Evidence of a Paleochannel Prior to the Present Le Sueur River Channel in Mankato, MN

by
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A thesis submitted in the fulfillment of the requirements for the degree of
Bachelor of Arts
(Geology)
at
GUSTAVUS ADOLPHUS COLLEGE
2009

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ABSTRACT

Approximately 9,400 years ago, Glacial River Warren rapidly carved out the modern Minnesota River Valley. A river will create a state of equilibrium and the features of the river will reflect the balance between the amount of water flow and the amount of sediment accessible for transport. Its tributaries have responded to the new base level of the Minnesota River by carving channels. Today these valleys are not proportional to their current water flow. The Le Sueur River is a tributary to the Blue Earth River, which flows into the Minnesota River. It appears that the Le Sueur River had a different channel. This channel has large valley walls and relatively no stream flow, is located south west of Mankato, MN. Evidence suggests of a recent stream capture event, since Glacier River Warren that leading to an increased sediment supply flowing into the Minnesota River. Bedrock topography suggests that there was a relatively recent (Holocene) stream capture event of the Le Sueur River by the Blue Earth River. Rapid down-cutting led to erosion, and the increased load of sediment flowing into the Minnesota River may be contributing to water quality problems.

ACKNOWLEDGEMENTS

I would like to thank all who have helped me accomplish and helped guide me through this research project. I would especially like to thank my advisor, Dr. Laura Triplet for helping me through the processes of interpretation, along with Carrie Jennings for coming up with the idea of this project. I want to give a big thanks to a Mankato State University geology professor, Dr. Chad Wittkop, for the multiple times I have needed assistance with GIS, giving me the LIDAR data, and helping me interpret some concepts about the paleochannel. Thanks to Andrea Johnson, a Grad student at University of Minnesota, Duluth, who I had accompanied out in my field site to investigate any PSA within a ravine of the paleochannel. A final thanks to the rest of the geology department, Dr. James Welsh and Dr. Alan Gishlick, for the extra support in this accomplishment, as well as my fellow Gustavus geology majors.

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Introduction

The most significant land surface processes that affect earth's surface globally are caused by fluvial processes. Water affects every land formation by mechanical and/or physical weathering (Oxford, 2009) by eroding, sculpting, or carving the landscape and can cause catastrophic events. Running water of a stream or river can begin either from an outflow from a spring, lake, marsh, or as an accumulation of water that gradually collects over time from upland areas, or from melt waters of a glacier (Allaby et al, 2008). Streams are a dynamic system in which they frequently adjust to changes within the landscape and can alter the existing terrain. Streams tend to meander back and forth across their down-valley axes, as they try to reach the lowest point or base sea level. The stream may respond by avulsing into a new channel as it meanders to seek the most efficient way to the base level. The moving water of the stream erodes its outer banks, deposit sediment within its beds, and degrade into its bed causing its valley to widen relative to its water flow.

These fluvial systems tend to create valleys proportional to their water discharge. Their valley development can depend on several elements that may vary the shape, and the dimensions of the valley. Within the southwestern portion of Minnesota exists the modern Minnesota River Valley that is not proportional to its current water flow. The valley extends from the western part of Minnesota at the boundaries South Dakota at Big Stone Lake and flows southeast toward Mankato, MN for a course of 150 miles. At Mankato, the river veers north east toward the Twin Cities, where it connects to the Mississippi River. The dimensions of the valley seem phenomenal in part because the depth from the valley floor to the top can vary as much as 200 feet and 1 to 3 miles wide (Matsch, 1972). Today, the Minnesota River's current discharge cannot fill the entire valley, and its tributaries also have steep walls and sides. The geologic history of Minnesota will help to understand how much time it took to develop this particular landscape.

Warren Upham, a geologist who studied Glacial Lake Agassiz, realized that the region had undergone more than one glaciation (Matsch, 1972). Multiple lobes made their way through portions of eastern North Dakota and the majority of Minnesota. Some of the main lobes that are associated with the Minnesota River Valley include the Des Moines Lobe and the Red River Lobe (Fisher, 2004). One major ice lobe of the Laurentide Ice Sheet extended southward coming from the Lake Superior lowland called the Superior lobe. Another ice lobe that was recognized after the Superior lobe (Blumentritt et al., 2009), was at the end of the last glacial period during the Pleistocene. The last lobe, which flowed along what is now the Minnesota River Valley was the Des Moines Lobe (Matsch, 1972). Figure 1a shows a simplified drawing of the different lobes that came though the southern Minnesota area. Figure 1b is a better extent and flow of the Des Moines Lobe that changed the landscape.

The Des Moines lobe, approximately 900 kilometers in length, had a relatively low profile (Clark, 1992), and the lobe advanced to its maximum extent about 14 and 12 thousand years ago, during a deglaciation (Clayton and Moran, 1982; Hallberg and Kemmis, 1986). The lobe brought more that just tills to this region, it brought proglacial lakes, paleofloods, paleorivers, and paleochannels. As the Des Moines Lobe retreated it formed Glacial Lake Minnesota, south of the city of Mankato, and Glacial Lake Agassiz which formed an ice dammed lake against the Laurentide Ice Sheet in the Red River lowland (Matsch, 1972 and Blumentritt et al., 2009). Glacial Lake Agassiz covered an area of approximately 200,000 square miles and

