AN ABSTRACT OF THE THESIS OF

Cameron L. Cooper for the Master of Science Degree in Physical Science

presented on November 30, 2001.

Title: Using Geographic Information Systems (GIS) to Investigate Paleo-Drainage of the Lower Smoky Hill River, Central Kansas

Abstract Approved: ______________________

Committee Members: Dr. James S. Aber
Dr. Dan Merriam
Dr. Richard O. Sleezer, Chairperson

The focus of this study is the drainage history for the Smoky Hill River in central Kansas. The present interpretation is that during early Pleistocene time the Smoky Hill River flowed southward into the Arkansas River Basin through a bedrock channel known as the McPherson Valley. During mid-to-late Pleistocene the Smoky Hill River was diverted into the Kansas River system by a capture event resulting from incision and headward erosion by the Kansas River. The purpose of this study was to use Geographic Information Systems (GIS) techniques to understand more thoroughly the geomorphic history of the Smoky Hill River and capture events that have affected its course. A bedrock topography map was constructed from well logs in Kansas Geological Survey (KGS) Bulletins and Water Well Completion Records (WWC5) to search for bedrock channels marking previous positions of the Smoky Hill River and to study the influence of bedrock topography on present and past drainage patterns. Field studies were conducted to establish the positions of high-terraces

along the Smoky Hill River Valley that correspond to previous positions of the channel. Correlations between high-terrace deposits and modern soil map units were used to plot paleo-flow directions and postulate previous stream positions.

Results from this study suggest that the ancestral Smoky Hill River connected to the Arkansas River during late Pliocene/early Pleistocene. High-terrace deposits of fluvial origin were found throughout the study area. The elevation and composition of these terraces suggest that the ancestral Smoky flowed at a higher elevation than at present. The elevations of the terraces were compared to the bedrock divide (McPherson Ridge) that separates the modern Smoky Hill River from the Little Arkansas River. It was found that the terraces were approximately 50 m (165 ft) higher than the bedrock divide that is approximately 407 m (1335 ft) above mean sea level. Some geologists have suggested that the McPherson Channel was actually formed by glacial meltwater from the Kansas River Basin. This study may suggest glacial meltwater from the northeast to be an invalid explanation for the erosion of the paleo-channel. The apparent lack of exotic pebbles such as Sioux Quartzite in high-terraces and Equus Beds sediments disagree with this interpretation. Also, elevation differences between the spillover point (McPherson Divide) near Lindsborg of 407 m (1335 ft) and the glacial dam at 320 m (1050 ft) across the Kansas River Valley suggests that the connection between the two valleys was not the result of a glacial meltwater lake, but more likely a result of the ancestral Smoky Hill River flowing southward through the McPherson Valley.

# USING GEOGRAPHIC INFORMATION SYSTEMS (GIS) TO INVESTIGATE THE PALEO-DRAINAGE OF THE LOWER SMOKY HILL RIVER, CENTRAL KANSAS

A Thesis
Presented to
The Department of Physical Sciences

EMPORIA STATE UNIVERSITY

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

by

Cameron L. Cooper

December 2001

Thesis
2001
C

Approved by Major Advisor
Dr. R.O. Sleezer

Approved by Committee Member
Dr. James S. Aber

Approved by Committee Member
Dr. Dan Merriam

Approved by Department Chair
Dr. DeWayne Backhus

Approved for the Dean of Graduate
Studies and Research
Dr. Timothy M. Downs

# ACKNOWLEDGEMENTS

I would like to extend my deepest gratitude and appreciation to the following persons. I would like to thank Dr. James Aber for his time and field assistance for this project. To Dr. Richard O. Sleezer for his time and devotion and belief in this thesis. He has provided much help and guidance as a mentor and a friend. To Dr. Dan Merriam for his unparalleled knowledge of Kansas Geology and help on this project. I want to especially give credit to my family and friends for their encouragement and support. I would like to express deepest gratitude to my wife and best friend who has always believed in me.

## TABLE OF CONTENTS

## FIGURES

# Chapter 1. Introduction

## Background

As the Smoky Hill River flows through McPherson County, Kansas, the river exhibits an anomalous northward bend from the town of Lindsborg to the city of Salina before connecting with the Kansas River (Fig. 1). This northward bend has been interpreted as resulting from the capture of the ancestral Smoky Hill River by the Kansas River. Prior to capture, the Smoky Hill River apparently flowed southward into the Arkansas River between the towns of Marquette and Lindsborg in McPherson County (Frye *et al.,* 1943; Williams and Lohman, 1949; Waterman and Krieger, 1950; Lane and Miller, 1965).

Evidence for this ancestral stream system are the high-terrace deposits located upstream along the Smoky Hill River Valley and the buried bedrock channel in McPherson and Harvey Counties in Kansas (Frye *et al.,* 1943; Williams and Lohman, 1949; Lane and Miller, 1965). The northern extent of the buried channel known as the "McPherson Channel" or "McPherson Valley" is located a few kilometers south of Marquette and Lindsborg. The bedrock channel is believed to have connected drainage from the ancestral Smoky Hill River to the Arkansas River Basin toward the south (Udden, 1891; Beede, 1898; Frye *et al.,* 1943; Williams and Lohman, 1949; Fent, 1950; Lane and Miller, 1965).

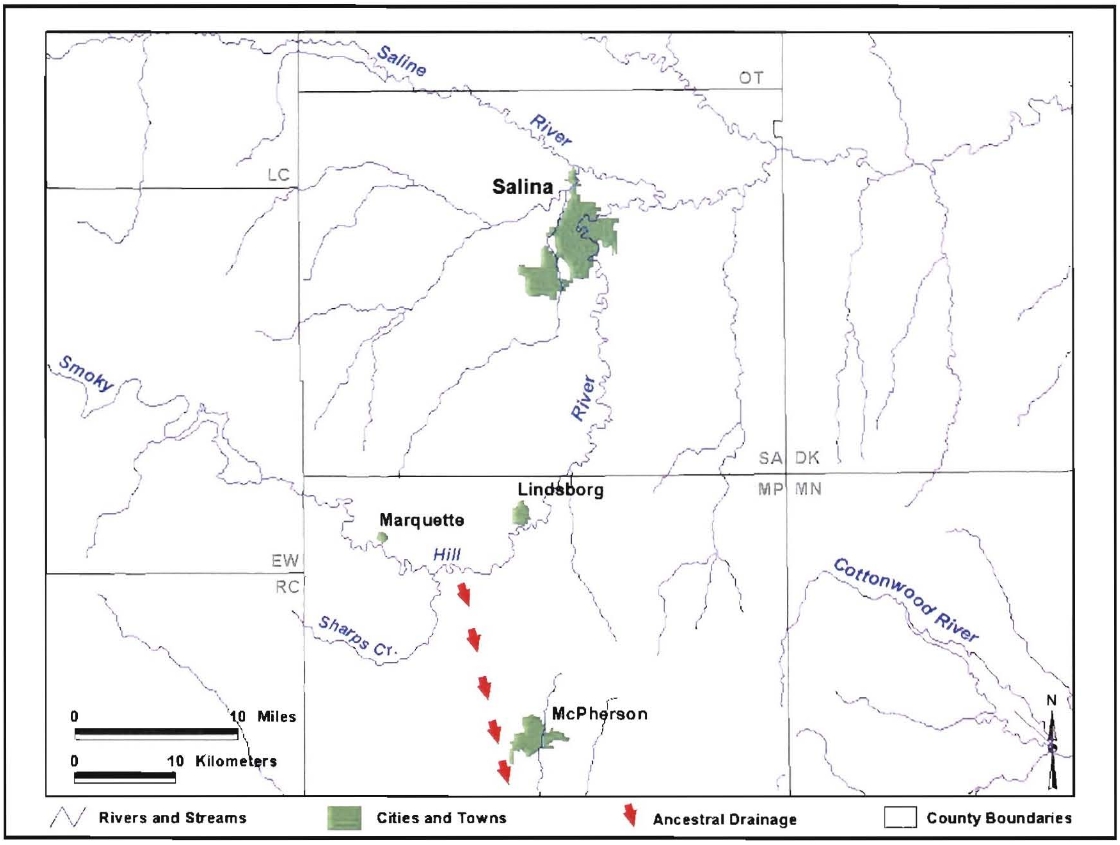



Figure 1. Location of the lower Smoky Hill River in central Kansas.

While the capture sequence discussed in the previous paragraph is the generally accepted explanation for the Smoky Hill River's anomalous northward turn, no modern studies of the geomorphic history of this river system have been conducted. In addition, the plausibility of the link between the ancestral Smoky Hill River and the McPherson Channel has not been investigated thoroughly using modern techniques. The purpose of this study is to provide evidence that should clarify the connection between the ancestral Smoky Hill River and the McPherson Channel. Geographic information systems (GIS) provide a convenient set of tools to investigate the spatial relationships between the bedrock divide at the northern end of the McPherson Channel, paleo-terraces, and the present-day streams.

## Previous Studies

Geologists have proposed two hypotheses for the development of the McPherson Channel. The first involved a fluvial or meltwater lake connection between the Kansas River valley and the McPherson Channel (Sharp, 1894; Frye and Leonard, 1952) in McPherson County. Sharp (1894) was among the first to advance the meltwater lake hypothesis for the formation of the McPherson Equus Beds. Sharp believed that glacial ice flowing out of the Big Blue River Valley blocked the Kansas River Valley during a glacial advance. The resulting meltwater lake from the Kansas River supposedly backed water up the Kansas River Valley to a low point near Lindsborg where water spilled over a drainage divide into the Little Arkansas River Basin thus creating the McPherson Channel and depositing Equus Beds sediments. Because this spillover point corresponded to an area where relatively soft Permian shales outcropped, it was believed the meltwater carved out the McPherson Channel very rapidly. Eventually, the ice dam was breached possibly resulting in catastrophic flooding as glacial meltwater flowed down the Kansas River Valley. After this event, the "McPherson Channel" was stranded well above the Smoky Hill River Valley to be filled in later by fluvial events to create the present Equus Beds aquifer in McPherson and Harvey counties (Sharp, 1894).

Later research published by Haworth and Beede (1897) and Beede (1898) was unable to validate the glacial lake hypothesis proposed by Sharp (1894). Haworth and Beede (1897) and Beede (1898) investigated the elevation of the drainage divides between the Smoky Hill River and Arkansas Rivers and concluded that the glacial lake hypothesis was not feasible. The elevation of the drainage divide between the Kansas and the Smoky Hill Rivers west of Manhattan is approximately 320 m (1050 ft). The present drainage divide between the Smoky Hill and Arkansas River Valleys in McPherson County is approximately 450 m (1500 ft). Water backed up behind a glacial dam near Manhattan could not have risen to the necessary elevation to flow over the McPherson Ridge because lower overflow points existed closer to Manhattan.

Based on available evidence Haworth and Beede (1897) and Beede (1898) rejected Sharp's (1894) glacial lake hypothesis. However, they could not put forth a better working hypothesis for the formation of the McPherson Valley. The main problem associated with validating a connection to the Equus Beds from either a glacial lake or the ancestral Smoky Hill River from the west was the elevation needed for each to cross the drainage divide that now separates the Smoky Hill from the Arkansas River. At this time no high-terrace deposits had been located along the Smoky Hill River. High-terrace deposits would indicate that Smoky Hill River channel was much higher in the landscape at some time in the past. Possibly high enough to allow it to flow over the drainage divide between the Smoky Hill and Arkansas River drainage basin to the south. It seems that the modern channel of the Smoky Hill River would need to have flowed approximately 61 m (200 ft) higher at Lindsborg to flow south into the McPherson Valley. Likewise, a meltwater lake near Manhattan would need to be at least 137 m (450 ft) higher than the present stream level flow over the same divide at Lindsborg. Each hypothesis seemed to contain questionable circumstances concerning their involvement in the formation of the Equus Beds.

Later discoveries by Frye (1939) and Lohman and Frye (1940) suggested that the present drainage divide between the Smoky Hill River and Arkansas River was actually capped by as much as 33 m (110 ft) of loess. This allowed for the drainage divide into the McPherson Valley to be considerably lower in elevation than previously thought. This result strengthens the ancestral Smoky Hill and glacial lake hypotheses for development of the McPherson Channel.

High-terrace deposits of Pleistocene age that range from 23-46 m (75-150 ft) above the modern Smoky Hill floodplain were described by Frye *et al.* (1943). A lower divide between the Smoky Hill and the Arkansas Rivers and evidence for high-terraces along the Smoky Hill River valley provided strong evidence for a paleo-connection between the two basins. However, studies conducted by Lohman and Frye (1940) and Frye and Leonard (1952) again suggested the McPherson Channel resulted from erosion by glacial meltwater from the northeast. Figure 2 illustrates the alleged connection with glacial meltwater near Manhattan and the modern Smoky Hill River toward the southwest.

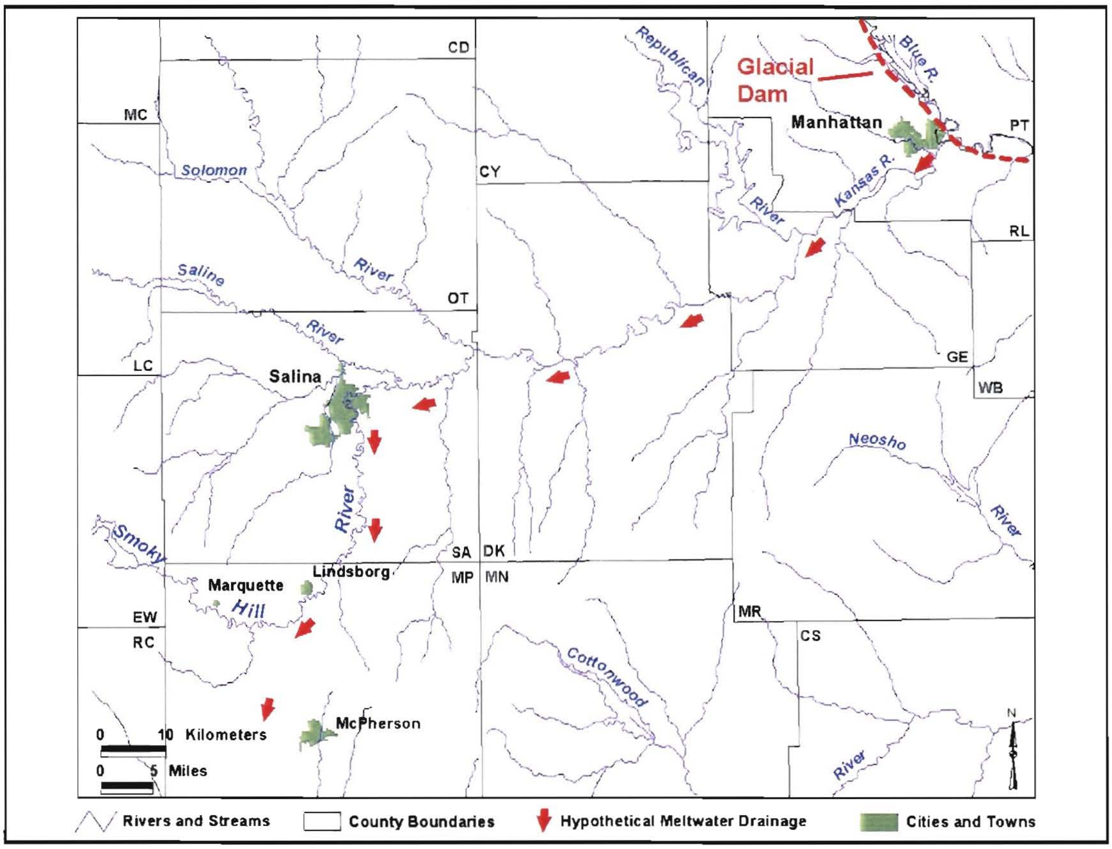



Figure 2. Map showing location of Smoky Hill River in reference to the glacial dam near Manhattan.

Lohman and Frye (1940) based their idea for a meltwater connection from the northeast on the interpretation that the fluvial sediments in the Equus Beds contained red Sioux Quartzite. The Sioux Quartzite is metamorphosed Proterozoic sandstone whose likely source area was southwestern Minnesota and adjacent South Dakota. As the pre-Illinoian ice lobes advanced into Kansas they transported these glacial erratics into the northeastern part of the state (Aber, 1991).

Frye and Leonard (1952) suggested that the glacial meltwater from pre-Illinoian glaciations was diverted to the southeast through the McPherson Channel. This interpretation is similar to Sharp's (1894) glacial lake meltwater interpretation in that they both suggest an established connection between the northeast ice front near Manhattan and the southwest Smoky Hill River sometime during a glacial advance into Kansas. Frye and Leonard's (1952) idea differs from Sharp's glacial lake in that it suggests that the connection between the glacial front is not the result of glacial lake overflow, but rather backed up fluvial meltwater, which connected and eroded the McPherson Valley in McPherson County. Both Sharp (1894) and Frye and Leonard (1952) differ from other interpretations for the development of the Equus Beds because they suggest an established connection between meltwater drainage, either by lake or fluvial meltwater, through the McPherson Valley before the capture by the Kansas River. Other geologists suggest the connection toward the north happen after the ancestral streams flowed through the McPherson Valley from the west (Udden, 1891; Beede, 1898; Frye *et al.,* 1943; Williams and Lohman, 1949; Fent, 1950; Lane and Miller, 1965).

Later studies conducted by Williams and Lohman (1949) and Bayne and Fent (1963) suggested no erratics of Sioux Quartzite in the fluvial sediments of the McPherson Channel. This conclusion was somewhat contradictory to Sharp (1894), Lohman and Frye (1940), and Frye and Leonard's (1952) hypotheses for development. Again, it strengthened the idea that no direct drainage connection between pre-Illinoian glaciations that extended into Kansas twice and the formation of the McPherson Channel ever existed.

The more generally accepted hypothesis proposed to explain the Equus Beds involved the ancestral Smoky Hill River flowing through the McPherson Valley with no meltwater or glacial lake connection from the eastern glaciated area. In addition, it has been suggested that a bedrock channel known as the Wilson Valley allowed the ancestral Saline River to flow into the Smoky Hill in northwest Ellsworth County (Frye, 1940; Frye *et al.,* 1943; Bayne and Fent, 1963; Bayne, Franks, Ives, 1971). When the Wilson Valley was an active channel, the Saline and Smoky Hill Rivers may have combined to drain most of central Kansas toward the south into the Arkansas River Basin. Frye, et al. (1943) suggested that high-terraces in northwestern Ellsworth County are similar in composition and grade to high-terraces occurring along the Smoky Hill River and even farther south to the top of the channel sands in the Equus Beds (Frye *et al.,* 1943; Bayne and Fent 1963).

