SECTION 319 NONPOINT SOURCE POLLUTION CONTROL PROGRAM

ASSESSMENT/PLANNING PROJECT FINAL REPORT

RED RIVER VALLEY TILE DRAINAGE WATER QUALITY ASSESSMENT – PHASE II

Final Report Part 2: Results

By

Dr. Thomas Scherer and Roxanne Johnson Vondrachek

North Dakota State University, Fargo, ND

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Executive Summary

The main goal of this project was to assess the quality and quantity of water discharged from representative tile drains recently installed on saline soils and, when possible, collect water samples from nearby surface water sources. Eight tile sites, each located in a different county in eastern North Dakota, were selected for water quality and flow monitoring. From April to November, weekly samples were collected at each site, if water was flowing. Rain volume and timing was measured at each site. Flow measurement equipment was installed at seven of the sites. At four of the sites additional data was collected (when possible) including water samples upstream and downstream from the outlet and overland flow from a nearby comparable nontiled field. There are gaps in the data due to equipment malfunctions or no tile flow. Some of the equipment malfunctions were due to natural occurrences (hail storms, wind, etc.) and some were due to vandalism.

The most valuable lesson learned from this project is that precipitation events, whether in large single events or accumulations over several days, determine the quantity of water flow from tile systems. Tile flow does not begin in the spring until most of the frost is out of the field. The timing and quantity of rain events determine the mass loading of dissolved minerals in the discharged water. Above average rain amounts during the autumn months (September to December) can affect tile flow the following spring depending on winter snow accumulations and early spring rain events. The portion of rain that flowed from the tile systems ranged from a low of 11 to a high of 30 percent.

Tile flow removes accumulated salts from fields but it may take years to reduce the total dissolved salt (TDS) concentrations to acceptable levels. At six of the sites, the average TDS concentration decreased throughout the project period. There is a significant correlation ($R^2 > 0.96$) between TDS and most of the major cations and anions in the water. At six of the sites, sulfate (SO_4) made up over 65% of the TDS in the tile outflow. Average TDS concentrations varied from about 500 to over 11,000 milligrams per liter. The largest flows occurred during the spring and early summer of 2011 where the annual TDS loading to the receiving waterways ranged from a low of 587 to 9627 pounds per acre from the seven flow monitoring sites.

The concentration of nitrate-nitrogen (NO_3-N) in the discharge water is highly variable with the largest amounts occurring in the April to June period. The NO_3-N load to receiving waterways ranged from zero to over 17 pounds per acre. However, the annual averaged site loads ranged from a little over 1 to 11 pounds per acre. These are very low N losses to many farmers and crop consultants. The total load to receiving waterways, in pounds of NO_3-N, for the entire 4-year project ranged from a low of 900 to 6,390 for the eight sampling sites.

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Introduction

Over the last decade, the installation of subsurface drainage (tile) has been increasing in the Red River Valley (eastern North Dakota and northwestern Minnesota). The adoption of this technology in the RRV is mainly due to above average rainfall, rising water tables in production fields, higher land values and anticipated higher yields. For several years, many farmers have had difficulty planting in the spring or harvesting in the fall due to the wet conditions. The increased rainfall also caused soil salinity to become a problem due to rising water tables. Potentially, increased soil salinity could impact the yields on about 2.5 million acres in the Red River Valley (RRV). Tile drainage can control the water table and reduce soil salinity but very little is known about the quality of the water leaving tiled fields with salt affected soils. In addition, there are questions about the quantity of water as well as the impact of tile water on the quality of the receiving streams in the RRV.

To improve our understanding of the impact of tile drainage, this project was implemented. From 2009 to 2013, a tiled field in 8 different counties (table 1) was monitored for water quality on a weekly basis from April to December. In addition, the flow rate was measured at 7 of the 8 sites.

STORET No.	County	Acres	Year Tile Installed	Tile Diameter (inches)	Tile spacing (feet)	Tile depth (feet)	Design Drainage Ceefficient (inches/day)	Outlet	Primary Soil Type	Secondary Soil Type	Saline
385521	Cass	74.7	2008	4	60	3	0.375	Pump	Fargo silty clay	Dovray silty clay loam	
385471	Grand Forks	150	2007	3	50	3	0.375	Gravity	Wyndmere-Tiffany fine sandy loam	Arveson loam	
385464	Traill	154.8	2007	3	40	2.5	0.375	Pump	Fargo silty clay	Fargo-Hegne silty clay	
385469	Ransom	300	2008	4	80	3	0.375	2 Pumps	Divide Loam	Wyndmere-Tiffany loam	
385465	Richland	142	2008	4	40	3	0.375	Pump	Beardon silty clay loam	Borup silt loam	Y
385522	Sargent	155	2008	4	60	3	0.375	Gravity	Colvin-Borup silt loam	Gwinner-Peever complex	Y
385524	Walsh	170	2009	4	50	3	0.375	Pump	Overly silty clay loam	Overly silty clay loam	
385462	Steele	114.8	2008	3	40	3	0.375	Gravity	Beardon-Kindred silty clay loam	Colvin silt loam	Y

Table 1. Characteristics of the eight monitoring sites that comprised this project.

The goals of this project were to:

1. Measure the water quality of the outflow from tile drains in the Red River Basin at eight representative sites.

2. Measure the amount of salinity in the outflow of tile drains located on salt affected soils.
3. Measure the quantity and quality of water leaving a field via tile and surface runoff from at least 4 sites to determine mass discharge of mineral constituents.
4. Present results at meetings and in printed publications.
5. Use the results to help develop best management practices (BMP) for land that is tile drained in North Dakota.

Methods of Measurement

Water Sampling

Only when water was flowing were samples taken from the tile and other sampling sites. From April to near December 1, local Soil Conservation District technicians visited each site on a weekly schedule and collected samples. The technicians were trained by North Dakota Department of Health (NDDH) and North Dakota State University (NDSU) personnel in the approved sampling techniques at the beginning of this project.

As required by the NDDH, all bottles and caps were rinsed three times with the water to be sampled prior to collection and a preservative (supplied by the NDDH) was added at collection time. Preservatives used were:

- Nitric acid (2 milliliters) in a trace metal grade was added to a 250-ml water sample for testing of cations and trace metals.
- Sulfuric acid (2 ml) in a 1:5 concentration was added to a 500-ml water sample for testing of nutrients.
- Refrigeration was required for one 500-ml water sample (no acid) for anion testing.

For quality control purposes, duplicates were taken following every tenth sample as per NDDH requirements.

All samples were kept in coolers with ice or refrigerated. Within two weeks of collection they were sent in coolers to the North Dakota Department of Health water analysis laboratory. Included with the water samples were the required sample custody reports. Water parameters analyzed by the ND Department of Health included:

Cations: Aluminum (Al^{3+}), barium (Ba^{2+}), beryllium (Be^{2+}), calcium (Ca^{2+}), copper (Cu^{+}), iron (Fe^{2+}), magnesium (Mg^{2+}), potassium (K^{+}), silver (Ag^{+}), sodium (Na^{+}), and zinc (ZN^{2+}).

Anions: Chloride (Cl^{-}), bromide (Br^{-}), carbonates (CO_3^{2-}), nitrate (NO_3^{-}), nitrite (NO_2^{-}), phosphate (PO_4^{3-}), fluoride (Fl^{-}), and sulfate (SO_4^{2-}).

Trace Metals: Aluminum (Al^{3+}), boron (B), selenium (Se), arsenic (As), zinc (Zn^{2+}), manganese (Mn^{2+}), copper (Cu^{+}), nickel (Ni^{2+}), molybdenum (Mo) and lead (Pb^{4+}).

Mineral Chemistry: Bicarbonates (HCO_3), conductivity, pH, potassium (K), sodium adsorption ratio (SAR), total alkalinity, total hardness, total dissolved solids, cadmium (Cd), ammonia nitrogen (NH_3-N) and hydroxide (OH).

Samples were analyzed in the laboratory using methods approved by the EPA under Section 304(h) of the Clean Water Act. Methods include inductively coupled plasma mass spectrometry to separate ions on the basis of their mass-to-charge ratio followed by detection with an electron multiplier or Faraday detector (method 200.8), inductively coupled plasma-atomic emission spectrometry (optical spectrometry) to measure characteristic atomic-line emission spectra (method 200.7), automated colorimetry (method 353.2), and semi-automated colorimetry (method 350.1). Water Quality data from this project are available from the North Dakota Department of Health, Bismarck, ND using the EPA STORET database numbers.

Measurement of Rain Amounts

Two rain gauges were setup at each of the 8 tile sampling sites. The tops of the two rain gauges were at the same height opposite each other on a 5-foot pole. One gauge was a National Weather Service (NWS) approved accumulating volume rain gauge and the other was an automated tipping bucket rain gauge with a datalogger. The accuracy of both types is 0.01 inches. The tipping bucket rain gauges were calibrated each year (in March) prior to deployment. The rain gauges were set out as soon as feasible (around April 10) in the spring and they were removed from the sites around December 1 each year. The NWS rain gauge amounts were recorded when water quality samples were collected at each site. A log of on-site observations by the PI, including precipitation, was kept throughout the season.

Measurement of Flow

Flow measurements were obtained from seven of the eight sampling sites. Five of the seven sites had lift pumps and flow measurements were calculated by recording the on/off time of the pump. All the pumps have float controls similar to common household sump pumps. The pump run period and the pump off periods were recorded by a datalogger connected to a current sensing relay.

Recording the time a pumped turned on and the time when it shut off, along with pump and installation characteristics, provided accurate flow estimations. In addition, the time delay between the onset of a rain event and tile flow initiation could be determined.

The pump horsepower, maximum pump flow rate and maximum daily pumping volume are given in Table 2. The maximum daily pumping volume is important to know because there were times when some pumps ran continuously for more than a day.

Under typical flow situations, the pumps usually ran for about 1 to 2 minutes before they emptied the sump to the point where the float turned them off. The flow rate from the tile system into the sump along with sump storage capacity determined how long the pump was off. Under low flow conditions, there were often one to several days between pump events and under high flow conditions the pump could turn on and off up to 15 times per hour.

	Cass	Walsh	Traill	Ransom	Richland
Number of Pumps	1 Lift Pump	1 Lift Pump	Lift Pump	2 Lift Pumps	1 Lift Pump
Pump Horsepower & Maximum Flow Rate (gpm)	10 hp, 1050 gpm	5 hp, 700 gpm	10 hp, 1150 gpm	5 hp each, 700 gpm	10 hp, 980 gpm
Acres	74.7	130/140	154.8	300	142
Maximum Possible Daily Pump Volume (gallons)	1,512,000	1,008,000	1,656,000	2,016,000	1,411,000

Table 2. Daily pumping capacities for the sites with lift stations.

The Grand Forks site has a gravity outlet that doesn't become submerged thus a circular flume in the discharge pipe was used to determine the flow rate. The water level in the tile main, upstream from the flume, was measured with an accurate pressure transducer and flow rate was calculated using the rating equation for the flume. Water levels behind the flume were recorded every 5 minutes. The Ransom site also had a gravity outlet but the bottom of the discharge pipe was submerged much of the time. For this site, an ultrasonic unit was programmed to record, every five minutes, the depth of flow and velocity in the discharge pipe. Based on the discharge pipe diameter, these parameters were used to calculate the flow rate for each 5-minute period.

Discussion and Results

The distance from the most southerly sampling site was about 190 miles from the most northern site. As with any project of this duration with spatially separated locations, there were some problems with the various pieces of equipment that led to gaps in the recorded data. Some of the equipment was damaged by weather events such as rain and hail; some by vandalism or repair work on the lift pumps and some data were lost due to datalogger failures or human error. The lost flow rate data could not be recovered, however, the data gaps in the rain amounts were supplemented by averaging the rain amounts from the three nearest North Dakota Agricultural Weather Network (NDAWN) stations.

The number of water samples collected and analyzed varied significantly by site (table 3). The differences in numbers of samples could be due to lack of flow from the tile system, not able to obtain a sample due to flooding or change in conservation district personnel. Each of the samples were analyzed for the elements and minerals mentioned in the methods section of this report.

Site Location	Inclusive Sample Dates	Number of Samples Analyzed
Cass County	10/2/2009 to 6/25/2013	81
Grand Forks County	7/7/2009 to 7/2/2013	104
Ransom County	11/5/2009 to 6/4/2013	31
Richland County	4/22/2010 to 7/2/2013	107
Sargent County	8/10/2009 to 5/22/2013	32
Steele County	6/2/2009 to 6/25/2013	30
Traill County	9/17/2009 to 6/10/2013	28
Walsh County	4/12/2010 to 7/6/2013	79
	Total for the Project	**492**

Table 3. Sampling period and total samples collected from the 8 tile sites.

Relationships of Water Sample Analytes

A correlation analysis was performed on the analytes in the 492 water samples to determine relationships (details in Appendix 1). In general, total dissolved solids (TDS) concentration had a statistically significant correlation with many of the major mineral constituents in the water samples. For example, the TDS concentration had a very high correlation ($r > 0.97$) with sodium (Na), magnesium (Mg), bicarbonate (HCO_3) and sulfate (SO_4) as well as hardness (Ca + Mg). These results are nearly the same as an analysis of water from a tile site near Fairmount, ND (Jia and Scherer, 2013). This would indicate that once a statistical relationship between TDS and these minerals is established for a given water source, they can be estimated using only TDS measurements.

Sulfate is a major constituent of TDS (table 4). Note that the Grand Forks and Ransom sites have soils with a higher sand content than the other sites which may explain the lower sulfate levels. It is not unusual to find high sulfate concentrations since it is a major constituent in groundwater and soil throughout North Dakota. Frequently, naturally occurring sulfate concentrations exceed the EPA's Safe Drinking Water secondary contaminate levels.

Site	Percent of SO_4 in TDS	Average SAR
Cass County	69	4.3
Grand Forks County	20	0.15
Ransom County	35	2.8
Richland County	69	9.3
Sargent County	69	3.7
Steele County	65	7.3
Traill County	51	3.3
Walsh County	68	2.4

Table 4. Percent of the total dissolved solids concentration comprised of sulfate and the average sodium absorption ratio (SAR) for the 8 sampling sites.

TDS also has a high correlation with SAR (r = 0.90) as shown in table 4. SAR is a measure of the ratio between sodium and the sum of calcium and magnesium concentrations in the water. It is an important parameter because high sodium in the water will disperse clay particles causing soil sealing that reduces infiltration. SAR is dimensionless with no units, but any value less than 6 is considered acceptable. Note that the average SAR of the Richland and Steele county samples exceed 6 meaning these waters could *potentially* have adverse effects on the soils downstream from the tile discharge point.

The concentration of the trace metals and other minor constituents in many samples could not be measured because they were below the detection limit of the analytic instrumentation. The analysis showed that the following trace elements were below the detection limit in over 98% of the samples: titanium, beryllium, silver, lead, antimony, chromium, and cadmium. Arsenic and aluminum were below the detection limit in 70% and 72% of the water samples, respectively. Iron and manganese were below the detection limit in about 60% of the samples, boron in 42%, copper in 35%, selenium in 32%, nickel in 19% and zinc in 17% of the water samples. Barium was detected in almost all water samples. Trace elements are measured in micrograms per liter or parts per billion and of the samples were there were detectable amounts, none exceeded the standards set forth in the Safe Drinking Water Act.

The fields drained by the tile at each site had crops where fertilizer containing phosphorus, potassium and nitrogen were applied. Naturally we would expect some of these to be present in the tile water. All are nutrients when present in water. The correlation analysis demonstrated that phosphorus and potassium concentrations in the water had very poor relationships with the other constituents (r < 0.4). Phosphorus (P) is a concern in surface water because it contributes to eutrophication. Phosphorus attaches to soil and is not mobile but it moves with surface runoff into streams and water bodies. The average P concentration in the tile water at each site is shown table 5. These results are very similar to the P values of tile water taken by Xinhua Jia at research sites near Kragnes, MN and Fairmount, ND. The detection limit for phosphorus is 0.004 mg/l and each site had several samples with P levels below the detection limit.

Site	Cass	Grand Forks	Ransom	Richland	Sargent	Steele	Traill	Walsh
Average P Concentration (mg/l)	0.15	0.03	0.03	0.07	0.08	0.02	0.06	0.10

Table 5. The average phosphorus concentration in the water samples for each sampling site.

The relationship between total nitrogen and TDS had a medium correlation (r = 0.67), again similar to previous studies (Jia and Scherer, 2013). Total nitrogen was measured in all the water samples and nitrate-nitrogen (NO_3-N) was found to comprise over 95% of the total nitrogen. Most N is applied to a field as fertilizer but other sources of N are deposition by rain and soil mineralization of organic matter. According to the National Trends Network (http://nadp.sws.uiuc.edu/ntn/) the annual deposition of nitrogen in rainwater, in the form of nitrate, ammonium and inorganic N, is about 2 pounds of N per acre in the Red River Valley. According to Franzen (2010) and Sims (2009) at least 40 pounds per acre are available through soil mineralization from the previous crop.

Based on this analysis, we chose to examine the concentrations and mass loading of NO_3-N and TDS on the water that exits the tile drainage systems in this project.

Hydrologic Response of Tile

Rain events are the primary driving force for water flow from a tile system but some flow can be attributed to melting snow in early spring. However, we have observed that tile does not flow from about December 1 until most of the frost is out of the ground around April 1. This is evident by examining the daily flow and rain amounts for the 4-year period of this project. For example, figure 1 shows the Cass County data for the period of record. The rain and flow graphs for the other 6 sites with flow measurements are in Appendix II.

