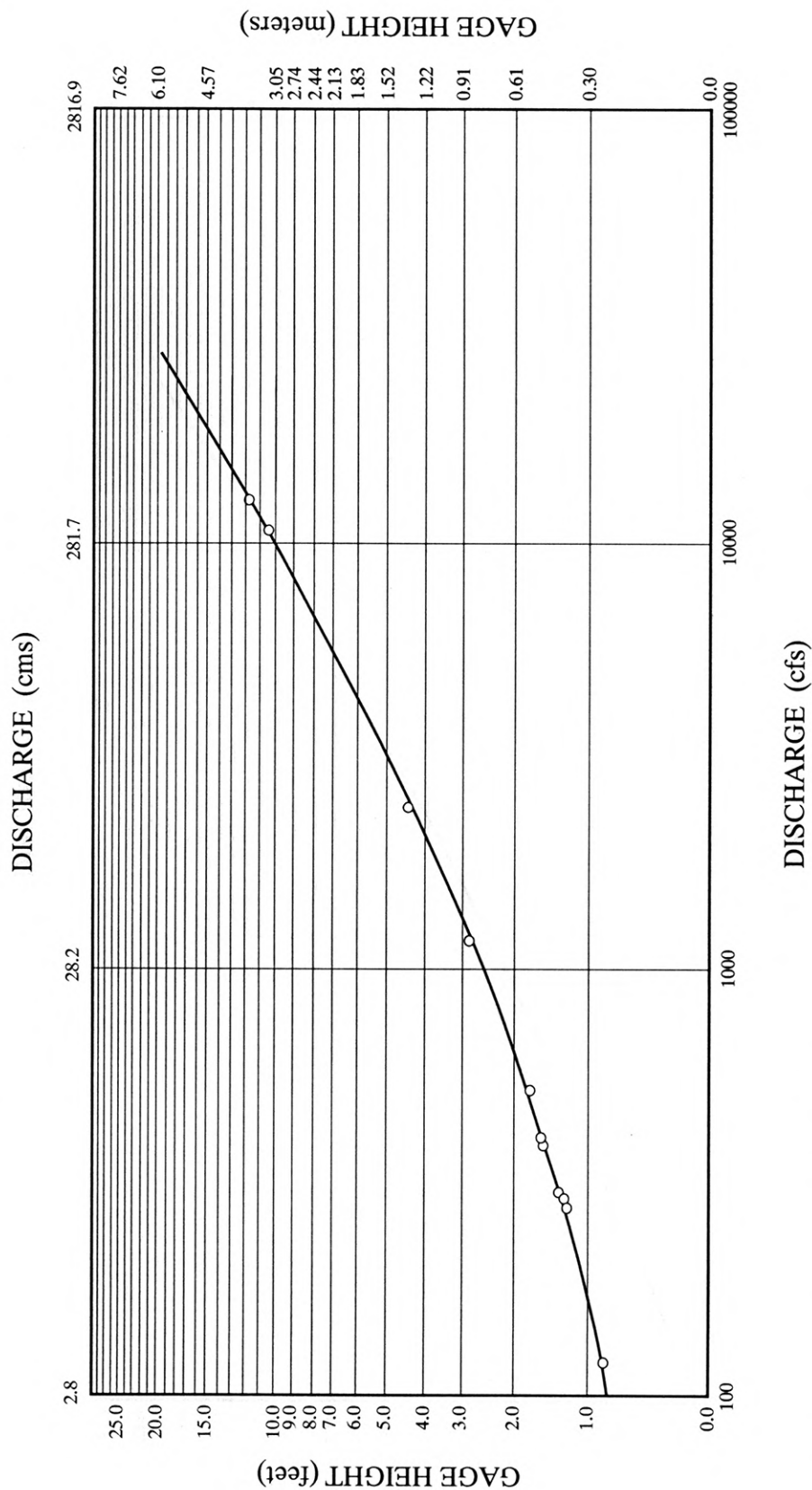


FIGURE 48. Due to degradation of the river channel in previous years, 3.0 feet (2.74 m) must be mathematically added onto the plotted gage height to accurately determine the mean sea level represented in this curve. Source: USGS 1992

Lower Big Blue River Channel Rating Curve - 1981

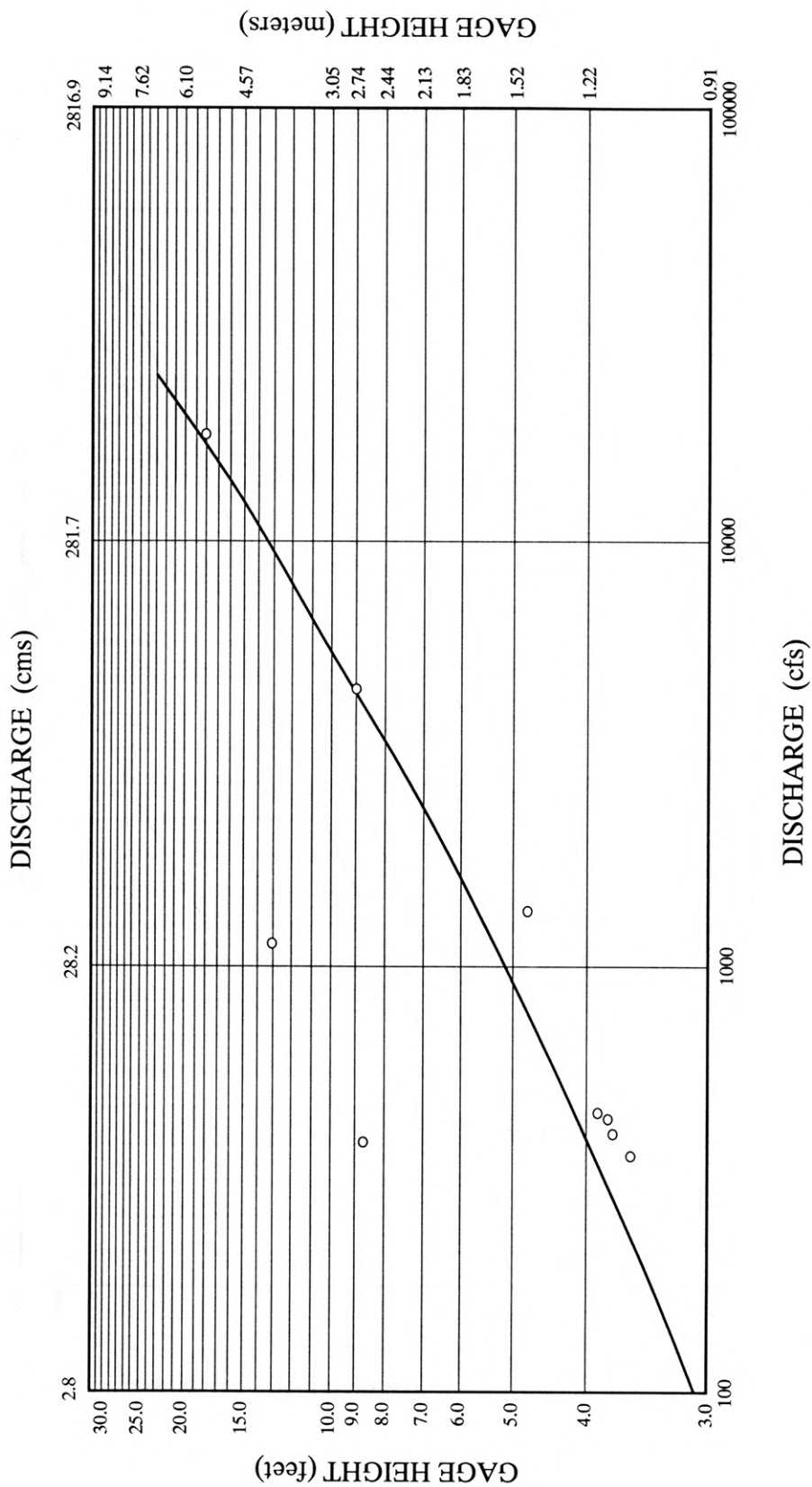


FIGURE 49. The NGVD was decreased by 3.0 feet (2.74 m) in 1974, therefore mathematical adjustment to gage height would no longer be necessary until downcutting once again forced a datum adjustment. Source: USGS 1992

Lower Big Blue River Channel Rating Curve - 1991

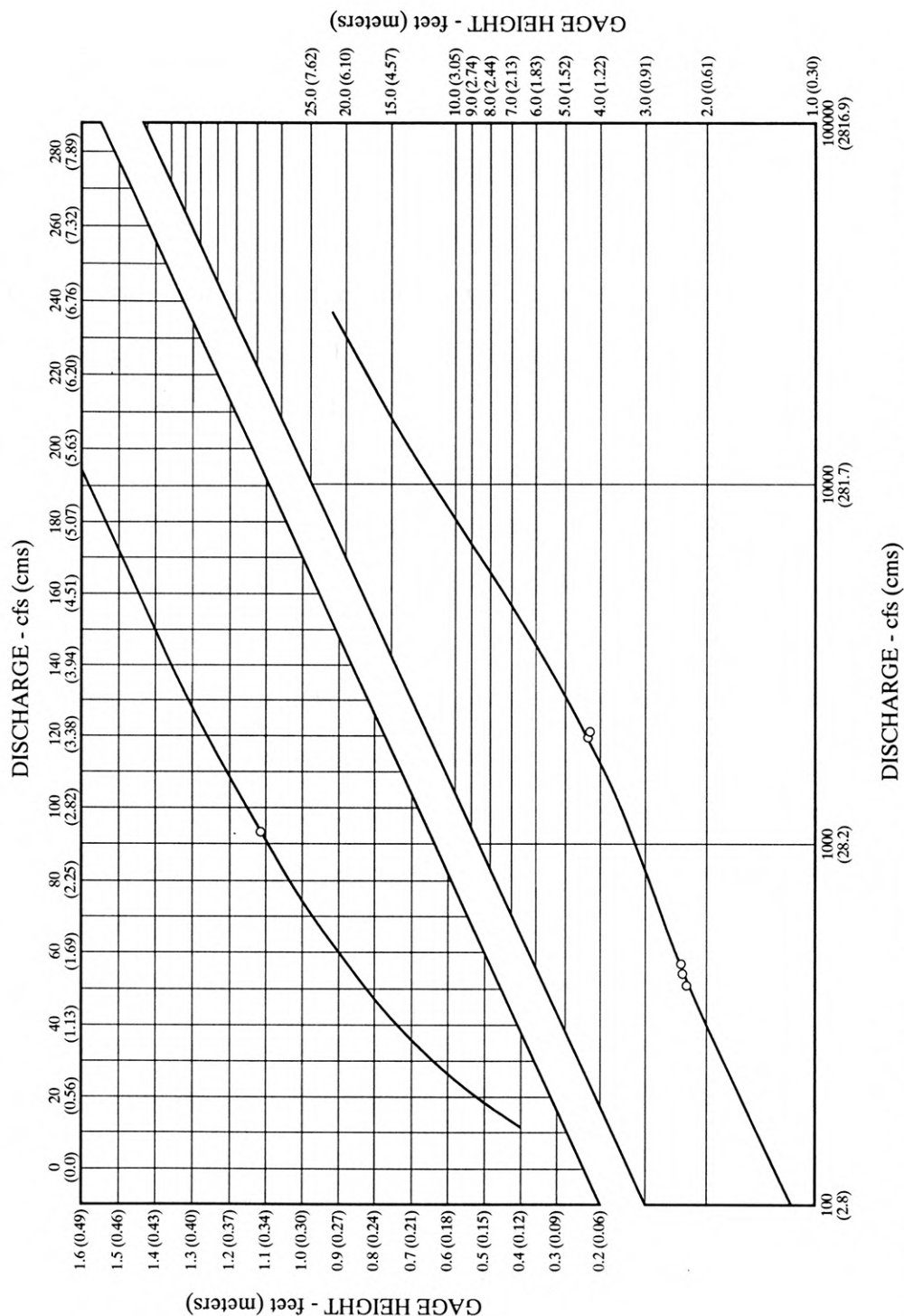


FIGURE 50. Gage height in 1991 with respect to 1,000 cfs (28.2 cms) was 3.2 feet (0.98 m). As the gage height approaches zero, mathematical gage height adjustment or decreasing the NGVD will be necessary again. Source: USGS 1992

to 988.86 feet (301.40 m) on October 1, 1974 to adjust for channel degradation. The gage height will be compared at a discharge benchmark of 1,000 cfs (28.2 cms).

Discharges over 2,100 cfs (59.2 cms) in 1951 are plotted on a logarithmic scale to establish a near linear mean curve. For lower discharges, such as those under 2,100 cfs (59.2 cms) in 1951, an arithmetic scale is utilized for ease of plotting lower discharge measurements (LaCock 1994). The surface water level of the Big Blue River for a discharge of 1,000 cfs (28.2 cms) in 1951 was 1,007.16 feet (206.98 m) above mean sea level.

Channel degradation dropped the gage height significantly after 1951. The gage height has to remain as a positive integer due to the log based plot. In order to compensate for the channel downcutting which occurred after 1951, 3.0 feet (0.91 m) had to be arbitrarily added to the gage height from the period of November 18, 1954 through September 30, 1974. The adjusted mean sea level for a discharge of 1,000 cfs (28.2 cms) in 1961 and 1971 was 998.16 feet (304.24 m) and 997.36 feet (304.00 m), respectively.

The gage height for 1981 did not require 3.0 feet (0.91 m) to be mathematically added since the NGVD was lowered in 1974. The mean sea level for a discharge of 1,000 cfs (28.2 cms) in 1981 was 993.86 feet (303.93 m).

The channel rating curve for 1991 was plotted on a logarithmic scale for discharges over 280 cfs (7.89 cms) and on an arithmetic scale to better illustrate those lower discharge measurements under 280 cfs (7.89 cms). The mean sea level for a discharge of 1,000 cfs (28.2 cms) in 1991

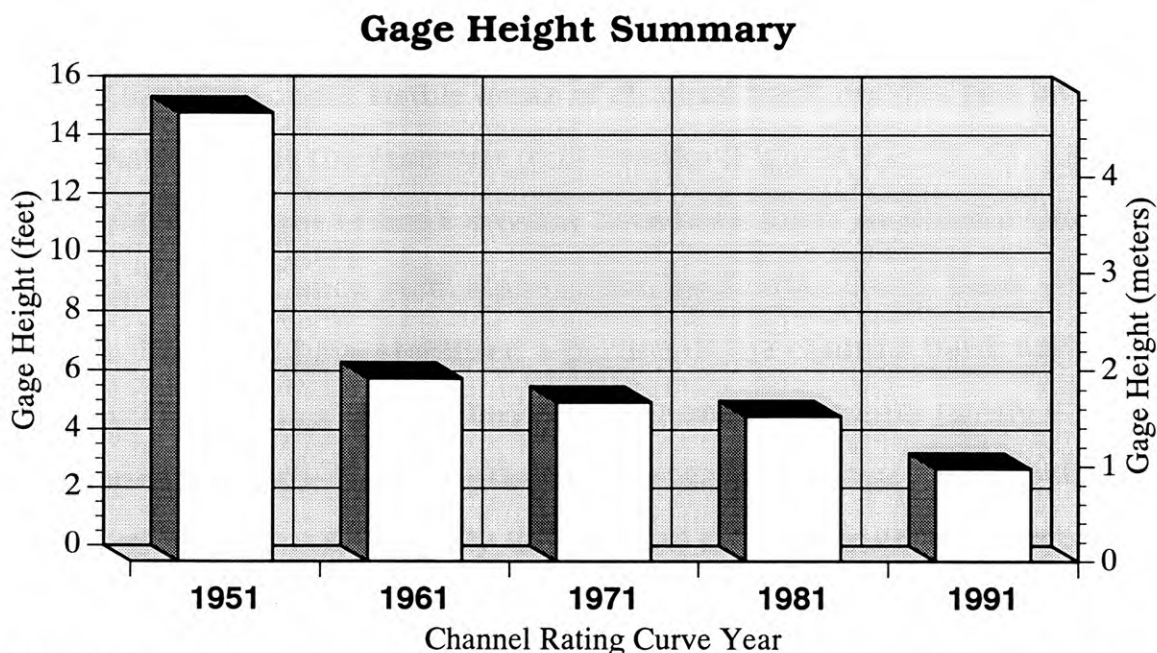


FIGURE 51. Decreasing gage height measured for 1,000 cfs (28.2 cms) discharge, of the lower Big Blue River.

was 992.06 feet (302.38 m). Evidence of channel degradation at the location of the gauging station along the lower Big Blue River is supported by a decline in gage height of 12.1 feet (3.69 m) over the last forty years (Figure 51).

Field Observations

Field observations of the lower Big Blue River were conducted to further examine and characterize zones of erosion, deposition, or quasi-equilibrium. There were two reaches of the lower Big Blue River which were of particular interest: the uppermost three mile (4.8 km) reach below the dam, which will be referred to as the "erosion zone," and the channel portion approximately six miles (9.7 km) downstream from Tuttle Creek Dam, where sand dredging activities once occurred, which will be referred to as the "dredging zone".

The Erosion Zone

One of the more visible areas of channel bank erosion can be seen immediately below the reservoir outlet works (Figures 52, 53, 54). Efforts to reduce the degree of bank erosion have been fairly successful where applied, however, once bank stabilization applications end, bank collapse begins. The COE have stabilized a portion of the channel bank with "riprap." Riprap is a layer of large durable rock fragments tightly positioned along the bank to preserve the channel shape from erosional waves or currents. Essentially the channel bank is artificially armored with the application of riprap bank stabilization. Once the riprap ends, the channel banks are visibly impacted with mass wasting processes resulting from: 1) high stream power; 2) clear water discharge; 3) narrow channel width; 4) channel bank composition (alluvium); and 5) poor channel development. Within this reach of the lower Big Blue River there are several complex channel adjustments occurring simultaneously. Stream power (refer to Chapter 1 for stream power discussion) is at its highest point when leaving the outlet works for the lower Big Blue River because: 1) channel width is at its narrowest point and is stabilized with riprap; 2) mean monthly discharge has been increased $21.6 \pm 3.5\%$ since the closure of the dam; 3) the water that is discharged is essentially sediment free (clear water discharge); and 4) there has been an increase in intermediate (approximately two-thirds to three-quarters bankfull) stage frequencies since closure of the dam. The channel bank mass wasting suggests that the river is in a condition where stream power exceeds resisting power, thus leading to channel bank erosion. Eventually, the channel should reach a condition of

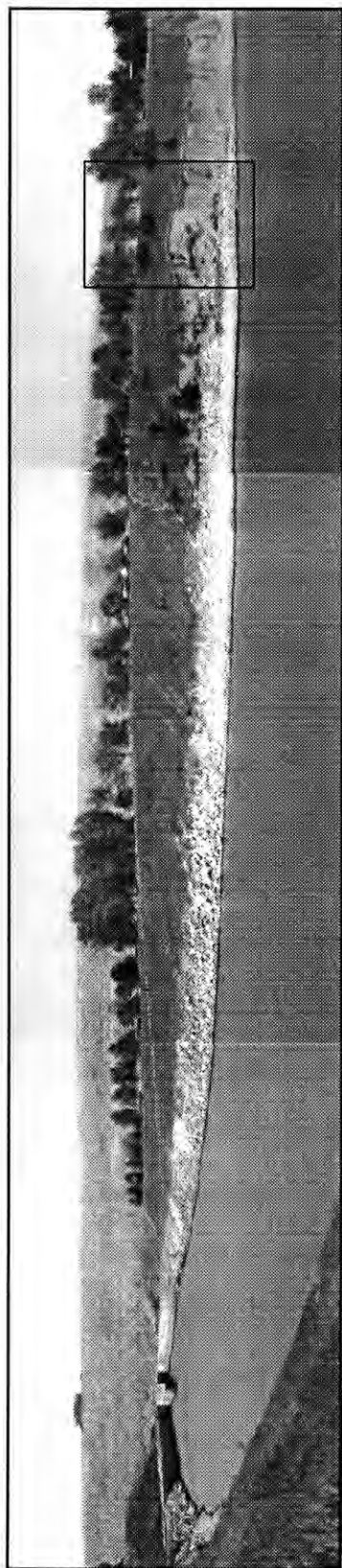


FIGURE 52. The north bank immediately downstream of the reservoir outlet works is partially stabilized with riprap, whereas the unprotected channel bank shows evidence of mass wasting processes (inset Figure 54). (Photo by: Author 1991)

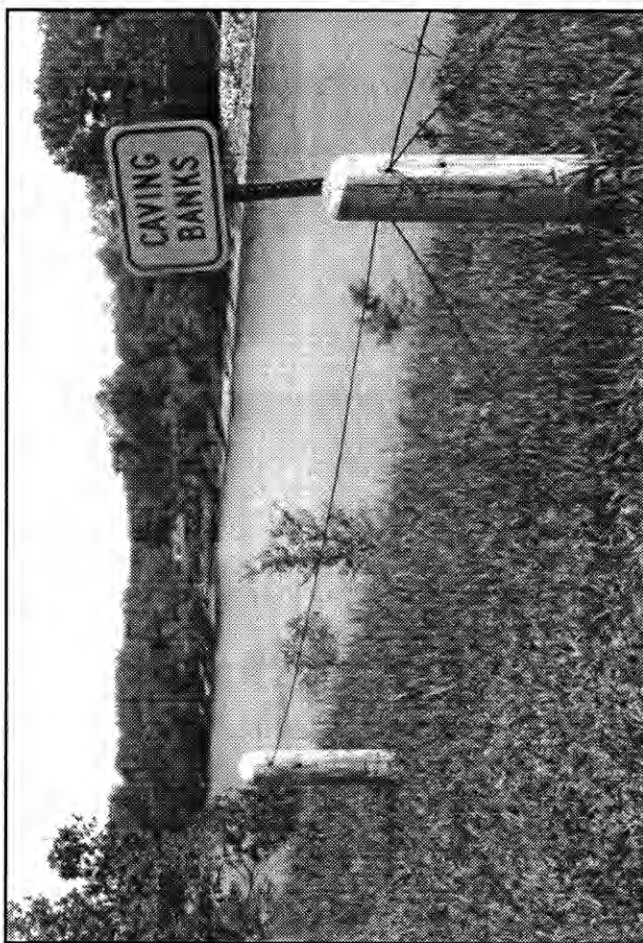


FIGURE 53. Mass wasting of the northern bank required warning signs to be post for public safety. (Photo by: Author 1991)

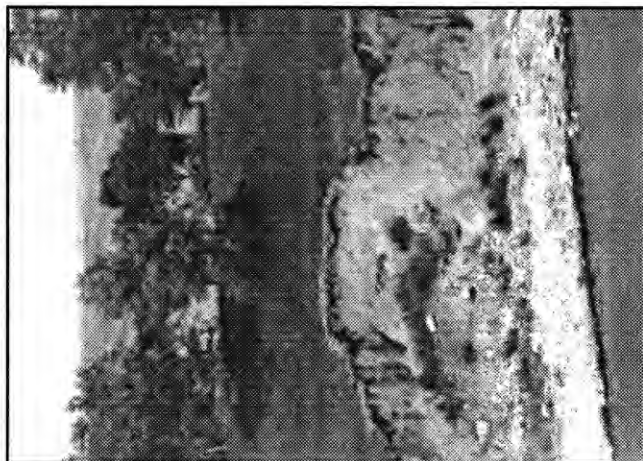


FIGURE 54. Inset photo of Figure 52. (Photo by: Author 1991)

equilibrium with the available sediment load and the discharge exiting the dam.

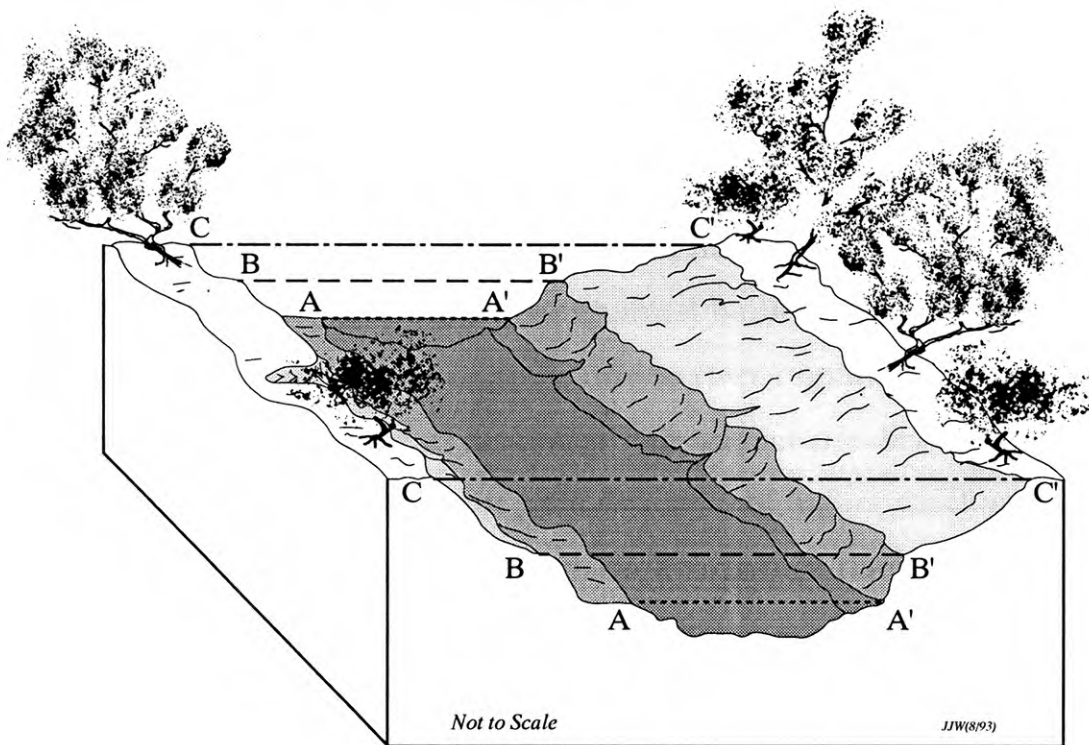
Water discharge from the reservoir is visibly less sediment laden than the waters contained in the reservoir. Sediment records were not available for the lower Big Blue River, however, it is estimated that Tuttle Creek Reservoir traps 95 to 98 percent of the suspended sediment which is flowing into the reservoir (Simons et al. 1984). The sediment trap estimate is based on the total tonnage of sediment of all size fractions which are transported in and out of the reservoir. The clear water discharge from the reservoir outlet works far exceeds the critical-power threshold and readily transports any eroded bedload downstream.

The lower Big Blue River is at its narrowest point near the outlet works. Channel shape has been maintained through bank stabilization efforts. As discussed by Bull (1979, 1991), if discharge, channel slope and specific weight of water were to remain constant, stream power is significantly increased as channel width decreases. However, by maintaining the channel width, river stage is increased which directly increases the river slope.

The channel bank material in this portion of the river is comprised of alluvial deposits which do not have a high clay content. Therefore the channel bank is susceptible to bank pore saturation and erosional waves and currents. Furthermore, this particular reach of the river was altered during the construction of the dam. The river channel from the outlet works to the confluence of the lower Big River and the River Pond backwaters was excavated and is not part of the natural river channel path. By altering the river channel path, the newly exposed bank

sediments could have a lower resisting power and thus be more susceptible to erosion.

Natural river bank development is typically not present in the bank morphology within the erosion zone of the lower Big Blue River (Figure 55). There are generally three channel bank development levels: 1) depositional bar (Hedman 1970), or channel sidebars; 2) active channel (Hedman et al. 1974); and 3) bankfull (Wolman 1955).



-REFERENCE LEVEL-

-  Bankfull (C - C')
-  Active Channel (B - B')
-  Depositional Bar (A - A')

FIGURE 55. Channel bank development typically evolves into three reference levels. Depositional bar, or side channel bars represents low discharge deposition, generally below the water surface. Active channel represents the wetted perimeter under normal or mean discharge flows. Bankfull represents flood discharge event with a 2-year recurrence interval. (Adapted from: Osterkamp and Hedman 1981).

Depositional-bar or channel side bars represent deposition of sediments during periods of low discharge, and thus are in a condition where stream power does not exceed resisting power. Active channel represents a period of normal discharge and may be in a condition of erosion, deposition, or quasi-equilibrium where neither net erosion nor deposition is occurring. Bankfull represents a phases of high discharge typically representing flood stage conditions. Here the stream power is extremely high due to high discharge values and stream power generally exceeds resisting power, resulting in a condition of erosion. The channel bank development seen in the erosion zone of the lower Big Blue River appears to be in a condition where active channel and lower bankfull stages are the same stage, referred to as an intermediate stage. In the case of the lower Big Blue River, the channel bank is subject to abrupt changes in discharge and river stage due to river regulation. Change in discharge frequency or mean discharge can impact the development of the channel bank. During short periods (days) of higher discharges (greater than mean discharge values), the river stage rises, saturates the channel bank pore space, and is subject to mass wasting or gravity erosional processes once the discharges are reduced. This surge of discharge rapidly raises and lowers the wetted surface of the active channel, therefore a well defined active channel/bankfull channel boundary does not mature. Rather, as seen below the Tuttle Creek Dam, a sheer channel bank is formed. The formation of steep channel banks has been found to be associated with sustained flows of less than bankfull stage (Simons et al. 1984).