The anomalous northward bend of the Smoky Hill River was thought to have been created when the Kansas River eroded headward and captured the Smoky Hill River near Lindsborg (Williams and Lohman, 1949; Fent, 1950; Waterman and Krieger, 1950; Lane and Miller, 1965; Bayne and Fent, 1963; Bayne, Franks, Ives 1971). The result was that Smoky Hill River valley was incised and the McPherson Channel eventually was abandoned after it was partially filled with fluvial sediments at some time during the Pleistocene (Udden, 1891; Haworth and Beede, 1897; Beede, 1898; Frye *et al.,* 1943; Williams and Lohman, 1949; Fent, 1950; Lane and Miller, 1965).

### Description of Study Area

The general study area is located in the lower Smoky Hill River Valley in central Kansas (Fig. 3), but the primary focus area for this study is in Ellsworth (EW) and McPherson (MP) counties. Water well-log data from the adjoining counties of Rice (RC), Saline (SA), Ottawa (OT), Dickinson (DK) and Marion (MN) were also included to provide additional data to prevent edge effects when interpolating bedrock elevation grids.

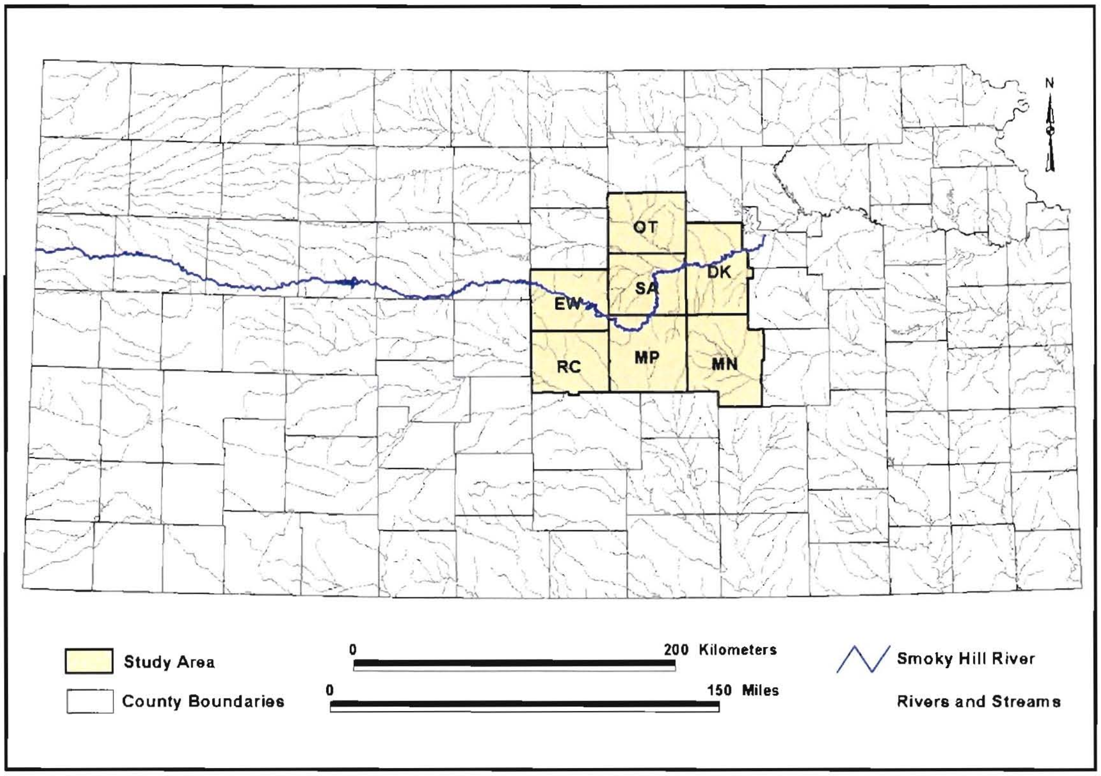



Figure 3. Study area with modern Smoky Hill River (blue line) in central Kansas.

The study area included portions of four physiographic regions: the Smoky Hill Uplands toward the west, Wellington-McPherson Lowlands and Arkansas River Lowlands toward the south and the western edge of the Flints Hills toward the east. Drainage basins in the study area include the Smoky Hill, Saline, and Solomon rivers that all currently drain into the Kansas River system. Also, included is the Little Arkansas River in McPherson County, which drains into the Arkansas River Basin toward the south, and the Cottonwood River that drains into the Neosho Basin toward the southeast in Marion County (Fig. 4).

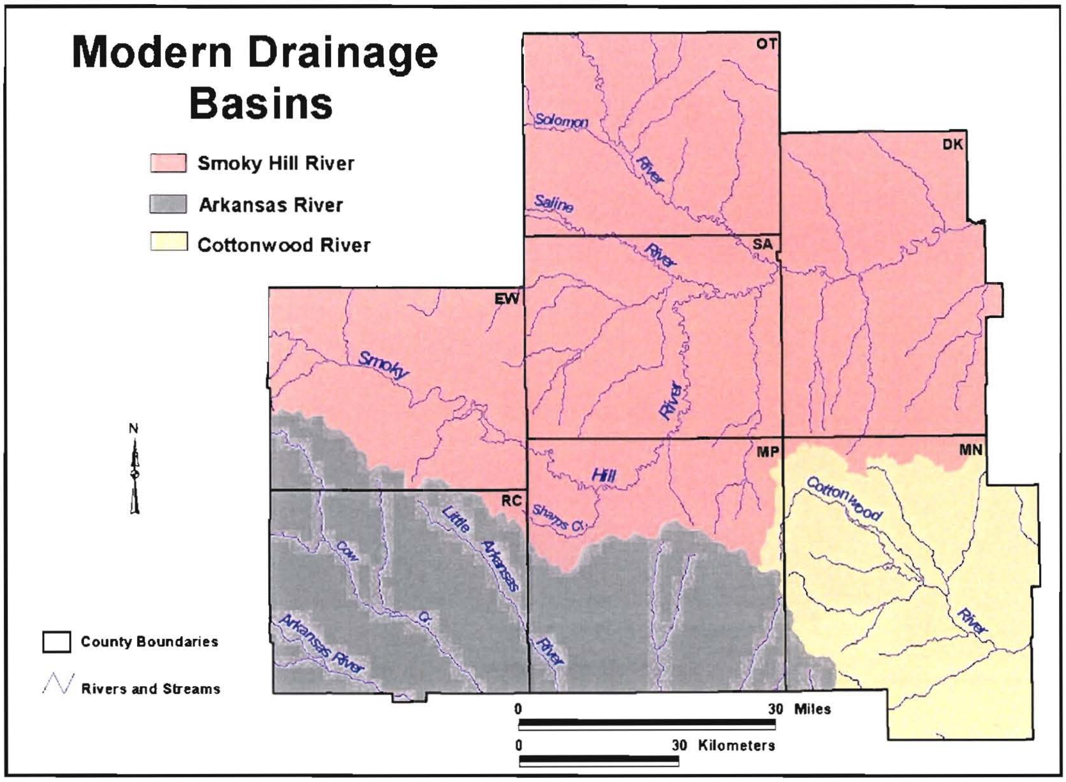



Figure 4. Study area showing modern drainage basins. Map were generated using coverages downloaded from the Data Access and Support Center (DASC) at the Kansas Geological Survey.

Figure 5 is the surface geology map of the study area. The surface geology is mainly sedimentary rocks of Permian and Cretaceous age. These strata dip gently toward the west resulting in the older formations outcropping at the eastern edge of the study area and younger formations outcropping toward the west (Waterman and Krieger, 1950). Other surficial materials include Quaternary dune sand, alluvium, loess and volcanic ash.

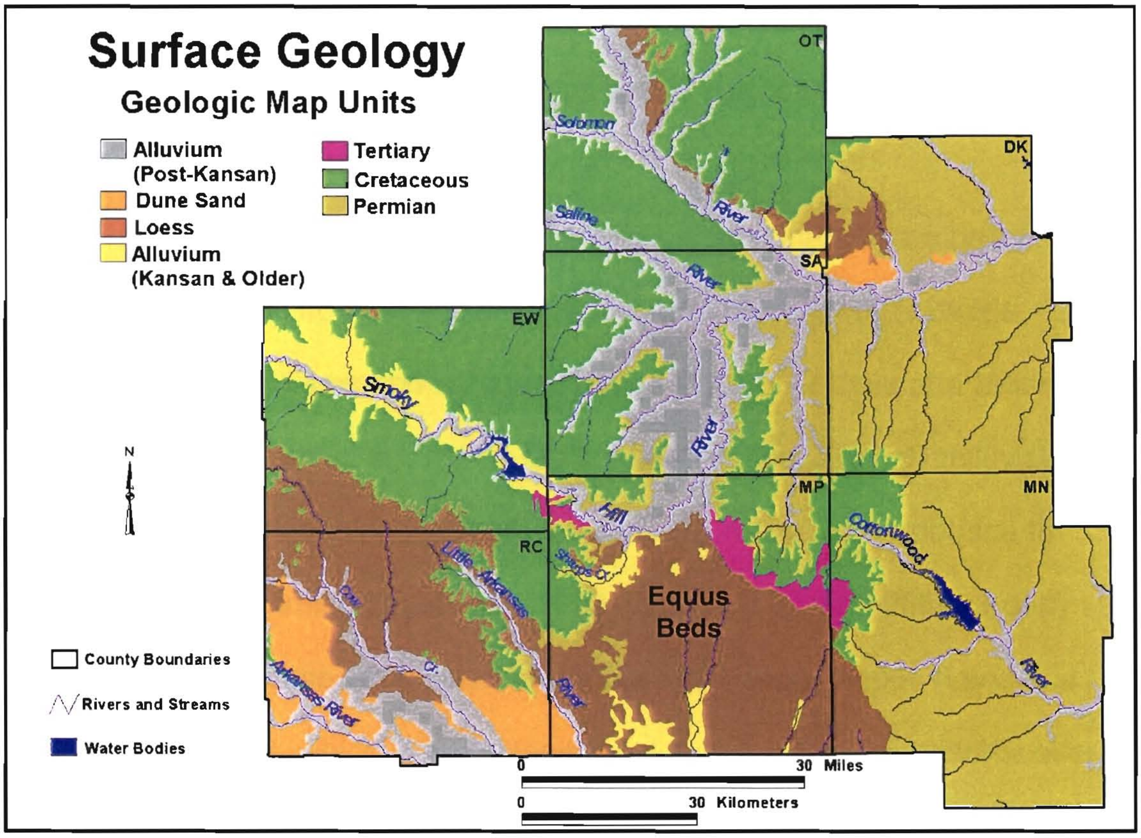



Figure 5. Surface geology map of the study area. Map generated using surficial geology coverages downloaded from the Data Access and Support Center (DASC) at the Kansas Geological Survey.

In McPherson County there is a buried bedrock paleo-valley known as the "McPherson Channel" or "McPherson Valley." This bedrock valley is filled with unconsolidated sediments that form an extensive unconfined alluvial aquifer known as the "Equus Beds." Paleontologically, these sediments include an extensive array of flora and fauna. The area was called the 'Equus Beds' because of the vast amount of Tertiary and Pleistocene fossils including horse teeth, that are located in the fluvial sediments (Udden and Beede, 1897; Beede, 1898). The Equus Beds deposits have also yielded a multitude of other fossilized mammal bones including rodent, horse, rhinoceros, giant sloth and mastodon (Frye and Hibbard, 1941).

The sediments in the bottom of the McPherson Channel are believed to be aggraded channel fill from an ancient river system (Udden, 1891; Beede, 1898; Frye *et al.,* 1943; Williams and Lohman, 1949; Fent, 1950; Lane and Miller, 1965). The coarse gravel sediments are covered by finer alluvial, colluvial, and eolian sediment. These unconsolidated sediments range from Neogene to Recent in age (Williams and Lohman, 1949; Lane and Miller, 1965). Poorly sorted colluvial deposits are located at the base of steeper slopes (Lane and Miller, 1965). Loess, which is wind blown silt, forms the surficial material over a large portion of the study area, and can range up to approximately 35 m (110 ft) in thickness in parts of McPherson County (Frye, 1939, Lohman and Frye, 1940). Sand dunes are present southwest of the study area north of Burrton and Hutchinson in Reno and Harvey Counties. Fluvial sediments ranging from coarse gravel to clay are present in alluvial valleys and in high-terrace locations.

Volcanic ash has also been noted within the alluvium at several locations within McPherson and Ellsworth Counties (Izett and Wilcox, 1982).

The total thickness of unconsolidated material within the McPherson Channel ranges from less than 1 m to about 80 m (~265 ft) in the deepest part of the buried channel. The bedrock valley was formed as a result of river erosion into soft shales of Permian age. The principal stratum affected by this erosion was the Wellington Formation (Waterman and Krieger 1950; Lane and Miller, 1965). The Wellington consists of shale with interbedded gypsum, anhydrite, impure limestones and thick beds of halite such as the Hutchinson Salt member (Lane and Miller, 1965; Walters, 1977). These relatively nonresistant strata played a crucial role in the drainage development of the Smoky Hill River.

A bedrock divide known as the "McPherson Ridge" separates the modern Smoky Hill River from the modern Little Arkansas River to the south (Beede, 1898). It also separates the modern Smoky Hill Channel from the McPherson Valley that is now filled with Equus Beds sediments. The divide consists of Permian bedrock capped by younger alluvium and loess (Frye, 1939). The modern Smoky Hill River currently flows at a lower elevation than the connection to the buried "McPherson Valley." With regard to McPherson Ridge and the McPherson Valley the principal question has always been the origin of the water that apparently crossed the McPherson Ridge to carve out the McPherson Valley.

Sinkholes are present in areas underlain by the Wellington Formation as evidenced by Lake Inman and the Big Basin in McPherson County. Both features are believed to have formed from dissolution of evaporite deposits in the Wellington Formation (Williams and Lohman, 1949; Walters, 1977). The presence of sinkholes in this area provides additional evidence for the lack of resistance to erosion and dissolution processes affecting the subsurface Wellington Formation. These same dissolution processes may have had a profound affect on the formation of the McPherson Channel. Collapse features could have provided large conduits for fresh surface water to dissolve and erode underlying evaporite deposits and soft shales.

Stratigraphically above the nonresistant Permian strata are the Cretaceous units, the Kiowa Shale and Dakota Formations. The more resistant sandstones of the Dakota Formation cap the hills surrounding the Smoky Hill River valley in the study area. These rocks form the high bedrock escarpment that gives the Smoky Hills their name. The Ogallala Formation of Tertiary age caps the Cretaceous bedrock in some parts of the study area.

## Statement of goals

The principal goals for this study were: (1) Creation of a comprehensive bedrock topography map of the lower Smoky Hill River Channel using GIS, (2) Field investigations to establish the location and elevation of fluvial terrace deposits that indicate past positions of the Smoky Hill River Channel, (3) The final goal was to use GIS to compare the bedrock topography and high-terrace deposits to determine the most likely scenarios for stream capture and channel migration between the Smoky Hill River system to the Kansas River system.

# Chapter 2. Methods and Procedures

## Development of Bedrock Coverage

The purpose for developing a bedrock elevation coverage was to illustrate the spatial configuration and elevation of the underlying bedrock divide between the modern Smoky Hill River and the buried McPherson Channel in McPherson County. Water well logs from the surrounding counties of Ellsworth, Saline, Ottawa, Marion, Dickinson were included to help illustrate buried features that may suggest connection to adjacent drainage basins.

The bedrock elevation coverages were developed using Earth Systems Research Institute (ESRI) GIS software such as *Arcview* and *ARC/INFO*. The bedrock elevation coverages were constructed from descriptive water well logs available from Kansas Geological Survey Bulletins and Water Well Completion Records (WWC5) that are archived at the Kansas Geologic Survey (KGS). Water well logs were also used from an existing bedrock coverage developed by Richard Sleezer and Dave Young (unpublished data) to aid in completing a more accurate spatial representation of the stream capture events.

For this study approximately 3000 well logs were examined for quality before incorporation in the database. Of the well logs reviewed only 1623 were selected, 481 taken from KGS Bulletins and 1142 from the WWC5 database. Water well logs lacking credible lithologic descriptions and having questionable interpretations of bedrock were excluded. Some common inconsistencies observed when reviewing WWC5 well logs were the interpretation of compacted alluvium and caliche as lithified bedrock (Table 1).

Table 1. An example of a well log that was not used in the database. Taken from WWC5 in Ellsworth County.

| Sample log of a test hole at the SWSESE 1/4. Sec. 5, T.14s, R8w., Ellsworth County; drilled by Rodney Cook Water Well Drilling 1977. Surface Altitude,?. | | |
|---|---|---|
| Quaternary—Pleistocene McPherson Formation | Thickness Feet | Depth Feet |
| Clay | 35 | 35 |
| Shale | 105 | 140 |
| Clay | 15 | 155 |
| Sandy clay | 21 | 176 |
| Clay | 4 | 180 |
| Sandstone | 5 | 185 |
| Clay | 7 | 192 |

It is unlikely that unconsolidated and consolidated materials would be stacked in such a sequence (sandstone above clay). It is more likely that authors of WWC5 well logs mistook unconsolidated sediments for bedrock because they appeared to be cemented. For example, caliche in soil may be mistaken for limestone or sandstone bedrock and compacted micaceous sandy lenses in alluvial sediments can also be mistaken for sandstone.

Water well logs from Kansas Geological Survey Bulletins seemed to a have the most consistent lithologic descriptions. Table 2 is an example of a well log that is representative of those used in this project. Although the coverages developed may contain errors transferred from the original well logs, the intent is to represent the large-scale spatial variability of the lower Smoky Hill River and McPherson Valley bedrock channel.

Table 2. An example of a well log with a detailed lithologic description taken from Waterman and Krieger (1950).

| Sample log number 52 of a test hole at the SE cor. Sec. 22, T.24s, R2w., McPherson County; drilled by State Geological Survey 1943. Surface Altitude, 1364.4 feet. | | |
|---|---|---|
| Quaternary—Pleistocene<br>McPherson Formation | Thickness<br>Feet | Depth<br>Feet |
| Silt and clay, brown | 4 | 4 |
| Silt and clay, dark-gray to tan | 30 | 34 |
| Silt, soft sandy, gray-green | 9 | 43 |
| Silt and clay, gray | 11 | 54 |
| Sand, coarse to fine, and gravel, fine | 6 | 60 |
| Gravel, coarse to fine, and sand | 10 | 70 |
| Gravel, medium to fine | 9 | 79 |
| Permian—Leonardian<br>Wellington Formation | | |
| Shale, hard-laminated, blue-gray | 1 | 80 |

In order to develop a database that would allow for a point coverage to be constructed, multiple steps were executed. The first step was to convert the location of each well log into longitude and latitude coordinates. The well locations for each well log were given in U.S. Public Land Survey legal descriptions. The U.S. Public Land Survey legal description coordinate system lists well locations in the following sequence: township, range, section, quarter section, quarter-quarter section and quarter-quarter-quarter section (10-acre tract). An example of this would be a lithologic log that described its location as T14S, R3W, sec. 23, NW ¼, SE ¼, SW ¼.

