AN ABSTRACT OF THE THESIS OF

Ruben D. Byerley for the Master of Science Degree in Physical Sciences with an Earth Science Emphasis presented on April 20, 1995.

Title: Chert Gravel Sources, Hydrology, Transportation, and Deposition Within the Lower Neosho River, Southeastern Kansas.

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This study involves the creation and analysis of a geographical information system (GIS) database depicting six counties of southeastern Kansas, the analysis of stream-gage records, and field observations to determine potential chert gravel sources and the hydrology involved in transporting these gravels into the lower Neosho River to replenish gravel bars. The GIS, IDRISI, was used to create several maps depicting upland chert gravel sources, low-terraces, and floodplain alluvium in the vicinity of and surrounding the lower Neosho River and its main tributaries. Stream-gage records taken at the Iola gaging station, water budget years 1917 - 1992, were analyzed to determine the peak annual discharge for each year and the mean annual flood for the lower Neosho River before and after John Redmond Reservoir. The areal coverages of local upland chert gravels, low-terrace sediment, and floodplain alluvium were determined using IDRISI. Field observations were noted on the typical channel and gravel bar features of the lower Neosho River.

The flooding behavior of the lower Neosho River has changed significantly since the impoundment of John Redmond Reservoir. The lower Neosho River had a mean annual flood close to bank-full flow before the reservoir, and after the reservoir the mean

annual flood was reduced to well below bank-full flow. This means the lower Neosho River has stabilized since the impoundment of the reservoir and no longer floods on a regular basis.

Chert gravels, derived from upstream sources in the Flint Hills region, formerly replenished the gravel bars and riffles on the lower Neosho River due to frequent flooding events. Now, John Redmond Reservoir acts as an absolute barrier to the transportation of tractive sediment downstream. The only chert gravel sources with the potential to enter the lower Neosho River channel are from the low-terrace and floodplain alluvium. The upland chert gravels are not a viable source due to their high and remote topographic positions above and away from the river valley. The lack of floods of magnitude, bank-full or out-of-bank, has significantly reduced the erosion of channel banks and bed. Therefore, the chert gravels entering and replenishing downstream gravel bars and riffles are a finite, non-renewable resource. The threatened Neosho madtom, *Noturus placidus*, catfish species uses riffles as a habitat. The dredging of riffle-bars on the lower Neosho River would significantly affect the catfish species because of the lack of chert gravels entering the river channel to replace the extracted gravels.

CHERT GRAVEL SOURCES, HYDROLOGY, TRANSPORTATION,

AND DEPOSITION

WITHIN THE LOWER NEOSHO RIVER,

SOUTHEASTERN KANSAS

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CHAPTER 1. INTRODUCTION TO TOPIC AND PROBLEM

Problem Statement:

This study emphasizes the hydrology involved in the transportation and deposition of chert gravel sediment and the ability of chert gravel sources to supply the lower Neosho River to replenish gravel bars. The study covers six counties of southeastern Kansas: Allen, Anderson, Coffey, Neosho, Woodson, and Wilson counties (Fig. 1). The access is examined for chert gravel to migrate via tributaries, channel erosion, flooding events, and weathering out of hill tops and high terraces into the lower Neosho River basin.

Chert Gravel:

There are three plausible chert gravel sources with potential to supply the lower Neosho River channel and replenish gravel bars. Most of these gravel sources are well-documented and plentiful. The problem is the ability of gravel from these sources to gain access to the river channel itself.

The headwaters of the Neosho River originate in the Flint Hills region providing a rich source of chert gravel to replenish gravel bars, but a barrier exists to the gravel ever reaching the lower Neosho River channel. Since John Redmond Reservoir was impounded in 1961, it has provided a man-made obstacle to the transportation and deposition of chert gravel into and within the lower Neosho River channel. Chert gravel is pebble and cobble sediment that becomes trapped at the reservoir and settles to the bottom of it. Only fine sediment, such as the size of soil colloids, flow into the lower Neosho River channel from the base of John Redmond Reservoir.

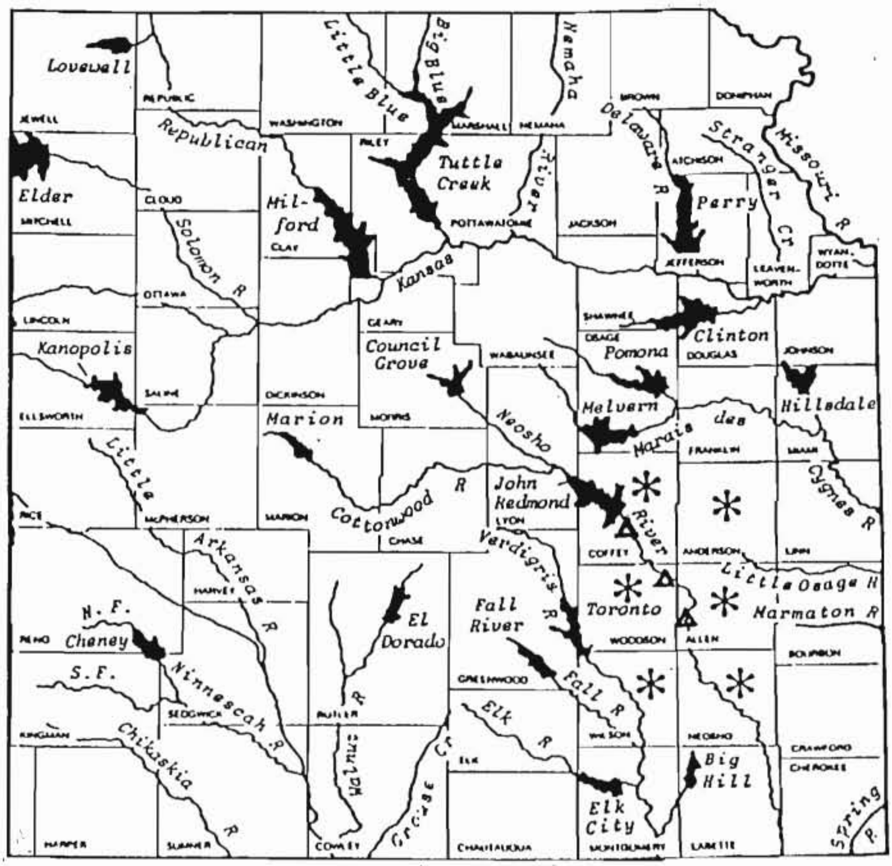

Fig. 1. Map of the six-county study region of southeastern Kansas. Asterisks denote the counties of the study region. The lower Neosho River originates at the base of John Redmond Reservoir in Coffey County and meanders through southeastern Kansas. The headwaters of the Neosho River, the Cottonwood and Neosho Rivers, originate from the Flint Hills region. Triangles denote gravel bar sites (Aber and Byerley 1994b).

The Olpe and Kenoma-Olpe complex soil series consist of old upland alluvial chert gravels. These chert gravels are located on high terraces and are an abundant source within the study region. There are two problems with the ability of these chert gravels to become reworked into the lower Neosho River channel to replenish gravel bars. First, these gravels are located high above and far from the Neosho River and its main tributaries. Second, chert is resistant to any form of erosion or weathering, which prevents the gravels from being removed and transported from their present positions into the river channel.

The chert gravel sources within the low terraces surrounding the modern valley floodplains and basal alluvial fill underneath the modern valley floodplains have direct access to the lower Neosho River channel to replenish gravel bars. The chert gravels that constitute the low terraces and basal alluvial fill enter the river via meander migration and channel erosion by the main river. The problem is that this gravel source is poorly documented by soil survey reports. Therefore, it is difficult to determine the abundance or lack of gravel constituting these soils.

The lower Neosho River originates at the base of a large catchment area, John Redmond Reservoir in Coffey County, and extends through southeastern Kansas (Fig. 1). The headwaters of the Neosho River, the Neosho and Cottonwood Rivers, originate from the Flint Hills region (Fig. 1). Meander migration and channel erosion by the main river and its associated tributaries within the Flint Hills region provide for an ample source of chert gravel which is transported downstream. The transportation of chert gravel sediment is restricted downstream by numerous low-water dams and the John Redmond Reservoir. These man-made controls on the flow of the river have prevented the natural transportation and deposition of chert gravel downstream. The chert gravel is transported downstream to the reservoir and subsequently settles to the bottom of it. No sediment the size of chert gravel is ever transported downstream from the base of the reservoir into the lower Neosho River channel during normal flow conditions. It is only during a flooding vent, when the river reaches bank-full or leaves its banks, that the river generates enough elocity to transport sediment the size of chert gravel downstream to replenish gravel bars.

The gravel bars within the lower Neosho River channel, all of which have a large hert content, are dynamic features heavily influenced by the geomorphic features within e channel itself. These gravel bars are stationary landforms as evidenced by topographic aps dating back to the 1970's. Three representative gravel bars at different sites were searched and documented for this study to determine similiarities and differences among e gravel bars of the lower Neosho River channel. The three sites chosen to study gravel ars within the lower Neosho River channel were Burlington, Neosho Falls, and Humboldt Fig. 1).

eosho Madtom and Dredging Operations:

The natural habitat for the native Kansas catfish Neosho madtom, *Noturus lacidus*, are the riffles that accompany the chert gravel bars of the lower Neosho River hannel and other rivers of this region. The Neosho madtom is a threatened catfish pecies drawing a lot of political attention lately in an attempt to save it and its habitat. In n attempt to save the few remaining populations of Neosho madtom, the Kansas Department of Wildlife and Parks has imposed a ban on the dredging of all the rivers in outheastern Kansas.

In the past, dredging operations have extracted gravels from the lower Neosho iver channel and elsewhere for commercial use. The primary commercial use for chert ravel is for road maintenance and construction purposes. This is a cheaper method of btaining gravel as compared to extracting gravel from other sources such as high-terrace r hill-top gravels or quarrying limestone.

em Solving:

The goal of this study is to provide geologic and hydrologic information that s the origin, transportation, and deposition of chert gravel in the vicinity of and unding the lower Neosho River of southeastern Kansas. This goal has been nplished utilizing various research methods and tools. GIS data bases were created, n-gage records were analyzed, and field observations were conducted to acheive this

Several GIS data bases were created to reach this goal. The GIS data bases depict tial chert gravel sources within the six-county study region and their accessibility to odern lower Neosho River valley. The GIS data bases show the interrelationship g the hydrologic, geologic, and geographic features of the six-county study region.

Another goal of this study is to analyze the stream-gage records taken at the Iola g station, located in the middle of the study region, to determine how effective John nond Reservoir is in controlling the flooding behavior of the lower Neosho River nel. During a flooding event is the only time chert gravel sediment enters the river via nel erosion of the alluvial soils that compose the banks and bed or from one of the aries to replenish gravel bars. Also, during a flood gravel bars are dismantled and sediment transported downstream to other locations.

The goal of the field study, conducted March of 1994, was to observe three sentative gravel bar sites within the lower Neosho River channel. This involved the of gravel bars and channel characteristics of the lower Neosho River. Also, the s associated with the gravel bars were studied to determine suitable habitats for the ho madtom.

nent of Significance:

This study is significant in providing a detailed understanding of the origin, portation, and deposition of chert gravel sediment within the lower Neosho River in. The GIS data bases depict the sites of the hill-top and high-terrace chert gravels, alluvial soils surrounding the lower Neosho River channel present on the modern ley low terraces and floodplains, and the main hydrologic features throughout the six-nty study region. The GIS software is utilized to quantitatively determine the areal erages of mapped alluvial soils and gravel sources. The stream-gage records are the is for quantitative analysis of the flooding behavior of the lower Neosho River before after the impoundment of John Redmond Reservoir. The flooding behavior of the er Neosho River is crucial to this study because it is only during a flood that the nnel carries enough discharge to rework chert gravel already present within the channel to uncover chert gravel within the banks and basal alluvial fill surrounding and lerneath the modern river valley. Field observations provide physical evidence for vel bar composition, placement within channel, local influences surrounding and within river channel, typical bar features, and size distribution, texture, growth, and color terns for gravel sediment.

CHAPTER TWO. LITERATURE REVIEW

of Literature:

The body of researched literature involved three topics: 1. The origin and the sitional pattern of hill-top and high-terrace chert gravel deposits within the modern age basin of the lower Neosho River of southeastern Kansas; 2. The hydrology ved in the transportation and deposition of chert gravel sources in the lower Neosho to replenish gravel bars; 3. The riffle and bar sequences that provide a habitat for leosho madtom in the modern lower Neosho River.

h Strategy:

The search strategy involved research at the William Allen White Library at oria State University and the science library at the University of Kansas in Lawrence. search strategy at the William Allen White Library involved interlibrary loans, a NFRAME DIALOG System search, government documents, periodicals, and larly journal articles pertaining to chert gravel origins and the hydrology involved in transportation and deposition in Kansas. The data base used for the MAINFRAME LOG System search is GEOREF. The science library at the University of Kansas was to research books, government documents, and scholarly journal articles on chert el origins in Kansas and the hydrology involved in their transportation and deposition. unpublished theses pertaining to chert gravels located in the Physical Science office at oria State University were used as references for further chert gravel studies.

Top and High-Terrace Chert Gravel Sources of Southeastern Kansas:

The chert gravel deposits located on the high-terraces and hill-tops in the vicinity e modern lower Neosho River valley of southeastern Kansas are a potential source for gravel bar replenishment. The locations of these widespread gravel deposits above the modern valley provide the potential for gravel to be reworked into the river channels by erosion. The locations, origins, and ages for these hill-top and high-terrace chert gravel sediment deposits in eastern Kansas, including the southeastern study region, have been well documented for the following drainage basins: Cottonwood, Verdigris, Neosho, Marais des Cygnes, and Walnut (Frye and Leonard 1952; Frye 1955; Bayne and Fent 1963; Seevers and Jungmann 1963; Aber 1985, 1988, 1992; Aber and Johnston 1990). These chert gravel deposits are located on the hill tops and high terraces constituting the Olpe, Olpe-Dennis, and Kenoma-Olpe soils of southeastern Kansas as evidenced by county soil survey reports (Fleming *et al.* 1978, 1982; Sallee 1977; Swanson 1982, 1989; Swanson and Googins 1977). Aber (1985) stated the upland chert gravel deposits rest on the Lower Permian bedrock of the Flint Hills region and to the east on Upper Pennsylvanian bedrock of the Osage Plains, particularly along the Cottonwood and Neosho valleys.

One of the earliest studies attributed the chert gravel deposition of southeastern Kansas to glacial action or drift. The geologist, Mudge, who was quoted in a study written by Parker (Mudge *in* Parker 1884), called the chert gravel "modified drift" in context with its proposed glacial origin. In an earlier study by Mudge (1875), he hypothesized that the chert gravels and the presence of erratic quartz and quartzite pebbles within them in eastern Kansas were due to glacial meltwaters that had transported the gravels and pebbles into the region. Wooster (1934) also attributed the presence of this combination of chert gravels and erratic quartz and quartzite pebbles to glacial meltwaters that transported the sediment into eastern Kansas via the McPherson valley. The geographic location for Parker's (1884) study was around Burlington, Kansas, which is located at the beginning of the study region at the mouth of the lower Neosho River in Coffey County.

Aber (1985) discussed several problems with the glacial theory. The age of the chert gravels found in east-central and southeastern Kansas is attributed to the late Tertiary, that does not correspond with the dates for the Kansan glaciation that reached northeastern Kansas. There is no plausible answer for the diversion of glacial meltwater into the McPherson valley because it is topographically higher than the southwestern limit of the Kansan glacier. The mineralogy of the erratic quartzite pebbles in east-central and southeastern Kansas is different from quartzites of northeastern Kansas, but corresponds with sources in western Kansas.

The age determination for the chert gravel deposits of east-central and southeastern Kansas is problematic. The chert gravel deposits of eastern Kansas lack suitable fossils or material for radiometric dating (Aber 1985). Therefore, the method for determining the late Tertiary age of the chert gravel deposits of east-central and southeastern Kansas is by their high topographic positions above the modern valleys (Frye and Leonard 1952). The age assigned to these upland chert gravel deposits is the Pliocene (Bayne and O'Connor *in* Zeller 1968). Frye and Leonard (1952) observed that when chert gravel deposits and their corresponding elevations are traced eastward from the Flint Hills region, the gravel deposits increase in their elevation above the modern valleys until they reach a peak in Anderson County. Frye (1955) noted the elevation of chert gravel deposits in easternmost Anderson County reaches 75 m (250 feet) above the modern valley floors.