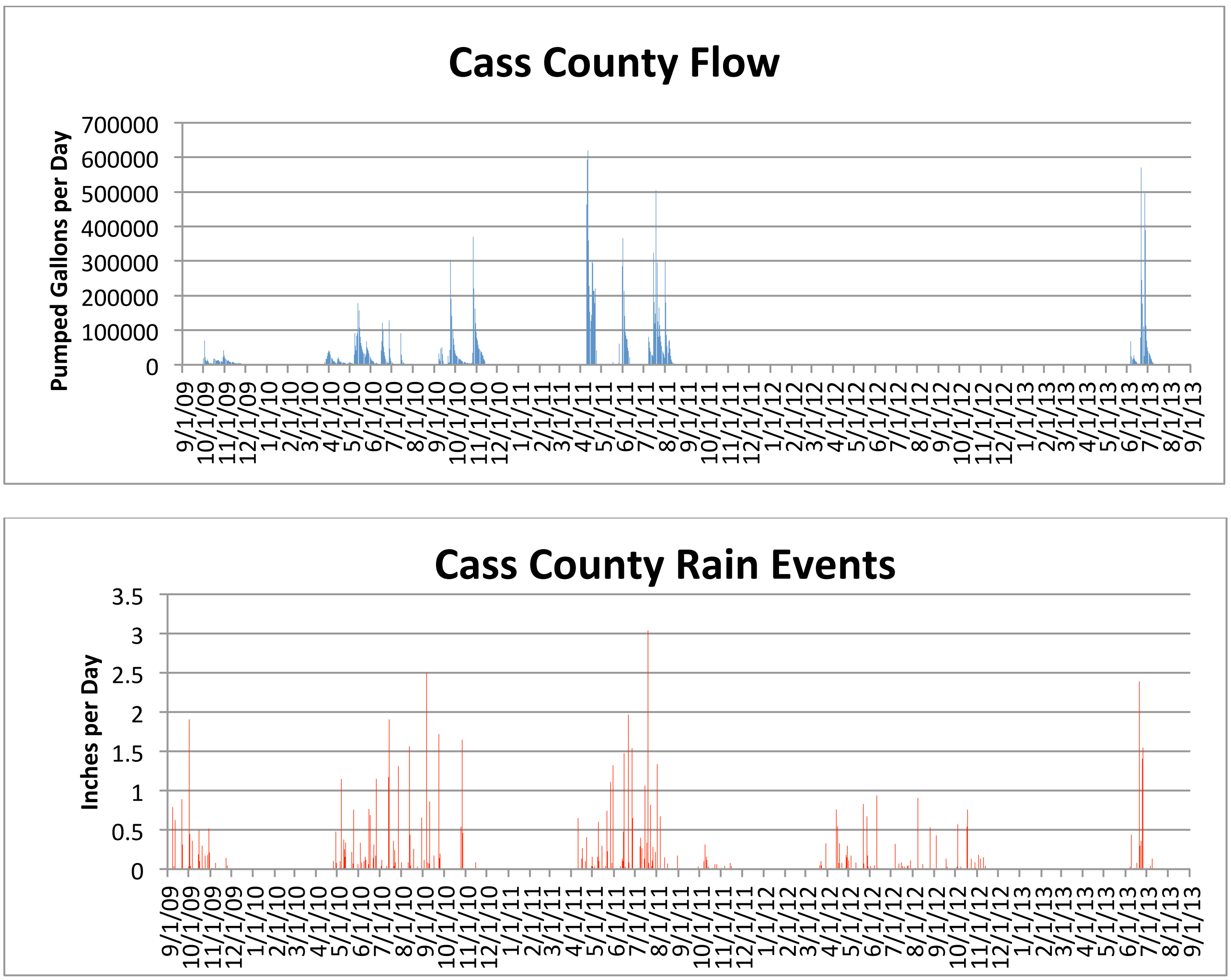

Figure 1. Daily flow and rain amounts received at the Cass County tile site over the 4-year period of record. Graphs for the other sites are in Appendix II.

From September 1 to December 1 2009, the Red River Valley received about 5 inches of rain above normal with the result being a very wet spring in 2010. The recorded precipitation during 2010 was 4 to 6 inches over normal and again an excess amount was received during the autumn months. The winter of 2010-2011 had above average snow and it took a long time to melt resulting in a record flood in the RRV. Tile flows from almost all the sites were greatest during the spring of 2011. After July 15, 2011 there were no significant rain events and flow either stopped completely or was very low. The dry conditions continued until June of 2013 when over 6 inches of precipitation was received in a two-week period. At this time, tile flow was recorded at each site.

Rain events that trigger tile flow can be a single large downpour (3 to 5 inches in a day) or can be smaller amounts scattered over several days that add up to several inches. Water does not flow from a tile system until the water table rises and intersects with the tile laterals. Based on monitoring in other tile projects, after the growing season (late September), the water table is usually 2 to 3 feet below tile elevation (Jia, personal communication). This is due to crop evapotranspiration during the growing season (figure 2). Crop evapotranspiration during the growing season consumes the majority of available soil moisture. For example, in 2010 over 27 inches of rain was measured at the Richland County site from April 22 to November 18. During this time period, corn water use amounted to around 20 inches, about 3 inches flowed out of the tile and the rest was surface runoff.

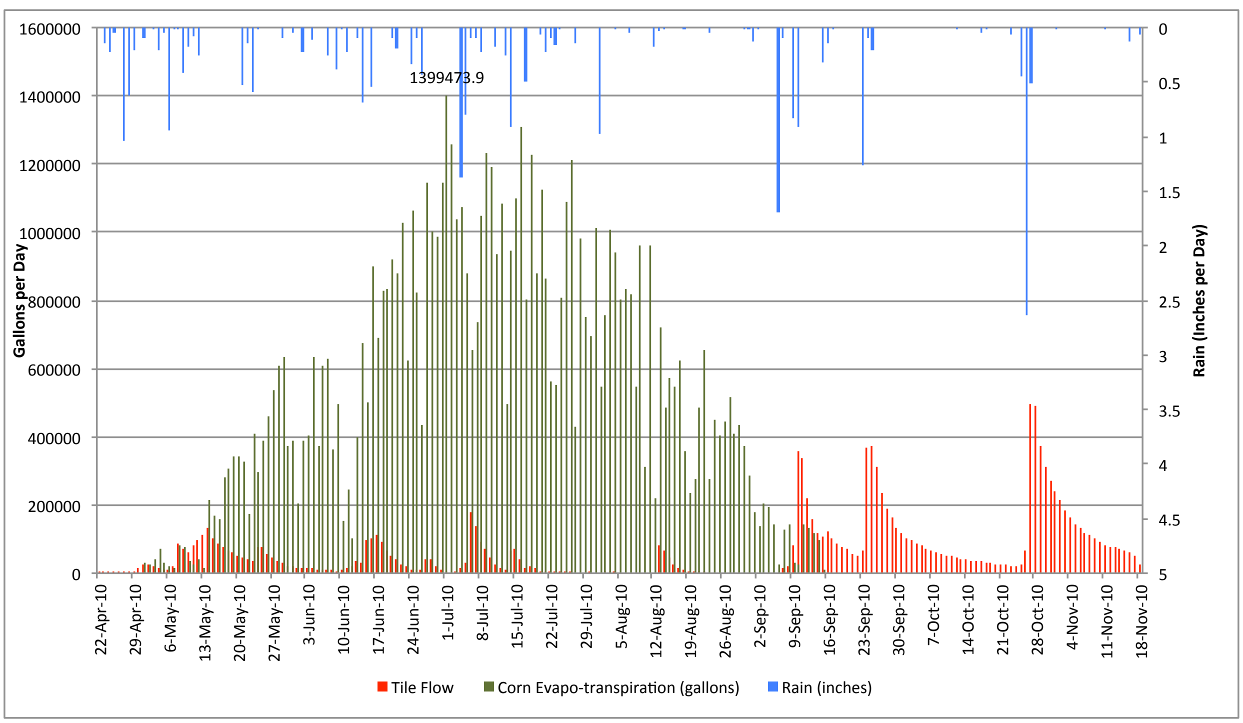

Figure 2. The flow measured at the Richland site along with rain events and amounts. This site had 142 acres of corn and the green bars show the water use in gallons on a daily basis throughout the growing season.

After the growing season it may take 4 to 5 inches of precipitation to infiltrate enough water into the soil to raise the water table to tile elevation. When the water table is near the elevation of the tile laterals (within 6 inches), the tile outflow responds, usually 3 to 12 hours after a rain event. There is a large rise in flow right after each significant rain event then an exponential drop with a long period of continually decreasing flow that can last more than 10 days, unless more rain is received at the site.

Mean Seasonal TDS and NO_3-N Concentration

It takes time for water to dissolve minerals (residence time) and since tile flow is rain driven, it would seem that there isn't enough time for the infiltrating water to dissolve large amounts of salts. However, research has shown that over 70% of the water enters through the bottom half of the tile. Water takes an almost circular path to get to the tile line. Previous studies (Xinhua Jia, personal communication) demonstrated that salts stratify in the water table below the tile. This means the water that enters the tile after a rain event may have resided in the soil for a long time. We have tried to relate surface soils in the field to the concentration of dissolved minerals in the tile water, but it may be that the subsoil (below 5 feet) has more of an effect. However, we do not have reliable information on the characteristics of the deeper soils at the project sites and it is beyond the scope of this study to examine this particular aspect of tile drainage. The mean TDS concentrations along with the number of samples and standard deviation by season are shown in table 6.

Total Dissolved Salts (mg/l)

Year	*Time Period*		Cass	Richland	Ransom	Sargent	Traill	Steele	Grand Forks	Walsh
2009	July - Sept	n	1	NS	NS	2	2	8	8	NS
		Mean	4600	NS	NS	4545	7130	6906	480	NS
		std. dev	na	NS	NS	55	na	1102	29	NS
	Oct - Dec	n	15	NS	1	3	6	NS	8	NS
		Mean	8323	NS	1060	7783	7126	NS	480	NS
		std. dev	1970	NS	na	99	331	NS	59	NS
2010	Apr - June	n	30	47	2	4	2	4	20	10
		Mean	7547	14253	874	6428	6000	6473	533	6889
		std. dev	702	2508	122	690	160	998	13	1097
	July - Sept	n	11	16	8	NS	4	3	16	17
		Mean	6405	15025	1041	NS	6825	4817	477	6549
		std. dev	2730	1749	41.6	NS	1037	2285	34	543
	Oct - Dec	n	6	5	2	NS	NS	NS	8	5
		Mean	8507	15440	1070	NS	NS	NS	549	6538
		std. dev	584	372	20	NS	NS	NS	18	1534
2011	Apr - June	n	5	9	6	7	8	4	10	12
		Mean	6566	12911	987	5587	6054	6535	542	5099
		std. dev	2422	805	169	1711	1416	1295	13	1611
	July - Sept	n	8	9	7	3	6	6	7	13
		Mean	7344	10466	1059	6253	7137	6678	522	6208
		std. dev	917	2157	20	547	496	1542	29	845
	Oct - Dec	n	NS	NS	NS	1	NS	NS	6	1
		Mean	NS	NS	NS	2810	NS	NS	459	6710
		std. dev	NS	NS	NS	na	NS	NS	27	na
2012	Apr - June	n	1	14	2	7	NS	2	10	11
		Mean	8440	11209	1040	6134	NS	6890	492	5679
		std. dev	na	3908	20	860	NS	680	9	1272
	July - Sept	n	NS	NS	NS	NS	NS	NS	1	6
		Mean	NS	NS	NS	NS	NS	NS	474	6010
		std. dev	NS	NS	NS	NS	NS	NS	na	370
	Oct - Dec	n	NS	NS	NS	NS	NS	NS	1	2
		Mean	NS	NS	NS	NS	NS	NS	455	5395
		std. dev	NS	NS	NS	NS	NS	NS	na	125
2013	Apr - June	n	4	7	3	2	1	4	10	10
		Mean	4449	6559	1005	3760	5480	5280	482	3720
		std. dev	2896.6	2449	35	210	na	1284	30	2122

n - *number of samples*
NS - *No Samples were Collected*
na - Only one sample, no standard deviation

Table 6. A listing of the number of samples (n), mean TDS and standard deviation by 3-month collection periods for each year and sampling site.

Note that the Richland site had concentrations that, at times, exceeded 15,000 mg/l whereas the Grand Forks and Ransom sites had TDS values below 1000 mg/l. Looking at the April to June 2013 period shows that the mean TDS of the Richland site had dropped to less than 6,600 mg/l but the Grand Forks and Ransom TDS concentrations stayed the same.

The nitrate (NO_3-N) concentrations of the water samples from each site are shown in the table 7. The largest amount of fertilizer containing nitrogen (N) is applied in the spring, prior to and after planting. However, significant amounts of N in the form of anhydrous ammonia can be applied in late fall when the soil temperature drops below 50 degrees Fahrenheit. Very little N is applied to fields planted to legumes such as dry beans and soybeans. Since N is an applied mineral, the highest concentrations in the tile water are after field application in the April to June time period.

NO3-N (mg/l)

Year	*Time Period*		Cass	Richland	Ransom	Sargent	Traill	Steele	Grand Forks	Walsh	Average of all Sites
2009	July - Sept	n	1	NS	NS	2	2	8	8	NS	
		Mean	6	NS	NS	5.58	3.93	31.1	1.09	NS	9.54
		std. dev	na	NS	NS	0.43	0.42	21.4	0.71	NS	
	Oct - Dec	n	15	NS	NS	4	8		9	NS	
		Mean	14.7	NS	NS	5.14	4.62		0.92	NS	6.35
		std. dev	1.47	NS	NS	0.43	1.16		0.85	NS	
2010	Apr - June	n	30	47	1	9	2	4	20	13	
		Mean	19.77	21	1.78	6.41	4.2	27.2	3.46	5.91	11.22
		std. dev	4.52	2.39	na	1.36	0.025	7.02	1.18	3.25	
	July - Sept	n	11	16	7	NS	4	3	16	13	
		Mean	6.3	23	1.18	NS	4.41	12.1	1.76	1.89	7.23
		std. dev	3.06	2.44	1.28	NS	0.99	6.55	1.245	1.35	
	Oct - Dec	n	7	5	2	NS	NS	NS	8	6	
		Mean	6.65	27.34	2.06	NS	NS	NS	2.41	1.36	7.96
		std. dev	0.37	2.21	na	NS	NS	NS	0.63	1.39	
2011	Apr - June	n	5	9	7	12	8	4	10	12	
		Mean	6.55	31.89	3.22	6.3	9.04	28.7	3.67	4.38	11.72
		std. dev	0.79	5.25	1.42	1.85	2.78	8.52	1.88	1.85	
	July - Sept	n	8	9	7	2	5	6	7	13	
		Mean	3.067	28.39	7.81	8.35	6.55	27.5	2.54	1.75	10.74
		std. dev	0.57	3.75	2.47	na	0.233	10.2	1.27	1.66	
	Oct - Dec	n	NS	NS	NS	1	NS	NS	6	1	
		Mean	NS	NS	NS	8.33	NS	NS	0.826	0.64	3.27
		std. dev	NS	NS	NS	na	NS	NS	0.326	na	
2012	Apr - June	n	1	14	2	6	NS	2	10	12	
		Mean	0.17	26.06	1.035	9.86	NS	31.9	1.76	1.29	10.30
		std. dev	na	4.59	0.01	0.656	NS	0.6	0.958	0.77	
	July - Sept	n	NS	NS	NS	NS	NS	NS	1	6	
		Mean	NS	NS	NS	NS	NS	NS	1.1	0.91	1.01
		std. dev	NS	NS	NS	NS	NS	NS	na	0.05	
	Oct - Dec	n	NS	NS	NS	NS	NS	NS	1	2	
		Mean	NS	NS	NS	NS	NS	NS	1.16	0.75	0.96
		std. dev	NS	NS	NS	NS	NS	NS	na	0.125	
2013	Apr - June	n	4	7	3	2	1	4	9	10	
		Mean	14.54	17.68	1.99	8.75	20.8	37.7	4.55	6.56	14.07
		std. dev	10.01	5.52	0.059	0.595	na	10.2	2.69	3.91	

n - *number of samples*
NS - *No Samples were Collected*
na - Only one sample, no standard deviation

Table 7. A listing of the number of samples (n), mean NO_3-N and standard deviation by 3-month collection periods for each year and sampling site. Note that the largest values occur from April to June.

This is also the time period when rain events are more frequent, thus we would expect to find the greatest mass loads of NO_3-N entering the receiving waterways.

Temporal Trends in TDS and NO_3-N Concentrations

The tile systems were installed on the project sites for one or both of the following reasons: high water tables or increasing salinity. Tile flow will remove salts from the soil over time thus a reduction in tile water TDS is to be expected. Since NO_3-N is an applied mineral, we would expect to see an increase in the spring. The results are shown for each site in figures 3 to 10.

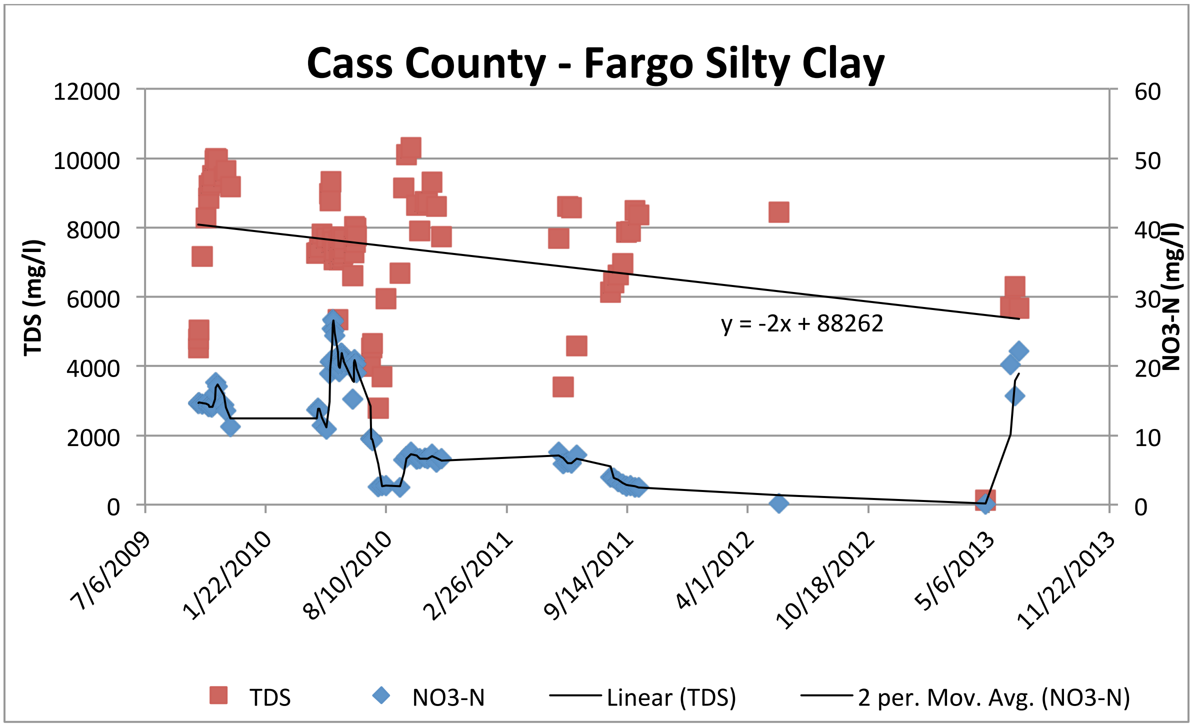

Figure 3. TDS and NO_3-N concentrations for the Cass County site. A regression derived trend line indicates a slow reduction in TDS. A 2-point moving average is applied to the NO_3-N values.