Downstream 1.4 miles (2.2 km) from Tuttle Creek Dam is the



FIGURE 56. Rocky Ford Dam photographed from the southeast, located 1.4 miles (2.2 km) downstream from Tuttle Creek Reservoir. (Photo by: Author 1991)

Rocky Ford Dam (Figure 56). This spillwater dam acts as a stilling basin for the water discharged from the reservoir. The slope is effectively reduced from the outlet works to the point where waters flow over Rocky Ford Dam. With the reduction in slope, a reduction in stream power is expected. Additionally, Rocky Ford Dam acts as a secondary sediment trap for sediment transported from resulting upstream erosion. It has been speculated by the COE (1973) that in the event Rocky Ford Dam was abruptly removed, channel degradation

of 14 feet (4.3 m) could be expected to the base of the Rocky Ford Dam.

Rocky Ford Dam is constructed on the Americas Limestone member, a hard restive unit, of the Foraker Limestone Formation (Beaver 1992). This resistant limestone unit plays an important role in the reduction of channel degradation below Rocky Ford Dam. Once the lower Big Blue River flows over Rocky Ford Dam, the critical-power threshold is exceeded due to the abrupt change in slope and velocity. The river elevation drops from 10 to 14 feet (3.0-4.8 m) (Figure 57), depending on backwater conditions of the Kansas River, which increases stream power. Without the resistive limestone at the base of Rocky Ford Dam, the degradation below Rocky Ford would likely be far greater than

FIGURE 57. Rocky Ford Dam as seen looking west, has a 10 to 14 foot (3.0-4.8 m) drop in elevation. Elevation drop depends on backwater effects from the Kansas River. (Photo by: Author 1991)



what is currently seen. It is for this reason that the channel is at one of its widest points along the lower Big Blue River. Critical-power threshold is exceeded, downcutting is impeded by channel bed armoring, therefore channel widening is a result of the excess stream power (Figure 58).

Historically, the channel has consistently been at one of its widest points immediately below Rocky Ford Dam (Figure 59). Today, during low flow the river typically flows in the western channel below Rocky Ford.

During high flow periods, the lower Big Blue River divides around the



FIGURE 58. Below Rocky Ford Dam viewed from the west, bank erosion can be visually identified during periods of low discharge. (Photo by: Author 1991)

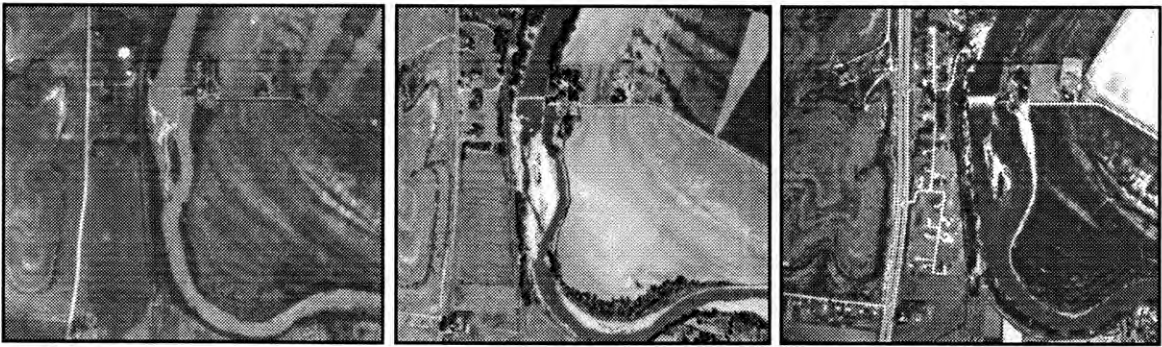


FIGURE 59. Below Rocky Ford Dam, viewed with northwest towards the top of the page, has historically been the widest point of the lower Big Blue River. The channel has progressively widened from 1937 (left), 1956 (center), to 1974 (right) . (Photo Sources: NARA 1937; ASCS 1956; COE 1974)

small island centrally located in the river channel. The small island in the channel below Rocky Ford remains there due to three factors: 1) the island is well vegetated which helps stabilize against non-overtopping flows; 2) armoring below Rocky Ford Dam is sufficient to prevent net channel degradation; and 3) during periods of high flow, the vegetation may slow the overtopping flow velocity sufficiently to result in deposition of sand and silt. The channel island has been documented since 1937 in aerial photographs.

Beyond Rocky Ford Dam, the river continues to exceed critical-power threshold as is evident by the degree of erosion. Bank stabilization techniques have been implemented with varying degrees of success. Within the remaining three miles (4.8 km) of the reach of the lower Big Blue River referred to as the erosion zone, there are three bank stabilization techniques utilized in addition to riprap: 1) dump rock; 2) refield jetties; and 3) bank junking. Dump rock (Figure 60) is similar to riprap, however, riprap is purposely position along the river bank whereas dump rock is dumped down the bank incline in mass quantity. There are over 4,500 cubic yards (3,440 m³) of dump rock

FIGURE 60. Dump rock consists of limestone and concrete rubble. Channel banks which are subject to high erosion are stabilized with the more resistive layer of rock. *(Photo by: Author 1991)*

along the ten mile (16.1 km) extent of the lower Big Blue River (COE 1973).

Rehfield jetties (Figure 61) are engineered structures made of steel that serve as a breakwater. There are 466 rehfield units (COE 1973) located immediately upstream from the Casement Road Bridge, approximately

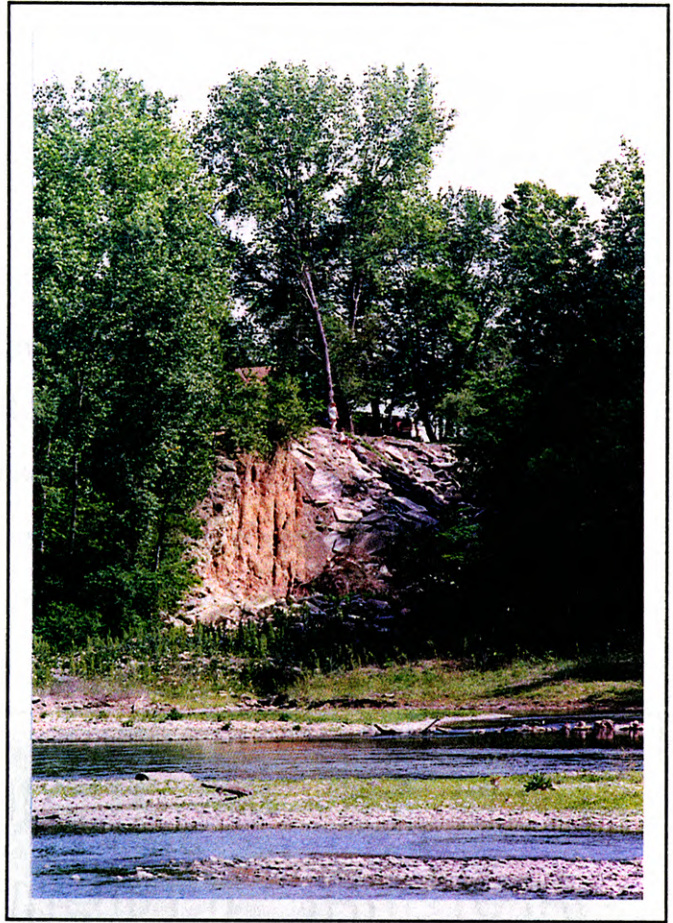


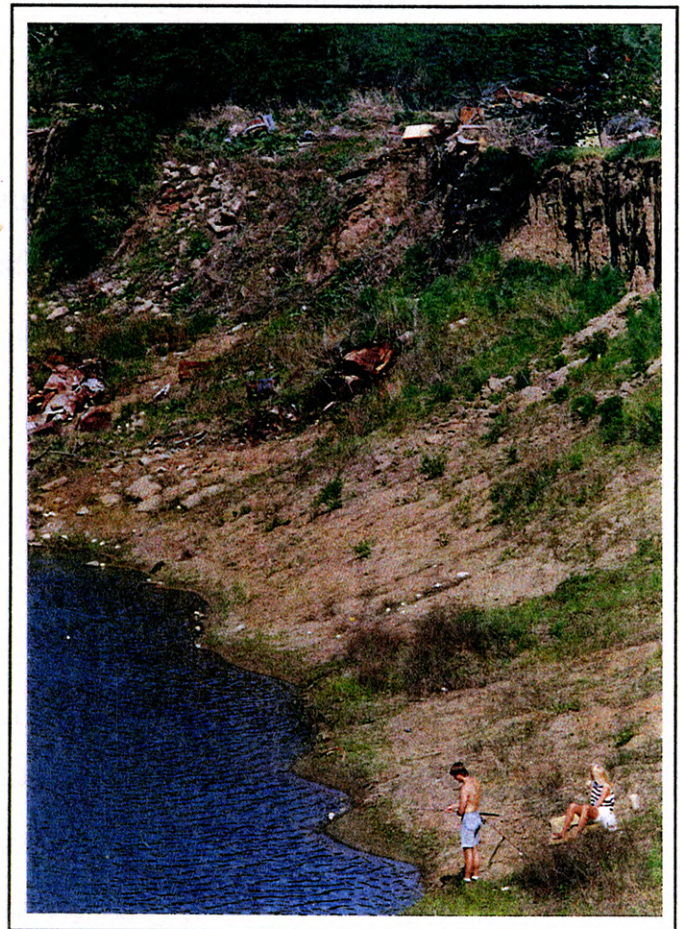
FIGURE 61. Rehfield jetties immediately upstream from the Casement Road Bridge, along the northern bank. Casement Road Bridge is 2.5 miles (4.0 km) downstream from Tuttle Creek Reservoir. *(Photo by: Author 1991)*

2.5 miles (4.0 km) downstream from Tuttle Creek Dam.

Looking downstream from the Casement Road Bridge, the third bank stabilization method, bank junking, can be identified (Figure 62). Discarding scrap-metal and junk car bodies along the river bank has historically been a technique utilized on many river systems. The junk car bodies are essentially performing the same function as the refield jetty. Junking the channel bank may slow bank erosion, but it, creates pollution and is generally an eyesore.

Within the erosion zone there are many complex channel adjustments. Bank caving occurs near the outlet works, channel widening below Rocky Ford Dam, channel bank erosion above and below the Casement Road Bridge, and channel degradation at the Casement Road Bridge. During periods of low flow the available sediment load is redistributed within the river channel in the form of side-channel bars or sand bars. The decrease in discharge results in a decrease in

FIGURE 62. Downstream from the Casement Road bridge on the south bank, scrap metal and junk car bodies are used to stabilize the south bank. The Casement Road bridge is approximately 2.5 miles (4.0 km) downstream from Tuttle Creek Reservoir. (Photo by: Author 1991)



stream power below the resisting power threshold which results in deposition. Typically the channel bar features are primarily seen during low flow periods. During periods of mean or higher flows the stage of the lower Big Blue River is sufficient to cover the low flow deposition features and stream power exceeds resisting power, resulting in increased sediment transport downstream.

Backwater effects from the Kansas River additionally influence deposition conditions. As stage height of the Kansas River rises and falls, the river stage of the lower Big Blue River below Rocky Ford Dam is directly influenced. During periods of high Kansas River stage the backwater effect on the lower Big Blue River increases the river stage, reduces river slope, decreases river velocity, and results in decreased stream power below the resisting power threshold. As a result deposition occurs.

Channel adjustments which are occurring downstream of Rocky Ford Dam appear to take the form of degradation. This conclusion is supported by the decline in gage height at the Casement Road Bridge gauging station. An additional factor that may contribute to degradation is the former sand dredging operations which have occurred further downstream from Casement Road Bridge.

The Dredging Zone

The final area of concern is the former dredging zone located approximately six miles (9.7 km) downstream from Tuttle Creek Reservoir. Sand dredging operations were reported to have occurred along the Big Blue River for nearly forty years (Kershaw 1992). It is

unknown as to the specific period in which dredging activities occurred on the lower Big Blue River. However, historical aerial photography indicates dredging operations on the lower Big Blue River have significantly altered the channel morphology between the late 1960's and 1988, the year dredging activities ceased on the lower Big Blue River (Figure 63).

Studies have concluded that sand and gravel dredging activities have three impacts on the lower Kansas River: channel morphology,



FIGURE 63. Complex channel adjustment in response to sand dredging activities on the lower Big Blue River. A) 1962; B) 1969; C) 1973; D) 1989. (Photo Sources: DOT 1962; ASCS 1969; DOT 1973; NASAAM 1989)

riparian ecology, and economic (Simons et al. 1984; COE 1990).

Channel morphology is greatly impacted by sand dredging activities. Channel widening, upstream and downstream erosion, and increased channel gradient are commonly associated with sand dredging operations (Simons et al. 1984). Artificial channel widening and degradation, due to the removal of sand sized particles during dredging activities causes a ponding effect. Sediment which is removed or trapped at the dredging site is no longer available for downstream transportation, resulting in downstream erosion. Often a knickpoint will form and migrate upstream.

The ecological impacts of dredging are closely associated with morphology impacts. The degree of ecological impact depends on the degree of degradation, erosion, and channel widening, which directly affects the biological community of the fluvial system. Channel degradation alters the substrate and results in conditions intolerable for many benthic invertebrates and indigenous fish. Channel erosion and widening impacts riparian environments and upsets the natural development of wetland ecosystems (COE 1990).

Economic impacts are directly associated with the degree of degradation and erosion. Physical damage to such features as bridges pilings, piers, and pipelines is commonly encountered. Bank stabilization efforts are undermined, which promotes bank decay and mass wasting of adjacent land. Bank erosion and channel widening may threaten structures or human-made improvements constructed on the floodplain. Water supply is adversely effected by channel widening. With the increased channel cross-sectional area, a reduction in river stage and

floodplain water table often occurs (COE 1990).

Ecological and economic impacts associated with dredging activities on the lower Big Blue River could not be effectively assessed given the scope of this study, however, channel adjustments such as channel widening in response to dredging activities was identified. It is unknown to what degree channel degradation, if any, occurred as a result of dredging activities. Channel widening was identified to occur between the years of 1967 and 1988. Upstream and downstream erosion from the dredging zone were readily identified in aerial photography. It is possible that the channel gradient was not significantly increased due to underlying resistive stratum which would reduce any headcutting effects upstream. Degradation may have been limited by armoring of the channel bed. The lack of downstream channel widening may be due to backwater effects of the Kansas River. The increased stream power due to dredging activities may have been effectively balanced by aggradation associated with backwater effects. Dredging activities on the lower Big Blue River ceased in 1988. The channel recovery in the form of channel narrowing is slowly occurring, however the effects of former sand dredging activities can still be identified (Figures 64, 65).

FIGURE 64. The northern channel meander, pictured here, reflects the highest degree of channel healing once dredging activities ceased on the lower Big Blue River. (*Photo by: Author 1991*)



FIGURE 65. The southern meander, pictured here, has not significantly recovered from the channel shape which was present during dredging activities. (*Photo by: Author 1991*)

CHAPTER 5: CONCLUSIONS

Tuttle Creek Reservoir provides social and economic benefits to Manhattan, Kansas residents, and surrounding communities. There are many benefits to river regulation, however, as identified in this study, there are associated impact, as well. Beneficial aspects of river regulation are primarily the reduction in peak flood stage events, uniform regulation of downstream navigable waters, and recreational opportunities.

Regulated river channels, such as the lower Big Blue River, are directly or indirectly impacted as a result of impoundment. Results of this study indicate the lower Big Blue River is in a state of complex channel adjustment in response to natural and human events spanning 1857 to 1991. Impacts such as increased mean monthly discharge subsequent to dam closure, reduction in available sediment load, and increase in the intermediate stage discharge frequencies have resulted in channel erosion below the dam, channel degradation along the reach of channel near Casement Road Bridge, and channel widening below Rocky Ford Dam and within the dredging zone.

Historically, significant flood events have occurred in the Big Blue and Kansas River watersheds (e.g., 1903, 1908, 1935, 1943, and 1951). Social and economic impacts suffered as a result of these events were the catalyst for the construction of the Tuttle Creek Reservoir. Since the closure of the dam in 1959, there has been a reduction of the mean monthly peak discharge. Precipitation occurring in the Big Blue watershed is now pooled in the reservoir and released over a longer

period of time. Prior to the construction of the dam, devastating peak flood stage discharges could occur.

The lower Big Blue River has undergone minimal lateral migration over the last 135 years. Significant river channel migration has primarily been a response to flood events which have occurred on the Big Blue River. Subsequent to the flood of 1951, the channel path within the valley stabilized. Since the closure of Tuttle Creek Dam the lower Big Blue River channel has not undergone significant lateral migration. There are a number of channel adjustments which have occurred in the post-closure period (e.g., channel widening and bank erosion), however these adjustments were found to be localized.

Channel sinuosity of the lower Big Blue River has decreased over the last century by $29.3 \pm 3.5\%$. Channel straightening has primarily been due to flood events along the Big Blue River, although human-channel straightening has also taken place. During the construction of the Tuttle Creek Reservoir approximately two miles (3.2 km) of the Big Blue River channel was rerouted to facilitate the closure of the dam. As a result of the channel rerouting, a slight decrease in sinuosity was identified, although this decrease is minimal compared to natural sinuosity changes that have occurred over the last forty years. A second human-activity which has altered the channel morphology occurred downstream from the dam approximately six miles (9.6 km). From the late 1960's to 1988, sand dredging operations were conducted on the lower Big Blue. As a result of these dredging activities the channel within the dredging zone has undergone significant channel adjustment. A minor increase in sinuosity (1.62 to a maximum of 1.65) was identified

within the period in which dredging operations were conducted.

One of the most significant changes that resulted from Tuttle Creek Dam is the increase of mean discharge seen subsequent to closure. Mean monthly discharge increased by $21.6 \pm 3.5\%$ in the post-closure period. This increase in mean discharge is not consistent with case studies reported in the literature. The discharge increase may be attributable to one or more factors: 1) extrapolated pre-closure discharge data utilized in this study did not accurately represent the discharge patterns prior to closure; 2) regulated discharge was managed differently with respect to the river regulation environments reported in the literature; or 3) there may have been a regional increase of net precipitation over the last four decades resulting in an increase in mean discharge. The median mean monthly discharge value significantly increased by $49.2 \pm 3.5\%$ from the pre-closure period to the post-closure period. In addition to an increase in median mean discharge, a minor shift in the discharge frequencies from smaller magnitude discharges to intermediate sized discharges took place. The peak discharge decreased by $38.3 \pm 3.5\%$ from the pre-closure period to the post-closure period. Statistical evidence to support pre-closure and post-closure discharge pattern differences were identified with the Wilcoxon signed-rank test and Anova F-test for variance. The Wilcoxon signed-rank test compared pre- and post-closure mean discharges values and found that the pre-closure and post-closure mean discharges were significantly different. Additionally, the Anova F-test compared the pre- and post-closure period discharge variances and found that the two periods had significantly different variances.

The lower Big Blue River is undergoing degradation along the reach near the Casement Road Bridge. The degradation was identified in the channel rating curve records between 1951 and 1991. A nine foot (2.74 m) drop in gage height during the 1951-1961 period was identified. This significant decrease in gage height represented a channel adjustment resulting from the 1951 flood. Over the forty year period of 1951-1991, a net drop in gage height of 12.1 feet (3.69 m) occurred. It is unknown if the degradation is localized or is representative along the entire reach of the lower Big Blue River. Historical phases of river channel degradation or aggradation were not assessed in this study, nor could inferences be made concerning net aggradation or degradation of the river channel without channel depth measurements at various locations along the lower Big Blue River, which were not within the scope for this study.

Field observations conducted in conjunction with this study identified zones of channel bank erosion along the upper three mile (4.8 km) reach of the lower Big Blue River and within the zone of former sand dredging operations six miles (9.7 km) downstream from Tuttle Creek Reservoir (Figure 66). A variety of bank stabilization techniques have been applied to the upper reaches of the lower Big Blue River, however, stabilization efforts are present only in zones of high erosion. Zones of moderate erosion, such as below the outlet works riprap, are progressively encroaching on recreational areas and roadways of the River Pond area. The erosion seen immediately downstream from the reservoir is due to multiple factors: 1) clear water discharge from the reservoir; 2) increased mean discharge, resulting in increased water

LOWER BIG BLUE RIVER CHANNEL SUMMARY

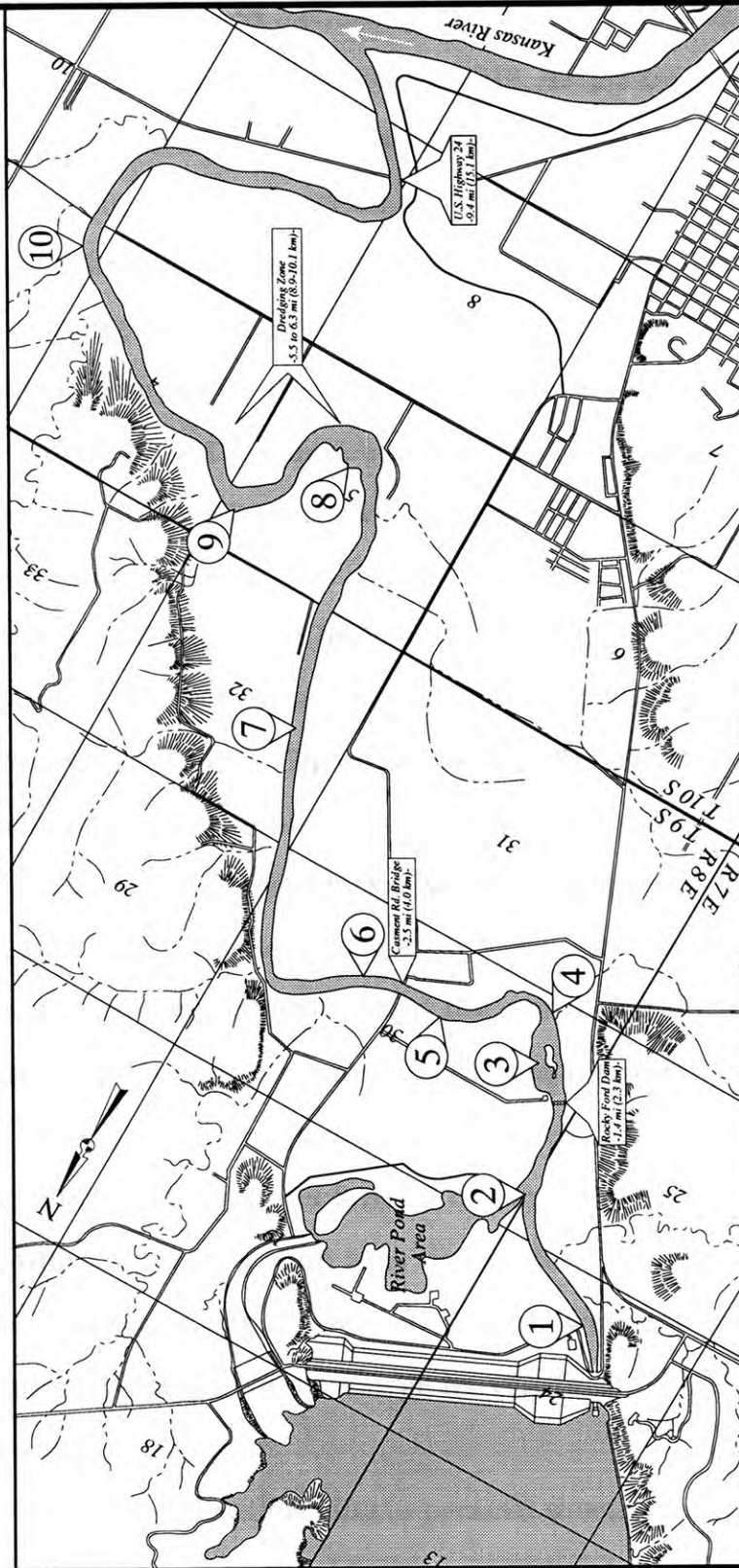


FIGURE 66. 1989 channel position.

1. Outlet Works; bank caving; riprap
3. Channel widening; armoring; island
5. Bank stabilization - refield jetties
7. Downtcutting or quasi-equilibrium
9. Channel widening/healing; former dredging
2. End of channel rerouting
4. Bank stabilization - dump rock
6. Bank stabilization - bank junking
8. Channel widening; former dredging
10. Reach of backwater affects

Source: NASAAM Aerial Photography

velocity; 3) increased frequency of intermediate river stages, resulting in bank destabilization and mass wasting; 4) porous alluvial composition of channel banks; and 5) lack of channel armoring.

During the construction of Tuttle Creek Dam, approximately 2.1 miles (3.3 km) of the Big Blue River channel was rerouted. The reach of the lower Big Blue River from the outlet works to the inlet of the River Pond Area represents the downstream portion of the rerouted channel.

Rocky Ford Dam acts as a stilling basin for the clear water discharge released from the reservoir. The water velocity is effectively decreased immediately upstream from Rocky Ford, stream power decreases, and sediment bedload is deposited. However, there are only 1.4 miles (2.3 km) of channel to transport sediment prior to encountering the Rocky Ford Dam. Once the water spills over the Rocky Ford Dam, the critical-power threshold is exceeded because of increased slope and velocity. Excessive degradation would be expected at the base of Rock Ford, however, there is a highly resistive stratum which hinders downcutting. Degradation could not occur due to the well-armored channel bed, therefore channel widening resulted.

An isolated zone of deposition is also present below Rocky Ford. A single channel island has formed in the wake of the spillwater dam. Deposition at this location may be due to: 1) well armored channel bed within this reach of the river; 2) a fairly well vegetated surface; or 3) slowing of overtopping discharge by vegetation which results in deposition.

Bank stabilization efforts present downstream of Rock Ford Dam include dump rock, reef field jetties, and bank junking. Channel bank

erosion between Rocky Ford Dam and along the reach of channel in the vicinity of the Casement Road Bridge can be easily identified in aerial photography as well as in the field.

The reach of channel between the erosion zone (3 miles/4.8 km) and the dredging zone (5.5 miles/8.8 km) downstream from Tuttle Creek Reservoir, was not detailed within this study. Historical aerial photography reflects insignificant lateral migration and consistent channel widths between 1951 to 1989 along this reach of the lower Big Blue River. Such evidence would suggest the channel is in a condition of downcutting (degradation) or in a phase of quasi-equilibrium (no net degradation nor aggradation).

Sand dredging operations have been found to cause channel morphologic adjustments. Studies conducted along the Kansas River have identified excessive channel erosion, degradation, and aggradation as a result of sand and gravel dredging operations. Channel impacts present along the lower Big Blue River are consistent with other research conducted along the Kansas River. Channel degradation or aggradation could not be fully assessed within the scope of this study. However, significant channel bank erosion was identified within the dredging zone. Channel banks were highly altered as a result of dredging operations. Today the lower Big Blue River is in a condition of channel healing through channel narrowing and revegetation of channel banks within this reach of the river.

The reach of the lower Big Blue River between the dredging zone and the mouth of the river was not detailed in this study. It is suspected that this reach of the river is subject to frequent backwater affects

associated with the Kansas River. Backwater impacts on the lower Big Blue River due to the influence of the Kansas River may be better addressed in future studies.

Future Study Considerations

The concepts and potential research topics associated with the lower Big Blue River are numerous. Only the most visibly impacted areas within the upper reaches of the lower Big Blue River were examined here. Complex channel adjustments of the lower Big Blue River within Kansas River backwater zone would be an area of future interest. To what degree do backwater effects influence upstream aggradation or deposition? Quantitative work in this area may assist reservoir management in regulation strategies.

Potential influences of the lower Big Blue River on the River Pond area were not included in this study. Information as to pond sedimentation, beach erosion, or shoreline adjustments attributed to the lower Big Blue River would be a helpful management tool for the planning and development of future recreational areas below the reservoir.

It would be interesting if the raw data values for the pre-closure period were available to recalculate discharge trends and thereby verify the results reported in this study.

This study did not address potential upstream impacts of Tuttle Creek Reservoir. Potential impacts associated here may be useful for valley land use planning.

Quantitative analysis of channel degradation and aggradation were

outside the scope of this investigation. Channel measurements over a period of time along the reach of the lower Big Blue River would produce evidence of aggradation or degradation. Currently, only channel degradation near the Casement Road Bridge has been identified.

Lastly, channel adjustments which have occurred beyond 1991 could be addressed in future investigations. Fluvial system impacts attributed to the flood of 1993 would be a worthy research topic.

REFERENCES

- Andrews, E.D. 1986. Downstream effects of Flaming Gorge Reservoir on the Green River, Colorado and Utah. *Geological Society of America Bulletin* 97: 1012-1023.
- Bagnold, Ralph A. 1960. Some aspects of the shape of river meanders. *United States Geological Survey Professional Paper* 282-E. pp. 135-143.
- Barber, Paul. 1972. (July 25) *Tuttle Creek project*. Letter to Jean Dallas, Curator of Riley County Historical Museum.
- Beaver, Chuck. 1992. Personal Communication, October.
- Belcher, R.C. 1975. *The Geomorphic Evolution of the Rio Grande*. Baylor Geologic Studies, Bulletin No. 29, p. 64.
- Bloom, A.L. 1978. *Geomorphology: a systematic analysis of late Cenozoic landforms*. Englewood Cliffs, N.J.:Prentice-Hall.
- Brice, James. 1964. Channel patterns and terraces of the Loup Rivers in Nebraska. *United States Geological Survey Professional Paper* 422-D. pp. 1-41.
- Buehre, Jerry. 1991. Personal Communication, August.
- Bull, W.B. 1979. Threshold of critical power in streams. *Geological Society of America Bulletin*, 90 : 453-464.
- Bull, William B. 1991. *Geomorphic responses to climate change*. New York: Oxford University Press, New York.
- Chelikowsky, J. R. 1972. *Structural geology of the Manhattan, Kansas area*. Kansas Geological Survey Bulletin No. 204, Part 4 : 1-13.
- . 1976. *Pleistocene drainage reversal in the upper Tuttle Creek Reservoir area of Kansas*. Kansas Geological Survey Bulletin No. 211, Part 1 :1-4.
- Cline, R.L. 1974. Geomorphology of the lower Saline River Valley in north central Kansas. Master's Thesis. Department of Geology, Kansas State University, Manhattan, Kansas.
- Corps of Engineers. 1960 *Review Report on Flood Control, Kansas River and Tributaries, Kansas, Nebraska, and Colorado*. Kansas City District, U.S. Army Corps of Engineers.

