THE IMPACTS OF AGRICULTURAL DITCHING ON THE HYDRAULIC GEOMETRY OF STREAMS

by
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A thesis submitted in partial fulfillment of the requirements for the degree of
Bachelor of Arts
(Geology)
at
GUSTAVUS ADOLPHUS COLLEGE
1998

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under the supervision of Professor Mark D. Johnson

ABSTRACT

Artificial ditches constructed along three tributaries of the Minnesota River (Rush River, High Island Creek, and Buffalo Creek) have increased the total stream length 4 to 5 times the original stream length, decreased the overall slope significantly, and increased the order of the stream basin in two cases. Inspection of county ditch records show that the majority of ditches were constructed in the 1960's. Several different approaches were employed to determine if this increase in drainage network altered the hydraulic geometry or flow characteristics of the streams. Due to incomplete records and due to land use and precipitation changes over the same period as ditch construction, identification of clear changes was difficult. Nonetheless, theoretical approaches and the presence of a post-settlement alluvium indicate that there have been changes and that ditching may contribute to these changes by increasing flood magnitude and frequency.

ACKNOWLEDGMENTS

This research was done as a joint summer project between student and advisor with a research grant from the National Science Foundation's Council for Undergraduate Research. This funding made it possible to pursue the questions of interest with much more freedom and in more detail than would have otherwise been possible. I want to thank Mark Johnson, my advisor, for giving me the incentive to pursue this grant and for his cooperation and encouragement throughout the summer of research and in the following year presenting the research at the Geological Society of America regional meeting. I also want to thank several people in the Sibley County Courthouse who assisted me in finding records. Jeff Majeski and Al Herschman in the Public Works office provided county ditch maps and the oldest aerial photos of the county, along with their insight on sedimentation and water flow in ditches. Gene Isakson, the Sibley County engineer, provided cross-sectional records of the Rush River at a few places and his observations of water flow changes in the river within the last few decades. Ray Grimwell, an assistant highway engineer, provided information on how far back records of stream cross-section go. The Records office in the county courthouse put up with me translating the original county surveys onto twenty-one quadrangles and recording ditch lien dates, a long process indeed. The Agricultural stabilization and Conservation Service and Farmer's Service Agency offices in Sibley County provided aerial photos of the area from different years, and allowed us to work in their offices. The Farmer's Service Agency of Nicollet County allowed us to use their planimeter to measure stream lengths. I also want to thank Gustavus geology graduate Dave Davis, who gave me information on precipitation fluctuations within the century, and who pointed me to his graduate advisor, Dave Mulla, in the Soil Science department of the University of Minnesota. Thanks to Dr. Mulla for sharing some of his research on the effects of precipitation changes on river flow in the last century. I also want to thank Dean Braatz, the Hydrologist in Charge at the North Central River Forecast Center, for gathering his colleagues to discuss our research and the possible effects ditching may be having on stream flows. I would also like to thank those people who live along the streams of study who shared their observations and concerns about changes in the streams and speculations on causes for these changes; and a special thanks to Wyatt Bienfang, who pointed me towards other people to talk to and who showed me a place from which to look out over the Rush River valley.

CONTENTS

FIGURES AND TABLES

INTRODUCTION

In the last century, arable land in the Midwest has been extensively drained to expand and to improve agriculture. This has been done by the construction of open ditches and the installation of tile lines. Ditches are human-made open water channels that extend from the ends of natural streams and then effectively drain into those streams. Tile lines are underground pipes of corrugated metal or plastic that run directly underneath fields and drain into ditches or natural streams. This alteration of the natural stream systems has created concern both for changing water quantity flowing through the river and for water quality. As a summer research project funded by the National Science Foundation, my advisor, Mark D. Johnson, and I took on the question of changing hydraulic geometry and its implications for changing quantities of flow through ditched stream systems.

Fluvial theory states that a river will create an equilibrium state and its physical characteristics will reflect a balance between the amount of water flowing through the system and the amount of sediment available for transport (Ritter and others, 1995). The hydraulic geometry of a stream is indicative of this state of fluvial equilibrium. The variables of hydraulic geometry of a stream are width, depth, slope, velocity, and sinuosity (Schumm, 1987). If the amount of water flowing through the system has changed within the century due to ditching, we hypothesize that the variables of hydraulic geometry have changed accordingly. Therefore, a visible change in hydraulic geometry correlated in time with ditching may give insight into the effects ditching has had on streams.

PUBLIC AND PROFESSIONAL PERCEPTION OF DITCHING

The Federal government has historically been more involved with water resources planning and development than it has in many other areas of public concern; the government's constitutional power to develop water resources was recognized early in United States history (Holmes, 1972). By the 1960's, the Soil Conservation Service had a small watersheds project that provided assistance to local organizations or state agencies in constructing works of improvement on small streams and on private lands. These works were done for agricultural water management, flood prevention, fish and wildlife development, and water supply. Although lots of energy was put into managing water resources, little time was spent studying the effects of water resource management practices. The conflict between preservationist ideas of John Muir and conservationist ideas of Gifford Pinchot could still be seen in water resource issues even in the latter half of the century (Holmes, 1979); it appears by the extent of agricultural ditching that the conservationist attitude of maximizing the use of resources for the greatest use for the most people has prevailed.

This attitude is illustrated in the file for Sibley County Ditch 55, part of the north branch of the Rush River dug in 1956, there existed a "petition to improve the natural watercourse" for the "reclamation of wet and overflowed lands." It stated that

> this stream has been permitted to fill up with silt and refuse, trees and vegetation, as a result of the windstorms during the dry years of the 1930's and due to other causes, with the result that there are large areas of land in the vicinity of said watercourse which are low and wet and at certain seasons of every year are covered with water, thereby rendering said lands unproductive and useless,

and "waters become stagnant and foul, rendering an unhealthy atmosphere." The same statement or one similar to it was found in files for several other ditches.

Since the early 1950's, the Minnesota River basin has been hit with its five highest floods in recorded history of the river, which has brought about concern. There has been some public speculation that a reason for this apparent increase in flooding has been from flow added to streams by ditches. Some people, however, feel that ditches do not increase risks of flooding, but rather decrease the risk in certain situations. After the flood of 1997, two articles came out in the Mankato, Minnesota newspaper, *The Free Press* ,expressing that opinion from two scientists. Dave Mulla of the University of Minnesota said that the floods were a result of a normal trend of increasing rain and snow (Krohn, 1997a), and Henry Quade of Mankato State University said that agricultural flow through ditching has minimal impact on flooding (Krohn, 1997b). In a letter sent out to an electronic mail list of geomorphologists about the research, many different responses were received. A former farmer and geologist stated that he has seen first hand the increased flow due at least in part to ditching (William S. Hecht, personal communication). A professor of geography from the University of South Carolina said that he thought that drainage ditches have likely decreased channel capacity downstream (Allan James, personal communication). A geologist at the USGS in Minnesota thought that both erosion and deposition must be very different in streams since before settlement (Jim Almendinger, personal communication). An NRCS geologist thought that perhaps drained wetlands act more as a sponge until soil saturation is reached, perhaps then not always contributing to larger flows from precipitation events (Norm Stephens, personal communication). Part of our study was to interview people who live on the streams we studied in order to see how they felt ditching had affected the streams' flows. The near unanimous response was one of great concern for the streams because of the flow increases they had observed even in the past ten years. In any case, the effects of ditching on natural streams has been controversial.

