4-16-2014

Determining the Source of Anomalous Segments in a Karst Stream

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Recommended Citation

Schroeder, Kathryn Emily, "Determining the Source of Anomalous Segments in a Karst Stream" (2014). *Theses and Dissertations.* Paper 179.

DETERMINING THE SOURCE OF ANOMALOUS SEGMENTS IN A KARST STREAM

Kathryn E. Schroeder

39 Pages August 2014

Southeastern Minnesota is characterized by an extensive karst network. In Kentucky, Carter Caves State Resort Park is a similar karst area that has exhibited karst anomalies, or ‘bumps,’ in a longitudinal stream profile. This study aimed to determine if these same karst anomalies can be found in southeast Minnesota, where LiDAR data are available, and if these bumps are actually karst features. Profiles of carbonate and siliciclastic streams were observed to determine if the presence of anomalies in only carbonate streams, both lithologies, or neither. Another objective was to determine if GIS could be an effective method at generating these profiles. Field data were collected to verify the GIS derived profiles. Stream shapes were also analyzed to determine what dominant processes occur in the area. No karst features were identified within profiles of streams in southeast Minnesota. However, GIS proved to be a useful tool in creating profiles from 1- and 3-meter DEMs. GIS was able to locate where changes in slope occurred; this was verified by field data. Some differences in profile can be attributed to the continuously changing morphology due to scour and fill processes that occur in these streams. Filled DEMs were also created, but ultimately not used because they eliminated some important features. Stream gradient index values were calculated that accounts for the distance from the source, length of reach, and elevation change of the reach. Values were calculated for carbonate and siliciclastic reaches of streams and were found to be statistically similar to each other, indicating that stream-bed lithology is not a dominant process affecting the stream shape in this area. Four main stream shapes were identified: linear, concave, convex, and stepped. Linear streams were the dominant shape, followed by concave. There was no statistically significant difference between shapes for the carbonate and siliciclastic rocks. This further supports the claim that lithology is not playing a role in the streams' morphology in this study area. It is likely that the erosion of legacy sediments from past farming practices is playing the largest role in sculpting the streams. Another factor affecting shape is land use, which increases erosion in this area.

DETERMINING THE SOURCE OF ANOMALOUS SEGMENTS IN A KARST STREAM

KATHRYN E. SCHROEDER

A Thesis Submitted in Partial
Fulfillment of the Requirements
for the Degree of

MASTER OF SCIENCE

Department of Geography-Geology

ILLINOIS STATE UNIVERSITY

2014

DETERMINING THE SOURCE OF ANOMALOUS SEGMENTS IN A KARST STREAM

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CONTENTS

TABLES

FIGURES

CHAPTER I

INTRODUCTION

A karst landscape is formed by the dissolution of soluble rock, commonly limestone or dolomite (Dougherty, 1985). Landforms associated with karst include sinkholes, caverns, lack of surface streams, and large springs (Dougherty, 1985). In mature and well-developed karst systems, a series of underground streams can develop; this development is dependent on various factors, which include base flow elevation of streams, stratigraphy, movement of water in the unsaturated zone, and chemical variations (White, 2009). The degree of development in karst terrain varies greatly depending on climate and terrain (White, 1988). Terrains can range from rough depressions with isolated towers and rolling hills, to gently rolling topography with soil cover and minimal depressions (White, 1988).

A study in Carter Caves State Resort Park (CCSRP), Kentucky, found that profiles of streams in carbonate reaches showed anomalous segments near the entrances to caves and swallets (Woodside, 2008). These anomalies, or bumps, show an initial drop in elevation and are followed by a sharp increase in elevation where less erosion is taking place (Figure 1). The anomalies are believed to be caused by water being rerouted underground, which results in less erosion downstream of the end of a bump.

Longitudinal stream profiles are extremely useful in observing a stream’s shape and features that are present (Larue, 2011). The overall shape, either concave or convex, will be apparent, as will anomalies such as knickzones, steps, pools, or bumps. This study is concerned with identifying potential karst features that appear as a bump in a stream profile. Stream profiles were analyzed in order to determine if these features are present and if they are associated with karst features. Based on stream profiles from Woodside (2008), the changes in slope produce a shape that is distinct in profile (Figure 1). However, it is important not to confuse these anomalies with other features, such as pools, steps, or knickzones. Pool- riffle sequences are features of a streambed with deeper pools characterized by decelerating water, and shallower riffles characterized by accelerating water (Halket, et al., 2013). Pool-riffle sequences are features of streams with a mobile stream bed comprised of gravel to sand sized clasts (Milne, 1982). Pools will have water accumulating in the stream, while changes in slope due to karst development would result in water being rerouted underground. Steps have a characteristic drop and horizontal feature in profile. Knickzones are points in a stream's profile with a higher stream gradient, which typically coincides with increased erosion and a steeper gradient immediately downstream of the knickzone (Larue, 2011).

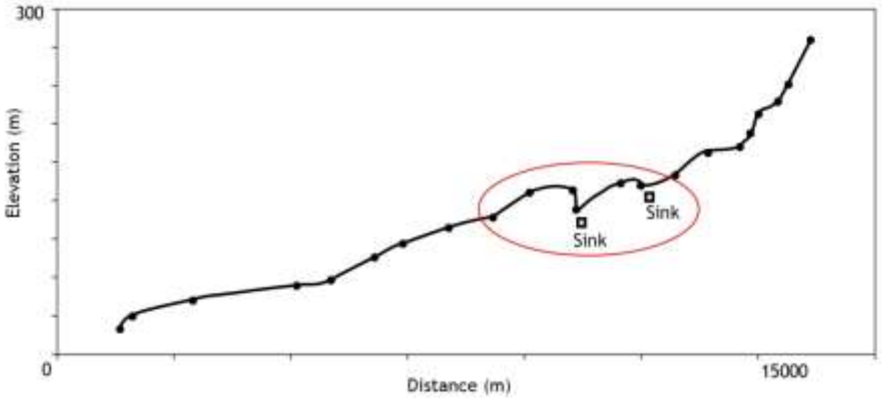


Figure 1- Example of Anomalous Segments along Profile of a Stream (Woodside, 2008)

In glaciated valleys, profiles tend to show steps that typically occur in a hanging valley, after a tributary joins the main trunk of a glacier due to the increased weight and erosive potential of the glacier, (MacGregor et al., 2000). In the longitudinal profiles developed at CCSRP, some anomalies appeared to look similar to a glaciated profile, rather than looking like a karst feature. However, the scales of the steps were not the same magnitude as a typical glacial step. Southeast Minnesota is located in the Driftless Area where the most recent glaciations did not reach. Thus, the presence of anomalies in a profile are unlikely the result of glacial-like steps, since no glaciers went through this area during the Illinoian and Wisconsinan glaciations.

The main factors affecting a stream's shape are climate, tectonic activity, lithology (Hack, 1957; Pazzaglia et al., 1998) and land use (Knox, 1977; Knox, 2006). Because many rivers and streams are so long and can cover large distances, they are able to capture these changes in environment along their longitudinal profile (Carlston, 1969). A stream in equilibrium has a concave-up shape, however most streams will vary from the typical concave-up shape for smaller segments of the stream (Carlston, 1969). This could include streams that are comprised of multiple linear segments or convex-up segments while maintaining an overall concave-up shape. Depending on the climate, tectonics, and lithology at a particular segment of stream, the shape of a stream's profile will reflect these changes.

In southeast Minnesota, perhaps the most significant factor that affects a stream profile's shape is land use (Knox, 1977, 2006). American settlement in the driftless area began in the 1820s with mining towns and then began to increase more rapidly in the 1850s (Knox, 1977, 2006). As settlement increased, conversion of land from natural prairie and forestland to agricultural farm fields began to take place (Knox, 2006). Agricultural replacement of prairie and forestland affects runoff, soil erosion, and river morphology (Knox, 2006). This land conversion has significantly increased the magnitudes of floods, which increases erosion (Knox, 1977). Runoff becomes greater due to less dense vegetative cover, which increases raindrop contact with the soil, reduces hydraulic roughness at the soil surface, and reduces organic matter in soil (Knox, 1977). Increased surface runoff allows for more erosion and transportation of sediment into streams (Knox, 2006).

The objective of this study is to determine if karst features can be identified by examining a stream's profile. The goal is to see if anomalies can be identified, if they are unique to karst streams, and if they are indicative of karst features. To do this, the longitudinal profiles of the carbonate and siliciclastic portions of streams were examined to identify the presence of anomalies. If these anomalies are identified, it can be determined whether the anomalies are present within the siliciclastic portion as well as the carbonate portion, or if we just see them in the carbonate reaches. To investigate the presence of anomalies, a secondary objective emerged: to determine the effectiveness of GIS in constructing stream profiles. Stream profiles were generated using two different resolution DEMs: 1- and 3-meters. Additionally, a comparison of filled 3-m DEMs to unfilled 3 m DEMs was conducted to insure that the generation of stream networks using filled DEMs did not alter the true nature of the data. The premise of a filled DEM is that any potential data errors, or perceived "sinks", within the DEM are removed. As a depression, the sinks will collect water and stop flow from continuing downstream of the depression. However, this can be a problem because in karst areas, the "sinks" may represent actual karst depressions. Finally, stream profiles were examined to understand what process (climate, base level, lithology, and tectonic activity) is causing these profiles to have the shapes that they have in this area. The importance of this work lies in the ability to use GIS and remotely sensed data to identify the presence of anomalies along stream profiles that can aid in identifying hidden karst features. If the anomalies are determined to be true karst features, then we can use a longitudinal stream profile to identify hidden karst features. We determined the presence of karst features by field verifying certain stream reaches. If they are identified, this method can prove to be especially helpful where cave entrances are either hidden or absent. GIS is also important because it is a very cost effective way to construct profiles and is extremely useful when it can replace or be used in addition to fieldwork, which is both costly and time consuming.