- _____. 1951, *Army engineers release storm and flood studies*. Kansas City District, U.S. Army Corps of Engineers. (58) : 1-3.
- _____. 1972, *Flood plain information: Kansas and Big Blue Rivers, Manhattan, Kansas*. Kansas City District, U.S. Army Corps of Engineers.
- _____. 1973, *Lower Kansas River basin lake regulation manual: Tuttle Creek lake*. Kansas City District, U.S. Army Corps of Engineers. 2 : II-4.
- _____. 1976. *Final environmental statement: operation and maintenance, Tuttle Creek Lake, Kansas*. Kansas City District, U.S. Army Corps of Engineers.
- _____. 1977, *Impact of commercial sand dredging in the lower Kansas River*. Kansas City District, U.S. Army Corps of Engineers. pp. 1-36.
- _____. 1978, *Bank erosion inventory: Kansas river and tributaries bank stabilization study*. Kansas City District, U.S. Army Corps of Engineers. Appendix F, No. 28.
- _____. 1979, *Channel migration investigation, historic channel change maps, Kansas River and tributaries bank stabilization study*. Kansas City District, U.S. Army Corps of Engineers. Sheet No. 11.
- _____. 1988, *Tuttle Creek Lake*. Map 556-732. Washington: U.S. Government Printing Office.
- _____. 1989, *Engineering and design manual: sedimentation investigations of rivers and reservoirs*. U.S. Army Corps of Engineers. Manual No. EM 1110-2-4000.
- _____. 1990, *Commercial dredging activities on the Kansas River, Kansas*. Kansas City District, U.S. Army Corps of Engineers.
- Devore, Jay L. 1987. *Probability and statistics for engineering and the sciences*. Monterey: Cole Publishing Company, California.
- Dolan, R., Howard, A., and Gallenson, A. 1974. Man's impact on the Colorado River in the Grand Canyon. *American Scientist* 62 : 392-401.
- Domenico, Patrick A., and Schwartz, Franklin W. 1990. *Physical and chemical hydrogeology*. New York: John Wiley & Sons.
- Elks, J.E. 1979. *Air-photo interpretation of floodplain features: a means of determining Kansas River history*. Master's Thesis, Department of Geology, University of Kansas.

- Fenneman, N.M. 1938. *Physiography of Eastern United States*. New York: McGraw-Hill Book Company.
- Fetter, C.W. 1988. *Applied hydrogeology*. Columbus: Merrill Publishing Company.
- Franz, Jim. 1992. Personal Communication, March.
- Friggens, Paul. 1953. Battle of the Blue. *The Farm Journal*.
- Frye, J.C. 1945. Valley erosion since Pliocene "algal limestone" deposition in central Kansas. *Kansas Geological Survey Bulletin*. No. 60, Part 3, pp. 85-100.
- Furness, L.W., Albert, C.D. and Lenard, R.B. . 1967. *Kansas River, Bonner Springs to mouth--degradation of channel*. Kansas Geological Survey, Water Resources Division, Lawrence, Kansas. pp. 1-12.
- Gregory, K.J. and Park, C.C. 1974. Adjustment of River Channel Capacity Downstream from a Reservoir. *Water Resources Research*. 10: 870-873.
- Harrison, A.S. 1950. *Report on special investigation of bed sediment segregation in a degrading bed*. California Institute of Engineering Research Series. No. 33.
- Hedman, E.R. 1970. Mean annual runoff as related to channel geometry in selected streams in California. U.S. Geological Survey Water-Supply Paper 1999-E. pp. 1-17.
- Hedman, E.R., Kastner, W.M., and Hejl, H. R., 1974. Selected streamflow characteristics as related to active-channel geometry of streams in Kansas. Kansas Water Resources Board Technical Report No. 10. pp. 1-21.
- Hedman, E.R., and Kaster, W.M., 1977. Streamflow Characteristics Related to Channel Geometry in the Missouri River Basin. *U.S. Geological Survey Journal of Research*. 5 (3) : 285-300.
- Hedman, E.R., and Osterkamp, W.R., 1982. Streamflow characteristics related to channel geometry of Streams in western United States. *U.S. Geological Survey Water-Supply Paper No. 2193*. pp. 1-17.
- Hickin E.J., and Nansen, G.C.. 1975. The character of channel migration on the Beatton River, northeast British Columbia, Canada. *Geological Society of America Bulletin*, 83 :487-494.
- Historical Plat Book of Riley County, Kansas*. 1881. Bird and Mickle Map Company: Chicago, pp. 15-33.

- Hooke, J.M. 1979. An Analysis of the Process of River Bank Erosion. *Journal of Hydrology*, 42 :39-62.
- Hoppie, James. 1980. *Morphologic responses to the Solomon River to geologic influences..* Masters Thesis, Department of Geology, University of Kansas, Lawrence, Kansas.
- Horton, R.E. 1945. Erosional development of streams and their drainage basins--hydro-physical approaches to quantitative morphology. *Geological Society of America Bulletin*, 56 : 275-370.
- Howard, Allan and Dolan, Robert. 1981. Geomorphology of the Colorado River in the Grand Canyon. *The Journal of Geology*; 89(3):269-298.
- Keller, A. E. 1972. Development of alluvial stream channels: a five stage model. *Geological Society of America Bulletin*, 83 : 1531-1536.
- Kershaw, Dan. 1992. Personal Communication, October.
- Knox, James C. 1976. Concept of the graded stream. In *Theories of landform development*, eds. W.N. Melhorn and R.C. Flemal, 169-198. editors, Binghamton: State University of New York.
- Kilpatrick, F.A., and Barnes, H.H., Jr. 1964. Channel geometry of Piedmont streams as related to frequency of floods. *U.S. Geological Survey Professional Paper*, 422-E, pp. 1-10.
- LaCock, Butch. 1992. Personal Communication, August.
- LaCock, Butch. 1994. Personal Communication, March.
- Langbein, W.B. 1964. Geometry of River Channels. Proceeding of the American Society of Civil Engineers, *Journal of the Hydraulics Division*. HY2, 90: 301-312.
- Langbein, W.B. and Leopold, L.B.. 1964. Quasi-equilibrium States in Channel Morphology. *American Journal of Science*, 262 : 782-794.
- Langbein, W.B. and Leopold, L.B.. 1966. River meanders-theory of minimum variance. *U.S. Geological Survey Professional Paper*, 422-H, pp. 1-15.
- Lauterbach, D. and Leder, A. 1969. The influence of reservoir storage on statistical peak flows. *Floods and their computation 2*, International Association of Scientific Hydrology, 281.
- Lawson, J.M. 1924. Effect of Rio Grande storage on river erosion and deposition. *Engineering News Record*, September 3.

- Leopold, Luna B. and Maddock, Thomas Jr. 1953. The Hydraulic Geometry of Stream Channels and Some Physiographic Implications. *U.S. Geological Survey Professional Paper*, 56, pp. 275-370.
- Leopold, Luna B., Wolman, M.G. 1957. River channel patterns—braided, meandering, and straight. *U.S. Geological Survey Professional Paper*, 282-B, pp. 39-85.
- Leopold, Luna B., Wolman, M.G., and Miller, J.P.. 1964. *Fluvial processes in geomorphology*. San Francisco and London: W.H. Freeman and Company.
- Livesey, R.H. 1963. *Channel armoring below Fort Randall Dam*. United States Department of Agriculture Miscellaneous Publication. No. 970, pp. 461-470.
- Manhattan Free Press. 1991. *Rocky Ford Power Company harnesses the Blue River*. December 26, 1 (49).
- Manhattan Mercury. 1929. *Present electric power plant outgrowth of an early day grist mill*. October 4, Section 4.
- McCrae, R.O. 1954. *Geomorphic effects of the 1951 Kansas River flood*. Master's Thesis. Department of Geology, University of Kansas, Lawrence, Kansas.
- McGrew, J. Chapman, Jr., and Charles B. Monroe. 1993. *An introduction to statistical problem solving in geography*. Dubuque: Wm. C. Brown Publishers, Iowa. pp. 156-161.
- Medina, Kyle. 1992. Personal Communication, August.
- Melton, F.A. 1959. Aerial Photographs and Structural Geomorphology. *Journal of Geology*, 67 (4) : 351-370.
- Mithen, Jeanne. 1992. Personal Communication, July.
- Meyer, Philip E. 1962. *Tuttle Creek dam: a case study in local opposition*. Master's Thesis. University of North Carolina.
- Miller, Katherine E. 1987. *The controversial Tuttle Creek dam*. Unpublished. Seminar of American History, Kansas State University, Manhattan, Kansas.
- Moore, C.M. 1969. Effects of small structures on peak flow. In *Effects of watershed changes on streamflow*, eds. C.M. Moore and C.W. Morgan, 101-117. Austin: University of Texas Press, Texas.
- Morisawa, M. 1968. *Streams: their dynamics and morphology*. New York: McGraw-Hill.

- Morton, Charlotte, Editor. No Date. *Letters and information regarding Tuttle Creek Dam in the Blue River Valley of Kansas*. Carmel, California.
- Northop, W.L. 1965. Republican river channel deterioration. U.S. Department of Agriculture Miscellaneous Publication 970 : 409-424.
- O'Brien, Walter J., MacRoberts, Paul B. , Pogge, Ernest C., and Smith, Robert L. 1972. Modeling discharge and conservative water quality in the lower Kansas River basin. *Kansas Geological Survey, Bulletin* 204, Part 3, pp. 1-18.
- Osterkamp, W.R., and Hedman, E.R. 1981. *Channel geometry of regulated streams in Kansas*. Kansas Water Office: State of Kansas, Technical Report No. 15. pp. 1-31.
- Petts, G.E. 1979. Complex response of river channel morphology subsequent to reservoir construction. *Progress in Physical Geography*. 3 (3) : 328-362.
- Petts, G. E., and Lewin, J. 1977. Physical effects of reservoirs on river systems. In Hollis, G.E., Editor, *The impact of man on the hydrological cycle*. Norwich: Geobooks.
- Plummer, Charles C., and McGeary, David. 1979. *Physical geology*. Dubuque,: William C. Brown Company Publishers, Iowa.
- Poresky, Barbara. No Date. *Exhibit text (file) about Rocky Ford Dam*. Riley County Historical Museum. Manhattan, Kansas.
- Putnam, J. E. April, 1986. *Description/History of Gauging Station on Big Blue River near Manhattan, Kansas*. U.S. Geological Survey, Water Resources Division.
- Reany, B.V. 1952. Tuttle Creek Dam work starts but controversy gets hotter. *Kansas Construction Magazine*. December.
- Richards, K.S., and Wood, R. 1977. Channel and flow geometry: a geomorphological perspective. In *River channel changes*, ed. K.J. Gregory, K.J., pp. 369-388. Chichester: Wiley.
- Ritter, Dale. 1978. *The drainage basin development, morphometry and hydrology. Process Geomorphology*. Dubuque Iowa: WCB Publishers.
- Schumacher, A.H., Backus, Kimball , and Peterson, D.M. 1953. *Report on the reduction in agricultural production in the Big Blue River Valley attributable to Tuttle Creek Dam*. Kansas City, Missouri.

- Schumm, S.A. 1960. The shape of alluvial channels in relation to sediment type. *U.S. Geological Survey Professional Paper*. 352-B. Washington: U.S. Government Printing Office. pp. 17-30.
- Schumm, S.A., and Lichty, R.W., 1963. Channel widening and flood-plain construction along Cimarron River in southwestern Kansas. *U.S. Geological Survey Professional Paper*, 352-D, pp. 71-88.
- Schumm, S.A. 1969. River Metamorphosis. Proceedings of the American Society of Civil Engineers, *Journal of the Hydraulics Division* HY1: 255-273.
- Simions, Li and Associates. 1984. *Analysis of channel degradation and bank erosion in the lower Kansas River*. MRD Sediment Series, No. 35. Fort Collins, Colorado.
- Smith, N. 1971. *A history of dams*. London: Peter Davies.
- Stewart, John H., and LaMarche, Valmore C., Jr. 1967. Erosion and deposition produced by the flood on December 1964 on Coffe Creek Trinity County, California. *U.S. Geological Survey Professional Paper*, 422-K, pp. 1-22.
- Tank, Ronald W. 1983. *Environmental geology*. New York—Oxford: Oxford University Press.
- Tarbuck, Edward J., and Lutgens, Frederick K. 1984. *The earth: an introduction to physical geology*. Columbus: Charles E. Merrill Publishing Company.
- U.S. Department of Agriculture: Soil Conservation Service. 1952. *Blue River watershed: drainage from aerial photographs*. Drawing No. F5R-12,329.
- U.S. Department of Agriculture: Soil Conservation Service. 1975. Soil survey of Riley county and part of Geary county, Kansas. pp. 71.
- U.S. Geological Survey. 1992. *Discharge statistics of the Big Blue river near Manhattan, Kansas*. Lawrence, Kansas.
- Webb, Vincent. 1969. *Forced resettlement and attitude changes: a study of cognitive dissonance*. Unpublished. Master's Thesis. University of Nebraska, Omaha.
- Wolman, M. G., 1955. The natural channel of Brandywine Creek, Pennsylvania. *U.S. Geological Survey Professional Paper*, 271, pp. 1-56.
- Wolman, M.G., and Leopold, L.B. 1957. River floodplains: some observations on their formation. *United States Geological Survey, Professional Paper*, 282-C, pp. 87-107.

Wolman, M.G. 1967. *Two problems involving river channel changes and background observations*. Quantitative Geography Part 11, pp 67-107.

Aggradation - the process of building up the land surface by the deposition of sediment.

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APPENDIX I

Alluvial Deposits - also known as alluvium, are deposits of sediment (sand, silt, clay, and gravel) that have been transported by a river or stream and deposited in a basin of fluvial process. **-Glossary and Symbols-**

Anticline - a fold in the geologic structure of the earth's crust, which older aged are situated above the younger.

ABCS - Agricultural Conservation and Soil Conservation Service

Backwater Effects - the stream current is impeded by a dam or other obstruction, causing the water level to rise upstream. e.g., bridge abutment, dam, etc.

Bank dumping - a term used to define the process of bank material being armor the channel bank with scrap material and junk material.

Bank Pore Saturation - a condition where the pores of the soil are saturated with water.

Bankfull - a condition where the river is flowing in its channel.

Bedload - the part of the sediment load which is transported along the bottom of the channel.

Benthic - forms of life which are bottom dwellers.

Berm - a raised area of land which is formed by the deposition of sediment.

Big Blue River - refers to the surface water body which flows from southeastern Nebraska to the Gulf of Mexico.

GLOSSARY

Active Channel - a channel on the alluvial plain in which surface runoff flows

Aggradation - process of building up the land surface through deposition (depositing) sediment

Alluvial Deposits - also known as alluvium, is a typical term for clay, silt, sand, and gravel, or otherwise unconsolidated material deposited as a result of fluvial processes

Anticline - a fold in the geologic stratum, typically convex upward where older aged are stratigraphically in the core

ASCS - Agricultural Stabilization and Conservation Service

Backwater Effects - the stream increases in stage (height) due to downstream flow is retarded: e.g., bridge, dam, confluence with a larger river

Bank Junking - term used to define the process of bank stabilization by armoring the channel bank with scrap metal and junk car bodies

Bank Pore Saturation - a condition where the air pore space present in a channel bank is replaced with water

Bankfull - a condition where the river is flowing a capacity

Bedload - the part of the total stream load which is transported immediately above the bed of the channel

Benthic - forms of marine life who are bottom dwellers

Berms - terrace like or bench like surface which was developed in a cycle of erosion

Big Blue River - refers to the surface water flow which flows from southeastern Nebraska to the mouth near Manhattan, Kansas

Braided Channel - a river channel which divides and follows two or more channels which flow in the same gradient direction

Breakwater - a structure engineered to break up the force of currents or waves thus protecting the channel bank from erosion

Bulkheads - a stone or concrete wall which is constructed specifically to resist channel bank erosion

Casement Road Bridge - a reference point along the lower Big Blue River, approximately 2.5 miles (4.0 km) downstream from Tuttle Creek Reservoir: USGS gauging station no. 06887000 is located here

Channel - the deepest portion of a river

Channel Armoring - natural or artificial process which a more resistive surface covers a less resistive surface in the channel bank or bed

Channel Length - the distance of the river from a given point, usually the origin, measured along the channel axis to a ending point, usually the mouth of the river

Channel Rating Curve - graphical presentation of discharge at a given point along a river with respect to the elevation of the water surface

Channel Sidebars - deposition of coarse bedload or sediment transport along the channel bank toe or base, usually sand sized particles

Channel Slope - the gradient between the water surface and the horizontal direction (for small streams)

Clear Water Discharge - sediment free or low in sediment

COE - United State Army Corps of Engineers

Confluence - a point where two or more streams meet

Critical-power Threshold - the ratio of power available (stream power) to the power required (resisting power) for the transportation and entrainment of sediment bedload

Degradation - lowering of the land surface by means of an erosive process: synonymous with downcutting.

Deposition - the laying down of sediment material in the fluvial system

Depositional Bar - the process of deposition of coarse grained sediment bedload, typically sand sized particles: synonymous with channel sidebars

Discharge - the rate at which a river flows given in units of volume per unit of time: typically cubic feet per second (English); cubic meters per second (metric)

Discharge Frequency - the period or occurrence of a given magnitude of discharge over a period of time

DOT - Department of Transportation, State of Kansas

Downcutting - stream channel erosion which is reducing the bed elevation

Drift Deposits - a general term used to describe material transported by a glacier

Dredging - the intentional removal of coarse bedload sediments, typically sand and gravel sized particles

Dump Rock - the process of artificially armoring a channel inclined bank with rock and concrete debris: typically deposited in mass quantity

Equilibrium - a balance between form and process: resistance of channel bank erosion and stream erosive power

Erosion - the process of wearing away soil and rock by weathering, mass wasting, and the action of water, wind, and waves

Extrapolated - estimation of a value by a means which will return a representative value for the unknown value

Flood - any significant flow of high water that overtops the channel banks and covers land which is not normally under water

Flood Crest - the highest stage of a flood: synonymous with flood peak

Flood Frequency - the average occurrence of a flood event of a given magnitude over a period of time

Floodplain - land adjacent to a river in which river migration and deposition of sediments during flood stage can occur

Flood Stage - waters sufficiently high enough to leave the channel banks and cause damage to adjacent property at a location where flood stage is measured along the river

Fluvial - of or pertaining to river systems

Gage Height - the height of the water surface above a given arbitrary datum: e.g., NGVD

Gauging Station - a specific location along the reach of the river where systematic observations are recorded: e.g., discharge, velocity, area, gage height, etc.

Glacial Till - unconsolidated material deposited directly and underneath a glacier: synonymous with drift

Glaciation - a period of the formation, movement, and recession of glaciers or ice sheets

Grade - a channel in a condition of balance between erosion and deposition over a period of time

Headcutting - a term to describe a condition of sudden gradient increase in the channel slope

Histogram - a graphic presentation of frequency data

Hogback - a sharp ridge or barrier, natural or artificial, which the sides are inclined equally on either side

Hydraulic Roughness - the resistance to a flow exerted on the wetted perimeter of the channel bank

Indigenous - synonymous with native

Intermediate Stage - the height of the river surface which is between active channel stage and bankfull stage

Knickpoint - interruption in slope typically associated with headcutting

Loam - permeable soil composed of a mixture of clay, silt, sand, and usually organic matter

Loess - a widespread nonstratified fine grained blanket of sediment typically silt

Lower Big Blue River - the ten mile (16.1 km) reach of the Big Blue River which extends from Tuttle Creek Reservoir downstream to the confluence of the Big Blue River and the Kansas River

Mantle - general termed to describe the exterior covering of one kind or another

Mass Wasting - the erosional process which results in the displacement of rock or soil through gravitational forces

Meander - one or more of a series of sinuous loops or channel curves along the reach of the river

Mean Sea Level - the average height of the surface of the sea for all stages of tide as measured over a 19 year period

Morphology - the shape or form of a river channel or land surface

Multipurpose Pool - the surface elevation of a reservoir under normal operating conditions: Tuttle Creek Reservoir - 1,075 feet (327 m) above mean sea level

NARA - National Archives and Records, Washington, D.C.

NASAAM - National Aeronautics and Space Administration (AM, JS, MS)

NCIC - National Cartographic Information Center, Rolla Missouri

NGVD - National Geodetic Vertical Datum, 1929

Outlet Works - the reservoir structure in which impounded waters are systematically released under regulated conditions

Overbank Flows - the stage of a river where bankfull capacity is exceeded

Oxbow Lake - a crescent shaped body of standing water which is formed by the truncation of a channel meander, typically during a flood event

Parallel Fill - deposition equally along both channel banks of a fluvial system

Peak Flood Stage - the highest discharge or stage of a flood event

Pennsylvanian - a period in the Paleozoic era believed to have spanned between 320 and 280 million years ago

Permian - the last period in the Paleozoic era believed to have spanned between 280 and 255 million years ago

Physiographic - a topographic landform considered with respect to origin, cause, and history

Piers - a breakwater device utilized to protect and stabilize the channel bank

Pleistocene - an epoch of the Quaternary period believed to have spanned between two or three million years to 10,000 years ago

Purcell Dam - a low spillwater dam constructed of wood around 1860 in the general location of where Rocky Ford Dam now stands

Quasi-equilibrium - a balance between net degradation and net aggradation within a fluvial system for a period of time

Regime - a regular or systematic cycle of occurrences or pattern, or a condition of having wide spread influence

Rehfield Jetties - engineered structures made of steel used for bank stabilization designed to act as a breakwater

Reservoir - a pond or lake, natural or artificial, in which surface water can be stored and supplied from

Resisting Power - the power required to transport bedload: resisting factors

Riparian - pertaining to the being situated on or associated with a river channel

Riprap - a layer of large fragments of rock or concrete which are specifically positioned along a river bank for bank stabilization purposes

Rocky Ford Dam - a spillwater dam constructed of concrete located approximately 1.4 miles (2.2 km) downstream of Tuttle Creek Reservoir

Rocky Ford Power Plant - a hydroelectric facility active between the years of 1909 to 1965 where Rocky Ford Dam stands today

Scour - the process of erosion generally on the outside of meander curves typically during a flood event: removal of fine sediment

Sinuosity - the ratio of river channel length to that of valley length: channels with a sinuosity greater than 1.5 are considered meandering

Strath Terraces - synonymous with berm: the flat portion of a valley which is a result of an erosion cycle

Stratum - a layer of sedimentary rock usually separated by an overlying and underlying bed: part of the stratigraphic record

Stream Power - is the power available to transport bedload in a channel: driving force

Stream Velocity - rate of flow as measured by distance per unit of time: feet per second (English); meters per second (metric)

Suspended Sediment - the part of the total stream load that is carried for period of time in suspension, without contact with the channel bed

Syncline - a fold in which the core contains rocks stratigraphically younger

Threshold - the point at which a process or condition begins

Topographic Quadrangles - USGS maps reflecting landform, typically 7.5-minute series at 1:24,000 scale

Tributaries - a stream which feeds, joins, or flows into a larger stream

Tuttle Creek Dam (Reservoir) - the COE reservoir project located approximately ten miles (16.1 km) upstream from the mouth of the Big Blue River

USDA/SCS - United States Department of Agriculture: Soil Conservation Service

USGS - United States Geological Survey

Valley Length - distance of the river valley measured along the valley axis

Watershed - synonymous with drainage basin: an area from which surface water runoff is derived

Wetlands - an area of land which is permanently or intermittently covered with water such as a marsh, swamp, estuary like environment

Wilcoxon Signed-Rank Test - a nonparametric statistical test for the difference of means between two samples

SYMBOLS

acre-foot	The area of one acre (43,500 sq. feet) covered to a depth of one foot with water
cfs	Cubic feet per second
km	Kilometers: miles x 1.61 = km
m	Meters: feet x 0.3048 = m
ha	Hectares: acres x 0.4047 = ha
cms	Cubic meters per second: cfs x 0.0281
m ³	Cubic meters: cubic feet x 28320 = m ³
ω	Total stream power (omega)
γ	Specific weight of water, generally 1.0 (gamma)
Σ	Summation of observations or operations
σ^2	True variance of a population (sigma squared)
α	Level of significance, probability of rejection a null hypothesis when the hypothesis is true (alpha)
μ	True mean of a population (mu)
H_o	Null hypothesis
H_a	Alternative hypothesis
x	Data value or observation
$\bar{x}$	Arithmetic mean of a sample
y	median of a sample
n	Number of observations per sample

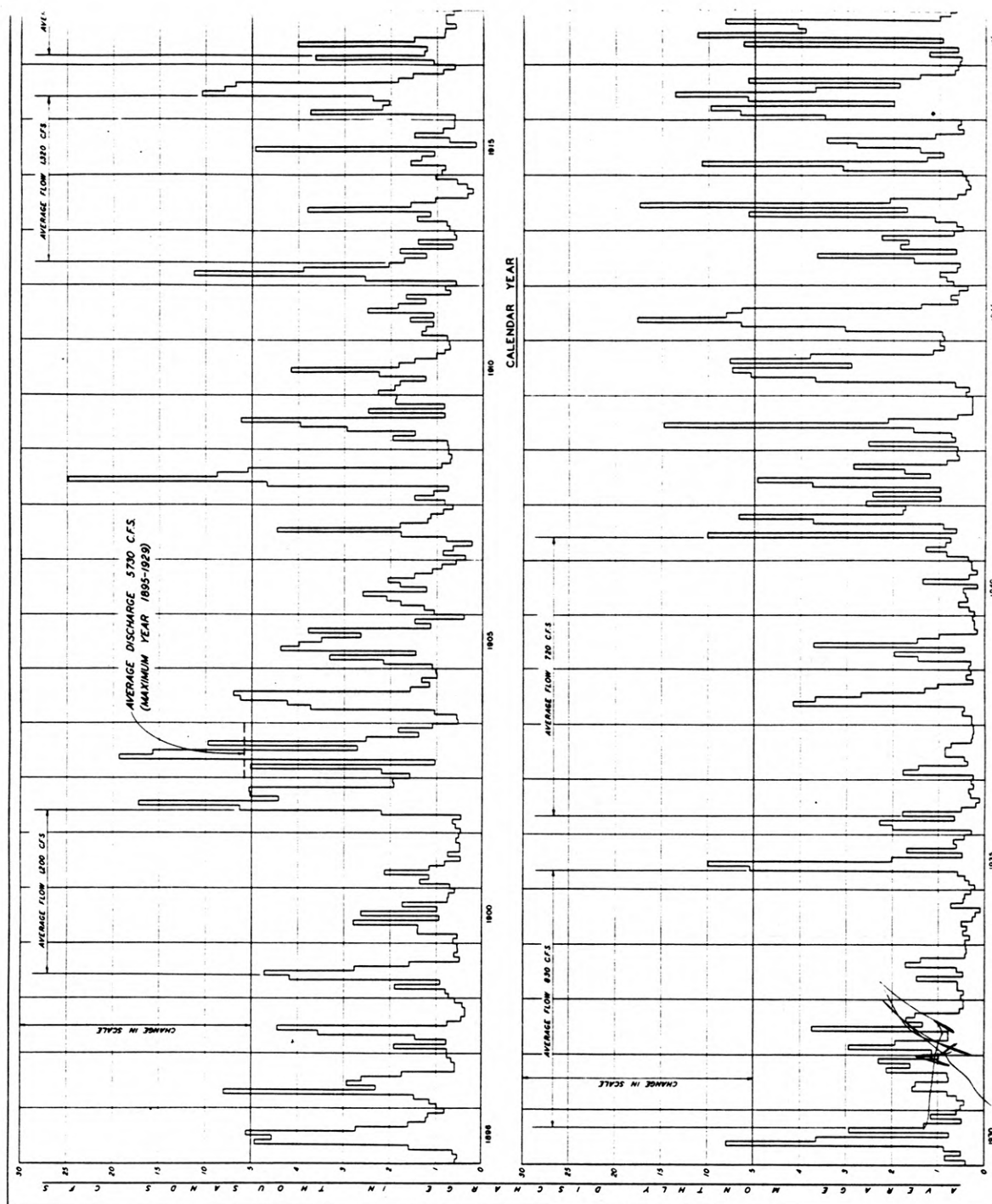
k	Number of samples
W_i	Sum of the signed ranks of a sample
p	Statistical probability of significance
Z	Test statistic
s	Standard deviation of a sample
F	Ratio of variance within a class of observations in a sample to the variance in the complete sample
ANOVA	Analysis of variance