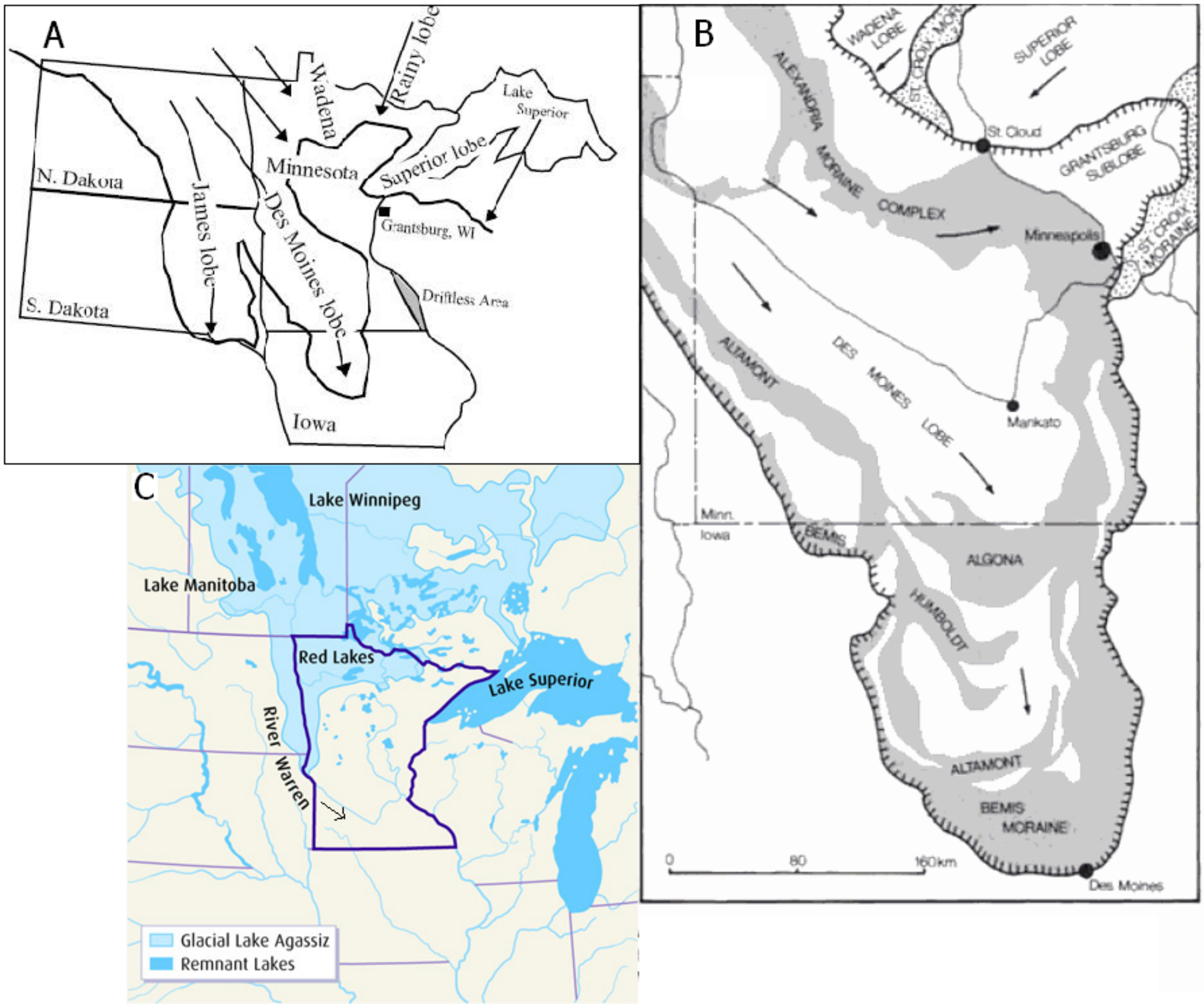


Figure 1. (A) A simplified drawing of the glacial ice lobes that had affected the landscape within Minnesota about 14,000 years ago (from Minnesota Geological Survey, 1872) (B) Shows a more complex diagram of the moraines of the Des Moines Lobe, its direction and its relationship to Mankato, MN. (Taken from Minnesota's Geology by Richard W. Ojakangas, Charles L. Matsch) (C) Shows the state of Minnesota and the extent of Glacial Lake Agassiz and the direction of water flow of its southern outlet by Glacial River Warren. (Map by Map Hero, Inc. for the Minnesota Historical Society, 2001)

during the early phase, the proglacial lake only had one southern outlet called Glacial River Warren (Elson, 1967 and Matsch, 1972), Figure 1C. This outlet brought great catastrophic floods to what is currently the Minnesota River Valley (Blumentritt et al., 2009). Its high volume stream had followed the original braided meltwater stream of the Minnesota River lowland area. It ultimately created a deep trench in southern Minnesota (Matsch, 1972).

Glacial Lake Agassiz, controlled largely by climatic variations during the Pleistocene Epoch and had drained a few times through Glacial River Warren (Matsch, 1972). An earlier phase of Glacial River Warren lasted about 10,800 ^{14}C year BP, until the ice sheet had receded far enough for Lake Agassiz to uncover new outlets to the east. It wasn't until the next advancement phase of the glaciers, where a second drainage through River Warren had ended approximately 9,400 ^{14}C year BP (Fisher, 2003). This caused the channel to expand causing it to widen and deepen the valley and had resulted in downcutting into glacigenic sediment, shale, sandstones and Precambrian rocks of granite bedrock (Matsch and Wright, 1967; Fisher, 2004). Ultimately, this created significant erosion and removal of sediment within the channel (Fisher, 2004).

Gradually the ice sheet melted back, and exposed new outlets for Glacial Lake Agassiz, greatly diminishing the flow of Glacial River Warren. What is left today, the Minnesota River, is only small fraction of the former discharge of Glacial River Warren and is an example of an underfit stream (Matsch, 1972). The flooding event of Glacial River Warren that carved out the Minnesota River Valley had major effects on the drainage of Glacial Lake Minnesota and Minnesota River's tributaries. The tributary streams responded by downcut their own channels. Often with tributaries will respond to major changes, such as flooding events, and extend themselves headward. Erosion seems to be very active and may have significant effects (Matsch, 1972).

The Mississippi River is one of the most economically important rivers in North America, and is geographically the largest (Engstrom et al, 2009). Recently there has been much concern about water quality issues within the Mississippi River with high amounts of phosphorus and high sediment loads. The Minnesota River has been linked to an excess amount of suspended solids, or turbidity, from erosional processes (Engstrom, 2009). Many studies and reconstructions have been conducted to try to pinpoint a source of the sediment and phosphorus loading within the Mississippi River, and then establish management and restoration for the river. Poor water quality issues may be related to the drainage basin, which is nearly have the state of Minnesota (100,000 square kilometers), which includes a large urban area, the Twin cities, and 28,000 square kilometers of row-crop agriculture. Gradual increases of sediment loads began a little after the European settlement (circa 1830). A study conducted on Lake Pepin, a lake that is a natural impoundment of the upper Mississippi River near the Twin Cities, shows that sediment accumulation rates have increased sharply between 1940 and 1970, then level off, and mainly contributed to the Mississippi River. However, the sediment continues to increase to present day. Lake Pepin formed approximately 10,000 ^{14}C years ago. It has been suggested that the infill of the lake has accelerated in the 170 years since settlement (Engstrom et al., 2009).

One potential source of the sediment contributing to the Mississippi water quality issue is the rates of erosion of the tributaries on the Minnesota River (Engstrom, 2009). The Minnesota River contributes about 85-90% of the total suspended sediment that flows into Lake Pepin (Kelley and Nater, 2000). Some morphologic changes, like aggradations or incisions of the channel, may affect a stream's capacity to erode its channel. The erosion from the stream may increase the amount of sediment loads that alter a stream (Woltemade, 1994), thus filling in the Lake Pepin at an increasing rate (Kelley and Nater, 2000). Within the Minnesota River Valley system, one potential tributary of concern is located south of the point where the river Minnesota

River flows northeast, at Mankato, MN. Two channels exist in the south western part of Mankato, around the ski area, Mount Kato, Figure 2. The Blue Earth River and the Le Sueur River currently confluence together and flow into the Minnesota River. The other channel only has a small stream, which is known as the paleochannel.

The paleochannel is a large channel that is just west of the current Le Sueur River. Paleochannel simply implies that a river, a paleoriver, had once occupied the channel, and maybe referred to as an avulsion or the capture event. An avulsion is a natural process that occurs when water flow diverts out of an established river channel into a new channel permanently. However, it isn't entirely known exactly why rivers avulse channels (Slingerland and Smith, 2004). Other studies, similar to the catastrophic flooding events, have indicated that the erosive, transport and depositional possibility vary with variables as slope, valley width, channel capacity and confinement of flow between terraces (Woltemade, 1994).

OBJECTIVE

The objective of this study is to show and understand the relationship between the Blue Earth and Le Sueur Rivers and to show how they relate to the proposed paleochannel. Interpretations will be made based on the gathered information. Future studies may be done to get actual dates. Until this past summer (2008), there has little work done on this problem. Wittkop created a few stream profiles of the Le Sueur River and the paleochannel in the fall of 2008.

