Sediment Mobilization in Ravines Draining Minnesota Cropland

By:

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Abstract

In recent years, studies have found that Lake Pepin, a naturally-dammed lake on the Mississippi River on the border of Minnesota and Wisconsin, is filling in with sediment at an alarming rate. Most of this sediment comes from the Minnesota River, which contributes about 80% of all the sediment being deposited in Lake Pepin, even though it contains only 35% of the upstream area. This study focuses on understanding sediment derived from ravine erosion in a tributary of the Minnesota River basin through event monitoring of two ravines in the Le Sueur River watershed. Ravines represent one of the key sediment sources in the Le Sueur watershed, with sediment mobilized through ravine widening and headcutting. In addition, sediment may be mobilized through riverbank and bluff erosion and erosion of the topsoil. A major effort is underway to reduce the amount of sediment in the Minnesota River and Lake Pepin, so we must discover what is causing the sediment to be mobilized and when. Dominant land use in the area is agricultural with over 90% of the crops consisting of row crops. Field drainage in these agricultural areas is heavily influenced by the installation of drainage ditches and drain tile. While this has increased crop yield, it has altered the natural drainage of the area. Southern Minnesota is covered by a thick layer of glacial till allowing the landscape to rapidly respond to hydrologic conditions within a relatively short amount of time, and those changes could include ravine widening or elongation. To better understand how ravines respond to different hydrologic events, we monitored ravines over the course of one monitoring season. From April-October 2013, three Sigma 930 automated samplers measured discharge and collected water samples for total suspended sediment analysis at three sites in two ravines. Sediment concentration was found to increase on the rising limb of a discharge event and decrease steeply on the falling limb. Time since the peak discharge did not have a significant effect on sediment concentration. Ravine discharge was found to be the dominant control on sediment mobilization.

Acknowledgements

I would like to thanks Professor Laura Triplett for advising me throughout the research process, without her help and occasional prodding would not have had the satisfaction of finishing this endeavor. I would also like to thank the Gustavus Geology Department as a whole. Thank you for the advising, help, and patience throughout this process, I could not have done it without you. Thank you to Dr. Karen Gran and Martin Bevis for allowing to work on their project and make part of it my own. Lastly, I would like to thank Gustavus Adolphus College for the use of equipment and lab space. This project was funded by the Minnesota Agricultural Water Resource Center through a grant to the University of Minnesota, Duluth

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Introduction:

The Le Sueur River watershed in south-central Minnesota is at the head of the Blue Earth and Le Sueur Rivers. Both of these rivers flow into the Minnesota River, and eventually flow into the Mississippi River. Sedimentation rates in Lake Pepin, a naturally dammed lake on the Mississippi River on the border of Minnesota and Wisconsin, have increased over time. In some areas of the Mississippi River the turbid water is classified as "impaired" according to Clean Water Act (MCPA, 2005). This increased sediment load lowers downstream surface water quality, degrades aquatic habitat, and decreases recreational value (Schottler, 2013)

To find the source of the sediment, researchers have been monitoring tributaries, stream banks, and bluffs. Wilcox et al. 2009 found that the Minnesota River has been the dominant supplier of sediment to Lake Pepin for the last 150 years. These researchers also found that the Le Sueur and Blue Earth subwatersheds contribute the most sediment to the Minnesota River (Wilcock et al., 2009) The Le Sueur subwatershed is a major contributor to Lake Pepin accounting for 24%-30% of the sediment being transported to that body of water (Engstrom et al., 2000). To preserve the health of these water bodies, it is imperative that we discover the origin and quantity of this sediment and when it is being mobilized.

The sediment flux from the Le Sueur watershed has been studied by many researchers to determine the causes of the high volumes of exported sediment. Engstrom et al. (2000) analyzed lake sediment cores from Lake Pepin and found that sedimentation rates drastically increased by 10 fold during the 1800s. They hypothesized that the greater amount of flux must have been a result of logging and tilling of the prairie for farmland. Gran et al. 2009 studied the effects of geomorphology on sediment load in the Le Sueur River (Gran et al., 2009). The researchers attempted to quantify the sediment load using LiDAR data and stream samplers. This LiDAR data was used to remotely assess the amount of sediment eroded from stream banks and ravines. Stream samplers were used to collect water samples in order to calculate sediment load. It was concluded that the sediment load is one order of magnitude higher than the pre-settlement era. Additionally, Gran et al. identified bluff slumping, ravine and stream bank erosion, and erosion of upland agricultural areas as potential sources of sediment (Gran et al., 2009).

What has changed in this region to cause an increase in sediment loading after the 1800s? For one, conversion of land for agricultural purposes, which is of extreme importance in this area. The Minnesota Pollution Control Agency determined that about 87% of land along the Le Sueur River is used for agriculture with row crops such as corn and soy beans constituting about 90% of the crops (MPCA, 2007). In an attempt to increase the yield from these fields, famers have installed draintiles and drainage ditches to speed the drainage from the fields.

The installation of dense drainage networks and modification of the natural drainage in the area has possibly altered sedimentation rates and mobilization. While there has been an effort to quantify the amount of sediment and its origin, there has been little research pertaining to sediment mobilization in this system. It is this study's focus to analyze several ravines in the Le Sueur River watershed to identify what hydrologic factors affect the mobilization of sediment.

Geologic Setting

The Le Sueur River watershed is located in Southern Minnesota. The bedrock consists of Cambrian quartz arenite sandstone overlain by Ordovician dolostone and topped by Quaternary glacial till and glacial lake sediments. The till and lake sediments were deposited by the retreat of the Laurentide ice sheet after the last ice age, about 10,000 years ago (Patterson, 1997). During the rapid draining of glacial Lake Agassiz, the outlet river glacial River Warren, carved the current Minnesota River Valley. As Warren's water level decreased, the base level for the Le Sueur River and all its ravines also dropped. The base level drop coupled with the unconsolidated till and lake sediments have caused incision throughout the watershed (Gran et al., 2009).