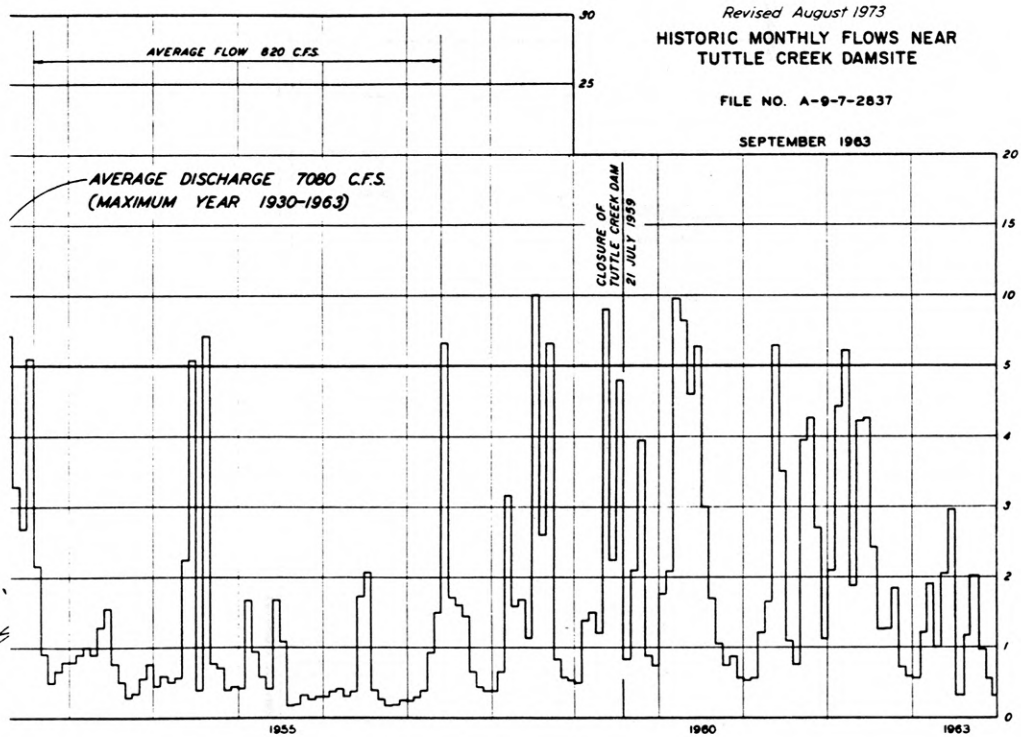
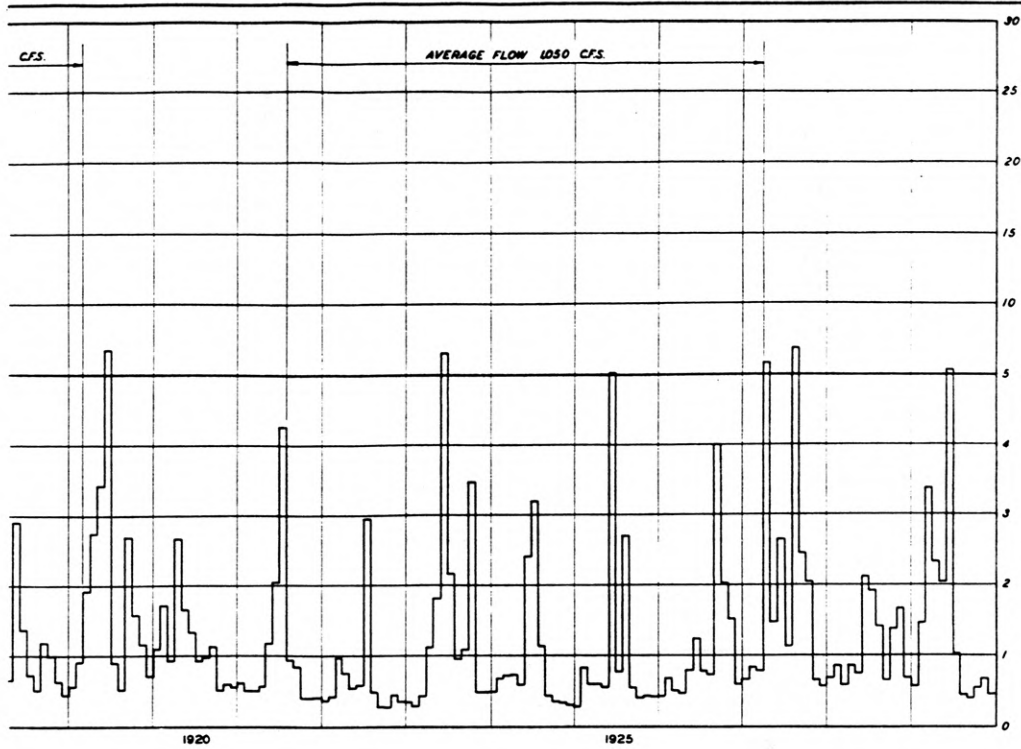
APPENDIX II

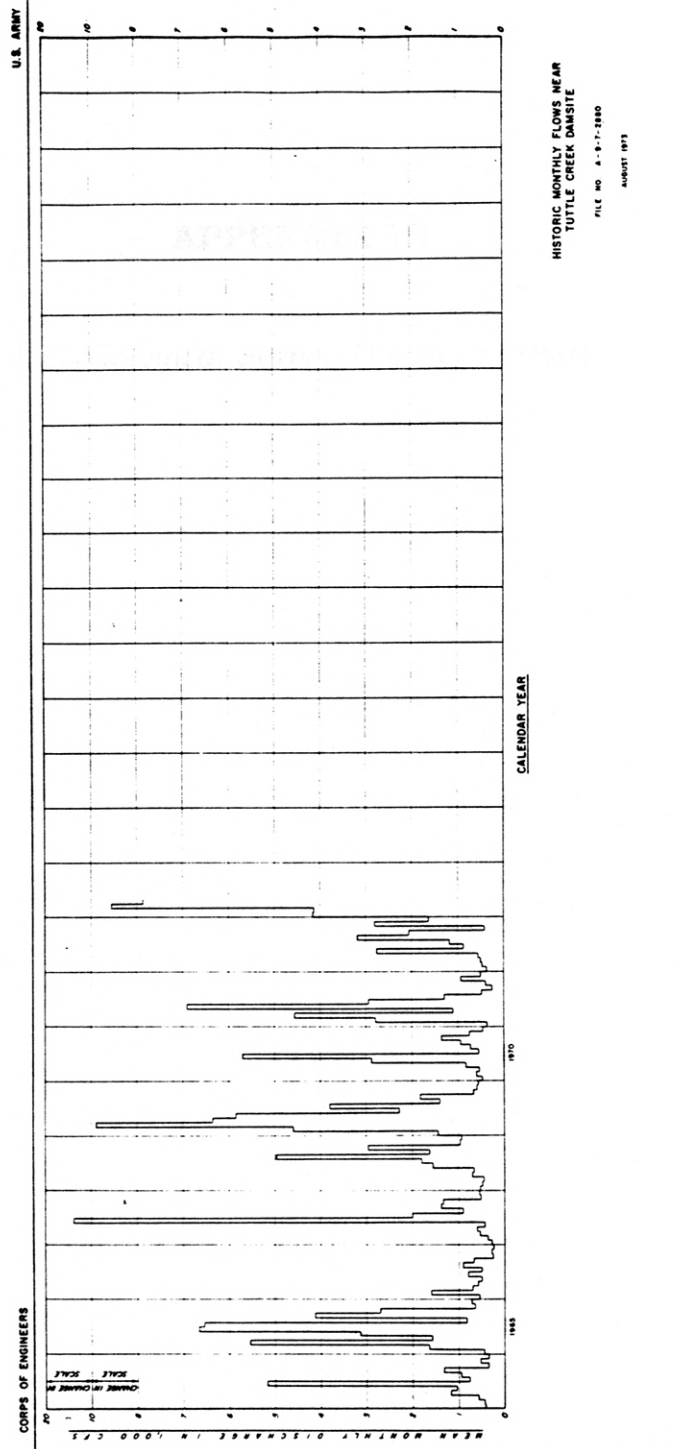
-U.S. Army Corps of Engineers Discharge Data-

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN	MEDIAN	MODE	STDEV	MAX VALUE	MIN VALUE
1927				5870	1490	2665	1145	6925	2465	2055	665	565	2,179	1,318	#N/A	2,109	6,925	565
1928	685	865	580	860	750	2,140	1,930	1,415	650	1,385	1,675	685	1,135	863	685	549	2,140	580
1929	570	1,475	3,395	2,340	2,055	5,280	1,025	430	380	540	670	445	1,550	848	#N/A	1,510	5,280	380
1930	410	845	505	865	7,880	3,640	760	2,915	1,295	490	1,145	610	1,780	855	#N/A	2,172	7,880	410
1931	510	435	585	800	1,550	1,475	745	790	2,100	1,585	2,270	980	1,152	890	#N/A	625	2,270	435
1932	1,125	2,915	1,920	765	765	3,715	735	1,675	1,485	525	445	445	1,426	1,228	765	1,021	3,715	445
1933	500	435	565	565	1,440	450	585	1,685	1,355	405	365	390	728	533	565	472	1,685	365
1934	405	300	450	360	470	235	175	85	700	425	395	265	355	378	#N/A	160	700	85
1935	185	300	390	550	5,230	9,900	1,980	455	1,640	580	645	410	1,855	565	#N/A	2,898	9,900	185
1936	275	1,970	2,260	635	1,750	4,490	190	100	300	340	230	285	735	320	#N/A	778	2,260	100
1937	230	1,750	1,410	350	425	840	840	710	275	240	225	235	628	388	840	508	1,750	225
1938	260	260	460	415	4,115	3,650	2,645	1,275	990	230	370	280	1,246	438	260	1,415	4,115	230
1939	345	285	1,435	1,955	435	3,695	1,450	980	155	225	225	265	954	390	225	1,056	3,695	155
1940	215	340	565	360	420	465	155	1,335	340	170	280	290	411	340	340	314	1,335	155
1941	365	815	1,285	845	735	10,000	630	885	3,710	6,580	1,780	1,705	2,445	1,085	#N/A	2,959	10,000	365
1942	2,570	970	2,425	970	3,720	4,910	1,190	1,725	2,825	815	560	605	1,940	1,458	970	1,377	4,910	560
1943	590	2,505	620	710	1,535	14,675	2,080	590	260	260	260	260	2,029	605	260	4,054	14,675	260
1944	410	330	620	3,660	5,285	7,245	2,880	7,535	3,775	1,100	870	970	2,890	1,990	#N/A	2,637	7,535	330
1945	880	935	3,025	17,640	8,050	6,295	1,395	600	750	750	575	380	3,906	1,165	#N/A	5,108	17,640	380
1946	685	825	1,000	600	530	1,535	3,635	625	1,825	1,640	2,230	665	1,316	913	#N/A	924	3,635	530
1947	475	600	1,070	5,515	1,670	17,270	2,060	595	410	305	350	415	2,561	598	#N/A	4,858	17,270	305
1948	490	3,060	10,530	1,255	890	1,385	2,760	3,415	1,060	455	580	515	2,200	1,158	#N/A	2,827	10,530	455
1949	3,470	6,465	9,720	2,000	5,660	13,525	3,680	1,850	5,605	1,405	655	580	4,551	3,575	#N/A	3,929	13,525	580
1950	560	515	1,240	595	6,405	915	11,430	3,940	4,100	8,360	1,000	745	3,317	1,120	#N/A	3,652	11,430	515
1951	610	900	2,230	3,190	6,400	27,820	20,120	5,615	8,615	1,940	1,420	955	6,651	2,710	#N/A	8,621	27,820	610
1952	1,150	1,055	4,875	7,250	3,200	2,685	5,190	2,075	870	480	630	755	2,518	1,613	#N/A	2,202	7,250	480
1953	755	935	965	875	1,240	1,535	730	495	290	330	540	700	783	743	#N/A	362	1,535	290
1954	435	605	490	550	2,160	5,155	350	6,780	795	670	410	415	1,568	578	#N/A	2,139	6,780	350
1955	390	1,770	890	570	375	1,650	1,005	155	190	310	230	270	650	383	#N/A	563	1,770	155
1956	295	365	380	310	350	1,695	2,000	375	225	165	185	230	548	330	#N/A	615	2,000	165
1957	205	310	355	920	1,450	6,560	1,650	1,530	1,440	630	415	360	1,319	775	#N/A	1,738	6,560	205
1958	250	675	3,075	1,575	1,600	1,150	9,985	2,570	6,690	790	585	500	2,454	1,363	#N/A	2,960	9,985	250
1959	490	1,465	1,450	1,200	8,775	2,265												

										Pre-closure Discharge Values Reported in cfs			
MEAN	650	1,165	1,899	1,555	3,028	5,188	3,006	1,775	1,782	1,186	721	541	
MEDIAN	483	835	1,035	853	1,575	3,163	1,788	1,305	1,025	533	568	445	
MODE	685	435	565	360	#N/A	1535	#N/A	#N/A	#N/A	#N/A	230	445	
STDEV	676	1,231	2,411	1,776	3,586	6,051	4,088	1,859	2,046	1,816	570	307	
MAX VALUE	3,470	6,465	10,530	7,250	17,640	27,820	20,120	7,535	8,617	8,360	2,270	1,705	
MIN VALUE	185	260	355	310	350	235	155	85	155	167	186	230	







APPENDIX III

-U.S. Geological Survey Discharge Data-

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN	MEDIAN	MODE	STDEV	MAX VALUE	MIN VALUE
1959							4,703	809	2,088	3,832	858	708	2,608	1,458	#N/A	3,075	8,775	490
1960	1969	2155	4468	13240	4447	6258	2939	1623	1043	708	517	535	3,325	2,062	#N/A	3,611	13,240	517
1961	510	602	1254	1659	5514	4230	1105	752	3315	4612	2852	1128	2,294	1,457	#N/A	1,746	5,514	510
1962	2349	4975	4588	2917	1312	5958	2093	766	232	634	492	251	2,214	1,703	#N/A	1,999	5,958	232
1963	278	338	452	448	1844	1071	2661	1078	1390	1234	1018	175	999	1,045	#N/A	735	2,661	175
1964	178	77	239	669	1287	1241	4537	619	803	1216	923	160	996	736	#N/A	1,199	4,537	77
1965	164	345	5509	1687	2283	5124	8143	1078	1308	4680	1366	487	2,681	1,527	#N/A	2,554	8,143	164
1966	589	1508	511	509	812	399	705	310	1339	1268	1252	535	811	647	#N/A	416	1,508	310
1967	256	271	48	50	53	10850	2895	650	477	561	688	1196	1,500	519	#N/A	3,047	10,850	48
1968	895	637	251	431	747	1449	1078	2935	2091	2284	2943	1464	1,434	1,264	#N/A	935	2,943	251
1969	1053	2945	12200	6231	5776	1752	3737	982	1843	438	1235	489	3,223	1,798	#N/A	3,431	12,200	438
1970	105	650	497	619	2875	5576	371	543	882	1223	755	421	1,210	635	#N/A	1,547	5,576	105
1971	341	2927	3574	763	7326	3870	1557	383	409	404	128	734	1,868	749	#N/A	2,180	7,326	128
1972	376	338	670	322	2693	678	937	1712	2597	366	1767	3059	1,293	808	#N/A	1,028	3,059	322
1973	3272	5586	644	10770	4666	2770	1374	3711	2305	11070	20110	4969	5,937	4,189	#N/A	5,538	20,110	644
1974	3311	4306	1957	1609	2383	1814	464	531	743	490	1145	426	1,598	1,377	#N/A	1,244	4,306	426
1975	209	21	65	3840	1174	6222	5049	1020	260	77	71	1209	1,601	640	#N/A	2,178	6,222	21
1976	325	594	801	2706	3263	706	1447	307	382	310	368	355	964	488	#N/A	1,005	3,263	307
1977	330	322	308	301	744	3259	946	2907	6937	1073	1433	1218	1,648	1,010	#N/A	1,934	6,937	301
1978	1084	475	6342	9413	5768	2148	5242	1350	1599	452	554	1410	2,986	1,505	#N/A	2,946	9,413	452
1979	500	558	11360	12240	3184	1410	5048	737	357	229	2487	2405	3,376	1,908	#N/A	4,188	12,240	229
1980	983	1491	2158	8729	1414	2942	721	581	563	486	505	307	1,740	852	#N/A	2,338	8,729	307
1981	476	457	412	388	158	91	1281	3816	1186	1495	336	1547	970	467	#N/A	1,038	3,816	91
1982	517	3919	3813	1825	4744	12750	11910	1836	1143	279	746	1677	3,763	1,831	#N/A	4,249	12,750	279
1983	1231	3816	3953	5623	4333	4305	8367	623	507	1981	1127	2225	3,174	3,021	#N/A	2,346	8,367	507
1984	817	4466	2641	10370	13970	5844	15510	1056	390	63	545	1972	4,804	2,307	#N/A	5,507	15,510	63
1985	1085	1363	1738	943	3729	2091	2078	5825	2768	5926	1494	1590	2,553	1,908	#N/A	1,728	5,926	943
1986	1465	1991	1633	1660	8435	1896	14000	5259	2219	13370	2147	2880	4,746	2,183	#N/A	4,634	14,000	1,465
1987	1256	1226	3575	15400	15210	7261	3022	1874	3291	534	56	2205	4,576	2,614	#N/A	5,347	15,400	56
1988	925	1467	638	199	339	926	1417	708	43	981	733	487	739	721	#N/A	440	1,467	43
1989	476	459	456	500	418	361	1945	1311	8181	1908	756	496	1,439	498	#N/A	2,200	8,181	361
1990	507	522	771	398	1631	7842	3088	3876	717	745	366	315	1,732	731	#N/A	2,243	7,842	315
1991	410	462	442	458	1415	3566	721	1130	188				977	462	#N/A	1,046	3,566	188
MEAN	883	1,602	2,437	3,654	3,561	3,646	3,637	1,622	1,610	1,971	1,642	1,236			Post-Closure Discharge Values Reported in cfs			
MEDIAN	514	644	1,028	1,634	2,538	2,856	2,086	1,067	1,093	745	756	1,128						
MODE	476	338	#N/A	#N/A	#N/A	#N/A	721	1078	#N/A	#N/A	#N/A	535						
STDEV	820	1,622	3,016	4,553	3,608	3,074	3,918	1,450	1,816	3,087	3,510	1,077						
MAX VALUE	3,311	5,586	12,200	15,400	15,210	12,750	15,510	5,825	8,181	13,370	20,110	4,969						
MIN VALUE	105	21	48	50	53	91	371	307	43	63	56	160						

10/02/92

UNITED STATES DEPARTMENT OF THE INTERIOR - GEOLOGICAL SURVEY - KANSAS

STATION NUMBER 06887000 BIG BLUE R NR MANHATTAN, KS STREAM SOURCE AGENCY USGS
 LATITUDE 391414 LONGITUDE 0963416 DRAINAGE AREA 9640.00 DATUM 988.86 STATE 20 COUNTY 161

DISCHARGE, CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1958 TO SEPTEMBER 1959
 DAILY MEAN VALUES

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	1240	594	532	372	530	2190	1550	994	10300	1040	948	1310
2	1170	590	556	496	500	1840	1360	935	4660	3620	695	862
3	1090	568	564	567	520	1570	1200	915	3390	3110	670	685
4	1040	615	588	450	520	1380	1130	1920	2860	7940	630	584
5	972	620	576	500	520	1250	1310	12000	2490	28000	606	566
6	918	572	556	500	540	1160	1220	16700	2420	28100	618	606
7	1040	572	516	500	560	1050	1100	24000	2270	15000	640	618
8	960	576	516	500	560	952	1020	21900	1940	9690	690	622
9	888	568	424	500	580	855	845	15600	1740	6560	915	586
10	804	556	420	500	600	910	845	9200	1650	4830	915	542
11	882	560	444	500	600	1010	820	11700	1440	4470	915	511
12	762	584	420	500	700	982	770	10800	1340	3560	860	450
13	789	580	379	530	1000	1040	740	7230	1290	2760	765	450
14	760	564	412	550	2800	970	805	5400	1200	2320	680	448
15	782	572	412	560	4000	890	750	4930	1150	2140	635	447
16	694	580	404	540	3000	895	725	4660	1060	2110	952	421
17	670	600	492	480	2400	875	740	4160	1050	1690	954	422
18	690	625	508	500	2180	840	690	3580	996	1710	715	470
19	685	720	516	500	1780	820	815	3030	960	2340	655	3380
20	655	675	540	450	1130	1120	1950	3980	960	1910	835	6990
21	673	630	552	400	1220	1300	3280	6820	2370	1470	1210	5080
22	653	600	532	350	1260	1020	1840	8990	4190	1620	1100	3440
23	664	576	560	300	1140	875	1350	7990	3870	1430	1010	3310
24	635	564	536	400	1340	725	1370	9880	3610	1430	1020	5170
25	615	568	560	500	2440	785	1370	10100	2660	1190	865	2930
26	630	605	568	520	2860	785	1320	7500	1740	1050	825	2120
27	650	560	556	520	3050	2400	1340	7170	1370	1010	710	7960
28	610	552	572	540	2640	6300	1320	6710	1100	1000	680	7160
29	614	520	568	560	---	3960	1190	4780	1010	948	645	3070
30	645	540	416	580	---	2340	1120	12100	910	860	1430	1430
31	645	---	315	550	---	1750	---	26300	---	870	1050	---
MEAN	791	587	500	491	1463	1446	1196	8773	2267	4703	809	2088
MAX	1240	720	588	580	4000	6300	3280	26300	10300	28100	1210	7960
MIN	610	520	315	300	500	725	690	915	910	860	606	421
AC-FT	48650	34920	30760	30180	81260	88940	71180	539500	134900	289200	49760	124200

CAL YR 1958 MEAN 2477 MAX 27500 MIN 150 AC-FT 1794000
 WTR YR 1959 MEAN 2104 MAX 28100 MIN 300 AC-FT 1523000

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STATION NUMBER 06887000 BIG BLUE R NR MANHATTAN, KS STREAM SOURCE AGENCY USGS
 LATITUDE 391414 LONGITUDE 0963416 DRAINAGE AREA 9640.00 DATUM 988.86 STATE 20 COUNTY 161

DISCHARGE, CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1959 TO SEPTEMBER 1960
 DAILY MEAN VALUES

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	996	1230	680	735	1060	1200	29400	3000	2230	3110	1440	3090
2	1700	1190	699	635	1500	1300	29000	3200	2040	2730	1530	2560
3	9380	1030	730	492	2880	1270	28600	3000	1870	2570	1490	1730
4	11700	1030	720	432	4290	1250	28000	2600	1810	2380	1460	1340
5	10200	942	710	570	4820	1130	29000	2300	1720	1850	1340	1160
6	9050	852	645	670	4440	1100	29100	2500	1650	1640	1270	966
7	10800	888	675	595	3700	1000	29800	5400	1650	1810	1250	942
8	11800	978	718	645	2980	1000	29200	5200	1670	1690	1190	823
9	10500	1220	682	705	2820	972	22400	3700	1730	1730	1140	762
10	8650	1070	660	745	3500	972	11000	3100	1670	2020	1270	730
11	4700	1020	660	738	3740	948	5300	5500	2210	2830	1360	720
12	3150	906	665	775	3150	984	12000	3030	6060	3290	1230	730
13	2420	846	665	6090	2060	858	22000	2510	8840	9040	1120	793
14	1960	828	660	7740	1440	900	20000	2380	10400	10000	1000	691
15	1670	695	717	6840	1310	894	16000	2330	7420	8910	966	823
16	1380	630	635	7190	1520	882	14000	5970	7230	5870	849	603
17	1270	580	660	3180	1790	924	8600	8090	8580	4340	1050	568
18	1180	635	657	1340	2050	930	4000	5770	8190	2980	1190	595
19	1190	780	719	1000	1800	918	3200	6320	7650	2680	1420	620
20	1140	805	529	906	1520	948	3000	4730	5920	2440	1970	580
21	1030	795	600	1120	1190	1100	2900	3820	5190	2110	1630	576
22	1010	785	657	1000	1090	1280	2600	5490	8950	2090	1340	610
23	1110	810	573	850	948	1520	2500	8880	11500	1830	1090	595
24	2810	834	625	900	1010	1730	2400	9090	13000	1630	990	740
25	2240	800	625	990	858	1920	2300	7780	13100	1500	3570	1310
26	1220	720	630	996	1060	2720	2200	6290	13200	1350	4650	2070
27	1000	745	834	942	1260	9060	2100	4640	11900	1330	1590	1560
28	894	740	1380	918	1300	18100	2100	3510	9920	1270	1190	1160
29	858	660	1010	990	24400	2400	2890	2890	7200	1250	1470	972
30	870	700	795	918	---	27300	2300	2530	3910	1140	3250	858
31	906	---	750	918	---	29000	---	2300	---	1290	4000	---
MEAN	3832	858	709	1696	2155	4468	13240	4447	6258	2939	1623	1043
MAX	11800	1230	1380	7740	4820	29000	29800	9090	13200	10400	4650	3090
MIN	858	580	529	432	858	858	2100	2300	1650	1140	849	568
AC-FT	235600	51060	43570	104300	123900	274700	787600	273400	372400	180700	99780	62040
CAL YR 1959	MEAN 2402	MAX 28100	MIN 300	AC-FT 1739000								
WTR YR 1960	MEAN 3594	MAX 29800	MIN 432	AC-FT 2609000								

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 LATITUDE 391414 LONGITUDE 0963416 DRAINAGE AREA 9640.00 DATUM 988.86 STATE 20 COUNTY 161

DISCHARGE, CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1960 TO SEPTEMBER 1961
 DAILY MEAN VALUES

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	1090	660	540	516	550	600	1500	852	7840	1160	635	576
2	888	516	512	424	550	600	1200	834	6630	1160	1260	640
3	816	500	508	488	510	600	1100	840	5000	1120	1420	3780
4	1000	512	496	590	450	572	890	1030	3500	1060	775	6520
5	876	504	650	568	450	516	850	5000	2500	996	690	4640
6	828	488	620	600	500	605	912	11000	3200	996	804	1230
7	690	484	605	540	530	548	804	11000	3000	972	804	645
8	670	464	620	552	550	615	858	9000	3500	966	715	695
9	670	556	476	548	540	645	1330	5800	4000	1010	685	882
10	655	480	540	576	532	590	2380	2930	4500	1090	660	740
11	610	476	595	610	540	572	2760	2070	6620	1010	660	630
12	605	496	536	615	625	660	2990	1690	6370	888	888	600
13	572	508	480	625	595	1600	1470	1690	6140	870	775	9500
14	640	504	440	605	630	2560	5660	1400	6210	978	695	15800
15	590	500	660	516	730	2040	3050	1320	6200	1100	710	2610
16	572	512	524	576	810	1470	2020	1170	6000	1070	775	2350
17	870	552	548	580	770	1100	1620	1370	5580	2010	750	3100
18	1220	500	528	576	740	1000	1440	1810	5190	1770	610	7990
19	1020	496	572	600	655	860	1280	1910	4920	1250	700	11700
20	852	576	488	520	655	790	1150	2010	4510	948	615	8170
21	675	512	360	340	700	740	1130	2160	4200	1300	544	3120
22	635	532	352	322	655	870	1030	5000	3890	2020	720	1620
23	600	504	456	350	650	1100	1010	9000	3560	1580	690	1110
24	580	512	508	400	615	1400	1060	11000	3080	997	775	912
25	520	524	540	416	590	940	978	12000	2630	397	740	1230
26	516	516	532	456	605	820	960	11800	2200	1150	725	1790
27	556	528	536	452	580	870	864	12300	1770	1130	600	2090
28	504	524	540	448	568	2600	906	11900	1550	1150	655	2090
29	548	536	685	448	---	5000	888	11200	1370	760	780	1580
30	528	540	572	470	---	4000	852	10600	1240	715	780	1100
31	568	---	576	500	---	2000	---	9460	---	625	700	---
MEAN	709	517	535	511	603	1254	1659	5514	4230	1105	753	3315
MAX	1220	660	685	625	810	5000	6290	12300	7840	2020	1420	15800
MIN	504	464	352	322	450	516	804	834	1240	397	544	576
AC-FT	43570	30770	32920	31390	33470	77080	98700	339000	251700	67930	46280	197200

CAL YR 1960 MEAN 3287 MAX 29800 MIN 352 AC-FT 2386000
 WTR YR 1961 MEAN 1727 MAX 15800 MIN 322 AC-FT 1250000

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 LATITUDE 391414 LONGITUDE 0963416 DRAINAGE AREA 9640.00 DATUM 988.86 STATE 20 COUNTY 161