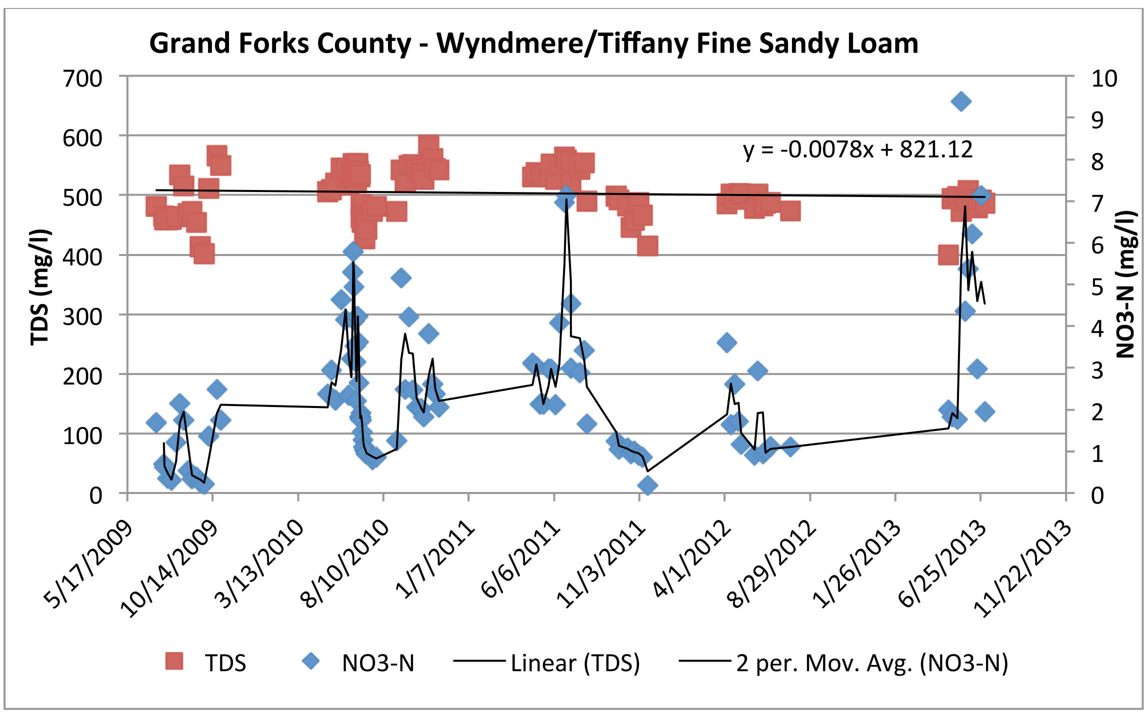

Figure 4. TDS and NO_3-N concentrations for the Grand Forks County site. A regression derived trend line indicates no change in TDS concentration. A 2-point moving average is applied to the NO_3-N values.

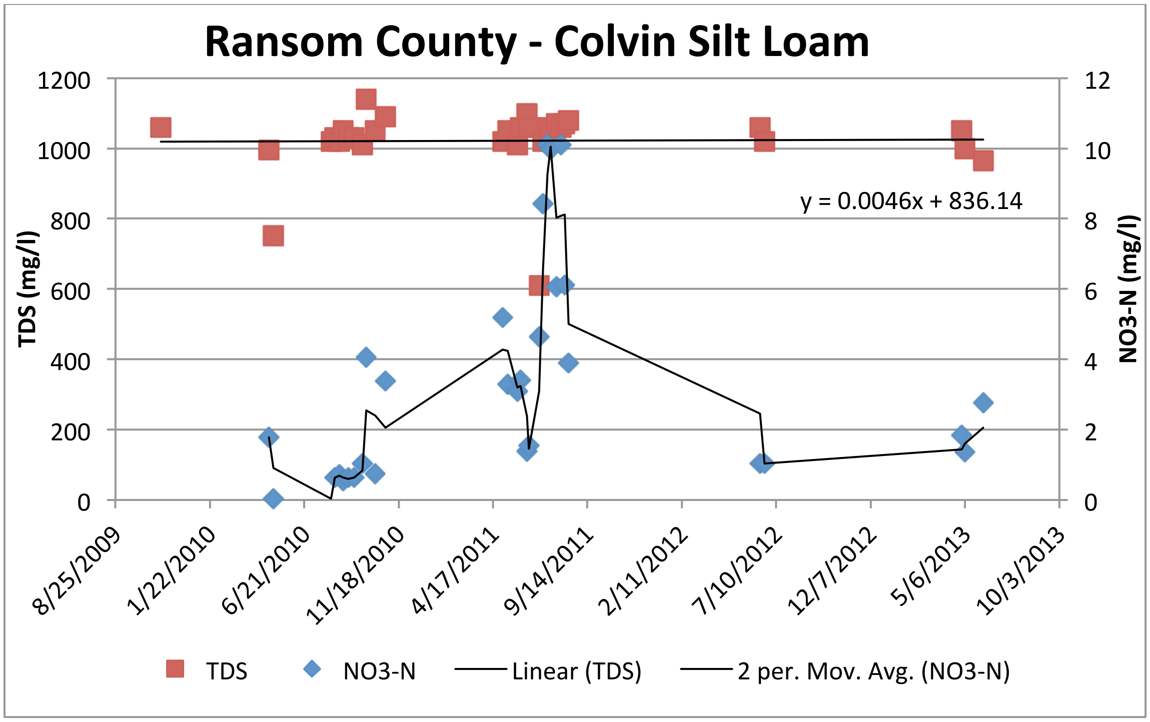

Figure 5. TDS and NO3-N concentrations for the Ransom County site. A regression derived trend line indicates no change in TDS concentration. A 2-point moving average is applied to the NO3-N values.

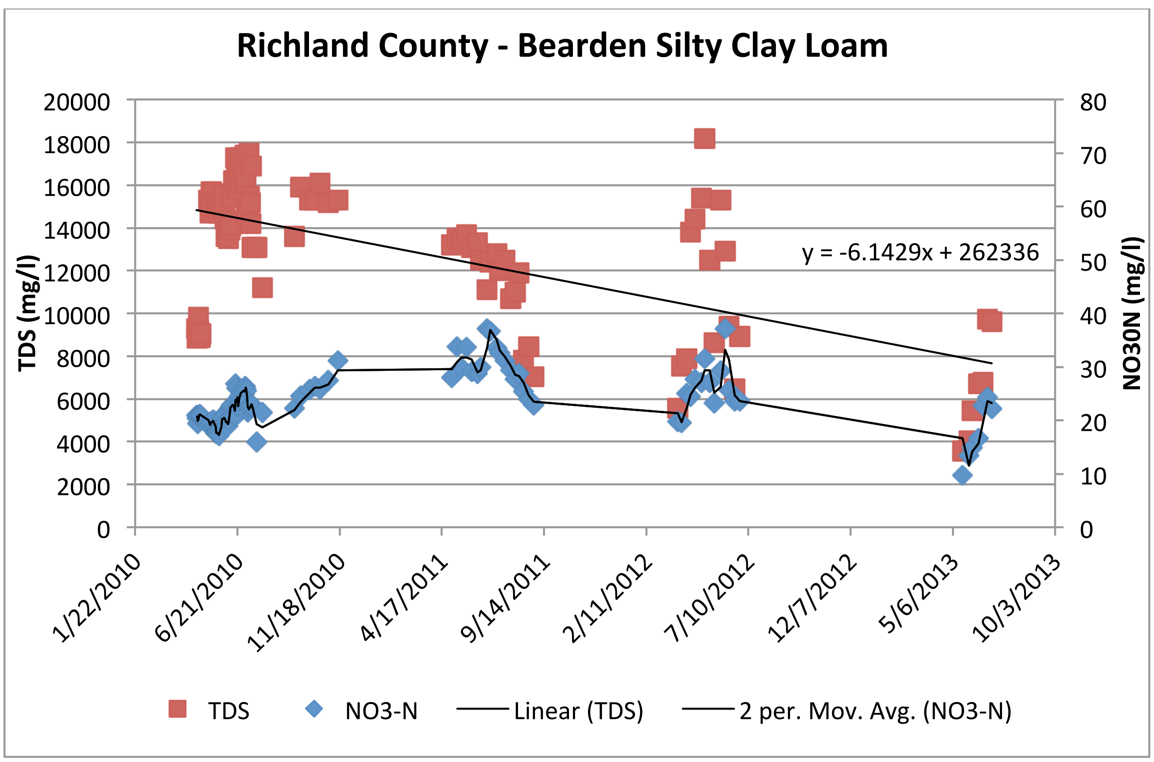

Figure 6. TDS and NO3-N concentrations for the Richland County site. A regression derived trend line indicates a slow reduction in TDS concentration. A 2-point moving average is applied to the NO3-N values.

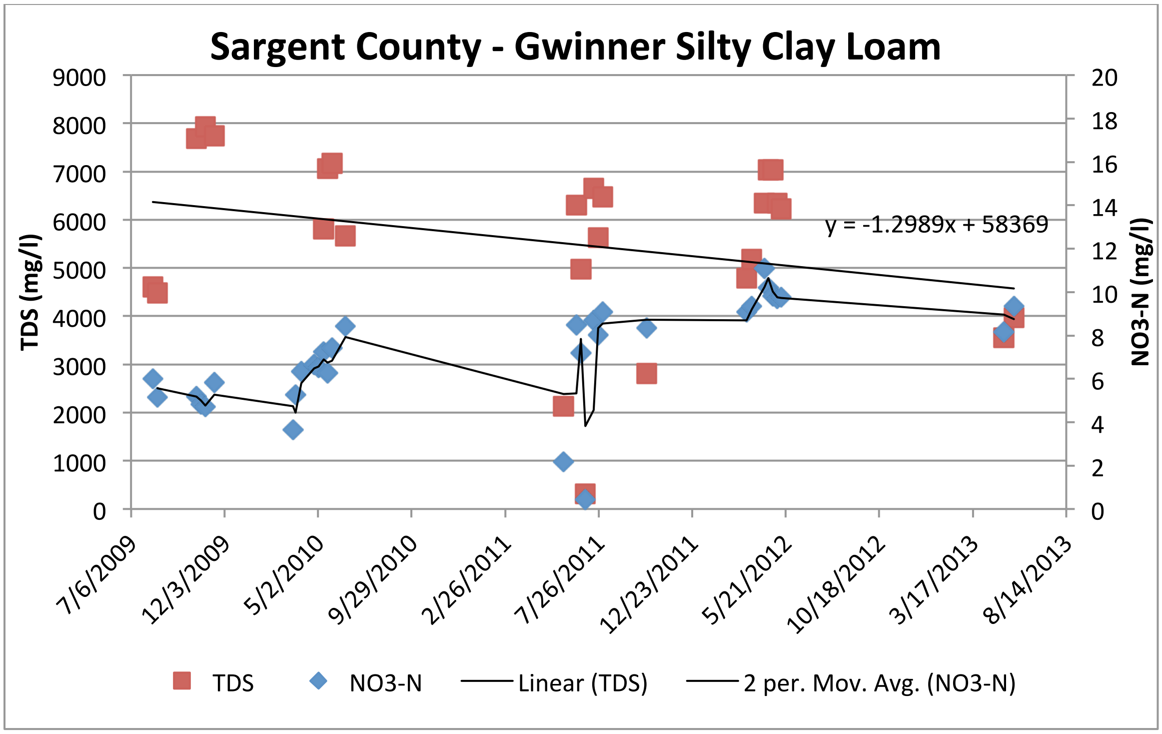

Figure 7. TDS and NO3-N concentrations for the Sargent County site. A regression derived trend line indicates a slow reduction in TDS concentration. A 2-point moving average is applied to the NO3-N values.

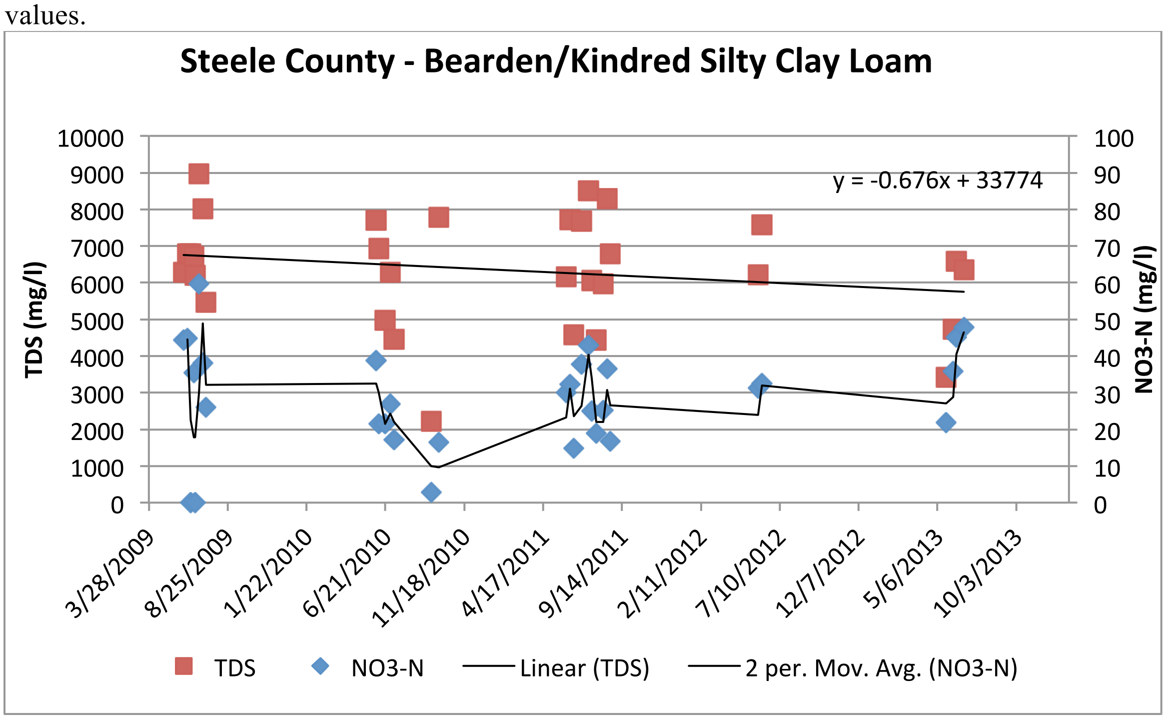

Figure 8. TDS and NO3-N concentrations for the Steele County site. A regression derived trend line indicates a very slow reduction in TDS concentration. A 2-point moving average is applied to the NO3-N values.

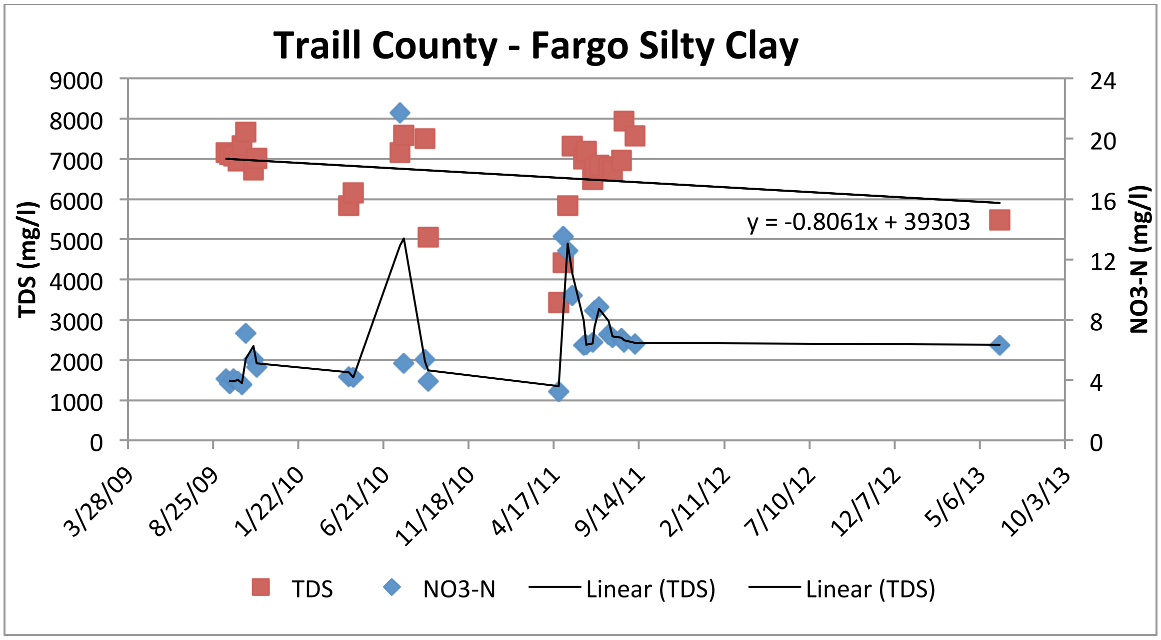

Figure 9. TDS and NO3-N concentrations for the Traill County site. A regression derived trend line indicates a slow reduction in TDS concentration. A 2-point moving average is applied to the NO3-N values.

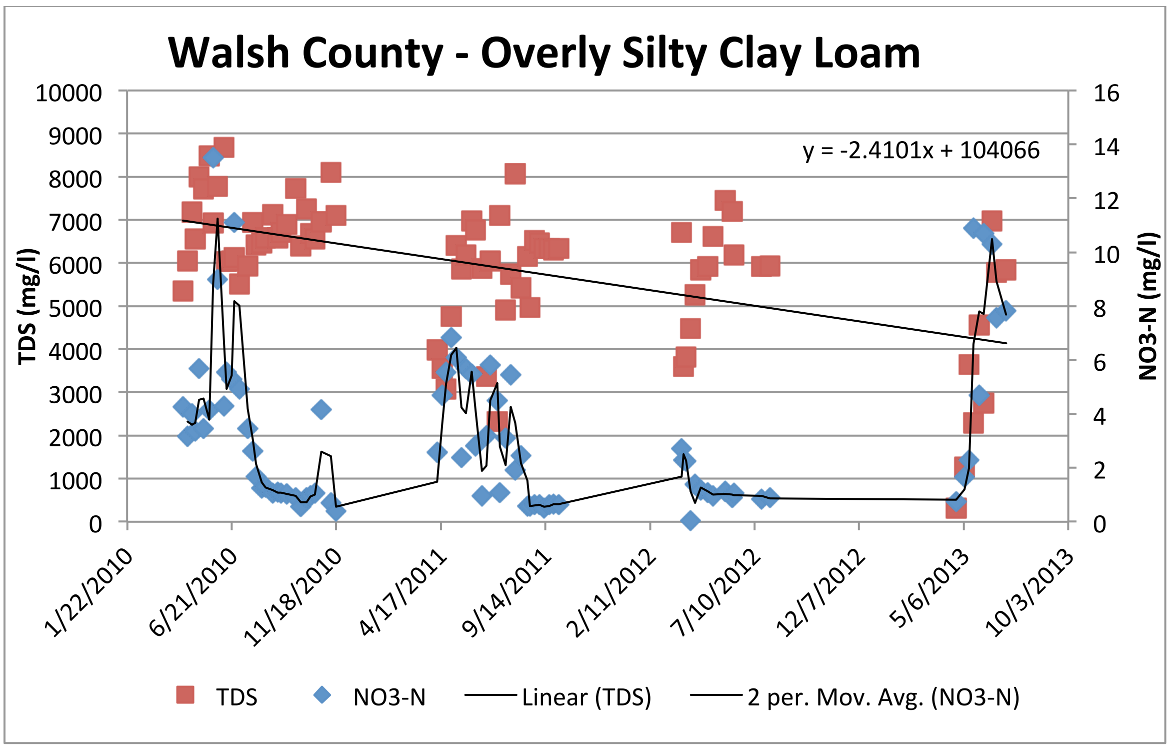

Figure 10. TDS and NO3-N concentrations for the Walsh County site. A regression derived trend line indicates a slow reduction in TDS concentration. A 2-point moving average is applied to the NO3-N values.

With the exception of the Grand Forks and Ransom sites, the trend line for TDS concentration at all the other sites have a negative value. This indicates that the concentrations are decreasing with time. From a farmer's perspective, the tile is accomplishing the task of removing dissolved salts from the soils in the field. The TDS regression trend lines for the Grand Forks and Ransom sites are almost flat indicating that these sites have reached an equilibrium point with respect to TDS loading.