History of Southeast Minnesota

In this area, there are three (3) historic phases of sediment storage, which have been decreasing since the 1940s (Trimble, 1999). The first began in 1853 due to the dramatic increase in agricultural activity in the area, and lasted until 1938. This first period is characterized by huge sediment loads, averaging 405 X 10^3 mg/year sediment going into storage (Trimble, 1999). During the second period, storage rates considerably backed off to 209 X 10^3 mg/year. The period lasted from 1938-1975. The final period was characterized by the smallest storage rate of 80 X 10^3 mg/year during 1975-1993 (Trimble, 1999). This decrease is due to better land practice strategy rather than climate changes. Over the 140 years, sediment flux has varied greatly; however, sediment yield has remained fairly constant. Today, old farming practices are still influencing the channel morphology due to the erosion of legacy sediments, which are deposits of these old farms.

The Driftless area in this region is named so because it lacks any glacial drift, or deposits (Dogwiler, 2010). This area incorporates southwestern Wisconsin, northwestern Illinois, northwestern Iowa, and southeastern Minnesota. However, the area investigated in this study is considered a pseudo-driftless area because it was glaciated by pre-Illinoian glaciers (Hobbs, 1999). At the beginning of the Pleistocene, the Mississippi River flowed along the maximum boundary of the ice sheet lobe, and reached its current location after the Nebraskan glaciation (Anderson, 1988; Hobbs, 1999). Valleys up until the end of the Pliocene were characterized by significantly less relief, so the deeply incised valleys that we see today must have been incised later in the Pleistocene. This suggests that the topography seen today in the Driftless area is not from pre-glacial times, but was formed in the Pleistocene after glaciations had begun (Hobbs, 1999). Early Pleistocene stream levels would have been at the level of the bluff tops before the deep incision began.

Geology of the Study Area

The study focuses on the Driftless Area of southeastern Minnesota (Figure 2); where well-developed karst features are present (Runkel et al., 2003). Streams within three counties: Fillmore; Winona; and Houston; were examined. The geology of these counties consists of predominantly carbonates, units of limestone and dolostone, with some units of siliciclastic rocks, sandstone, and shale (Figure 2). This study area is hilly, unglaciated, and dominated with limestone bluffs that are stream dissected into the

Mississippi River (Knox, 1985). An emphasis was placed on Fillmore County because of the greater variety in lithological units through which the streams have incised.

Upper Cambrian

The oldest unit present is the Mt. Simon Sandstone, which consists of coarse and fine sand in beds ranging from several feet to 30 feet thick (Runkel et al., 2003). It is present along the Mississippi River in Winona and Houston counties in shallow bedrock.

Overlying the Mt. Simon sandstone is the Eau Claire formation, which consists of sandstone that is fine-grained, feldspathic, and glauconitic, and a siltstone and shale. The Ironton and Galesville sandstones are a 12-14 meter thick unit (Runkel et al., 2003) of fine to coarse grained quartz sandstone, with lithic fragments and feldspar increasing at paleotopographic highs (Mossler, 2008).

Above the Ironton and Galesville sandstones is the Tunnel City Group. The Tunnel City Group includes glauconitic, feldspathic sandstones and a feldspathic siltstone (Mossler, 2008). Overlying the Tunnel City Group is the St. Lawrence Formation, which is comprised of a dolostone and a siltstone component (Mossler, 2008). In southeastern Minnesota, the carbonate facies is dominant and overlain by the siltstone facies (Runkel, 2003). This unit ranges from 33-36 meters.

The Jordan Sandstone is 20-21 meters thick (Runkel, 2003), and is comprised of a fine- to coarse- grained, quartz sandstone at the base, overlain by a very fine-grained feldspathic sandstone (Mossler, 2008).

Lower Ordovician

The Prairie du Chien Group consists of 97-104 meters of primarily carbonate rocks (Runkel, 2003). Dolostones dominate with minor components of fine- to coarse-grained sandstones (Mossler, 2008). Large phreatic caves are present in the lower Ordovician aged rocks (Runkel, 2003).

Upper Ordovician

The St. Peter Sandstone is 21-24 meters of very well-sorted sandstone (Runkel et al, 2003). Some caves are present in this sandstone unit; however, they are the result of the erosion of poorly cemented sand rather than dissolution (Alexander and Lively, 1995). The St. Peter Sandstone includes interbedded sandstone, siltstone, and shale (Mossler, 2008). This sandstone is one of the most homogenous units, compositionally and texturally, that has been described (Runkel, 2003).

The Glenwood Formation is comprised of about 1.5 meters of siltstones and shales (Runkel et al., 2003). The Platteville Formation consists of 6-9 meters of primarily limestone and dolomitic limestone with thin shale layers that contain some bentonite (Mossler, 2008). In this formation, caves are large enough to enter and sinkholes are present. This formation caps many of the bluffs in western Fillmore County (Mossler, 2008).

The Decorah Shale is 13-15 meters thick and includes shale with some smaller beds of carbonates (Runkel, 2003). At the base is a limestone interbedded with thinly bedded shale, and is overlain by a fossiliferous shale with thin, interbedded layers of coquina limestone and calcareous shale (Mossler, 2008).

The Galena Group, Dubuque Formation, and Maquoketa Formations make up part of the upper carbonate aquifer in this area, and are comprised of limestone or dolostone. Extensive dissolution has produced large cavern systems (Runkel et al., 2003). The Galena Group is 56-64 meters thick and contains limestone and dolomite units with some thin shale interbeds (Mossler, 2008). The Dubuque Formation is roughly 10 meters thick and contains interbedded limestone and thin beds of calcareous shale (Mossler, 2008). It is more dolomitic towards the base and less dolomitic in the upper facies (Mossler, 2008). The Maquoketa Formation is 20-24 meters thick and is comprised of a thinly bedded, fossiliferous limestone that is interbedded with shaly dolostone (Mossler, 2008).

Middle Devonian

The only Middle Devonian unit present in this study area is the Spillville Formation, which is 6-26 meters thick and only outcrops in southwestern Fillmore County (Mossler, 2008). This unit consists of a massive, vuggy, fossiliferous dolostone (Mossler, 2008).

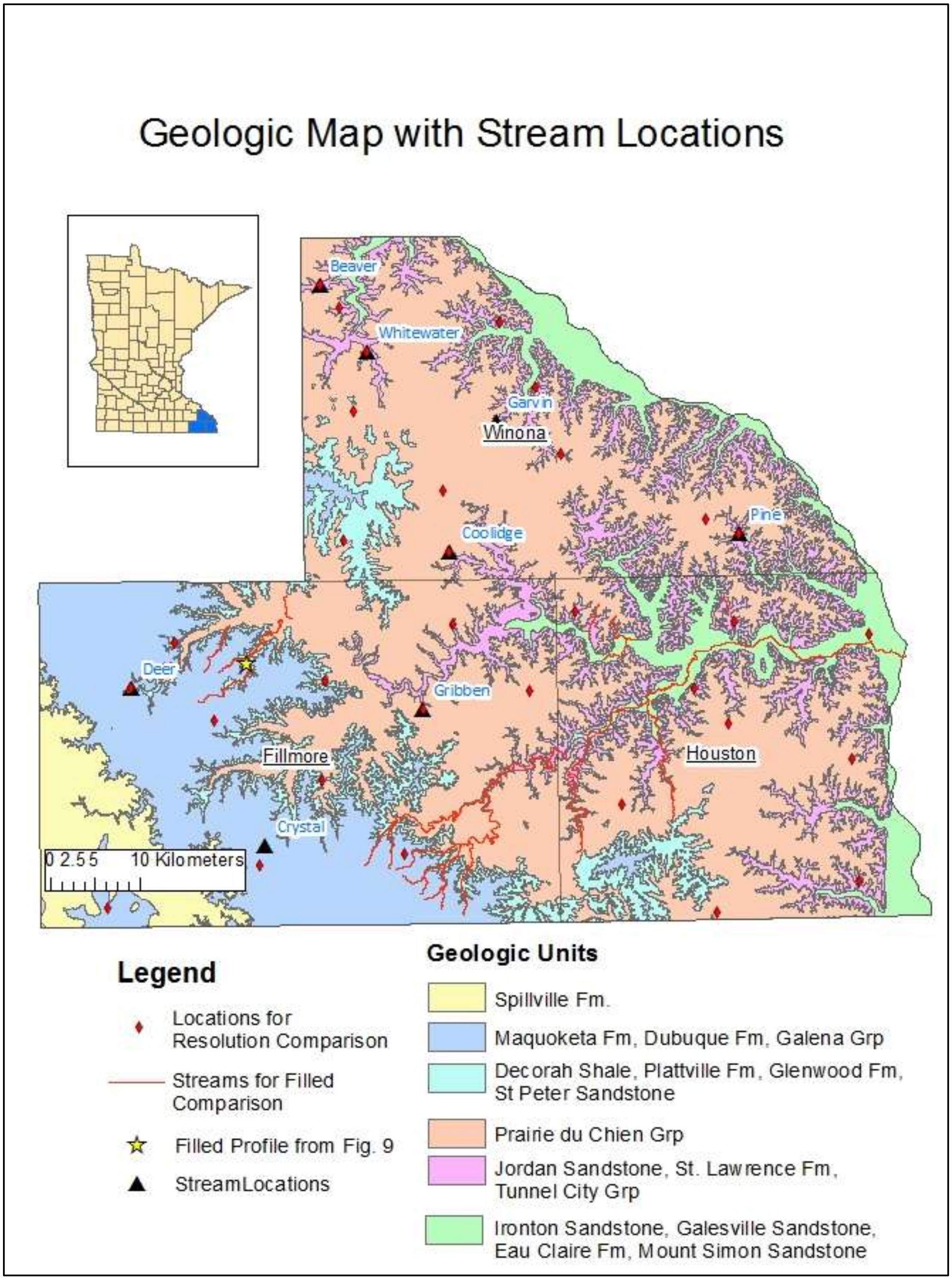


Figure 2- Geologic Map of Fillmore, Winona, and Houston Counties with the Locations of 6 Streams that were Surveyed in September, 2013.

