Red Lake River Watershed

Farm to Stream

Tile Drainage

Water Quality Study

Final Report

Revision 3

March 20, 2009

RED LAKE RIVER WATERSHED FARM TO STREAM TILE DRAINAGE WATER QUALITY STUDY

FINAL REPORT, REVISION 3

MARCH 20, 2009

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Beltrami County

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- Molly MacGregor, MPCA Red River Basin Coordinator, was instrumental in the grant application process.
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- Kevin Yaggie, Landowner and Farmer, Red Lake County
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- Greg Hilgeman – Landowner
- Paul Imle – Landowner
- John Gunvalson – Landowner

Abstract

With the Red Lake River Watershed Farm to Stream Tile Drainage Study, the Red Lake Watershed District and its project partners studied the water quality characteristics of tile drainage within the Red River Basin. The common opinions about tile drainage that serve as the hypotheses being tested during this study were that tile drainage would have:

1. Lower total phosphorus concentrations
2. Lower total suspended solids concentrations
3. Higher nitrate concentrations
4. Lower peak flows from a field
5. Greater total volume of drainage from a field over time.

Data seems to support these theories, with some exceptions. When main line tile drainage is used in wild rice paddies without internal surface drainage, it has all the same benefits as conventional tile drainage (low phosphorus and sediment) and has low nitrate levels instead the high levels that were found in conventional agriculture tile drainage. The affects of tile upon flow peaks and volumes were as expected for most storm events. There was some variation in results that show that the effects of tile are dependent upon antecedent conditions and the intensity of rainfall events.

Executive Summary

As the amount of tile drainage in northwestern Minnesota increases, so does the interest among natural resource and water management professionals regarding the effect this trend will have upon water quality within the Red River Basin. Prior to this study, there were differing opinions about what water quality from tile drainage would be like, even though little data had been collected. For instance, the tiling methods would be different from southern Minnesota – flatter terrain needs no surface inlets. So, the effects in this area may be different from others. Theories being tested with this study are:

- Tile drainage should have lower suspended solids concentrations than surface drainage.
- Tile drainage should have lower total phosphorus concentrations than surface drainage
- Tile drainage will likely have higher nitrate concentrations than surface drainage
- Storm runoff from a tile drained field should have lower peak flows than a surface drained field
- Storm runoff from a tile drained field will likely have a greater total volume of runoff over time than a surface drained field.

Data collected for this study up to this point support these theories, although some exceptions do exist. With conventional agriculture, there seems to be a water quality trade-off. We get lowered sediment and phosphorus concentrations, but nitrate concentrations are increased. Monitoring of wild rice paddies during drawdown in late summer has shown that connecting mainline tile directly to an outlet structure has a tremendous water quality benefit when compared other methods of draining the paddies. Benefits of main line tile drainage in wild rice paddies were that drainage water was clean, clear, and had low nitrate levels.

The flow component of the study was conducted in cooperation with HDR Engineering. The flow records show that peak flows from a surface drained field are most often greater than peak flows from a tile drained field. While the installation of tile appears to limit peak flows from a field, it prolongs the drainage of a field. This results in a greater total volume of drainage from a field over time. Antecedent conditions and rainfall intensity create variation in drainage rates and amounts from surface and tile drainage.

A major recommendation of this study would be the complete conversion of wild rice paddies to main line tile drainage. There should also be further research into the effect that higher levels of nitrates and specific conductivity in tile discharge may have upon our rivers. Other recommendations would be to continue research into reduction of nitrate loss and water quantity/quality studies in other areas of the Red River basin.

Problem Identification/Background

Introduction

This study was designed to gather real-world data to better understand the potential impact that increased tile drainage may have within the Red River Basin. Prior to this project, there were a lot of differing opinions about how the increasing amount of tile drainage in the Red River Basin would affect water quality.

Tile drainage using surface inlets can cause problems with sediment, nutrient and hydrology. The affects of tile drainage in the Red River Valley are expected to be different than, for example, the Minnesota River Basin. The Red River Valley has a flatter topography that allows for installation of tile without surface inlets. If installed without the surface inlets, tile drainage is expected to filter out sediment and nutrients and provide added capacity for infiltration (soil water storage) during storm events. The Red River Valley also has tighter clay soils.

Although there was great confidence in these theories, there was also a lack of actual water quality data from tile drainage within the basin. This study was designed to provide actual data from tile drainage in several different areas throughout the Red Lake Watershed District. In this study, tile drainage water quality has been compared with surface drainage water quality. The study also compares flow (surface. vs. tile) and different methods of tile drainage. Both conventional agriculture and wild rice paddy drainage are examined.

The Red Lake Watershed District had the opportunity to conduct this study for several reasons. First of all, the RLWD has the ability to conduct the project. The RLWD has been conducting regular water quality monitoring and sampling for more than 20 years on rivers and streams throughout the district. The RLWD has the necessary technical resources in full-time water quality staff, up-to-date equipment, plus the financial ability to initiate and/or provide cost-share intensive studies. RMB Environmental Laboratories, a Minnesota Department of Health certified laboratory conducted the sample analysis. The RLWD has also recently completed the Minnesota Board of Water and Soil Resources funded Red River Watershed Assessment Protocol Project under which the *Standard Operating Procedures for Water Quality Monitoring in the Red River Watershed* and the *Red River Watershed Water Quality Reporting Handbook* were created. The Protocol project gave the RLWD the opportunity to produce examples of what can be done with a water quality monitoring program (website, online water quality database, FLUX modeling, and comprehensive water quality report). The RLWD water quality program has developed a working relationship with the MPCA and has involved landowners in its planning process. In fact, one of the important factors in the development of this particular project was the desire of local farmers to learn more about the water quality of what is flowing from their tile.

There actually were so many landowners interested in the study that, although they were included in the search for suitable monitoring sites, it was not possible to include all of their farms in the study. In addition to landowner interest, there also was interest in the study from the Red River Basin Water Quality Team, local scientists, Minnesota Pollution Control Agency, University of Minnesota Extension Service, and the Red Lake Nation Department of Natural Resources. The original focus of the project was tile drainage installed in wild rice paddies, but it was expanded to include conventional agriculture (grains/row crops). The Red Lake Watershed District has received a $17,500 grant from the Northwest Minnesota Foundation to study the effects of tile drainage on water quality. The Red Lake Watershed Farm to Stream Project will compare different tiling techniques, tile drainage with surface drainage, and agricultural drainage with natural drainage. The original total predicted cost of the project was $35,000. Due to increasing interest in the project, additional funding for accurate flow monitoring was provided by the Red River Watershed Management Board. The Marshall-Beltrami SWCD also received a grant for collecting tile drainage water quality samples in Beltrami County. The study was conducted in 2005 and 2006 with the possibility that flow monitoring may continue into the future. With an extension of the grant from the Northwest Minnesota Foundation, the study was continued through 2007. It would be beneficial to continue the flow monitoring portion (and perhaps storm runoff water quality sampling) into 2008 and maybe longer. Results are presented here in the form of a scientific report and are summarized in the form of informational pamphlets as well. Study results will also be available on the RLWD website (http://www.redlakewatershed.org).

The amount of tile drainage within the Red River Valley has been increasing, as has interest in its effects upon water quality and flow volume. It was anticipated that the water quality characteristics of tile drainage within the Red River Basin will differ from southern Minnesota. One of the main reasons for this is a lack of surface inlets in tile systems within the Red River Basin. According to *Agricultural Drainage Issues and Answers*, “surface inlets provide a fairly pathway for sediment and other contaminants in surface runoff to reach nearby surface waters.” The theories being tested with this study are based upon some sampling conducted by the Marshall-Beltrami Soil and

Water Conservation District, studies from other regions, and predictions of scientists. These theories include, but are not limited to:

- Tile drainage should have lower suspended solids concentrations than surface drainage.
- Tile drainage should have lower total phosphorus concentrations than surface drainage
- Tile drainage will likely have higher nitrate concentrations than surface drainage
- Storm event runoff from a tile drained field should generate lower peak flows than a surface drained field
- Drainage from a tile drained field will likely generate a greater total volume of runoff over the course of a growing season than a surface drained field.

Even though tile drainage may reduce the amount of soil erosion, total suspended solids loadings, and total phosphorus concentrations, there is still concern that it may increase concentrations of nitrates in streams and rivers. Some drainage management practices may be able to reduce nitrogen losses through increased denitrification and reduced leaching. These methods include proper nutrient management, shallow tile drainage, and controlled tile drainage.

Water quality samples were collected and analyzed for total suspended solids, total phosphorus, orthophosphorus, total nitrogen (total Kjeldahl nitrogen + nitrate + nitrites), and nitrates. Field measurements were collected for dissolved oxygen, temperature, conductivity, pH, turbidity, and transparency where possible. Turbidity analysis was conducted at all sampling sites. Although it was not feasible to get accurate flow measurements from every monitoring site for this study, supplemental funding was received from the Red River Watershed Management Board to make an accurate comparison between tile and surface drainage flows. Monitoring sites were chosen for each comparison (water quality and/or quantity) so that the characteristics of the watershed would be comparable. The different types of tile drainage outlets that will be compared for the water quality study include gravity outlets, pumping stations, and water control structures. The primary goal of this study is to successfully collect water quality and flow data from gravity tile drainage outlets, pumped tile drainage outlets, controlled tile drainage outlets, surface drainage, and reference sites. Study areas are located in the Clearwater River watershed in Red Lake and Clearwater Counties, and also in the Thief River watershed near the town of Grygla.

Project Goals

- Characterize sediment and nutrient concentrations from a tile drainage system that is representative of installations in the Red River Basin.
- Document sediment and nutrient concentrations from different types of tile outlets.
- Compare sediment and nutrient concentrations from tile drainage to the concentrations from:
    - Other tile drainage systems
    - Surface drained field ditches
    - Streams with minimal impact (natural background levels)
- Accurately study the effect that tile drainage has upon flow.
    - Peak flow volumes versus surface drainage
    - Total flow volume versus surface drainage
- Collect an amount of data that is sufficient for drawing conclusions.
- Provide information that can be used for decision making within the Red River Basin.

Benefits of Tile Drainage to the Farmers

It is well documented that tile drainage has many benefits to the farmers that install it. According to University of Minnesota Associate Professor and Extension Engineer Dr. Gary Sands and University of Minnesota Extension Service Regional Extension Educator Hans Kandel, some of these benefits come from an increase in crop yields and improved field conditions and include:

1. Increased Profits
2. Extended growing season
3. Decreased plant stress
4. Reduced wetness-related diseases
5. Decreased soil compaction
6. Decreased salts on the farmers' land
7. Increased infiltration
8. Less ditches needed within the field = more area to grow crops
9. Reduced soil erosion from runoff
10. Timely tillage, planting, and harvesting
11. Potential for no-till
12. Increase in land value

13. Treatment of salt-affected soils
14. Less energy use (wet areas "bog down" machinery)
15. Financial risk management
16. Less hassle and stress…more sleep

Wild rice farmers and Red Lake Nation Department of Natural Resources staff point out the fact that main line tile drainage also has benefits for wild rice farming. Benefits are greatest when the main line of the tile system is directly connected to a water control structure. These benefits include but are not limited to:

1. More evenness of rice quality and maturity
2. Less ditch maintenance
    a. No internal ditches (see photo on following page)
    b. Less sediment loading
3. Fewer ruts during harvest (see photo on following page)
4. More control over drainage
5. No top soil loss
6. Ends of tile outlets don't get plugged if main line tile is used instead of internal perimeter ditches

Figure 1. Installation of wild rice paddy tile drainage

Concerns Identified by Previous Literature

- Nitrate (N) loss and discharge
- Effects on wetlands
    - Interception of lateral groundwater movement
    - Drainage of semi-permanent or seasonal wetlands with a ditch or a pipe inlet.
        - These are used by shorebirds and waterfowl during spring migration.
    - Hickenbottom surface inlets are used to drain depressions. The presence of a surface inlet provides strong evidence that there may have once been a wetland at the site that has been drained.
- Tile drainage may increase peak flows when installed under certain conditions.
    - When installed in permeable, well drained soils.
    - When installed with surface inlets
- Will tile drainage increase the duration of effective discharge (channel-forming flow – largest sediment load) in rivers?
- Southern Minnesota research has shown that modern drainage and tiling has increased flows and incision in the Minnesota River watershed
- Changes in flow regimes may affect in-stream biota
- Water treatment costs to remove nitrates
- Hypoxia in the Gulf of Mexico caused by excess nitrogen
- Surface inlets create a direct pathway for runoff, sediment, and nutrients to rapidly enter a waterway.

Types of Tile Drainage Outlets

<u>Gravity Tile Outlets</u>

Gravity tile outlets are the most basic form of tile drainage outlet. It simply involves allows the ends of each tile line or the end of a main-line tile to drain into a waterway. There are no structures at the end of the pipe. For this system to work properly there has to be suitable outlet into which the tile can drain.

Pumped Tile Outlets

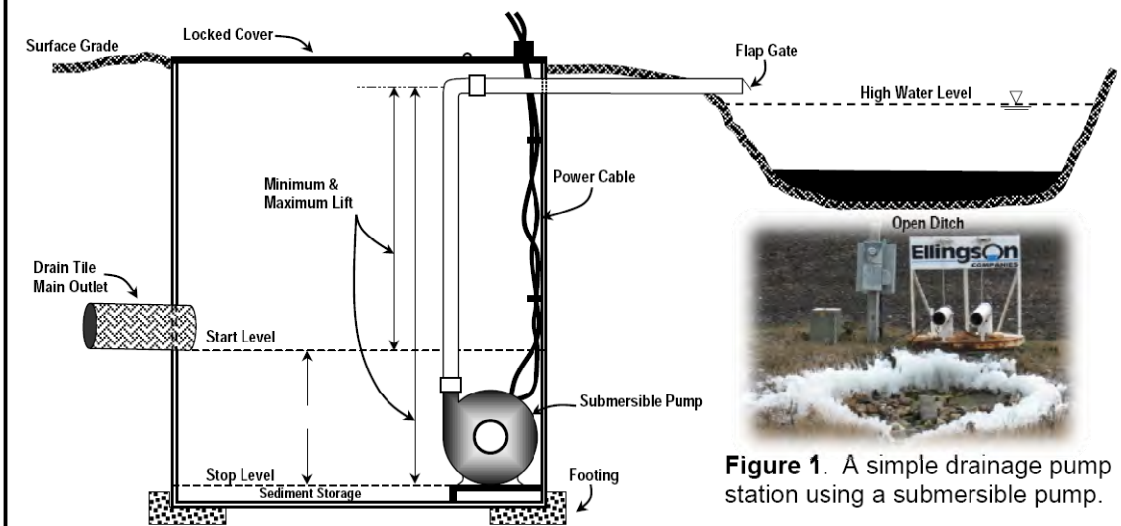


Figure 1. A simple drainage pump station using a submersible pump.

Pumped tile outlets are used when there isn't a natural gravity outlet or if it is not permissible to deepen the receiving waterway. There is usually a plunge pool or rip-rap at the outlet. These outlets add expenses to the tiling operation (equipment, energy, maintenance). Storage (start level to stop level) is incorporated each pumped outlet system. This storage is meant to reduce wear on the pump motor, but could theoretically have slight benefits to water quality (denitrification) and hydrology (storage of water to mitigate peak runoff). The storage below the bottom water level is used to allow for sediment storage.

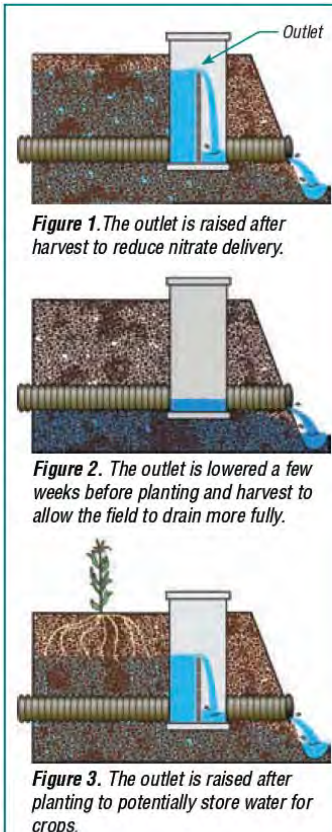


Figure 1. *The outlet is raised after harvest to reduce nitrate delivery.*

Figure 2. *The outlet is lowered a few weeks before planting and harvest to allow the field to drain more fully.*

Figure 3. *The outlet is raised after planting to potentially store water for crops.*

Controlled Drainage

Controlled drainage is a form of drainage water management that uses a control structure on a tile outlet (usually a main) to vary the depth of drainage. This drainage strategy is meant to conserve as much nitrogen in the field as possible by reducing the amount of nitrate lost through subsurface drainage. Basically, water is drained only as deep as necessary, dependent upon the time of year. Controlled drainage has a great potential for reducing nitrate discharge by reducing the total volume of drainage outflows and increasing the anaerobic zone for denitrification.

Red River Basin Water Quality Issues

Many streams and rivers within the Red River Basin, especially within the Red River Valley ecoregion, have elevated concentrations of sediment. Many of these streams are listed on the MPCA's 303(d) List of Impaired Waters as being impaired by turbidity. Eutrophication within Lake Winnipeg due to excess phosphorus loading is another major problem within the Red River Watershed.

Flooding is, of course, a problem in the Red River Basin. A key strategy to reducing flood severity is the reduction of peak flows. Flashy flows with high peaks also increase streambank erosion and sediment concentrations in rivers.

Eutrophication on Lake Winnipeg's Grand Beach

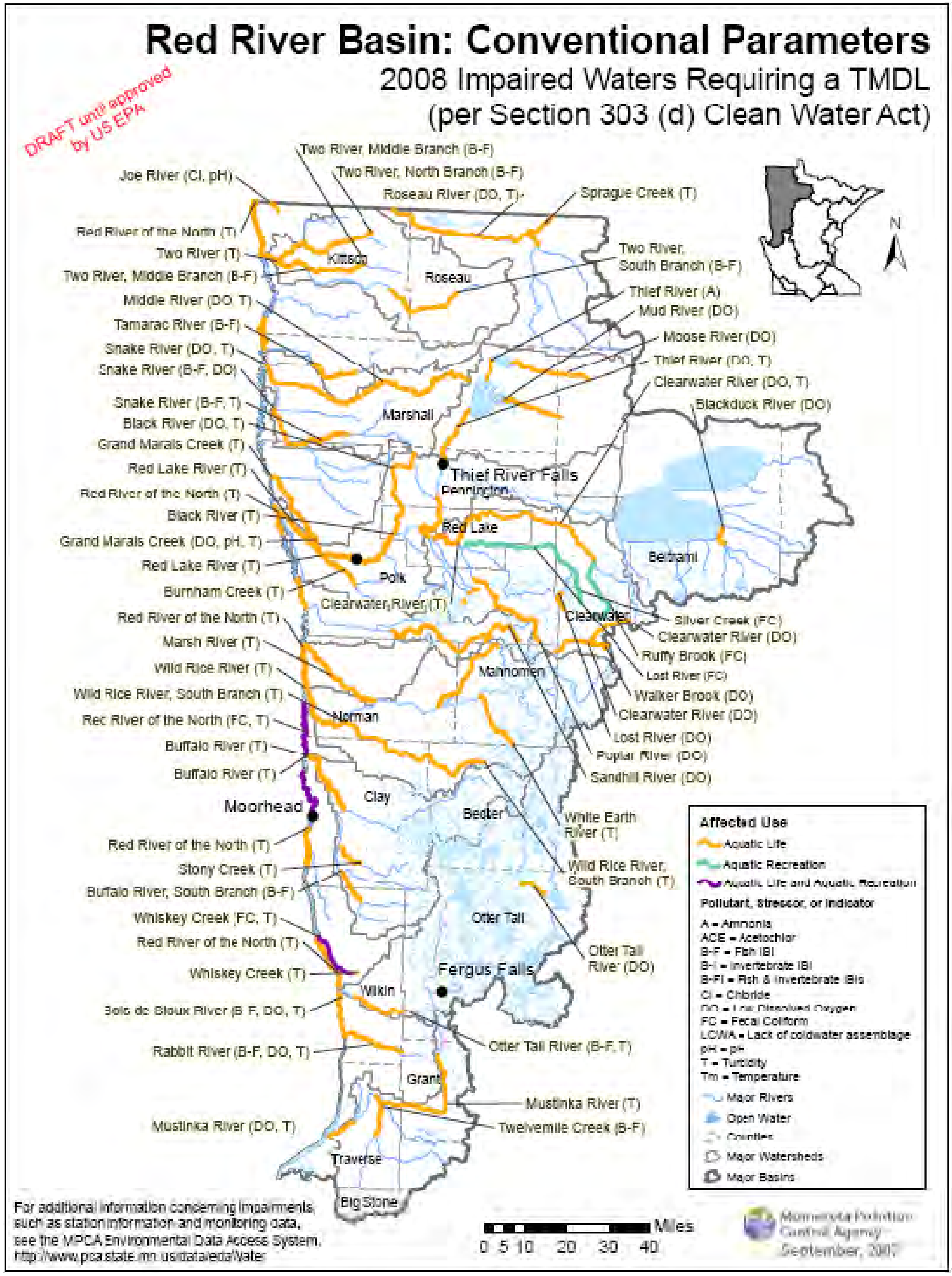


Figure 2. Red River Basin Water Quality Impairments

Project/Task Description

Project Area

This project focuses on tile drainage data from within the Red River Basin. Most of the information collected prior to this study was from outside of the basin where there are different landscapes and tiling practices. This study took place, specifically, within the Red Lake Watershed District and within the Thief River and Clearwater River major subwatersheds.

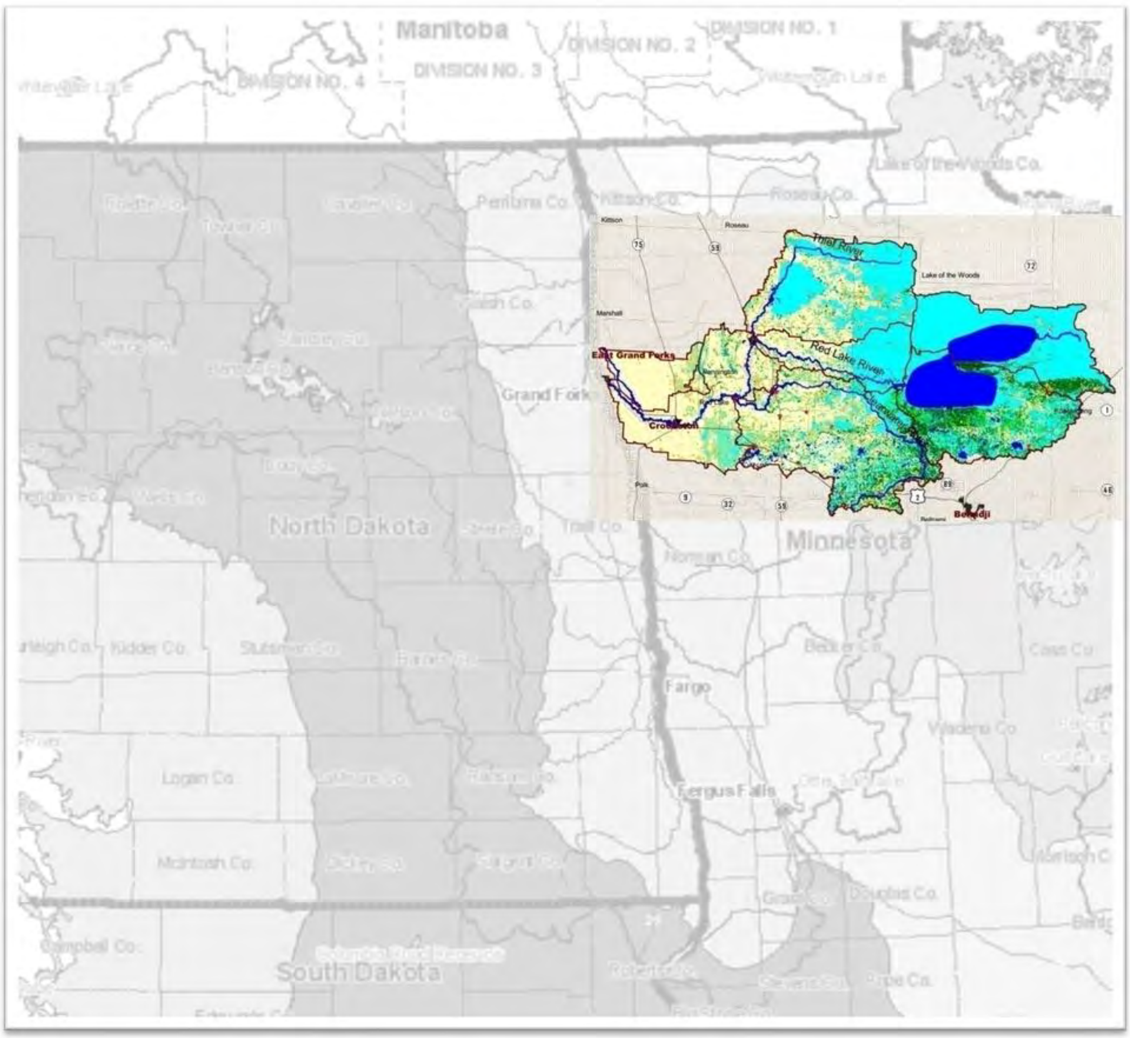


Figure 3. RLWD Location in the Red River Basin

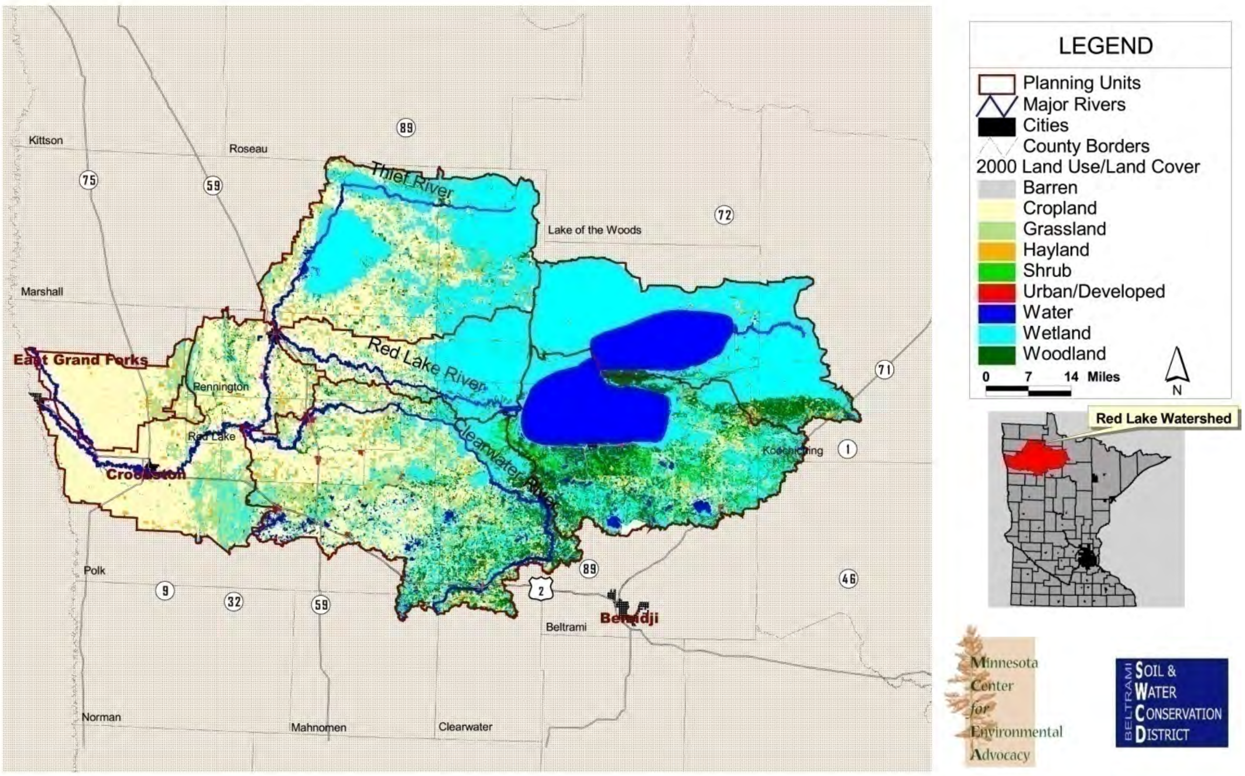


Figure 4. Red Lake Watershed District Map

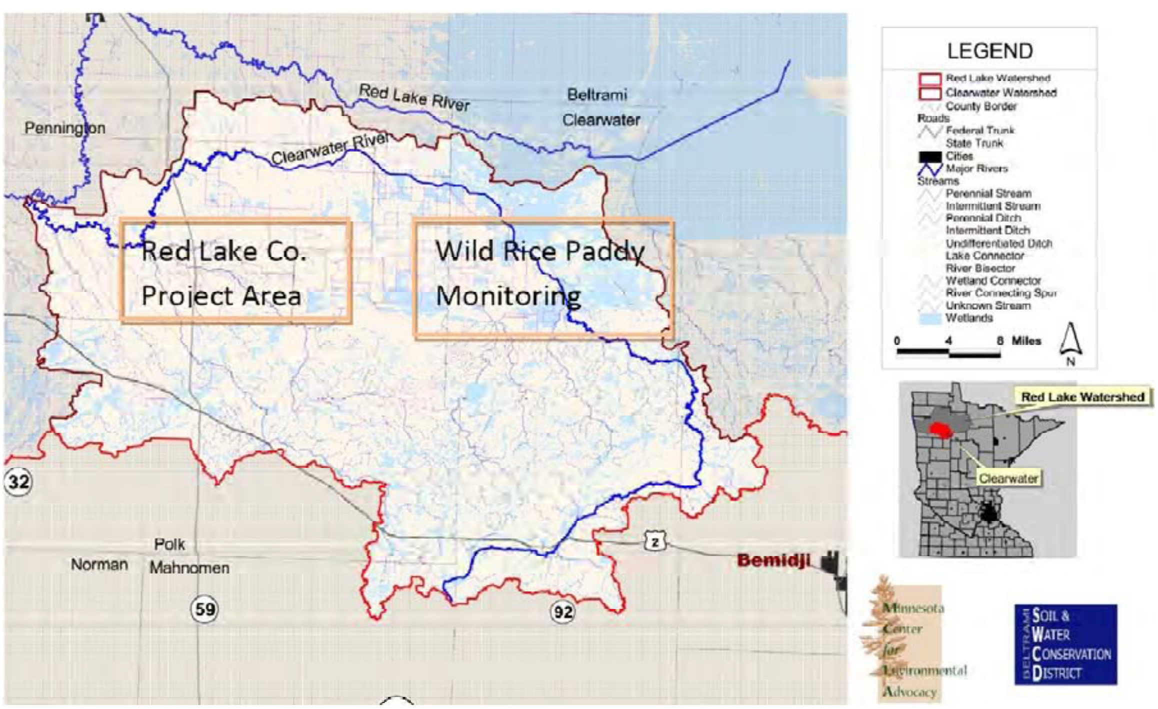


Figure 5. Clearwater River Watershed Map

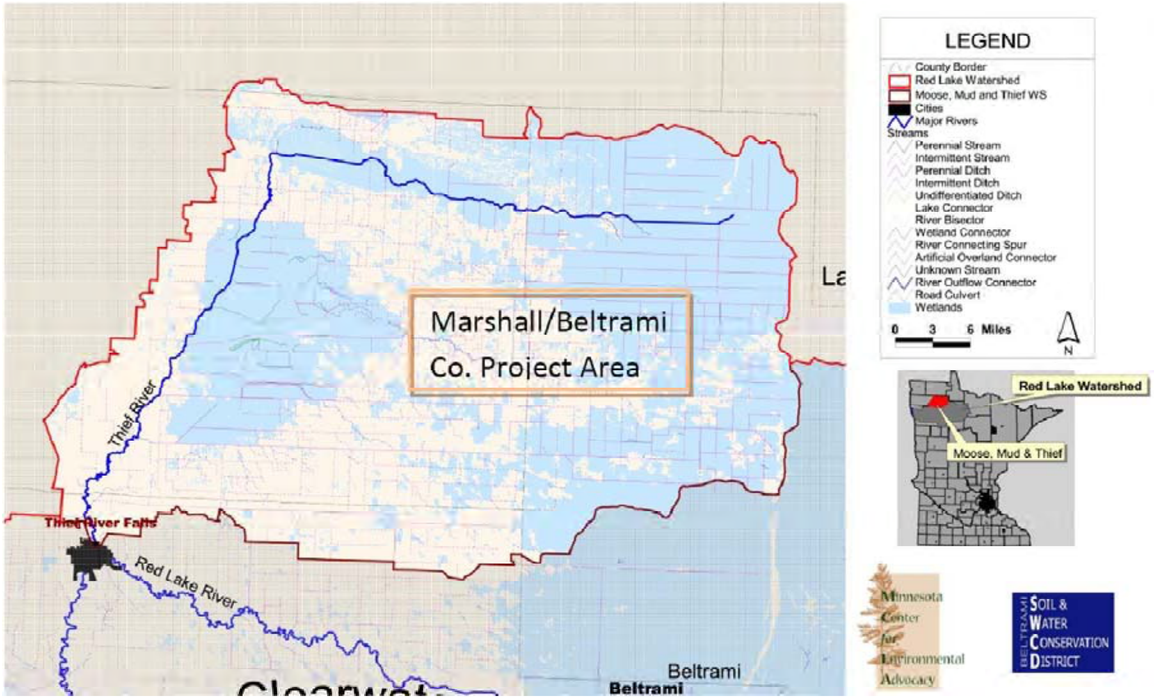


Figure 6. Thief River Watershed Map

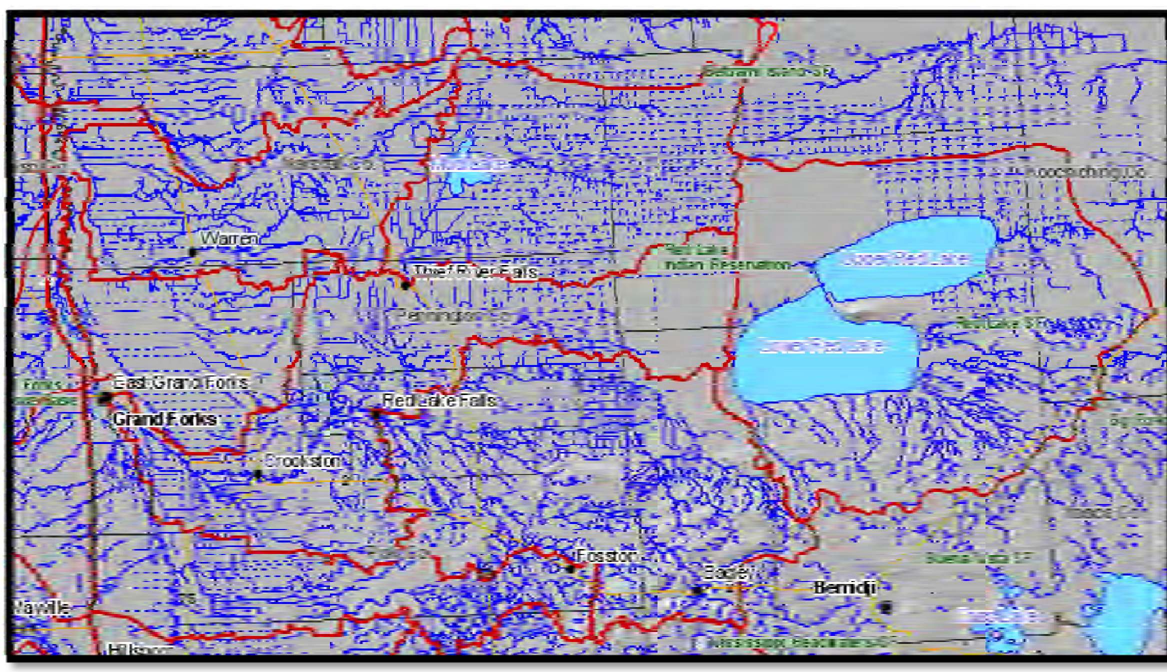


Figure 7. RLWD Shaded Relief and Streams

Much of the Red River Basin has a flat topography and was once the lake bed of glacial Lake Agassiz. In southern Minnesota, surface inlets are used to drain ponded areas in more uneven topography. Because of the flat topography in the Red River Basin, pattern tiling can provide even drainage throughout the field without the use of surface inlets. This study focuses on tile installations **without** surface inlets.

The monitoring sites in Red Lake County lie within the Red River Valley Ecoregion. The tile monitoring sites near Grygla, within the Thief River watershed, are in the Northern Minnesota Wetlands Ecoregion. The Red Lake Nation wild rice paddy monitoring sites are located near the eastern boundary of the Red River Valley Ecoregion.

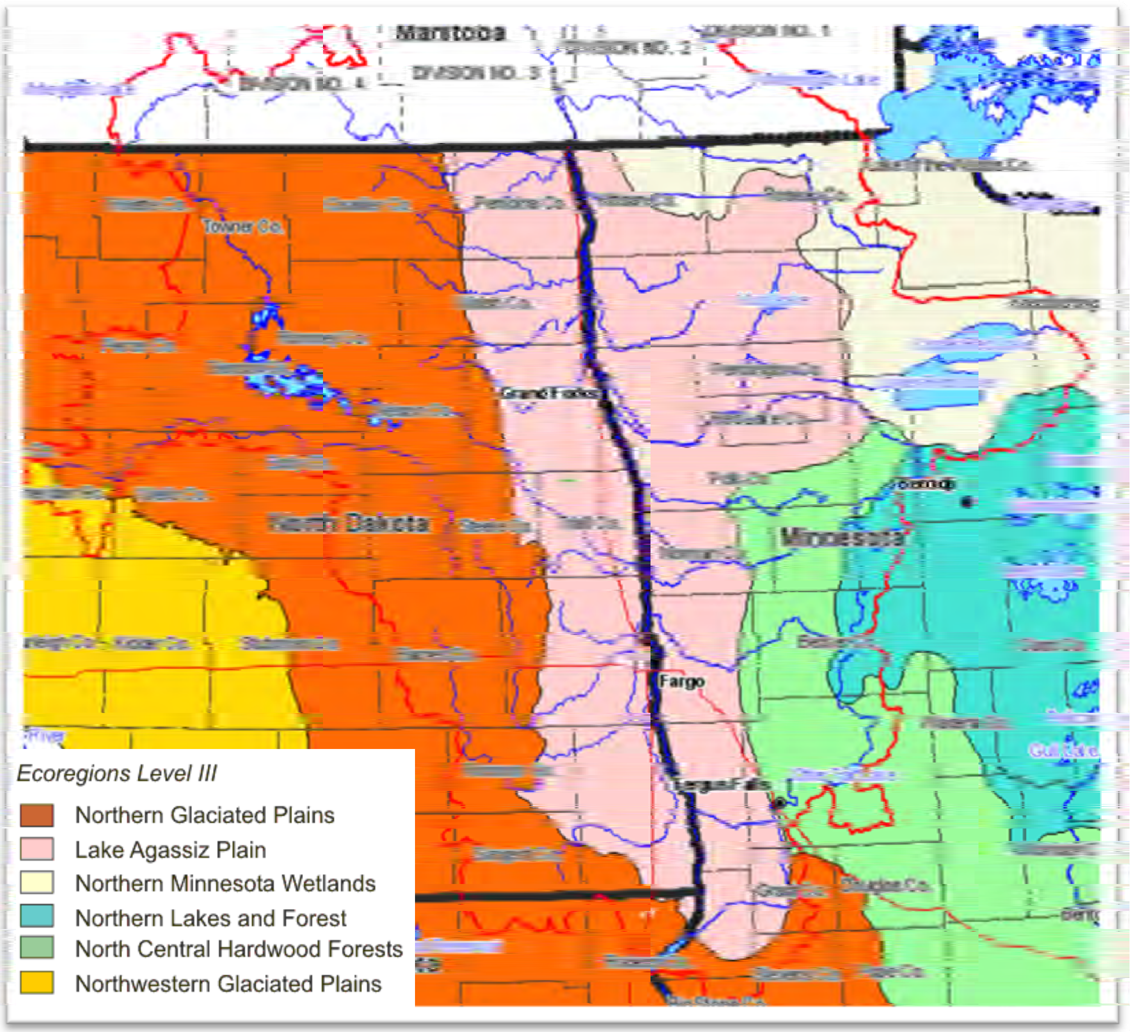


Figure 8. Red River Basin Ecoregions in Minnesota and North Dakota

Sampling Sites

Monitoring for this project is essentially taking place in three areas. These areas include:

- Red Lake County – near the town of Brooks
- Clearwater County wild rice paddies along the Clearwater River north of Gonvick
- Marshall County – near the town of Grygla.