A question often asked is "how long will it take to reduce the soil salts to acceptable agronomic levels?" For the six sites with decreasing TDS, a target of 2000 mg/l was set as an acceptable TDS discharge concentration for crop production (table 8). Using the trend line equations shown on figures 3 through 10, the time in years to reach this discharge concentration were calculated.

County Site	Cass	Richland	Sargent	Steele	Traill	Walsh
Estimated Years	8 to 9	6 to 7	9 to 10	19 to 20	17 to 18	6 to 7

Table 8. Estimated years for TDS of the discharge water to decrease to 2000 mg/l.

It might be very informative to sample these sites in the year 2020 to see if the TDS concentrations have indeed dropped to an acceptable level.

As shown in the figures 3 through 10, the two point moving average applied to the NO_3-N concentrations clearly show that peak concentrations occur in the April to June time frame.

Effects of Tile Flow on Receiving Stream Water Quality

A question often asked is the impact of tile water TDS and NO_3-N concentrations on the receiving waterway. For the duration of the project, we were able to obtain consistent upstream and downstream water samples from the Richland and Grand Forks county sampling sites. The plots of the TDS and NO_3-N concentrations are shown in figures 11 and 12.

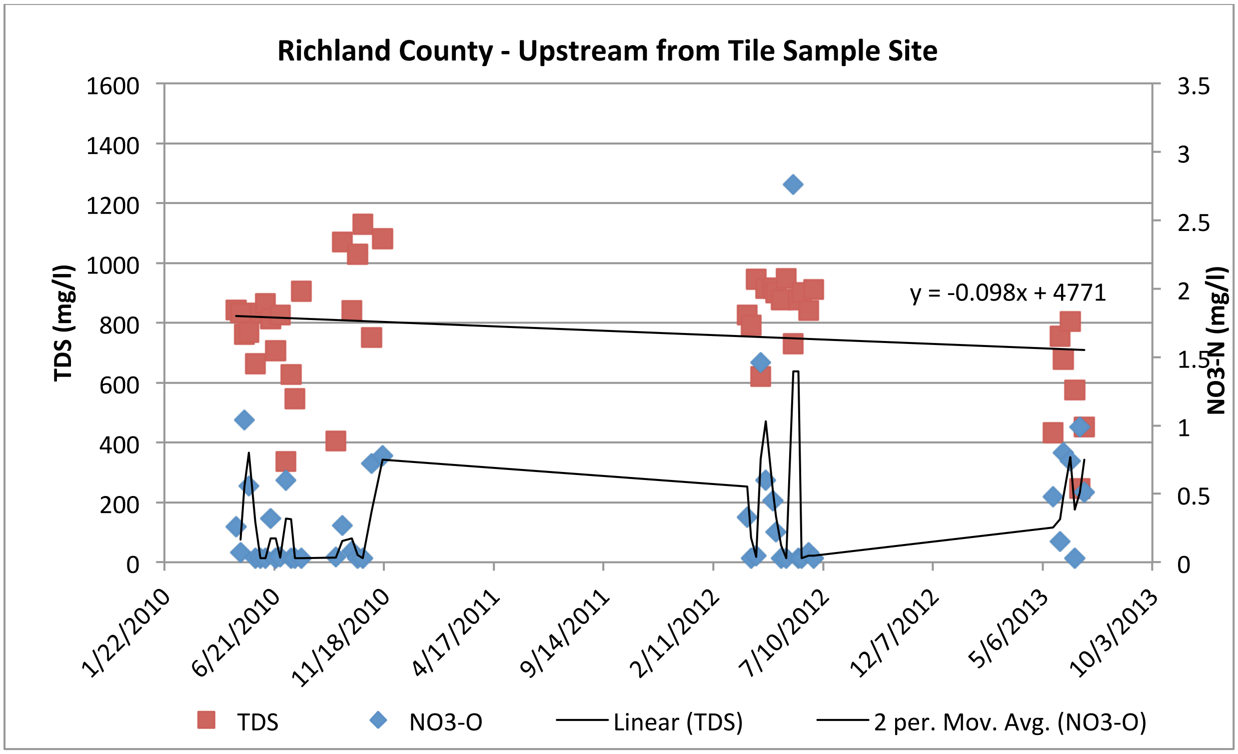

Figure 11. TDS and NO_3-N concentrations in the receiving ditch upstream from the Richland County tile discharge site. A 2-point moving average is applied to the NO_3-N values.

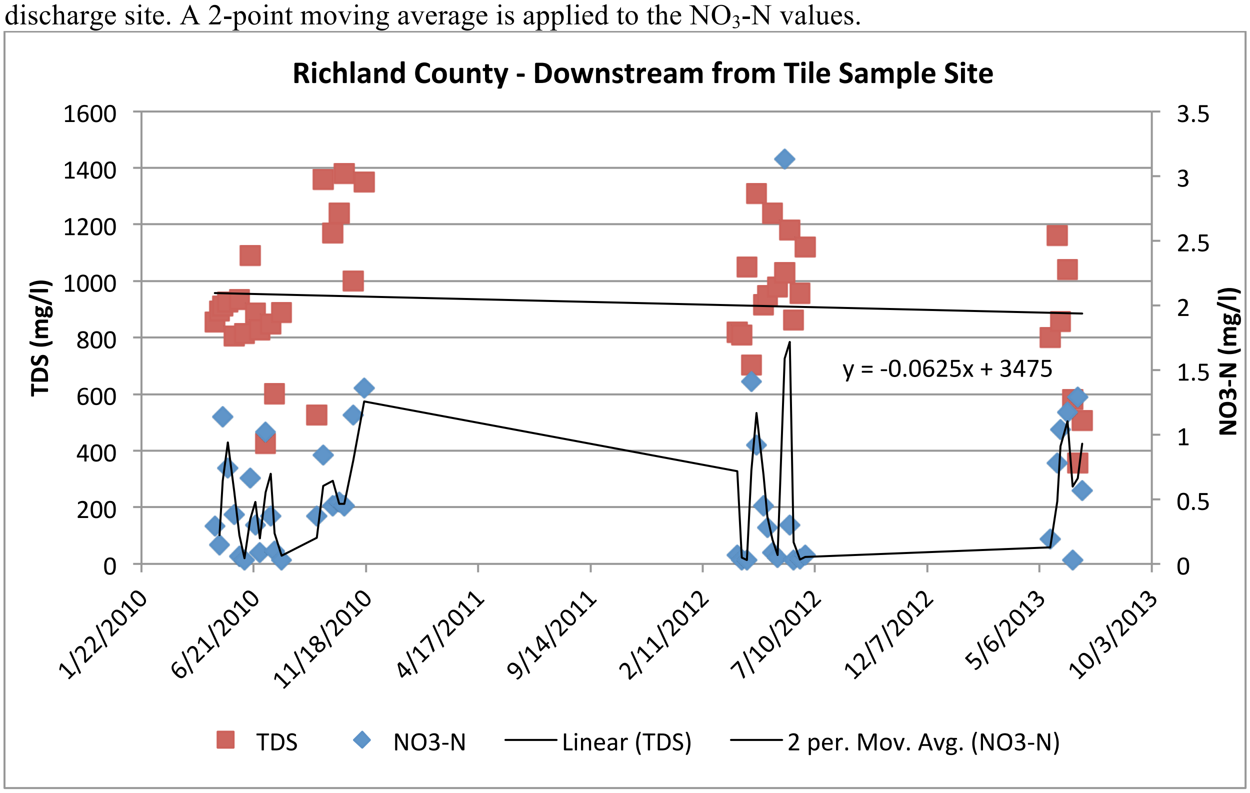

Figure 12. TDS and NO_3-N concentrations in the receiving ditch downstream from the Richland County tile discharge site. A 2-point moving average is applied to the NO_3-N values where the highest values are in the April to June time period.

The Richland site had the highest TDS values of all the monitored sites. The average TDS concentration (red squares) in the downstream samples is about 180 mg/l greater than the upstream samples and the average NO3-N concentrations are about 0.2 mg/l greater than the water in the upstream samples. It is obvious that the high concentration of the tile water is impacting the concentrations in the receiving stream. This is not true for the Grand Forks site where the tile water TDS (average about 550 mg/l) was the same as the receiving waterway, both upstream and downstream.

Mass Loads Discharged to Waterways

As mentioned previously, rain events are the driving force for flow from tile drainage systems. Rain amounts received at each site varied each year and each location (table 9).

County	Year			
	2010	2011	2012	2013
Steele	5.5**	14.1	14.5	8.9
Traill	19.2	18.0	13.9	8.5
Richland	27.1	17.5	15.8	7.1
Ransom	28.3	25.7	14.3	9.9
Grand Forks	25.5	19.4	11.2	9.5
Cass	25.6	22.2	11.9	6.8
Sargent	---	20.2	6.5	5.8
Walsh	22.4	21.8	17.7	10.6

Table 9. Rain amounts collected at each site. The 2013 amounts are for the period from April 1 to July 9 when the project ended. (** - Rain amounts only measured from June to August)

Mass loads discharged into receiving waters are dependent on the amount of rain received at each site and the percentage that flows out the tile outlet (table 10). The average percent of rain the flows from the tile system for all sites in 2010, 2011, 2012 and 2013 were 15, 25, 11 and 22 percent, respectively. However, there were large variations due to some sites having large rain events while other sites had lesser amounts.

	Fraction of Rain that Flowed from the Tile Outlet (percent)				
Year	**2010**	**2011**	**2012**	**2013**	**Site Average**
Traill	23%	19%	0.4%	17%	15%
Richland	12%	23%	1.9%	4%	11%
Ransom	26%	31%	27%	35%	30%
Grand Forks	3%	27%	1.1%	18%	12%
Cass	12%	20%	---	20%	18%
Sargent	---	31%	33%	12%	25%
Walsh	10%	26%	0.1%	47%	21%
Annual Average	15%	25%	11%	22%	

Table 10. Percent of rain amounts in tile flow at each site.

For example, in 2012 at 4 of the sites the rain fraction that flowed from the tile was less than 2% whereas the Ransom and Sargent sites, the most southern, had 27% and 33% of the rain flow to the tile outlet.

The TDS and NO_3-N loads, based on averaged concentrations, discharged to receiving waters for the full period of this project are shown in Table 11. The TDS loading varied significantly between sites (Appendix 3). In 2010 the average TDS loading for all sites was 4,516 lbs/ac but that varied from 96 lbs/ac at Grand Forks to 10,387 lbs/ac at the Richland site. In 2013, the TDS loading average was 1,543 lbs/ac with a low of 183 lbs/ac at Grand Forks to 5,095 lbs/ac at the Walsh site.

The NO_3-N loading followed a similar pattern as the TDS but at much lower levels. For example, in 2010 the average NO_3-N loading for all sites was 5.54 lbs/ac with a low of 0.47 lbs/ac at the Grand Forks site and a high of 16.6 lbs/ac at the Richland site. By comparison, in 2013 the NO_3-N loading average for all sites was 3.96 lbs/ac with a low of 1.34 lbs/ac at the Sargent county site and a high of 9.11 lbs/ac at the Walsh site.

County Site	Flow Volume (gallons)	Average TDS Concentration (mg/l)	TDS Load (lbs/ac)	Average NO_3-N Concentration (mg/l)	NO_3-N Load (lbs/ac)
Traill	38,972,532	6,193	10,919	11.0	17
Richland	29,799,993	11,067	21,627	24.4	45
Ransom	187,143,000	1,029	5,286	2.5	18
Grand Forks	31,818,335	491	925	2.7	6
Cass	18,726,000	6,847	14,134	7.6	19
Sargent	38,017,220	5,324	17,936	8.1	31
Walsh	53,163,737	5,555	14,803	3.2	14

Table 11. Total TDS and NO_3-N loads, pounds per acre, over the 4-year project period for each site with flow measurement. The loads were calculated using the sum of the annual loads (table A3-1).

The discharge from the Ransom site is much greater than the other sites and it is probably due to geography, topography and poor surface drainage (figure A2-2 in Appendix 2). This site has a dual pump system located in a very flat area of the state. On several visits to the site, after significant rain events, the outlet ditch was full due to surface runoff. The pumps were pumping water but it could not leave the area, so the pumped water stayed in the field. We do not know what percentage of the flow was recorded during these periods, but we do know that this site is very prone to water logging thus will have a higher flow than the other sites.

The total TDS load *in tons* for the project period is shown in Table 12. The lowest TDS loading, are the Grand Forks County and Cass County sites. The Sargent and Walsh sites have very similar TDS concentration but there is a 500-ton difference in loading.

County Site	Flow Volume (gallons)	Average TDS Concentration (mg/l)	TDS Load (tons)	Average NO_3-N Concentration (mg/l)	NO_3-N Load (pounds)
Traill	38,972,532	6,193	846	11.0	2,635
Richland	29,799,993	11,067	1,536	24.4	6,390
Ransom	187,143,000	1,029	793	2.5	5,400
Grand Forks	31,818,335	491	69	2.7	900
Cass	18,726,000	6,847	530	7.6	1,425
Sargent	38,017,220	5,324	1,390	8.1	4,805
Walsh	53,163,737	5,555	1,258	3.2	1,960

Table 12. TDS in total tons and NO_3-N loads in total pounds for each site during the project period with flow measurement. The total loads were calculated using the sum of the annual loads (table A3-1).

The average project NO_3-N concentrations are also shown in Table 12 with a low of 2.5 mg/l at the Grand Forks site and 24.4 mg/l at the Richland site. For the project period, the Grand Forks site has the lowest loading at 900 pounds of N and the Richland site had the largest with 6,390 pounds. However, the Ransom site had an average concentration of 2.5 mg/l of NO_3-N yet due to the high flow volume the N load is slightly larger the Sargent site.

It is clear that a significant TDS and NO_3-N load was discharged over the 4-years of this project. In particular, many tons of dissolved minerals were flowing with the water. From a farmer's perspective, the tile is performing as expected. The NO_3-N loss in the water ranged from a little over 1 to about 11 pounds per acre per growing season and from a farmer's perspective that is very little. More pounds of applied N are lost due to other causes.

We also looked at the TDS and NO_3-N loading on particular days during the project period. To do this, we used the flow volume recorded on the day a water sample was taken. We used the data from the Richland and Walsh sites because they had the most complete record of flow volume with consistent sampling over the full length of the tile project. At the Richland site (figures 13 and 14), the peak TDS load occurred in 2011 when more than 20 tons of dissolved minerals and about 100 pounds of N were discharged into the receiving stream on that day in late June of 2011. Also note that under most tile flow conditions the TDS load was 2.5 to 4 tons per day and the N load was closer to 10 lbs/day.

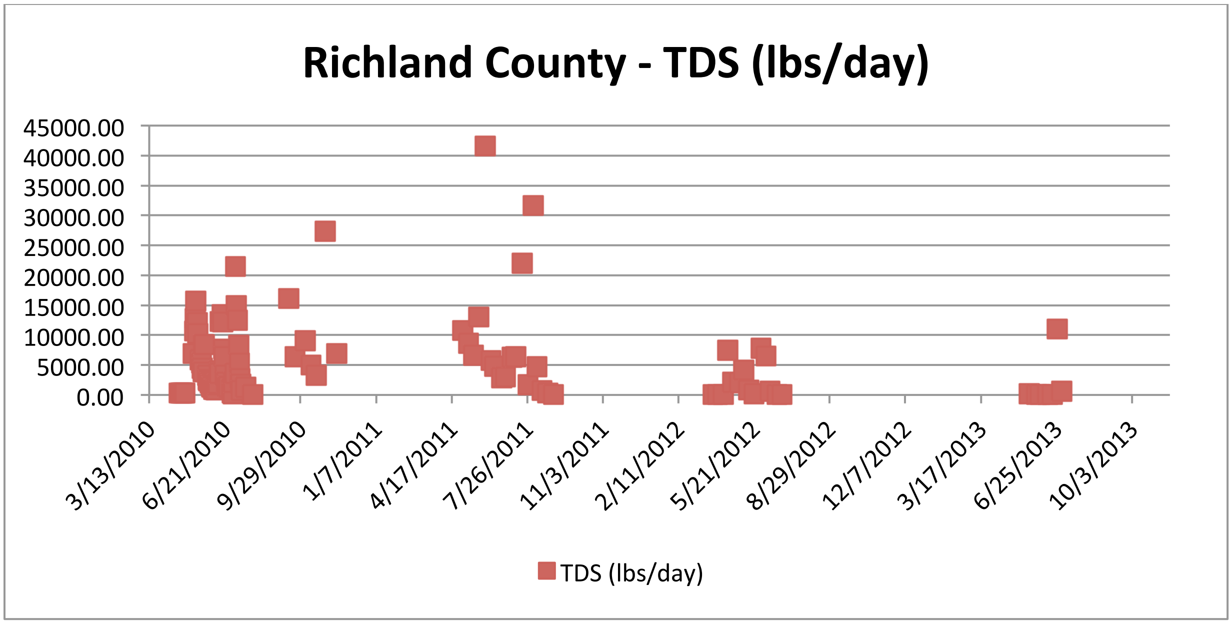

Figure 13. The weight of the dissolved minerals in the tile water on the day a water sample was taken at the Richland County site.

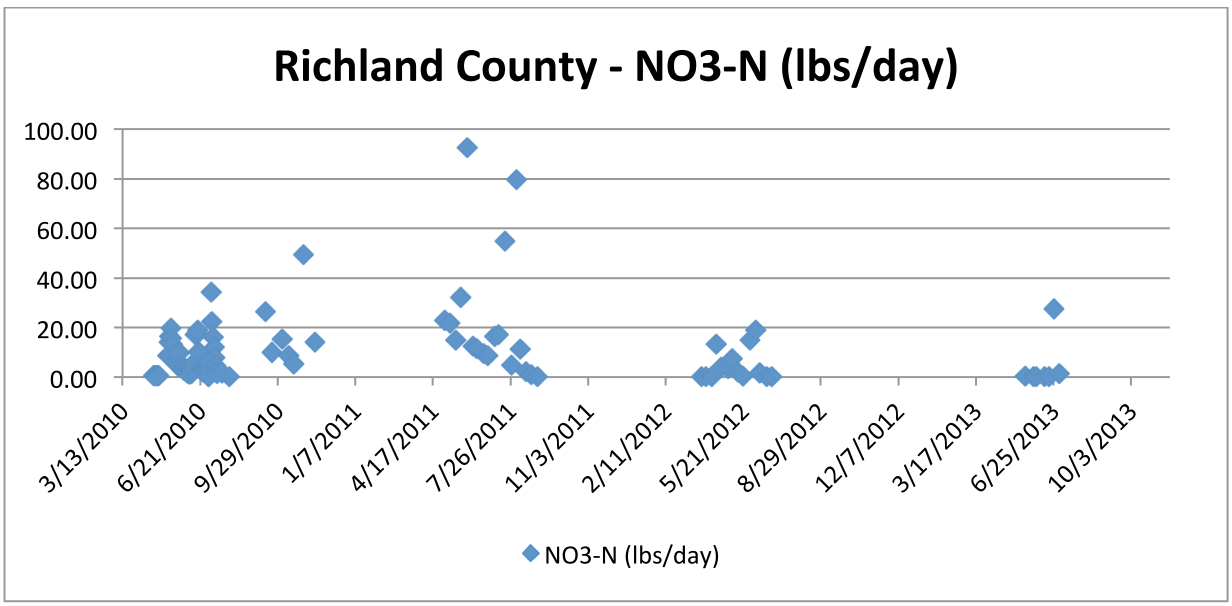

Figure 14. The weight of dissolved nitrogen in the tile water on the day a water sample was taken at the Richland County site.