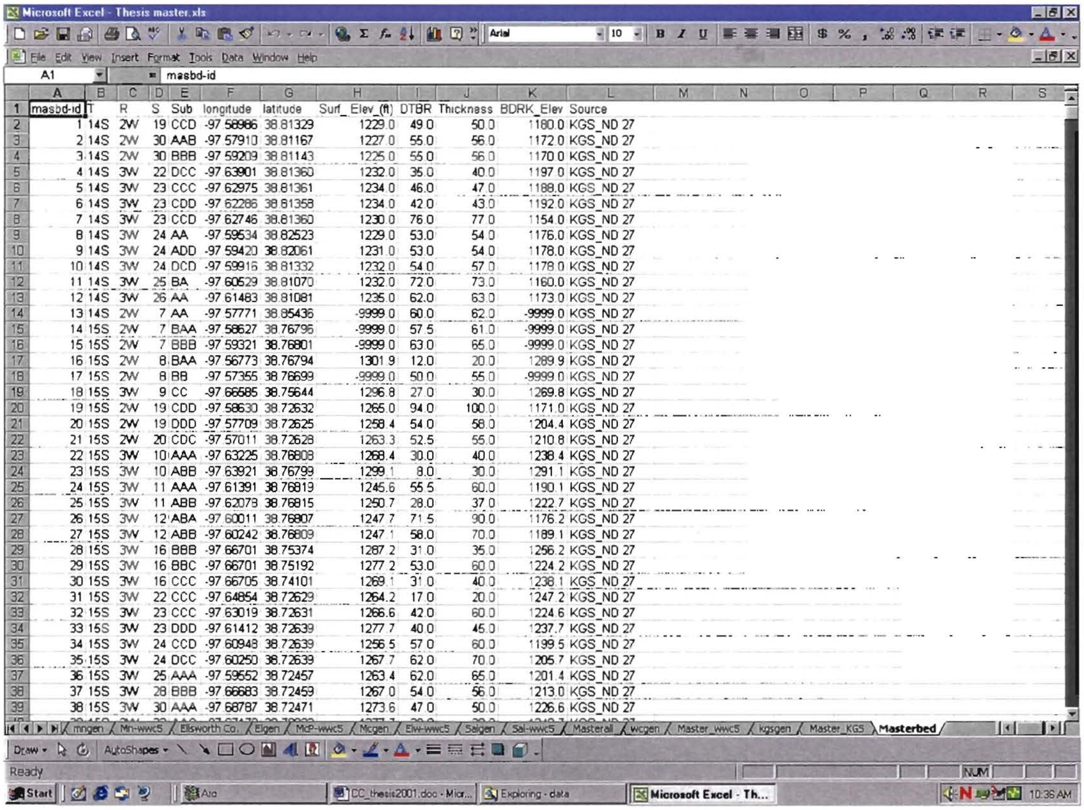
In order for the well logs to be converted into longitude and latitude using the LEO II program (Ross, 1994), the directional coordinates (NW SE SW) had to be changed to General Land Office survey coordinates. In GLO coordinates the well location is converted to township, range and section numbers, followed by letters that indicate the subdivision of the section in which the well is located. The subdivisions were designated a, b, c, or d in a counterclockwise direction starting at the northeastern corner. The b is the 160-acre tract in which d is quartered from b in a 40-acre tract and c would be quartered from the b in a 10-acre tract (Table 3). The description for each well log was saved as an ASCII text file and entered into notepad as T14S_R_3W_23_cdb.

Table 3. Converting U.S. Public Land Survey legal description must be changed so that LEO can relate the direction from 1/4 section to letter (a, b, c, d) designation for converting to longitude and latitude.

| Direction | Abbreviation | Code |
|---|---|---|
| Northeast | NE | A |
| Northwest | NW | B |
| Southwest | SW | C |
| Southeast | SE | D |
| Example: NW ¼ SE ¼ SW ¼ = cdb | | |

Once the legal locations were converted into longitude and latitude coordinates, the next step was to generate a point coverage. A point coverage is a single x (latitude) and y (longitude) coordinate that represent a geographic area or in this case water well log location. The point coverage was created using the <generate> command in *ARC/INFO.* After the point coverage was generated it was projected into Lambert Conformal Conic Projection to match existing background coverages such as surface geology.

Attributes for the well log coverage were entered into a Microsoft Excel spreadsheet (Fig. 6). The database was saved in dBase IV format (*.dbf), and then converted to an *ARC/INFO* data table using the <dbaseinfo> command. The tables were attached to the point attribute files (*.pat) for the well log coverage using the <joinitem> command in *ARC/INFO*.



| masbd-id | T | R | S | Sub | longitude | latitude | Surf_Elev_(ft) | DTBR | Thickness | BDRK_Elev | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 14S | 2W | 19 | CCD | -97.58986 | 38.81329 | 1229.0 | 49.0 | 50.0 | 1180.0 | KGS_ND 27 |
| 2 | 14S | 2W | 30 | AAB | -97.57910 | 38.81167 | 1227.0 | 55.0 | 56.0 | 1172.0 | KGS_ND 27 |
| 3 | 14S | 2W | 30 | BBB | -97.59209 | 38.81143 | 1225.0 | 55.0 | 56.0 | 1170.0 | KGS_ND 27 |
| 4 | 14S | 3W | 22 | DCC | -97.63901 | 38.81360 | 1232.0 | 35.0 | 40.0 | 1197.0 | KGS_ND 27 |
| 5 | 14S | 3W | 23 | CCC | -97.62975 | 38.81361 | 1234.0 | 46.0 | 47.0 | 1188.0 | KGS_ND 27 |
| 6 | 14S | 3W | 23 | CDD | -97.62286 | 38.81358 | 1234.0 | 42.0 | 43.0 | 1192.0 | KGS_ND 27 |
| 7 | 14S | 3W | 23 | CCD | -97.62746 | 38.81360 | 1230.0 | 76.0 | 77.0 | 1154.0 | KGS_ND 27 |
| 8 | 14S | 3W | 24 | AA | -97.59534 | 38.82523 | 1229.0 | 53.0 | 54.0 | 1176.0 | KGS_ND 27 |
| 9 | 14S | 3W | 24 | ADD | -97.59420 | 38.82061 | 1231.0 | 53.0 | 54.0 | 1178.0 | KGS_ND 27 |
| 10 | 14S | 3W | 24 | DCD | -97.59916 | 38.81332 | 1232.0 | 54.0 | 57.0 | 1178.0 | KGS_ND 27 |
| 11 | 14S | 3W | 25 | BA | -97.60529 | 38.81070 | 1232.0 | 72.0 | 73.0 | 1160.0 | KGS_ND 27 |
| 12 | 14S | 3W | 26 | AA | -97.61483 | 38.81081 | 1235.0 | 62.0 | 63.0 | 1173.0 | KGS_ND 27 |
| 13 | 14S | 2W | 7 | AA | -97.57771 | 38.85436 | -9999.0 | 60.0 | 62.0 | -9999.0 | KGS_ND 27 |
| 14 | 15S | 2W | 7 | BAA | -97.58627 | 38.76796 | -9999.0 | 57.5 | 61.0 | -9999.0 | KGS_ND 27 |
| 15 | 15S | 2W | 7 | BBB | -97.59321 | 38.76801 | -9999.0 | 63.0 | 65.0 | -9999.0 | KGS_ND 27 |
| 16 | 15S | 2W | 8 | BAA | -97.56773 | 38.76794 | 1301.9 | 12.0 | 20.0 | 1289.9 | KGS_ND 27 |
| 17 | 15S | 2W | 8 | BB | -97.57355 | 38.76699 | -9999.0 | 50.0 | 55.0 | -9999.0 | KGS_ND 27 |
| 18 | 15S | 3W | 9 | CC | -97.66585 | 38.75644 | 1296.8 | 27.0 | 30.0 | 1269.8 | KGS_ND 27 |
| 19 | 15S | 2W | 19 | CDD | -97.58630 | 38.72632 | 1265.0 | 94.0 | 100.0 | 1171.0 | KGS_ND 27 |
| 20 | 15S | 2W | 19 | DDD | -97.57709 | 38.72625 | 1258.4 | 54.0 | 58.0 | 1204.4 | KGS_ND 27 |
| 21 | 15S | 2W | 20 | CDC | -97.57011 | 38.72628 | 1263.3 | 52.5 | 55.0 | 1210.8 | KGS_ND 27 |
| 22 | 15S | 3W | 10 | AAA | -97.63225 | 38.76808 | 1268.4 | 30.0 | 40.0 | 1238.4 | KGS_ND 27 |
| 23 | 15S | 3W | 10 | ABB | -97.63921 | 38.76799 | 1299.1 | 8.0 | 30.0 | 1291.1 | KGS_ND 27 |
| 24 | 15S | 3W | 11 | AAA | -97.61391 | 38.76819 | 1245.6 | 55.5 | 60.0 | 1190.1 | KGS_ND 27 |
| 25 | 15S | 3W | 11 | ABB | -97.62078 | 38.76815 | 1250.7 | 28.0 | 37.0 | 1222.7 | KGS_ND 27 |
| 26 | 15S | 3W | 12 | ABA | -97.60011 | 38.76807 | 1247.7 | 71.5 | 90.0 | 1176.2 | KGS_ND 27 |
| 27 | 15S | 3W | 12 | ABB | -97.60242 | 38.76809 | 1247.1 | 58.0 | 70.0 | 1189.1 | KGS_ND 27 |
| 28 | 15S | 3W | 16 | BBB | -97.66701 | 38.75374 | 1287.2 | 31.0 | 35.0 | 1256.2 | KGS_ND 27 |
| 29 | 15S | 3W | 16 | BBC | -97.66701 | 38.75192 | 1277.2 | 53.0 | 60.0 | 1224.2 | KGS_ND 27 |
| 30 | 15S | 3W | 16 | CCC | -97.66705 | 38.74101 | 1269.1 | 31.0 | 40.0 | 1238.1 | KGS_ND 27 |
| 31 | 15S | 3W | 22 | CCC | -97.64854 | 38.72629 | 1264.2 | 17.0 | 20.0 | 1247.2 | KGS_ND 27 |
| 32 | 15S | 3W | 23 | CCC | -97.63019 | 38.72631 | 1266.6 | 42.0 | 60.0 | 1224.6 | KGS_ND 27 |
| 33 | 15S | 3W | 23 | DDD | -97.61412 | 38.72639 | 1277.7 | 40.0 | 45.0 | 1237.7 | KGS_ND 27 |
| 34 | 15S | 3W | 24 | CCD | -97.60948 | 38.72639 | 1256.5 | 57.0 | 60.0 | 1199.5 | KGS_ND 27 |
| 35 | 15S | 3W | 24 | DCC | -97.60250 | 38.72639 | 1267.7 | 62.0 | 70.0 | 1205.7 | KGS_ND 27 |
| 36 | 15S | 3W | 25 | AAA | -97.59552 | 38.72457 | 1263.4 | 62.0 | 65.0 | 1201.4 | KGS_ND 27 |
| 37 | 15S | 3W | 28 | BBB | -97.66683 | 38.72459 | 1267.0 | 54.0 | 56.0 | 1213.0 | KGS_ND 27 |
| 38 | 15S | 3W | 30 | AAA | -97.68787 | 38.72471 | 1273.6 | 47.0 | 50.0 | 1226.6 | KGS_ND 27 |

Figure 6. Database created in Excel spreadsheet from bedrock control points.

The coverages were cleaned and built using the <clean> and <build> commands to establish topology or spatial linkage between point locations and attribute tables. Attributes in the water well log database include the longitude and latitude coordinates from which the point coverage was built, the legal description, the source (WWC5 or KGS Bulletin), land elevation (surface), depth to consolidated bedrock, and the elevation of the bedrock.

Although bedrock point coverage contains 1644 points, it does not cover the entire study area. For instance, the well-log coverage does not contain bedrock elevation data for areas where bedrock is exposed at the surface. A method was needed to combine the bedrock elevation data from the well log coverage with bedrock elevation data for the areas surrounding the buried channels to give a clearer view of bedrock topography and to prevent edge effects when interpolating bedrock topography points to surfaces as grids and triangulated irregular networks (TINs).

The first step was to create a point coverage containing bedrock elevation data for areas where bedrock was exposed at the surface. A TIN depicting surface topography was created from 1:250K digital elevation models (DEMs) with no vertical exaggeration using the <createtin> command in *ARC/INFO*. After the completion of the surface elevation TIN, a fishnet was created that would overlie the entire study area. A fishnet is essentially a line coverage that represents a regular grid pattern. The lines were set to intersect at 200 m (656 ft) spacings. The <intersect> command in *ARC/INFO* was then used to create a point at each grid intersection. Figure 7 is an example of the fishnet that was overlain onto the study area to obtain elevation for exposed bedrock polygons.

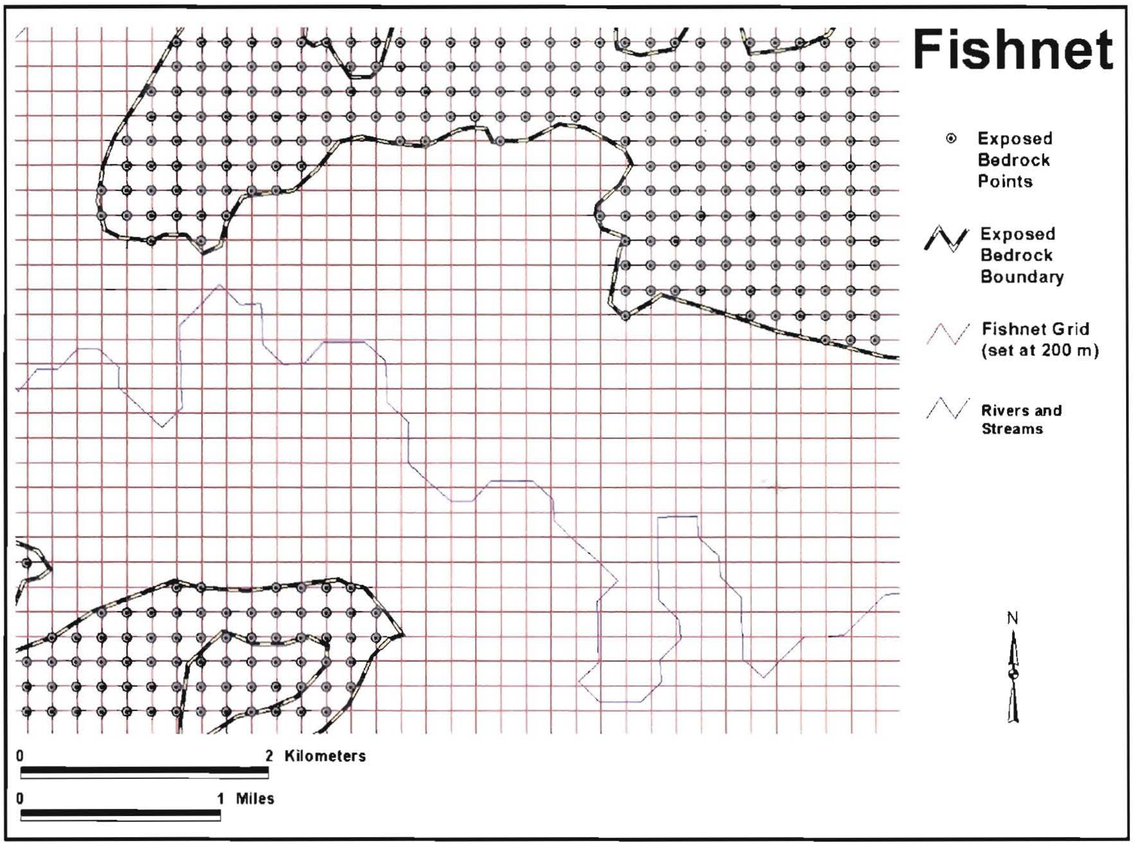



Figure 7. A fishnet was used to figure surface elevation of exposed bedrock. This aided in developing a TIN with less edge effects.

The resulting point coverage was clipped using the surface geology polygons that represented areas where consolidated bedrock was assumed to be exposed at the land surface. The <tinspot> command was then used to assign elevation data from the surface topography TIN to the resulting clipped point coverage.

## Development of Bedrock TIN

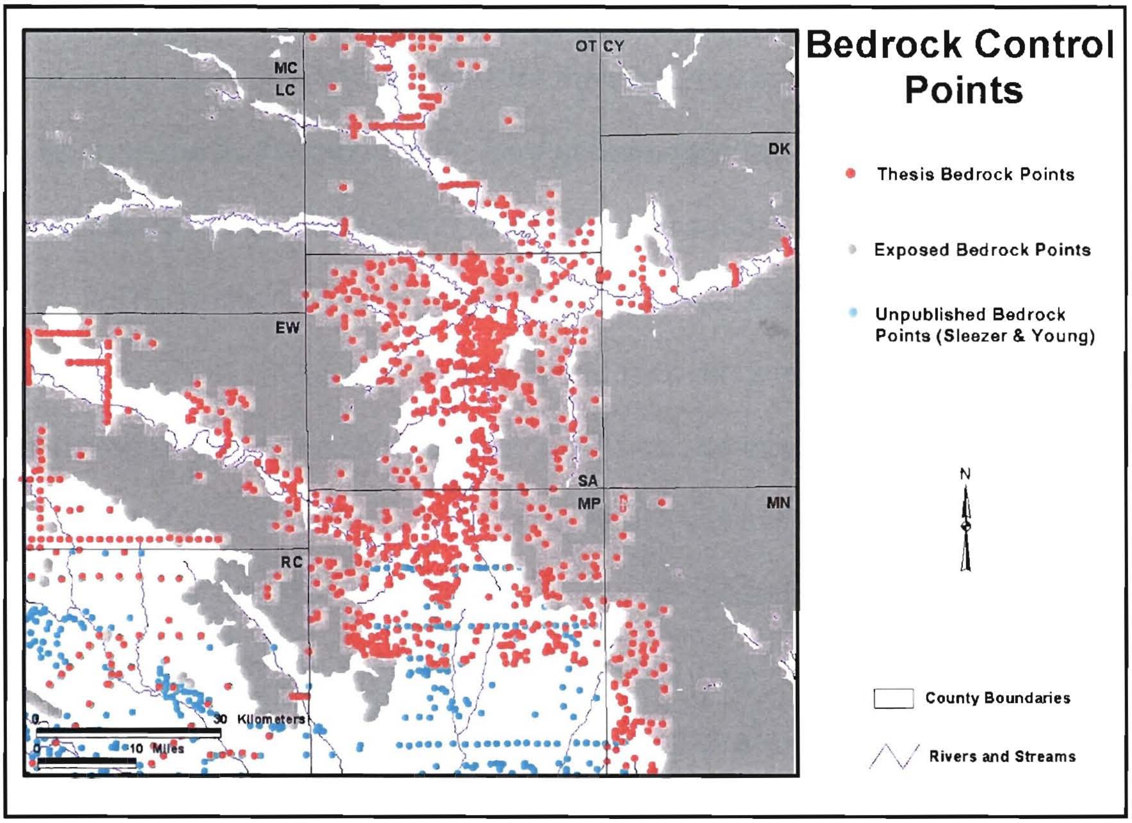



Figure 8. Combined point coverage used to create TIN (Triangulate Irregular Network).

