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Agricultural Land Use, Watershed Characteristics, and Hydrological Forces Contributing to the Impairment of a Shallow Lake in the Western Corn Belt Ecoregion

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By

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Abstract

Agricultural Land Use, Watershed Characteristics, and Hydrological Forces Contributing to the Impairment of a Shallow Lake in the Western Corn Belt Ecoregion

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The Lake Titlow watershed (approximately 35,000 acres) in south-central Minnesota is part of the Minnesota River Basin. The lake is listed in the draft 2010 Clean Water Act Section 303d for nutrient pollution, eutrophication, and biological indicators for impairment of aquatic life and recreational use. Over 90 percent of pre-settlement wetlands are currently drained for agricultural land use. The Lake Titlow watershed is over 80% row crops and land use is implicated as a primary cause of impairment in the lake.

Water samples were collected from the Lake Titlow tributaries McLeod-Sibley Judicial Ditch Number 18 (JD18), Sibley County Ditch Number 18 (CD18), and Ditch 250 (D250) during 2009 and 2010 and were analyzed for total suspended solids (TSS), total phosphorus (TP), and nitrate-nitrite nitrogen (NOx). Investigative methods included continuous recording stream stage and through the use of rating curves, discharge. Runoff, sediment loads, and nutrient loads were then determined from the field data. Four rain gauges collected precipitation each year and were used to assess the impact of precipitation on runoff and loading. Four characteristic precipitation events were selected for each of the calendar years 2009 and 2010 to estimate the loads of sediment and nutrients to the lake and more fully understand the specific roles that land use, hydrologic soil group, slope, and precipitation play with regard to causing sediment and nutrient loading in the lake.

Results indicate runoff and loads are significant and highly variable by position within the watershed, areas referred to herein as subsheds. The row crop land use, soils characteristics, and precipitation do contribute to overall runoff and loads; however, they do not control subshed variability. Although the low-sloping land surfaces of the watershed should not contribute to overall runoff and loads, results indicate that subtle slope changes in the JD18Lo and CD18Lo subsheds could contribute to the variability of loads seen in these portions of the watershed.

The location and type of best management practices to implement is debatable because the results of this study indicate that large runoffs and loads could originate within any given subshed during any given rainstorm event. This study was unable to precisely identify the root cause of the variability in subshed runoff and loading. Therefore, it is suggested to look at other factors (e.g., antecedent soil moisture, rainfall intensity, mass wasting, etc.) to explain the subshed variability in the sediment and nutrient loading in future studies of this lakeshed.

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I thank my Mom for her support in more ways than one. I also thank my sons, Tom, other family, and friends for believing in and encouraging me in this long endeavor. I am very grateful for completing this thesis project which has taken a number of years and has come together despite several life events throughout this work.

1. Introduction

1.1 The Prairie Pothole Region, Shallow lakes, and Agricultural Drainage

The entire Prairie Pothole Region (PPR) is approximately 347,492 mi^2 (900,000 km^2) with large portions of Iowa, Minnesota, Montana, North Dakota and South Dakota accounting for approximately one third of this area (Fig. 1) (Gleason et al. 2011). Over 50% of North American migratory waterfowl rely on potholes for reproduction (Smith 1995). Countless potholes were drained to provide additional agricultural acreage. A vast majority of the remaining potholes in the PPR are now subject to higher nutrient and sediment loading and thus, lower water quality (Lenhart et al. 2010). Shallow Prairie Pothole lakes may be more susceptible to the degradation of their water quality by external sediment and nutrient loading (Marsden 1989) or internal regeneration of previously deposited materials (Bostrom et al. 1988).

Figure 1. The Prairie Pothole Region of North America (Source: ppjv.org/prairie-conservation, accessed 01/06/2017).

One of these shallow lakes, Lake Titlow, Sibley County, Minnesota, is adjacent to the city of Gaylord (Fig. 2). It has a surface area of 1.56 mi^2 (4.047

km^2), with a maximum depth of 5 feet (1.524 m) and an average depth of 3 feet (0.914 m) (Hoppie 2008). A study of water quality in the lake during the open-water season of 2008 concluded Lake Titlow is hypereutrophic (Carlson Trophic Index 75) and is a sink for nitrogen, phosphorus, sediment (Gurung 2009). Lake Titlow is listed in the draft 2010 Clean Water Act Section 303d for nutrient pollution, eutrophication and biological indicators for impairment of aquatic life, and recreational use in the 2011 Minnesota Pollution Control Agency (MPCA) list of impaired waters (MPCA 2011).

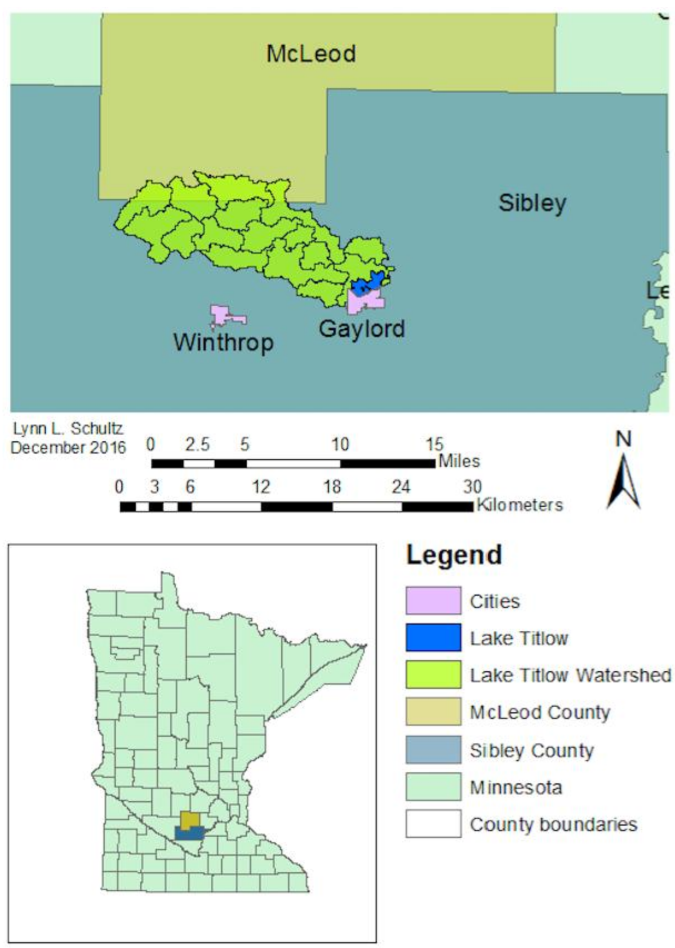

Figure 2. Location of the Lake Titlow watershed in McLeod and Sibley Counties, Minnesota.

In an effort to improve water quality of Lake Titlow, the City of Gaylord, Minnesota, hired Short Elliot Hendrickson Inc. (SEH) in 2010 to study to examine the watershed for placement of the most effective, and cost efficient best management practices (BMPs). SEH is an engineering, architectural, environmental, and planning company. The study used the model Soil and Water Assessment Tool (SWAT). The results concluded that four subbasins with the northern tributary, known as Judicial Ditch (JD) 18, produced the largest amounts of TSS, TP, and nitrate-nitrite (hereafter referred to as NOx). A further consideration of the SEH report is that the SWAT model assumes consistent nutrient coefficients from areas with comparable land use, and that sediment and nutrient loads are inconsistent across areas of similar land use, usually originating from small poorly managed watershed areas (SEH 2010; Mulla 2006). To better manage this watershed to improve the lake water quality, it is crucial to identify areas with higher sediment and nutrient loads to allow better placement of wetlands, ponds or other improvement practices.

Improving Lake Titlow water quality for aquatic life will lessen the effect of toxic substances on the aquatic and the surrounding terrestrial community. Improvements will help support a healthy, diverse, and reproducing population of aquatic organisms and in turn wildlife will benefit from a sustainable habitat. Furthermore, recreational opportunities will improve for wading, swimming, boating, fishing, and other forms of aquatic recreation (Minnesota Department of Natural Resources (MNDNR), 2012).

Thus, additional study of the watershed is warranted. Assessment of the Lake Titlow watershed, or “lakeshed” will increase the understanding of the effects of an agriculture dominated land use and loading of sediment, nitrogen and phosphorus to a shallow lake. Assessment will also characterize watershed drivers, sublakeshed fluxes of sediment, nitrogen and phosphorus, and provide a baseline to help determine the effectiveness of future best management practices (BMPs). Finally, an assessment of the lakeshed will provide a complete example of nitrogen (N) and phosphorus (P) nutrients, and total suspended solids (TSS) in a shallow lake watershed in the southeastern PPR, of the Western Corn Belt Plains (WCBP) ecoregion.

1.2. Research Goals and Outcomes

The primary purpose of this research, in this highly modified (over 80% agricultural) watershed, is to study the hydrodynamics and fate and transport of sediment and nutrients that influence water quality in the streams and lake using ditch system monitoring and water sample analysis data from the spring through fall of 2009, and 2010. The goal is to characterize water, nutrient and sediment transport to support the remediation of the Lake Titlow watershed. These goals will be accomplished by: (1) collecting and analyzing storm event drainage ditch water quality samples for nitrate/nitrogen (NOx), total phosphorus (TP), and total suspended solids (TSS); (2) assessing spatial distribution of factors that contribute, in part, to the hydrology of the basin (e.g. slope, precipitation and soil composition/texture) on discharge of streamflow and contaminant loads to Lake

Titlow; (3) Characterize land use throughout the watershed during times of water quality monitoring.

Outcomes of this research include: (1) Estimates of total sediment and nutrient loading to Lake Titlow that derive from runoff through agricultural drainage systems; (2) Calculate loads of NOx, TP, TSS, and volume of water in the Lake Titlow hydrologic system (3) Analyze input of sediment, nutrients and water to investigate and characterize the water quality of Lake Titlow; (4) Link meteorological, hydrologic, and land use data to assess the relative importance of each factor's contribution to the water quality of Lake Titlow.

Because this document is intended to be a guide for further work throughout this watershed and other similar watersheds, the units herein will be United States customary or metric units of measure. The type of unit depends on what can be easily visualized and utilized because it is the commonly used unit of measure in this field of study. Metric units will be used when discussing water chemistry and loads, again because that is the current practice among individuals undertaking the work of soil and water conservation in this region.

2. Literature Review

2.1. Agricultural drainage, the PPR, Crop Mix, and Land Conservation

Agricultural drainage began as a way to increase agricultural yield by carrying water away from the soil profile (to lower the water table below plant roots) using underground pipes and open ditches (Helland 1999). The percentage of wetland drainage varies for the following states: 89% in Iowa; 42% in Minnesota; 27% in Montana; 49% in North Dakota; and 35% in South Dakota (Dahl 1990). In agricultural watersheds, sediment and nutrients are transported along with water to drainage ditches (Dunne et al. 2007). The largest percentage of wetland drainage and grassland loss is in the southeast region of the PPR (Fig. 3) where it is highly favorable for agriculture (Gleason et al. 2011). Over 90% of native grasslands have been lost in the PPR (Mac et al. 1998). Precision farming has created an increased need for tile drainage through analyzing crop yields foot by foot, observing higher yields in drained field areas, and locating areas where yield can be increased through better water drainage. Some areas have more of a need for increased drainage than what can be immediately supplied, thus, farmers purchase pull-behind tile plows to install drainage tile themselves (Olson 1999).

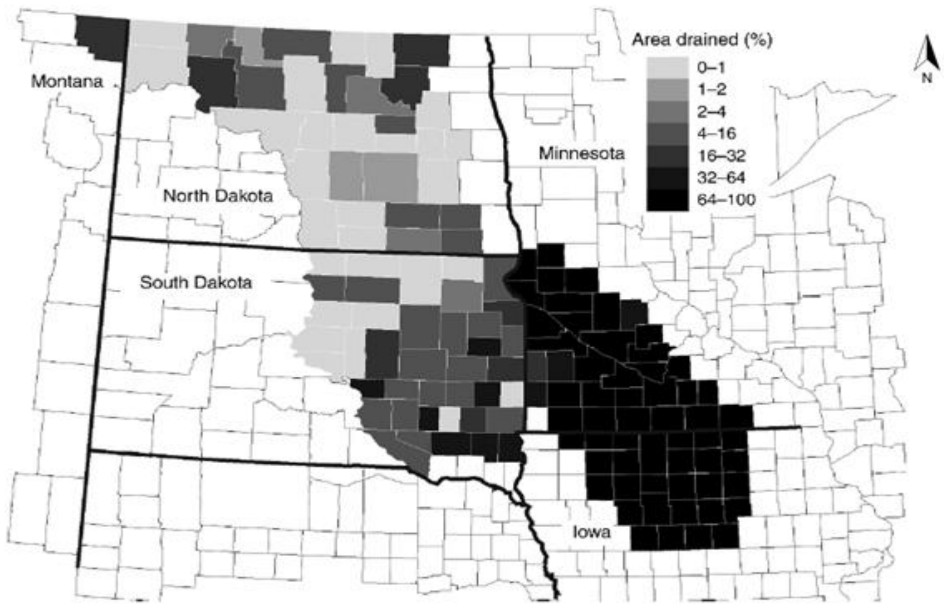

Figure 3. Prairie Pothole Region wetland drainage percent by county (Gleason et al., 2004).

The crop mix in the PPR has changed in recent years to become mostly corn and soybeans due to federal subsidy, ethanol mandates, biodiesel mandates and crop genetics (Gascoigne et al. 2013). In 2007, Iowa, Minnesota, North Dakota and South Dakota planted the highest number of acres in corn ever recorded and cropland production across the four states totaled approximately 132,819 mi^2 (344,000 km^2). Over 1,563 mi^2 (4,047 km^2) of corn planting was added to these four states from 1997-2007 (Gascoigne et al. 2013). Minnesota planted 625 mi^2 (1619 km^2) in 2011 for a total of 12,656 mi^2 (32,780 km^2). Soybean acreage has also increased, with Minnesota planting 11,250 mi^2 (29,137 km^2) of soybeans in 2011, according to the United States Department of Agriculture-National Agricultural Statistics Service in 2011 (USDA-NASS) (Fig. 4). Oil and gas production has increased in the PPR too (Gascoigne et al. 2013).

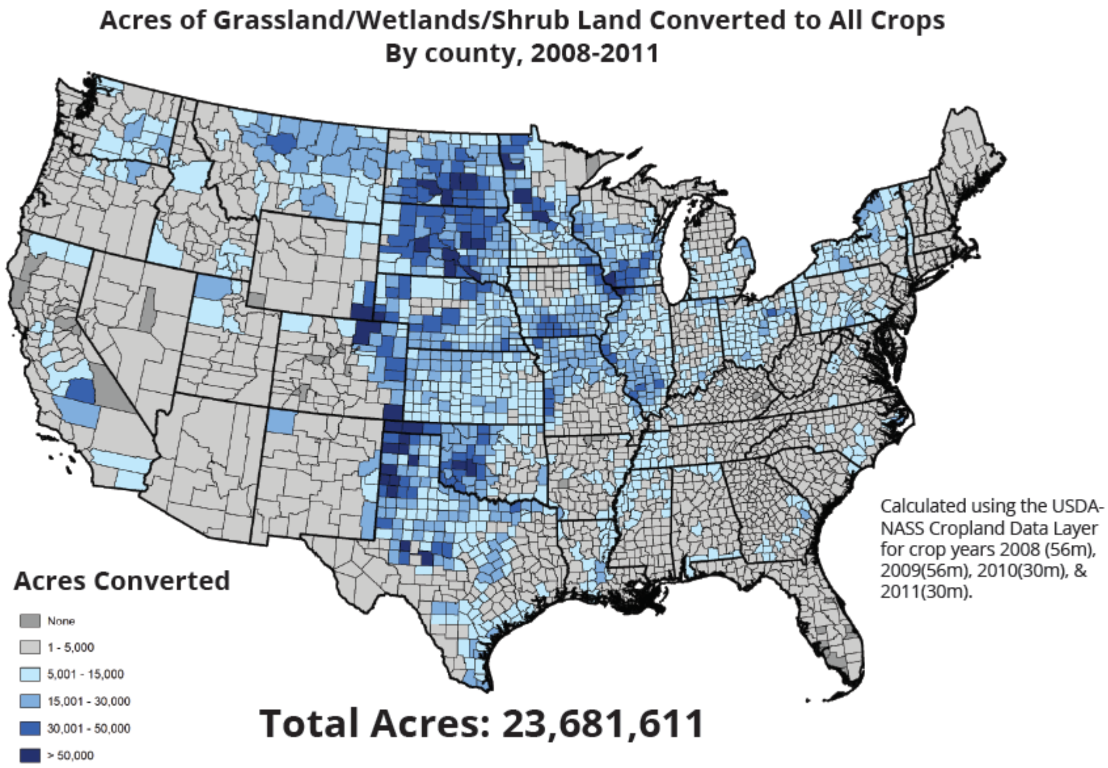

Figure 4. Acres converted to cropland, by county, 2008-2011 in the contiguous United States (Faber et al. 2012).

The main land conservation program in the PPR is the United States Department of Agriculture's (USDA) Conservation Reserve Program (CRP). It began as part of the Food Security Act of 1985, also known as the Farm Bill, and its purpose is to reduce erosion and nonpoint source pollution (Gascoigne et al. 2013). The program encourages farmers to voluntarily enroll erosion prone cropland and sensitive acreage to be planted with perennial vegetative cover for an annual rental payment. Acreage in CRP was at its peak in 2007 and by 2010 it decreased over 1563 mi^2 (4,047 km^2), a loss of approximately 19% (Table 1). Although it is reauthorized in all farm bills, continued decline of enrolled CRP acreage is expected if commodity prices stay high as CRP contracts expire

(Gascoigne et al. 2013). From 2014 and 2017, 2,812 mi^2 (7,284 km^2) will expire, according to the USDA Farm Service Agency (United States Department of Agriculture Farm Service Agency 2011).

Table 1. Conservation Reserve Program (CRP) acreage in North Dakota, South Dakota, Minnesota, and Iowa in 2007 and 2010, and percent change (Gascoigne et al. 2013).

State	Enrolled CRP acres		Percentage change
	2007	2010	
North Dakota	1,970,561	1,638,546	−16.8
South Dakota	1,828,054	1,640,550	−10.3
Minnesota	3,387,164	2,717,520	−19.8
Iowa	1,559,031	1,112,472	−28.6
Region total	8,744,810	7,109,088	−18.7

2.2. Minnesota Ecoregion Lake Water Quality

The US Environmental Protection Agency (USEPA) mapped land use, soils, landforms and potential natural vegetation to identify ecoregions in the United States (Omernik 1987). In Minnesota ecoregions (Fig. 4) similarities in lake depth, surface area and chemistry exist. Four of Minnesota's seven ecoregions contain the majority of Minnesota's lakes: North Central Hardwood Forest (CHF), Northern Lakes and Forests (NLF), Western Corn Belt Plains (WCP), and Northern Glaciated Plains (NGP). Lakes in each ecoregion were chosen as being representative and sampled to provide values (Table 2) for comparison between ecoregions (Minnesota Pollution Control Agency 2012).

Table 2. Ecoregion lake surface water quality values in summer (June-September). Values are based on the ecoregion reference lakes interquartile range (25th-75th percentile) (Heiskary and Wilson, 1990).

Parameter	NLF	CHF	WCP	NGP
# of lakes	32	43	16	13
Total Phosphorus (ug/l)	14 - 27	23 - 50	65 - 150	122 - 160
Chlorophyll mean (ug/l)	4 - 10	5 - 22	30 - 80	36 - 61
Chlorophyll maximum (ug/l)	< 15	7 - 37	60 - 140	66 - 88
Secchi Disk (feet) (meters)	8 - 15 (2.4 - 4.6)	4.9 - 10.5 (1.5 - 3.2)	1.6 - 3.3 (0.5 - 1.0)	1.3 – 2..6 (0.4 – 0.8)
Total Kjeldahl Nitrogen (mg/l)	0.4 – 0.75	< 0.60 - 1.2	1.3 - 2.7	1.8 - 2.3
Nitrite + Nitrate-N (mg/l)	<0.01	<0.01	0.01 - 0.02	0.01 - 0.1
Alkalinity (mg/l)	40 – 140	75 - 150	125 - 165	160 - 260
Color (Pt-Co Units)	10 – 35	10 - 20	15 - 25	20 - 30
pH (SU)	7.2 - 8.3	8.6 - 8.8	8.2 - 9.0	8.3 - 8.6
Chloride (mg/l)	0.6 – 1.2	4 - 10	13 - 22	11 - 18
Total Suspended Solids (mg/l)	< 1 – 2	2 - 6	7 - 18	10 - 30
Total Suspended Inorganic Solids (mg/l)	< 1 – 2	1 - 2	3 - 9	5 - 15
Turbidity (NTU)	< 2	1 - 2	3 - 8	6 - 17
Conductivity (umhos/cm)	50 – 250	300 - 400	300 - 650	640 - 900
TN:TP ratio	25:1 - 35:1	25:1 - 35:1	17:1 - 27:1	13:1 - 17:1

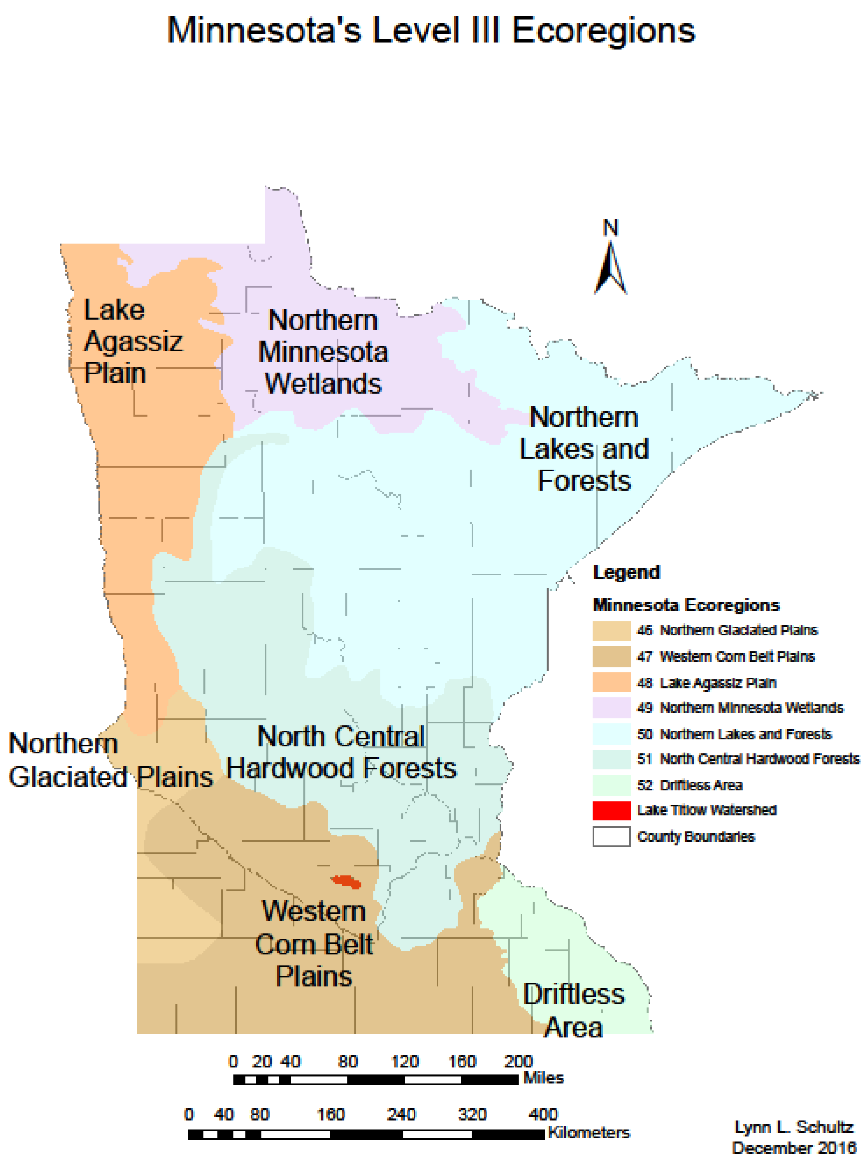

Figure 5. Minnesota's Level III ecoregions. The divisions are based on similar ecosystems (United States Environmental Protection Agency 2012).

2.3. Minnesota Ecological Zones and Shallow Lakes Map

There are approximately 4,000 shallow lakes in Minnesota in three different ecological zones: Laurentian mixed forest (forest), Eastern broadleaf forest (transition) and tall-grass prairie (Fig. 5). Over 90% of wetlands in the prairie zone have been drained (Minnesota River Basin Data Center 2011).

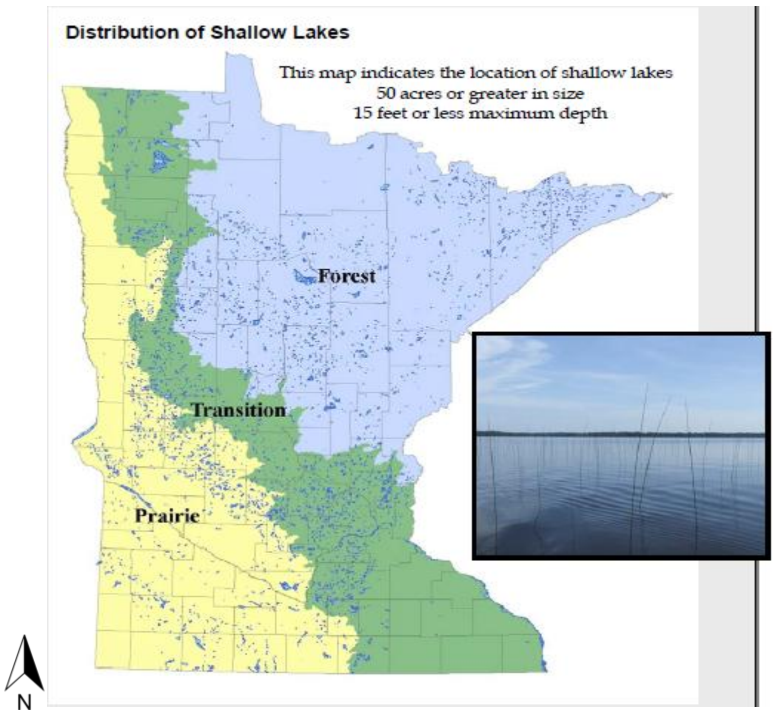

Figure 6. Shallow lakes across Minnesota's three ecological zones : Forest, Transition and Prairie. The map shows the location of shallow lakes 50 acres or larger and 15 feet deep or less (Hansel-Welch and Kudelka 2010).

2.4. Regional and Local Climate

The PPR has a mid-continental climate. Air temperatures can exceed 104F^{o} (40°C) in the fairly short, hot summers and drop below -40^{o}F (-40°C) in the fairly long, cold winters (Millett et al. 2009). In the PPR a precipitation gradient runs north to south and west to east, with greatest precipitation in the southeast.

The Koppen-Geiger climate types for the PPR include arid, temperate and cold (Fig. 7) (Peel et al. 2007). A significant amount of the total annual precipitation in the PPR occurs through isolated thunderstorms that can bring several centimeters of rain to localized areas but leave adjoining watersheds completely dry. Winds can attain speeds of 31 to 37 miles/hour (50 to 60 km/hr) (Gilbert et al. 2006) and can play a significant role in promoting evaporation and sediment or algae resuspension in PPR shallow lakes.

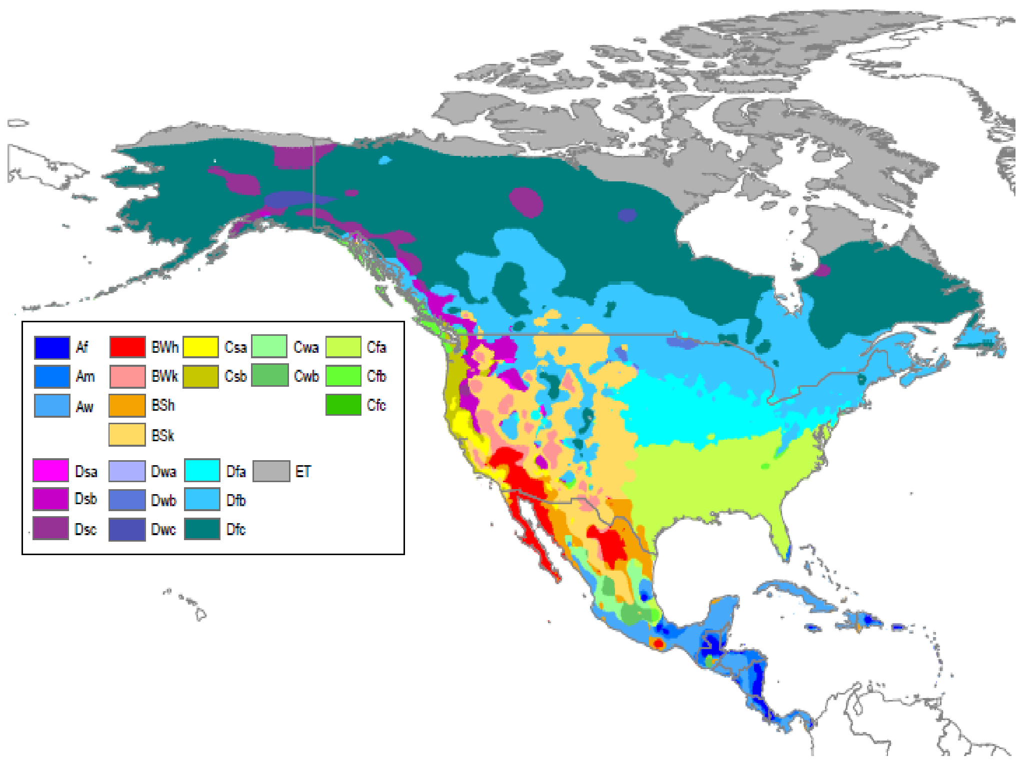

Figure 7. Koppen-Geiger climate type map of North America. Dominant climate type (by first letter in legend) D=cold (54.5%); B=arid (15.3%); E=polar (11.0%); and A=tropical (5.9%) (Peel et al. 2007).

The humid continental climate of the Midwest United States has had above average summer and winter precipitation over the last three decades.

Large heat waves have been more common, since the 1980s, than any time since the Dust Bowl of the 1930s (Karl et al. 2009).

Precipitation in Minnesota averages about 19 in/yr (480 mm/yr) in the northwest to over 32 in/yr (810 mm/yr) in the southeast (Fig. 8). Annual average open-water season evaporation rates range from 22.8-29.4 in/yr (580-747 mm/yr) (Dadaser-Celik and Stefan 2008). Evaporation is lower in the east, compared to the west. Generally, precipitation and thus, runoff are greatest in the east and less in the western part of southern Minnesota (Heiskary et al. 2003). Precipitation has increased by about 20% in southern Minnesota, since 1900 (http://www.pca.state.mn.us/oea/reduce/climatechange.cfm).

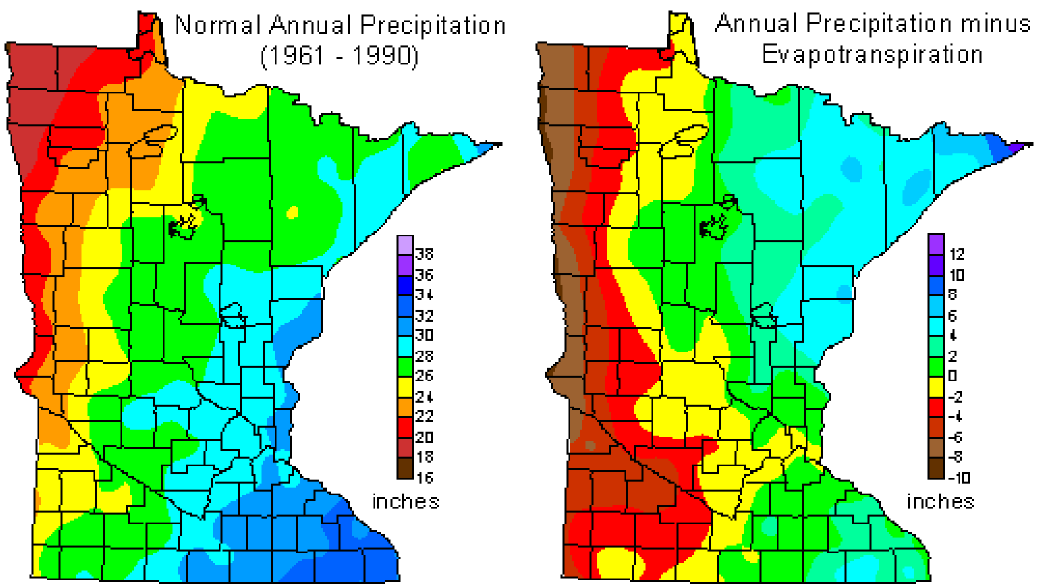

Figure 8. Normal annual precipitation and evapotranspiration in Minnesota (Minnesota Department of Natural Resources 2012).

2.5. Prairie Potholes, Water Balance, Flow regime, and Artificial Drainage

Prairie potholes are important hydrologically for several reasons. They can store flood water, recharge groundwater, reduce down-stream runoff, act as a flow-through system and/or receive water from groundwater (spring feed) based on climate, landscape position, water table levels and geological substrate (Euliss et al. 1999). Hydrologic regimes are dictated by climate and geology, and affect vegetation and habitat (Winter 1989). Atmospheric deposition is the largest source of water, and evapotranspiration is the largest loss of water for prairie potholes (Winter and Rosenberry 1998).

Flow regime of a stream refers to the magnitude, timing, frequency, duration and rate of change of water flow. When runoff causes stream levels to quickly rise and fall, it is called stream flashing. The rapid rise in water level from storms or snowmelt usually lasts from hours to a couple of days. Riparian zones that are degraded usually experience stream flashing (Hoorman and McCutcheon 2011). Artificial drainage and ditching for agriculture has contributed to fluctuations in flow (RRAP 2004).

The water flows from storm events have increased frequencies and magnitude in watersheds with drainage ditches, subsurface drains and wetland area losses (Allan 2004). In agricultural watersheds, annual and storm flows typically increase but base flows usually decrease because of reduced infiltration and sporadic water export (Poff et al. 1997). Transport of sediment by sheet and rill flow and enlargement of drainage ditches occurs in row cropping areas (Wilcock 2009). Drainage tiles transport sediment in increased runoff rates due to their unimpeded pathways to streams, which in turn, can create a rapid rise in water level (Wilcock 2009).