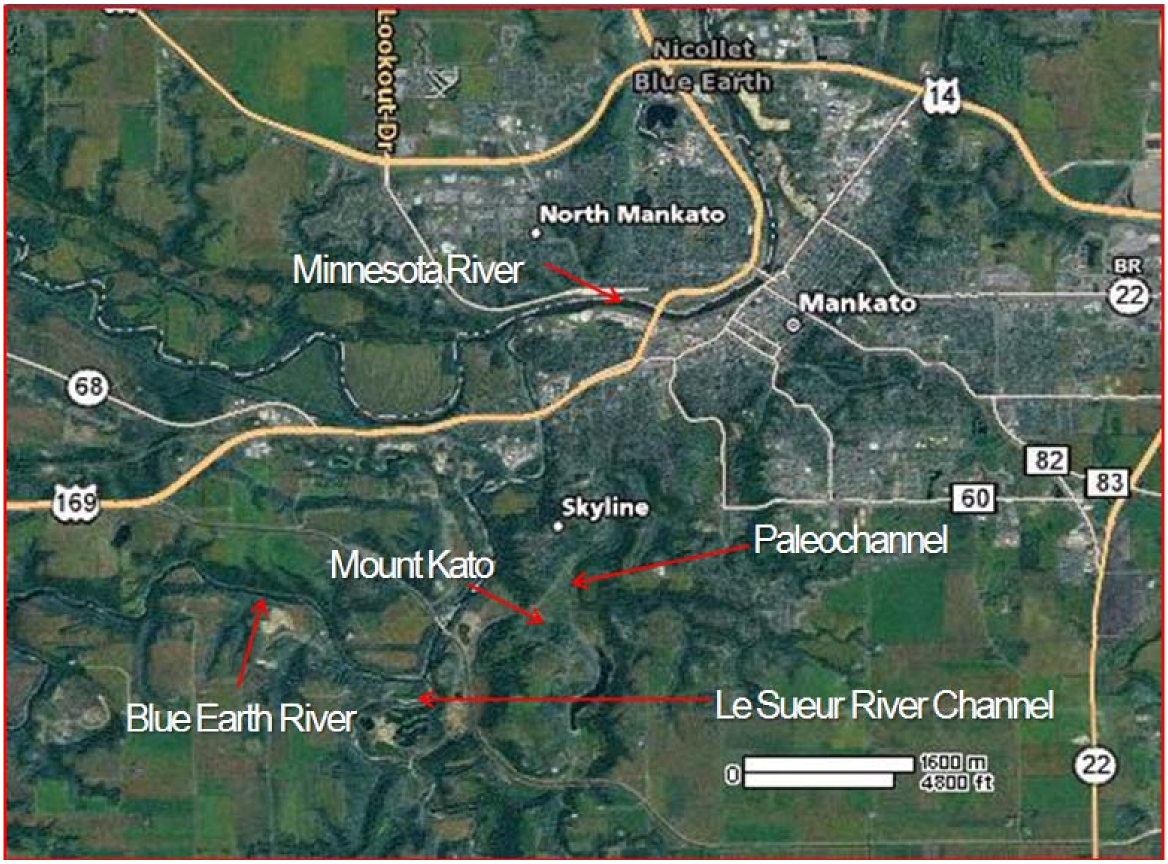


Figure 2: Shows the locations of the Blue Earth River, Mount Kato, the Le Sueur River, Minnesota River and the proposed paleochannel in Mankato, MN (map modified from Mapquest.com).

METHODS

Map Analysis & Field Methods

Aerial photos, topographic maps, geographic information systems (GIS) (ArcView), light detection and range data (LIDAR) from 2006. and digital elevation models (DEM), and field mapping were all used to study the extent of the Le Sueur River area of Mankato west. Field observations were made throughout areas of the channels which include the small bend in the old channel, a ravine that dips toward the Le Sueur River, and Rasmussen woods. Recorded features in these locations include bedrock outcrops, wetland areas, lakes, streams and terraces along with photos. A new LIDAR map was created in GIS, to reflect these observations and locations using a global positioning system (GPS).

Before beginning any field work or map analysis, literary research was done to acknowledge the fundamentals of river systems, avulsions, and general geologic history of my study area, as stated in the introduction. A variety of evidence has been collected in response to the fundamentals, to establish that there is a paleochannel in the west portion of Mankato, MN. Most of the evidence is based on observations and speculations of the data collected. Observations were made both in the field and interpreting published maps of the study area. Some research has been done on the City of Mankato for past land uses.

RESULTS

The paleochannel with steep valley walls and a relatively flat valley floor is outlined in Figure 3. The elevation is slightly higher than the current Blue Earth and Le Sueur River confluence, seen in Figure 5A and 5B. A small stream, called Indian Creek, now drains into the Minnesota River. Figure 4, shows the current stream flow in the fall within the paleochannel, the spring there is an actual flow, from the melting snow.

Using the LIDAR data, a map was produced to make a DEM shade relief map of the Blue Earth and Le Sueur River confluence, Figure 5A. A grayscale, Figure 5A, and a colored DEM, Figure 5B, and a colored DEM, Figure 5B, were made to interpret the elevations of the channel walls. Features that were located in the study site were mapped onto the grayscale DEM. In ArcScene, a 3D image of the paleochannel was made to give a sense of the geomorphology using the DEM image in Figure 6.

Areas of potential depositional sites were identified and mapped on the grayscale DEM in Figure 7. A wetland area exists near the top or mouth of the paleochannel. A gravel pit exists within the current Le Sueur River, prior to its confluence with the Blue Earth River. In several areas only slumped sediment were found, are also marked on the map. A deep ravine dips toward the current Le Sueur River. Potential terraces were found around the paleochannel and within the ravine. A rather large lake that sits within the paleochannel was mapped out, along with small alluvial fan to the east. Within the small narrow bend of the paleochannel, sixteen areas of exposed bedrock outcrops were observed. Most of this bedrock was predominately medium to fine grained dolomite, Figures 8A and 8B, of the Oneota Dolomite formation. Most of the paleochannel's walls have slumped sediment and are covered with forested areas, therefore no bedrock is exposed.

History within the Paleochannel

The Mankato area consists of six different bedrock units. The Franconia Formation was deposited in the Late Cambrian and consists of a yellowish gray sandstone and dolostone that overlies an earlier formation Ironton and Galesville Sandstone, but do not outcrop within this area. On top of the Franconia Formation is the St. Lawrence Formation is a yellowish gray to a grayish orange, dense to finely crystalline, silty dolostone. This formation can range up to 45 to 75 feet thick. Most of this formation is covered with glacial deposit and alluvial deposits and therefore doesn’t outcrop. Jordan Sandstone was deposited next, and is a light gray, coarsening upwards sandstone and that consists of two interlayered facies. The formation is approximately 70 to 100 feet thick. The Oneota Dolomite is a light brown to grayish orange, medium to thick bed of dolostone, Figure 8A and 8B. This formation can be up to 50 feet thick in some places within the region. The Shakopee formation is a light brown to grayish orange, thin to medium bed of sandstone and dolostone. The last bedrock type is Cretaceous rocks of sandstone and clays. (Mossler, 2003).

The topography map from 1974, Figure 3, shows an area that has steep valley walls and a relatively flat valley floor. The map was also used to find some features within the channel that may indicate the paleoriver’s flow. The map indicates several areas within this area to have gravel pits. Gravel pits are important to interpret because they show the stratigraphy with respect the past events. Currently, there are no gravel pits within the paleochannel. The gravel pits would have removed sediment, and thus filled in since.