PREVIOUS WORKS

Minimal previous work has been done in the specific area of ditching. A study involving quantitative geomorphology of ditched stream networks was done at Mankato State University in Mankato, Minnesota. Ainars Silis did a Master's thesis on a quantitative geomorphological study of drainage ditches in southern Minnesota in 1979. He made calculations of drainage area, drainage density, length of overland flow, length of open ditch, length of closed ditch, length of main stream, longest basin length, longest basin width, ditch gradient, ditchshed gradient, texture ratio, and channel maintenance of all ditches within a four county area. He then found the correlation between most of these variables. The conclusions of Silis's study are that the ditched watersheds' functional size has been greatly increased, and that the fluvial landscape has become "geomorphically mature" by the doings of humans. A more widely circulated publication headed by Henry Quade (1980) about the analysis of the extent of drainage ditches, the quantitative and descriptive drainage ditch geomorphology, ditch vegetation, and water quality in ditches and natural streams included Silis's thesis within it. Silis states that no research in the area was done before this study, and we found that little was done after the study also. This lack of research on agricultural ditches is surprising considering the concerns that citizens seem to have about the subject. Silis (1979) states in his thesis that "the public in general is concerned about the impact on water quality and quantity regarding extensive artificial drainage development."

Three other studies were useful to our research. Timothy Beach (1994) did a study on three watersheds in southern Minnesota looking for the existence of post settlement alluvium, which is sediment deposited on the floodplain of streams over an older, well-developed soil. The existence of the buried soil indicates a period of stability or equilibrium, and the layer on top indicates either increased erosion of the land, increased discharge in the stream, or both. Beach found this alluvium in many places and radio-carbon dated organics within it to post-settlement times. He states that the Rush River has deposits of this kind of alluvium on its floodplain. Pierce and Thompson (1981) concluded in a study of comparative water flow in drainage ditches and natural streams that the order of the stream or ditch is what mostly determines flow. This would imply that if agricultural ditches increased the stream basin order, flow would be greater at the downstream reaches of the stream system. Patton and Baker (1976) developed empirical equations for the peak and mean flows of streams based on the stream system's physical characteristics. We could apply these to the changed characteristics of stream systems due to ditching to predict what flow change would be.

STUDY AREA

The three watersheds chosen for analysis were the Rush River, High Island Creek, and Buffalo Creek, all of which are tributaries to the Minnesota River as it flows north from Mankato to Minneapolis/St. Paul. We defined High Island Creek and Buffalo Creek upstream from their intersection before flowing into the Minnesota River. All three watersheds lie mostly within Sibley County, Minnesota. High Island Creek, the northernmost stream system, has an area of 206 square miles. Buffalo Creek, just south of High Island Creek, has an area of 30 square miles. The Rush River, the southernmost stream system of the three, has a watershed area of 383 square miles. These areas were defined using the topography of the region as shown on 1:100,000 scale United States Geological Survey maps, and they were calculated by tracing the defined area on graph paper and then measuring the area. All three of these stream systems are significantly ditched. Figure 1 shows the three watersheds before and after ditching. We had hoped to compare similar watersheds, some that were extended by ditching and some that were still in their natural state, but this was not possible. Any watersheds within the region were ditched. Stream systems that are not ditched usually occur in areas that do not need artificial drainage and may be different

