Monitoring and Mitigating Agricultural Pollution In The Seven Mile Creek Watershed For Healthier Streams

By

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Under the Supervision of Dr. Laura D. Triplett

Abstract

The Seven Mile Creek (SMC) Watershed, located between St. Peter and Mankato in southern Minnesota, is a relatively small watershed that is typical of much of southern Minnesota. Much of the land in the SMC Watershed is used for agriculture, specifically to produce soybeans and corn. Excess water exits the soybean and corn fields through drainage tiles and carries nutrients such as nitrate and phosphorus into SMC. The nutrients then drain into the Minnesota River, followed by the Mississippi River, and are finally deposited into the Gulf of Mexico. This creates algae blooms, which make the water susceptible to hypoxic conditions. In this way the watersheds of southern Minnesota like the SMC watershed are contributing to the decline in shrimp and other aquatic populations. This is both an environmental crisis and an economic dilemma for the fishing industry. Working to solve this problem, farmers in the SMC watershed are implementing new methods to mitigate the amount of nitrate entering the SMC. It is imperative that some form of monitoring coincides with these strategies to decrease the amount of pollution, so that a definitive answer is reached as to whether or not these mitigation strategies are effective. Over the summer of 2016 three sites within the SMC watershed were monitored for nitrate and total suspended solids (TSS). Four major precipitation events occurred throughout the season causing major fluctuations in nitrate -nitrogen and TSS concentrations. Concentrations of the two variables are dependent on precipitation levels. The maximum concentration of TSS observed in the tributary flowing beneath Highway 99 (tributary 99) was 11 mg/L and the average concentration was 2 mg/L. The maximum concentration of TSS observed in the tributary flowing beneath county road 13 (tributary 13) was 12 mg/L and the average concentration observed was 3 mg/L. For tributary 99 the maximum nitrate-nitrogen concentration observed was 44 mg/L, while the average concentration of nitrate-nitrogen was 28 mg/L. The maximum concentration of nitrate-nitrogen observed in tributary 13 was 45 mg/L, and the average concentration of nitrate-nitrogen was 20 mg/L.

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TABLE OF CONTENTS

FIGURES AND TABLES

Introduction

The Seven Mile Creek (SMC) watershed drains into the Minnesota River (MNR), which in turn drains into the Mississippi River. This watershed is large and declines steeply just before entering the MNR. The surface water of SMC is being contaminated by agricultural runoff in the form of nutrients, pesticides, insecticides, excessive sediment, and *Escherichia coli*. These pollutants threaten the biodiversity of the MNR as well as the organisms occupying the coastal region of the Gulf of Mexico. As immense loads of nitrate-nitrogen drain into the Gulf of Mexico, the hypoxic zone there spreads. Phytoplankton in the Gulf feast on the excess nitrates and bloom. Once the phytoplankton die and sink to the seafloor their organic remains are decomposed by aerobic bacteria, which depletes the coastal areas of the Gulf of oxygen (Rabalais et al. 2002). It is by this process that farms located in the Midwestern United States contribute to the expansion of the second largest hypoxic zone on the planet. The annual load of nitrate-nitrogen generated in the Minnesota River Valley alone has been estimated to be anywhere between 1.8 to 21.9 Kg/ha/yr (Randall and Mulla 2001). Determining which methods of mitigation are effective in the SMC watershed will be applicable to much of the land used for agriculture in the Midwest.

The socioeconomic impact of this phenomenon is tremendous. Fishermen are being forced to travel further and further out to sea in order to locate the shrimp their local economies so desperately depend on. If the seasonal hypoxic zone grows large enough to the point that it is no longer economically feasible for commercial fishing to take place in the Gulf of Mexico the area will be forced to find alternative means of stimulating local economies.

Nicollet County has been given a grant of $1.7 million to mitigate the environmental impacts agriculture is causing in the SMC area. Such mediation efforts include restoring wetlands and creating buffer zones that would effectively quarantine pollutants. It is important that monitoring coincides with these efforts to reduce the pollution, for it will be impossible to determine whether or not the management strategies are effective without hard evidence. Using the $1.7 million grant in an attempt to minimize runoff without monitoring the SMC watershed would be a waste of money.

Monitoring of the SMC watershed is extensive with several ongoing projects currently being conducted. However, none of the current water quality studies of SMC include the two major tributaries that are feeding the main stem. Much information can be gained from monitoring the main stem, but in terms of locating sources of nitrates and determining which containment methods are most effective at preventing runoff from entering the streams it is vital for monitoring to occur upstream from the locality of current investigation.

Previous Work

This will not be the first time that the water quality of the SMC watershed has been monitored. Others have measured the different pollutants present in the major tributaries flowing into the park. Similar studies conducted on the SMC watershed discovered that application timing of nitrates resulted in differing levels of nitrate loss. Nitrates applied during the spring did not enter the watershed in amounts as significant as those applied during the fall (Nangia et al. 2010). Kuehner (2001) monitored tributaries 99 and 13 (figure 1) for nitrate and total suspended solids (TSS) in 2000 and 2001, recording nitrate-nitrogen concentrations of up to 27-28 mg/L. Average nitrate-nitrogen concentrations reported by Kuehner (2001) were between 13 and 14 mg/L. The median TSS range for tributaries 99 and 13 as reported in Kuehner's study were between 10 and 14 mg/L. The maximum TSS concentration recorded, 2096 mg/L, occurred at the main stem site following a major storm event during the summer of 2001. Many Gustavus undergraduate students have studied the SMC watershed for their senior thesis in years past. The most recent student to do this conducted the preliminary research for this study. One Frödén (2016) monitored the TSS, *E. Coli*, and water flow of the SMC along the same three sites to be monitored in this very study (figure 1).