The data distribution for the bedrock elevation TIN was created from the combined bedrock control points shown in Figure 8. Bedrock control points in red are data points from both KGS Bulletins and WWC5 water well records. Points in blue are from unpublished data by Richard Sleezer and Dave Young. Bedrock points in gray are areas of exposed surface geology. This is the area in which a fishnet was used to discern bedrock elevation.

All three bedrock point coverages were used in unison to develop a single bedrock map. A TIN (Triangulated Irregular Network) was created from the bedrock control data set. The purpose for creating the bedrock TIN was to determine possible paleo-flow paths for the ancestral Smoky Hill River and the elevation of the buried bedrock divide that separates the modern Smoky Hill River from the buried McPherson Channel to the south.

A TIN partitions a surface into a set of contiguous, non-overlapping, triangles in which a height value is recorded for each triangle node (bedrock elevation point). The heights between nodes can be interpolated thus allowing for the definition of a continuous surface. A TIN was created from the bedrock control data set constructed using the <createtin> command in *ARC/INFO* with no vertical exaggeration (z-factor). The resulting map helps to interpret buried features that suggest previous stream positions that are now buried under unconsolidated sediment.

**Determining Bedrock Divide**

In order to quantify the bedrock divide between the modern Smoky Hill and Arkansas Rivers, a method for discerning the elevation of the bedrock divide elevation was developed. First, the bedrock topography TIN was examined to locate areas where the lowest channel elevations occurred. The TIN was then converted to a raster data grid using the <tinlattice> command in *ARC/INFO* (Fig. 9). A series of transects were then drawn across the bedrock valley that intersected the areas with the lowest channel elevations. The Arcview cursor was then moved along each transect to more quantitatively identify the lowest bedrock elevation. At the lowest point identified on each transect, a circular polygon centered on that transect point was drawn using *Arcview*. Individual circular polygons were summarized to determine the low, high, and average elevations contained within each circular area. Once the minimum elevation was determined within each circle they were compared to determine the bedrock divide under the channel that represented the actual spillover point between the Smoky Hill and Arkansas River drainage basins.

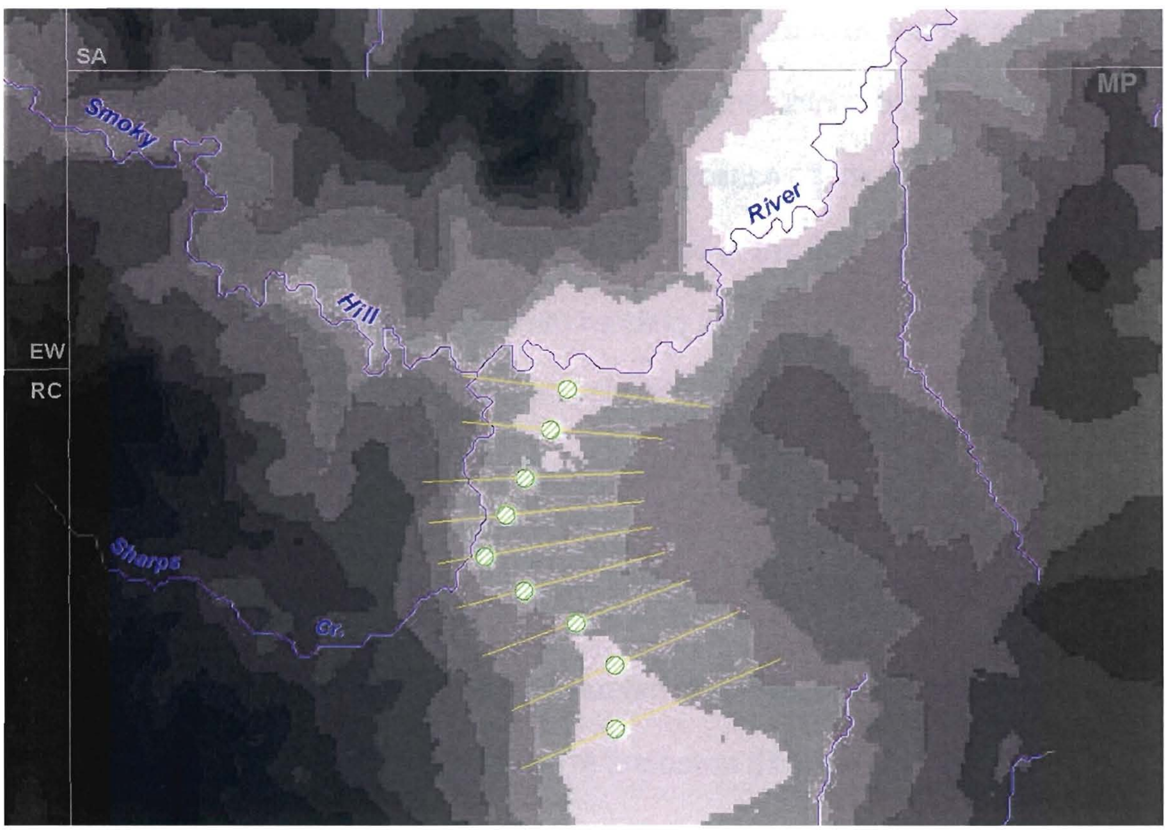



Figure 9. Circular polygons were overlain onto the grid and then summarized to produce the minimum elevation contained within the circle.

## Field Methods

Field studies were conducted to investigate high-terrace deposits in the vicinity of eastern Ellsworth County and northern McPherson County. Because terrace deposits are indicators for past stream positions, investigating their spatial distribution and elevation should help determine the configuration of the ancestral Smoky Hill River drainage system.

Starting from Kanopolis Reservoir in Ellsworth County, sand and gravel pits were located on USGS 7.5 minute topographic quadrangles. Field reconnaissance was then carried out to locate sand pits identified on topographic maps. Several sites were unable to be sampled because of access problems. Access problems were primarily due to private ownership of land and general inaccessibility to former sand and gravel pits because of changes in land use or absence of passable roads. At each site located in the field a digital photograph and GPS (Global Positioning Systems) reading of the elevation and location were taken. Also, a sample of the sediments contained in the each terrace were collected and taken back to the lab for analysis.

## Compilation of Soil Coverages

Soil coverages were compiled to determine if soils sampled in high-terrace locations could possibly be related to the ancestral Smoky Hill River that is alleged to have flowed into the McPherson Channel from the west. The soil coverages were compiled from soil survey geographic (SSURGO) and 1:24K Detailed Soil coverages. The SSURGO coverages were imported into

*ARC/INFO* from National Resource and Conservation Survey (NRCS) on-line database located at (http://www.ftw.nrcs.usda.gov/ssur_data). Counties that were not SSURGO certified such as Ellsworth and McPherson were available on-line from the Data Access and Support Center (DASC) at the Kansas Geological Survey (http://gisdasc.kgs.ukans.edu) as 1:24K detailed soils coverages. These soil coverages were tiled by 7.5-minute USGS topographic quadrangles. The individual 1:24K detailed soil coverage tiles were combined using the <mapjoin> command in *ARC/INFO* to create a single soil coverage for Ellsworth and McPherson counties. Both types of soil coverages were projected to a common map projection and combined using the <mapjoin> command in *ARC/INFO* to create a single soil coverage for the entire study area. Each of the counties' attribute databases was converted from a (*.dbf) file to a (*.pat) using the <dbaseinfo> command in *ARC/INFO.* The tables were attached to the polygon attribute file (*.pat) using the <joinitem> command in *ARC/INFO.* The county coverages were cleaned and built with <clean> and <build> commands in *ARC/INFO.*

As mentioned earlier, a GPS reading was recorded for each high-terrace soil (sand/gravel pit) located in the field. The GPS locations were used to generate a point coverage using <generate> command in *ARC/INFO.* The points were projected from geographic coordinates to the Lambert Conic Conformal Projection used for all coverages in this project. The GPS point locations were then overlaid on the soil coverages. GPS points that fell within a certain soil polygon were selected and converted to a shapefile (*.shp) using *Arcview.* Each soil polygon was overlain on top of a 1:250K DEM, which allowed for a reasonable way to calculate the average elevation within each selected soil polygon. The calculated elevation data was then used to determine if soils located in Ellsworth County are in grade with similar soils in McPherson County (Fig. 10).

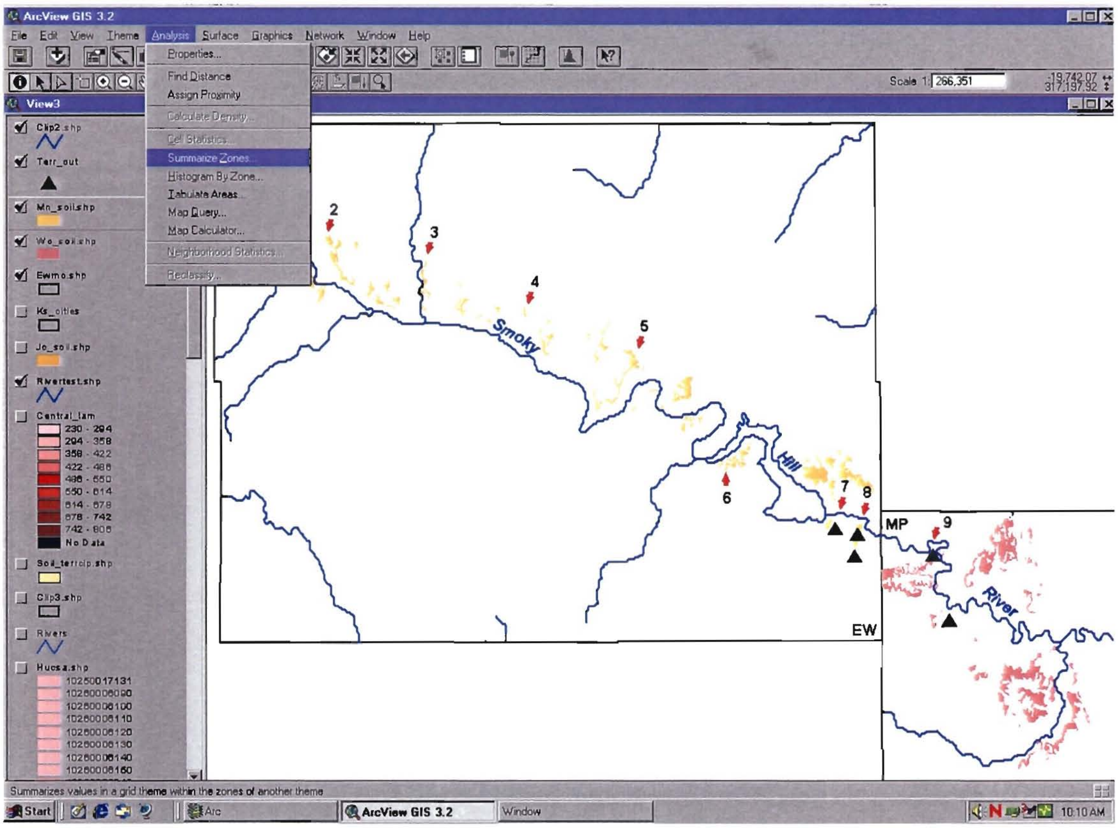



Figure 10. Each soil polygon elevation was averaged using the "Summarize Zone" tool in *Arcview* 3.2.

## Chapter 3. Results

### Bedrock Topography (TIN)

Figure 11 is the Triangulated Irregular Network (TIN) of bedrock topography created from the bedrock control points. The TIN depicts the bedrock surface under the study area, without the overlying unconsolidated sediments. The intent is to discern buried features, such as bedrock channels or windgaps that may suggest prior flow paths of the ancestral Smoky Hill River.

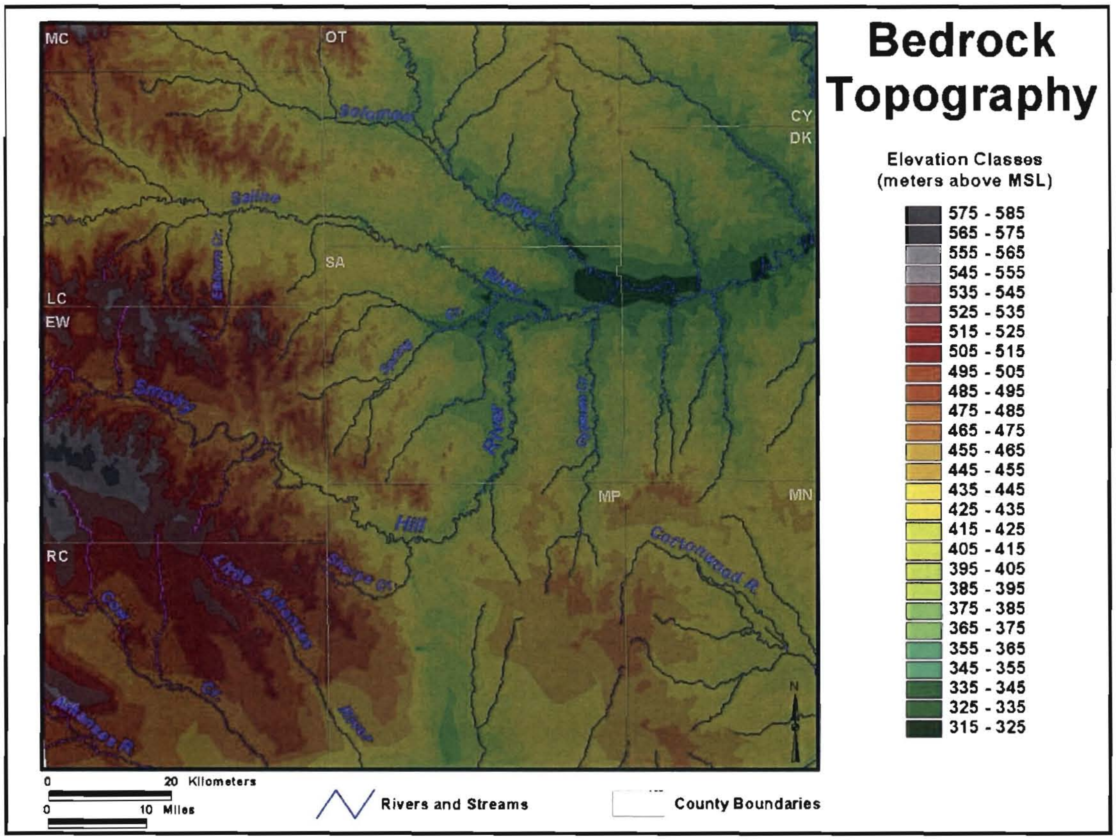



Figure 11. TIN (Triangulated Irregular Network) bedrock topography map created water well logs.

The TIN is shaded so that areas in light gray to darker red form the high-bedrock escarpment of the Smoky Hills toward the west. Areas in light to darker green represent lower bedrock elevations, which are generally interpreted as modern stream valleys or possibly abandoned paleo-channels. The map also has county boundaries (light gray) and modern rivers and streams (dark blue) as spatial references.

The most salient feature on the bedrock topography map is the "McPherson Valley" bedrock channel in McPherson County (Fig. 12). The abandoned bedrock channel seems to occupy a relatively wide channel that trends north and south through McPherson County. The channel is approximately 24-32 km (15-20 mi) wide from west to east across the county. At the western edge of the county the valley obtains a minimum elevation of approximately 380 m (1250 ft). The land surface elevation near McPherson is 450 m (1480 ft) in elevation. In comparison, the bedrock channel is approximately 70 m (230 ft) lower than the surface topography near McPherson. It seems that early streams excavated deep channels into the local bedrock.

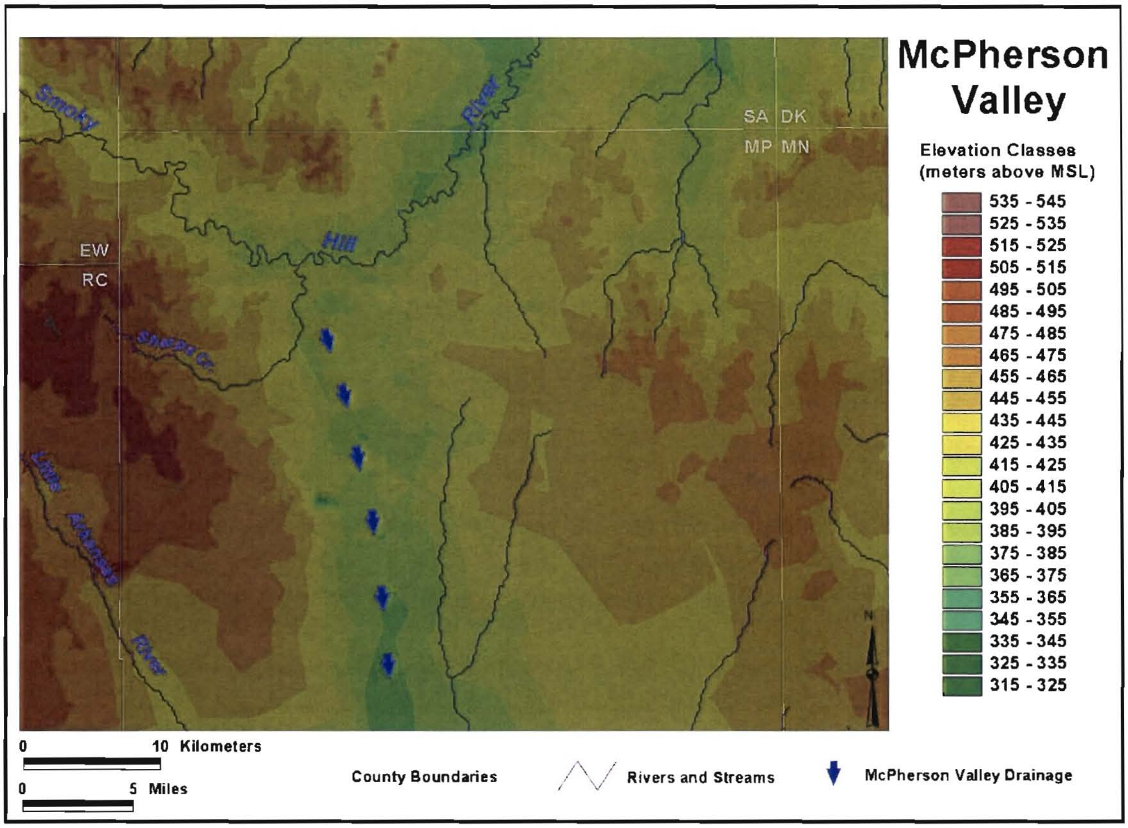



Figure 12. The McPherson Valley paleo-channel in McPherson County, Kansas. The buried channel formed from river incision over soft Permian bedrock.