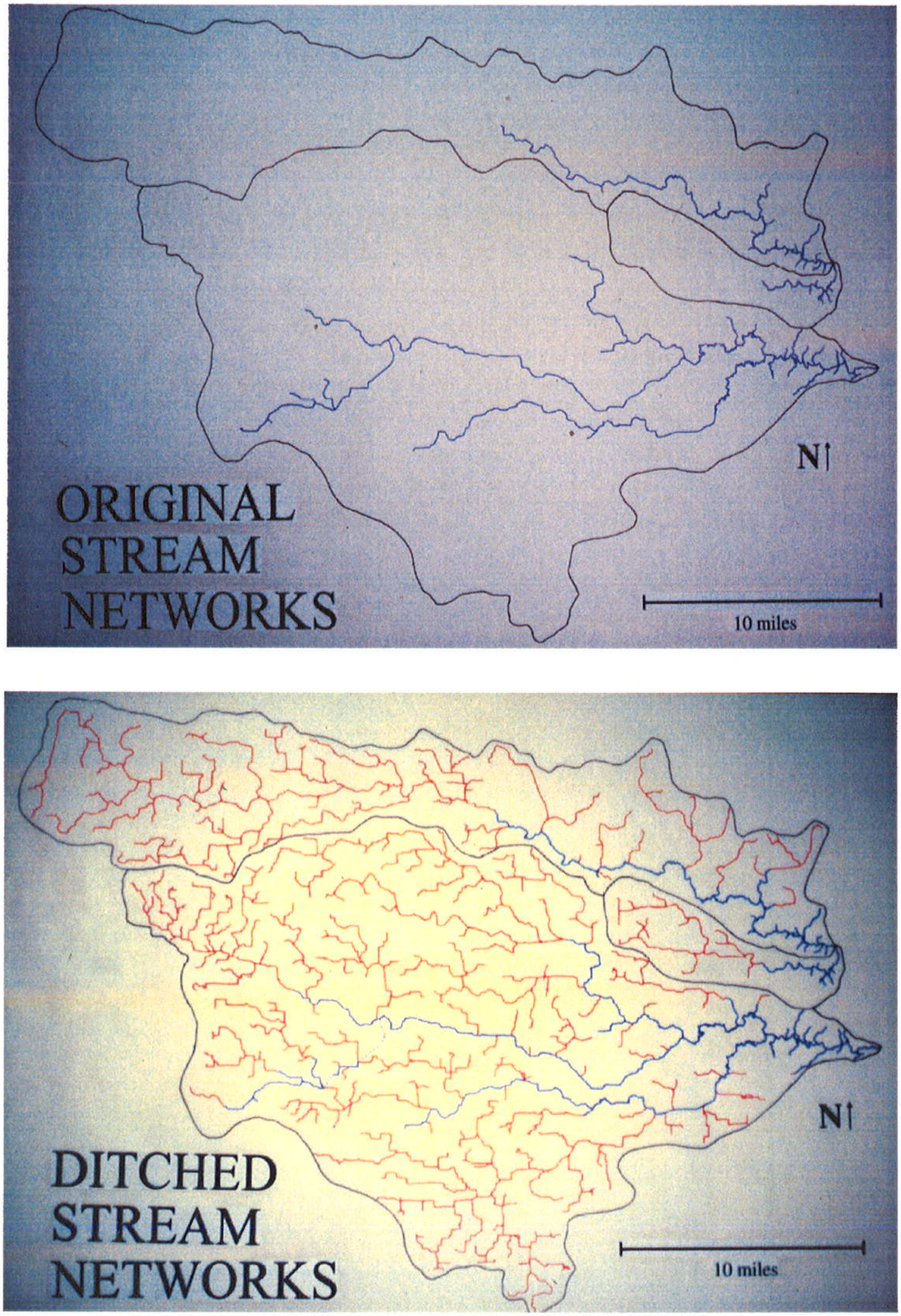


Figure 1. Three watersheds before and after ditching. Blue lines indicate original streams, and red lines indicate ditches. Watersheds outlined in black with High Island Creek, Buffalo Creek, and the Rush River watersheds on map from north to south.

enough in character as to not be comparable. We hoped that in looking at three differently sized watersheds, we could make comparisons.

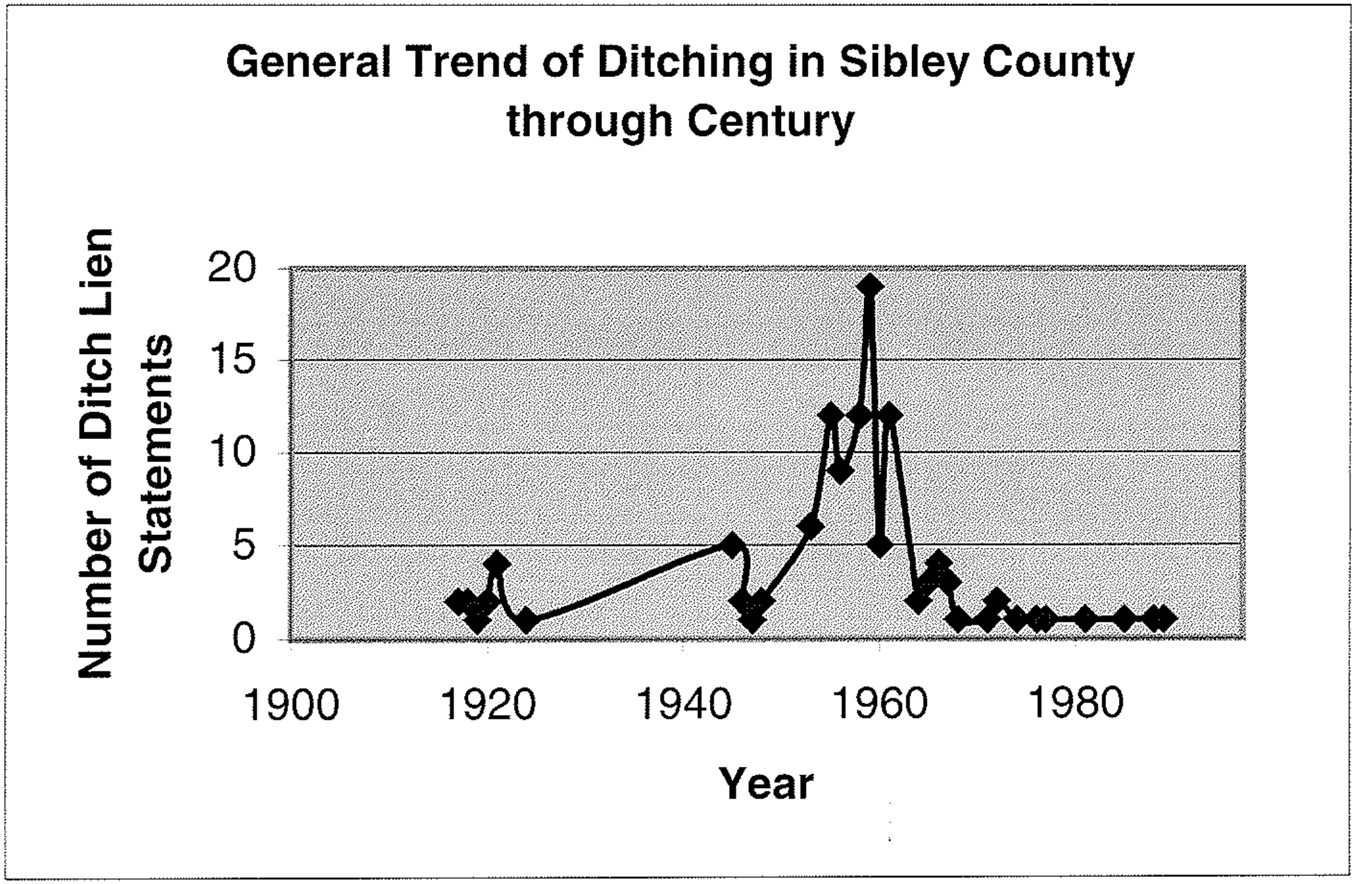
DITCHING HISTORY

Approximate dates of ditch construction were obtained from ditch lien statements held in the Sibley County courthouse in Gaylord, Minnesota. A ditch lien is a form similar to a mortgage that a farmer will sign with the county to have an agricultural ditch dug on their farmland. Figure 2 shows the number of ditch lien statements per year, and thus shows the general trend of ditching in the century. This frequency graph does not take into account the varying lengths of ditches; because of the large number of lien statements, we assume that the lengths average. More detailed files on the history of each individual ditch are also available in the Sibley County courthouse. In these, exact dates of ditch construction could often be found. However, the process of going through these files quickly proved to be too time consuming to be a valuable procedure to obtain the information needed. We found in looking through some of the files that ditch construction usually occurred two to ten years after the signing of the lien statements. It is clear from the lien statements then that the period of greatest ditching was in the 1960's.

RESEARCH APPROACHES

Because of the many variables of hydraulic geometry, we tried several different avenues of study to find changes in any of the variables. The seven approaches we tried are as follows: 1) We looked for records of stream cross-section at the same point in the stream over time. 2) We attempted to look at stream flood hydrographs of storm events over time to view changes in peaks and lag times of the streams after precipitation events. 3) We also tried to look at the ratio of the amount of precipitation to the amount of runoff through stage records to see if the percentage of

Figure 2. Number of ditch lien statements signed per year in Sibley County.



water from precipitation that was running off through the stream system had increased. 4) We looked for a post settlement alluvium (PSA) in the floodplain. 5) We examined the sinuosity of downstream portions of the streams to find changes in meander magnitude. 6) We studied the changes in the physical character of the streams from the original state to the ditched state by using a Horton analysis (measuring length, slope, and stream order). 7) We then applied a mathematical model to find the theorized increase in flood magnitude due to ditching.

