Comparing Tributaries of the Minnesota River

By

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ABSTRACT

The Minnesota River and its tributaries are all the same age and cut through similar geologic substrate. Due to their close proximity to each other, they also receive approximately the same amount of rainfall. However, differences have been observed in the hydrology of different rivers. For example, one may flood while others have more typical flow levels. Rush River, Little Cottonwood River, and High Island Creek are all tributaries to the Minnesota River with similar lengths and drainage areas. This study compared their elevation profiles, underlying geology, and the presence of drainage ditches along their length to look for differences between these tributaries. Drainage ditches are indicative of artificial drainage in the surrounding fields, and the amount of artificial drainage can cause differences in the amount of water flowing through a stream. ArcGIS was used to create the elevation profiles and identify drainage ditches using a 1 meter DEM (Digital Elevation Model), and was also used to line up surface geology with the stream. All three tributaries were found to have very similar slope profiles, but large differences in the amount of drainage ditching present. This study determines that the similarities of the slope profiles are due to the shared geology and glacial history of the region. It also determines that slope profile does not impact the amount of water flowing through the area, but the presence of artificial drainage does.
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# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abstract</td>
<td>2</td>
</tr>
<tr>
<td>Introduction</td>
<td>6</td>
</tr>
<tr>
<td>Geologic Setting</td>
<td>6</td>
</tr>
<tr>
<td>Methods</td>
<td>8</td>
</tr>
<tr>
<td>Results</td>
<td>9</td>
</tr>
<tr>
<td>Discussion</td>
<td>13</td>
</tr>
<tr>
<td>References</td>
<td>15</td>
</tr>
</tbody>
</table>
## FIGURES AND TABLES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 1</td>
<td>Map of the Streams Studied</td>
<td>7</td>
</tr>
<tr>
<td>Figure 2</td>
<td>Detail of Rush River</td>
<td>8</td>
</tr>
<tr>
<td>Figure 3</td>
<td>Comparison of Stream Elevation, Geology, and Artificial Drainage</td>
<td>10</td>
</tr>
<tr>
<td>Figure 4</td>
<td>Elevation Profiles</td>
<td>13</td>
</tr>
</tbody>
</table>
INTRODUCTION

The Minnesota River, located in southern Minnesota, runs 370 miles through a fairly homogenous landscape for much of its length. The surficial geology is composed mostly of glacial till, and the landscape is dominated by agriculture, and is fairly flat. The exception to this is the Minnesota River valley, which is approximately 70 meters deep in the study area.

Tributaries to the Minnesota River all cut through the same material, and are the same age due to the glacial processes that have shaped this landscape. In spite of these similarities, some of the tributaries are more prone to flooding than others.

Various studies have examined the tributaries of the Minnesota River. They generally focus on the amount of sediment eroded before and after wide scale farming changed the landscape. Due to the nature of the till underlying the area, erosion rates have always been high. Some of the tributaries have had knickpoint migration rates of an average 3.0-3.5 meters per year over the past 11,500 years (Gran et al 2009). The amount of sediment presently being eroded by the Minnesota River and its tributaries increased significantly after the development of widespread agriculture, although different methods of estimating how much have produced values of 1.3-3.4 times the Holocene average rate, and 10 times the Holocene average (Gran et al 2009).

One factor known to increase average annual flow in agricultural watersheds is artificial drainage. The presence of drainage tile beneath a field causes water to flow more quickly through the soil and out into drainage ditches that bring it into a river. The water’s shortened residence time on and in the soil reduces the amount of evapotranspiration that is able to happen, allowing more water to enter a river in a shorter period of time (Schottler 2013).

The purpose of this research is to examine the possible causes of differences between the tributaries of the Minnesota River, especially differences in flow level. In order to accomplish this, I constructed slope profiles of three tributaries to the Minnesota River: Rush River, Little Cottonwood River, and High Island Creek. The slope profiles were constructed from 1 meter digital elevation models (DEMs) of the surrounding area, and compared them to the surface geology through which the rivers run. I also looked at which sections of the river are actually agricultural drainage ditches (referred to here as “ditching”), and how that relates to the slope profile and underlying geology.