The Red Lake County sites on Bachand and Yaggie land will be used to monitor water quality and quantity. The sites are located east of Brooks, MN in Red Lake County. The flow monitoring at the Red Lake County sites is sponsored by the Red River Watershed Management Board and involves installation of specialized flow measurement structures. The flow monitoring is directed by Nate Dalager from HDR Engineering for the Red River Watershed Management Board. The RLWD conducts regular water quality monitoring at these sites and provides assistance to the water quantity monitoring part of the project. These sites will monitor the following types of agricultural drainage:

- Surface drainage from a surface drained field
- Tile drainage
- Surface drainage from a tiled field

The Clearwater County monitoring sites compared water quality among different drainage systems and outlet types in wild rice paddies. Red Lake Nation rice paddies were monitored in 2005 and 2006. The types of drainage compared were:

- Surface drainage via internal ditches
- Pattern tile drainage with regularly spaced outlets that discharge into internal perimeter drainage ditches
- Main line tile drainage **without** internal surface drainage ditches. The main line tile brings water through the paddy's dike and into a ditch (which ideally would be well maintained and stable).

The sites in Marshall and Beltrami County are located within 7.7 miles of each other and compare water quality among:

- Gravity tile
- Pumped tile
- Surface drainage

- Natural background (non-impacted)

TheMarshall/Beltrami County sites are primarily monitored by Lisa Newton of the Marshall-Beltrami County Soil and Water Conservation District.

Site Descriptions

Red Lake County Sites:

Bachand Tile + Surface.

This site was monitored and sampled at the beginning of the project before it was possible to sample surface and tile drainage separately from this field. Samples and field measurements were taken from the upstream end of the culvert. The water at this site originated from both surface and tile drainage. Samples are no longer collected here, but instead are collected separately at the Bachand Surface and Bachand Tile monitoring sites. This site and the Bachand Tile and Bachand Surface sites are located along Hwy 92, east of Brooks, Minnesota. This field is located in Section 8 of Lambert Township in Red Lake County. Water quality samples were collected where flow from the Bachand field crosses Highway 92 on the south side of Section 8.

Fertilizer application on the Bachand field during the study has been:

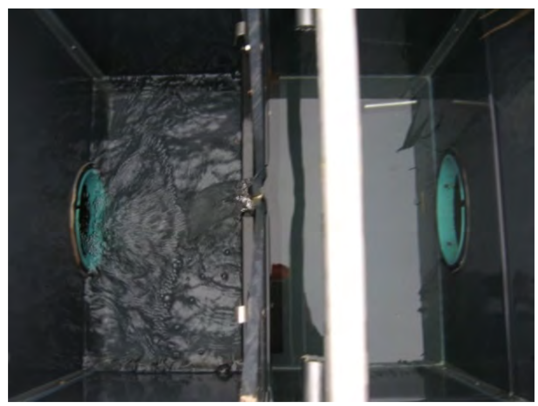
- 2005: 15N – 30P – 60K dry applied with seed plus 100 units of anhydrous ammonia.
- 2006: No fertilizer

The crops grown on this field during the study have been:

- 2005 – Spring Wheat
  - Planted on April 14th
  - Harvested on August 25th
- 2006 – Soybeans
  - Planted on May 15th
  - Harvested on September 20th

- 2007 – Soybeans
- 2008 - Wheat

Bachand Tile



This is the water control structure that was installed on the end of a main line tile line. Field Drainage, Inc. of Brooks, Minnesota installed the structure. Water comes into the structure through the tile line, flows over a v-notch weir, and then exits the structure through a short length of pipe. A HOBO Water Level Data Logger is placed on the bottom of the field (upstream) side of the water control structure to collect a continuous record (1 measurement every 15 minutes) of water levels within the water control structure. This water level data can be translated into flow using a table and/or equation for calculating flow over v-notch weirs. A rating curve has been developed for the weir within this structure.

The tile drainage at this site was installed in 1995. The tiles were placed at about 40 inches deep with 120 foot spacing. The longest run of tile line in the field is ¾ mile. The diameter of the outlet pipe is 8 inches.

Field measurements for dissolved oxygen, conductivity, temperature, and pH can be taken at this site, with some caution. The probe was rinsed with water flowing over the weir before it was placed into the water pooled on the upstream side of the weir.

Bachand Surface

This monitoring site is used to monitor the surface drainage from the Bachand field. An h-flume was installed to catch and measure any surface runoff that comes from the Bachand field. Dip samples can be taken from the end of the structure. There is a HOBO Water Level Data Logger installed within the stilling well on the side of the structure to collect a continuous record (1 measurement every 15 minutes) of water levels within the flume. Level logger readings are correlated with manual measurements of water depth at the end of the flume. The water level data can be translated into flow using a table and/or equation for calculating flow through an h-flume.

The stilling well has a locking cap that is secured with a RLWD padlock. Some landscaping has been done to ensure that water coming from the field funnels through the structure. Erosion control fiber blanket was installed around the structure to minimize erosion from ground disturbed during installation.

The site is affected by backwater from the Hill River. A decision was made to raise the structure after the 2007 monitoring season in order to continue monitoring and have more confidence in the data. This was accomplished in the spring of 2008 and successfully maintained a level of head above the tail-water and reduce erosion.

Yaggie 1

We needed to find a surface drained field nearby the Bachand field in order to make valid water quality and flow comparisons. This was actually the second site that was seriously considered as a surface drained site, but the first surface drained site in Red Lake County where samples were collected. The first site considered was south of Hwy 92 on a field owned by Keith Swenson - near a University of Minnesota tile drainage research plot. When it was determined that the Swenson site would not work for accurate flow measurement without adverse affects to the farmer’s crop, new sites were scouted for the project. The next choice was the Yaggie 1 site. The site is located on the north side of Section 1 of Poplar Township in Red Lake County, just east of the middle of the north end of the section. This monitoring site receives water from surface drainage on Kevin Yaggie and LeRoy Robert Carriere land. Initially, the outfall end of the culvert looked like a good place for a flume. Unfortunately, when water levels in the Lost River rose during a runoff event shortly after we started monitoring, we learned that the river water rises to the level of the culvert. This would make unobstructed flow measurement impossible during periods of high flow. The downstream end of the culvert is lower because of the drop structure on the upstream end. This site was abandoned in favor of Yaggie 2.

Yaggie 2

This site is located west of Yaggie 1 along a township road in Poplar River Township. There is more of a fall between the downstream end of this culvert and the Lost River than there is at the Yaggie 1 site. This topography allows for unobstructed flow through the h-flume. Therefore this site became the official site for measuring flow from a surface-drained field. The h-flume used for flow measurement and this site is identical to the one at the Bachand Surface site. This site is located along north side of Section 1 of Poplar Township in Red Lake County, near the northwest corner of the section. The rear of the flume was sealed with Quikrete to make sure the water would flow out of the correct end of the flume.

Clearwater County Wild Rice Paddy Sites:

RLN Surface

This site is the outlet of a Red Lake Band of Chippewa wild rice paddy that is drained only by internal surface ditches. Samples were collected at the water control structure where water was discharged from the paddy. This is a good site for flow measurement because the water control structure exhibits weir flow. Flow was measured using a HOBO Water Level Data Logger housed within a stilling well that was attached to the side of the water control structure. An additional HOBO Water Level Data Logger was suspended within the stilling well for the collection of data for barometric compensation for the area. This wild rice paddy discharges directly into the Clearwater River. This outlet is located near the northeast corner of Section 22 of Hangaard Township in Clearwater County.

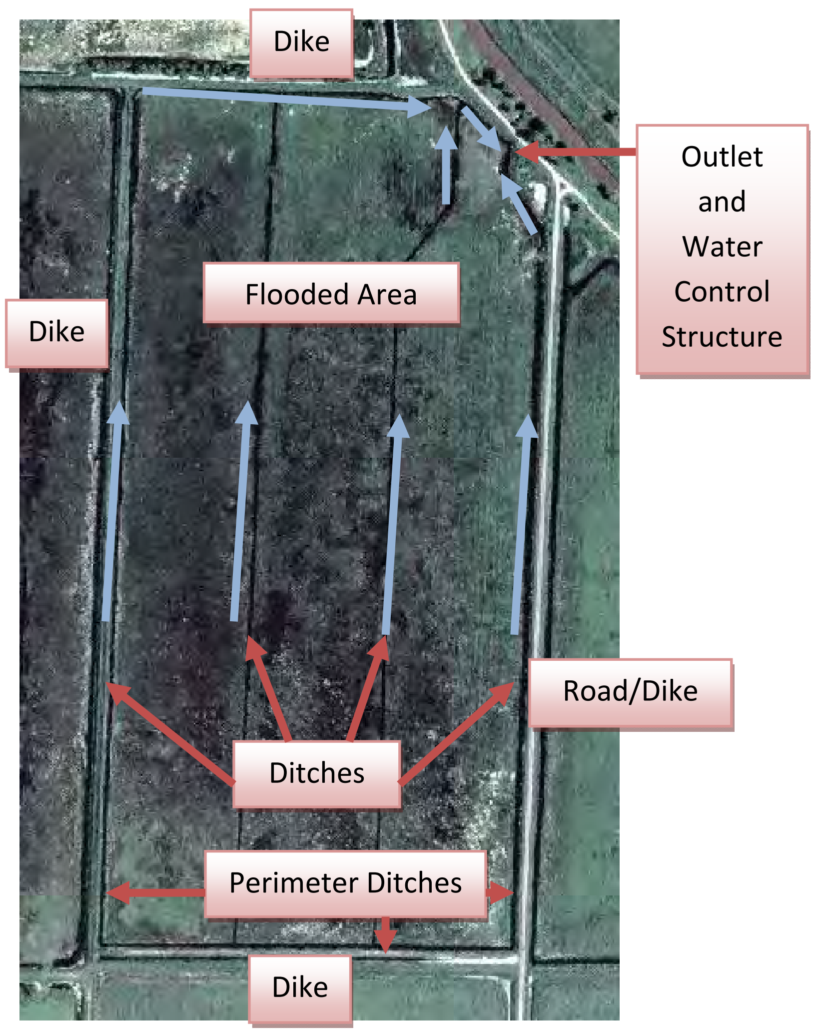


Figure 9. Surface drained paddy aerial photo and diagram.

RLN Tiled

This site is located at the outlet of a Red Lake Band of Chippewa wild rice paddy that has tile drains within the paddy that drain into internal perimeter surface ditches. These ditches carry water along the inside of the dike surrounding the paddy toward an outlet on the NE corner of the paddy. Due to backwater from the next paddy, this site didn't consistently exhibit weir flow, so flow wasn't reliably quantifiable at this site. The outlet structure of this paddy is located on a dike that runs east-to-west just off of the west side of a minimum maintenance access road that runs north-to-south along the border of Sections 34 and 35 of Hangaard Township in Clearwater County. The outlet structure and dike are located just north of the midway point of Section 34 of Hangaard Township.

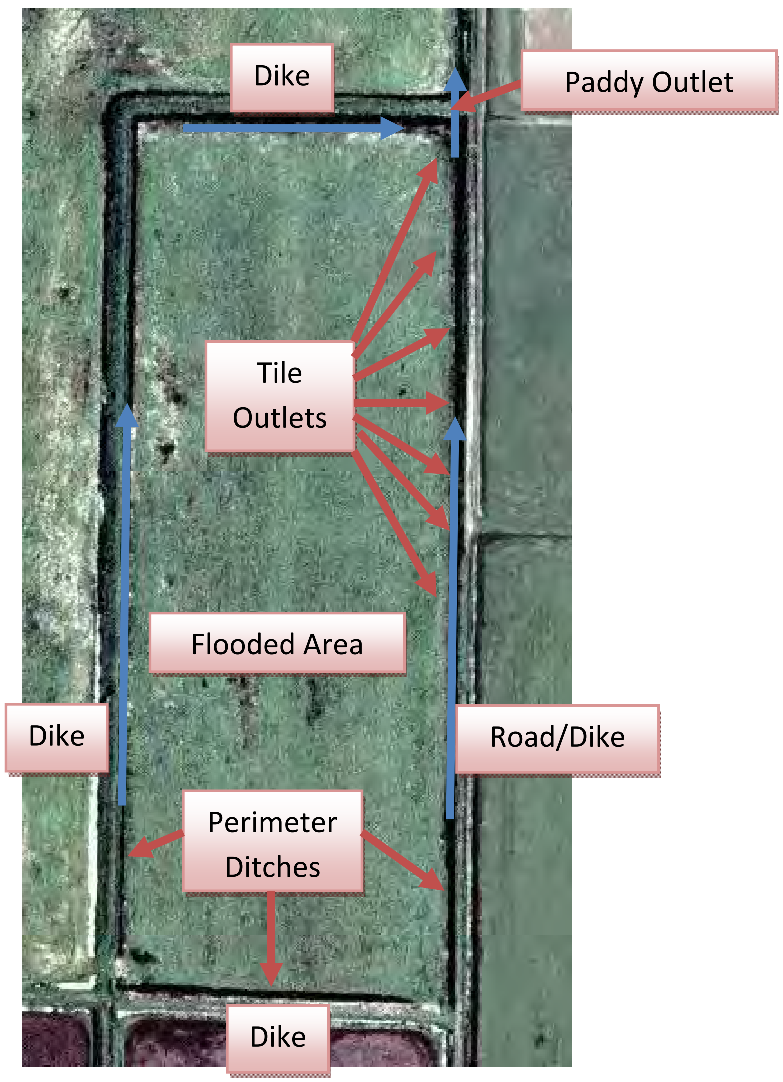
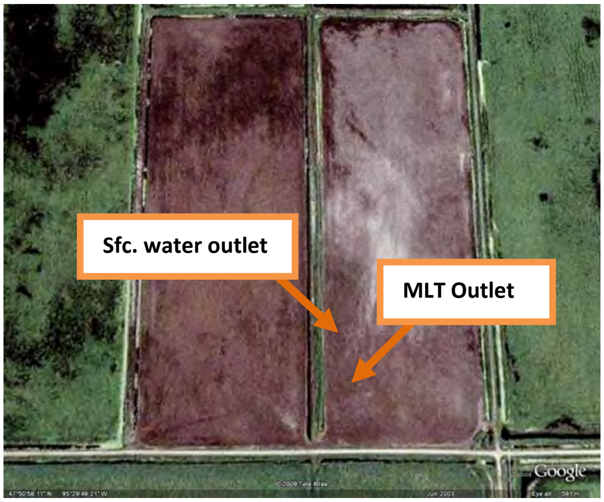


Figure 10. Diagram of a tile drained field with internal perimeter ditches.

RLN Main Line Tile

This water control structure drains water from a paddy in which tile lines drain into a main line tile. The main line tile is directly connected to an outlet structure and surface drainage ditches within the paddy are eliminated. The main line tile is extended through the dike (which is a road) and the connected water control structure is on the opposite side of the dike from the paddy. The control structure releases water into a ditch that flows to the Clearwater River. The structure is located on the north side of the northwest corner of the northeast corner of Section 3 of Winsor Township in Clearwater County, along the south side of the road that runs along the border of Winsor and Hangaard Township. The system does not need interior surface ditching. So it does not have the erosion problems exhibited by the other paddy drainage systems.

Note the lack of ditches and ruts in this harvested paddy.



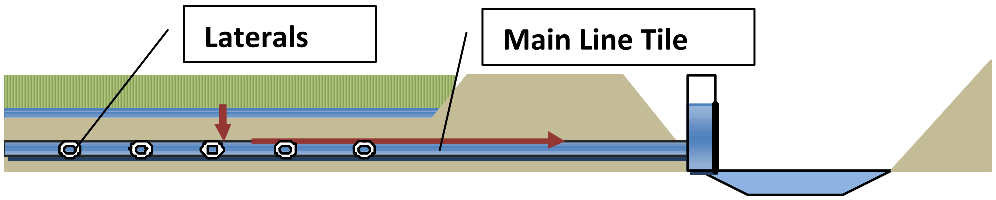


Figure 11. Diagram of a Red Lake Nation Main Line Tile System and Outlet.

This type of system is ideal, but it may not be possible to remove all surface ditches from within the paddy in all cases. There often is a separate structure on these systems that handles the topmost surface water. The surface drainage structure is used to bring the water down to a certain point. The main line tile is used to drain the paddy the rest of the way down to the desired level.

Clearwater Rice

This wild rice operation is owned by (State Senator) Rod Skoe. Don Barron, a retired soil scientist and advocate of this project, is also involved with this wild rice operation. Tile drainage was installed on this farm as part of the Implementation Phase of the

Clearwater Nonpoint Study Clean Water Partnership project. Several candidate sites were examined at this farm for use in this study. The small size of the structures, unfortunately, was not conducive to flow monitoring or water sampling. Flow monitoring wouldn't be possible without interfering with the operation of the structures. The structures are also narrower and placed within the dike so it was difficult to collect a sample (even with a vertical Kemmerer sampling device) without disturbing the rust that lines the inner walls of the structure. Only one sample was collected in 2005 from a main-line tile outlet.

Marshall County Sites:

Stanley GT1 and Stanley GT2 (Gravity Outlets)

These sites monitor water quality concentrations from gravity tile outlets on a Stanley Farms field. This field is drained by regularly spaced drain tiles that outlet into a township ditch along County Hwy 54. GT1 was initially the most visible and easily sampled of the tile outlets. It can be accessed by driving on a trail along the edge of the field that begins in Arnold Stanley's yard. It is approximately 890 feet north of the farmstead and south of the third power line pole north of the farmstead.

GT2 is located near County Road 55 on the north side of the field. It is northernmost tile outlet on this field. GT2 is not as easy to access as GT1 during wet periods. During wet periods, it is necessary to walk across a wet township road ditch and the water level in the receiving ditch may be high enough to cover the tile outlet. It was sampled more frequently because it runs longer into dry periods than GT1. So, GT1 will be sampled during wet periods (or whenever it is flowing) and GT2 will be sampled during dry periods (or whenever GT1 isn't flowing). These sites are located on the west side of Section 13 of Valley Township in Marshall County. They are on the east side of County Highway 54 and are along the field north of Arnold Stanley's home.

The tiling system on this field was installed in the year 2000. The depths range from 3.5 to 6 feet. The spacing is approximately 100 feet. Each of the 50 tile lines installed in the field is 2,500 feet long.

Crops grown on this field during the study were:

- 2005 – Canola, planted on April 20th
- 2006 – Soybeans, planted on May 16th

Fertilizer application on this field during the study has involved:

- 125N – 30P – 60K applied at seeding in 2005
- 30P – 60K applied at seeding in 2006\

Sparby – Surface Drained Field

This field is surface drained and a portion of the field flows to a single point, through a culvert, and into a township ditch. Samples are collected at the outfall of the downstream end of the culvert. This site is located on the west side of Section 7 of Valley Township in Marshall County. The Sparby monitoring site does have a small drainage area. So, surface runoff events and sampling opportunities have been infrequent at the site.

Beltrami County Sites:

Stanley PT (Pumped Outlet)

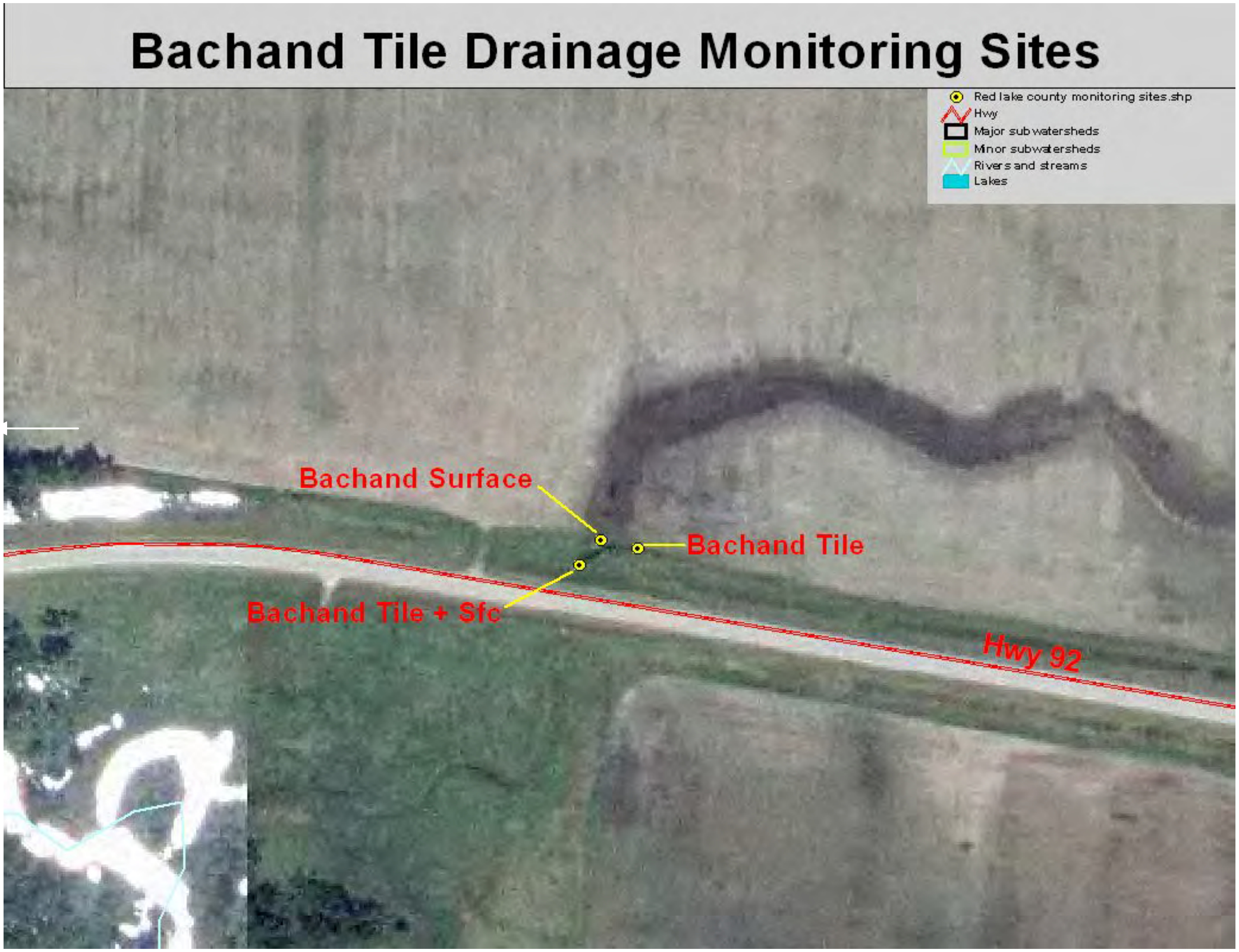
This is a Stanley Farms' pumped tile outlet. Samples are collected at the end of the black corrugated outlet pipe while the pump is running. The pump can be triggered to run by opening the cover to the reservoir and raising the float. A new pump was installed in the fall of 2005. Samples are collected from the pump that is closest to the road (first pump installed). This site is located where Sections 12 and 13 of Marshall County and Sections 7 and 18 of Beltrami County meet. The pumps are along the north side of Marshall County Highway 55/Beltrami County Highway 44 (gravel road) at the section line.

Wheat was grown at this site in 2006 and was harvested by early August.

Beltrami Natural

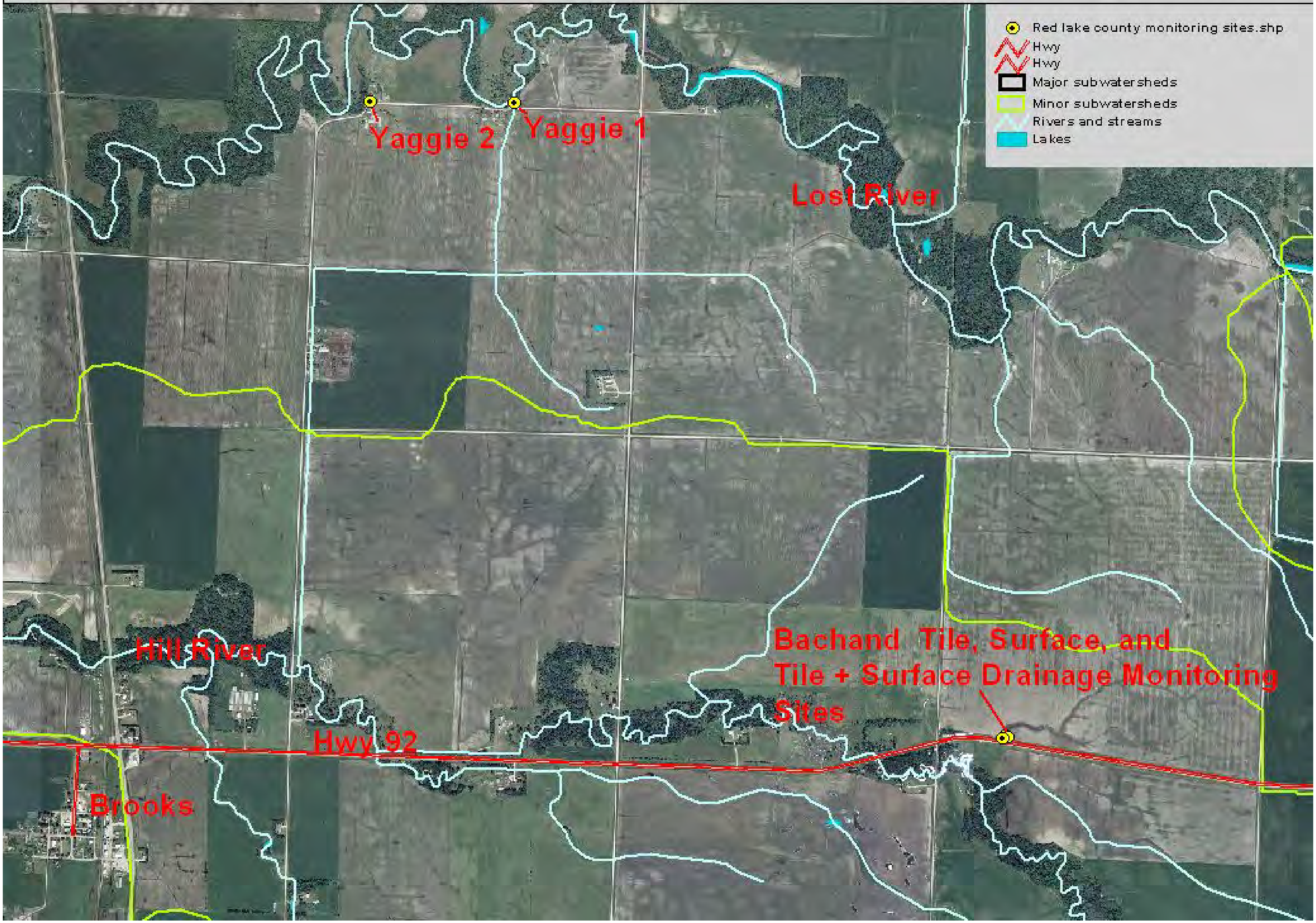
This site is used to collect data on natural background water quality concentrations in the Marshall-Beltrami County area. The water that flows through this site comes from forested public land on the east side of the project area. The monitoring site is located where Benwood Road NW turns north along the north side of Section 3 of Benville Township.

Maps

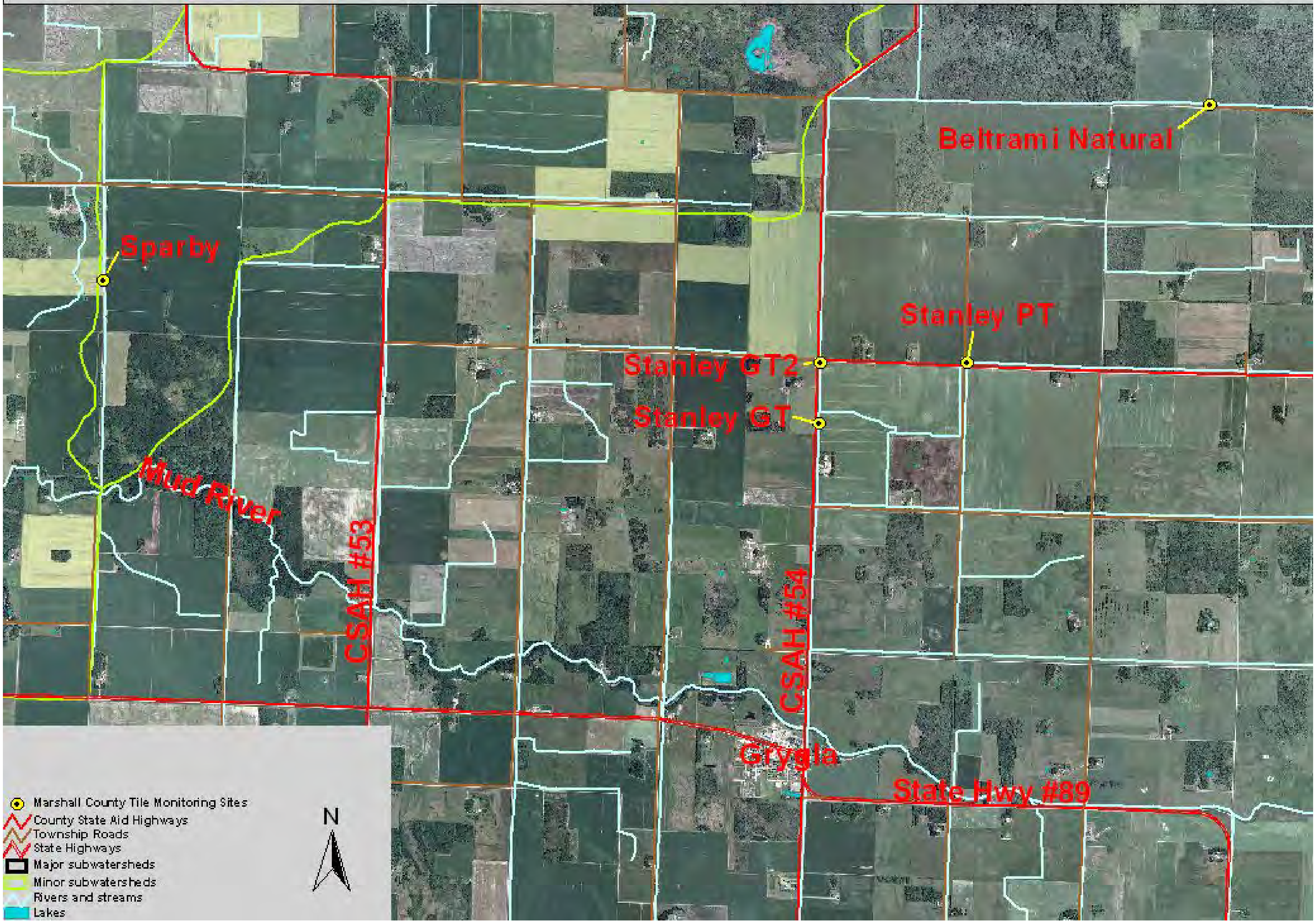


Bachand Tile Drainage Monitoring Sites
Red lake county monitoring sites.shp
Hwy
Major subwatersheds
Minor subwatersheds
Rivers and streams
Lakes
Bachand Surface
Bachand Tile
Bachand Tile + Sfc
Hwy 92

Red Lake County Tile Drainage Monitoring Sites

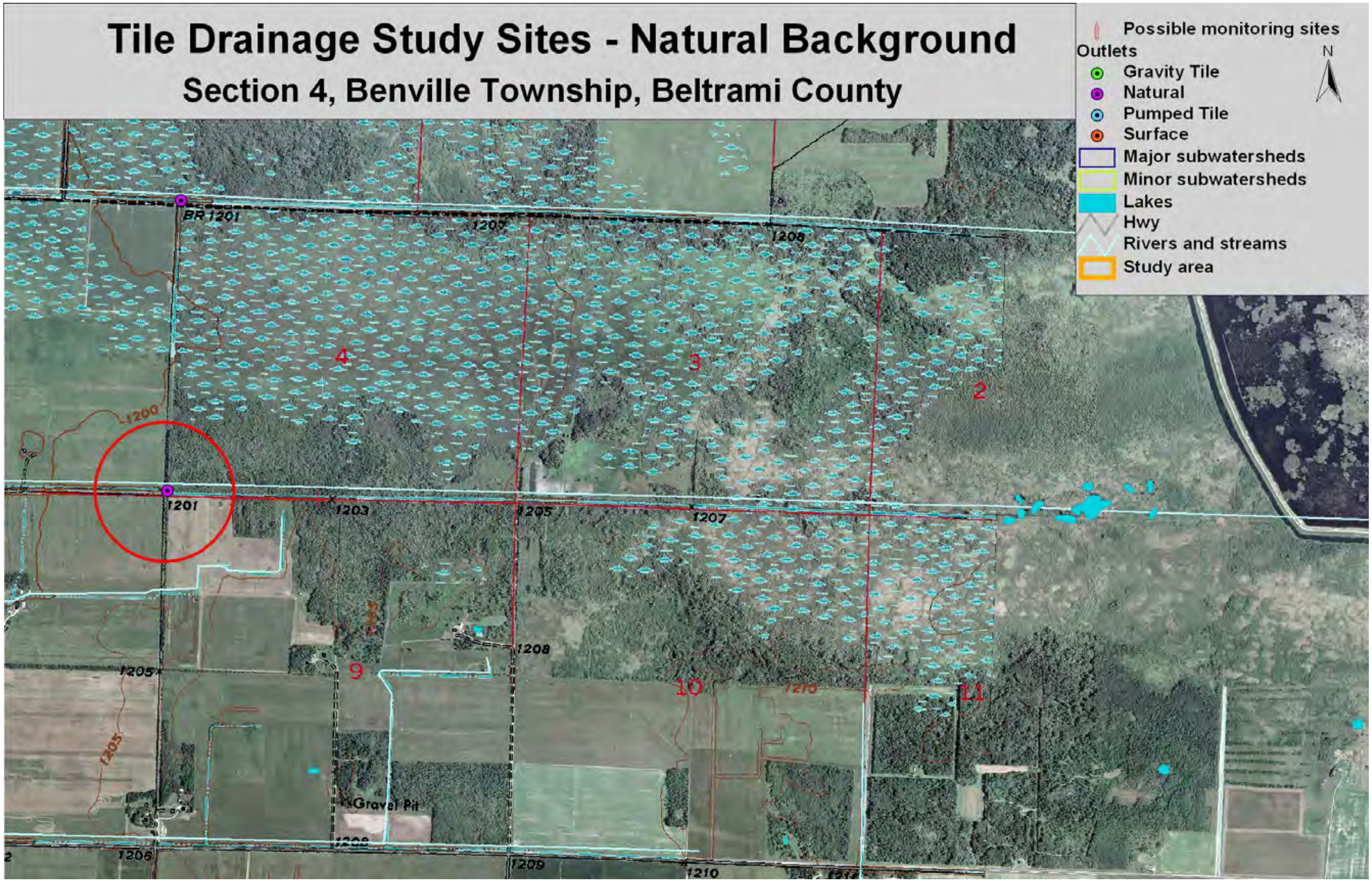


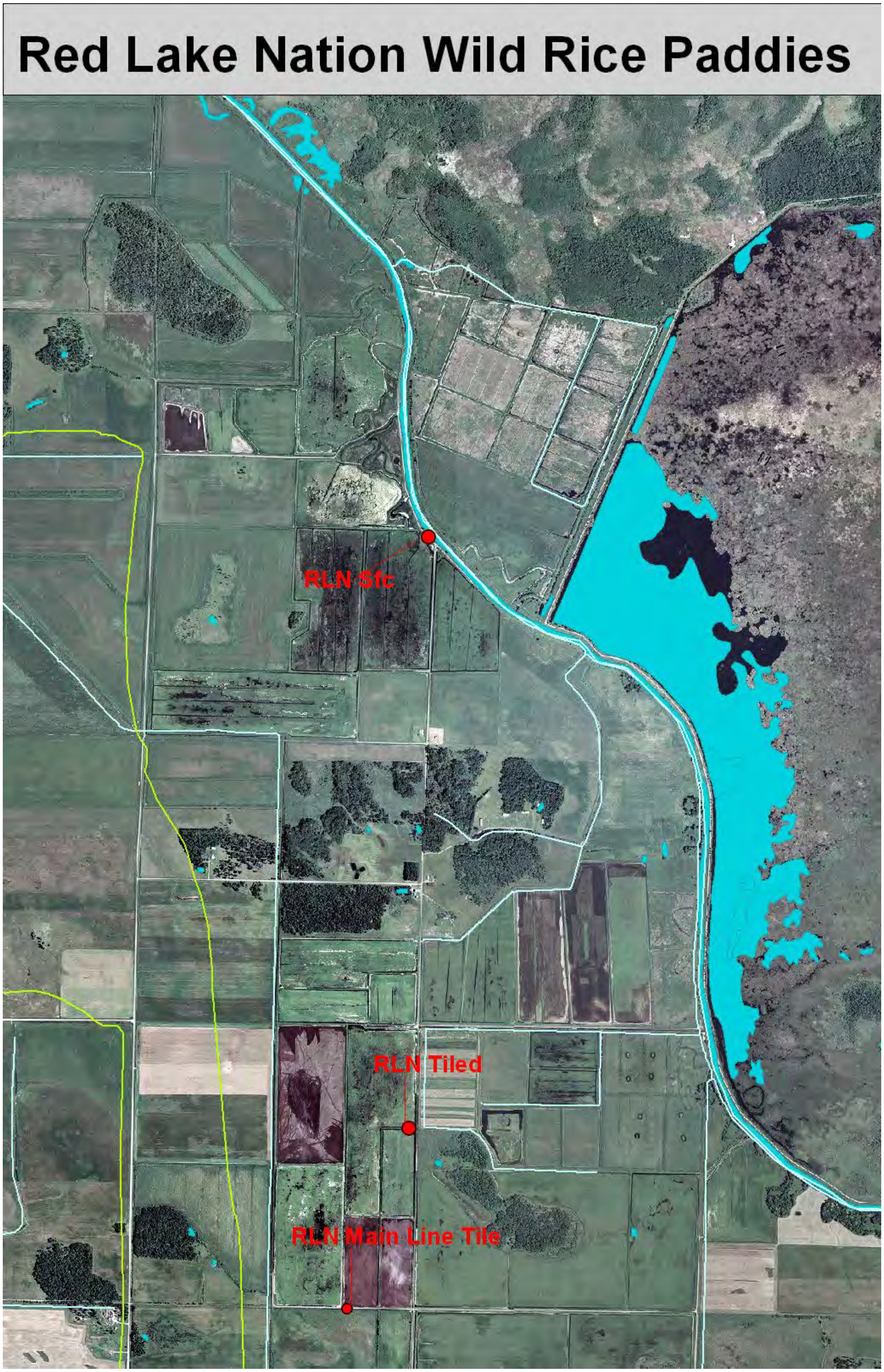
Marshall/Beltrami County Tile Drainage Monitoring Sites



Tile Drainage Study Sites - Natural Background

Section 4, Benville Township, Beltrami County




Red Lake Nation Wild Rice Paddies
RLN Sfc
RLN Tiled
RLN Main Line Tile

Site Photos

Bachand Site – Tile and Surface Drained Field Monitored for Flow and Water Quality

Figure 12. Bachand Tile Drainage Water Control Structure

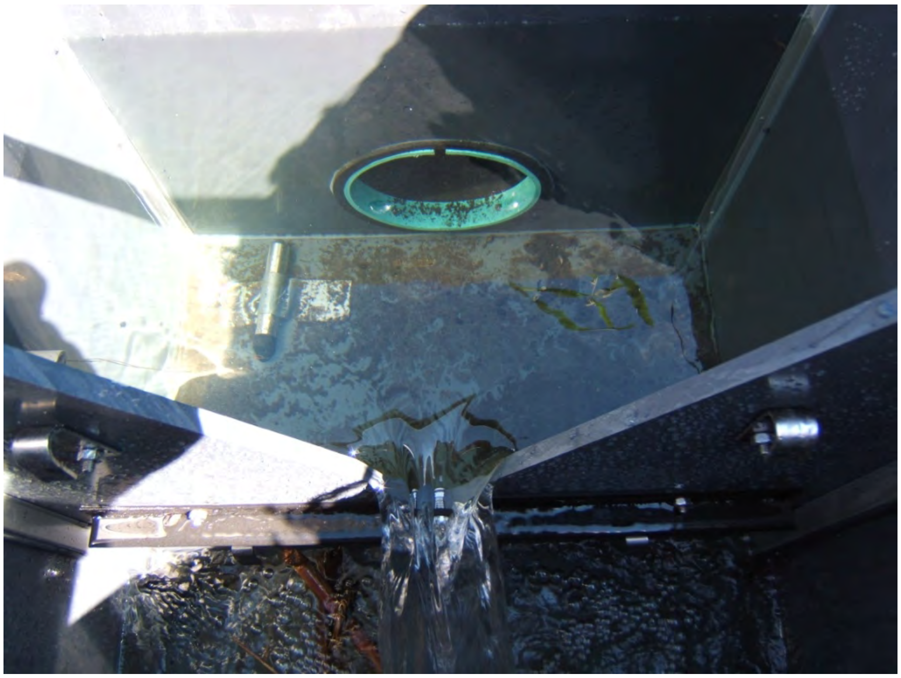


Figure 13. V-Notch Weir and HOBO Water Level Data Logger in the Bachand Water Control Structure

Figure 14. H-Flume for Surface Flow Measurement at the Bachand Site

Figure 15. Rainfall and Barometric Pressure Monitoring Equipment at the Bachand Site

Figure 16. Bachand Field, Post-Harvest 2005

<u>Yaggie 2 Site – Surface Drained Field Monitored for Flow and Water Quality</u>

Figure 17. H-Flume on Downstream End of Yaggie 2 Culvert

Figure 18. Upstream View from Yaggie 2 Monitoring Site

<u>Yaggie 1 Site – Surface Drained Field Dropped in Favor of the Yaggie 2 site</u>

Figure 19. Downstream End of Yaggie 1 Culvert

Figure 20. Drop Structure at the Upstream End of Yaggie 1 Culvert

Stanley GT – Gravity Tile Drain Outlet Monitored for Water Quality

Figure 21. Stanley GT1 Gravity Tile Monitoring Site

Figure 22. Stanley GT 2 Alternate Gravity Tile Monitoring Site

Figure 23. Stanley GT2 Tile Outlet

Stanley PT – Pumped Tile Outlet Monitored for Water Quality

Figure 24. Stanley Farms Pumped Tile Outlet

Sparby – Surface Drainage Site Monitored for Water Quality

Figure 25. Sparby Surface Drained Field

Figure 26. Culvert at Sparby Monitoring Site from Which Samples Are Collected

<u>Beltrami Natural – Unimpacted Site for Monitoring Natural Background Water Quality</u>

Figure 27. Beltrami County Reference Monitoring Site and View Upstream

RLN Surface – Wild Rice Paddy Drained with Only Interior Surface Ditches

Figure 28. Surface Drained Wild Rice Paddy, Outlet, and Stilling Well

Figure 29. Surface Drained Wild Rice Paddy Outlet Structure

RLN Tiled – Wild Rice Paddy with Tile Drains Emptying into Interior Surface Ditches

Figure 30. Pattern Tiled Wild Rice Paddy, Outlet, and Stilling Well

RLN Main Line Tile – Tile Drained Paddy with a Main Line Outlet and No Ditches

Figure 31. Main-Line Tile Drained Paddy - Note the Absence of Ditches

Figure 32. Main Line Tile Outlet Structure

Sampling Process Design

Site Selection

Priority sites were selected based upon whether or not all flow from a definable area of a field could be accounted for, preferably at a single monitoring site. In order to make valid comparisons, sites had to be reasonably close to each other and have similar watershed characteristics (soils, land use, topography). Even if a field is tiled, the surface drainage needed to be measurable as well. Such fields were considered for the flow monitoring part of the study that was being funded by the Red River Watershed Management Board. This was not an easy situation to find, particularly with pumped systems.