In contrast, the TDS and NO_3-N load at the Walsh County site (figures 15 and 16) had two rain events where the peak discharge was on the order of 25 to 30 tons of dissolved minerals and over 100 pounds of N on a day in June 2010. This occurred when the pump ran continuously for more than a day (figure A2-7, Appendix 2). However, almost all the other samples show very low loading rates.

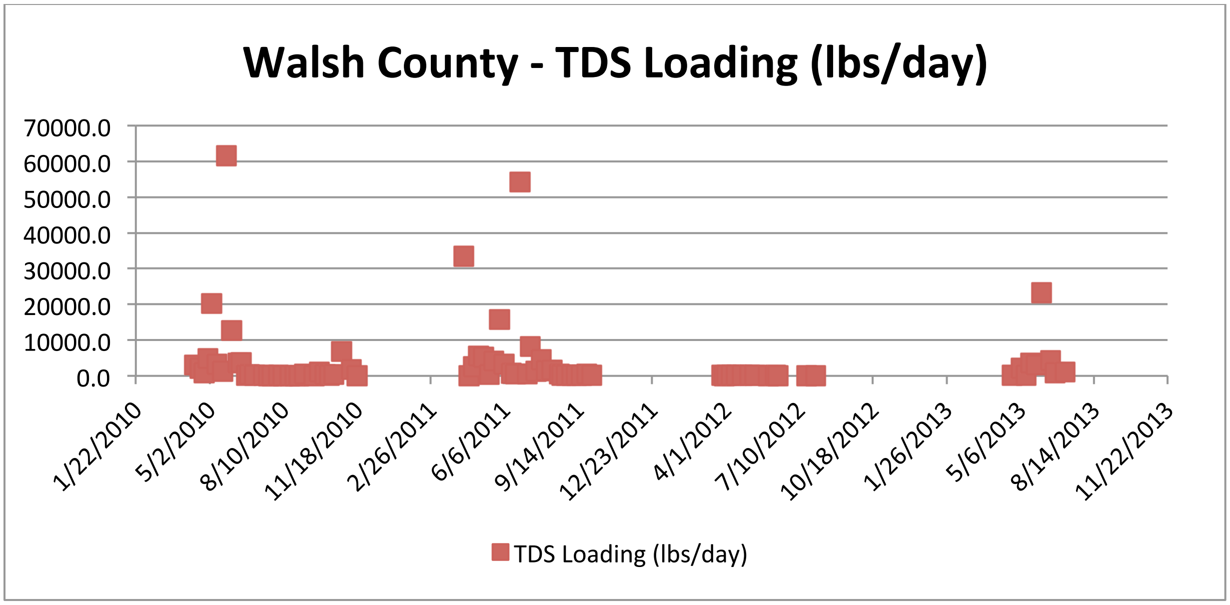

Figure 15. The weight of the dissolved minerals in the tile water on the day a water sample was taken at the Walsh County site.

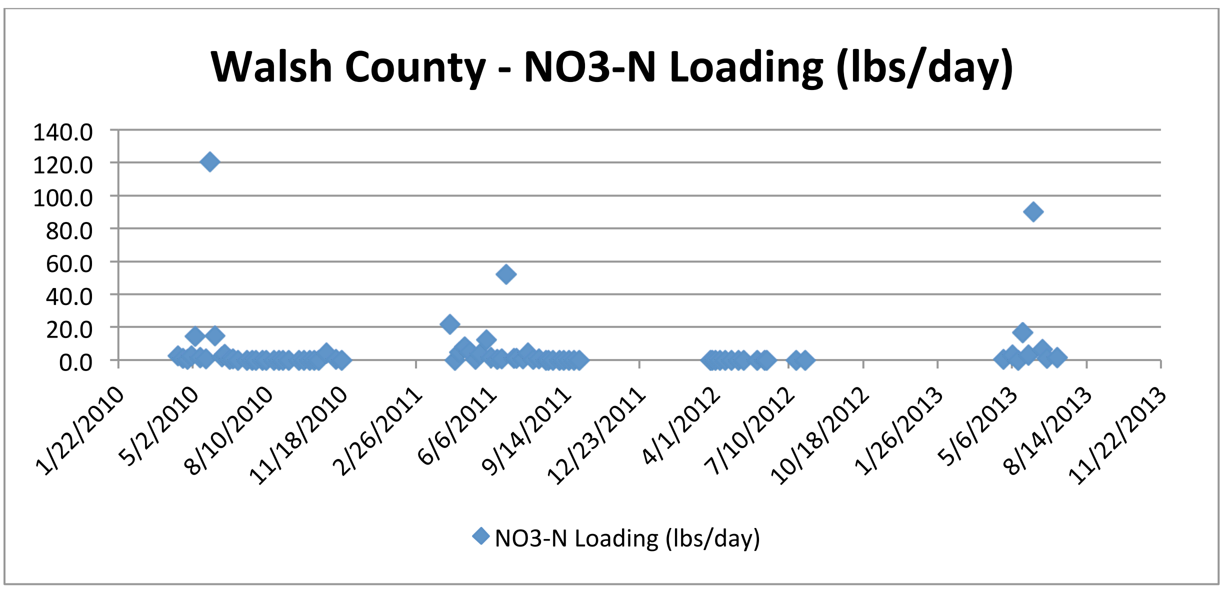

Figure 16. The weight of dissolved nitrogen in the tile water on the day a water sample was taken at the Walsh County site.

Water samples were taken only once per week and thus days when the loading was much greater were missed. Yet, it is clear that the largest mass loads into receiving waterways takes place after large rain events. However, it must be remembered that the flow in receiving waterways is also very large due to surface runoff.

Statistical Analysis

A statistical analysis was performed to determine the relationship of TDS and NO_3-N concentrations to soils, location, topography, flow volume, rain amounts, year and month of measurement. The analysis is shown in detail in Appendix 4. Monthly mean values of flow volume, rain amounts, TDS and natural log of (NO_3-N) concentrations along with a county parameter were used in the analysis. The county parameter served as a proxy for soils, topography and cropping pattern impacts on the concentrations at each location. The models fit the data remarkably well with R^2 values of 0.75 for the ln(NO_3-N) and 0.87 for the TDS predictor equations. The modeling also produced P-values that denote statistical significance. A P-value less than 0.1 is considered significant indicating that variable is an important contributor

Based on the P-values, the NO_3-N analysis showed that the location (county), monthly means and annual mean flow volumes were significant. When analyzing individual counties, Grand Forks is not significant, but the rest are. As shown in Table A3-1 and A3-2, Grand Forks County had the smallest contribution of NO_3-N load in pounds per acre of all 8 sites. The significance of the other sites means that the soil, topography and cropping mix all affect NO_3-N concentrations and that each is unique. Additionally, mean pump volume was highly significant but mean monthly rain amounts were not significantly correlated with NO_3-N concentrations. The monthly analysis shows that the NO_3-N concentrations in April, May, June and July are significant but the other months are not significantly correlated. This reinforces the graphical results shown in figures 3 to 12.

The TDS analysis shows that location (county), monthly means and the year they occurred were very significant. Interestingly, mean monthly flow volume and rain amounts are not significant. For individual counties, the Sargent and Traill County locations are not significantly correlated but the other 6 counties are highly significant indicating that the model could predict TDS concentrations based on the measured parameters shown in Appendix 4. The TDS concentration was highly correlated with the year in which the samples were taken and that means each year will be different based on rain and flow amounts. Interestingly, the TDS concentration was significantly correlated with the months of March and April, but not any of the other months. It is interesting in that these two months had the least number of water samples.

This analysis used mean monthly values, thus the models can only be used for prediction using these same parameters. They cannot be used for predictions based on daily or weekly means.

Conclusions

1. Tile flow occurs in response to rain events when the water table is near the tile elevation. Large spring and fall rain events contribute significantly to tile flow. A single large rain event or small rain events spread out over several days can trigger tile flow. In the spring, tile flow does not occur until most of the frost is out of the field. The fraction of rain that flowed from the tile varied from 11% to 30%. During the growing season, crop

evapotranspiration consumes most available soil moisture.

2. In tile drainage water from saline affected soils, the TDS concentration has a high correlation with sodium, magnesium, sulfate, hardness and bicarbonate constituents of the water sample

3. Sulfate (SO_4) was the dominant mineral in the tile water averaging over 65% of TDS at all sites except Grand Forks and Ransom counties.

4. Trace metals and other minor minerals in the tile water often occur in concentrations below the detection limit of laboratory analysis methods.

5. Statistically, the flow and dissolved solids concentrations of the tile water is unique to each site. Soil series, topography and geology along with crop mix and rotations are what make each site unique and affect the flow and mineral concentration in the tile water.

6. The TDS of tile water decreased with time for all sites except Grand Forks and Ransom counties. Based on the trend line, it is estimated that the TDS of the Walsh and Richland sites will decrease to around 2000 mg/l in 7 years, Sargent and Cass around 9 to 10 years with Steele and Traill taking about 18 to 20 years. The Richland site had the largest TDS concentration and increased the TDS in the receiving stream about 180 mg/l. The average TDS load to the receiving streams for the 4-years varied from 65 tons at the Grand Forks site to 1,375 tons at the Richland site. During large flow events over 20 tons of minerals can be discharged into the receiving stream.

7. As shown graphically and statistically, the maximum NO_3-N concentrations and loading occurred in the April to June time period each year. The average annual amount of N in the drainage water varied from about 1 pound per acre from the Grand Forks site to a maximum of about 10 pounds per acre at the Richland site. However, the 4-year total of N that flowed into the receiving water stream varied from a low of 719 pounds at the Grand Forks site to 6,070 pounds at the Richland site. With large flow events, N losses can exceed 100 pounds per day.

8. Maximum loading of the receiving waterway is dependent on both concentration and the flow rate of the tile system. Tile systems with low concentrations and high flow will produce as much loading to waterways as tile systems with high concentrations and low flow rates.

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Appendix 1

A statistical correlation analysis of measured water quality parameters for the 492 samples collected during the project period from the 8 tile sites. Dr. Curt Doetkott of the NDSU Statistical Consulting Service performed the analysis. Trace elements where over 98% of the samples were below the laboratory detection limit were eliminated from the analysis. The numbers in parenthesis indicate the level of correlation with the analyte listed in the left-hand column.

Water Quality Group	Analyte		Significant Corrleations (R>0.40)																
	Sodium		Alkal (0.64)	AnSum(0.93)	B (0.41)	Ca (0.54)	CatSum (0.94)	Cond (0.93)	Cu (0.65)	Hard (0.85)	K (0.50)	Mg (0.83)	NO3+NO2 (0.68)	TotalN (0.69)	%Na (0.71)	Ni (0.45)	SAR (0.96)	SO4 (0.94)	TDS (0.95)
	Potassium		B (0.70)	Ca (0.43)	CatSum (0.48)	Cond (0.45)	Hard (0.43)	NO3+NO2 (0.43)	TotalN (0.45)	NA (0.50)	%Na (0.55)	SAR (0.55)	SO4 (0.41)	TDS (0.44)					
	Calcium		B (0.57)	CatSum (0.61)	Cond (0.65)	Hard (0.62)	K (0.43)	Mg (0.45)	Na (0.54)	Ni (0.42)	SAR (0.47)	SO4 (0.58)	TDS (0.61)						
	Magnesium		Alkal (0.62)	AnSum (0.97)	Ca (0.45)	CatSum (0.96)	Cond (0.96)	Cu (0.68)	Bicarb (0.62)	Hard (0.98)	NO3+NO2 (0.58)	TotalN (0.59)	Na (0.83)	%Na (0.56)	Ni (0.63)	SAR (0.79)	SO4 (0.97)	TDS (0.97)	
	Hardness		Alkal (0.61)	AnSum (0.96)	Ca (0.62)	CatSum (0.98)	Cond (0.96)	Cu (0.64)	BiCarb (0.61)	K (0.43)	Mg (0.98)	NO3+NO2 (0.54)	TotalN (0.55)	Ni (0.65)	SAR (0.80)	SO4 (0.95)	TDS (0.97)		
	Cation Sum		Alkal (0.64	AnSum (0.98)	Ca (0.61)	Cond (0.98)	Cu (0.67)	Hard (0.98)	K (0.48)	Mg (0.96)	NO3+NO2 (0.62)	TotalN (0.63)	Na (0.94)	%Na (0.64)	Ni (0.59)	SAR (0.89)	SO4 (0.98)	TDS (0.99)	
	Percent Sodium		Alkal (0.52)	AnSum (0.65)	CatSum (0.64)	Cond (0.68)	Cu (0.49)	Bicarb (0.52)	Hard (0.56)	K (0.55)	Mg (0.56)	NO3+NO2 (0.68)	TotalN (0.70)	NA (0.71)	SAR (0.86)	SO4 (0.65)	TDS (0.66)		
General Chemistry	SAR		Alkal (0.63)	AnSum (0.89)	Ca (0.47)	CatSum (0.89)	Cond (0.90)	Cu (0.64)	Hard (0.80)	K (0.55)	Mg (0.79)	NO3+NO2 (0.76)	TotalN (0.78)	NA (0.96)	%Na (0.86)	SO4 (0.89)	TDS (0.90)		
(Cations and Anions)	Sulfate		Alkal (0.65)	AnSum (0.99)	Ca (0.58)	CatSum (0.98)	Cond (0.98)	Cu (0.71)	Hard (0.95)	K (0.41)	Mg (0.97)	NO3+NO2 (0.67)	TotalN (0.68)	NA (0.94)	%Na (0.65)	Ni (0.60)	SAR (0.89)	TDS (0.996)	
	Chloride		No correlations >0.4																
	Bicarbonate		Alkal (0.999)	AnSum (0.64)	Cond (0.64)	Hard (0.61)	Mg (0.62)	Na (0.52)											
	Anion Sum		Alkal (0.64)	CatSum (0.99)	Cond (0.99)	Cu (0.69)	Bicarb (0.64)	Hard (0.96)	Mg (0.97)	NO3+NO2 (0.65)	TotalN (0.67)	Ni (0.62)	SAR (0.89)	SO4 (0.99)	TDS (0.99)				
	Alkalinity		Bicarb (0.99)	SO4 (0.65)	CatSum (0.65)	TDS (0.65)	Na (0.64)	AnSum (0.64)	SAR (0.63)	Cond (0.63)	Mg (0.62)	Hard (0.61)	Na% (0.52)						
	TDS		Alkal (0.65)	AnSum (0.999)	Ca (0.61)	CatSum (0.992)	Cond (0.992)	Cu (0.70)	Hard (0.97)	K (0.44)	Mg (0.97)	NO3+NO2 (0.67)	TotalN (0.68)	Na (0.95)	NA (0.66)	%NA (0.61)	SAR (0.90)	SO4 (0.996)	
	Conductivity		Cu (0.69)	Ca (0.65)	CatSum (0.98)	Cu (0.68)	Bicarb (0.63)	Hard (0.96)	K (0.45)	Mg (0.96)	NO3+NO2 (0.67)	TotalN (0.68)	Na (0.93)	%Na (0.68)	Ni (0.62)	SAR (0.90)	SO4 (0.98)	TDS (0.99)	
	pH		No correlations >0.4																
	Total P		No correlations >0.4																
Nutrients	Total N		AnSum (0.67)	CatSum (0.63)	Cond (0.68)	Cu (0.56)	Hard (0.55)	K (0.45)	Mg (0.59)	NO3+NO2 (0.96)	Na (0.68)	%Na (0.68)	SAR (0.76)	SO4 (0.67)	TDS (0.67)				
(N and P)	Nitrate/Nitrite		AnSum (0.66)	CatSum (0.62)	Cond (0.67)	Cu (0.56)	Hard (0.54)	K (0.43)	Mg (0.58)	TotalN (0.96)	Na (0.68)	%NA (0.68)	SAR (0.76)	SO4 (0.67)	TDS (0.67)				
	Total Kjeldahl N		No correlations >0.4																
	Ammonia		No correlations >0.4																
	Barium	0.4% of samples LTD	Zn (0.47)																
	Zinc	17.4% of samples LTD	Ba (0.47)																
	Nickle	19.4% of samples LTD	AnSum (0.62)	Ca (0.42)	CatSum (0.59)	Cond (0.62)	Cu (0.45)	Hard (0.64)	Mg (0.63)	NA (0.45)	SO4 (0.60)	TDS (0.61)							
	Selenium	32.2% of samples LTD	No correlations >0.4																
	Copper	34.6% of samples LTD	AnSum (0.69)	CatSum (0.67)	Cond (0.68)	Mg (0.68)	NO3+NO2 (0.56)	TotalN (0.56)	Na (0.65)	%Na (0.49)	Ni (0.45)	SAR (0.64)	SO4 (0.71)	TDS (0.70)					
	Boron	42% of samples LTD	Ca (0.57)	K (0.70)	Na (0.41)														
	Iron	59.8% of samples LTD	Al (0.80)																
	Manganese	60.6% of samples LTD	No correlations >0.4																
Trace Elements	Arsenic	70.2% of samples LTD	No correlations >0.4																
	Aluminum	72.5% of samples LTD	Fe (0.80)																
	~~Cadmium~~	98.4% of samples LTD																	
	~~Chromium~~	98.6% of samples LTD																	
	~~Antimony~~	99.2% of samples LTD																	
	~~Lead~~	99.8% of samples LTD																	
	~~Silver~~	100% of samples LTD																	
	~~Berylium~~	100% of samples LTD																	
	~~Titanium~~	100% of samples LTD																	

Appendix 2

Daily flow and rain accumulations for the period of record at the Richland, Ransom, Traill, Walsh, Sargent and Grand Forks County monitoring sites. In 2009 and 2010, autumn rain amounts exceeded historical averages by over 5 inches. The winter of 2011 had significant snow accumulations and didn't melt until around April 13. Late summer of 2011 to early June 2013 was a dry period.