DISCHARGE, CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1961 TO SEPTEMBER 1962
 DAILY MEAN VALUES

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	1700	5000	1260	881	15300	1400	4510	1170	6150	4050	1430	206
2	7700	2980	766	878	13900	1600	3680	1180	7130	3460	1740	212
3	5880	3860	860	938	12500	1600	2090	1000	8430	2270	2050	219
4	3100	4170	899	1020	11800	1700	3480	694	8670	1210	2750	222
5	1810	3060	919	950	12000	1600	7080	782	9170	1220	3410	217
6	610	2550	886	1000	8130	1600	9040	796	9690	1240	4540	219
7	902	1890	795	1000	4320	1360	8650	911	9530	1290	2990	226
8	863	1730	2330	1000	3650	635	7470	1060	9450	1300	408	242
9	1170	1590	3100	950	3810	827	3690	1160	9270	1350	260	236
10	3310	1470	1290	950	4040	404	1880	1160	9050	1090	230	231
11	9180	1440	764	900	3810	1440	2100	1130	8870	829	225	231
12	13100	1400	679	900	3370	1790	2290	1170	8740	811	225	231
13	13100	1390	1040	850	2810	2330	2270	1150	8610	861	221	231
14	13700	1270	1150	850	2790	2720	2230	1020	7970	1340	217	233
15	13400	1280	1320	850	3280	3200	2210	734	6740	2160	216	234
16	7740	3500	1300	800	5540	3220	1290	781	4680	2570	216	228
17	2680	7710	1340	800	5560	3200	1090	781	3770	2770	210	232
18	6470	7720	1270	750	3300	3170	1530	783	3390	3100	207	234
19	7540	5520	1180	750	2940	3340	1860	780	2980	3110	207	234
20	1950	3300	1200	700	2820	3360	1870	1610	2550	3480	210	235
21	1500	2430	1110	700	2390	4020	1850	223	2530	5190	213	250
22	1370	2070	1030	700	2170	3170	1820	1060	2520	4250	173	240
23	1340	2020	1010	700	2030	8510	1810	1640	2510	620	207	240
24	1250	2950	1000	700	1870	9690	1800	1630	2500	2960	245	240
25	1180	3410	1000	700	1720	13700	1840	1630	3050	3610	225	240
26	1150	2740	950	1500	1240	24500	1200	1620	4750	2790	230	240
27	1130	2080	900	4000	1000	21900	1760	1450	4690	1410	193	240
28	1120	1830	900	7000	1200	10200	1750	2150	3660	1040	77	240
29	1080	1660	900	10000	---	3300	1740	550	3590	1170	74	237
30	6760	1550	900	13900	---	1580	1640	2700	4090	1170	52	240
31	9190	---	923	15200	---	1170	---	6180	---	1160	107	---
MEAN	4612	2852	1128	2349	4975	4588	2917	1312	5958	2093	766	232
MAX	13700	7720	3100	15200	15300	24500	9040	6180	9690	5190	4540	250
MIN	610	1270	679	700	1000	404	1090	223	2500	620	52	206
AC-FT	283600	169700	69360	144400	276300	282100	173600	80700	354500	128700	47120	13810
CAL YR 1961	MEAN 2301	MAX 15800	MIN 322	AC-FT 1666000								
WTR YR 1962	MEAN 2796	MAX 24500	MIN 52	AC-FT 2024000								

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 LATITUDE 391414 LONGITUDE 0963416 DRAINAGE AREA 9640.00 DATUM 988.86 STATE 20 COUNTY 161

DISCHARGE, CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1962 TO SEPTEMBER 1963
 DAILY MEAN VALUES

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	253	719	258	253	282	365	421	2400	725	9620	223	519
2	253	551	212	262	285	331	380	2810	725	10000	202	466
3	250	551	238	278	310	365	380	2250	1010	10300	242	514
4	250	551	250	278	290	682	411	1300	1450	9500	235	460
5	258	542	242	282	270	192	443	932	1450	9330	336	505
6	291	542	242	282	290	137	448	902	1370	7850	466	471
7	282	546	246	282	320	154	432	902	810	5610	227	551
8	262	551	250	282	322	121	489	902	715	3680	216	1070
9	258	561	258	282	370	278	454	902	680	1760	235	1590
10	258	542	238	287	331	360	454	878	600	902	274	1540
11	258	514	250	290	331	370	443	890	320	872	575	1300
12	258	542	250	270	340	370	443	914	365	854	757	1290
13	258	542	262	270	345	365	448	932	370	988	746	1590
14	262	542	250	270	350	400	454	902	331	994	1360	2220
15	258	542	295	280	384	331	454	902	533	896	1870	2820
16	258	590	223	280	365	365	443	908	677	854	1850	2770
17	253	769	242	280	327	384	443	1450	620	854	1870	2120
18	258	769	250	280	355	375	437	3970	375	849	1860	1490
19	258	757	253	280	360	395	432	7120	355	837	1900	1210
20	266	763	253	280	355	384	432	8360	350	837	1860	1210
21	258	661	304	280	350	460	443	4270	1200	831	1860	1380
22	266	216	216	280	355	774	400	819	1340	825	1610	1690
23	546	231	253	280	380	763	477	561	299	752	1360	1840
24	1740	216	253	280	355	769	437	523	327	400	1640	1490
25	1740	192	253	280	355	780	432	561	336	355	1850	1210
26	1740	202	253	280	350	769	375	571	370	355	2170	1230
27	1750	250	270	280	389	780	405	1330	331	331	2180	1550
28	1750	250	266	280	365	791	360	2800	350	370	1600	1870
29	1740	258	266	280	---	615	421	2630	4080	360	926	1870
30	1740	304	250	280	---	395	963	1700	9640	287	505	1850
31	1210	---	253	280	---	395	---	860	---	231	427	---
MEAN	635	492	252	278	339	452	448	1844	1071	2661	1078	1390
MAX	1750	769	304	290	389	791	963	8360	9640	10300	2180	2820
MIN	250	192	212	253	270	121	360	523	299	231	202	460
AC-FT	39040	29290	15470	17110	18810	27800	26690	113400	63740	163600	66310	82680

CAL YR 1962 MEAN 2189 MAX 24500 MIN 52 AC-FT 1585000
 WTR YR 1963 MEAN 917 MAX 10300 MIN 121 AC-FT 663900

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DISCHARGE, CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1963 TO SEPTEMBER 1964
 DAILY MEAN VALUES

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	1910	886	190	175	80	72	958	1930	550	10800	630	1200
2	1890	886	181	178	80	73	370	1910	994	10800	940	1190
3	1570	892	187	178	84	73	362	1910	560	10700	1240	1520
4	1250	886	187	178	81	75	382	1910	334	10700	1070	1500
5	1250	892	187	178	81	67	402	1900	330	10600	760	850
6	1250	886	187	178	83	73	406	1930	346	10500	475	850
7	2130	904	187	178	73	72	370	1880	330	10400	446	856
8	3010	874	178	184	78	76	382	1900	338	10300	157	470
9	2380	1080	172	172	80	72	382	1900	338	8510	222	169
10	2200	1220	172	175	80	72	386	1560	342	6540	327	172
11	2380	1220	172	175	78	72	530	928	350	5520	338	172
12	1850	1220	172	175	81	70	814	910	374	4140	338	166
13	1840	1290	172	175	78	72	625	910	327	2680	346	175
14	1840	1410	172	175	78	70	366	928	374	1630	362	402
15	1810	1410	172	175	81	69	490	808	386	1050	346	736
16	1840	1410	172	175	75	72	1130	366	730	1040	330	736
17	1500	1400	172	175	75	70	1440	386	1200	1010	330	856
18	640	1380	172	175	78	72	976	680	354	994	295	994
19	295	1400	172	175	75	80	535	1610	354	1280	222	976
20	299	1400	172	172	76	84	550	1890	358	1770	320	1050
21	309	1400	172	175	75	166	430	1890	446	1770	178	1040
22	253	1410	172	184	75	306	184	1880	406	2010	178	1040
23	186	1370	172	190	75	334	194	1890	390	2440	178	988
24	178	1380	172	190	75	378	181	1890	385	2440	625	862
25	350	922	172	187	78	386	430	1370	382	2440	1350	856
26	620	190	172	187	72	378	1050	565	706	2420	1210	868
27	916	253	172	190	72	406	1270	480	2840	1740	1180	856
28	742	253	172	190	73	378	1270	640	4600	1030	1220	856
29	446	239	172	190	70	690	1450	358	7020	1350	1150	850
30	438	190	172	190	---	1260	1780	394	10800	1250	1220	862
31	680	---	175	148	---	1280	---	394	---	802	1210	---
MEAN	1234	1018	176	179	77.2	239	670	1287	1241	4537	619	804
MAX	3010	1410	190	190	84	1280	1780	1930	10800	10800	1350	1520
MIN	178	190	172	148	70	67	181	358	327	802	157	166
AC-FT	75870	60600	10800	10990	4440	14710	39860	79140	73870	279000	38070	47840
CAL YR 1963	MEAN 1005	MAX 10300	MIN 121	AC-FT 727400								
WTR YR 1964	MEAN 1013	MAX 10800	MIN 67	AC-FT 735200								

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UNITED STATES DEPARTMENT OF THE INTERIOR - GEOLOGICAL SURVEY - KANSAS

STATION NUMBER 06887000 BIG BLUE R NR MANHATTAN, KS STREAM SOURCE AGENCY USGS
 LATITUDE 391414 LONGITUDE 0963416 DRAINAGE AREA 9640.00 DATUM 988.86 STATE 20 COUNTY 161

DISCHARGE, CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1964 TO SEPTEMBER 1965
 DAILY MEAN VALUES

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	1170	834	147	181	348	1560	1960	419	12400	1800	2150	468
2	1700	820	150	165	245	1500	1920	385	11100	5010	2110	596
3	2080	887	150	160	238	1500	1900	415	7580	1850	2080	852
4	2190	1190	178	161	201	1530	1870	458	6310	986	1550	896
5	2190	1110	240	160	121	1550	1840	703	6010	2030	1060	856
6	2100	884	242	162	120	1530	1830	925	5970	6150	1040	858
7	1870	619	200	162	119	1530	1800	682	5980	7550	1030	855
8	1650	623	148	163	116	1530	1790	431	5960	12100	996	674
9	1650	614	148	156	120	1520	1780	416	5100	12800	987	490
10	1860	619	163	159	120	1900	1770	411	440	12600	979	526
11	1870	620	152	159	120	4350	1750	415	420	12500	903	470
12	1770	605	151	604	120	6180	1740	646	1300	12400	961	480
13	1620	703	148	308	118	5060	1750	1580	2370	13700	1090	474
14	1320	1000	150	186	118	5050	2450	1710	2540	15900	1470	617
15	740	1020	150	135	119	5040	3020	1710	2880	16900	1470	1250
16	756	666	150	38	117	5060	3040	1700	4820	18600	1470	1870
17	756	114	140	44	119	6330	3030	1420	6030	18500	1470	1870
18	745	109	150	120	119	8940	3010	932	6030	18300	1350	1900
19	750	901	158	118	118	12400	2980	927	6020	15800	939	1890
20	580	2000	153	115	120	9950	3020	933	5980	4050	937	2460
21	384	2610	153	115	118	9930	2340	928	5960	720	937	1600
22	495	3130	153	115	116	8910	668	931	5940	687	937	660
23	828	3350	155	120	253	7250	425	927	5910	678	934	1900
24	840	1760	153	115	675	9100	398	940	5880	1310	962	2160
25	828	162	154	120	1160	11500	456	933	5870	3700	785	1970
26	834	150	154	118	1480	11800	414	1680	5950	6490	470	1950
27	828	149	155	117	1470	9050	420	2850	6540	7430	468	1930
28	846	150	156	143	1460	7320	405	6760	5300	7400	467	1910
29	822	150	157	207	---	5710	400	12600	460	7370	472	1900
30	824	148	159	245	---	3580	422	12500	460	4930	472	2910
31	810	---	159	242	---	2580	---	12500	---	2200	469	---
MEAN	1216	923	161	165	345	5509	1687	2283	5124	8143	1078	1308
MAX	2190	3350	242	604	1480	12400	3040	12600	12400	18600	2150	2910
MIN	384	109	140	38	116	1500	398	385	420	678	467	468
AC-FT	74790	54940	9870	10140	19180	338800	100400	140400	304900	500700	66280	77840
CAL YR 1964	MEAN 1002	MAX 10800	MIN 67	AC-FT 727500								
WTR YR 1965	MEAN 2346	MAX 18600	MIN 38	AC-FT 1698000								

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STATION NUMBER 06887000 BIG BLUE R NR MANHATTAN, KS STREAM SOURCE AGENCY USGS
 LATITUDE 391414 LONGITUDE 0963416 DRAINAGE AREA 9640.00 DATUM 988.86 STATE 20 COUNTY 161

DISCHARGE, CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1965 TO SEPTEMBER 1966
 DAILY MEAN VALUES

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	3950	1030	187	594	590	1990	454	620	734	811	15	802
2	5050	1020	180	586	590	2010	20	620	740	810	15	590
3	7230	1020	180	580	590	1460	150	617	496	810	13	244
4	8610	1020	177	580	610	313	211	705	243	810	11	241
5	9320	1020	311	582	595	187	212	1260	243	810	131	243
6	9310	1020	470	591	586	190	212	1450	238	809	504	242
7	9280	1010	472	591	588	185	213	1450	239	819	510	242
8	9240	1010	475	591	605	185	289	1460	193	812	370	242
9	9200	1010	475	591	599	185	589	1430	110	816	177	242
10	9160	1010	486	591	909	185	604	1440	100	807	174	555
11	8060	1020	492	591	1980	187	613	1460	94	971	337	810
12	4790	510	487	594	2000	190	621	1330	96	1300	601	810
13	4090	54	480	591	2000	188	619	930	96	1300	464	1240
14	4100	49	480	591	2000	188	615	926	96	1300	95	1860
15	4080	48	508	591	2000	188	614	929	98	763	90	1620
16	4070	48	565	591	1990	1790	610	1190	96	165	341	1620
17	4070	32	565	591	1990	2830	612	1150	94	161	803	1630
18	4050	28	565	591	1990	541	610	172	256	162	810	1630
19	4030	28	565	591	1990	221	612	229	1060	475	804	1620
20	4000	74	566	591	1990	221	615	382	1060	973	811	1630
21	3980	560	570	591	2010	218	615	171	1060	918	822	1620
22	3370	1740	570	591	2010	220	615	170	1070	918	486	1810
23	2090	3450	597	591	2010	208	615	479	1060	918	33	2210
24	2080	3900	603	594	2000	208	615	634	857	921	23	2480
25	1680	3900	586	597	2000	209	615	204	527	924	17	2480
26	1050	3930	586	597	2000	213	619	200	348	924	15	2480
27	1040	3990	582	597	2000	215	622	384	94	565	13	2390
28	1030	3980	580	590	1990	215	620	963	90	31	13	2230
29	1030	2810	580	580	---	217	622	737	116	25	12	2240
30	1020	657	580	580	---	216	624	742	371	19	300	2130
31	1030	---	590	580	---	284	---	738	---	16	801	---
MEAN	4680	1366	487	590	1508	512	509	812	399	705	310	1339
MAX	9320	3990	603	597	2010	2830	624	1460	1070	1300	822	2480
MIN	1020	28	177	580	586	185	20	170	90	16	11	241
AC-FT	287800	81280	29970	36250	83730	31450	30300	49930	23750	43370	19060	79700
CAL YR 1965	MEAN 2704	MAX 18600	MIN 28	AC-FT 1958000								
WTR YR 1966	MEAN 1100	MAX 9320	MIN 11	AC-FT 796600								

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 LATITUDE 391414 LONGITUDE 0963416 DRAINAGE AREA 9640.00 DATUM 988.86 STATE 20 COUNTY 161

DISCHARGE, CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1966 TO SEPTEMBER 1967

DAILY MEAN VALUES

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	1800	955	1470	314	378	47	89	50	56	18200	966	1100
2	1800	944	1370	314	435	49	51	51	47	17700	948	1100
3	1780	944	1020	256	435	50	53	54	45	10700	954	1130
4	1770	944	1020	188	435	48	47	54	47	3110	948	1100
5	1770	944	1010	188	439	46	48	62	48	3050	924	600
6	1770	948	1010	192	430	45	48	65	47	2990	924	60
7	2020	951	1000	244	364	50	46	57	52	2930	894	50
8	2410	1180	1000	237	272	44	46	54	55	2890	520	50
9	2390	1520	956	232	270	46	47	53	51	2850	516	48
10	2380	1310	882	230	270	47	45	51	69	2810	516	283
11	2700	961	569	230	310	48	46	54	91	2780	516	1050
12	3200	951	223	230	388	49	47	50	182	2760	516	1310
13	2790	951	217	230	395	50	57	51	67	2020	516	1090
14	2130	966	215	230	401	49	46	52	8710	366	519	786
15	2100	1030	215	230	405	48	48	50	20000	500	516	730
16	1570	1040	215	230	405	49	47	51	19900	493	516	900
17	274	1040	217	230	372	50	46	50	19900	536	516	902
18	104	1040	218	230	316	48	46	53	20000	593	515	810
19	96	1040	219	230	314	48	49	52	23900	801	510	330
20	111	1070	221	230	185	52	48	54	22100	1450	512	150
21	100	1110	247	230	50	46	50	53	11500	1420	512	70
22	95	1120	309	230	52	48	49	52	4300	1210	512	70
23	94	1590	308	230	47	47	51	51	18300	942	512	70
24	94	3190	306	231	47	44	50	52	23600	948	510	70
25	94	2420	306	260	47	48	56	51	23500	646	508	70
26	94	1490	306	349	47	52	54	50	22800	318	521	100
27	94	1480	313	346	48	46	56	51	22900	858	582	70
28	138	1480	309	346	48	47	53	50	22200	924	776	70
29	600	1480	312	346	---	47	54	57	21100	930	912	70
30	1520	1480	314	346	---	45	52	59	20000	996	649	70
31	1410	---	314	346	---	57	---	72	---	1010	905	---
MEAN	1268	1252	536	257	272	48.1	50.8	53.7	10850	2895	650	477
MAX	3200	3190	1470	349	439	57	89	72	23900	18200	966	1310
MIN	94	944	215	188	47	44	45	49	45	318	508	48
AC-FT	77950	74520	32950	15780	15080	2960	3020	3300	645800	178000	39990	28380
CAL YR 1966	MEAN 805	MAX 3200	MIN 11	AC-FT 583000								
WTR YR 1967	MEAN 1544	MAX 23900	MIN 44	AC-FT 1118000								

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DISCHARGE, CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1967 TO SEPTEMBER 1968
 DAILY MEAN VALUES

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	70	45	1580	912	646	629	1180	1000	1830	1460	186	2140
2	70	42	1570	915	644	630	1200	1080	1840	1460	481	2140
3	70	39	1560	912	650	629	750	1260	1840	1560	234	2130
4	60	34	1570	913	644	633	91	1470	1840	1710	204	2120
5	60	31	1560	915	645	636	85	1470	1880	1710	198	2100
6	60	28	1560	914	640	513	87	1730	1930	1710	195	2100
7	55	26	1550	921	633	63	84	2030	1930	1710	195	2110
8	55	24	1560	920	635	53	85	2020	1390	1700	333	2100
9	55	24	1560	912	637	52	84	1620	960	1710	580	2100
10	50	23	1560	912	643	52	87	986	627	1600	600	2090
11	50	24	1550	913	640	53	84	987	52	1700	590	2090
12	50	23	1540	910	640	50	85	984	832	1700	1940	2090
13	445	23	1540	907	631	49	87	1010	1850	1700	5020	2090
14	1400	22	1220	906	630	50	88	684	1900	1690	5060	2080
15	1410	22	918	906	632	50	83	251	1890	1700	5070	2080
16	739	22	920	911	636	50	88	247	1860	1090	5070	2070
17	96	171	919	926	635	51	90	245	1850	436	5050	2070
18	80	1210	921	919	636	51	84	245	1850	356	5060	2070
19	39	1560	918	920	642	50	87	241	1850	188	5050	2080
20	311	1590	921	920	643	49	86	244	1840	288	8800	2080
21	1980	1590	918	920	631	47	86	288	1830	507	12900	2090
22	2010	1590	917	922	631	49	270	524	1320	698	11000	2090
23	945	1590	918	913	635	47	985	549	905	815	4650	2100
24	666	1580	918	914	635	48	997	364	906	1150	598	2080
25	2360	1580	913	920	636	49	1010	58	903	193	622	2070
26	2360	1580	912	920	636	50	1000	45	894	204	1370	2070
27	1230	1420	918	918	636	48	1000	42	893	214	1670	2070
28	38	1570	918	920	638	105	999	43	1030	235	1840	2070
29	418	1580	918	844	627	582	1000	136	1470	440	2150	2070
30	123	1580	921	649	---	1190	1000	463	1470	1130	2150	2080
31	67	---	914	650	---	1190	---	856	---	659	2130	---
MEAN	562	688	1196	896	637	252	431	747	1449	1078	2935	2091
MAX	2360	1590	1580	926	650	1190	1200	2030	1930	1710	12900	2140
MIN	38	22	912	649	627	47	83	42	52	188	186	2070
AC-FT	34550	40950	73550	55090	36670	15470	25670	45960	86210	66290	180500	124400
CAL YR 1967	MEAN 1494	MAX 23900	MIN 22	AC-FT 1081000								
WTR YR 1968	MEAN 1082	MAX 12900	MIN 22	AC-FT 785300								

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 LATITUDE 391414 LONGITUDE 0963416 DRAINAGE AREA 9640.00 DATUM 988.86 STATE 20 COUNTY 161

DISCHARGE, CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1968 TO SEPTEMBER 1969
 DAILY MEAN VALUES

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	2080	2020	2890	1500	2050	17200	6230	9350	2650	1440	1910	958
2	2070	2020	3730	1270	2050	17300	2940	4940	3140	1460	1640	1270
3	2100	2010	4730	805	2040	20500	2580	2540	4220	1450	1390	3860
4	2080	2010	4710	800	2050	24100	3100	2070	718	1450	1390	5050
5	2070	2020	3690	796	2090	23600	4880	2480	1430	1430	1390	5100
6	2060	2000	1180	698	2680	21000	6460	2930	4300	1440	1380	5090
7	2060	1990	462	461	4600	14000	10300	2940	4300	2220	1380	5080
8	2060	2560	463	460	4580	8090	10400	7280	2830	4040	1380	5050
9	1680	3010	461	461	4590	7530	7090	16300	1130	4070	1370	4570
10	1080	3020	460	458	3360	6510	1840	12000	1110	4050	1360	2020
11	1270	3000	462	456	2090	4430	590	4710	1120	5670	1360	1330
12	1570	3000	459	455	2100	4400	3480	3240	1130	7720	1360	1330
13	1570	3000	455	455	2100	4370	8300	3270	1120	6530	1080	1320
14	1580	2990	460	458	2130	4000	9510	3040	1120	3090	250	1320
15	1380	2980	460	461	2130	2860	9420	2340	1090	1890	670	1320
16	1150	2980	460	462	2120	2780	8650	2340	1090	1380	674	1320
17	1140	2980	460	461	2120	3150	6750	2300	1270	1360	674	1310
18	1140	3090	521	460	3130	4120	5190	2290	1440	1360	673	1190
19	1130	4700	699	465	3940	1610	2370	2290	1430	1820	668	777
20	1120	4710	1520	746	1800	227	2330	2270	1410	2760	574	770
21	2690	4710	1520	1080	1790	2140	2280	2320	1420	6010	487	770
22	4810	4260	1520	1080	1820	8550	2550	2770	1450	6010	485	714
23	4830	2910	1520	1460	1820	10100	7840	8900	1470	6030	485	480
24	4810	2910	1520	2050	1850	11100	16500	15100	1470	6490	485	470
25	4810	2920	1520	2050	2320	18900	12500	15000	1470	6150	485	470
26	4810	2910	1520	2060	3070	27000	6180	14900	1440	6080	656	470
27	3550	2900	1520	2060	4850	27500	4650	13200	1440	6050	957	470
28	2040	2900	1500	2060	11200	26900	3010	7010	1470	6030	959	470
29	2020	2890	1500	2050	---	23700	8700	3510	1440	5510	958	470
30	2020	2890	1500	2050	---	18600	10300	2720	1440	2900	959	465
31	2030	---	1500	2050	---	11900	---	2700	---	1950	962	---
MEAN	2284	2943	1464	1053	2945	12200	6231	5776	1752	3737	982	1843
MAX	4830	4710	4730	2060	11200	27500	16300	16300	4300	7720	1910	5100
MIN	1080	1990	455	455	1790	227	590	2070	718	1360	250	465
AC-FT	140500	175100	90000	64740	163600	750100	370800	355100	104200	229800	60400	109700

CAL YR 1968 MEAN 1435 MAX 12900 MIN 42 AC-FT 1042000
 WTR YR 1969 MEAN 3611 MAX 27500 MIN 227 AC-FT 2614000

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DISCHARGE, CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1969 TO SEPTEMBER 1970
 DAILY MEAN VALUES

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	480	530	3030	56	124	510	505	1000	3780	490	226	438
2	480	530	3020	56	236	515	490	1010	9910	495	222	384
3	480	760	3020	56	505	505	456	1010	10700	485	226	354
4	485	1010	2790	56	510	500	388	878	10600	480	222	480
5	490	1020	1400	58	510	500	388	490	10200	480	222	772
6	480	1020	152	56	510	500	388	490	9860	480	222	766
7	475	1010	118	56	510	500	388	379	5490	480	654	766
8	475	1020	115	58	505	505	438	222	814	480	1470	766
9	475	1010	115	78	742	505	626	226	784	480	1460	577
10	465	1010	118	97	1180	495	588	226	1100	480	1460	379
11	362	1010	115	130	1180	495	411	3520	4100	480	1450	379
12	362	1010	110	130	1170	495	406	9820	11200	485	1010	384
13	393	1010	62	130	1180	490	402	9830	14100	406	465	442
14	393	1000	58	127	1180	495	402	9790	14000	170	375	397
15	346	1010	58	127	1180	490	406	9690	9030	177	226	393
16	262	1010	56	130	934	495	406	7740	3000	240	222	411
17	262	1010	56	130	505	495	411	2160	7980	166	222	397
18	266	1000	56	127	505	500	447	406	9860	173	222	393
19	258	760	54	127	500	495	406	233	9840	163	219	682
20	270	346	54	127	500	490	406	229	7530	159	236	634
21	354	346	56	127	500	495	648	229	3240	379	233	700
22	525	346	54	124	505	495	1010	229	1170	784	226	857
23	530	520	56	121	505	495	1020	229	1110	784	219	736
24	530	1300	54	124	505	495	1010	236	1470	550	520	700
25	525	2030	54	124	505	495	1020	1910	2080	226	990	1520
26	525	2270	56	124	510	485	1020	7340	1900	226	990	2450
27	525	3040	56	124	510	495	1020	9930	962	222	802	2460
28	525	3040	58	124	520	495	1010	6190	500	229	465	2450
29	535	3030	56	124	---	495	1020	1100	495	222	460	2450
30	535	3030	56	124	---	495	1040	1050	490	222	460	1890
31	535	---	56	124	---	495	---	1330	---	222	460	---
MEAN	439	1235	489	106	651	497	619	2875	5576	371	544	882
MAX	535	3040	3030	130	1180	515	1040	9930	14100	784	1470	2460
MIN	258	346	54	56	124	485	388	222	490	159	219	354
AC-FT	26980	73460	30090	6500	36150	30570	36850	176800	331800	22840	33430	52500
CAL YR 1969	MEAN 3231	MAX 27500	MIN 54	AC-FT 2339000								
WTR YR 1970	MEAN 1185	MAX 14100	MIN 54	AC-FT 858000								

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STATION NUMBER 06887000 BIG BLUE R NR MANHATTAN, KS STREAM SOURCE AGENCY USGS
 LATITUDE 391414 LONGITUDE 0963416 DRAINAGE AREA 9640.00 DATUM 988.86 STATE 20 COUNTY 161

DISCHARGE, CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1970 TO SEPTEMBER 1971
 DAILY MEAN VALUES

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	500	2670	305	307	480	3850	1460	993	12700	533	452	413
2	386	1400	366	307	475	3840	1460	989	12600	530	451	410
3	216	783	487	332	475	3090	1470	1730	12400	548	451	403
4	216	488	487	310	478	1980	1460	2420	8430	627	450	410
5	216	485	489	310	533	1970	1220	2410	3120	542	446	404
6	224	454	487	314	696	1950	953	2410	3070	1640	448	405
7	220	391	491	314	698	1950	720	2390	3060	2710	450	405
8	232	396	492	312	698	2390	508	2370	3020	2410	450	410
9	248	392	494	306	602	2090	506	2370	3010	2280	447	402
10	224	591	497	300	388	1000	507	4510	3110	2400	445	402
11	220	958	492	300	391	1010	508	10600	4480	2370	446	406
12	939	960	492	300	390	1600	509	10600	4120	2200	446	407
13	2990	960	495	300	381	2460	508	10600	3410	2140	447	405
14	2980	958	495	300	381	2470	501	10600	3400	2110	446	403
15	2980	953	498	300	387	2980	503	10500	3120	2100	447	407
16	2740	957	495	300	507	3860	504	10500	3070	2100	446	448
17	1300	959	500	300	1890	3890	507	10400	3040	2110	445	434
18	500	960	500	341	3760	3880	505	7110	3030	2110	388	415
19	590	964	497	345	4900	3870	506	3830	3020	2060	260	406
20	960	953	495	330	8190	3890	511	3850	3010	2040	258	406
21	968	953	439	295	8260	3890	507	3570	3000	1810	259	405
22	967	951	314	294	8240	3880	508	3370	2990	1010	259	408
23	971	859	308	292	8210	5290	581	5640	2980	1900	229	407
24	970	431	309	292	8190	10600	722	8330	2470	2570	147	410
25	974	303	307	346	8120	10500	727	14600	2210	1150	175	412
26	1320	306	305	471	6540	8470	741	14400	1080	1010	307	411
27	1950	305	305	470	3840	3400	838	13900	1080	994	327	410
28	2260	305	305	474	3850	3390	987	13400	973	871	416	407
29	2890	305	305	474	---	3380	988	13100	540	468	416	406
30	2890	305	307	477	---	2480	990	12800	545	470	413	404
31	2880	---	305	468	---	1490	---	12800	---	465	414	---
MEAN	1223	755	421	341	2927	3574	764	7326	3870	1557	383	409
MAX	2990	2670	500	477	8260	10600	1470	14600	12700	2710	452	448
MIN	216	303	305	292	381	1000	501	989	540	465	147	402
AC-FT	75220	44940	25910	20990	162500	219800	45450	450400	230300	95760	23570	24360
CAL YR 1970	MEAN	1207	MAX	14100	MIN	56	AC-FT	873500				
WTR YR 1971	MEAN	1960	MAX	14600	MIN	147	AC-FT	1419000				