Many of the fields considered for the study had complicated flow patterns that couldn't be easily monitored at a single location, or even at just a pair of locations, flow monitoring at all water quality sites was not be feasible. Concentration comparisons using water collected directly from tile outlets can still be made. These concentrations can be compared to concentrations found within the rivers to which the drainage flows. They can also be compared with any standards that exist, such as State water quality standards, ecoregion nutrient standards, wastewater discharge standards, and drinking water standards. There is an argument that high concentrations of a parameter in a small amount of flow will have a minimal effect upon water quality in a large watercourse. A counter-argument is that the cumulative effect of a large number of small flows with high concentrations can definitely begin to affect water quality in a larger watercourse. So, as tile drainage expands within the Red River Basin, the concentrations within watercourses will begin to be increasingly affected by the concentrations from tile drainage. This study will give us a better idea of whether this affect will be positive and/or negative.

Addressing Comparability

The goals of the project involve comparing water quality from tile drainage to natural background and to surface drainage water quality. It is impossible to remove all variables that might affect comparability among monitoring sites in the real world. We strove to find sites with watershed characteristics that were as comparable as possible. Comparability can easily come into question if sites are located too far apart. Soils can vary spatially and rainfall can vary both spatially and temporally. Three clustered groups of monitoring sites were identified that represent different areas within the Red Lake Watershed District. Pairs of sites were used to make comparisons between different types for drainage. Ideally, the study would monitor tile drainage (multiple outlet types), surface drainage, and natural background sites within a reasonable distance of each other. Fortunately, four types of sites were found near Grygla, Minnesota in Marshall and Beltrami Counties for water quality monitoring. Fields with and without tile drainage were found in close proximity to each other in Red Lake County near the town of Brooks. Also, several methods of wild rice paddy drainage were available for monitoring on one farm in Clearwater County.

Finding sites with similar land use is another necessity when comparing types of agricultural drainage. If possible, the watershed of a drainage monitoring site should almost completely consist of single type of land use. For example, it would not be a fair comparison if one of the watersheds was 50% CRP and the other was 100% cropped. This study is being done to compare different types of drainage, not different types of land use. The one exception would be Beltrami Natural site, which is specifically chosen for its land use characteristics, but is used as a standard against which to compare all the sites in Marshall and Beltrami Counties.

Sampling Methods

The sampling methods for this study are described in detail within the Red Lake Watershed Farm to Stream Project Quality Assurance Project Plan. This is available for download at the RLWD website:
(http://www.redlakewatershed.org/projects/Tile%20Drainage%20Study%20QAPP.pdf).

Hard copies of the QAPP are available at the RLWD Office.
The scope of the water quality monitoring for this study was focused on concentrations of nutrients and was limited to the primary parameters in question, which are listed below.

- Total Suspended Solids (TSS) measured in mg/L
- Turbidity measured in Nephelometric Turbidity Units (NTU)
- Total Phosphorus (TP) measured in mg/L
- Orthophosphorus (OP) measured in mg/L
- Nitrates measured as nitrogen in mg/L
- Total Kjeldahl Nitrogen (to calc. Total Nitrogen) measured in mg/L
- Total Nitrogen, measured in mg/L
- Field Measurements of Dissolved oxygen, temperature, conductivity, pH
- Continuous rain, barometric pressure, temperature
- Continuous water level in flumes (surface drainage) and a tile water control structure

Statistical Analysis Methods

Most of the water quality data analysis was conducted in Microsoft Excel 2007. Because of nutrient concentrations that were below the laboratory's minimum reporting limit and some turbidity readings that were higher than what the HACH 2100P could measure, this study has produced some censored data. Although an actual numerical value for a censored data point is not recorded, it is still data and is needed for data analysis. Censored data cannot be used "as-is" for data analysis because the actual value is not known and because it is not reported in a number format that can be directly entered and used for data analysis within a spreadsheet (<.005, >1000). The *Red River Watershed Water Quality Reporting Handbook* describes the RLWD's methods for dealing with censored data during analysis and the reasoning behind the methods. Basically, a second "modified" column is created in a Microsoft Excel spreadsheet next to the column that contains censored data. A number can be substituted for the censored data based on the reporting limit (0, reporting limit, or ½ the reporting limit).

For this study, data below the minimum reporting limit was modified to ½ the reporting limit for data analysis. The standard protocol for results that are greater than the highest measurable level (>1000 NTU turbidity, >100 or >122 transparency) is for the modified value to be the highest measurable value, plus one. So, a >122 transparency tube reading would be entered as 123 in the modified data. Some turbidity reading that were initially too high to measure with a HACH 2100P were diluted to estimate the turbidity level in the sample. The reading is officially reported as >1000, but an estimation is useful for comparison purposes and comparing sites because some of the levels found in this study were much higher than 1001. It must be made clear that if, during analysis, the minimum level for a parameter is below the reporting limit, it is reported as less than the reporting limit (<.005) and not as the modified value since this actual value is unknown. The same reporting method should be used for too-high-to-measure (>1000) data points as well.

All the data for the study was combined into a table and a series of pivot tables were used to easily summarize data.

Water Quality Results

Water quality data from the monitoring sites were compared with each other and against state and ecoregion standards for water quality in streams and rivers. Water quality results for tile drainage were also compared to drinking water standards. Note the clear differences in TP, TSS, Nitrates, TN, and turbidity in the following table.

Table 1. Water quality data summary - overall averages.

AVERAGES	Surface	Tile
Total Phosphorus (mg/L)	0.87	.02
Total Suspended Solids (mg/L)	124.92	1.96
Nitrates (mg/L)	2.57	21.31
Total Nitrogen (mg/L)	5.61	22.36
Turbidity (NTU)	149.58	.71

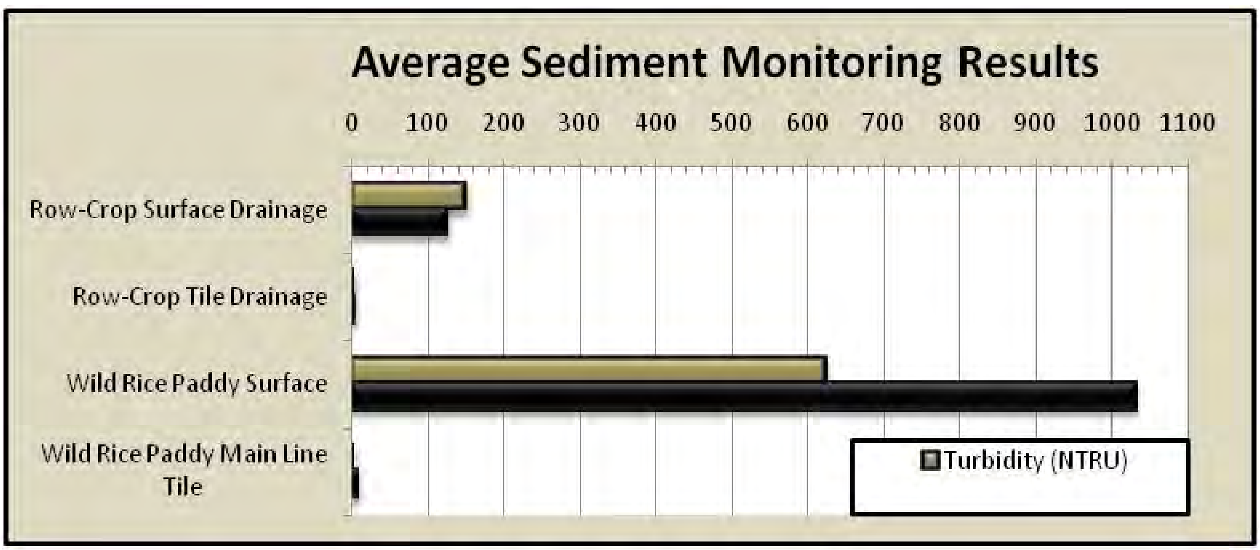


Figure 33. Average TSS and Turbidity Chart

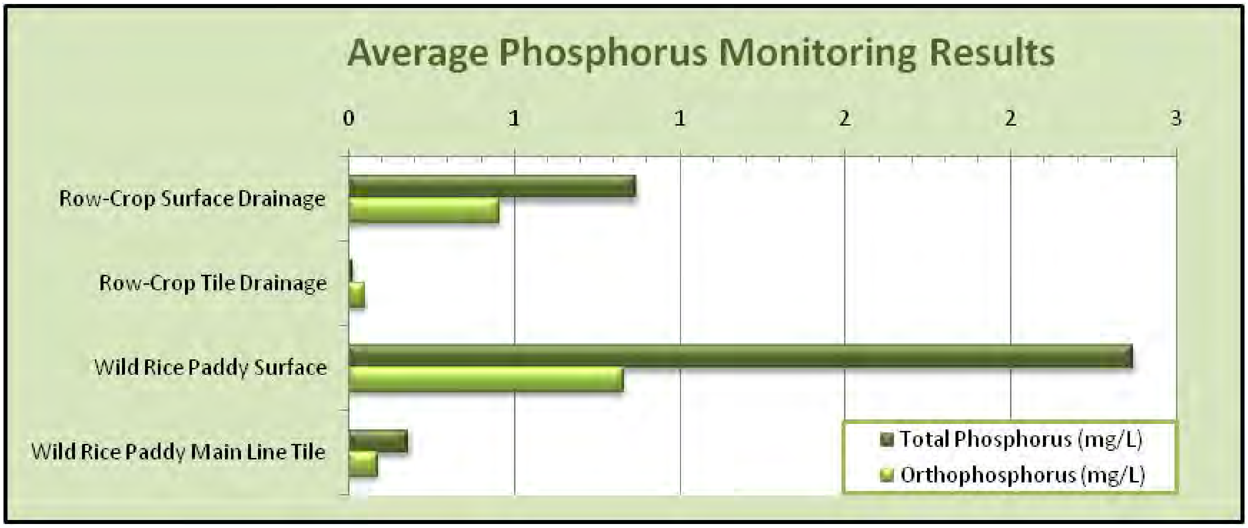


Figure 34. Phosphorus Comparison Chart

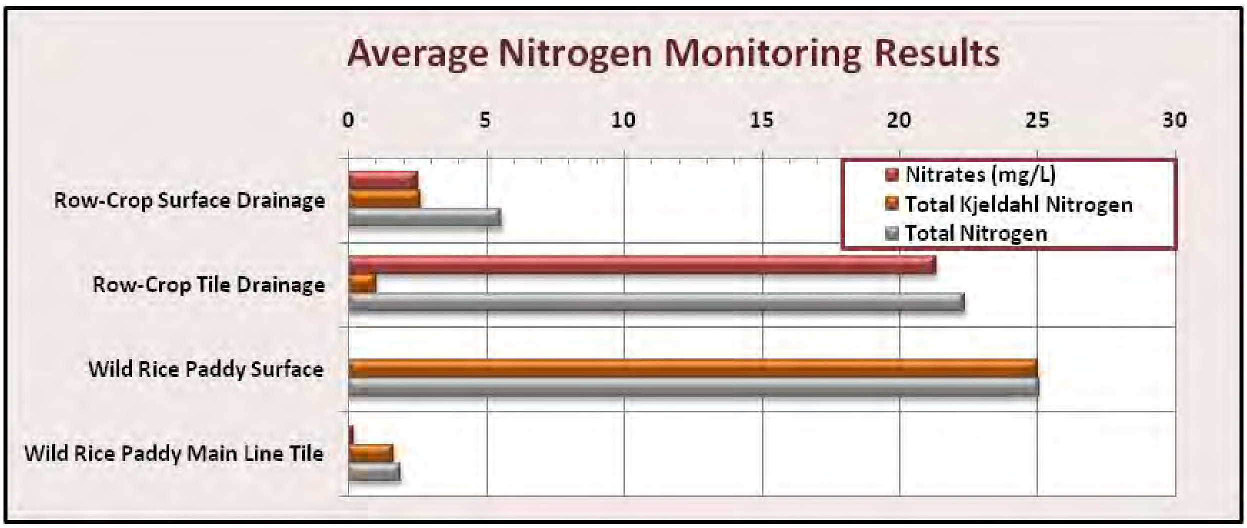


Figure 35. Average Nitrogen Comparison Chart

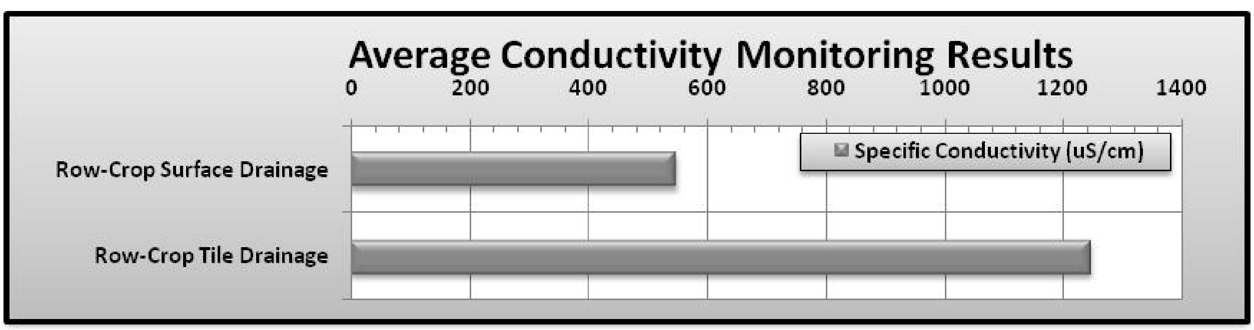


Figure 36. Average Conductivity Comparison Chart

Red Lake County Sites

- Runoff from the surface drained field had much higher turbidity, TSS, and TP levels compared to tile drainage
- Flow from tile drains had barely measurable (if at all) TSS levels. The average concentration was just slightly higher than the laboratory's 1 mg/L minimum detection limit.
- Tile nitrates ranged from 4.85 to 43.5 mg/L.
- The water quality at the Red Lake Co. tile site was better, on average, than the water quality at the Marshall Co. tile monitoring sites.
- Greater than 95% of the total nitrogen concentration of nearly all samples from the Bachand tile drainage site was in the nitrate form.
- Normally, most of the total nitrogen concentration in a surface drainage sample was composed of total Kjeldahl nitrogen. This varied by the time of the year, however, and there were cases where nitrates made up a greater percentage of the total nitrogen concentration in a surface runoff sample.
- Tile drainage does not completely eliminate surface runoff from a field. The Bachand surface drainage had high levels of sediment and nutrients at times. Nitrate and sediment concentrations seemed to by surprisingly independent of the rate of flow. Some of the high nitrate concentrations occurred during low flows. The relatively steep slope of the field ditch could have allowed water to pick up sediment and nutrients even when flow volumes/rates are moderate. It also seemed like an increase in flow didn't always produce an increase in turbidity, total suspended solids, or nutrients. There was no buffer between the field and the sampling location that may have helped remove sediment.

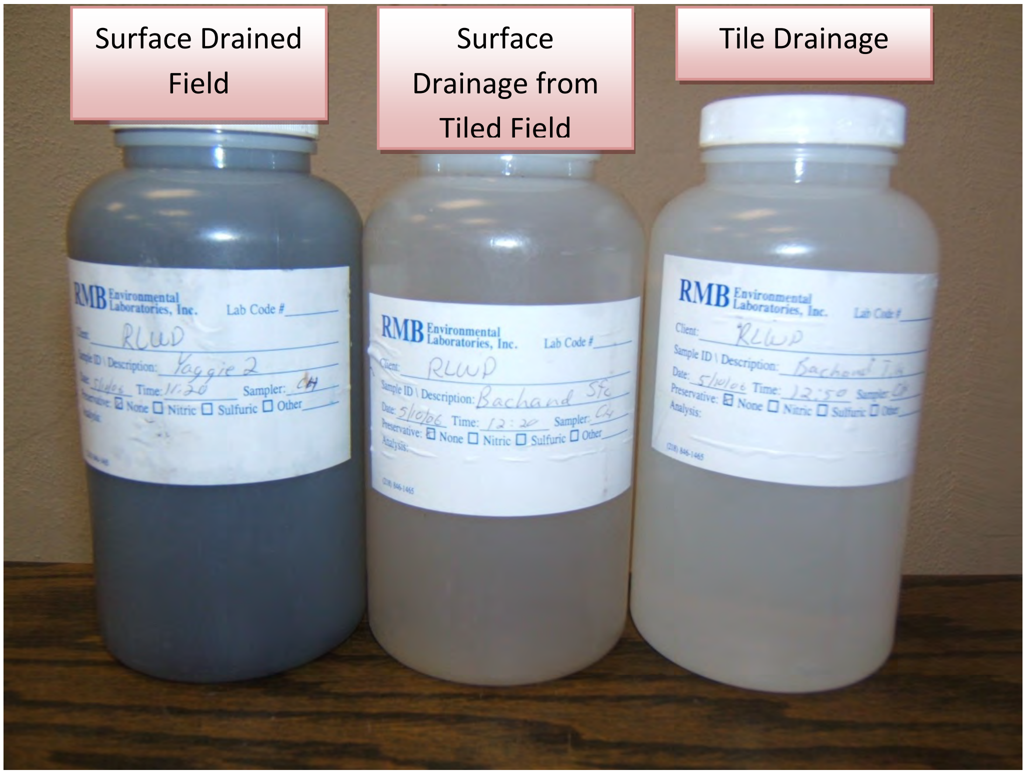


Figure 37. Photo of sample bottles from Red Lake County monitoring sites.

One question brought up at a meeting was about whether or not conductivity concentrations would decrease over time due to leaching of salts from the soil. A trendline placed through the data collected for the study at the Bachand Tile site shows a slight downward trend. However, there is not enough data to make a definite conclusion and the downward trend of the line is very slight.

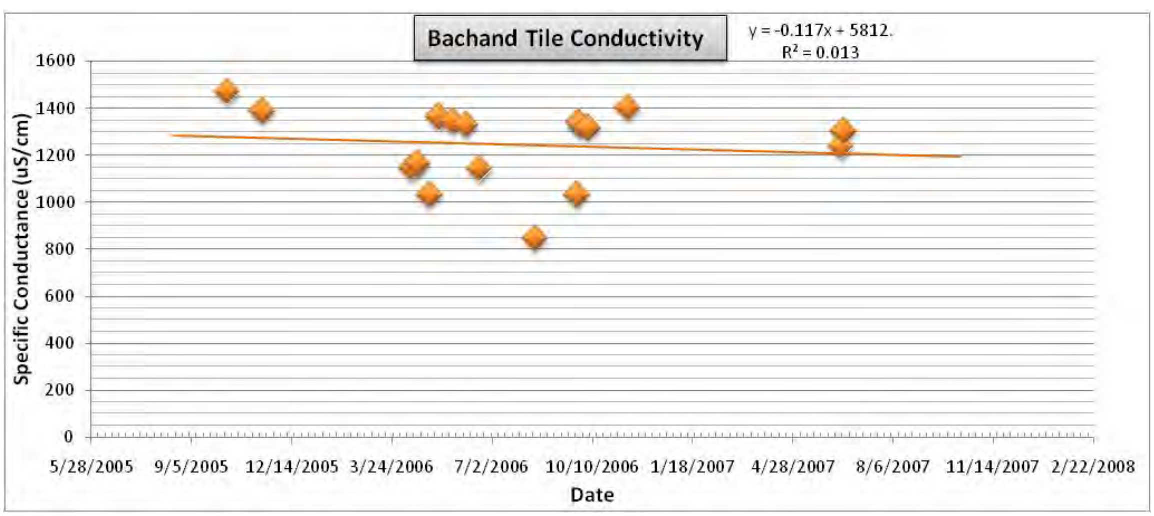


Figure 38. Conductivity time series plot for the Bachand Tile monitoring site.

Although the study was originally scheduled to be completed after the 2006 monitoring season, sampling was continued for summer runoff events at the Red Lake County sites. It was difficult to obtain a sufficient number of paired surface and tile drainage runoff samples. There were few storms that produced runoff during working hours. 2006 and 2007 were fairly dry years as well. "Fortunately," (for this study) there were some large rainfall events in June of 2007 that provided an opportunity to get samples from surface runoff.

Figure 39. Mud flowing through the outlet of paddy that has multiple gravity tile outlets and a perimeter ditch. Pattern tile does not help unless it is main line tile and eliminates internal surface drainage in paddies.

Clearwater County Wild Rice Paddies

Wild rice growers along the Clearwater River have begun installing tile drainage in their paddies. This practice provides numerous benefits to the farmer. **Main-line tile drained paddies** also release **clean water**. This study has found that main-line tile not only has all the same benefits of conventional agricultural tile drainage, but also has **low nitrate concentrations**.

To achieve these benefits, the tiling system **must** be a **main line** tiling system that is exits the paddy through the dike, is connected to a water control structure, and discharges into a stable ditch. The peat soil in the paddies is highly erodible. Even clean water from the end of a tile line will be laden with sediment by the time it leaves the paddy through an internal drainage ditch.

Efforts should be made to provide **financial support** to wild rice farmers who wish **to install main-line tile**. Switching to main-line tile drainage should work to lessen the negative impact of wild rice paddy drainage upon **water quality in the Clearwater River**.

Flow was measured at the outlet structure of the surface drained paddy in 2005. Total suspended solids and nutrient concentrations were extrapolated between sampling events and multiplied by flow volumes to create a record of sediment and nutrient loading through this outlet.

Table 2. Soil and Nutrient Loss from RLN SFC in 2005

2005 Sediment and Nutrient Losses from Surface Drained Wild Rice Paddy	Tons	Cost	Dump Truck Loads of Soil	Comment/Rate
Total Suspended Solids	135.3	$5,412.91	14	2000 lbs/cubic yard = 135 cubic yards, 10 per dump truck, $40/cubic yard
Nitrogen	4.50	$1,914.38		$425/ton
Phosphorus	0.2	$57.27		$300/ton
Total Losses	135.3	$7,384.56	14	

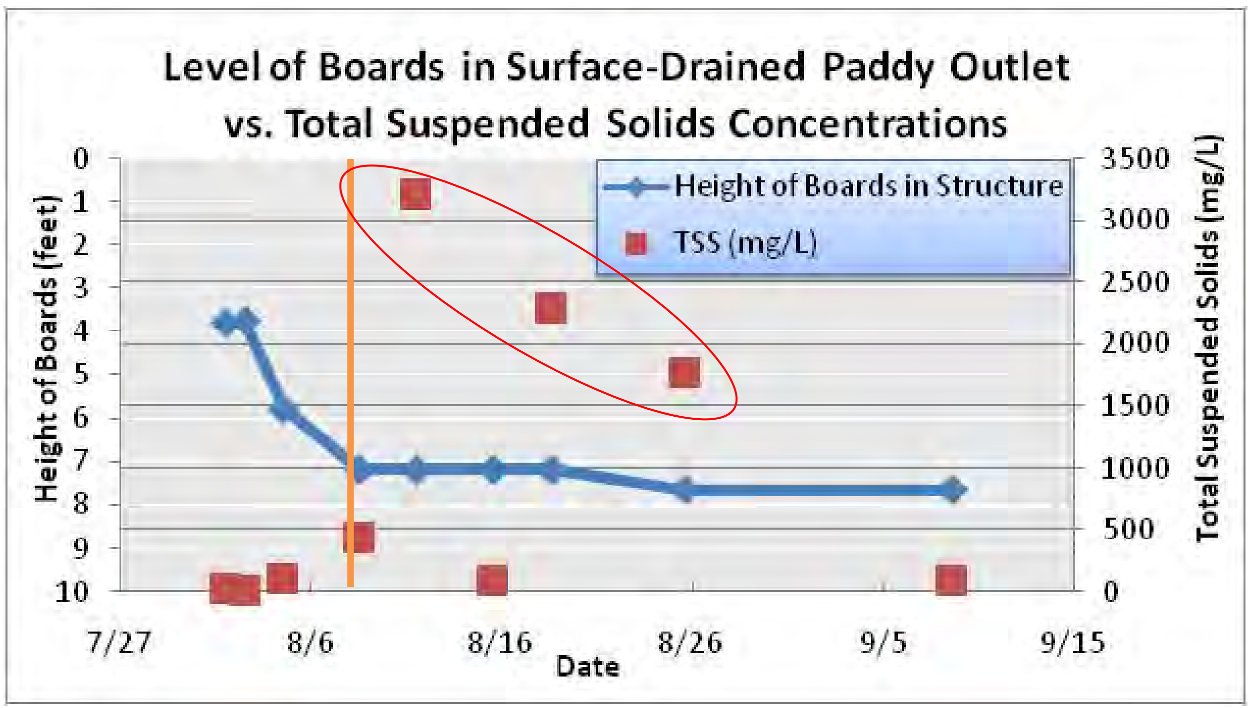


Figure 40. Water quality problems at the surface drained paddy outlet began when nearly all of the boards were removed from the structure.

Figure 41. Wild rice paddy surface drainage and main line tile water samples.

A sample was collected for fecal coliform analysis from the Red Lake Nation Surface Drained Paddy monitoring site. The concentration was 720 col/100ml which is several times higher than the state standard of 200 col./100ml. This is cause for concern because the Clearwater River has been listed as impaired by fecal coliform where these paddies discharge into the river (Ruffy Brook to the Lost River) in the 2002-2008 MPCA 303(d) Lists of Impaired Waters. Also, a study conducted by Svedarsky et al in 1994 showed that fecal coliform concentrations increased drastically from upstream of the wild rice growing area. The concentrations **upstream** only averaged 3.3 and 10.7 cfu/100ml during the first and second halves of the drawdown period, respectively. On the **downstream** end of the wild rice growing area, however, concentrations were at 396.0 and 323.3 cfu/100ml, respectively during the first and second halves of the drawdown period.

The reach of the Clearwater River from its confluence with Ruffy Brook to its confluence with the Lost River is one of the impaired reaches being examined by the Clearwater River Dissolved Oxygen and Fecal Coliform TMDL Study. The reach is listed as impaired for aquatic recreation by fecal coliform and impaired for aquatic life by low dissolved oxygen. E. coli (replacing fecal coliform as the state bacteria indicator standard) samples were collected 5 times each month at two sites along the Clearwater River from June through October in 2007 for the TMDL study. After the first year of monitoring, the channelized reach monitoring site (CR96 crossing, 7 miles east of Roland) qualified as impaired during the month of July. This coincided with the timing of wild rice paddy discharge. Duckweed was present in the river, indicating paddy discharge. The high bacteria concentrations have mostly been limited to the channelized reach of the river and didn't extend downstream to the monitoring site near the town of Plummer. After the completion of the second year of sampling for the TMDL study, the Clearwater River now appears to meet the state standards for aquatic recreation (E. coli) despite the occasional high concentrations found in the channelized reach. Because the river only just barely meets the standards, a TMDL will still be written for the reach and loading reductions will likely be needed to incorporate a margin of safety.

The Red Lake Nation wild rice farm is not the only wild rice producer to have installed tile drainage. In fact, some farms have nearly every paddy converted to tile drainage. Potential monitoring sites were identified at the Clearwater Rice farm and one set of samples was collected there. No further samples were collected because the water control structures were too narrow to allow for collection of a sample without contamination. The sampler would scrape rust deposits off the side of the structure as it was lowered. The Red Lake Nation wild rice paddy water control structures, on the other hand, were large and allowed for flow monitoring and water quality sampling.

Other best management practices have been used on wild rice farms to help protect water quality in the Clearwater River. Ditches receiving drainage from wild rice paddies can be set up as settling ponds to capture sediment. Other wild rice producers have made efforts to install tile drainage, water control structures, and other strategies for minimizing loss of soil and nutrients while minimizing their impact on the river. Main line tile may not be feasible in every single paddy. In these cases, limiting discharge to surface water and not allowing flowing ditch water to leave the paddies may be an option. Sediment traps or settling ponds may be another option.

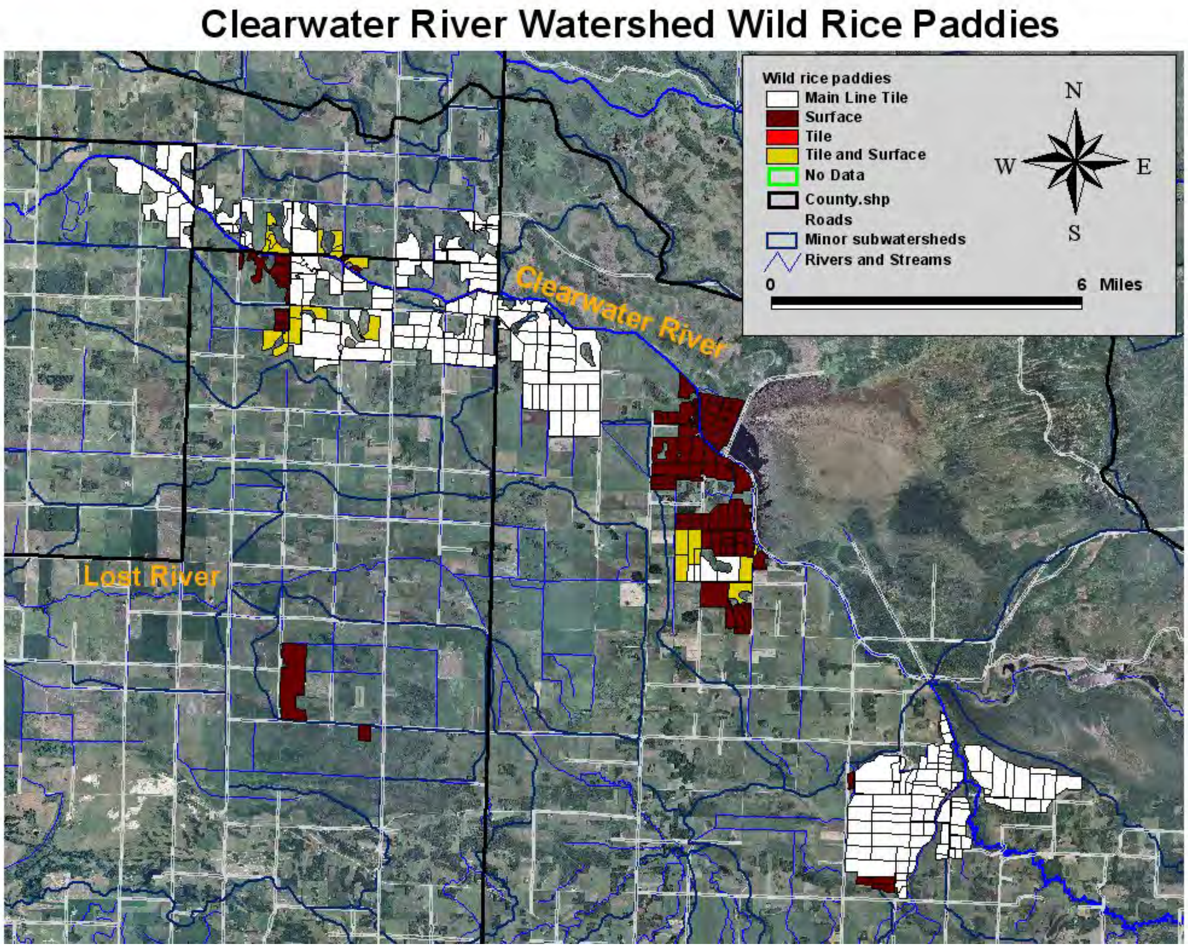


Figure 42. Wild rice production along the Clearwater River

Although this study reveals that wild rice production is having a negative impact upon water quality in the Clearwater River, the wild rice producers have been proactive about trying to reduce their impact upon the river. They implement BMPs, maintain a buffer along the river, and create settling ponds. As mentioned earlier, several of the producers have begun installing main line tile drainage in their paddies. Several of these were installed as part of the Phase II (implementation phase) of the Clearwater River Clean Water Partnership project using money loaned to the RLWD from the MPCA. The Red Lake Nation farm converted a field from surface to main line tile drainage during each of the first two years of this study.

Water quality in the wild rice paddies that still have internal perimeter surface drainage ditches was not as bad as long as some boards were in place and the water flowing through the structure was from the top of the water column. Once the boards were removed from the water control structure, more flow began within the ditches themselves and, thus, more erosion occurred, as demonstrated in the following photograph.

Figure 43. The red line demonstrates the water level in surface drained paddy when turbidity and total suspended solids problems began occurring.

The total nitrogen concentrations within the wild rice paddies are almost completely controlled by the total Kjeldahl nitrogen (ammonia N and organic N) concentrations. Total nitrogen from the paddies with surface drainage was nearly 100% total Kjeldahl nitrogen. The percentage of total Kjeldahl nitrogen from the main line tile was only slightly less.

Sand/sediment transport in the Clearwater River and sediment from commercial wild rice production were two natural resource related issues raised and documented during the most recent RLWD 10-year planning process. Photographic monitoring of the Clearwater River along with some field water quality measurements conducted during the wild rice paddy drawdown period show the impact that wild rice paddy sediment loss is having upon the Clearwater River. A large sediment bar accumulated at the outlet of the surface drained paddy we monitored each year. The water quality within the Clearwater River changes drastically from upstream of the wild rice farming area to downstream of this area during the paddy drawdown period.

Table 3. Clearwater River water quality relative to wild rice paddies on August 3rd, 2006

Clearwater River - Location Relative to Wild Rice Growing Area		Turbidity Probe (FNU)	Dissolved Oxygen (mg/L)	Temperature	Conductivity
Upstream		0.3	11.4	24.7	359
Downstream		37	9.51	26.84	701

Figure 44. Sediment bar at RLN Surface outlet in 2005

Figure 45. Clearwater River sediment bar at RLN Surface outlet in 2006

Figure 46. Map of Wild Rice Farming Areas

There are a number of tile drainage systems along the Clearwater River that feature main line tile, but are not hooked up to an outlet structure. So, there is some erosion that occurs between the tile outlet and the water control structure as shown in the photo to the right. These need to be hooked up to a structure or some kind of combination structure that can control both surface and tile drainage. Expediting the process of getting these hooked up will achieve a great water quality benefit at a low cost. This would also benefit producers as these open-ended tile systems can get plugged by sediment and, sometimes, muskrats.

Marshall & Beltrami County Sites

Near the town of Grygla, water quality samples were collected to compare **gravity tile** drainage, **pumped tile** drainage, **surface drainage**, and **natural background** drainage. Most of this sampling was conducted by the Marshall-Beltrami SWCD. Sampling was extended into 2007 and possibly longer in order to get more data, particularly during runoff events.

- Pumped tile nitrates 1/2 as high as gravity tile nitrate concentrations
- TSS more measurable from pumped tile
- Greater than 90% of the total nitrogen concentration from tile drainage is in the nitrate form.

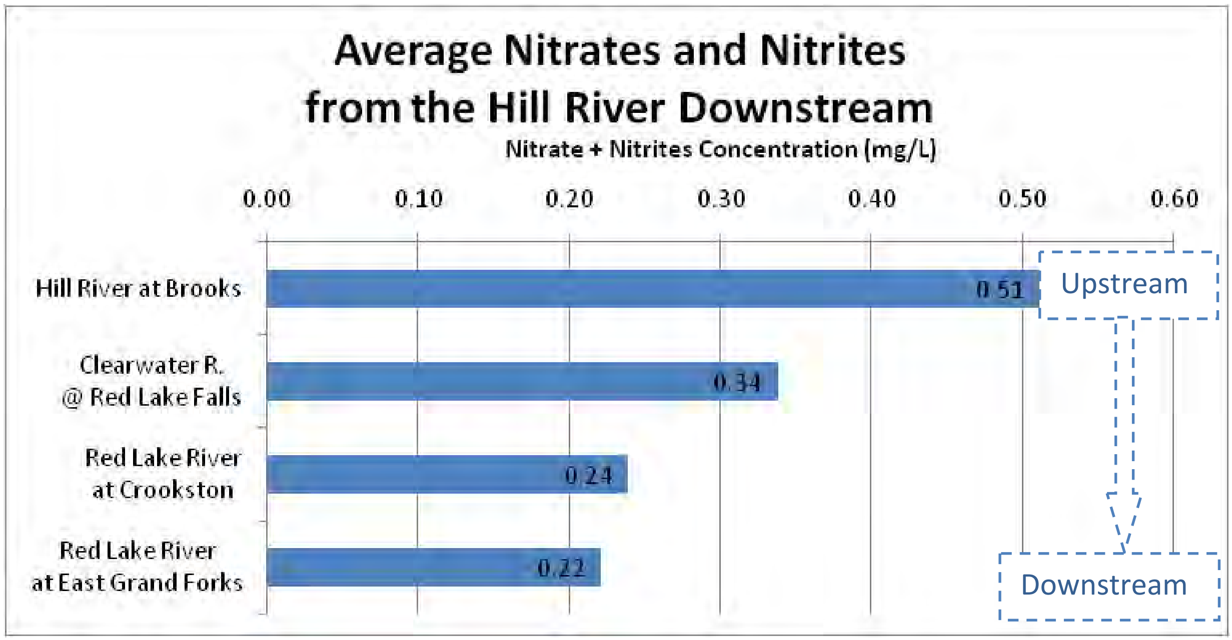
Additional, Investigative Sampling

Some additional samples were taken at various sites to help answer some questions that came to mind during the study.

What happens to the water quality characteristics of tile water as it travels downstream?