2.5.1. Nonpoint Source (NPS) Pollution Problem and Mitigation

NPS pollution occurs when water travels over or through the ground, gathers pollutants and carries them to rivers, lakes, coastal waters or ground water. The USEPA identified NPS pollution as the United States' biggest water quality problem (Loague 2001). Reducing NPS nutrient loads can be achieved with changes in land use patterns and/or land management practices such as implementing structural best management practices, matching fertilizer application rates to soil needs and changing plowing methods to reduce nutrient runoff (Rast and Holland 1988).

2.5.2. Soil characteristics and Nonpoint Source Pollution

Soil aggregate stability and soil texture influence the degree of rill and interill erosion (Neyshabouri et al. 2011). Minnesota's fine-textured soils (clay loam, silty clay loam, silty clay and clay soils) can be transported further by erosion than larger textured soils, and therefore have a higher potential of supplying P to surface water (Randall et al. 2002). A report by Schoumans and Breeuwsma (1997) shows soils with high P contributed 40% of the total phosphorus load and another 40% came from soils with moderate P saturation and a high hydrological connectivity to the drainage network.

2.5.3. Erosion and Water Quality

Erosion is the detachment and transport of soil materials to another place, usually by the action of wind or water and sometimes ice. Accelerated or anthropogenic erosion occurs after land is converted for agriculture, mining or construction and can increase erosion rates by two or three orders of magnitude. Eroded sediment degrades water quality and habitat in streams and lakes. Fluvial erosion of stream channels depends on water depth, velocity, and the size and cohesiveness of the stream channel material (Toy 2008).

2.5.4. Total Suspended Solids (TSS) Problem and Agriculture

TSS are the inorganic and organic particles in water that can be measured and are an indicator of water quality. TSS can be transported, by water, from one area, and deposited in another. In the United States, agricultural land is a major NPS of TSS loads in 40% of impaired rivers, streams, and lakes (Schubauer-Berigan et al. 2005). The USDA estimated off-site costs of agricultural erosion to be 2 to 6 billion dollars. In Minnesota, TSS is considered one of the most damaging pollutants (Gieseke 2000).

TSS can decrease light availability, interfere with fish respiration, cover fish spawning sites, interfere with filter feeding organisms, fill in backwater areas, degrade and/or eliminate fish and wildlife habitat, cause siltation of drainage ditches and irrigation channels, alter benthic organism habitat, transport adsorbed chemicals and nutrients (P), and negatively affect aesthetics. Periodic dredging of TSS is required to maintain water levels of navigation channels, lakes, ports, and marinas (Gieseke 2000).

2.5.5. Phosphorus (P) Element, Primary Production, and P Pathways

P is an essential element for plant growth (Filippelli 2002) and frequently limits primary production (Jones 2008). Too much P loading increases phytoplankton, increases turbidity, toxic algae may grow, submerged macrophytes can die out due to light limitation, less desirable fish species become favored and top-down control of phytoplankton by zooplankton can decline. Reduction of external P loading is required to attain long-term water quality improvements (Sondergaard et al. 2001). Reducing total P (TP) below 0.05-0.1 mg/L P for shallow temperate lakes causes significant and sustaining changes to water clarity and the biological community (Jeppesen et al. 2005). Internal loading or recycling of P from the lake sediment to the water column (wind resuspension, redox-related recycling, plant senescence, benthivorous fish resuspension) can continue for a time after external P reduction (Heiskary and Lindon 2005). P pathways are shown in Figure 9. The length and magnitude of internal loading is connected to the flushing rate of the lake, external loading history and the sediment's chemical attributes (Sondergaard et al. 2001).

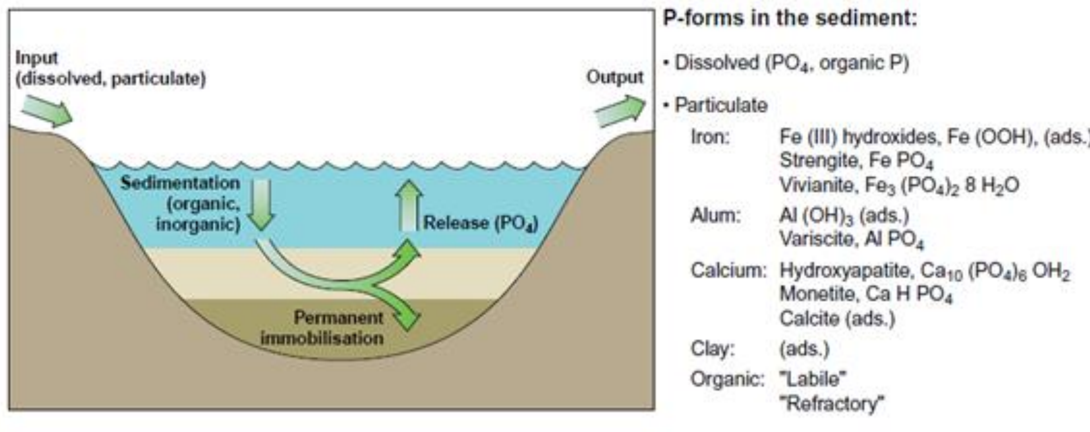

Figure 9. Theoretical illustration of the input, output and immobilization of P, along with some of the most important pathways and P compounds (organic and inorganic) in the water and sediment of shallow lakes (Sondergaard et al., 2001). (ads=adsorption)

2.5.6. Nitrate-nitrite Ions, Water Quality, and Fertilizer

Nitrate (NO_3^-) and nitrite (NO_2^-) are natural inorganic ions used by algae and plants for growth. Microbes in soil or water decompose wastes that contain organic nitrogen, and convert it into ammonia. The ammonia is oxidized to nitrite that is easily oxidized to nitrate, the major compound in surface water and groundwater (Carpenter et al. 1998). Nitrate is very soluble in water (Mueller et al. 1996). Rain or snowmelt can create runoff that transports the nitrates and nitrites into streams and lakes. An excess of fertilizer and manure application creates extra N that can leach to aquatic ecosystems, volatilize into the atmosphere, and redeposit somewhere else (Carpenter 1998).

Nitrate application is the highest in the Corn Belt (Criss 2004), an area of the Midwestern US (Smith 2004). Nitrate is toxic at high concentrations in drinking water for infants and cattle. Nitrate causes methemoglobinemia (interferes with oxygen-carrying capacity of blood) (Amdur et al. 1991). The nitrate level considered safe for infants is 10 mg/L, and 40-100 mg/L is dangerous for cattle (Sandstedt 1990).

2.5.7. The FLUX Model Purpose and Methods

The FLUX model, invented by William Walker of the United State Army Corps of Engineers (USACE) during the 1980s, was designed to calculate and estimate nutrient and sediment loading of a stream. This DOS version of FLUX was converted to a Windows version, and called $FLUX_{32}$. The model uses grab-sample sediment and nutrient concentration results, and daily flow files for a chosen period of time. The output is total mass discharge and error statistics. Data can be automatically or manually stratified to increase the accuracy and precision of loads. There are six calculation methods available:

- Method 1 calculates direct load averages, and is used for point sources, and when flow and concentration are inversely related
- Method 2 multiplies flow-weighted mean concentration by the mean flow to get an average
- Method 3 multiplies flow-weighted mean concentration by the mean flow to get an average, but amends bias when concentration fluctuates with flow
- Method 4 and 5 are regression methods. They do not work well with data that has a lot of zero flows, but account for differences of the average sampled flow, and average total flow

- Method 6 is a regression method. It is used when there is a strong correlation between flow and concentration

2.6. Best Management Practices to Alleviate Nonpoint Source Pollution

Best management practices (ie: two-stage ditches, buffer zones, constructed wetlands) can be implemented to manage agricultural nonpoint source (NPS) runoff, stormwater, and remove pollutants (TSS, P, N) (Coveney et al. 2002). The two-stage ditch is a structural practice that is akin to fluvial form and process (D'Ambrosio et al 2015). A trapezoidal (conventional) ditch has steep sides that easily erode, but can be changed to a two-stage ditch which makes the ditch sides less erodible (Fig. 10). The two-stage ditch is based on principles of fluvial geomorphology (Ward et al. 2004; Powell et al. 2007b; Rhoads and Massey, 2011). The first stage is a lower stage (the inset channel) and the second stage (the bench) creates a floodplain that is designed to minimize flooding in fields (Ward et al 2008). This structural practice has been adopted into Part 654 Stream Restoration Design in the National Engineering Handbook (United States Department of Agriculture-Natural Resource Conservation Service, 2007) and it has seen application in the upper Midwest region of the U.S. (Magner et al., 2012). Two-stage ditch studies have shown that turbidity, TSS, TP can be reduced during floodplain inundation, but may not be useful for managing high inorganic N loads (Davis et al, 2015.).

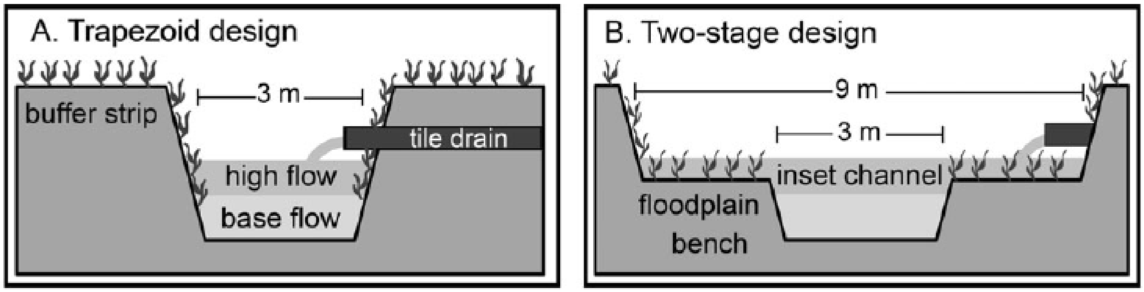

Figure 10. Side views of agricultural ditch types: A is a conventional ditch; B is a two-stage ditch (Ursula et al., 2015).

Buffer zones and constructed wetlands are structural practices that decrease the velocity of runoff, filter sediment and pollutants, and lessen soil erosion of banks of water bodies (Editorial 2005). Buffer zones are a band of perennial vegetation along ditches or water bodies (Qi and Altinakar 2011) (Fig. 11).

Figure 11. Riparian buffer strips are shaded in the small lake watershed (Correll 2013).

Constructed wetlands use natural processes of wetland vegetation, soils and microbes to improve water quality. There are three types of constructed wetlands: the surface flow (SF), subsurface flow (SSF) and hybrid (a combination of SF and SSF) systems. Two systems are shown in Figure 12. Processes that can occur in constructed wetlands to improve water quality include: settling of suspended particulates; chemical transformation; filtration and chemical precipitation; ion exchange and adsorption on plant surfaces, sediment, litter and substrate; plants and microorganisms breakdown and transform pollutants; plants and microorganisms uptake and transform nutrients; pathogens can be reduced through natural die-off and predation.

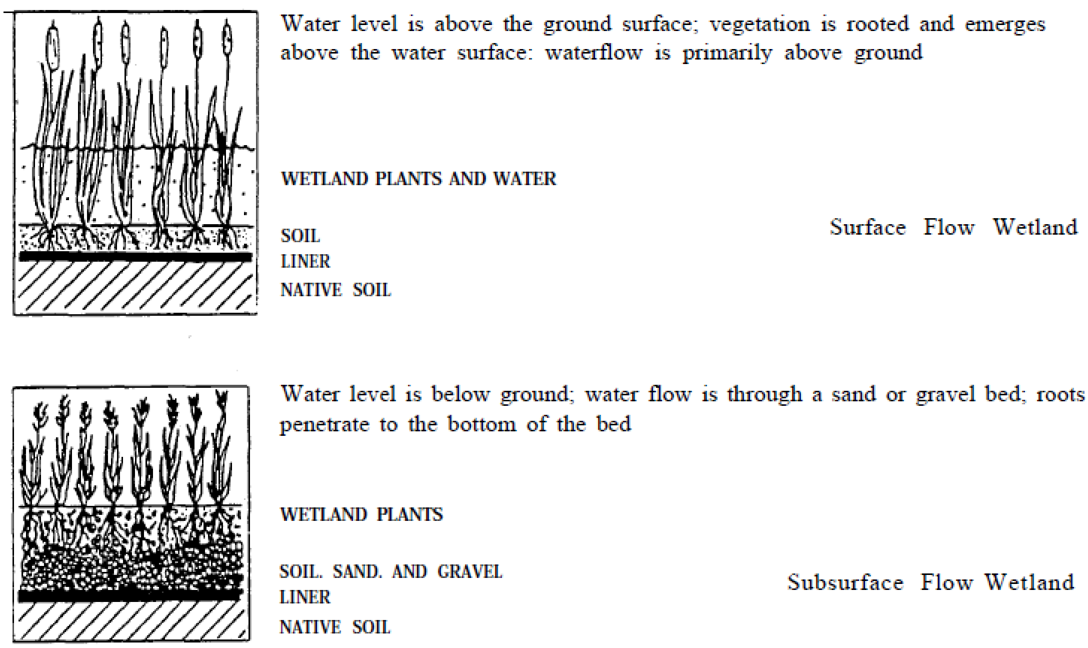

Figure 12. Surface flow (SF) and subsurface flow (SSF) constructed wetlands (Water Pollution Control Federation 1990).

3. Study Site

Lake Titlow is located in the Western Corn Belt Plains ecoregion (Fig. 13) in Sibley County, Minnesota, adjacent to the north side of the city of Gaylord. Latitude and longitude are 44.568 N and 94.206 W. The Lake surface area is 1.56 mi^2 acres (4.047 km^2), with a maximum depth of 5 feet (1.524 m), and an average depth of 3 feet (0.914 m) (Hoppie 2008).

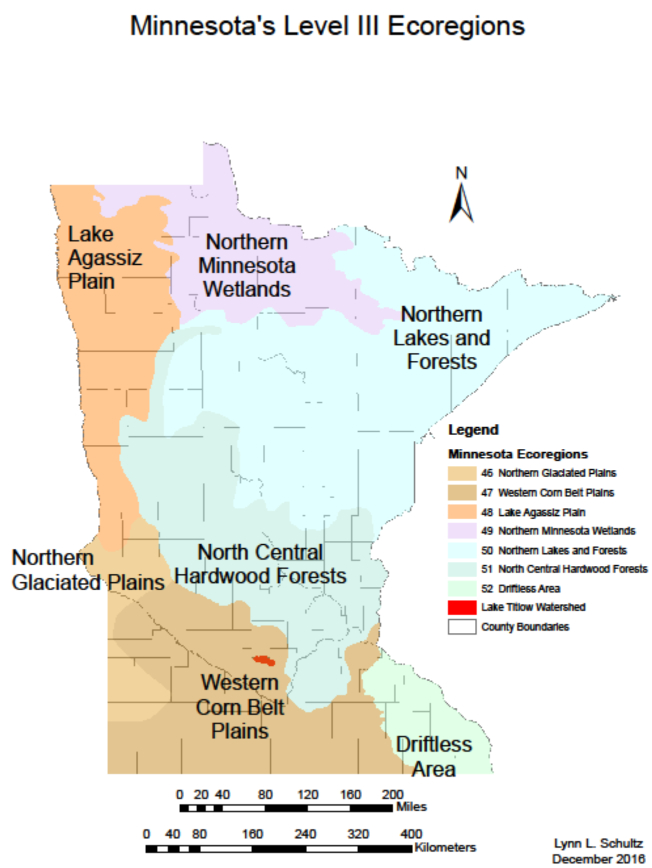

Figure 13. The Lake Titlow watershed is located in the Western Corn Belt Plains Ecoregion (United States Environmental Protection Agency 2012).

The lakeshed is 55.7 mi^2 (144.24 km^2). Over 80% of land use is fields of corn, soybeans, small grains, and forage cultivation. Other lakes cover 9.2 mi^2 (23.91 km^2) and wetlands cover 2.3 mi^2 (5.98 km^2). Over 95% of the lakeshed has a 3% slope or less. Lake Titlow has an elevation of 987.5 feet (301 m) (Rush River Assessment Project 2004).

Sibley County has 550 miles (885 km) of public judicial (includes more than one county) and county drainage ditches. Drainage systems in this agricultural watershed cover 94% of the lakeshed. It is drained by three ditch systems that run into the lake: McLeod-Sibley Judicial Ditch Number 18 (JD18), Sibley County Ditch 18 (CD18), and Ditch 250 (D250). Total areas and percentages of these three sub-lakesheds are listed in Table 3.

Table 3. Total subshed areas and percentages in the Lake Titlow lakeshed, Sibely, and McLeod Counties, Minnesota.

Site	Acres	Rank	Percent of watershed
JD18Up	12697	1	40
CD18Up	5648	3	18
JD18Lo	7411	2	23
CD18Lo	4914	4	15
D250	1383	5	4

Five water sampling sites are used in this study from the 2009 and 2010 monitoring seasons. There are two on JD18 (upland & lowland), two on CD18 (upland & lowland), and one on D250 (Table 4; Fig. 14). The four rain gauge sites are described in Table 5.

Table 4. Lake Titlow water sampling site names, locations and descriptions.

Site Name	Site Location	Site Description
JD18Up	10th St. or County Road 58 Gaylord, MN	Sample is taken just downstream of the cement culvert
JD18Lo	481st Ave. Gaylord, MN	Approximately 0.75 miles upstream of the lake; sample site is just downstream of a two-bay cement box culvert
CD18Up	521st Ave. Gaylord, MN	Sample is taken just downstream of small round cement culvert
CD18Lo	481st Ave. Gaylord, MN	Approximately 0.75 miles upstream of the lake; sample site is just downstream of a one-bay
D250	250th Street Gaylord, MN	Sample taken on downstream side of culvert

Table 5. Lake Titlow watershed rain gauge names, locations and site descriptions.

Site Name	Site Location	Site Description
North Rain Gauge	501st Ave. Gaylord, MN	Located on a fence post in the Northern part of the lakeshed
South Rain Gauge	521st Ave. Gaylord, MN	Located on a post next to CD18Up site
West Rain Gauge	561st Ave. Gaylord, MN	Located in the western part of the lakeshed
East Rain Gauge	Eastern Side of Lake Titlow	Located in Lake Titlow

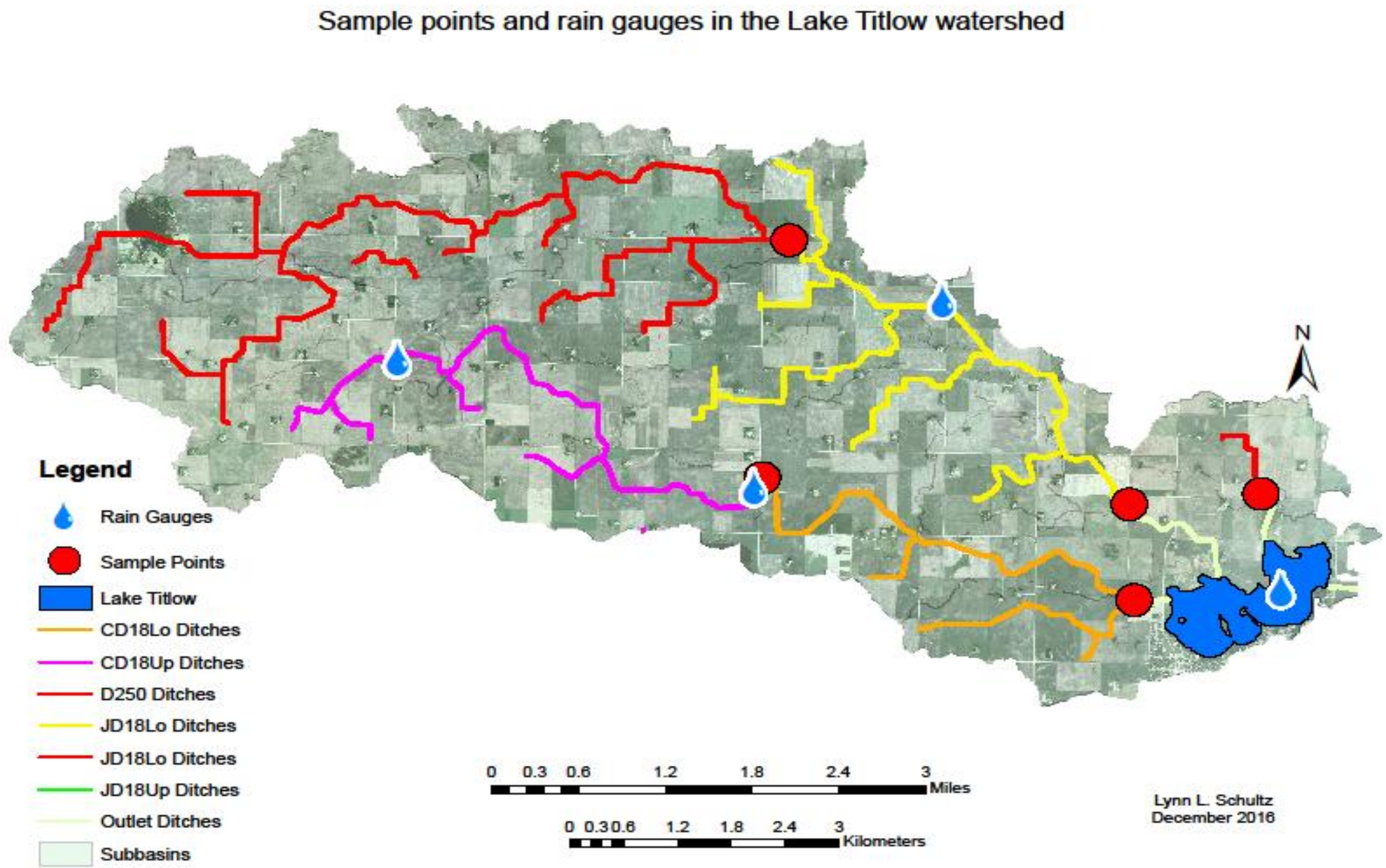

Figure 14. The Lake Titlow watershed sampling points and rain gauges used in the 2009/2010 study, Sibley and McLeod counties, Minnesota.

4. General Methods

The units herein will be United States (U.S) customary or metric units of measure depending on the commonly used unit of measure in this field of study. Metric units will be used when discussing water chemistry and loads, and U.S. customary units will be when discussing areas and rainfall amounts. Using a mixture of metric and U.S. customary units is usual practice among individuals undertaking work in soil and water conservation.

4.1. Water Sampling, and Testing

4.1.1. Baseline Ditch Water Sampling

Sampling was scheduled to begin in April and continue into November of each monitoring year. Water samples were taken at five different sampling sites at mid-depth of the three inlet ditches (JD18Up, JD18Lo, CD18Up, CD18Lo, D250). The samples were collected using acid washed bottles. The samples were labeled, put in a cooler with ice, and analyzed within the allotted time. Most water samples were analyzed at Minnesota State University Mankato (MSUM) in Mankato, MN but some water samples were analyzed at Minnesota Valley Testing Lab (MVTL) in New Ulm, Minnesota.

4.1.2. Storm Event Water Sampling

Three automated samplers (Isco model 6712 with Isco 720 flow module and YSI 600 OMS temperature, conductivity and optical turbidity sensor) were installed at the two inlet sites (JD18Lo and CD18Lo). The automatic samplers were equipped with Isco model 720 submersible pressure transducers that had a vented cable to automatically adjust the water level according to barometric pressure. Temperature, conductivity, water level, and turbidity were recorded every five minutes, and were downloadable to an Isco Rapid Transfer Device (RTD) for transfer to a computer.

Storm hydrographs from 2008 show the rising and the crest in the ditches persisted for less than 24 hours. Therefore, the automated samplers were set to be triggered by a 10% rise of water level to collect 500 mL of water in four bottles, every two hours, for eight hours. If the water level exceeds 20% of the pre-storm level, four 500 mL water samples were collected at two hour intervals, over another eight hours. The bottles of storm water samples were combined by using 75% of the middle bottles and 25% of the beginning and ending bottles then labeled and put in a cooler on ice. The samples were taken to MVTL for testing, or to MSUM for analysis of total phosphorus (TP), nitrate nitrogen (NO_3^- - N), nitrite nitrogen (NO_2^- - N), and total suspended solids (TSS) within the 48-hour holding time. The upland sites (JD18 Up and CD18 Up) and D250 were sampled manually at mid-depth to test for TP, NO_3^- - N, NO_2^- - N, and TSS.

4.1.3. Storm Water Quality Parameters Measured at All Sites

Certain measurable factors in water can indicate the level of pollution. These factors can change throughout the season.

To assess the water quality of the ditches, the following parameters were measured at all sites:

- TP
- N-NO_2 + NO_3 (herein known as NOx)
- TSS

4.1.4. Water Quality Analyses of Baseline, and Storm Water Samples

Samples were bottled in the field, and put in a cooler on ice. They were analyzed by MVTL, and at MSUM in the Surface Processes laboratory. Table 6 lists the parameters, methods, holding times, and who did the analyses. Methods were the same for the two years of this study.

4.1.4.1. TSS Method

The TSS method was standard method 2540D. First a 1.85 in (47 mm) Pall glass fiber filter paper was heated in a muffle furnace at 1,022 F^o (550 C^o) for at least 15 minutes. The filter was cooled, weighed, and put in a laboratory oven for at least one hour at 221 F^o (105 C^o), then cooled, and reweighed. If the filter weighed within 0.5 mg of the original weight, the filter was used. If not, this procedure was redone.

The watershed water samples were vigorously shaken for at least one minute to resuspend particles. A 100 to 400 mL volume of each sample (a smaller sample was taken of turbid water, and a larger sample was used of clear samples) was taken, and drawn through the filter using vacuum pressure. After filtration, the paper filter was put in a 221 F^o (105 C^o) oven for at least one hour, removed, cooled, and weighed. The same filtered sample had this process repeated. The weight of the filter paper was subtracted from the final weight of the sample, and divided by the water amount to give TSS in mg/L.

4.1.4.2. Total Phosphorus Method

Hach method 8190 was used for TP. Phosphates in the sample were converted to reactive orthophosphate (PO_4^{3-}) prior to analysis. This was accomplished by pretreating with acid and heating at 200 F^o for 30 minutes to create hydrolysis of the inorganic forms. The organic phosphates were changed to orthophosphate using heat, acid, and persulfate. With acid as a medium, the orthophosphate reacted with molybdate to give a phosphomolybdate complex. Ascorbic acid was used to reduce the complex to give a concentrated molybdenum blue color. The samples were read colorimetrically on a Hach DR 2800 spectrophotometer, and TP given in mg/L phosphate (PO_4^{3-}).

4.1.4.3. NO_2 – N and NO_3 –N Methods

Hach Method 10206 was used to analyze the samples for nitrate. A 1.0 mL volume of sample was put in a vial with reagent, and inverted 2-3 times to mix. After reacting for fifteen minutes, the vial was put in the spectrophotometer, and results were given in mg/L NO_3^- - N.

Hach Method 10207 was used to analyze the samples for nitrite. A 2.0 mL sample was put in a vial with reagent, and inverted two to three times. After ten minutes, the vial was wiped to ensure cleanliness, and put in the spectrophotometer to be measured at 550 nanometers. Results were given in NO_2^- - N mg/L.

Table 6. Water quality parameters, sample holding times, methods and whose responsibility for analysis for the Lake Titlow watershed, Sibley and McLeod Counties, Minnesota.

Parameter	Maximum Holding Time	Method	Responsibility
N-NO2+NO3	28 days	Methods 10206 & 10207	MVTL, MSU
TP	48 hours	Method 8190	MVTL, MSU
TSS	7 days	SM 2540D	MVTL, MSU

4.1.5. Quality Assurance/Quality Control of the Water Samples

USEPA quality assurance/quality control (QA/QC) measures were followed. Field duplicates were collected for all sites. Field blanks were polypropylene bottles full of double deionized water. Field duplicates and blanks were 10% of all samples.

4.2. Precipitation, Flow, and Water Quality Parameter Loads

4.2.1. Precipitation Measurement and Eight Events of this Study

Precipitation was measured from March to November of each year using event-based, data logging, 8-inch standard tipping bucket rain gauges manufactured by Onset, Inc. The gauges were located in sites named North, South, West, and East (Fig. 14). The rain gauges for 2010 were at the same locations as the rain gauges in 2009 (Fig. 14). Continuous rain data were retrieved using a shuttle in the field, and transferred to a laptop in the lab, processed into 15-minute daily, storm, monthly, and annual totals. The precipitation events were chosen for this study due to the FLUX model results having too much error because of the small, flashy streams in this watershed. The chosen rainfall events span the seasons, and involve small, medium, medium-large, and large rain events (Tables 10 and 11).

4.2.2. Stage and Discharge of the Lake Titlow Tributaries

Stage and discharge were recorded at the upland sites (JD18 Up and CD18 Up) and the D250 site on data loggers at 20 second intervals (Fig. 14). The data was downloaded to the computer. Staff gauges were permanently installed at JD18Lo, CD18Lo, and D250, to monitor and validate the stage and discharge data logger hydrographs. JD18 Up and CD18 Up were measured from the top of the culverts to the water level to validate the stage and discharge data logger hydrographs (Fig. 14).

Stream velocity in the ditches was measured with a Marsh-McBirney Flo-mate electromagnetic flowmeter, and a submersible pressure transducer. Discharge was calculated using the methods recommended by the United States Geological Survey (USGS) that uses depth, width and velocity. The flowmeter was calibrated before using in the field, and a spin test was conducted for quality control.

4.2.3. Rating Curves and Hydrographs for the Lake Titlow Tributaries

A rating curve is a statistical relationship where discharge is calculated using only stage height from a range of stages and discharges at a specific stream location (Winter 2008). Converting water depth to water discharge was done using the rating curve equation. A rating curve was established by measuring water discharge at several different stages for each ditch. At least five measurements were taken in each ditch, at each of the five sites. Rating curves were calculated for each ditch using 2009 data, and for each ditch using 2010 data. A hydrograph shows the discharge in a stream over a period of time. The rating curves and stage data were processed into seasonal hydrographs for 2009 and 2010. The cumulative flow was calculated by multiplying the five-minute flow data by 300 seconds and adding the individual values. The inflows from the three ditches (JD18, CD18, and D250) were summed to determine the overall output of the watershed.

4.2.4. TSS, TP, and NOx Load Calculations for the 2009 and 2010 study years

TSS, TP, and NOx loads were first calculated using the FLUX model using the 2009, and 2010 season TSS, TP, and NOx sample results, and the daily flow records. Resulting FLUX coefficient of variation values (CVs) were higher than ideal. The CV is the standard error of the mean loading divided by the mean loading, and indicates error. A CV <0.1 usually works for mass balance modeling (Walker 1999). Getting a CV of <0.1 may not be possible in small, flashy streams with strong concentration/flow relationships. A CV value between 0.1 and 0.2 may work for model purposes, particularly for minor tributaries. If CVs are higher, changing and extending the stream monitoring to get more data may produce better CVs, especially for major tributaries.

Thereafter, flow loads were determined manually for the eight chosen rainfall events using time series data and spreadsheet calculations. The event hydrographs, and TSS, TP, and NOx sample data for each event were cross-plotted and regressed to get the best-fit equations that were needed to determine the load of each water quality parameter.

4.3. Mapping Methods

4.3.1. Maps of the Distribution of Rain Storm Total Precipitation

Information about rain amounts is vital because rainfall is the driver of runoff, and sediment, and nutrient loading. Therefore, the point data from the four rain gauges was interpolated using ArcGIS. A database table was created and joined to the point feature layer of the rain gauges for the Lake Titlow Watershed for each rain event. The precipitation amounts for the precipitation events were interpolated using the inverse distance weighting (IDW) method. In the IDW tool the power (optional) was set to portray five lines on each rainfall distribution map by using a number that was one fifth of the difference in rain amounts from the rain gauge with the least rain and the rain gauge with the most rain for each rainfall event. The Spatial Analyst Extension Contour tool was used to create the isohyets for each precipitation event. The interpolation of the rain data portrays the rain amount variation of the eight storms in the watershed (Appendix 4).

4.3.2. Land use Maps of the Lake Titlow Watershed, 2009-2010

Land use is a major factor in runoff water quality, and knowledge of land use provides information to improve management of the land to improve the water quality. The 2009 and 2010 land use maps were created from the USDA-NASS website:
http://nassgeodata.gmu.edu/CropScape/ using the Lake Titlow watershed layer to define the area of interest. Acreage for each defined land use was calculated by multiplying the raster pixel count by the conversion factor (0.222394 for 30 meter pixels; 0.774922 for 56 meter pixels) that is provided on the Cropland Data Layer website. Percentages of agricultural land use were calculated because they help to compare, and contrast the runoff water quality from each subshed.

4.3.3. Subbasins, and Subsheds of the Lake Titlow Watershed

Dividing the watershed into smaller parts (subbasins, shubsheds) is helpful because it is easier to identify what parts contribute higher sediment, and nutrient loading. Subbasins were created by SEH using ArcSWAT Version 2.3.4. for ArcMap 9.3. The 30 meter Digital Elevation Model (DEM) from the United States Geological Survey, and the Minnesota Department of Natural Resources (MDNR) 24K Streams shapefile from MDNR Management Information Services were used to delineate the watershed. A total of sixteen subbasins were created. Then they were grouped by the ditch, and the upland, and lowland orientations.

4.3.4. Drainage Ditches, Streams, and Lake Layers

The drainage ditches, stream, and lake layers were important to visualize the surface water layout in the watershed. The basemap 24K shapefile was downloaded from the MDNR website. It was clipped using the subshed shapefile (from SHE, Inc.) in ArcMap 10.3. The surface water is portrayed in several maps.

4.3.5. Elevation Data Source and Mapping

The elevation data were needed to map the elevation of the watershed subsheds because elevation change is a factor in water erosion and nonpoint source pollution. One meter LiDAR data was downloaded from the Minnesota Geospatial Information Office website: http://www.mngeo.state.mn.us/chouse/elevation/lidar.htmL#data. The tiles were mosaiced in ArcMap 10.3, and clipped to the watershed using the subshed layer (SEH) area to create the elevation map.

4.3.6. Soil Data Source and Mapping

Soil data were needed because different types of soil have different qualities that affect the amount of rainfall infiltration or runoff. The soil data were acquired to map the hydrologic soil groups (HSG) of the subsheds. The data were obtained from the USDA-NRCS SSURGO database. They were clipped to the watershed in ArcMap 10.3 using the subsheds layer (from SEH, inc.). The percent HSG was calculated for the C/D soil group per subshed.