Complications

Poor or incomplete records and other complications made the first four studies impractical. In the first approach, we found that some cross-sectional records exist over time at bridge sites, but there are very few records and none that predate ditching. In the records we examined, however, the width did appear to be increasing. Also, widths of certain parts of streams were recorded in units of links by the first surveyors of the area in their field notes from the 1850's. These widths, however, are likely water widths rather than channel widths. Since the width of water flowing through a stream is quite variable and prone to great changes even within a period of days, this data collected in the field books could not be used for our purposes. For the second and third approaches, we found that only one stream gage existed in the area; it is located on High Island Creek and was installed in the 1970's after the peak of ditching. Stage records were not available over a long enough period of time to make any comparisons.

Two major overlying complications that arose in the study: the existence of tile drainage and the increase of precipitation over the century. Tiling is privately done, and records are not compiled and in many cases may not exist. The dynamics of flow through tiles is not well understood, and its effects on streams may be different under different conditions. For this reason, we can only quantify the ditched stream systems excluding tiles. In this paper, the effects of ditching will be referred to without further reference to tiling. The reader, however, should be aware that any changes we may see within the period of ditching also acknowledges the existence of tile lines. The second major complication, precipitation, increased significantly in the late 1940's and 1950's (National Climatic Data Center, 1998). This happened near to the same time that the majority of ditches were dug. Discharge changes and resulting hydraulic geometry changes which could have been more easily attributed to ditching are very difficult to separate from changes due to precipitation.

Post Settlement Alluvium

Post settlement alluvium (PSA) on the floodplain of a stream is indicative of changes in stream character since the time of settlement by an agricultural society. Sediment load of a stream is a function of the stream's equilibrium (Schumm and others, 1987). A layer of alluvial floodplain sediment (PSA) over a buried topsoil layer that can be dated to the time of European settlement in our study area clearly shows a change in the stream systems since the onset of agriculture. We found lighter layers of sand and silt over a darker, organic layer of sediment in the lower reaches of both High Island Creek and the Rush River. A photo of these sediments that we found on the Rush River floodplain is shown in Figure 3. This is very similar to what Beach (1994) described as PSA in his studies. He also indicated that he found PSA dated to the time of settlement in the Rush River stream system. Though this alluvial sediment does show change in the stream system, it is very hard to separate the variables contributing to it. Land clearing and vegetation changes from farming happened in a very similar time frame as ditching did. The amount of post settlement alluvium caused by increased discharge alone cannot be measured.

Figure 3. Sediments found in Rush River floodplain deposits. At the level of the top of the pick handle is a dark, vegetated layer of sediment. Above this is a lighter layer of fine sand and silt, interpretted to be post settlement alluvium.

Sinuosity

Sinuosity is one of the variables of hydraulic geometry, and thus is integrally related to the equilibrium state of a stream system. Meander geometry is related to the amount of water flowing through the system and the amount and size of sediment available for transport (Schumm, 1968). A visible change in the sinuosity of a stream throughout this century may point to discharge changes. We examined seven sets of air photographs that were taken throughout the century by the Farmer's Service Agency of Sibley County. The photos dated from 1934, 1950, 1957, 1964, 1971, 1980, and 1990/1991, thus straddling the main surge of ditching. All the photos were of the same scale, so we followed this procedure: We selected a specific downstream reach of the stream and traced the shape of that portion from each of the seven years of photos. An area covering two township sections were traced for both Buffalo and High Island Creek, and an area covering six sections was traced for the Rush River and broken into three two-section parts. Figure 4 shows an example of one of those tracings with the river in pencil. We then drew in a line axial to the valley, shown in Figure 4 in red ink, and transferred it to each of the tracings from every year. We used a planimeter at the Nicollet County Farmer's Service Agency to measure the penciled length of the stream and the inked valley length. Then we calculated sinuosity, P, by dividing stream length by valley length for every year of photos. Graphs of sinuosity versus time for all three streams are shown in Figure 5. We found that although there were distinct sinuosity changes in every measured reach, those changes did not follow an overall trend for all streams. If there had been a significant trend, it would have been difficult to attribute the changes to ditching since precipitation has increased over the century and meander rate changes are difficult to quantify according to discharge. A change in sinuosity after the mid-1960's, however, may be more indicative of discharge changes due to ditching rather than precipitation because precipitation increased mostly in the early 1950's and remained high over the years following. The stream systems may have