- Drainage from the Bachand field travels through a creek for about 300 yards before entering the Hill River. On a couple different occasions extra samples were taken during low flow (so that the main source of flow would be the tile – no surface runoff). Both sets of sample results indicate a 1 mg/L reduction in nitrate levels. The reduction occurred after tile water had traveled over 260 yards toward the Hill River in a small creek. 1 mg/L is not enough of a reduction to avoid a measurable impact upon conductivity and nitrate levels within the river. If the water had more time of travel or a longer residence time prior to entering a river, nitrate levels could theoretically be reduced to acceptable levels.
- The RLWD's long-term monitoring program shows that NO2 and NO3 levels decrease with an increase in stream order.

Table 4. Nitrates in downstream waters.



How much of an effect does tile drainage water quality have upon the river into which it flows?

- In limited spot measurements and sampling on the Hill River, nitrate concentrations increased from upstream to downstream of the Bachand tile inflow. Conductivity also increased.
- Samples collected in 2000 – 2002 by the Marshall-Beltrami SWCD show an increase in nitrates from upstream to downstream within a ditch that receives tile drainage.

Should we expect a great difference in tile water quality further west in the Red River Valley where soils have a higher clay content?

- Samples from tile drainage of a farmstead and of a field in western Polk County suggest that the nitrate and phosphorus concentrations will be similar to the Red Lake and Marshall County tile drainage sites. However, the conductivity level in the field tile drainage water was significantly higher (3854 µS/cm). Turbidity and total suspended solids were more measurable, but this could be due to the sampling method that was used. Because the outlet end was under water, samples were collected from an access pipe using a Kemmerer vertical sampler at one site. The other Polk County sample set came from tile water that had been collected in a storage tank (another source of TSS contamination). At the Red Lake, Marshall, and Beltrami County monitoring sites, water samples were collected directly with sample bottles (minimal chance of contamination). When it is necessary to use the Kemmerer sampler, there is a chance of contamination from the surfaces within the sampler itself and from contact between the sampler and the sides of the access pipe/water control structure. This is the same reason the Clearwater Rice wild rice paddies were not used for the study.

Combined Comparisons and General Observations

In order to get an idea of how each type of drainage could affect water quality in rivers, streams, and lakes, we must first have a good idea of what levels are "good" and what levels are "bad." The following water quality standards will help provide a sense of "scale" when reviewing the water quality data collected for this study.

Drinking Water Standards

Turbidity:

- At no time can turbidity (cloudiness of water) go above 5 nephelometric turbidity units (NTU); systems that filter must ensure that the turbidity go no higher than 1 NTU (0.5 NTU for conventional or direct filtration) in at least 95% of the daily samples in any month. As of January 1, 2002, turbidity may never exceed 1 NTU, and must not exceed 0.3 NTU in 95% of daily samples in any month.

Nitrates (measured as nitrogen)

- 10 mg/L
    - Infants below the age of six months who drink water containing nitrate in excess of the MCL could become seriously ill and, if untreated, may die. Symptoms include shortness of breath and blue-baby syndrome.

Applicable State Water Quality Standards for Streams and Rivers

Turbidity:

- No greater than 25 NTU

Dissolved Oxygen:

- No less than 5 mg/L

Fecal Coliform:

- Monthly geometric mean
    - No greater than 200 cfu/100ml
- Sample Maximum
    - No greater than 2000 cfu/100ml

E. coli:

- Monthly geometric mean
    - No greater than 126 cfu/100ml
- Sample Maximum
    - No greater than 1260 cfu/100ml

<u>Ecoregion Standards for Streams and Rivers</u>

Red River Valley Ecoregion: Applicable to Red Lake County Sites, Polk County Sites

- Temperature: 19.9° C
- pH: 8.3
- Conductivity: 658 µS/cm
- Nitrates and Nitrites: 0.2 mg/L
- Total Phosphorus: 0.322 mg/L
- Total Suspended Solids: 56.5 mg/L
- Turbidity: 23 NTU

Northern Minnesota Wetlands: Applicable to Marshall and Beltrami County sites

- Temperature: 17.2° C
- pH: 7.9
- Conductivity: 250 µS/cm
- Nitrates and Nitrites: 0.08 mg/L
- Total Phosphorus: 0.092 mg/L
- Total Suspended Solids: 17.2 mg/L
- Turbidity: 10 NTU

Water Quality in Red Lake County Receiving Waters (Rivers)

Table 5. Water quality in the Hill River (downstream of the Bachand field) near Brooks.

Data	Year					
	2003	2004	2005	2006	2007	Grand Total
Average of Turbidity (NTU)	2.83	12.50	7.84	3.48	2.75	**6.00**
Average of Conductivity (uS/cm)	464.73	469.33	450.14	377.00	540.67	**445.93**
Max of Conductivity (uS/cm)	542.30	544.00	538.00	488.00	568.00	**568.00**
Average of TSS (mg/L)	3.50	34.25	10.75	14.88	4.33	**14.03**
Average of NO2+NO3 Modified	0.36	0.95	0.51	0.65	0.27	**0.56**
Max of NO2+NO3 Modified	0.80	1.84	0.98	1.07	0.74	**1.07**
Average of Ortho_P_mg_L	0.03	0.04	0.08	0.03	0.04	**0.05**
Average of TP_mg_L	0.07	0.14	0.12	0.05	0.04	**0.09**
Average of TKN Modified	0.78	1.11	1.15	0.48	1.06	**0.91**

Table 6. Water quality in the Lost River (upstream of the Yaggie field) at Oklee over the last 10 years.

Parameter	Year											
	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	All Years
Average of Turbidity (NTU)	1.30	16.20	13.27				10.84	16.54	13.44	10.02	5.86	11.78
Average of Conductivity (uS/cm)	631.00	668.33	568.50	560.50	593.75	564.20	537.68	493.56	607.20	515.50	619.29	566.38
Max of Conductivity (uS/cm)	631.00	841.00	707.00	637.00	644.00	654.00	730.00	679.00	740.00	647.00	743.00	841.00
Average of TSS (mg/L)	2.02	15.00	13.25	8.50	12.00	9.00	12.00	15.60	11.33	8.50	2.00	11.26
Average of NO2+NO3 (mg/L)		0.53	0.23	0.25	0.35	0.29	0.33	0.55	0.11	0.23	0.11	0.32
Max of NO2+NO3 (mg/L)		1.48	0.48	0.62	0.46	0.79	0.98	1.39	0.30	0.54	0.24	1.48
Average of Orthophosphorus (mg/L)	0.02	0.02	0.02	0.03	0.02	0.02	0.03	0.05	0.03	0.02	0.04	0.03
Average of Total Phosphorus (mg/L)	0.04	0.07	0.04	0.09	0.06	0.06	0.08	0.10	0.07	0.04	0.04	0.06
Average of Total Kjeldahl Nitrogen	0.25	0.75	0.90	1.14	0.56	0.88	1.14	1.38	0.92	0.60	0.70	0.88

Table 7. Water quality in the Lost River north of Brooks (downstream of the Yaggie field).

Data	Year					
	2003	2004	2005	2006	2007	All Years
Average of Turbidity (NTU)	3.73	7.98	34.50	2.71	2.28	10.93
Average of Conductivity (uS/cm)	530.55	534.10	583.57	476.00	654.67	540.43
Max of Conductivity (uS/cm)	772.60	757.00	717.00	643.00	741.00	741.00
Average of TSS (mg/L)	3.00	9.25	7.00	4.75	2.67	5.47
Average of Nitrates and Nitrites (mg/L)	0.73	1.10	0.75	0.31	0.13	0.63
Max of Nitrates and Nitrites (mg/L)	2.03	3.03	1.70	0.87	0.36	0.36
Average of Orthophosphorus (mg/L)	0.11	0.04	0.06	0.01	0.02	0.05
Average of Total Phosphorus (mg/L)	0.17	0.09	0.09	0.03	0.04	0.09
Average of Total Kjeldahl Nitrogen (mg/L)	1.26	1.59	1.09	0.71	1.33	1.19

There also are many other surface and tile drainage systems that drain into the Lost River between Oklee and Brooks so there are a lot of factors affecting changes in water quality between the previous two tables. Water quality monitoring sites located along the Clearwater. Lost, Hill, and Mud Rivers seem to have high nitrates + nitrites concentrations compared to other streams in the Red Lake Watershed District. The increase in the concentration of nitrates and nitrites on the Lost River (probably mostly nitrates) is significant enough to cause some concern. The 75th percentile values for nitrates and nitrites at the Hill River and the Lost River crossings north of Brooks, respectively, are .99 mg/L and .91 mg/L. These values are much higher than the MPCA's 75th percentile values for minimally impacted streams and about twice as high as the 75th percentile concentration in the Clearwater River at Red Lake Falls.

Water Quality in Clearwater County Receiving Waters (Clearwater River)

The RLWD has long-term monitoring sites on the Clearwater River that are located upstream and downstream of the wild rice drainage monitoring project area. These sites are located at the outlet of Clearwater Lake (Site #52) and at the USGS near the town of Plummer and the Highway 59 crossing of the Clearwater River (Site #780).

Table 8. Water quality statistics for the Clearwater River through 2007.

Data	52 (Upstream)	780 (Downstream)	Combined
Count of Sampling Dates	62.00	→ 82.00	144.00
Average of DO_mg_L	10.31	→ 9.45	9.82
Max of DO_mg_L2	15.45	→ 14.81	15.45
Average of Field_Conductivity_uS_cm	404.60	→ 531.59	476.92
Max of Field_Conductivity_uS_cm2	508.00	→ 723.00	723.00
Average of Turbidity_NTU	2.47	→ 11.22	7.64
Max of Turbidity_NTU	2.72	→ 15.35	8.22
Average of TSS_mg_L2	33.00	→ 62.00	1.00
Max of TSS_mg_L	0.04	→ 0.38	0.38
Average of NO2-NO3_mg_L	5.72	→ 29.20	2.49
Max of NO2-NO3_mg_L2	0.19	→ 1.73	1.73
Average of TKN_mg_L	0.48	→ 1.06	0.73
Max of TKN_mg_L2	2.31	→ 2.70	2.70
Average of Ortho_P_mg_L2	0.01	→ 0.07	0.04
Max of Ortho_P_mg_L	0.11	→ 0.31	0.31
Average of TP_mg_L	0.02	→ 0.13	0.07
Max of TP_mg_L2	0.07	→ 0.51	0.51

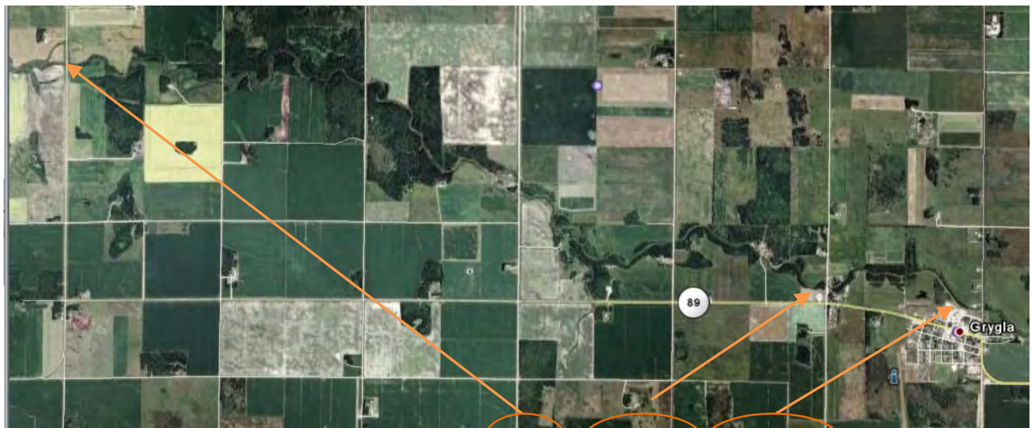
Natural background water quality in Beltrami County

What would pristine water quality conditions be like in the Marshall-Beltrami County monitoring area? The natural background water quality within Beltrami County was monitored to help answer this question at the monitoring site named Beltrami Natural. The water quality monitoring results from this site are included with the analysis of the other sites for comparison.

Water Quality in Marshall County Receiving Waters (Mud River)

The RLWD and the Marshall County Water Planner have several long-term water quality monitoring sites along the Mud River. The RLWD monitors at the Highway 89 crossing of the Mud River (Site #757) which is downstream of the project area. The Marshall County Water Planner monitors this site as well as a couple of sites located closer to the project area at the Highway 54 crossing in Grygla (D4) and another site on the Mud River just downstream of Grygla (D5). The statistics in the following table are based upon the most recent 10 years of monitoring by the RLWD and the last 3 years of monitoring by the Marshall County Water Plan.

Table 9. Water quality statistics from the Mud River



Data	757	D4-MUD	D5-MUD	Grand Totals
Count of date	94.00	17.00	15.00	126.00
Average of Temp_C2	14.58	17.12	16.85	15.20
Max of Temp_C	29.60	26.30	29.90	29.90
Average of ph_field2	7.46	6.98	7.21	7.37
Max of ph_field	9.03	7.58	8.08	9.03
Average of Field_Conductivity_uS_cm2	497.19	518.47	518.33	502.58
Max of Field_Conductivity_uS_cm	1802.00	1599.00	1387.00	1802.00
Average of DO_mg_L2	9.68	6.77	7.40	9.10
Max of DO_mg_L	15.66	13.93	16.42	16.42
Average of Turbidity_NTU	6.05	7.66	7.48	6.51
Max of Turbidity_NTU2	30.30	21.00	15.70	30.30
Average of TSS Modified	15.22	16.65		15.50
Max of TSS Modified2	278.00	34.00		278.00
Average of NO2+NO3 Modified	0.48	0.65	0.82	0.55
Max of NO2+NO3 Modified2	3.38	3.39	3.67	3.67
Average of TKN Modified	1.29	1.38	1.32	1.31
Max of TKN Modified2	12.00	3.13	2.55	12.00
Average of Ortho_P_mg_L	0.02	0.03	0.10	0.03
Max of Ortho_P_mg_L2	0.14	0.13	0.58	0.58
Average of TP_mg_L	0.08	0.06	0.13	0.08
Max of TP_mg_L2	1.55	0.16	0.55	1.55

Results

Table 10. Average water quality results by drainage type.

General Site Type	Specific Site Type	Data									
		Count of Specific Site Type	Average of Modified Turbidity (NTU)	Average of Total Suspended Solids (mg/L)	Average of Total Phosphorus (mg/L)	Average of Orthophosphorus (mg/L)	Average of Nitrates (mg/L)	Average of Total Kjeldahl Nitrogen (mg/L)	Average of Total Nitrogen (mg/L)	Average of Conductivity (uS/cm)	Average of DO (mg/L)
⊟ Surface	Surface Drainage From Tiled Field	11	223.00	278.00	0.78	0.20	5.56	3.30	8.83	701.00	8.28
	Surface Drained Field	49	122.88	56.89	0.91	0.55	1.24	2.55	4.18	458.04	9.54
Surface Total		**60**	**149.58**	**124.92**	**0.87**	**0.45**	**2.57**	**2.71**	**5.61**	**549.15**	**9.07**
⊟ Tile	Gravity Tile	15	0.52	1.61	0.03	0.07	28.16	1.57	29.73		
	Main Line Gravity Tiled Field	39	0.38	1.29	0.01	0.04	21.55	0.68	22.15	1245.94	10.45
	Pumped Tile	15	1.59	3.57	0.02	0.05	14.02	1.27	15.35		
Tile Total		**69**	**0.71**	**1.96**	**0.02**	**0.05**	**21.31**	**1.08**	**22.36**	**1245.94**	**10.45**
⊟ Wild Rice Paddy	Surface Drained Wild Rice Paddy	16	622.32	1030.33	2.37	0.83	0.03	25.03	25.04		
	Main Line Tile Drained Wild Rice Paddy	10	2.51	7.05	0.19	0.09	0.27	1.70	1.96	1232.67	1.84
	Tile and Sfc Drained Wild Rice Paddy	9	293.64	2244.00	0.91	0.28	0.05	13.86	13.90		
Wild Rice Paddy Total		**35**	**348.73**	**1050.63**	**1.35**	**0.47**	**0.11**	**15.25**	**15.35**	**1232.67**	**1.84**
⊟ Tile and Surface	Mix leaving field	9	7.53	23.63	0.09	0.07	15.48	1.30	16.78	1097.00	9.82
Tile and Surface Total		**9**	**7.53**	**23.63**	**0.09**	**0.07**	**15.48**	**1.30**	**16.78**	**1097.00**	**9.82**
⊟ Background	Natural Background	15	1.19	1.27	0.02	0.02	0.04	0.68	0.64	242.50	10.29
Background Total		**15**	**1.19**	**1.27**	**0.02**	**0.02**	**0.04**	**0.68**	**0.64**	**242.50**	**10.29**
Grand Total		188	111.38	294.65	0.53	0.23	9.63	5.05	14.72	998.48	9.25

Although **all** wild rice paddy drainage had low nitrate levels, the total Kjeldahl nitrogen (ammonia + ammonium + organic N) levels from the paddies with **surface** drainage were extremely high compared to the main line tile drained sites. The levels of total suspended solids and turbidity coming from the surface drained wild rice paddies were alarmingly high. There was one sample from the tile and surface drained paddy for which total suspended solids was the only measurement. So, that is why the turbidity and nutrient statistics may not seem to correlate with the total suspended solids concentrations at that site. Also, the average conventional agriculture surface drainage average for total suspended solids may have been higher, but a TSS sample from Yaggie 1 leaked during transport and the sample was lost.

Table 11. Highest concentrations observed during water quality monitoring.

Specific Site Type	Data: Max of Turbidity	Max of Total Suspended Solids (mg/L)	Max of Orthophosphorus (mg/L)	Max of Total Phosphorus (mg/L)	Max of Nitrates (mg/L)	Max of Total Kjeldahl Nitrogen (mg/L)	Max of Total Nitrogen (mg/L)	Max of Conductivity (uS/cm)	Max of Dissolved Oxygen (mg/L)
Gravity Tile	3.97	5	0.13	0.10	40.60	5.70	46.30		
Main Line Gravity Tiled Field	2.60	3	0.24	0.01	43.51	1.41	44.48	1470	13.45
Mix leaving field	28.20	90	0.18	0.31	21.50	3.10	22.22	1262	10.62
Natural Background	5.16	4	0.05	0.08	0.18	1.18	1.25	248	11.61
Pumped Tile	6.19	7	0.09	0.06	19.50	1.85	20.38		
Surface Drainage From Tiled Field	>1000	1980	0.60	3.28	12.95	4.64	21.80	1174	8.89
Surface Drained Field	>1000	840	1.52	4.04	13.20	4.80	16.46	1044	15.34
Surface Drained Wild Rice Paddy	>1000	4292	2.17	6.84	0.13	80.10	80.04		
Main Line Tile Drained Wild Rice Paddy	9.71	38	0.17	1.04	0.61	2.30	2.37	1431	4.76
Tile and Sfc Drained Wild Rice Paddy	>1000	17940	0.44	2.40	0.19	69.60	69.79		

Note that it is possible for surface runoff to have high nitrate levels. The maximum nitrate levels at the Red Lake County monitoring sites were recorded during an October 2006 (post-harvest) runoff event. This runoff was sampled directly from the point where it leaves the field. With the depth of the ditch and the topography of the field, it is definitely conceivable that there will be some nitrates and minerals that dissolve into the runoff, particularly any seepage that may be occurring.

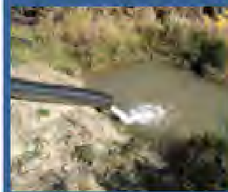
Table 12. Lowest observed concentrations of water quality parameters.

Specific Site Type	Min of Turbidity (NTRU)	Min of Total Suspended Solids (mg/L)	Min of Total Phosphorus	Min of Orthophosphorus (mg/L)	Min of Nitrates (mg/L)	Min of Total Kjeldahl Nitrogen (mg/L)	Min of Total Nitrogen (mg/L)	Min of Conductivity (uS/cm)	Min of DO (mg/L)
Gravity Tile	0.11	<1	0.010	0.029	<.03	0.685	1.73		
Main Line Gravity Tiled Field	0.10	<1	<.005	0.013	4.850	<.5	6.05	845	7.22
Mix leaving field	0.34	<1	0.014	0.026	4.310	0.074	7.41	932	9.02
Natural Background	0.27	<1	0.005	0.010	<.02	0.090	0.00	237	8.97
Pumped Tile	0.47	<1	0.010	0.027	<.03	0.716	1.73		
Surface Drainage From Tiled Field	13.90	3	0.100	0.053	<.02	1.760	0.86	387	7.8
Surface Drained Field	2.53	4	0.091	0.032	<.02	0.606	0.61	212.2	7.51
Surface Drained Wild Rice Paddy	3.56	5	0.088	0.209	<.02	3.600	3.60		
Main Line Tile Drained Wild Rice Paddy	0.15	<1	<.005	0.032	<.02	0.900	1.51	977	0.35
Tile and Sfc Drained Wild Rice Paddy	11.00	12	0.427	0.152	<.02	2.700	2.70		

All of the conventional agriculture tile drainage had at least one sample that had a total suspended solids concentration that was so low that it was below RMB Environmental Laboratories minimum reporting limit. It takes some very clear water to get a reading that low. All of the different types of wild rice paddy drainage had at least one sample with a nitrate concentration below the lab's minimum reporting limit. Although the turbidity levels from pumped tile didn't get as low as some of the readings from gravity tile, they are still low compared to rivers in the area (although a little higher than the natural background site). The pumped tile got closer to matching the 10 milligrams per liter drinking water standard than the other gravity tile drainage did.

Note: There have only been a few sets of field measurements (dissolved oxygen, pH, and specific conductivity) from the Bachand Surface monitoring site.

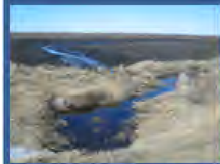
Table 13. Number of water quality measurements at each site

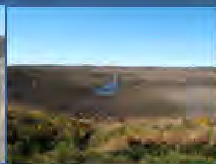


General Site Type	Site	Count of Turbidity	Count of Total Suspended Solids	Count of Total Phosphorus	Count of Orthophosphorus	Count of Nitrates	Count of Total Kjeldahl Nitrogen	Count of Total Nitrogen	Count of Conductivity	Count of Dissolved Oxygen
Surface	Bachand Surface	8	8	8	6	8	5	8	3	3
	Sparby	5	5	5	5	5	5	5	1	1
	Yaggie 1	4	3	4	3	3	3	3		
	Yaggie 2	13	10	10	9	10	10	10	4	4
Surface Total		30	26	27	23	26	23	26	8	8
Tile	Bachand Tile	30	26	26	24	25	24	25	17	17
	Stanley GT	13	14	14	14	14	14	14		
	Stanley PT	14	14	14	14	14	14	14		
Tile Total		57	54	54	52	53	52	53	17	17
Wild Rice Paddy	CR Tile	1	1	1	1	1	1	1		
	RLN Main Line Tile	7	8	8	8	8	8	8	2	2
	RLN Main Line Tile 3	1	1	1	1	1	1	1	1	1
	RLN Surface	13	13	13	13	13	13	13		
	RLN Surface 2		2	2	2	2	2	2		
	RLN Tiled	8	9	8	8	8	8	8		
Wild Rice Paddy Total		30	34	33	33	33	33	33	3	3
Tile and Surface	Bachand Tile plus Surface	4	4	4	4	4	4	4	2	2
Tile and Surface Total		4	4	4	4	4	4	4	2	2
Background	Beltrami Natural	14	15	15	15	15	14	14	2	2
Background Total		14	15	15	15	15	14	14	2	2
Grand Total		**135**	**133**	**133**	**127**	**131**	**126**	**130**	**32**	**32**

As the above table shows, a sufficient number of samples were collected from tile drainage. Due to a lack of runoff events, however, there were fewer samples collected from surface drainage. The project was extended for an additional year in an attempt to collect more paired surface and tile samples. The data that has been collected is sufficient for making general conclusions and has reveals some clear differences between different drainage systems.

Table 14. Marshall versus Red Lake County Water Quality Comparison





General Site Type	County	Data: Count of Sites Visits with some water quality data	Average of Turbidity (NTU)	Average of Total Suspended Solids (mg/L	Average of Total Phosphorus (mg/L)	Average of Orthophosphorus (mg/L)	Average of Nitrates (mg/L)	Average of Total Kjeldahl Nitrogen (mg/L)	Average of Total Nitrogen (mg/L)	Average of Conductivity (uS/cm)	Average of Dissolved Oxygen (mg/L)
Surface	Marshall County	5	16.75	12.20	1.880	0.962	0.79	3.162	5.36	1044	15.34
	Red Lake	25	176.14	151.76	0.644	0.314	2.99	2.590	5.67	478	8.17
Surface Total		30	149.58	124.92	0.873	0.455	2.57	2.714	5.61	549	9.07
Tile	Marshall County	27	1.07	2.59	0.027	0.060	21.09	1.421	22.54		
	Red Lake	30	0.38	1.29	0.007	0.037	21.55	0.679	22.15	1246	10.45
Tile Total		57	0.71	1.96	0.017	0.049	21.31	1.078	22.36	1246	10.45

This comparison shows that there happened to be a fairly equal number of water quality measurements taken from tile drainage sites in between the two counties. There were few opportunities to collect data from the Marshall County surface drained field, however. The higher sediment related averages from Red Lake County reflect opportunities to collect data from more significant runoff events. Red Lake County water quality was consistently better. This may be due to soil types, the type of tile (main line), depth of the tile, and the length of time that the tile has been installed.

- Water quality data was collected on 135 out of more than 200 site visits. Because of dry weather, there often was no flow to sample during a site visit. Sites were visited regularly and also after/during rain storms to check for flow and to check on equipment.
- Tile drainage turbidity levels were normally less than 1 NTU (drinking water standard).
- Only minimal phosphorus and TSS were found at tile drainage outlets.
- Nitrates from tile ranged from the mid-teens to over 40 milligrams per liter.
- Tile water had good dissolved oxygen concentrations (in Red Lake Co.) at the outlets, but high conductivity levels.
- Surface drainage had higher turbidity levels—sometimes extremely high.
- Surface drainage had higher OP concentrations
- Surface drainage had lower concentrations of total nitrogen, despite having higher concentrations of total Kjeldahl Nitrogen. This is the case because the concentrations of nitrates in tile water samples were so high.
- Surface drainage had lower nitrate levels
- The median and geometric mean concentrations of TSS at the gravity tile sites are nearly equal to the lab’s minimum detection/reporting limit
- Greater than 90% of the total nitrogen concentration from tile drainage is in the nitrate form.

- Tile drainage doesn't appear to improve the water quality of surface runoff that occurs on tile-drained fields.
- Although nitrate concentrations at the Stanley Farms Pumped Tile monitoring site were still high compared to drinking water standards and concentrations in receiving waters, they were lower and more stable than the concentrations from the gravity tile sites monitored for this project.
- In June of 2007, low nitrate concentrations were found in three tile samples – Stanley Pumped Tile (<.03 mg/L on 6/18), Stanley Gravity Tile (<.03 mg/L on 6/18), and Bachand Tile (4.85 mg/L on 6/7).

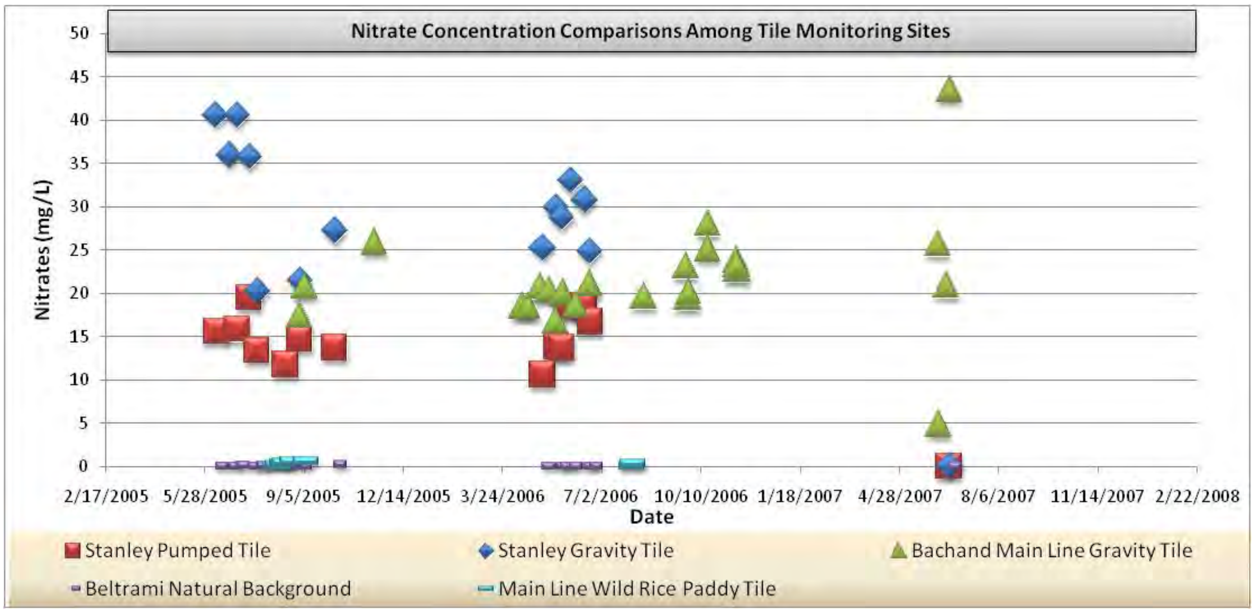


Figure 47. Nitrate concentration comparison among tile monitoring sites.

Reducing Nitrates and Nitrogen Losses

The high concentration of nitrates coming from tile drainage outlets can be mitigated using conservation drainage while maintaining the benefits of tile drainage.

- **Restore wetlands or storage basins to collect drainage water prior to discharge into ditches, streams and rivers.** Excess nitrates are removed through denitrification and plant uptake in these ponds.
- **Controlled subsurface drainage.** Using a water control structure at the tile outlet to raise the water table can minimize leaching and nitrate loss during the post-harvest and winter months where there is no plant uptake of nitrogen.
- **Alternative cropping systems with perennial crops**
- **Improved soil N testing methods.**

- **Shallow drainage –** reduces drainage water volume and nitrate losses.
- **Woodchip bioreactors –** remove nitrates from drainage water. A bioreactor consists of a trench filled with woodchips through which the drainage water is allowed to flow.
- **In-ditch treatment –** can be enhanced by designing drainage ditches to reduce bank erosion, trap sediment, and remove nutrients.
- **Fertilizer Management.** Nitrogen losses can be minimized by avoiding fall application of fertilizer. Also, avoid application of fertilizer when fields are wet, or when heavy rainfall is expected.
- **Improved Management of animal manures.**
- **Pumped tile outlets.** The pumped tile outlet sampled for this study had lower nitrate concentrations on average than nearby gravity tile outlets. This is likely depends on the length of time that the water sits in the well of the pumping station. Some of the nitrate could escape to the atmosphere in the form of a gas through the process of denitrification.

Flow Study

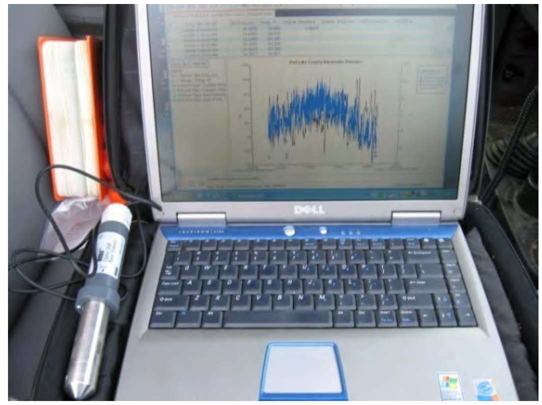
How does the installation of tile drainage affect peak runoff rates?
How does the installation of tile affect the total volume of drainage from a field?

Methods

Monitoring sites with definable watersheds and similar land use in Red Lake County are being used for continued monitoring of flow rates and volumes from fields. Surface and tile water flow are measured separately at the tile drained field while surface runoff is also measured from a field that doesn't have tile. The data will be used to compare peak flows and total flow volumes from surface drainage and tile drainage. Flow records begin when tile flow begins. Initial runoff from snowmelt is not included in this study. Tile at the study site did not flow during the initial snowmelt runoff.

Flow monitoring was extended through the 2007 and 2008 monitoring seasons to acquire more data and runoff events needed to make conclusions. Data analysis concentrates on post-thaw (growing season) runoff. The gravity tile systems monitored for this study are a non-factor in spring runoff because the ground is frozen and there is no flow from tile.

Figure 48. Onset HOBO Level Logger



Flows were measured by directing surface flow through h-flumes and running tile flow over a v-notch weir within a water control structure. Onset HOBO water level loggers were used to collect continuous records (1 measurement every 15 minutes) of water levels within the flow measurement structures. This water level data can be translated into flow using a table and/or equation for calculating flow through an h-flume. The h-flumes had built-in stilling wells for installation of the water level loggers. The level logger in the tile water control structure was placed on the bottom of the structure. Gauge zero readings were established each year for each flow measurement structure. The gauge zero of an h-flume was set at the point where water is sitting at the edge of the lip of the structure, but is not quite yet flowing out of the structure. The gauge zero for the v-notch weir in the tile drainage water control structure was set at the bottom of the v-notch weir. Manual water measurements were collected with every site visit to get good correlations between manual water level readings and automated level logger readings. Rating curves were developed for the h-flume and v-notch weir flow measurement structures.

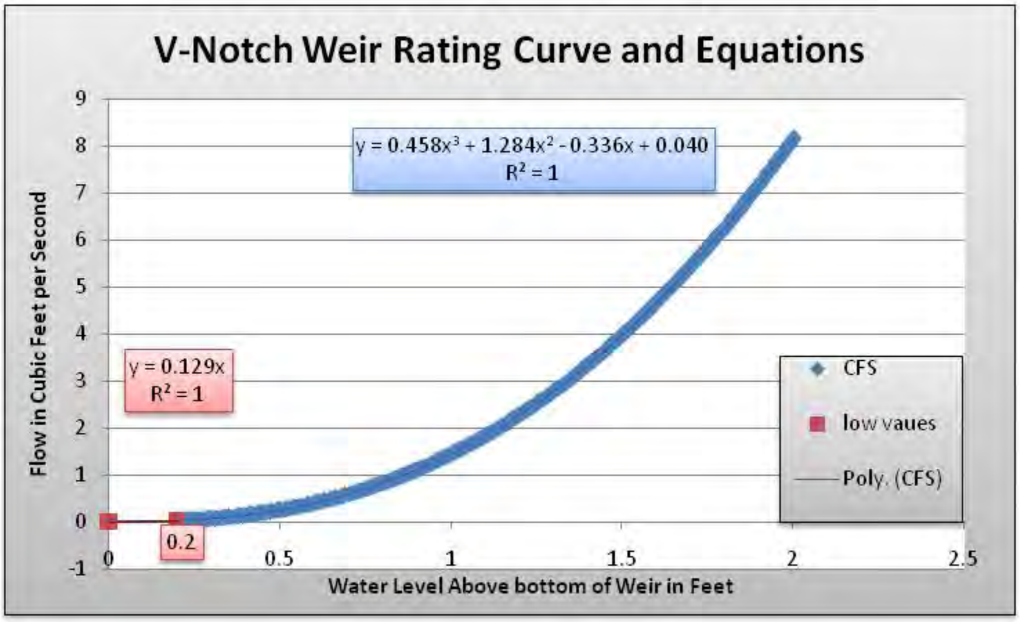


Figure 49. 60° V-Notch Weir Rating Curve and Equations

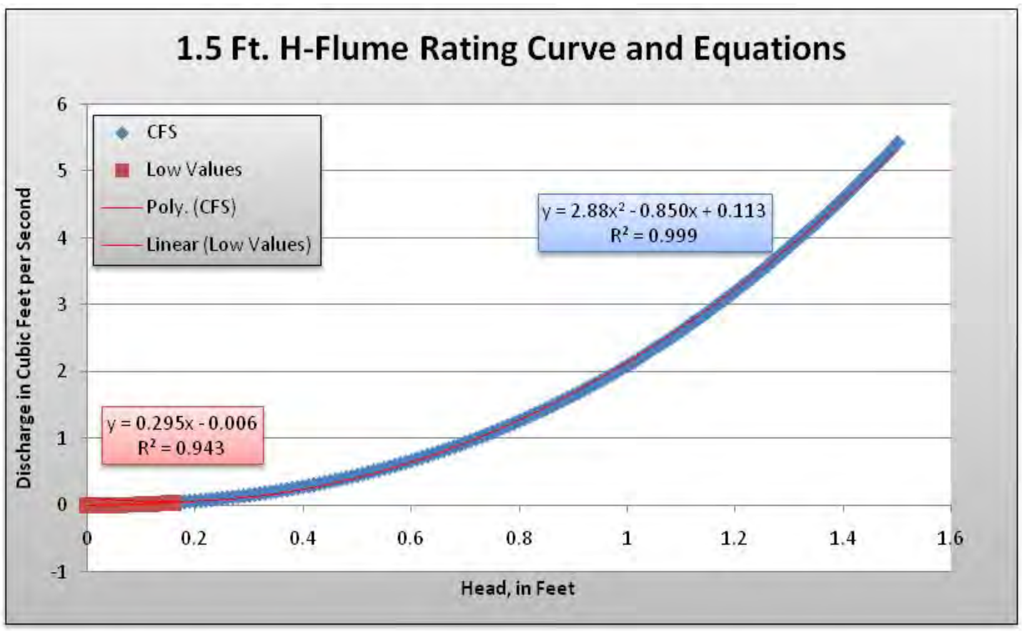


Figure 50. 1.5 Ft. H-Flume Rating Curve and Equations

Calculation of peak flows and event flow volumes required the following procedures:

1. General data was collected for the study area.
   - Statewide precipitation maps
   - Study area precipitation data
   - Study area temperature data
   - Crop information and average water consumption rates
2. Selection of storm events that caused an increase in drainage and runoff above previous baseline levels. This criterion was used to eliminate spotty rainfall events that may have rained significantly more on one field than another.
   - September 2005
   - May 2006
   - August 2006
   - June 2007
   - May 2008
   - September 2008
   - October 2008
3. Information was collected for each storm runoff event.
   - NOAA/NWS shaded rainfall maps
   - Hydrograph of each event
   - Table of event statistics and data
4. Peak Flow Calculations
   - Within the defined duration of a storm event, peak flow rate was identified for each flow measurement structure.
   - The simultaneous rate of flow was calculated for each 15 minute time step in the Bachand field record to identify the peak rate of total drainage from the Bachand field.
5. Total event drainage volume calculation
   - Duration of event is defined.
   - Flow rate multiplied by the 15 minute time step for each data point.
6. Total drainage volume calculation for each year's period of record.
   - Period of record defined by the extent of simultaneous contiguous records of flow at all three flow-measurement structures.
   - Flow rate multiplied by the 15 minute time step for each data point.