Incision through this till has created ravine landforms throughout the watershed. As ravines naturally develop, they can rapidly deepen and widen. Additionally, this unconsolidated sediment allows the landscape to rapidly respond to hydrologic conditions within a relatively short time as water and sediment are deposited in the Le Sueur River. Due to varying, field conditions, irrigation, precipitation these ravines are subject to variable flow throughout the year.

This study was focused on two ravines in the Le Sueur River basin. While surrounded by farmland, the ravines are vegetated by deciduous trees with some understory growth. These ravines were monitored at three sites (two sites in one ravine). The total area monitored by these three samplers was 2,064.48 acres. Site 1 was located off of County Road 8 near the mouth of the ravine. Site 2 was located near the head of another ravine off of West Terrace

View. Site 3 was located farther down the same ravine as site 2 close to the Le Sueur River along 190th Lane.

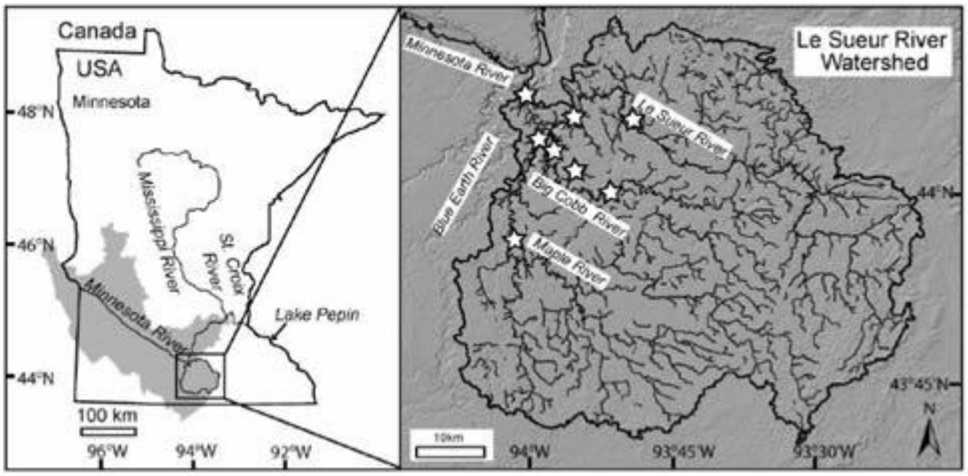

Figure 1) Gran et al., 2009

<u>Methods</u>

Three automated sigma 930 samplers were placed into two ravines at three different sites. Over the 2013 hydrologic season, these samplers collected water samples during hydrologic rises (precipitation events). These samples were filtered through .03 micron glass fiber filters to obtain sediment and organic material. These filters were then dried for eight hours and massed to obtain the mass of sediment and organic matter in the sample. Next, these samples were placed in a furnace at 550 Celsius for four hours to burn off organic matter. The filters were then massed to find the total suspended sediment.

The samplers also collected water height throughout the season using pressure transducers that were anchored on the stream bed. Discharge was then calculated using rating curves provided by Dr. Karen Gran (UMD).

To identify the greatest control on sediment mobilization, variables were subjected to bivariate correlation tests. A Pearson Correlation value was calculated to determine the significance and kind of relationship. Three tests for each ravine were performed using different variables to determine their significance to sediment mobilization.

Results

Ravine 1 sediment concentrations were negligible (below detection) for most of samples collected. During large flow events however, concentrations increased, then decreased rapidly (Figure 2) Average discharge for Ravine 1 was 1.79 cfs. This includes discharge rates during which parts of the ravine may have been frozen. The average sediment concentration sampled during a set high condition was 375 mg/L. The highest discharge (18.3 cfs) was found on June 22 but was not coupled with the greatest concentration (7396 mg/L) found on June 23 (Figure 3).

Sediment concentration in upper Ravine 2 followed a similar pattern of rapid increase during large flow events, with a sharper decrease of sediment concentrations than were observed in Ravine 1 (Figure 4). The average discharge for the 2013 hydrologic season was 0.87 cfs. This average discharge includes discharge from when parts of the ravine may have been frozen. The average sediment concentration sampled above the high point was 93.7 mg/L. The greatest discharge in Upper Ravine 2 was 13.1 cfs on June 23 and the greatest sediment concentration was 823 mg/L on June 23. While these peaks were met on the same day and in the same event, peak concentration was reached just less than an hour before peak discharge (Figure 5).

The bivariate correlation tests found that the dominant control on sediment concentration is discharge. In Ravine 1, there was a moderate positive correlation (r= 0.365, p= 0.01, n=107). In Upper Ravine 2, there was a very strong positive correlation (r= 0.842, p= 0.01, n= 39). These positive correlations indicate that as discharge increases, sediment concentration also increases. These tests are found in figure 6 and figure 7.