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DISCHARGE, CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1971 TO SEPTEMBER 1972
 DAILY MEAN VALUES

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	406	433	108	742	283	518	318	534	2700	495	1450	3780
2	406	348	108	739	283	513	310	899	1460	495	1470	3810
3	401	261	108	750	280	517	308	1960	1460	484	1480	3920
4	405	101	108	737	285	517	298	1980	1450	493	1860	3940
5	403	102	108	737	281	517	305	1980	1200	493	2400	3960
6	402	98	108	667	282	512	309	2000	807	489	2410	3840
7	404	98	108	302	279	520	309	1980	805	489	2700	3980
8	403	98	108	290	279	515	305	2100	805	489	3700	1080
9	401	99	108	288	279	522	309	2480	707	489	3700	3990
10	401	100	107	291	280	524	317	2490	550	489	3700	3990
11	401	100	105	291	280	524	313	2490	545	492	3690	3960
12	396	102	106	293	280	526	313	2500	442	489	3670	2070
13	396	102	456	292	280	523	312	2490	252	487	3660	118
14	401	102	1210	292	280	528	312	2490	292	717	3660	1680
15	401	103	1220	293	279	565	307	2490	250	1040	2450	3890
16	401	106	1220	291	278	524	310	2690	248	1040	950	3910
17	401	118	1200	291	277	529	306	3360	248	1050	948	3900
18	418	106	1210	292	273	521	306	3370	248	1090	948	3870
19	396	100	1210	291	275	523	306	3370	331	1370	948	3860
20	404	105	1200	291	275	527	307	3360	494	1480	948	3850
21	397	105	1200	291	275	614	309	3350	489	1470	780	3810
22	397	105	1200	291	321	984	301	3350	489	1460	483	2480
23	396	108	1200	291	515	986	301	3350	489	1450	478	541
24	396	108	1200	297	518	986	300	3330	489	1460	501	530
25	397	105	1190	291	518	984	295	3320	489	1450	530	523
26	403	107	1190	296	518	986	307	3320	496	1450	489	528
27	403	103	1190	290	519	983	309	3300	537	1470	492	528
28	399	113	1180	290	521	982	344	3300	539	1450	500	525
29	474	111	1180	290	520	983	504	3290	539	1450	500	517
30	430	108	1070	292	---	982	518	3280	517	1450	513	517
31	409	---	744	285	---	862	---	3280	---	1450	1070	---
MEAN	405	128	734	376	338	671	322	2693	679	973	1712	2597
MAX	474	433	1220	750	521	986	518	3370	2700	1480	3700	3990
MIN	396	98	105	285	273	512	295	534	248	484	478	118
AC-FT	24890	7650	45140	23140	19460	41250	19170	165600	40400	59840	105300	154500
CAL YR 1971	MEAN	1866	MAX	14600	MIN	98	AC-FT	1351000				
WTR YR 1972	MEAN	973	MAX	3990	MIN	98	AC-FT	706300				

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DISCHARGE, CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1972 TO SEPTEMBER 1973
 DAILY MEAN VALUES

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	538	520	2940	2060	5000	54	5150	2530	1510	982	2300	2060
2	538	1030	2940	2060	5000	52	5190	1310	2200	885	2500	2060
3	544	1030	2930	2460	5000	40	5230	268	2210	585	3650	2050
4	544	1030	2930	3390	5000	50	6430	246	2180	575	4350	2020
5	544	1030	2920	3380	5000	50	14400	996	2160	565	4350	2000
6	538	1040	2930	3380	5000	50	18100	2330	2160	657	4340	2000
7	532	1020	2940	3380	7160	50	19600	3010	2160	937	4340	2030
8	532	1180	2930	3360	10500	50	20300	3050	2180	937	4430	2040
9	532	1480	2920	3350	10400	50	19900	5260	2160	937	4410	2030
10	532	1460	2910	2810	10400	50	19900	5260	2140	950	4410	2020
11	455	1460	2900	1510	10300	50	19700	6830	2130	950	3680	2020
12	193	1460	2910	1500	6140	50	19500	10500	1940	944	1070	2040
13	186	1670	2890	1500	1460	50	19300	10400	1780	937	4240	2830
14	182	2010	2880	1520	5050	50	19100	12000	6130	956	4230	3960
15	179	2040	2870	1560	5100	50	17900	16200	7910	950	4220	3960
16	179	2060	2870	1540	5090	3630	13300	16000	7880	950	4200	3990
17	182	2050	2860	1540	5080	7650	10600	15700	7800	950	4180	3960
18	182	2050	2860	2070	5060	7620	10600	14200	6500	950	4160	3940
19	182	2040	2860	3460	5060	9860	10600	6450	2060	970	4150	3940
20	220	2030	2890	3480	5040	16200	10500	2320	1940	1500	4250	3940
21	348	2030	2870	3480	5030	16000	10400	1820	1920	2300	4360	3160
22	356	2020	3150	4010	5020	15900	8340	565	1900	2300	4340	2060
23	348	2020	3900	4940	7040	15600	2680	596	1900	2320	4300	2110
24	348	2030	3890	4960	9940	15600	2490	873	1890	2220	4270	2080
25	348	2030	3880	4960	6630	15700	2410	867	1880	2290	4250	2090
26	348	2020	3860	4980	588	16200	2360	861	1870	2320	4240	2100
27	348	2340	3850	5000	236	14900	2320	849	1600	2220	3590	500
28	348	2940	3860	4960	82	9850	2300	843	1020	2300	2070	50
29	348	2940	3290	4960	---	12400	2290	837	1000	2180	2060	50
30	352	2940	2130	4940	---	16900	2310	831	989	2020	2040	50
31	352	---	2070	4940	---	11200	---	831	---	2060	2050	---
MEAN	366	1767	3059	3272	5586	6644	10770	4666	2770	1374	3711	2305
MAX	544	2940	3900	5000	10500	16900	20300	16200	7910	2320	4430	3990
MIN	179	520	2070	1500	82	40	2290	246	989	565	1070	50
AC-FT	22530	105100	188100	201200	310200	408500	641100	286900	164800	84490	228200	137100
CAL YR 1972	MEAN 1301	MAX 3990	MIN 118	AC-FT 944400								
WTR YR 1973	MEAN 3838	MAX 20300	MIN 40	AC-FT 2778000								

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DISCHARGE, CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1973 TO SEPTEMBER 1974
 DAILY MEAN VALUES

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	50	24000	17700	3220	7240	3820	1550	3040	2430	465	450	545
2	50	23900	17500	3190	7260	3810	1340	2990	2430	465	450	712
3	50	23800	17200	3140	7260	3780	1060	2900	2440	470	445	928
4	50	23600	15500	3120	7270	2940	1040	2860	2450	475	450	928
5	50	21000	9980	3110	7090	1620	1030	2860	2450	470	500	928
6	2400	18600	4610	3090	7170	1610	1030	2870	2550	470	560	928
7	6040	18600	4490	3080	7210	1600	1030	2870	2460	470	555	928
8	8560	18700	4390	3040	7180	1600	1010	2850	2630	465	555	928
9	10600	18600	4320	3030	7000	1590	1010	2340	2600	465	560	928
10	12900	18600	3890	3020	6940	1610	1020	1120	2500	465	555	928
11	2600	18500	2760	3010	5000	1600	1020	1100	2500	460	550	928
12	75	19800	2730	3000	2800	1610	1030	1100	2500	460	550	916
13	50	20900	2680	3000	1800	1600	1040	1100	2490	465	550	910
14	50	20800	2660	2980	946	1790	1020	1600	2450	460	545	910
15	50	20700	2620	2980	928	2120	1020	2480	2440	460	545	916
16	50	20500	2630	2980	922	2100	1020	2480	2420	460	545	916
17	3600	20400	2860	2980	922	2100	1110	2450	2420	465	565	910
18	13300	20300	3260	3030	916	2090	1240	2420	2420	465	540	826
19	12900	20100	3240	3080	1630	2080	1340	2440	1910	465	540	505
20	13400	19100	2920	3180	2970	2070	1550	2500	1380	465	540	500
21	18100	20400	1820	3200	3300	1800	1700	2500	1240	460	540	500
22	21300	20200	1180	2220	3840	1610	1400	2500	904	460	540	495
23	21200	20000	1140	1110	3840	1580	1800	2500	892	455	540	540
24	23100	19900	1180	1090	3820	1570	2960	2500	730	455	540	670
25	25800	19700	1290	1580	3830	1570	2860	2510	475	530	540	760
26	24700	19300	2140	3110	3830	1570	2840	2510	470	460	540	874
27	24600	18700	3770	3120	3830	1570	2830	2500	450	455	540	625
28	24500	18400	3610	4240	3820	1570	2830	2500	465	455	535	306
29	24300	18200	3410	7220	---	1560	3380	2500	465	450	535	302
30	24400	17900	3320	7270	---	1560	3170	2510	470	455	535	302
31	24400	---	3250	7230	---	1570	---	2440	---	455	550	---
MEAN	11070	20110	4969	3311	4306	1957	1609	2383	1814	464	532	743
MAX	25800	24000	17700	7270	7270	3820	3380	3040	2630	530	565	928
MIN	50	17900	1140	1090	916	1560	1010	1100	450	450	445	302
AC-FT	680800	1196000	305600	203600	239100	120300	95760	146500	108000	28550	32700	44220
CAL YR 1973	MEAN 6416	MAX 25800	MIN 40	AC-FT 4645000								
WTR YR 1974	MEAN 4422	MAX 25800	MIN 50	AC-FT 3202000								

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 DAILY MEAN VALUES

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	470	993	612	580	6.0	23	1120	1940	2880	8070	4090	495
2	678	979	475	580	6.0	19	1850	1960	3650	9070	2320	495
3	684	972	213	580	6.2	16	1850	1950	6100	10300	2310	497
4	684	965	210	580	21	14	1850	1940	10400	10200	1770	401
5	690	965	210	580	17	12	1850	2320	10400	10200	931	233
6	690	958	216	580	17	12	1850	2840	10400	10100	936	203
7	678	958	213	582	20	11	2550	2840	10400	10000	919	203
8	600	958	207	1480	18	9.0	3250	2830	10400	9940	849	201
9	296	972	207	403	16	12	3240	2190	10400	9870	735	200
10	292	979	208	104	16	19	5820	1420	10500	9780	734	205
11	292	965	210	44	15	16	8370	1410	9310	7420	734	209
12	292	965	210	30	14	16	8330	1110	5540	2580	730	198
13	300	965	280	24	14	12	8320	776	5210	2490	742	200
14	198	958	540	23	14	11	8330	773	5130	2470	740	200
15	60	944	535	21	14	10	8270	769	5080	2450	723	200
16	51	951	535	21	15	10	8220	768	5110	2380	722	200
17	51	951	535	20	22	11	8180	769	5070	1870	722	201
18	51	944	540	21	28	15	8160	770	5050	525	767	203
19	47	944	535	28	26	14	5130	704	5110	515	932	220
20	49	944	535	29	26	13	2010	502	5130	511	920	304
21	150	1450	535	29	34	14	2000	500	5130	510	916	307
22	375	2050	535	30	58	15	1780	503	5130	510	916	307
23	380	2050	540	31	42	13	1470	394	3000	512	911	311
24	440	2040	540	28	36	11	1460	84	1000	2150	911	306
25	755	2050	535	14	35	8.5	1470	77	3000	4850	923	308
26	965	2040	540	8.9	31	20	1500	81	5870	4880	907	308
27	965	1590	540	7.4	23	37	1480	74	5770	4890	814	388
28	972	618	540	6.3	22	14	1590	84	5370	3180	498	108
29	972	618	540	6.0	---	500	1950	146	5130	4760	496	100
30	1050	618	560	6.0	---	564	1950	1030	5990	4780	494	114
31	1040	---	580	6.0	---	567	---	2850	---	4770	494	---
MEAN	491	1145	426	209	21.9	65.8	3840	1174	6222	5049	1020	261
MAX	1050	2060	612	1480	58	567	8370	2850	10500	10300	4090	497
MIN	47	618	207	6.0	6.0	8.5	1120	74	1000	510	494	100
AC-FT	30180	68160	26200	12860	1210	4040	228500	72210	370200	310500	62690	15520
CAL YR 1974	MEAN 1579	MAX 7270	MIN 47	AC-FT 1143000								
WTR YR 1975	MEAN 1661	MAX 10500	MIN 6.0	AC-FT 1202000								

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 DAILY MEAN VALUES

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	100	73	482	500	183	468	700	7760	2450	1510	1150	285
2	98	97	1010	500	287	603	1020	7630	1450	2030	1020	386
3	98	81	1010	493	465	758	1020	7540	1440	2030	370	390
4	98	73	901	488	467	784	1020	7490	1210	2010	362	390
5	98	72	464	488	466	759	1020	6980	891	2010	323	388
6	98	72	449	489	463	760	1090	4710	894	1990	247	389
7	126	71	450	440	464	761	1250	3970	791	1990	246	386
8	114	69	453	440	466	758	1230	3890	495	1970	246	386
9	96	70	448	537	467	871	1460	3820	489	1980	246	383
10	91	64	451	515	468	1000	1930	3200	490	1960	243	382
11	68	67	454	500	567	1010	1930	1650	492	1950	243	382
12	67	67	452	480	782	995	1620	1180	494	1930	247	384
13	66	63	453	470	788	986	1020	1170	488	1930	243	387
14	66	66	463	462	787	993	797	1170	488	1920	243	386
15	65	69	822	355	794	995	794	1180	483	1920	243	411
16	63	70	2020	185	796	987	747	1180	482	1070	243	387
17	66	70	2020	183	788	986	1110	1170	500	487	241	384
18	65	70	2030	183	787	970	1490	1310	493	457	241	386
19	66	73	2030	183	786	966	2050	1490	479	524	241	386
20	66	75	2020	180	791	965	3430	1500	482	964	241	381
21	66	66	2020	183	791	962	3780	1410	397	905	243	381
22	66	64	2020	183	778	966	4090	1170	199	865	243	380
23	66	68	2010	183	782	960	3810	1230	252	936	243	384
24	66	69	2010	183	721	747	3760	2280	413	1240	243	382
25	66	70	2010	185	461	546	3730	4130	536	1220	243	389
26	67	73	2000	180	456	552	4740	4120	536	1200	243	384
27	68	68	2000	180	460	546	6750	4120	536	1190	243	381
28	69	69	2000	182	460	549	7780	3890	657	1180	238	380
29	67	88	1570	182	457	552	8100	2930	1100	1180	240	380
30	68	76	474	183	---	545	7920	2920	1090	1160	240	382
31	68	---	496	182	---	547	---	2950	---	1160	240	---
MEAN	77.8	71.4	1209	325	594	802	2706	3263	707	1447	308	382
MAX	126	97	2030	537	796	1010	8100	7760	2450	2030	1150	411
MIN	63	63	448	180	183	468	700	1170	199	457	238	285
AC-FT	4780	4250	74370	19990	34170	49280	161000	200600	42040	89000	18920	22730

CAL YR 1975 MEAN 1604 MAX 10500 MIN 6.0 AC-FT 1161000
 WTR YR 1976 MEAN 993 MAX 8100 MIN 63 AC-FT 721200

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UNITED STATES DEPARTMENT OF THE INTERIOR - GEOLOGICAL SURVEY - KANSAS

STATION NUMBER 06887000 BIG BLUE R NR MANHATTAN, KS STREAM SOURCE AGENCY USGS
 LATITUDE 391414 LONGITUDE 0963416 DRAINAGE AREA 9640.00 DATUM 988.86 STATE 20 COUNTY 161

DISCHARGE, CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1976 TO SEPTEMBER 1977
 DAILY MEAN VALUES

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	384	362	366	330	330	308	300	306	4050	2280	626	7540
2	385	361	366	330	330	313	301	306	3450	2200	628	7200
3	386	360	366	330	330	312	306	3350	3350	2170	742	7380
4	389	358	362	330	331	313	317	306	3410	2170	1060	7380
5	383	359	362	330	343	308	298	303	3240	2200	1050	7080
6	380	363	362	330	346	308	301	302	3110	2140	1100	6890
7	282	361	362	330	334	310	304	299	3090	2120	1050	6880
8	83	359	358	330	326	314	304	299	2710	2110	1050	6860
9	80	367	358	330	324	316	302	298	1420	1740	686	6810
10	79	366	362	330	324	315	299	295	502	1090	102	6750
11	80	366	358	330	321	317	299	294	502	1110	100	6680
12	113	362	358	342	321	314	298	294	500	1090	96	7060
13	277	362	354	338	320	312	305	294	500	884	96	4770
14	282	362	354	334	319	312	302	317	507	488	100	4090
15	316	364	356	333	318	311	302	331	1350	480	100	9540
16	351	366	357	330	318	308	299	333	2380	482	971	9490
17	352	368	360	330	321	311	301	321	2500	482	3740	9600
18	358	371	358	330	317	306	296	299	2500	475	5540	9600
19	354	373	358	333	314	306	300	350	2500	375	6750	9530
20	354	373	351	330	315	304	304	390	2500	222	6780	9450
21	355	372	352	330	317	303	305	390	2500	222	6790	8440
22	357	370	354	331	321	301	302	390	3500	222	6800	5760
23	363	374	350	332	319	306	300	390	4430	222	6910	5760
24	358	372	352	329	314	306	299	390	5230	222	6870	5740
25	356	381	354	326	314	302	298	978	6800	218	4840	5710
26	357	398	349	331	310	302	300	1800	6820	217	2170	5690
27	361	386	350	332	310	302	302	2020	6510	219	2100	5660
28	358	384	350	329	312	333	305	2430	6510	219	2100	5630
29	359	382	343	328	---	298	2350	6450	219	4350	4350	5610
30	365	366	349	329	---	297	306	4940	424	7390	3520	3520
31	362	---	340	328	---	296	---	3350	---	628	7430	---
MEAN	310	369	356	331	322	309	302	744	3259	946	2907	6937
MAX	389	398	366	342	346	333	317	3350	6820	2280	7430	9600
MIN	79	358	340	326	310	296	296	294	500	217	96	3520
AC-FT	19070	21950	21880	20340	17890	18970	17960	45760	193900	58200	178700	412800
CAL YR 1976	MEAN 965	MAX 8100	MIN 79	AC-FT 700700								
WTR YR 1977	MEAN 1419	MAX 9600	MIN 79	AC-FT 1027000								

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UNITED STATES DEPARTMENT OF THE INTERIOR - GEOLOGICAL SURVEY - KANSAS

STATION NUMBER 06887000 BIG BLUE R NR MANHATTAN, KS STREAM SOURCE AGENCY USGS
 LATITUDE 391414 LONGITUDE 0963416 DRAINAGE AREA 9640.00 DATUM 988.86 STATE 20 COUNTY 161

DISCHARGE, CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1977 TO SEPTEMBER 1978
 DAILY MEAN VALUES

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	1520	957	445	1580	445	900	15300	2090	1580	7900	7750	407
2	1510	954	97	1580	440	90	15200	3260	2240	7860	7710	405
3	1110	956	94	1580	440	402	15200	3260	3800	7850	5520	408
4	452	817	94	1580	440	1510	15100	3260	3810	7770	1640	408
5	450	435	239	1580	445	1520	15100	2820	3800	5530	1030	409
6	451	434	825	1570	440	1540	15100	1780	3790	1580	1010	407
7	510	434	838	1580	445	1540	15100	1800	2990	3410	1010	405
8	459	451	1110	1560	445	1550	15100	2300	2000	5660	1010	405
9	456	1070	1630	1560	445	1540	15100	7460	1540	5670	1010	405
10	456	2950	1630	1560	445	1400	15100	10100	1010	5670	836	405
11	982	2980	1630	1560	445	652	11900	10100	1000	5640	209	405
12	1960	2980	1630	1560	440	324	4060	10000	987	5630	661	405
13	1960	2980	1630	1550	440	997	3970	9980	985	5660	664	407
14	1960	2980	1630	1540	440	5220	3960	9910	983	4560	664	403
15	1950	2970	1400	1550	440	5500	3940	9860	982	2000	666	405
16	1950	2960	1200	1550	440	5640	3920	9830	935	1970	664	406
17	1490	2950	1180	1540	440	7590	3920	9840	868	1960	664	400
18	978	2110	1170	1200	445	10700	3930	9770	858	1550	665	400
19	974	1190	1170	454	445	10800	3970	9710	880	1070	657	400
20	975	1180	1160	450	445	10800	5970	9600	1090	1860	660	1500
21	978	1170	1160	450	440	10900	10200	9510	1480	3690	659	4810
22	978	1020	1340	450	445	10900	10200	7600	1490	3700	661	5060
23	978	763	1620	450	470	10900	10200	3030	1480	3720	665	5070
24	978	758	1610	450	480	10900	10200	3010	1480	5150	670	5040
25	978	755	1610	450	470	11000	10100	3000	1480	7980	670	5000
26	978	755	1600	445	465	11000	9990	3000	1480	8000	670	4910
27	978	763	1600	445	615	10900	9920	3000	2450	7960	668	4880
28	978	758	1610	445	1070	10800	7350	3010	3740	7960	664	2920
29	972	758	1600	445	---	10800	1660	5520	7900	7900	646	541
30	969	758	1600	445	---	12500	1620	2360	7700	7850	620	535
31	956	---	1600	445	---	15800	---	1600	---	7780	572	---
MEAN	1073	1433	1218	1084	475	6342	9413	5768	2148	5242	1350	1599
MAX	1960	2980	1630	1580	1070	15800	15300	10100	7700	8000	7750	5070
MIN	450	434	94	445	440	90	1620	1600	858	1070	209	400
AC-FT	66000	85280	74880	66650	26400	390000	560100	354700	127800	322300	83040	95130
CAL YR 1977	MEAN 1645	MAX 9600	MIN 94	AC-FT 1191000								
WTR YR 1978	MEAN 3111	MAX 15800	MIN 90	AC-FT 2252000								

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UNITED STATES DEPARTMENT OF THE INTERIOR - GEOLOGICAL SURVEY - KANSAS

STATION NUMBER 06887000 BIG BLUE R NR MANHATTAN, KS STREAM SOURCE AGENCY USGS
 LATITUDE 391414 LONGITUDE 0963416 DRAINAGE AREA 9640.00 DATUM 988.86 STATE 20 COUNTY 161

DISCHARGE, CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1978 TO SEPTEMBER 1979
 DAILY MEAN VALUES

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	535	410	1830	490	502	1500	23600	2500	1880	3360	1980	528
2	536	410	1830	500	498	3750	23800	2500	1880	3390	1370	528
3	533	405	1810	500	498	8030	23900	2500	1870	3370	1370	528
4	506	405	1810	500	501	8410	23900	3810	1860	3340	1350	523
5	457	400	1820	500	503	8530	23900	4000	1850	3400	1340	562
6	456	405	1810	500	503	8420	23900	4000	1600	3480	1200	716
7	457	395	1810	500	499	8290	23900	5920	1120	3600	773	690
8	459	395	1800	500	503	9930	23900	6000	800	3560	396	687
9	460	395	1800	500	501	14300	23900	6000	779	4320	376	687
10	460	396	1800	500	503	14400	23900	6000	768	5630	379	687
11	463	392	1800	500	504	14400	23900	6000	763	5560	370	632
12	462	393	1800	500	504	14500	23200	3590	755	5510	366	434
13	454	396	1790	500	503	14500	19200	2500	750	5500	403	430
14	454	392	1790	500	503	14400	13300	2500	891	5630	507	422
15	450	396	1790	500	498	14400	8260	4420	1080	5640	501	424
16	448	404	1790	500	505	14400	5000	4040	1080	5720	503	427
17	445	397	1780	500	503	14300	3230	2640	1080	5960	503	341
18	445	395	1790	500	499	14600	2500	2640	1070	5830	498	120
19	440	393	1780	500	498	4500	2500	2620	1060	5830	498	112
20	440	630	1780	500	498	650	2500	2620	1060	5700	498	112
21	435	638	1780	500	498	4000	2500	2950	1060	5710	622	112
22	437	282	1300	500	498	4500	2500	3140	1070	5780	799	112
23	428	61	534	500	498	5200	2500	2440	1070	5860	801	112
24	426	361	523	500	498	6310	2500	1900	1060	5820	796	112
25	428	383	523	509	498	7080	2500	1670	1440	5800	796	112
26	423	379	523	510	620	7850	2500	1650	2200	5790	808	112
27	425	837	523	504	991	16100	2500	1640	2180	5840	784	112
28	418	1830	523	503	1500	23600	2500	1630	2190	5840	672	112
29	420	1840	523	503	---	23900	2500	1610	2660	5760	535	112
30	415	1830	500	503	---	23700	2500	1600	3380	5640	534	112
31	416	---	460	501	---	23600	---	1670	---	4310	531	---
MEAN	453	555	1410	501	558	11360	12240	3184	1410	5048	737	357
MAX	536	1840	1830	510	1500	23900	23900	6000	3380	5960	1980	716
MIN	415	61	460	490	498	650	2500	1600	750	3340	366	112
AC-FT	27830	33020	86720	30790	31000	698300	728300	195800	83910	310400	45340	21240
CAL YR 1978	MEAN 3002	MAX 15800	MIN 61	AC-FT 2174000								
WTR YR 1979	MEAN 3167	MAX 23900	MIN 61	AC-FT 2293000								

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 LATITUDE 391414 LONGITUDE 0963416 DRAINAGE AREA 9640.00 DATUM 988.86 STATE 20 COUNTY 161

DISCHARGE, CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1979 TO SEPTEMBER 1980
 DAILY MEAN VALUES

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	112	4640	1180	861	1220	6840	5580	1680	1430	589	722	577
2	112	3880	1240	861	1210	6790	8180	1660	2790	586	891	575
3	111	4840	1230	861	1200	4850	12000	1650	5800	597	887	575
4	110	4020	1200	861	1200	1560	11800	1630	5830	586	805	574
5	110	3580	1210	861	1200	1540	11000	1630	5820	581	660	575
6	110	3480	1210	861	1200	1540	10800	1620	6740	581	653	570
7	111	3480	1210	848	1210	1590	12000	1620	8720	581	647	640
8	110	3480	1880	848	1220	316	15700	1610	8650	581	545	711
9	111	3480	2450	848	1210	359	15600	1260	7770	575	289	710
10	110	3500	3270	848	1210	350	15600	723	5550	772	281	707
11	110	3530	4070	868	1210	210	15500	711	5010	780	280	711
12	117	3540	4210	868	1100	125	15300	711	3570	579	422	717
13	168	2910	4230	868	803	70	15200	705	3120	575	600	717
14	171	1180	4240	848	796	37	15000	914	1930	791	612	711
15	171	1170	4240	848	796	31	14900	1220	1730	1130	615	715
16	171	1160	4220	848	792	27	13400	1250	1210	1140	608	716
17	171	1150	4230	841	788	23	8750	1230	868	1140	608	705
18	194	1150	4220	841	780	19	6160	1220	861	985	556	705
19	182	956	4200	854	775	17	5990	1350	861	754	453	636
20	172	772	4170	841	787	18	5940	1640	854	747	574	409
21	185	1360	3340	976	785	17	5880	1650	848	746	575	400
22	180	3000	1840	1240	786	1740	5830	1650	854	735	575	397
23	168	3100	1830	1250	780	3530	4420	1650	848	729	575	395
24	168	2940	1820	1250	778	3550	2240	1640	841	729	575	395
25	168	2360	1820	1250	988	3530	1870	1650	841	721	575	395
26	168	1210	1460	1250	2610	3530	1380	1680	901	636	575	395
27	170	1200	868	1240	4150	3540	1350	1650	1030	691	572	395
28	171	1180	868	1240	4760	3620	1330	1650	1030	687	570	391
29	171	1180	868	1250	6900	4150	1410	1650	1030	681	570	391
30	382	1180	868	1240	---	7190	1750	1500	917	680	570	395
31	2440	---	861	1230	---	6180	---	1430	---	677	575	---
MEAN	229	2487	2405	984	1491	2158	8729	1414	2942	721	581	563
MAX	2440	4840	4240	1250	6900	7190	15700	1680	8720	1140	891	717
MIN	110	772	861	841	775	17	1330	705	841	575	280	391
AC-FT	14090	148000	147900	60490	85770	132700	519400	86940	175100	44360	35730	33530

CAL YR 1979 MEAN 3391 MAX 23900 MIN 110 AC-FT 2455000
 WTR YR 1980 MEAN 2044 MAX 15700 MIN 17 AC-FT 1484000

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STATION NUMBER 06887000 BIG BLUE R NR MANHATTAN, KS STREAM SOURCE AGENCY USGS
 LATITUDE 391414 LONGITUDE 0963416 DRAINAGE AREA 9640.00 DATUM 988.86 STATE 20 COUNTY 161