GEOLOGIC SETTING

The primary geology of south-central Minnesota, where this study takes place, is glacial till deposited by the retreat of the Laurentide Ice Sheet approximately 14,000 years ago, underlain by Ordovician dolostone and Cambrian Sandstone (Mossler and Chandler 2012). As the ice sheet melted, it retreated northward. Eventually a large lake of melt water called Glacial Lake Agassiz formed, kept in place by the moraines deposited by the retreating ice. The lake covered large portions of Minnesota, North Dakota, South Dakota, Manitoba, Saskatchewan, and Ontario (Sansome 1983). Between 9,000 and 12,000 years ago (Sansome 1983), one of the moraines failed, allowing water to drain from Lake Agassiz through Glacial River Warren. The initial flood incised a huge channel, doing approximately 70 m
of vertical incision in the area around Mankato, Minnesota, in a very short period of time. Glacial Lake Agassiz drained through this channel several times, and the valley created later became the Minnesota River Valley (Johnson et al 1998).

The creation of such a huge channel resulted in a sudden drop in base level for all nearby rivers. This drop created a knickpoint or series of knickpoints for these rivers, which have since migrated upstream. Since these rivers are all formed in relatively non-cohesive till, rather than strongly-lithified bedrock, they are incising at a rapid rate (Gran et al 2013).

This study looks at three tributaries of the Minnesota River: Rush River, High Island Creek, and Little Cottonwood River, all of which are located in south-central Minnesota (Figure 1). Rush River has a watershed area of 403 miles$^2$, High Island Creek has an area of 239 miles$^2$, and Little Cottonwood River has an area of 169 miles$^2$.

![Figure 1: Locations of the three rivers studied in relation to the Minnesota River. Inset shows their location in the state of Minnesota. State outline and river locations obtained from the Minnesota DNR.](image)

Rush River is located north of the Minnesota River, in the form of three branches (North, Middle, and South) which then join together as shown in Figure 2. Most of this river, particularly before the branches join together, consists of artificial drainage ditches. This river is mostly located in Sibley County.
High Island Creek is north of the Minnesota River. It starts in Renville County, then flows east into Sibley, then McLeod, and finally back into Sibley County, where it joins the Minnesota River. It is about 70 miles long, approximately half of which consists of drainage ditches.

The Little Cottonwood River is located on the south side of the Minnesota River, and flows through Cottonwood, Brown, and Blue Earth Counties before reaching the Minnesota River. It is 83 miles long. The Little Cottonwood is unique for the area in that three quarters of it remains natural and un-ditched. The landscape is dominated by cropland, with 84% of land cover in the watershed being cropland, 5% being developed, and the remaining 11% consisting of rangeland, wetland, and forest (MPCA 2016). A thorough land-use report like the MPCA one is not available for the other two rivers, but they are all located in the same region, which is notable for being largely agricultural. As such, it is assumed that their watersheds consist of similar land-use distribution.

METHODS

Most of this research was done through ArcGIS version 10.4. Data was downloaded from several sources. Elevation data came from the Minnesota Geospatial Information Office (MnGeo 2010 and 2012) and includes 1m DEMs of Nicollet, Brown, Renville, and Sibley counties, and portions of Cottonwood, Blue Earth, and McLeod counties.

Elevation profiles were formed for each of the rivers to be studied using ArcGIS. First, a 2D line was digitized along each river using a 1m hillshade formed from the DEM of the portion of the river to be digitized. A shapefile showing an older version of the rivers’ centerlines was used as a general guide.
as to where approximately the river started, and when the river path was unclear. Some situations where the river path was unclear included when the river was shallow enough not to be easily visible in the hillshade, and when the river flowed through a lake. The line was digitized using zooms of approximately 1:600 to 1:2,500, depending on the width of the river and how straight or curved it was. The 2D lines were digitized in sections, as the elevation data was not mosaicked together.

Once the 2D line section had been digitized, it was draped over the DEM of that section using the tool Interpolate Shape to form a 3D line. That line was then converted into an elevation profile using the 3D analysis toolbar. The data from the elevation profile was exported to a text file, and opened in Microsoft Excel as a tab-delimited file. Since the elevation profiles had been digitized in segments, they were “stitched together” in Excel. Rush River has several branches that join together, so each segment was stitched together separately.