**Bedrock Divide**

If either the ancestral Smoky Hill River or meltwater drainage from the northeast flowed south through the McPherson Valley, then one of the two systems must have flowed over the drainage divide that now separates the modern Smoky Hill River from the Little Arkansas. Accurate determination into the elevation of the bedrock drainage divide that separates the modern Smoky Hill River from the Arkansas River system is imperative for determining the most likely scenario for the formation of the McPherson Valley. The drainage divide between the two basins would represent the lowest elevation in which either the glacial lake from the northeast or the ancestral Smoky Hill River toward the west would need to be elevated in order to flow across the divide into the Arkansas River.

Figure 13 is the grid created from the bedrock elevation TIN. On each transect the circular polygon represents the area with the lowest bedrock elevation within this paleo-channel. The location of the bedrock divide was determined by locating the area in which elevations decreased to the north and south. The bedrock divide, which separates the Smoky Hill River from the Arkansas River toward the south, is represented in Figure 13 (purple dotted line). Blue arrows denote the drainage divide where water north of the bedrock divide flows into the Smoky Hill River while water south of the divide flows southward into the Arkansas River Basin (Fig. 13). The minimum elevation for the bedrock divide is approximately 407 m (1335 ft).

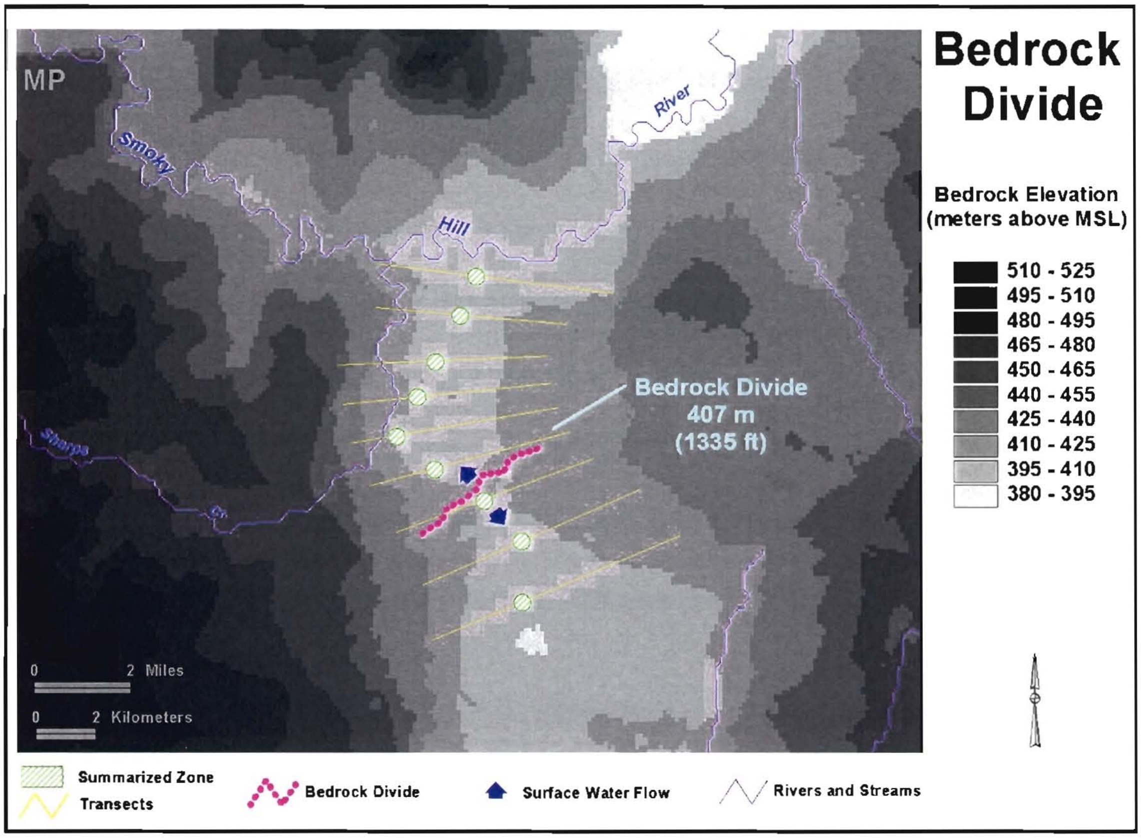



Figure 13. Grid created from bedrock control points. The bedrock divide is approximately 407 m (1335 ft) in elevation.

If a river near Salina eroded headward to capture the Smoky Hill River near Lindsborg then the bedrock channel near Salina should be lower in elevation than the bedrock channel of the beheaded stream. The elevation of the bedrock channel near Salina is approximately 350 m (1150 ft). The drainage divide between the modern Smoky Hill River and the Arkansas River System toward the south is approximately 407 m (1335 ft) in elevation. The lower elevation near Salina seems to be consistent with the interpretation that a headward eroding stream from the Kansas River system captured the ancestral

Smoky Hill River that was flowing southward through the McPherson Valley and diverted its drainage to the northeast.

**Cross sections of McPherson Valley**

In order to investigate past stream position and thickness of sediments deposited by the ancestral Smoky Hill River in the McPherson Valley, two cross-sections were selected from bedrock points in McPherson County. Transects A and B are from well logs described in William and Lohman's (1949) report of geology and hydrology of south-central Kansas (Fig. 14).

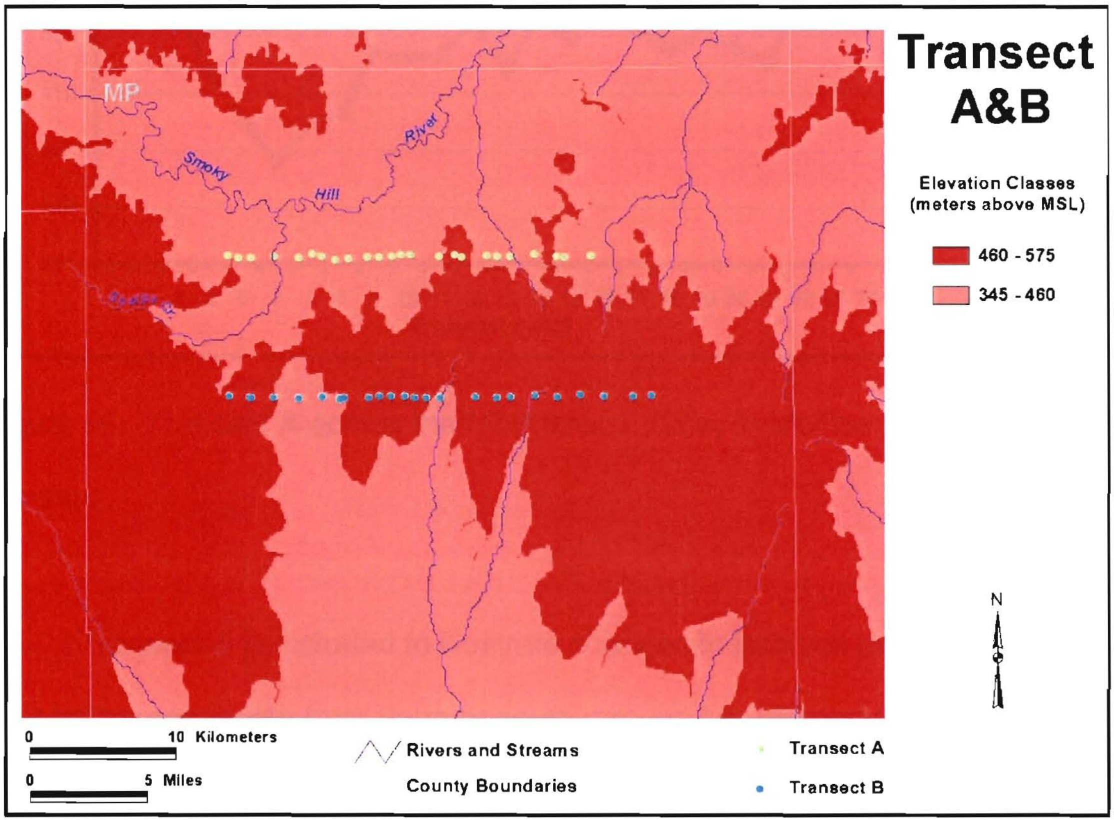



Figure 14. Location of Transects A and B in McPherson County.

The intent of each transect is to illustrate the depth of incision into the local bedrock and elevation of coarse sediments deposited in McPherson Valley. Transect (A) is located in northern McPherson County and is approximately 25 km (15 miles) from west to east across the subsurface McPherson Channel (Fig. 15). It seems from Figure 15 that the ancestral stream and its tributaries may have eroded multiple channels into the underlying bedrock.

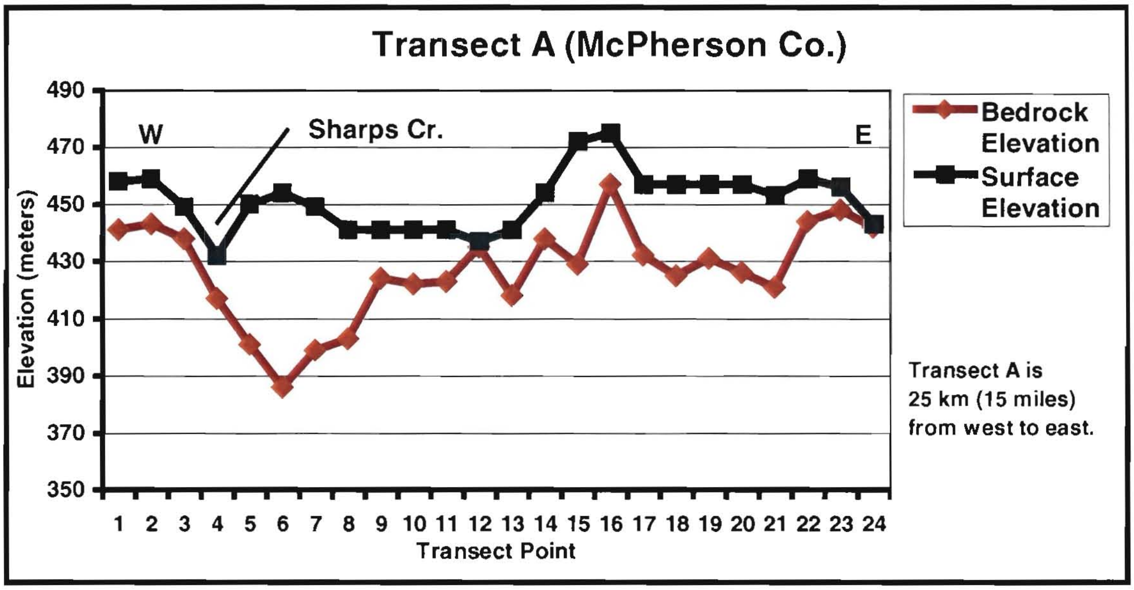



Figure 15. Transect A across the McPherson Valley in McPherson County, Kansas.

Transect B is included to illustrate changes in bedrock morphology along the McPherson Valley from north to south through McPherson County (Fig. 16). The cross-section is approximately 10 km (6 mi) south of transect A and 29 km (18 mi) from west to east across the buried McPherson Valley. Coarse gravel deposits, which are presumed to be fluvial in origin, are represented as a yellow line in Figure 16. The top of the alluvial deposits is positioned at an elevation of approximately 439 m (1440 ft). These coarse sediments are composed mainly of sand and gravel and are approximately 60 m (196 ft) in thickness.

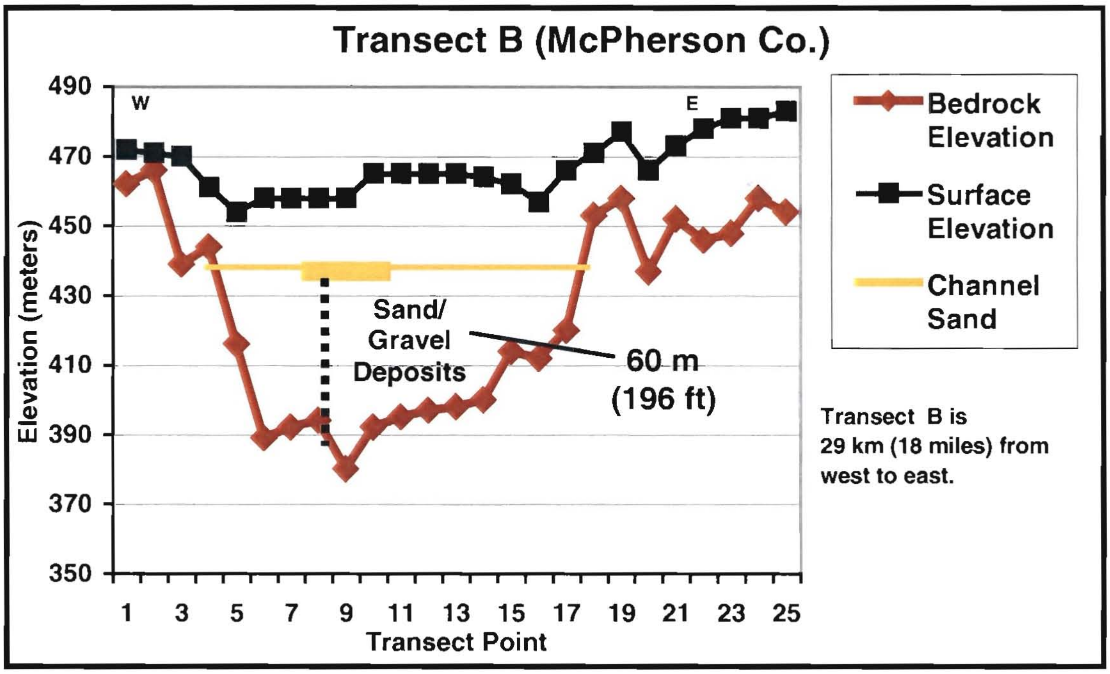



Figure 16. Transect B across the buried McPherson Valley in McPherson County, Kansas.

## Field Study Results of High-terrace Soils

Field research was conducted to investigate the high-terrace deposits located along the Smoky Hill River valley in southeastern Ellsworth and northwestern McPherson Counties. Correlations between high-terrace deposits and modern soil map units were used to plot paleo-flow directions and postulate previous stream positions and elevations. High-terraces 7-8 seem to correspond to the Meadin sandy loam in Ellsworth County. Site 9 in McPherson County corresponds to the Wells loam (Fig. 17).

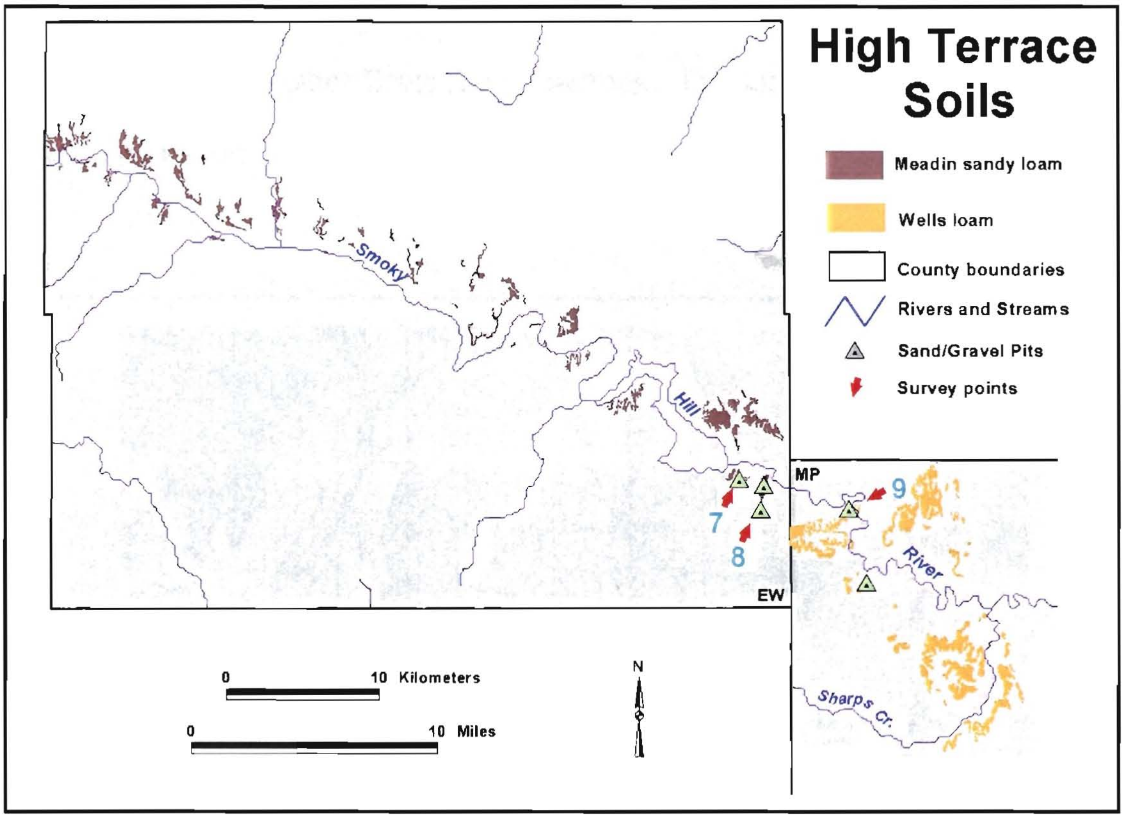



Figure 17. Map showing high-terrace (SSURGO) soils located in Ellsworth and northwestern McPherson Counties that correlated with sampled sites 7-9.

## Meadin Sandy Loam

Site 7 was an abandoned sandpit southeast of Kanopolis reservoir located in sec. 3, T17S, R6W in Ellsworth County. The sandpit is located at an elevation of approximately 466 m (1530 ft) and is about 30 m (100 ft) above the modern flood plain. The sand and gravel located in the terrace contains exotic gravels such as milky quartz, tan quartzite, chert (non-Flint Hill), and dark flint. Other unconsolidated materials include sandstone concretions (reworked Dakota), and mammal bones. These sediments range in thickness from 6-15 m (20-50 ft) and are resting on much older Cretaceous bedrock. The location of this sand pit is labeled site seven (7) in Figure 18.