Geographic and Geologic Setting

The SMC watershed is located in the Minnesota River Valley of Nicollet county between Saint Peter, Minnesota and Mankato, Minnesota. SMC stretches 6.1 miles over the landscape before flowing into the MNR. The majority of the land (86%) within the SMC watershed is used to grow soybeans and corn. As of fifteen years ago there were 15 miles of tile drainage and 24 miles of open ditches in the watershed (Kuehner 2001). This outdated estimate is the best we have of the current amount of tile drainage in SMC, although more has certainly been added in the last decade and a half.

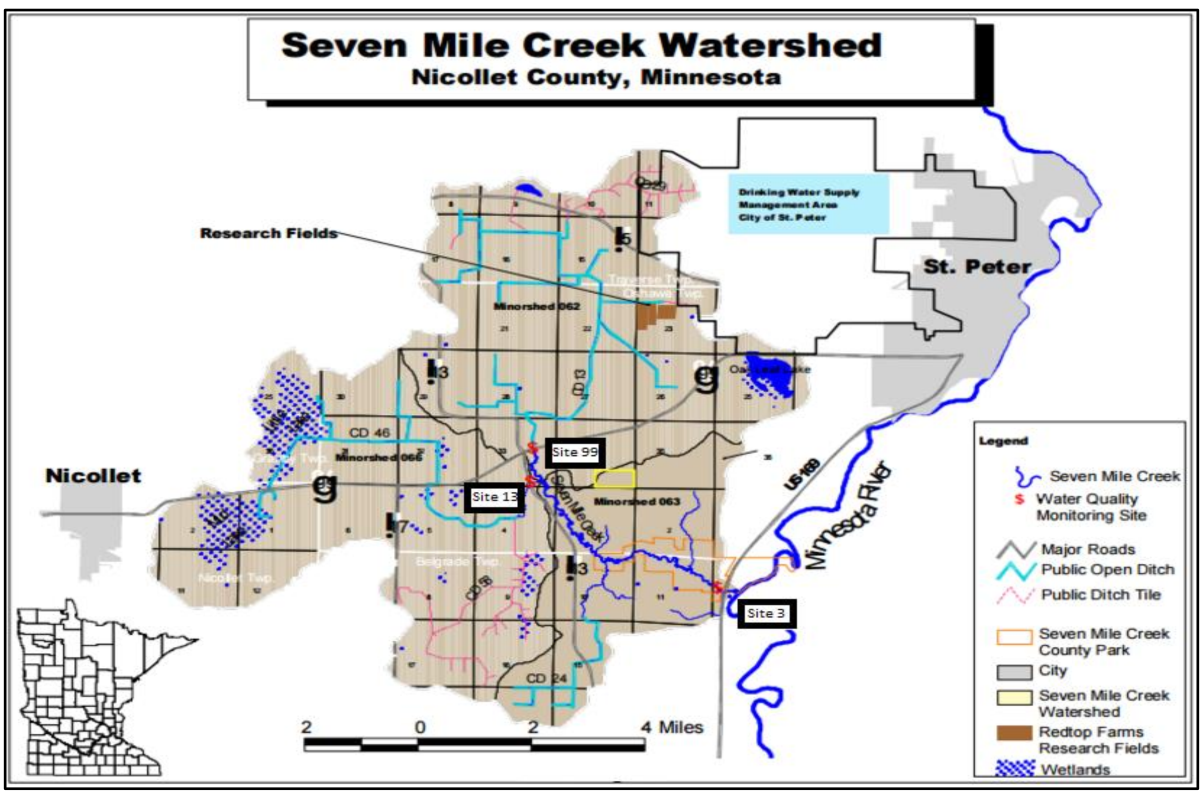

Figure 1. Map depicting the SMC watershed and the three monitoring sites (Kuehner 2001).

The geology is comprised of Early Paleozoic sedimentary rock, dolostone, and Quaternary sediments. Throughout the SMC watershed glacial till was deposited during the Quaternary period. The surficial units of till are unconsolidated and loose throughout the region (Baratta and Petersen 2016). Nicollet county is mostly composed of rolling and level topography with river gorges and ravines created by the incising of the MNR and its tributaries (Baratta and Petersen 2016).

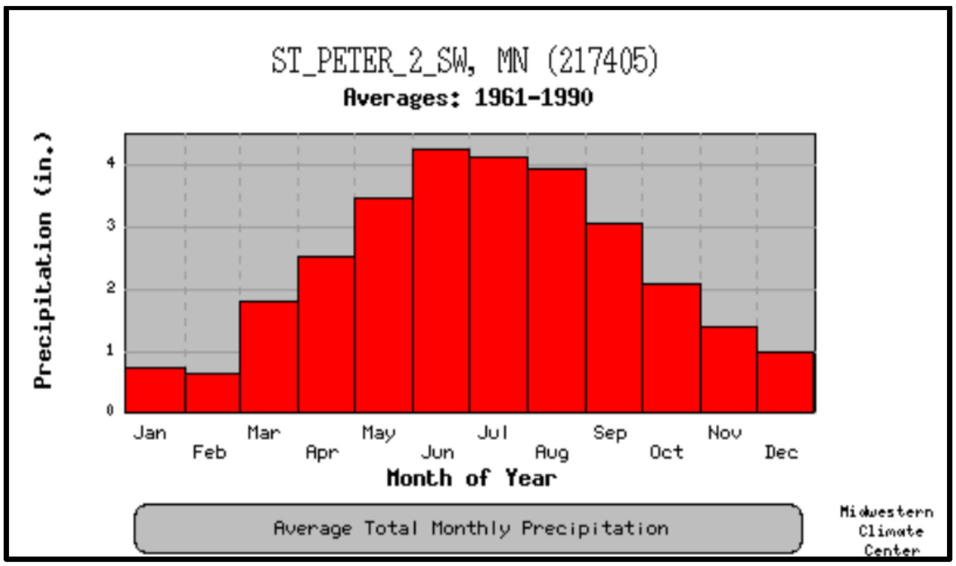

Figure 2. Average monthly precipitation rates in inches between 1960 and 1991 (Kuehner 2001)