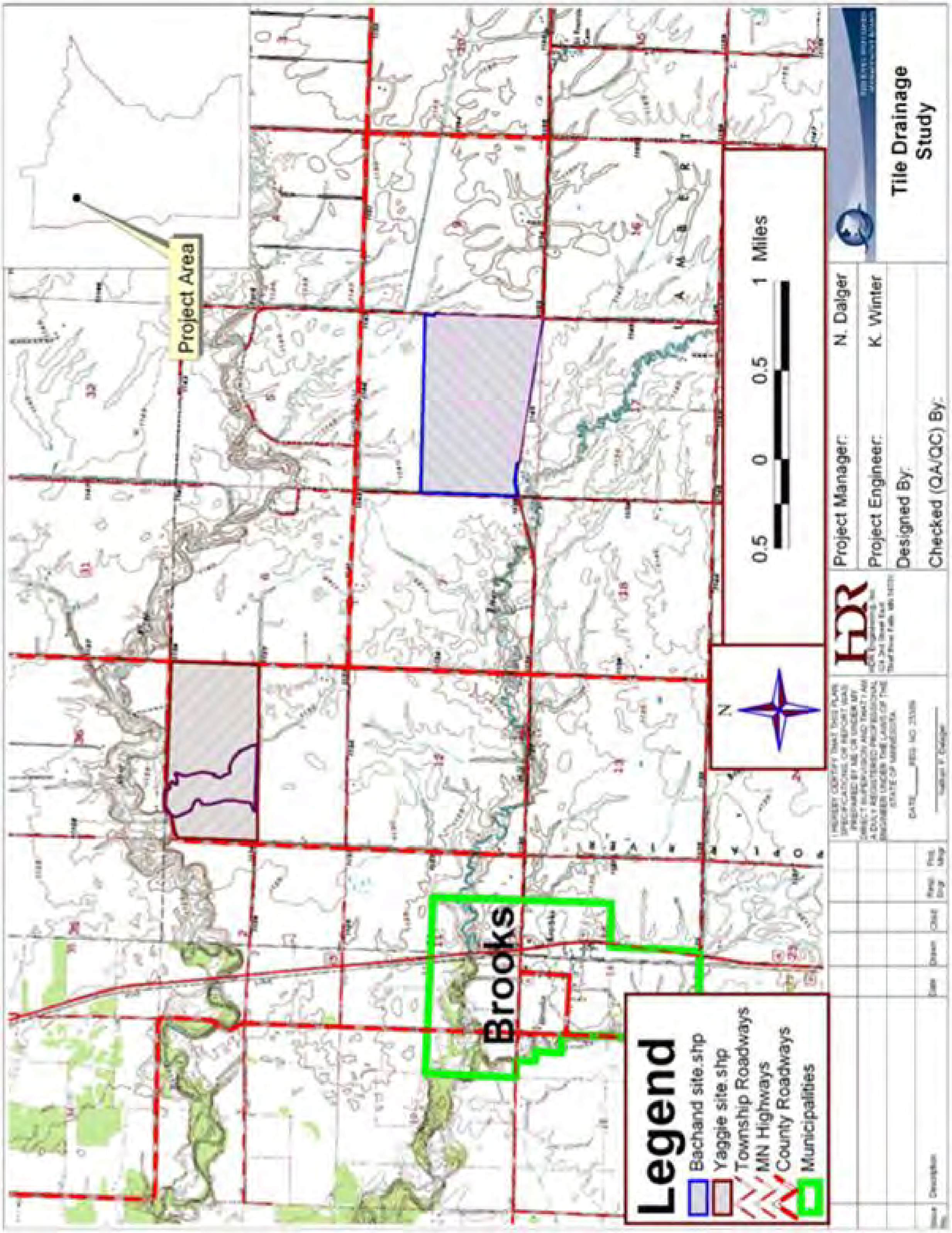


Figure 51. Flow Study Areas

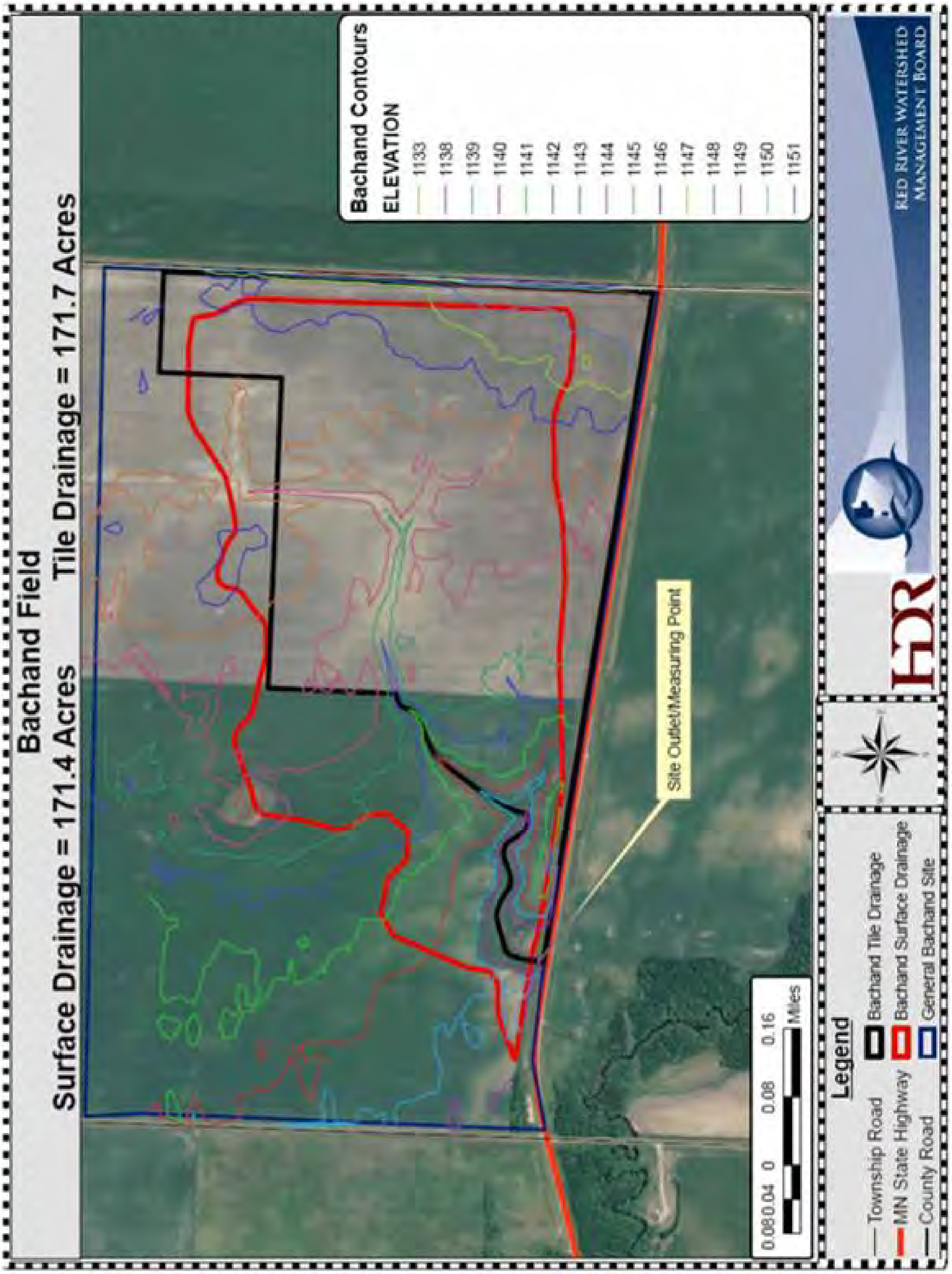


Figure 52. Surveyed topography of the Bachand field drainage area, by HDR Engineering

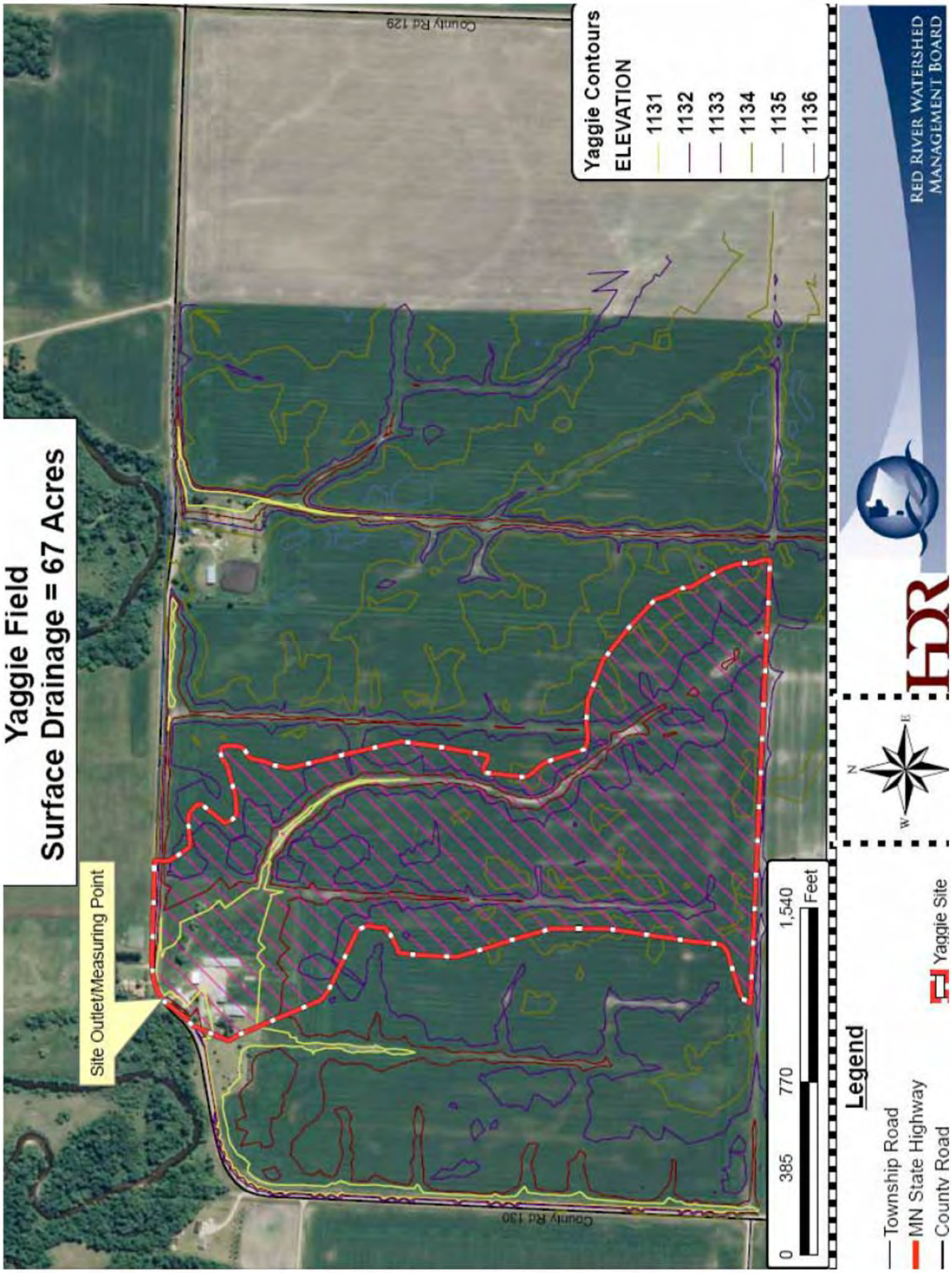


Figure 53. Surveyed topography of the Yaggie field drainage area, by HDR Engineering

Climatological Information

Rainfall was measured and recorded at the Bachand tile drained field (Red Lake County) monitoring site using a Stevens-Greenspan tipping-bucket rain gauge and AxSys data logger. Data was logged on 15 minute intervals and summarized to daily totals. The Minnesota State Climatology Working Group website was used to fill in any gaps that occurred in the on-site rain gauge data with data from nearby gauges and to get yearly/growing season totals for the study area.

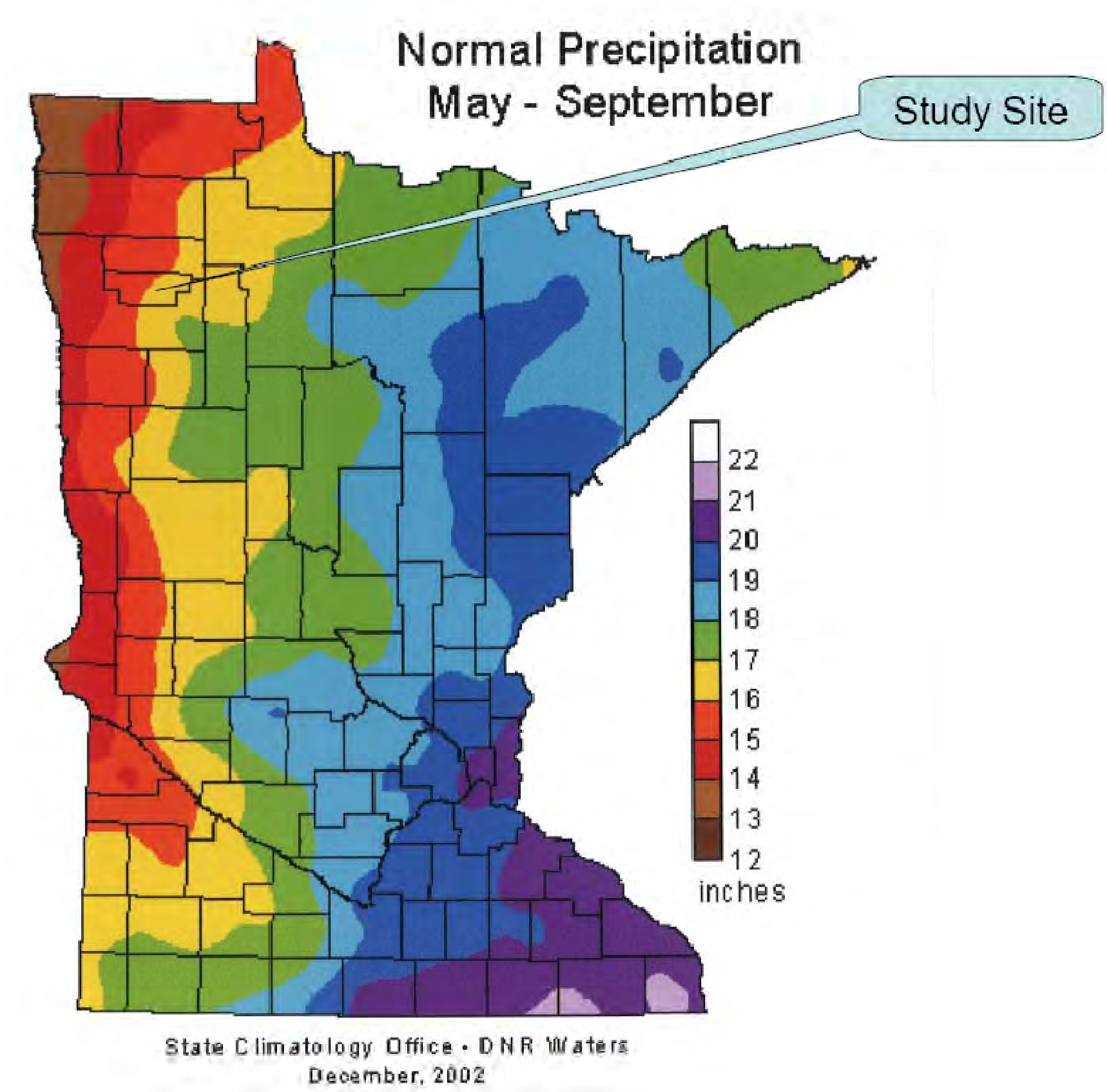


Figure 54. Normal growing season precipitations

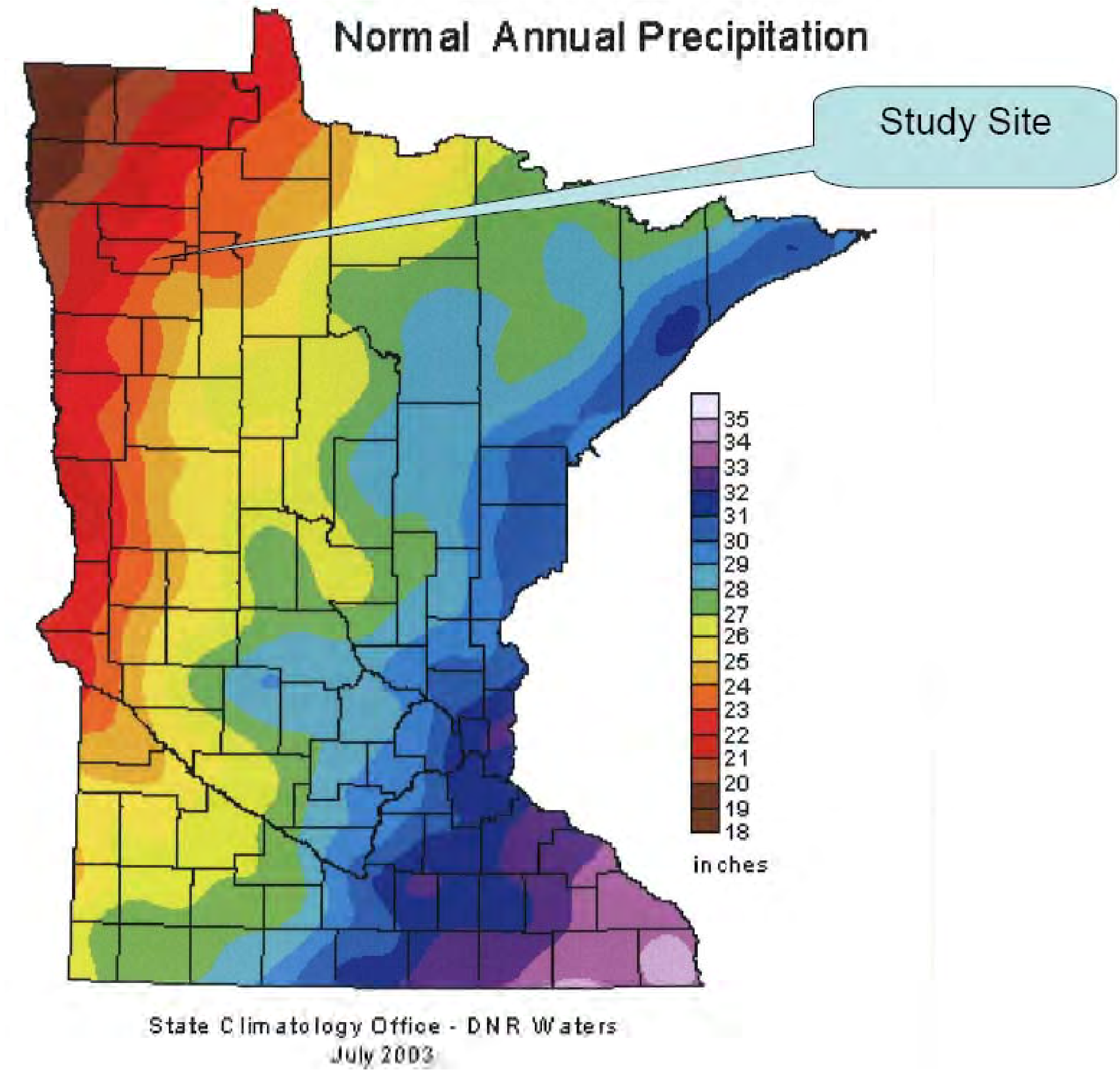


Figure 55. Minnesota Normal Annual Precipitation

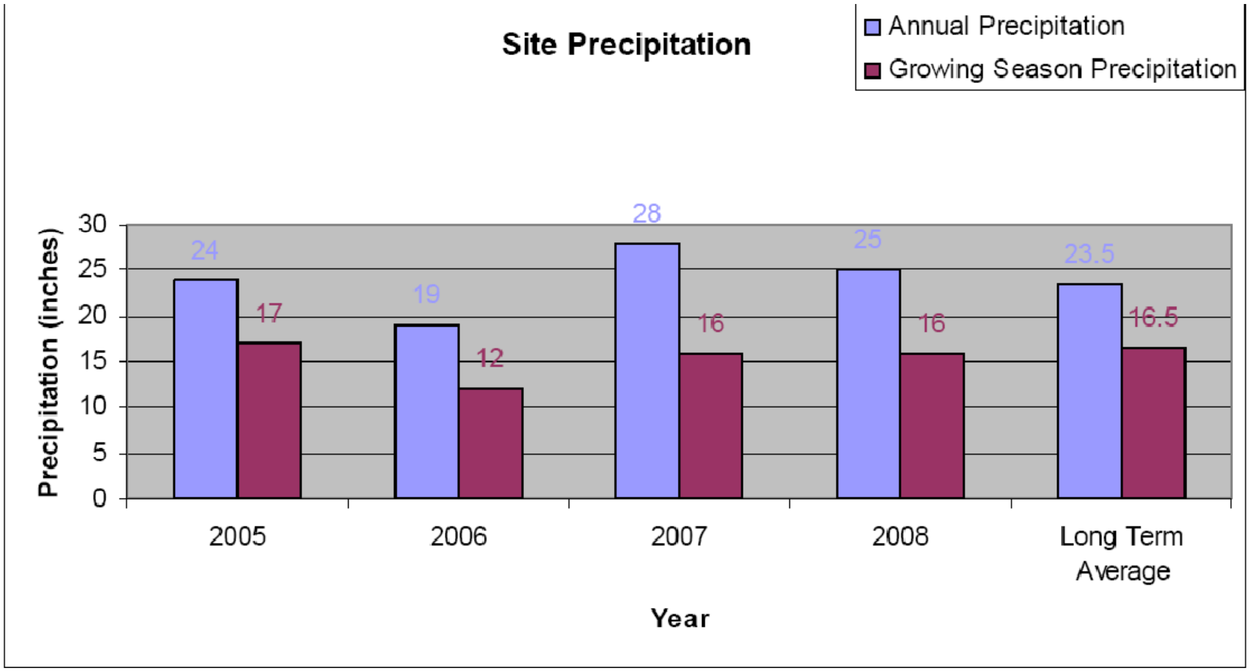


Figure 56. Study area precipitation totals from the Minnesota State Climatology Office.

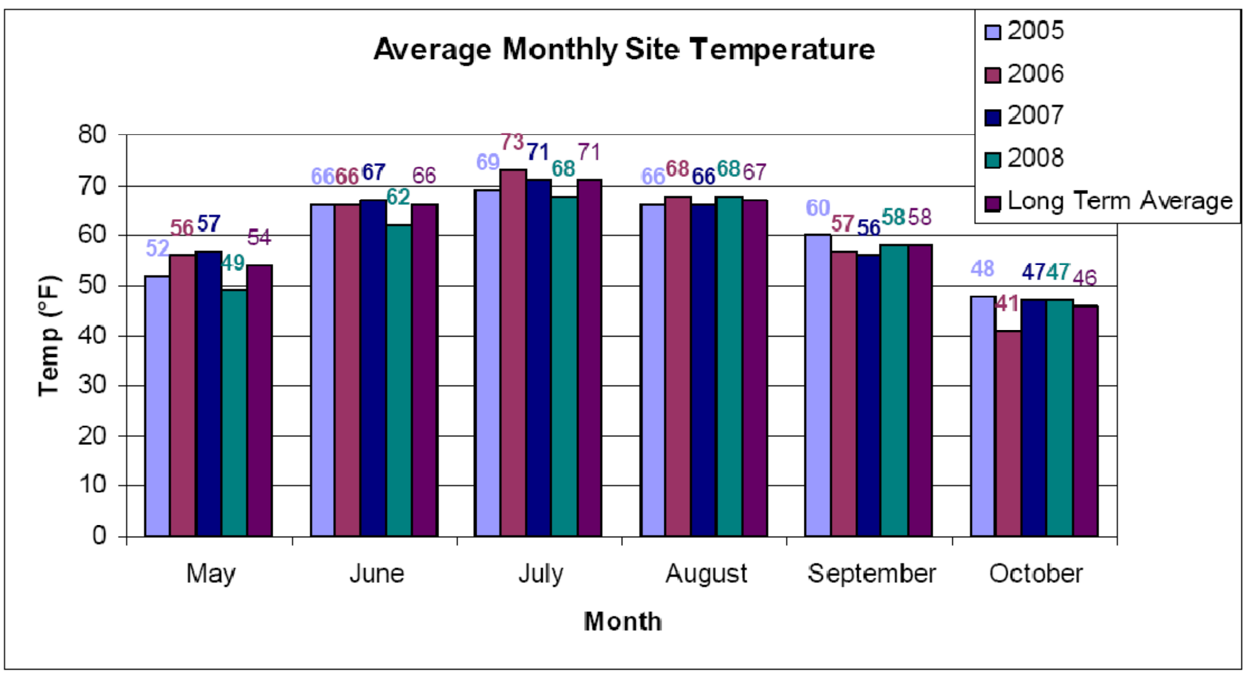


Figure 57. Average monthly temperature for the study area (Minnesota State Climatology Office).

Crops

Table 15. Crops grown at flow study sites

	2005	2006	2007	2008
Bachand	Spring Wheat	Soybeans	Soybeans	Wheat
Yaggie 2	Soybeans	Wheat	Soybeans	Wheat

Table 16. Water consumption by crop type

Table 2. Average water use for CORN in inches/day

Temperature F	Week after emergence: 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
50-59	.01	.02	.03	.04	.05	.06	.08	.09	.09	.10	.10	.10	.09	.07	.06	.05	.04	.03
60-69	.02	.03	.04	.06	.08	.09	.11	.12	.13	.15	.14	.14	.13	.11	.09	.07	.06	.04
70-79	.03	.04	.05	.07	.10	.12	.15	.16	.17	.19	.19	.18	.17	.14	.11	.09	.07	.05
80-89	.03	.05	.07	.09	.13	.15	.18	.20	.22	.24	.23	.22	.21	.17	.14	.11	.09	.06
90-99	.04	.06	.08	.11	.15	.18	.21	.24	.26	.28	.27	.26	.25	.20	.17	.13	.11	.07
Corn growth stages		↑ 3 leaf			↑ 8 leaf			↑ 1st tassel	↑ silk		↑ blister kernel			↑ early dent	↑ dent			

Table 3. Average water use for SOYBEANS in inches/day

Temperature F	Week after emergence: 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
50-59	.02	.02	.04	.04	.06	.07	.08	.09	.09	.09	.09	.08	.07	.05	.05	.03	.02
60-69	.02	.03	.05	.07	.09	.10	.11	.13	.13	.13	.13	.11	.10	.08	.07	.04	.02
70-79	.03	.05	.07	.09	.12	.13	.15	.17	.18	.18	.17	.15	.13	.10	.09	.05	.03
80-89	.04	.06	.10	.13	.16	.19	.20	.21	.22	.22	.21	.18	.16	.13	.11	.06	.03
90-99	.05	.07	.11	.14	.17	.20	.22	.25	.26	.26	.25	.22	.19	.16	.13	.08	.05
Soybean growth stages				↑ 3rd trifoliate				↑ 1st flower	↑ full flower			↑ upper pod filling			↑ 1st yellow pod		

Table 7. Average water use for WHEAT in inches/day

Temperature F	Week after emergence: 1	2	3	4	5	6	7	8	9	10	11	12	13	14
50-59	.02	.03	.05	.06	.08	.09	.10	.10	.09	.09	.07	.05	.03	.02
60-69	.03	.05	.07	.09	.12	.13	.15	.14	.13	.13	.10	.07	.05	.03
70-79	.04	.07	.10	.12	.17	.17	.19	.19	.18	.17	.13	.10	.07	.04
80-89	.05	.08	.12	.16	.20	.22	.24	.24	.22	.21	.16	.12	.08	.04
90-99	.06	.10	.15	.18	.24	.26	.29	.28	.26	.25	.19	.15	.10	.05
Wheat growth stages			↑ tillering		↑ jointing		↑ heading		↑ early milk		↑ early dough	↑ hard dough		

Soil Types

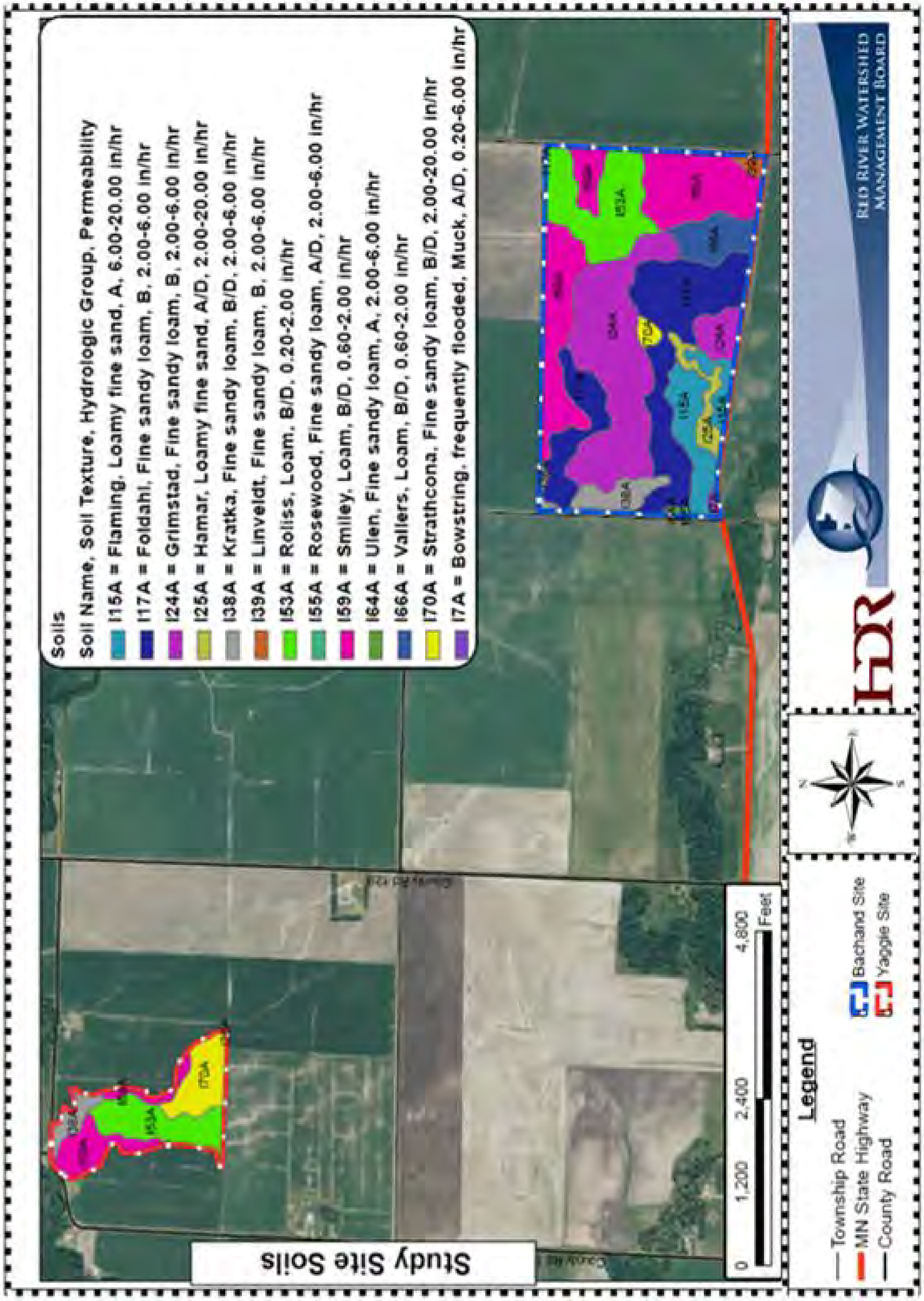


Figure 58. Flow site soil types

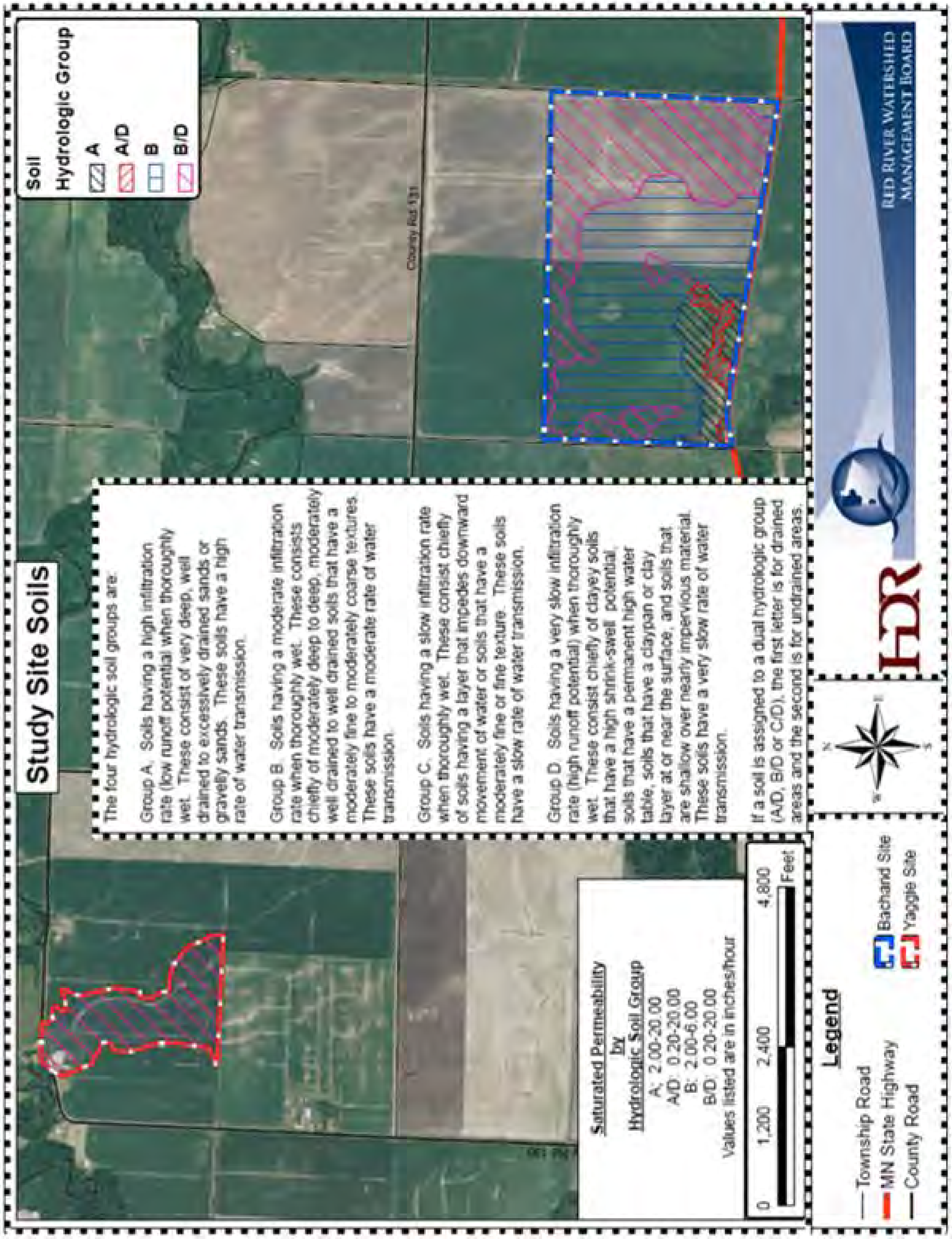


Figure 59. Soil hydrologic groups for flow sites

Water Level and Flow Records

The water level records from the HOBO water level loggers were downloaded and compiled throughout each monitoring season. The water level records were converted into flow records using the rating curve for each structure. The following three graphs are examples of the raw data files collected from each site.

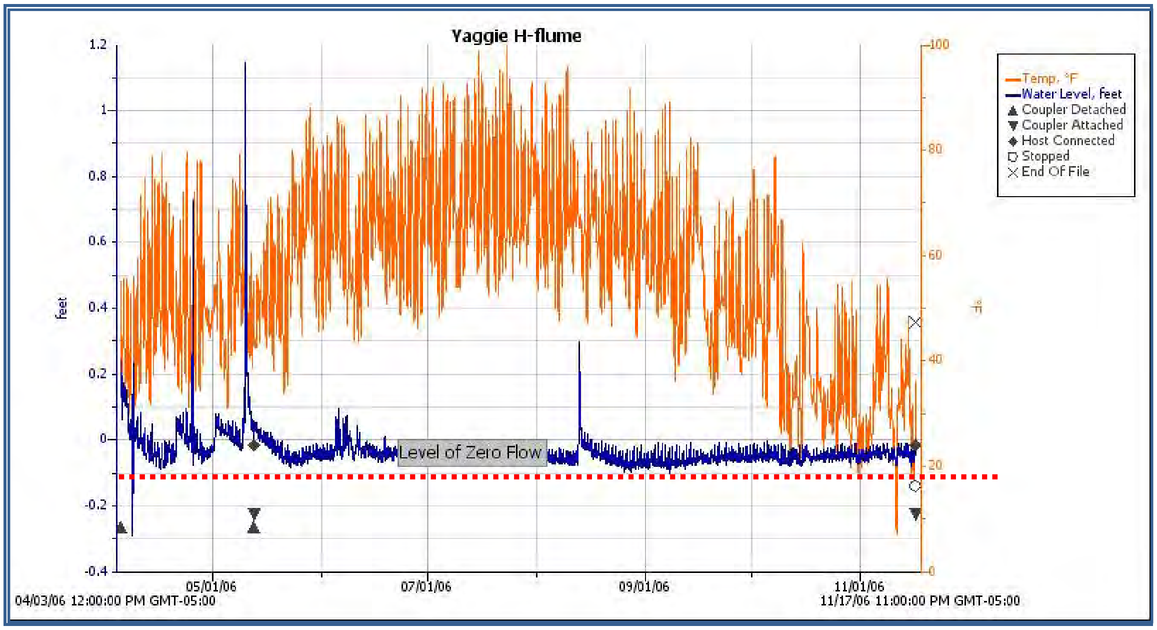


Figure 60. 2006 Plot of the HOBO water level record at the Yaggie Flume

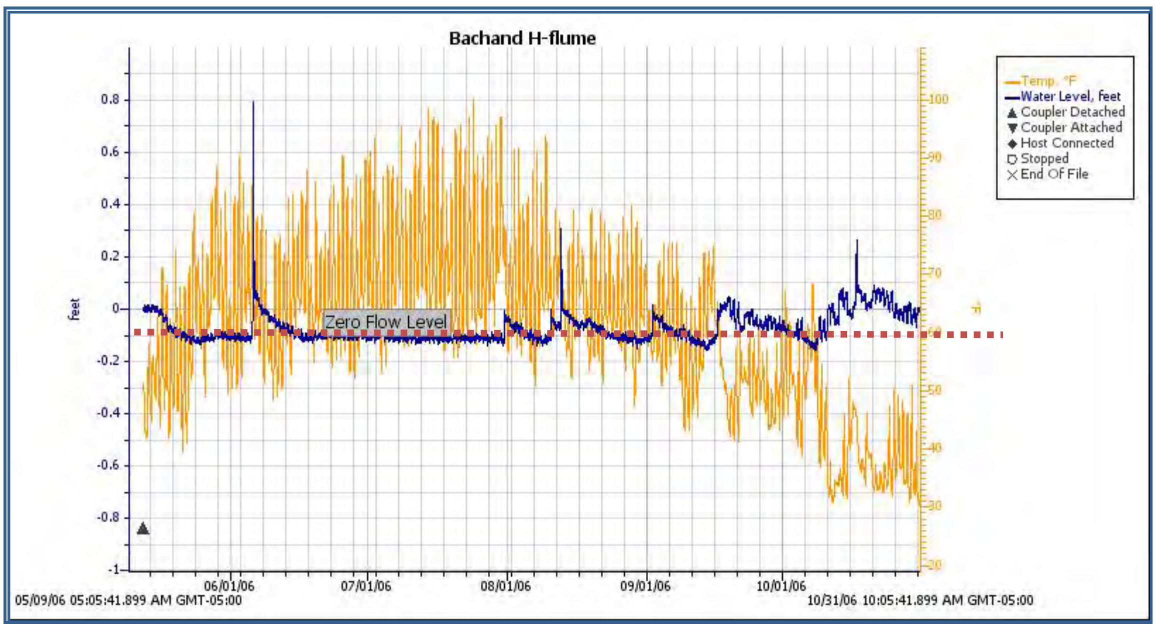


Figure 61. 2006 Plot of the HOBO water level record at the Bachand H-Flume

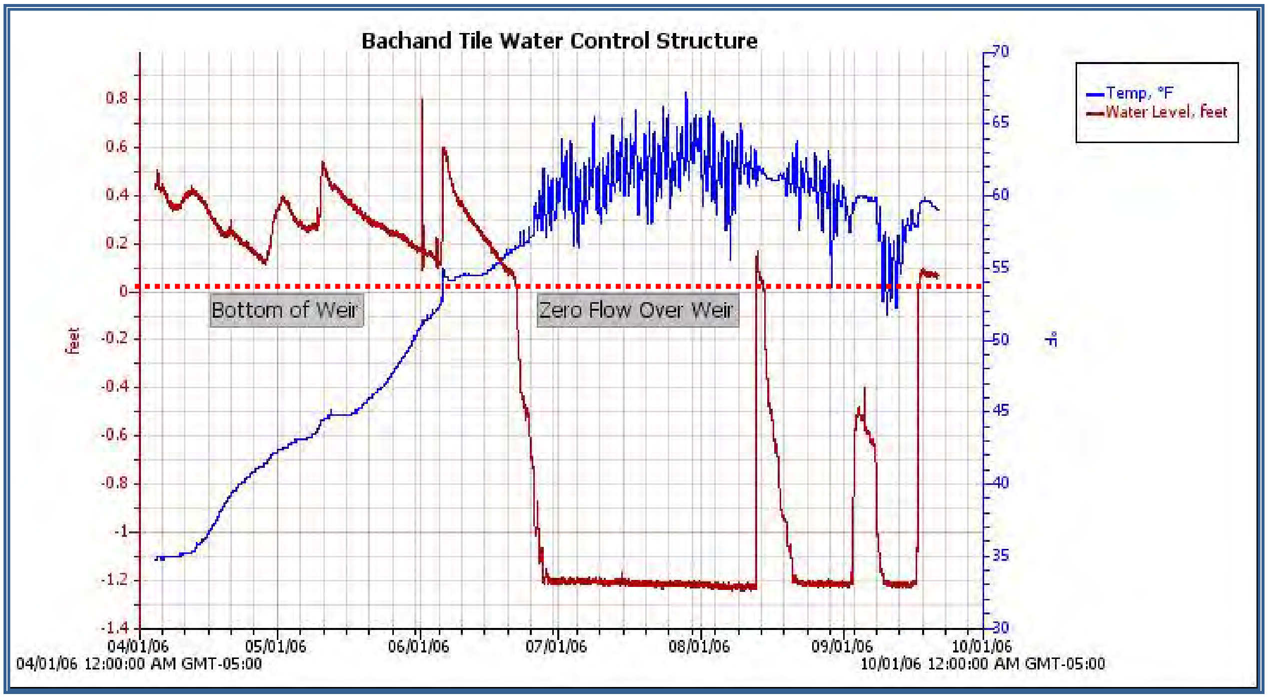


Figure 62. 2006 Plot of the HOBO water level record at the Bachand Tile Water Control Structure

In the first year of the study, site selection and setup efforts delayed the start of continuous monitoring until August of that year. We were still able to capture the effects of some rain events.