Another early geologist, West (1885), described the origin of the chert gravel deposits in eastern Kansas as an effect of the submergence of southeastern Kansas under a shallow sea. The conditions surrounding the origin of the Upper Pennsylvanian bedrock of eastern Kansas was a shallow sea during the Carboniferous Period. This is evidenced by the abundance of marine fossils within the stratigraphy of this bedrock. This hypothesized origin for the chert gravel deposits is unfounded. The chert gravels lack a fossil record. The age of the chert gravel deposits is the late Tertiary not the

Carboniferous Period, according to nearly all later studies. Also, the linear pattern of the chert gravels and the manner in which these gravel deposits mirror modern river valleys within the region are proofs of the deposits alluvial origin (O'Connor 1953; Frye 1955; Aber 1985).

Chert gravel deposition in eastern Kansas was explained by Haworth (1896) and Wooster (1914) as the direct result of the weathering of cherty limestones that were once present within southeastern Kansas. They believed peneplain erosion had occurred. The cherty limestones had naturally eroded away at their site of origin, retreating west into the Flint Hills region, leaving behind the more resilient chert component of the limestones. Wooster (1914) believed a specific cherty limestone formation, the Wreford Limestone currently found in the Flint Hills region, was at one time present in eastern Kansas and had undergone peneplain erosion leaving behind the abundant chert gravel deposits as it backwasted westward to its present position in the Flint Hills region.

Since the 1950's there has been a consensus among geologists that the chert gravel deposits of eastern Kansas are alluvial in origin (O'Connor 1953; Frye 1955; Aber 1985; Law 1986; Krueger 1993). O'Connor (1953) observed that the linear pattern of upland chert gravel deposits of east-central Kansas follows the upper portions of the modern Neosho and Verdigris drainage basins, but not the southern portions of these drainage basins. The chert gravel deposits are more widespread in Coffey and Anderson Counties than the other four counties of the study region. He observed that the pattern of chert gravel deposition and the path of the modern Neosho and Verdigris drainage basins trended to the southeast to the point where gravel deposits veer east toward Missouri, while the rivers continued southeastward.

Frye (1955) accepted and elaborated on the concept of the alluvial deposition of the chert gravels that follow the upper portions of the modern drainage basins of east-central Kansas. He discovered that the upland chert gravel deposits in Anderson County were on a drainage divide between the Missouri and Arkansas drainage basins. He hypothesized the river system that deposited these old alluvial chert gravels followed the Missouri instead of the Arkansas drainage basin such as the modern Neosho River presently does.

Aber (1985) proposed a preglacial river system he named the "Old Osage River" to explain the alluvial deposition of the chert gravels in eastern Kansas. He proposed the source of the chert gravel was the cherty limestones of the Flint Hills region, but the Flint Hills were not a barrier to drainage. The "Old Osage River" flowed west to east over the Flint Hills transporting and depositing chert gravel sediment along with erratic quartz and quartzite pebbles from the High Plains of western Kansas. Previously, the Flint Hills was thought to be a major barrier of Tertiary drainage between central and eastern Kansas (Frye and Leonard 1952; Frye 1955; Bayne and Fent 1963). Seevers and Jungmann (1963) had discussed Tertiary drainage across the Flint Hills region, but had not demonstrated how it was accomplished.

Law (1986) substantiated Aber's (1985) data concerning a major drainage basin that flowed from west to east over the Flint Hills into east-central Kansas. He calculated pebble and cobble roundness values of data taken from samples extending from Chase into Anderson Counties and determined the larger and less rounded sediment was closer to the headwaters located to the west. He also determined the gradient for this drainage basin by plotting the elevation of gravels and calculated that the gradient was similiar to the modern gradient of the Neosho River.

Krueger (1993) further studied the chert gravel deposits associated with the proposed "Old Osage River" that flowed through east-central Kansas. She noted an asymmetrical pattern of deposition for the gravels in Chase County as noted in gravel studies of other counties in eastern Kansas (Law 1986; Sleezer 1990; Aber 1992). After studying chert gravel deposits and their corresponding elevations, she proposed that a tributary to the north joined with the main stem and another tributary joined with the main stem of the "Old Osage River" in southern Coffey County. The tributary that joined with the main stem of the river in southern Coffey County exhibited a drainage pattern similiar to the modern Neosho and Cottonwood Rivers. She concluded by hypothesizing that the main stem of the river continued to flow in a southeastward direction, exiting the state of Kansas towards Oklahoma instead of Missouri as previously suggested and proposed (O'Connor 1953; Frye 1955).

Channel Bank and Bed Chert Gravel Sources of the Modern Valley:

A central aspect of this study is to determine the ability of possible chert gravel sources surrounding and within the alluvial channel banks and bed of the lower Neosho River to enter into the channel to replenish gravel beds. Under normal flow conditions the alluvial channel banks and bed of a river erode at a slow rate depending upon the hydraulic geometry of that reach of the river. Leopold and Maddock (1953) defined hydraulic geometry as the interrelationship of the width, depth, velocity, sediment load, slope, and discharge of water, the slope, resistance, and roughness of the bed, and the cohesiveness of the surrounding banks to create the geometric pattern of a given reach within a river channel. Leopold and Maddock explained two of the general erodibility characteristics of channel banks and bed in relation to hydraulic geometry as follows (1953:52):

> The increased bed shear in a wide shallow reach having a given velocity promotes a tendency to scour. A narrow deep reach of the same velocity is apparently characterized by less shear on the bed but greater shear on the bank.

Leopold *et al.* (1964) discussed the ability of a reservoir, such as John Redmond, to trap 95 to 99 percent of the sediment that previously passed through, lower peak discharges, and increase base flow. Osterkamp and Hedman (1981) documented the consequences of regulating the lower Neosho River. There was a marked reduction in channel width downstream from John Redmond Reservoir just a decade after it was impounded, all stoppage of sediment the size of pebble and cobble gravels at the reservoir dam, and the possibility of channel degradation downstream. By calculating the mean discharge of the river and active channel width from examining the stream-gage records of a given reach they determined the Neosho River is stable and highly regulated.

Channel degradation is a direct result of reservoir dams. Channel degradation occurs downstream in a regulated river due to the increase in baseflow and loss of coarse sediment such as chert gravel pebbles to replenish the gravel bars and bed (Leopold *et al.* 1964; Osterkamp and Hedman 1981). The bed is lowered due to the loss of sediment downstream from the dam and the channel banks cave in due to the increase in baseflow discharge. Therefore, channel degradation creates a narrower, deeper channel less prone to bank-cutting and meander migration. Osterkamp and Hedman (1981) did not observe any obvious downstream channel bank and bed degradation on the Neosho River because many reaches of this river flow on bedrock and more time needed to elapse before the signs of degradation were evident. They hypothesized downstream channel bank and bed erosion did and would occur where alluvium was found.

Channel bed build-up or armoring occurs upstream within proximity of the reservoir dam due to a leveling of the slope within that reach (Leopold *et al.* 1964). The reduction in peak flows negate the regulated rivers ability to transport larger and coarser sediment such as pebble and cobble gravels downstream. Instead, the roughness of the upstream channel bed creates an armoring effect in which the larger and coarser sediment becomes trapped and accumulates while the finer and smaller sediment is transported downstream.

The channel banks of the lower Neosho River are cohesive and typical of other channel banks of the eastern half of the United States (Leopold and Wolman 1957). They are composed of fine-grained sediment such as silt and clay (Osterkamp and Hedman 1981) and many roots from vegetation and large trees. Only large floods are capable of tearing out cohesive banks with a strong root matrix (Leopold and Wolman 1957).

Floods are the most rapid agents for the erosion of alluvial channel banks and bed, floodplains, and low terraces. The floodplains and low terraces surrounding river valleys are eroded by flood waters and meander downcutting by river channels (Leopold *et al.* 1964). During flooding events the banks and bed of an alluvial stream are scoured and with considerable rapidity the sediment derived from this action creates a sediment-rich flow within the channel (Leopold and Maddock 1953; Hedman *et al.* 1974). Leopold and Wolman (1957) described what a powerful agent of erosion a large flood is on channel banks, in which a single high flow can affect more change in channel shape in the direction of increasing width than many succeeding days of lower flow.

By studying channel width and flood discharges taken at stream-gaging stations, Wolman and Leopold (1957) hypothesized floods that reach bank-full cause the most erosion to supply sediment such as chert gravel downstream to replenish gravel bars. They decided the banks eroded the most rapidly when the river rose to bank-full and when it receded back to bank-full from the surrounding floodplain. In similiar studies by Hedman *et al.* (1974), it was determined in Kansas the most erosive floods appear to be over the bank not bank-full.

The best way to study the flooding behavior of a river is by following the standard principles of stream hydraulics (Davis and DeWiest 1966; Richards 1982). This is the analysis of a complete and long-term stream-gage record for a given cross-sectional reach of a river. The flooding behavior of the cross-sectional reach is determined by the *mean annual flood* which is the average of maximum annual discharges for a given time period (Richards 1982).

The flooding behavior may be determined for periods before or after the impoundment of a reservoir. In Kansas, the stream-gaging stations only operated sporadically until the 1920's when a more consistant system was incorporated (Burns 1971). Therefore, a complete stream-gage record exists for most regulated Kansas rivers before and after rivers, such as the lower Neosho, were impounded for reservoirs. Jordan and Hedman (1970) determined the percentage of error in the annual runoff computed from a typical gaging station in Kansas as follows: 44 percent for 5 years of record, 30 percent for 10 years of record, and 20 percent for 25 years of record. In Kansas, the more complete and long-term a stream-gage record is the more accurate it should be.

Riffles and Bars:

Riffles and gravel bars have characteristic channel features. Leopold *et al.* (1964) studied gravel bar, riffle, and pool sequences in meandering gravel river systems, such as the lower Neosho River, and made several observations. They found riffles are chutes formed over gravel bars and pools are positioned between the bars. Gravel sediment transported downstream settles into either riffles or pools according to sediment size distribution, channel obstacles or geometry, and streamflow characteristics. The smaller pebbles and sand settle into pools and the larger pebbles and cobbles settle into riffles (Leopold *et al.* 1964; Richards 1982). Riffles and bars are considered relatively stationary features, in which accreted sediment migrates slowly through and is lost downstream (Leopold *et al.* 1964). Braided, meandering, and straight natural channels all exhibit riffles and bars spaced at intervals of 5-7 channel widths (Leopold and Wolman 1957; Leopold *et al.* 1964; Richards 1982). During a reconnaissance survey, Edds (1993) assumed that riffles and bars on the lower Neosho River also would be spaced at intervals of 5-7 channel widths. However, subsequent field studies have shown in meandering streams, such as the Neosho River, the norm is for selective bank erosion and point-bar or berm development (Leopold and Wolman 1957; Leopold *et al.* 1964; Hedman and Kastner 1972; Richards 1982). Richards (1982) noted that the coarser sediment composed the upstream portions of gravel bars and the finer sediment downstream.

The threatened Neosho madtom catfish uses chert gravel riffles of the lower Neosho River as a habitat. The Neosho madtom prefers shallow-water riffles that consist of loose and rounded chert gravels free of fine-matrix sediment (Cross 1967; Cross and

Collins 1975). The dredging of the gravel bars and associated riffles of rivers such as the lower Neosho have threatened the Neosho madtom habitat. Leopold *et al.* (1964) provided a solution to the dredging of fish habitats. The fish habitats may be maintained by providing artificial gravel bars and associated riffles, 5-7 width intervals apart. Gravel may be artificially deposited within the appropriate interval widths in a river channel and after a few flooding events the gravel bars and riffles will stabilize to become suitable fish habitats.

CHAPTER 3. METHODOLOGY

Introduction to Data Base:

The data base consists of various geographic information relating to chert gravel origin and the hydrology involved in the transportation and deposition of the gravels within the lower Neosho River basin southeastern Kansas. The six counties of the southeastern Kansas study region are: Allen, Anderson, Coffey, Neosho, Woodson, and Wilson Counties (Fig. 1). Data bases depicting the six-county study region of southeastern Kansas and its key geologic and hydrologic features were created and quantitatively analyzed. A quantitative analysis of stream-gage records taken at the Iola gaging station was conducted. Field observations of the typical gravel bar and channel features found within the lower Neosho River basin were performed.

Soil Survey Reports:

Soil survey reports were obtained from the United States Department of Agriculture, Soil Conservation Service, for Allen, Anderson, Coffey, Neosho, Woodson, and Wilson Counties (Fleming *et al.* 1978, 1982; Sallee 1977; Swanson 1982, 1989; Swanson and Googins 1977). These surveys depict the old alluvial upland Olpe, Olpe-Kenoma and Olpe-Dennis, and the modern low-terrace and floodplain soil series within and surrounding the major drainage basins. These reports provide a detailed description of all the soil series within the political boundaries of each representative county. Soil survey reports consist of 1 : 20,000 scale section maps of entire counties. The advantage of these section maps are that every soil series is delineated within the political boundaries of the county and their physical relationships to the drainage systems are depicted. In addition, the soil survey reports provide information on classifications, uses, slopes, and management practices of all the soil series within the counties. The section maps provide a gray-tone two-dimensional perspective to the study region without contour lines.

The soil survey reports were used to highlight the three categories of soil series with alluvial origins. The three categories of alluvial soil series are grouped as follows (Aber and Byerley, 1994a):

Soils of floodplains in major valleys (Fig. 2):

Ivan Series	Osage Series
Lanton Series	Verdigris Series

Soils of low terraces in major valleys (Fig. 3):

Dennis Series	Mayes Series
Hepler Series	Okemah Series
Kenoma Series	Summit Series
Leanna Series	Woodson Series
Mason Series	

Soils of high-terrace and hill-top gravel (Fig. 4):

Olpe Series	Kenoma-Olpe Series
Olpe-Dennis Series	

The hill-top and high-terrace Olpe, Kenoma-Olpe, and Olpe-Dennis soil series consist of a well-documented and potentially abundant source of old alluvial chert gravel sediment (Fig. 4). The floodplain and low-terrace soils surrounding and within the major drainage basins of the region are alluvial or stream deposited soils, but are not a well-documented source of chert gravel. It is assumed the floodplain (Fig.2) and low-terrace

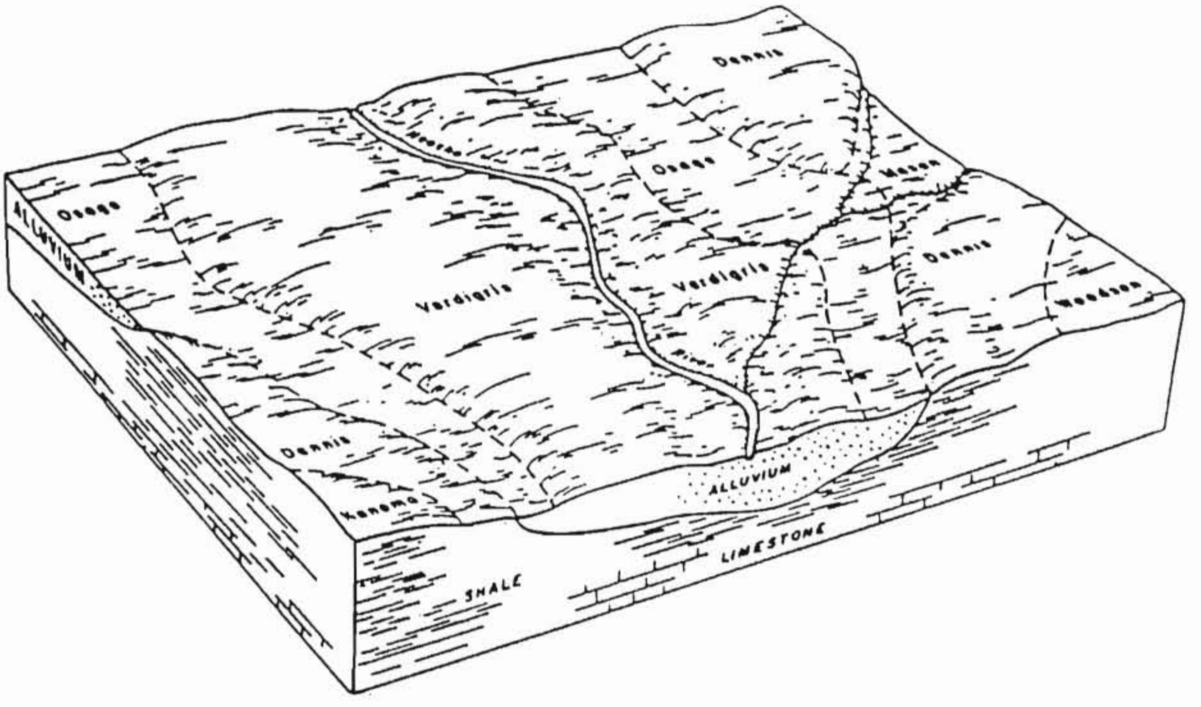

Fig. 2. Typical soil patterns of the Verdigris-Osage association, found on the floodplains of the drainage basins of the southeastern Kansas study region. Taken from Fleming *et al.* (1978, fig. 5).