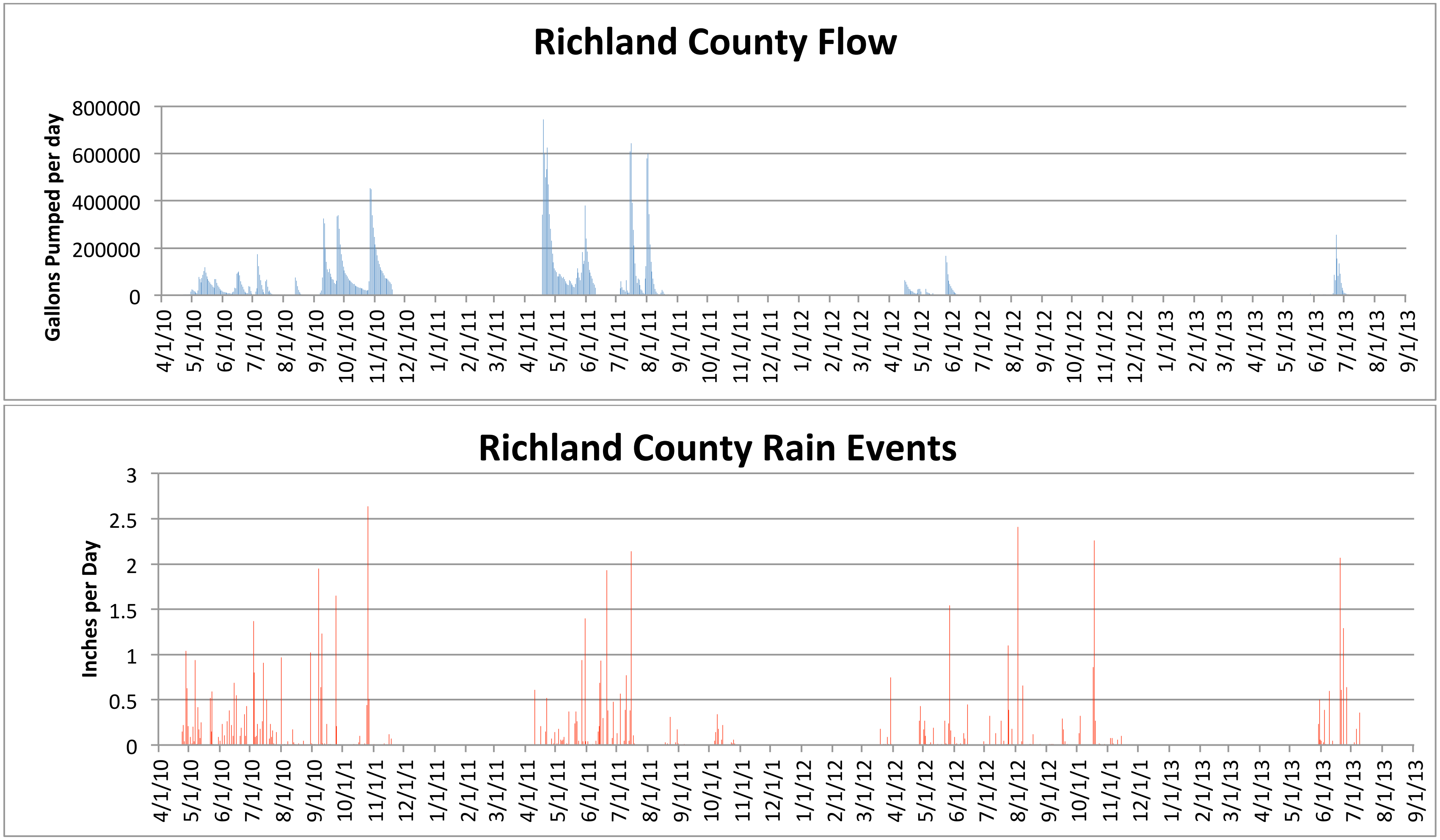


Figure A2-1. Richland county tile flow and rain amounts

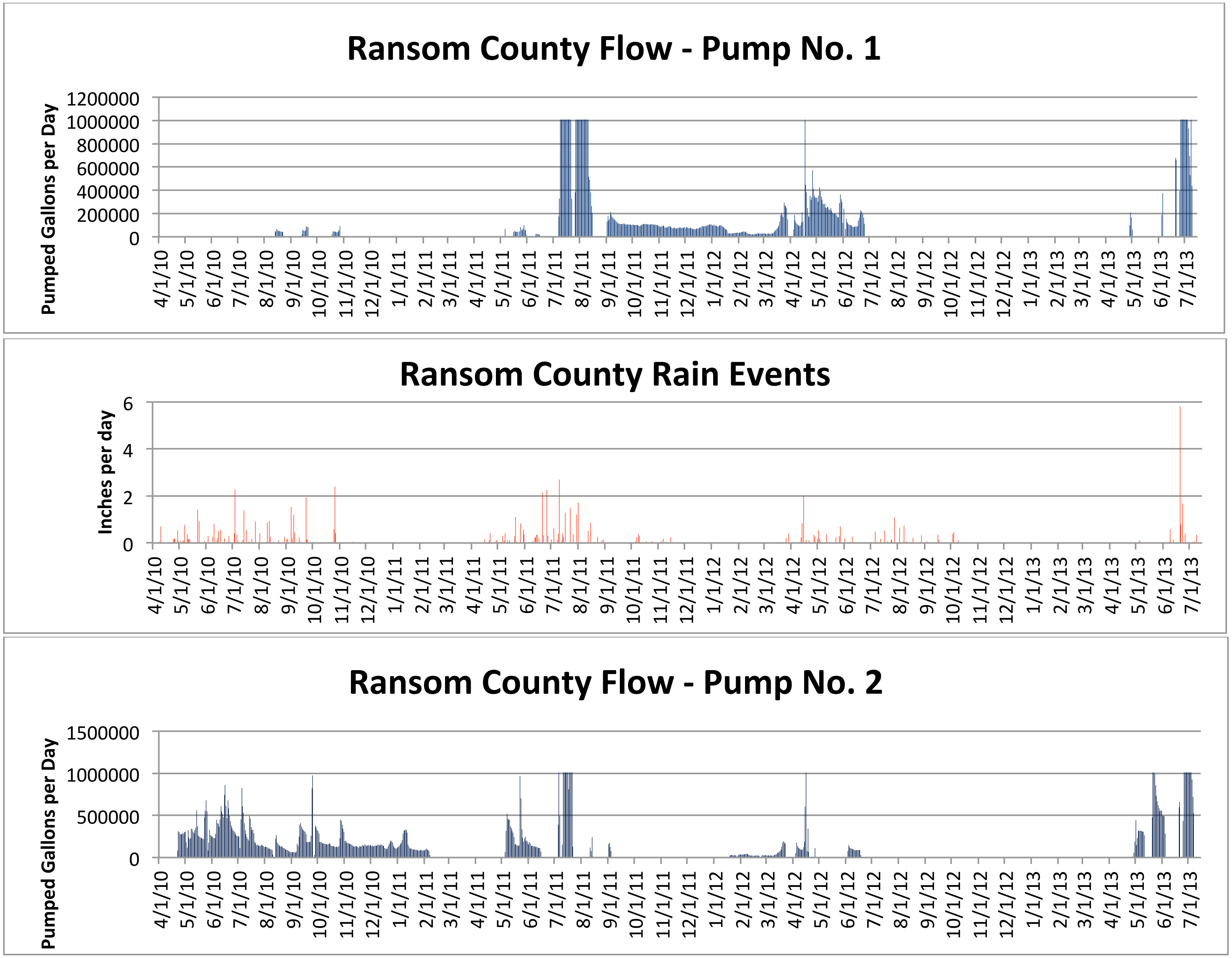
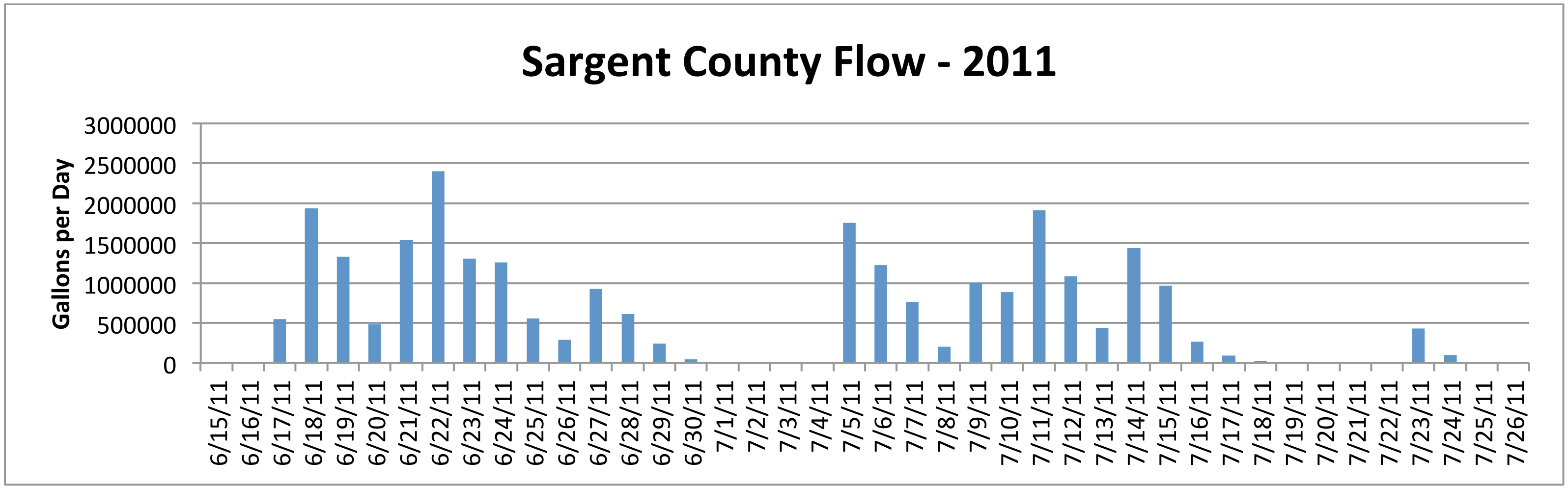


Figure A2-2. Ransom county tile flow and rain amounts. The outlet had 2 pumps.



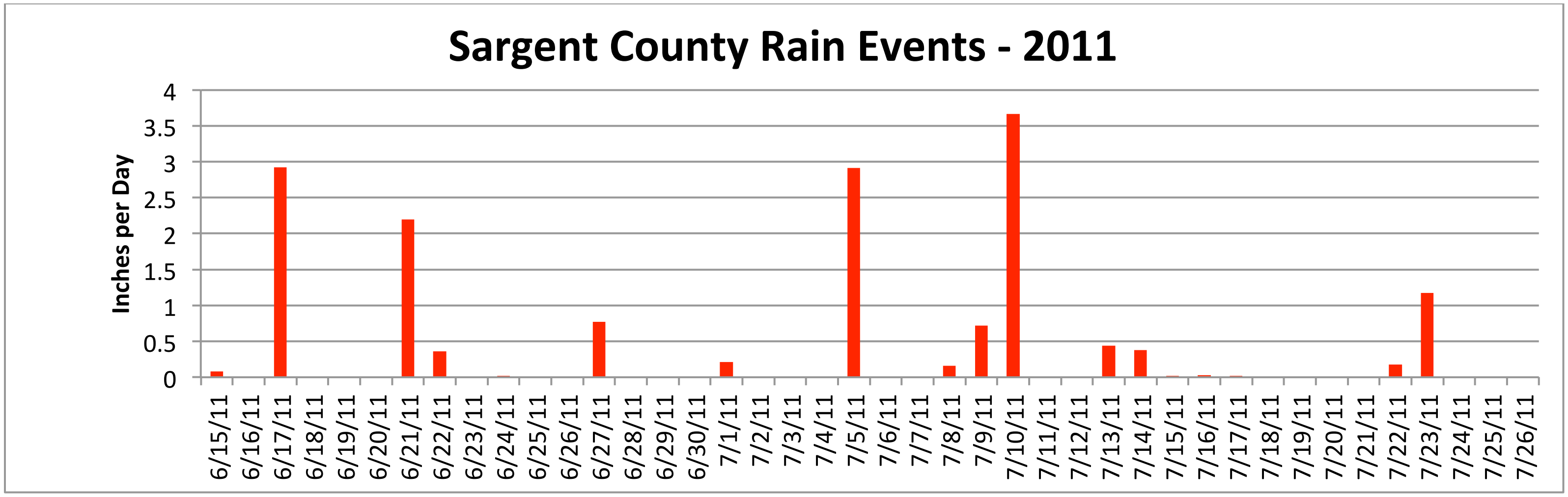


Figure A2-3. Sargent County daily flow volume and rain data for 2011. Due to vandalism, flow was not recorded after 7/26/11.

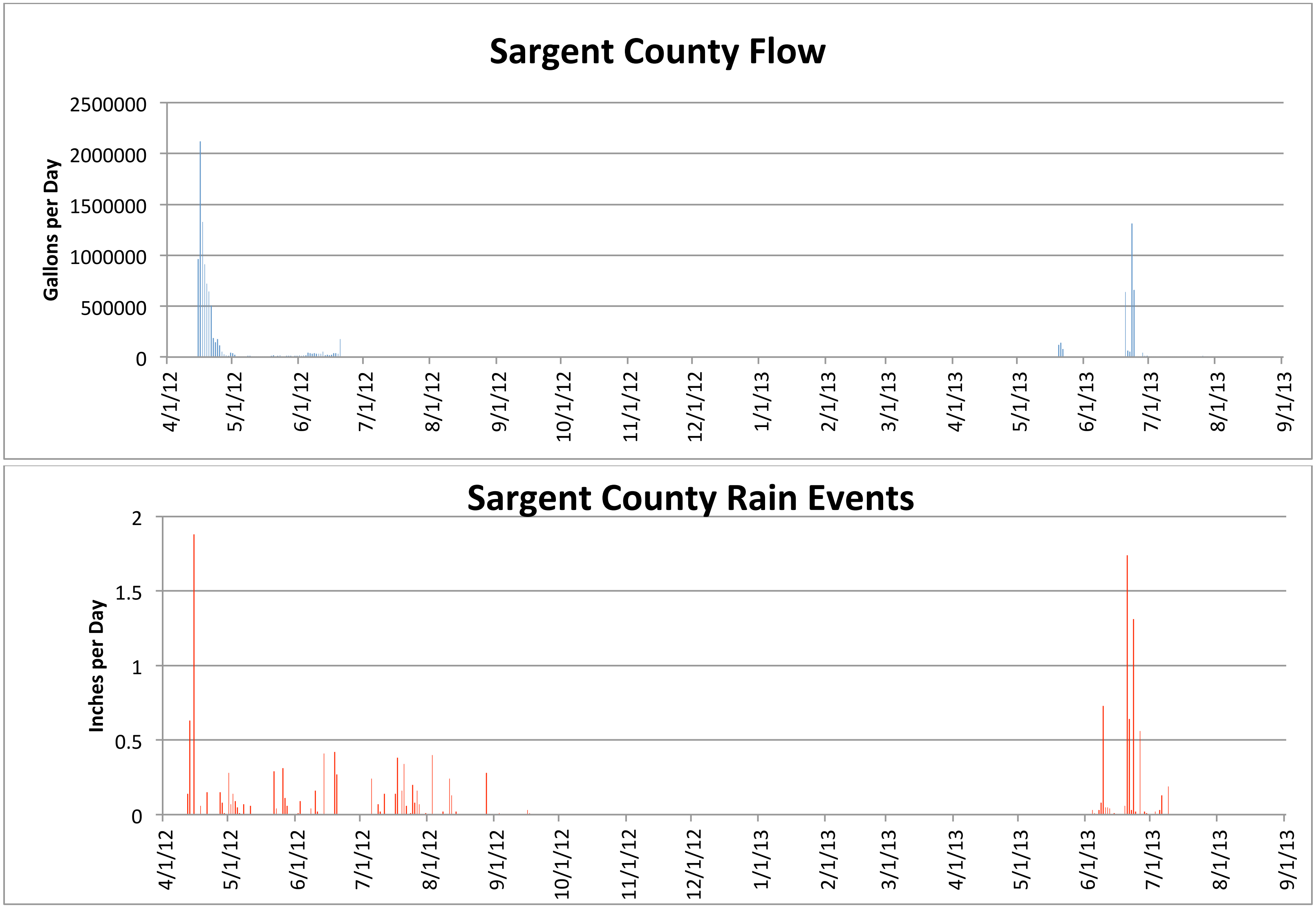


Figure A2-4. Sargent County daily flow volume and rain data for 2012 and 2013.