CHAPTER II

METHODS

Longitudinal Profile Construction and Comparison

To identify concave anomalies, longitudinal stream profiles were constructed for reaches of streams in carbonate and siliciclastics systems using ESRI's ArcGIS 10.2. DEMs of 1- and 3-meter resolutions were obtained from the Minnesota DNR website (http://www.mngeo.state.mn.us/chouse/elevation/lidar.html). The DEMs were created from LiDAR data collected in 2008. Errors within the DEM can be present as depressions, or sinks (Jacoby, 2011). These errors can be caused by a single cell that is represented with a lower elevation than surrounding cells, a pit, or a group of cells that are lower in elevation than surrounding cells, a depression (Arnold, 2010).To reduce the potential error, filled DEMs were generated from the 3-meter DEM. This filled DEM will eliminate cells that are significantly lower than surrounding cells in the original DEM, so that in the filled DEM it appears more continuous (Arnold, 2010). This can create a more well-connected stream network, however, in a karst system; it can potentially remove actual karst features, e.g. sinkholes or swallets. The problem with using unfilled DEMs is that the sinks can disrupt the flow calculated in the flow accumulation raster (Arnold, 2010). Using the filled DEMs, stream networks were created for each county using ArcGIS's Spatial Analyst Hydrology toolset (Figure 3). Using ArcGIS's 3D-Analyst

'Interpolate Line' tool, profiles were created by tracing a line along streams; this process generated a cross-sectional profile of that stream segment (Figure 4). Profiles were created to compare streams generated from the filled DEM and unfilled DEM. To compare the streams, the two stream profiles were plotted on the same graph to determine if there are any significant differences between the streams. Differences would include sinks only present in the unfilled DEM while the filled DEM filters them out.

Figure 3- Flow Chart for Creating Stream Network.

Figure 4- Flow Chart for Creating a Stream Profile.

To assess the importance of DEM resolution, the profiles generated from the 1- and 3-meter DEM were compared using two different methods. The first method was a qualitative analysis; profiles were plotted on top of each other to see how well they matched. The second method was a quantitative analysis of the resolutions in which the elevation values for the 1-meter DEM were plotted against the 3-meter DEM elevation. A slope of 1 for the best-fit-line would indicate that the two resolutions generated exactly the same profile. A *t* test with $\alpha = 0.05$ was used to determine if slope was equal to 1.

Stream Gradient Index

Once the profiles were generated, streams were compared using Hack's stream gradient index (Hack, 1973). This stream gradient index (SL) relates slope of a reach to the length of the entire stream (*L)*. The equation is:

$$SL = \frac{\Delta H \times L}{\Delta L} \quad (1)$$

where ΔH is the change in elevation, and ΔL is the length of the specific reach being evaluated (Figure 5). Equation (1) can help identify irregularities and anomalies among sections. To allow for better comparison among streams of various lengths, *SL* values were plotted against *L*.

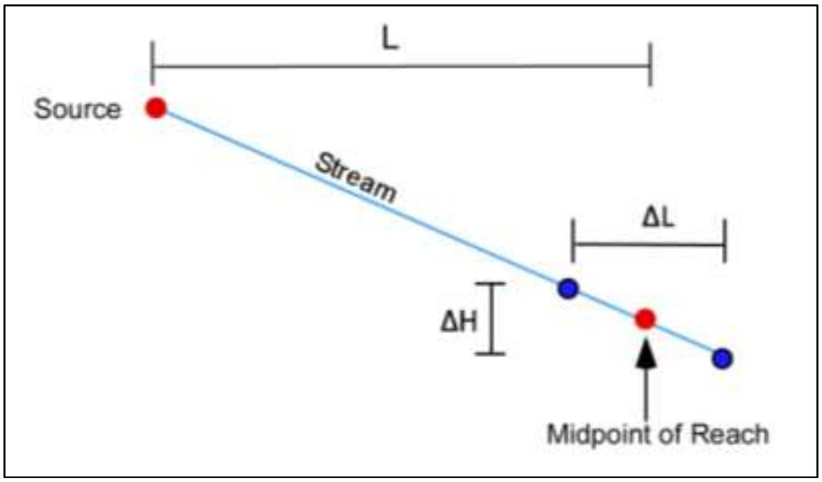


Figure 5- Schematic of a Stream Profile Illustrating the Variables Used to Calculate the Stream Gradient Index.

Field Survey

Field data were collected in Fillmore and Winona counties for 6 reaches of streams on September 14-15, 2013 using a Spectra Precision GL422 Grade Laser equipment (Figure 6). A laser station was set up at a high point on the stream bank. The laser provides a horizontal laser reference, which can be used to compare elevations of different features. At specific points along the thalweg, the height from the streambed to the laser station was measured. To determine the height, the Laserometer HL700 was attached to a stadia rod that was adjusted until the Laserometer was at the elevation of the signal from the laser station (Spectra Precision Laser). The measurement from the stadia rod was recorded as the height (Figure 7). The location, latitude and longitude, and elevation of the base stations and measurement locations were obtained using a Trimble GPS unit. To ensure accurate distance between measurement locations, the distance was calculated using a Rangefinder.

Figure 6- Spectra Precision GL422 Grade Laser Equipment Used to Survey the Streams.

Figure 7- Laserometer HL700 was Attached to the Top of the Stadia Rod that was Raised until it Reached the Laser Station.

Stream Shape Comparison

To compare the shape of streams, 35 streams were generated in carbonate reaches and 38 from siliciclastic reaches using a 3-meter, unfilled DEM in Fillmore County. Each stream was assigned to a category of the four predominant stream types present in the area: linear, concave, convex, and steps. For the linear stream segments, a slope was calculated for each to determine if they have a similar slope or a variety of slopes. A similar slope would indicate similar processes and distance from the Mississippi River, the local base level, while a variety of slopes would indicate different processes are contributing to the streams' shape and are located in different regions relative to the Mississippi River. A statistical analysis was conducted on the linear segments of carbonates versus siliciclastics using a *t*-test with an α of 0.05.

CHAPTER III

RESULTS

Filled vs. Unfilled

Profiles of 33 streams were compared using filled versus unfilled DEMs. 27 were solely GIS derived with 16 from Fillmore County and 11 from Houston County. An additional six (6) were GIS generated and verified from field-surveying. Stream profiles created from the unfilled 3-meter DEMs were plotted alongside profiles created from the 3-meter filled DEMs (Figure 8). There were no significant features that were present in either DEM that did not appear in the other. The only exception is that when profiles were created with a distance of thousands of meters rather than hundreds of meters, large step-like patterns appeared only in the filled DEM (Figure 9). These steps can range from a distance of hundreds of meters up to several thousand meters. Elevation changes in steps ranged from about 2-10 meters.

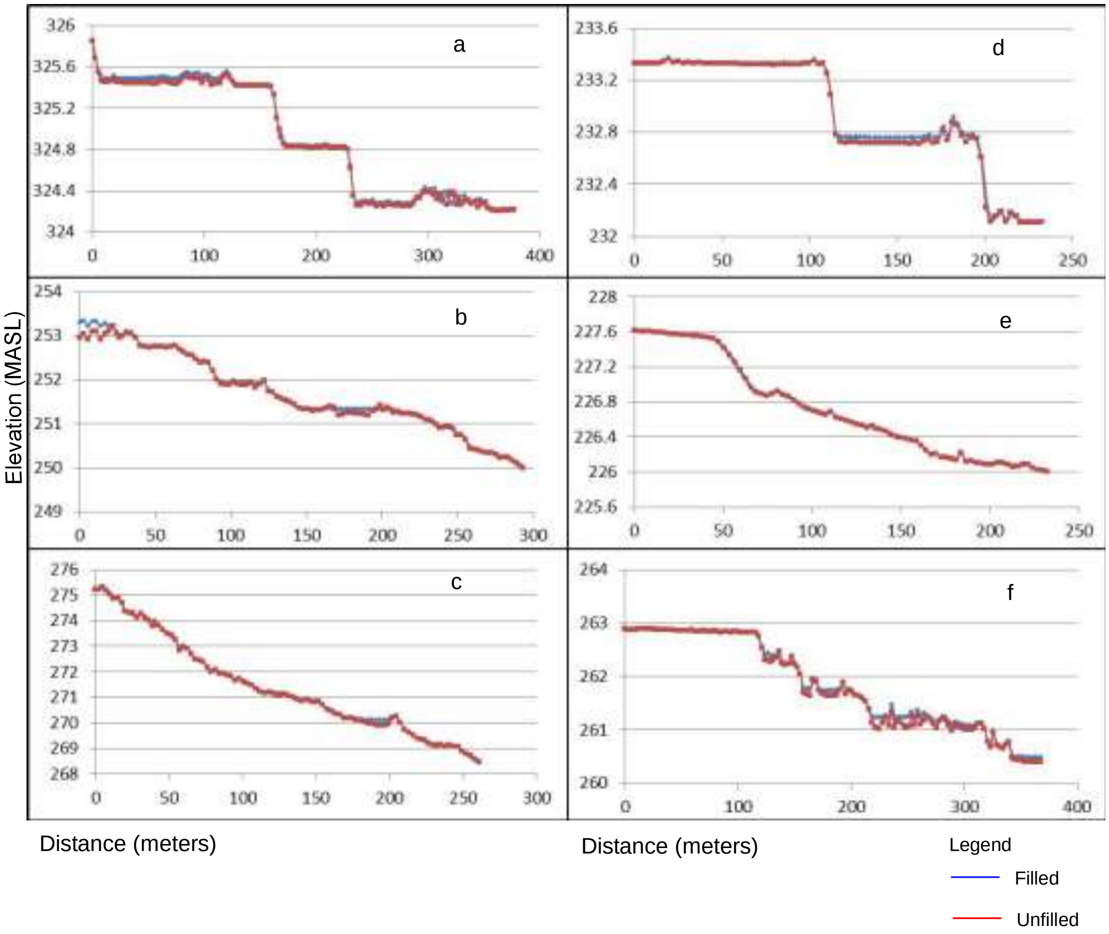


Figure 8- Stream Profiles Generated from Filled DEMs and Unfilled DEMs for Six Streams. a- Deer Creek, b- Gribben Creek, c- Coolridge Creek, d-Beaver Creek, e- South Fork of the Whitewater River, f- North Branch of Pine River (See Figure 2 for Stream Locations).