6. Results

Initially, the subshed daily flows and water quality data were processed using the FLUX computer program to estimate the sediment and nutrient loads in the waterhsed. The resulting FLUX CVs reflected that the uncertainty in the loading estimate was too high. Because the uncertainty was too high, four precipitation events were chosen from each of the two study seasons. There is one low precipitation event, one high event, and two that are in between. Analyzing these eight events will still allow the goal to be met of characterizing the watershed to identify the subsheds that contribute higher loads of each parameter.

This chapter provides details for the eight events of this study in 2009 and 2010. The order of the results are: the water quality analyses; precipitation; rating curves; hydrographs; FLUX model results; individual rain events; storm hydrographs; loads; discharge; runoff; land use; slope; elevation; TSS, TP, and NOx.

The subshed areas are compared using three different methods that are referred to as cumulative, exclusive, and per square mile subsheds. The cumulative JD18Lo subshed includes the JD18Up loads. The exclusive JD18Lo subshed is without the JD18Up subshed loads. It is the same for the CD18Lo subshed. The per square mile subsheds have the loads divided using the square miles of the subshed.

6.1. TSS, TP, and NOx Results from the 2009 and 2010 Study Seasons

Water samples from the JD18, CD18 and D250 drainages were collected and analyzed for TSS, TP and NOx during 2009 and 2010. Both sampling seasons started in April, but the 2009 season ended mid October and the 2010 season ended mid November. About twice as many samples were collected in 2010 versus 2009 (16 and 34, respectively). The TSS, TP, and NOx results that were below the minimum limit of detection are represented as <2 mg/L. TSS amounts from all sites were higher in 2010. TP results were higher at the JD18Up, CD18Up and D250 in 2009, but higher at JD18Lo and CD18Lo in 2010. NOx results were higher at all sites in 2010. Sediment and nutrient result ranges for each sampleshed are shown in Table 7, and results for all 2009 and 2010 samples are shown in Appendix 1.

Table 7. Range of water sample results for total suspended solids (TSS), total phosphorus (TP) and nitrate-nitrite nitrogen (NOx), by sampleshed, for the 2009 and 2010 study seasons of the Lake Titlow watershed, Sibley and McLeod counties, Minnesota.

Water Sample Results						
	TSS (mg/L)		TP (mg/L)		NOx (mg/L)	
	2009	2010	2009	2010	2009	2010
JD18Up	<2-68	0.5-116	.023-1.74	0.032-0.490	<2-18.6	1.1-24.3
CD18Up	<0.2-36	0-42	.015-.673	0.013-0.386	<0.2-21.6	0-22.7
JD18Lo	<2-47	0.4-3097	.02-.972	0.035-1.229	<0.2-20.2	2.3-21.8
CD18Lo	2-53	0-855	.02-.457	0.023-1.088	<0.2-19.6	0-22.6
D250	<2.0-17	0-43	.027-1.3	0.048-0.7	<0.2-21.7	0.4-23

6.2. Precipitation Results of the Four Rain Gauges

The four rain gauges were in the same locations in the Lake Titlow watershed for 2009, and 2010 (Fig. 14). Table 8 compares the annual totals of each rain gauge for each year. The entire watershed had more rain in 2010. Rain totals were 19.69-25.51 inches in 2009, and 25.62-31.87 inches in 2010. Appendix 2 lists the dates, times, and amounts of rain recorded by the tipping bucket rain gauge in 2009. Appendix 3 lists the dates, times, and amounts of rain recorded by the tipping bucket rain gauge in 2010.

Table 8. Rain totals (inches) from the four rain gauges (April-November) for both years of this study of the Lake Titlow watershed, McLeod and Sibley Counties.

Rain Gauge	2009 Totals	2010 Totals
West	19.69	25.62
South	22.33	30.60
North	25.51	29.42
Lake	20.00	31.87

6.3. Stream Ratings, and Rating Curves for the Lake Titlow Tributaries

Streams were measured several times for width, discharge, and stage at each sampling site during the 2009, and 2010 seasons. A rating curve was made by plotting each of the measurements for each site to show the relationship between stage, and discharge. The JD18Up (Fig. 15), CD18Up, and CD18Lo rating curves resulted in two different best fit lines, one for low flow, and one for high flow. For these sites, the stage-discharge relationship used to create a continuous discharge record used two different equations. The JD18Lo and D250 sites resulted in one best fit line that was used to create continuous discharge records. The discharge records were processed into hydrographs (Appendix 4).

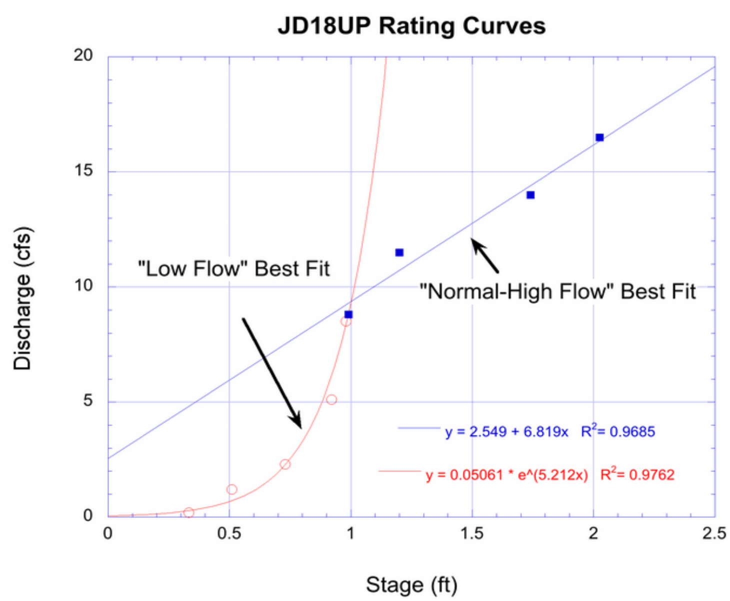

Figure 15. Rating curve with one best fit line for low flow and another best fit line for high flow.

6.4. Whole Season Hydrographs for the Lake Titlow Watershed, 2009, and 2010

Hydrographs show a continuous flow record and can be useful because they illustrate the variation in time of the flow volume. The sample site hydrographs show the difference in the 2009 and 2010 study years. It is apparent on the hydrographs that the higher rainfall in 2010 caused higher flows at all the sites (Figs 16-18).

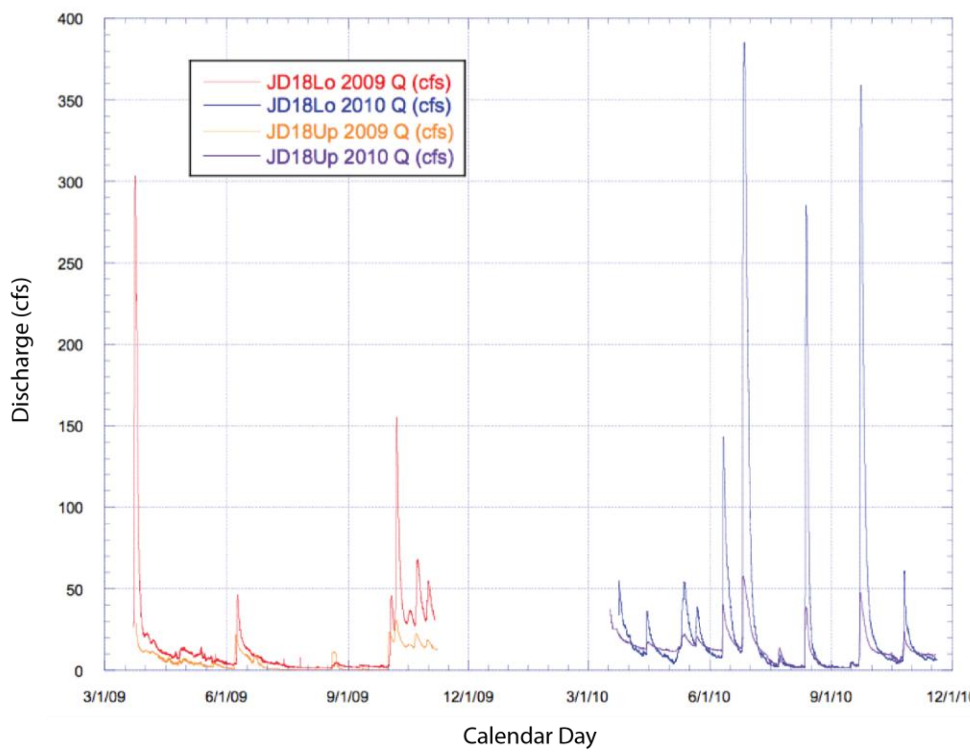

Figure 16. The hydrograph for 2009 and 2010 from the JD18Up and JD18Lo sample sites in the Lake Titlow watershed, Sibley and McLeod counties, Minnesota.

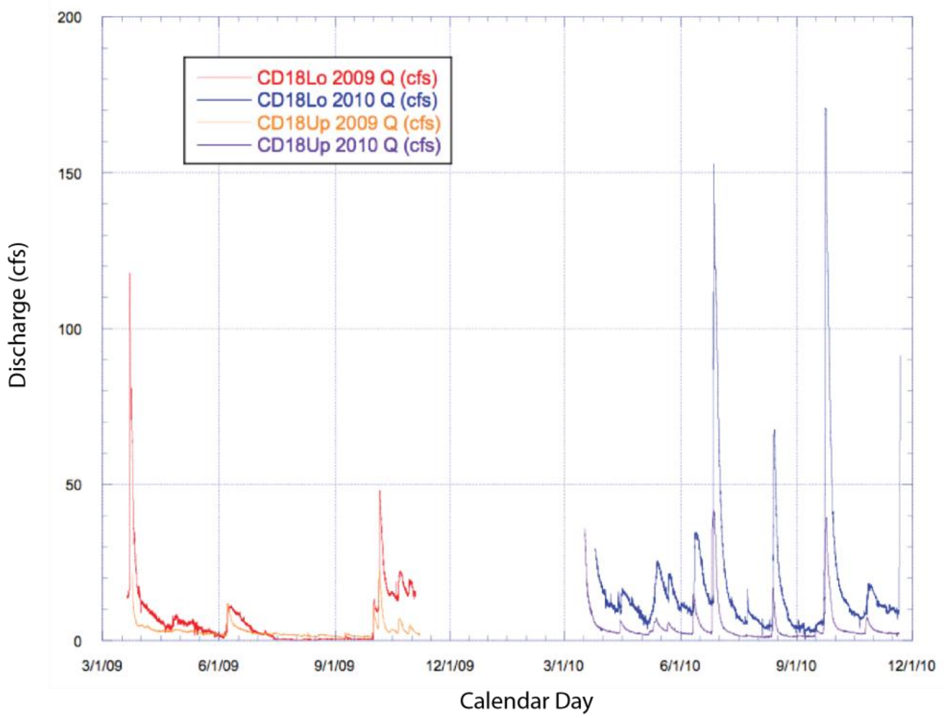

Figure 17. The hydrograph for 2009 and 2010 from the CD18Up and CD18Lo sample sites in the Lake Titlow watershed, Sibley and McLeod counties, Minnesota.

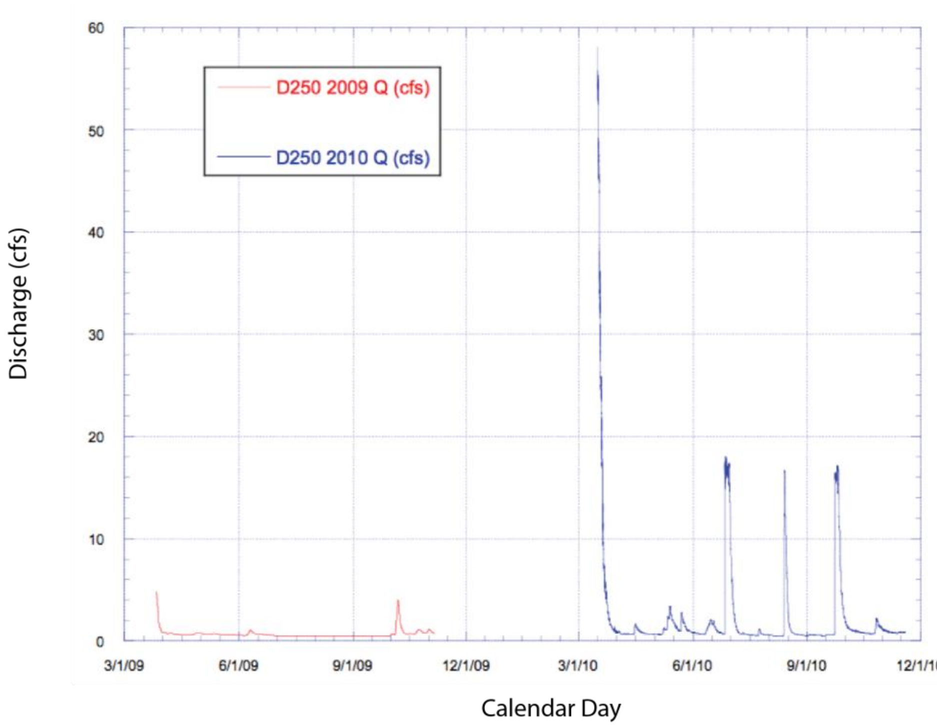

Figure 18. The hydrograph for 2009 and 2010 from the D250 sample site in the Lake Titlow watershed, Sibley and McLeod counties, Minnesota.

6.5. The FLUX Model Results

FLUX uses six different methods to estimate sediment and nutrient loads and its results can be stratified by flow or time of year. FLUX was run several times using no stratification, flow stratification, and seasonal stratification to see which method produced the lowest coefficient of variation values (CV) (Tables 9 and 10).

- Method 1 calculates direct load averages, and is used for point sources, and when flow and concentration are inversely related
- Method 2 multiplies flow-weighted mean concentration by the mean flow to get an average
- Method 3 multiplies flow-weighted mean concentration by the mean flow to get an average, but amends bias when concentration fluctuates with flow
- Method 4 and 5 are regression methods. They do not work well with data that has a lot of zero flows, but account for differences of the average sampled flow, and average total flow
- Method 6 is a regression method. It is used when there is a strong correlation between flow and concentration

Table 9. FLUX CV results, method, and stratum for TSS, TP, and NOx loads for the JD18Up subshed.

JD18Up 2009 FLUX	**Number of Samples**	**Method**	**Stratum**	**C.V.**
TSS	15 (all)	2	Overall	0.4857
TSS	15 (all)	2	Split at Q mean	0.46
TSS	15 (all)	2	<1/2Q mean, medium flow, >2xmean	0.4325
TP	15 (all)	2	Overall	0.3311
TP	15 (all)	2	Split at Q mean	0.3207
TP	15 (all)	2	<1/2Q mean, medium flow, >2xmean	0.2775
NOx	15 (all)	2	Split at Q mean	0.06793
NOx	15 (all)	2	<1/2Q mean, medium flow, >2xmean	0.06131

Table 10. FLUX CV results, method, and stratum for TSS, TP, and NOx loads for the JD18Lo subshed. Lower half of table illustrates results when outliers are removed.

JD18Lo 2009 FLUX	**Number of Samples**	**Method**	**Stratum**	**C.V.**
TSS	30	2	<1/2Q mean, medium flow, >2xmean	0.1919
TP	30	2	<1/2Q mean, medium flow, >2xmean	0.1010
NOx	30	2	<1/2Q mean, medium flow, >2xmean	0.0462
JD18LO 2009 FLUX	**Number of Samples**	**Method**	**Stratum**	**C.V.**
TSS	16	2	<1/2Q mean, medium flow, >2xmean	0.1919
TP	30	2	<1/2Q mean, medium flow, >2xmean	0.1010
NOx	30	2	<1/2Q mean, medium flow, >2xmean	0.0462

6.6. Individual Rain Events 2009 and 2010

Precipitation is the driving factor for discharge, runoff, sediment, and nutrient loading. Four precipitation events were chosen in 2009 (Table 11; Fig. 19) and in 2010 (Table 12; Fig. 19) from similar times over the study season. The precipitation events range from 0.0146 feet (0.18 inches) to 0.2823 (3.39 inches) per exclusive drainage. The August and September 2010 rain events had larger amounts than the August and October 2009 rain events at all subsheds. The 2010 April rains had smaller amounts at all subsheds. JD18Up & CD18Up received less rain in June 2010 than in June 2009. JD18Lo, CD18Lo & D250 all received more rain in June 2010 than in June 2009. Isohyetals were created for each event (Figs. 19 through 27), and show the distribution of rain over the Lake Titlow watershed.

Table 11. Average precipitation per exclusive subshed in 2009 from four rain events in the Lake Titlow watershed, Sibley and McLeod Counties, Minnesota.

Site	**Average Precipitation (ft) 4/26/2009**	**Average Precipitation (ft) 6/8/2009**	**Average Precipitation (ft) 8/19/2009**	**Average Precipitation (ft) 10/1/2009**
JD18Up	0.0551	0.1187	0.1605	0.2163
CD18Up	0.0650	0.1115	0.1652	0.2207
JD18Lo	0.0729	0.0942	0.1911	0.1988
CD18Lo	0.0908	0.0869	0.2014	0.2131
D250	0.0674	0.0989	0.2179	0.2022

Table 12. Average precipitation per exclusive subshed in 2010 from four rain events in the Lake Titlow watershed, Sibley and McLeod Counties, Minnesota.

Site	**Average Precipitation (ft) 4/13/2010**	**Average Precipitation (ft) 6/26/2010**	**Average Precipitation (ft) 8/13/2010**	**Average Precipitation (ft) 9/24/2010**
JD18Up	0.0146	0.0740	0.2251	0.2531
CD18Up	0.0187	0.0888	0.2211	0.2541
JD18Lo	0.0344	0.2091	0.2721	0.2590
CD18Lo	0.0393	0.2113	0.2458	0.2823
D250	0.0394	0.2241	0.2500	0.3250

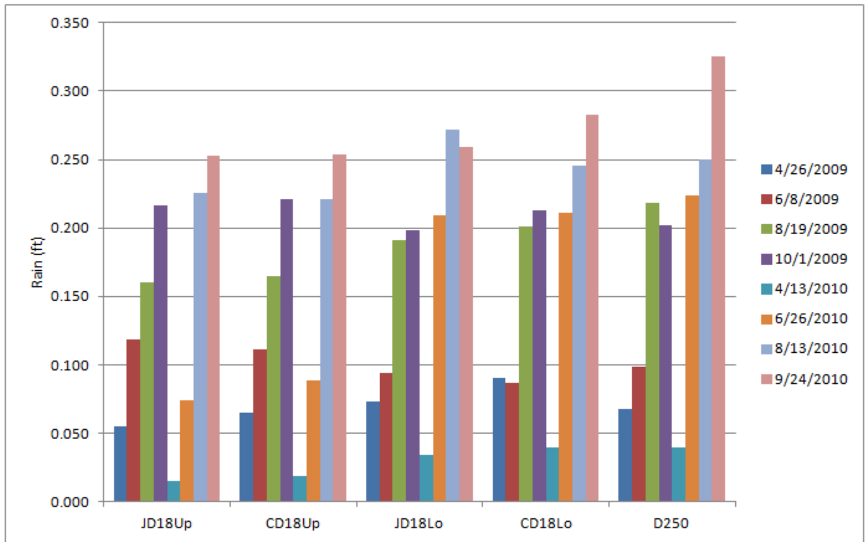

Figure 19. The eight precipitation events from 2009 and 2010 for this study in the Lake Titlow watershed, Sibley and McLeod counties, Minnesota.

6.7. Individual Storm Hydrographs for the Eight Events, 2009 and 2010

Hydrographs show the change in discharge over a period of time as shown below in Figure 20 for the JD18Lo subshed June 2010 precipitation event. Storm hydrographs show the stream response to each rainfall event and are shown at each sample station in this study (Appendix 6).

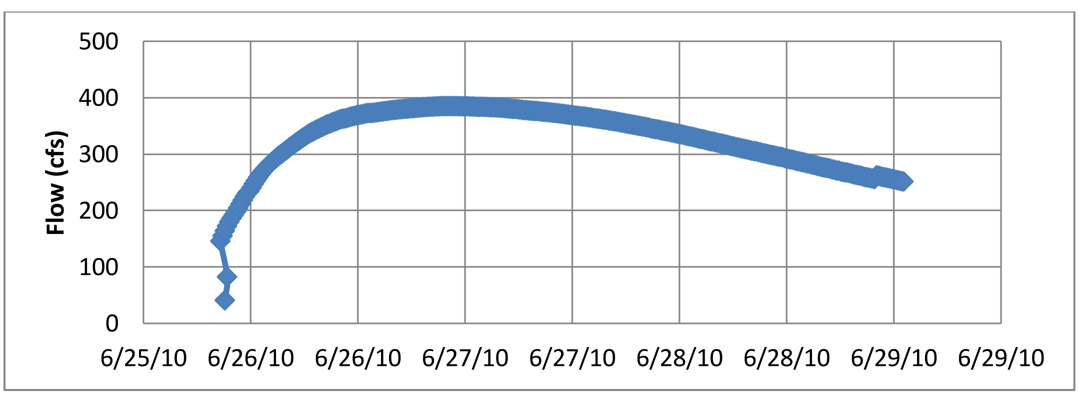

Figure 20. Hydrograph for the June 26, 2010 rainfall event at JD18Lo, Sibley County, Lake Titlow watershed.

6.8. TSS, TP, and NOx Loads per Cumulative, Exclusive, and per Square Mile Subshed

To help better understand the watershed TSS, TP, and NOx loading, the subshed areas are compared in three different ways that are referred to as cumulative, exclusive, and per square mile subsheds. The cumulative JD18Lo subshed includes both the JD18Up and JD18Lo subsheds. The exclusive JD18Lo subshed is without the JD18Up subshed. It is the same for the CD18Lo and CD18Up subsheds. The per unit area subsheds have the loads divided using the square mile area of each subshed.

The TSS, TP, and NOx loads for the 2009 and 2010 varied by year and by cumulative, exclusive, and per square mile subsheds (Appendix 7). The cumulative, exclusive, and per unit area loads do not always agree on what subshed contributed the most TSS, TP, or NOx.

Cumulative TSS was:

- 16-756 kg (D250, and JD18Lo, respectively, 2009) (Table 38)
- 54-6913 kg (D250, and CD18Lo, respectively, 2010) (Table 38)

Exclusive TSS was:

- 16-490 kg (D250, and JD18Lo, respectively, 2009) (Table 39)
- 54-6483 kg (D250, and CD18Lo, respectively, 2010) (Table 39)

TSS per square mile was:

- 2.56-42.31 kg (JD18Up, and JD18Lo, respectively, 2009) (Table 40)
- 5.77-844.18 kg (JD18Up, and CD18Lo, respectively, 2010) (Table 40)

Cumulative TP was:

- 0.03-4.38 kg (JD18Up and JD18Lo, respectively, 2009) (Table 41)
- 0-8.66 kg (D250 and CD18Lo, respectively, 2010) (Table 41)

Exclusive TP was:

- 0-2.44 kg (CD18Lo and JD18Up, respectively, 2009) (Table 42)
- 0-5.35 kg (D250 and CD18Lo, respectively, 2010) (Table 42)

Per square mile TP was:

- 0-0.48 kg (JD18Up, CD18Up and CD18Lo at 0 kg, and D250 at 0.48 kg, 2009) (Table 43)
- 0-0.70 kg (D250 at 0 kg and CD18Lo at 0.70 kg, 2010) (Table 43)

Cumulative NOx was:

- 43.50-602.09 kg (CD18Up and D250, respectively, 2009) (Table 44)
- 75.70-276.81 kg (D250 and CD18Lo, respectively, 2010) (Table 44)

Exclusive NOx was:

- 0-602.09 kg (JD18Lo and CD18Lo at 0 kg, and D250 at 602.09 kg, 2009) (Table 45)
- 0-254.08 kg (JD18Lo and CD18Lo at 0 kg, and D250 at 254.08 kg, 2010) (Table 45)

NOx per square mile was:

- 0-97.87 kg (JD18Lo and CD18Lo at 0 kg, and D250 at 97.87 kg, 2009) (Table 46)
- 0-115.49 kg (JD18Lo and CD18Lo at 0 kg, and D250 at 115.49 kg, 2010) (Table 46)

6.9. Rain Distribution Maps of the Eight Rain Events in 2009 and 2010 in the Lake Titlow Watershed

The eight rainfall events are interpolated and mapped to show the rain distribution of each storm in this study because it is the rain that generates runoff that carries sediment and nutrients to the streams, ditches, and lake. Each map contains isohyetals that illustrate the rainfall accumulations across the subsheds. The maps (Appendix 5) show the interpolated rain amounts from the four watershed rain gauges for each study event. Traditional rainfall patterns of lesser amounts in the West, and larger amounts in the East hold true for six of the eight events. The June and October 2009 rain events had higher rain amounts in the western part of the watershed.

For illustrative purposes, the October 2009 event is shown in Figure 21.

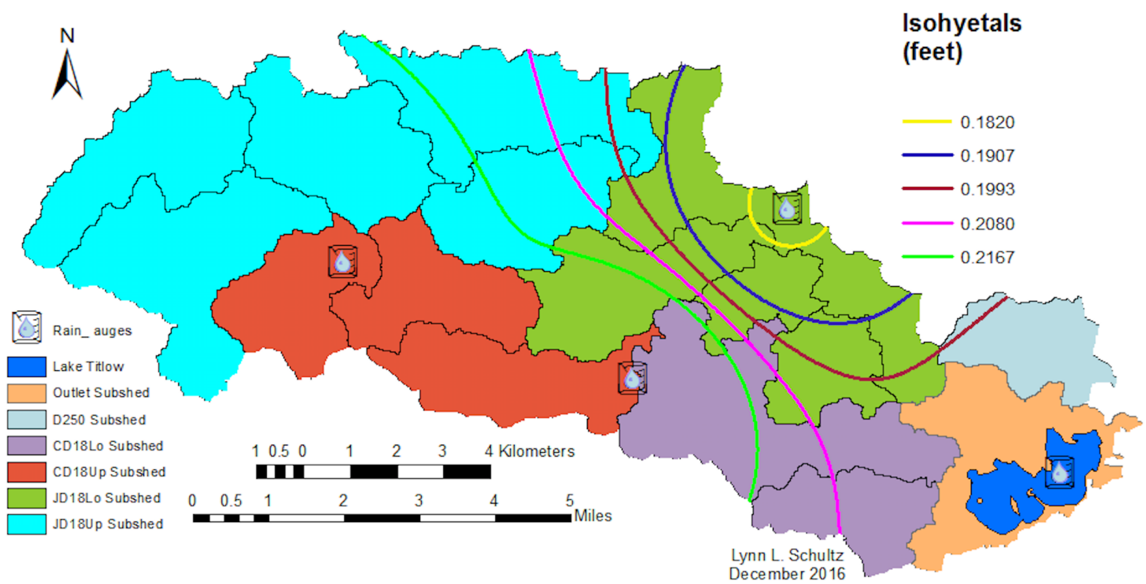

Figure 21. Rain Distribution of the October 2009 precipitation event in the Lake Titlow watershed, Sibley and McLeod counties, Minnesota. This is one of the two rain events that had larger rain amounts in the western part of the watershed during the 2009 and 2010 monitoring seasons.

6.10 Land Use Map (2009, 2010) and Exclusive Drainage Area Sizes of the Watershed

For 2009 and 2010 corn land use ranges from 41% (D250 2009) to 58% (CD18Lo 2009) per exclusive drainage. For 2009 and 2010 soybean land use ranges from 25% (JD18Up 2009) to 44% (JD18Lo 2009) per exclusive drainage (Tables 14 and 15; Fig. 22). There were more acres in corn than soybeans in 2009 and 2010. When corn and bean acreage are added together for each site, they all had more acres farmed in 2010 than 2009. The percent difference for D250 was <1% (Table 13).

JD18Lo had almost the same percent beans and corn in 2009. JD18Lo had about 700 more acres of corn in 2010 and about 500 less acres of beans in 2010. JD18Up had almost 1600 acres more of beans in 2010 than 2009 and about 1100 less acres of corn in 2010 than 2009. CD18Up had about 500 more acres of corn in 2010 than in 2009 and about 400 less acres of beans in 2010 than 2009. CD18Lo had about 500 less acres of corn in 2010 than in 2009 and about 550 more acres of beans in 2010 than 2009. D250 had about 60 more acres of corn in 2010 than 2009 and about 50 less acres of beans in 2010 than 2009. All sites had more acres in corn, by percent of total land use, for both years except JD18Lo which had more beans in 2009 (Tables 14 and 15; Figs 23 and 24).

JD18Up is the largest subshed, containing 12697 acres (5138 hectares). JD18Lo is the second largest subshed. It consists of 7411 acres (2999 hectares). CD18Up is the third largest subshed, including 5648 acres (2286 hectares). CD18Lo is fourth largest subshed. It contains 4914 acres (1988 hectares). D250 is the smallest subshed, containing 1383 acres (560 hectares). It is worthy of noting the larger overall size of the JD18Up subshed: All of its subbasins are over 2000 acres (809 hectares).

Table 13. Percent farmed of corn plus beans per exclusive subshed in the Lake Titlow watershed McLeod, and Sibley Counties.

Percent acres farmed by year by exclusive subshed		
Site	2009	2010
JD18Up	79	82
CD18Up	82	84
JD18Lo	85	88
CD18Lo	85	86
D250	77	77

Table 14. Percent corn and soybean land use per cumulative drainage in 2009 and 2010 in the Lake Titlow watershed, Sibley and McLeod counties, Minnesota.

Cumulative per Site	**Land Use% Corn 2009**	**Land Use% Corn 2010**	**Land Use% Beans 2009**	**Land Use% Beans 2010**
JD18Up	53.38	44.39	25.29	38.00
CD18Up	43.77	52.69	38.13	31.17
JD18Lo	48.26	46.22	31.59	36.97
CD18Lo	50.20	50.02	33.39	34.75
D250	41.01	45.42	35.85	32.15

Table 15. Percent corn and soybean land use per exclusive drainage in 2009 and 2010 in the Lake Titlow watershed, Sibley and McLeod counties, Minnesota.

Per Exclusive Site	**Land Use% Corn 2009**	**Land Use% Corn 2010**	**Land Use% Beans 2009**	**Land Use% Beans 2010**
JD18Up	53.38	44.39	25.29	38.00
CD18Up	43.77	52.69	38.13	31.17
JD18Lo	41.26	51.05	43.55	36.59
CD18Lo	57.60	46.95	27.89	38.89
D250	41.01	45.42	35.85	32.15

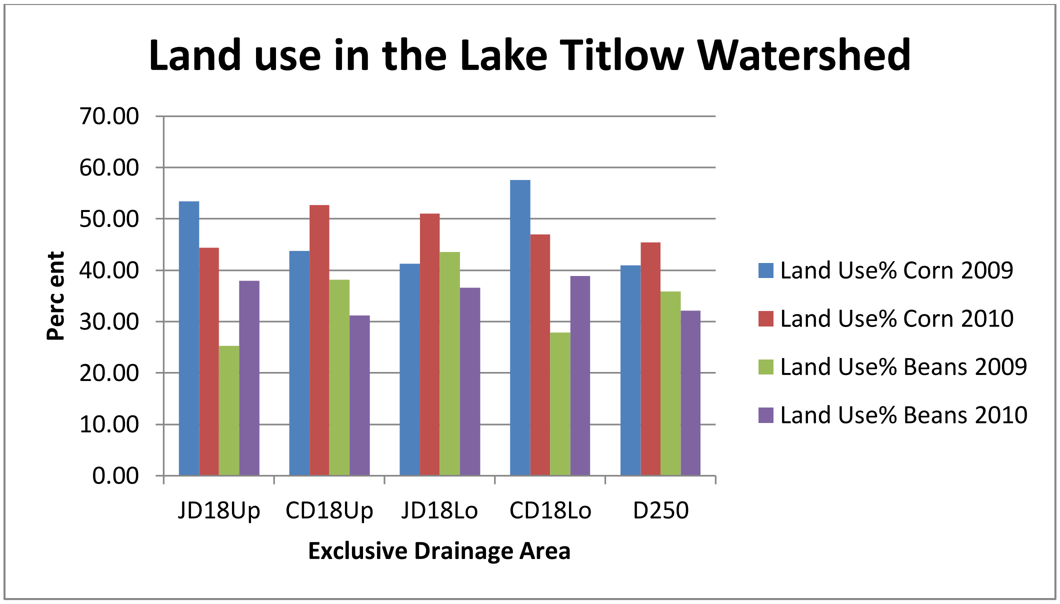

Figure 22. Corn and soybean land use in percent of exclusive subshed for 2009 and 2010 in the Lake Titlow watershed, Sibley and McLeod counties, Minnesota.