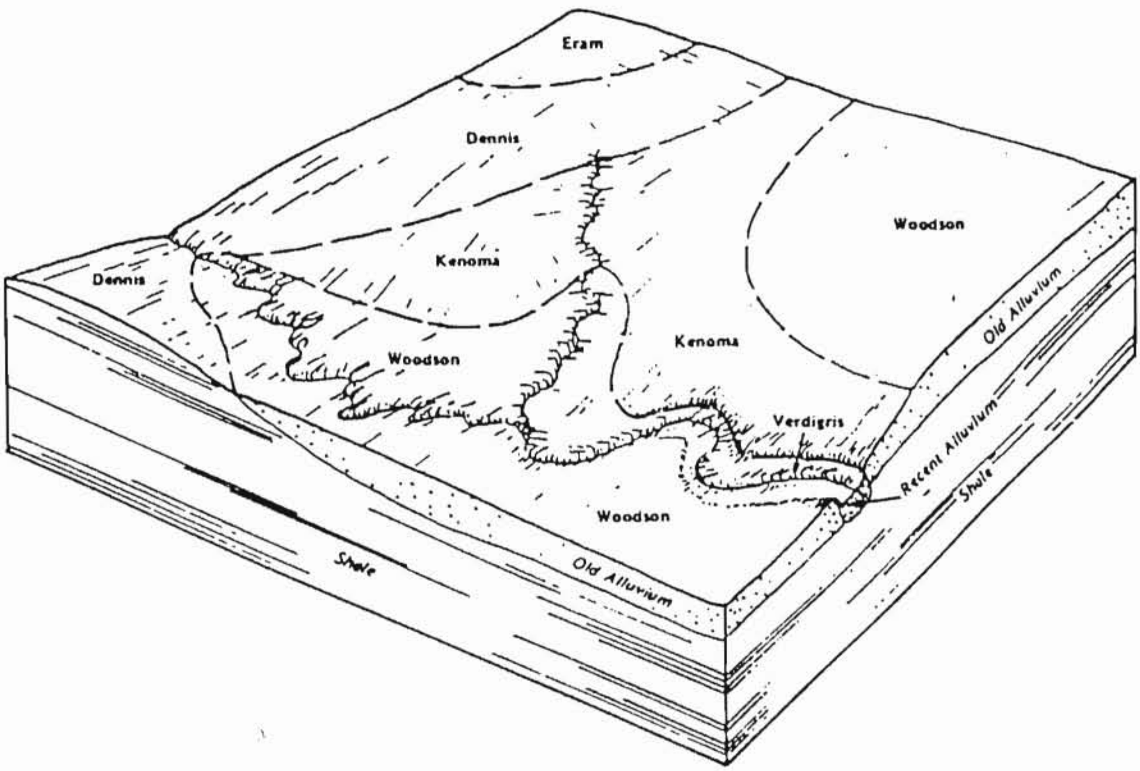

Fig. 3. Typical soil patterns of the Woodson-Kenoma-Dennis association, found on low terraces surrounding the drainage basins of the southeastern Kansas study region. Taken from Swanson (1989, fig. 3).

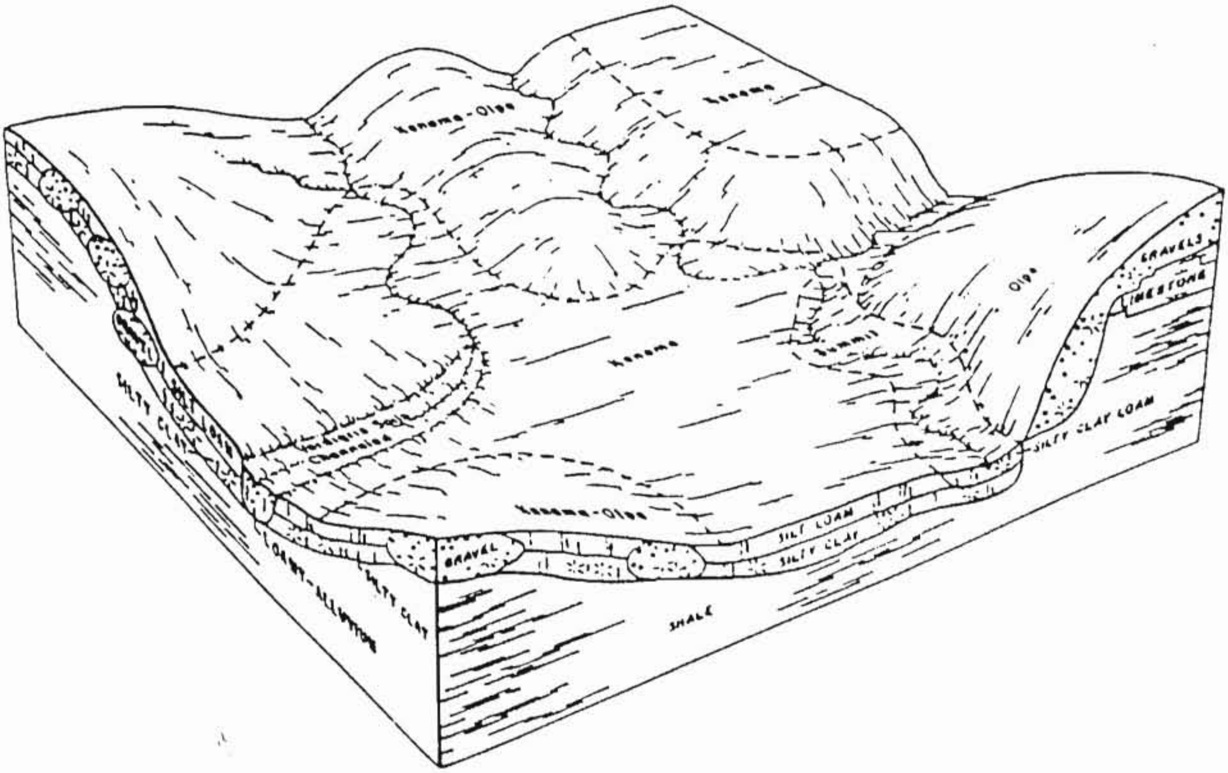

Fig. 4. Typical soil patterns of the Kenoma-Olpe association, found on the high terraces and hill tops of the southeastern Kansas study region. Taken from Swanson (1982, fig. 8).

(Fig. 3) soils of the study region consist of a small, but unknown amount of gravel sediment.

The Olpe soil series and a couple other variations of this soil series are located throughout the study region. The Olpe soil series and variations of it are found on the hill tops and high terraces of the study region with slopes ranging from 2 to 15 percent and are formed in gravelly old alluvium with some loess (Fleming *et al.* 1978, 1982; Sallee 1977; Swanson 1982, 1989; Swanson and Googins 1977). In Neosho County, the Olpe soil series is mapped in association with low-terrace soils and is called the Olpe-Dennis association (Fleming *et al.* 1982). In Wilson County, the Olpe soil series is also mapped in association with low-terrace soils and is called the Kenoma-Olpe association (Swanson 1989). In Allen County, the Olpe soil series is predominantly found without an association and is called the Olpe soil series (Fleming *et al.* 1978). In Anderson, Coffey, and Woodson Counties, the Olpe soil series is found both with and without an association with the low-terrace Kenoma soils and is called the Olpe soil series at some sites and the Kenoma-Olpe soil series at other sites (Sallee 1977; Swanson 1982; Swanson and Googins 1977). The typical description of the Olpe soil series is adapted from the Soil Survey of Neosho County, Kansas (Swanson 1982):

A1-- 0 to 25 cm (0 to 10 inches); very dark brown (10YR 2/2) gravelly silt loam, dark grayish brown (10YR 4/2) dry; moderate fine granular structure; slightly hard, friable; many fine roots; 15 percent rounded chert pebbles; medium acid; gradual smooth boundary.

B1-- 25 to 36 cm (10 to 14 inches); dark brown (7.5YR 3/2) gravelly silty clay loam, brown (7.5YR 4/2) dry; moderate medium granular structure; hard, firm; many fine roots; 20 percent rounded chert pebbles; medium acid; gradual smooth boundary.

B21t-- 36 to 66 cm (14 to 26 inches); dark reddish brown (5YR 3/4) very gravelly silty clay loam, reddish brown (5YR 5/4) dry; moderate fine subangular blocky structure; very hard, very firm; common fine roots; 70 percent rounded chert pebbles; slightly acid; gradual smooth boundary.

B22t- 66 to 91 cm (26 to 36 inches); dark brown (7.5YR 4/4) very gravelly silty clay, strong brown (7.5YR 5/6) dry; moderate fine subangular blocky structure; very hard, very firm; few fine roots; 80 percent rounded chert pebbles; medium acid; gradual smooth boundary.

B3t--- 91 to 152 cm (36 to 60 inches); mixed yellowish red (5YR 4/6) and strong brown (7.5YR 5/6) very gravelly silty clay, yellowish red (5YR 5/6) and reddish yellow (7.5YR 6/6) dry; few fine faint very pale brown (10YR 7/3) mottles; weak fine subangular blocky structure; very hard, very firm; few fine black concretions; 80 percent rounded chert pebbles; medium acid.

The highlighted low-terrace, floodplain, and hill-top and high-terrace soils were transposed from the soil survey 1 : 20,000 maps to 1 : 24,000 scale topographic maps of the entire six-county study region. The small difference in scales between the soil survey maps and the topographic maps did not cause difficulty in relation to the transposition of the locations of the different soil groupings to the topographic maps. The chert gravel locations were transposed to the topographic maps by hand.

The 1 : 24,000 scale topographic maps for the entire six-county study region were purchased from the Kansas Geological Survey in Lawrence, Kansas. Each of the topographic maps makes up one quadrangle of the study region. The quadrangles are all named after some significant geographic feature found within the map such as the largest center of population. The major advantage of these quadrangles are the highly visible displays of geographic, geologic, and hydrologic features. The number of quadrangles that make up the study region is 64 (see Appendix A).

Steps and Procedures for the GIS Vector Data Base:

A geographical information system (GIS) was used to create a data base consisting of a series of computer generated maps depicting the spatial features of the six-county study region and a corresponding attribute data base that differentiates the various features such as chert gravel deposits, low-terrace, and floodplain soils. A GIS data base is essential in displaying and quantitatively analyzing the pertinent features of the study region. A GIS is the combination of a computer hardware and software package with many functions that include collecting, storing, retrieving, analyzing, and displaying spatial information from the real world (Burrough 1986). *IDRISI* is the GIS software package used in the Emporia State University Geospatial Laboratory. The director of the IDRISI Project, J. Ronald Eastman (1992:3), states:

> IDRISI is a grid-based geographic information and image processing system developed by the Graduate School of Geography at Clark University. It is designed to provide professional-level geographic research tools on a low-cost non-profit basis. Since its introduction in 1987, IDRISI has grown to become the largest raster-based microcomputer GIS and image processing system on the market.

A map digitizing system called *TOSCA* was used for data entry purposes. TOSCA is the universal and specialized digitizing software package distributed with, but independent of IDRISI. TOSCA has the capability to take existing paper maps and convert them into digital form (Eastman 1992). Also, the TOSCA software package exhibits several important editing functions for existing digital maps.

Six individual 1 : 100,000 metric scale county maps plus all the chert gravel, low-terrace, and floodplain soils, the major hydrologic features, and the largest centers of population within the counties delineated on the 1 : 24,000 scale topographic maps were digitized. The UTM (Universal Transverse Mercator) grid, zone 15, was utilized to create a vector data base of the southeastern Kansas study region. The 1 : 100,000 metric scale county maps were used as base maps to digitize from.

The digitizing process involved in the creation of the vector data base was multifaceted. All of the spatial features of interest delineated or present on the 1 : 100,000 county or 1 : 24,000 quadrangle topographic maps were digitized and assigned a specific attribute value to differentiate the individual features (Table 1). The topographic base maps were taped to the digitizing table, the minimum and maximum x and y UTM projection coordinates were demarcated on the maps, entered into the TOSCA program, and served as control points that TOSCA checked for errors.

A mouse was used to digitize the features of interest off of the base maps. The mouse records the x/y positions of point locations on the base maps in the established UTM plane coordinate system. During this process these point locations also appear on the computer screen. Therefore, this is an interactive process involving the user, digitizing table and mouse, and computer.

The output data derived from the digitizing process is always in the vector format. The various forms of vector output data are lines, polygons, and points (Fig. 5). All

Features	Values
Major Hydrologic Features:	1
Political Boundaries:	2
Most Populated City:	3
Upland Chert Gravel:	5
Floodplain Alluvium:	6
Low-Terrace Alluvium:	7

Table 1. Categories of digitized features and their assigned attribute values.

vectors have a beginning node and an ending node that may be joined with other vectors creating larger and more intricate vectors. An example of this procedure was the six line files created for each county to exhibit their major and intricate drainage features. These line files are composed of many lines joined by nodes.

Many vector files were created and saved using TOSCA. The files were predominantly saved as polygon files under specific groupings for all six counties of the study region: alluvial hill-top and high-terrace soils consisting of chert gravels, alluvial low-terrace and floodplain soils, political boundaries, and the centers of largest human populations. Each of the six counties had one line file saved pertaining to their major hydrologic features.

TOSCA has the capability to append or join files. Therefore, the many polygon files created from digitizing the features on the topographic quadrangles were appended to form three separate file groupings for each county: alluvial high-terrace and hill-top chert gravels, low-terrace, and floodplain soils. Also, all the digitized features from both the county and quadrangle topographic maps were appended according to various groupings to form comprehensive files of the entire study region of southeastern Kansas.

The digital vector maps were edited using the TOSCA module and then further processed using IDRISI modules. The EDIT module was used extensively to create script files and attribute values files for each of the six counties of the study region and a pallette file to view the vector files with. Seven script files were created, one for each of the six counties and a seventh for the entire study region of southeastern Kansas. The script files prepare vector images to view with the PLOT module. The script file overlays vector images (Figs. 6 & 7), and provides the user with tools such as the ability to write text, and choose the font, color, and the drawing space in preparation to view with the PLOT module. For each of the six counties and the entire study region the following vector files were overlayed by creating script files: the political boundaries, major hydrologic features of study region, the cities with largest populations, alluvial high-terrace and hill-top soils

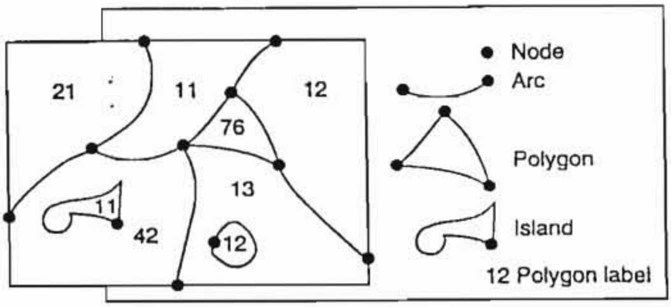

Fig. 5. Basic digitized output data provided by digital mapping systems such as TOSCA. These basic structures are always in the vector format. Taken from Avery and Berlin (1992, fig. 8-8).