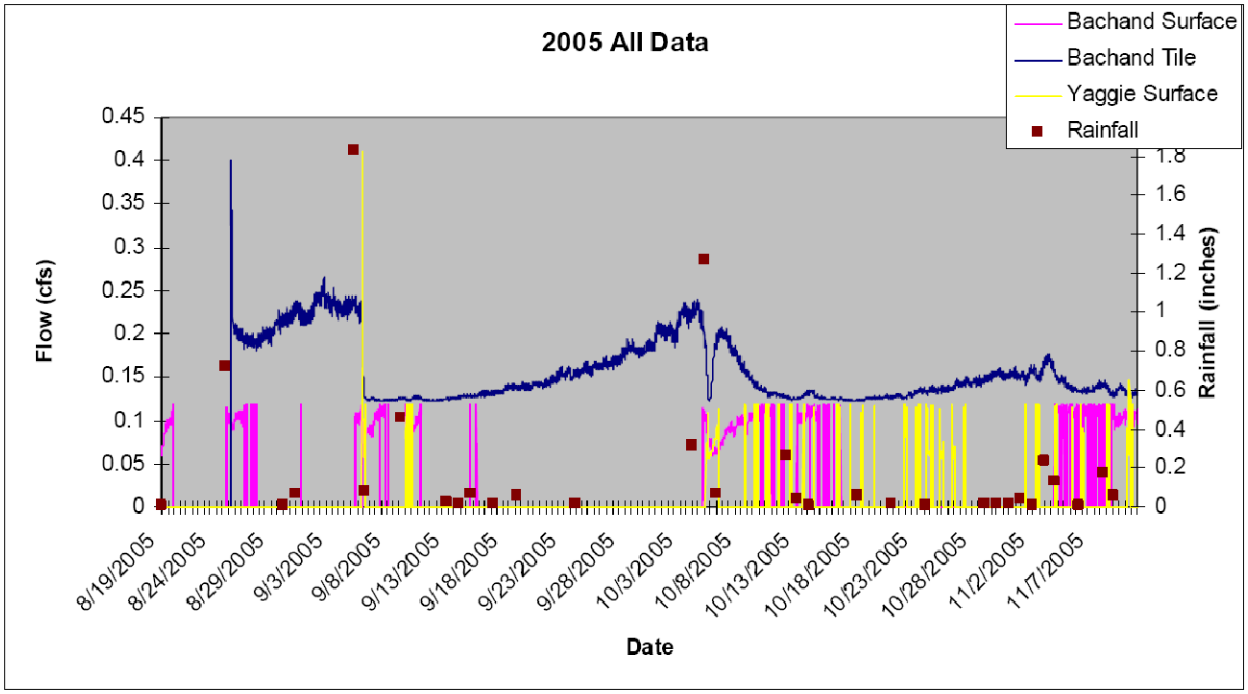


Figure 63. 2005 flow hydrograph

The 2006 hydrograph demonstrates how the peak rates of flow from the surface drained field dwarf the peak flows from the tile drainage, even though the surface drained site has a smaller watershed area.

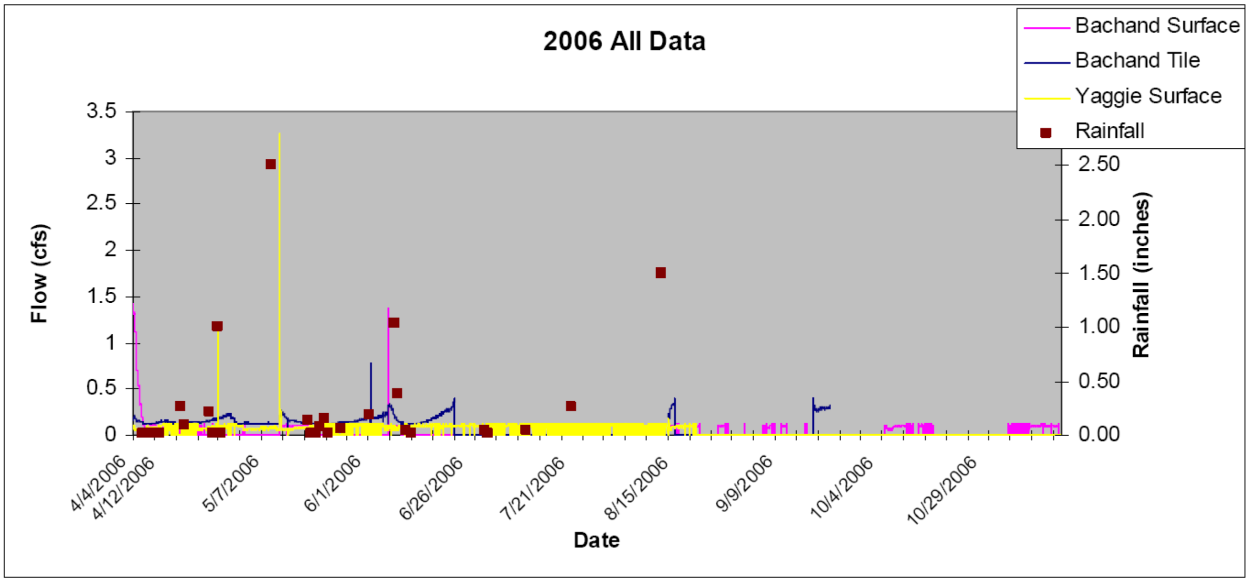


Figure 64. 2006 flow hydrograph

The 2007 flow record from the Yaggie surface drained field was edited to a shorter time frame due to a HOBO water level logger that malfunctioned.

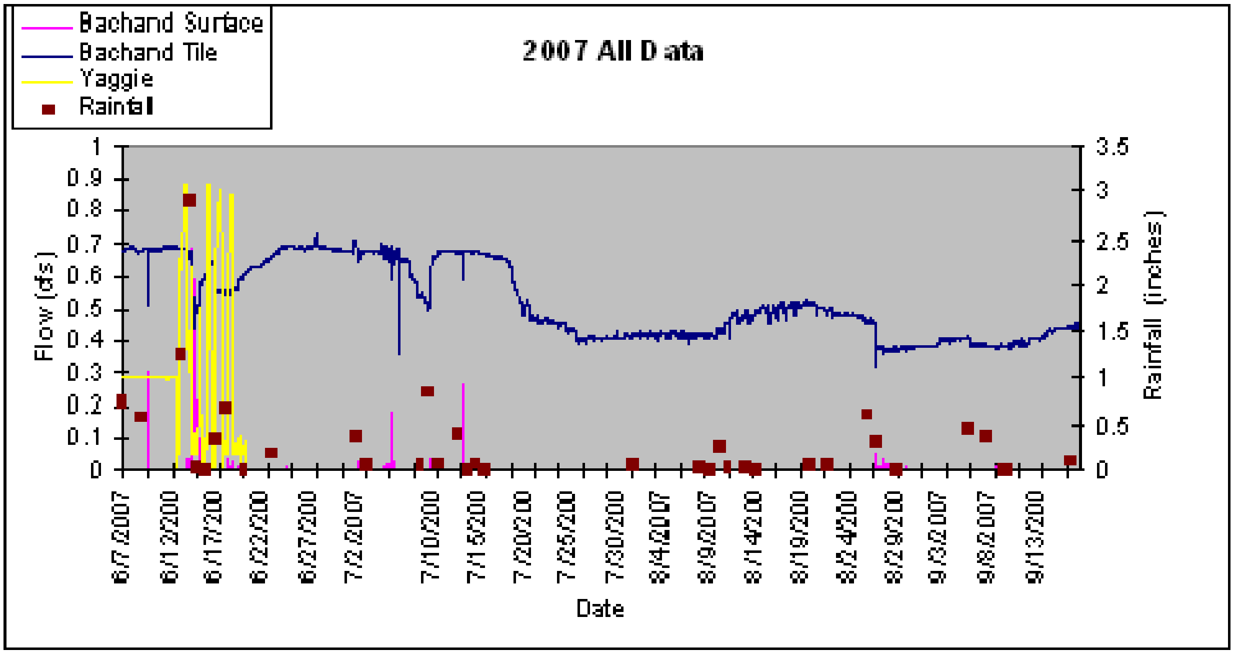


Figure 65. 2007 flow hydrograph

A good, accurate, complete record of flow was collected at each site during the 2008 monitoring season. The Bachand Surface h-flume was modified to avoid the effects of backwater conditions. Loggers were re-launched in the early fall so that there would be plenty of memory storage for the late fall readings. Significant rainfall and runoff events were captured in October.

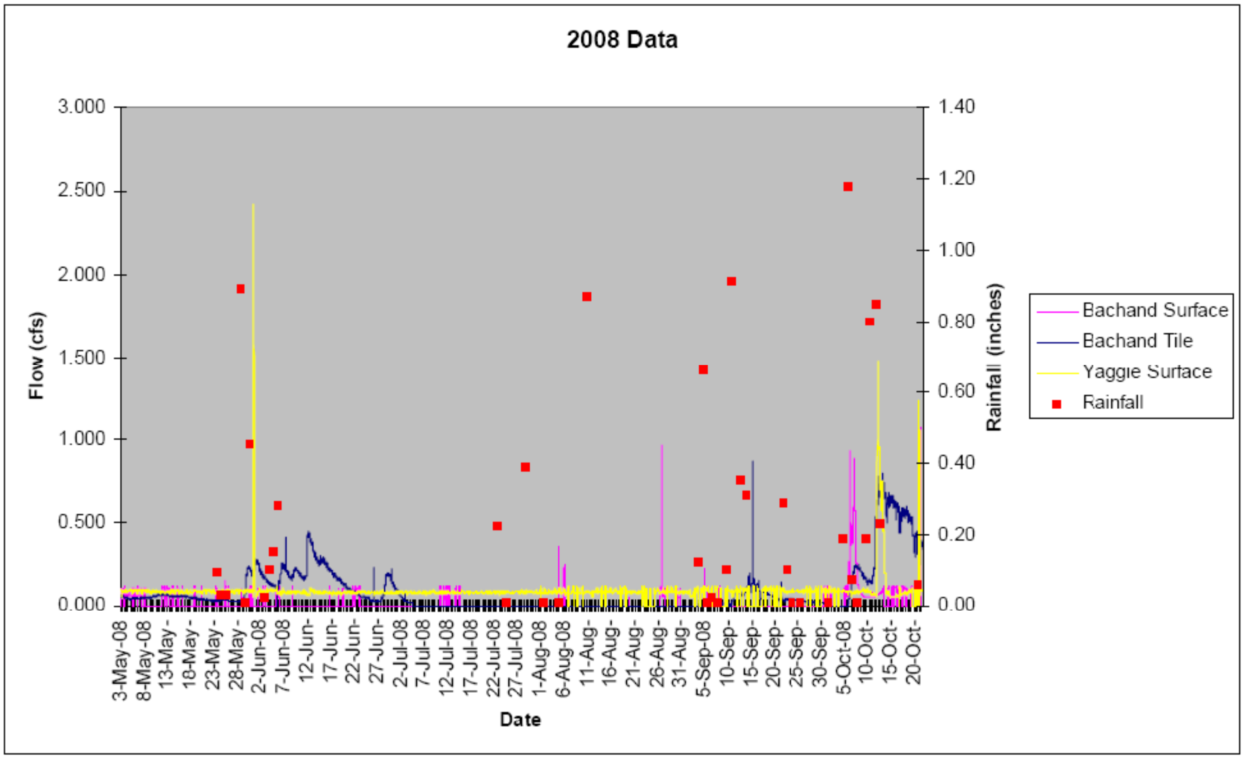


Figure 66. 2008 flow hydrograph

As shown by the following table, the record of flow was not 100% complete for each year. The records in 2005 and 2008 were very complete. In 2006 and 2007, there are some gaps because the HOBO Water Level Loggers stop logging when their memory is full. Fortunately, this usually occurred during the late summer/early fall when there was not much runoff. The 2007 record for the Yaggie site was abbreviated because the HOBO Level Logger began malfunctioning part of the way through the year. The 2008 record was nearly complete (except for the time needed to collect data from loggers) because of avoidance of backwater, proper logger management, and reliable performance from water level loggers.

Flow Data Points Collected				
Site	**2005**	**2006**	**2007**	**2008**
Bachand Tile	12,756	16,294	16,266	21,195
Bachand Surface	11,426	19,357	21,679	17,562
Yaggie2 Surface	8,741	21,692	14,385	18,113
Date of First Measurement				
Site	**2005**	**2006**	**2007**	**2008**
Bachand Tile	8/5/2005	4/4/2006	4/2/2007	5/2/2008
Bachand Surface	8/19/2005	4/4/2006	4/2/2007	5/8/2008
Yaggie2 Surface	8/19/2005	4/4/2006	4/2/2007	5/2/2008
Date of Last Measurement				
Site	**2005**	**2006**	**2007**	**2008**
Bachand Tile	12/16/2005	11/17/2006	11/16/2007	12/9/2008
Bachand Surface	12/16/2005	11/16/2006	11/16/2007	11/7/2008
Yaggie2 Surface	11/18/2005	11/16/2006	11/16/2007	11/7/2008
Percent Completeness Between 1st and Last Measurement				
Site	**2005**	**2006**	**2007**	**2008**
Bachand Tile	100.00%	74.80%	74.40%	100.00%
Bachand Surface	100.00%	89.20%	99.10%	99.99%
Yaggie2 Surface	100.00%	100.00%	65.80%	99.98%
Missing Data Affecting Results: The Yaggie 2 flume's level logger was malfunctioning in 2007. The Bachand Sfc flume was affected by Hill River Backwater in 2006				

Figure 67. Flow data quality

Peak Flow

The data collected support the hypothesis that installing tile drainage (without surface inlets) can reduce peak flows. During runoff generating storm events, the hydrograph of flow from the surface drained field exhibits an abrupt spike in the rate of flow. The hydrograph from the tile drain shows an attenuated rate of flow that is prolonged relative to surface drainage.

To arrive at this conclusion, peak flow rates from each drainage-way (Bachand tile, Bachand surface, combined Bachand field drainage, Yaggie surface) were normalized by acre and compared for 7 events. The peak flows from the field without tile drainage were almost always greater than peak flows from the tiled field.

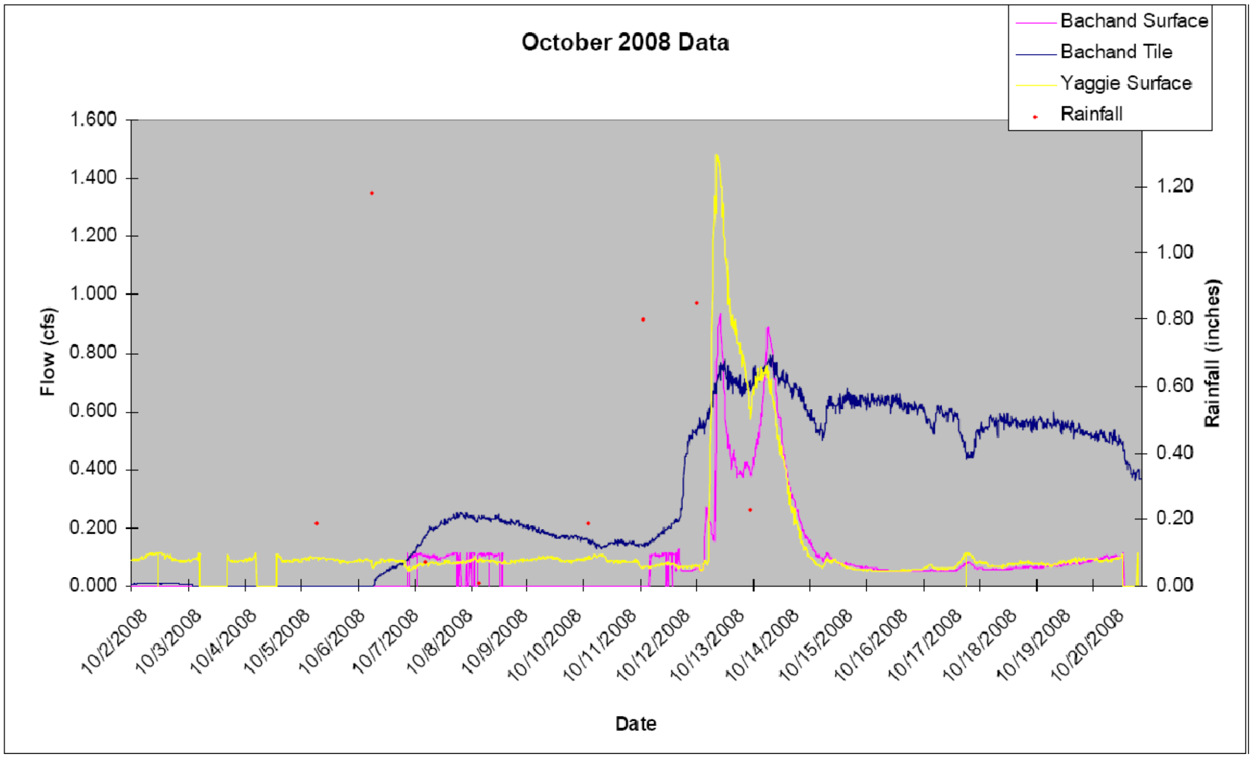


Figure 68. Example runoff event hydrograph showing peak flows (before normalization)

Table 17. Peak flow per acre

	Peak Flow Per Acre (CFS/acre)				
Event	Bachand Tile	Bachand Sfc	Bachand Total	Yaggie Sfc	Total rainfall (in)
September 2005	0.0015	0.0007	0.002	0.0060	1.91
May 2006	0.0015	0.0007	0.002	0.0487	0.25
August 2006	0.0024	0.0007	0.003	0.0024	1.43
June 2007	0.0040	0.0040	0.0068	0.0130	3
May/June 2008	0.0017	0.0009	0.0023	0.0361	1.62
September 2008	0.0051	0.0007	0.005	0.0033	2.1
October 2008	0.0046	0.0050	0.01	0.0220	3.26
Average	**0.0030**	**0.0018**	**0.0045**	**0.0188**	**1.94**

Note that peak flows are normalized by acre. Bachand field combined peak flows represent the greatest rate of simultaneous combined flow from tile and surface drainage recorded during an event. Flow rates were calculated for each water level reading. Water levels were recorded at a 15-minute interval.

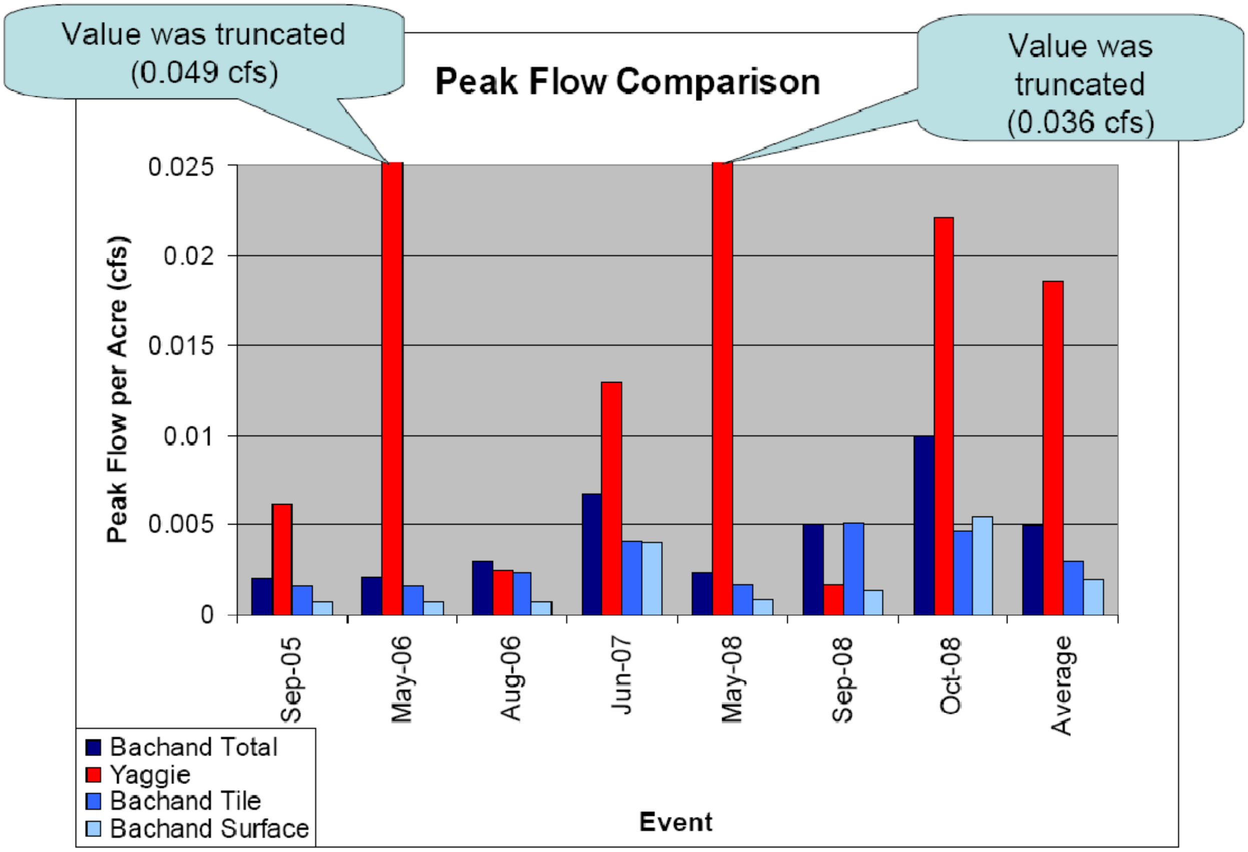


Figure 69. Peak Flow Summary chart

Total Volume

Total runoff volume was calculated for individual events and for each year's period of record. The following steps were used to calculate the flow volume for each runoff event:

1. Runoff events were initiated when runoff departed from base flows during a storm event.

2. The observation window for each event was closed when event flows receded back to base flow levels.

3. Volume was then calculated for surface and tile flows during the observation window. The area under curves equals the total volume from event.

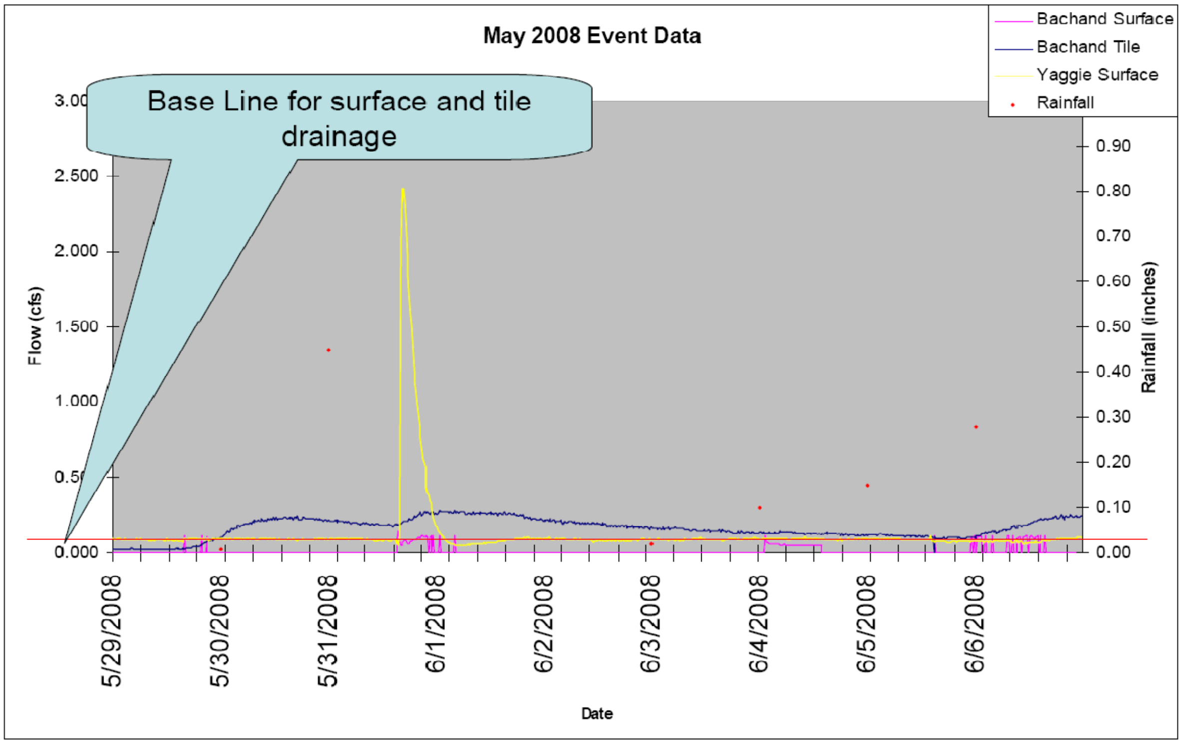


Figure 70. Finding the base line flow for each runoff event

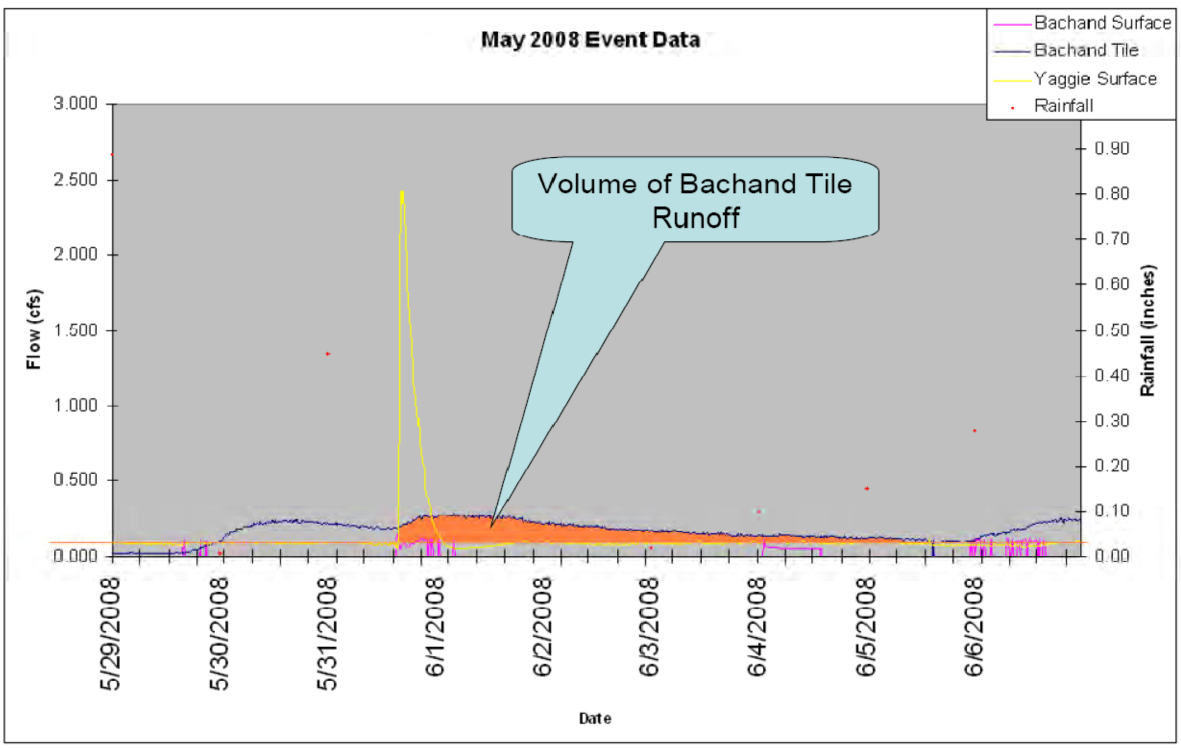


Figure 71. Calculating runoff event volume for tile drainage

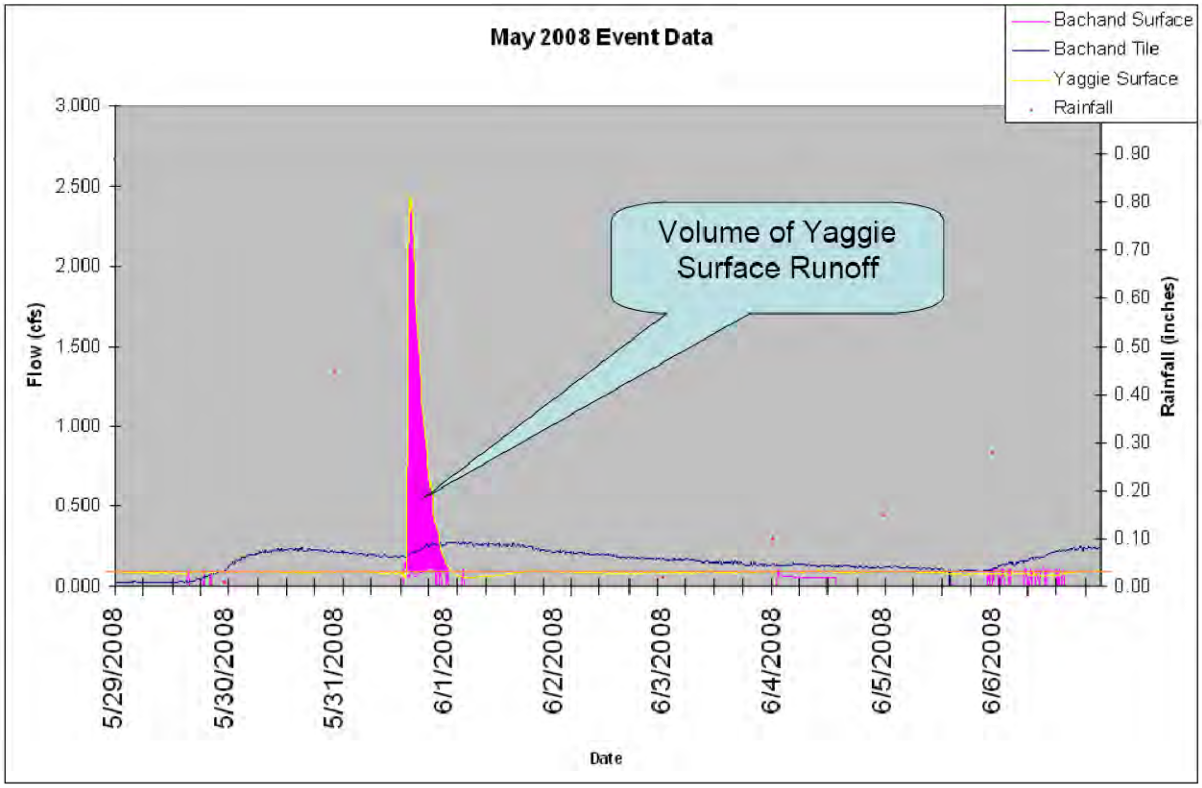


Figure 72. Calculating runoff event flow volume for surface drainage

Event flow volume refers to the volume of flow measured from the point where flow increases from the base flow level during a storm event to the point where the rate of flow returns to the base flow level after the storm event is over. Several events were selected and used for this analysis. The two fields that were part of this study have different watershed areas. Therefore, in order to make fair comparisons in the final analysis, flows are normalized by calculating the inches of runoff per acre. This “cancels-out” watershed area as a factor in the results. The year’s entire flow record is taken into consideration when determining the assumed base flow level for each event. The data analysis shows that, at the event scale, the runoff volume is greater for a tile and surface drained field than it is for a field with just surface drainage.

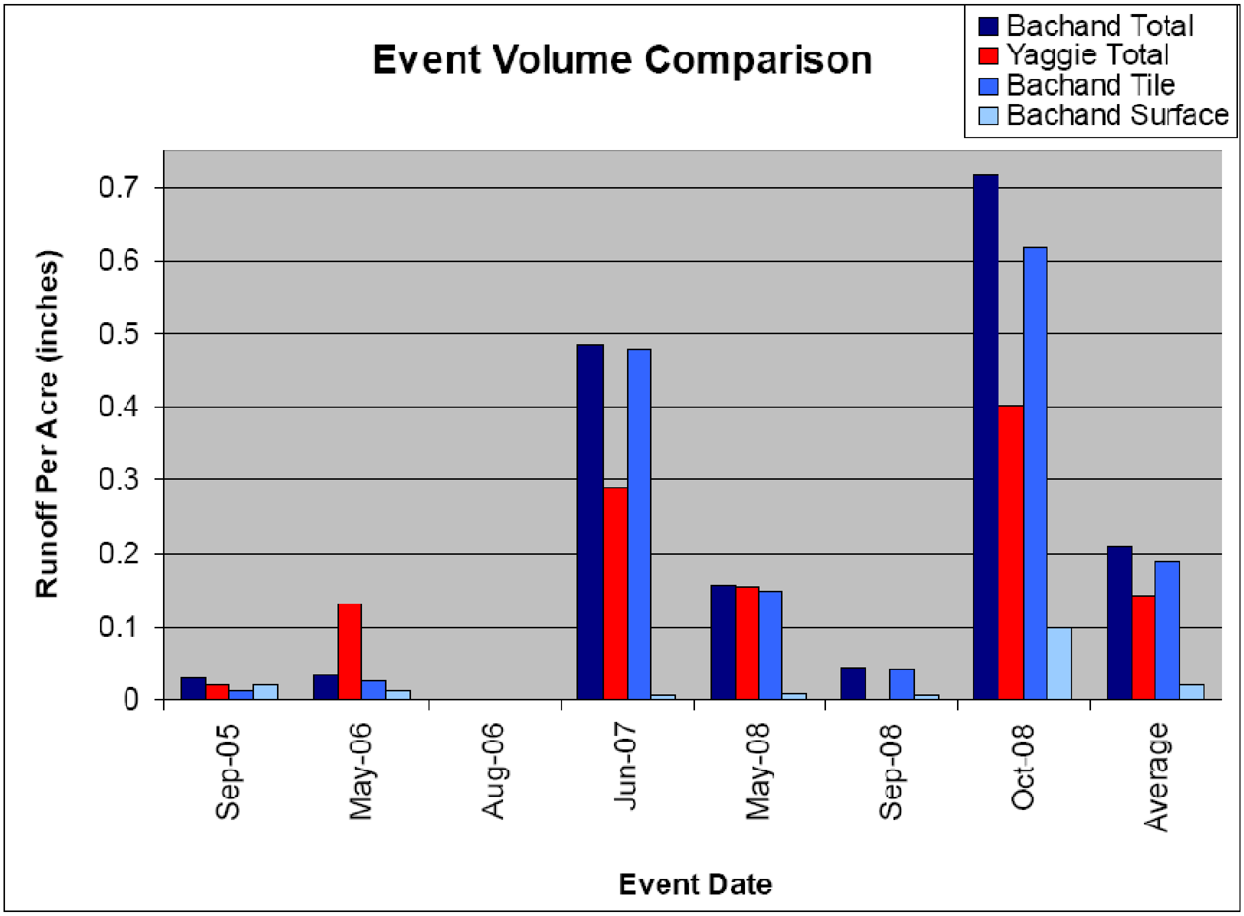


Figure 73. Comparison of event runoff volumes

Table 18. Total Event Runoff Summary

	Total Event Runoff (inches/acre)				
Event	Bachand Tile	Bachand Sfc	Bachand Total	Yaggie Sfc	Total rainfall (in)
September 2005	0.0100	0.0200	0.0300	0.0200	1.910
May 2006	0.0250	0.0086	0.0340	0.1310	0.250
August 2006	0.0005	0.0001	0.0006	0.0003	1.430
June 2007	0.4800	0.0054	0.4854	0.2900	3.000
May/June 2008	0.1480	0.0080	0.1560	0.1530	1.620
September 2008	0.0399	0.0044	0.0443	0.0006	2.100
October 2008	0.6180	0.1000	0.7180	0.4030	3.260
Average	**0.189**	**0.021**	**0.210**	**0.143**	**1.939**

The long term total volume comparison is based on the total runoff in inches from each field over each year's period of record (approximately equal to the growing season for most years). The results of this analysis show that the tiled field does indeed discharge a greater amount of water over the long term than a surface drained field. To give the reader a sense of scale, the measured volumes are compared against the annual average for the site from the DNR climatology website (1971 – 2000) in the following chart.

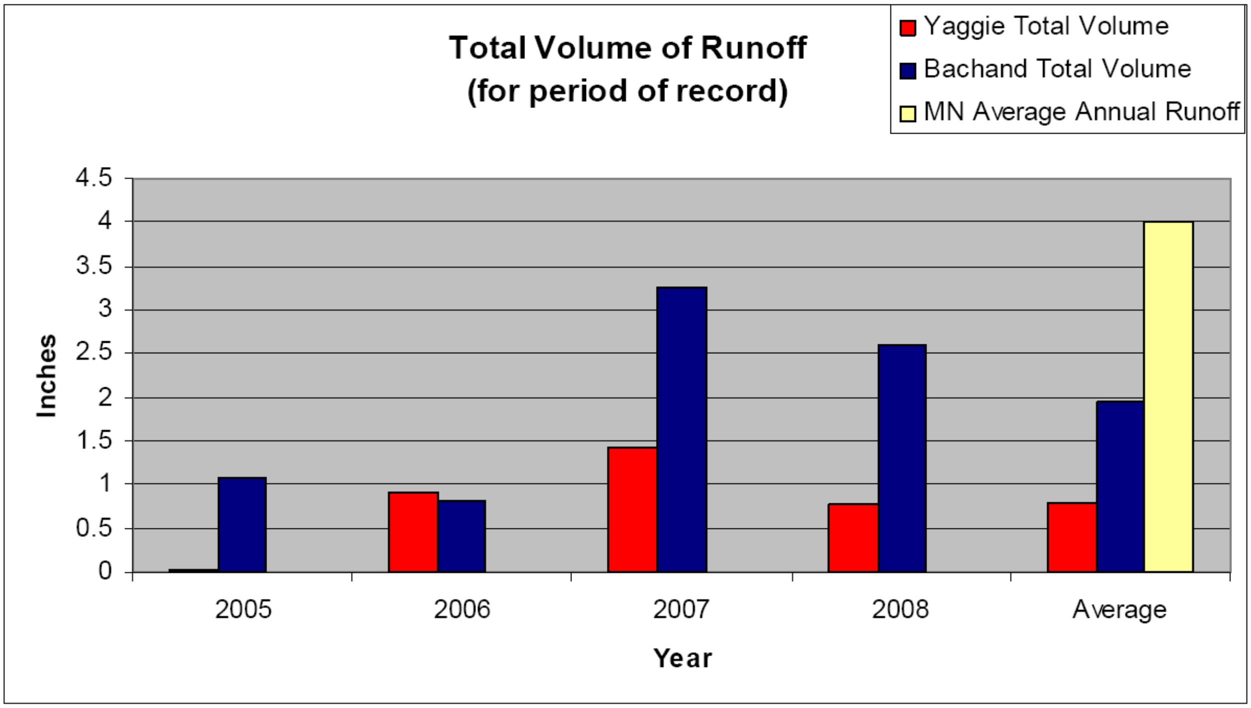


Figure 74. Comparison of total runoff volumes

The recession of the tile drain hydrograph is much more gradual than that of surface drainage after a rain event. The surface drainage is much more "flashy." It is interesting that the general shape or slope of the recession of the tile hydrograph is similar to the hydrographs of subsurface drainage from other studies (specifically, Oquist et al).