The correlations between sediment concentration and the time since the peak flow, both within the last 24hrs and 48hrs, were not as strongly correlated as discharge. The Pearson correlation values between sediment concentration and time since peak, within 24hrs and 48 hrs. in Ravine 1, were -0.239 and 0.189 respectively. The time since peak (24hrs.) is a weak negative correlation (r=-.239, P=0.05, n=107). As time from the peak increases, sediment concentration decreases. There was no or negligible correlation between time since peak within 24 hrs. and sediment concentration. In Upper Ravine 2, the Pearson correlation values between sediment concentration and time since peak, within 24hrs and 48 were r=0.086 and r=-0.066 respectively. Neither value suggests correlation or significance (Manganella)

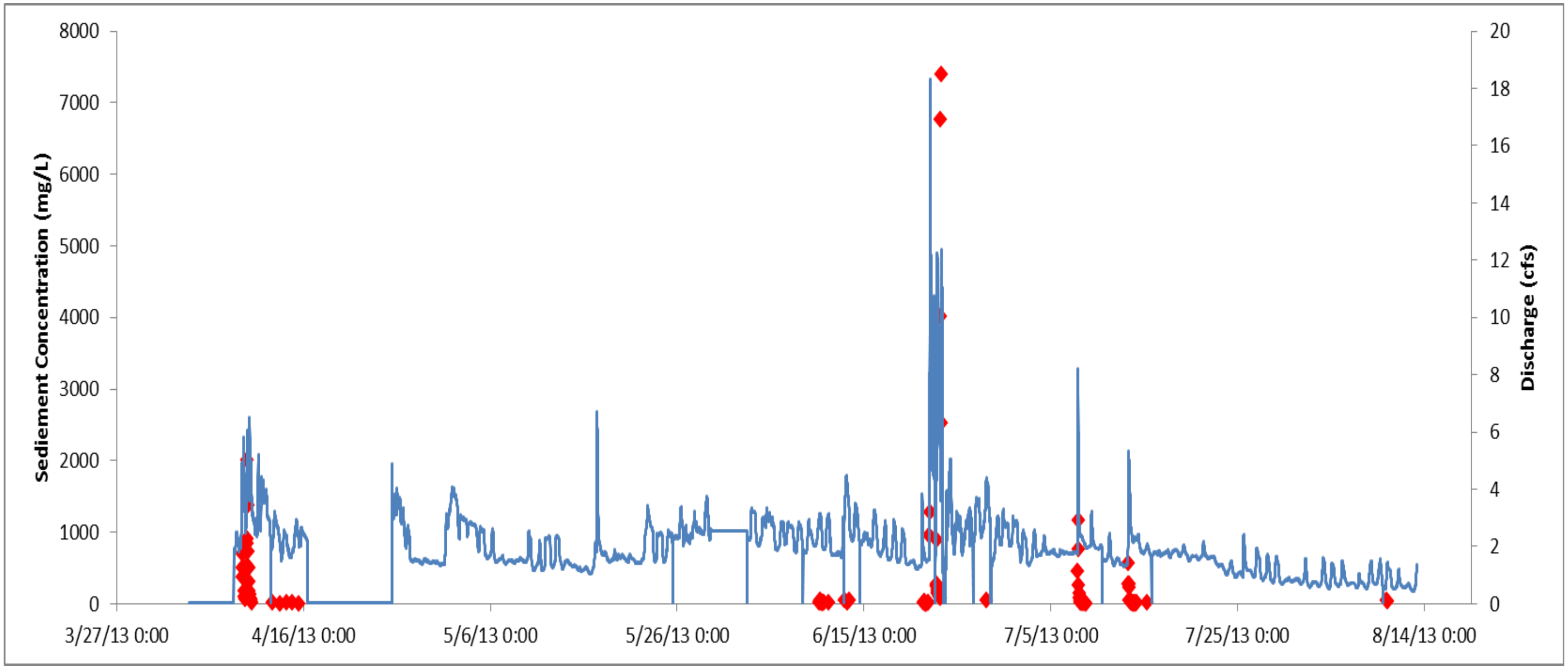

Figure 2). Ravine 1. Sediment concentrations (red points) were plotted with discharge (blue line) for the 2013 hydrologic season. It is important to note the steep increases and decreases in discharge and the frequent variability of discharge within the Ravine 1.