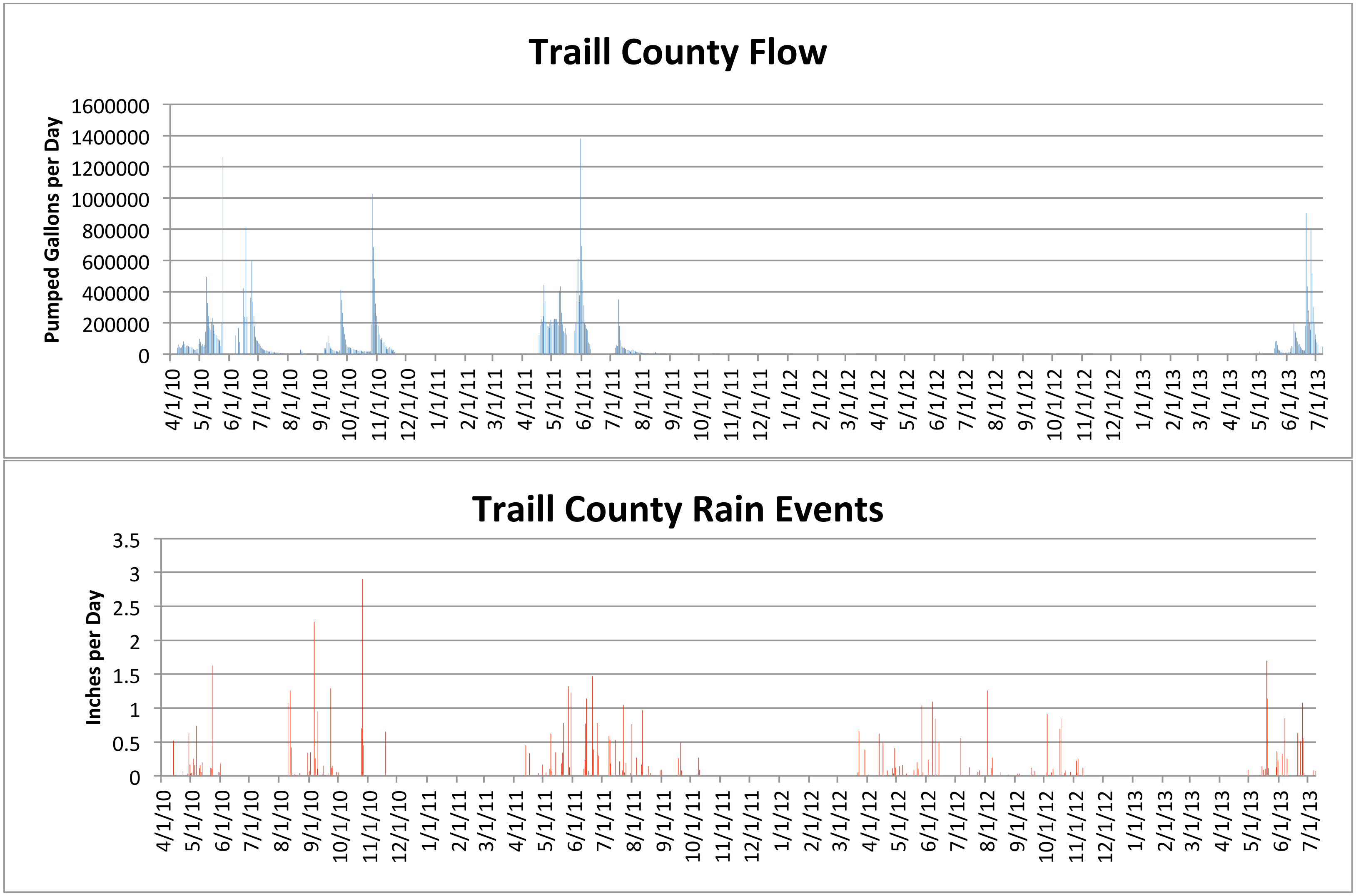


Figure A2-5. Traill county tile flow and rain amounts

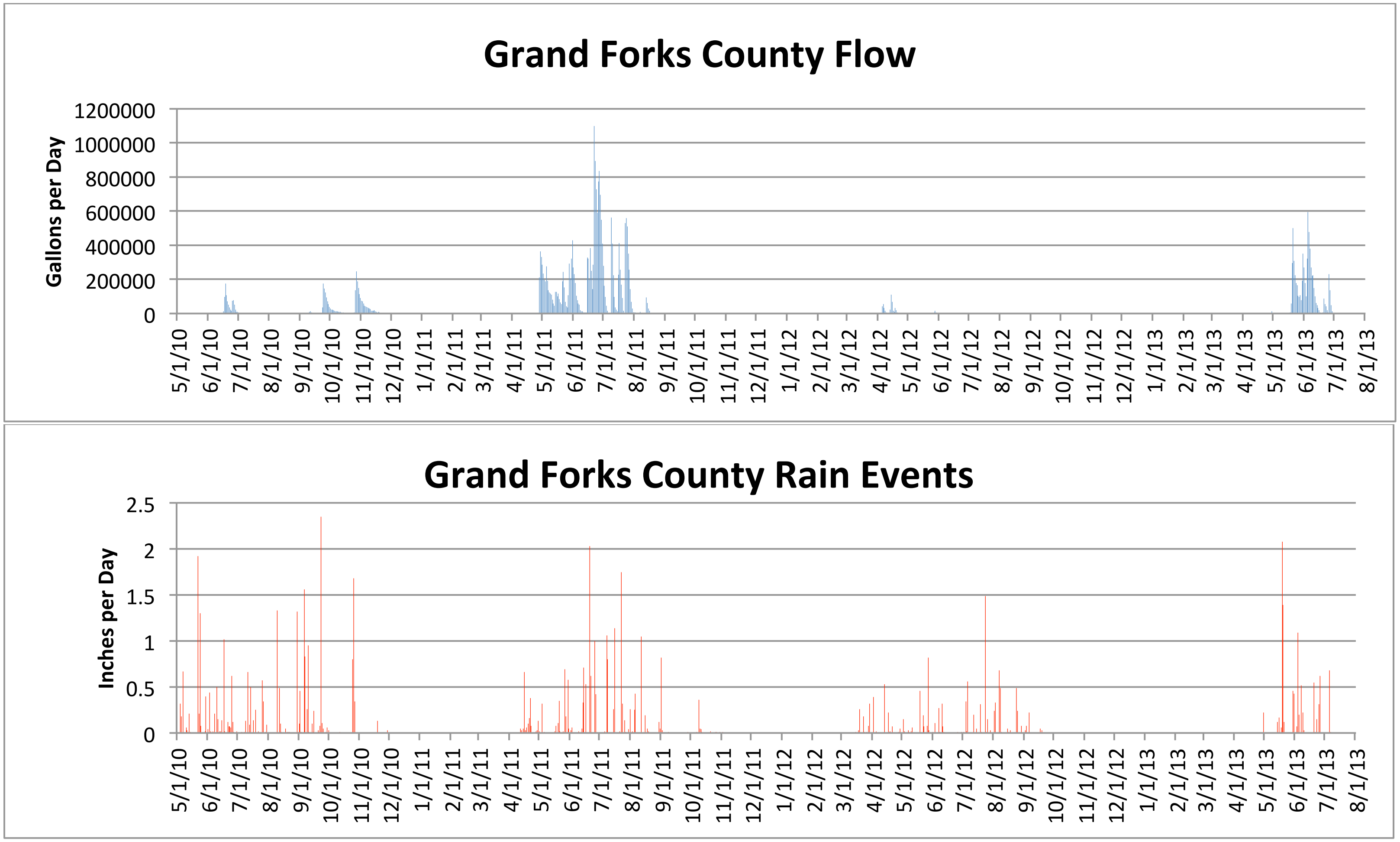


Figure A2-6. Grand Forks county tile flow and rain amounts

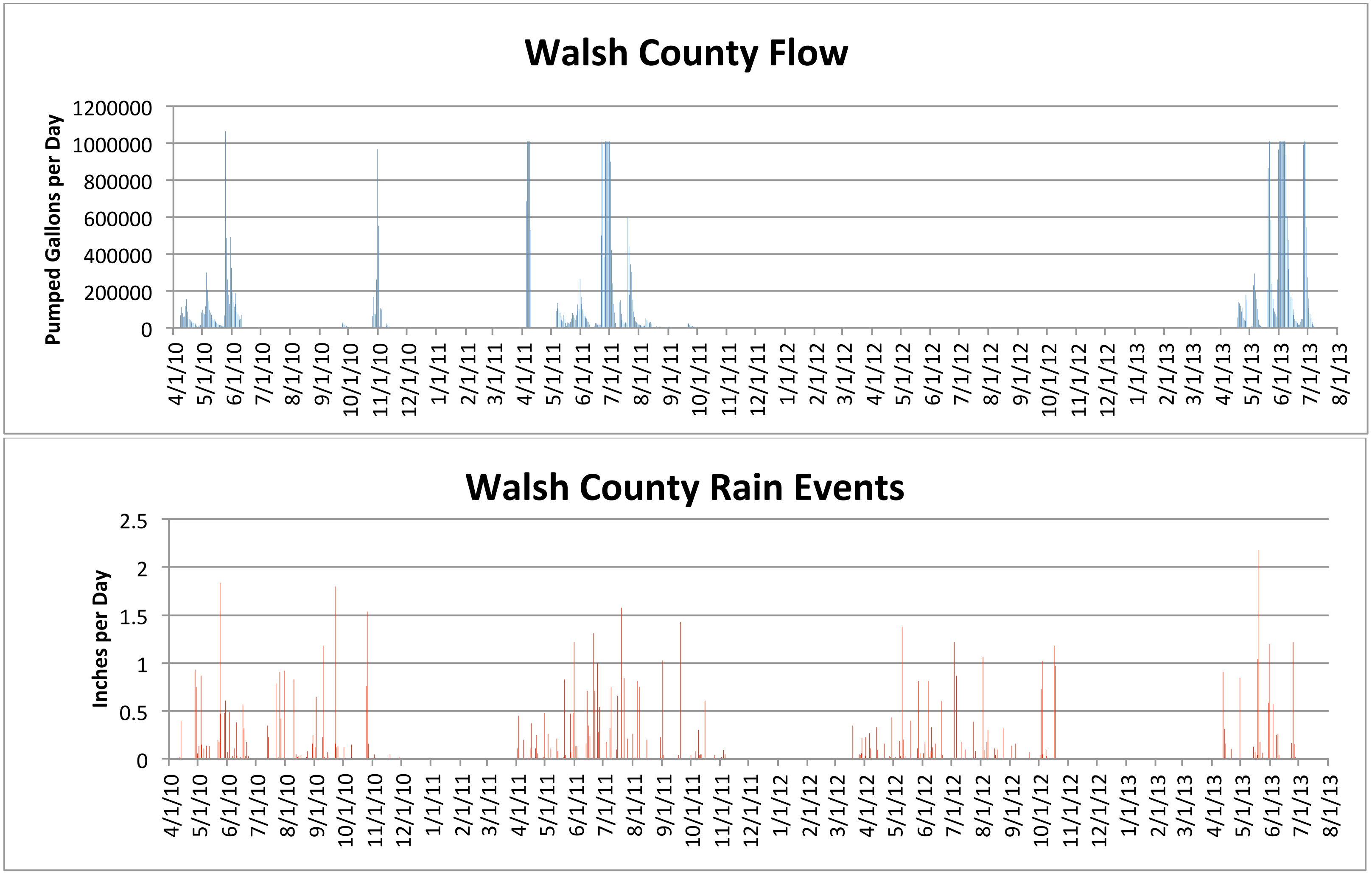


Figure A2-7. Walsh county tile flow and rain amounts

Appendix 3 – Mass Loads of TDS and NO_3-N, Annual and Tri-Monthly

If the flow rate or volume of flow has been measured for the time period when the water sample was collected, the mass load of the dissolved minerals can be can be calculated. The basic equation is:

$$Mass\ Load\ (lbs) = \left(8.336\ x10^{-6} * Volume\ (gal) * Concentration\ \left(\frac{mg}{l}\right)\right)$$

Implied in this equation is that the volume used for the calculation occurred over some period of time. It could be a daily, weekly, monthly or annual volume, but the time units must be included in the reporting. For example, if on the day of water sampling the measured flow rate was 500 gallons per minute, we could estimate the volume of flow for the day by multiplying by 1440 minutes. The flow total for the day would be 720,000 gallons. Dividing by the acres drained, the pounds per acre (lbs/ac) can be calculated. Reporting as pounds per acre makes sense to determine the impact on the field but the total load in pounds or tons, depending on concentration, makes more sense for reporting load to the receiving waterway.

The mass loading on a per acre basis for each site where flow measurements were reported is shown in table A3-1. The loading is shown by 3-month time periods and total for the duration of sampling and measurement.

The percent of rain that flowed from the tile system along with the **average annual** per acre loading is shown on table A3-2. There were no flow measurements for the Steele County site but rainfall measurements are listed.

Mass Loading in Pounds per Acre														
		2009		2010			2011			2012			2013	Total for Sampling Period
Site		July - Sept	Oct - Dec	April - June	July - Sept	Oct - Dec	April - June	July - Sept	Oct - Dec	April - June	July - Sept	Oct - Dec	April - June	
Traill	Flow (Gallons)			10235000	3027000	5088000	12632000	1513000	74000	155000	90000	8000	6150300	38972300
	TDS (mg/l)	7130	7126	6000	6825		6054	7131					5480	
	TDS (lbs/ac)			3303	1111		4113	580					1813	10919
	NO3-N (mg/l)	4	5	4	4		9	7					21	
	NO3-N (lbs/ac)			2	1		6	1					7	17
Richland	Flow (Gallons)			2448000	4508000	4828000	8895000	5352000		1214000			2555000	29800000
	TDS (mg/l)			14253	15025	15440	12911	10466		11209			6559	
	TDS (lbs/ac)			2048	3976	4376	6742	3288		799			984	22213
	NO3-N (mg/l)			21	23	27	32	28		26			18	
	NO3-N (lbs/ac)			3	6	8	17	9		2			3	47
Ransom	Flow (Gallons)			24735000	20993000	15515000	16434000	49541000		31556000			28500000	187274000
	TDS (mg/l)		1060	874	1041	1070	987	1059		1040			1005	
	TDS (lbs/ac)			601	607	461	451	1458		912			796	5286
	NO3-N (mg/l)			2	1	2	3	8		1			2	
	NO3-N (lbs/ac)			1	1	1	1	11		1			2	18
Grand Forks	Flow (Gallons)			839000	817000	1738000	15248000	5846000		500000			6830000	31818000
	TDS (mg/l)	480	480	532	477	549	542	521	459	492	474	455	482	
	TDS (lbs/ac)			25	22	53	459	169		14			183	925
	NO3-N (mg/l)	1	1	3	2	2	4	3	1	2	1	1	5	
	NO3-N (lbs/ac)			0	0	0	3	1		0			2	6
Cass	Flow (Gallons)		656000	2828000	1395000	1810000	5672000	3623000	2800				2738000	18724800
	TDS (mg/l)	4600	8323	7547	6405	8507	6566	7344		8440			4449	
	TDS (lbs/ac)		607	2372	993	1711	4139	2957					1354	14134
	NO3-N (mg/l)	6	15	20	6	7	7	3		0			15	
	NO3-N (lbs/ac)		1	6	1	1	4	1					4	19
Sargent	Flow (Gallons)						13483000	12654000		9030000			3288900	38455900
	TDS (mg/l)	4545	7783	6428			5587	6253	2810	6134			3760	
	TDS (lbs/ac)						4051	4255		2979			665	11951
	NO3-N (mg/l)	6	5	6			6	8	8	10			9	
	NO3-N (lbs/ac)						5	6		5			2	17
Walsh	Flow (Gallons)			7280000	271000	1054000	12982000	8411000	76000	71000	9000	7000	23003000	53164000
	TDS (mg/l)			6889	6549	6538	5099	6208	6710	5679	6010	5395	3720	
	TDS (lbs/ac)			2986	106	410	3941	3109	30	20	3	2	4196	14803
	NO3-N (mg/l)			6	2	1	4	2	1	1	1	1	7	
	NO3-N (lbs/ac)			3	0	0	3	1	0	0	0	0	7	14

Table A3-1. Mass of TDS and NO3-N in the water from the tile systems for 3-month increments for the project duration at the 7 flow monitored sites.

	Year	2009				2010				2011			
County and Storet Number	Acres Drained	Measurement Period	Tile Drainage Volume (gallons)	Measured Rain Amount (inches)	Rain Fraction that flows through Tile	Measurement Period	Tile Drainage Volume (gallons)	Measured Rain Amount (inches)	Rain Fraction that flows through Tile	Measurement Period	Tile Drainage Volume (gallons)	Measured Rain Amount (inches)	Rain Fraction that flows through Tile
Steele - 385462	115	6/2 - 8/17		4.5		7/5 - 9/29		5.45		4/28 - 10/13		14.06	
Traill - 385464	155					4/8 - 11/19	18,350,625	19.18	23%	4/18 - 12/31	14,218,950	17.96	19%
Richland - 385465	142					4/23 - 11/18	11,784,305	27.1	11%	1/1 - 8/30	14,246,560	17.5	21%
Ransom - 385469	300					4/22 - 12/31	61,180,000	28.35	26%	1/1 - 11/2	65,975,000	25.67	31%
Grand Forks - 385471	150					6/6 - 11/19	3,394,100	25.52	3%	4/28 - 10/17	21,093,985	19.43	27%
Cass - 385521	75	9/1 - 11/25	656100	8.04	4%	3/26 - 11/13	6,033,600	25.62	12%	2/15 - 11/19	9,297,800	22.24	20%
Sargent - 385522	155					6/17 - 8/20		1.12		6/15 -7/26	26,136,900	20.2	31%
Walsh - 385524	140					4/8 - 11/19	8,604,800	22.37	10%	4/5 - 11/2	21,468,950	21.79	26%
TDS and NO3-N Loading		Concentration		Mass Loading		Concentration		Mass Loading		Concentration		Mass Loading	
		TDS (mg/l)	NO3-N (mg/l)	TDS (lbs/ac)	NO3-N (lbs/ac)	TDS (mg/l)	NO3-N (mg/l)	TDS (lbs/ac)	NO3-N (lbs/ac)	TDS (mg/l)	NO3-N (mg/l)	TDS (lbs/ac)	NO3-N (lbs/ac)
Traill - 385464	155					6,500	4.3	6421	4.25	6,600	7.8	5052	5.96
Richland - 385465	142					15,000	24	10377	16.62	11,500	30	9627	25.09
Ransom - 385469	300					1,050	1.8	1787	3.06	1,020	5.2	1872	9.53
Grand Forks - 385471	150					510	2.5	96	0.47	500	2.5	587	2.93
Cass - 385521	75	6500	10	474.0	0.73	7,500	10.8	5034	7.25	7,000	5	7241	5.17
Sargent - 385522	155					6,400	6.4			5,000	7.5	7035	10.54
Walsh - 385524	140					6,600	3.05	3382	1.56	6,200	2.2	7933	2.81
							Average =	4516	5.54		Average =	5621	8.86

	Year	2012				2013			
County and Storet Number	Acres Drained	Measurement Period	Tile Drainage Volume (gallons)	Measured Rain Amount (inches)	Rain Fraction that flows through Tile	Measurement Period	Tile Drainage Volume (gallons)	Measured Rain Amount (inches)	Rain Fraction that flows through Tile
Steele - 385462	115	3/18 -11/14		14.53		4/8 - 7/30		8.88	
Traill - 385464	155	3/5 - 11/10	252,619	13.89	0.4%	4/30 - 7/8	6,150,338	8.51	17%
Richland - 385465	142	3/30 - 10/19	1,214,110	15.8	2.0%	3/28 - 7/9	2,555,018	7.1	9%
Ransom - 385469	300	1/1 - 10/11	31,555,000	14.33	27.0%	6/4 - 7/9	28,237,700	9.88	35%
Grand Forks - 385471	150	4/4 - 12/13	500,250	11.23	1.1%	4/29 - 8/21	6,830,000	9.51	18%
Cass - 385521	75	3/9 - 11/12		11.92		1/1 - 7/9	2,738,500	6.79	20%
Sargent - 385522	155	4/12 - 11/15	9,030,320	6.46	33.2%	4/30 - 8/21	2,850,000	5.79	12%
Walsh - 385524	170	5/11 - 11/27	86,987	17.66	0.1%	4/18 - 7/8	23,003,000	10.58	47%
TDS and NO3-N Loading		Concentration		Mass Loading		Concentration		Mass Loading	
		TDS (mg/l)	NO3-N (mg/l	TDS (lbs/ac	NO3-N (lbs/ac	TDS (mg/l)	NO3-N (mg/l)	TDS (lbs/ac)	NO3-N (lbs/ac)
Traill - 385464	155					5,480	20.8	1,813	6.88
Richland - 385465	142	11,209	26.06	799	1.857	6,559	17.68	984	2.65
Ransom - 385469	300	1,040	1.04	912	0.912	1,005	1.99	789	1.56
Grand Forks - 385471	150	470	1.3	13	0.036	482	4.55	183	1.73
Cass - 385521	75	8,440	0.17			4,449	14.54	1,354	4.43
Sargent - 385522	155	6,134	9.86	2979	4.789	3,760	8.75	576	1.34
Walsh - 385524	170	5,700	0.95	2524	0.421	3,720	6.65	4,196	7.50
			Average =	1445	1.603		Average =	1413	3.73

Table A3-2. Fraction or measured rain amounts that flowed out the tile and the mass loading of TDS and NO_3-N by year.

Appendix 4
Statistical Analysis

A statistical analysis was performed to determine the relationship of TDS and NO_3-N to soils, location, topography, flow volume, rain amounts, year and month of measurement. Dr. Curt Doetkott of the NDSU Statistical Consulting Service performed the analysis. The outputs from the modeling are shown below.

A multiple linear regression model that used TDS and the natural log (ln) of NO_3-N concentrations as the independent variables with mean monthly pump volume; mean monthly rain and a county estimate as the dependent variables. A county variable was included in the analysis and served as a proxy for the combination of field soil types, topography and cropping pattern at a particular location.