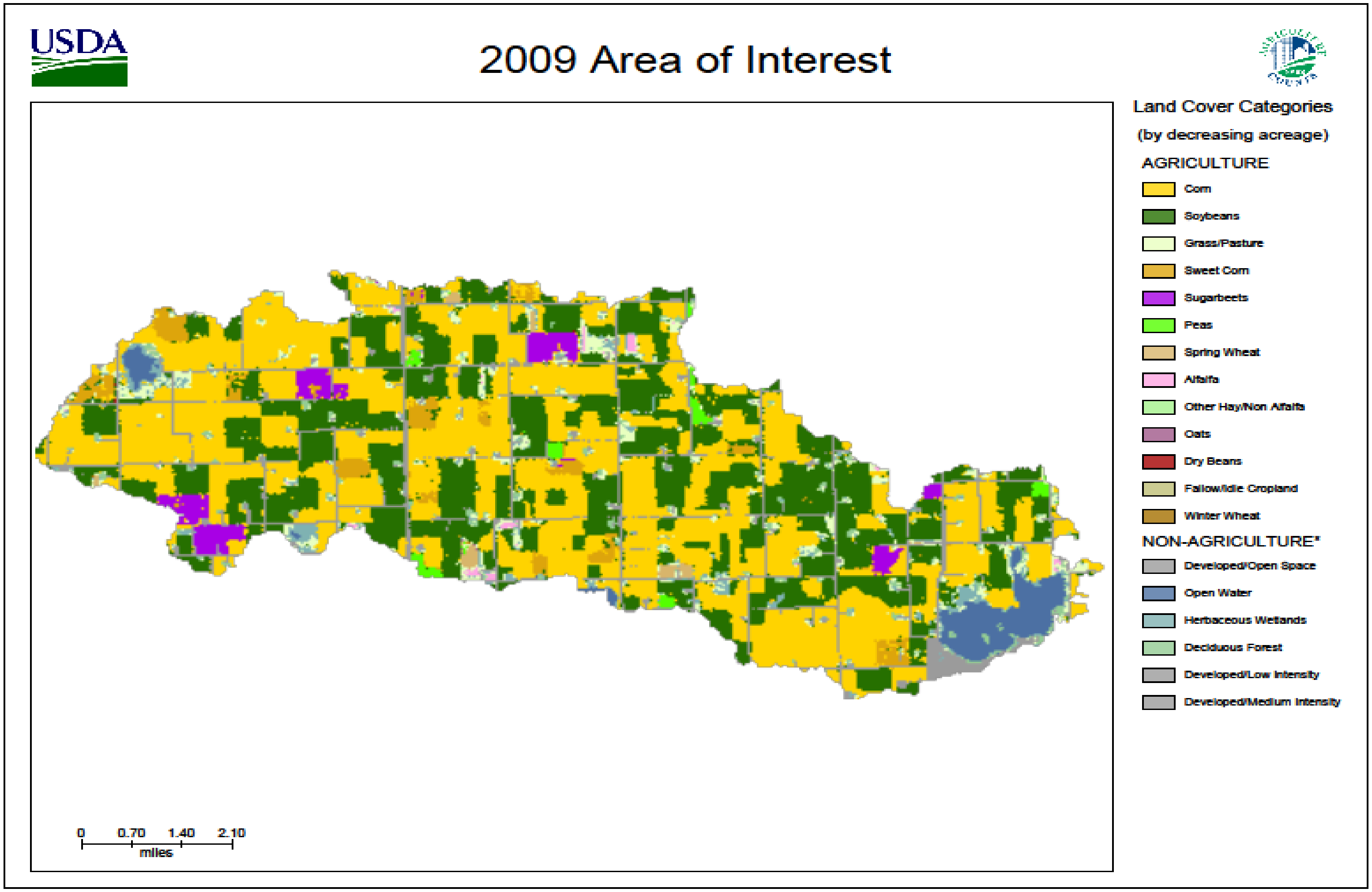

Figure 23. Land use in 2009 in the Lake Titlow watershed, Sibley and McLeod counties, Minnesota (USDA 2016).

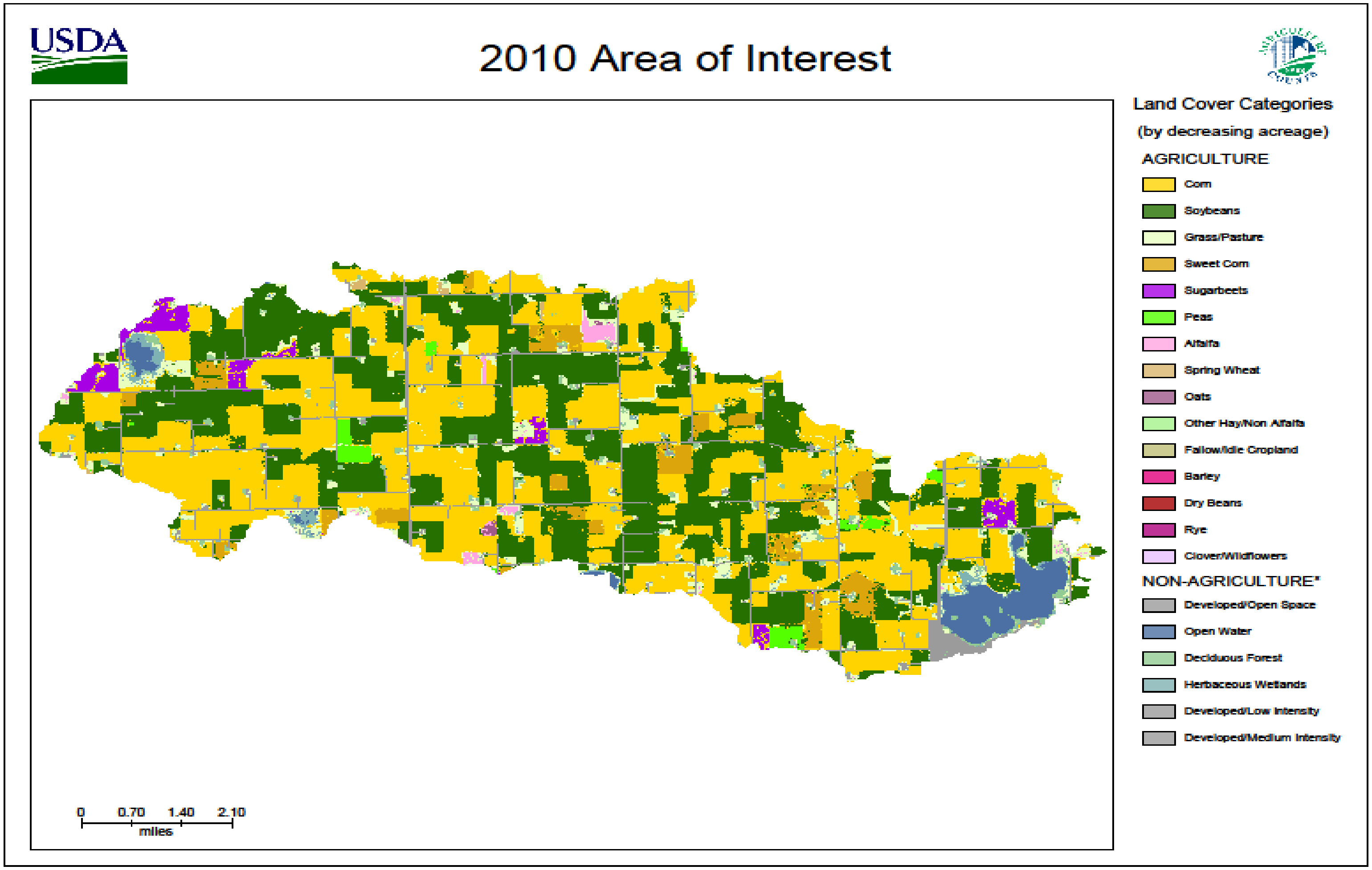

Figure 24. Land use in 2010 in the Lake Titlow watershed, Sibley and McLeod counties, Minnesota (USDA 2016).

6.11. Ditch Map of the Lake Titlow Watershed

The pathways of surface water drainage of the Lake Titlow watershed were mapped to study how individual ditches were connected and how runoff moves from upland areas toward the lake. The ditches are color coded by subshed and show the straightness or curviness of the waterway. The apparent reach of each ditch into each subbasin is shown in Figure 25.

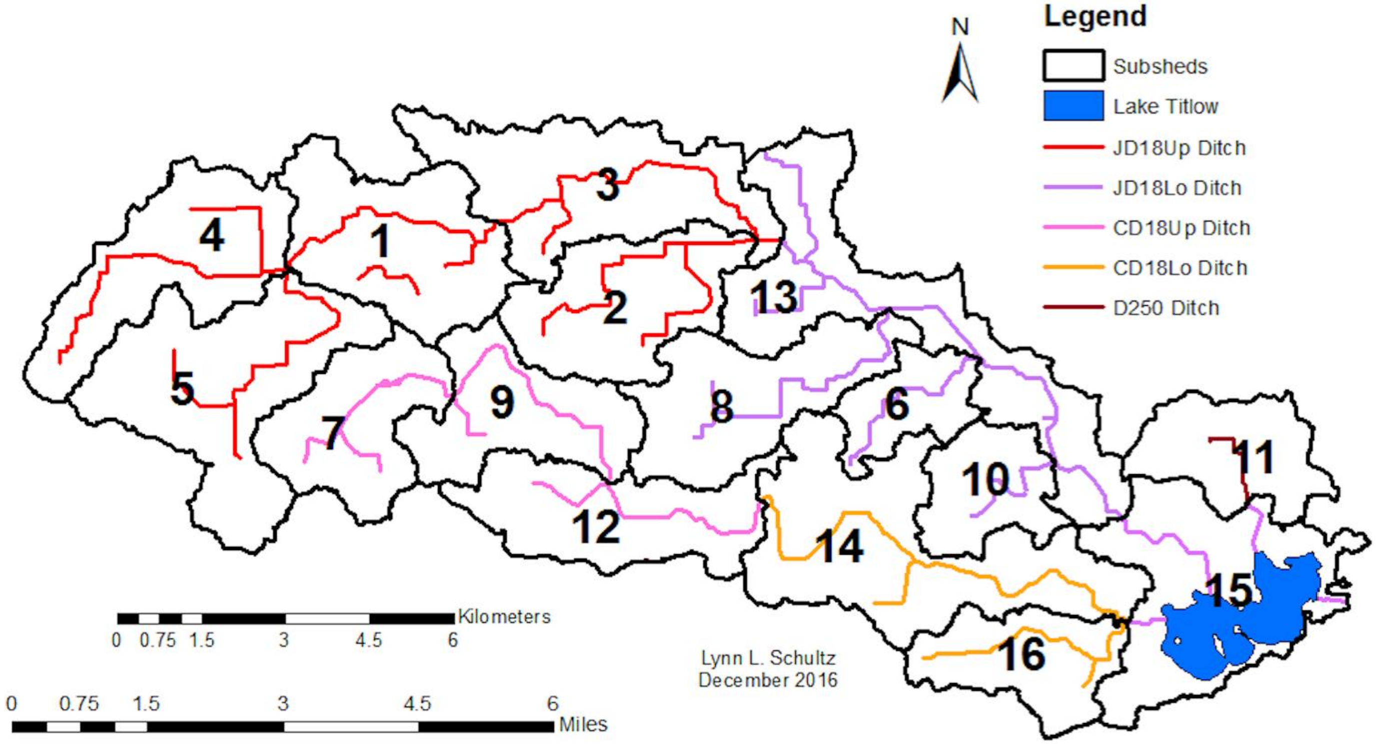

Figure 25. Tributaries and subsheds of the Lake Titlow watershed, Sibley and McLeod counties, Minnesota

6.12. Elevation Map of the Lake Titlow Watershed

JD18Up subbasins 4 (1079 feet; 2306 acres) and 5 (1086 feet; 3152 acres) have the highest elevations and the most difference in elevation (62 feet; 57 feet) of any subbasins. D250 (1027 feet; 1383 acres) and subbasin 10 (JD18Lo; 1027 feet; 1144 acres) both have the lowest elevation and less difference in elevation (39 feet; 33 feet). Subbasin 10 (JD18Lo) is the second to smallest subbasin with 1144 acres (Table 33; Fig. 26).

The three subbasins with over 3000 acres (5, 13, 14) all have over 50 feet difference in elevation. CD18Up subbasin 7 has the highest minimum elevation at 1033 feet. Subbasins 11 (D250) and 14 (CD18Lo) have the two lowest minimum elevations at 988 feet. Subbasin 6 (JD18Lo) is the smallest (905 acres) and has a difference in elevation of 43 feet. Subbasin 14 is the largest (3517 acres) and has a difference in elevation of 52 feet (Table 33; Fig. 26).

Table 33. Elevation per subshed in the Lake Titlow watershed, Sibley and McLeod Counties, Minnesota.

Site	**Subbasin**	**Minimum Elevation (feet)**	**Maximum Elevation (feet)**	**Difference in Elevation (feet)**	**Ac**	**Average difference in elevation (feet)**
JD18Up	1	1018	1060	42	2401	48
	2	1015	1050	35	2073	
	3	1009	1051	42	2765	
	4	1017	1079	62	2306	
	5	1029	1086	57	3152	
JD18Lo	6	994	1037	43	905	44
	8	997	1047	50	2156	
	10	994	1027	33	1144	
	13	994	1045	51	3206	
D250	11	988	1027	39	1383	39
CD18Up	7	1033	1063	30	1737	33
	9	1024	1056	32	1837	
	12	1020	1056	36	2073	
CD18Lo	14	988	1040	52	3517	47
	16	991	1033	42	1397	

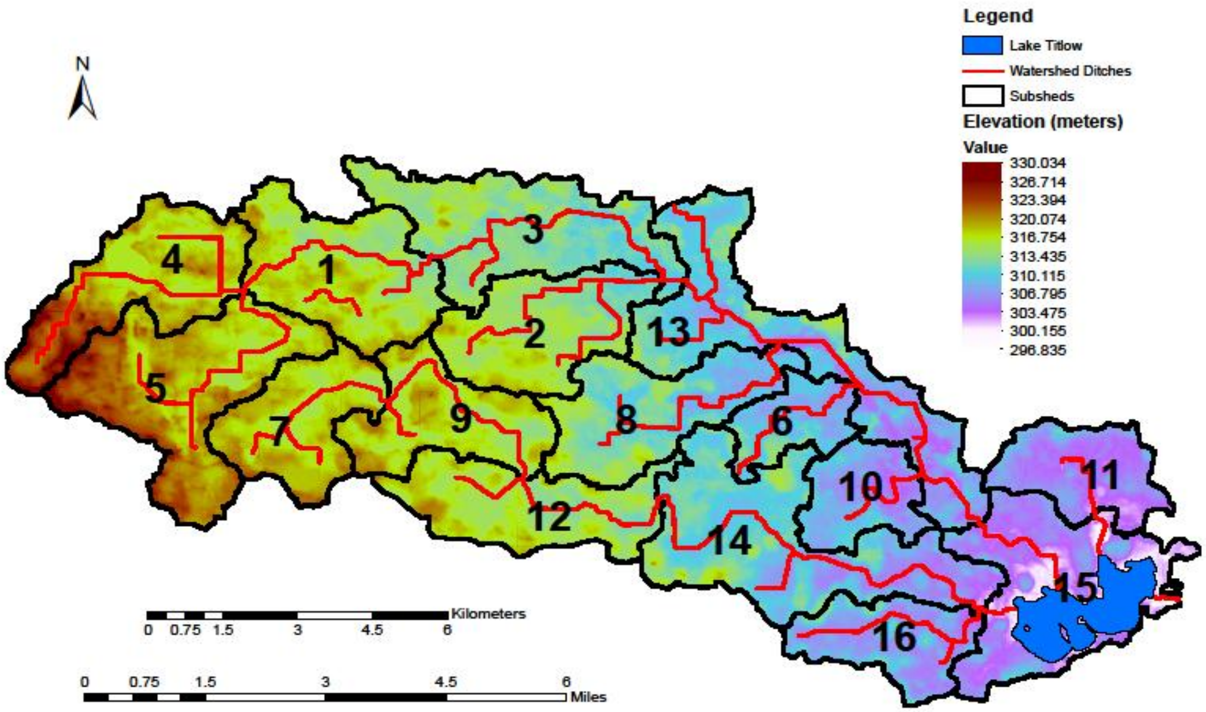

Figure 26. Elevation map of the Lake Titlow watershed, Sibley and McLeod counties, Minnesota.

6.13. Hydrologic Soil Group (HSG) C/D Map of the Lake Titlow Watershed

Soils are grouped together based on similarities in runoff potential during comparable storm and cover conditions (Soil Survey Staff 2015). Group C has moderately high runoff potential when completely wet. These soils are usually 20 to 40% clay, and less than 50% loam. The usual soil texture can be loam silt loam, sandy clay loam, clay loam, and silty clay loam. Group D soils have high runoff potential when completely wet. These soils are greater than 40% clay, less than 50% sand, and have clayey textures. When a soil has a dual classification the first letter applies to the drained soil condition and the second letter applies to the undrained condition. The drained condition means the seasonal water table is below 60 centimeters (24 inches) (USDA 2007).

The variability in soils ranges from 81% HSG C/D in the CD18Lo subshed to 90% in the CD18Up subshed. D250 (89%) has the second highest percent C/D soil. JD18Up and JD18Lo both have 83% HSG C/D. CD18 has the largest variation in percent HSG C/D (81% at CD18Lo to 90% at CD18Up). Figure 28 shows the HSG C/D map units for each subbasin.

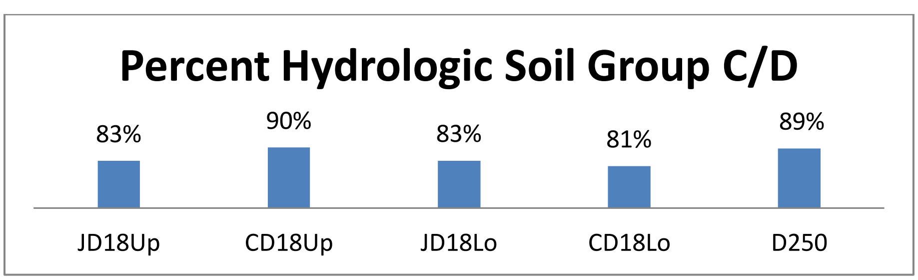

Figure 27. Percent hydrologic soil group C/D per exclusive drainage in the Lake Titlow watershed, Sibley and McLeod counties, Minnesota.

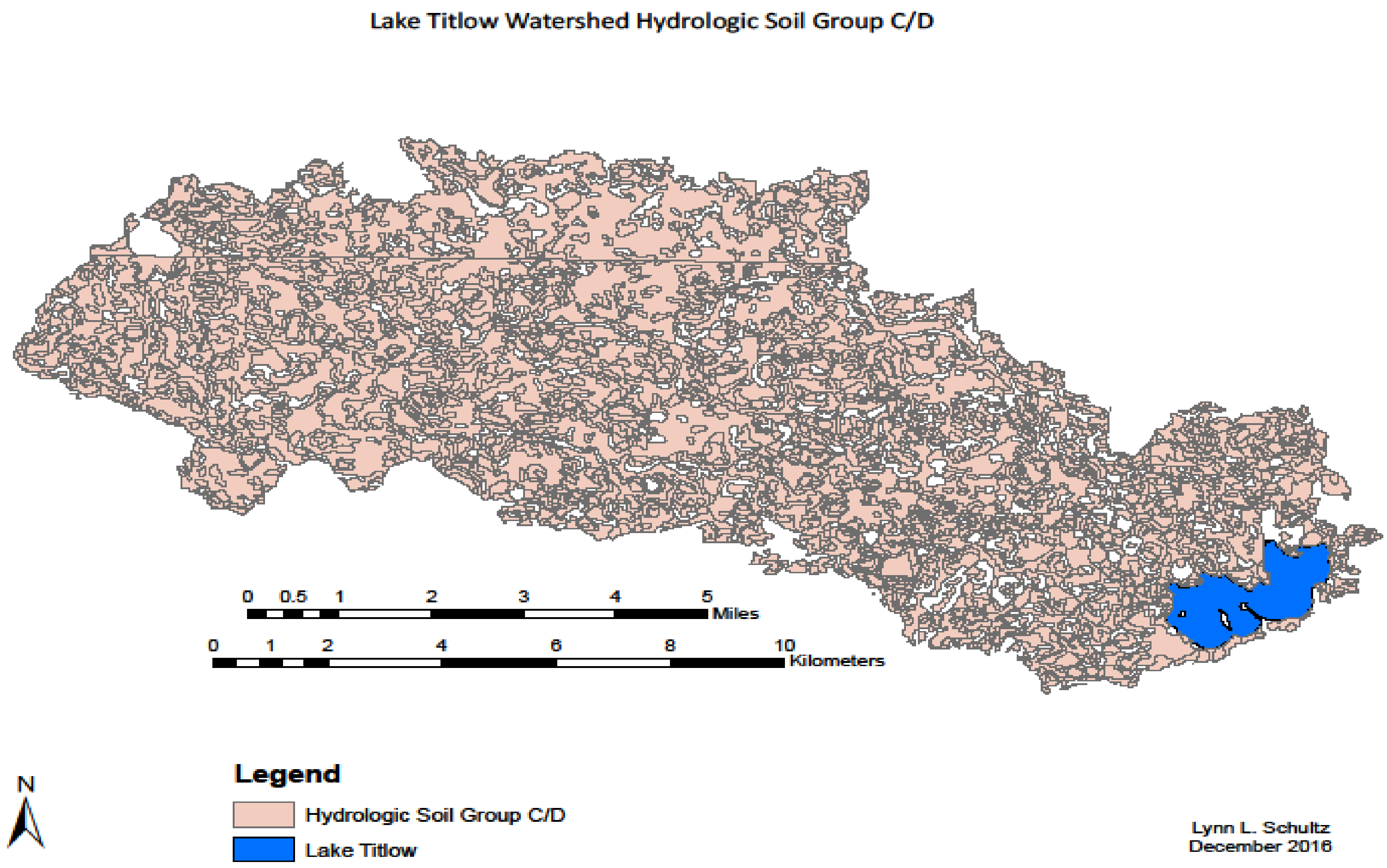

Figure 28. Map of the hydrologic soil group C/D in the Lake Titlow watershed, Sibley and McLeod Counties, Minnesota. HSG C/D map unit areas are in color and outlined in grey (Soil Survey Staff 2015).

6.14. The Cumulative, Exclusive, and Per Square Mile Discharge and Runoff of the Subsheds

In 2009, cumulative discharge ranges from 67,235 to 9,015,535 cubic feet (D250 and JD18Lo, respectively) (Table 16). In 2010, cumulative discharges vary from 203,389 to 90,828,131 cubic feet (D250 and JD18Lo, respectively) (Table 16). In 2009, exclusive discharge ranges, or those that can be assigned to individual subsheds, vary from 0 to 5,323,225 cubic feet (CD18Lo and JD18Up, respectively) (Table 18). In 2010, exclusive discharge ranges from 203,389 to 80,712,183 cubic feet (D250 and JD18Lo, respectively) (Table 18). In 2009, the ranges of discharges that were found per square mile of the individual subsheds varied between 0 and 365,369 cubic feet (CD18Lo and JD18Lo, respectively) (Table 20) while discharges for similar subsheds in 2010 were between 92450 and 6,969,964 cubic feet (D250 and JD18Lo, respectively) (Table 20). The D250 and CD18Lo subsheds have the lowest discharge over the eight events, but which one is lowest varies by cumulative, exclusive, and per square mile discharge. The highest discharge is usually from JD18Lo but JD18Up was highest by exclusive subshed for one precipitation event.

In 2009, cumulative runoff varied between 511 and 102,903 cubic feet (D250 and JD18Lo, respectively) (Table 17). In 2010, the range in cumulative runoff was between 80,772 and 64,371,297 cubic feet (D250 and JD18Lo, respectively) (Table 17). In 2009, the range in runoff estimates that can be assigned to individual subshed varied from 0 to 3,759,407 cubic feet (CD18Lo and JD18Up, respectively) (Table 19). In 2010, exclusive runoff values exhibit a range from 80,772 to 60,994,788 cubic feet (D250 and JD18Lo, respectively)

(Table 19). In 2009, the runoff from each subshed, on a per square mile basis was as low as 0 but as high as 238,036 cubic feet (CD18Lo and JD18Lo, respectively) (Table 21). In 2010, these values were significantly larger. They varied from 13,684 to 5,267,253 cubic feet (JD18Up and JD18Lo, respectively) (Table 21). The D250, CD18Lo, and JD18Up subsheds have the lowest runoff over the eight events, but which one is lowest varies by cumulative, exclusive, and per square mile runoff. The highest runoff consistently originates from JD18Lo; this is true for seven of the eight precipitation events. JD18Up is responsible for creating the most runoff, per square mile, for the one event not attributable to JD18Lo.

Table 16. Total discharge per cumulative drainage for the eight events in this study of the Lake Titlow watershed, Sibley and McLeod Counties, Minnesota.

Cumulative Drainage	Discharge (cf) 4/26/09	Discharge (cf) 6/8/09	Discharge (cf) 8/19/09	Discharge (cf) 10/1/09	Discharge (cf) 4/14/10	Discharge (cf) 6/25/10	Discharge (cf) 8/12/10	Discharge (cf) 9/22/10
JD18Up	1,282,084	4,001,186	157,886	5,323,225	2,852,582	10,115,948	6,741,674	8,975,638
CD18Up	583,147	1,767,240	310,030	1,591,826	980,183	9,609,379	2,655,001	5,396,763
JD18Lo	3,170,036	8,232,154	497,416	9,015,535	6,597,191	90,828,131	46,573,300	70,747,058
CD18Lo	1,110,590	4,325,697	256,540	2,757,963	2,744,733	23,109,449	11,910,469	27,153,493
D250	172,360	236,290	67,235	481,966	203,389	1,719,797	2,048,883	2,013,290

Table 17. Runoff per cumulative drainage for the eight events in this study of the Lake Titlow watershed, Sibley and McLeod Counties, Minnesota.

Cumulative Drainage	Runoff (cf) 4/26/09	Runoff (cf) 6/8/09	Runoff (cf) 8/19/09	Runoff (cf) 10/1/09	Runoff (cf) 4/14/10	Runoff (cf) 6/25/10	Runoff (cf) 8/12/10	Runoff (cf) 9/22/10
JD18Up	473,656	2,578,761	98,084	3,759,407	270,945	3,376,509	4,829,488	5,636,078
CD18Up	81,437	1,023,394	83,296	930,154	359,133	7,058,943	1,942,999	4,836,799
JD18Lo	935,990	5,335,221	102,903	6,135,250	3,056,680	64,371,297	38,454,473	54,848,204
CD18Lo	167,536	2,439,375	17,492	1,647,893	734,468	13,220,190	8,053,088	17,366,735
D250	16,564	78,665	511	292,365	80,772	1,640,034	1934475	1906975

Table 18. Total discharge per exclusive drainage for the eight events in this study of the Lake Titlow watershed, Sibley and McLeod Counties, Minnesota.

Exclusive Drainages	Discharge (cf) 4/26/09	Discharge (cf) 6/8/09	Discharge (cf) 8/19/09	Discharge (cf) 10/1/09	Discharge (cf) 4/14/10	Discharge (cf) 6/25/10	Discharge (cf) 8/12/10	Discharge (cf) 9/22/10
JD18Up	1,282,084	4,001,186	157,886	5,323,225	2,852,582	10,115,948	6,741,674	8,975,638
CD18Up	583,147	1,767,240	310,030	1,591,826	980,183	9,609,379	2,655,001	5,396,763
JD18Lo	1,887,952	4,230,968	339,530	3,692,310	3,744,609	80,712,183	39,831,626	61,771,421
CD18Lo	527,443	2,558,458	0	1,166,137	1,764,549	13,500,070	9,255,467	21,756,729
D250	172,360	236,290	67,235	481,966	203,389	1,719,797	2,048,883	2,013,290

Table 19. Runoff per exclusive drainage for the eight events in this study of the Lake Titlow watershed, Sibley and McLeod Counties, Minnesota.

Exclusive Drainage	Runoff (cf) 4/26/09	Runoff (cf) 6/8/09	Runoff (cf) 8/19/09	Runoff (cf) 10/1/09	Runoff (cf) 4/14/10	Runoff (cf) 6/25/10	Runoff (cf) 8/12/10	Runoff (cf) 9/22/10
JD18Up	473,656	2,578,761	98,084	3,759,407	270,945	3,376,509	4,829,488	5,636,078
CD18Up	81,437	1,023,394	83,296	930,154	359,133	7,058,943	1,942,999	4,836,799
JD18Lo	462,334	2,756,460	4,819	2,375,843	2,785,735	60,994,788	33,624,985	49,212,126
CD18Lo	86,099	1,415,980	0	717,739	375,336	6,161,246	6,110,089	12,529,936
D250	16,564	78,665	511	292,365	80,772	1,640,034	1,934,475	1,906,975

Table 20. Discharge per exclusive drainage per square mile for the eight events in this study of the Lake Titlow watershed, Sibley and McLeod Counties, Minnesota.

Exclusive Drainage	Discharge (cf) 4/26/09	Discharge (cf) 6/8/09	Discharge (cf) 8/19/09	Discharge (cf) 10/1/09	Discharge (cf) 4/14/10	Discharge (cf) 6/25/10	Discharge (cf) 8/12/10	Discharge (cf) 9/22/10
JD18Up	64,752	202,080	7,974	268,850	144,070	510,906	340,489	453,315
CD18Up	66,267	200,823	35,231	180,889	111,384	1,091,975	301,705	613,269
JD18Lo	163,036	365,369	29,320	318,852	323,369	6,969,964	3,439,691	5,334,320
CD18Lo	68,677	333,133	0	151,841	229,759	1,757,822	1,205,139	2,832,907
D250	78,345	107,405	30,562	219,076	92,450	781,726	931,310	915,132

Table 21. Runoff per exclusive drainage per square mile for the eight events in this study of the Lake Titlow watershed, Sibley and McLeod Counties, Minnesota.

Exclusive Drainage	Runoff (cf) 4/26/09	Runoff (cf) 6/8/09	Runoff (cf) 8/19/2009	Runoff (cf) 10/1/2009	Runoff (cf) 4/14/2010	Runoff (cf) 6/25/2010	Runoff (cf) 8/12/2010	Runoff (cf) 9/22/2010
JD18Up	23,922	130,240	4,954	189,869	13,684	170,531	243,914	284,650
CD18Up	9,254	116,295	9,466	105,699	40,811	802,153	220,795	549,636
JD18Lo	39,925	238,036	416	205,168	240,564	5,267,253	2,903,712	4,249,752
CD18Lo	11,211	184,372	0	93,456	48,872	802,246	795,584	1,631,502
D250	7,529	35,757	232	132,893	36,714	745,470	879,307	866,807

6.15. Cumulative and Exclusive Slope of the subsheds

Slope is important to water quality because it influences the amount of erosion by rainfall. Land with a higher slope has increased erosion. The percent slope of the exclusive drainages ranges from 1.64 to 1.88 (Figs. 29 and 30). JD18Lo has the highest slope (1.88%) and D250 has the least (1.64%). When viewed on the basis of slopes within each exclusive drainage, there is not much variation within the watershed (1.64 to 1.71%) (Table 22).

Table 22. Slope percent by cumulative subshed (JD18Up + JD18Lo and CD18Up + CD18Lo) and slope percent by exclusive subshed (JD18Lo and CD18Lo without JD18Up and CD18Up). The mean slopes were generated in ArcMap using 1 m LiDAR.

Mean Cumulative Slope				
JD18Up	JD18Lo	CD18Up	CD18Lo	D250
1.71	1.79	1.75	1.81	1.64
Mean Exclusive Slope				
JD18Up	JD18Lo	CD18Up	CD18Lo	D250
1.71	1.88	1.75	1.86	1.64

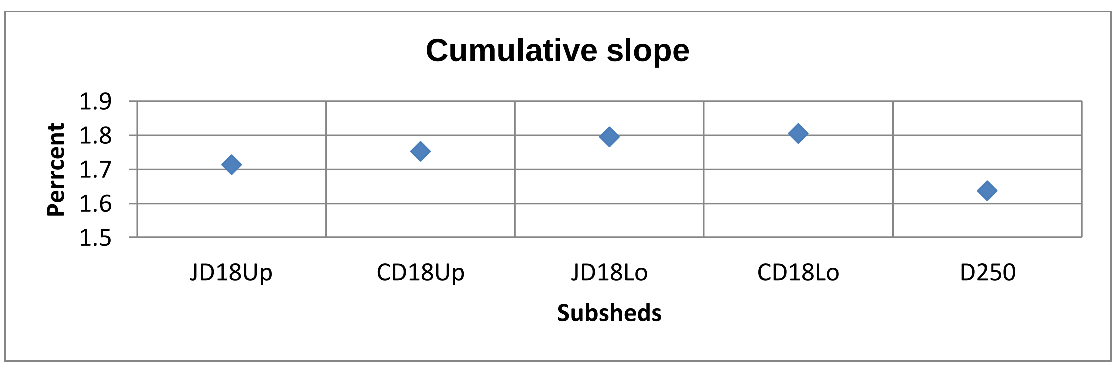

Figure 29. Slope percent per cumulative subsheds of the Lake Titlow watershed, McLeod and Sibley Counties, Minnesota. Cumulative refers to JD18Lo and CD18Lo including their upland subsheds (JD18Up and CD18Up).

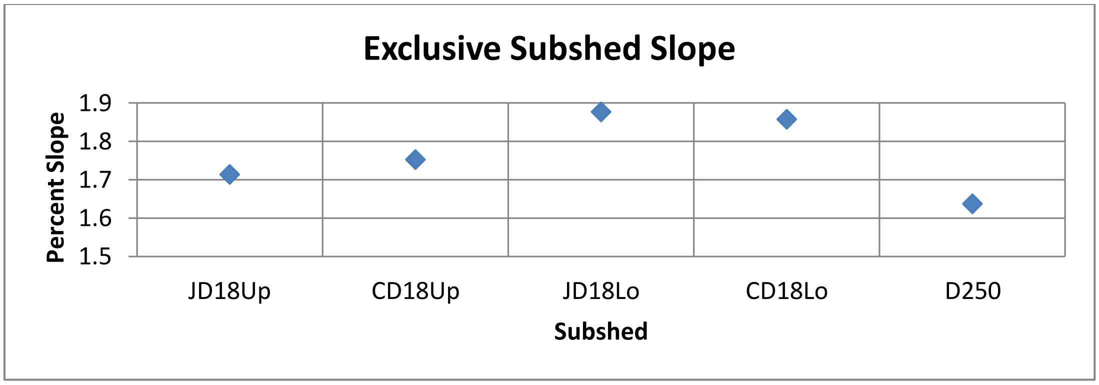

Figure 30. Slope percent per exclusive subsheds of the Lake Titlow watershed, McLeod and Sibley Counties, Minnesota. Exclusive refers to JD18Lo and CD18Lo not including their upland subsheds (JD18Up and CD18Up).

6.16. TSS, TP, and NOx versus Runoff for Exclusive Subshed and Per Unit Area

Runoff transports the TSS, TP, and NOx to the sampling points. As shown in the following figures (83 through 88), the NOx has less of a correlation to the amount of runoff because it is more water soluble than the TSS and TP. The relationship among runoff, TSS, and TP is logical as more energy from the water will move more TSS and its associated TP (Figs. 31 through 36).