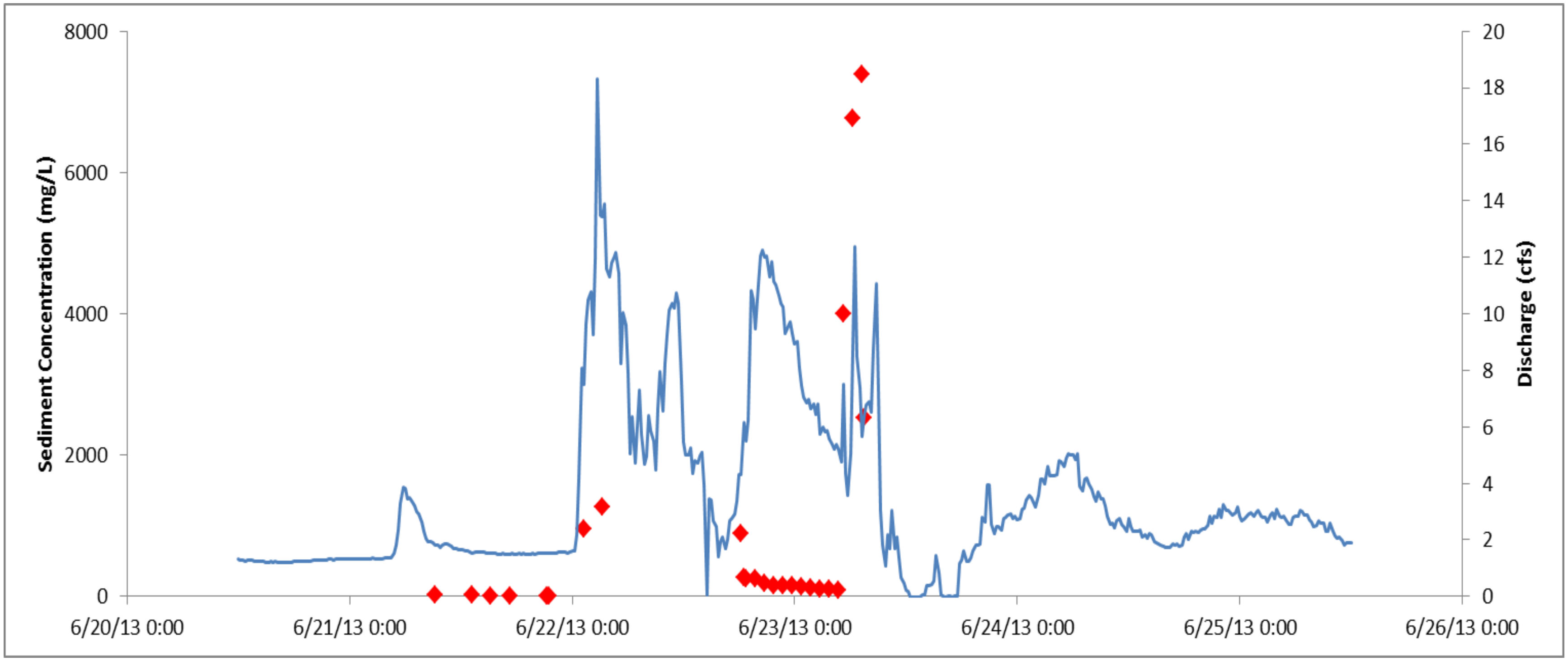

Figure 3). Ravine 1. . Sediment concentrations (red points) were plotted with discharge (blue line). This enlarged portion of the hydrologic season includes the greatest discharge (18.3 cfs) and sediment concentrations (7396 mg/L).

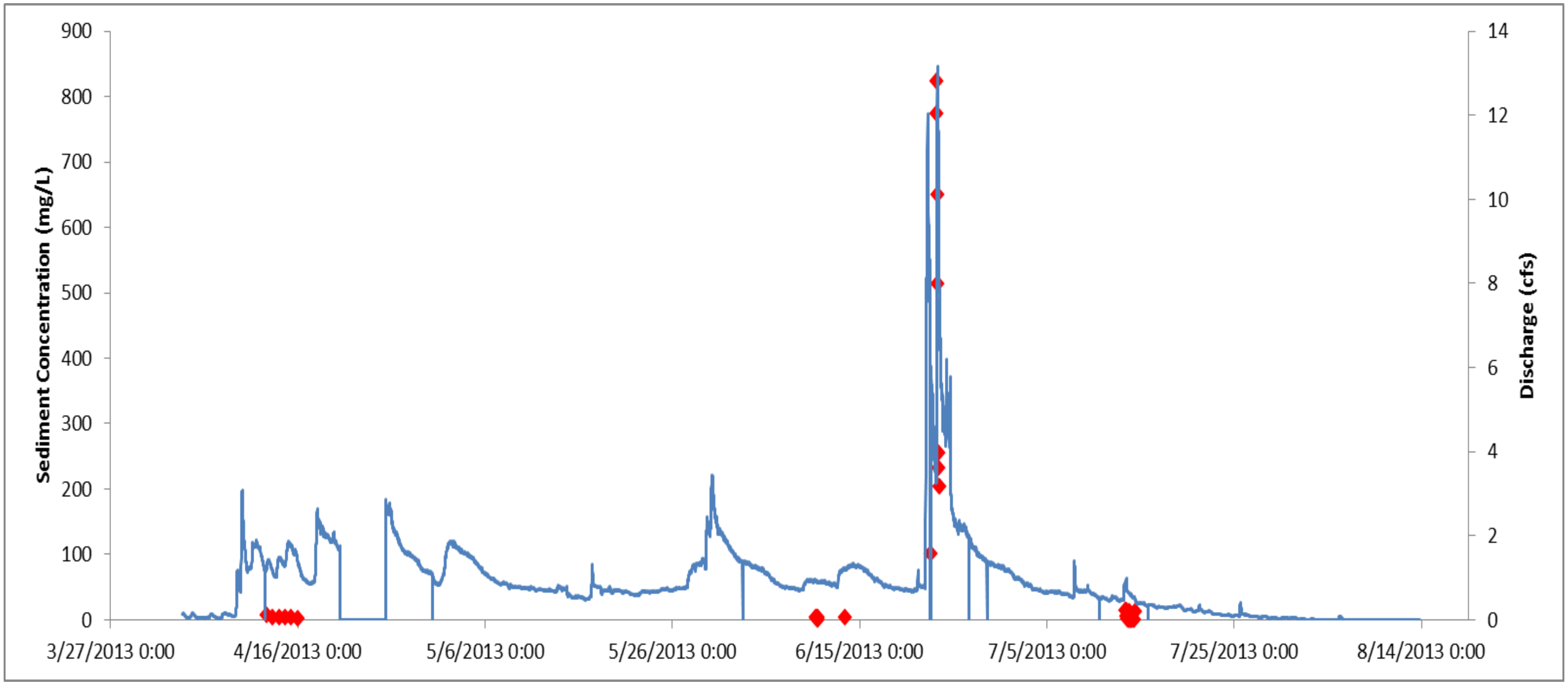

Figure 4. Upper Ravine 2. Sediment concentrations (red points) were plotted with discharge (blue line) for the 2013 hydrologic season. It is important to note that there is only one large discharge event. While the increases in discharge are sharp similar to Ravine 1, the falling limb is gentler.