The Bachand tile seemed to have a more sustained flow than the tile drains monitored in Marshall County. Although it was designed avoid blockage of flow, there should be some consideration as to whether or not the structure had any effect in moderating flows through the tile. In an individual storm event, the tile response may depend on whether or not it was flowing already and how saturated the ground was at the time.

Challenges Encountered

As stated earlier in this report, the initial challenge for this study was finding suitable sites. Sites had to be close enough in proximity and have similar land use characteristics for comparability.

Backwater became an issue during some runoff events where the Hill River flooded. One of the requirements for obtaining accurate flow estimates using the h-flume and v-notch weir flow measurement structures is having open flow over the lip or the structure. If backwater rises above the level of the lip of the structure, discharge is reduced for a given stage compared to a free outfall. This could lead to an overestimation of flows if backwater is not recognized and addressed. Knowledge of backwater conditions was obtained by installing a HOBO Water Level Logger in the tailwater pool at the Bachand site. This improves the accuracy of surface drainage flow estimates from this field. We will know when the water levels in the flumes were being influenced by backwater from the Hill River and we will be able to avoid overestimating the surface drainage flow from this field. HEC-RAS modeling was used to adjust 2005-2007 data that was influenced by backwater.

Another, more successful safeguard against backwater was the raising of the surface drainage h-flume at the Bachand field. The inlet to the structure was also landscaped and stabilized to make sure that water flows into the structure.

Making sure the h-flumes were level was important, yet challenging part of achieving accurate results.

A water level logger was installed in the tailwater pool at the Bachand site.

Figure 75. Raising the h-flume

Over the winter of 2005-2006, ice storms filled the h-flumes with ice. There was some concern over whether or not this would obstruct spring runoff. The ice was fairly easily washed away during the spring runoff and the problem did not occur in any of the subsequent winters. Ice in the flumes did not affect the results of this study either, as flow monitoring did not begin until after spring thaw was completed. This study focuses on the relative effects of tile drainage. The gravity tile system in this field was not a factor during the winter and during spring runoff because the ground was frozen and the tile was not flowing.

We needed to be sure that all flow went through the flumes instead of around or under them. Landscaping was done at the Bachand h-flume to funnel water into the flume.

Quikrete® was used to “seal” the rear of the Yaggie 2 flume around the culvert so that water would not flow out of the back of the flume.

The Yaggie 2 monitoring site accumulated much ice during the winter of 2005 - 2006

2006 spring runoff at Red Lake County monitoring sites.

Discussion on Flow in Receiving Waters

Water level logger installed in Hill River

Due to curiosity about the amount of influence tile drainage can have on flow patterns in receiving waters, a HOBO Water Level Logger was also installed in the Hill River downstream of where drainage from the Bachand tile drained field enters the river. The logger data was referenced to manual measurements of water level collected by measuring down from a reference point. For this study, the reference point is given an arbitrary elevation of 100. The flow data from the Bachand Tile outlet appears to correlate with water level elevations in the river, but only in certain ways and at certain water levels. This introduces questions about whether or not the one variable (tile flow) is actually influencing the other (river water levels) or if both are being simultaneously and similarly influenced by other variables like precipitation and/or ground water levels.

- Changes in flow from tile seem to coincide with changes in flow in the river. However, the level of flow in the river does not seem to be controlled by flow from the tile. It is more likely that there are factors such as precipitation and groundwater levels may be affecting the tile flow and river levels alike. In a small snippet of time, the flow from tile and flow in the river reflect each other. The data collected in this study is
- Compare elevation of tile water with elevation of water in the river
    - Elevation of culvert
    - Elevation of water control structure

Increases in flow from the Bachand tile outlet often, but not always match increases in flow within the Hill River. There are “spikes” in the river water level that are barely noticeable in the tile flow record. These spikes within the river are likely caused by runoff events (surface drainage).

Recession after spikes in Hill River water levels looks similar to the recession in tile flow hydrographs.

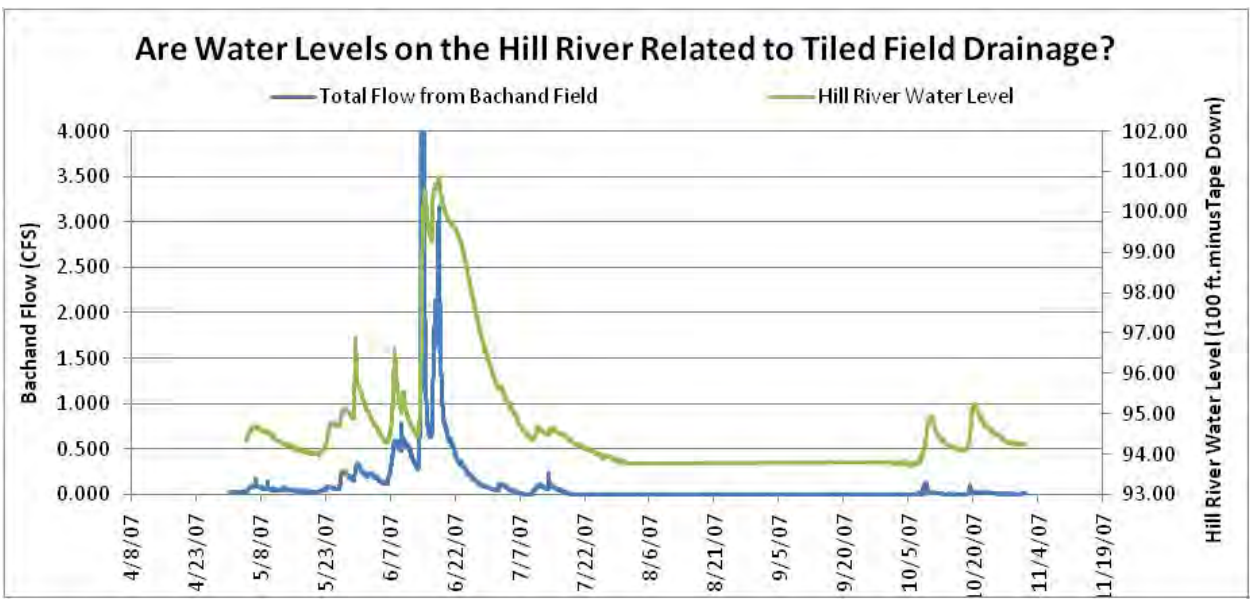


Figure 76. 2007 Hill River Water Levels and Tile Flow Rates

Conclusions

Generally, conventional agriculture tile drainage should have a positive impact on the problems of high turbidity, total suspended solids, and total phosphorus in the Red River Basin. Unfortunately, there are "side effects" of high nitrate and conductivity levels. Minnesota scientists are researching possible methods for reducing these "side effects."

The wild rice paddies were an exception in that the wild rice paddy main-line tile water had all the water quality benefits of conventional agriculture tile, but without the high nitrate levels.

Tile drainage for conventional agriculture has little benefit to water quality when the ground is frozen and the tile is not running (during spring runoff). The benefits are also lessoned when the ground is saturated enough for surface runoff to occur.

The existence of a grassed waterway appeared to moderate water quality.

Data analysis supports the hypotheses that were expressed at the beginning of the project. Peak flows generated from a surface drained field clearly exceed the peak flows from a tile drained field (tile and surface drainage included). The duration of flow from tile is much longer than the duration of flow from surface drainage. So, the total volume of drainage from a tiled field is clearly greater than the total volume of drainage from a field that lacks tile drainage.

- Tile drainage in the Red River Basin reduces peak flows from an individual field relative to surface drained fields during runoff events.
- Tile drainage in the Red River Basin increases the total volume of runoff in the long-term relative to surface drained fields.
- Antecedent conditions have a significant role on the influence of tile drainage during a runoff event. A rainfall event will have a varying effect upon runoff due to varying levels of initial soil moisture, rainfall amount, rainfall intensity, and rainfall duration.
- These results pertain only to tile drainage systems with similar soils and topography in Red River Basin that do not have surface inlets.

Recommendations for Future Monitoring and Studies

Plenty of data was collected during this study to characterize the water quality from tile drainage. Data deficiencies may exist in the quantity of paired samples and field measurements from tile drainage and surface runoff, and in the amount of data collected in the lower part of the Red River Valley. There are several factors that made collection of paired storm runoff data difficult. There are storms happen at night when no one is around to sample. Much of the rain from smaller events soaks into the ground and doesn't quite turn into runoff, especially when the rainfall follows a dry spell.

Monitoring and research efforts should also be targeted at evaluating what happens to the concentrated discharges of nitrates after they enter a river system. There is ongoing research evaluating the use of wetlands to filter nitrates and other pollutants from tile drainage runoff. Also, extra monitoring could be done in the lower red river valley, closer to the Red River where soils have higher clay content. Dr. Gary Sands of the University of Minnesota Extension service is one person that has been active in researching such issues. Any data collected by the RLWD essentially belongs to the public. So, this data will be made available to others to enhance their research efforts. Additional knowledge may be gained by combining data from multiple monitoring efforts.

Still more information that could be collected to answer questions brought up during presentations and meetings would include soil sample analysis from fields, soil salt content analysis (types of salts in the soil), what constituents are causing high conductivity readings.

Flow monitoring will continue as long as it is feasible. The data will continue to be useful in backing up results, especially since the methods and structures have seen improvement.

Several ideas for data analysis have been presented, but not yet addressed:

- Total discharge vs. time, soil type
- Soil type vs. time vs. discharge
- Individual rainfall event amounts vs. discharge

This study used a gravity tile system for the flow study. The tile was shallow (40 inches) enough that it would freeze during the winter and would not be a factor until the snow melted and ground thawed. There are pumped systems in the Red River Valley, however, that will begin flowing earlier in the year, sometimes during the spring runoff. If these outlets are running, what effect would they have upon peak flows and total flow volumes? Would the results be similar to the effects documented by this study? The challenge in monitoring these fields will be in measuring the surface runoff. The flatter topography in which these are installed will disallow the use of weirs for flow measurement and there will likely be many surface drainage outlets to monitor for each pumped tile drainage system.

A strategy that may improve the precision of a field scale runoff study would be changing the time step of measurements. A time step of 15 minutes was used for this study as a compromise between logger memory and precision. Benefits to decreasing in the time step would lie in the possibility of catching peak flow levels that are missed by the 15 minute time step and getting a greater number of measureable surface runoff readings. Drawbacks would come from a decrease in battery life and an increase in labor for sensor maintenance.

Education Efforts

This project seems to have generated more interest than any other recent water quality project the RLWD has completed.

A brochure has been created that summarizes the project and its findings. The RLWD has printed 165 copies of this brochure for distribution at presentations, meetings, at the RLWD office. Copies have been mailed to project participants.

This final report for the Red Lake Watershed Farm to Stream Tile Drainage Study is available for viewing and downloads on the RLWD website and is also available in hard copy at the RLWD office. Of course, if you are reading this, you already have a copy.

I have given presentations about this study to the 2006 and 2007 Agricultural Drainage Workshops held in Moorhead, Minnesota. I have also presented to the Minnesota-Iowa Drainage Research Forum, RLWD Board of Mangers, RLWD Overall Advisory Committee, and the Red River Basin Water Quality Team. In 2008, presentations about this study are scheduled for the February 14th Tile Drainage Forum at North Dakota State University, February Red River Basin Water Quality Team meeting in Thief River Falls, and the March Red River Basin Water Quality Team Meeting in Moorhead.

Please visit the Red Lake Watershed District website (www.redlakewatershed.org) for the quality assurance project plan, reports, presentations, and more information on this project and other Red Lake Watershed District projects.

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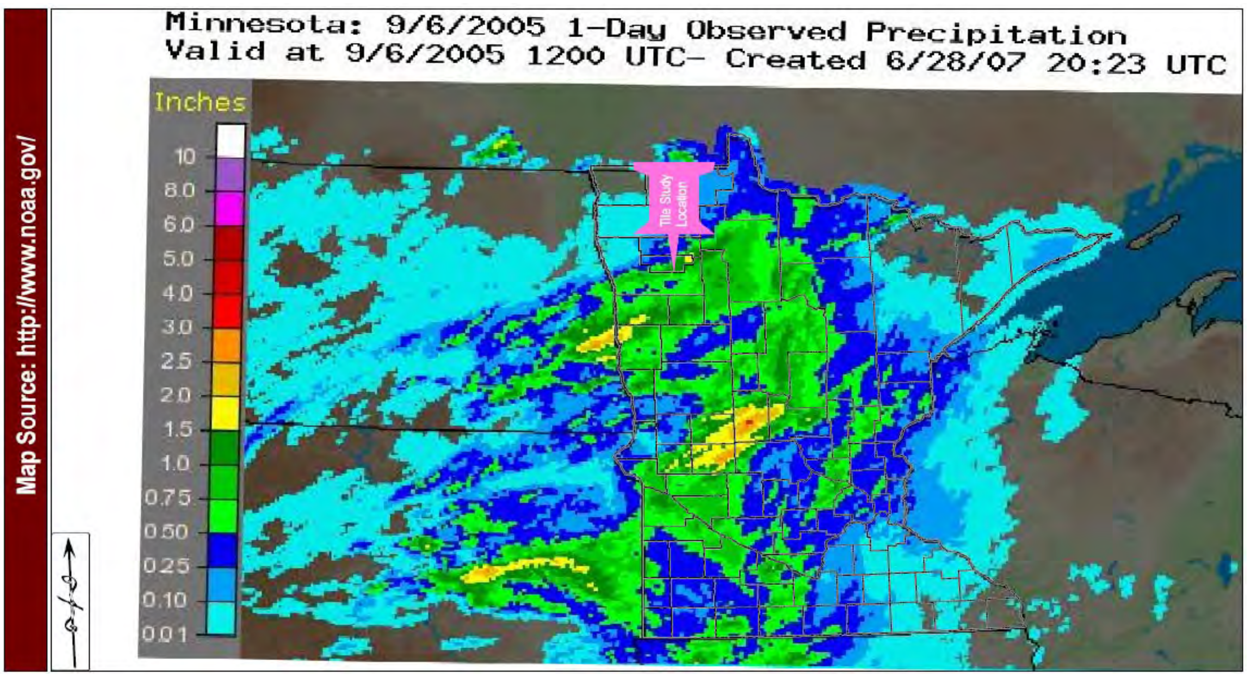
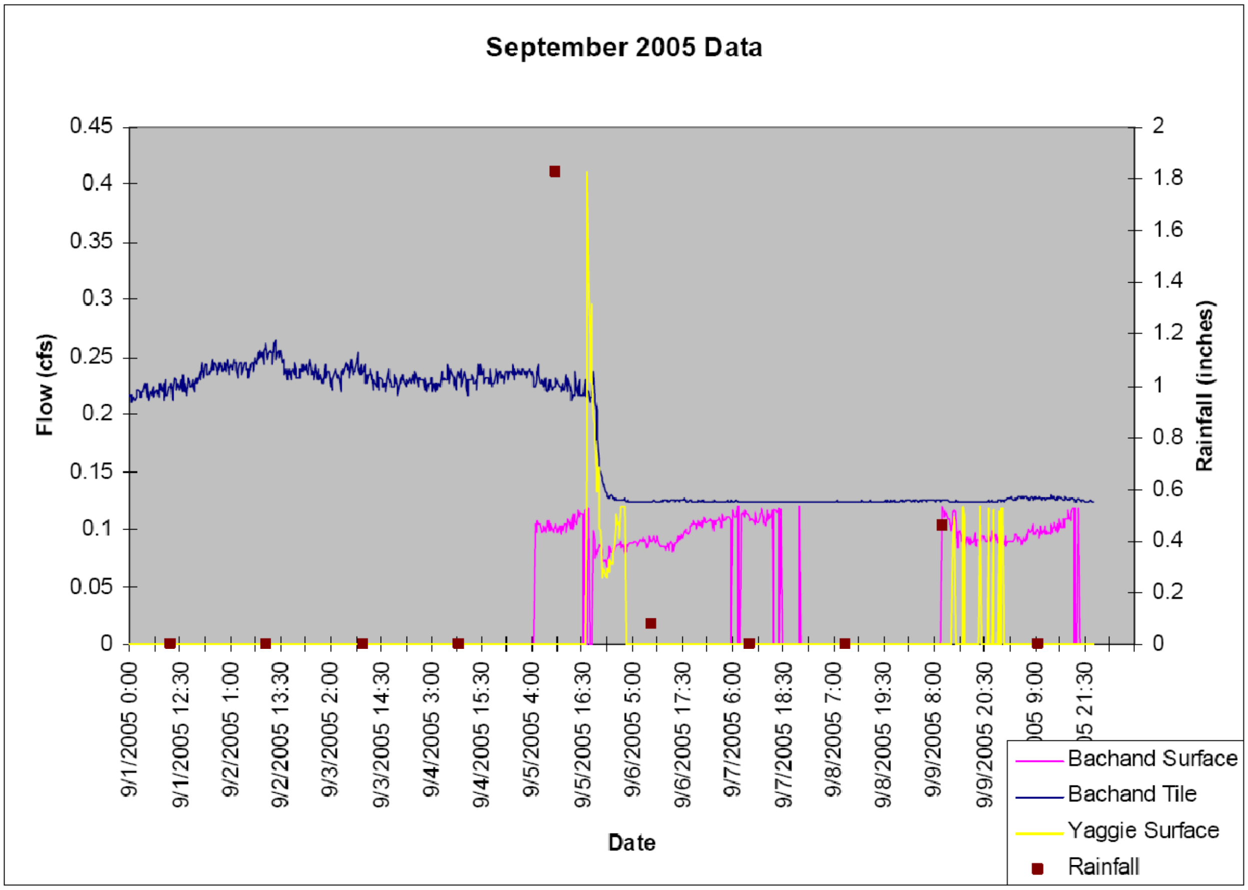
Appendix A.

Flow Analysis of Individual Runoff Events

September 2005 Runoff Event

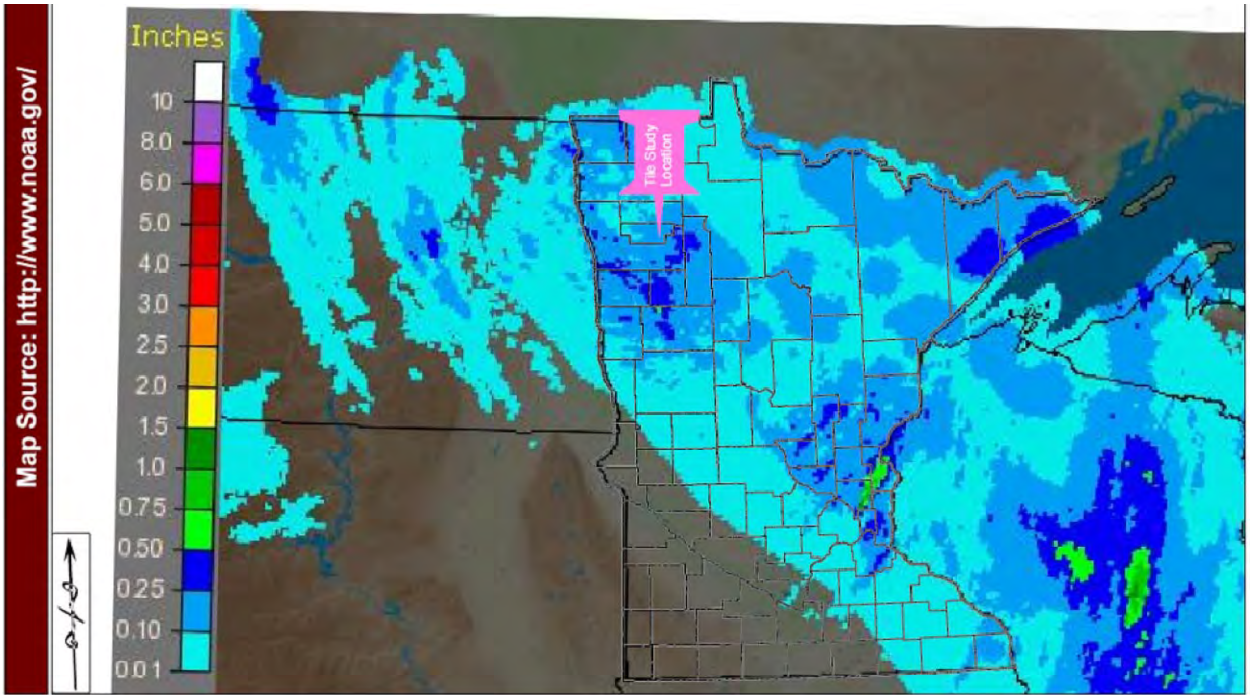
Field (crop)	Size (acre)	Cumulative Rainfall (inches)	Runoff Per Acre (inches)	Runoff (% of Total Rainfall)	% Reduction Of Volume (Bachand compared to Yaggie)	Peak Flow (cfs)	Peak Flow Per Acre (cfs)	% Reduction of Peak Flow Per Acre (Bachand compared to Yaggie)
Yaggie (Soybeans)	67	1.91	0.02	1.05	N/A	0.41	0.006	N/A
Bachand Tile (Wheat)	171.7	1.91	0.01	0.52	N/A	0.26	0.0015	N/A
Bachand Surface (Wheat)	171.4	1.91	0.02	1.05	N/A	0.12	0.0007	N/A
Bachand Total (Wheat)	171.7	1.91	0.03	1.57	-49.5 (volume Increased)	0.347	0.002	66





May 2006 Runoff Event

Field (crop)	Size (acre)	Cumulative Rainfall (inches)	Runoff Per Acre (inches)	Runoff (% of Total Rainfall)	% Reduction of Volume (Bachand compared to Yaggie)	Peak Flow (cfs)	Peak Flow Per Acre (cfs)	% Reduction of Peak Flow Per Acre (Bachand compared to Yaggie)
Yaggie (Wheat)	67	2.5	0.131	5.24	N/A	3.26	0.0487	N/A
Bachand Tile (Soybeans)	171.7	2.5	0.025	1	N/A	0.26	0.0015	N/A
Bachand Surface (Soybeans)	171.4	2.5	0.0086	0.34	N/A	0.12	0.0007	N/A
Bachand Total (Soybeans)	171.7	2.5	0.034	1.36	74	0.365	0.002	95.6



Map Source: http://www.noaa.gov/
Inches
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5.0
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2.5
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1.0
0.75
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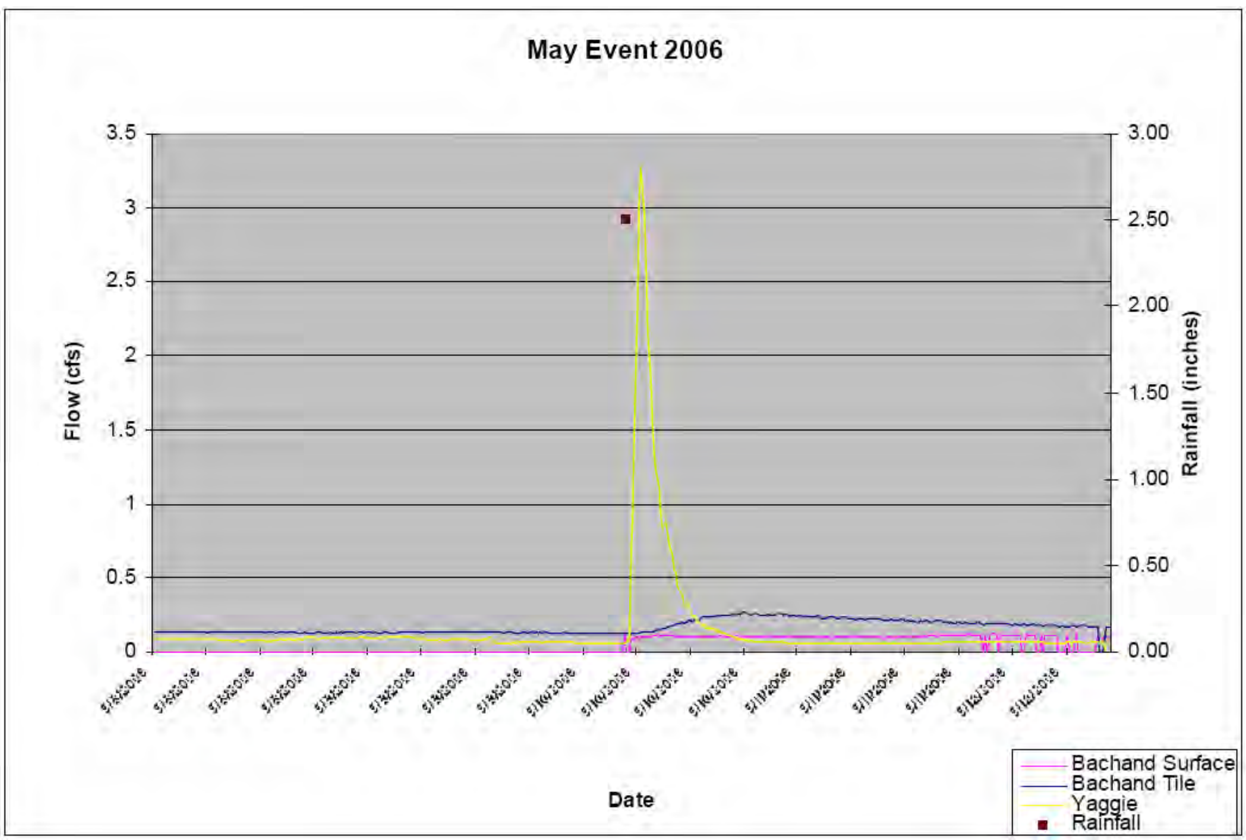
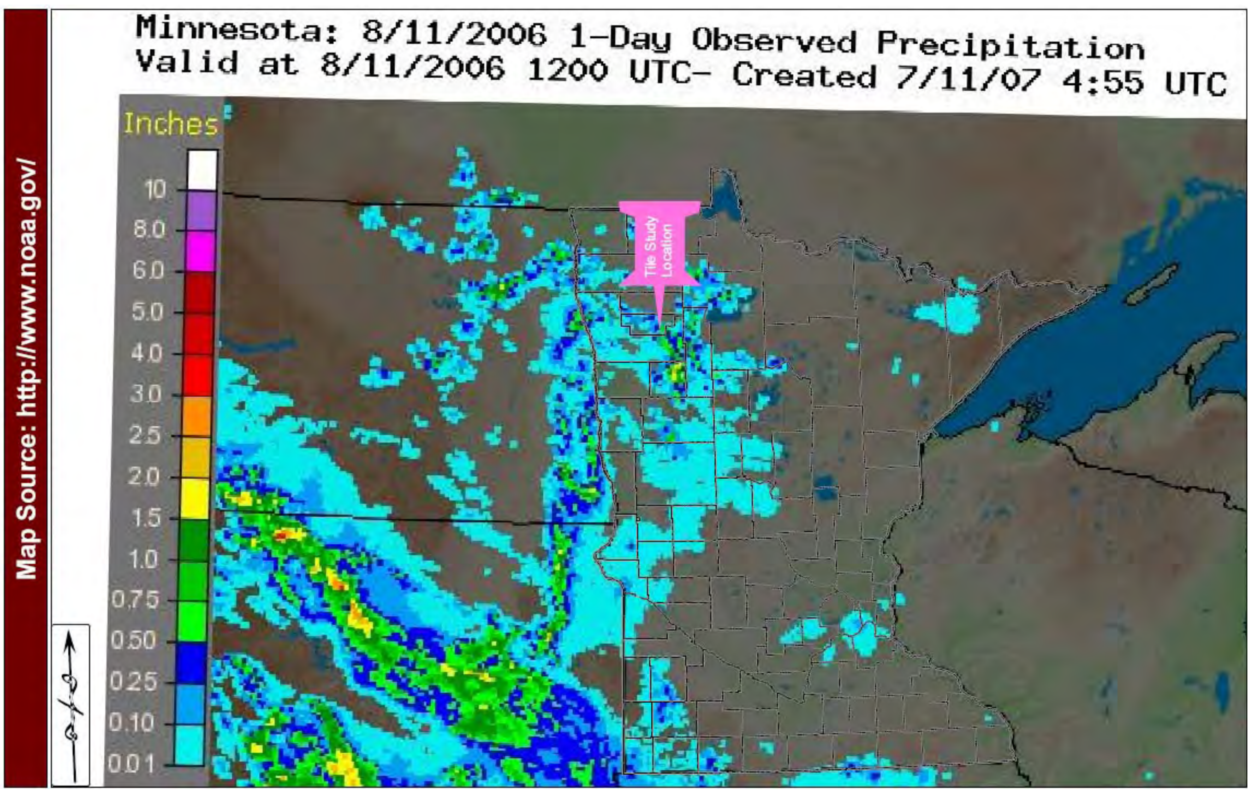
0.10
0.01
Tile Study Location

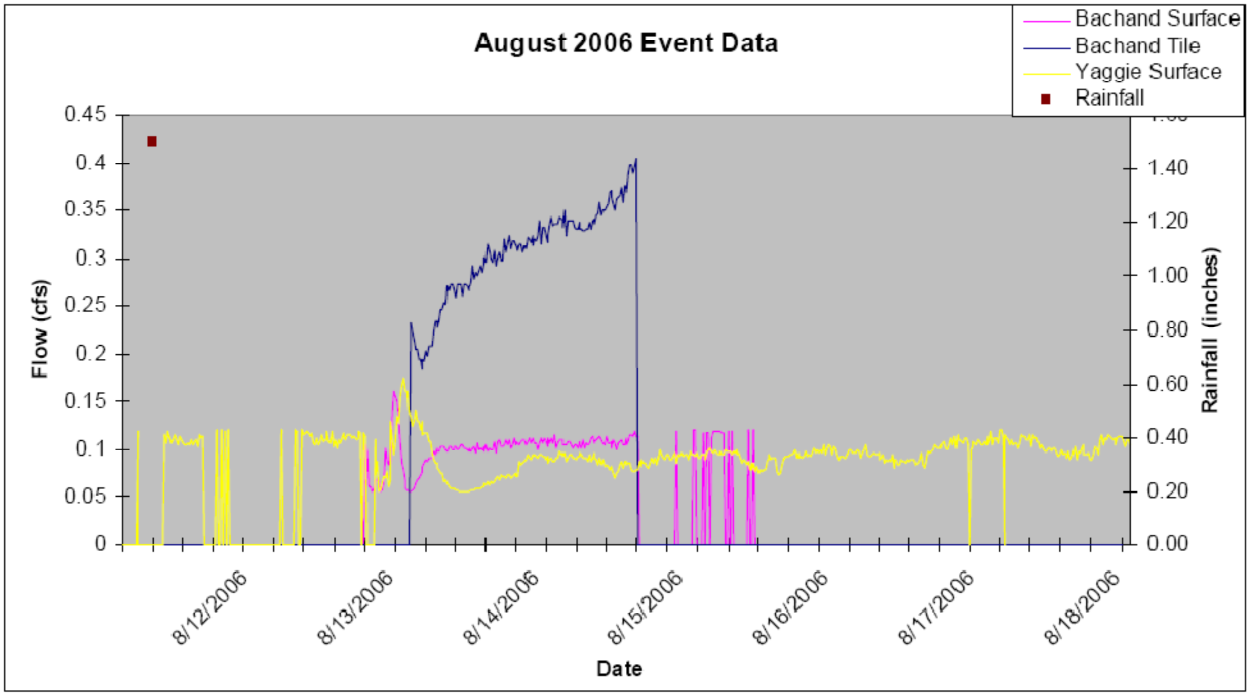


May Event 2006
Flow (cfs)
Rainfall (inches)
Date
Bachand Surface
Bachand Tile
Yaggie
Rainfall

August 2006 Runoff Event

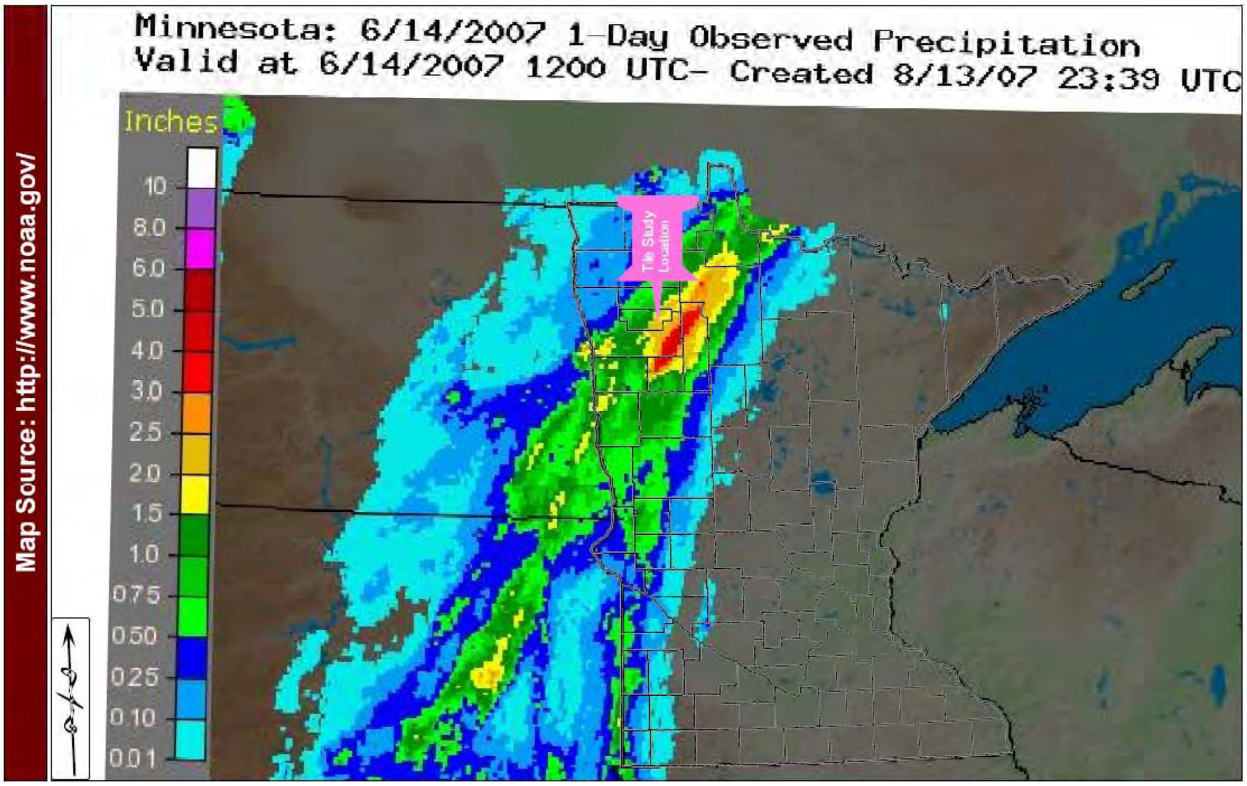
Field (crop)	Size (acre)	Cumulative Rainfall (inches)	Runoff Per Acre (inches)	Runoff (% of Total Rainfall)	% Reduction of Volume (Bachand compared to Yaggie)	Peak Flow (cfs)	Peak Flow Per Acre (cfs)	% Reduction of Peak Flow Per Acre (Bachand compared to Yaggie)
Yaggie (Wheat)	67	1.43	0.0003	0.021	N/A	0.162	0.0024	N/A
Bachand Tile (Soybeans)	171.7	1.43	0.0005	0.035	N/A	0.405	0.0024	N/A
Bachand Surface (Soybeans)	171.4	1.43	0.0001	0.007	N/A	0.121	0.0007	N/A
Bachand Total (Soybeans)	171.7	1.43	0.0006	0.042	-100 (Volume Increased)	0.518	0.003	-26.3 (Flow Increased)





June 2007 Runoff Event

Field (crop)	Size (acre)	Cumulative Rainfall (inches)	Runoff Per Acre (inches)	Runoff (% of Total Rainfall)	% Reduction of Volume (Bachand compared to Yaggie)	Peak Flow (cfs)	Peak Flow Per Acre (cfs)	% Reduction of Peak Flow Per Acre (Bachand compared to Yaggie)
Yaggie (Soybeans)	67	3	0.29	9.67	N/A	0.886	0.013	N/A
Bachand Tile (Soybeans)	171.7	3	0.48	16	N/A	0.686	0.004	N/A
Bachand Surface (Soybeans)	171.4	3	0.0054	0.18	N/A	0.696	0.004	N/A
Bachand Total (Soybeans)	171.7	3	0.4854	16.18	-67.4 (volume Increased)	1.155	0.0068	47.7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Inches
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6.0
5.0
4.0
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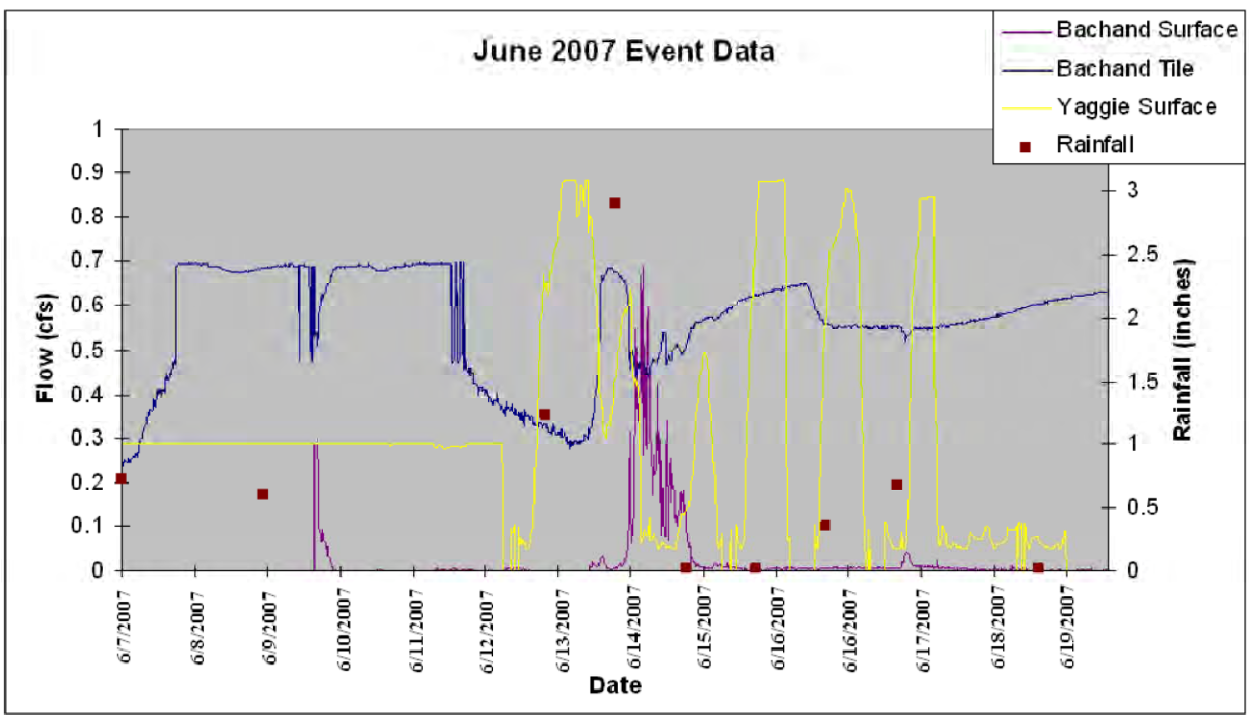
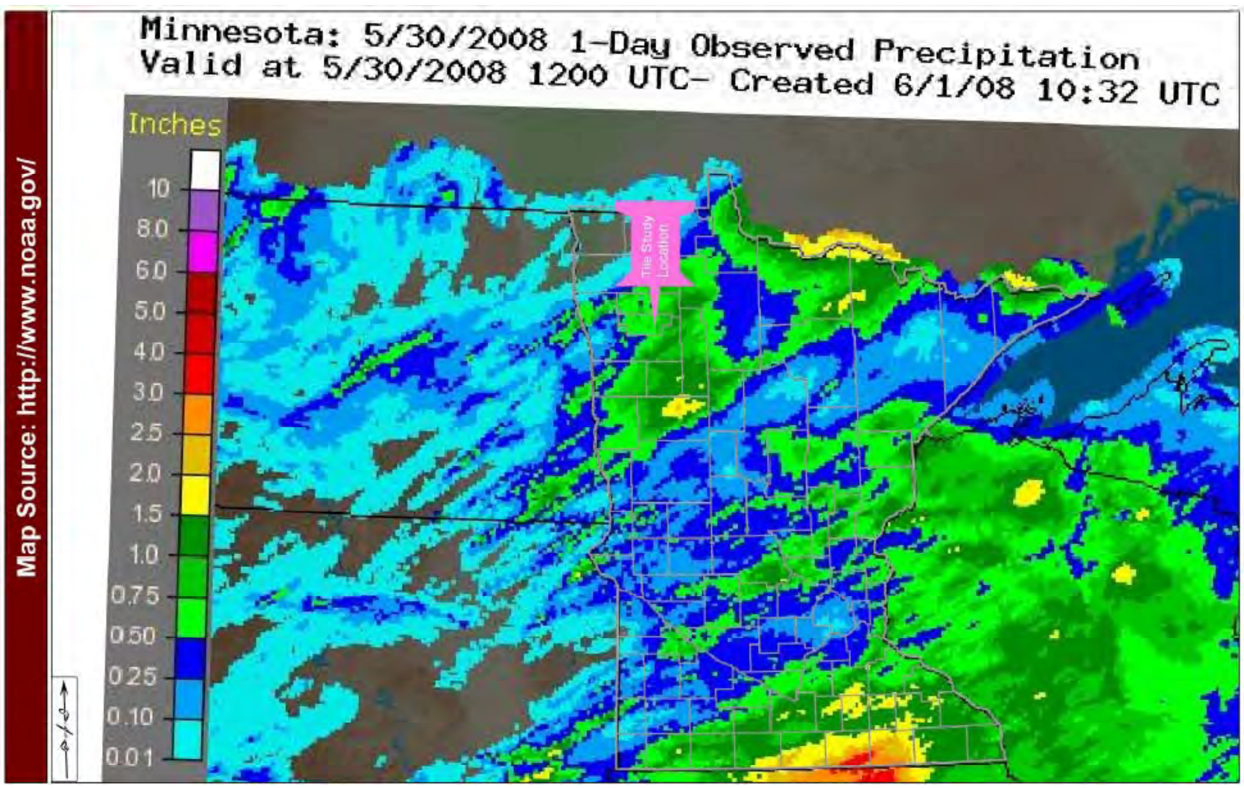
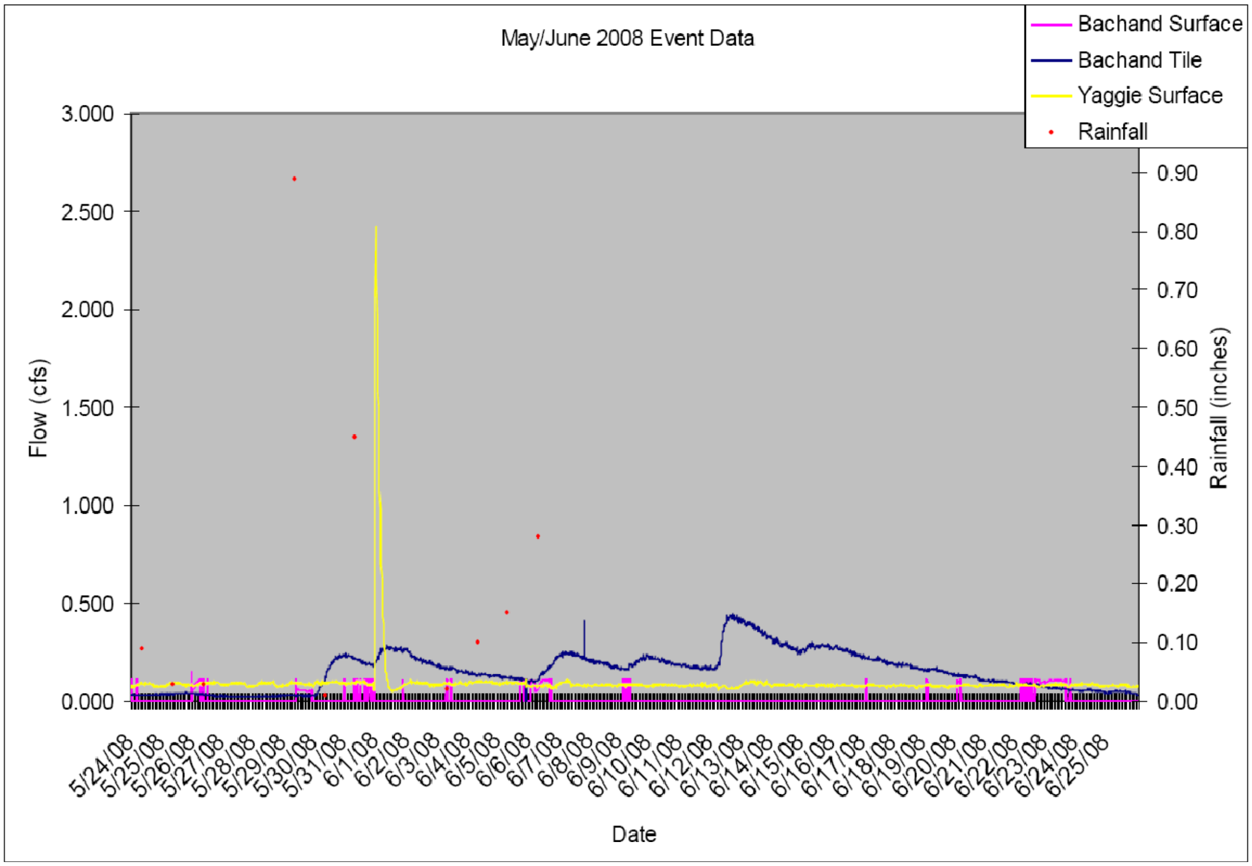
0.25
0.10
0.01
Tile Study Location