Air photos from 1949 and from 2003 helped to identify what the land use of the area was prior to going out in the field. It appears and has been researched that Indian Lake is artificial as well as the wetland area in the northern part of the channel. According to the air photo from 1949, both areas seemed have been farmed, even the area of the small bend. Linear features indicate farm fields respectively. When looking at the air photo from 2003, there appears to be a lake in the paleochannel. It can be concluded that the lake it artificial. Indian lake was constructed as a wetlands restoration project in 1988 (refer to www.co.blue-earth.mn.us). This area had been a 50-acre wetlands basin but was drained in the 1920s for farmland, which is seen on Figure 10. In 1988, a bypass route along the south side of Mankato was built; however, the project had encroached on a 2.5 acre wetland area. Blue Earth County was required to mitigate, either by creating a new wetland, or restoring a degraded wetland. Blue Earth County was also able to acquire a 70-acre forested valley upland area to help the ecology of Indian Lake. The entire Indian Lake restoration project now has 120-acre regional park for recreation and environmental resources. An area, shown as in red on the DEM figure 6, may have been an alluvial fan from a side ravine. Since this area was a wetland prior to the farm fields, the alluvial fan still may be a source to core, as long as one was to get below the layer that was farmed. The alluvial fan technically would dip toward the lake and be higher toward the tree line.

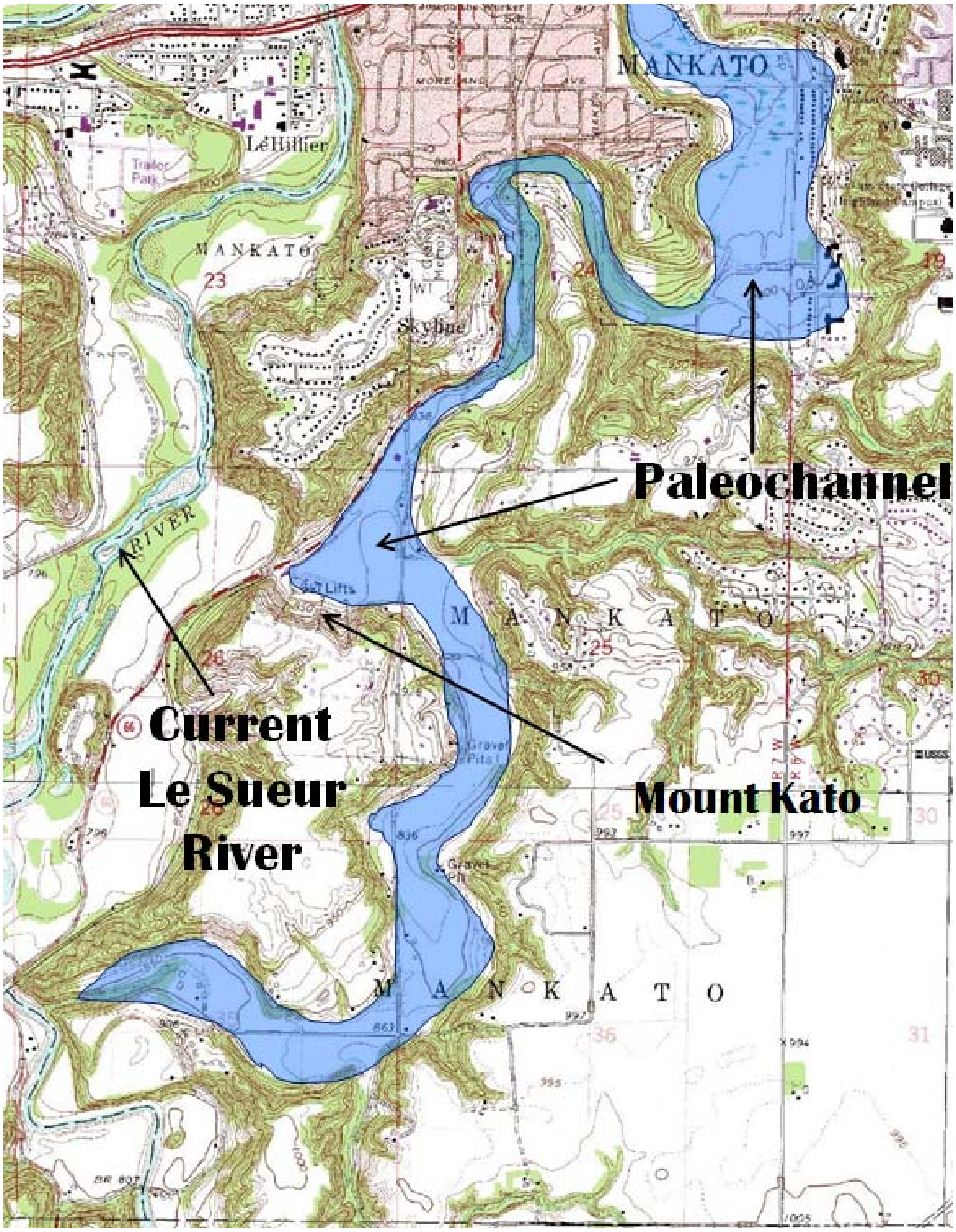
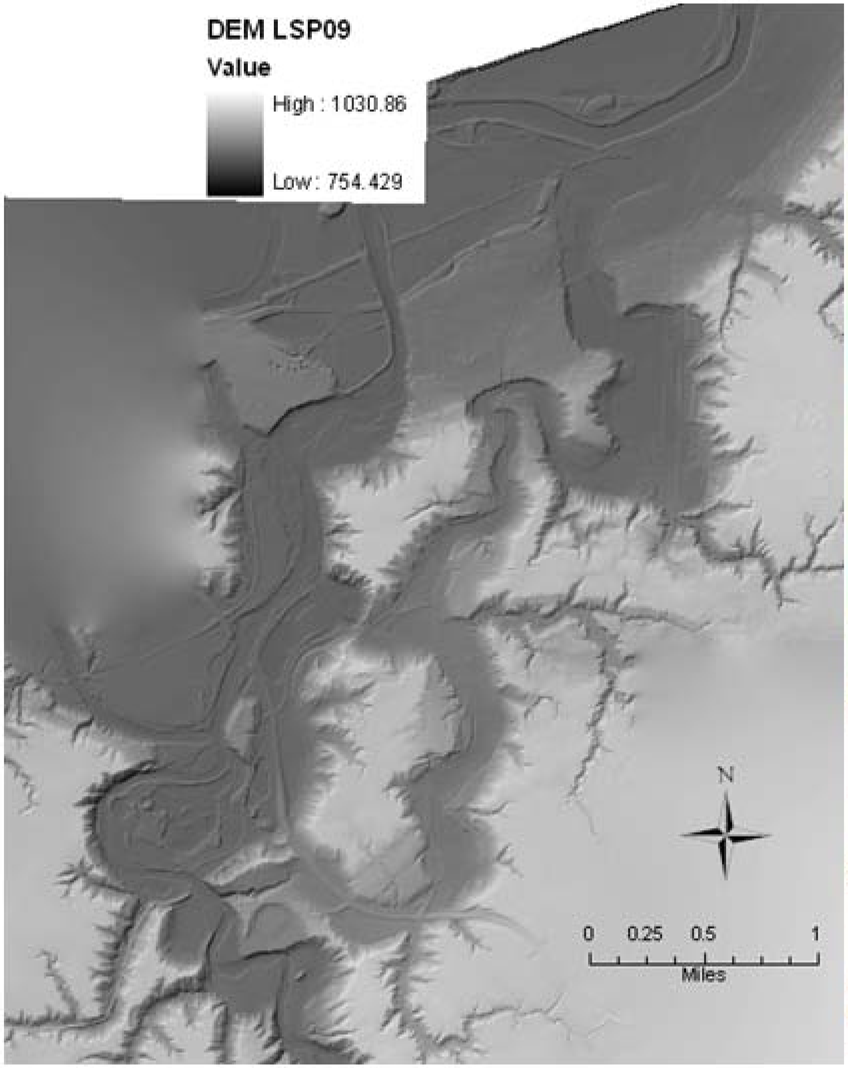


Figure 3: Topographic map of the Mount Kato in relationship to the paleochannel (outlined in blue) and the Le Sueur River.