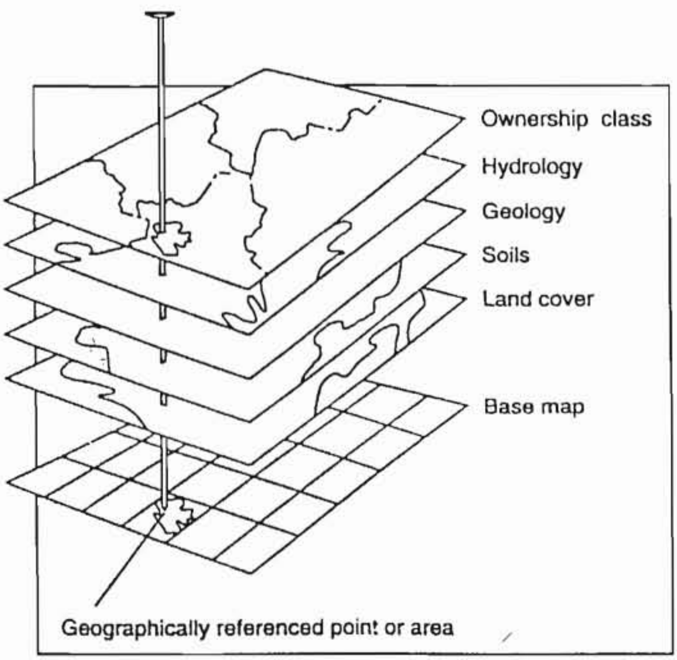

Fig. 6. Typical GIS data base structure. A geographically referenced series of overlays in either the vector or raster formats. Taken from Avery and Berlin (1992, fig. 8-2).

consisting of chert gravel, and alluvial low-terrace and floodplain soils. The names of the vector images created by the script file are: ALLEN, ANDERSON, COFFEY, NEOSHO, WOODSON, WILSON, AND STUDYP. The attribute value files were created to assign values to the specific geographic, geologic, and hydrologic features of interest within the study region. The pallette file was created to use with the PLOT module to view the vector images created with the script files. The pallette file corresponds with the attribute value files to assign color schemes with specific geographic, geologic, and hydrologic features of the study region. The name of the pallette file created to view the vector images with is SEKS.

Steps and Procedures for the GIS Raster Data Base:

The vector files are good for display purposes, but IDRISI lacks the ability to quantitatively analyze or print out these digital maps. Eastman (1992) described IDRISI as a raster based microcomputer GIS. Therefore, the vector files were converted into raster format (Fig. 8) in order to quantitatively analyze and print out the resulting raster images. A raster image is a data grid in which each cell of the grid is assigned an attribute value that corresponds with the geologic, geographic, or hydrologic feature being represented. In turn, this data grid corresponds with the grid of pixels on the computer screen to display an image. The user observes an image made up of small square cells or pixels. This image is not so aesthetically pleasing to the eyes as the vector image, but the IDRISI modules are more capable to analyze quantitatively an image or send an image to a printer.

A series of steps and procedures were required to create, quantitatively analyze, and print out the raster images. In order to convert the vector files into the raster format a blank grid was created for each of the polygon and line files composing the six-county study region using the INITIAL module. The blank grids were created using the same x and y UTM projection coordinates of the original vector files. The POLYRAS and

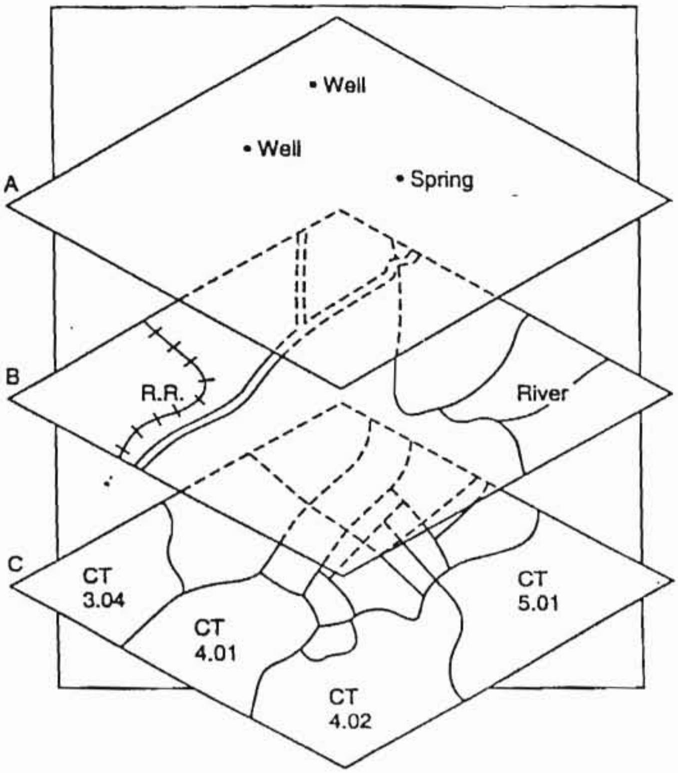

Fig. 7. Point (A), line (B), and polygon (C) overlays in vector format. Taken from Avery and Berlin (1992, fig. 8-3).

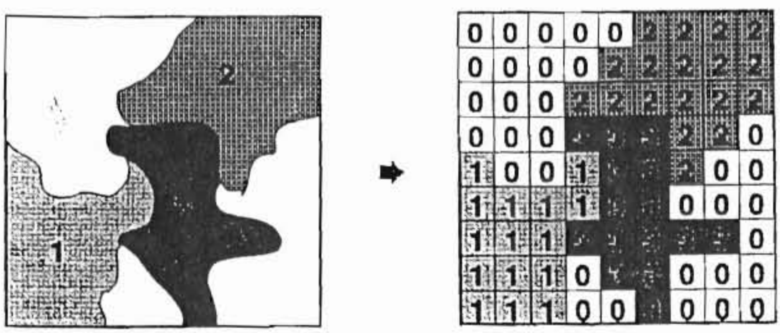

Fig. 8. Grid cells of the raster format. Each cell is assigned an attribute value that corresponds with a geologic, hydrologic, or geographic feature on earth to create an image composed of squares. Taken from Eastman (1992, fig. 3).

LINERAS modules were used with the blank images to create raster representations of the vector polygon and line files while keeping the original UTM plane projection coordinates.

The size of each pixel composing the raster images is a 100 by 100 m square. The position of each pixel within the six raster images begins at 0 on the x axis. The position of each pixel within four of the six raster images begins at 0 on the y axis, except for Anderson and Woodson Counties that begin at 55 and 91. The OVERLAY module was used to build up the raster images (Fig. 6). The end result of overlaying the raster images were six complete images, one for each of the six counties of the southeastern Kansas study region. The AREA module was used to calculate the areal coverages for each of the six counties in km^2 for the following features of interest: alluvial high-terrace and hill-top soils consisting of chert gravel, low-terrace, and floodplain soils of alluvial origin. The six raster images of the southeastern Kansas study region were named as follows: ALL3, AND3, COFF3, NEO3, WOOD3, WIL3. The pallette file PRINT was created using the COLOR module for printing purposes. The images were printed using the PAINT module, and transparencies were also made.

Equipment Used to Create GIS Data Base:

A Gateway 2000 486SX-33V Intel Personal Computer with 600 megabytes of hard drive and 8 megabytes of RAM with a 16 inch Gateway 2000 Crystal Scan super VGA monitor was used to create and edit this GIS data base. A Hitachi digitizing table was used to digitize the base maps and create vector images in the Emporia State University Geospatial Laboratory. The Hewlett Packard Paint Jet XL300 color printer in the Emporia State University Geospatial Laboratory was used to print raster images and transparencies.

Steps and Procedures for the Iola Hydrologic Record Data Base:

Stream-gage records were obtained from the United States Geological Survey in Lawrence, Kansas for all the the gaging stations on the lower Neosho River to determine discharge behavior before and after the impoundment of John Redmond Reservoir. The stream-gage records taken at the Iola gaging station were chosen for quantitative analysis because they met two criteria. First, the Iola gaging station is located at an ideal site in the middle of the study region on the lower Neosho River. Second, the Iola stream-gage records are more complete and cover a longer time interval, when compared to the records taken at other gaging stations on the lower Neosho River.

The Iola stream-gage records date from water-budget year 1917 to 1992 inclusive. A water-budget year begins on October 1st and ends on September 30th of the next year. The maximum annual discharge values were highlighted for each water-budget year 1917 to 1992 inclusive (see Appendix B).

The maximum annual discharge values were obtained to quantitatively analyze the flooding behavior of the lower Neosho River before and after the impoundment of John Redmond Reservoir. The maximum annual discharge is the most important factor in the analysis of long-term records of river flood behavior. The maximum annual discharge values were entered into spreadsheets.

Three separate spreadsheets were created and quantitatively analyzed using the *Microsoft Works for Windows* software package. The maximum annual discharge values were entered for all the water-budget years 1917 to 1992 inclusive in the first spreadsheet. The maximum discharge values for the water-budget years 1917 to 1960, before the impoundment of John Redmond Reservoir, were entered into the second spreadsheet. The maximum discharge values for the water-budget years 1961 to 1992, after the impoundment of John Redmond Reservoir, were entered into the third spreadsheet. The maximum annual discharge values were rearranged in order of magnitude, from highest to lowest, for the second and third spreadsheets using a sorting function. Therefore, all the maximum annual discharge values were rearranged according to magnitude for both before the impoundment of John Redmond Reservoir and after the impoundment of John Redmond Reservoir.

The *mean annual flood* and its standard deviation was determined for the second and third spreadsheets using average and standard deviation calculation functions. The mean annual flood is the average of yearly maximum discharges and has a typical recurrence interval of 2 to 3 years. Therefore, the mean annual flood and its standard deviation were determined for periods before the impoundment of John Redmond Reservoir and after the impoundment of John Redmond Reservoir.

The *Microsoft Works for Windows Spreadsheet* (MWWS) software package was used to create three charts depicting the numerical data in all three spreadsheets. A chart was created for the first spreadsheet depicting the maximum annual discharges in cubic feet per second (cfs) of the lower Neosho River taken at the Iola, Kansas gaging station from water-budget years 1917 to 1992 inclusive. A chart was created for the second spreadsheet depicting the maximum annual discharges in order of magnitude and in cfs of the lower Neosho River taken at the Iola, Kansas gaging station before the impoundment of John Redmond Reservoir. A chart was created for the third spreadsheet depicting the maximum annual discharges in order of magnitude and in cfs of the lower Neosho River taken at the Iola, Kansas gaging station after the impoundment of John Redmond Reservoir.

Steps and Procedures for Field Observations of Gravel Bars:

The focus of the field observations was the study of gravel bars in relationship to channel geometry within the lower Neosho River of southeastern Kansas. Three different sites were chosen for accessibility and as representative examples of the different gravel bar types encountered within the lower Neosho River channel. These three gravel bar sites were located at Burlington in Coffey County, Neosho Falls in Woodson County, and Humboldt in Allen County (Fig. 1).

Standard instruments were used for field operations. The gravel bar sites were measured from the center at 20 degree intervals and survey flags were planted on the perimeter of each of the sites at these intervals. The distance of prominent land forms from the gravel bar sites such as dams and channel banks were measured. A shovel, pick, paper and plastic bags, and boxes were used to take sediment samples at strategic points on each of the gravel bar sites. A permanent black ink magic marker was used to properly label the bags and boxes the samples were deposited into. A camera was used to take black and white as well as color photographs at each site.

A total of fifteen samples were taken from different strategic points on five gravel bars at different sites. There were four locations sampled from head to lee on the Burlington gravel bar labeled A-D. There were five locations sampled from head to lee on two gravel bars at Neosho Falls labeled A-E. There were six locations sampled from head to lee on two gravel bars at Humboldt labeled A-F.

A field notebook was used to note all numerical data and pertinent observations. The measurements taken at each site were recorded in the notebook. Also, any observations concerning gravel bar features were recorded at each site in the notebook. According to scale, reproductions of the gravel bar sites and surrounding features were drawn on graph paper and placed in the notebook. The resident biologist, James Sumner, provided insights on the suitability of the observed riffles as potential Neosho madtom habitats and these insights were noted.

The samples collected at the gravel bar sites were analyzed for size distribution and color at the laboratory at Emporia State University. Size distribution analysis was achieved by wet sieving and dry weighing to separate out the following sediment fraction grades: >25 mm, 16-25 mm, 8-16 mm, 4-8 mm, 2-4 mm, <2 mm. Sand and silt sized samples were disposed of. Only the samples of chert pebble grade 16-25 mm were used for color analysis using the *GSA Rock Color Chart*. The following students participated in the field and laboratory studies at Emporia State University: R.D. Byerley, C.W. Mata Jr., D.A. Pollock, J.L. Sumner, K. Takashima.

CHAPTER 4. RESULTS.

GIS Data Bases:

The GIS maps, created using IDRISI, depict the areal coverage of alluvial upland chert gravel deposits in each of the six counties of the study region. The gravels of the study region form an asymmetrical pattern as previous studies of other regions of eastern Kansas have documented (Law 1986; Sleezer 1990; Aber 1992; Krueger 1993). The gravels are found on the northern sides of the west to east and on the western sides of the north to south reaches of the lower Neosho River and its main tributaries. The GIS maps depict a widespread distribution of upland chert gravels that follows the upper reaches of the lower Neosho River in Coffey County and extends into Anderson County. The lower reaches of the Neosho River in Allen, Neosho, Woodson, and Wilson Counties are surrounded by fewer chert gravel deposits. O'Connor (1953) noted the lack of gravel deposits following the lower reaches of the Neosho River. The six county raster maps display the areal coverage of upland chert gravels in relation to the modern drainage of southeastern Kansas (see Plates I - VI in Appendix C).

The alluvial floodplain and low-terrace soils compose the channel banks and surrounding terrain of the modern major river valleys. The sediment derived from these soils enters the river via bank erosion due to meander migration, flooding events, and channel degradation on the lower Neosho River. As these soils are potential sources of chert pebble and cobble gravel sediment to replenish gravel bars, they are of interest to this study. The percentage of chert gravel sediment composing these soils is undocumented. Most of the sediments composing the channel banks of the lower Neosho River are silt and clay (Osterkamp and Hedman, 1981). The six county raster maps depict the areal coverage of alluvial floodplain and low-terrace soils surrounding the lower Neosho River. The areal limits of the alluvial floodplain soils are well defined, but the areal limits of the low-terrace soils are arbitrary in some places. In many cases, the low-terrace soils extend onto upland bedrock terrains and this is why arbitrary boundaries were emplaced for them.

The basic geographic and major hydrologic features are depicted on the six-county raster maps. The basic geographic features for each county are political boundaries and largest cities. The following cities and corresponding counties in Kansas are depicted on the raster images: Iola in Allen County, Garnett in Anderson County, Burlington in Coffey County, Chanute in Neosho County, Yates Center in Woodson County, and Neodesha in Wilson County.

The six county raster maps were analyzed to calculate the areal coverages of the following alluvial features: upland chert gravels present on high terraces and hill tops, alluvium of floodplains, and alluvium of low terraces (Table 2). The total areal coverages of floodplains and adjacent low terraces of the modern major river valleys of the study region are 547 km² for the former and 410 km² for the latter. The total areal coverage of Olpe soils within the study region is 144 km². The high-terrace and hill-top gravels of the study region are rarely in close proximity to the modern river valleys. In fact, Anderson County exhibits neither floodplains nor low terraces, but has 50 km² of hill-top and high-terrace gravels. Also, southern Coffey County exhibits neither an extended area of floodplains nor low terraces, but has widespread upland chert gravel deposits.

Results and Interpretations of the Iola Stream-Gage Records:

The mean annual flood was calculated using stream-gage records taken at the Iola gaging station on the lower Neosho River before and after the impoundment of John Redmond Reservoir. These stream-gage records were analyzed for water-budget years 1917 - 1992 inclusive. The results of this analysis proves larger peak discharges occurred with more variability from year to year before the impoundment of John Redmond Reservoir in 1961 than after (Fig. 9).

County	Floodplain	Low Terrace	Upland Gravels
Allen	77	98	14
Anderson	-	-	50
Coffey	141	145	59
Neosho	152	61	8
Woodson	29	36	5
Wilson	148	70	8
Total	547	410	144

Table 2. Estimates of areal coverage in km² for alluvium of floodplain and low terraces of the major river valleys and surrounding hill-top and high-terrace gravels within the six-county study region of southeastern Kansas (Aber and Byerley, 1994b).