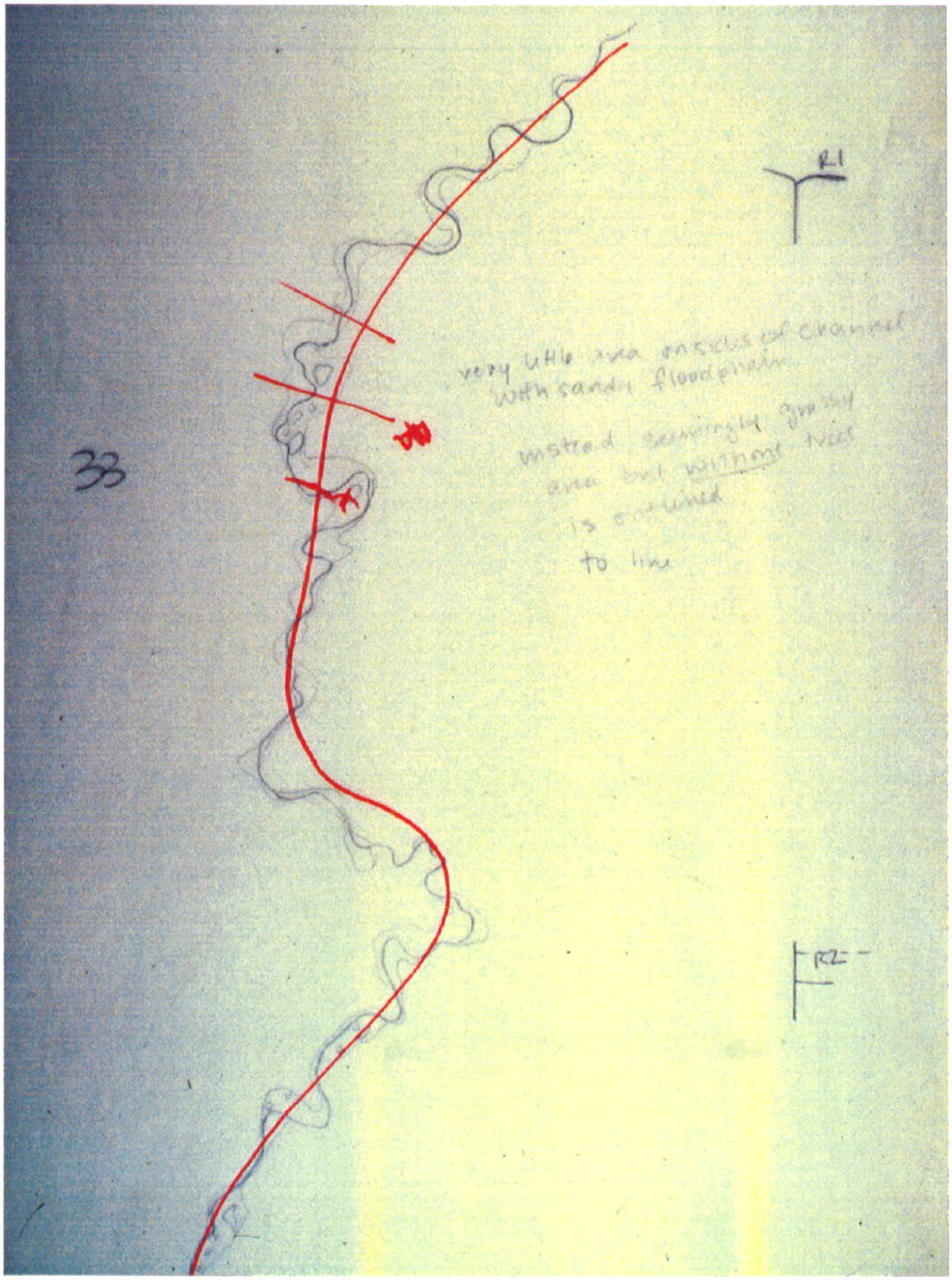
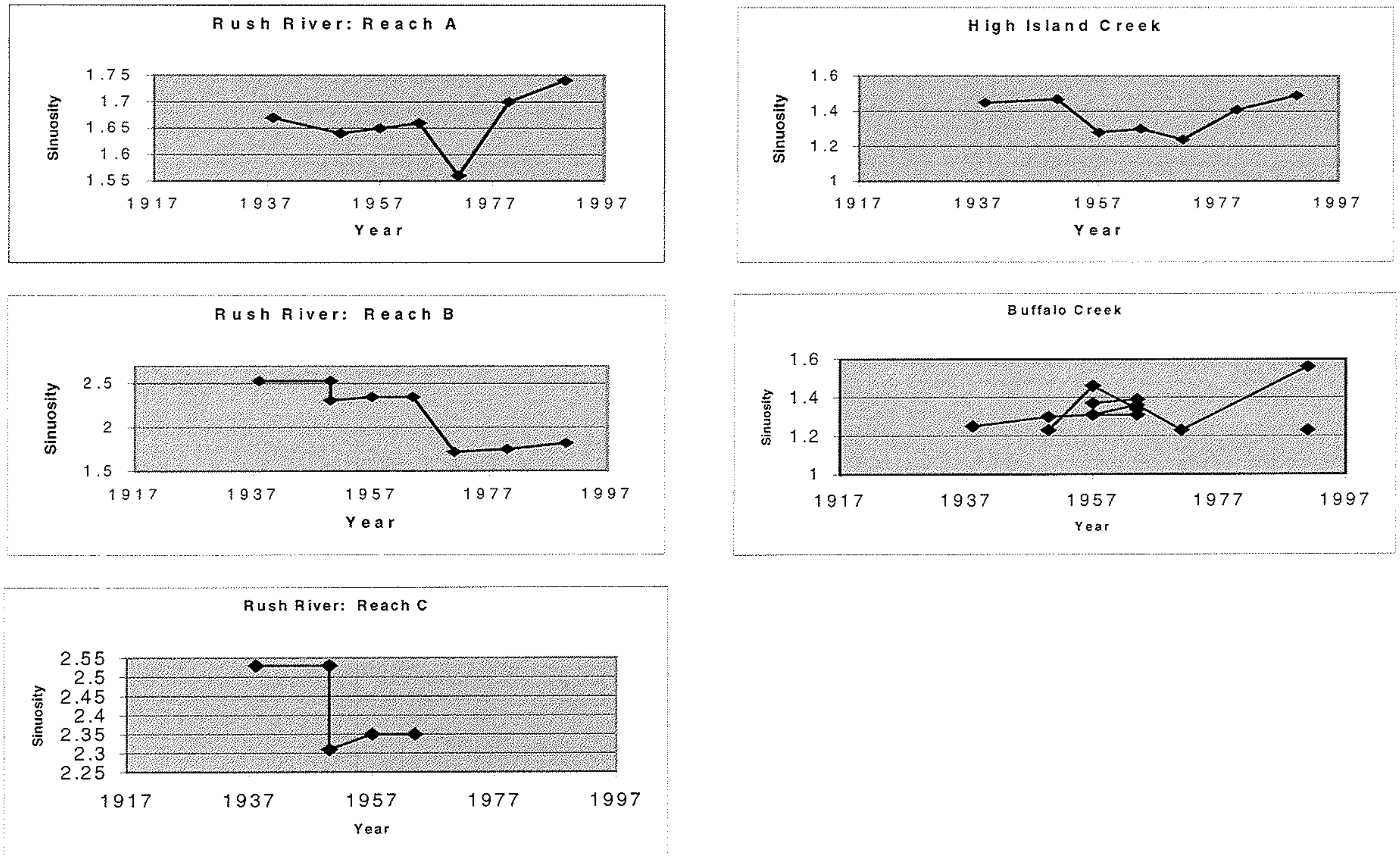


Figure 4. Method of measuring sinuosity from aerial photos. Stream traced in pencil and valley trend in red.

Figure 5. Graphs of sinuosity over time for all watersheds.



reached an equilibrium state with the amount of precipitation by the time the majority of ditching occurred.

One thing to notice in Figure 5 is that the sinuosity of each measured reach decreases from 1964 to 1971. An important observation is that this decrease in sinuosity follows not only the peak of ditch construction, but it also follows the two largest floods on record in the lower Minnesota River basin at the time of the last taken aerial photograph. These floods were in 1965 and 1969. Furthermore, the third and fourth largest floods occurred in 1951 and 1952, yet the sinuosity changed comparatively little following these floods. The question brought to mind then is: Did ditching of the early 60's decrease lag times and increase peak discharges during the 1965 and 1969 floods resulting in a drop in sinuosity? A useful follow-up investigation would be to measure sinuosity on the same reaches on the stream for the next set of aerial photos that are taken. These will likely be taken in the year 2000. Since a very large flood occurred in 1997, perhaps sinuosity changes over this time would give better insight into what ditching is doing.