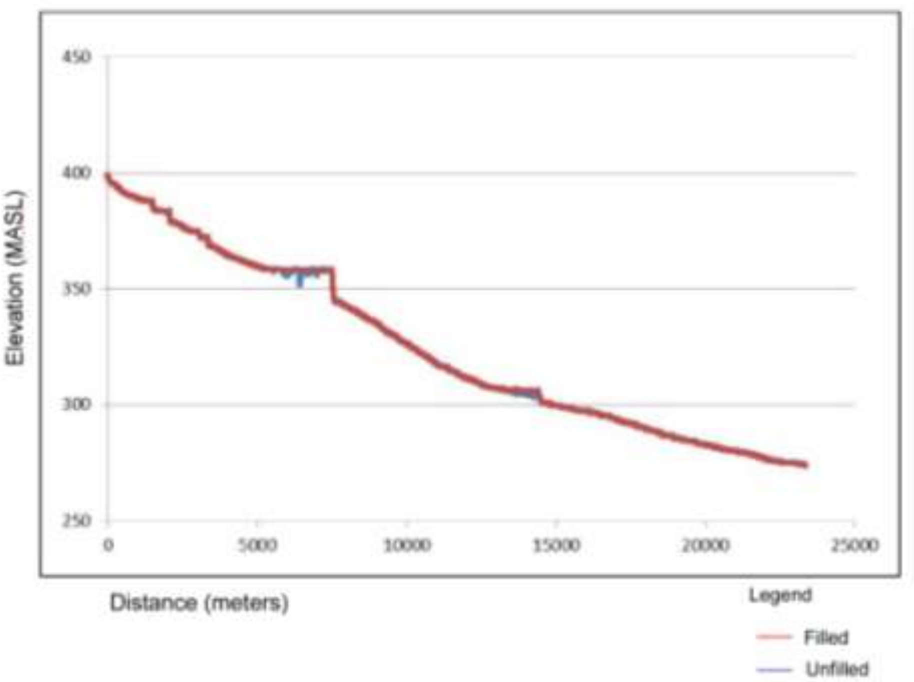


Figure 9- Steps Present in Long Stream Profiles Using a Filled DEM (Red) Plotted Against the Unfilled DEM. Location Shown in Figure 2.

DEM Resolution Comparison

Profiles from a new dataset of 27 streams distributed throughout Fillmore, Winona, and Houston counties were used for the resolution comparison. Qualitatively, there was little variation between profiles generated from 1-meter DEMs as compared to those created from 3-meter DEMs (Figure 10). For the most part, the 1-meter DEM showed more detail, but it did not show any anomalous segments that the 3-meter DEM did not. Overall, the shapes of the profiles appear similar; only when the vertical scale is exaggerated can minor differences in detail between the two DEM resolutions be observed. However, in some of the streams (Beaver Creek, Whitewater River, and Pine Creek), the 3-meter DEM actually shows more bumps than the 1-meter DEM (Figure 10), which is the opposite of what was expected due to the higher resolution of the 1-meter DEM.

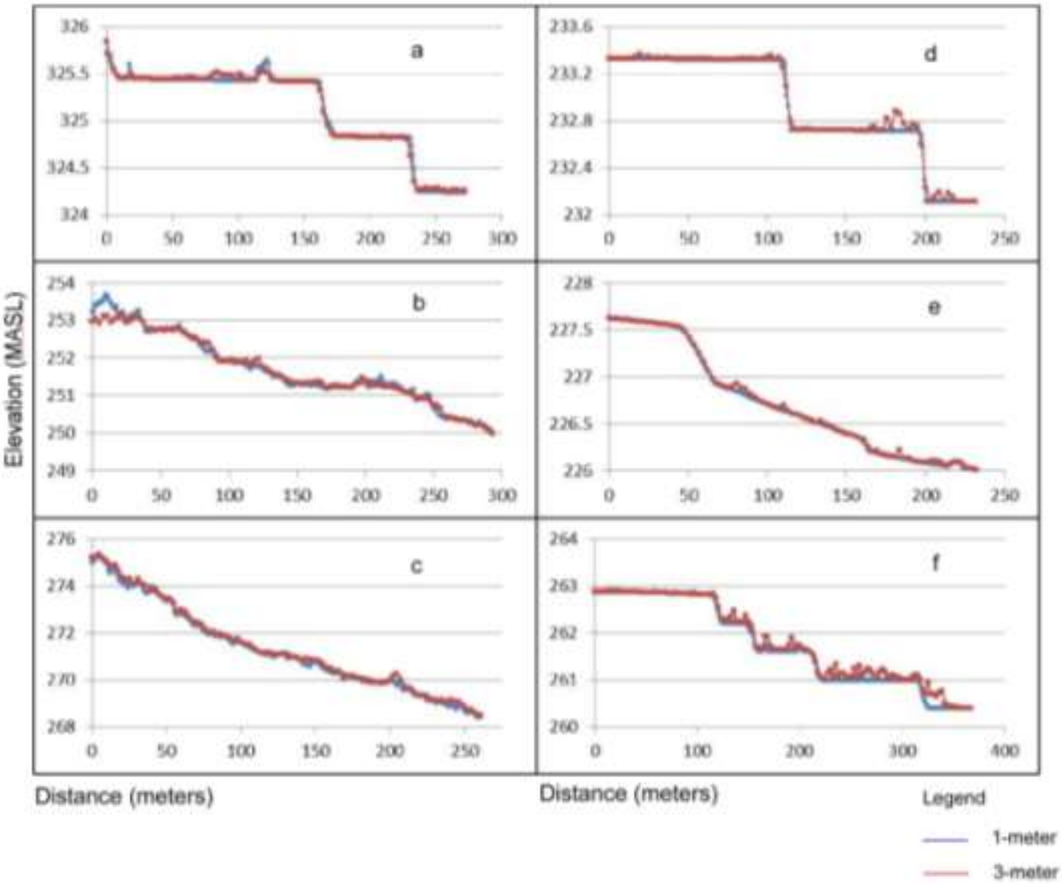


Figure 10- Stream Profiles Generated from 1-meter DEMs and 3-meter DEMs. a- Deer Creek, b- Gribben Creek, c- Coolridge Creek, d-Beaver Creek, e- South Fork of the Whitewater River, f- North Branch of Pine River.

A quantitative analysis shows that the 1-meter DEMs produced stream profiles that had similar points (distance versus elevation) to profiles created from the 3-meter DEM (Figure 11). The closer the relationship is to 1:1, the more statistically similar they are. If the slope is far from 1, then the different resolutions cannot be considered the same. In all cases, the slope is near 1.0, with an average slope of 0.979 for all 6 streams, and values ranging from .9189 to 1.0432. In addition to the six (6) streams surveyed in the field, profiles for 27 streams throughout Fillmore County were generated using GIS. The average slope for the 27 streams was 0.9949, with values ranging from 0.940 to

1.020 (Table 1). The statistical analysis of the 1-m DEM against the 3-m DEM indicate that the data were not statistically different, t(14500)=-0.060, *p*=0.951. When all of the 1-m DEM data and 3-m DEM data are plotted together, the resulting trend line has a slope of 0.999 with a correlation coefficient (*r*) = 0.9999 (Figure 12).