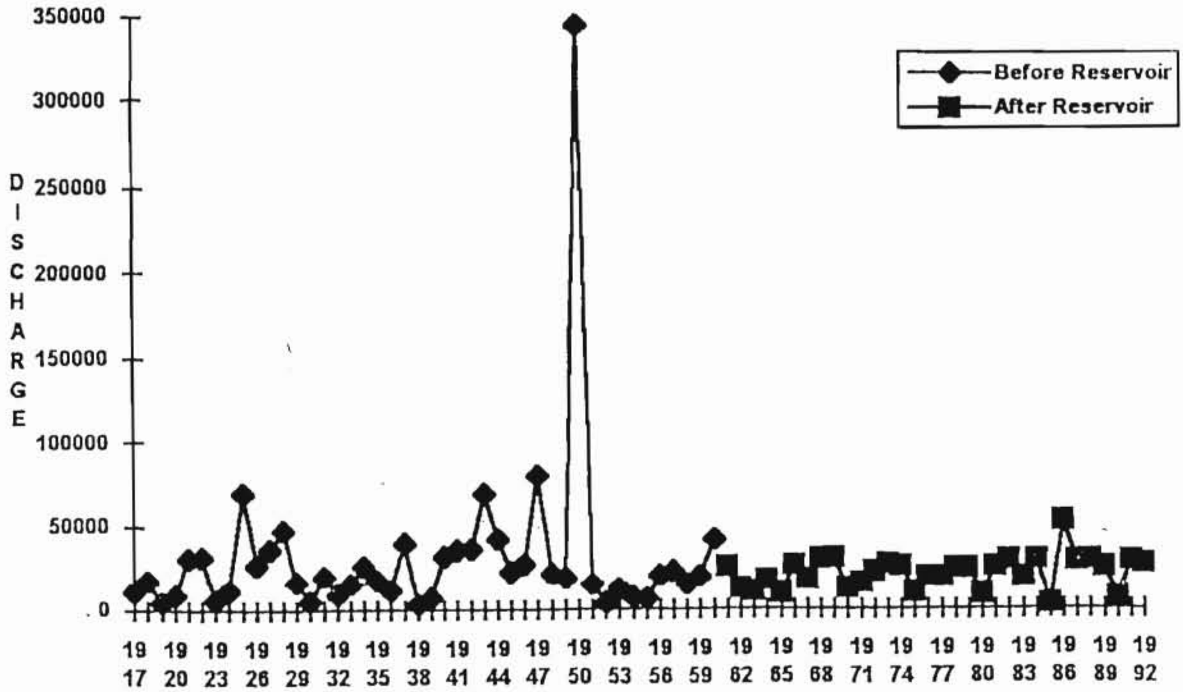

Figure 9. Peak annual discharges for water-budget years 1917 - 1992 inclusive, before and after the impoundment of John Redmond Reservoir. Data from stream-gage records taken at Iola gaging station (see Appendix B).

Before the impoundment of John Redmond Reservoir, the mean annual flood on the lower Neosho River at the Iola gaging station was 31,400 cfs with a standard deviation of 50,820 cfs. These figures are indicative of the high variability of peak discharges that occurred on the natural Neosho River channel before regulation. Also, the mean annual flood before John Redmond Reservoir corresponds closely with the bank-full flow at the Iola gaging station. Butch LaCock (USGS, Lawrence, pers. com.) has determined that bank-full flow is 32,300 cfs based on the discharge rating curve at Iola.

After the impoundment of John Redmond Reservoir, the mean annual flood became 21,700 cfs with a standard deviation of only 8925 cfs. These calculations are indicative of a reduction of approximately 30 percent in mean annual flood and much less variability in peak discharges after John Redmond Reservoir. Also, this mean annual flood is well below bank-full flow for the Iola cross-sectional reach. Therefore, the reservoir provides for a strongly regulated and consistant downstream discharge that rarely reaches bank-full flow or higher.

Flooding and Chert Gravel Transportation and Deposition:

A central theme of this study is that only during large floods are chert gravels eroded out of their present positions within the surrounding low-terrace and floodplain alluvium or reworked from the gravel bars, bedload, or alluvial fill beneath and within the channel. Only during large floods are chert gravels transported downstream and deposited within gravel bars. Wolman and Leopold (1957) claimed the most erosive flooding events were at bank-full flow, but Hedman *et al.* (1974) observed out-of-bank flooding events were the most erosive in Kansas. The bank-full flow and out-of-bank flooding events are necessary to erode cohesive channel banks (Wolman and Leopold 1957). The channel banks surrounding the lower Neosho River are composed of cohesive sediments.

Before the impoundment of John Redmond Reservoir, the natural Neosho River channel experienced many flooding events at or near the Iola bank-full flow estimate of

32,300 cfs and many out-of-bank flooding events (Fig. 10). The infamous 1951 flood, which occured during water budget year 1950, reached a maximum discharge around 350,000 cfs.

After the impoundment of John Redmond Reservoir, the regulated Neosho River only experienced a single flooding event having a peak discharge of bank-full flow or greater (Fig. 11). In 1986, due to reservoir management, the lower Neosho River experienced a peak discharge that exceeded 50,000 cfs. The summer flood of 1993, water-budget year 1992, reached a peak discharge of only 26,400 cfs, well below bank-full flow, even though a far greater volume of discharge had flowed through the channel in 1993 than in 1986.

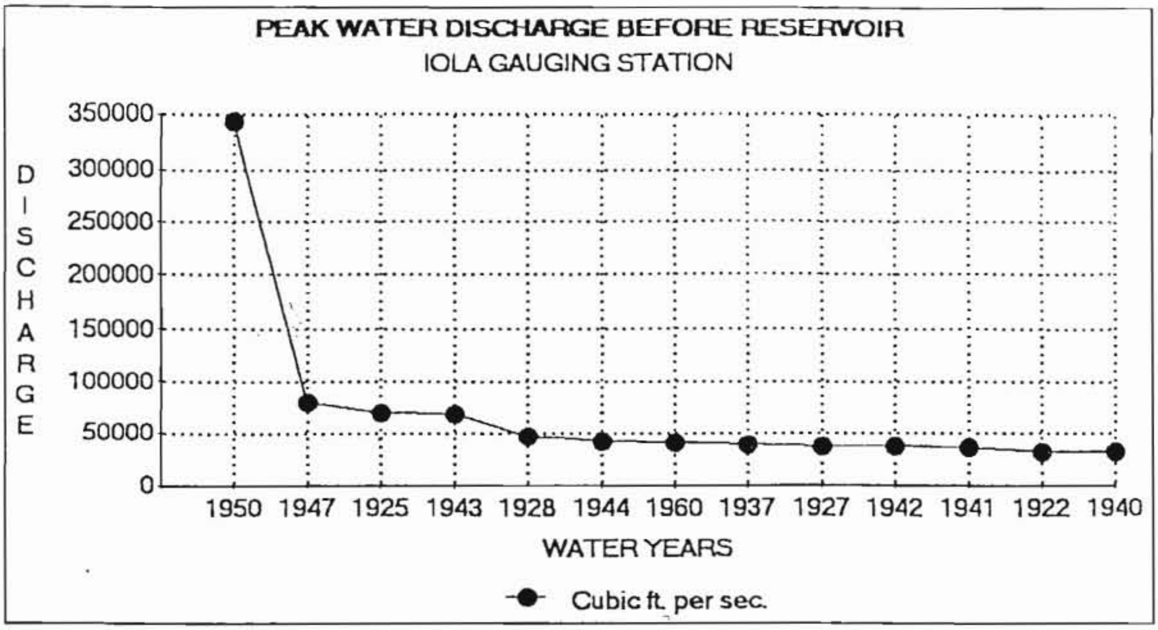

Fig. 10. Before the reservoir, there were many peak annual discharges on the lower Neosho River at Iola near or above the bank-full flow estimate of 32,300 cfs. There were several large out-of-bank floods that exceeded 50,000 cfs.

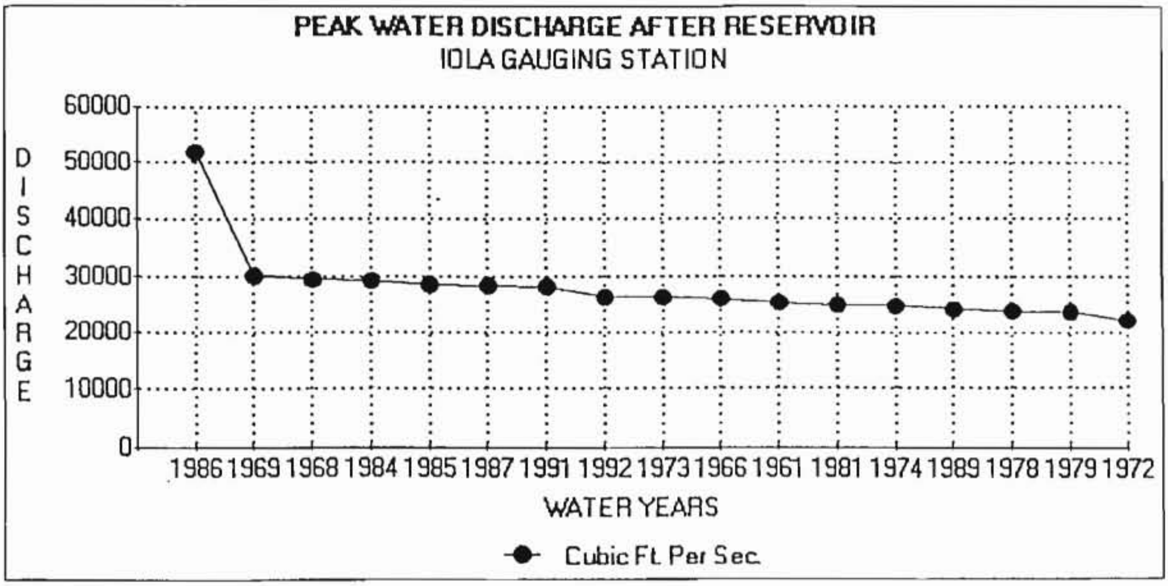

Fig. 11. After the reservoir, nearly all the peak annual discharges are below the bank-full flow estimate of 32,300 cfs for the lower Neosho River at Iola, except for water budget year 1986. In 1986, the peak annual discharge exceeded 50,000 cfs.

Gravel Bars and Riffles:

The following gravel bar sites and associated riffles were analyzed for general geometry and suitability for Neosho madtom habitats within the lower Neosho River: Burlington, Neosho Falls, and Humboldt (see Fig. 1 for general locations). The river channel was quite low, generally 1 - 2 feet (30 - 60 cm) deep at the time of the field study. Therefore, the conditions for observing channel and gravel bar features of the lower Neosho River were ideal. These gravel bar sites are stationary as evidenced by 20-year-old topographic maps.

The Burlington gravel bars and riffles are heavily influenced by the upstream low-water dam and associated plunge pool beneath it. This low-water dam and plunge pool are in close proximity, 60 meters, of the gravel bars and riffles. The main gravel bar is large enough to be qualified as an island. Leopold *et al.* (1964) discussed the creation of gravel bars or islands within close proximity of dams and plunge pools. The build-up or armoring of sediment within close proximity of a dam and plunge pool is created by the high-energy flow conditions associated with them and results in the leveling of the slope of the channel bed. The island is stable enough to support tree root growth that is exposed on the west side due to stream erosion. The island has an asymmetrical lobate or "teardrop" configuration. The channel to the west of the gravel island was deeper and the island exhibited more erosional features on this side.

In general, the gravel island is composed of sandy pebble gravel with some silt intermixed in the more elevated portions. The low-lying and rounded head and the tapering lee portions of the island are composed of large, flat limestone cobbles called flagstones, derived from the bedrock under the plunge pool (Figs. 12 & 13). The flagstones are tilted upstream, a condition called imbrication. The highest segment of gravel bar is the midsection, it is elevated 2 m above the base of the island. This segment is covered by small sand dunes and trees. The west flank of the island exhibits rippled sand due to previous high-flow conditions within the channel.

There are several riffles within the channel in front of and beside the main gravel island (Figs. 12 & 14). The resident biologist, James L. Sumner, had previous experience with the Neosho madtom and its habitat. He judged these riffles as suitable Neosho madtom habitats. These riffles are formed in low-water conditions and composed of well-sorted coarse pebble gravels with little to no sandy matrix material infilling the spaces inbetween.

Fig. 12. Photograph of the head portion of main gravel island at Burlington dam site. Head of the gravel island in the center; upstream riffle to the far right; stream-flow is from left to right. Photo by J.S. Aber, 3/94.

Fig. 13. Photograph of the lee portion of the main gravel island at the Burlington dam site. This segment consists of chert-pebble gravel covered by limestone flagstones derived from plunge pool. Stream-flow is from left to right. Photo by J. S. Aber, 3/94.

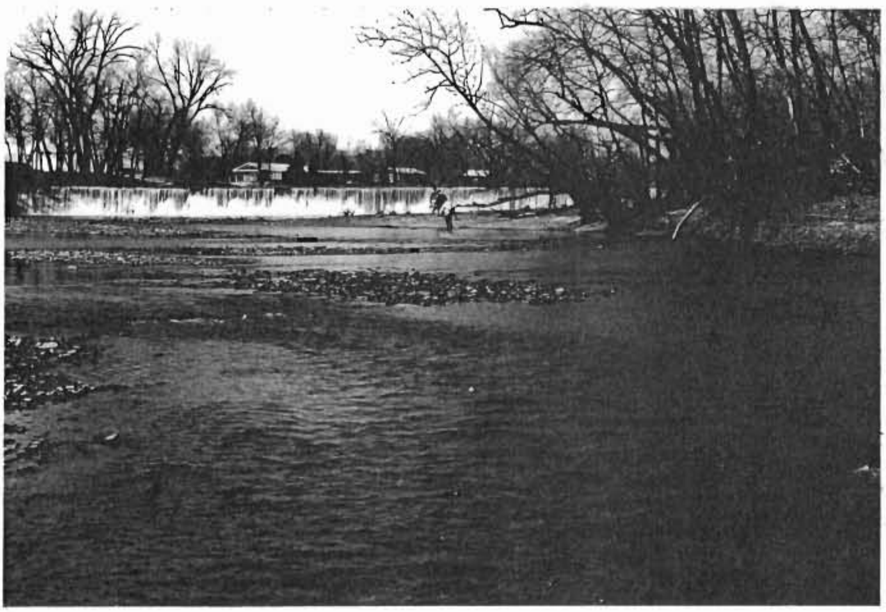

Fig. 14. Photograph of the upstream Burlington low-water dam. The main island is to the right and the riffles are in the center. The riffles are suitable Neosho madtom habitats. Photo by J.S. Aber, 3/94.

The Neosho Falls site consists of two naturally formed gravel bars, void of man-made obstructions within the channel. A low-water dam and a high-water bridge are located further upstream from the gravel bars, but they are far enough away not to influence directly their formations. It was judged this is a gravel-bar complex formed under normal-flow conditions and exhibits the standard channel geometry for naturally occuring bars and riffles within the lower Neosho River channel.

The gravel-bar complex mimics a braided river with a series of gravel bars separated by channels (Fig. 15). The gravel bar to the east formed next to the channel bank and the gravel bar to the west formed in the middle of the channel. The west gravel bar formed in the middle of the channel above a resistant clay substratum. The bars are low-lying and nearly flat, the highest elevation reached above the base of the low-water level mark was 2 feet (60 cm). The elevated portion of the west gravel bar is stable

Fig. 15. Photograph of gravel-bar complex at Neosho Falls. Note the braided configuration of gravel bars separated by channels. View downstream; photo by J. S. Aber, 3/94.

enough to sustain sparse vegetation. The surface of the gravel bars is composed of imbricated chert gravel pebbles and locally derived flat sandstones at the head with chert-pebble gravel infilled with a sandy matrix material downstream towards the lee. The length to width ratios of these gravel bars are 3:1 to 4:1. The riffles at this site are not suitable habitat for the Neosho madtom, because they are composed of chert gravel pebbles infilled with a sandy matrix material. The following physical channel and bar features and their locations are mapped for the Neosho Falls site (Fig. 16):

1. The superposed gravel dunes present at the heads of the large bars and sometimes on the flanks.
2. The lobate or "teardrop" geometry of the gravel bars.
3. The large gravel bars exhibiting blunt heads upstream and tapering lees downstream.
4. The larger sediments, such as the size of flagstones and some cobbles, exhibiting imbrication at the heads of gravel bars.
5. The rippled sand eroded from the channel bank adjacent to the east gravel bar.
6. The restriction of shallow riffles and submerged bars to the upstream and downstream ends of the gravel-bar complex.