June 2007 Event Data
Bachand Surface
Bachand Tile
Yaggie Surface
Rainfall
Flow (cfs)
Rainfall (inches)
Date
6/7/2007
6/8/2007
6/9/2007
6/10/2007
6/11/2007
6/12/2007
6/13/2007
6/14/2007
6/15/2007
6/16/2007
6/16/2007
6/17/2007
6/18/2007
6/19/2007

May/June 2008 Runoff Event

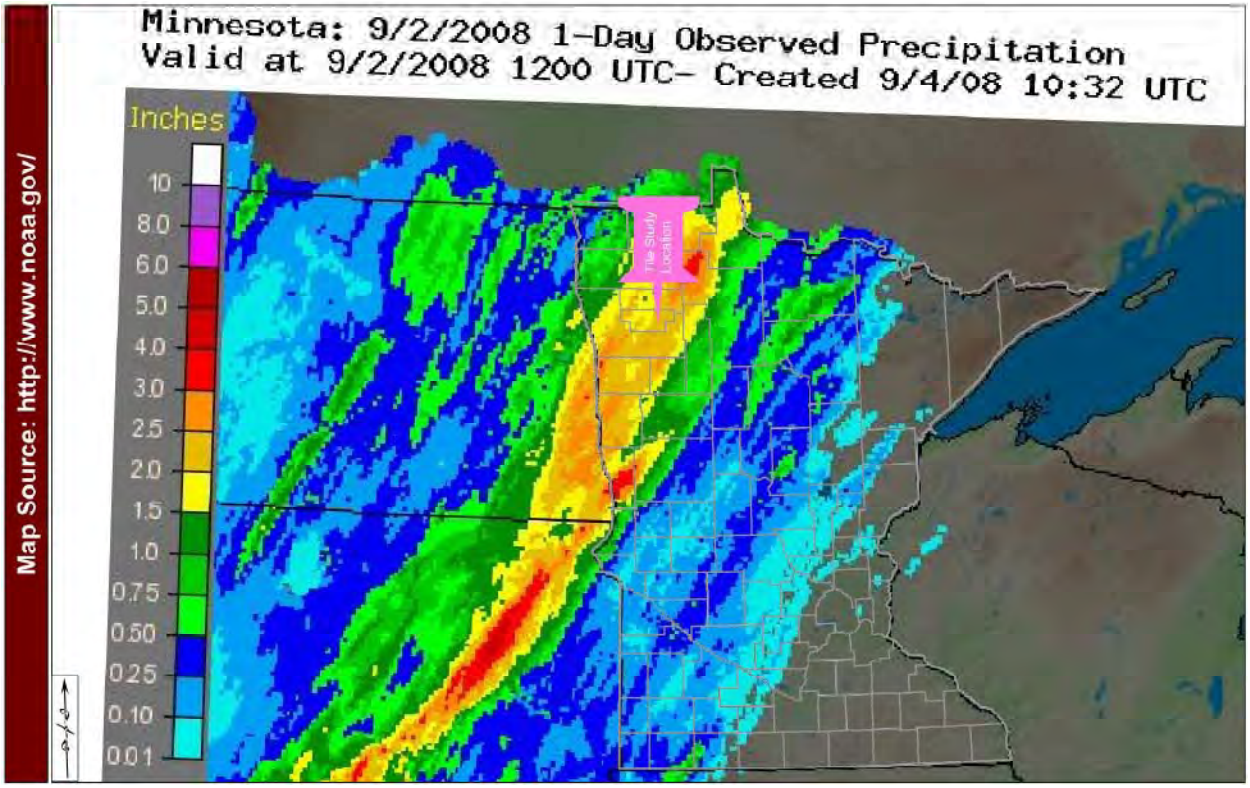
Field (crop)	Size (acre)	Cumulative Rainfall (inches)	Runoff Per Acre (inches)	Runoff (% of Total Rainfall)	% Reduction of Volume (Bachand Compared to Yaggie)	Peak Flow (cfs)	Peak Flow Per Acre (cfs)	% Reduction of Peak Flow (Bachand Compared to Yaggie)
Yaggie (Wheat)	67	1.62	0.153	9.44	N/A	2.422	0.0361	N/A
Bachand Tile (Wheat)	171.7	1.62	0.148	9.14	N/A	0.282	0.00165	N/A
Bachand Surface (Wheat)	171.4	1.62	0.008	0.49	N/A	0.149	0.00087	N/A
Bachand Total (½ Wheat ½ Corn)	171.7	1.62	0.156	9.63	-2.01 (volume Increased)	0.395	0.0023	93.6

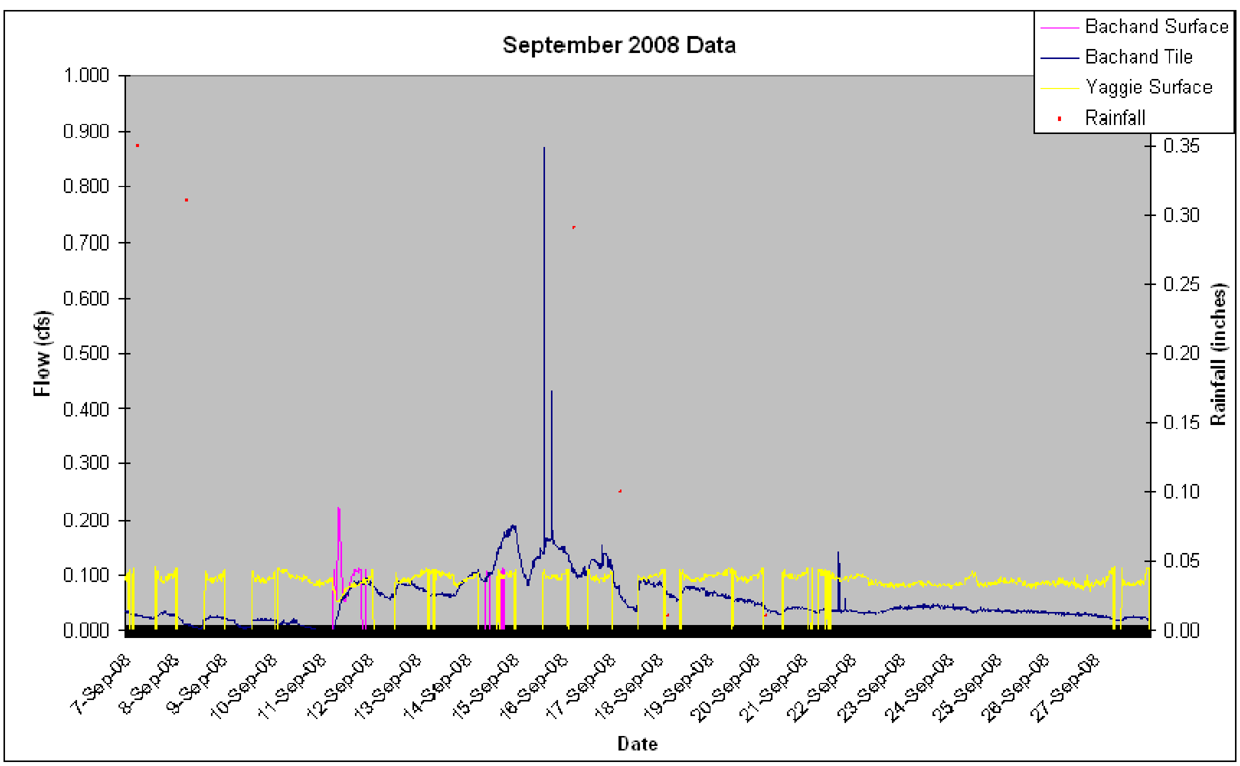




September 2008 Runoff Event

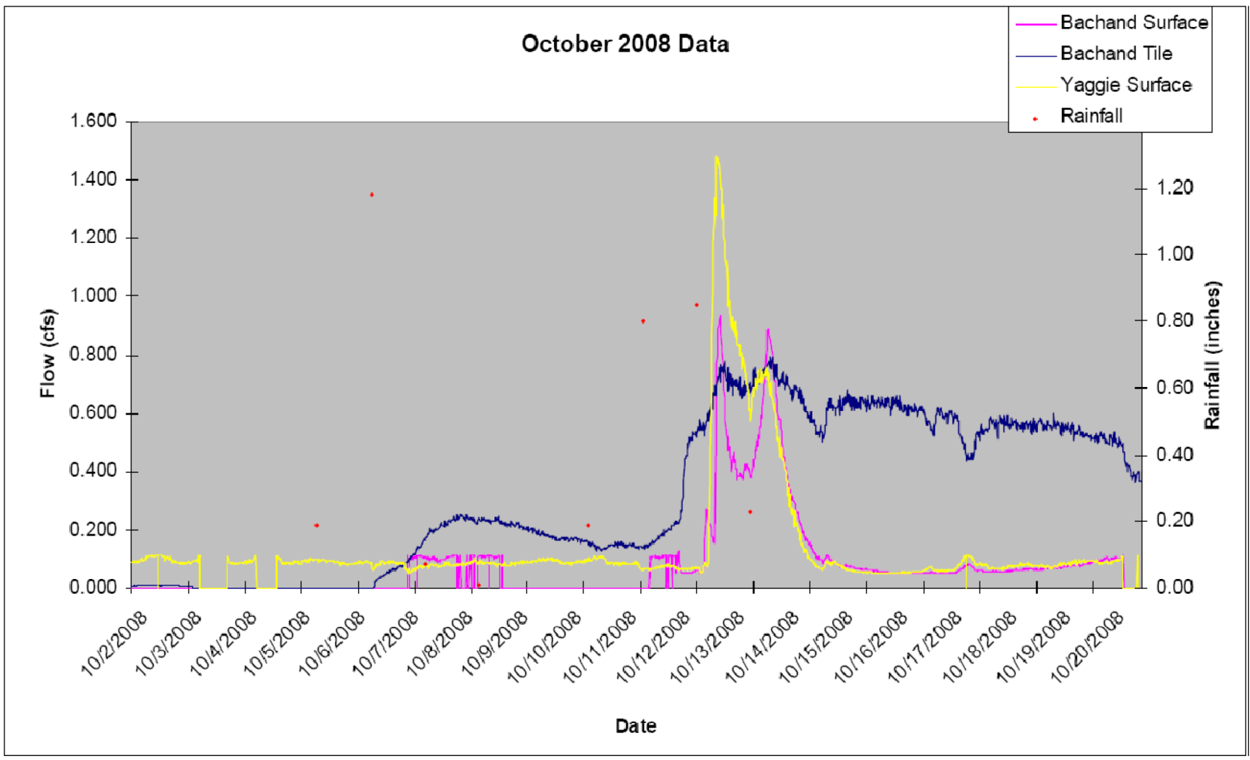
Field (crop)	Size (acre)	Cumulative Rainfall (inches)	Runoff Per Acre (inches)	Runoff (% of Total Rainfall)	% Reduction of Volume (Bachand Compared to Yaggie)	Peak Flow (cfs)	Peak Flow Per Acre (cfs)	% Reduction of Peak Flow (Bachand Compared to Yaggie)
Yaggie (Wheat)	67	1.71	0.00058	0.0339	N/A	0.223	0.00333	N/A
Bachand Tile (Wheat)	171.7	1.71	0.0399	2.33	N/A	0.872	0.0051	N/A
Bachand Surface (Wheat)	171.4	1.71	0.0044	0.257	N/A	0.114	0.000665	N/A
Bachand Total (½ Wheat ½ Corn)	171.7	1.71	0.0443	2.59	-7536 (volume Increased)	0. 872	0.005	-53.1 (Flow Increased)

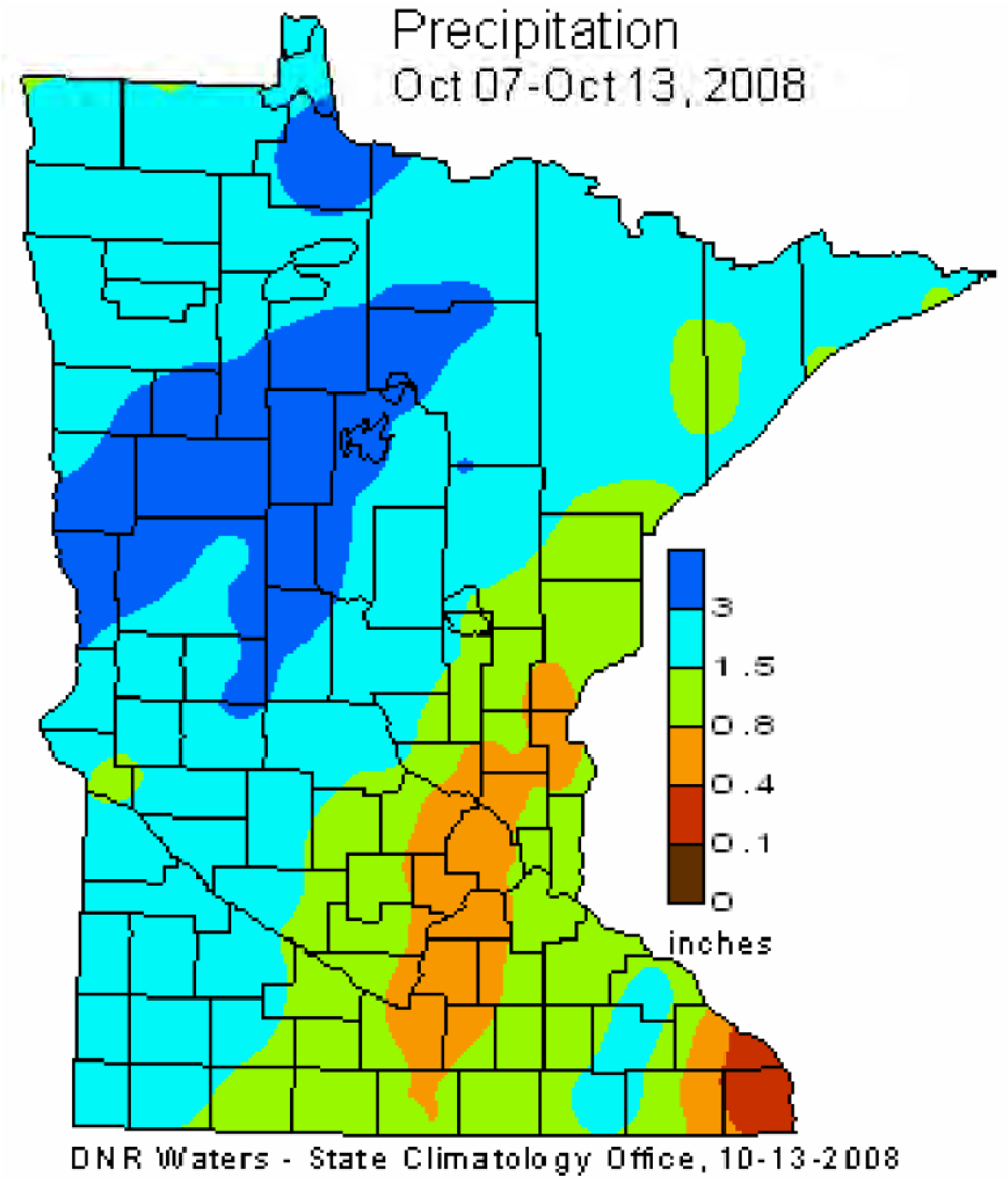

Minnesota: 9/2/2008 1-Day Observed Precipitation
Valid at 9/2/2008 1200 UTC- Created 9/4/08 10:32 UTC
Map Source: http://www.noaa.gov/
Inches
10
8.0
6.0
5.0
4.0
3.0
2.5
2.0
1.5
1.0
0.75
0.50
0.25
0.10
0.01
Tile Study Location


September 2008 Data
Bachand Surface
Bachand Tile
Yaggie Surface
Rainfall
Flow (cfs)
1.000
0.900
0.800
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.000
Rainfall (inches)
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
7-Sep-08
8-Sep-08
9-Sep-08
10-Sep-08
11-Sep-08
12-Sep-08
13-Sep-08
14-Sep-08
15-Sep-08
16-Sep-08
17-Sep-08
18-Sep-08
19-Sep-08
20-Sep-08
21-Sep-08
22-Sep-08
23-Sep-08
24-Sep-08
25-Sep-08
26-Sep-08
27-Sep-08
Date

October 2008 Runoff Event

Field	Size (acre)	Cumulative Rainfall (inches)	Runoff Per Acre (inches)	Runoff (% of Total Rainfall)	% Reduction of Volume (Bachand Compared to Yaggie)	Peak Flow (cfs)	Peak Flow Per Acre (cfs)	% Reduction of Peak Flow (Bachand Compared to Yaggie)
Yaggie (Wheat)	67	3.26	0.403	12.36	N/A	1.48	0.022	N/A
Bachand Tile (Wheat)	171.7	3.26	0.618	18.96	N/A	0.794	0.0046	N/A
Bachand Surface (Wheat)	171.4	3.26	0.10	3.07	N/A	0.933	0.005	N/A
Bachand Total (½ Wheat ½ Corn)	171.7	3.26	0.718	22.0	-77.99 (volume Increased)	1.676	0.01	54.55




Precipitation
Oct 07-Oct 13, 2008
3
1.5
0.8
0.4
0.1
0
inches
DNR Waters - State Climatology Office, 10-13-2008

Appendix B.

Rainfall Data

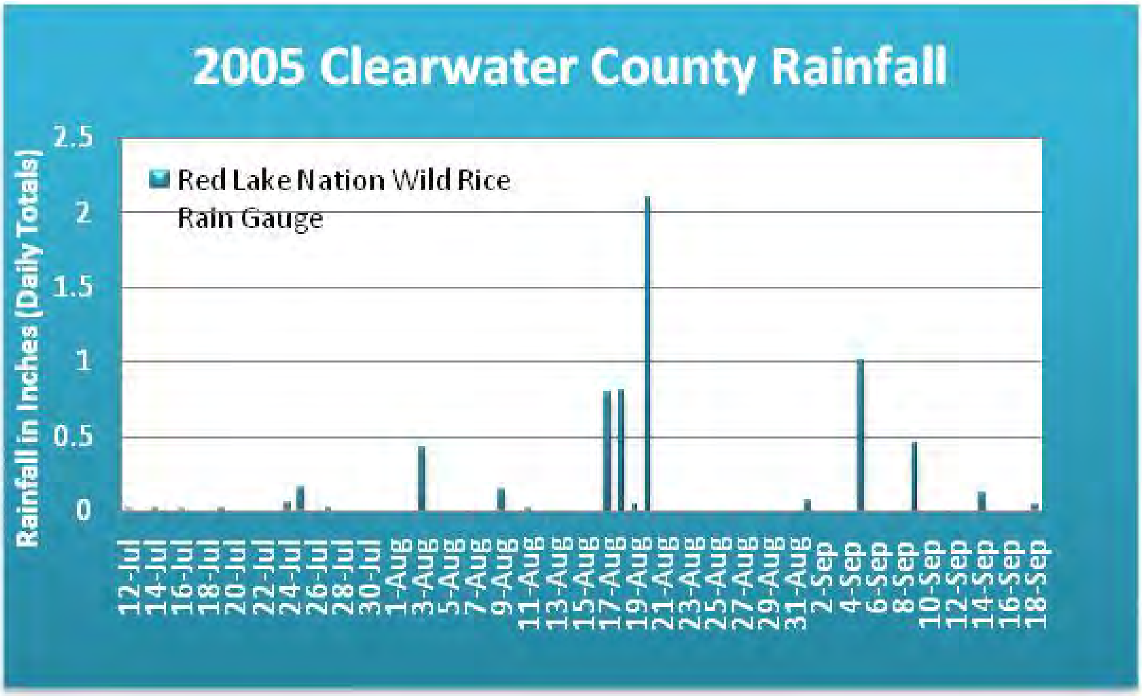


Figure 77. 2005 Clearwater County Rainfall

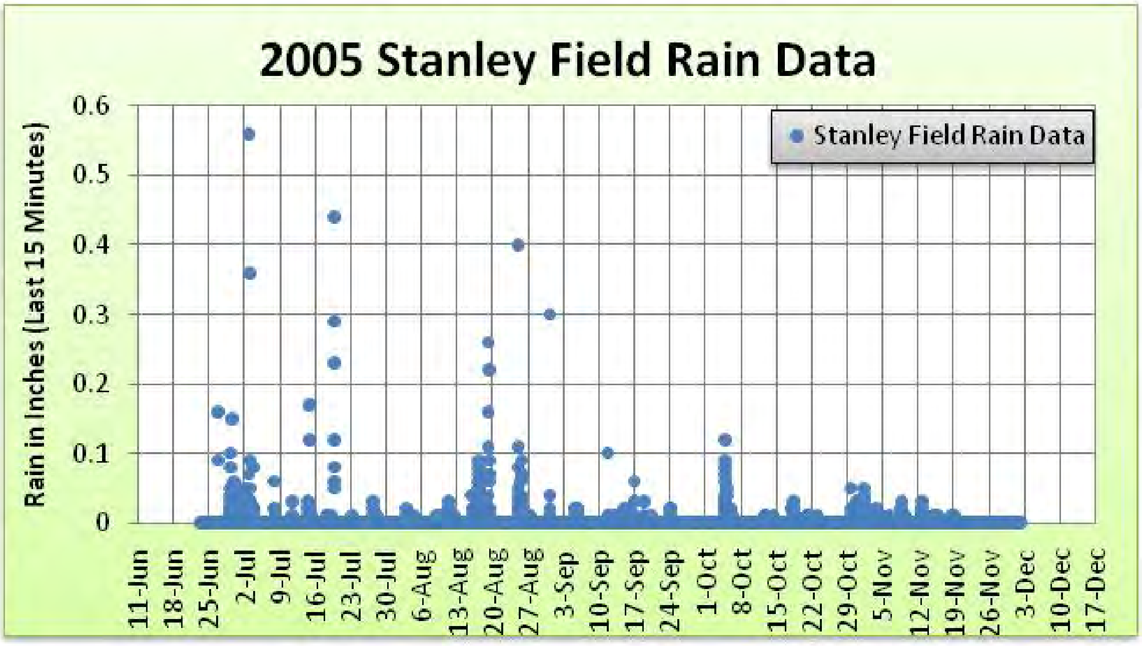


Figure 78. 2005 Marshall County Rain Data

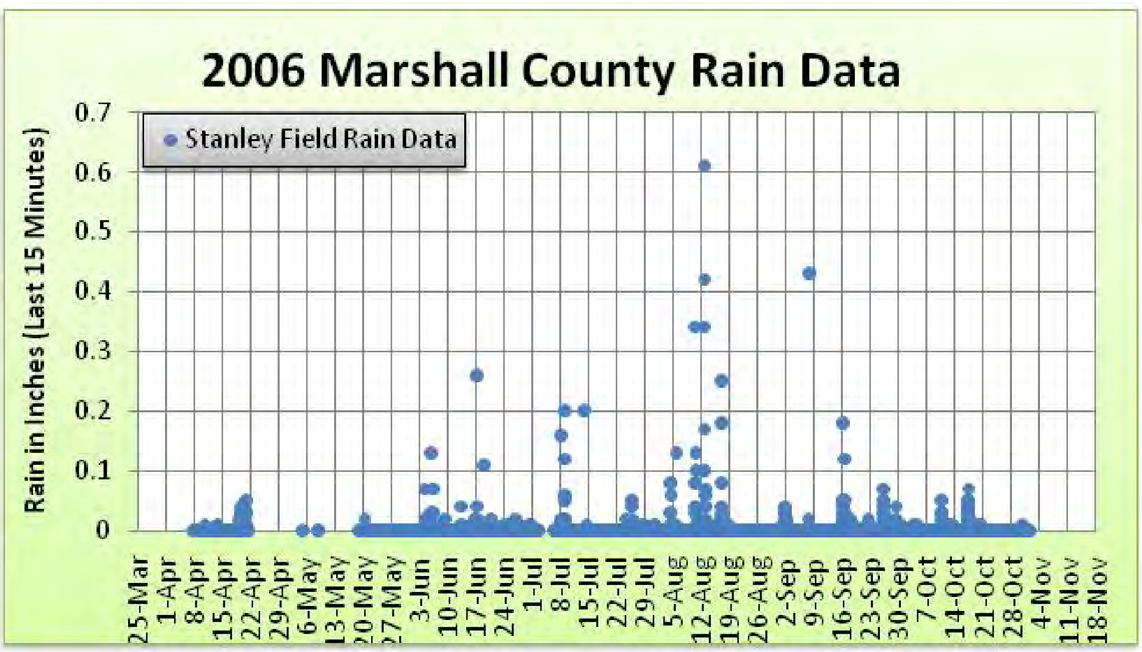


Figure 79. 2006 Marshall County Rain Data

Table 19. Red Lake County Rainfall Record

Rainfall Totals				
Yearly Totals (Inches of Rain)				
	19.86	12.63	20.41	11.18
Percent Completeness				
	94%	100%	99%	100%
Date	2005 Daily Totals	2006 Daily Totals	2007 Daily Totals	2008 Daily Totals
2-Apr	0	0	0	0
3-Apr	0	0	0	0
4-Apr	0	0	0	0
5-Apr	0	0	0	0
6-Apr	0	0	0	0
7-Apr	0	0	0	0
8-Apr	0	0	0	0
9-Apr	0	0	0	0
10-Apr	0	0.01	0	0
11-Apr	0.3	0	0	1.06
12-Apr	0.3	0.01	0	0
13-Apr	0.13	0.01	0	0
14-Apr	0	0.01	0	0
15-Apr	0	0	0	0
16-Apr	0	0	0.03	0
17-Apr	0	0	0.02	0
18-Apr	0	0	0	0
19-Apr	0	0.27	0	0
20-Apr	0	0.04	0.32	0
21-Apr	0		0.5	0
22-Apr	0	0	0.06	0.23
23-Apr	0	0	0	0
24-Apr	0	0.07	0	0.75
25-Apr	0	0	0	0.05
26-Apr	0	0.06	0	0.54
27-Apr	0	0	0	0.08
28-Apr	0	0.23	0	0
29-Apr	0	0	0	0
30-Apr	0.23	0	0.06	0
1-May	0		0	0
2-May	0	0.2	0	0
3-May	0	0.12	0	0
4-May	0	0	0.47	0
5-May	0	0	0.05	0
6-May	0	0	0.26	0
7-May	0	0.11	0	0.05
8-May	0	0.12	0	0
9-May	0.66	0.43	0	0
10-May	0.11	0.6	0	0.03

Rainfall Totals				
Date	2005 Daily Totals	2006 Daily Totals	2007 Daily Totals	2008 Daily Totals
11-May	0.04	0	0	0.2
12-May		0	0	0
13-May		0.21	0	0
14-May		0	0	0.03
15-May	0.46	0	0	0.06
16-May	0	0	0	0.02
17-May	0	0	0	0
18-May	0.06	0	0.04	0
19-May	0.07	0.08	0.02	0.03
20-May	0	0	0	0.05
21-May		0	0.17	0
22-May		0	0.29	0
23-May	0.66	0	0.14	0
24-May	0	0	0.01	0.09
25-May	0.09	0.02	0.03	0.03
26-May		0	0.68	0.03
27-May	0.21	0	0	0
28-May		0	0	0
29-May	0.42	0	0.5	0.89
30-May	0	0	0.01	0.01
31-May	0	0	0	0.45
1-Jun	0.03	0	0.12	0
2-Jun	0.08	0	0.01	0
3-Jun	0.43	0	0.03	0.02
4-Jun		0	0	0.1
5-Jun		0	0	0.15
6-Jun		0.68	0.45	0.28
7-Jun		0	0.73	0
8-Jun		0	0	0.05
9-Jun	1.48	0	0.6	0
10-Jun		0.09	0	0
11-Jun		0	0	1.55
12-Jun		0	0	0.55
13-Jun	0.69	0	1.24	0.05
14-Jun	0.49	0	2.9	0.38
15-Jun	0	0	0.02	0
16-Jun	0	0	0.01	0
17-Jun	0	0	0.35	0
18-Jun	0	0	0.67	0
19-Jun	0	0.06	0	0
20-Jun	0	0	0.01	0
21-Jun	0	0.08	0	0
22-Jun	0	0	0	0.03
23-Jun	0	0	0.18	0
24-Jun	0.23	0.04	0	0

	Rainfall Totals			
Date	2005	2006	2007	2008
25-Jun	0	0	0.02	0
26-Jun	0	0	0	0
27-Jun	1	0	0	1.25
28-Jun	0	0	0	0.16
29-Jun	0	0	0	0
30-Jun	0.24	0	0	0
1-Jul	0	0	0	0
2-Jul	0	0.24	0.37	0
3-Jul	0.67	0	0.04	0
4-Jul	0	0	0	0
5-Jul	0	0	0	0
6-Jul	0	0	0	0
7-Jul	0	0	0	0
8-Jul	0	0	0	0
9-Jul	0	0.23	0	0
10-Jul	0	0	0.91	t
11-Jul	0.07	0	0.08	0.04
12-Jul	0	0	0	0.42
13-Jul	0	0	0.39	0
14-Jul	0	0	0.01	0
15-Jul	0	0	0.08	0
16-Jul	0	0	0.01	0
17-Jul	0	0	0	0.12
18-Jul	0.09	0	0	0
19-Jul	0.01	0	0	0
20-Jul	0	0	0	0.12
21-Jul	0.01	0	0	0
22-Jul	0	0	0	0
23-Jul	0	0	0	0.22
24-Jul	0	0	0	0
25-Jul	0.26	0	0	0.01
26-Jul	0.01	0	0	0
27-Jul	0	0.41	0	0
28-Jul	0.01	0	0	0
29-Jul	0	0	0	0.39
30-Jul	0	0	0	0
31-Jul	0	0.17	0	0
1-Aug	0	0	0.05	0
2-Aug	0	0	0	0.01
3-Aug	0.4	0	0	0
4-Aug	0	0	0	0
5-Aug	0	0	0	0.01
6-Aug	0	0	0	0
7-Aug	0	0	0	0
8-Aug	0	0	0.02	0

	Rainfall Totals			
Date	2005	2006	2007	2008
9-Aug	0.05	0	0.01	0
10-Aug	0	0	0.27	0
11-Aug	0.1	1.43	0.03	0.87
12-Aug	0.01	2.85	0	1.5
13-Aug	0	0	0.03	0.03
14-Aug	0	0	0.01	0
15-Aug	0	0	0	0
16-Aug	0	0	0	0
17-Aug	1.67	0.06	0	0
18-Aug	0.01	0	0	0
19-Aug	0.92	0	0	0
20-Aug	0	0	0.07	0
21-Aug	0	0	0	0
22-Aug	0	0	0.05	0
23-Aug	0	0	0	0
24-Aug	0	0	0	0
25-Aug	0.72	0.09	0	0
26-Aug	0	0	0.61	0
27-Aug	0	0	0.33	0.36
28-Aug	0	0	0	0
29-Aug	0	0	0.01	0
30-Aug	0.01	0	0	0
31-Aug	0.07	0	0	0
1-Sep	0	0	0	0
2-Sep	0	0	0	2.75
3-Sep	0	1.12	0	0
4-Sep	0	0	0	0.12
5-Sep	1.83	0	0	0.66
6-Sep	0.08	0	0.46	0.01
7-Sep	0	0	0	0.02
8-Sep	0	0	0.37	0.01
9-Sep	0.46	0	0	0
10-Sep	0	0	0.01	0.1
11-Sep	0	0	0	0.91
12-Sep	0	0	0	0
13-Sep	0.03	0	0	0.35
14-Sep	0.02	0	0	0.31
15-Sep	0.07	0	0	0
16-Sep	0	0	0	0
17-Sep	0.02	0	0.1	0
18-Sep	0	0	0.01	0
19-Sep	0.06	0	0	0
20-Sep	0	0	0.44	0
21-Sep	0	0	0.2	0
22-Sep	0	0	0	0.29

	Rainfall Totals			
	2005	2006	2007	2008
	Daily	Daily	Daily	Daily
Date	Totals	Totals	Totals	Totals
23-Sep	0	0	0	**0.1**
24-Sep	0.02	0	0.22	**0.01**
25-Sep	0	0	0	**0**
26-Sep	0	0.16	0	**0.01**
27-Sep	0	0.01	0.01	***0***
28-Sep	0	0.02	0	***0***
29-Sep	0	0.2	0.01	***0***
30-Sep	0	0.01	0.24	***0***
1-Oct	0	0	0	***0***
2-Oct	0	0	0.06	***0***
3-Oct	0	0.06	0.01	**0**
4-Oct	0.32	0	0	**0**
5-Oct	1.27	0	0.01	**0.19**
6-Oct	0.07	0	0.04	**1.18**
7-Oct	0	0	0.42	**0.07**
8-Oct	0	0	1.3	**0.01**
9-Oct	0	0	0.38	**0**
10-Oct	0	0.18	0	**0.19**
11-Oct	0	0	0	**0.8**
12-Oct	0.26	0	0.01	**0.85**
13-Oct	0.04	0	0	**0.23**
14-Oct	0.01	0	0	**0**
15-Oct	0	0	0	**0**
16-Oct	0	0.48	0.03	**0**
17-Oct	0	0.93	0.04	**0**
18-Oct	0.06	0	0.74	**0**
19-Oct	0	0.04	0.24	**0**
20-Oct	0	0.01	0	**0**
21-Oct	0.02	0	0	**0.06**
22-Oct	0	0	0	**0.3**
23-Oct	0	0	0	**0**
24-Oct	0.01	0	0	**0.16**
25-Oct	0	0	0	**0**
26-Oct	0	0	0	**0.14**
27-Oct	0	0	0	**0**
28-Oct	0	0	0	**0**
29-Oct	0.02	0	*0*	**0**
30-Oct	0.02	0	*0.15*	**0**
31-Oct	0.02	0	*0*	**0**
1-Nov	0.04	0	*0*	**0**
2-Nov	0.01	0	*0*	**0**
3-Nov	0.24	0	*0*	**0**
4-Nov	0.13	0	*0*	**0.04**
5-Nov	0	0	*0.22*	**0.56**
6-Nov	0.01	0		**0.74**

	Rainfall Totals			
	2005	2006	2007	2008
	Daily	Daily	Daily	Daily
Date	Totals	Totals	Totals	Totals
7-Nov	0	0.04	*0*	**0.02**
8-Nov	0.18	0.02	*0*	**0**
9-Nov	0.06	0	*0*	**0**
10-Nov	0	0	*0*	***0***
11-Nov	0	0		***0***
12-Nov	0.42	0	*0*	***0***
13-Nov	0.08	0	*0*	***0.16***
14-Nov	0.27	0	*0*	***0***
15-Nov	0.15	0	*0*	***0.04***
16-Nov	0.02	0	*0*	***0.06***
17-Nov	0	0.05	*0.08*	
18-Nov	0.03	0	*0*	
19-Nov	0	0	*0.03*	
20-Nov	0	0	*0*	
21-Nov	0	0	*0*	
22-Nov	0	0	*0*	
23-Nov	0.01	0	*0*	
24-Nov	0	0		
25-Nov	0	0	*0*	
26-Nov	0	0	*0*	
27-Nov	0	0	*0.12*	
28-Nov	0	0.27	*0.04*	
29-Nov	0	0	*0.04*	
30-Nov	0	0	*0*	
1-Dec	0	0	SNOW *0.05*	
2-Dec	*0*	0	SNOW *0.6*	
3-Dec	*0*	0	SNOW *0*	
4-Dec		0	SNOW *0*	
5-Dec	*0*	0	SNOW *0.55*	

Readings in *italics* are from the nearest monitoring station available from the Minnesota State Climatology Office