Precipitation varies throughout the year in Nicollet county (figure 2). Peak precipitation occurs during June and July, reaching levels of more than four inches on average. The average annual precipitation rate for Nicollet county is 28.01 inches (Kuehner 2001). Precipitation ultimately percolates or flows to the MNR, which acts as the local base flow for SMC and its other tributaries. The MNR flows through the Minnesota River Valley, which was carved out by the draining of Lake Agassiz during the Wisconsonian glaciation. A catastrophic flood event resulted when the Early Holocene glacial lake overcame the Big Stone Moraine and fed the

Glacial River Warren (Fisher 2004). Glacial River Warren was the outlet flow of Lake Agassiz from which the Minnesota River Valley was created.

The majority of land cover in the SMC watershed is reserved for agriculture. Drain tile and ditches drain the fields of excess rainwater, keeping the soil from becoming saturated. Nitrate-nitrogen and TSS are flushed off of fields via the drain tiles and ditches as well. The uplands of the SMC watershed are relatively flat and were once covered in lakes before the area was drained and then converted into crop fields. As lakes in the watershed were drained, ditches were added to route excess water from fields into SMC (Kuehner 2004). The uplands of the watershed drop off suddenly to the lowlands where SMC merges with the Minnesota River.

Methods

Site Selection

Sites were selected based on the previous locations of the Minnesota Pollution Control Agency's (MPCA) monitoring sites. Site 99 is located in the public ditch between two farms fields off of highway 99and has been named accordingly. Site 13 is located along county road 13 in the public ditch that flows beneath the road. The two sites can be seen in figure 1 along the headwaters of SMC. Site 3 is located along the main stem of SMC within the park boundaries.

Sample Collection

Samples from the sub watersheds were collected in Nalgene bottles placed in the thalweg of each stream. Placement of the containers in the thalweg made for the most accurate representation of the sub-watersheds' water quality. Collection occurred periodically, but samples were collected before major rain events, twice during the rising limb of discharge, and twice during the falling limb. Samples were refrigerated following collection for the appropriate amount of time depending on which pollutant they were tested for.

Nitrates

Ion chromatography was used to determine the concentration of nitrate-nitrogen present in the subwatersheds. Samples were tested within 48 hours of collection as per protocol. Until each sample was analyzed for nitrates it was refrigerated. Samples were lightly shaken prior to testing to prevent any pollutants from settling to the bottom of the Nalgene canister. The samples were then poured into the ion chromatograph vial, placed into the chromatograph, and analyzed.

Total Suspended Solids

Analyzing samples for total suspended solids (TSS) began with shaking the sample before filtration. Vacuum filtration was used to separate the water from the TSS. After filtration was completed the sample was dried and then fired to burn off any organic matter. The resulting mass of TSS was then divided by the liters of sample filtered to produce the concentration in mg/L. This is the standard method used to calculate TSS by the American Public Health Association (Eaton and Greenberg 1999).

Discharge

Stage height was measured using a sonar apparatus. The amount of time taken for sound waves to travel to the surface of the tributary and return to the device was converted into stage height and then recorded by the data collector once every fifteen minutes. The two stage monitors were calibrated each time data was downloaded from sites 99 and 13. Data was downloaded approximately once every week. Trips to the sites occurred several times throughout precipitation events. Ideally sampling occurred twice as the hydrograph of SMC rose and twice as the hydrograph descended. The distance to water was measured manually using a tape measure and then compared to the recorded data. Stage level was then converted to discharge using rating tables developed by the Minnesota Department of Natural Resources in 2012.

Flux

Annual loads of nitrate-nitrogen and TSS and other flow data were calculated using the Flux32 software version 3.37. Time series, figures 3-4 and 6-7, were created using Flux as well. Daily flows and concentrations of the pollutants were entered into Flux for each constituent. The concentrations of samples collected on the same day were averaged, and samples flagged for exclusion were excluded. Daily flows were substituted in place of sample flows. A few constituent data points were recorded as being collected during the year 1900, so the year was changed manually to 2016. Loads were calculated using Method 8: time series.

Results

Flow

The flow measured at sites 99 and 13 have similar peak distribution (figure 3). When the flow of tributary 99 begins to rise, so too does that of tributary 13. Four large peaks mark the timing of significant precipitation events throughout the spring and summer. While these peaks correlate between the two subwatersheds, they are more exaggerated on the plot of 99. The highest peak for tributary 99 occurred on the 5/29/16, reaching 75 cfs. The corresponding peak for tributary 13 only reached 42 cfs. Another curious discrepancy between the two graphs occurs around 6/17/16. For site 99 the peak that is present here has relatively the same height as the peak that precedes it. However, for site 13 the second peak in this series is significantly smaller than the first. Flow is highest during late May and early June, while it is lowest during late July and early August.