The Humboldt low-water dam and plunge pool site consists of two downstream gravel bars on opposite sides of the channel located adjacent to the banks. The larger of the two gravel bars is to the east. It consists of three superposed lobate dunes composed of locally derived large flagstones of sandstone, chert gravels, and man-made materials from bank erosion at the head, pebble gravels at the midsections, and sandy pebble gravels towards the lee (Fig. 17). The superposition of the dunes probably resulted from the high flows of 1993. The smaller bar adjacent to the west bank is heavily damaged due to vehicle use. The riffles are located downstream, but are not suitable Neosho madtom habitats because they lack the open-framework structure that the riffles at the Burlington

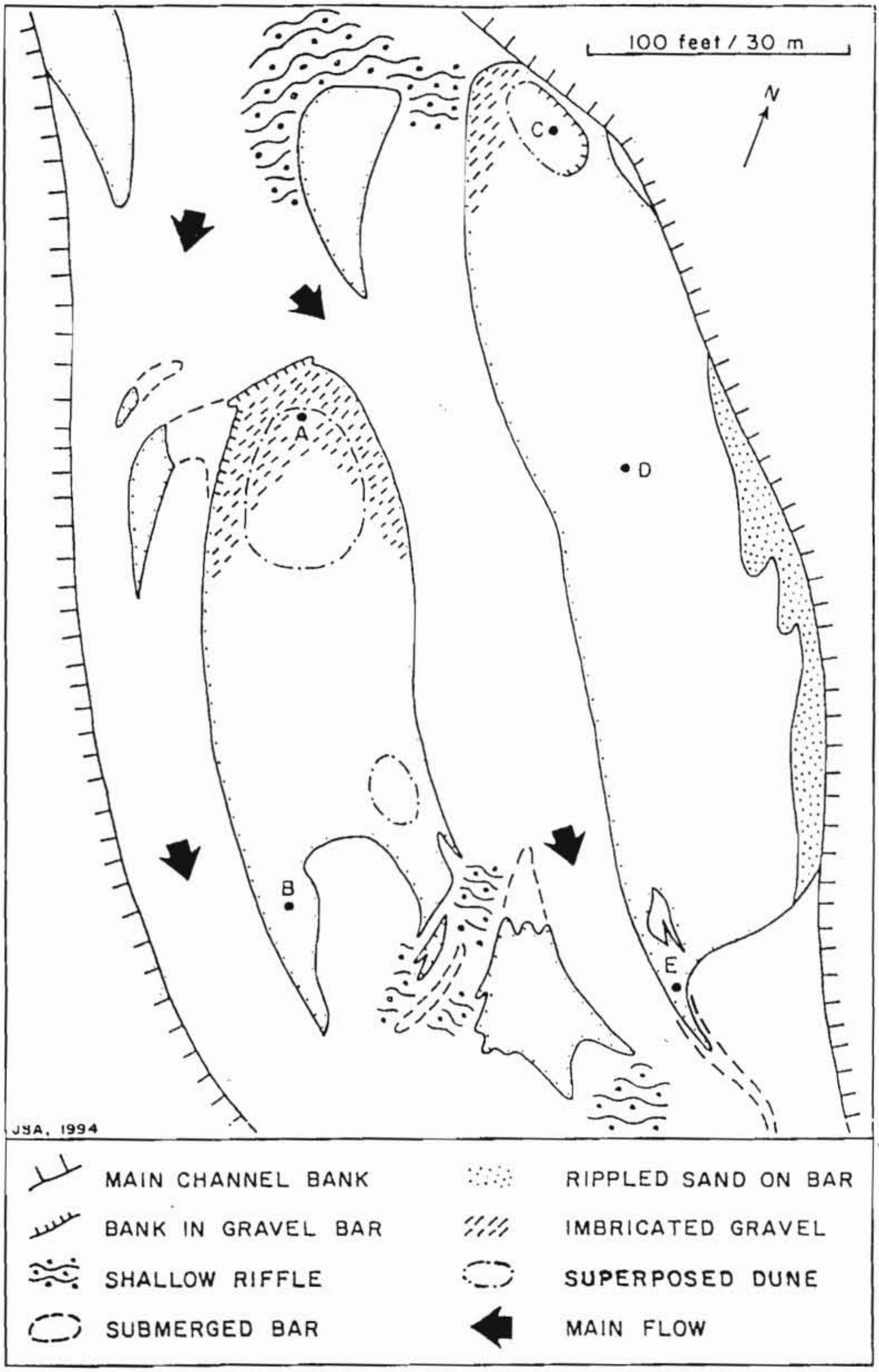

Fig. 16. Survey map of the gravel-bar complex at Neosho Falls, Kansas. The letters correspond with sample sites (Aber and Byerley, 1994a).

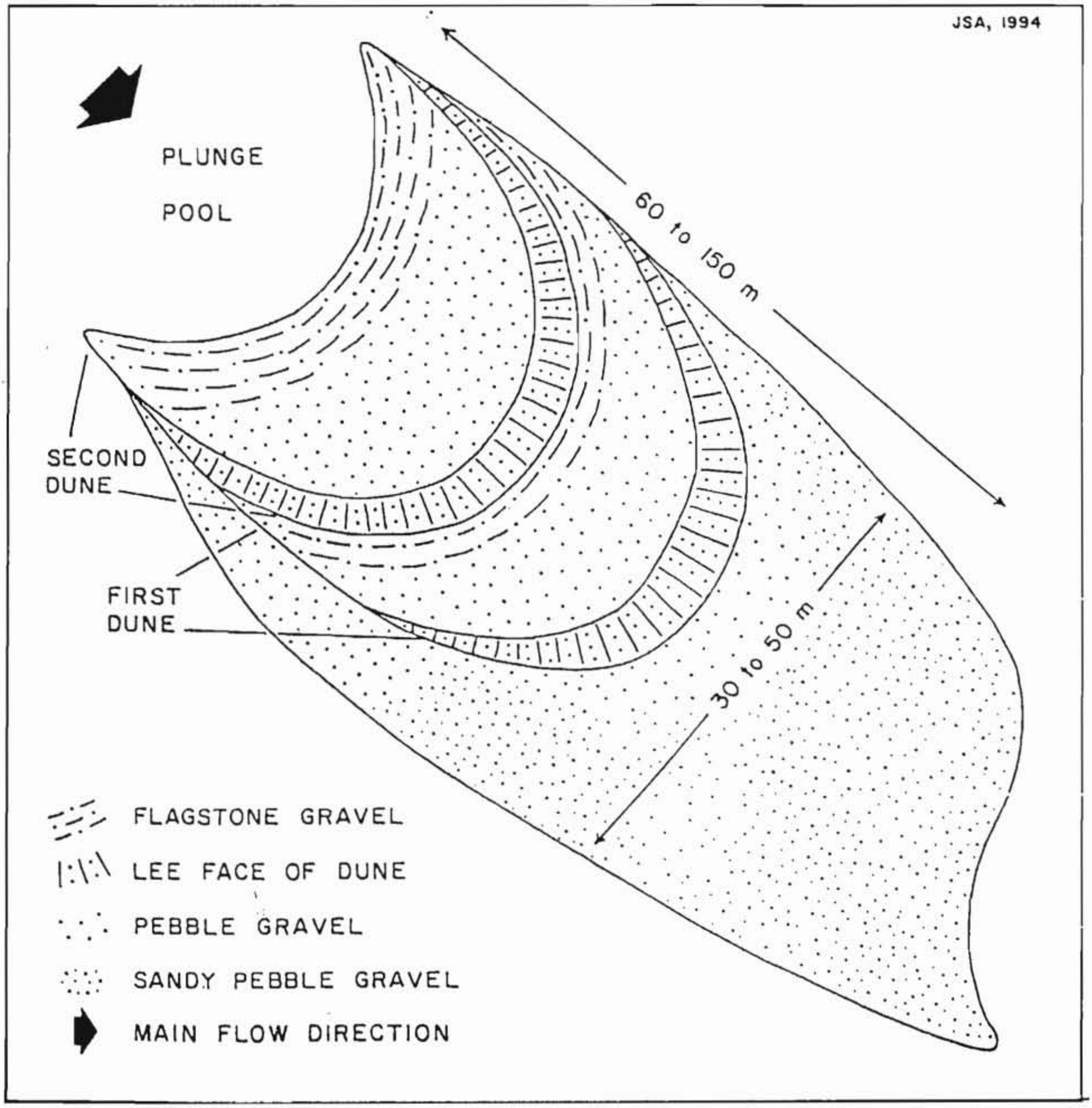

Fig. 17. Schematic illustration of the form and dimensions of gravel bars on the lower Neosho River such as the one at Humboldt, Kansas. This gravel bar type consists of superposed gravel dunes with differing sediment compositions (Aber and Byerley, 1994a).

site exhibited. The chert gravels composing these riffles are infilled with a sandy matrix similiar to the riffles seen at Neosho Falls.

All three gravel bars and associated riffles observed on the lower Neosho River shared common characteristics with respect to their origins, compositions, suitability for Neosho madtom habitats, and channel geometry. Gravel bars and riffles form in the center and adjacent to the banks at sites where the appropriate channel bed conditions exist. The presence of erosion resistent sediment such as clay in the substratum or a low-water dam and plunge pool upstream are deciding factors as to whether a gravel bar is to form and remain at that location. Gravel bars and riffles are strongly influenced by local sources of sediment derived from underneath the plunge pool and the surrounding channel banks. The water velocity within the channel, flooding events, and the position of the gravel bar within the meander of the channel all influence gravel bar position and geometry. The point-bar sequence, in which the sediment builds up on the inside berm and erosion on the outside, does not exactly apply. The lower Neosho River meanders and the bank that receives the greatest water velocity exhibits erosional features and the opposite side is depositional. The gravel bar is a lobate configuration; sediment is gained upstream at the blunt and rounded head and lost downstream at the tapering lee.

Basal Chert Gravels Within the Alluvial Fill of the Modern Floodplain:

Basal chert gravel sources within the alluvial fill underneath the modern floodplains surrounding the Fall River in Wilson County, Kansas and the lower Neosho River in Neosho County, Kansas appear abundant. Mining operations of basal chert gravels from underneath floodplains surrounding the lower Neosho River near the town of St. Paul in Neosho County, Kansas were observed. Also, Foreman (1995) observed basal chert gravels weathering out of the alluvial fill underneath the modern floodplain surrounding the Fall River in Wilson County, Kansas during field studies.

Laboratory Results for Texture and Color Analysis of Gravel Bar Sediment Samples:

The results show variability in the size distribution for sediment sampled (see Appendix D). The sediment appeared to be uniformly distributed at each site. The heads of the gravel bars were covered with larger and coarser material and the lees with smaller and finer material. This apparently is only the surface appearance of the gravel bars sampled. The most prevalent size grade for samples taken at all three study sites was 8 - 16 mm. The typical sediment samples tested were 10 percent to over 20 percent matrix (< 2 mm) material and only a few samples tested had more than 5 percent coarse gravel > 25 mm in size.

The color of the pebbles tested were predominantly yellowish brown (10 YR). Most of the samples were in the moderate yellowish brown (10 YR 5/4) or dark yellowish brown (10 YR 4/2) range. The color pattern is for darker chert pebbles upstream at Burlington, Kansas and lighter pebbles at the two other sites downstream.

CHAPTER 5. INTERPRETATIONS.

Chert Gravel Sources:

The ability of chert gravels upstream of, surrounding, and underneath the modern lower Neosho River valley to erode out of their present positions and enter the channel are limited. It is assumed at least 95 to 99 percent of all tractive sediment transported downstream from the Flint Hills region reaches John Redmond Reservoir and settles down to the bottom of it. Therefore, the lower Neosho River receives little to no sediment from upstream of the reservoir. The only other possible chert gravel sources are upland chert gravels in the area, and the low-terrace and floodplain alluvium surrounding and underneath the modern lower Neosho River valley. The upland chert gravels are not a viable source due to their high topographic positions above and remote locations away from the modern drainage valley. The low-terrace and floodplain alluvium are composed primarily of fine-grained sand, silt, and clay, but not a well-documented source of chert gravel sediments. Even at locations where basal chert gravels appear abundant and are mined from the alluvial fill underneath modern floodplains, it is difficult to determine how abundant of a resource these gravels really are. Therefore, the low-terrace and floodplain soils that comprise the surrounding channel banks and the alluvial fill underneath the modern lower Neosho River are the only viable sources with the potential to resupply the channel with chert gravel.

Chert Gravels and Flooding:

The channel banks surrounding the lower Neosho River are composed of a cohesive combination of fine sand, silt, and clay sediment with some chert gravels held together within a strong root matrix. Only during strong flooding events does erosion of these channel banks take place. The most erosive floods that create the largest amount of change in channel geometry due to stream downcutting or the reworking of the bed-load sediments are during bank-full and out-of-bank flooding events. These types of flooding events were much more frequent before the advent of John Redmond Reservoir than after.

The mean annual flood for the Neosho River before John Redmond Reservoir was close to bank-full flow. This indicates the channel experienced many erosive and channel altering bank-full and out-of-bank flooding events before 1961. The chert gravel sediment was transported from upstream sources in the Flint Hills region, eroded out of the channel banks, and reworked from the bed to be deposited downstream. The chert gravel sources were plentiful and the hydrology of the region sufficient to adequately resupply gravel to downstream bed and bars.

After the advent of John Redmond Reservoir in 1961, the mean annual flood was reduced to well below bank-full flow. The lower Neosho River has stabilized and shows downstream changes such as channel degradation and narrowing of the channel width. The lower Neosho River channel is narrower, deeper, and less prone to bankcutting and meander migration, which lessens the chance for erosion of floodplain alluvium. Now, the Neosho River experiences few erosive out-of-bank or bank-full discharges due to reservoir management.

Since 1961, the only flooding event having a discharge rate of bank-full flow or greater was in 1986 and this was due to reservoir management not the result of a natural flow event. This event resulted in a one-day out-of-bank flow discharge rate that went back to below bank-full flow the next day. Even during the flood of 1993 (water-budget year 1992) the discharge rate reached only 26,400 cfs due to reservoir management; even though a far greater volume of discharge had flowed through the channel over time than in 1986.

Reservoir management has eliminated the natural ability of the river to produce erosive bank-full or greater discharges. Therefore, the river no longer has the ability to erode the channel banks and rework the bed-load sediment to resupply gravel to downstream reaches and bars. Instead, reservoir management has increased the baseflow which has swept away existing bed-load material and lowered the slope. Some reaches of the lower Neosho River flow on bedrock, because bed-load has all been swept away. Also, all water discharged from the reservoir into the lower Neosho River is void of any sediments larger than colloids. This sediment-free discharge does not help resupply downstream beds and bars. The supply of chert gravel sediment that in the past frequently replenished the gravel bars and bed of the lower Neosho River no longer exists due to the John Redmond Reservoir.

Chert Gravel Bars, Riffles, and Dredging:

The chert gravel sources of the lower Neosho River are limited and due to John Redmond Reservoir the river no longer has the ability to erode the channel banks and bed to replenish chert gravel bars and their associated riffles. Therefore, the supply of chert gravel sediment to replenish the gravel bars and riffles of the lower Neosho River are finite. Unless the chert gravel bars and riffles are artificially replaced after dredging, by placing gravel mounds at the appropriate 5 - 7 channel widths, the river eventually will become depleted of gravel sediment. The upland chert gravels surrounding the modern river valley could be mined and used to construct artificial riffles on the lower Neosho River.

A follow-up study to Edds (1993) reconnaisance survey of riffle-bar sites on the Neosho River has determined over half of the proposed sites no longer exist or are not chert gravel riffles at all (Eberle and Stark 1995). Out of 934 predicted riffle-bar sites on the Neosho River only an estimated 330 sites are actually riffle-bars or still remain since the reconnaisance survey. This is further evidence chert gravel bars and riffles within the lower Neosho River channel are not being replenished with gravels and so dredging of these gravels may pose a problem.

According to Cross (1967) and Cross and Collins (1975), the suitable habitat for the Neosho madtom are riffles with an open-framework structure, free of a fine-grained sandy matrix in-filling. Most of the riffles accompanying the chert gravel bars of the lower Neosho River, observed during field studies in March of 1994, were not open-framework structures, void of a sandy matrix in-filling. Therefore, the number of suitable Neosho madtom habitats may be limited. The dredging of the gravel bars and riffles on the lower Neosho River may affect the Neosho madtom habitat because the river lacks the ability to transport and deposit new gravels on a sustained long-term basis. The threatened status of the Neosho madtom is a symptom of human control of the lower Neosho River by the impoundment of John Redmond Reservoir and the subsequent management of that reservoir. Even if dredging operations continue to be banned on the lower Neosho River, the Neosho madtom may be doomed due to human controls having created a situation in which chert gravel sources resupplying this section of the river are finite and non-renewable in the future.