Figure 4: Shows Indian Creek's floodplain during the fall, no flow, but has periodic water flow during different seasons.



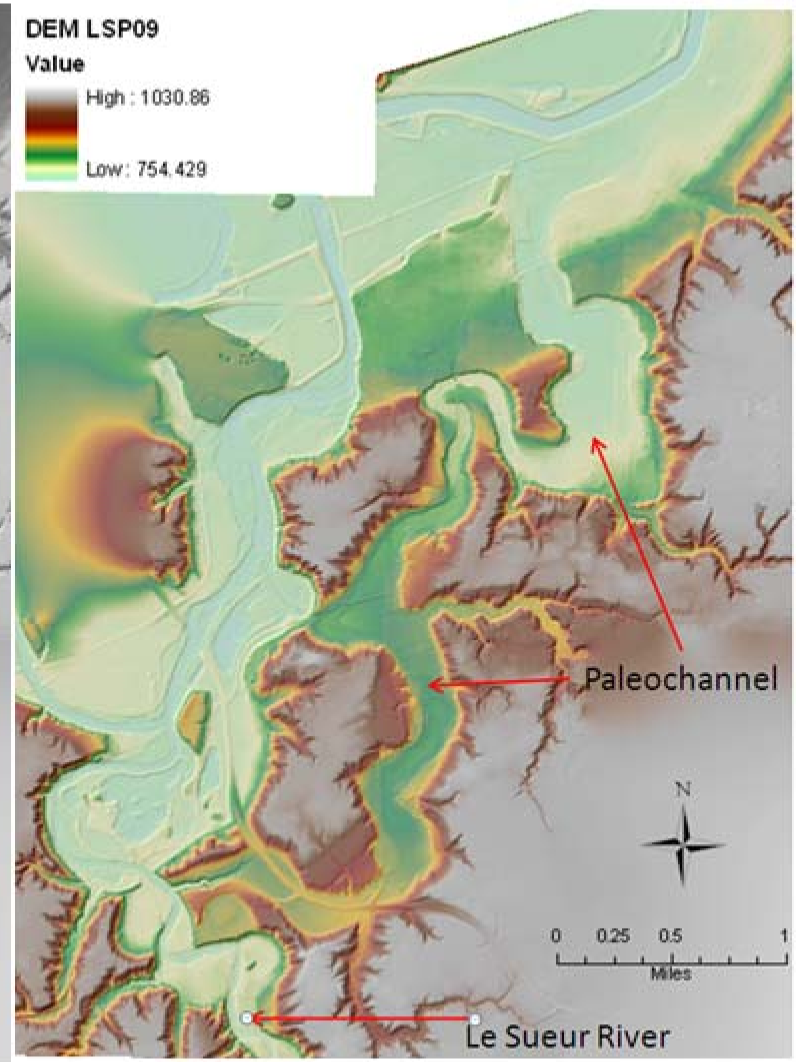


Figure 5A: Gray scaled DEM image using the 2006 LIDAR data from Blue Earth County.
Figure 5B: Colored DEM image with the same LIDAR data, but shows a better contrast of the paleochannel's slope.

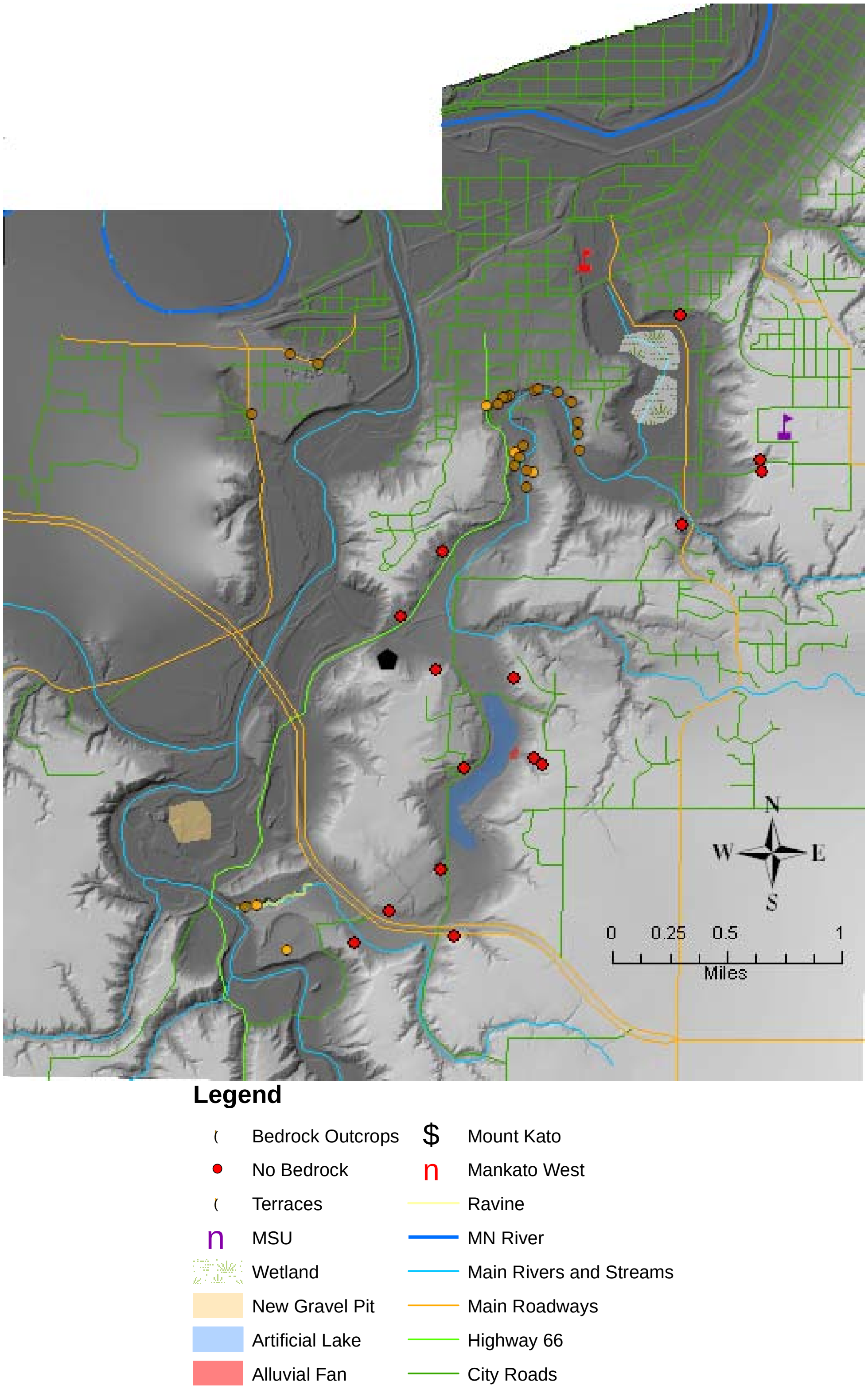


Figure 6: Features mapped out onto the grayscale DEM.