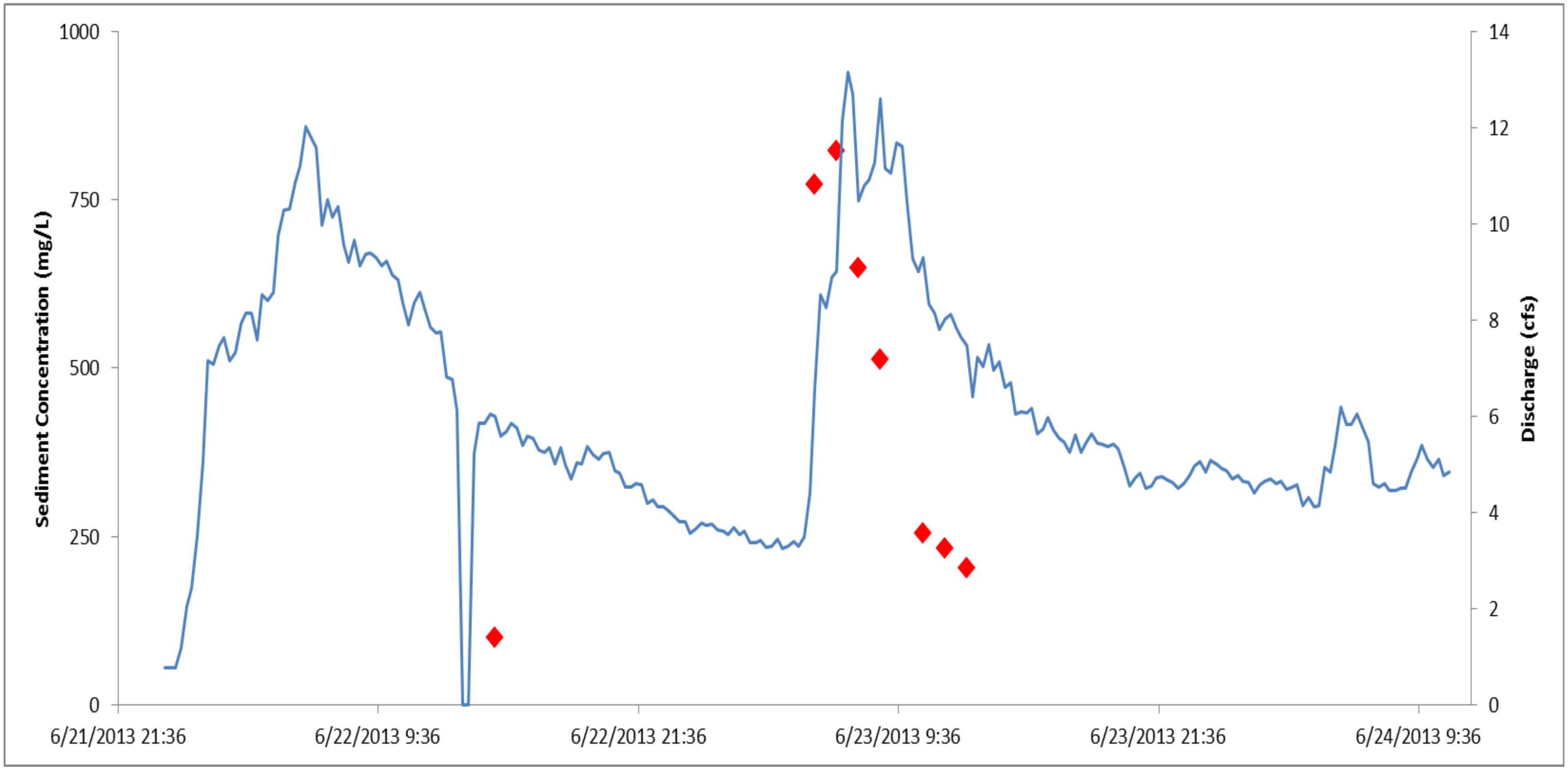

Figure 5). Upper Ravine 2. Sediment concentrations (red points) were plotted with discharge (blue line). This enlarged portion of the hydrologic season includes the greatest discharge (13.1 cfs) and the greatest sediment concentration (823 mg/L).

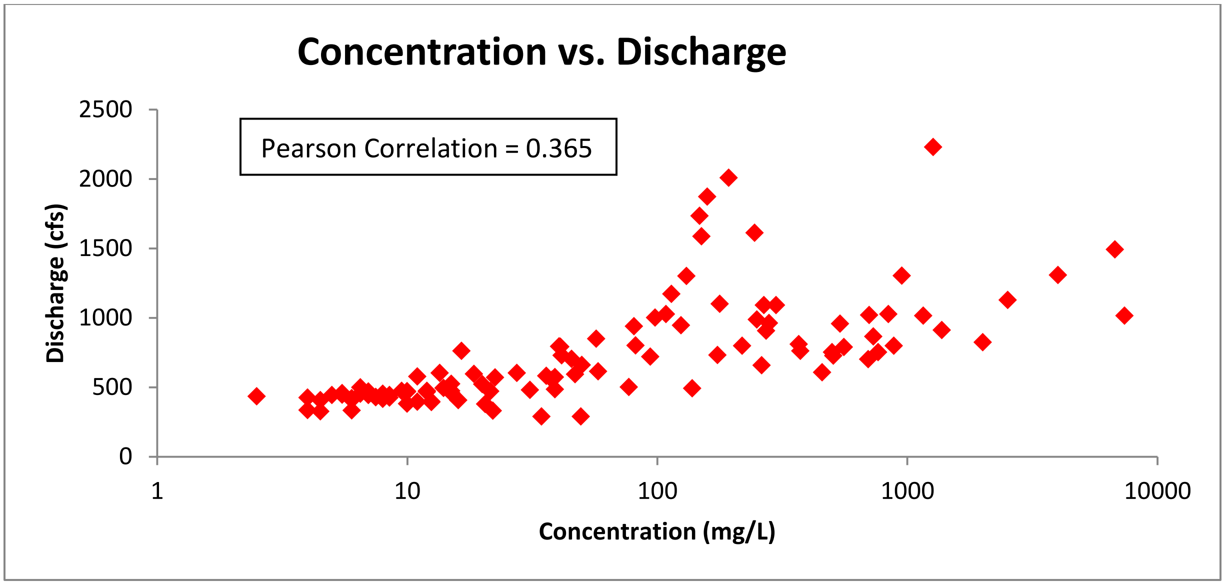

Figure 6) Ravine 1. Concentration is plotted versus discharge. The horizontal axis is displayed in the log scale. The Pearson Correlation is a moderate positive correlation on the 0.01 level. (r=0.365, P=0.01, N=107) As the discharge increases, the concentration also increases.