The model equations from the analysis are:

$$\ln(NO_3N) = Intercept + C_1 + C_2 * (MMpv) + C_3 * (MMr)$$

and

$$TDS = Intercept + C_4 + C_5 * (MMpv) + C_6 * (MMr)$$

where:
C_1 – NO3-N county estimate (Walsh County is = 0.0 since it was the basis in the analysis)
$C_2 = 1.562 \times 10^{-6}$
$C_3 = -0.3229$
C_4 = TDS county estimate (Walsh County is = 0.0 since it was the basis in the analysis)
$C_5 = 1.117 \times 10^{-3}$
$C_6 = -312.5$
MMpv – mean monthly pump volume
MMr – mean monthly rain amounts

Class Level Information		
Class	**Levels**	**Values**
year	5	2009 2010 2011 2012 2013
month	9	Apr Aug Jul Jun Mar May Nov Oct Sep
county	7	Cass Grand Forks Ransom Richland Sargent Traill Walsh

Number of Observations Read	114
Number of Observations Used	114

The SAS System - The GLM Procedure

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	20	127.3130298	6.3656515	14.14	<.0001
Error	93	41.8625973	0.4501355		
Corrected Total	113	169.1756271			

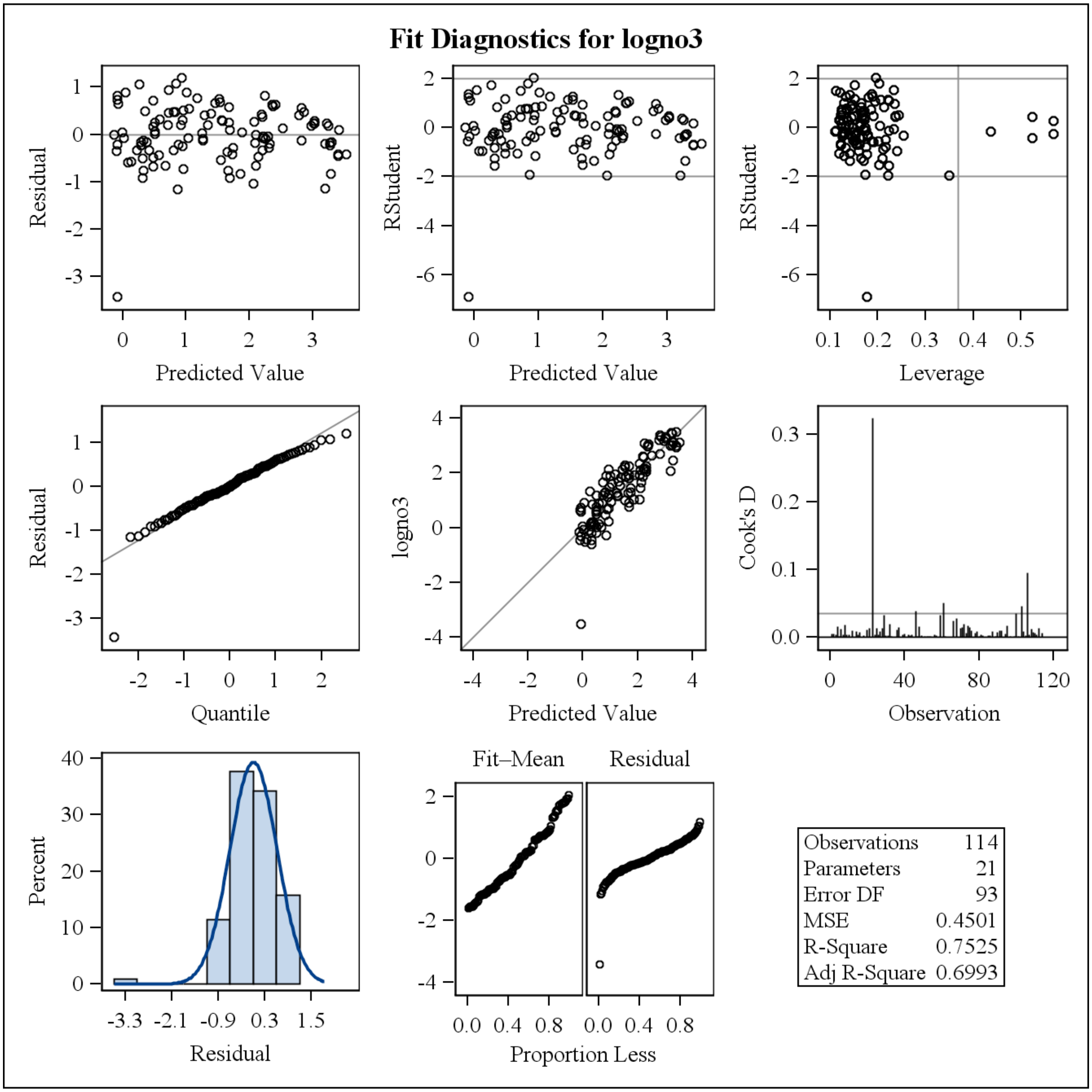
R-Square	Coeff Var	Root MSE	logno3 Mean
0.752549	45.73231	0.670921	1.467062

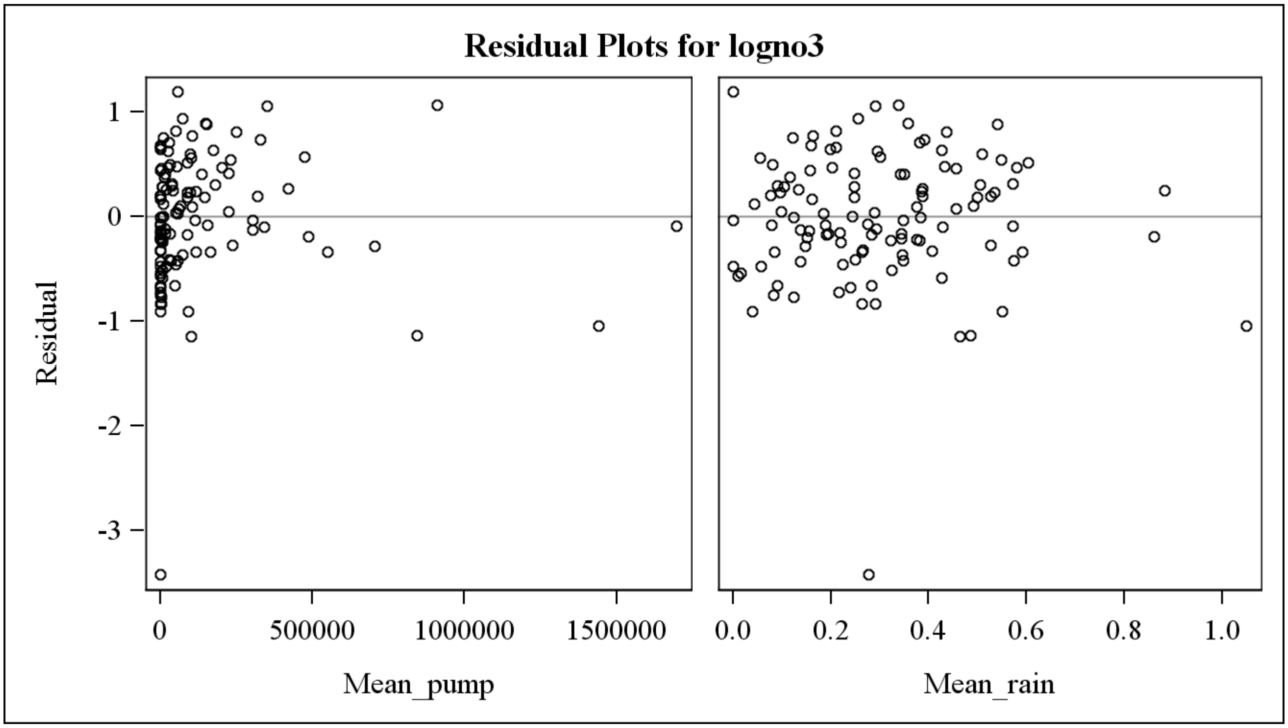
The regression results for the natural log (ln) of NO3-N concentrations on the following variables:

Source	DF	Type III SS	Mean Square	F Value	Pr > F
county	6	102.6669265	17.1111544	38.01	<.0001
year	4	4.6367883	1.1591971	2.58	0.0426
month	8	5.4822887	0.6852861	1.52	0.1600
Mean_pump	1	8.8483634	8.8483634	19.66	<.0001
Mean_rain	1	0.2792828	0.2792828	0.62	0.4329

Parameter	Estimate		Standard Error	t Value	Pr > |t|
Intercept	0.379651013	B	0.32776082	1.16	0.2497
county Cass	1.337675500	B	0.23154057	5.78	<.0001
county GrandForks	0.148800755	B	0.19739590	0.75	0.4529
county Ransom	-0.887585173	B	0.27281491	-3.25	0.0016
county Richland	2.492558903	B	0.20821220	11.97	<.0001
county Sargent	1.166566932	B	0.26609294	4.38	<.0001
county Traill	1.231725744	B	0.26080861	4.72	<.0001
county Walsh	0.000000000	B	.	.	.
year 2009	1.033958416	B	0.57741187	1.79	0.0766
year 2010	0.031836964	B	0.22101454	0.14	0.8858
year 2011	-0.167542883	B	0.21336665	-0.79	0.4343
year 2012	-0.480940914	B	0.24645601	-1.95	0.0540
year 2013	0.000000000	B	.	.	.
month Apr	0.474045473	B	0.27839177	1.70	0.0919
month Aug	0.202346586	B	0.29382532	0.69	0.4927
month Jul	0.457870576	B	0.27034979	1.69	0.0937
month Jun	0.657032042	B	0.26137625	2.51	0.0137
month Mar	0.841709437	B	0.55058443	1.53	0.1297
month May	0.484173689	B	0.26161233	1.85	0.0674
month Nov	-0.227181201	B	0.37404165	-0.61	0.5451
month Oct	0.143370433	B	0.29484087	0.49	0.6279
month Sep	0.000000000	B	.	.	.
Mean_pump	0.000001562		0.00000035	4.43	<.0001
Mean_rain	-0.322887910		0.40992207	-0.79	0.4329

Note The X'X matrix has been found to be singular, and a generalized inverse was used to solve the normal equations. Terms whose estimates are followed by the letter 'B' are not uniquely estimable.





Residual Plots for logno3
Residual
1
0
-1
-2
-3
0
500000
1000000
1500000
Mean_pump
0.0
0.2
0.4
0.6
0.8
1.0
Mean_rain

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	20	1635723766	81786188	33.10	<.0001
Error	93	229760792	2470546		
Corrected Total	113	1865484557			

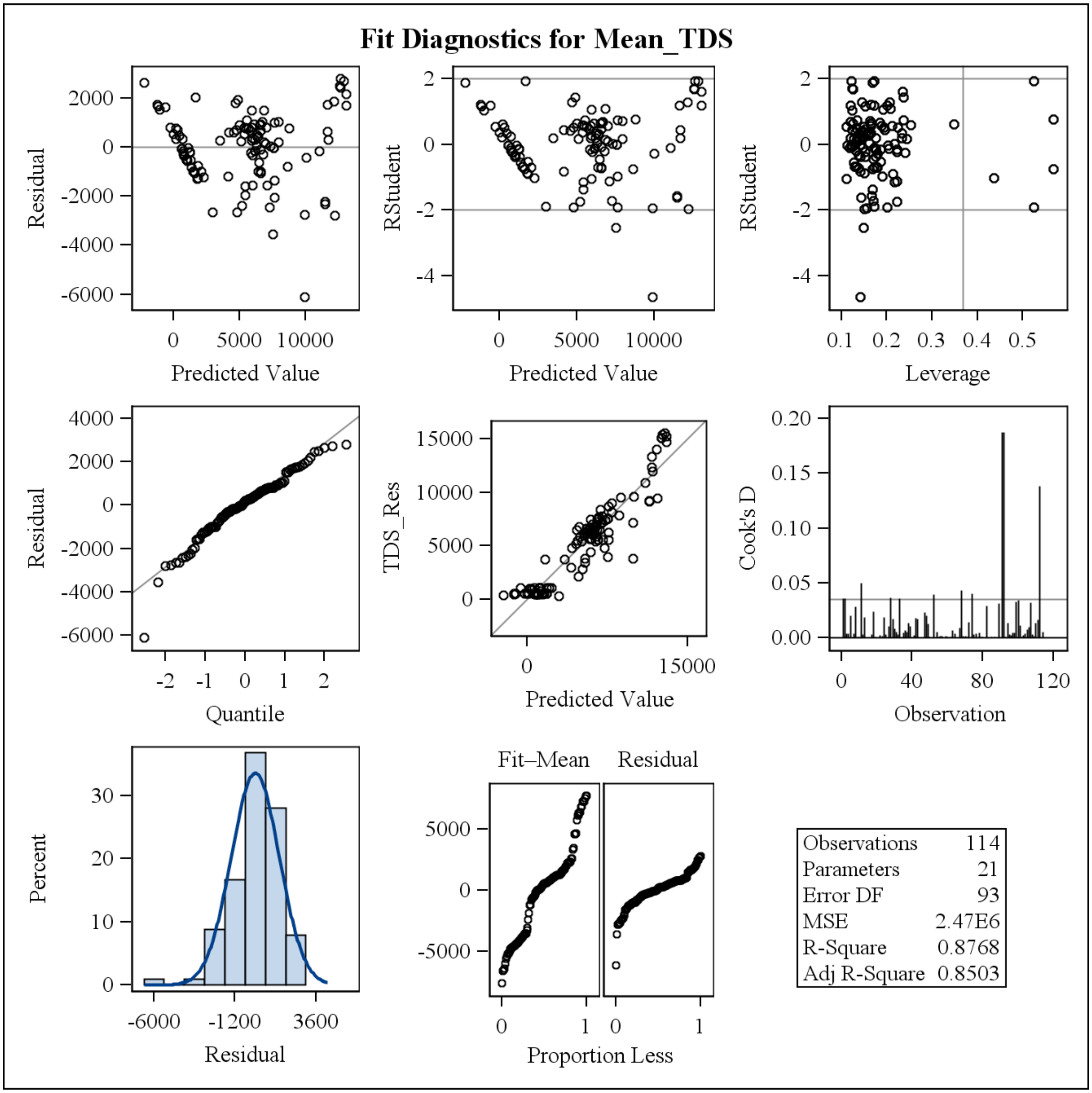
R-Square	Coeff Var	Root MSE	Mean_TDS Mean
0.876836	29.45707	1571.797	5335.891

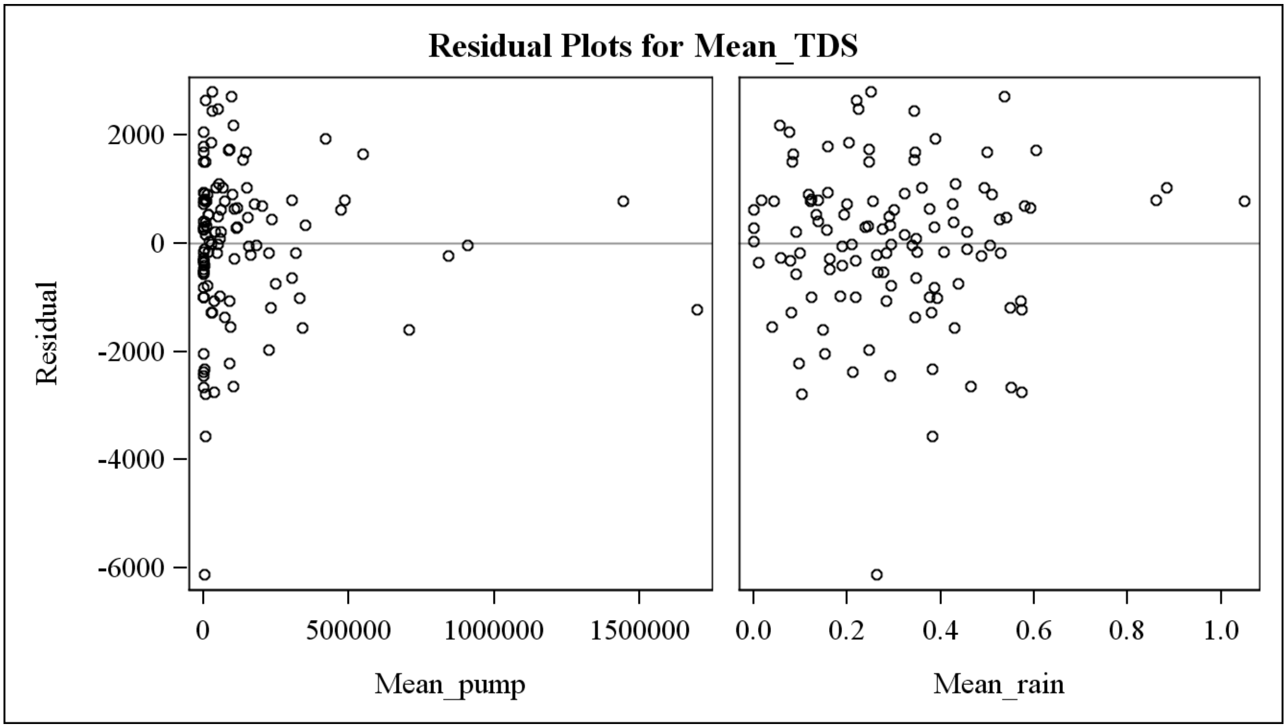
The regression results for the Mean TDS concentrations on the following variables:

Source	DF	Type III SS	Mean Square	F Value	Pr > F
county	6	1420558193	236759699	95.83	<.0001
year	4	67918593	16979648	6.87	<.0001
month	8	50260007	6282501	2.54	0.0150
Mean_pump	1	5027927	5027927	2.04	0.1570
Mean_rain	1	261599	261599	0.11	0.7456

Parameter	Estimate		Standard Error	t Value	Pr > |t|
Intercept	4463.527739	B	767.859767	5.81	<.0001
county Cass	942.872094	B	542.440334	1.74	0.0855
county GrandForks	-5186.068616	B	462.448094	-11.21	<.0001
county Ransom	-5270.455281	B	639.135552	-8.25	<.0001
county Richland	5974.099375	B	487.787930	12.25	<.0001
county Sargent	-681.532842	B	623.387708	-1.09	0.2771
county Traill	598.245553	B	611.007865	0.98	0.3301
county Walsh	0.000000	B	.	.	.
year 2009	3456.195282	B	1352.728332	2.55	0.0122
year 2010	2609.717831	B	517.780527	5.04	<.0001
year 2011	1612.370899	B	499.863483	3.23	0.0017
year 2012	2172.934483	B	577.383387	3.76	0.0003
year 2013	0.000000	B	.	.	.
month Apr	-1462.423091	B	652.200713	-2.24	0.0273
month Aug	-662.124273	B	688.357570	-0.96	0.3386
month Jul	-356.816448	B	633.360401	-0.56	0.5745
month Jun	-374.270165	B	612.337700	-0.61	0.5425
month Mar	-4946.198902	B	1289.878484	-3.83	0.0002
month May	-429.783775	B	612.890768	-0.70	0.4849
month Nov	-76.244877	B	876.283916	-0.09	0.9309
month Oct	-136.337181	B	690.736751	-0.20	0.8440
month Sep	0.000000	B	.	.	.
Mean_pump	0.001177		0.000825	1.43	0.1570
Mean_rain	-312.498311		960.342549	-0.33	0.7456

Note:	The X'X matrix has been found to be singular, and a generalized inverse was used to solve the normal eq Terms whose estimates are followed by the letter 'B' are not uniquely estimable.




Residual Plots for Mean_TDS
Residual
2000
0
-2000
-4000
-6000
0
500000
1000000
1500000
Mean_pump
0.0
0.2
0.4
0.6
0.8
1.0
Mean_rain