CHAPTER 6. CONCLUSIONS.

1. The areal coverage of alluvial floodplain soils is a total of 547 km² within the six-county study region. The areal coverage of alluvial low-terrace soils is a total of 410 km² for the six-county study region. The areal coverage of old upland alluvial soils consisting of chert gravel is a total of 144 km² for the six-county study region.

2. The high-terrace and hill-top chert gravel deposits are widespread and numerous within the six-county study region, especially Coffey and Anderson Counties, but they are not viable sources to replenish gravel bars within the lower Neosho River channel. The chert gravels are resistant to erosion, topographically located high above the major drainage valleys, and in some segments of the study region are isolated from a major drainage valley altogether.

3. Low-terrace and floodplain alluvium surrounding and underneath the lower Neosho River channel used to be eroded on a frequent basis due to bank-full and out-of-bank flooding events. The alluvial sediment derived from these erosive flooding events included some chert gravels. In the more southern counties of the study region, Neosho and Wilson Counties, basal chert gravels were observed being mined or eroded out of floodplain alluvium surrounding the Fall and Neosho Rivers. Since the advent of John Redmond Reservoir in 1961, the chert gravels no longer enter the channel to replenish gravel bars on a frequent basis due to the lack of floods of magnitude.

4. John Redmond Reservoir and the management of discharge into the lower Neosho River channel has had a profound effect on downstream hydraulics and river channel features. The reservoir serves as a man-made and absolute barrier to the transportation of chert gravels downstream. Due to reservoir management, the baseflow has increased since 1961, sweeping away bed-load sediment and not replacing it. Reservoir

management has stabilized the lower Neosho River by disallowing discharges into it at bank-full or above.

5. The chert gravel sources within the lower Neosho River to replenish gravel bars and riffles are finite. The extraction of the chert gravels currently present within the channel would not be replaced. The Neosho madtom and its habitat may be in danger due to the depletion of gravels and the species dependence on open-framework structures free from in-filling material. The placing of artificial riffles, mined from upland chert gravel deposits, at 5 -7 channels widths could provide for suitable Neosho madtom habitats in the future.

REFERENCES

Aber, J.S. 1985. Quartzite-bearing gravels and drainage development in the eastern Kansas. *Ter-Qua Symposium, Series* 1:105-110.

Aber, J.S. 1988. Upland chert gravels of east-central Kansas. *Kansas Geological Survey, Guidebook Series* 6:17-19.

Aber, J.S. 1992. Chert-gravel, drainage development, and sinkholes in the Walnut Basin, south-central Kansas. *Transactions of the Kansas Academy of Science* 95(1-2):109-121.

Aber, J.S. and Byerley, R.D. 1994a. Progress Report for July 1993 to June, 1994. Unpub. report for Kansas Dept. of Wildlife and Parks, June 1994.

Aber, J.S. and Byerley, R.D. 1994b. Preliminary Report of Findings, December 1994. Unpub. report for Kansas Dept. of Wildlife and Parks, December 1994.

Aber, J.S. and Johnston, P.L. 1990. Geology of the Flint Hills. *Kansas Academy of Science, Guidebook* 3:7-16.

Avery, T.E. and Berlin, G.L. 1992. *Fundamentals of remote sensing and airphoto interpretation*, 5th Ed. Macmillan, New York, 472 p.

Bayne, C.K. and Fent, O.S. 1963. The drainage history of the upper Kansas River basin. *Transactions of the Kansas Academy of Science* 66:363-377.

Burns, C.V. 1971. In-channel hydraulic geometry of streams in Kansas. *Kansas Water Resources Board Tech. Rept. No.* 8, 31 p.

Burrough, P.A. 1986. *Principles of geographcial information systems for land resources assessment*. Oxford Science Publ., Monographs on Soil and Resources Survey No.12, 194 p.

Cross, F.B. 1967. Handbook for fishes of Kansas. *University Kansas Museum Natural History, Misc. Publication* 45.

Cross, F.B. and Collins, J.T. 1975. Fishes in Kansas. *University Kansas Museum Natural History, Public Education Series* 3.

Davis, S.N. and DeWiest, R.J.M. 1966. *Hydrogeology.* J. Wiley & Sons, New York, 463 p.

Eastman, J.R. 1992. *IDRISI User's Guide.* Clark University, Worcester, Massachusetts, 178 p.

Eberle, M.E. and Stark, W.J. 1995. *Distribution and abundance of the Neosho madtom (Noturus placidus) in Kansas, with an assessment of the amount of suitable habitat.* Unpub. report for the Kansas Dept. Wildlife and Parks, 9 p.

Edds, D. 1993. *Neosho and Cottonwood River gravel bars on aerial photos.* Unpub. report for Kansas Dept. Wildlife and Parks, 98 p.

Fleming, E.L., Campbell, H.V. and Weihrouch, R.D. 1982. Soil Survey of Neosho County, Kansas. *U.S. Department Agriculture, Soil Survey Report*, 99 p.

Fleming, E.L., Fortner, J.R. and Swanson, D.W. 1978. Soil Survey of Allen County, Kansas. *U.S. Department Agriculture, Soil Survey Report*, 86 p.

Foreman, B.L. 1995. Mammals of the late Pleistocene (Rancholabrean) Wilson Ford local fauna, Wilson County, Kansas. *Kansas Academy of Science, Volume* 14:21.

Frye, J.C. 1955. The erosional history of the Flint Hills. *Transactions of the Kansas Academy of Science* 59:79-86.

Frye, J.C. and Leonard, A.B. 1952. Pleistocene geology of Kansas. *Bulletin of the Kansas Geological Survey* 99:1-230.

Haworth, E. 1896. Surface gravels of the Carboniferous area. *University Geological Survey of Kansas, Volume* 1:246-255.

Hedman, E.R., and Kastner, W.M. 1972. Mean annual runoff as related to channel geometry of selected streams in Kansas. *Kansas Water Resources Board Tech. Rept. No.* 9, 25 p.

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 Tech. Rept. No.* 10, 21 p.

Jordan, P.R., and Hedman, E.R. 1970. Evaluation of the surface-water data program in Kansas. *Kansas Water Resources Board Bulletin No.* 12, 49 p.

Krueger, R. 1993. *Chert gravel and drainage development in Chase County, Kansas.* Unpub. Master's thesis, Emporia State University, 63 p.

Law, M.S. 1986. *Mapping of upland chert gravel deposits, east-central Kansas.* Unpub. graduate research report, Emporia State University, 30 p.

Leopold, L.B., and Maddock, T. Jr. 1953. The hydraulic geometry of stream channels and some physiographic implications. *U.S. Geological Survey Professional Paper* 252:1-56.

Leopold, L.B., and Wolman, M.G. 1957. River channel patterns: braided, meandering and straight. *U.S. Geological Survey Professional Paper* 282-B:39-85.

Leopold, L.B., Wolman, M.G. and Miller, J.P. 1964. *Fluvial processes in geomorphology.* Freeman, San Francisco, 522 p.

Mudge, B.F. 1875. Geology of Kansas. *Fourth Annual Report of the Kansas State Board of Agriculture*: 107-127.

O'Connor, H.G. 1953. Geology, mineral resources, and groundwater resources of Lyon County, Kansas. *State Geological Survey of Kansas, Volume 12 (part 1: Rock Formations)*:5-24.

Osterkämp, W.R. and Hedman, E.R. 1981. Channel geometry of regulated streams in Kansas as related to mean discharge, 1970 - 1980. *Kansas Water Office Tech. Rept. No.* 15, 32 p.

Parker, J.D. 1884. The Burlington gravel beds. *Kansas City Review of Science and Industry* 8(7):386-387.

Richards, K. 1982. *Rivers: Form and process in alluvial channels*. Methuen, London, 361 p.

Sallee, K.H. 1977. Soil Survey of Anderson County, Kansas. *U.S. Department Agriculture, Soil Survey Report*, 58 p.

Seevers, W.J. and Jungmann, W.L. 1963. Terrace development along Marais des Cygnes and Neosho River valley, Kansas. *Transactions of the Kansas Academy of Science* 66:393-396.

Sleezer, R.O. 1990. *Drainage development and chert gravel deposits in Butler County, Kansas*. Unpub. Master's thesis, Emporia State University, 37 p.

Swanson, D.W. 1982. Soil Survey of Coffey County, Kansas. *U.S. Department Agriculture, Soil Survey Report*, 105 p.

Swanson, D.W. 1989. Soil Survey of Wilson County, Kansas. *U.S. Department Agriculture, Soil Survey Report*, 123 p.

Swanson, D.W. and Googins, R. L. 1977. Soil Survey of Woodson County, Kansas. *U.S. Department Agriculture, Soil Survey Report*, 67 p.

West, E.P. 1885. The last sumersion and emergence of southeastern Kansas from Carboniferous seas, or those affecting the Carboniferous formations in Kansas. *Transactions of the Kansas Academy of Science* 9:106-109.

Wolman, M.G., and Leopold, L.B. 1957. River flood plains; some observations on their formation. *U.S. Geological Survey Professional Paper* 282-C:1-57.

Wooster, L.C. 1914. The chert gravels of eastern Kansas. *Transactions of the Kansas Academy of Sciences* 27:58-62.

_____. 1934. The chert gravels of Lyon County, Kansas. *Transactions of the Kansas Academy of Science*, 37:157-159.

Zeller, D.E. 1968. The stratigraphic succession in Kansas. *Bulletin of the Kansas Geological Survey* 189:1-81.

Appendix A: County and Quadrangle Topographic Maps.

The 1 : 100,000 metric scale county maps that were used as base maps to digitize from are:

Allen County, Kansas 100,000-scale Metric Topographic Map (1986)

Anderson County, Kansas 100,000-scale Metric Topographic Map (1987)

Coffey County, Kansas 100,000-scale Metric Topographic Map (1982)

Neosho County, Kansas 100,000-scale Metric Topographic Map (1981)

Woodson County, Kansas 100,000-scale Metric Topographic Map (1987)

Wilson County, Kansas 100,000-scale Metric Topographic Map (1987)

The 1 : 24,000 topographic quadrangles used as base maps to digitize from are:

Aliceville

Altoona

Blue Mound

Bronson

Buffalo

Burlington

Bush City

Buxton

Centerville

Chanute

Coyville

Earlton

Elsmore

Erie

Five Mounds

Fredonia

Galesburg

Garnett East

Garnett SE

Garnett West

Gridley

Gridley NW

Gridley SE

Harris

Appendix A-continued

Hartford
Humboldt
Iola
Iola SE
John Redmond
La Fontaine
La Harpe
Lebo
Leon
Leroy
McClune NE
Middletown
Moran
Moran SE
Morehead
Neodesha
Neosho Falls
New Albany
New Strawn
Ottumwa
Piqua
Potterville
Quincy
Rollin
Shaw
South Mound
Stark
Thayer
Toronto
Toronto NE
Toronto SE
Vilas
Walnut
Waverly East
Waverly SE
Waverly West
Welda
Westphalia
Yates Center
Yates Center SE

Appendix B: Maximum Annual Discharges.

owing maximum annual discharges are in cfs and were taken from the Iola stream-
ords that span water budget years 1917 - 1992:

1917 = 11,000	1938 = 2,860
1918 = 17,400	1939 = 6,950
1919 = 4,500	1940 = 31,800
1920 = 9,320	1941 = 35,600
1921 = 28,000	1942 = 36,300
1922 = 31,800	1943 = 68,200
1923 = 6,070	1944 = 42,200
1924 = 11,300	1945 = 22,400
1925 = 69,200	1946 = 27,100
1926 = 27,000	1947 = 79,300
1927 = 36,300	1948 = 21,000
1928 = 47,400	1949 = 18,800
1929 = 16,800	1950 = 344,000
1930 = 5,290	1951 = 15,000
1931 = 20,200	1952 = 3,920
1932 = 9,320	1953 = 12,400
1933 = 15,300	1954 = 7,340
1934 = 25,900	1955 = 6,230
1935 = 17,400	1956 = 20,300
1936 = 11,300	1957 = 22,900
1937 = 39,100	1958 = 15,000

Appendix B-continued

1959 = 19,400

1960 = 41,300

1961 = 25,400

1962 = 12,300

1963 = 10,100

1964 = 16,800

1965 = 8,800

1966 = 26,100

1967 = 17,400

1968 = 29,500

1969 = 30,200

1970 = 12,300

1971 = 15,200

1972 = 24,100

1973 = 26,400

1974 = 24,900

1975 = 9,600

1976 = 18,900

1977 = 19,000

1978 = 23,800

1979 = 23,700

1980 = 8,620

1981 = 25,000

1982 = 20,900

1983 = 18,500

1984 = 29,300

1985 = 28,600

1986 = 51,900

1987 = 28,400

1988 = 20,900

1989 = 24,300

1990 = 6,260

1991 = 28,200

1992 = 26,400

Appendix C: Color Plates For Individual Counties.

Color scheme for county maps:

Alluvial upland chert gravels	Bright red
Low terrace alluvium (major valleys only)	Brown
Floodplain alluvium (major valleys only)	Yellow
Major hydrologic features (rivers and lakes)	Dark blue
Principal city (largest center of population)	Pale pink
General county area	Green

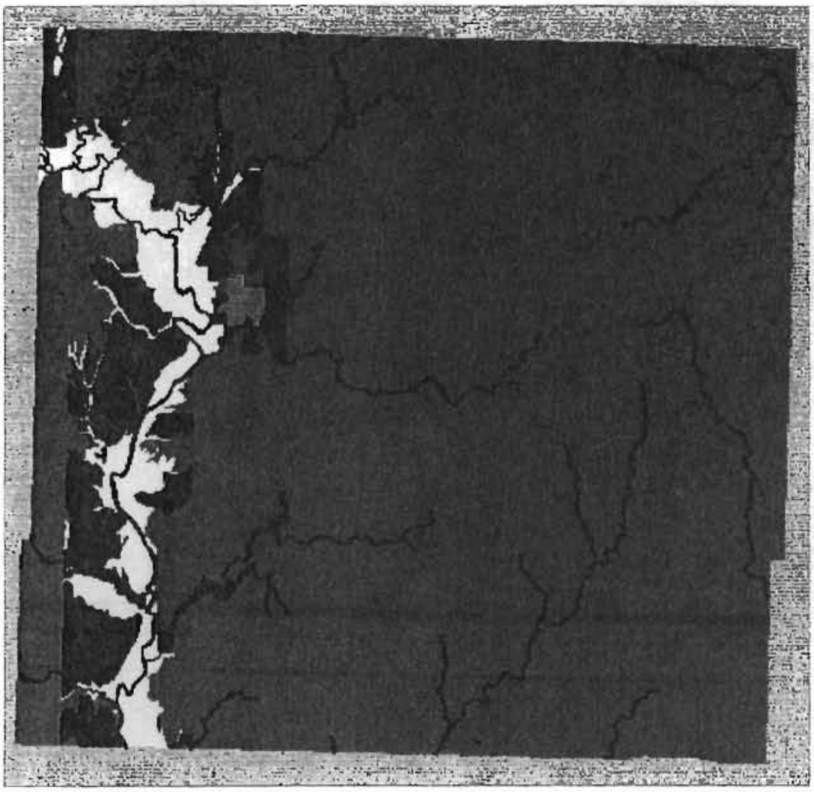

Plate I. Allen County, Kansas.