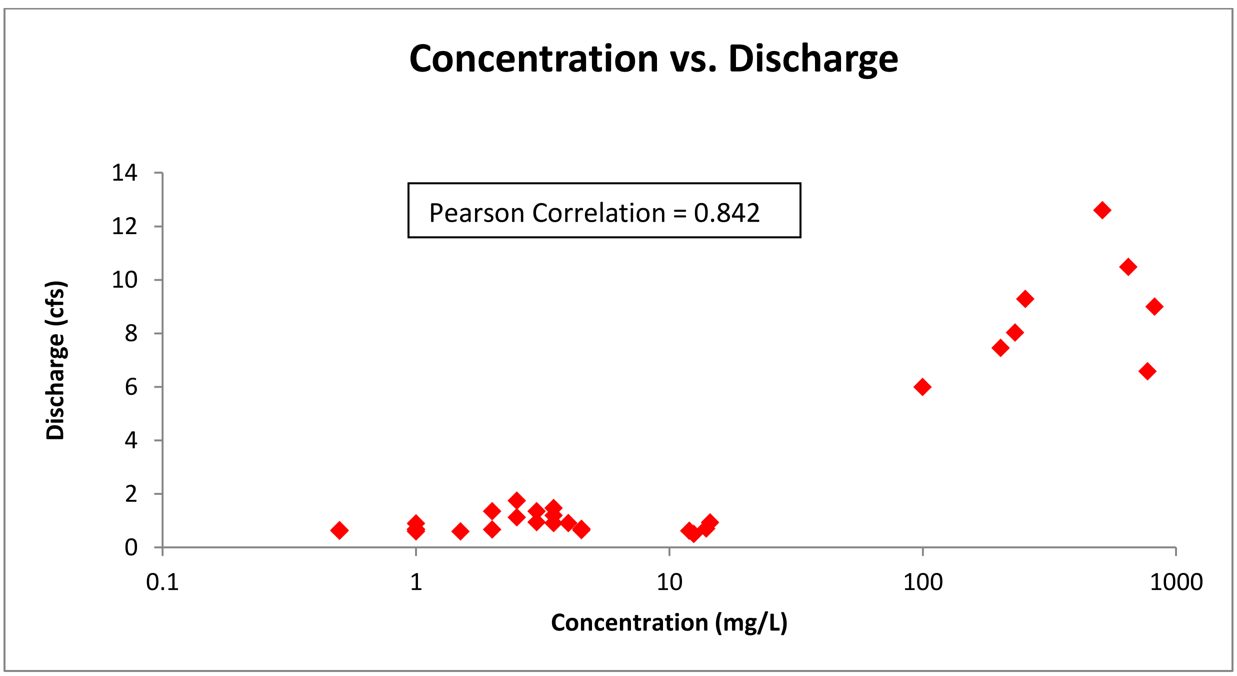

Figure 7) Upper Ravine 2. Concentration is plotted versus discharge. The horizontal axis is displayed in the log scale. The Pearson Correlation is a very strong positive correlation on the 0.01 level. (r=0.842, P=0.01, N=39)This positive relationship indicates that as discharge increases, the sediment concentration also increases.

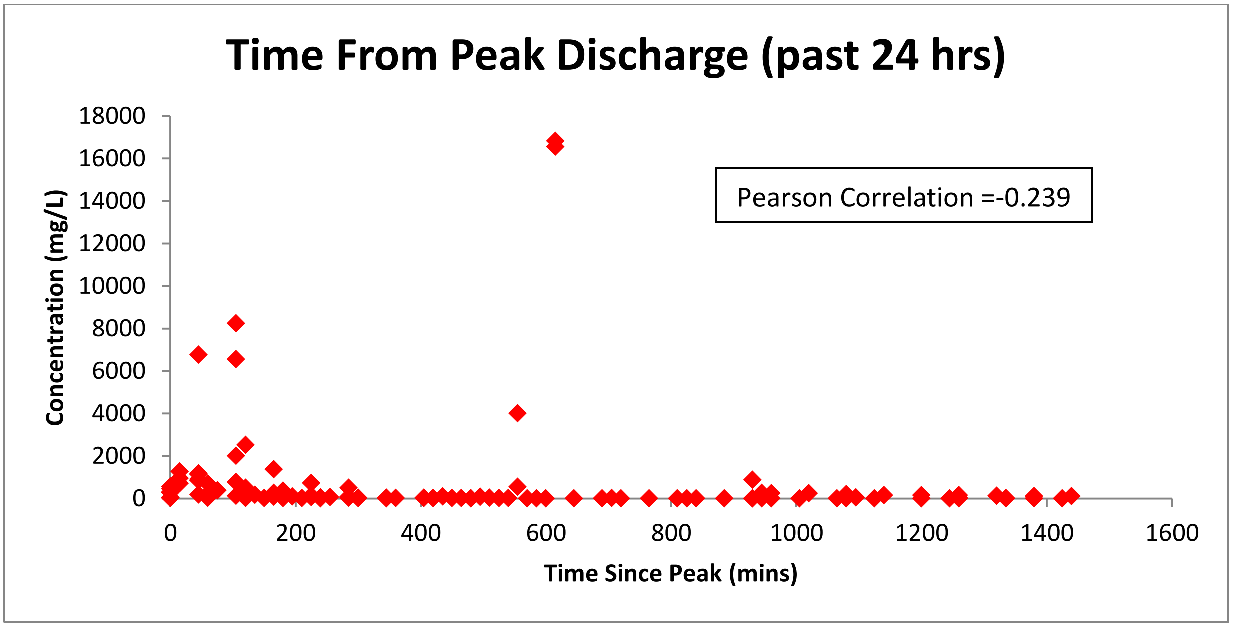

Figure 8) Ravine 1. Concentration is plotted versus time since the peak within the last 24 hrs. This is a weak negative correlation on the 0.05 level. (r=-0.239, P=0.05, N=107). The weak correlation indicates that time since peak has some influence on the sediment concentration. Additionally, the negative value indicates the as time increases, concentration decreases.