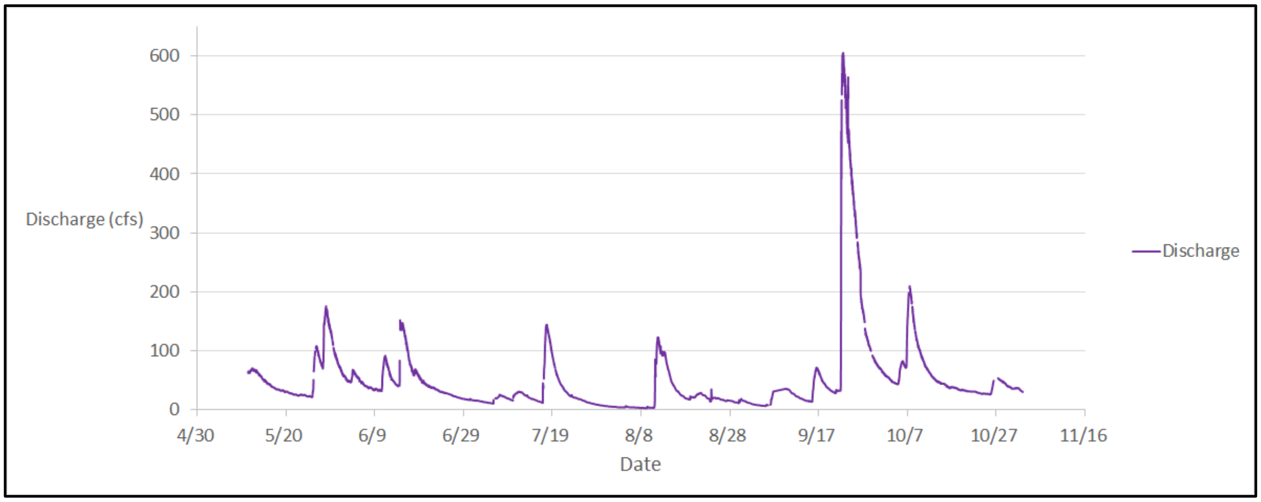

Figure 3. Seven Mile Creek main stem level and discharge values for the fall, spring, and summer of 2016 (data provided by the MN DNR and MPCA): Six major peaks mark the discharge time series of the main stem during the year of 2016. These six peaks coincide with major precipitation events that occurred throughout the year.

Nitrate

Sample collection for nitrate began in early June. The nitrate levels of tributary 99 did not react similarly to the flow of the tributary (figure 6). Contrary to this relation, the nitrate levels of 13 seem to correlate with the flow of the subwatershed over time (figure 5). Levels of nitrate seem to peak following the peaks of flow.

The nitrate levels of tributary 99 are consistently higher throughout the 2016 season than the nitrate levels of tributary 13 (figure 4). However the peaks of nitrate that occur around August 18th 2016 and June 19th 2016 are greater for tributary 13 than they are for tributary 99. All other peaks are greater for tributary 99. The nitrogen levels of tributary 13 peaked before 99 following the precipitation event that occurred on August 18th 2016. For the precipitation event that occurred slightly before June 19th 2016 the nitrate levels of tributary 99 peak before the nitrate levels of tributary 13. All other peaks of nitrate for tributary 13 are dwarfed by those of tributary 99.

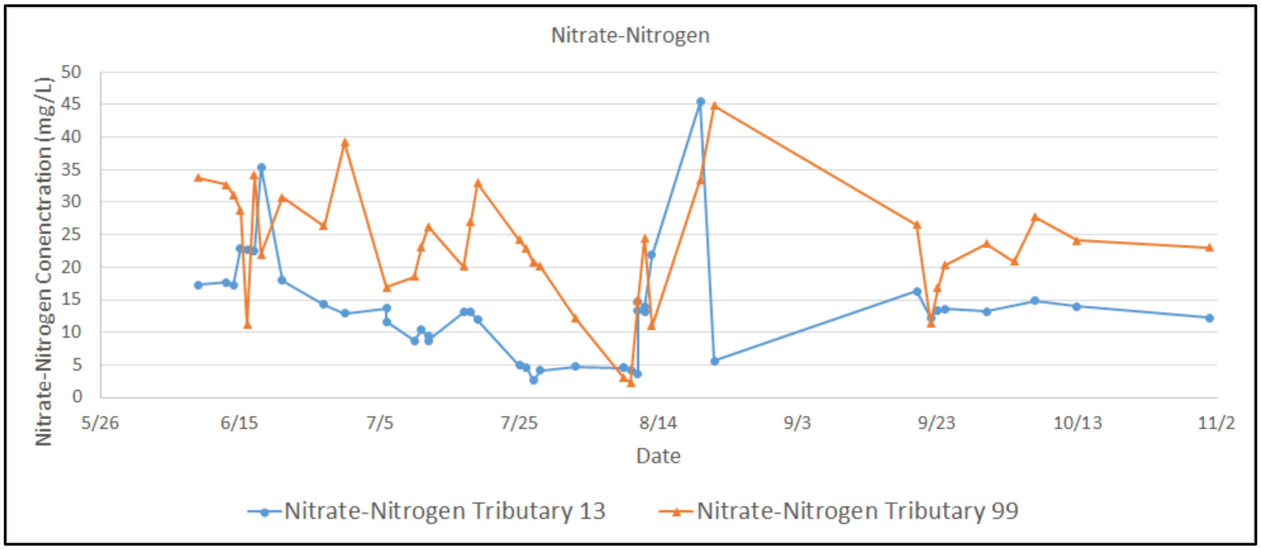

Figure 4. Sampled Nitrate-nitrogen concentrations of Tributaries 99 and 13 through 2016: Sampling of the two tributaries for nitrate-nitrogen began in early June and continued until the first of November. Generally, the concentration of nitrate-nitrogen in tributary 99 was greater than that of tributary 13 at any given time throughout 2016.