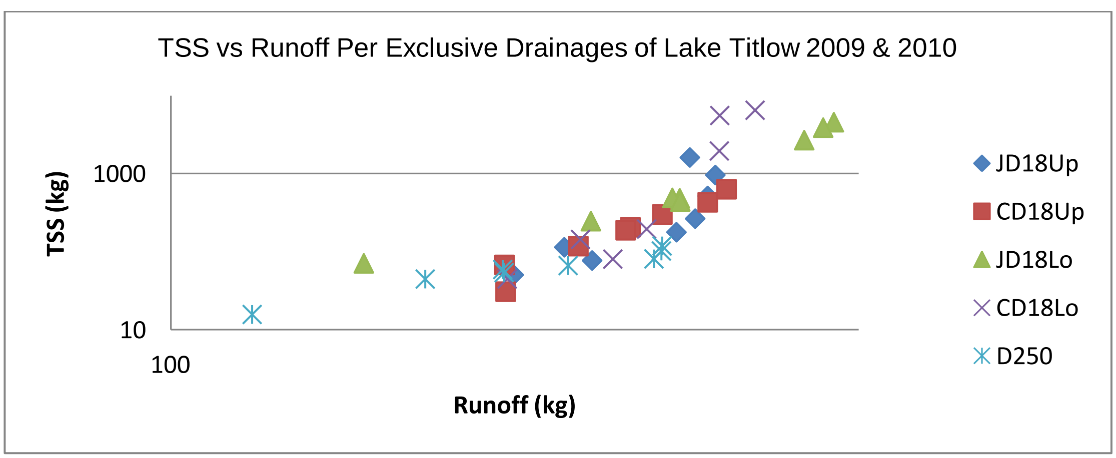

Figure 31. TSS versus runoff per exclusive drainage for the eight events in this study of the Lake Titlow watershed, Sibley and McLeod Counties, Minnesota.

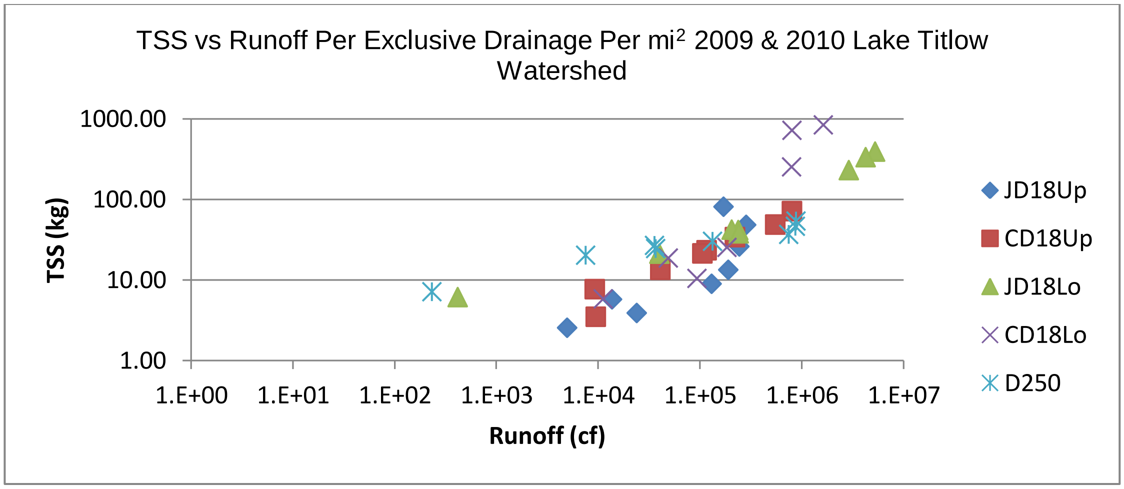

Figure 32. TSS versus runoff per exclusive drainage per square mile for the eight events in this study of the Lake Titlow watershed, Sibley and McLeod Counties, Minnesota.

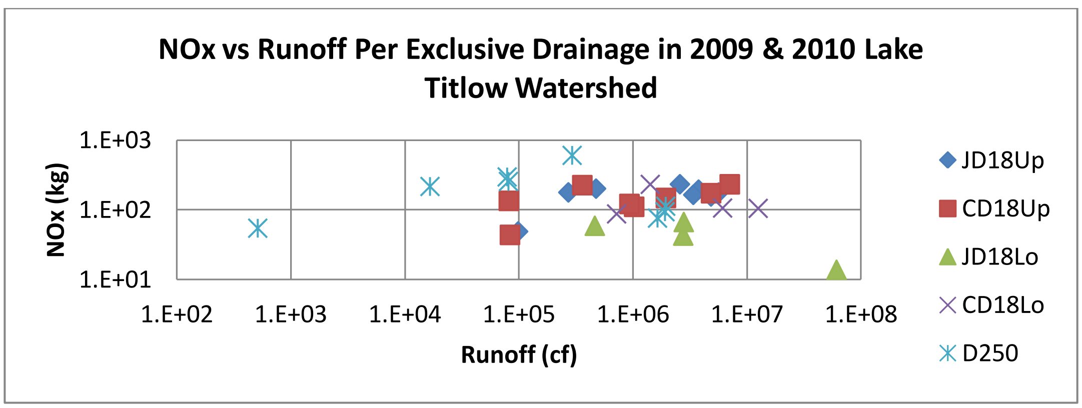

Figure 33. NOx versus runoff per exclusive drainage for the eight events in this study of the Lake Titlow watershed, Sibley and McLeod Counties, Minnesota.

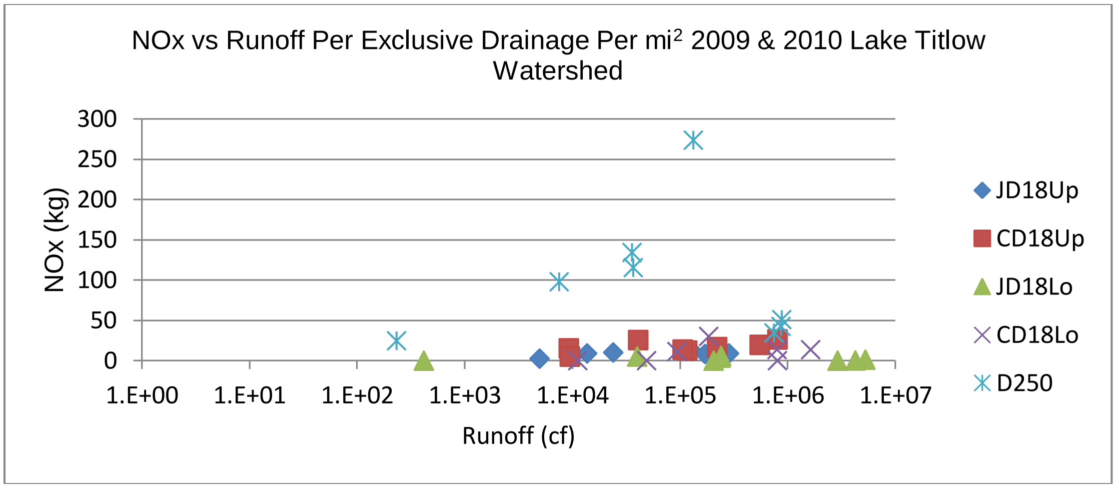

Figure 34. NOx versus runoff per exclusive drainage per square mile for the eight events in this study of the Lake Titlow watershed, Sibley and McLeod Counties, Minnesota.

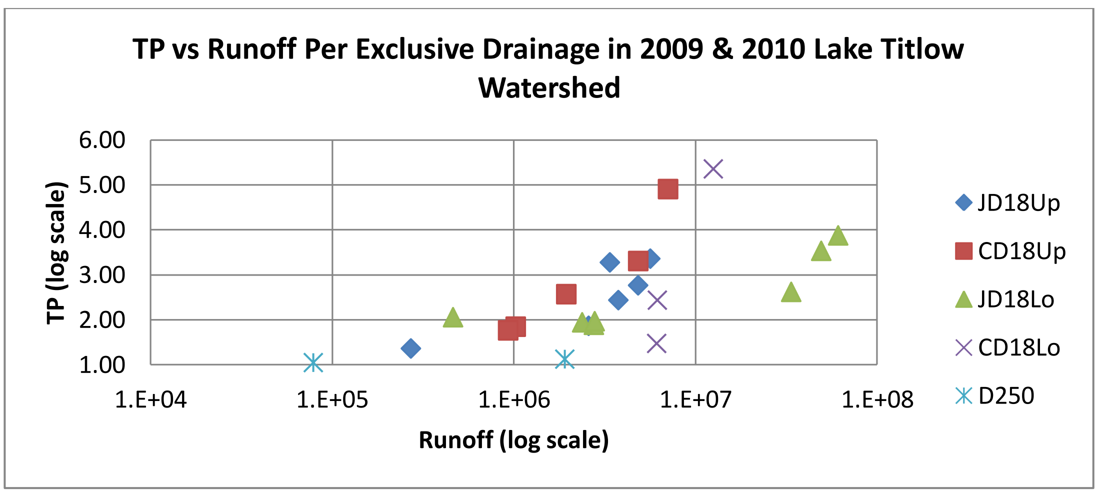

Figure 35. TP versus runoff per exclusive drainage for the eight events in this study of the Lake Titlow watershed, Sibley and McLeod Counties, Minnesota.

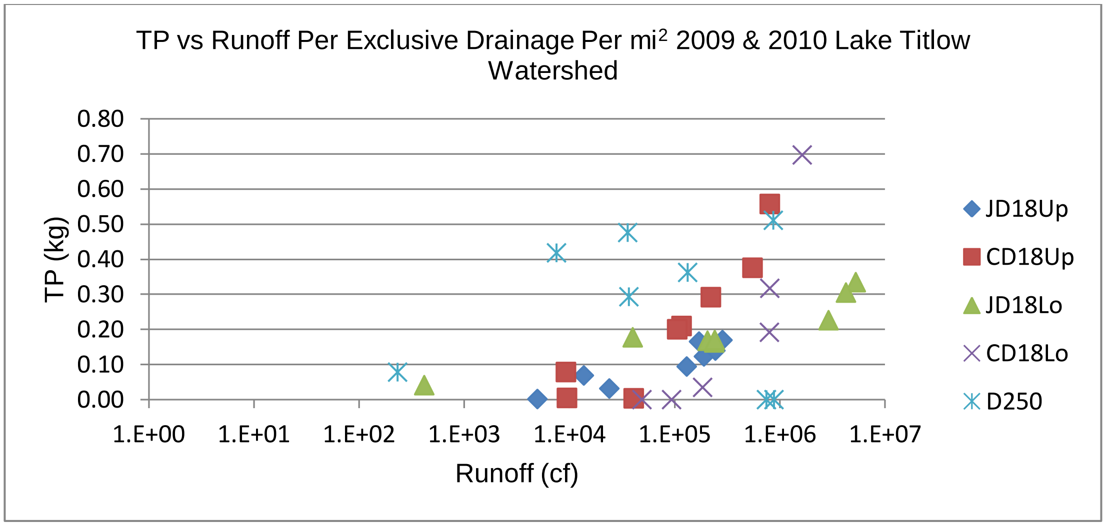

Figure 36. TP versus runoff per exclusive drainage per square mile for the eight events in this study of the Lake Titlow watershed, Sibley and McLeod Counties, Minnesota.

7. Discussion

The Lake Titlow watershed is located in southern Minnesota and is part of the North Branch Rush River watershed that is part of the Lower Minnesota River major watershed that is part of the Upper Mississippi River watershed that drains into the Gulf of Mexico. This approximately 35,000 acre watershed is located in the Western Corn Belt Ecoregion of the Prairie Pothole Region. This mostly agricultural watershed has two main ditches that drain into Lake Titlow, CD 18, and JD18 (the largest subshed). A minor tributary is D250 whose small area (1383 acres), elevation of 988 feet, and adjacency to Lake Titlow (elevation 987.5 feet), can cause the sample results to mimic the lake water quality parameter concentration when the lake water level is higher and backflow occurs from the lake.

SEH Inc., completed their assessment of the watershed in 2010. They examined the watershed for placement of the most effective and cost efficient best management practices (BMPs). SEH ran the Soil and Water Assessment Tool (SWAT) model to predict water, nutrient, and chemical loads using simulated and real rainfall data and flow data from 2009, an abnormally dry year. The results concluded that JD18Lo (subbasins 6, 8, 10, 13) produced the largest amounts of TSS, TP, and NOx. SEH's recommended BMPs that focused on nutrient management, conservation tillage, strip-cropping, and cover crop/rotations. They suggested that assessing the drainage ditches and recording bank erosion/conditions would provide information on where fixes are needed; using a technique in the lake could improve water quality; and installing a drawdown structure for the lake water level to manage fish, or vegetation could be helpful. Restorable wetland areas were identified for the entire watershed that could lessen the NPS pollution to Lake Titlow (SEH 2010).

The research presented herein aimed to expand the SEH results by incorporating additional rainfall and runoff data and by using alternate means of examining the watershed characteristics. The initial round of analyses and interpretation used the FLUX model to estimate nutrient and sediment loading to the streams, but the resulting FLUX coefficient of variation values (CVs) were higher than ideal. The CV indicates uncertainty in the loading estimate and is the standard error of the mean loading divided by the mean loading (Walker 1999). A CV of <0.1 is usually sufficient to estimate mass balances (Walker 1999). Although, getting a CV of <0.1 may not be possible in small, flashy streams with strong concentration/flow relationships, or if there is not enough sample data input to get desired results, or both (Walker 1999). Using this study data the majority of CVs for TSS and TP were >0.1, although the NOx CVs were usually <0.1.

To circumvent the uncertainty of the FLUX model estimates, four individual rain events for each year of monitoring were selected to represent the range of runoff and loading values that exist within the watershed after low, middle low, middle high and high rain events. These rain events were chosen to capture the variability of runoff, sediment and nutrient responses of the subsheds to different rain amounts in an effort to identify the subshed origin of the largest runoff, and loads during different parts of the season. The discharge, runoff, and loads were calculated manually. There are four rain storm events in 2009 and four rain storm events in 2010, starting in April, and ending in October. Manual calculation of the sediment, and nutrient loads increased the accuracy and precision of loads because they are proportional to the flow for each real event, although a drawback of this method is that numerous samples are usually needed to show the true load pattern (Meals et al. 2013).

Results illustrate processes that can lead to excessive runoff as well as sediment and nutrient loading to the agricultural stream system of the Lake Titlow watershed. Lakeshed physical attributes of hydrologic soil group, elevation, slope, land use, and size of subbasins were examined in the evaluation of the subsheds. Hydrologic parameters of discharge, runoff, and precipitation are assessed in relation to TSS, TP, and NOx.

Thus, the goal of providing an understanding of the hydrologic processes, sediment, and nutrient transport through the watershed of a shallow lake modified by agricultural practices has been achieved. In the following sections the roles of each physical, meteorological, hydrological, and anthropogenic factor influencing runoff, and the transport of sediment and nutrients through the lakeshed are discussed.

7.1. Lakeshed Runoff, Water Quality Parameters, and Watershed Factors

7.1.1. Runoff in the Watershed

Runoff (a principal contributor to soil erosion) is increased in agricultural areas with modified drainage systems and can differ between large, and small storms (Vandegrift and Stefan. 2010). The 2009 year was an abnormally dry precipitation year, whereas the 2010 year was an above normal precipitation year, giving the discharge and runoff from these years very different results. The 2009 and 2010 hydrographs for JD18, CD18, and D250 (Figs. 20 through 22) illustrate the differences in runoff from these Lake Titlow tributaries. The discharge peaks show that JD18 carries over twice as much water volume as CD18 and over six times as much as D250. The highest discharge of this study for cumulative JD18 was 380 cubic feet per second (cfs), for cumulative CD18 it was 170 cfs, and for D250 it was 70 cfs. The cumulative JD18 drainage system encompasses 63% of the watershed, and produced the largest amount of discharge and runoff for every event in this study. D250 is not really a factor in discharge and runoff volume because it is only 4% of the watershed.

Decreasing runoff volume is desirable because it decreases erosion rates of ditches, transport of sediment, and nutrient loads (Mulla et al. 2006). Therefore, quantification of runoff for each event from each subshed from different rain storm amounts helps to characterize the subsheds and provide the information to help choose BMPs that can mitigate the volume of runoff to the lake. Runoff distribution of exclusive JD18Lo, and CD18Lo subsheds is disproportionate to their upland counterparts. For example, the June 2010 event at JD18Lo produced over four times the cubic feet of water which is over 400% of the flow of JD18Up, and 26% of JD18Lo's annual flow. This event only accounted for 11% of JD18Up's annual flow. It would be expected that the exclusive JD18Lo subshed would have about half of the runoff of the JD18Up subshed because JD18Lo encompasses 37% of the JD18 drainage system, and JD18Up is 63% (Table 43). The ‘Lo’ subsheds are closer to the lake and produce a disproportionate amount of runoff. The lakeshed runoff was 20% more in 2010, and precipitation was 24% more in 2010. There was 8.14 Mcf of runoff in 2009 and 177.4 Mcf in 2010. Consequently, increased rainfall leads to larger runoff and loads in the overall lakeshed, but the relationship does not apply to subsheds.

Table 23. The runoff from the June 2010 study event at JD18Up and JD18Lo subsheds of the Lake Titlow watershed, Sibley, and McLeod counties, Minnesota.

Site	Mcf	% Annual Flow	% Flow Relative to JD18UP	% of JD18 Subbasin Surface Area
JD18UP	32	11	100	63
JD18LO	145	26	453	37

7.1.2. WCBP Ecoregion Water Quality Parameters

The various ecoregions of Minnesota have different physical and chemical attributes that Influence lake, and stream water quality. The WCBP Ecoregion is over 75% row crops, and the leading water quality problems are sedimentation and high nutrients from farm field sediment and fertilizers (USEPA 2000). Typical stream water quality parameter values for the WCBP Ecoregion are shown in Table 41 (MPCA, accessed 11/20/16).

The subshed water sample results for each of the water quality parameters were not consistently highest from any particular subshed for the two years of study events. There were a total of 138 measurements of TSS, TP, and

NOx. The average concentration of each of these parameters was higher than the average for streams in the WCBP Ecoregion: NOx was 3 times higher, TP was 14 times higher, and TSS was 45 times higher than average WCBP ecoregion stream values.

Given that the average sediment and nutrient load results were outside the average of the typical stream values for the WCBP ecoregion (Table 41), the ditch water quality is in clear need of improvement. It appears that it is this loading that is the root cause of Lake Titlow's 2010 listing on the Clean Water Act's Section 303d for nutrient pollution, eutrophication and biological indicators for impairment of aquatic life and recreational use (MPCA 2011). Specifically, the sediment and nutrients moving through JD18 and CD18 are a problem and in order to improve the quality of water in the lake, agricultural BMPs must be implemented in the lakeshed.

Table 24. Typical stream water quality concentrations (mg/L) in the WCBP Ecoregion (MPCA, accessed 11/20/16) and ranges for Lake Titlow watershed samples for 2009 and 2010, Sibley and McLeod Counties, Minnesota.

Sample	**Water Quality Parameter**		
Typical WCBP Ecoregion	TSS (10-61 mg/L)	TP (.16-.33 mg/L)	NOx (1.4-7.4 mg/L)
JD18UP	0.5-116	0.055-1.74	1.1-18.6
JD18LO	3.8-2989	0.0475-0.972	2.3-20.2
CD18UP	0-36	0.0125-0.673	0-21.6
CD18LO	1.8-673.75	0.03-1.0875	0-19.6
D250	0-15.4	0.045-1.3	0.4-21

As closer look at the results was undertaking to identify the specific locations within the watershed that would benefit most from implementing BMPs. During this investigation, it was found that the 2010 study events had 91% more TSS, 9% more TP, and 21% less NOx than the 2009 study events; however, the concentrations of TSS, TP, and NOx were variable by subshed for the study events. For the very large rain event in September 2010, the CD18Lo site produced the highest loads of TSS, and TP with only 25 percent of the runoff of JD18Lo, even though CD18Lo is only 15% of watershed. This sediment and nutrient loading event was disproportionate for the size of this subshed.

As shown in the work of Magdalene (2004) in similar agriculturally-dominated lands, extreme precipitation and conventional farming practices combine to produce large loading events. Here, the highest NOx was in the fall, following the period of time when plants can uptake nitrogen. However, the highest NOx came from the smallest subshed, D250 (4% of the watershed)

(Table 42). This small subshed is close to the lake and about the same elevation (Lake Titlow elevation is 987.5 feet and D250 is 988 feet on the lake side), so it acts like a backwater of the lake during higher flows.

JD18Up and CD18Up had higher amounts of NOx compared to their lowland counterparts for all storm events except the June 2009 for the CD18 drainage system. JD18Lo had only 14% of the NOx that JD18Up had for the eight study events, and CD18Lo had only 30% of the NOx that CD18Up had for all storm events except June 2009 where CD18Lo had 48% more NOx than CD18Up. The lower amount of NOx at the downstream sample sites, JD18Lo and CD18Lo, demonstrates that the lakeshed is still filtering NOx from the streams before the water reaches Lake Titlow during both an abnormally dry and an above average precipitation year.

Table 25. The TSS, TP, NOx highest loads in the subsheds of the Lake Titlow watershed, Sibley and McLeod Counties, Minnesota, for the two year (2009-2010).

Site	TSS (kg) 9/21/2010	TP (kg) 9/21/2010	NOx (kg) 10/1/2009
JD18Up	959.61	3.36	193.90
CD18Up	430.13	3.31	120.80
JD18Lo	3885.50	3.53	0.00
CD18Lo	6483.32	5.35	87.01
D250	102.41	1.12	602.09

7.1.3 Meteorological, physical, and land use factors

As shown previously in this work, rain storm events drive the runoff that promotes low water quality in Lake Titlow; however, the physical characteristics and land use practices impact the timing and magnitude of watershed runoff and consequently, the quality of the water that reaches the ditches. Row cropping causes higher runoff, and increases the amount of sediment, and nutrients in the runoff (Toy 2008).

Rain storm amounts are variable and result in differing runoff that can be amplified by soil type and affect erosion. The intra-annual rain event amounts were significantly different, as were the total seasonal rainfall amounts for 2009 and 2010. When wet, the soils have a high runoff potential (Magdalene 2004). In 2010, there was an overall higher rain amount which caused more runoff and discharge pulses to the drainage systems. Sediment load from the four 2010 rain events had an increase of 91% over the 2009 sediment loads from the four rain events. The majority of watershed precipitation events that occurred during this study exhibit the historical pattern of having less rain in the west and more rain in the east for six of the eight events. June and October 2009 had the highest amounts of rain in the western part of the watershed. For the overall watershed, the results of this study show that 24% more rainfall led to 20% more runoff. However, this relationship does not apply to individual subsheds, only collective areas of the watershed. If historical patterns of less rain in the west than the east hold true, then JD18Lo and CD18Lo are at higher risk of erosion than JD18Up and CD18Up. Although, climate change patterns of larger rains in a shorter amount of time will increase erosion in all subsheds.

In general, the lakeshed soils are clay-rich. Over 80% of the lakeshed surface area consists of HSG C/D. When thoroughly wet, these soils have low infiltration rates and high runoff potential (USDA 2007). Throughout the 2010 season, the lakeshed had higher rainfall amounts at all rain gauges (Table 24) and the soil likely maintained a higher moisture content. Therefore, the runoff potential of the soil was likely increased in 2010 and rainfall reached the ditches more quickly. The fine texture of clay soil inhibits infiltration and thus generates larger runoff volumes. When the runoff reaches the ditch, it becomes concentrated and then moves at a greater velocity and creates a larger erosive force on the soil of the ditch channel (University of Michigan, accessed 12/11/16). For this lakeshed, it is critical to note that there is virtually no difference in HSG C/D soil percentages in the upland and lowland areas (Table 26). Therefore, given the established relationships that exist among soils, runoff, and erosion, and given that all soils in all subsheds are virtually indistinguishable, it is concluded that the soils of the watershed do influence its runoff and loads but they do not account for the variability seen among its subsheds.

Table 26. Percent hydrologic soil group C/D for each subshed in the Lake Titlow watershed, Sibley and McLeod Counties, Minnesota.

Site	**Hydrologic Soil Group % C_D**
JD18Up	83
CD18Up	90
JD18Lo	83
CD18Lo	81
D250	89

This lakeshed is essentially flat, having an average subshed slope of 1.6-1.9%. The JD18Lo and CD18Lo subsheds do have steeper slope than JD18UP and CD18Up by 9% (Table 30). Larger loads exit at JD18Lo and CD18Lo for some of the eight precipitation events. JD18Lo had larger TSS loads for all 2009 and 2010 events; CD18Lo had larger TSS loads for August 2009 and all 2010 events; JD18Lo had larger TP loads for April, June, and August 2009 and April, June and September 2010; CD18Lo had larger TP loads for August 2009 and September 2010; JD18Lo and CD18Lo did not have larger NOx loads for any of this study's precipitation events. Thus, these results imply that slope may be a factor in creating variable nutrient and sediment loads within the subsheds of Lake Titlow.

Past research has concluded that agricultural land use creates more runoff, nutrient, and sediment loading to streams and lakes (Miller et al. 2012). The Lake Titlow watershed is highly modified with >80% row cropping. Even though there was an increase, by about 10%, in row cropping in 2010 (Table 27), the 2009 and 2010 field plantings were similar. Overall, corn is about 55% and beans are about 45% of combined corn/bean acreage both years. The individual subsheds have a similar distribution of corn and beans. The runoff and load differences in this lakeshed are not readily correlated with differences in corn and bean distribution because the runoff and loads have large differences between precipitation events and years; however, the distribution of different types of plantings by subshed or by year do not have large differences.

Table 27. Corn and soybeans by subshed in 2009 and 2010 in the Lake Titlow watershed, Sibley and McLeod Counties. Acres were calculated using Cropscape (United States Department of Agriculture, Dec. 2015).

JD18Up Land use			**JD18Lo Land use**	
Class Name	2009 Acres	2010 Acres	2009 Acres	2010 Acres
Corn	6291	5282	2949	3290
Soybeans	3208	4823	3230	2711
CD18Up Land use			**CD18Lo Land use**	
Class Name	2009 Acres	2010 Acres	2009 Acres	2010 Acres
Corn	2216	2820	2741	1981
Soybeans	2157	1760	1369	1910

8. Conclusion and Recommendations

The conclusions of this study clearly demonstrate that the runoff and loads originating in the area above Lake Titlow during the 2009 and 2010 monitoring seasons are significant and contribute to the impairment of water in the lake. The results also help indicate the areas within the watershed that likely contribute the most sediment and nutrients to the lake. Runoff, the vector of both the sediment and nutrients appears to correspond to precipitation, with the average values from all areas during the wet year (2010) being two to three times larger than those from the dry year (2009). Within the watershed, these results confirm those found earlier by SEH, indicating that the subshed associated with JD18Lo provides a significantly disproportionate amount of runoff (5x greater than any other subshed) to the lake.

With regard to specific sediment and nutrient loads, it is interesting to note that the abnormally dry year (2009) precipitation events produced its highest TSS loads per unit area at D250 (30.30 kg / mi^2); this value, however, is skewed by backflow and the limited size of the subshed and thus, the value for CD18Lo (25.45 kg / mi^2) should be regarded as the peak value of TSS for the watershed during a dry year. With respect to TP, 2009 study event resulted in the highest TP loads per exclusive subshed of 231.79 kg at JD18Up, most of which resulted from a single, highly erosive event. Similar to TSS, NOx loads per unit area at D250 (602.09 kg / mi^2) were large and likely unrepresentative of the genuine impact of this small area on the overall lake. A more representative estimate of the large NOx loads entering the lake is provided by the results from CD18Lo, where 230.85 kg per mi^2, at CD18Lo, and 602.09 kg at D250.

Showing some commonality with 2009, the above average precipitation year (2010) study events resulted in the highest TSS loads per exclusive subshed at CD18Lo (844.18 kg / mi^2). The highest TP loads, however, shifted from JD18Up to CD18Lo (5.35 kg/mi^2), indicating that the subsheds above that CD18Lo contribute significant loads to the lake regardless of the rainfall regime. Futher to the point that the CD18 drainage contributes appreciable sums of nutrients to the lake, note that NOx loads per exclusive subshed were largest at CD18Up (231.21 kg/mi^2) during 2010.

The results of this research provide additional understanding to origin and distribution of the loads that impact Lake Titlow: runoff is greater in the JD18 drainage, however, sediment and nutrient loads per unit area are actually greater in the CD18 drainage. Furthermore, these results show that while land use, soils, and rainfall across the entire area of investigation contribute to the high runoff and loads of the lakeshed, they are not individually responsible for the significant subshed variability that was observed in 2009 or 2010. Alternatively, ground surface slopes of the lakeshed should not theoretically contribute to the rapid, large runoffs and loads in this lakeshed; however, there are subtle slope differences among the subsheds that could contribute to the disproportionate increases in both runoff and load that are observed in the JD18Lo and CD18Lo subsheds that lie near the lake.

Improving water quality in the streams and lakes of a mostly agricultural watershed requires the use of agricultural BMPs. The main nonpoint source pollutants are sediment, phosphorus, and nitrogen (Minnesota Department of Agriculture, 2012). Based on this research of the Lake Titlow watershed the following BMPs are recommended to reduce runoff, sediment, and nutrients in the ditch flow: two stage ditches, constructed wetlands, and buffer strips (filter strips, field borders).

Two-stage ditches can trap sediment, remove nitrogen, and improve habitat. After vegetation is established, they are basically self-sustaining because they imitate natural fluvial processes. These could be installed watershed wide because current ditches are the traditional trapezoidal design. Considering the results from this lakesed, two-stage ditches would help stabilize and decrease erosion of the ditch channel, and provide vegetation to help remove nitrogen from the stream. Although, construction of two-stage ditches could require additional land that is currently utilized for row cropping and may not be available for water conservation because of the financial value of the land to the landowner (Miller et al 2012).

Constructed wetlands are man-made wetlands that remove sediment and nutrients from runoff. Surface flow wetlands provide anaerobic water for denitrification processes, but need a sufficient organic carbon source to maximize denitrification (Isenhart, 1992). Subsurface wetlands are effective at settling out TSS, but nitrogen and phosphorus removal is varied (Schueler, 1992). The size and placement of constructed wetlands is key to sediment and nutrient removal and to prevent sedimentation of the constructed wetland. In this lakeshed, considering the results, constructed wetlands could help alleviate TSS if they are large enough to accommodate the runoff volume. Wetlands have been shown to have a variable effect on removing nitrogen and phosphorus, and there are issues properly locating wetlands in drainage systems because landowners do not want to give up cropland for their construction (Miller et al 2012).

Filter strips and field borders are strips of permanent vegetation at the edge of a field and are a common BMP practice to decrease sheet flow runoff, sediment, and nutrients entering surface waterways. The vegetation provides resistance to the water. Therefore, it reduces runoff volume and causes the sediment and associated phosphorus to settle out of the runoff. Dissolved phosphorus and nitrogen are decreased less than sediment bound nutrients, but reduction increases with increased width of the filter strip (Table 45) (Miller et al. 2012; Blanco-Canqui et al. 2004; Helmers et al. 2008; Schmitt et al. 1999). Considering the Lake Titlow study results, field borders would protect soil on the edge of the field from wind and water erosion. Filter strips could decrease runoff volume, sediment and nutrients; however, there is little research on nutrient removal in tile drained fields (Miller et al. 2012).

Table 28. Percentage of pollutant reduction for filter strips (Arora et al. 1996; Webber et al. 2009; Eghball et al. 2000).

Pollutant	Mean	Minimum	Maximum	Number of Entries	Source
Sediment	86	76	91	6	1
Total Phosphorus	65	38	96	4	2, 3
Nitrogen	27	27	27	1	3
Atrazine	58	45	71	6	1
Metolachlor	72	68	78	6	1
Cyanazine	69	59	77	6	1

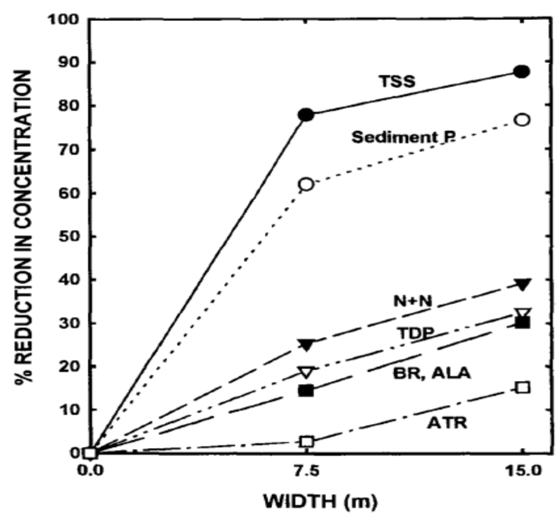

Figure 37. Percentage reduction in pollutants in relation to width of filter strips for two year old grass, and grass-shrub-tree plots. Abbreviations are N+N, nitrite plus nitrate; TN, total nitrogen; ATR, atrazine; ALA, alachlor; TDP, total dissolved phosphorus

The location and type of BMPs to implement is debatable because the results of this study indicate that large runoffs and loads could originate within any given subshed during any given rainstorm event, and because this study was unable to precisely identify the root cause of the variability in subshed runoff and loading. Therefore, it is suggested to look at the following factors to explain the subshed variability in the sediment and nutrient loading: tillage practices; fertilizer applications; the extent of the drainage tile network; antecedent soil moisture; rain intensity/duration; mass wasting; and more years of study. Knowledge of these factors can help identify what BMPs would provide the highest mitigation of the nonpoint source pollution.

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Appendix 1: Dates, Times, and Water Sample Analysis Results for the 2009 and 2010 Season

The following tables list the subshed sample dates, times, and TSS, TP, and NOx results for the 2009 and 2010 study events.

Table 29. Dates, and times of water samples taken during the 2009 study season of the Lake Titlow watershed, Sibley and McLeod Counties, Minnesota.