Horton Analysis

We performed a Horton analysis on the Rush River, High Island Creek, and Buffalo Creek. This involved measuring order, average length, total length, and slope of the individual links of the stream system. We did this by using 21 United States Geological Survey 7.5 minute quadrangles of the three watersheds. We referred to the maps from the original 1854-1855 surveys of Sibley County to determine the course and extent of the rivers prior to ditching. Where tributaries extended beyond the county border, we used the Marschner Maps of Natural Vegetation in Minnesota from 1874 to complete the record. We outlined natural streams in blue, straightened streams in green, and ditches in red, orange, and purple for the three different watersheds to discern one stream system from another. Then we ordered stream links of both original natural stream systems and present ditched systems according to the Strahler method (1957) and counted them. Figure 6 shows the ordering of streams by the Strahler method. We measured a sample of the first and second order streams and all of the greater order streams for average length, total length, and slope. Table 1 lists these values that we calculated for each stream system in natural and ditched states. Figure 7 shows graphs of the Rush River for total length vs. order, number of links vs. order, and slope vs. order. High Island Creek and Buffalo Creek showed very similar trends.

All three stream systems were naturally third order basins prior to ditching. Buffalo Creek remained a third order basin after ditching, High Island Creek became a fourth order basin, and the Rush River became a sixth order basin. The change in average length of ordered streams was variable between natural and ditched systems, showing no trend. The total length of each stream increased significantly; Buffalo Creek total length increased 325%, High Island Creek increased 374%, and the Rush River increased 345%. The number of first, second, and third order streams increased greatly, often by an order of magnitude. The slope of the first, second, and sometimes third order streams decreased greatly with ditching, often one and sometimes two orders of magnitude less than natural streams. While the increase in order and length of the stream systems would point to much greater flows in the streams due to ditching, the very low slope of the ditches themselves indicates that they do not have a potential energy gradient large enough to push water through nearly as fast as a natural stream.

The great overall change in the drainage network indicated by this Horton analysis implies that discharge responses would no doubt be somehow altered by agricultural ditching. Pierce and Thompson (1981) in their survey of flow in streams and ditches in southern Minnesota found that the order of any stream is more important in predicting the flow than is its classification as a natural stream or a ditch. According to these observations, it seems that the flow of both the Rush River

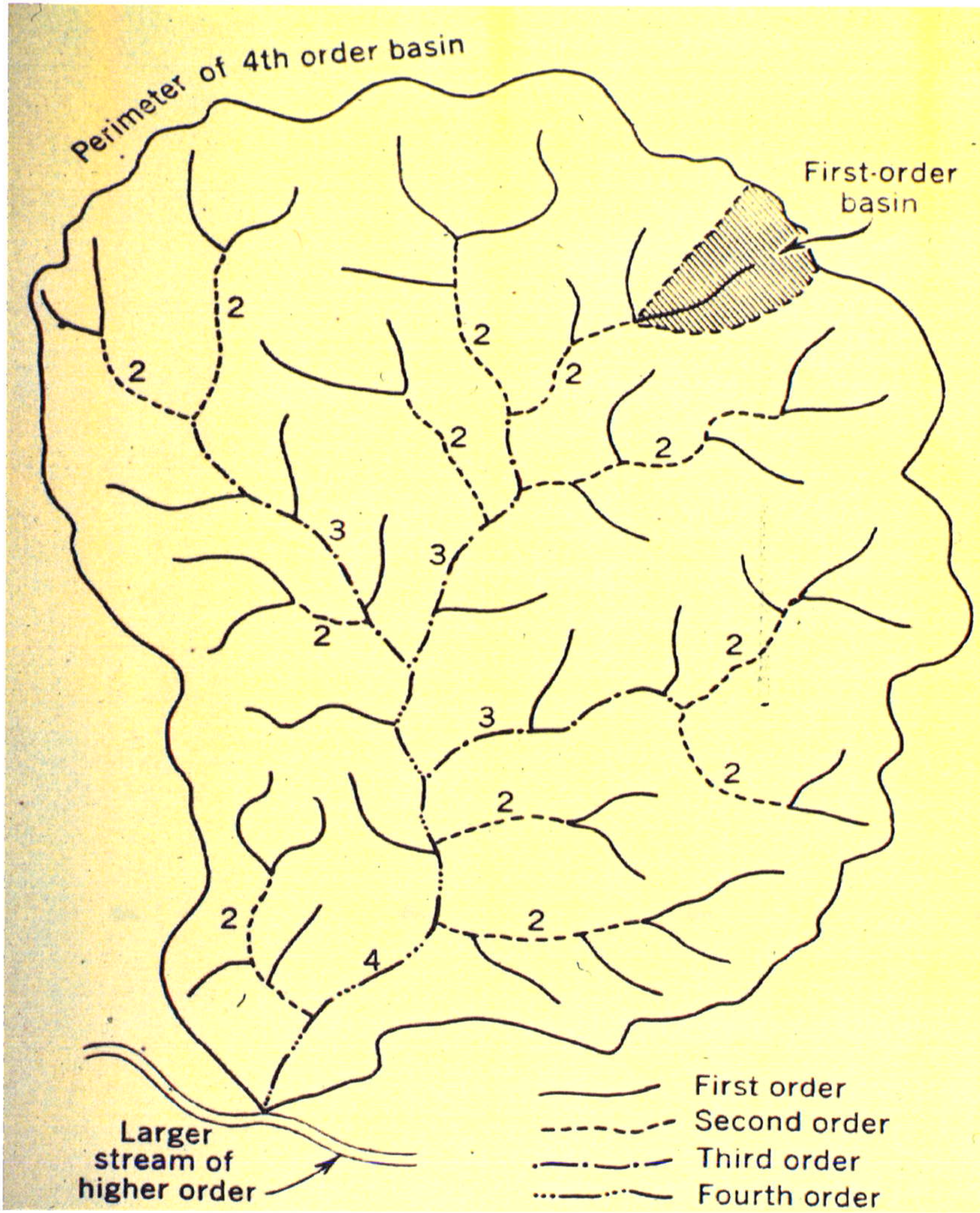


Figure 6. Strahler method of stream ordering.

Table 1. Measured Horton analysis values for all three streams.