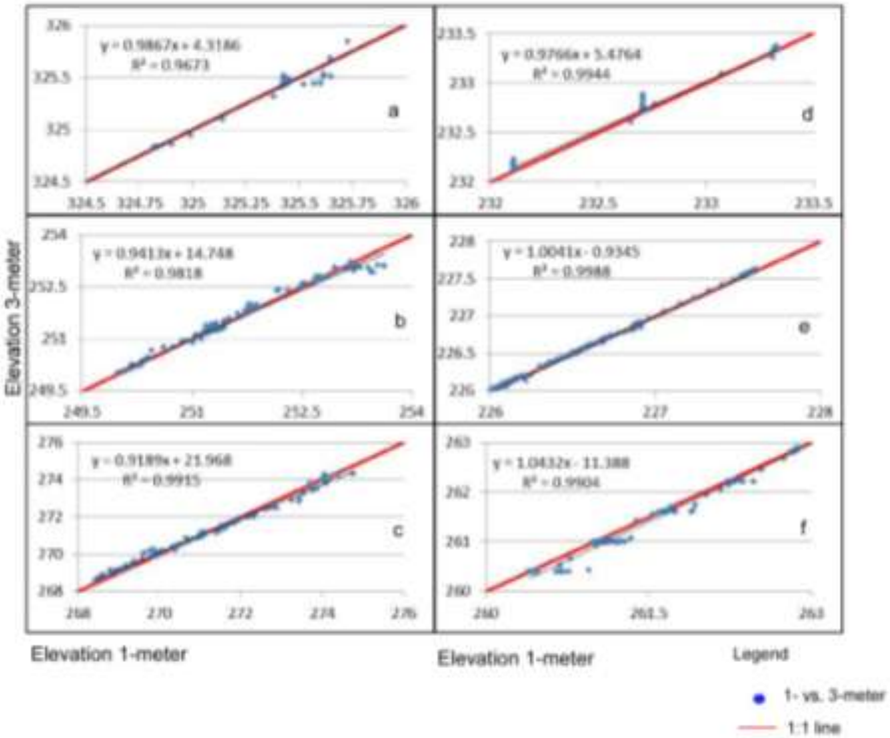
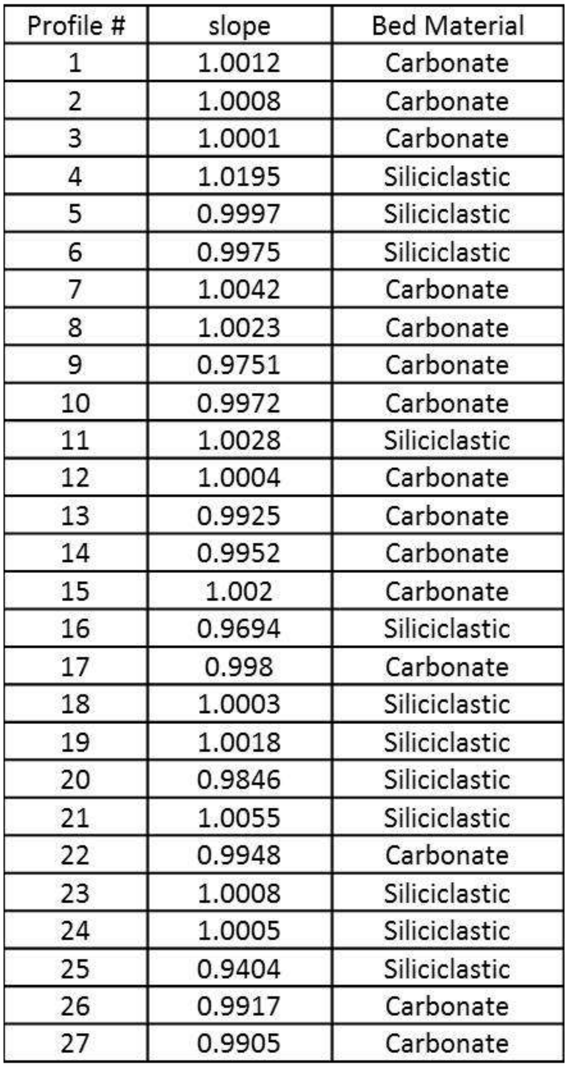


Figure 11- Elevation Values of the 1-meter Plotted Against the 3-meter DEM. a- Deer Creek, b- Gribben Creek, c- Coolridge Creek, d-Beaver Creek, e- South Fork of the Whitewater River, f- North Branch of Pine River. The Straight Line Represents the 1:1 Line Where the Profiles Would be Identical.

Table 1- 27 Streams and the Slope Value when Comparing Elevation 1-meter vs. Elevation 3-meter.



Profile #	slope	Bed Material
1	1.0012	Carbonate
2	1.0008	Carbonate
3	1.0001	Carbonate
4	1.0195	Siliciclastic
5	0.9997	Siliciclastic
6	0.9975	Siliciclastic
7	1.0042	Carbonate
8	1.0023	Carbonate
9	0.9751	Carbonate
10	0.9972	Carbonate
11	1.0028	Siliciclastic
12	1.0004	Carbonate
13	0.9925	Carbonate
14	0.9952	Carbonate
15	1.002	Carbonate
16	0.9694	Siliciclastic
17	0.998	Carbonate
18	1.0003	Siliciclastic
19	1.0018	Siliciclastic
20	0.9846	Siliciclastic
21	1.0055	Siliciclastic
22	0.9948	Carbonate
23	1.0008	Siliciclastic
24	1.0005	Siliciclastic
25	0.9404	Siliciclastic
26	0.9917	Carbonate
27	0.9905	Carbonate

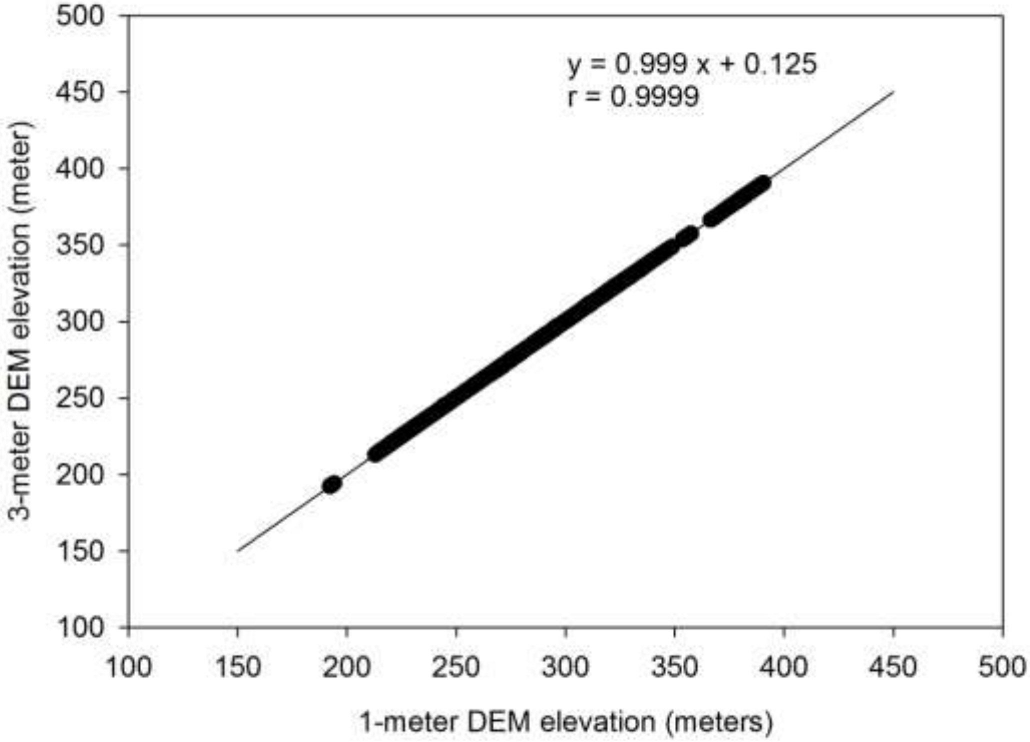


Figure 12- Elevations Generated from 1-meter DEMs Versus 3-meter DEMs for the Same Point. The Data Represent the Collective Points along the 27 GIS Generated Stream Profiles.

Field vs. ArcGIS-generated

Stream profile data from field surveys were plotted along with profiles created in ArcGIS (Figure 13). Five (5) of the six (6) streams that were field surveyed in Minnesota were in siliciclastic reaches and have a distinct pool and riffle sequence. The sixth stream was located in a carbonate stream, but also featured a pool and riffle sequence. Siliciclastic reaches were selected because the presence of any features similar to those thought to be karst anomalies would indicate that the features are not actually due to karst. No pirated streams were observed along the stream reaches, which was problematic because that is where the karst anomalies are likely to be found. Data for two other streams were collected for Crystal Creek in 2010 and Garvin Brook in 2012 (Figure 14).

When the streams surveyed in the field were compared to the profiles created in GIS, the pools appeared shallower in the GIS generated profile, and typically follow water level rather than the stream bed. This makes sense since the elevation data come from LiDAR data, which cannot penetrate the water's surface. While an identical stream profile is not generated, GIS is able to capture where the abrupt changes in slope occur. In the field generated profile, it is clear where the stream enters into a pool. In the GIS-generated profile, there is also usually a drop at the start of the pool, even though the pool is not as deep. However, GIS was only able to capture some of the pools. Many of the pools were represented in GIS by an upward bump (Figure 13). However, the overall trend of the stream profile is more accurate. Garvin Brook elevations were similar but did not match as a result of error associated with the ability of the GPS to provide the elevation.

Differences between the DEM derived elevation and the field elevation ranged from 1 meter to 2 ½ meters. Field elevations were collected using a handheld Trimble GPS unit. GPS satellite reception was limited by tree canopy and stream valley walls, which limited the accuracy of the elevation measurements. Horizontal distance was very accurate between field and GIS profiles in all streams.

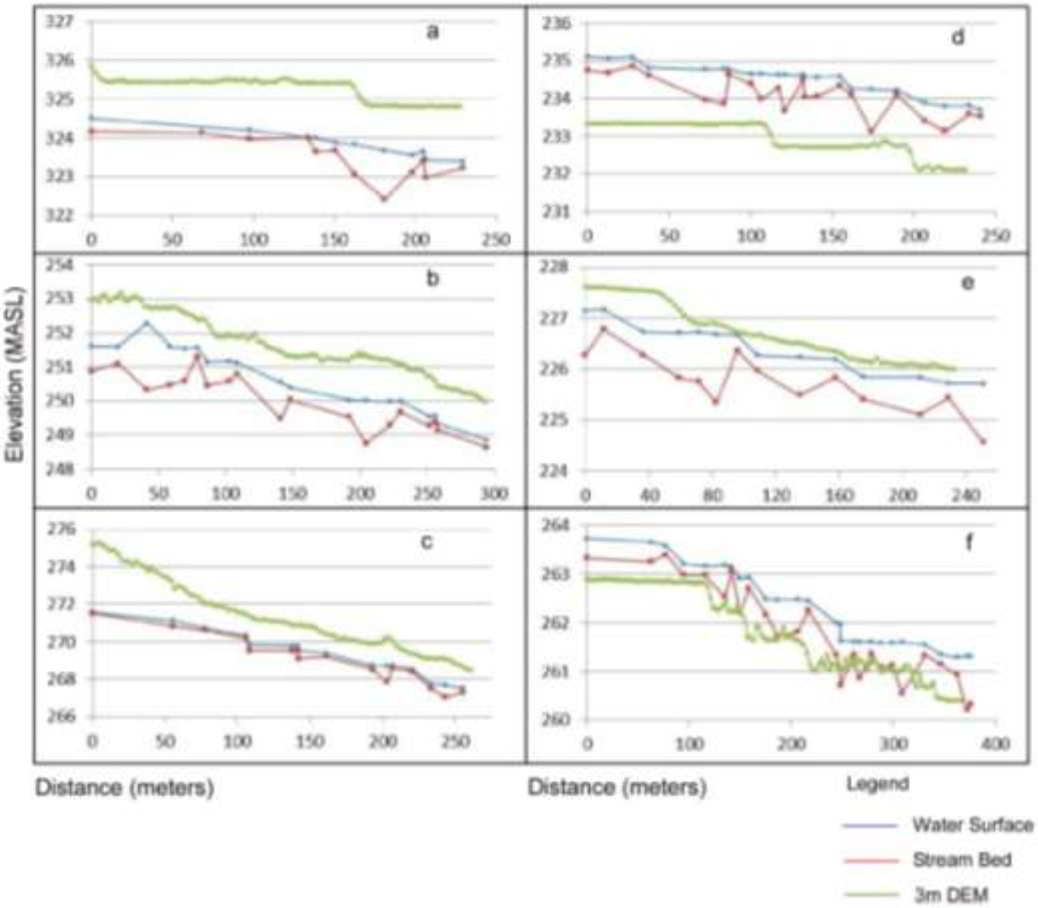


Figure 13- Field Streams vs. Streams Created in GIS. a- Deer Creek, b- Gribben Creek, c- Coolridge Creek, d-Beaver Creek, e- South Fork of the Whitewater River, f- North Branch of Pine River.