After all of the elevation profiles had been joined together, they were graphed, and the graphs were placed on a large PowerPoint slide where they were stretched and compressed until each river and river segment was displayed using the same vertical and horizontal exaggerations as each other (Figure 3). The segments for Rush River were lined up by distance, with segments that were an equal distance from the base of the river aligned vertically, in a semblance of the shape that the river takes.

In ArcGIS the digitized stream lines were displayed over a geologic map of the surficial geology of the area (Hobbs and Goebel 1982), and distances were measured using the measure tool to find the length of each unit. The 1m DEMs were also examined visually to find where they had been artificially straightened instead of allowed to meander naturally, and the length of these segments of drainage ditch were measured the same way. Both sets of measurements were drawn on the elevation profiles in Microsoft PowerPoint, and visually compared.

RESULTS

Stream Morphology

Of the three slope profiles digitized, all showed similarities in knickzone location. In all three cases, the stream has a knickzone approximately 70 ± 5 meters above base level (the Minnesota River). The initial knickzone is always located approximately 30,000 ± 5,000 meters upstream. The Little Cottonwood River also has a second knickzone, located 100,000 meters upstream. The other two rivers do not have this second knickzone.

Surficial Geology

The surficial geology of each river segment was compared with the corresponding slope profile to see how they worked together (Figure 3). The lower section of each stream is underlain by alluvium, although the amount varies by stream. In Rush river, the alluvium goes from base level all the way up to the knickzone, approximately 30,000 meters upstream. Where the stream splits, this alluvium underlies both the South Branch and the joined portion of the North and Middle branches. In both High Island Creek and Little Cottonwood River, the alluvium only underlies about 10,000 meters of stream length.
Alluvium is not displayed on the slope profiles in Figure 3 because it is a recent deposit and is assumed to have had little influence on the stream profile.

Except for the alluvium, these streams are largely underlain by till deposited by ground moraines during the last glacial maximum. All glacial deposits underlying these streams come from the Des Moines lobe (Hobbes and Goebel 1982).

Although ground moraine deposits are the most common in the area, a portion of the South Branch of Rush River is underlain by deposits from a stagnation moraine. This section of the river shows no real difference in slope from the areas up and downstream of it, which are both underlain by ground moraines. Another departure from the ground moraine sediments is in the Little Cottonwood River. There a large section, approximately 85,000 meters long, which is underlain by glacial outwash.

**Artificial Channelizing**

All three of the streams have sections that are artificially straightened and channelized into drainage ditches. These are clearly visible on a 1 meter DEM (Figure 3). In all three cases, the ditching is located towards the headwaters of the stream, with the downstream sections allowed to meander freely.

In the Little Cottonwood River, ditching is quite minor, with a section about 10,000 meters long (less than a tenth of the total stream length) turned into drainage ditches. This is discontinuous, with channelized sections interspersed with sections of river that meander. These sections are located at the downstream end of the upper knickzone (Figure 3).
Figure 3: Elevation profiles for Little Cottonwood River, High Island Creek, and Rush River. The solid line is elevation profile. Spikes visible in the profile are caused by culverts. Whether the section is ditched or meandering is indicated by the orange and blue background, and the underlying geology is shown in the green, purple, or dark blue color of the profile line. Rush River is laid out in several segments, placed according to their distance from the mouth of the river.

Both High Island Creek and Rush River have significantly more ditching, both in terms of total length ditched and in terms of percentage of the river affected. In Rush River, all three branches are channelized from their headwaters until the upstream end of the knickzone. This tends to be just over 50,000 meters of stream length per branch, and the channelization ends just where the slope of the river suddenly becomes steeper. Unlike Little Cottonwood, this ditching is continuous, with no meandering at all.

Like Rush River, ditching in High Island Creek is continuous the first 55,000 meters of river length. Unlike Rush River, the change from ditched to meandering stream is not marked by any change.
in the stream profile. The stream at that point keeps a fairly consistent slope, and the knickpoint does not occur for another 30,000 meters.