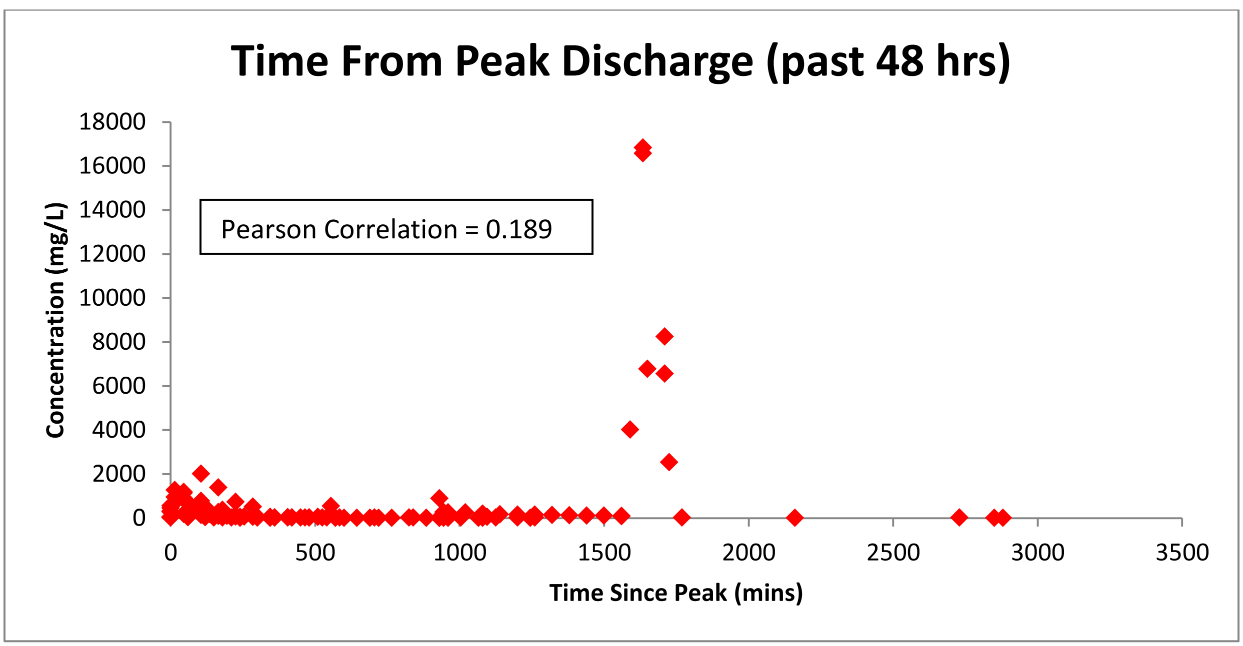

Figure 9) Ravine 1. Concentration is plotted versus time since the peak within the last 48 hrs. The Pearson Correlation value indicates that there is no or negligible correlation between the variables. (r=0.189, N=107). This correlation is not significant.

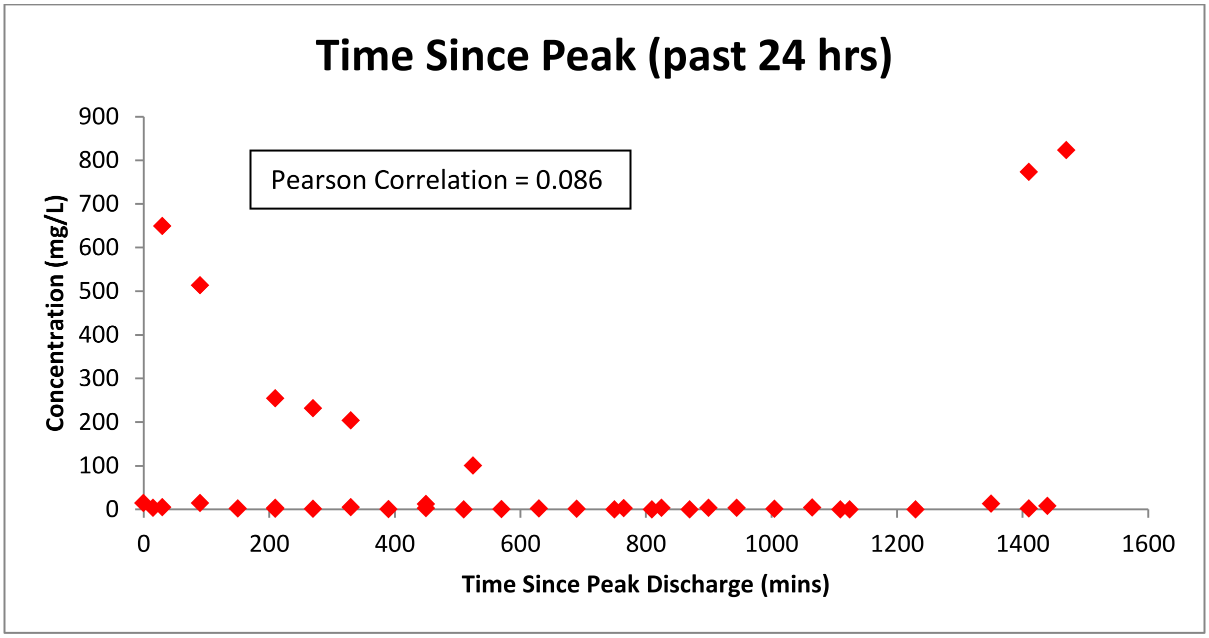

Figure 10) Upper Ravine 2. Concentration is plotted versus time since the peak within the last 24 hrs. This Pearson Correlation indicates that there is no or negligible correlation between the variables. (r=0.086, N=39). This correlation is not significant.