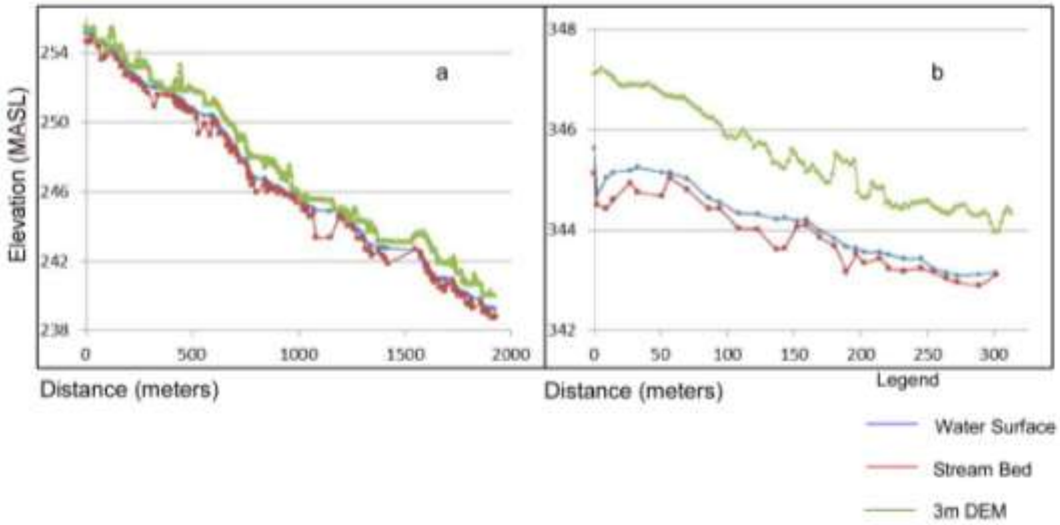


Figure 14- Stream Profiles of Water Surface and Water Level Surveyed in the Field (Dogwiler 2010, 2012) and Profiles created for Garvin Brook (a) and Crystal Creek (b).

Hack's Stream Gradient Index

The 46 carbonate reaches of streams had a median *SL* value of 21.312 and the siliciclastic stream reaches had a median *SL* value of 30.560 (Figure 15). The box and whisker plot in Figure 15 shows that the median and mean values for carbonate rocks are lower than for siliciclastic rocks. However, it is not statistically significant because the 25th-75th percentiles considerably overlap. A statistical analysis for carbonates vs. siliciclastics indicates that the data were not statistically different, t(46)=1952, *p*=0.079. *SL* generally increases as *L* increases; however, there is not a strong correlation (Figure 16).

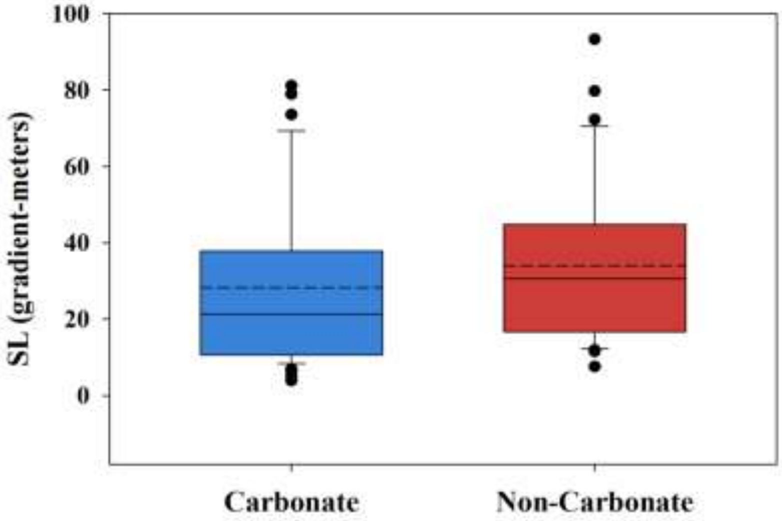


Figure 15- Box and Whisker Pot of SL Values for Carbonates and Siliciclastics. Whiskers Represent 5th and 95th Percentiles. Boxes Represent 25th to 75th Percentiles with Solid Middle Line Representing the Median and Dashed Line Representing the Mean.

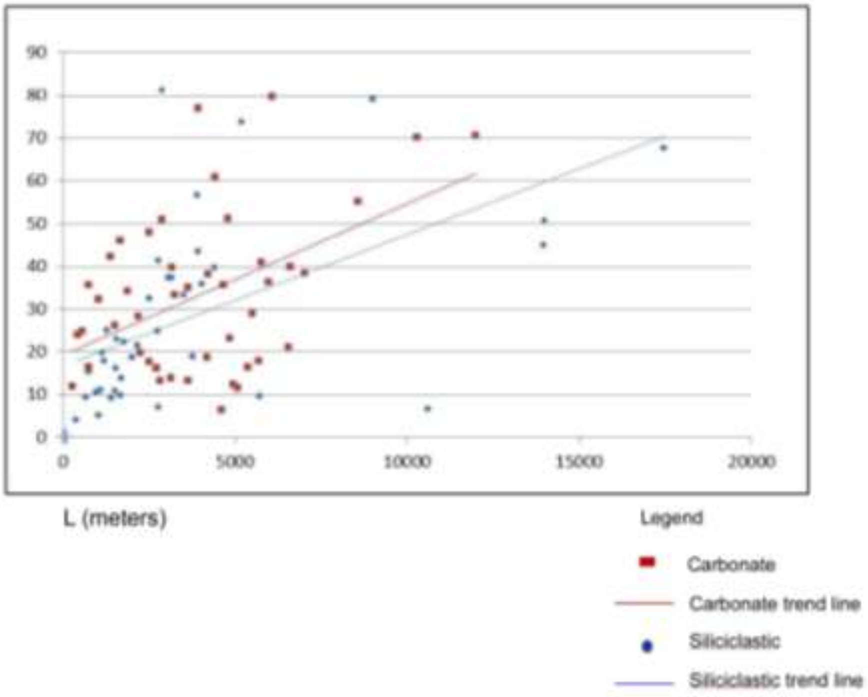


Figure 16- Chart Showing *L* Values Plotted Against *SL* Values.

Profile Shape Analysis

In total, 73 stream profiles were generated and used. The four main stream types found in Fillmore County were linear, concave, convex, and steps (Table 2 and Figure 17). To determine the shape type for each stream, the profile as a whole was evaluated regardless of the segment types making up the profile, i.e. if a concave profile contained steps it was classified as a concave. Stream profile distances ranged from hundreds of meters to 85,000 meters. The dominant stream type was linear, closely followed by concave. 78% of the streams were either linear or concave (Table 2). There were only a total of 6 streams with steps and 8 with convex shapes of the 73 that were sampled. While the distances for profiles did range dramatically, at all distances linear and concave profiles were dominant. Of the 8 streams found with a convex-up shape, 6 had distance values range from 2,800 meters to 8,500 meters. The last two had distances of 25,000 and 26,000 meters. All profiles with a larger horizontal distance than the concave profile at 26,000 meters were either convex or straight.

The 73 streams were distributed throughout Fillmore County, but the geology in the area was dominated by carbonate rocks. Most of the non-carbonate rocks are located in the northeast quarter of the county, so that is where a majority of the non-carbonate streams were sampled. The majority of the streams in both carbonate and non-carbonate rocks had a linear shape, with slope values ranging from -0.0004 to -0.0609 and with an average slope of -0.0101. The statistical analysis for linear segments of carbonates versus siliciclastic indicates that the data were not statistically different, t(28)=-0.072, *p*=0.943.

Table 2- The Number (n) and Percent (%) of Streams for Each Shape Present within Each Lithology.