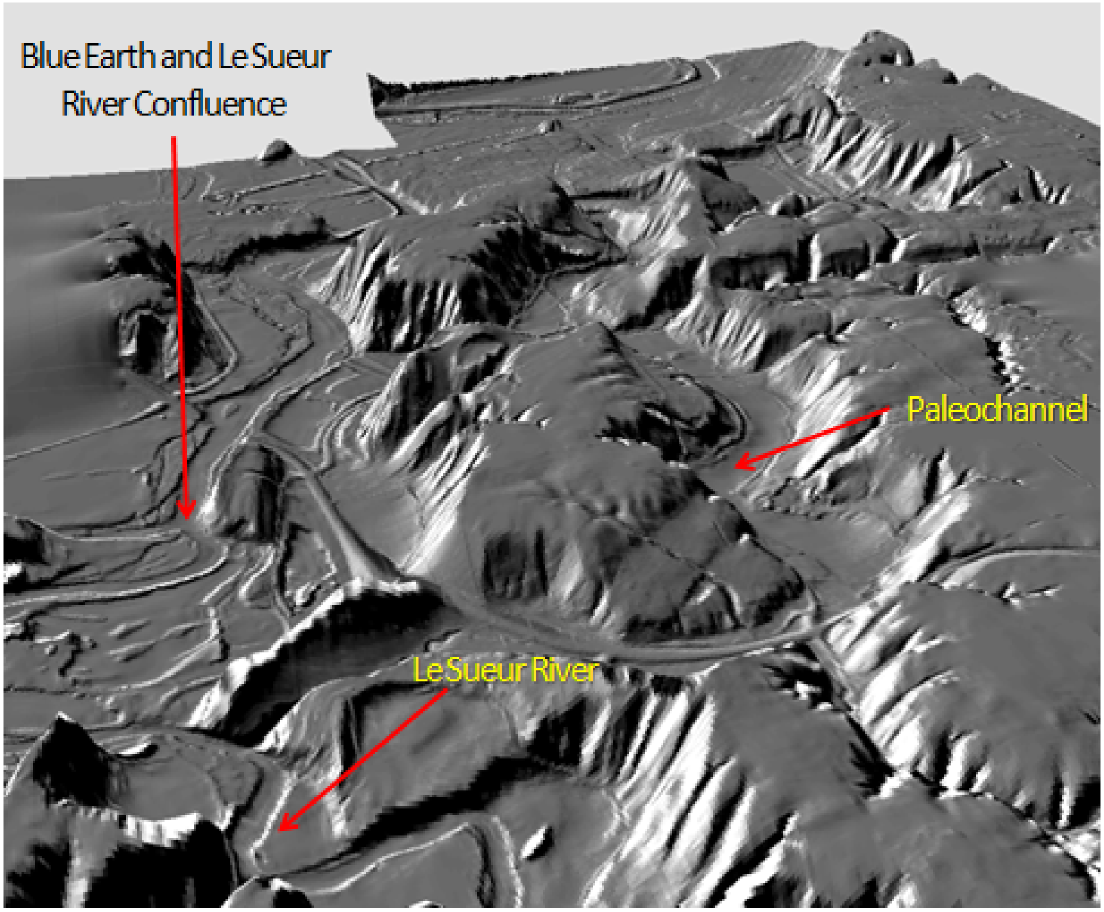


Figure 7: Geomorphology of the paleochannel with the Blue Earth River and Le Sueur River confluence, with a slight vertical exaggeration.

DISCUSSION

There were a few challenges when mapping the boundaries and the original course of the Le Sueur River. The paleochannel is bordered by many roads and few residential areas, the construction of which likely altered the natural slopes of the paleochannel walls. Many modifications have been made within the paleochannel, for instance the bypass had built up and filled in sediment near the base of the paleochannel. This would have distorted the natural boundaries and its slope. However, it can be seen using Figures 5A and 5B the path that the Le Sueur River would have flowed. Figure 9 is the potential route for the Le Sueur River's original flow through the paleochannel. In Figure 6, different features within the paleochannel are identified and was created to be used out in the field to get a better understanding of the channel. Not many areas of deposition were found, mainly due to the modifications within the channel would have altered them. Based on observations and interpretations, those have lead to potential reasons for the avulsion of the Le Sueur River.

The capture event would have created a new knickpoint that would have been working its way back up the Le Sueur River, as the river is trying to come to a new equilibrium. A knickpoint is defined by the point of abrupt change in the longitudinal profile of a stream valley. Wittkop had made a few stream profiles which were made from the terrace levels of the paleochannel, and areas within the current Le Sueur River. According to his stream profile, the paleochannel's profile is rather steep. This may suggest a couple of things: either that the capture event is rather old because the knickzone had not migrated far upstream or that the paleochannel was more resistant, which inhibited headward migration of the knickzone, in which the bedrock may play a role (Chad Wittkop, personal communication).

Possible Scenarios for the Le Sueur River Capture

Scenario 1: The Blue Earth River captured the Le Sueur River by eroding a little section of a ridge. The Blue Earth River may have meandered southward and eroded a section through the ridge or suspected avulsion site, and allowing the Le Sueur River to flow down into the Blue Earth River and ultimately into the Minnesota River.

Scenario 2: As the Le Sueur River had flowed through its original channel, it would tend to erode through much material. As the river flowed around its cutbank, prior to the entrance of the paleochannel, it had eroded and broken through the ridge. This would cause the river to jump down to flow into the Blue Earth River.

Scenario 3: A small tributary of the Blue Earth River may have flowed along the north side of that ridge, eroding it and eventually allowing the Le Sueur River to jump down into the Blue Earth River.

Scenario 4: The bedrock within the narrow bend of the paleochannel, may indicate a partial reason for the river avulsing from its original channel. Most of the wall consists of the St. Oneota Dolostone. According to the bedrock geology map on Figure 12 of Mankato West, the lower portion of the hill to be Jordan Sandstone and above that is the St. Oneota Dolomite. Figure 8A shows the bedrock seems to be layers between the sandstone and the dolomite. The section of the blue box, is Figure 8B is closer view of the formation. The formation seems to be weathering away, but the section that is blockier (bottom) is weathering at a slower rate than the layer above it. No other areas of bedrock were exposed within the paleochannel, except in this section. This may show the resistance level of the bedrock to erode. At the small bend, the paleoriver of the Le Sueur would have a narrower channel to flow through, and may have caused the water to backup within the southern part of the channel causing it to find a new flow path.

Figure 8A: Good exposure of the Oneota Dolomite bedrock formation, at small bend of the paleochannel. Small bend contains at least 16 other exposed outcrops. Figure 8B: Close up of the exposed outcrop viewed from the yellow box on Figure 8A, to see the layering of the formation.