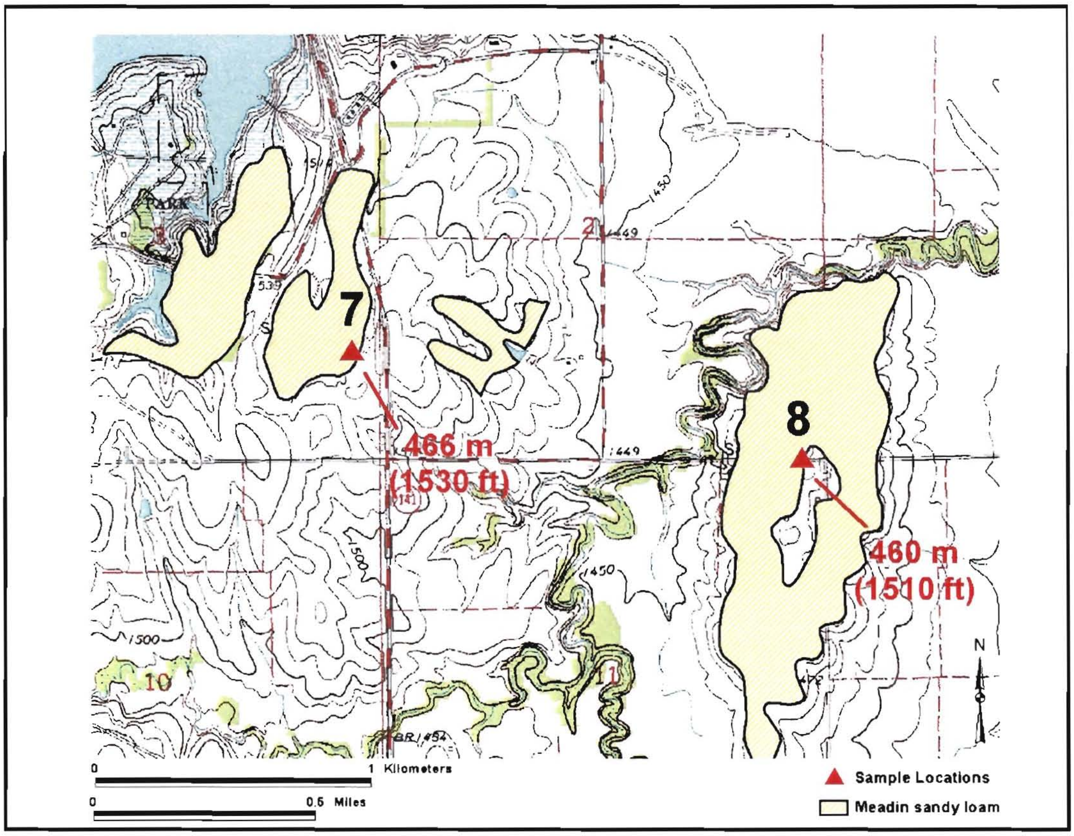



Figure 18. Locations of high-terrace (Meadin sandy loam) soils and sample locations in Ellsworth County. GPS data points that fell within certain soil polygons (yellow polygons) were selected and averaged.

Site 8 is also located in Ellsworth County, sec. 3, T17S, R6W, (Fig. 18). This sandpit is approximately 1.6 km (1 mi) east of site 7 and its elevation is approximately 460 m (1510 ft). Figure 19 is a digital photograph of the excavation pit at this terrace deposit.

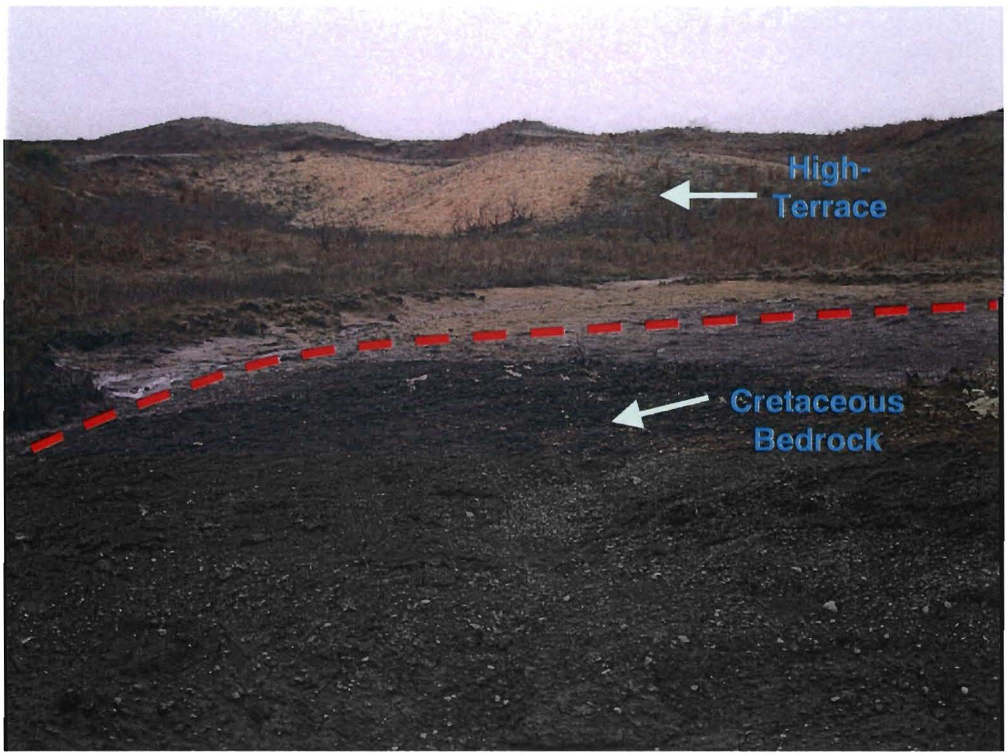



Figure 19. Meadin sandy loam (background) overlying Cretaceous bedrock (foreground) in a high-terrace along the Smoky Hill River valley in Ellsworth County, Kansas.

The composition of the terrace deposits at site 8 are similar to the arkosic sand and gravel deposits at site 7. These unconsolidated sediments are between 6-15 m (20-50 ft) in thickness. The sands are resting on much older Cretaceous bedrock. They contain exotic gravels such as milky quartz, tan quartzite, dark flint, chert (non-Flint Hill), and rhyolite. Other unconsolidated materials include sandstone concretions (reworked Dakota), petrified wood, and mammal bone fragments (Fig. 20).

Figure 20. Selection of exotic gravels from the Meadin sandy loam in Ellsworth County, Kansas, including mammal bone (far left) and petrified wood (bottom right).

At high-terrace sample site 8, a large piece of light tan chert was collected with numerous percussion marks (Fig. 21). Percussion marks are crescent shaped scars indicative of gravels (quartzite or chert) that have been rolled and tumbled in a fluvial system, usually for great distances. Gravels of this nature may suggest an active drainage development before deposition.


Figure 21. An erratic chert pebbles from Meadin sandy loam in Ellsworth County, Kansas. Note percussion marks which area indicative of extended transport.

According to the Ellsworth County soil survey and GIS SSURGO soil coverages for the county, high-terrace deposits (7-8) correspond with the Meadin sandy loam soil (Barker and Dodge 1989). The Meadin series soil occurs on the upland surface and is composed of "soils formed in loamy and sandy material over coarse sand and gravel (Barker and Dodge, 1989)." The taxonomic classification of these soils is described as sandy, mixed, mesic Entic

Haplustolls. A representative soil profile of the Meadin loam is described as follows (Barker and Dodge 1989).

A--0 to 7 inches (18 cm); dark grayish brown (10YR 4/2) sandy loam, very dark grayish brown (10YR 3/2) moist; weak fine granular structure; slightly hard, very friable; about 10 percent fine and medium pebbles; slightly acidic; gradual smooth boundary.

AC--7 to 14 inches (18 to 36 cm); dark grayish brown (10YR 4/2) gravelly sandy loam, very dark grayish brown (10YR 3/2) moist; weak medium granular structure; slightly hard, very friable; about 15 percent fine and medium pebbles as much as 15 mm in diameter; slightly acid; gradual wavy boundary.

2C--14 to 60 inches (36 to 152 cm); very pale brown (10YR 7/4) gravelly coarse sand, light yellowish brown (10YR 6/4) moist; single grained; loose; about 35 percent pebbles as much as 30 mm in diameter; neutral.

**Wells Loam**

The third terrace (site 9) is located at sec. 9, T17S, R5W, in northwestern McPherson County. The terrace deposit occupies an elevation of 457 m (1500 ft) (Fig. 22). The terrace is between 6-15 m (20-50 ft) in thickness and is positioned on older Cretaceous bedrock. Figure 23 is a digital photograph of the exposed terrace deposit at this location.

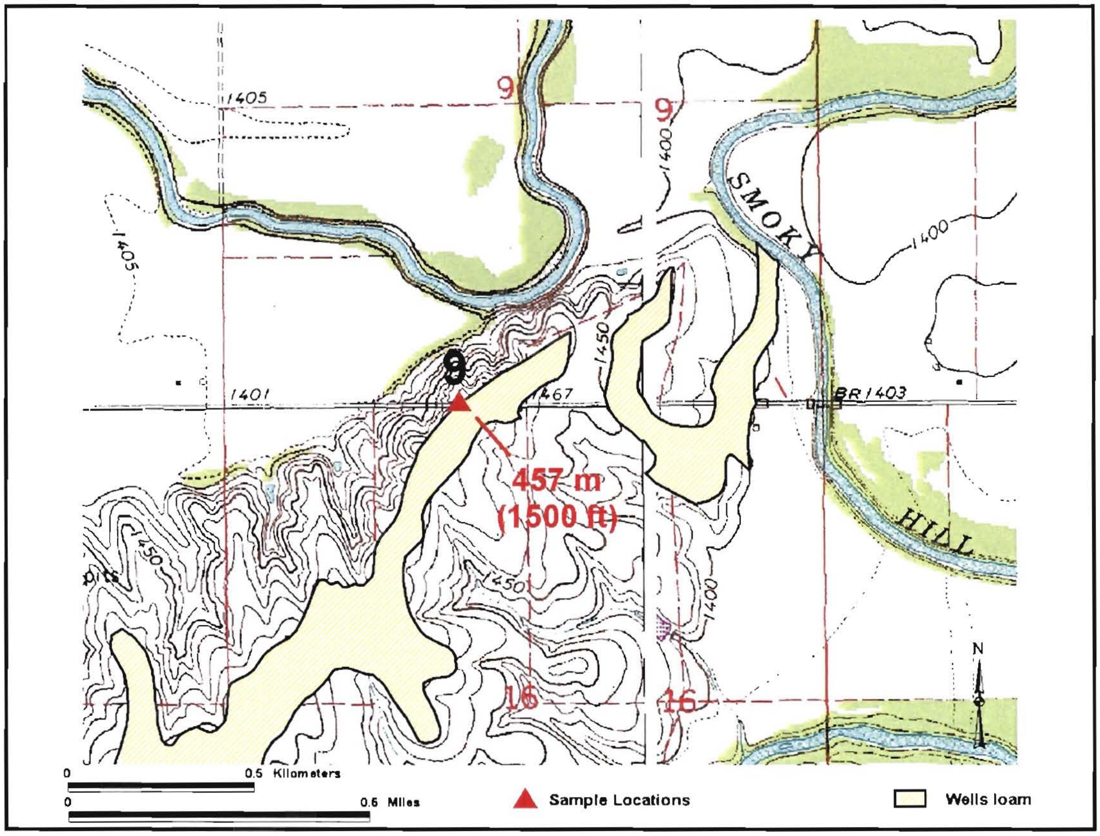



Figure 22. Location of the high-terrace (Wells loam) soil in Ellsworth County. GPS data points that fell within certain SSURGO (yellow polygons) soil polygon were selected and averaged.

Figure 23. High-terrace (site 9) soil located in McPherson County, Kansas.

The terrace at site 9 is approximately 30 m (100 ft) higher than the modern flood plain. Figure 24 is a digital photograph taken from the modern flood plain of the Smoky Hill River. The photograph illustrates the valley entrenchment of the Smoky since the deposition of sand and gravel in these high-terraces.

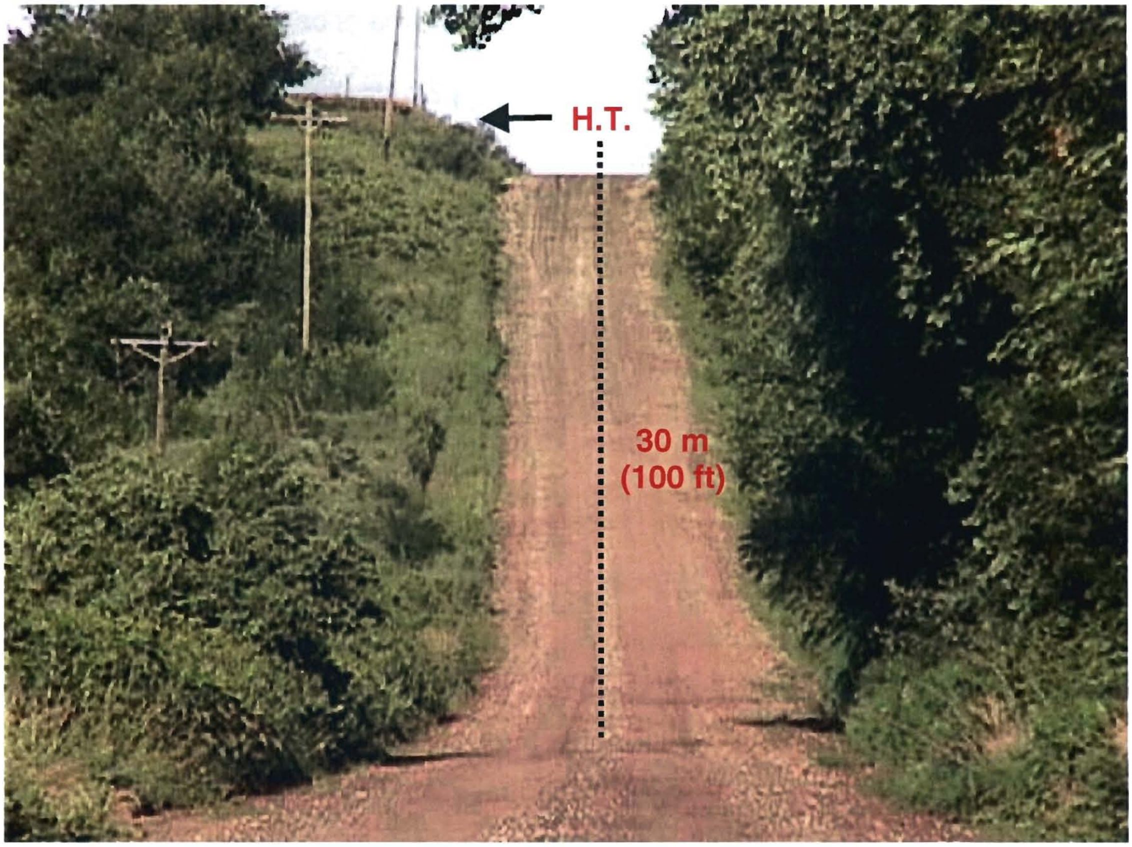



Figure 24. High-terrace (H.T.) located in northwestern McPherson County, Kansas (site 9). The high-terrace may have been deposited by the ancestral Smoky Hill River flowing at a higher elevation during the past.

According to McPherson County soil survey and GIS SSURGO soil coverages, the high-terrace deposits at site 9 correspond to the Wells loam soil polygons (Rott, 1983). The Wells loam soil occurs on the upland surface and is composed of "old river alluvium (Rott, 1983)." The terrace contains exotic gravels such as milky quartz, tan quartzite, dark flint, and chert (non-Flint Hills). Other unconsolidated materials contained at site 9 are sandstone concretions (reworked Dakota), petrified wood, mammal bones fragments, and volcanic ash. As with the high-terraces at other locations in Ellsworth County (7-8), there were no Sioux Quartzite glacial erratics noted at site 9. Figure 25 is a digital photograph of exotic gravels and petrified wood (middle) collected from the Wells loam in McPherson County.

Figure 25. Erratic gravels from the Wells loam in McPherson County with petrified wood (center).

The taxonomic classification of the Wells loam in McPherson County is described as a Fine-loamy, mixed, mesic Udic Argiustolls. A representative soil profile of the Wells loam is described as follows (Rott 1983).

A--0 to 11 inches (28 cm); brown (7.5YR 4/2) loam, dark brown (10YR 3/2) moist; moderate medium granular structure; slightly hard, friable, many fine roots; medium acid; gradual smooth boundary. (8 to 12 inches thick).

BA--11 to 15 inches (28 to 38 cm); reddish brown (5YR 4/3) sandy clay loam, dark reddish brown (5YR 3/3) moist; moderate medium granular structure; slightly acid, gradual smooth boundary.

Bt--15 to 37 inches (38 to 94 cm); reddish brown (5YR 4/4) sandy clay loam, dark reddish brown (5YR 3/4) moist; moderate medium blocky structure; hard, firm, few fine roots; slightly acid; gradual smooth boundary.

BC--37 to 49 inches (38 to 125 cm); reddish brown (5YR 5/4) sandy clay loam, reddish brown (5YR 4/4) moist; weak medium blocky structure; hard, firm; slightly acid; gradual smooth boundary.

C--40 to 60 inches (102 to 152 cm); reddish yellow (5YR 6/6) sandy loam, yellowish red (5YR 5/6) moist; massive; hard, friable; many pebbles and coarse sand grains; mildly alkaline.

Volcanic ash was observed in high-terraces in both Ellsworth (Meadin sandy loam) and McPherson (Wells loam) counties. The volcanic ash occurs just above the coarse sandy alluvial deposits in sampled terraces 8-9. The ash is approximately 0.1-0.5 m (0.3 -1.5 ft) in thickness at both locations. Figure 26 is a digital photograph of the high-terrace deposits at site 9, which contain volcanic ash.


Figure 26. Close-up of the Wells loam located in McPherson County, Kansas. Terrace is composed of old alluvium that contains abundant exotic pebbles as well as volcanic ash.

Figure 27 is a close-up photograph of the volcanic ash in Figure 26. The ash seems to be somewhat clean in composition with little to no mixing. Fluvial processes probably concentrated the ash and deposited it in depressions on terraces 8-9.

Figure 27. Fragments of volcanic ash located in high-terrace deposits in northwestern McPherson County, Kansas.

According to Izett and Wilcox (1982), the ash in McPherson County is rhyolitic in composition and is believed to have originated in northwestern United States from the Yellowstone Caldera in Wyoming. The youngest volcanic ash recognized in McPherson County is probably the Lava Creek B ash bed. This ash bed has been dated at approximately 0.62 million years age (mya). If the ash in Figure 27 is Lava Creek B then these sediments would have been deposited at about the time of the mid-Pleistocene pre-Illinoian glaciations. The oldest ash that has been noted in McPherson County is identified as the Huckleberry Ridge ash bed. This ash bed is dated at approximately 2.02 mya, which is much older than Lava Creek B and would place the deposits at a late-Pliocene or early Pleistocene age. Although there is a great disparity between the dating of the two ash beds, they give an approximate range in age for drainage through the McPherson Channel.

**GIS Analysis of Meadin and Wells Soils**

The apparent correlation between soil map units and terrace deposits was investigated further using GIS techniques. The basic idea was to determine whether or not the soil polygons that apparently correspond with terrace deposits could have been deposited by the ancestral Smoky Hill River system. Starting from western Ellsworth County a Meadin SSURGO soil polygon was selected out and average elevations were calculated every 8 kilometers (5 miles). The same was done with soils located in sample sites 7-9 (Fig 28). The object was to determine if the changes in elevation between polygons were consistent with the hypothesis that they were deposited by a single stream system.