Geology	Linear (n, %)	Concave (n, %)	Convex (n, %)	Steps (n, %)	Other (n, %)	Total (n, %)
Siliciclastic	15, 42.9%	12, 34.3%	3, 8.6%	3, 8.6%	2, 5.7%	35, 47.9%
Carbonate	17, 44.7%	13, 34.2%	5, 13.2%	3, 7.9%	0, 0.0%	38, 52.1%
Total	32, 43.8%	25, 34.2%	8, 11.0%	6, 8.2%	2, 2.7%	73, 100%

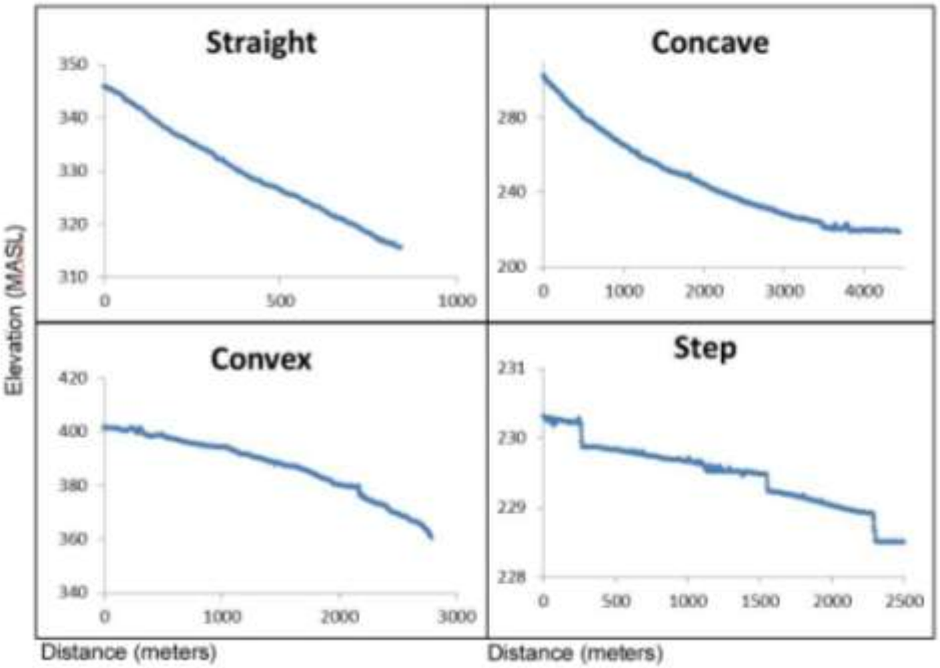


Figure 17- Examples of the Four Main Stream Shape Types Found in Fillmore County, MN.

CHAPTER IV

DISCUSSION

Identification of Features in Profile

Along the surveyed streams in southeastern Minnesota, no karst features were identified. The primary features observed were pool and riffle sequences, which were identified in streambeds of both carbonates and siliciclastic. The presence of pool and riffle sequences was expected within all streambed lithologies. However, it was also expected that the bumps, or anomalies, would also have been present. Pool and riffle sequences are found within streams that have continuously changing morphologies. Within these streams, especially with gravel size beds, the pools and riffles migrate downstream (Milne, 1982). With well-developed karst features in the area Runkel, 2003; Gao et la., 2005; Gao and Alexander, 2003), it was expected that significant karst features would be observed within the carbonate sections of stream with water being rerouted underground, resulting in karst anomalies in the stream profile. However, streams within the carbonate rocks lacked karst features similar to those present in the Carter Caves area. While southeastern Minnesota has extensive karst, a significant difference between this area and CCSRP is the dominance of pool-riffle sequences within a majority of the streams. The streams of interest in CCSRP were dry stream channels where water is being pirated to the subsurface. This difference in channel morphology is likely why the karst features found in CCSRP are not also present in southeast Minnesota. Streams characterized by clastic transport are unlikely to have significant karst development within the streambed.

Aside from the pool and riffle sequences, the only other identified feature was a step pattern (Figure 9). The steps were identified in the stream profiles using GIS. No steps were found in field surveyed streams. The step pattern could be a consequence of the DEM vertical resolution not being high enough, making the data appear discontinuous. The steps can also be due to the near-channel terraces or knickpoints between the glaciated and unglaciated regions (Stout, 2013). Most of the steps were less than 1 meter, and the resolution of the data ranged in a vertical accuracy of between 0.144 meters and 0.248 meters, depending on the land type. So it is possible that some of these smaller steps are attributed to vertical error. However, some of the steps that are present within this study can also represent where changes in slope of the streambed are occurring. For example, some steps appear in the GIS-generated profile at the location where a pool was found in the streambed in the field verified profile (Figure 13).

Filled vs. Unfilled

The profiles for filled vs. unfilled look very similar (Figure 8). There are a few small differences where pools have been removed in the filled DEM; however, some of the removed pools are real and are present in the field survey (Figures 8 and 13). For example, in the North Branch of Pine Creek, at a distance between 225 and 300 meters, the unfilled DEM shows a series of pools, while the filled DEM does not (Figure 8). In Figure 13, looking at the stream bed profile, a series of pools is present within the profile. These pools are better represented by the unfilled DEM. Because they are also present in the field survey, they cannot be attributed to error; therefore, the filled DEM is filtering out pools and classifying them as error in the data rather than actual features. It is still possible that some of the sinks in the unfilled DEM may be due to error within the data; however, the filled DEM should be used with some caution because it levels out some of the important characteristics of the stream in the process of rectifying error. While there may still be error present, it does not appear to be substantial enough to justify using the filled DEM over an unfilled DEM. Arnold (2010) also explains that filled DEMs were considerably more useful when DEMs were generated using lower resolution data that was not generated from LiDAR data. It is possible that the sinks present in coarser DEMs are simply error due to pits or depressions (Arnold, 2010). However, the DEMs in this study were generated from high resolution LiDAR data with a vertical error of less than 0.248 meters, so the potential for error is greatly reduced. Because the filled DEM removed important features visible within the original LiDAR data as a result of the high vertical resolution, the unfilled DEM was used for all subsequent analyses in this study.

GIS 1- vs. 3-meter

To compare the capability of generating stream profiles from the two different DEM resolutions, a qualitative approach was used. A visual examination of the 1-m and 3-m DEM profiles (Figure 10) suggests that they are similar. The main difference seen in some of the profiles are the many bumps that appear in 3-meter profile where the 1-meter profile keeps a consistent elevation value. This is likely because each 3-meter cell is averaging 9 one-meter cells and can be including areas of higher elevation that are outside of the stream channel. It is also possible that the boundary between two of the 3-meter cells is in the stream so that each cell is primarily averaging cells that are outside of the stream channel and have higher elevations. Averaging in the higher values can give the 3-meter cell a higher overall value, which could cause more bumps to be present in the 3-meter profile that are not present in the 1-meter profile.

The next step was to do a more quantitative comparison of the resolutions. Looking at Figure 11(results), all of the points follow the 1:1 line very closely, indicating that the 1-meter and 3-meter DEMs are very similar. Because the average slope for all 33 was very close to 1, it can be assumed that the two DEMs produce profiles that are the same. In addition to the slopes, a statistical analysis proved that the two resolutions are not statistically different. Because the 1- and 3-meter DEMs are ultimately the same, either can be used to provide the same results. However, the 3-meter DEM is significantly preferred over the 1-meter DEM due to computational requirements. A simple analysis using the 3-meter DEM can turn into significantly lengthier processing when using the 1-meter DEM.

Stream Shape

The streams in this area are dominated by linear and concave profiles with few convex or step profiles. These shapes are present in both carbonates and siliciclastic stream beds and do not appear to be present in either lithology more than the other. This suggests that the rock type is not playing a significant role in defining each stream's shape. 78% of the 73 stream profiles generated were either linear or convex, with very little variation between the shapes of carbonates and siliciclastics (Table 2). This is further supported by the fact that the stream gradient index values do not differ at all between carbonates and siliciclastics; there was no statistically significant difference. Looking at the slopes of linear segments, they were also shown to be statistically the same.

The primary factor causing these shapes is the incision into the valley of the legacy sediments (Stout, 2013). A study of the spatial relationship of profiles in the Root River Watershed found knickzones primarily at the boundary between glaciated and unglaciated regions (Stout, 2013). Downstream of these knickzones, the presence of near-channel terraces increase, which are possible locations of sediment contribution to streams due to stream channel widening or movement. A recent shift in the source of sediments to streams has been predominantly to the legacy sediments from floodplains and alluvial terraces (Stout, 2013). These sediments have sat in the valleys for years, and are now being reworked by the streams back into the system. Farther upstream, the stream profiles of tributaries have a shallower gradient, and are more convex-upward. The tributaries to the Root River that have a source nearer to the Mississippi River are much steeper and become more concave nearer to the Root River. The huge increase of these legacy sediments being brought back into the system is playing a large role in the shape of the streams.

Land use is also a significant factor affecting shape in the area (Knox, 1977; Knox, 2001; Knox, 2006). Land conversion to more agricultural fields in this area causes more flooding and runoff in storms or flooding events, which is causing more erosion in streams (Knox, 1977; Knox, 2001; Knox, 2006). This erosion also supports the shapes of the profiles that are seen in this area. Areas of less erosion will tend to have a more convex profile, while higher rates of erosion will produce the concave profiles (Pazzaglia, 1998). Because the scale of the profiles in this study is so small, they are probably being swamped by land-use changes, which have a huge local impact.

GIS- Field vs. DEM

Streams profiles generated in GIS using 3-meter DEMs show an accurate representation of water levels surveyed in the field. This is expected because the LiDAR data are only able to capture the elevation at the water surface, so profiles generated from LiDAR data are not able to represent the depths of the pools seen in the stream bed. The stream surface, which is seen in the GIS generated profiles, is able to capture where pools begin. For example, in the Deer Creek profile, there are two steps at 160 and 230 meters in the GIS generated profile (Figure 4 in results). The steps correlate with the two pools seen in the field data (Figure for reference). The step in the GIS profiles roughly starts where the riffle ends and the pool begins. There is the potential for stream channel migration between the time that the LiDAR data were collected and the stream survey conducted; however, no serious flooding events occurred that would have significantly reworked the streams enough to see pools in different places.

Since GIS is able to locate these important points, the user is able to determine where there will likely be pools and riffles in profile. The elevation difference of up to 2 meters between the field profile and GIS generated profiles can be attributed to the error in the handheld GPS unit. The trends of both the DEM data and the field data are similar except for the elevation differences.