Site	Date	Time	TSS mg/L	NO x mg/L	TP mg/L
JD18UP	4/1/09	10:15			
JD18 Lo	4/1/09	12:05	12	17.3	0.242
CD18UP	4/1/09	9:23			
CD18 Lo	4/1/09	11:34	18	17	0.174
D250	4/1/09	12:25	<2	17.4	0.333
JD18UP	4/20/09	11:22	4	15.9	0.04
JD18 Lo	4/20/09	10:17	<2	16.1	0.02
CD18UP	4/20/09	12:05	2	16.8	0.016
CD18 Lo	4/20/09	10:34	2	16.7	0.02
D250	4/20/09	9:51	2	19.6	0.047
JD18UP	4/27/09	19:40	3	14.8	0.039
JD18 Lo	4/27/09	10:37	9	18.3	0.054
CD18UP	4/27/09	19:55	<2	15.8	0.031
CD18 Lo	4/27/09	9:00	12	17.1	0.042
D250	4/27/09	10:03	5	18.7	0.041
JD18UP	5/9/09	18:18	2	12.4	0.023
JD18Lo	5/9/09	18:34	10	14.5	0.046
CD18UP	5/9/09	18:05	5	15.3	0.015
CD18 Lo	5/9/09	18:48	5	15	0.022
D250	5/9/09	19:00	<2	19.1	0.027
JD18UP	5/22/09	11:35	<2	8.74	0.057
JD18 Lo	5/22/09	10:55	4	11.3	0.049
CD18UP	5/22/09	11:25	3	11.8	0.031
CD18 Lo	5/22/09	11:05	3	12.1	0.028
JD18UP	7/28/09	12:40	14	<0.2	0.82
JD18 Lo	7/28/09	11:45	11	0.38	0.546
CD18UP	7/28/09	12:50	19	<0.2	0.539
CD18 Lo	7/28/09	12:00	6	<0.2	0.221
JD18UP	8/7/09	19:16	30	3.06	1.74
JD18 Lo	8/7/09	17:51	9	<0.2	0.627
CD18UP	8/7/09	18:57	36	0.95	0.569
CD18 Lo	8/7/09	17:33	5	<0.2	0.258
D250	8/7/09	18:00			
JD18UP	8/20/09	8:22	6	<0.2	1.66
JD18 Lo	8/20/09	9:17	8	0.65	0.615
CD18UP	8/20/09	7:53	14	0.52	0.464
CD18 Lo	8/20/09	10:30	6	1.16	0.435
D250	8/20/09	9:45	17	1.29	1.3
JD18UP	9/4/09	11:20	2	1.29	0.489
JD18 Lo	9/4/09	10:20	5	<0.2	0.411
CD18UP	9/4/09	11:40	11	0.21	0.429
CD18 Lo	9/4/09	10:50	3	<0.2	0.138
CD18 Lo	9/4/09	10:50	5	<0.2	0.143
D250	9/4/09	10:15			
JD18UP	9/11/09	12:55	<2	9.86	0.292
JD18 Lo	9/11/09	12:10	5	0.92	0.972
CD18UP	9/11/09	12:40	<2	0.47	0.673
CD18 Lo	9/11/09	12:20	10	5.69	0.25
D250	9/11/09	12:00	10	0.69	0.62

D250	5/22/09	10:42	<2	16.5	0.038

JD18UP	6/8/09	10:25	68	12	0.245
JD18 Lo	6/8/09	11:00	37	13.2	0.151
CD18UP	6/8/09	9:50	22	12.8	0.046
CD18 Lo	6/8/09	11:10	15	10.9	0.072
D250	6/8/09	11:25	3	19.7	0.059

JD18UP	6/17/09	11:30	3	18.6	0.043
JD18 Lo	6/17/09	12:25	47	18	0.092
CD18UP	6/17/09	11:05	<2	17.6	0.027
CD18 Lo	6/17/09	12:00	4	16.9	0.024
D250	6/17/09	12:50	4	21.7	0.064

JD18UP	7/9/2009	14:15	4	1.26	0.361
JD18 Lo	7/9/2009	13:35	5	1.69	0.279
CD18UP	7/9/2009	14:25	2	0.77	0.26
CD18 Lo	7/9/2009	13:51	2	0.39	0.158
D250	7/9/2009	12:45	4	<0.2	0.462

JD18UP	10/2/09	12:15	20	16.8	0.662
JD18 Lo	10/2/09	10:20	61	6.22	0.524
CD18UP	10/2/09	11:45	13	13.6	0.335
CD18 Lo	10/2/09	10:40	53	10.9	0.457
D250	10/2/09	10:00	4	13.7	0.443

JD18UP	10/6/09	10:35	17	14.3	0.505
JD18 Lo	10/6/09	10:10	19	14.6	0.188
CD18UP	10/6/09	10:25	22	16.9	0.324
CD18 Lo	10/6/09	10:00	13	14.3	0.151
D250	10/6/09	10:55	11	10.6	0.522

JD18UP	10/16/09	12:45	5	18.3	0.101
JD18 Lo	10/16/09	11:30	8	20.2	0.106
CD18UP	10/16/09	13:10	7	21.6	0.046
CD18 Lo	10/16/09	11:45	12	19.6	0.073
D250	10/16/09	11:05	3	21	0.096
D250	10/16/09	11:05	<2	20.9	0.099

Table 30. Dates, and times of water samples taken during the 2010 study season of the Lake Titlow watershed, Sibley and McLeod Counties, Minnesota.

Site	Sample Date	Sample Time	TSS mg/L	TP mg/l	Nox mg/L	Site	Sample Date	Sample Time	TSS mg/L	TP mg/l	Nox mg/L
D250	4/7/10	9:30	<2	0.053	18.900	D250	7/7/10	10:25	1.1	0.295	18.400
JD18LO	4/7/10	9:40	3	0.035	15.600	JD18LO	7/7/10	11:05	15.3	0.165	15.600
CD18LO	4/7/10	9:50	4	0.023	16.700	CD18LO	7/7/10	10:50	5.1	0.148	17.900
JD18UP	4/7/10	10:00	6	0.045	14.000	JD18UP	7/7/10	11:25	17.8	0.258	13.800
CD18UP	4/7/10	10:10	2	0.018	17.000	CD18UP	7/7/10	12:05	2.7	0.123	19.200

Site	Sample Date	Sample Time	TSS mg/L	TP mg/l	Nox mg/L	Site	Sample Date	Sample Time	TSS mg/L	TP mg/l	Nox mg/L
D250	4/13/10	11:05	0	0.058	23.000	D250	7/20/10	12:50	4	0.410	1.000
JD18LO	4/13/10	11:15	3.8	0.048	16.200	JD18LO	7/20/10	13:10	3.6	0.193	8.800
CD18LO	4/13/10	11:30	5.5	0.030	17.600	CD18LO	7/20/10	13:00	1.8	0.108	4.200
JD18UP	4/13/10	12:00	0.5	0.055	15.500	JD18UP	7/20/10	13:35	9.2	0.178	7.800
CD18UP	4/13/10	11:50	2	0.018	17.600	CD18UP	7/20/10	15:45	0.1	0.150	3.900

Site	Sample Date	Sample Time	TSS mg/L	TP mg/l	Nox mg/L
D250	4/15/10	11:42	5	0.044	17.900
JD18LO	4/15/10	11:52	26	0.080	14.300
CD18LO	4/15/10	12:22	43	0.060	13.700
JD18UP	4/15/10	12:57	12	0.071	12.800
CD18UP	4/15/10	12:43	29	0.116	15.000

Site	Sample Date	Sample Time	TSS mg/L	TP mg/l	Nox mg/L
D250	4/27/10	10:35	2.56	0.123	22.500
JD18LO	4/27/10	10:45	11.6	0.108	17.800
CD18LO	4/27/10	11:15	2.4	0.065	19.700
JD18UP	4/27/10	11:50	2.6	0.073	17.400
CD18UP	4/27/10	12:20	4.6	0.080	20.200

Site	Sample Date	Sample Time	TSS mg/L	TP mg/l	Nox mg/L
D250	4/30/10	20:10	<2	0.072	18.700
JD18LO	4/30/10	19:30	33	0.068	15.200
CD18LO	4/30/10	19:50	8	0.023	15.100
JD18UP	4/30/10	19:10	5	0.032	14.200
CD18UP	4/30/10	18:55	6	0.019	15.900

Site	Sample Date	Sample Time	TSS mg/L	TP mg/l	Nox mg/L
D250	5/10/10	12:52	0.6	0.048	22.000
JD18LO	5/10/10	11:36	14.2	0.078	16.400
CD18LO	5/10/10	12:15	7.5	0.078	16.800
JD18UP	5/10/10	14:14	39.4	0.060	15.300
CD18UP	5/10/10	14:45	4	0.013	17.700

Site	Sample Date	Sample Time	TSS mg/L	TP mg/l	Nox mg/L
D250	5/11/10	14:20	<2	0.072	20.000
JD18LO	5/11/10	14:30	12	0.052	15.700
CD18LO	5/11/10	14:45	18	0.046	15.700
JD18UP	5/11/10	15:25	8	0.070	14.600
CD18UP	5/11/10	15:35	27	0.042	16.400

Site	Sample Date	Sample Time	TSS mg/L	TP mg/l	Nox mg/L
D250	5/13/10	12:30	43.0	0.108	24.000
JD18LO	5/13/10	11:10	25.6	0.060	18.900
CD18LO	5/13/10	11:35	145.8	0.123	20.700
JD18UP	5/13/10	10:50	7.0	0.053	20.900
CD18UP	5/13/10	10:35	17.4	0.055	21.700

Site	Sample Date	Sample Time	TSS mg/L	TP mg/l	Nox mg/L
D250	5/19/10	14:50	0.2	0.058	24.5
JD18LO	5/19/10	12:00	44	0.145	21.8
CD18LO	5/19/10	11:15	4.2	0.028	20.9
JD18UP	5/19/10	7:30	10.7	0.045	16.5

Site	Sample Date	Sample Time	TSS mg/L	TP mg/l	Nox mg/L
D250	7/25/10	13:05	0.6	0.213	13.600
JD18LO	7/25/10	12:15	35	0.165	7.000
CD18LO	7/25/10	12:45	480	1.065	15.000

Site	Sample Date	Sample Time	TSS mg/L	TP mg/l	Nox mg/L
D250	7/28/10	15:45	3.5	0.223	8.500
JD18LO	7/28/10	16:00	4.3	0.178	11.900
CD18LO	7/28/10	16:15	0.25	0.058	5.700

Site	Sample Date	Sample Time	TSS mg/L	TP mg/l	Nox mg/L
D250	8/11/10	13:55	7.2	0.700	0.400
JD18LO	8/11/10	14:27	0.4	0.248	3.500
CD18LO	8/11/10	14:10	2.2	0.323	2.900
JD18UP	8/11/10	14:50	3.8	0.265	2.500
CD18UP	8/11/10	15:10	-0.5	0.513	0.700

Site	Sample Date	Sample Time	TSS mg/L	TP mg/l	Nox mg/L
D250	8/13/10	20:40	4.4	0.430	10.900
JD18LO	8/13/10	20:50	414.8	0.685	3.700
CD18LO	8/13/10	21:15	235.0	0.860	4.000
JD18UP	8/13/10	22:17	23.3	0.358	10.300
CD18UP	8/13/10	22:02	35	0.368	9.900

Site	Sample Date	Sample Time	TSS mg/L	TP mg/l	Nox mg/L
D250	8/27/10	14:50	3.3	0.103	5.100
JD18LO	8/27/10	14:20	1.9	0.000	6.200
CD18LO	8/27/10	14:00	0	0.035	0.000

Site	Sample Date	Sample Time	TSS mg/L	TP mg/l	Nox mg/L
D250	9/2/10	11:00	7	0.533	0.400
JD18LO	9/2/10	14:09	30.8	0.135	2.300
CD18LO	9/2/10	14:22	59.4	0.243	2.200
JD18UP	9/2/10	11:50	11.9	0.353	1.100
CD18UP	9/2/10	11:40	0.7	0.268	0.000

Site	Sample Date	Sample Time	TSS mg/L	TP mg/l	Nox mg/L
D250	9/10/10	0.569	0.9	0.183	1.800
JD18LO	9/10/10	0.598	13.1	0.127	5.000
CD18LO	9/10/10	0.590	2.7	0.128	5.500

CD18UP	5/19/10	15:35	4.6	0.093	20.7

Site	Sample Date	Sample Time	TSS mg/L	TP mg/l	Nox mg/L
D250	5/23/10	9:15	0.5	0.091	20.8
JD18LO	5/23/10	7:55	368	0.338	17.3
CD18LO	5/23/10	8:30	15.75	0.04	17.75
JD18UP	5/23/10	7:30	23.3	0.075	16.25
CD18UP	5/23/10	7:00	14.4	0.053	18.4

Site	Sample Date	Sample Time	TSS mg/L	TP mg/l	Nox mg/L
D250	6/2/10	12:05	0.7	0.108	22.6
JD18LO	6/2/10	11:15	34.6	0.08	16.4
CD18LO	6/2/10	11:45	5.3	0.035	17.2
JD18UP	6/2/10	10:15	14.8	0.075	15.0
CD18UP	6/2/10	10:05	2.4	0.028	17.4

Site	Sample Date	Sample Time	TSS mg/L	TP mg/l	Nox mg/L
D250	6/11/10	10:00	17.6	0.118	20.5
JD18LO	6/11/10	10:10	45.4	0.12	14.5
CD18LO	6/11/10	10:50	12.5	0.065	14.5
JD18UP	6/11/10	12:02	116	0.333	17.5
CD18UP	6/11/10	12:20	17	0.155	16.55

Site	Sample Date	Sample Time	TSS mg/L	TP mg/l	Nox mg/L
D250	6/12/10	9:40	-0.1	0.233	19.500
JD18LO	6/12/10	9:50	3097	1.229	18.400
CD18LO	6/12/10	10:25	854.9	0.793	19.600
JD18UP	6/12/10	11:00	21.8	0.200	24.300
CD18UP	6/12/10	11:15	15.5	0.103	22.200

Site	Sample Date	Sample Time	TSS mg/L	TP mg/l	Nox mg/L
D250	6/18/10	10:20	0.5	0.145	20.500
JD18LO	6/18/10	10:30	34.5	0.203	21.700
CD18LO	6/18/10	10:35	673.8	0.153	20.300
JD18UP	6/18/10	11:05	17.6	0.170	21.400
CD18UP	6/18/10	10:50	0.1	0.140	22.700

Site	Sample Date	Sample Time	TSS mg/L	TP mg/l	Nox mg/L
D250	6/24/10	13:17	0	0.175	17.300
JD18LO	6/24/10	13:26	17	0.193	16.600
CD18LO	6/24/10	13:45	1.8	0.143	14.900
JD18UP	6/24/10	14:10	8.7	0.178	16.000
CD18UP	6/24/10	14:23	0	0.055	16.500

Site	Sample Date	Sample Time	TSS mg/L	TP mg/l	Nox mg/L
D250	6/26/10	17:55	0.2	0.183	17.900

Site	Sample Date	Sample Time	TSS mg/L	TP mg/l	Nox mg/L
D250	9/17/10	11:30	3.3	0.153	6.500
JD18LO	9/17/10	11:50	76.5	0.373	7.300
CD18LO	9/17/10	12:15	80	0.030	4.000
CD18UP	9/17/10	12:55	0.1	0.083	15.400
JD18UP	9/17/10	12:50	5.1	0.023	13.000

Site	Sample Date	Sample Time	TSS mg/L	TP mg/l	Nox mg/L
D250	9/23/10	14:11	15.4	0.438	8.000
JD18LO	9/23/10	13:45	135.7	0.415	13.000
CD18LO	9/23/10	14:00	149.0	0.605	10.700
CD18UP	9/23/10	13:10	42.0	0.363	11.000
JD18UP	9/23/10	13:25	73.3	0.490	10.600

Site	Sample Date	Sample Time	TSS mg/L	TP mg/l	Nox mg/L
CD18LO	9/24/10	11:41	42.8	0.373	10.700
JD18UP	9/24/10	12:05	18.0	0.298	11.900
D250	9/24/10	11:20	4.3	0.400	9.600
JD18LO	9/24/10	12:50	29.5	0.395	7.600
CD18UP	9/24/10	12:40	19.1	0.270	10.900

Site	Sample Date	Sample Time	TSS mg/L	TP mg/l	Nox mg/L
CD18UP	10/9/10	15:40	0.4	0.045	18.300
D250	10/9/10	13:50	1.7	0.090	17.700
JD18UP	10/9/10	17:08	4.5	0.038	17.000
CD18LO	10/9/10	14:47	7.9	0.048	16.300
JD18LO	10/9/10	14:05	7.5	0.070	17.200

Site	Sample Date	Sample Time	TSS mg/L	TP mg/l	Nox mg/L
D250	10/24/10	14:09	3.3	0.103	17.200
JD18LO	10/24/10	15:06	0.9	0.060	17.200
CD18LO	10/24/10	14:54	1.6	0.030	17.100
JD18UP	10/24/10	15:32	-0.2	0.040	16.200
CD18UP	10/24/10	15:46	-0.2	0.053	17.200

Site	Sample Date	Sample Time	TSS mg/L	TP mg/l	Nox mg/L
D250	10/27/10	15:40	-0.7	0.128	15.200
JD18LO	10/27/10	15:50	60.8	0.175	16.100
CD18LO	10/27/10	16:30	106	0.160	17.100
JD18UP	10/27/10	17:00	3.6	0.113	21.000
CD18UP	10/27/10	17:10	9	0.060	19.600

Site	Sample Date	Sample Time	TSS mg/L	TP mg/l	Nox mg/L
D250	11/12/10	15:05	3.3	0.055	18.000

JD18LO	6/26/10	18:00	31.75	0.103	15.400	JD18LO	11/12/10	15:16	2.7	0.083	18.200
CD18LO	6/26/10	18:30	2.5	0.070	15.100	CD18LO	11/12/10	15:46	1.6	0.068	18.700
JD18UP	6/26/10	18:50	19.13	0.130	16.400	CD18UP	11/12/10	16:40	0.6	0.038	19.000
CD18UP	6/26/10	19:00	0.8	0.073	15.100	JD18UP	11/12/10	17:00	1.9	0.083	17.500

Site	Sample Date	Sample Time	TSS mg/L	TP mg/l	Nox mg/L	Site	Sample Date	Sample Time	TSS mg/L	TP mg/l	Nox mg/L
D250	6/28/10	11:45	2.5	0.388	12.500	D250	11/16/10	10:25	3.4	0.090	18.100
JD18LO	6/28/10	12:20	361	0.525	9.900	JD18LO	11/16/10	10:40	1.2	0.048	18.300
CD18LO	6/28/10	13:00	564	1.088	12.300	CD18LO	11/16/10	10:50	1.35	0.062	18.600
JD18UP	6/28/10	15:37	23.2	0.225	9.300	JD18UP	11/16/10	11:25	0	0.095	17.000
CD18UP	6/28/10	15:53	9	0.230	9.500	CD18UP	11/16/10	11:35	0.8	0.068	18.500

Appendix 2: Rain Amounts from the Four Rain Gauges 2009

This appendix contains all precipitation recorded using the four tipping bucket rain gauges during the 2009 sample season. The dates, times, and amounts are listed for each gauge.

Table 31. Precipitation totals for all rains during the 2009 study season of the Lake Titlow watershed, Sibley and McLeod Counties, Minnesota.

Rain Gauges in the Lake Titlow Watershed 2009 Season							
West Rain Gauge		South Rain Gauge		North Rain Gauge		Lake Rain Gauge	
Date Time	Rain (inches)	Date	Rain (inches)	Date	Rain (inches)	Date	Rain (inches)
04/04/2009 14:45:00	0.02	04/04/2009 15:45:00	0.03	04/04/2009 17:15:00	0.03	05/05/2009 05:00:00	0.18
04/05/2009 08:15:00	0.28	04/05/2009 07:30:00	0.24	04/05/2009 12:00:00	0.26	05/05/2009 14:45:00	0.03
04/24/2009 23:45:09	0.01	04/07/2009 10:15:01	0.02	04/19/2009 15:00:07	0.01	05/06/2009 18:00:00	0.14
04/25/2009 01:30:10	0.01	04/19/2009 01:45:07	0.01	04/25/2009 11:45:09	0.01	05/08/2009 23:00:00	0.61
04/26/2009 16:15:10	0.56	04/19/2009 12:00:07	0.01	04/26/2009 08:00:10	0.01	05/13/2009 06:45:00	0.03
04/29/2009 14:00:12	0.26	04/25/2009 00:45:09	0.02	04/26/2009 19:00:10	0.66	05/13/2009 17:45:00	0.07
04/30/2009 04:30:12	0.01	04/26/2009 06:45:10	0.66	04/27/2009 04:30:10	0.64	05/14/2009 18:45:00	0.05
05/04/2009 23:00:14	0.13	04/26/2009 17:45:10	0.60	04/30/2009 02:00:12	0.23	05/15/2009 17:30:00	0.28
05/09/2009 02:00:16	0.24	04/29/2009 15:15:12	0.24	05/05/2009 11:15:14	0.13	05/16/2009 08:15:00	0.01
05/10/2009 22:45:17	0.01	05/05/2009 03:00:14	0.18	05/09/2009 05:30:16	0.63	05/16/2009 17:45:00	0.01
05/15/2009 12:45:19	0.22	05/08/2009 17:30:16	0.72	05/13/2009 08:45:18	0.01	05/21/2009 17:00:00	0.22
05/23/2009 01:30:23	0.45	05/12/2009 21:30:18	0.02	05/14/2009 01:30:18	0.01	05/23/2009 19:30:00	0.49
05/26/2009 21:15:25	0.04	05/15/2009 12:15:19	0.19	05/16/2009 00:15:19	0.25	05/30/2009 01:45:00	0.01
05/29/2009 22:30:26	0.01	05/23/2009 01:30:23	0.33	05/23/2009 13:45:23	0.69	06/01/2009 00:15:00	0.14
05/31/2009 16:00:27	0.10	05/26/2009 20:45:25	0.01	05/27/2009 09:30:25	0.01	06/06/2009 16:45:00	0.61
06/06/2009 13:45:30	0.65	05/27/2009 05:45:25	0.01	06/01/2009 06:45:27	0.12	06/08/2009 05:00:00	1.19
06/07/2009 23:30:31	1.54	05/29/2009 22:30:26	0.01	06/06/2009 12:30:30	0.60	06/09/2009 17:45:00	0.03
06/09/2009 12:15:31	0.01	05/31/2009 17:00:27	0.04	06/07/2009 16:00:30	0.01	06/10/2009 12:00:00	0.03
06/10/2009 05:30:32	0.04	06/06/2009 12:15:30	0.49	06/08/2009 11:45:31	1.23	06/15/2009 23:30:00	0.06

06/15/2009 19:15:34	0.02	06/08/2009 00:30:31	0.91	06/10/2009 00:45:31	0.01	06/16/2009 18:30:00	0.30
06/16/2009 00:30:34	0.01	06/09/2009 23:15:32	0.01	06/10/2009 16:45:32	0.04	06/17/2009 10:45:00	0.04
06/16/2009 18:30:35	0.28	06/10/2009 06:00:32	0.04	06/16/2009 06:00:34	0.06	06/21/2009 22:45:00	0.07
06/17/2009 04:00:35	0.01	06/15/2009 20:00:34	0.01	06/17/2009 01:30:35	0.18	06/24/2009 11:00:00	0.03
06/21/2009 06:00:37	0.01	06/16/2009 13:15:35	0.19	06/17/2009 15:45:35	0.01	06/27/2009 08:45:00	0.28
06/22/2009 09:00:37	0.32	06/17/2009 05:00:35	0.02	06/21/2009 20:00:37	0.31	07/04/2009 08:30:00	0.08
06/23/2009 00:00:00	0.01	06/21/2009 06:00:37	0.01	06/22/2009 12:00:37	0.01	07/08/2009 05:45:00	0.72
06/24/2009 04:45:38	0.05	06/21/2009 17:30:37	0.22	06/24/2009 17:30:38	0.10	07/09/2009 08:45:00	0.02
06/25/2009 00:00:39	0.01	06/24/2009 06:00:38	0.06	06/27/2009 15:45:40	0.22	07/14/2009 10:15:00	0.08
06/26/2009 17:30:40	0.19	06/25/2009 05:45:39	0.01	07/04/2009 13:30:43	0.06	07/21/2009 05:45:00	0.23
07/03/2009 21:00:43	0.12	06/26/2009 00:00:39	0.19	07/08/2009 11:30:45	0.25	07/21/2009 16:45:00	0.01
07/04/2009 04:00:43	0.01	07/03/2009 00:00:43	0.08	07/09/2009 15:45:46	0.01	07/27/2009 04:30:00	0.02
07/07/2009 08:30:45	0.08	07/04/2009 00:28:48	0.02	07/14/2009 18:15:48	0.02	07/30/2009 01:30:00	0.02
07/07/2009 16:30:45	0.13	07/07/2009 00:00:45	0.22	07/21/2009 13:15:51	0.07	07/31/2009 22:15:00	0.47
07/19/2009 15:00:51	0.01	07/08/2009 00:00:45	0.01	07/23/2009 18:30:52	0.01	08/07/2009 12:15:00	1.15
07/26/2009 23:15:54	0.08	07/09/2009 00:00:45	0.01	07/27/2009 11:15:54	0.03	08/08/2009 04:00:00	0.72
07/29/2009 20:00:55	0.02	07/14/2009 00:00:48	0.01	07/30/2009 09:30:56	0.06	08/13/2009 16:15:00	0.05
07/31/2009 17:30:56	0.42	07/19/2009 00:00:50	0.01	08/01/2009 04:45:56	0.61	08/15/2009 18:45:00	0.06
08/08/2009 09:15:00	1.04	07/20/2009 00:00:51	0.03	08/07/2009 19:00:00	1.03	08/16/2009 05:30:00	0.51
08/15/2009 13:30:00	0.84	07/24/2009 11:15:53	0.01	08/08/2009 11:30:00	0.77	08/19/2009 17:30:00	2.69
08/15/2009 22:45:00	0.15	07/26/2009 23:30:54	0.06	08/13/2009 12:00:00	0.02	08/20/2009 06:15:00	0.01
08/19/2009 15:45:00	1.80	07/29/2009 22:45:56	0.06	08/15/2009 12:00:00	0.46	08/20/2009 20:15:00	0.08
08/20/2009 03:00:00	0.02	07/31/2009 17:15:56	0.45	08/16/2009 12:00:00	0.06	08/21/2009 08:00:00	0.03
08/20/2009 17:00:00	0.02	08/07/2009 06:45:00	1.18	08/19/2009 12:25:01	1.80	08/21/2009 08:00:00	0.03
08/25/2009 05:15:00	0.10	08/07/2009 22:15:00	0.53	08/19/2009 12:27:35	0.02	08/25/2009 11:00:00	0.29
09/09/2009 14:30:00	**0.11**	08/13/2009 09:30:00	0.03	08/19/2009 12:32:30	0.21	09/09/2009 21:15:00	2.02
09/11/2009 16:00:00	1.58	08/15/2009 13:00:00	0.20	08/19/2009 12:46:37	0.31	09/11/2009 20:15:00	0.04

09/11/2009 23:30:00	0.01	08/16/2009 00:45:00	0.34	08/21/2009 11:57:59	0.13	09/21/2009 15:00:00	0.37
09/21/2009 12:15:00	0.05	08/19/2009 04:30:00	1.57	08/21/2009 14:07:05	0.14	09/25/2009 12:15:00	0.67
09/25/2009 08:00:01	0.79	08/19/2009 13:15:00	0.78	08/25/2009 16:58:33	0.05	09/27/2009 12:00:00	0.01
10/01/2009 18:15:04	2.64	08/20/2009 10:30:00	0.04	09/10/2009 01:43:17	2.24	10/01/2009 16:00:00	2.45
10/02/2009 14:00:04	0.06	08/21/2009 02:00:00	0.24	09/10/2009 01:44:51	0.07	10/02/2009 04:00:00	0.01
10/02/2009 21:00:05	0.01	08/25/2009 06:00:00	0.06	09/10/2009 02:01:28	0.20	10/03/2009 09:00:00	0.01
10/03/2009 05:45:05	0.03	09/09/2009 15:30:00	**2.34**	09/10/2009 02:02:42	0.05	10/06/2009 16:45:00	1.11
10/06/2009 12:00:06	1.58	09/10/2009 07:00:00	0.01	09/12/2009 06:23:34	0.49	10/15/2009 08:15:00	0.18
10/10/2009 06:00:08	0.03	09/11/2009 16:15:00	0.91	09/13/2009 05:47:19	0.13	10/21/2009 19:00:00	0.33
10/12/2009 09:00:09	0.18	09/12/2009 03:00:00	0.01	09/21/2009 20:05:17	0.07	10/23/2009 13:15:00	0.14
10/15/2009 04:15:10	0.29	09/21/2009 08:30:00	0.02	09/25/2009 11:31:19	0.10	10/24/2009 20:15:00	0.01
10/15/2009 20:45:11	0.04	09/25/2009 08:00:00	0.90	09/25/2009 15:17:59	1.36	10/29/2009 16:45:00	0.24
10/16/2009 12:30:00	0.04	09/26/2009 05:00:00	0.01	09/25/2009 20:20:42	0.56	10/30/2009 08:30:00	0.03
10/21/2009 13:15:00	0.81	10/01/2009 16:00:00	2.70	10/01/2009 05:49:24	0.01	11/01/2009 22:15:00	0.01
10/23/2009 06:00:00	0.04	10/02/2009 06:30:00	0.02	10/01/2009 18:12:47	0.49	11/03/2009 20:45:00	0.17
10/24/2009 19:30:00	0.01	10/02/2009 13:30:00	0.01	10/01/2009 18:37:55	0.08	11/07/2009 22:15:00	0.01
10/30/2009 04:30:00	0.48	10/02/2009 22:30:00	0.01	10/01/2009 07:18:52	0.07	11/08/2009 03:30:00	0.01
10/30/2009 11:00:00	0.01	10/03/2009 06:45:00	0.03	10/01/2009 15:39:54	0.66		
11/03/2009 16:15:00	0.09	10/06/2009 12:15:00	1.42	10/03/2009 02:57:06	0.04		
11/05/2009 06:15:00	0.01	10/10/2009 07:30:00	0.02	10/03/2009 17:52:10	0.03		
11/13/2009 19:30:00	0.07	10/12/2009 09:00:00	0.21	10/06/2009 11:57:56	0.62		
11/24/2009 08:15:00	0.32	10/15/2009 03:30:00	0.38	10/06/2009 15:02:05	2.18		
11/24/2009 17:45:00	0.03	10/15/2009 08:30:00	0.01	10/06/2009 15:24:06	0.03		
11/25/2009 08:30:00	0.02	10/16/2009 00:15:00	0.03	10/06/2009 15:30:41	0.01		
12/01/2009 08:15:00	0.02	10/16/2009 13:00:00	0.01	10/06/2009 15:53:37	0.03		
		10/16/2009 22:00:00	0.04	10/06/2009 22:54:29	0.89		
		10/21/2009 12:45:00	0.62	10/10/2009 17:21:32	0.01		

		10/23/2009 06:00:00	0.07	10/12/2009 21:02:56	0.20		
		10/24/2009 22:45:00	0.03	10/15/2009 11:56:05	0.28		
		10/30/2009 02:15:00	0.58	10/16/2009 08:52:42	0.09		
		10/30/2009 06:45:00	0.01	10/22/2009 1:00	0.69		
		10/30/2009 15:30:00	0.01	10/23/2009 18:00	0.06		
		11/03/2009 11:30:00	0.11	10/25/2009 9:45	0.03		
		11/05/2009 09:00:00	0.01	10/30/2009 0:30	0.35		
		11/03/2009 16:45:00	0.01	10/30/2009 16:15	0.20		
		11/13/2009 18:15:00	0.09	11/4/2009 0:00	0.10		
		11/15/2009 07:00:00	0.01	11/4/2009 4:30	0.01		
		11/24/2009 08:00:00	0.37	11/14/2009 8:00	0.08		
		11/24/2009 18:30:00	0.04	11/25/2009 6:45	0.40		
		11/25/2009 03:00:00	0.01				
		11/25/2009 10:00:00	0.01				
		12/01/2009 08:15:00	0.01				
Total rain	19.69	Total rain	22.52	Total rain	25.51	Total rain	20.00

Appendix 3: Rain Amounts from the Four Rain Gauges 2010

The following table contains all precipitation recorded by the four tipping bucket rain gauges located throughout the Lake Titlow watershed during the 2010 sample season. The dates, times, and amounts are listed for each gauge.

Table 32. Precipitation totals for all rains during the 2010 study season of the Lake Titlow watershed, Sibley and McLeod Counties, Minnesota.