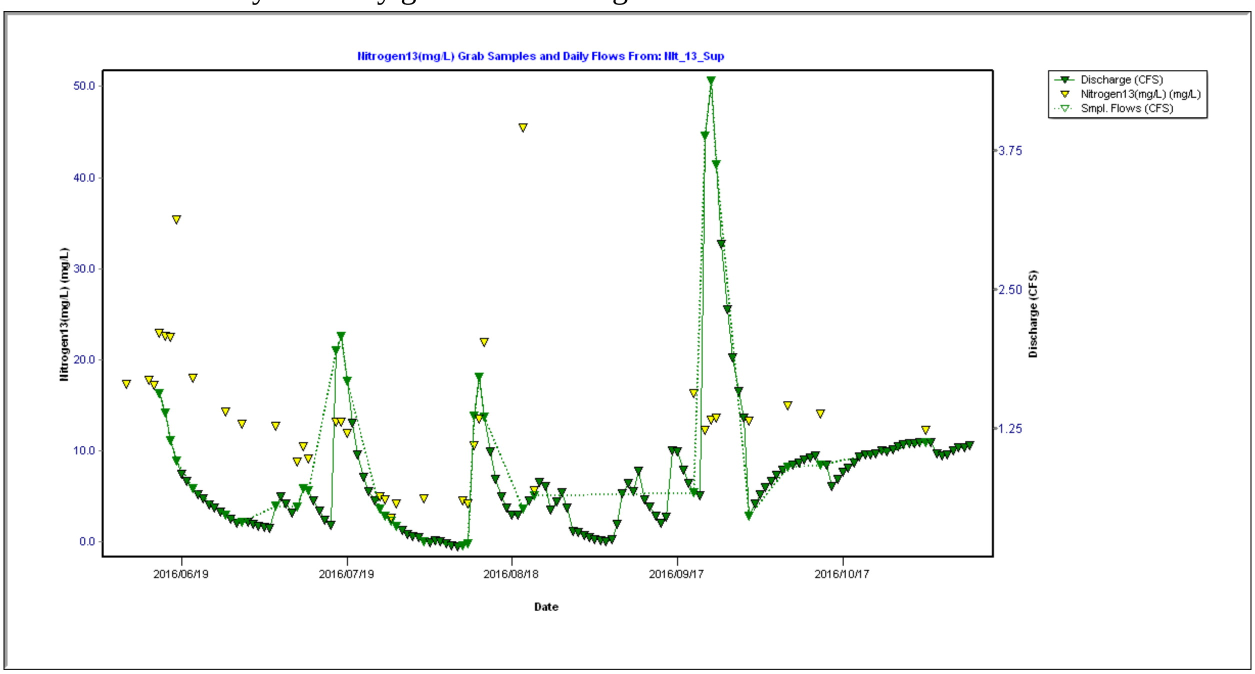

Figure 5. Flux graph depicting the flow and concentration of nitrate-nitrogen in tributary 13 between May 2016 and the first of November 2016: Four major precipitation events mark the time series above. Four peaks in nitrate-nitrogen concentration coincide with these spikes in precipitation.

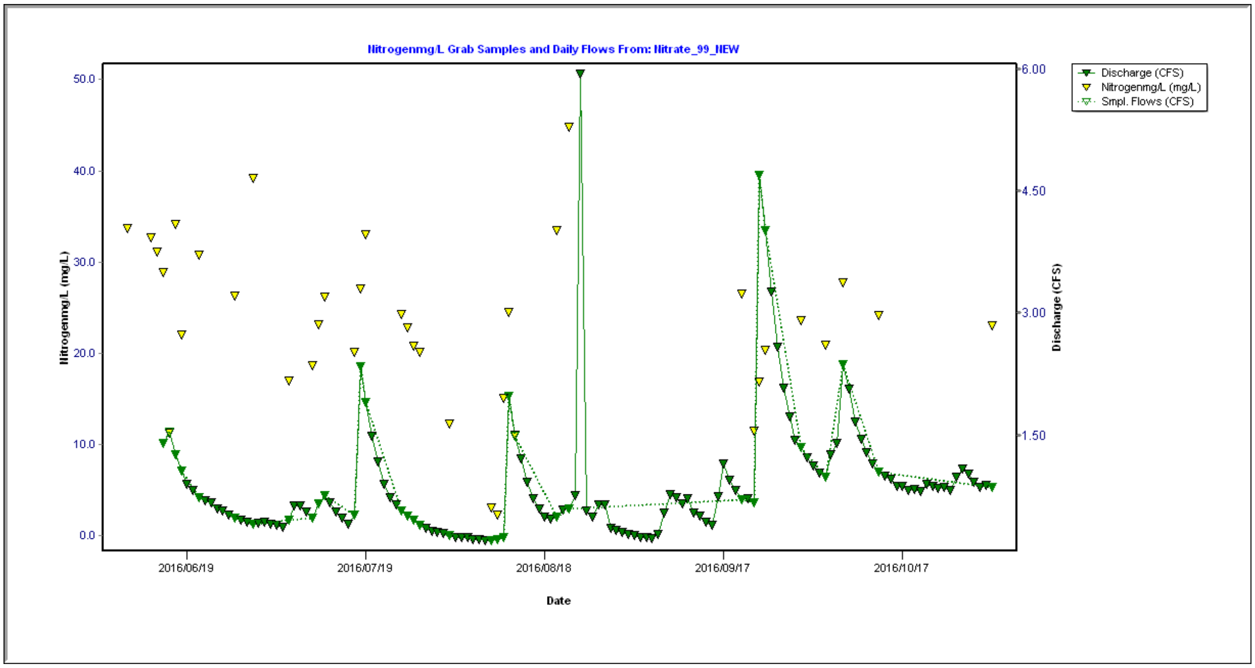

Figure 6. Flux graph depicting the flow and nitrate-nitrogen concentration of tributary 99 between May and October of 2016: six major precipitation events are visible on the time series above. Besides the outlier that was sampled on 6/30, the concentrations of nitrate-nitrogen of tributary 99 seem to fluctuate with levels of precipitation.