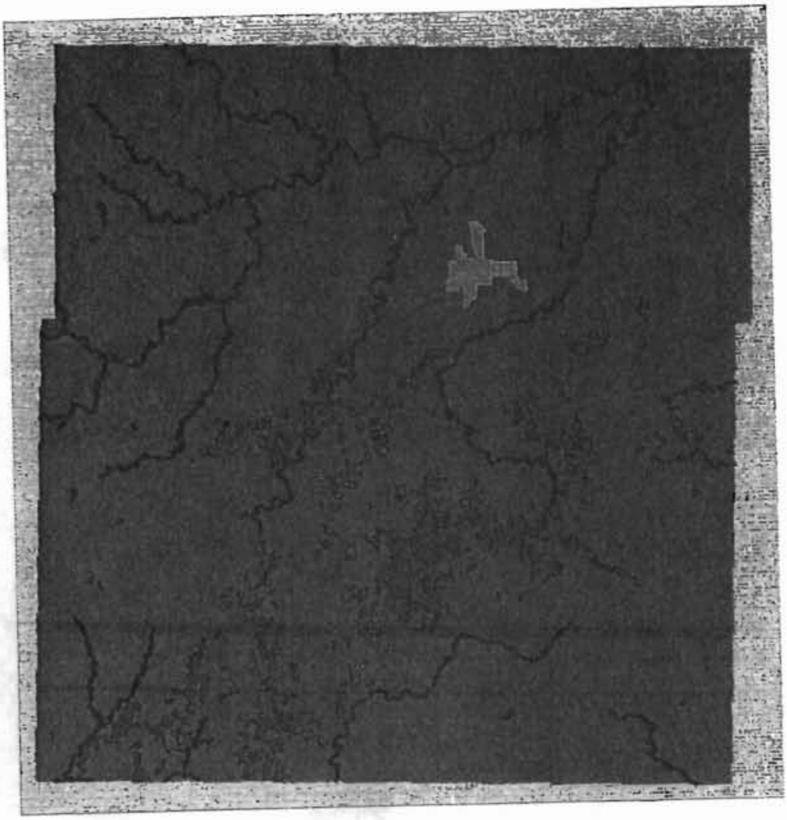

Plate II. Anderson County, Kansas.

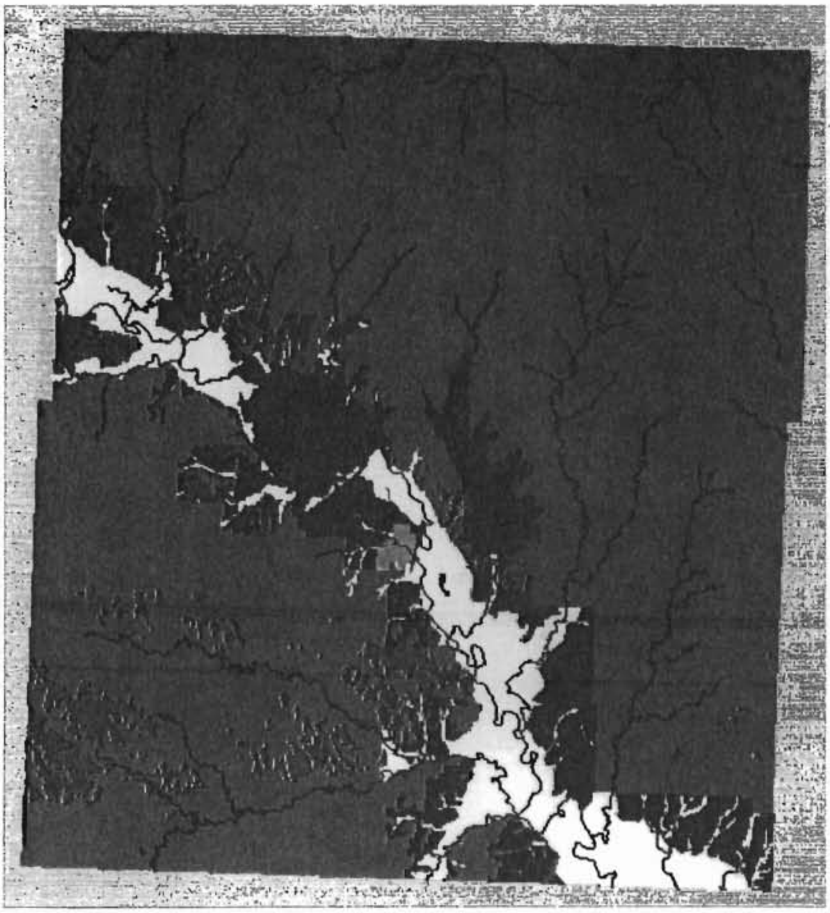

Plate III. Coffey County, Kansas.

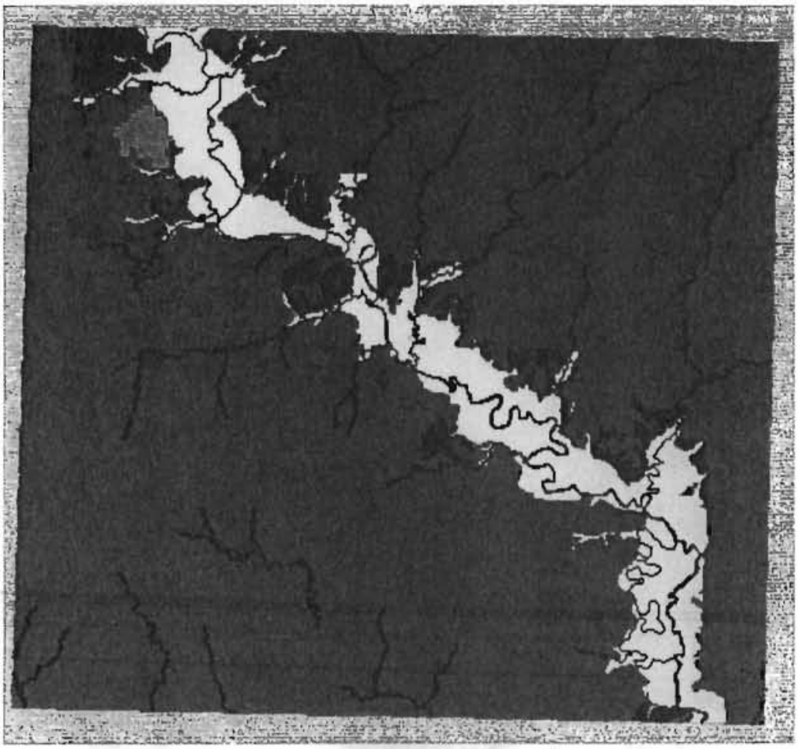

Plate IV. Neosho County, Kansas.

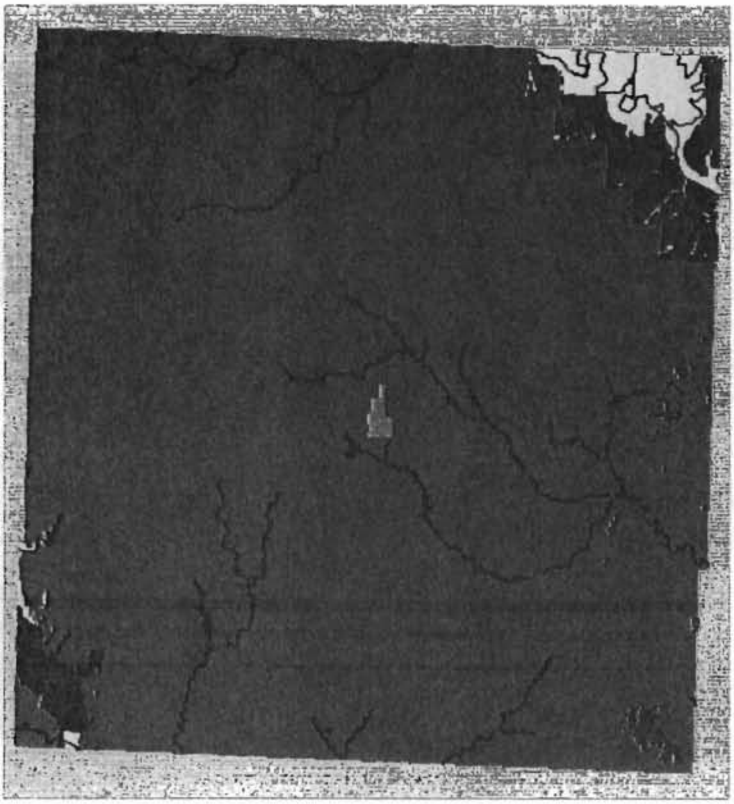

Plate V. Woodson County, Kansas.

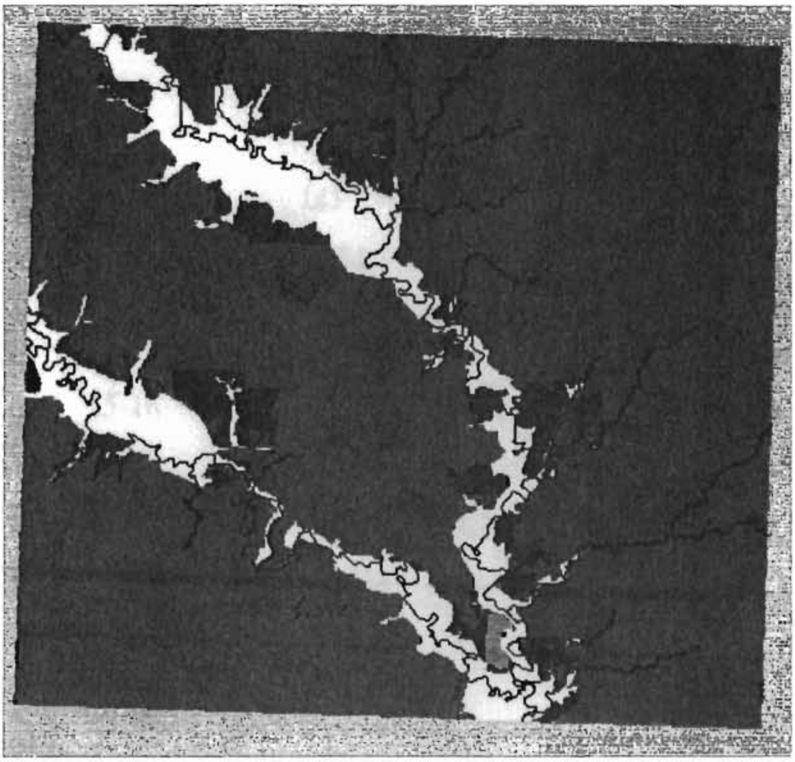

Plate VI. Wilson County, Kansas.

Appendix D: Laboratory Results.

Sample	Weight	(g)	(%)	Color 25-16	mm
Burlington A	Init	2354.3		10 YR 5/4	2
	> 25	0	0	10 YR 4/2	11
	25-16	204.0	8.7	10 YR 2/2	3
	16-8	729.2	31.0	5 YR 4/4	1
	8-4	876.8	37.2	5 YR 3/4	1
	4-2	420.0	17.8		
	< 2	124.3	5.3		
Burlington B	Init	2698.3		10 YR 5/4	2
	> 25	67.7	2.5	10 YR 4/2	18
	25-16	408.7	15.1	10 YR 2/2	4
	16-8	789.4	29.3	5 YR 3/2	5
	8-4	580.0	21.5	5 YR 3/4	6
	4-2	251.5	9.3		
	< 2	601.0	22.3		
Burlington C	Init	2214.3		10 YR 2/2	1
	> 25	0	0	10 YR 4/2	12
	25-16	132.7	6.0		
	16-8	500.6	22.6		
	8-4	644.1	29.1		
	4-2	436.5	19.7		
	< 2	500.4	22.5		

Sample	Weight	(g)	(%)	Color 25-16	mm
Burlington D	Init	2376.6		10 YR 2/2	4
	> 25	202.4	8.5	10 YR 4/2	18
	25-16	496.3	20.9	10 YR 6/2	1
	16-8	707.0	29.7	10 YR 5/4	3
	8-4	519.3	21.9		
	4-2	281.5	11.8		
	< 2	170.1	7.2		
Neosho Falls A	Init	2174.7		10 YR 2/2	2
	> 25	55.7	2.6	10 YR 4/2	11
	25-16	219.7	10.1	10 YR 8/2	1
	16-8	527.1	24.2	10 YR 5/4	6
	8-4	357.1	16.4		
	4-2	231.0	10.6		
	< 2	783.8	36.0		
Neosho Falls B	Init	2741.6		10 YR 2/2	3
	> 25	0	0	10 YR 5/4	15
	25-16	376.4	13.7	10 YR 4/2	14
	16-8	777.2	28.3	10 YR 6/6	1
	8-4	646.0	23.6	10 YR 6/2	2
	4-2	348.7	12.7	10 R 5/4	1
	< 2	593.3	21.6		

Sample	Weight	(g)	(%)	Color 25-16	mm
Neosho Falls C	Init	2430.1		10 YR 5/4	28
	> 25	88.1	3.6	10 YR 4/2	11
	25-16	485.6	20.0	10 YR 7/2	1
	16-8	720.8	29.7	10 YR 8/2	5
	8-4	543.8	22.4		
	4-2	268.0	11.0		
	< 2	323.5	13.3		
Neosho Falls D	Init	2499.8		10 YR 5/4	1
	> 25	0	0	10 YR 4/2	6
	25-16	285.6	11.4	5 YR 3/4	2
	16-8	642.3	25.7		
	8-4	593.3	23.7		
	4-2	280.1	11.2		
	< 2	698.5	27.9		
Neosho Falls E	Init	2438.2		10 YR 4/2	7
	> 25	0	0	10 YR 5/4	5
	25-16	127.0	5.2		
	16-8	648.1	26.6		
	8-4	514.8	21.1		
	4-2	301.0	12.3		
	< 2	847.3	34.8		

Sample	Weight	(g)	(%)	Color 25-16	mm
Humboldt A	Init	2257.3		10 YR 2/2	2
	> 25	138.3	6.1	10 YR 4/2	37
	25-16	495.7	22.0	10 YR 5/4	6
	16-8	646.9	28.7		
	8-4	346.2	15.3		
	4-2	275.1	12.2		
	< 2	355.1	15.7		
Humboldt B	Init	2361.8		10 YR 5/4	13
	> 25	61.7	2.6	10 YR 4/2	20
	25-16	361.7	15.3		
	16-8	744.8	31.5		
	8-4	619.1	26.2		
	4-2	381.9	16.2		
	< 2	192.6	8.2		
Humboldt C	Init	2911.8		10 YR 5/4	20
	> 25	20.1	0.7	10 YR 4/2	19
	25-16	614.8	21.1	10 YR 2/2	2
	16-8	780.8	26.8	5 YR 4/4	8
	8-4	428.5	14.7	5 YR 3/4	2
	4-2	254.9	8.8	10 R 3/4	1
	< 2	812.7	27.9		

Sample	Weight	(g)	(%)	Color 25-16	mm
Humboldt D	Init	2749.5		10 YR 2/2	2
	> 25	0	0	10 YR 4/2	24
	25-16	190.4	6.9	10 YR 8/2	2
	16-8	490.5	17.8	10 YR 5/4	9
	8-4	377.7	13.7		
	4-2	325.0	11.8		
	< 2	1365.9	49.7		
Humboldt E	Init	2514.0		10 YR 4/2	21
	> 25	141.5	5.6	10 YR 5/4	21
	25-16	492.9	19.6		
	16-8	467.7	18.6		
	8-4	357.0	14.2		
	4-2	196.3	7.8		
	< 2	858.6	34.1		
Humboldt F	Init	2756.0		10 YR 4/2	32
	> 25	315.9	11.5	10 YR 5/4	8
	25-16	533.5	19.4	5 YR 3/4	1
	16-8	625.2	22.7		
	8-4	435.1	15.8		
	4-2	265.4	9.6		
	< 2	580.9	21.1		

COLOR TOTALS BY SITE:

	Burlington (A-D)		Neosho Falls (A-E)		Humboldt (A-F)	
	No.	%	No.	%	No.	%
10 YR (yellowish brown)						
8/2			6	4.9	2	0.8
7/4			1	0.8		
6/2	1	1.2	2	1.6		
6/6			1	0.8		
5/4	7	8.5	55	45.1	77	30.9
4/2	49	59.8	49	40.2	153	61.4
2/2	12	14.6	5	4.1	5	2.0
5 YR (brown)						
4/4	1	1.2			8	3.2
3/4	7	8.5	2	1.6	3	1.2
3/2	5	6.1				
10 R (reddish brown)						
5/4			1	0.8		
3/4					1	0.4
Total	82		122		249	

* Colors arranged from lightest (8/2) to darkest (2/2) in each category.

Appendix E: Computer Raster Image Files.

(Disk in pocket on p. 79)

Raster Image File Description	File Name
1. Allen County, Kansas	ALL
2. Anderson County, Kansas	AND
3. Coffey County, Kansas	COFF
4. Neosho County, Kansas	NEO
5. Woodson County, Kansas	WOOD
6. Wilson County, Kansas	WIL

* All raster image files are viewed with the PRINT pallette file using the IDRISI COLOR module.

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Ruben D. Byerley

Signature of Author

4/20/95

Date

Chert Gravel Sources, Hydrology,
Transportation, and Deposition,
Within the Lower Neosho River,
Southeastern Kansas

Title of Thesis

Doug Cooper

Signature of Graduate Office Staff Member

May 2, 1995

Date Received