**DISCUSSION**

The form taken by the three elevation profiles shown in this study is mostly due to the base-level drop caused by Glacial River Warren, with some influence by the underlying geology as well. In all three rivers, there is a knickzone located at the same relative location: approximately 70 meters above base level, and 30,000 ± 5,000 meters upstream from where the river joins the Minnesota River. Additionally, most of the area under study has similar underlying geology.

A previous study of the area looked at three rivers similar to those studied here: the Cobb, Maple, and Le Sueur Rivers. All of them are located in south-central Minnesota, flowing into the Minnesota River and carving through the same glacial till that the Rush, Little Cottonwood, and High Island are. This study found knickzones on all three rivers located 30,000 – 35,000 meters upstream of where they join with the Blue Earth River, shortly before it joins the Minnesota (Figure 4). On two of the three streams, the Maple and Le Sueur Rivers, they also identify a second knickzone located at 120,000 – 140,000 meters upstream, which matches the one found 130,000 meters upstream along the Little Cottonwood River (Gran et al 2009).

![River longitudinal profiles](image)

Figure 4: Longitudinal elevation profiles of the Le Sueur River and its two primary tributaries, the Cobb and Maple Rivers, extracted from a 30 m DEM. The locations of the two knickpoints delineated on the Le Sueur River branch are shown (Figure and caption modified from Gran et al 2009).

The similarity of the locations of the knickzones on all six rivers suggest that the causes are shared by all of the rivers. They all share the same base level, which dropped suddenly, causing the presence of the knickzones. All of the rivers have the same underlying geology, glacial till. It is due to this that the knickzones have propagated upstream at the same rate. Gran et al 2009 also reached these same conclusions.
One factor that does not appear to have shaped the elevation profiles of these streams is channelization and artificial drainage. Profiles of both Little Cottonwood and High Island Creek show no relationship between knickzone location and the locations of channelization. In High Island Creek, drainage ditches are found in the upper portion of the stream, but the stream is allowed to meander normally well before it reaches the knickzone. Little Cottonwood, on the other hand, only has channelization over a small portion of its length, found at the downstream end of the upper knickzone.

Rush River, in contrast to the other two, does show something that may be a relationship between the location of its knickzones and channelization. Because of the separate branches that Rush River splits into, the knickzone approximately 30,000 meters upstream from the Minnesota River is located in two different places, in the South Branch and right where the North and Middle Branches meet. All three branches are completely channelized, but the river switches to meandering freely right at both of the knickzones. In spite of this, it is unlikely that stream channelization and knickzone location are actually related. All three of the tributaries to the Minnesota River have different amounts of channelization, but the location of the knickzones remains constant for all three tributaries.

Although channelization has not affected stream profile, it may affect stream discharge. This is not due to the presence of the ditches themselves, but the presence of artificial drainage in the surrounding fields, which is a system that the ditches are part of. Due to the artificial drainage, moisture drains more quickly out of the soil and into the stream. This reduces the amount of evapotranspiration that can take place, and the amount of water that can infiltrate into the groundwater. Both of these result in more water flowing down the streams, and doing it more quickly after a rainfall event, increasing the erosive ability of the stream (Schottler 2013). This increases the erosive ability of the stream, and can change its’ elevation profile over time.

One major assumption made in this study is the assumption that the presence of drainage ditches is a reflection of how much drain tile is present in the fields nearby. If that is not the case, for example if all of the fields are drained equally, then the conclusions reached here loose some of their weight. Additionally, the Minnesota and other similar rivers have experienced some widening in response to the presence of drainage tile (Schottler 2013). It seems likely that this should be reflected in their tributaries as well, in the form of profile change as well as width change. This study uncovered no evidence of stream profile change due to agricultural drainage, but it did not look at the streams over time, and did not look at their width. Both of those factors are other possible ways such change could have been visible.

In spite of these limitations, this paper reaches two main conclusions. The similarities in the slope profiles of the three tributaries are caused by the shared geologic history of the region, which has been the driving force behind the present form of the area. Unlike the slope profiles, differences in flooding among the tributaries are cause by differences in artificial drainage in their watersheds, which is a controlling factor in how much water is released to the streams, and how quickly.
REFERENCES