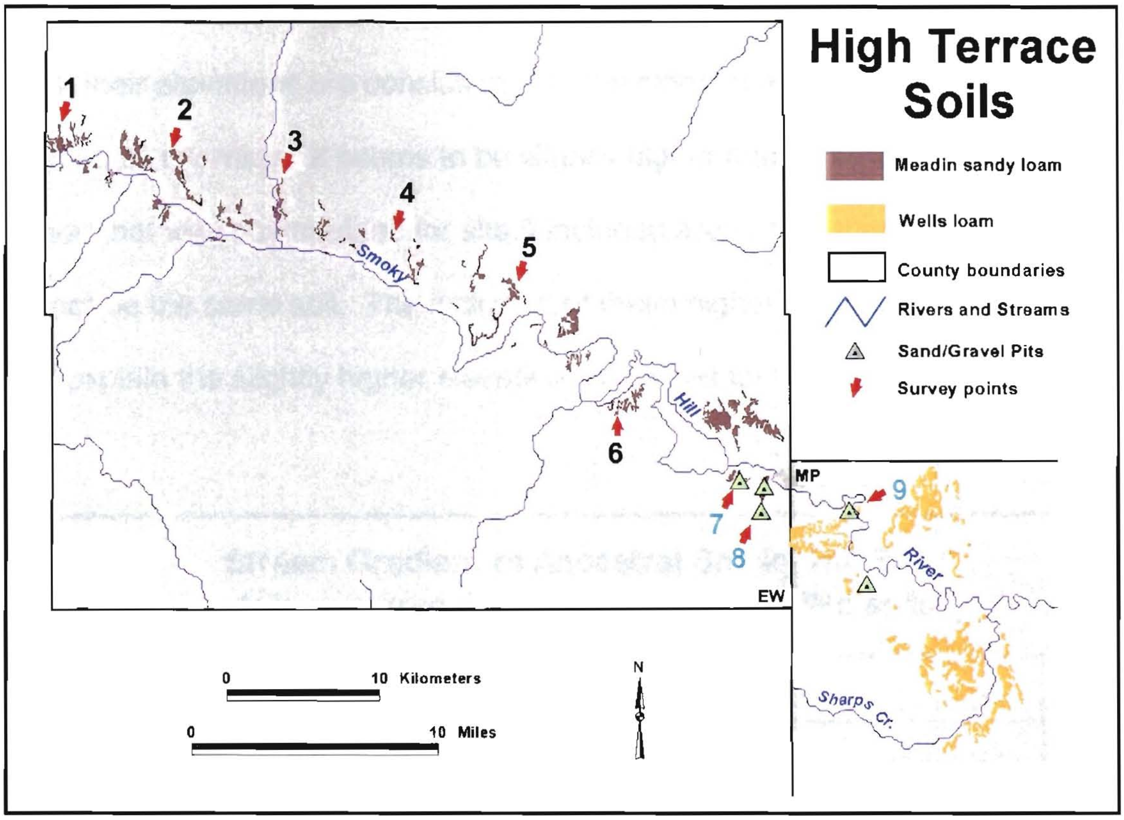



Figure 28. Soils 1-9 were summarized to produce the average elevation contained within each SSURGO soil polygon.

Box plots depicting the changes in elevation for Meadin sandy loam (1-8) and Wells loam soils (9) in Ellsworth and McPherson counties were created to show the elevation changes along the proposed stream channel. If the soil polygons do represent soils formed in fluvial sediments deposited by the ancestral Smoky Hill River System then their elevations should decrease from west to east. Figure 29 is the box plot generated using the soil polygon elevation data from polygons 1-9. The gradient of the soil polygons 1-9 is approximately 0.6 m per kilometer (3.3 ft / mile). The Meadin soils of Ellsworth County and the

Wells soils of McPherson County appear to be in grade with each other. In other words, their elevations are consistent with the slope of an ancestral channel. Site 9 is the only anomaly. It seems to be slightly higher than sites 7 and 8. The soil polygon that was summarized for site 9 included areas of higher topography that may not be the same soil. The inclusion of these higher areas in this map unit could explain the slightly higher elevation calculated for this map unit.

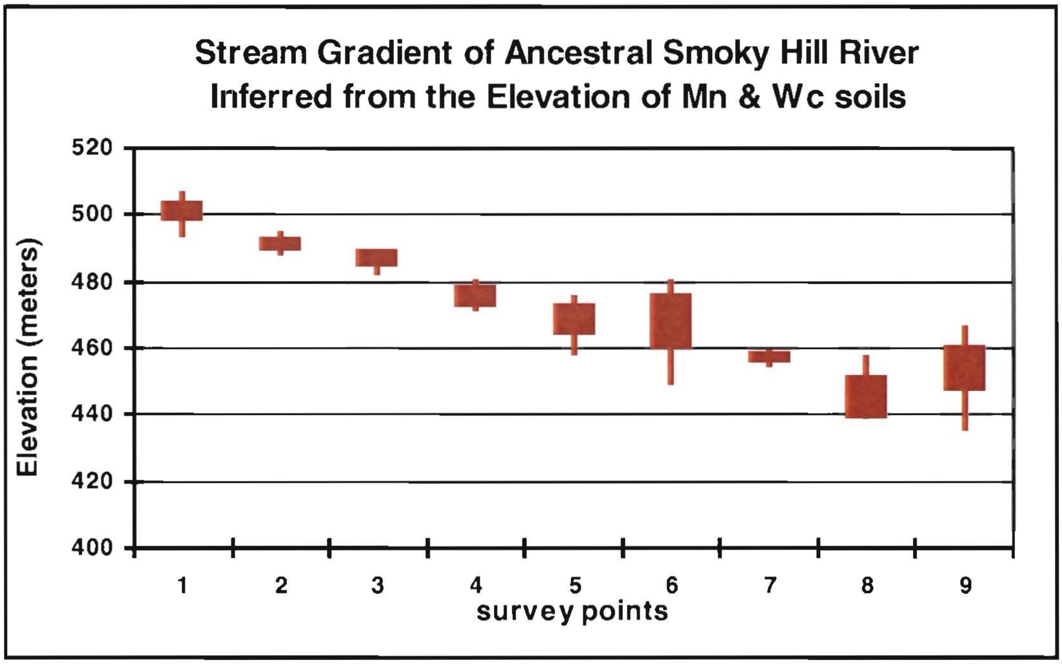



Figure 29. Statistical analysis of the high-terrace deposits in Ellsworth and McPherson counties.

According to the Ellsworth and McPherson County Soil Surveys and GIS SSURGO soil coverages the Wells loam and Meadin sandy loam are described as different soils, but in practice they seem to be similar or possibly just formed in the same parent material. The Wells loam is essentially in the same grade and of similar composition as the Meadin sandy loam in Ellsworth County. It seems that the parent material for these high-terrace soils may have been deposited by the ancestral Smoky Hill River at the time of paleo-connection to the McPherson Channel.

# Chapter 4. Interpretation

## Bedrock Topography

Figure 30 is the bedrock topography TIN created from bedrock control points. Figure 30 seems to suggest that at the confluence between the Solomon and Smoky Hill Rivers in northeastern Saline County the bedrock topography occupies an elevation of approximately 350 m (1150 ft) (A in Figure 30). This area is lower in elevation than the buried McPherson Valley in McPherson County, which is approximately 407 m (1335 ft) in elevation (B in Figure 30). The difference in bedrock elevation of the Smoky Hill River north of Salina appears consistent with the interpretation that the northern drainage route was established after a tributary near Salina eroded headward along the Wellington Formation and captured the Smoky Hill River near Lindsborg.

It seems that the Smoky Hill River is not the only river to have been subjected to stream captures and subsequent drainage diversions from prior flow paths in this area. In Figure 30 many of the headwaters of smaller tributaries that flow into major rivers seem to exhibit a 90-degree change in flow direction. For instance, Sharps Creek (C in Figure 30) in McPherson County seems to have been captured and diverted by the Smoky Hill River to the north, although it appears to have flowed southeast sometime during its drainage development. Elkhorn Creek is a tributary in northern Ellsworth County that also appears to exhibit similar stream morphology (D in Figure 30). The stream seems to have flowed in a southeastern direction before being captured and redirected into the Saline River. Spring Creek in southwestern Saline County (E in Figure 30) seems to be eroding headward toward the Smoky Hill River. It could capture the Smoky Hill River at some future date. The headwaters of the Cottonwood River also appear to drain in a southwest-northeast orientation and then abruptly turn to the east (F in Figure 30) to form a fishhook shape.

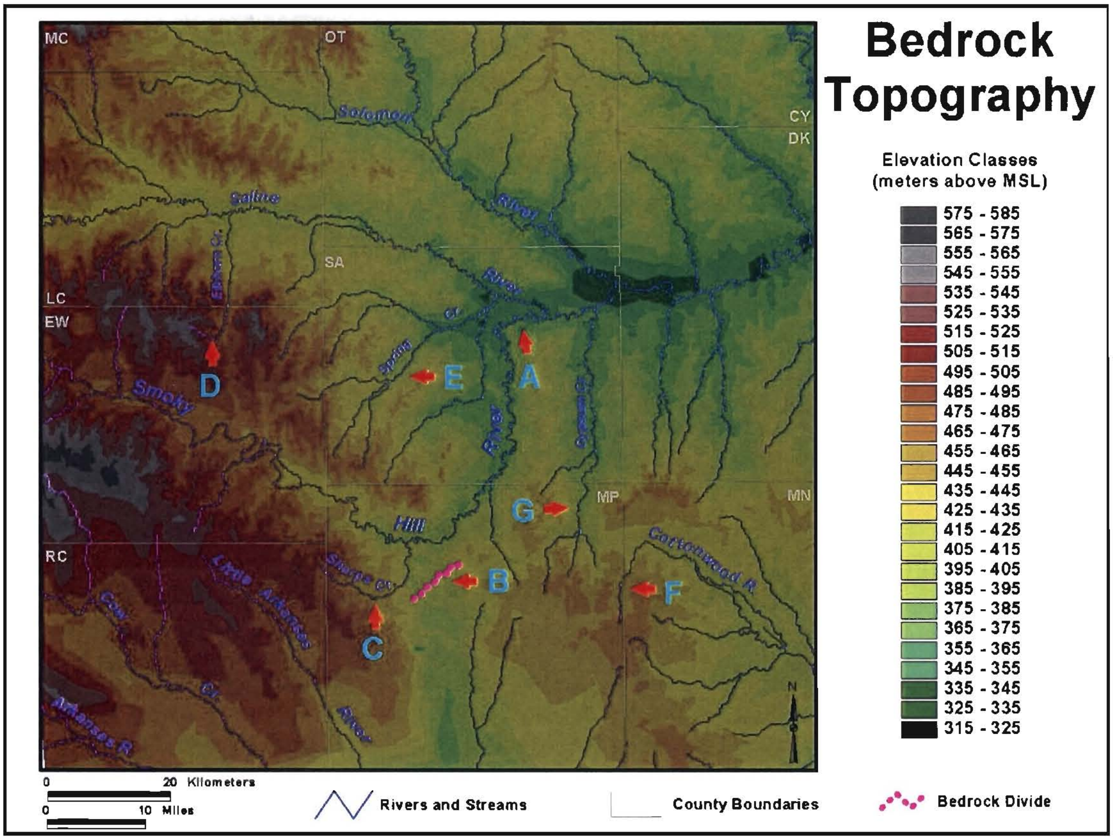



Figure 30. TIN (triangulated irregular network) created from bedrock control points.

Gypsum Creek in eastern Saline County flows parallel to the Smoky Hill River until merging with that river in Dickinson County (G in Figure 30). The drainage of Gypsum Creek seems to have been affected in much the same way as the Smoky Hill River. Both the Smoky Hill River and Gypsum Creek have developed a north-south orientation along the strike of the underlying bedrock. Gypsum Creek may not have formed at the same time as the capture of the Smoky Hill River into the Kansas River basin but it was affected by the same bedrock control factors. Both were probably aided by the dissolution underlying gypsum beds in the Wellington Formation by groundwater (Waterman and Krieger, 1950). The parallel flow of the Smoky Hill River and Gypsum Creek in Saline County helps to illustrate the persuasiveness of soft bedrock on stream morphology in this area.

The stream development occurring within this study area is not anomalous compared with other areas in Kansas. It seems that a majority of rivers and streams in Kansas may have been subjected to captures and diversions from previous drainage paths at different times in the past. For instance, the Arkansas River flows southeast in southwestern Kansas until it is diverted nearly 90-degrees, bending northeast in Ford County. This particular river system is a good example of a large river aside from the Smoky Hill River that has experienced stream diversion and capture resulting in this type of geomorphic development.

**Glacial Lake Hypothesis**

The glacial meltwater hypotheses connecting the Smoky Hill River systems with the Arkansas River System to the south as proposed by Sharp (1894) and Frye and Leonard (1952) is not needed to explain the formation of the

McPherson Channel and the deposition of the Equus Beds sediments. There are two primary reasons for not accepting Sharp's (1894) glacial lake hypothesis and Frye and Leonard's (1952) meltwater hypothesis. First, the maximum surface elevation of a meltwater lake near Manhattan would have been approximately 305m (1050 ft). It could have been even lower given depression of local bedrock near the ice advance. The bedrock divide near Lindsborg is located at approximately 407 m (1335 ft). If glacial meltwater backed up and formed a lake from Manhattan to Lindsborg, the elevation difference would be nearly 87 m (285 ft) from the east near Manhattan to west near the spillover point at Lindsborg. The difference in elevation between the two basins gives little reason to suggest a meltwater lake backed up and spilled over the drainage divide near Lindsborg to create the McPherson Channel, especially when lower outlet points existed closer to Manhattan. Figure 31 is a representation of the alleged meltwater connection between Manhattan and Lindsborg.

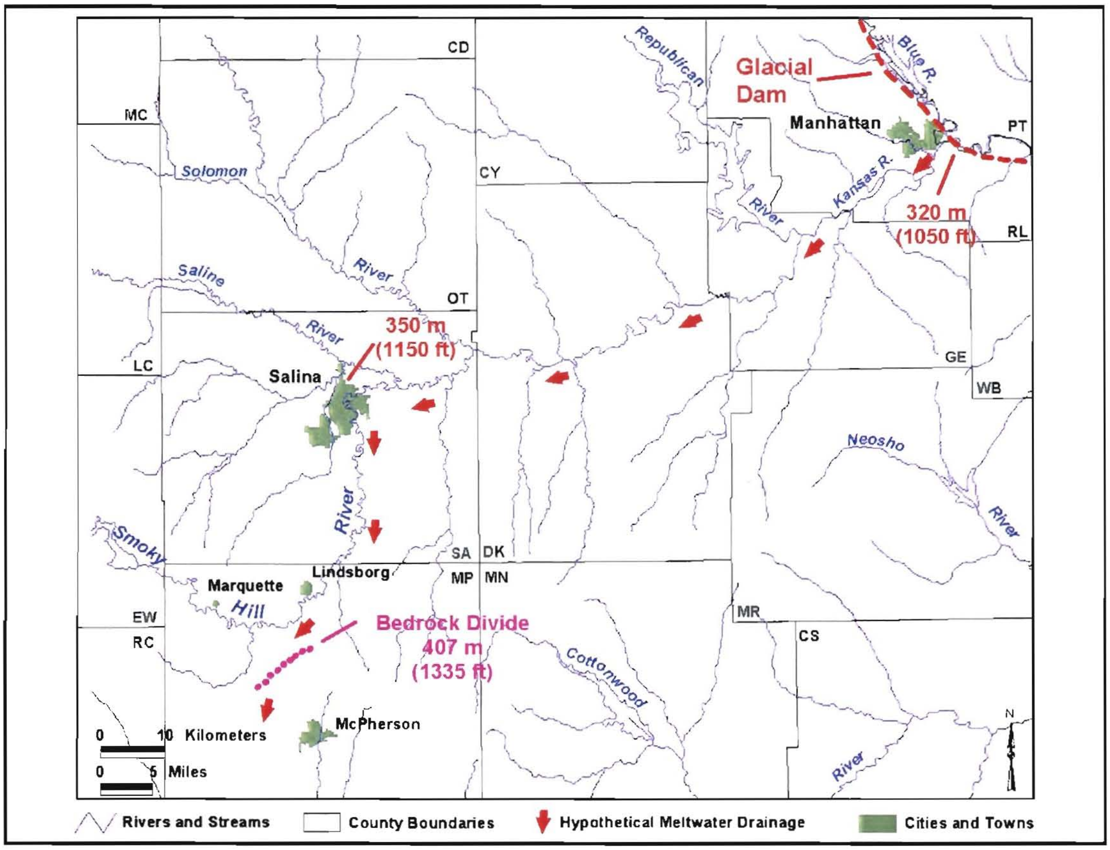



Figure 31. Map showing elevations of the glacial meltwater dam and McPherson bedrock divide.

The second piece of evidence contradicting the glacial meltwater hypotheses is the lack of northeastern glacial erratics such as Sioux Quartzite and Pipestone as well as other exotics from the Canadian Shield. In particular, Sioux Quartzite is an abundant glacial erratic associated with sediment from pre-Illinoian glaciations that extended into Kansas (Aber, 1991). If glacial lake meltwater from the Kansas River Basin as reported by Sharp (1894) connected to the McPherson Channel before water flowed northeast, then fluvial sediment contained in high-terraces along the Smoky Hill River and Equus Beds sediments would contain characteristic glacial erratics such as Sioux Quartzite.

If a glacial lake of this magnitude existed sometime in the past then perhaps the presence of glacial lacustrine sediments would be present between Lindsborg and Manhattan. Also, if meltwater flowed toward the southwest from the glacial front near Manhattan as reported by Leonard and Frye (1952), then it would seem reasonable that Smoky Hill River would have transported chert gravel eroded from the Flint Hills over which the meltwater crossed. No such sediments have been noted by this study or others to validate a southwest meltwater connection flowing through the McPherson Channel from the northeastern ice lobe that advanced into Kansas.

### High-terrace Soils and Ancestral Drainage

The high-terrace soils that occur along the Smoky Hill River valley in Ellsworth and McPherson County seem to be fluvial in origin. The sediments were probably deposited by the ancestral Smoky Hill River flowing at a much higher elevation. It seems from the distribution of these fluvial terraces the ancestral Smoky Hill River occupied a position and orientation similar to the present river system. In Figure 32 the Meadin and Wells soils were overlain on the bedrock TIN to illustrate the spatial pattern of the soils and the contour of the bedrock valley. The soils seem to form a spatial pattern similar to that of an old river system. The terraces extend south toward the bedrock divide into the McPherson Channel. The high-terrace (site 9) in McPherson County is located at an approximate elevation of 457 m (1500 ft) near the drainage divide into the McPherson Channel. The bedrock divide (McPherson Ridge) that separates the paleo-channel from the modern Smoky Hill River is approximately 407 m (1335 ft) in elevation. From the elevation and spatial pattern of the high-terrace sampled it seems that the ancestral Smoky Hill River could have easily flowed over this divide into McPherson and Harvey Counties (Fig. 32).