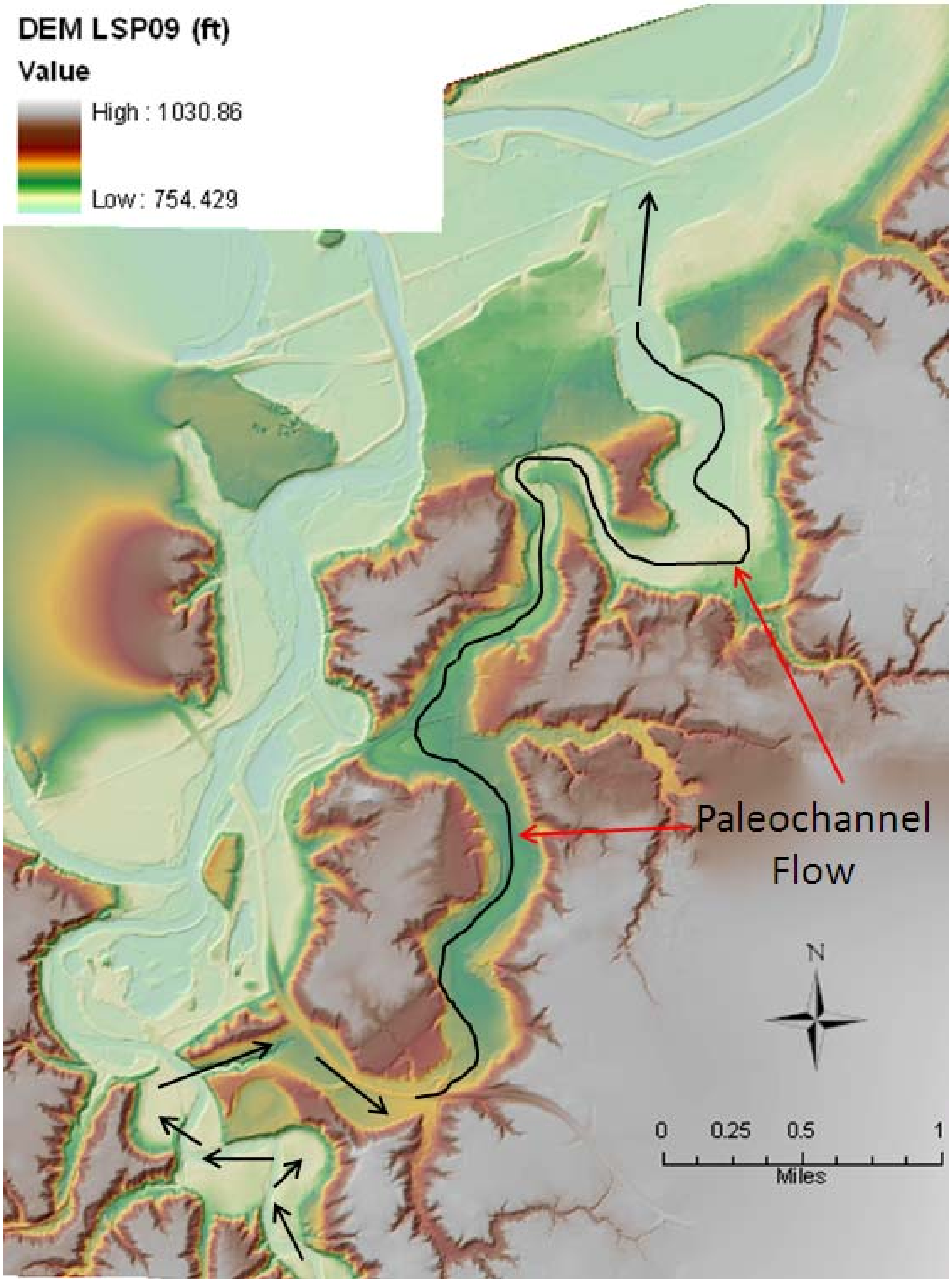


Figure 9: Shows the Le Sueur River's direction of flow when occupied the paleochannel.

Figure 10: Air photo from 1949 of Le Sueur River (left) and paleochannel. Shows land use and features that have changed since (taken from the MNDNR).

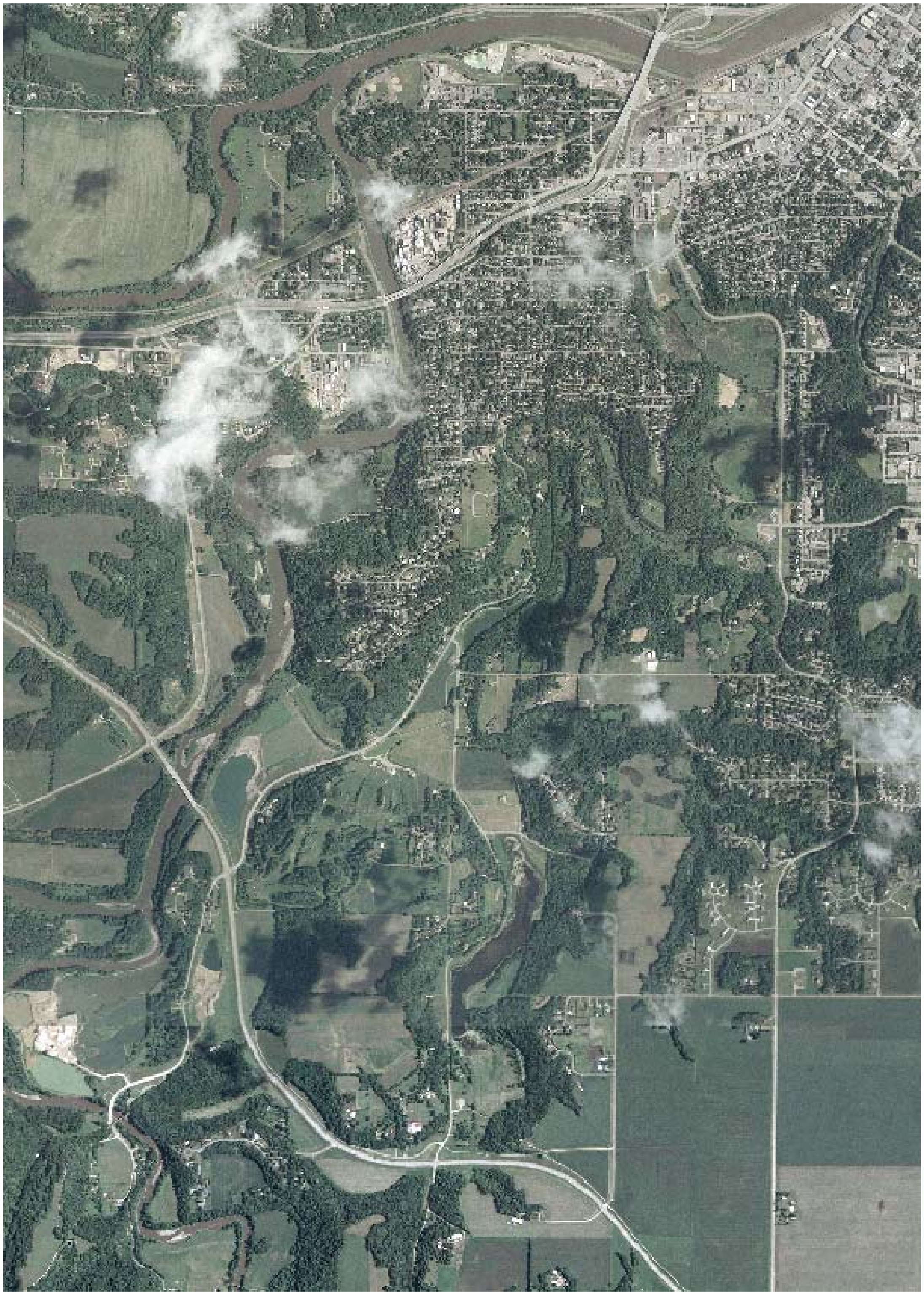


Figure 11: Air photo from 2003 shows the changes in the landscape over the past 50 years or so. Some major changes include the construction of Highway 90, and a few more wetlands areas like Indian Lake.