Rain Gauges in the Lake Titlow Watershed 2010 Season							
West Rain Gauge		South Rain Gauge		North Rain Gauge		Lake Rain Gauge	
Date	Rain (inches)	Date	Rain (inches)	Date	Rain (inches)	Date	Rain (inches)
03/10/2010 00:00:00	0.03	03/18/2010 09:15:00	0.01	03/09/2010 15:15:00	0.06	04/13/2010 03:00:00	0.49
03/26/2010 00:00:00	0.02	03/27/2010 04:30:00	0.01	03/23/2010 12:00:00	0.01	04/14/2010 14:00:00	0.08
04/07/2010 00:00:00	0.31	04/02/2010 13:00:00	0.01	04/06/2010 18:30:00	0.43	04/15/2010 08:00:00	0.57
04/14/2010 00:00:00	0.14	04/06/2010 17:30:00	0.48	04/13/2010 02:15:00	0.37	04/23/2010 21:00:00	0.05
04/16/2010 00:00:00	0.84	04/12/2010 23:15:00	0.50	04/14/2010 13:45:00	0.05	04/24/2010 10:00:00	0.20
04/25/2010 00:00:00	0.13	04/14/2010 12:30:00	0.05	04/15/2010 06:30:00	1.14	04/25/2010 16:00:00	0.11
04/26/2010 00:00:00	0.05	04/15/2010 05:00:00	1.00	04/24/2010 01:15:00	0.03	04/30/2010 05:00:00	0.26
05/01/2010 00:00:00	0.25	04/24/2010 06:45:00	0.12	04/24/2010 07:45:00	0.09	04/30/2010 16:00:00	0.26
05/02/2010 00:00:00	0.02	04/25/2010 15:00:00	0.06	04/25/2010 16:30:00	0.08	05/04/2010 19:00:00	0.02
05/07/2010 00:00:00	0.15	04/30/2010 05:15:00	0.33	04/30/2010 06:30:00	0.29	05/05/2010 12:15:00	0.01
05/08/2010 00:00:00	0.69	04/30/2010 14:45:00	0.08	04/30/2010 16:00:00	0.10	05/07/2010 13:00:00	0.16
05/09/2010 00:00:00	0.03	05/01/2010 10:15:00	0.01	05/06/2010 20:15:00	0.20	05/07/2010 21:15:00	0.74
05/11/2010 00:00:00	0.08	05/06/2010 19:45:00	0.20	05/07/2010 21:15:00	0.83	05/11/2010 12:45:00	0.47
05/12/2010 00:00:00	0.72	05/07/2010 19:45:00	0.81	05/11/2010 12:15:00	0.82	05/12/2010 19:00:00	0.15
05/13/2010 00:00:00	0.08	05/11/2010 10:30:00	0.83	05/13/2010 09:30:00	0.33	05/13/2010 03:30:00	0.41
05/14/2010 00:00:00	0.27	05/11/2010 23:45:00	0.01	05/19/2010 15:15:00	0.01	05/22/2010 11:45:00	1.06
05/20/2010 00:00:00	0.02	05/13/2010 01:45:00	0.26	05/21/2010 06:00:00	0.01	05/25/2010 03:00:00	0.03
05/22/2010 10:30:51	1.07	05/13/2010 08:30:00	0.01	05/22/2010 12:00:00	0.86	05/30/2010 13:45:00	0.02
05/31/2010 00:00:00	0.01	05/21/2010 05:45:00	0.01	06/01/2010 14:45:00	0.10	06/01/2010 14:30:00	0.58

06/02/2010 00:00:00	0.33	05/22/2010 10:45:00	1.13	06/04/2010 00:30:00	0.01	06/04/2010 04:00:00	0.61
06/05/2010 00:00:00	0.37	06/01/2010 13:15:00	0.31	06/05/2010 13:45:00	0.04	06/05/2010 16:00:00	0.15
06/06/2010 00:00:00	0.22	06/04/2010 02:45:00	0.39	06/07/2010 11:00:00	0.01	06/08/2010 14:00:00	0.25
06/09/2010 00:00:00	0.20	06/05/2010 15:45:01	0.18	06/08/2010 03:45:00	0.05	06/10/2010 12:15:00	0.07
06/11/2010 00:00:00	0.02	06/08/2010 08:00:04	0.39	06/11/2010 07:00:07	0.99	06/11/2010 08:00:00	0.75
06/12/2010 00:00:00	1.85	06/08/2010 13:30:04	0.02	06/12/2010 16:45:08	0.25	06/12/2010 15:45:00	0.23
06/13/2010 00:00:00	0.24	06/10/2010 11:45:06	0.03	06/14/2010 10:45:10	0.23	06/14/2010 11:30:00	0.20
06/15/2010 00:00:00	0.11	06/11/2010 06:15:07	1.23	06/15/2010 04:30:10	0.02	06/15/2010 17:30:00	0.01
06/16/2010 00:00:00	0.02	06/12/2010 16:45:08	0.27	06/15/2010 17:00:11	0.01	06/17/2010 19:15:00	0.44
06/17/2010 00:00:00	0.01	06/14/2010 10:45:10	0.26	6/17/2010 18:15	0.32	06/21/2010 14:00:00	0.01
06/18/2010 00:00:00	0.06	06/15/2010 04:30:10	0.03	06/21/2010 13:00:17	0.01	06/23/2010 05:15:00	0.52
06/19/2010 00:00:00	0.04	06/17/2010 18:00:13	0.20	06/23/2010 04:15:18	0.46	06/25/2010 12:45:00	0.35
06/22/2010 00:00:00	0.04	06/23/2010 04:15:18	0.40	06/23/2010 13:00:18	0.01	06/25/2010 20:15:00	0.22
06/24/2010 00:00:00	0.32	06/23/2010 13:00:18	0.01	06/25/2010 12:00:20	0.32	06/26/2010 23:00:00	2.73
06/25/2010 17:30:12	0.35	06/25/2010 19:15:21	0.60	06/25/2010 19:15:21	0.27	07/04/2010 06:45:00	0.12
06/26/2010 21:15:13	1.04	06/26/2010 22:00:22	2.49	06/26/2010 22:00:22	2.61	07/05/2010 20:00:00	0.01
06/26/2010 00:00:00	0.12	07/04/2010 10:45:29	0.35	07/04/2010 05:45:29	0.23	07/11/2010 02:00:00	1.11
06/27/2010 00:00:00	0.23	07/05/2010 23:00:30	0.02	07/04/2010 10:45:29	0.01	07/14/2010 10:00:00	0.07
06/28/2010 00:00:00	0.54	07/11/2010 02:30:35	0.46	07/05/2010 20:00:30	0.02	07/14/2010 15:30:00	0.01
06/29/2010 00:00:00	0.28	07/14/2010 08:15:38	0.02	07/05/2010 23:00:30	0.01	07/18/2010 00:15:00	0.54
06/30/2010 00:00:00	0.12	07/17/2010 22:45:42	0.25	07/11/2010 02:30:35	0.80	07/22/2010 13:00:00	0.48
07/01/2010 00:00:00	0.05	07/22/2010 04:30:46	0.47	07/14/2010 09:00:38	0.05	07/24/2010 01:45:00	1.54
07/02/2010 00:00:00	0.01	07/24/2010 00:30:48	1.23	07/14/2010 14:30:39	0.01	07/27/2010 20:45:00	0.39
07/05/2010 00:00:00	0.09	07/27/2010 20:30:51	0.32	07/17/2010 23:15:42	0.41	07/30/2010 06:00:00	0.28
07/07/2010 00:00:00	0.16	07/30/2010 04:45:54	0.37	07/22/2010 06:00:46	0.48	08/04/2010 19:00:00	0.34
07/12/2010 00:00:00	0.59	07/31/2010 04:15:55	0.01	07/24/2010 01:00:48	1.39	08/07/2010 11:00:00	0.43
07/15/2010 00:00:00	0.02	08/04/2010 17:45:59	0.29	07/27/2010 20:30:51	0.36	08/08/2010 01:45:00	0.01

07/19/2010 00:00:00	0.18	08/07/2010 10:15:00	0.45	07/30/2010 05:00:54	0.33	08/08/2010 22:00:00	0.01
07/23/2010 00:00:00	0.31	08/07/2010 18:00:00	0.01	07/31/2010 04:15:55	0.01	08/09/2010 01:00:00	0.33
07/24/2010 00:00:00	0.01	08/08/2010 23:45:00	0.35	08/04/2010 18:00:59	0.32	08/10/2010 09:45:00	0.18
07/25/2010 00:00:00	0.01	08/11/2010 02:15:01	0.81	08/06/2010 16:15:00	0.05	08/10/2010 16:45:00	0.34
07/27/2010 00:00:00	0.01	08/13/2010 14:15:02	2.81	08/07/2010 11:00:00	0.33	08/10/2010 21:45:00	0.01
07/28/2010 00:00:00	0.09	08/14/2010 19:15:03	0.01	08/09/2010 00:45:00	0.52	08/13/2010 04:30:00	2.49
08/09/2010 00:00:00	0.02	08/15/2010 04:00:03	0.01	08/10/2010 09:30:00	0.09	08/13/2010 15:15:00	0.43
08/10/2010 00:00:00	0.47	08/20/2010 06:30:05	0.02	08/10/2010 16:30:00	0.47	08/14/2010 19:45:00	0.01
08/11/2010 00:00:00	0.35	08/24/2010 00:00:07	0.43	08/10/2010 22:15:00	0.04	08/20/2010 04:45:00	0.01
08/14/2010 00:00:00	2.55	08/24/2010 10:15:07	0.01	08/12/2010 21:30:00	0.07	08/20/2010 11:30:00	0.01
08/21/2010 00:00:00	0.02	08/30/2010 06:45:10	0.05	08/13/2010 04:30:00	3.08	08/24/2010 01:15:00	0.58
08/25/2010 00:00:00	0.38	08/31/2010 05:30:11	0.55	08/13/2010 15:15:00	0.53	08/30/2010 08:00:00	0.08
08/31/2010 00:00:00	0.10	09/02/2010 06:15:12	0.95	08/14/2010 20:15:00	0.01	08/31/2010 06:45:00	0.50
09/01/2010 00:00:00	0.38	09/06/2010 19:00:14	0.10	08/20/2010 06:30:00	0.01	09/02/2010 07:15:00	1.31
09/03/2010 00:00:00	0.79	09/09/2010 17:30:15	0.20	08/24/2010 01:00:00	0.37	09/02/2010 18:30:00	0.02
09/08/2010 00:00:00	0.05	09/10/2010 20:45:16	0.08	08/24/2010 04:30:00	0.01	09/06/2010 12:45:00	0.01
09/10/2010 00:00:00	0.07	09/11/2010 06:15:16	0.01	08/30/2010 08:00:00	0.04	09/06/2010 20:30:00	0.04
09/11/2010 00:00:00	0.09	09/14/2010 11:00:17	0.01	08/31/2010 06:30:00	0.44	09/07/2010 07:00:00	0.03
09/12/2010 00:00:00	0.10	09/15/2010 10:15:18	0.43	09/02/2010 06:45:00	0.82	09/09/2010 15:45:00	0.08
09/15/2010 00:00:00	0.03	09/15/2010 20:45:18	0.48	09/02/2010 18:15:00	0.02	09/10/2010 21:00:00	0.28
09/16/2010 00:00:00	1.03	09/21/2010 04:45:21	0.23	09/06/2010 20:30:00	0.05	09/14/2010 13:30:00	0.02
09/17/2010 00:00:00	0.28	09/23/2010 18:30:22	3.17	09/09/2010 13:45:00	0.05	09/15/2010 21:45:00	0.95
09/22/2010 00:00:00	0.32	09/25/2010 08:15:23	0.13	09/11/2010 00:30:00	0.20	09/21/2010 06:00:00	0.27
09/23/2010 00:00:00	0.42	10/09/2010 10:15:29	0.01	09/14/2010 13:30:00	0.03	09/23/2010 19:00:00	4.28
09/24/2010 00:00:00	2.55	10/17/2010 22:15:34	0.06	09/15/2010 11:15:00	0.42	09/25/2010 08:15:00	0.12
09/26/2010 00:00:00	0.12	10/23/2010 14:00:36	0.05	09/15/2010 21:30:00	0.47	10/09/2010 11:15:00	0.06
10/10/2010 00:00:00	0.04	10/24/2010 01:15:36	0.39	09/21/2010 05:45:00	0.21	10/17/2010 21:00:00	0.03

10/18/2010 00:00:00	0.04	10/26/2010 14:00:38	1.30	09/23/2010 18:30:00	2.88	10/23/2010 14:15:00	0.08
10/19/2010 00:00:00	0.04	10/27/2010 16:45:38	0.04	09/25/2010 09:15:00	0.12	10/23/2010 22:00:00	0.01
10/24/2010 00:00:00	0.04	11/10/2010 19:00:45	0.06	10/09/2010 11:15:00	0.02	10/24/2010 02:00:00	0.41
10/25/2010 00:00:00	0.33	11/13/2010 16:15:46	0.41	10/17/2010 23:00:00	0.10	10/26/2010 01:00:00	0.85
10/26/2010 00:00:00	0.02	11/14/2010 11:30:47	0.15	10/23/2010 14:45:00	0.13	10/26/2010 17:45:00	0.49
10/27/2010 00:00:00	1.22	11/16/2010 11:45:48	0.04	10/24/2010 02:15:00	0.35	10/27/2010 02:45:00	0.01
10/28/2010 00:00:00	0.02	11/21/2010 12:00:50	0.02	10/24/2010 08:00:00	0.01		
10/30/2010 00:00:00	0.01	11/25/2010 14:30:52	0.01	10/26/2010 14:15:00	1.03		
11/14/2010 00:00:00	0.40	11/26/2010 13:15:53	0.04	10/27/2010 14:00:00	0.02		
11/15/2010 00:00:00	0.07	11/29/2010 17:30:54	0.20	11/10/2010 19:30:00	0.04		
11/17/2010 00:00:00	0.07			11/13/2010 16:15:00	0.30		
11/22/2010 00:00:00	0.03			11/21/2010 14:00:00	0.05		
11/26/2010 00:00:00	0.01			11/28/2010 11:30:00	0.02		
11/30/2010 00:00:00	0.21			11/29/2010 18:45:00	0.17		
Total rain	25.62	Total rain	30.60	Total rain	29.42	Total rain	31.87

Appendix 4. Stream ratings and rating curves for JD18, CD18 and D250

This appendix contains the tables of stream rating information and the rating curves that were created from the measurements of discharge and stage.

Table 33. The 2009, and 2010 JD18UP data for determining the stream rating for the Lake Titlow watershed, Sibley, and McLeod Counties, Minnesota. The ratings were performed by Bryce Hoppie, Scott Hommerding, Jason Stoltman, Ashley Brenke, and Lynn Schultz.

Date Time	Site	Name of person doing rating	Channel Width (feet)	Culvert top to water (feet)	Ditch Discharge (cfs)
4/14/2009 11:25	JD18Up	Hoppie	12	7.53	5.06
5/20/2009 11:10	JD18Up	Hommerding, Stoltman	12	7.92	2.32
6/8/2009 10:25	JD18Up	Hommerding, Stoltman	7.5	5.93	3.52
6/17/2009 11:30	JD18Up	Hommerding, Stoltman	13	5.45	7.99
7/29/2009 14:20	JD18Up	Hommerding, Stoltman	3.5	8.06	0.42
10/2/2009 12:25	JD18Up	Hommerding, Stoltman	13.3	6.08	113.74
5/28/2010 14:30	JD18Up	Hoppie, Brenke, Schultz	12' 8"	7' 2 3/4"	12.109
8/12/2010 13:25	JD18Up	Brenke, Schultz	12	7.92	1.193
10/17/2010 13:28	JD18Up	Brenke, Schultz	12.6	7.45	8.516

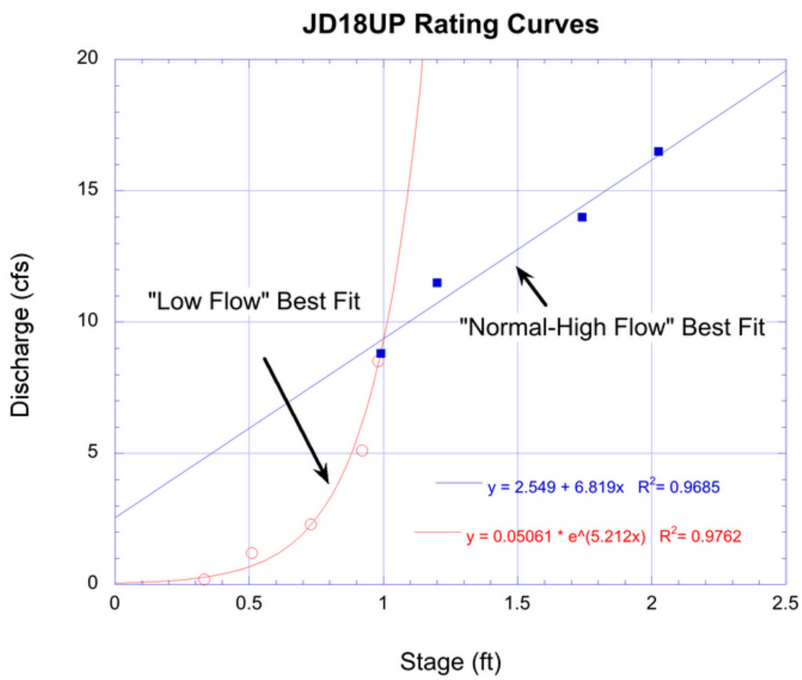

Figure 38. The rating curve for JD18Up (using 2009, and 2010 data) shows that there are different relationships between stage, and discharge at low flow, and high flow. Both equations were used in rating this stream. Data points are shown each time stream level was measured.

Table 34. The 2009, and 2010 JD18Lo data for determining the stream rating for the Lake Titlow watershed, Sibley, and McLeod Counties, Minnesota.

Date Time	Site	Name of person doing rating	Channel Width (feet)	Stage (feet)	Ditch discharge (cfs)
4/14/2009 13:03	JD18Lo	Hoppie, Hommerding	20.0	1.53	10.91
6/15/2009 16:00	JD18Lo	Hommerding Stoltman	17.0	1.97	13.49
7/29/2009 13:10	JD18Lo	Hoppie	9.52	0.7	2.13
3/16/2010 14:30	JD18Lo	Hoppie	20.0	?	415.60
6/17/2010 13:40	JD18Lo	Hoppie	20.2	2.339	47.772
8/12/2010 11:30	JD18Lo	Brenke, Schultz	17.0	0.816	5.846
10/29/2010 14:00	JD18Lo	Brenke, Schultz	20	?	40.397

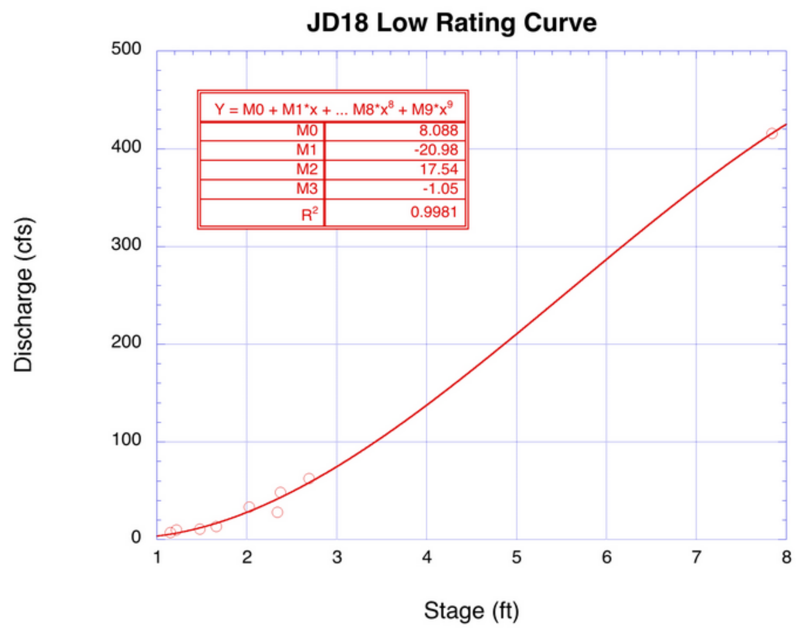

Figure 39. The rating curve with data points, for the JD18Lo subshed of the Lake Titlow watershed, Sibley, and McLeod Counties, Minnesota, created using 2009, and 2010 data. One best fit line equation was used in rating this stream.

Table 35. The 2009, and 2010 CD18UP data for determining the stream rating for the Lake Titlow watershed, Sibley, and McLeod Counties, Minnesota.

Date Time	Site	Name of person doing rating	Channel Width (feet)	Measured down from zenith at top of culvert (inches)	Measured discharge of ditch (cfs)
4/14/2009 9:20	CD18 Up	Hoppie	4.2	64.25	2.802
4/29/2009 16:00	CD18 Up	Hoppie	4.3	64.375	2.285
6/8/2009 9:50	CD18 Up	Hommerding, Stoltman	5.5	57.6	16.87
6/17/2009 11:05	CD18 Up	Hommerding, Stoltman	5.5	63.25	14.21
7/29/2009 14:37	CD18 Up	Hoppie	4.8	62	3.43
10/2/2009 11:50	CD18 Up	Hoppie	5.5	44.5	42.31
3/18/2010 10:45	CD18 Up	Hoppie	5.6	?	35.888

5/28/2010 13:40	CD18 Up	Hoppie, Brenke, Schultz	5.083	61.00	5.404
8/12/2010 14:55	CD18 Up	Brenke, Schultz	5.8	69.6	0.696
10/15/2010 13:39	CD18 Up	Brenke, Schultz	4.5	62.64	3.378

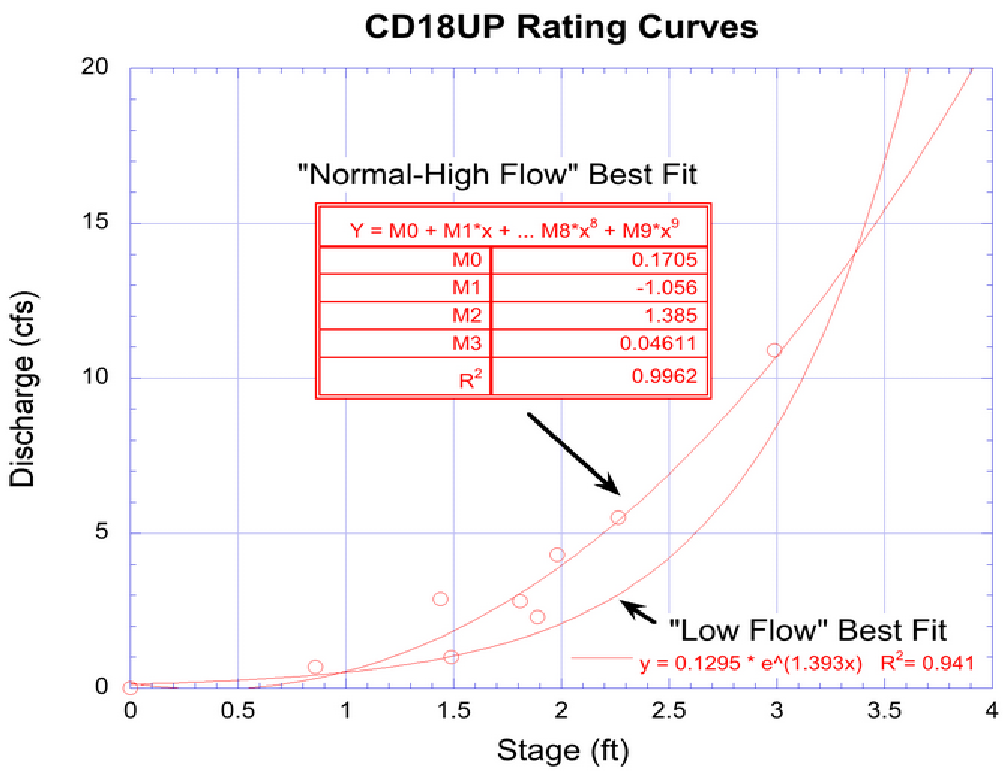

Figure 40. The rating curve and data points for the CD18Up subshed of the Lake Titlow watershed, Sibley, and McLeod Counties, Minnesota, created using 2009, and 2010 data. The curve shows two different relationships between stage, and discharge at low flow, and high flow.

Table 36. The 2009 and 2010 CD18Lo data for determining the stream rating for the Lake Titlow watershed, Sibley and McLeod Counties, Minnesota.

Date Time	Site	Name of person doing rating	Channel Width (feet)	Stage (feet)	Measured discharge of ditch (cfs)	Staff (feet)
4/14/2009 12:22	CD18Lo	Hoppie, Hommerding,	13.9	1.82	4.388	1.74
6/15/2009 11:45	CD18Lo	Hoppie, Hommerding	13.328	1.945	6.857	1.82
3/16/2010 13:40	CD18Lo	Hoppie	13	ISCO not installed yet	270.265	Not installed yet
6/14/2010 15:00	CD18Lo	Hoppie	14.0	?	30.275	2.51
8/3/2010 14:45	CD18Lo	Brenke, Schultz	14	1.664	0.057	1.51
10/29/2010 13:10	CD18Lo	Brenke, Schultz	13.8	?	17.321	2.07

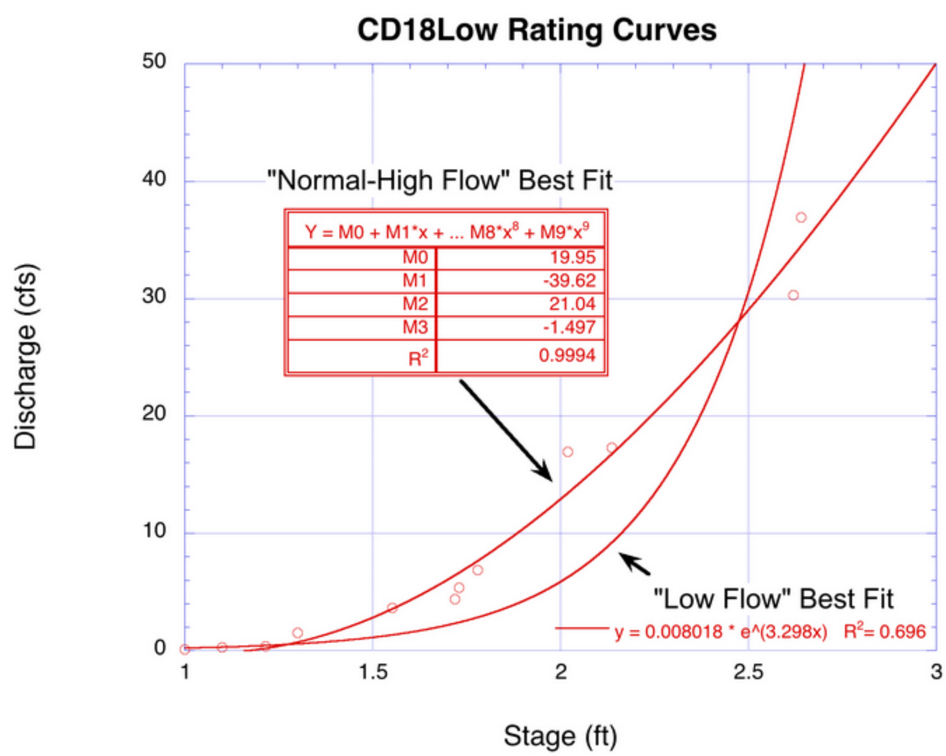

Figure 41. The rating curve, and data points for the CD18Lo subshed of the Lake Titlow watershed, Sibley, and McLeod Counties, Minnesota, created using 2009, and 2010 data. The curve shows two different relationships between stage, and discharge at low flow, and normal-high flow.

Table 37. The 2009, and 2010 D250 data for determining the stream rating for the Lake Titlow watershed, Sibley, and McLeod Counties, Minnesota.

Date Time	Site	Name of person doing rating	Channel Width (feet)	Stage (feet)	Measured discharge of ditch (cfs)
4/22/2008 2:00 p.m.	D250	Unknown	13.9	0.9650	0.6690
5/5/2008 10:50 a.m.	D250	Unknown	13.328	1.1740	1.4410
5/8/2008 2:15 p.m.	D250	Unknown	13	1.1720	1.0530
5/19/2008 11:00 a.m.	D250	Unknown	14	0.8830	0.6520
6/13/2008 6:35 p.m.	D250	Unknown	14	1.6280	6.0430

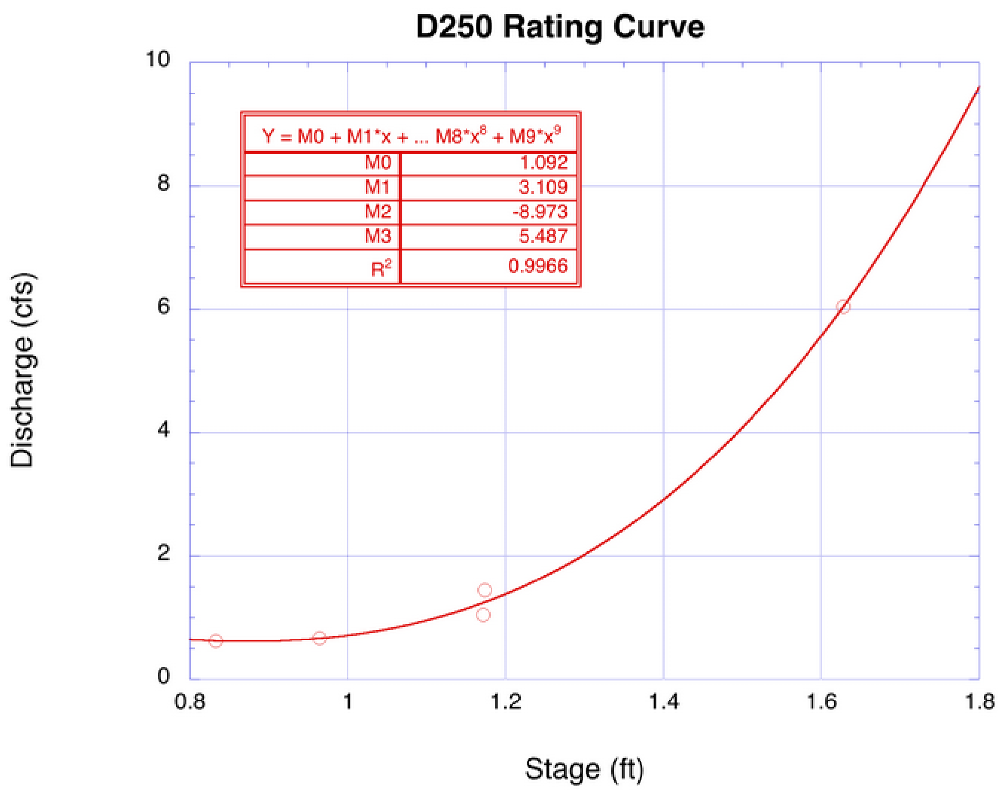

Figure 42. The rating curve with data points, for the D250 subshed of the Lake Titlow watershed, Sibley, and McLeod Counties, Minnesota, created using 2009, and 2010 data. One best fit line equation was used in rating this stream.

Appendix 5. Rain distribution maps of the eight storm events of this study

This appendix contains the maps that illustrate the distribution of rainfall across the watershed for the eight chosen precipitation events of this study.

Rain Distribution April 26, 2009
Lake Titlow Watershed

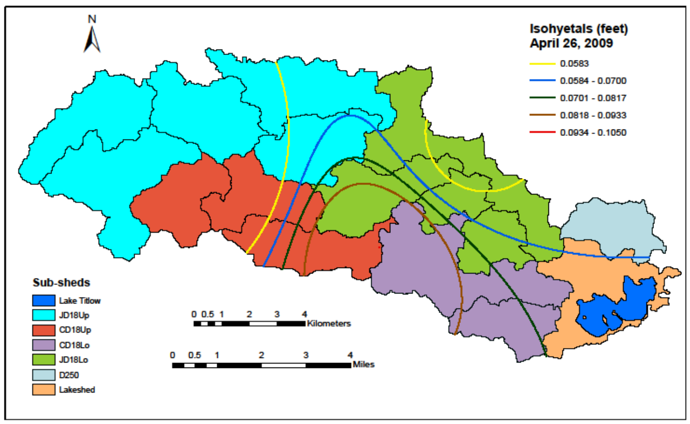

Figure 43. Rainfall distribution map of April 26, 2009 rain event at the Lake Titlow watershed Sibley, and McLeod Counties.

Rain Distribution June 8, 2009
Lake Titlow Watershed

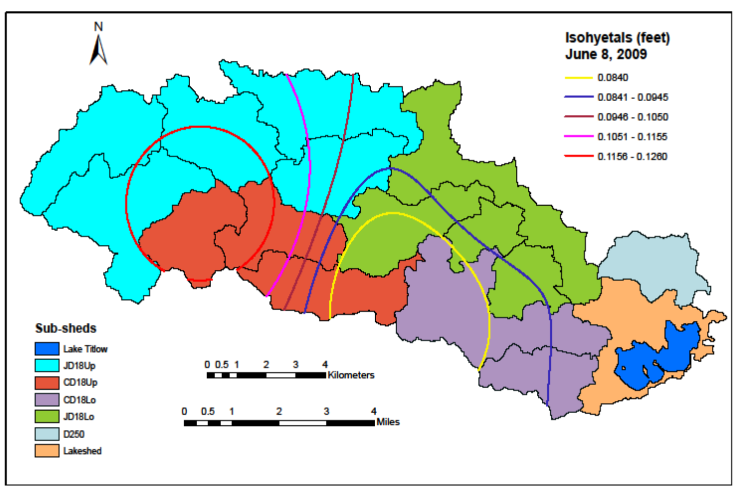

Figure 44. Rainfall distribution map for the June 2009 event at the Lake Titlow watershed, Sibley, and McLeod Counties, Minnesota.

Rain Distribution August 19, 2009
Lake Titlow Watershed

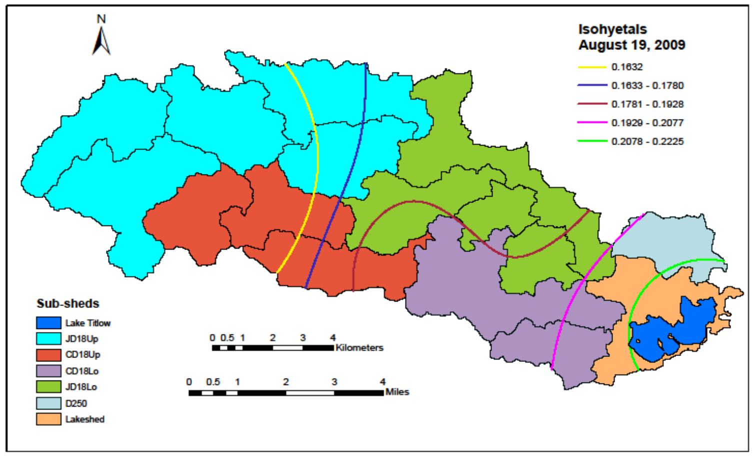

Figure 45. Rainfall distribution map for the August 2009 event at the Lake Titlow watershed, Sibley, and McLeod Counties, Minnesota.

Isohyetals October 1, 2009 Lake Titlow Watershed

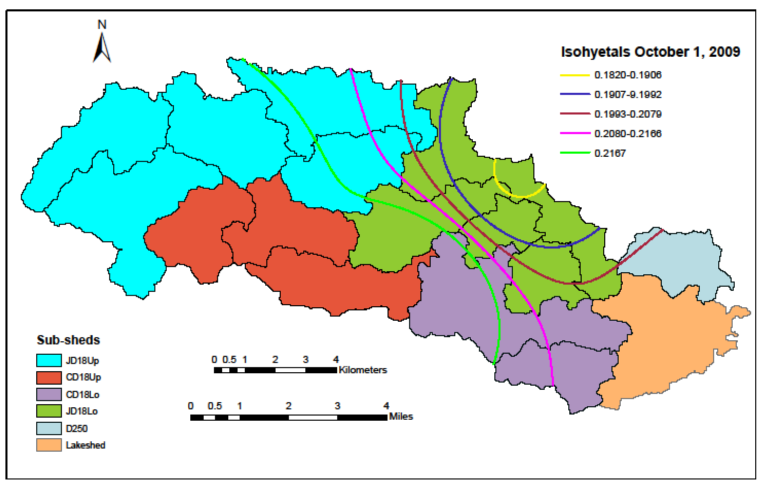

Figure 46. Rainfall distribution map for the October 2009 event at the Lake Titlow watershed, Sibley, and McLeod Counties, Minnesota.