DISCHARGE, CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1980 TO SEPTEMBER 1981
 DAILY MEAN VALUES

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	395	498	254	453	472	404	408	373	45	540	6820	996
2	391	526	250	450	472	404	403	353	49	544	6800	973
3	469	563	250	454	474	406	402	353	59	552	6820	966
4	627	565	250	455	474	412	400	369	50	590	6740	968
5	630	570	248	455	474	405	407	358	49	664	6690	962
6	624	575	247	456	479	404	399	353	46	652	6440	961
7	624	575	287	455	479	404	400	360	45	385	6390	960
8	624	575	273	455	479	404	400	358	45	151	6380	956
9	624	570	259	457	479	405	406	387	45	151	6370	962
10	623	578	257	480	480	404	406	356	42	149	6330	962
11	514	578	260	503	480	404	397	292	51	149	6310	963
12	400	581	256	496	480	404	395	58	45	149	6290	959
13	400	586	257	469	476	407	386	60	186	149	6270	955
14	404	581	257	474	464	419	370	44	519	149	5010	954
15	425	581	259	474	450	426	378	55	215	149	3600	1050
16	413	581	246	479	450	419	378	44	115	148	3570	1370
17	405	583	250	479	450	429	381	44	40	148	3550	1370
18	413	581	247	483	450	426	392	54	61	153	2930	1370
19	411	581	250	483	444	419	392	50	40	152	1880	1360
20	413	580	250	495	441	419	390	40	40	151	1870	1370
21	418	586	250	498	442	412	383	38	89	783	1550	1370
22	428	587	250	502	442	422	383	37	42	2040	982	1360
23	479	591	326	493	441	422	386	55	40	2030	976	1360
24	479	440	444	488	441	422	378	61	40	2030	972	1370
25	481	265	441	487	438	417	374	69	40	2030	972	1360
26	483	264	444	483	422	409	382	67	42	2050	969	1360
27	502	261	450	483	415	410	367	52	293	1350	964	1370
28	495	253	450	483	408	412	362	41	96	1820	962	1490
29	493	257	453	479	---	417	368	42	67	5790	962	1580
30	493	257	455	479	---	418	372	44	209	6940	962	1580
31	498	---	455	482	---	405	---	45	---	6960	967	---
MEAN	486	506	307	476	457	413	388	158	91.5	1281	3816	1186
MAX	630	591	455	503	480	429	408	387	519	6960	6820	1580
MIN	391	253	246	450	408	404	362	37	40	148	962	954
AC-FT	29910	30090	18890	29280	25380	25370	23100	9740	5440	78740	234600	70590

CAL YR 1980 MEAN 1726 MAX 15700 MIN 17 AC-FT 1253000
 WTR YR 1981 MEAN 803 MAX 6960 MIN 37 AC-FT 581200

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 LATITUDE 391414 LONGITUDE 0963416 DRAINAGE AREA 9640.00 DATUM 988.86 STATE 20 COUNTY 161

DISCHARGE, CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1981 TO SEPTEMBER 1982
 DAILY MEAN VALUES

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	1910	1010	316	511	1500	10500	5130	2020	11000	23000	3090	2380
2	1910	321	307	511	2970	10500	5090	2020	13800	15900	2440	2370
3	1920	316	309	511	2960	10500	5000	2020	20800	16300	1860	2360
4	1910	323	304	509	2950	9740	3780	2010	20700	16800	1510	2360
5	1900	317	308	505	2940	5990	134	2000	22500	17000	1170	2360
6	1900	311	311	503	2940	2970	106	2010	25200	17100	1060	2360
7	1800	311	313	498	2940	2950	106	1990	25500	16900	1030	1710
8	1580	331	311	493	2940	2950	1220	2000	25500	17000	1350	1090
9	1580	320	313	493	2200	2930	2920	2000	19900	15000	1670	971
10	1580	340	313	480	1130	2060	2920	2000	12100	12200	1640	849
11	1580	324	468	485	1070	1200	2920	2000	8010	7100	1620	850
12	1580	320	1080	490	837	1200	2920	2040	7930	7100	1600	850
13	1580	317	1080	485	832	1190	2900	2980	7890	7100	1590	848
14	1570	315	1410	485	840	1200	2900	5050	7890	8000	1570	888
15	1570	314	2550	485	846	1190	2880	5120	7890	13000	1560	852
16	1410	311	3230	488	1520	1180	2290	5120	7760	15900	1560	855
17	1060	311	4910	482	2740	1180	1150	5340	7740	15700	1560	869
18	1060	312	4550	482	2980	1180	1140	6050	7760	15500	1560	860
19	1060	311	1110	472	3020	1210	1150	6040	7730	15300	1560	860
20	1060	300	1090	447	3060	1190	1140	6230	7720	15500	1560	855
21	1230	302	3580	408	2890	1180	900	3600	7760	15600	1560	856
22	1360	304	6880	407	3400	2720	607	666	7600	15500	1560	842
23	1360	306	5630	390	7830	5270	601	841	7640	12500	2000	824
24	1360	302	1180	382	10600	5330	601	2150	7820	7890	2400	820
25	1360	302	1160	370	10500	5270	601	5530	7730	7830	2400	819
26	1360	303	1160	355	10500	5220	601	5330	7530	6390	2410	822
27	1360	297	1160	428	10400	5140	599	7810	7560	3280	2410	718
28	1360	300	988	511	10400	5090	611	13100	8920	3230	2410	444
29	1350	303	556	814	---	3540	605	17000	19000	3200	2410	311
30	1360	345	550	1090	---	1300	1230	14100	25700	3150	2400	433
31	1360	---	524	1070	---	5130	---	10900	---	3110	2390	---
MEAN	1495	337	1547	517	3919	3813	1825	4744	12750	11910	1836	1143
MAX	1920	1010	6880	1090	10600	10500	5130	17000	25700	23000	3090	2380
MIN	1060	297	304	355	832	1180	106	666	7530	3110	1030	311
AC-FT	91920	20030	95110	31820	217700	234400	108600	291700	758800	732100	112900	68010
CAL YR 1981	MEAN 980	MAX 6960	MIN 37	AC-FT 709300								
WTR YR 1982	MEAN 3817	MAX 25700	MIN 106	AC-FT 2763000								

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UNITED STATES DEPARTMENT OF THE INTERIOR - GEOLOGICAL SURVEY - KANSAS

STATION NUMBER 06887000 BIG BLUE R NR MANHATTAN, KS STREAM SOURCE AGENCY USGS
 LATITUDE 391414 LONGITUDE 0963416 DRAINAGE AREA 9640.00 DATUM 988.86 STATE 20 COUNTY 161

DISCHARGE, CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1982 TO SEPTEMBER 1983
 DAILY MEAN VALUES

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	368	542	2780	1080	1950	7840	9440	2840	3950	902	972	302
2	245	542	2800	1080	1940	7800	9640	2820	2600	2900	970	301
3	223	534	2840	1080	1920	7760	9520	2810	141	4430	965	301
4	218	536	2840	1080	1910	7710	9370	2810	90	6410	965	301
5	214	534	2830	1080	1920	7690	9360	2820	173	7650	965	300
6	213	539	2820	1080	1910	7630	7410	3180	137	7610	965	300
7	210	538	2820	1070	1900	7570	4750	3860	132	8740	965	299
8	219	539	2800	1080	1900	3870	4490	3860	2480	12900	965	345
9	208	542	2790	1080	1900	3850	4260	3850	5880	15700	965	495
10	207	540	2810	1070	1900	2870	4200	3840	5890	15700	965	496
11	209	543	2770	1080	1900	1760	4130	3890	5870	15600	964	495
12	210	531	2770	1070	1900	1530	4090	3810	5860	15500	892	500
13	209	532	2770	1080	1910	1500	4010	3870	6050	15400	749	494
14	209	534	2450	1520	1930	1470	3960	4250	6170	15700	749	495
15	203	529	1030	1930	1930	1450	3950	4160	6000	16300	746	495
16	189	534	531	1930	2100	1430	3940	4020	5960	16500	746	495
17	189	535	531	1930	3030	1430	3930	3980	5960	16500	531	493
18	189	537	532	1930	4850	1430	3910	4980	6110	16500	308	493
19	188	687	530	1930	4900	1440	3900	6090	6220	16500	305	506
20	184	842	516	1930	4890	1430	4980	6120	6180	12300	313	565
21	187	841	243	1350	4920	1430	5970	4870	6030	4020	309	556
22	189	845	798	753	5870	1430	5960	1960	6060	2120	309	572
23	189	837	803	752	7930	1430	5920	2200	6070	2050	311	567
24	189	833	813	752	7970	1900	5910	6230	6080	2020	309	553
25	350	833	800	752	7960	2330	5890	6110	6030	1990	306	556
26	539	837	799	913	7940	2560	5850	6040	5900	1960	302	554
27	538	839	884	1070	7910	3540	6010	5980	5970	1490	302	553
28	543	843	1070	1070	7870	5090	6140	5960	4020	1020	301	552
29	538	1740	1070	1080	---	6910	4970	5920	577	991	301	552
30	542	2760	1070	1070	---	9150	2840	5920	553	982	301	1730
31	540	---	1080	1480	---	9140	---	5270	---	978	303	---
MEAN	279	747	1677	1231	3816	3953	5623	4333	4305	8367	623	507
MAX	543	2760	2840	1930	7970	9150	9640	6230	6220	16500	972	1730
MIN	184	529	243	752	1900	1430	2840	1960	90	902	301	299
AC-FT	17150	44430	103100	75670	212000	243100	334600	266400	256200	514400	38320	30180
CAL YR 1982	MEAN 3758	MAX 25700	MIN 106	AC-FT 2721000								
WTR YR 1983	MEAN 2950	MAX 16500	MIN 90	AC-FT 2136000								

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STATION NUMBER 06887000 BIG BLUE R NR MANHATTAN, KS STREAM SOURCE AGENCY USGS
 LATITUDE 391414 LONGITUDE 0963416 DRAINAGE AREA 9640.00 DATUM 988.86 STATE 20 COUNTY 161

DISCHARGE, CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1983 TO SEPTEMBER 1984
 DAILY MEAN VALUES

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	4900	781	1990	483	1020	1720	3990	9200	8700	15600	1590	1470
2	4990	781	2010	483	1020	1960	6020	9630	6180	15600	1570	1470
3	5010	781	2010	710	1750	1960	8560	9320	6140	15500	1550	1460
4	3710	781	2000	949	2980	1960	9030	8670	6120	15400	1540	1460
5	1620	781	2000	939	2980	1950	9560	9480	6050	15600	1530	973
6	1020	785	1990	931	4020	1710	9160	11300	6020	17500	1530	480
7	1020	781	1990	931	6620	1480	8530	11300	6680	21300	1530	472
8	1010	781	2540	931	6680	1470	8370	11200	6350	21300	1530	475
9	1010	800	3810	930	6700	1470	8330	11100	7980	22800	1520	470
10	1020	781	3810	924	6700	1470	8230	11000	6920	24500	1310	474
11	1050	781	3780	924	6720	1480	8190	12000	6470	24300	844	472
12	1010	781	3780	926	6690	1680	8120	13500	6440	23900	521	468
13	1800	781	3760	920	6720	1950	8110	13500	4570	24600	514	473
14	2890	855	3730	924	6800	1950	8080	13400	1890	24800	510	410
15	2900	1020	3700	948	6810	1930	8040	14800	1840	24800	509	50
16	2890	1510	3690	1000	6750	1930	7980	16200	1760	24800	509	27
17	2890	1990	3680	1000	6760	1940	8650	16300	1680	24600	504	27
18	2880	1990	3710	1000	6800	1980	10700	16500	1600	24700	505	27
19	2940	1990	3820	1000	6770	2040	12800	16400	1350	22800	501	27
20	2880	1990	3360	1000	6810	2270	13000	16500	1450	19300	499	27
21	2180	1500	2050	1000	5690	2400	10100	16800	1460	15600	506	27
22	1550	1030	1320	1010	3020	3200	10100	16900	1480	12600	496	27
23	1550	1020	517	1010	2990	3140	10200	16900	2350	9110	491	27
24	1190	1020	511	754	2260	4710	11400	17000	2900	6830	687	27
25	789	1020	497	504	1510	4900	14000	16900	4000	3410	1220	36
26	784	1040	490	501	1500	5060	14000	16800	7130	2690	1360	71
27	782	1080	489	494	1480	4750	15100	16900	12300	1930	1480	77
28	784	1040	489	493	1470	4420	18800	16700	15800	1820	1480	74
29	792	1540	486	488	1480	4610	18900	16600	15800	1740	1470	73
30	791	1990	488	478	---	4330	15200	16400	15700	1680	1470	75
31	781	---	483	748	---	4040	---	13900	---	1630	1470	---
MEAN	1981	1127	2225	817	4466	2641	10370	13970	5844	15510	1056	391
MAX	5010	1990	3820	1010	6810	5060	18900	17000	15800	24800	1590	1470
MIN	781	781	483	478	1020	1470	3990	8670	1450	1630	491	27
AC-FT	121800	67040	136800	50250	256900	162400	617400	859100	347700	953500	64950	23260
CAL YR 1983	MEAN 3172	MAX 16500	MIN 90	AC-FT 2297000								
WTR YR 1984	MEAN 5043	MAX 24800	MIN 27	AC-FT 3661000								

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STATION NUMBER 06887000 BIG BLUE R NR MANHATTAN, KS STREAM SOURCE AGENCY USGS
 LATITUDE 391414 LONGITUDE 0963416 DRAINAGE AREA 9640.00 DATUM 988.86 STATE 20 COUNTY 161

DISCHARGE, CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1984 TO SEPTEMBER 1985
 DAILY MEAN VALUES

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	75	493	453	3320	460	4820	918	2610	2290	2430	2620	3420
2	66	489	450	3310	458	4790	861	2540	2800	1710	1150	3420
3	131	489	451	3300	458	4780	712	2600	2760	1030	375	3400
4	81	490	624	2140	462	2710	721	2510	2760	1030	41	3380
5	82	611	666	771	455	31	704	2460	2760	1030	2140	3380
6	81	740	596	772	579	1160	704	2440	2760	1030	21000	2380
7	80	747	509	768	730	3300	792	2450	2360	792	22600	1280
8	79	747	486	900	737	3310	702	2500	1610	536	23700	1230
9	78	686	489	1050	741	3300	690	2520	1280	531	23700	774
10	78	498	492	1030	736	3300	710	2480	1180	526	22000	362
11	78	489	482	1030	726	2930	711	2420	1080	525	14100	348
12	78	491	459	1030	731	1600	721	2390	1070	520	5640	353
13	79	494	219	1020	729	960	714	2390	1120	514	422	1700
14	82	494	733	1020	730	949	704	1010	1160	515	120	4510
15	90	476	2420	1020	728	946	821	1840	1100	509	59	4590
16	92	473	2440	1020	727	947	985	3410	1070	504	40	4690
17	69	476	2610	1020	717	944	980	4640	1560	504	31	4690
18	44	478	3000	1020	718	944	982	6440	2480	506	24	4690
19	37	617	3080	1030	723	946	985	6540	2480	509	55	4680
20	35	767	3420	1030	728	941	981	6450	2480	504	35	4630
21	34	772	3400	1010	724	939	983	6290	2480	510	30	4590
22	33	625	3390	755	1140	939	983	6210	2490	503	213	4690
23	33	469	3380	486	2360	939	979	6170	2470	504	5610	4670
24	33	470	3350	481	2710	935	945	5690	2460	510	5920	3080
25	38	473	3340	476	3320	933	946	4810	2460	2860	5900	1280
26	35	472	3340	470	5080	936	956	4770	2460	7540	5160	1240
27	35	466	3330	473	4910	937	1290	4780	2440	7550	3800	1250
28	34	465	3380	469	4860	935	1060	4740	2440	7520	3630	1260
29	33	462	3400	470	---	930	1670	4800	2440	7470	3520	1190
30	35	451	3370	475	---	928	2510	3550	2440	7490	3470	1870
31	118	---	3360	463	---	925	---	1870	---	6210	3460	---
MEAN	63.7	546	1972	1085	1363	1738	944	3729	2091	2078	5825	2768
MAX	131	772	3420	3320	5080	4820	2510	6540	2800	7550	23700	4690
MIN	33	451	219	463	455	31	678	1010	1070	503	24	348
AC-FT	3920	32470	121200	66700	75720	106900	56140	229300	124400	127800	358200	164700
CAL YR 1984	MEAN 4812	MAX 24800	MIN 27	AC-FT 3493000								
WTR YR 1985	MEAN 2027	MAX 23700	MIN 24	AC-FT 1467000								

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 LATITUDE 391414 LONGITUDE 0963416 DRAINAGE AREA 9640.00 DATUM 988.86 STATE 20 COUNTY 161

DISCHARGE, CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1985 TO SEPTEMBER 1986
 DAILY MEAN VALUES

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	3280	1990	1830	1490	1440	1470	1010	1030	2960	2610	1500	1430
2	3900	1960	2400	1490	1440	1500	1000	1030	2380	5180	1470	1400
3	3920	2020	3110	1490	1860	1500	1010	3050	2340	7950	1450	1380
4	3880	1570	3050	1480	2450	1500	1010	4820	2310	14300	1450	1380
5	3790	1020	3000	1480	2450	1500	1020	5680	2280	18300	1450	1380
6	2640	1220	2990	1490	2360	1500	1020	6940	2250	23300	1440	1390
7	1330	1710	2970	1480	2870	1280	1440	7040	1450	23300	1480	1380
8	1030	1510	2950	1470	3360	1010	2370	7050	107	23300	1450	1380
9	1970	996	2960	1480	3350	1010	2380	7350	85	22700	1470	1730
10	3230	940	2460	1480	3340	1010	2390	7330	1140	22500	1460	2350
11	3700	923	1020	1480	3320	990	2400	7190	2870	22500	1840	3290
12	5640	1220	1030	1470	3310	1020	2400	7120	3520	22900	4270	3060
13	8050	1790	1030	1470	3300	1280	2410	7070	4890	22600	9760	3110
14	8050	1980	1000	1470	2860	1520	2380	7040	4880	22500	13000	3050
15	8140	2000	995	1470	1910	1530	2370	7010	4880	22400	18200	3020
16	8190	2030	995	1470	1700	1500	2390	6020	2940	22400	18200	3010
17	8280	2030	994	1460	1530	1460	2210	3860	341	22700	14800	3000
18	8410	1790	990	1460	1240	1960	2010	3510	139	23000	7680	3010
19	8350	1320	987	1460	989	2400	1990	3280	596	22700	3990	2980
20	8220	1210	983	1460	983	2400	1990	3280	949	22800	3960	2960
21	8190	1200	984	1450	974	2800	1990	4520	953	18700	5130	2950
22	8320	1200	990	1440	979	3340	1990	10300	945	10200	6320	2940
23	8390	1200	991	1450	989	3340	1500	18100	1140	4080	6380	2940
24	8190	1200	981	1450	986	3330	1030	17900	1430	1600	6280	2940
25	8190	1130	979	1450	1240	2360	1020	18100	1430	1500	6230	2500
26	8320	1150	976	1440	1520	1020	1010	18000	1430	1380	6200	1220
27	8280	1510	976	1430	1500	1020	1020	18300	1430	1270	6150	923
28	8120	1520	976	1440	1490	1020	1010	18500	1420	1200	4600	926
29	7180	1650	975	1440	---	1020	1010	15400	1420	1150	2450	1700
30	4510	1830	1240	1440	---	1020	1030	10200	1990	1290	1520	1230
31	2010	---	1490	1440	---	1020	---	5460	---	1540	1460	---
MEAN	5926	1494	1590	1464	1991	1633	1660	8435	1896	14000	5259	2219
MAX	8410	2030	3110	1490	3360	3340	2410	18500	4890	23300	18200	3290
MIN	1030	923	975	1430	974	990	1000	1030	85	1150	1440	923
AC-FT	364400	88900	97790	89990	110600	100400	98800	518600	112900	860500	323400	132000
CAL YR 1985	MEAN 2570	MAX 23700	MIN 24	AC-FT 1861000								
WTR YR 1986	MEAN 4003	MAX 23300	MIN 85	AC-FT 2898000								

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 LATITUDE 391414 LONGITUDE 0963416 DRAINAGE AREA 9640.00 DATUM 988.86 STATE 20 COUNTY 161

DISCHARGE, CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1986 TO SEPTEMBER 1987
 DAILY MEAN VALUES

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	ADG	SEP
1	2030	5430	1440	1750	1360	1080	11500	25300	7580	4610	1880	4890
2	4690	1910	1440	1750	1350	1470	12100	24700	13100	5730	1880	4910
3	4820	1490	1440	1750	1340	2560	11500	24700	17200	5790	1870	4890
4	4940	1990	1440	1740	1340	2560	11500	24800	19400	5820	1860	4280
5	4540	2340	1980	1610	1340	2540	11700	24600	22600	5810	1850	2430
6	4380	2490	2590	1380	1340	2520	11700	20000	22600	5910	1840	2420
7	4340	2720	2630	1370	1340	2510	13600	4990	17900	5810	1580	1860
8	4890	2700	2630	780	1340	2490	16300	2230	8910	5770	1260	531
9	7340	2670	3170	164	1340	1960	17800	3370	2750	5730	1240	521
10	9940	3040	5120	154	1340	964	21300	13600	1030	4080	1230	1570
11	10100	3450	5490	151	1340	955	19900	23000	140	2300	1230	2880
12	10200	3440	5480	152	1340	959	5900	22800	373	2430	1240	2890
13	10400	3420	5450	153	1340	964	2220	22600	2160	2250	1250	2870
14	10400	3420	5430	152	1340	974	14800	22800	4430	2190	1240	2880
15	12100	3410	5400	325	1350	965	19900	22800	2180	2110	1230	2890
16	17000	3410	5370	1190	1330	1240	14100	22500	3790	2020	1230	2920
17	20000	2330	5340	1750	1330	1740	23100	22200	5660	1790	1220	3840
18	20000	204	4790	1740	1330	2610	21100	22700	5680	1370	1230	4760
19	19900	19	2460	1740	1330	3030	19900	23000	5680	1330	1740	4740
20	19900	99	1400	1740	1150	3510	7090	20900	5710	1310	2610	4720
21	20000	1450	1400	1740	954	4820	11000	17000	5740	1290	2610	4690
22	20000	1450	1590	1740	956	4610	18500	12700	5780	1280	2610	4670
23	20000	1450	1770	1740	959	4640	18700	7610	5940	1590	2330	4220
24	20200	1440	1760	1730	960	5500	11400	4610	6010	1960	1770	3810
25	20200	1440	1760	1730	956	6580	4200	4770	5910	1930	1780	3370
26	19900	1440	1760	1730	955	6970	13900	4630	5160	1930	1810	2870
27	20000	1440	1760	1550	954	6840	24500	4360	3600	1920	1780	2870
28	20200	1440	1750	1370	1030	6990	24300	5300	3640	1910	2080	2860
29	20300	1440	1750	1370	---	7190	24100	4930	3590	1910	2920	2840
30	18600	1450	1750	1360	---	8090	24400	5410	3590	1900	3670	2830
31	13300	---	1750	1350	---	11000	---	6480	---	1890	4030	---
MEAN	13370	2147	2880	1256	1226	3575	15400	15210	7261	3022	1874	3291
MAX	20300	5430	5490	1750	1360	11000	24500	25300	22600	5910	4030	4910
MIN	2030	19	1400	151	954	955	2220	2230	140	1280	1220	521
AC-FT	822400	127800	177100	77260	68100	219800	916400	935000	432100	185800	115200	195800
CAL YR 1986	MEAN 4799	MAX 23300	MIN 19	AC-FT 3474000								
WTR YR 1987	MEAN 5902	MAX 25300	MIN 19	AC-FT 4273000								

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DISCHARGE, CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1987 TO SEPTEMBER 1988
 DAILY MEAN VALUES

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	2820	22	1420	966	921	949	232	226	729	935	1830	3.5
2	1930	18	2270	965	913	952	223	222	727	938	1830	3.5
3	923	17	2280	971	919	946	210	224	729	942	1830	3.3
4	925	16	2770	776	914	942	207	217	728	946	1820	3.4
5	926	15	3260	519	911	942	204	216	726	949	1810	3.3
6	924	14	3250	341	909	942	196	217	726	950	1810	3.3
7	922	15	3250	115	910	946	195	216	728	950	1800	3.1
8	923	15	3240	108	912	943	191	216	732	949	1800	2.9
9	924	15	3220	107	913	943	195	213	730	965	1800	2.8
10	917	14	3220	107	920	946	182	213	726	952	1790	2.6
11	913	14	3210	108	910	942	178	213	727	951	1810	2.5
12	514	14	3190	108	909	939	175	290	728	951	1260	2.6
13	420	14	3180	108	916	931	172	424	729	951	471	2.4
14	993	15	3230	374	924	930	168	414	732	534	161	2.3
15	679	15	3270	767	608	932	168	413	730	1240	35	2.9
16	286	14	3250	765	161	935	200	408	952	1890	8.2	2.8
17	107	14	3240	765	1420	937	206	409	1170	1890	8.0	2.6
18	66	14	2430	765	2320	661	186	409	1170	1890	7.4	2.6
19	54	12	1430	974	2320	257	149	407	1170	1880	7.9	4.6
20	47	8.0	1420	1410	2340	243	147	403	1160	1870	8.1	2.8
21	40	7.9	1420	1790	2360	526	145	413	1160	1870	6.6	3.4
22	37	8.5	1420	2330	2350	390	141	401	1160	1870	6.6	7.2
23	34	9.4	1430	2340	2340	46	135	403	1160	1870	6.3	41
24	32	243	1240	2340	2330	62	133	395	1150	1860	5.8	160
25	32	140	976	1920	2330	235	448	395	1150	1860	5.3	162
26	33	136	979	1400	2320	240	256	392	1150	1850	4.7	160
27	31	142	979	1410	2310	232	244	393	1140	1850	4.5	159
28	29	141	973	1220	2300	237	241	346	1140	1850	4.0	176
29	29	138	972	949	1940	225	237	434	1080	1850	3.8	186
30	29	436	974	934	---	220	232	445	968	1840	3.6	186
31	21	---	970	928	---	221	---	540	---	1840	3.5	---
MEAN	534	56.6	2205	925	1467	638	200	340	927	1417	708	43.3
MAX	2820	436	3270	2340	2360	952	448	540	1170	1890	1830	186
MIN	21	7.9	970	107	161	46	133	213	726	534	3.5	2.3
AC-FT	32850	3370	135600	56890	84400	39260	11890	20880	55160	87140	43540	2580
CAL YR 1987	MEAN 4582	MAX 25300	MIN 7.9	AC-FT 3317000								
WTR YR 1988	MEAN 790	MAX 3270	MIN 2.3	AC-FT 573500								

10/02/92

UNITED STATES DEPARTMENT OF THE INTERIOR - GEOLOGICAL SURVEY - KANSAS

STATION NUMBER 06887000 BIG BLUE R NR MANHATTAN, KS STREAM SOURCE AGENCY USGS
 LATITUDE 391414 LONGITUDE 0963416 DRAINAGE AREA 9640.00 DATUM 988.86 STATE 20 COUNTY 161

DISCHARGE, CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1988 TO SEPTEMBER 1989
 DAILY MEAN VALUES

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	191	1300	481	487	475	447	482	496	399	550	761	240
2	198	1500	483	481	474	447	490	497	388	527	759	944
3	206	1490	487	481	491	448	490	491	178	912	757	951
4	543	1490	483	482	497	450	485	495	413	1590	756	990
5	980	1480	485	488	522	446	484	486	419	1610	759	3550
6	1010	1480	486	484	471	443	488	481	426	1690	1000	9540
7	1030	1480	489	482	467	442	490	481	447	1750	1250	12700
8	1030	1270	483	476	461	447	491	490	451	1680	1250	16500
9	1030	484	483	474	456	442	491	473	447	1620	1250	17000
10	1030	476	487	477	452	442	491	466	464	1600	1250	16500
11	1020	477	485	479	450	443	492	465	453	1580	1250	17900
12	1080	475	485	474	447	447	496	460	451	1590	1240	21500
13	1150	476	486	472	447	443	497	457	448	1820	1240	21300
14	1150	478	492	475	447	442	504	457	282	2100	1430	21300
15	1150	492	487	473	447	437	501	454	110	2090	2090	21300
16	1150	471	482	471	445	439	503	452	81	2090	2090	18000
17	736	473	486	473	447	446	510	454	79	2090	2080	12900
18	1120	478	487	475	448	439	512	456	81	2340	2080	9820
19	1130	476	492	474	452	440	511	449	152	3460	2130	6300
20	1130	472	491	472	452	446	511	444	324	4980	2090	3740
21	1130	473	489	472	455	438	511	453	429	4640	2010	1780
22	1130	475	489	473	455	438	512	447	436	3410	1820	1090
23	1130	476	492	475	452	440	517	447	428	3430	1710	1050
24	1130	479	490	474	452	444	517	447	428	3390	1480	1030
25	1130	480	493	476	452	447	517	319	429	2180	1370	1030
26	1120	481	495	470	453	447	514	165	439	951	1360	1030
27	1120	478	488	471	449	449	507	160	439	946	1370	1020
28	1120	476	487	482	447	469	507	162	438	946	1210	1290
29	1120	482	485	473	---	---	493	226	440	949	652	1570
30	1120	479	488	472	---	709	498	345	448	883	82	1560
31	1110	---	486	476	---	485	---	401	---	899	65	---
MEAN	981	733	487	476	459	456	500	419	362	1945	1311	8181
MAX	1150	1500	495	488	522	709	517	497	464	4980	2130	21500
MIN	191	471	481	470	445	437	482	160	79	527	65	240
AC-FT	60350	43630	29950	29280	25510	28040	29780	25740	21520	119600	80610	486800
CAL YR 1988	MEAN 738	MAX 2360	MIN 2.3	AC-FT 535700								
WTR YR 1989	MEAN 1355	MAX 21500	MIN 65	AC-FT 980800								

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UNITED STATES DEPARTMENT OF THE INTERIOR - GEOLOGICAL SURVEY - KANSAS

STATION NUMBER 06887000 BIG BLUE R NR MANHATTAN, KS STREAM SOURCE AGENCY USGS
 LATITUDE 391414 LONGITUDE 0963416 DRAINAGE AREA 9640.00 DATUM 988.86 STATE 20 COUNTY 161