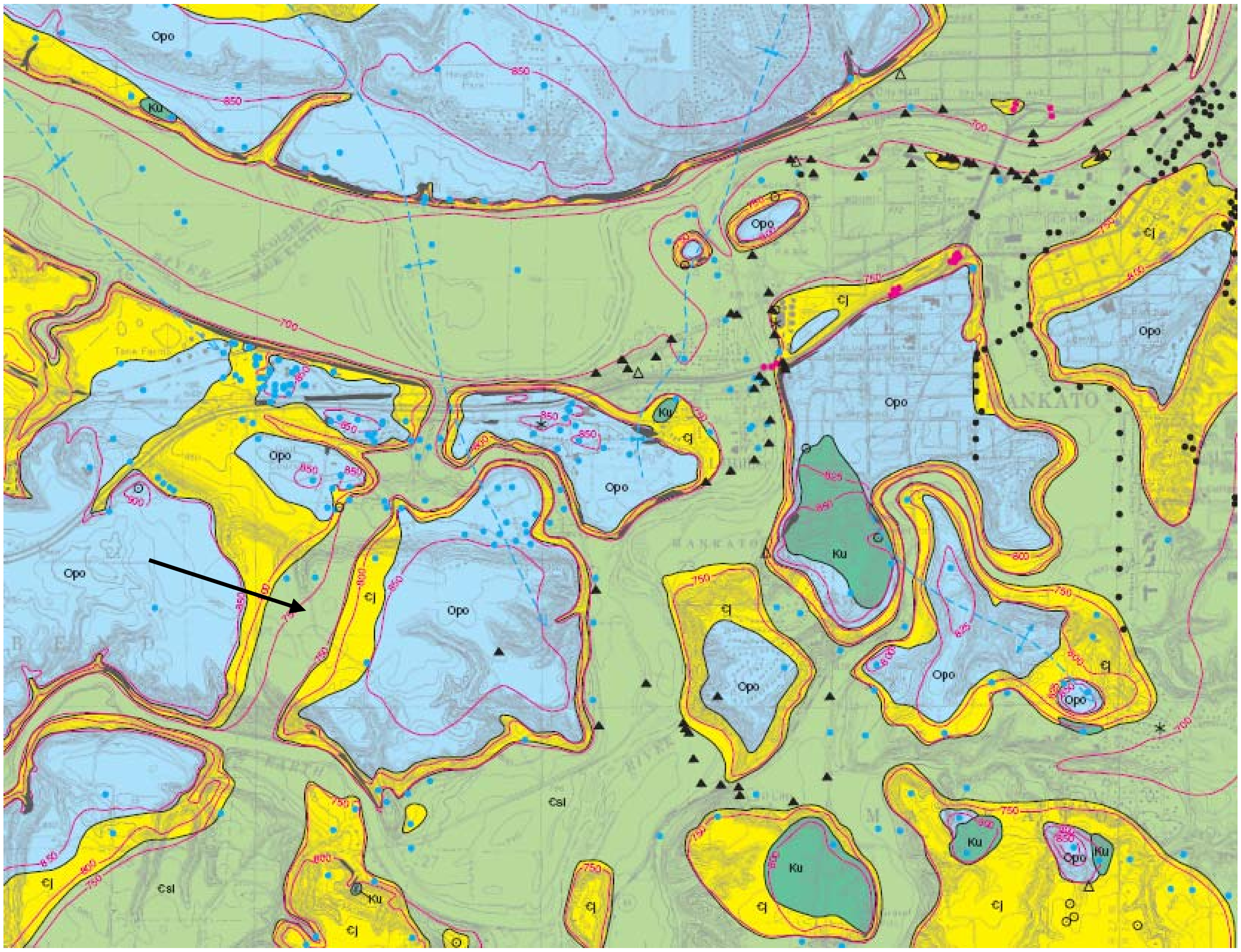
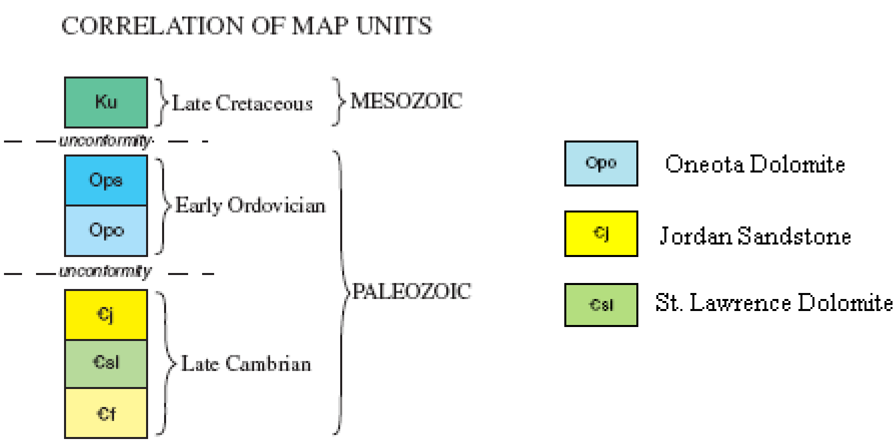


Figure 12: Bedrock geology of the Mankato west of Mount Kato, part of the Le Sueur Blue Earth Confluence and the paleochannel (modified from John F. Mossler).



CONCLUSIONS

After the Glacial River Warren carved out the modern Minnesota River Valley, its tributaries also responded to a new base level, including the Le Sueur and Blue Earth Rivers. Within the Mankato West area, is a relatively large valley that currently drains Indian Creek. Within the past 10,000 years, this channel had occupied the Le Sueur River. Depositional features as well as exposed bedrock have been mapped out within the extent of the paleochannel. These features help indicate the potentially how the Le Sueur paleoriver had avulsed its old channel and why. If this capture event happened relatively recently (i.e. 700 years) then this event would have contributed to the increased sediment that is flowing into the Minnesota River. The capture event could have happened not long after the last glaciations (i.e. 7000 years), then the sediment may be related to other factors like agriculture or development within the watershed. The relationship may help to estimate the volume of sediment removed from the post capture, which may conclude in an early event or a recent event. The paleochannel cuts through Pleistocene gravel terraces left by Glacial River Warren, which would suggest that the paleochannel must be Holocene age (Chad Wittkop, personal communicaion).

There is still a lot of work that needs to be accomplished to understand the Le Sueur River’s paleochannel. Out of the four possible scenarios, I would assume that the Blue Earth River had meandered southward a little and carved the section between the two rivers along with a combination of more than one influence on the system. It is more likely that the avulsion event occurred not to long after Glacial River Warren rather than recently.

Future Study

After further review, this system is much more complex than originally thought. It can be seen within Figure 12, the bedrock topography shows that a few different channels exist but are not apparent on a topography map. The arrow indicates a channel that must have been carved out after the last glacial lobe came through, because the channels carve through the bedrock. After the Des Moines lobe retreated, the glacier filled in these channels with till. This would have large effects of the flow path through the Le Sueur's paleochannel. Potentially, the right side of the paleochannel (located along Stoltzman Road) may have had a previous channel even before the last glacial event. After the Des Moines lobe retreated, till may have filled in the portion of the channel making it easier to carve through. I would suggest more studies to be done on the adjacent paleochannels to further understand this system.

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