Buffalo Creek

Natural:

order	number of links	total length	average length	average slope
1	5	12.73	0.75	<35.93
2	2	11.47	2.87	<58.6
3	1	10.2	10.2	21.6

Ditched:

order	number of links	total length	avergae length	average slope
1	18	3.94	0.79	97.7
2	4	2.4	1.2	116.6
3	1	1.71	1.71	40.9

High Island Creek

Natural:

order	number of links	total length	average length	average slope
1	19	15.83	0.83	122.6
2	2	26.92	13.46	71.1
3	1	2.64	2.64	22.8

Ditched:

order	number of links	total length	average length	average slope
1	89	100.13	1.13	<35.82
2	20	53.24	2.66	<8.97
3	4	11.97	2.99	<13.09
4	1	49.84	49.84	7.42

Rush River

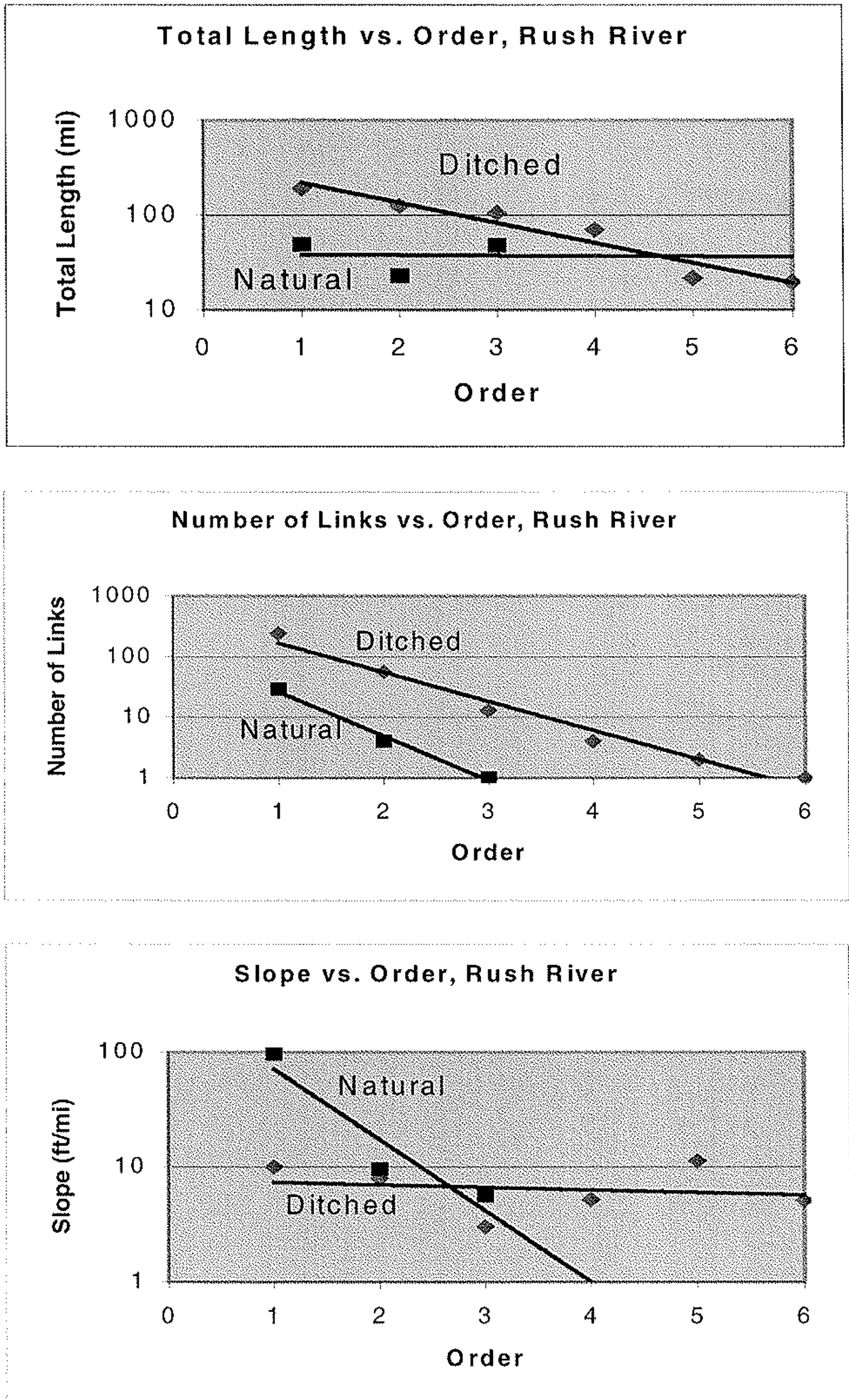
Natural:

order	number of links	total length	average length	average slope
1	29	49.01	1.69	84.56
2	4	23.03	5.75	9.58
3	1	48.4	48.4	5.78

Ditched:

order	number of links	total length	average length	average slope
1	241	195.21	0.81	<33.40
2	56	124.32	2.22	<34.73
3	13	105.69	8.13	<3.80
4	4	69.2	17.3	5.18
5	2	21.68	10.84	11.15
6	1	19.5	19.5	5.12

Figure 7. Graphs of total length, number of links, and slope vs. order for the Rush River.



and High Island Creek would be greater and flashier than that of the original streams of lower basin order.

Applied Mathematical Model

Using the measurement of watershed area for each of the three streams along with the Horton analysis measurements, certain stream parameters, both in natural and in ditched states, could be calculated and applied to empirical equations. Patton and Baker (1976) derived equations from studies of streams in Indiana to predict discharge based on physical characteristics of the streams. Because the landscape and land usage in Indiana is so similar to that of Minnesota, we felt we could apply these equations to our study area. Table 2 shows the calculated stream parameters for all three stream systems in both natural and ditched states and the percent increase due to ditching. These stream parameter values could then be plugged into the following empirical equations to estimate annual maximum peak flow (Q_{max}) and mean annual flood ($Q_{0.5}$) for the stream systems:

$$Q_{max}=424M^{0.46}(R)^{0.73}F_s^{0.21}$$

$$Q_{max}=424M^{0.82}(R_h)^{0.67}D^{0.56}$$

$$Q_{0.5}=115M^{0.53}R^{0.62}$$

We determined from this numerical analysis that both expected annual maximum peak flow and mean annual flood should increase between 6 and 13 times in magnitude from the changes imparted on the systems by ditching. The larger the watershed, the greater the expected increase. Because gaging stations have not existed through the century on these streams, no quantitative evidence exists for true increase in discharge. However, through observation of the streams by those living nearby show that flow has increased, the more qualitative measurement would likely

Table 2. Calculated stream parameters applied to empirical equation

Calculated Stream Parameters									
	Rush River			**High Island Creek**			**Buffalo Creek**		
Parameters	**natural**	**ditched**	**% inc.**	**natural**	**ditched**	**% inc.**	**natural**	**ditched**	**% inc.**
A	383.2	383.2	---------	205.5	205.5	---------	30.4	30.4	---------
D	0.31	1.40	350%	0.22	1.05	377%	0.27	1.10	307%
F_s	0.09	0.83	822%	0.11	0.55	400%	0.26	0.76	192%
R_h	0.0019	0.0019	---------	0.0018	0.0018	---------	0.0045	0.0045	---------
R	111.6	504.0	352%	81.4	388.5	377%	72.9	297.0	307%
M	29	241	731%	19	89	368%	5	18	260%

- **A, Area (mi^2):** area of the watershed
- **D, Drainage density:** measure of total stream length (all ordered links included) divided by watershed area
- **F_s, Stream frequency:** number of all stream links divided by watershed area
- **R_h, Relief ratio:** difference between the highest and lowest points in the watershed divided by the straight distance between them
- **R, Ruggedness number:** drainage density multiplied by the watershed relief
- **M, Shreve magnitude:** number of first order streams in the system

not be so big as the theoretical equations have predicted. These equations do not directly account for the slope of the stream itself; rather it only accounts for overall watershed gradient. Either these equations, developed in streams from a different area, cannot be applied to our streams of study, or the ditches are not acting as natural streams do.