CHAPTER V

CONCLUSION

No karst features were found in southeastern Minnesota in the surveyed profiles or the profiles created in GIS. The dominant feature in all streams was pool and riffle sequences. Stream gradient indices calculated for carbonate vs. siliciclastic reaches of streams showed mean values that were statistically the same between lithologies. This suggests that it is not lithology of streams that is affecting the gradient or shape. Erosion into near-channel terraces containing legacy sediments is one of the primary reasons causing the stream shapes in this area. The scale in this study was too small to capture the convexity seen by Stout et al. (2013). Land use activity was another primary factor affecting these stream shapes, and it dominated the scale at which this study done.

GIS proved to be a useful tool in creating profiles and doing analyses on DEMs and profiles. While it did not create an identical profile to those surveyed in the field, it was able to identify where pools and riffles occurred. However, due to flooding in recent years and a 5 year time difference between when data were collected, not all pools and riffles were accurately identified within the DEM due to a mobile stream bed. The unfilled DEM was chosen for this study over using an unfilled DEM in order to preserve the streambed features that a filled DEM can smooth out. Except for minor differences, the 1-meter and 3-meter DEM appeared and were calculated to be statistically similar. Due to its smaller file size, the 3-meter DEM is preferred.

Future work in the Carter Caves State Resort Park area, or other regions with dry stream beds would be beneficial to really determine if the karst anomalies can be identified in stream profile. While this study was not able to locate them in southeastern Minnesota, they can still potentially be found in other areas with dry stream beds where water is being rerouted underground. Unfortunately, no dry stream beds were found in this area.

More work is also needed for Hack's Stream Gradient Index. In this study, there was no statistical difference between *SL* values for carbonate and siliciclastic streambeds; however other regions that are more controlled by lithology might yield a bigger difference. It would also be interesting to learn how more tectonically active regions and various climates affect *SL* values. Additional work looking at the spatial relationship of the shapes of stream profiles in southeast Minnesota would help to understand where we are finding each shape type. Longer stream reaches would also be beneficial.

REFERENCES

Alexander Jr., E.C. and Lively, R.S., 1995: Karst-Aquifers, caves, and sinkholes: Text supplement to the geologic atlas of Fillmore County, Minnesota: Minnesota Geological Survey County Atlas C-8, pt. C, p. 10-18.

Anderson, R.C., 1988, Reconstruction of preglacial drainage and its diversion by earliest glacial forebulge in the upper Mississippi Valley region: Geology, v. 16, no. 3, p. 254-257. doi: 10.1130/0091-7613.

Arnold, N., 2010, A new approach for dealing with depression in digital elevation models when calculating flow accumulation values: Progress in Physical Geography, v. 34, no. 6, p. 781-809, doi: 10.11177/0309 1333 10384542.

Carlston, C.W., 1969, Longitudinal slope characteristics of rivers of the midcontinent and the Atlantic east gulf slopes: International Association of Scientific Hydrology Bulletin, v. 14, no. 4, p. 21-31.

Dogwiler, T., 2010, Rush-Pine Creek Watershed preliminary assessment and scoping plan: Southeastern Minnesota Water Resources Center, Winona State University.

Dougherty, P.H., 1985, An Overview of the Geology and Physical Geography of Kentucky *in* Caves and Karst of Kentucky, P.H. Dougherty, ed., Kentucky Geological Survey Special Publication 12 (in cooperation with the National Speleological Society), Series XI, Lexington, Kentucky, 196 p.

Fillmore Geologic Atlas, Part B [online database]. (1996) Minnesota Department of Natural Resources, Division of Ecological and Water Resources. Available: http://www.dnr.state.mn.us/waters/programs/gw_section/mapping/platesum/fillcga.html [September, 2013].

Gao, Y., Alexander, E. C., Jr., and Barnes, R. J., 2005, Karst database implementation in Minnesota: analysis of sinkhole distribution: Environmental Geology, v. 47, no. 8, p. 1083-1098, doi:10.1007/s00254-005-1241-2.

Gao, Y. and Alexander, Jr., E. (2003) A Mathematical Model for a Map of Relative Sinkhole Risk in Fillmore County, Minnesota. Sinkholes and the Engineering and Environmental Impacts of Karst (2003): pp. 439-449.
doi: 10.1061/40698(2003)39

Goldrick, G., Bishop, P., 2007, Regional analysis of bedrock stream long profiles: evaluation of Hack's SL form, and formulation and assessment of an alternative (the DS form): Earth Surface Processes and Landforms, v. 32, p. 649-671, doi 10.1002/esp.1413.

Hack, J.T., 1957, Studies of Longitudinal Stream Profiles in Virginia and Maryland: U.S. Geological Survey Professional Paper 294-B, p. 42-97.

Hack, J.T., 1973, Stream-profile analysis and stream-gradient index: Journal Research U.S. Geological Survey, v. 1, no. 4, p. 421-429.

Halket, I.H., Rasmussen, P.F., Doering, J.C., 2013, The effect of pool and riffle on dissolved, non-conservative mass transport in rivers: Water Quality Research Journal of Canada, v. 48, no. 3, p. 232-242, doi: 10.2166/wqrjc.2013.051.

Hobbs, H. C., 1992, Paleozoic Plateau of southeastern Minnesota, *in* Nater, E. A., ed., Soils geomorphology pre-conference tour guidebook, Oct. 29-Nov. 1, Annual Meeting of the Soil Science Society of America, Nov. 1-6, 1992, Minneapolis, Minnesota, p. unpaginated.

Jacoby, B.S., 2011, Uncovering the Speleogenesis of the Carter Cave System in Carter County, Kentucky [Master's Thesis]: Illinois State University, 76 p.

Knox, J.C., 2006, Floodplain sedimentation in the Upper Mississippi Valley: natural versus human accelerated: Geomorphology, v. 79, p. 286-310, doi: 10.1016.j.geomorph.2006.06.031.

Knox, J.C., 1977, Human impacts on Wisconsin stream channels: Annals of the Association of American Geographers, v. 67, no. 3, p. 323-342, doi: 10.1111/j.1467-8306.1977.tb01145.x.

Knox, J.C., 1985, Geologic History of Valley Incision in the Driftless Area, *in* Lively, R. S., ed., Pleistocene Geology and Evolution of the Upper Mississippi Valley, Abstracts and Field Trip Guide, Winona State University, August 13 - 16, 1985: St. Paul, MN, Minnesota Geological Survey, p. 5-8.

Larue, J.P., 2011, Longitudinal Profiles and Knickzones: the Example of the Rivers of the Cher in the Northern French Massif Central: The Geologists' Association, v. 122, p. 125-142.

LiDAR Elevation Data for Minnesota [online database]. (2008) St. Paul, Minnesota: Minnesota Geospatial Information. Available: http://www.mngeo.state.mn.us/chouse/elevation/lidar.html [March, 2013]

MacGregor K.R., Anderson, R.S., Anderson, S.P., Waddington, E.D., 2000, Numerical simulations of glacial-valley longitudinal profile evolution, v. 28, no. 11, p. 1031-1034.

MacSwain, J., 2012, Special driftless area conservation initiative funding available: National Resources Conservation Service: http://www.mn.nrcs.usda.gov/news/news_release/2012 (accessed April 23, 2013).

Milne, J.A., 1982, Bed-material size and the riffle-pool sequence: Sedimentology, v. 29, p. 267-278.

Mossler, J.H., 2008, Paleozoic stratigraphic nomenclature for Minnesota: Minnesota Geological Survey Report of Investigations 65, 76 p., 1 pl.

Pazzaglia, F. J., Gardner, T. W. and Merritts, D. J., 1998, Bedrock fluvial incision and longitudinal profile development over geologic time scales determined by fluvial terraces: Rivers Over Rock: Fluvial Processes in Bedrock Channels (eds K. J. Tinkler and E. E. Wohl), American Geophysical Union, Washington, D. C.. doi: 10.1029/GM107p0207.

Peterson, E. W., Sickbert, T. B., and Moore, S. L., 2008, High frequency stream bed mobility of a low-gradient agricultural stream with implications on the hyporheic zone: Hydrological Processes, v. 22, no. 21, p. 4239-4248, doi:10.1002/hyp.7031.

Runkel, A.C., Tipping, R.C., Alexander Jr., C.A., Green, J.A., Mossler, J.H., Alexander, S.C., 2003, Hydrogeology of the Paleozoic bedrock in southeastern Minnesota: Minnesota Geological Survey Report of Investigations 61, 205 p.

Stout, J.C., Belmont, P., Schottler, S.W., Willenbring, J.K., 2014, Identifying Sediment Sources and Sinks in the Root River, Southeastern Minnesota: Annals of the Association of American Geographers, v. 104, no. 10, p. 20-39.

Trimble, S.W., 1999, Decreased Rates of Alluvial Sediment Storage in the Coon Creek Basin, Wisconsin, 1975-93: Science, v. 285, no. 5431, p.1244-1246.

USGS National Hydrography Dataset [downloaded file]. (2012) Denver, CO: USGS. Available FTP: ftp://nhdftp.usgs.gov/DataSets/Staged/States/ [March 21, 2013].

USGS Mineral Resource Dataset [downloaded file]. (2007) Denver, CO: USGS. Available: http://mrdata.usgs.gov/geology/state/state.php?state=MN [February 7, 2013].

White, W.B., 1988, Geomorphology and Hydrology of Karst Terrains: Oxford University Press, 464 p.

White, W. B., 2009, The evolution of Appalachian fluviokarst: competition between stream erosion, cave development, surface denudation, and tectonic uplift.: Journal of Cave and Karst Studies, v. 71, no. 3, p. 159-167

Woodside, J., 2008, Examination of the Relationship Between Longitudinal Profile and Sediment Mobility Within a Fluviokarst System [Master's Thesis]: Illinois State University, 70 p.

Zimmerman, A.E., Church, M., Hassan, M.A., 2008, Identification of Steps and Pools from Stream Longitudinal Profile Data: Geomorphology, v. 102, p. 395-405.