Total Suspended Solids

The levels of TSS reflect the amplitude of the two subwatersheds' flow. The highest peak of TSS for 99 coincides with the highest peak of flow (figure 9). Concentrations of TSS nearly reach 115 mg/L at this peak. There is a relatively high peak that occurs in the TSS of 13 at this point as well (figure 8). However, there is a peak that reaches slightly higher levels on July 11th 2016. Concentrations of TSS for both subwatersheds between June 14th and June 26th are relatively low. Some of these values are zero. Peaks of the TSS tend to reach their maximum point earlier than those of flow.

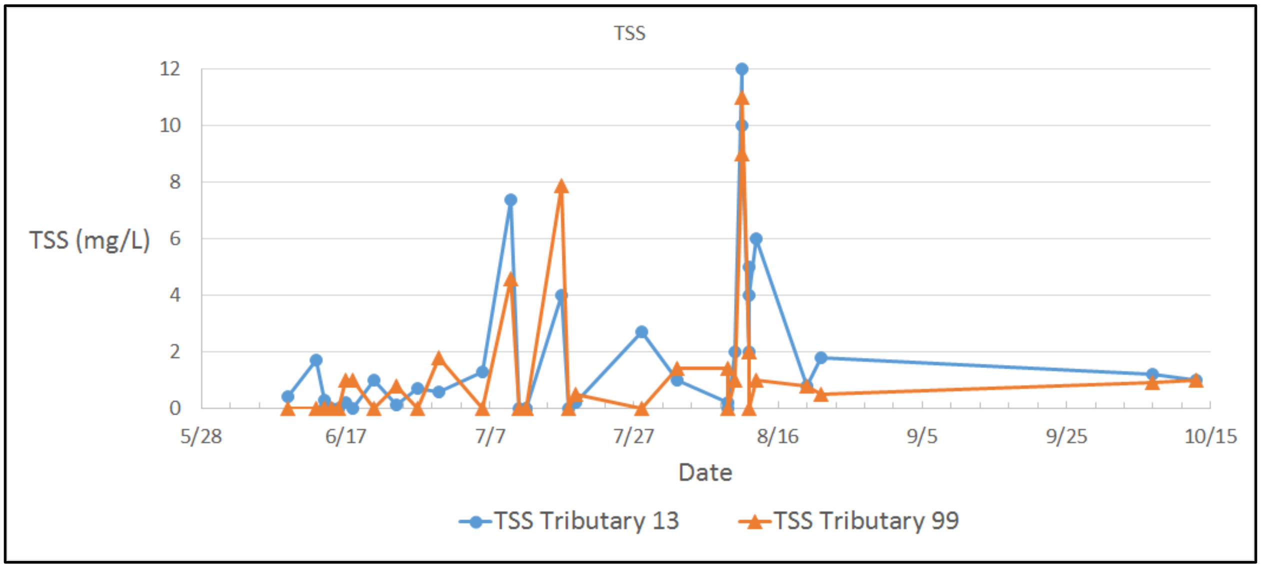

Figure 7. TSS time series of tributaries 99 and 13 for the year 2016: Sampling for TSS began in May of 2016 and ended in October of 2016. The lag between the two tributaries for TSS gives the above time series an interesting double helix appearance for the month of June. While TSS is nearly zero for one tributary, the other has a concentration of ~1 mg/ L. Only during the largest precipitation events do the two tributaries increase in concentrations of TSS simultaneously.

The highest peak of TSS for 99 coincides with the highest peak of flow (figure 9). Concentrations of TSS nearly reach 115 mg/L at this peak. There is a relatively high peak that occurs in the TSS of 13 at this point as well. However, there is a peak that reaches slightly higher levels on July 11th 2016. Concentrations of TSS for both subwatersheds between June 14th and June 26th are relatively low (figure 7). Some of these values are zero. Peaks of the TSS tend to reach their maximum point earlier than those of flow.

It is only during the largest precipitation event that occurred approximately September 22nd 2016 that the timing of TSS peaks for 99 and 13 are synchronized (figure 7). During the period between June and July, the tributaries’ TSS values appear in a sinusoidal manner. When one tributary experiences a trough, the other tributary experiences a peak.