CONCLUSIONS

The three stream systems we examined in southern Minnesota are greatly changed by ditching. The total length of streams increased between 300 and 400%, the overall slope decreased greatly, and the order of two streams increased. Increased magnitude of flooding due to physical changes imparted on streams by ditching was predicted by mathematical models to be 6 to 13 times the predicted flow for the same natural streams. One may very quickly assume from looking at a map and these figures that there would undoubtedly be increased flooding due to ditching. The nature of ditches, however, appears to be much different from natural streams. This is evident in the much lower slope, standing water in ditches, bed sediment being composed completely of silt, and the lack of meandering in the oldest ditches. Figures 8 and 9 show two views of a natural stream segment and a ditch from the same stream system. One can see that ditches and streams are very different. Ditching has most definitely affected the natural streams onto which they were built. Just how and to what degree they affect natural streams is not so easy to tell however. More studies need to be done in the area to more accurately ascertain the impacts of such a system.

SUGGESTIONS FOR FURTHER RESEARCH

Our research focused on quantifying the changing variables of hydraulic geometry that may be due to ditching. These changed variables are indicators of changing discharge. To really know quantitatively how discharge has changed requires measuring discharge directly. Ditches are still being dug, though at a slower rate. A possible field experiment would be to set up a gaging station at the downstream end of a newly dug ditch. Monitoring peak flow and lag time versus precipitation would give much more direct insight into just how ditches move water through stream systems. Another very valuable project would be to work on tile drainage. The dynamics of flow through tile lines is not well understood at all. An extensive field study monitoring tile flow hydrographs in relation to precipitation (both rain and snow) and ground temperature would create a much clearer picture of how tile drainage is contributing to flow.

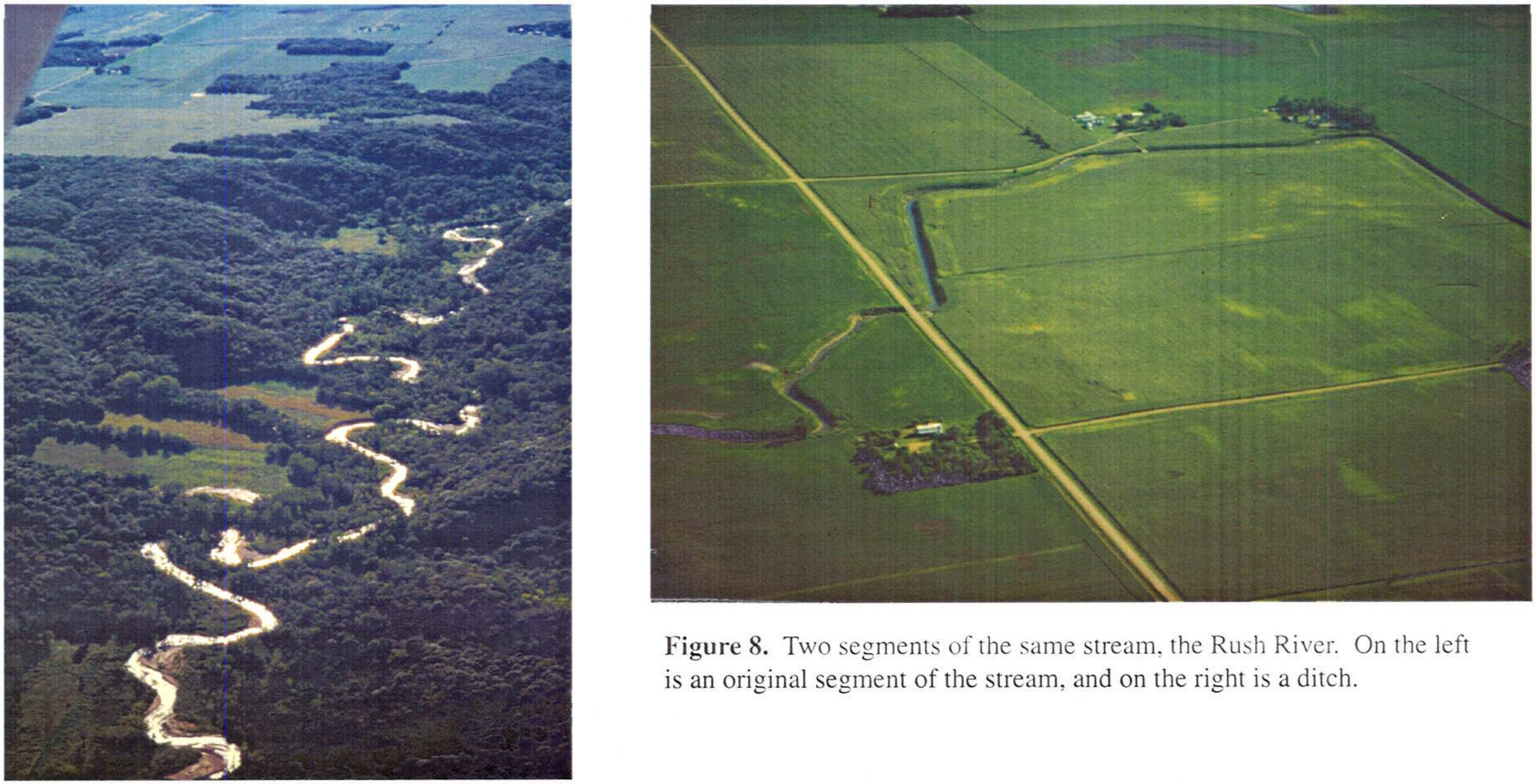


Figure 8. Two segments of the same stream, the Rush River. On the left is an original segment of the stream, and on the right is a ditch.

Figure 9. Original (above) and ditched segments (below) of the Rush River. Notice the tile line in the foreground of the bottom photo.

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