DISCHARGE, CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1989 TO SEPTEMBER 1990
 DAILY MEAN VALUES

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	1510	595	563	494	665	463	961	188	3240	11500	6700	687
2	1510	574	568	494	659	463	958	188	2970	11500	6740	687
3	1500	567	563	503	656	463	959	189	1080	10600	6900	685
4	1490	568	563	503	656	462	967	191	1450	9520	6670	687
5	1500	567	563	499	657	465	969	181	942	7500	6570	682
6	1700	575	572	499	662	482	720	181	855	3480	6530	679
7	1920	570	568	499	661	502	513	178	719	1470	6530	681
8	1920	574	563	499	662	477	522	391	1080	1370	6530	681
9	1920	575	563	504	595	470	531	199	1430	1320	5790	681
10	1920	574	568	504	459	468	540	177	1450	1300	3800	680
11	1920	575	562	501	459	467	380	176	1550	1280	3810	708
12	1920	580	375	497	457	653	230	221	1890	1270	2480	745
13	1910	580	85	494	464	966	228	187	1890	1260	670	743
14	1910	473	81	499	462	980	223	208	1890	1250	3770	739
15	1910	528	79	499	461	958	220	238	3340	1240	3820	733
16	1900	1420	78	500	457	948	218	223	9570	1240	5270	738
17	2120	1420	78	497	454	944	211	721	6980	1230	4790	739
18	2960	1420	79	494	459	946	210	3290	1750	1100	5080	742
19	2950	1420	79	496	459	944	208	3380	4680	961	4280	735
20	2940	1430	78	494	459	942	207	3430	6790	961	4050	720
21	2920	1420	78	488	460	944	207	3430	16700	960	3940	599
22	2920	1160	827	488	471	949	205	3400	18200	958	3870	593
23	2910	571	1480	492	460	953	200	3350	18500	957	2810	585
24	2900	568	1060	495	462	946	198	3310	18800	957	1410	587
25	2910	568	1050	485	459	944	204	3290	18700	960	1380	591
26	1960	568	936	488	459	946	197	3290	18900	1000	1370	591
27	620	570	720	489	461	950	195	3280	19000	979	1370	592
28	912	559	513	483	463	961	189	3280	18900	2260	1160	727
29	604	559	501	534	---	960	191	3270	17700	4860	695	1130
30	589	563	499	662	---	957	185	3280	13500	4870	689	1350
31	587	---	497	661	---	957	---	3250	---	5600	687	---
MEAN	1908	756	496	508	522	772	398	1631	7842	3088	3876	717
MAX	2960	1430	1480	662	665	980	969	3430	19000	11500	6900	1350
MIN	587	473	78	488	454	462	185	176	719	957	670	585
AC-FT	117300	45010	30520	31210	28990	47470	23690	100300	466600	189800	238300	42680
CAL YR 1989	MEAN 1436	MAX 21500	MIN 65	AC-FT 1040000								
WTR YR 1990	MEAN 1881	MAX 19000	MIN 78	AC-FT 1362000								

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UNITED STATES DEPARTMENT OF THE INTERIOR - GEOLOGICAL SURVEY - KANSAS

STATION NUMBER 06887000 BIG BLUE R NR MANHATTAN, KS STREAM SOURCE AGENCY USGS
 LATITUDE 391414 LONGITUDE 0963416 DRAINAGE AREA 9640.00 DATUM 988.86 STATE 20 COUNTY 161

DISCHARGE, CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1990 TO SEPTEMBER 1991
 DAILY MEAN VALUES

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	1540	478	341	342	468	468	411	455	2880	733	1110	216
2	1550	480	341	336	473	450	419	456	2990	437	1540	187
3	1550	490	336	336	468	448	426	461	5040	424	2180	154
4	1390	483	336	336	465	450	418	457	7530	424	2190	97
5	988	473	340	336	463	453	417	447	7620	424	2180	93
6	992	430	340	336	463	451	417	444	7720	424	2090	93
7	983	339	340	336	463	448	416	446	7620	426	1990	101
8	989	342	340	336	463	450	417	448	7510	424	1790	99
9	1090	341	340	336	463	450	410	448	7450	424	1200	95
10	407	342	340	339	463	449	411	448	7420	427	919	95
11	139	344	311	337	464	454	414	450	7390	439	918	94
12	82	344	273	336	470	453	401	448	6110	424	915	93
13	61	344	245	336	468	442	548	445	3250	424	915	87
14	52	340	205	400	460	443	460	444	1630	620	914	104
15	44	341	204	469	459	443	458	448	957	1310	914	154
16	39	341	203	475	459	446	463	434	937	2420	915	162
17	36	337	232	473	465	458	468	1220	1300	2430	913	174
18	33	340	311	473	467	444	463	2800	2010	1700	911	219
19	296	340	318	473	462	446	461	2800	2010	669	909	283
20	60	341	316	472	463	443	460	2800	2010	434	878	283
21	35	343	314	464	466	446	463	2810	2020	436	814	283
22	1310	340	310	466	460	440	460	2810	2020	433	815	282
23	2480	340	307	468	458	435	461	2810	2000	430	816	280
24	2480	340	305	468	456	434	459	2530	2000	431	810	279
25	1600	340	305	472	456	434	463	1990	2000	429	812	277
26	480	343	301	463	456	425	464	1990	1710	425	810	277
27	478	343	317	463	455	412	459	2090	1210	558	808	276
28	478	336	346	464	459	411	462	2040	880	725	806	276
29	476	336	344	469	---	444	458	2240	881	831	806	274
30	478	337	543	463	---	430	455	2920	883	1110	812	274
31	478	---	376	464	---	412	---	2850	---	1110	621	---
MEAN	745	367	315	411	463	442	459	1415	3566	721	1130	189
MAX	2480	490	543	475	473	468	801	2920	7720	2430	2190	283
MIN	33	336	203	336	455	411	410	434	880	424	621	87
AC-FT	45810	21830	19400	25260	25710	27200	27290	87030	212200	44350	69460	11230

CAL YR 1990 MEAN 1735 MAX 19000 MIN 33 AC-FT 1256000

WTR YR 1991 MEAN 852 MAX 7720 MIN 33 AC-FT 616800

APPENDIX IV

-Statview Statistical Software Results-

Macintosh Based

X1: Pre- (1927-59)

Mean:	Std. Dev.:	Std. Error:	Variance:	Coef. Var.:	Count:
1888.16	2964.08	150.67	8785761.59	156.98	387
Minimum:	Maximum:	Range:	Sum:	Sum of Sqr.:	# Missing:
85	27820	27735	730718	4771016622	0
t 95%:	95% Lower:	95% Upper:	t 90%:	90% Lower:	90% Upper:
296.27	1591.89	2184.43	248.45	1639.71	2136.61
# < 10th %:	10th %:	25th %:	50th %:	75th %:	90th %:
38	280	435	815	1927.5	5182.2
# > 90th %:	Mode:	Kurtosis:	Skewness:		
39	260	23.07	4.1		

X2: Post- (1959-91)

Mean:	Std. Dev.:	Std. Error:	Variance:	Coef. Var.:	Count:
2294.9	2993.54	152.17	8961260.55	130.44	387
Minimum:	Maximum:	Range:	Sum:	Sum of Sqr.:	# Missing:
21	20110	20089	888125	5497201651	0
t 95%:	95% Lower:	95% Upper:	t 90%:	90% Lower:	90% Upper:
299.22	1995.68	2594.11	250.92	2043.97	2545.82
# < 10th %:	10th %:	25th %:	50th %:	75th %:	90th %:
39	316.4	505.5	1216	2891.25	5584
# > 90th %:	Mode:	Kurtosis:	Skewness:		
39	•	8	2.64		

X1: Pre- (1927-59)

Bar:	From: (≥)	To: (<)	Count:	Percent:	- Mode
1	0	2000	295	76.23%	
2	2000	4000	48	12.4%	
3	4000	6000	14	3.62%	
4	6000	8000	14	3.62%	
5	8000	10000	7	1.81%	
6	10000	12000	3	.78%	
7	12000	14000	1	.26%	
8	14000	16000	1	.26%	
9	16000	18000	2	.52%	
10	18000	20000	0	0%	

X2: Post- (1959-91)

Bar:	From: (≥)	To: (<)	Count:	Percent:	- Mode
1	0	2000	261	67.44%	
2	2000	4000	63	16.28%	
3	4000	6000	32	8.27%	
4	6000	8000	8	2.07%	
5	8000	10000	6	1.55%	
6	10000	12000	6	1.55%	
7	12000	14000	6	1.55%	
8	14000	16000	4	1.03%	
9	16000	18000	0	0%	
10	18000	20000	0	0%	

Wilcoxon signed-rank X 1: Pre- (1927-59) Y 1: Post- (1959-91)

	Number:	Σ Rank:	Mean Rank:
- Ranks	219	44908	205.06
+ Ranks	168	30170	179.58

Z	-3.35	p = .0008
Z corrected for ties	-3.35	p = .0008
# tied groups	14	

One Factor ANOVA-Repeated Measures for X₁ ... X₂

Source:	df:	Sum of Squares:	Mean Square:	F-test:	P value:
Between subjects	386	4230406743.37	10959602.96	1.6	.0001
Within subjects	387	2651955381.5	6852597.89		
treatments	1	32011580.94	32011580.94	4.72	.0305
residual	386	2619943800.56	6787419.17		
Total	773	6882362124.87			

Reliability Estimates for- All treatments: .37 Single Treatment: .23

One Factor ANOVA-Repeated Measures for X₁ ... X₂

Group:	Count:	Mean:	Std. Dev.:	Std. Error:
Pre- (1927-59)	387	1888.16	2964.08	150.67
Post- (1959-91)	387	2294.9	2993.54	152.17

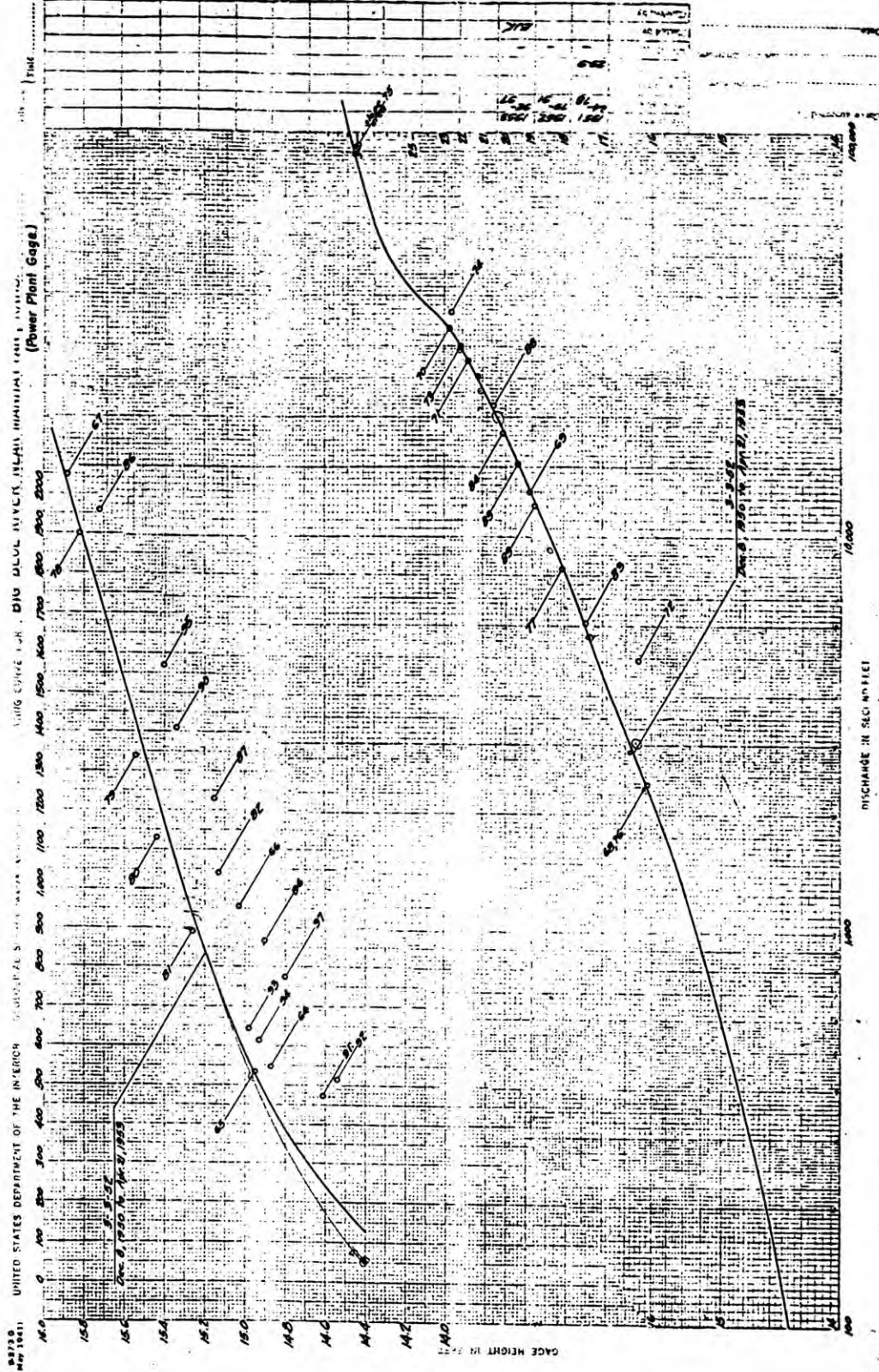
One Factor ANOVA-Repeated Measures for X₁ ... X₂

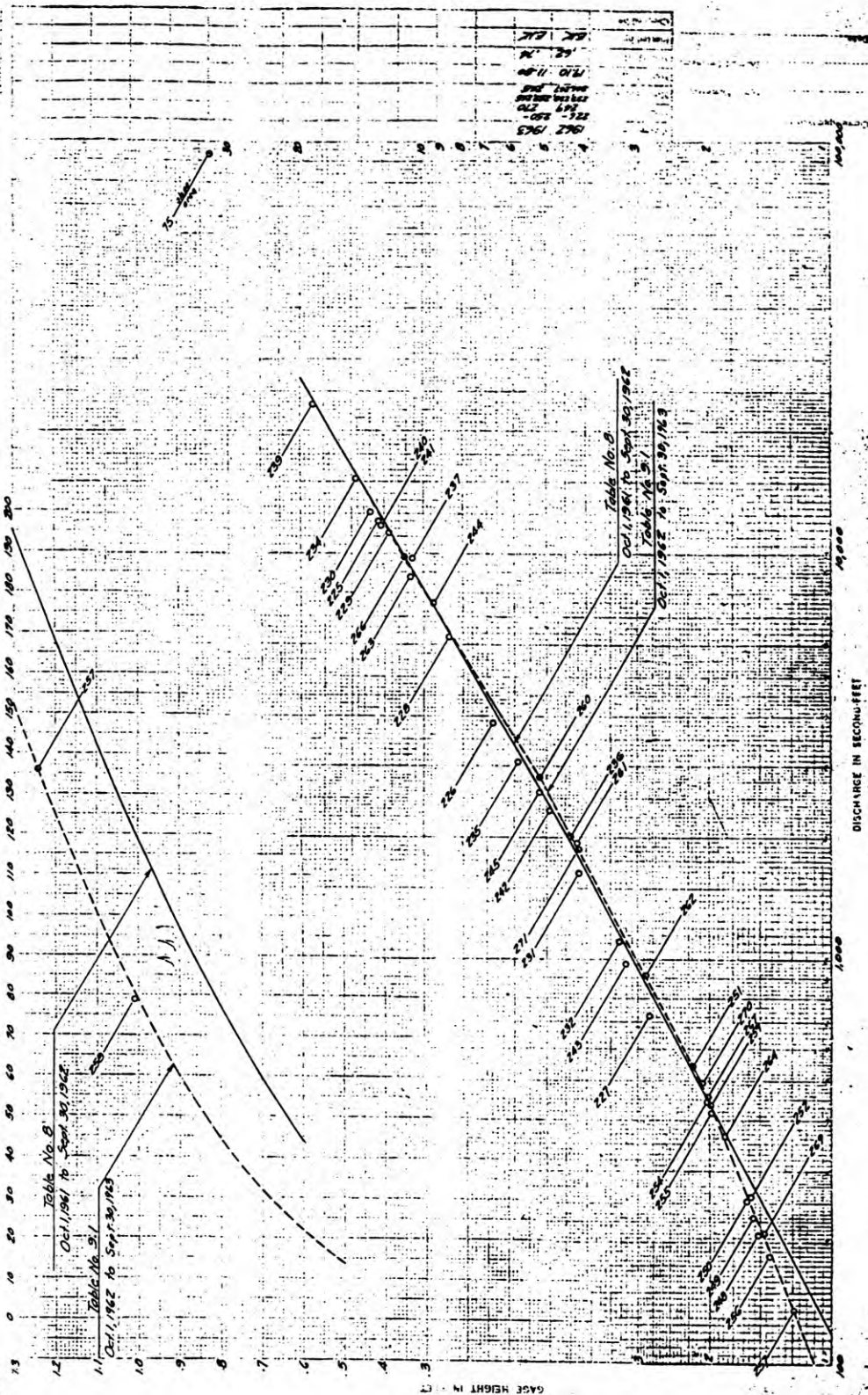
Comparison:	Mean Diff.:	Fisher PLSD:	Scheffe F-test:	Dunnett t:
Pre- (1927... vs. Post- (...)	-406.74	308.83*	4.72*	2.17

* Significant at 90%

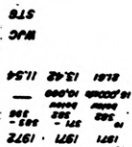
APPENDIX V

-USGS Channel Rating Curves-



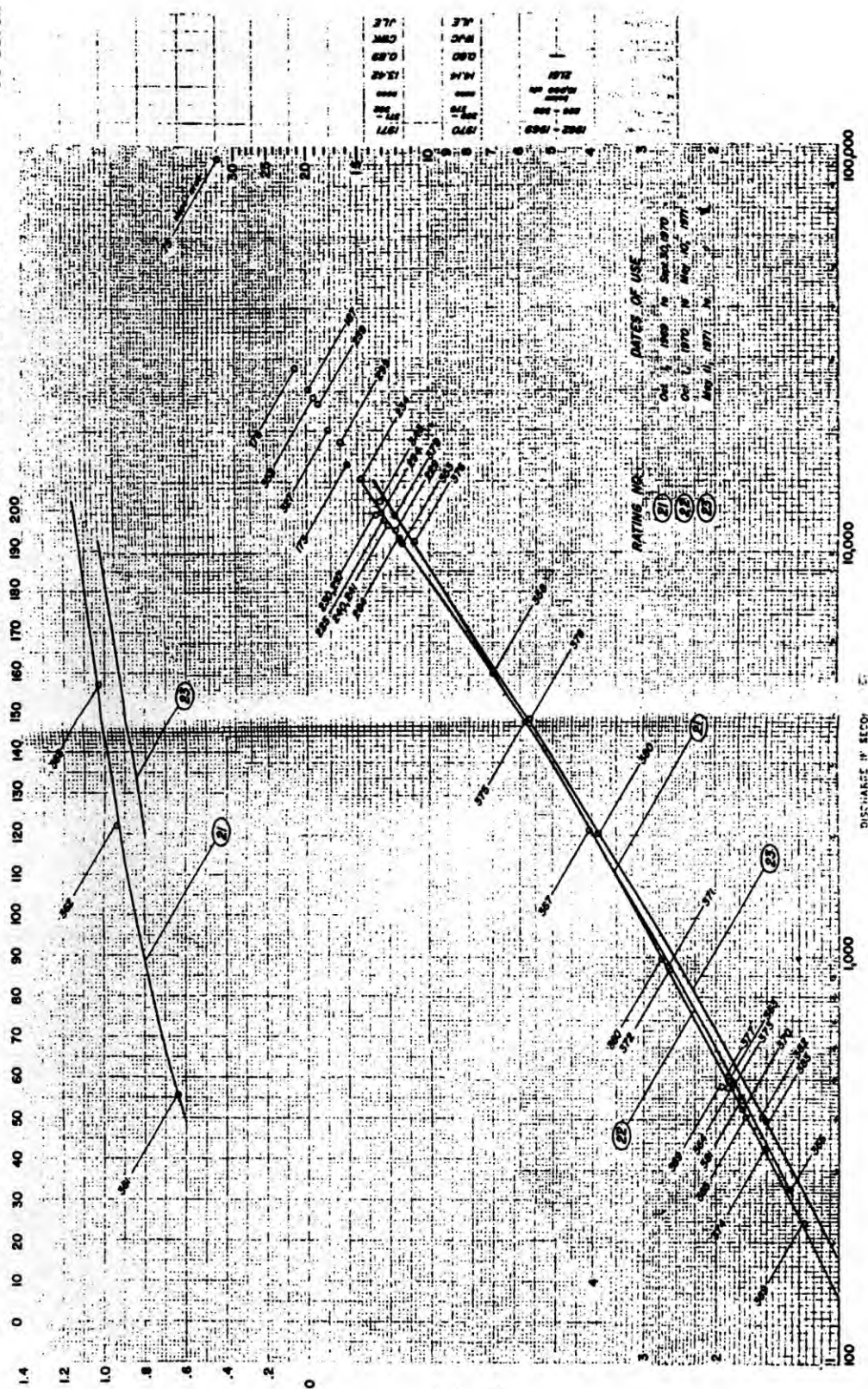


0188-9

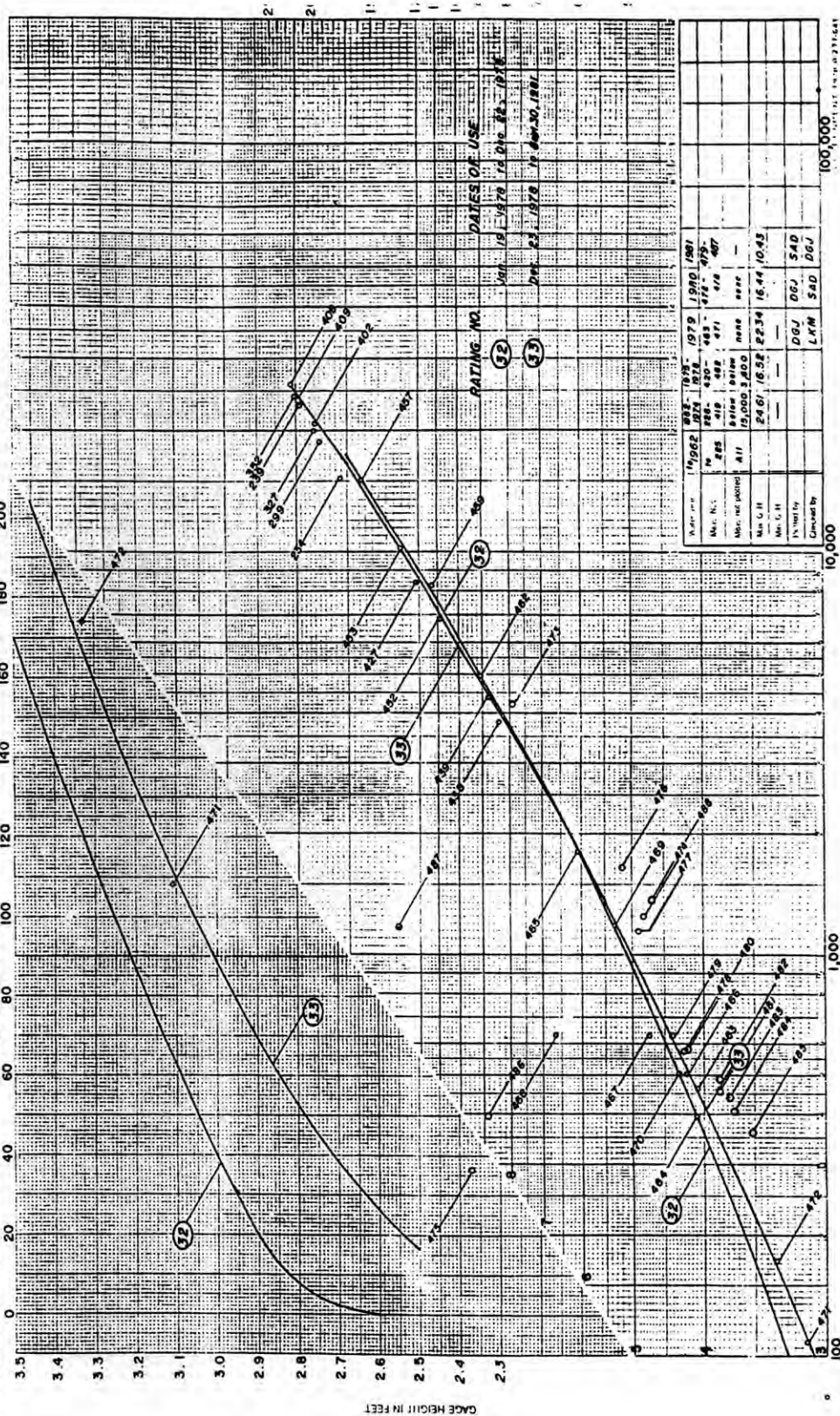


BIG BLUE RIVER NEAR MANHATTAN, KANSAS

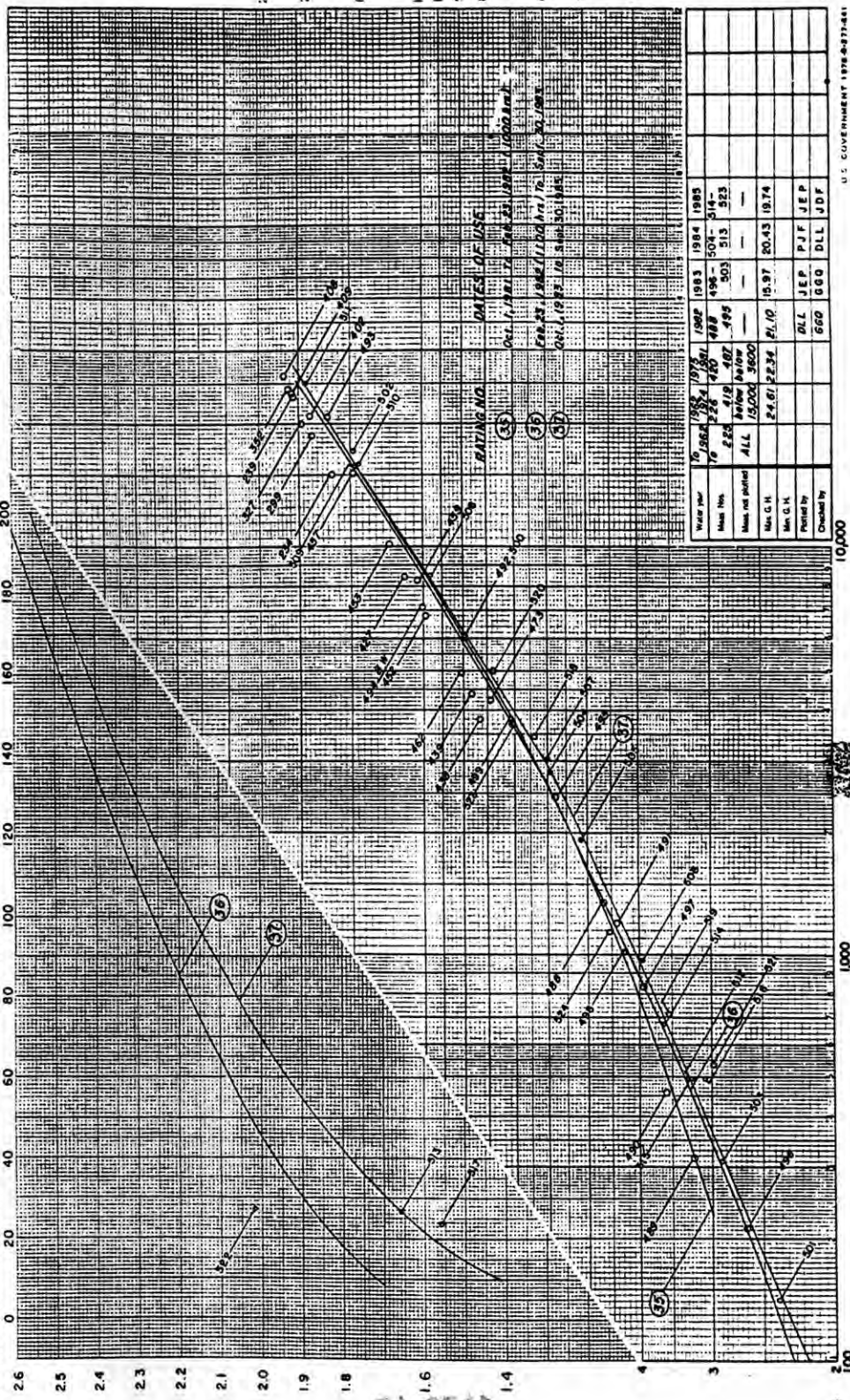
06-8870.C



UNITED STATES DEPARTMENT OF THE INTERIOR GEOLOGICAL SURVEY RATING CURVE FOR BIG BLUE RIVER NR. MANHATTAN, KS. STA NO 06887000



DISCHARGE IN CFS: FEET PER SECOND



U.S. GOVERNMENT PRINTING OFFICE: 1978-20-71-461

DISCHARGE IN CUBIC FEET PER SECOND

STAGE HEIGHT IN FEET

UNITED STATES GEOLOGICAL SURVEY WATER RESOURCES DIVISION RATING CURVE FOR BIG BLUE RIVER, McMANHATTAN, KANSAS STA NO. 06887000