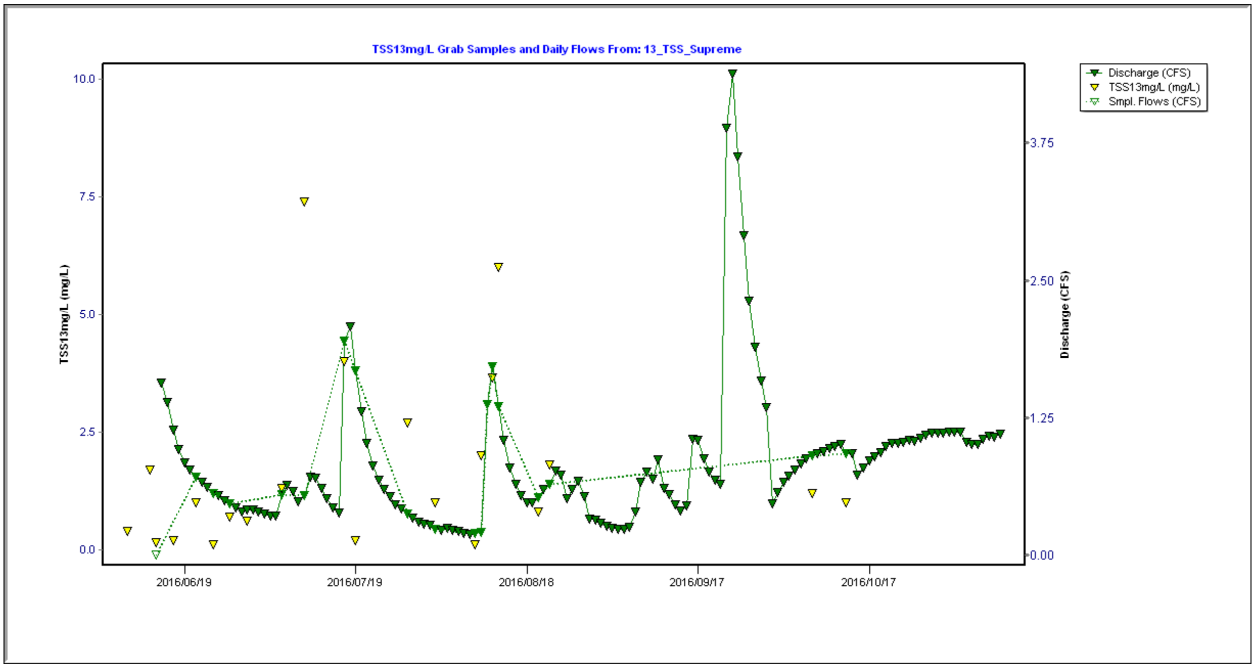

Figure 8. Flux graph depicting the flow and TSS concentration of tributary 13 between May and October of 2016: TSS of tributary 13 peaks with the onset of major precipitation events. It appears that initial rainwater to precipitate flushes

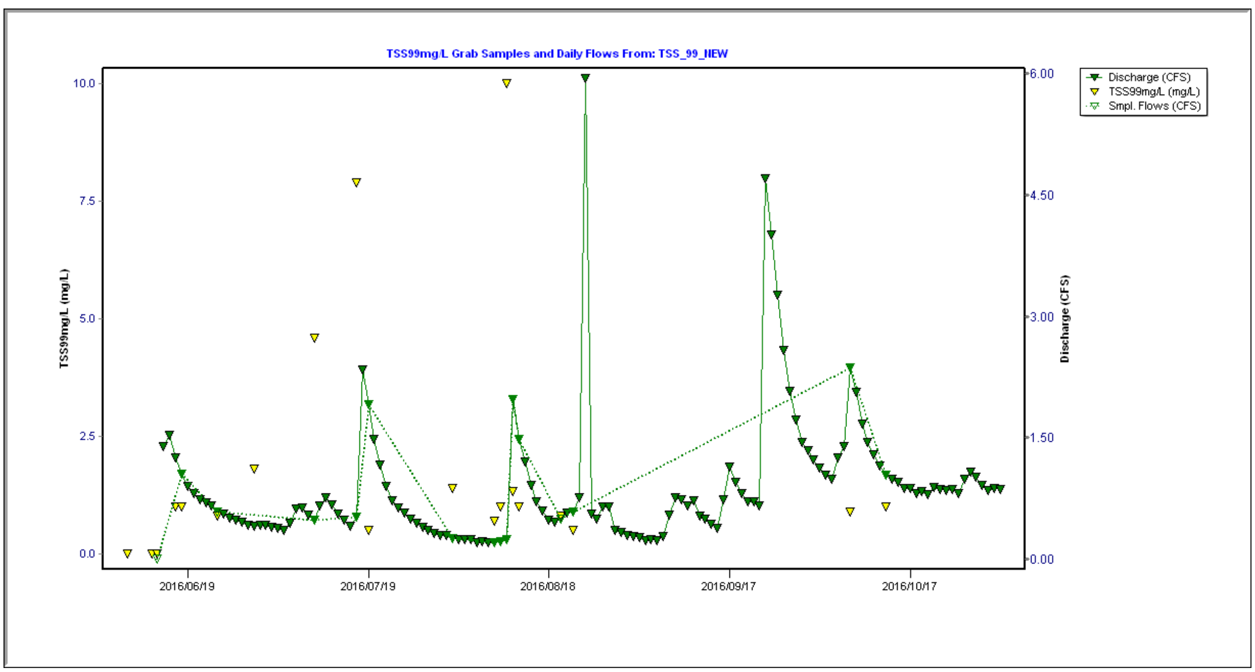

Figure 9. Flux graph depicting the TSS concentration of tributary 99 and its flow between May and October of 2016:

	Total Mass Over Monitoring Period (kg)	Average Daily Flux (kg/day)	Maximum Concentration (mg/L)	Average Concentration (mg/L)
Nitrate-Nitrogen Tributary 99	8490	60	44	28
Nitrate-Nitrogen Tributary 13	6040	40	45	20
TSS Tributary 99	450	3	11	2
TSS Tributary 13	980	7	12	3

Table 1. Table of average 2016 loads for nitrate-nitrogen and TSS calculated on Flux for both tributaries.

Discussion

Nitrate-nitrogen concentration sometimes increases with large increases in discharge, but at other times nitrate seems independent of discharge. In figures 5 and 6 it appears that the two variables correlate. Following peaks in precipitation nitrate-nitrogen concentrations of both tributaries peak as well. Nitrate-nitrogen concentrations do not rise with the largest peak in discharge for tributary 13, however. This is due to the sheer volume of precipitation percolating through the soil and diluting the nitrate-nitrogen running off of the fields and the precipitation event occurring during a time of the year when the crops are entering a stage in maturity called ‘fully canopy’ where nitrate-nitrogen intake is at its highest (Kuehner 2001).