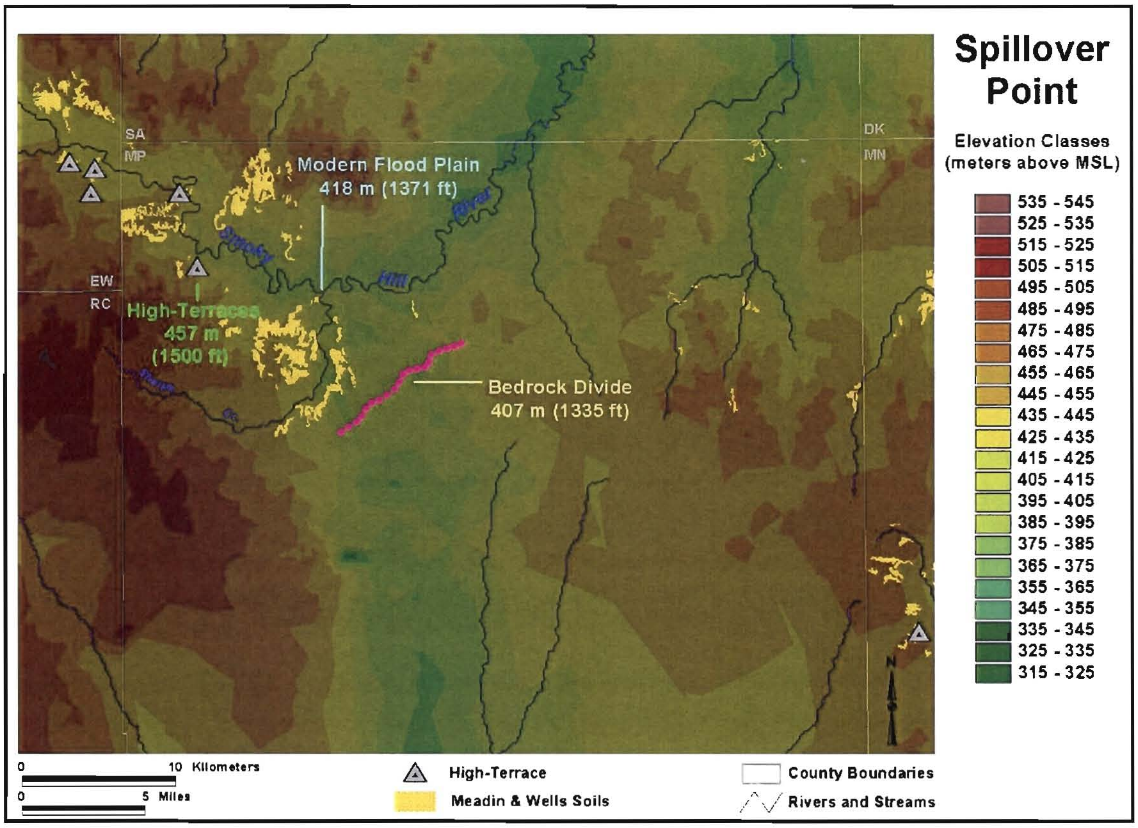



Figure 32. High-terrace deposits give evidence for prior flow of Smoky Hill River over the bedrock divide.

## Development of the McPherson Valley

As the ancestral Smoky Hill River flowed into McPherson County a marked change in channel migration and valley width is apparent. The ancestral river seems to have occupied a rather narrow valley in southeastern Ellsworth County and a significantly wider valley in McPherson County. Geologists such as Beede (1897) commented on the alleged disparity between the valley above the town of Marquette and the extreme flatness south toward the city of McPherson. He stated, "It is difficult to understand why it (Smoky Hill) should have excavated so great a channel and covered so great a flood plain here (south of McPherson) and so narrow a valley west of Marquette".

The cause of this disparity in erosion and channel migration is primarily a function of base level changes to the Smoky Hill River and soft Permian bedrock underlying the area of the bedrock valley (Fig. 33). From the results of this study it seems that multiple tributaries or channels may have existed in the past within McPherson County. These individual channels or tributaries probably aided in erosion of the wide alluvial plain located from east to west across McPherson County. The dark pink line in Figure 33 delineates the boundary of the Equus Beds. It helps to emphasize the width of fluvial activity within the McPherson Valley.

The light gray arrows within the Equus Beds east of the main bedrock channel are meant to indicate hypothetical locations for this stream as it eroded downward and westward across the study area. The stream that eroded the western channel (blue arrows) probably achieved deeper incision by eroding down the dip of the underlying Wellington Formation and into the Hutchinson Salt member.

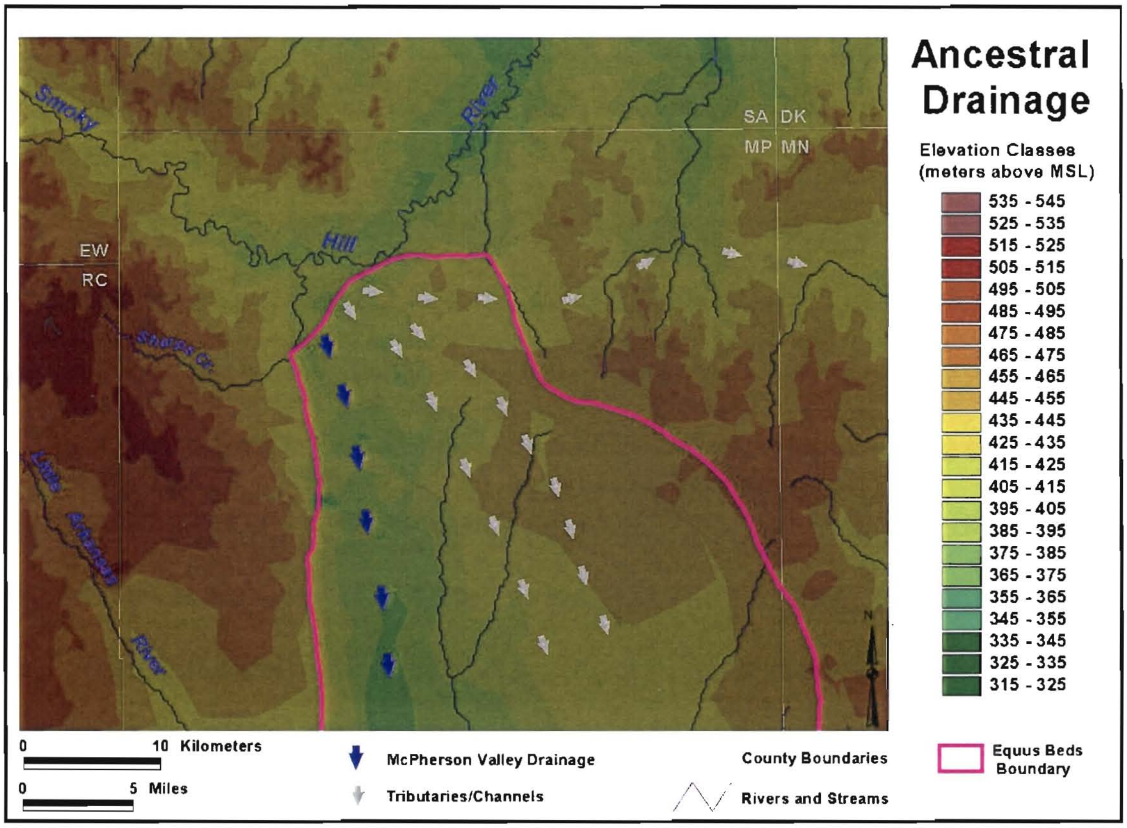



Figure 33. Hypothetical representation of ancestral drainage routes in McPherson County, Kansas.

Figure 33 also contains a hypothetical representation of drainage development of the McPherson Valley. The northern set of light gray arrows denotes a hypothetical connection to the Cottonwood River in northwestern Marion County. Aber (1991) has suggested that early (Neogene) river drainage crossed the Flint Hills toward the east of the study area. Aber has suggested that drainages crossed the highest parts of the Flint Hills from west to east and the alluvium of the Wellington-McPherson-Arkansas Lowlands once extended eastward across what is now the Flint Hills. His findings, in conjunction with evidence put forth by this thesis may suggest a connection from the Smoky Hill River to adjacent river basins such as the Cottonwood River toward the southeast.

Evidence for high-terrace deposits with similar composition to terraces located in this study area occur throughout the Cottonwood River. A similarity in composition between gravels occurring in Marion and McPherson County may suggest a connection from western streams flowing east across this area. It may be possible that early in the drainage development of the ancestral Smoky Hill River it flowed eastward connecting to the Cottonwood River, prior to eroding the McPherson Channel to the south. If so, it would have been flowing across the Flint Hills before being captured and diverted south to form the McPherson Channel in McPherson County.

As the ancestral Smoky Hill River began to erode the Cretaceous bedrock during the first stages of stream development, soft Permian shales of the Wellington Formation may have become exposed in McPherson County. These older streams may have flowed south through eastern McPherson and western Marion County aiding in erosion of the wide alluvial plain in this area before the McPherson Channel was more deeply incised toward the west of McPherson County. The soft bedrock of the Wellington Formation would have provided a path of least resistance for early streams toward the south.

As the river flowed into McPherson County a change in bedrock resistance would have occurred between the more resistant Cretaceous bedrock and softer underlying Permian shales. The difference between the erosional susceptibility of the Cretaceous and Permian bedrock and base level changes occurring during the Pleistocene would have greatly affected the rivers ability to entrench its valley as it flowed into McPherson County. The ancestral Smoky Hill River while flowing on more resistant Cretaceous bedrock in eastern Ellsworth would have occupied a rather narrow river valley. However, the river flowing onto the soft Permian shales would have behaved in a rather different manner. At this point the river would have experienced an increased ability to erode and entrench into the soft shales of the Wellington Formation especially if lower base level conditions existed. Although this soft shale would have provided a path of least resistance, it was probably the change in base level occurring during the Pleistocene that allowed the ancestral streams to entrench. This base level change would have occurred when glaciers developed thus lowering mean sea level. This would have caused rivers that were near base level to entrench their valleys in order to adjust to this new change in base level. Erosion and dissolution of the Hutchison Salt member of the Wellington Formation in conjunction with base level changes would have allowed the river to deeply entrench in the western portions of McPherson County creating the deepest parts of the McPherson Valley.

### Stream Capture and Diversion

Geologists have suggested that when the ancestral Smoky Hill River was flowing into the McPherson Channel during interglacial times the river had lost energy and deposited its bedload thus aggrading its alluvial plain and causing this river to become sluggish in discharge (Williams and Lohman, 1949; Fent, 1950; Lane and Miller, 1965). As the ancestral Smoky Hill River flowed in this sluggish phase through the McPherson Channel a river near Salina eroded headward eventually capturing the Smoky Hill River (Waterman and Krieger, 1950; Lane and Miller, 1965). The primary factors enhancing headward erosion were changes in base level associated with the climatic changes of the Pleistocene and the exposed, soft, Wellington Formation. Remnants of the Hutchison Salt member of the Wellington Formation are believed to be present beneath the younger alluvium where the Smoky Hill River now flows from Lindsborg to Salina (Waterman and Krieger, 1950). Rapid erosion of these soft formations would have given the sediment-chocked channel a lower outlet.

## Chapter 5. Conclusions

Based on the study of the bedrock topography and the high-terrace deposits located in the study area, the following conclusions can be made: (1) High-terrace soils investigated in the area strongly suggest that the ancestral Smoky Hill River may have flowed at an elevation of 457 m (1500 ft) near the inlet to the McPherson Channel. The minimum elevation of the McPherson Ridge is approximately 407 m (1335 ft). The high-terrace deposits along the Smoky Hill River valley are elevated some 50 m (165 ft) higher than the bedrock divide into the McPherson Channel providing strong evidence to support the hypothesis for ancestral Smoky Hill River flowing south into Arkansas River Basin sometime during the past. (2) The difference in elevation between the meltwater dam near Manhattan, which is at an elevation of 320 m (1050 ft) and the bedrock divide spillover point near Lindsborg of 407 m (1335 ft) is too great for a glacial meltwater explanation to be feasible for the erosion of the McPherson Valley, especially when lower outlets existed closer to Manhattan. (3) The ancestral Smoky Hill River and its tributaries may have eroded multiple channels or tributaries in McPherson County. (4) The climatic dynamics of the Pleistocene which lowered base level for streams during glacial maximum and the presence of the Hutchison Salt Member of the Wellington Formation were probably sufficient to allow the Smoky Hill River to rapidly deepen the McPherson Valley in western McPherson County. (5) The Smoky Hill River was captured by a river near Salina that probably also eroded headward along the strike of the Wellington Formation. The headward erosion by the Kansas River Basin that captured the Smoky Hill River may have been accelerated by a glacial advance thus controlling base level and dissolution of the underlying Hutchinson Salt Member believed to have occurred in the present area of the modern flood plain between Lindsborg and Salina (Waterman and Krieger, 1950). Since the elevation is lower toward the Kansas River basin, an increase in valley entrenchment by base level changes would have accelerated headward erosion toward the north-south trending Hutchison Salt beds near Salina. The climatic extremes of Pleistocene ice advances interacting with soft Permian bedrock may have caused the capture of the ancestral Smoky Hill River. (6) The volcanic ash occurring in high-terraces gives some idea about the age of the McPherson Channel which is presumed to be older than 0.62 mya (Lava Creek B) and possibly as old as 2.02 mya (Huckleberry Ridge). (7) The Smoky Hill River may have connected with adjacent river basins toward the east, such as the Cottonwood River. Aber (1991) has indicated that high-terraces of similar composition are present across eastern Kansas and may contain alluvial sediment from western sources. It is possible that sometime in the past the Smoky Hill River crossed the Flint Hills and connected to eastern river basins such as the Cottonwood River before being captured and diverted toward the south to form the McPherson Channel.

## Chapter 6. References


Aber, J.S., 1991, The glaciation of northeastern Kansas. Boreas, v. 20, p. 297-314.

Aber, J.S., 1997, Chert gravel and Neogene drainage in east-central Kansas: Kansas Geological Survey, Open-file Report, 37 p.

Barker, W.L., and Dodge, D.A., 1989, Soil Survey of Ellsworth County, Kansas: U.S. Department of Agriculture, Soil Survey Service, 49 p.

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

Bayne, K.B., Franks, P.C., and Ives, W.I., Jr., 1971, Geology and ground-water resources of Central Kansas, Ellsworth County, Kansas. Kansas Geological Survey, Bulletin 201, p. 29-71.

Beede, J.W., 1898, The McPherson Equus Beds. Kansas Academy of Science, Transactions, v.15, p. 104-110.

Beede, J.W., and Haworth, E., 1897, The McPherson Equus Beds. University Geological Survey, v. 2, p. 285-296.

Fent, O.S., 1950, Geology and ground-water resources of Rice County. Kansas Geological Survey Bulletin 85, p. 101-138.

Fent, O.S., 1950, Pleistocene drainage history of central Kansas. Kansas Academy of Science, Trans. 53, no. 1, p. 81-91.

Frye, J.C., 1939, Physiographic Significance of Loess near McPherson, Kansas, American Association of Petroleum Geologists Bulletin, v. 23, no. 8., p. 1232-1233.

Frye, J.C., and Leonard, A. B., 1952, Pleistocene geology of Kansas. Kansas Geological Survey Bulletin 99, p. 186-193.

Frye, J.C., Leonard, A. B., and Hibbard C.W., 1943, The westward extension of the Kansas "Equus Beds." Journal of Geology, v. 51, no. 1 p. 33-47.

Hibbard, C.W., and Frye, J.C., 1941, Stratigraphy and paleontology of a new middle and upper Pliocene formation of south-central Kansas: Journal of Geology. v. 49, p. 261-268.

Izett, G.A., and Wilcox, R.E., 1982, Map Showing Localities and Inferred Distributions of the Huckleberry Ridge, Mesa Falls, and Lava Creek Ash Beds (Pearlette Family Ash Beds) of Pliocene and Pleistocene Age in the Western United States and Southern Canada.

Lane, C.W., and Miller, D.E., 1965, Geohydrology of Sedgwick County, Kansas. Kansas Geological Survey Bulletin 176, p. 15-32.

Latta, B.F., 1949, Ground-water Conditions in the Saline, Dickinson and Geary Counties, Kansas. Kansas Geological Survey Bulletin 84, p. 96-141.

Lohman, S.W., and Frye, J.C., 1940, Geology and groundwater resources of 'Equus Beds' area of south-central Kansas. Economic Geology. v. 35, p. 839-866.

Mack, L.E., 1962, Geology and ground-water resources of Ottawa County, Kansas. Kansas State Geological Survey Bulletin 154, p. 100-141.

Ross, C.G., 1991, LEO II, automated legal and geographic reference conversion in Kansas, version II of the LEO system. Kansas Geological Survey Open-File Report 91-54.

Rott, D.E., 1983, Soil survey of McPherson County, Kansas: U.S. Department of Agriculture, Soil Conservation Service, 61 p.

Sharp, S.Z., 1894, Glacial effects in central Kansas. Kansas State Board of Agriculture, quarter ending March 13, 1894, part 2, p. 26-30.

Udden, J. A., 1891, Megalonyx beds in Kansas. American Geologist, v. 7, no. 6, p. 340-345.

Walters, R.F., 1977, Land subsidence in central Kansas related to salt dissolution. Kansas Geological Survey Bulletin 214, p.1-12.

Waterman, W.D., and Krieger, R.A., 1950, Geology and Hydrology of the Kanopolis unit in Ellsworth, McPherson, and Saline counties, Kansas. Kansas Geological Survey Open-File report, p. 9-13,120-184.

Williams C.C., and Lohman, S.W., 1949, Geology and groundwater resources of a part of south-central Kansas. Kansas Geological Survey Bulletin 79, p. 290-447.

Web data sources:

http://gisdasc.kgs.ukans.edu

http://www.ftw.nrcs.usda.gov/ssur_data

# Publication Rights

I, Cameron L. Cooper, hereby submit this thesis to Emporia State University as partial fulfillment of the requirements for an advanced degree. I agree that the Library of the University may make it available to use in accordance with its regulations governing materials of this type. I further agree that quoting, photocopying, or other reproduction of this document is allowed for private study, scholarship (including teaching) and research purposes of a nonprofit nature. No copying, which involves potential financial gain will be allowed without written permission of the author.

C Cooper
Signature of Author

11/30/01
Date

Using Geographic Information Systems (GIS) to Investigate Paleo-Drainage of the Lower Smoky Hill River, Central Kansas

Title of Thesis

Signature of Graduate Office Staff

2-5-02
Date Received

Distribution: Director, William Allen White Library
Graduate School Office
Author