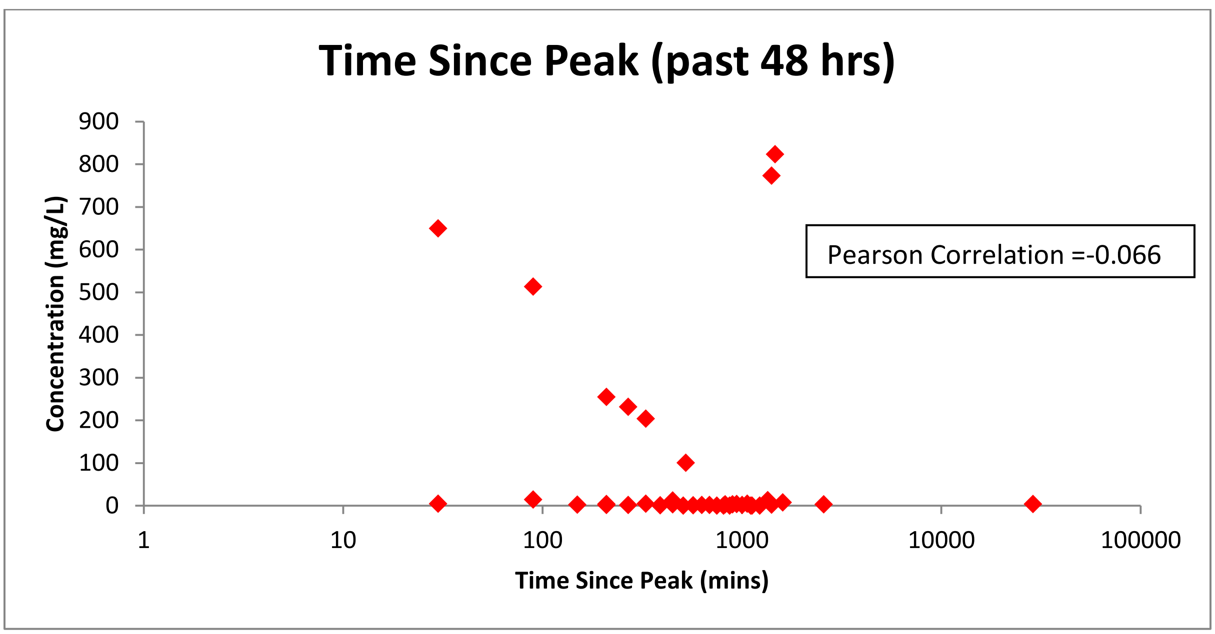

Figure 11) Upper Ravine 2. Concentration is plotted versus time since the peak within the last 48 hrs. The horizontal axis is represented in the logarithmic scale. This Pearson Correlation indicates that there is no or negligible correlation between the variable (r=-0.066, N=39). This correlation is not significant.

Discussion

The positive correlation between sediment concentrations and discharge makes sense when taking into account that a greater discharge would result in more water energy and greater capacity for sediment transport. We can conceive that as water discharge in the ravines increase, the ability to erode also increases. Erosion from the head, banks, and walls could contribute sediment to the stream. While this study did not track mass wasting events, it is likely that there bank or wall failures that could have contributed plumes of sediment. Because the glacial till in this area is unconsolidated, the response rate of these ravines to geomorphic changes is very fast. This same process of accelerated erosion by increased stream discharge has been identified by Belmont et al., (2011).

The weak negative correlation associated with sediment concentration and time since peak discharge within the last 24hrs. follows the same logic. As time increases away from a greater discharge, it seems likely that concentrations would decrease. I would argue that this correlation is misrepresented and should have a higher value for one simple reason: repeated events. Large discharge events followed by smaller increases in discharge will still have the initial large flow as the peak while sediment could be mobilized during the smaller events. Therefore, smaller discharge events following a large discharge event could cause concentrations to increase while ignoring the event that caused the mobilization of sediment. These kinds of events would cause time from peak and concentration to increase thereby skewing the Pearson correlation.

While this study utilized three automated samplers, only two were reported on in this report. This was to increase the accuracy of the data. The Lower Ravine 2 sampler intake was located in the stream bed where the exact discharge cannot be measured due to major channel changes. This sampler also experienced major technical difficulties which created sporadic measurements and sampling. For these reasons, data from this site was left out of this report.

Conclusions

The aim of this study was to identify the major factors that control sediment transportation in these ravines. During this season, the dominant control was identified as water discharge. We know that increased discharge increases the erosive power of these ravines and mobilizes sediment.

It is important to note that this study was only preliminary and more data should be collected to compare hydrologic seasons. More seasons need to be studied to collect a variety of season fluctuations. To create a more robust study, the ravines themselves should be studied to identify areas of mass wasting or storage.

As more drain tile installed in the watershed discharge into the ravines will increase. That, in turn, will increase the ability of the stream to erode the ravines and transport sediment. This influx of sediment into Minnesota rivers will degrade the clarity of water and may cause ecological damage to aquatic fauna and flora.

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