During two of the major precipitation events of 2016, nitrate-nitrogen concentrations of tributary 13 exceeded those of 99. Just after 6/15, nitrate-nitrogen peaked for tributary 99 before it did for tributary 13 (figure 4). The concentration of nitrate-nitrogen from samples collected on 6/15 show that 99 had a higher concentration than 13. The following day, tributary 13 exceeded 99 by 11.4 mg/L. Then on 6/17 the concentration of nitrate-nitrogen was 34.1 mg/L for tributary 99 and 22.5 mg/L for tributary 13. On 6/18 the measured concentration of nitrate-nitrogen for tributary 99 was 22 mg/L, while the measured concentration of nitrate-nitrogen for tributary 13 was 35.4 mg/L. The concentrations of nitrate-nitrogen in tributary 13 seem to correlate more with discharge than the concentration of nitrate-nitrogen in tributary 99. The concentrations of nitrate-nitrogen in tributary 99 fluctuate between 20 and 40 mg/L frequently, while the concentrations of nitrate-nitrogen in tributary 13 are more stable through time. The variability of nitrate-nitrogen concentrations in tributary 99 may be due to any number of causes. It is most likely a combination of different factors that are causing the concentrations of nitrate-nitrogen in tributary 99 to fluctuate so frequently. Fertilizer application timing and abundance, groundwater flow, or the location of buffer strips may have contributed to the changes in nitrate-nitrogen concentrations in tributary 99.

The majority of nitrate-nitrogen entering the SMC main stem is being delivered by tributary 99. The average load of nitrate-nitrogen transported by tributary 99 as calculated via flux is ~8,500 kg (table 1). The average load of nitrate-nitrogen carried by tributary 13 is slightly over 6,000 kg. Efforts to reduce the amount of nitrate-nitrogen escaping fields in the form of runoff are either more effective than those of fields surrounding tributary 99 or the fields contributing nitrate-nitrogen to tributary 99 require more fertilizer than do the fields surrounding 13. Application timing plays a large role in the amount of nitrate-nitrogen runoff generated by fields. (Nangia et al 2010). A combination of fertilizer application timing, amount, and mitigation strategies involved account for the higher concentrations of nitrate-nitrogen in tributary 99 over tributary 13.

Peaks in TSS correlate with precipitation events throughout 2016 (figures 8 and 9). Sediment flushed off of the fields as a precipitation event begins causes the concentration of TSS in the tributaries to increase rapidly. Concentrations are highest at the beginning of a rain event due to the relatively light amount of rainwater percolating through the soil and draining into the tributaries. The amount of sediment draining into the tributaries over the course of a rain event does not change drastically, but the hydrograph does fluctuate significantly. This leads to dilution of the TSS and thus lower concentrations during the peak of the hydrograph. The amount of TSS entering the tributaries at the time of the hydrograph's peak is greatest, while the concentration of TSS is relatively low.

The majority of TSS supplied to the main stem of SMC during 2016 was transported by tributary 13 (table 1). Tributary 13 consistently has higher concentrations of TSS than does tributary 99. According to the loads of TSS calculated by FLUX (Figure 10) the TSS load of tributary 99 is less than half the TSS load of tributary 13. The amount of sediment supplied by ravines in the park of SMC is unknown at this time. Using the data gathered in this study one could compare the concentrations of TSS in the tributaries to the concentrations of TSS measured in the main stem to determine how much TSS is delivered to SMC by ravines.

Previous monitoring of tributaries 99 and 13 was conducted by Kevin Kuehner in 2000 and 2001. This project was funded by the MPCA and sponsored by the Brown Nicollet Cottonwood Water Quality Board. Monitoring of the two tributaries occurred at the same sites used for monitoring as this report. Nitrate, TSS, phosphorous, and fecal coliform were among the variables monitored. TSS concentrations were shown to increase rapidly at the beginning of a precipitation event. Maximum TSS levels occurred at or near peak precipitation levels. Although concentration was highest during the beginning of storm events, it was not until maximum discharge that most of the TSS was being transported downstream. This model accurately represents the TSS fluctuations for the tributaries in 2016. The nitrate-nitrogen model followed by the tributaries in 2000 and 2001 increases rapidly during the onset of a precipitation of event.

Concentrations are highest during this time and nitrate-nitrogen levels are highest once the hydrograph has reached its peak. Precipitation diluting the nitrogen-nitrate accounts for lower levels at the beginning of a storm. Concentrations for 2000 and 2001 peaked in July and were directly correlated with precipitation. (Kuehner 2001).

One major uncertainty with these interpretations is the data itself. Unlike flow and discharge, TSS was not being measured constantly. Sampling only occurred in tandem with precipitation events. The highest frequency of sampling was twice a day for some of the major precipitation events. Concentrations may have peaked where peaks occur on the flux graphs, or the concentrations may have continued to rise, and most likely did so, beyond the peaks depicted above. Certainty for this interpretation would be greater if sampling had occurred with a higher frequency. One should keep this in mind when interpreting the data.

The mass of nitrate-nitrogen calculated for tributary 99 was nearly 2,500 kg higher than the mass of nitrate-nitrogen calculated for tributary 13 (Table 1). The concentration of nitrate-nitrogen was also calculated to be 8 mg/L higher for tributary 99 than tributary 13. While the reported values of nitrate-nitrogen were higher for tributary 99, the mass and concentration of TSS calculated by flux were higher for tributary 13 than they were for 99. Thus we can conclude that tributary 99 is delivered more nitrate-nitrogen to the main stem than 13, and that 13 is delivered more TSS to the main stem than did tributary 99 for the year 2016. The average concentration of TSS for either tributary is well below the Minnesota drinking water standard of 10mg/L. However, when TSS peaked during the onset of major precipitation events, that standard was exceeded. Nitrate-nitrogen exceeded the drinking water standard on a consistent basis. Following the peak discharge of precipitation events, nitrate-nitrogen reached its maximum concentrations.

The current state of agriculture pollutants in the SMC watershed is now known with finer detail. The data gathered for this study may be compared to the data gathered in future studies to identify seasonal trends and abnormalities. Moving forward Nicollet County will have a better understanding of the agricultural pollutants generated within the SMC watershed. Based on the results of this study, I suggest that Nicollet County focuses the majority of its nitrate-nitrogen mitigation efforts on the fields surrounding tributary 99 and its TSS mitigation efforts on the fields surrounding tributary 13.

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