Rain Distribution April 13, 2010
Lake Titlow Watershed

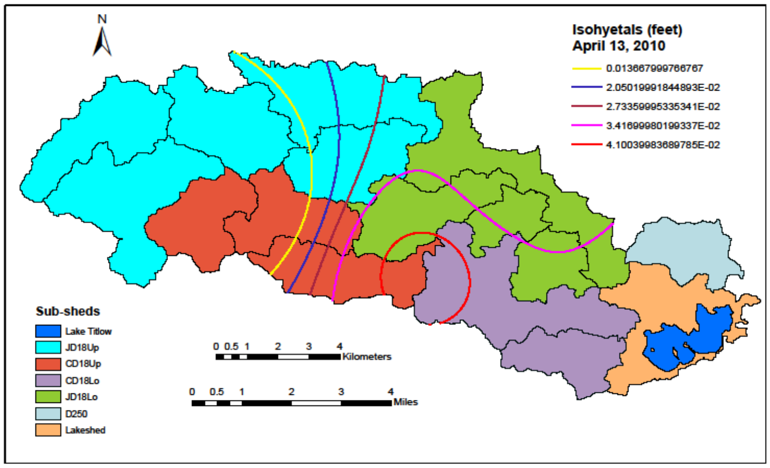

Figure 47. Rainfall distribution map for the April 2010 event at the Lake Titlow watershed, Sibley, and McLeod Counties, Minnesota.

Rain Distribution June 26, 2010 Lake Titlow Watershed

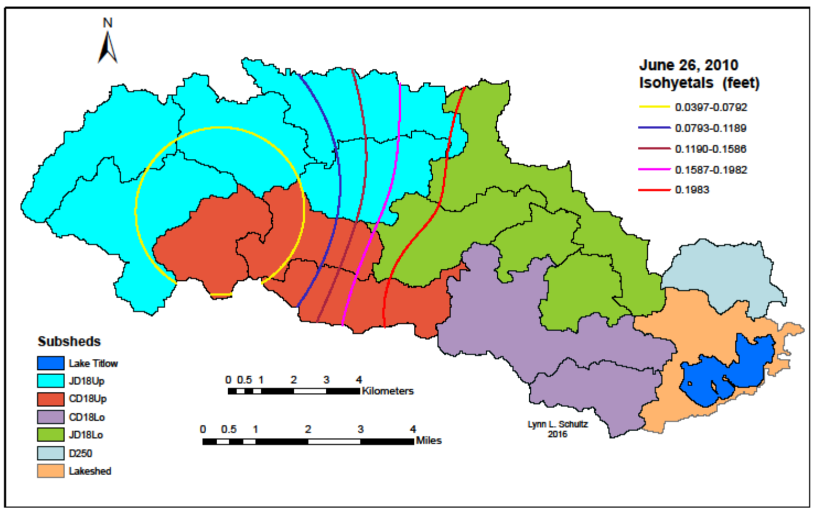

Figure 48. Rainfall distribution map for the June 26, 2010 event at the Lake Titlow watershed, Sibley, and McLeod Counties, Minnesota.

Rain Distribution August 13, 2010
Lake Titlow Watershed

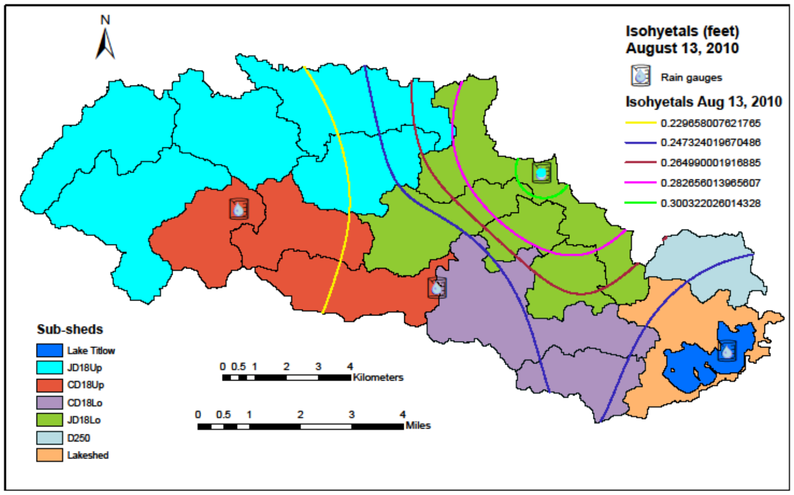

Figure 49. Rainfall distribution map for the August 2010 event at the Lake Titlow watershed, Sibley, and McLeod Counties, Minnesota.

Rain Distribution September 24, 2010
Lake Titlow Watershed

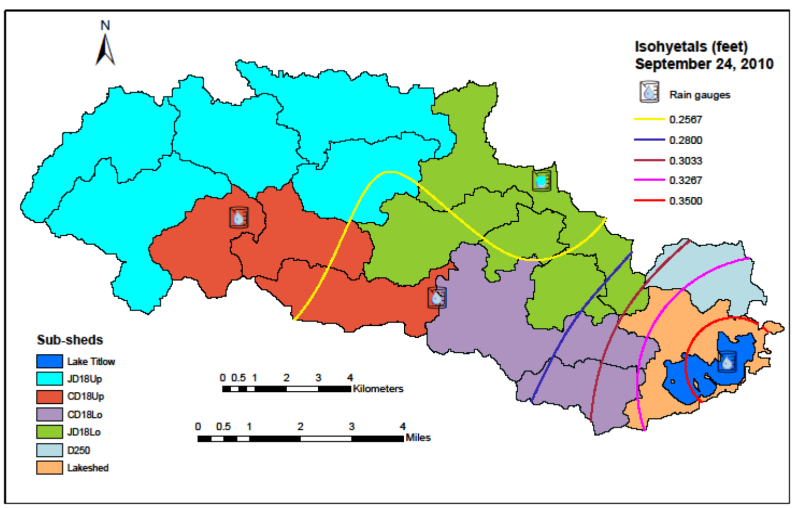

Figure 50. Rainfall distribution map for the September 24, 2010 event at the Lake Titlow watershed, Sibley, and McLeod Counties, Minnesota.

Appendix 6. Hydrographs of the eight storm events studied from 2009 and 2010

The following hydrographs are for each subshed for each of the eight events of this study.

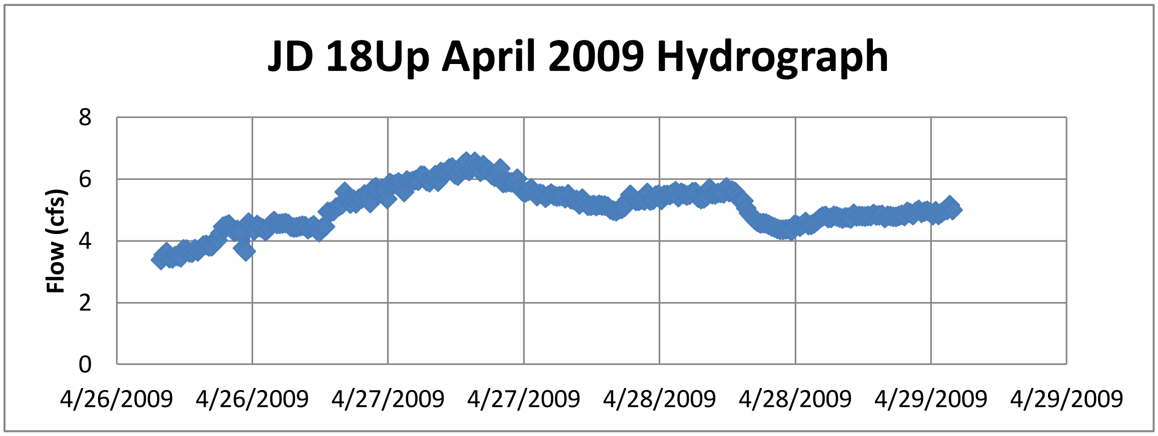

Figure 51. Hydrograph for the April 26, 2009 rainfall event at JD18Up, Sibley County, Lake Titlow watershed.

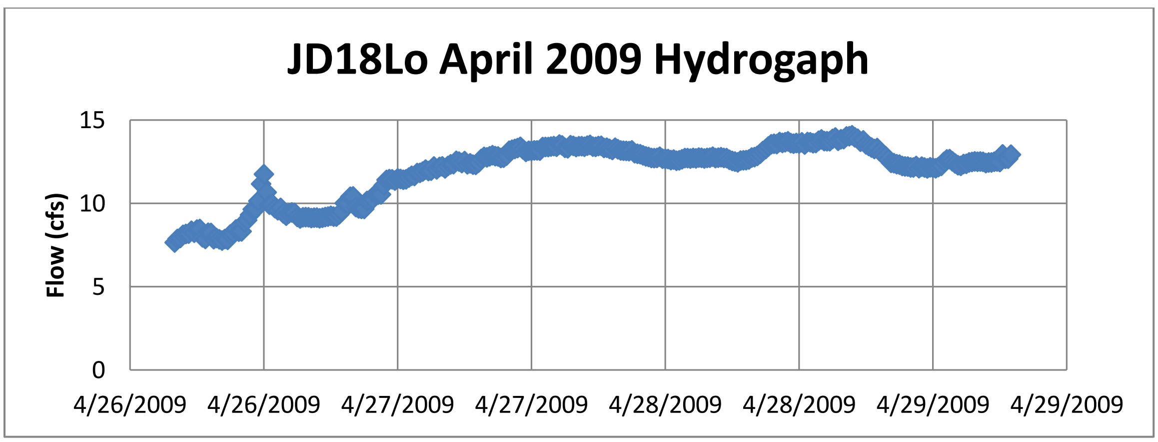

Figure 52. Hydrograph for the April 26, 2009 rainfall event at JD18Lo, Sibley County, Lake Titlow watershed.

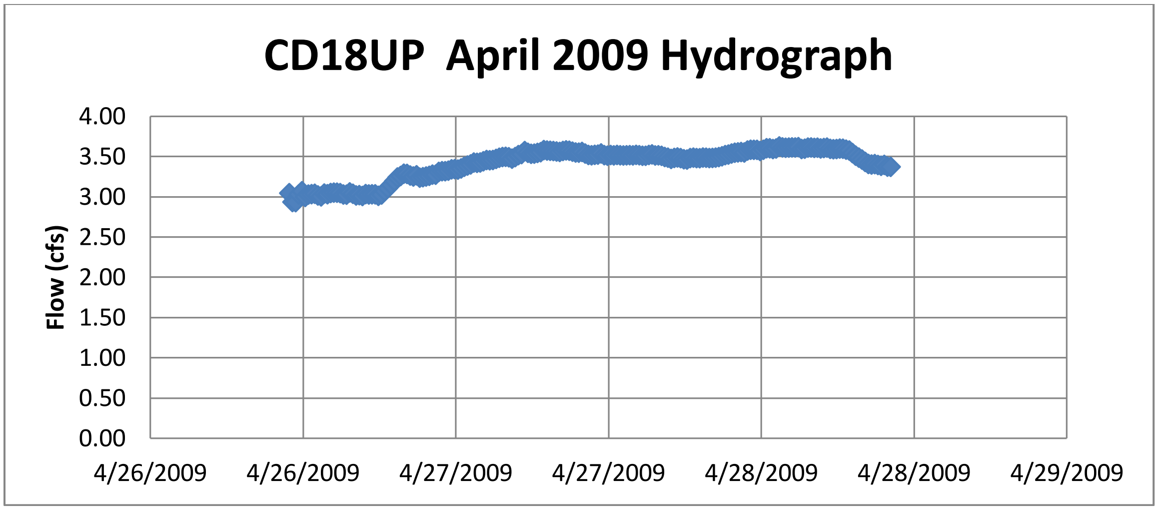

Figure 53. Hydrograph for the April 26, 2009 rainfall event at JD18Up, Sibley County, Lake Titlow watershed.

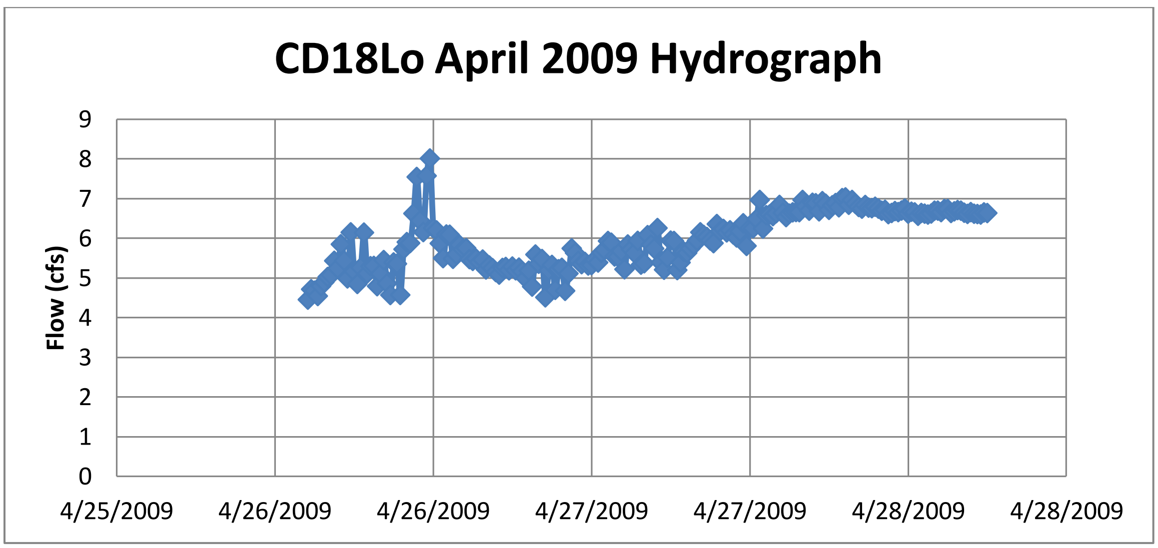

Figure 54. Hydrograph for the April 26, 2009 rainfall event at JD18Up, Sibley County, Lake Titlow watershed.

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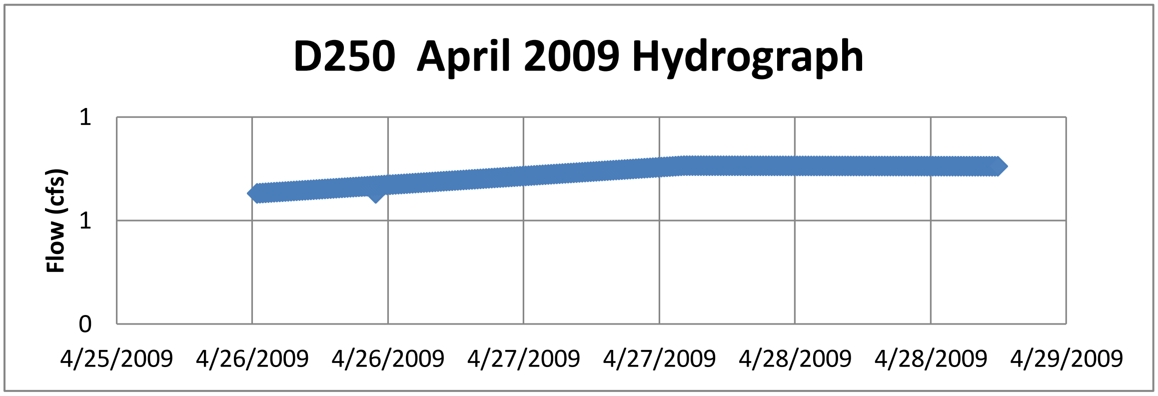

Figure 55. Hydrograph for the April 26, 2009 rainfall event at D250, Sibley County, Lake Titlow watershed.

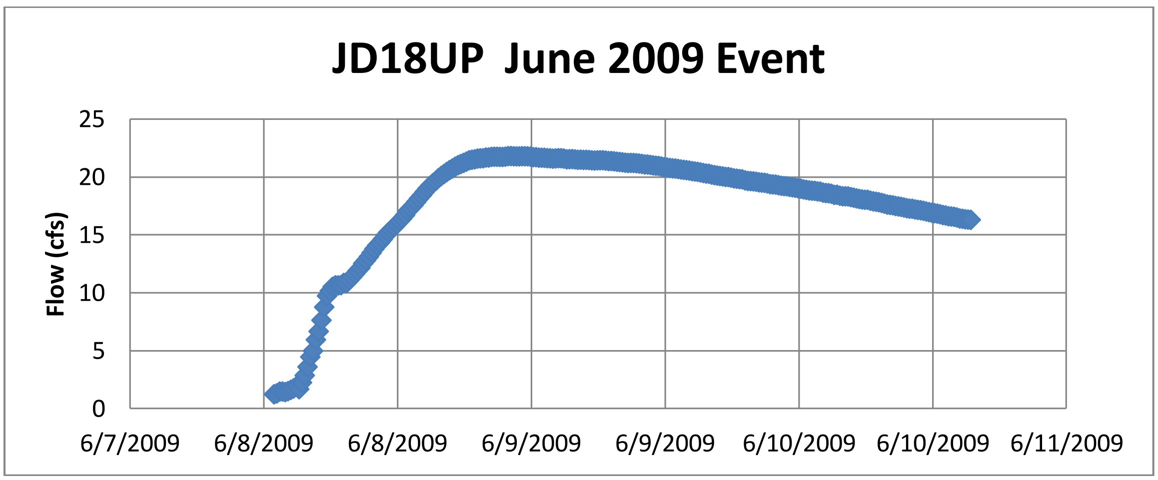

Figure 56. Hydrograph for the June 8, 2009 rainfall event at JD18Up, Sibley County, Lake Titlow watershed.

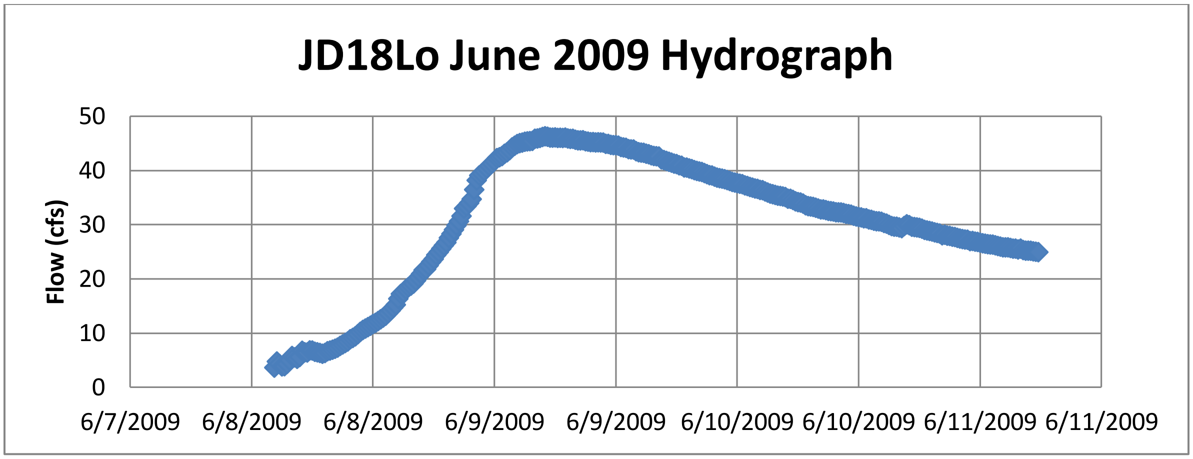

Figure 57. Hydrograph for the June 8, 2009 rainfall event at JD18Lo, Sibley County, Lake Titlow watershed.

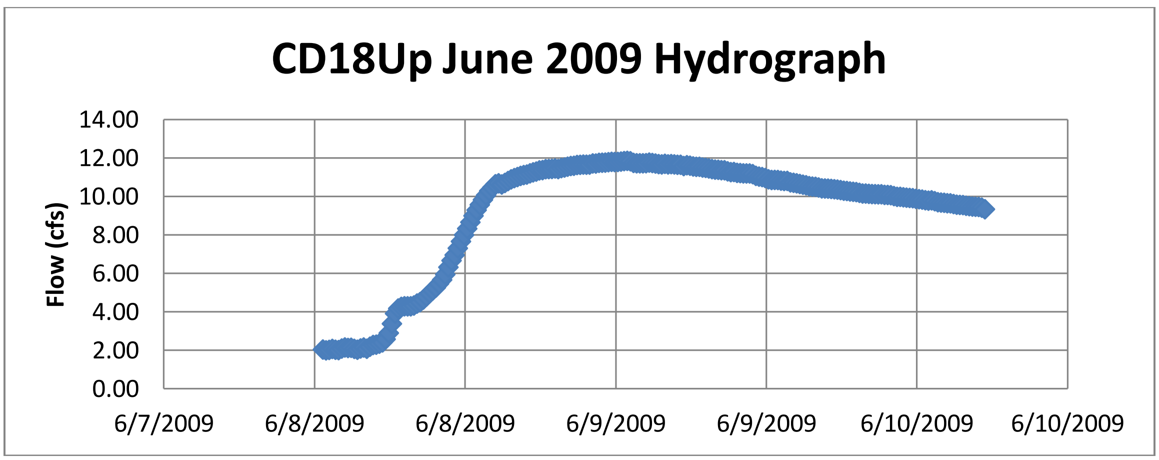

Figure 58. Hydrograph for the June 8, 2009 rainfall event at CD18Up, Sibley County, Lake Titlow watershed.

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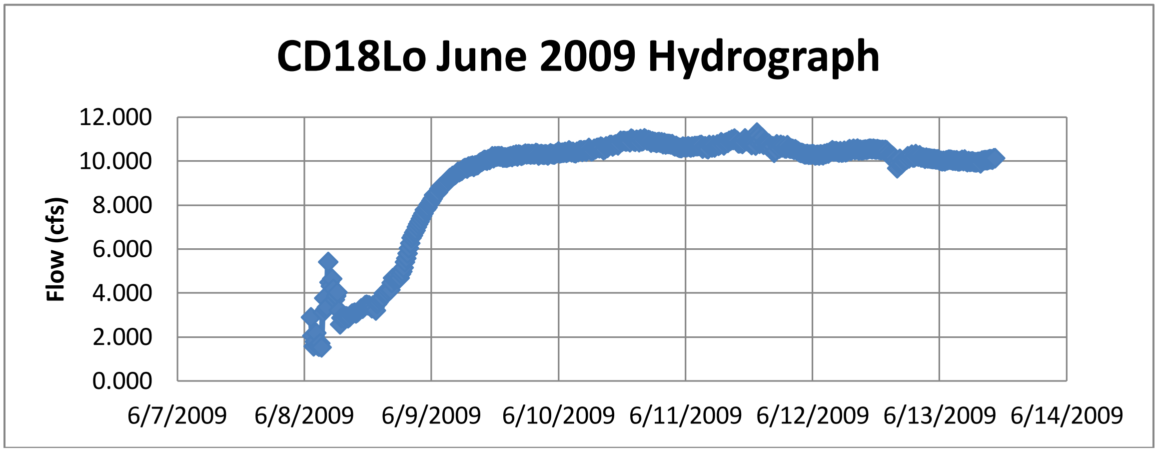

Figure 59. Hydrograph for the June 8, 2009 rainfall event at CD18Lo, Sibley County, Lake Titlow watershed.

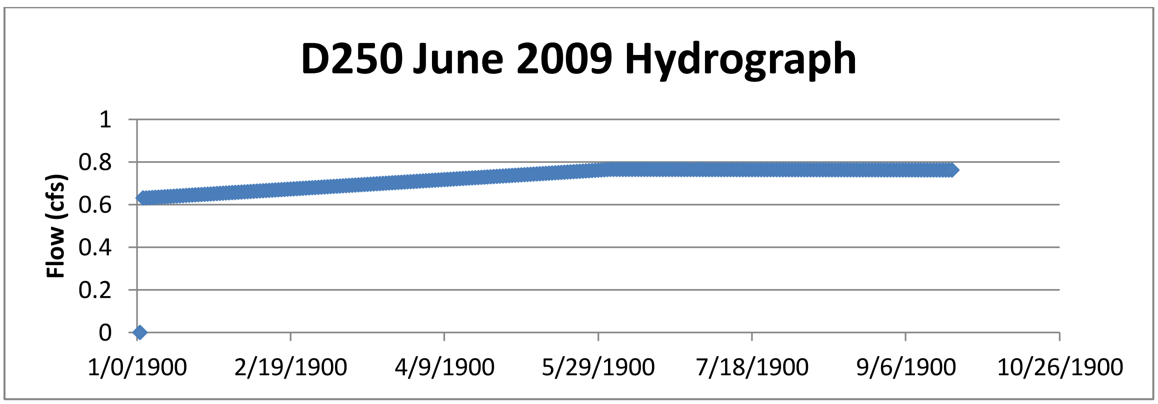

Figure 60. Hydrograph for the June 8, 2009 rainfall event at D250, Sibley County, Lake Titlow watershed.

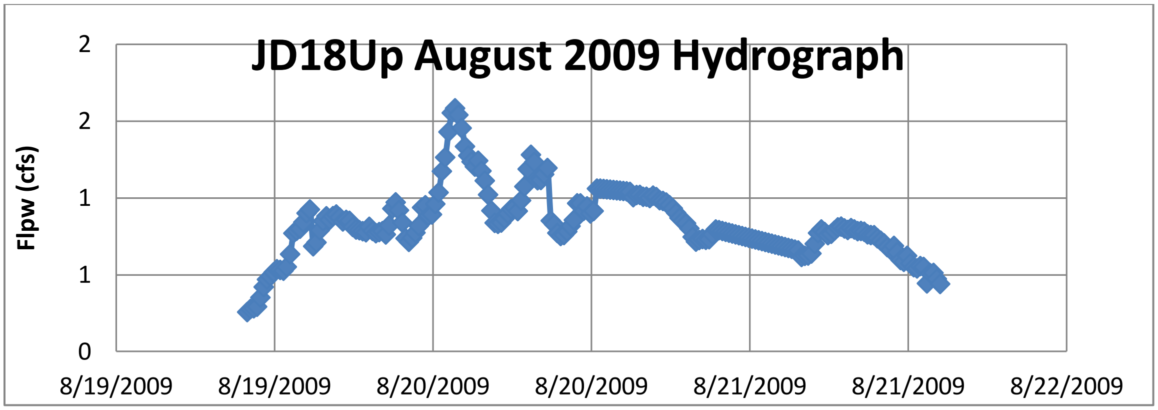

Figure 61. Hydrograph for the August 19, 2009 rainfall event at JD18Up, Sibley County, Lake Titlow watershed.

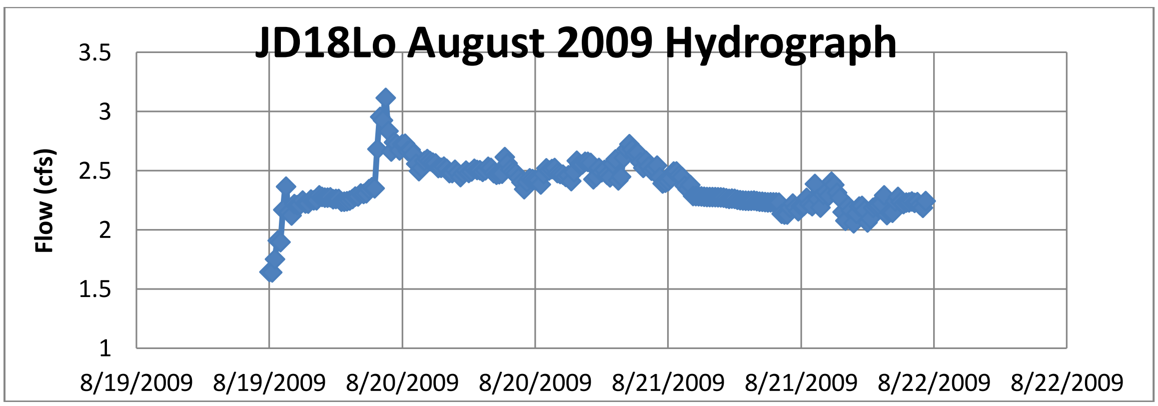

Figure 62. Hydrograph for the August 19, 2009 rainfall event at JD18Lo, Sibley County, Lake Titlow watershed.

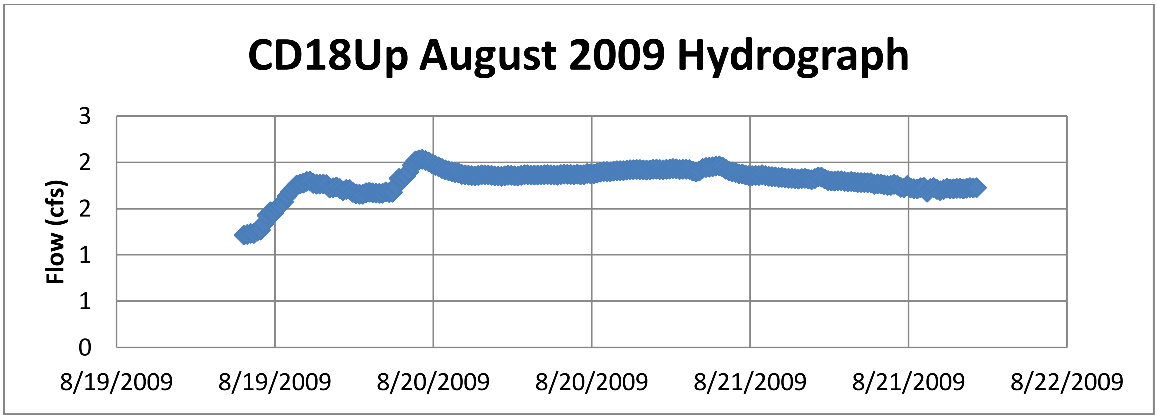

Figure 63. The hydrograph for the August 19, 2009 rainfall event at CD18Up, Sibley County, Lake Titlow watershed.

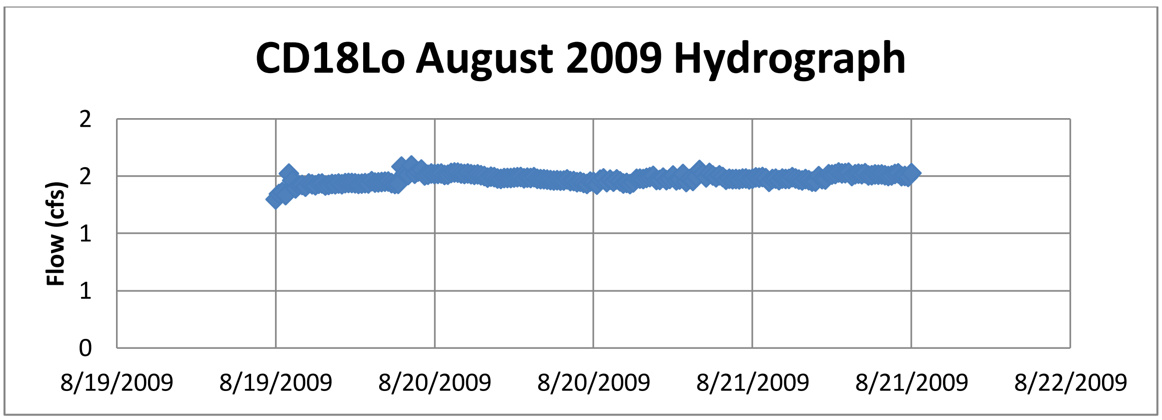

Figure 64. Hydrograph for the August 19, 2009 rainfall event at CD18Lo, Sibley County, Lake Titlow watershed.

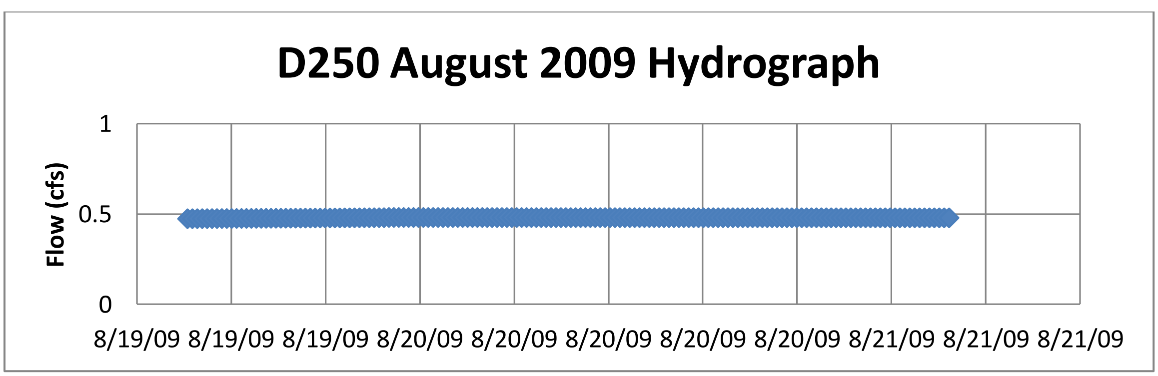

Figure 65. Hydrograph for the August 19, 2009 rainfall event at D250, Sibley County, Lake Titlow watershed.

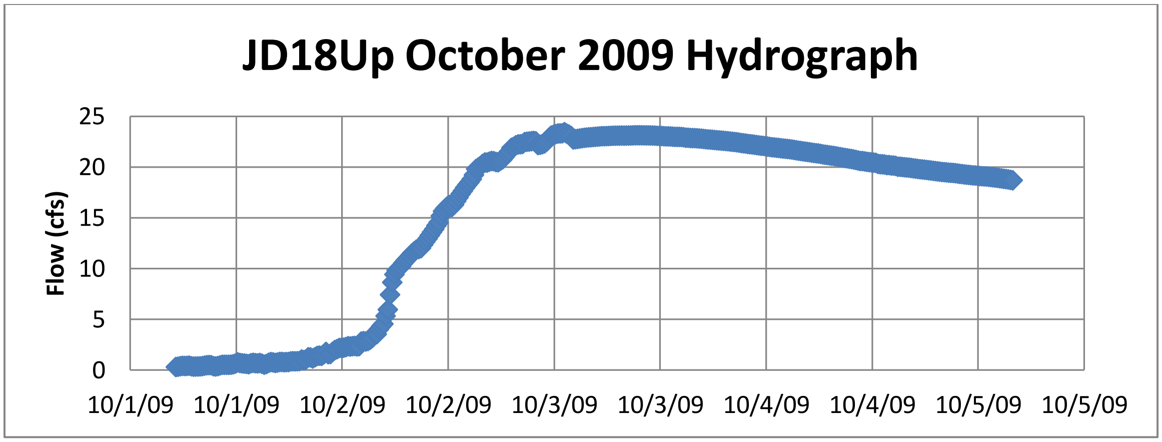

Figure 66. Hydrograph for the October 1, 2009 rainfall event at JD18Up, Sibley County, Lake Titlow watershed.

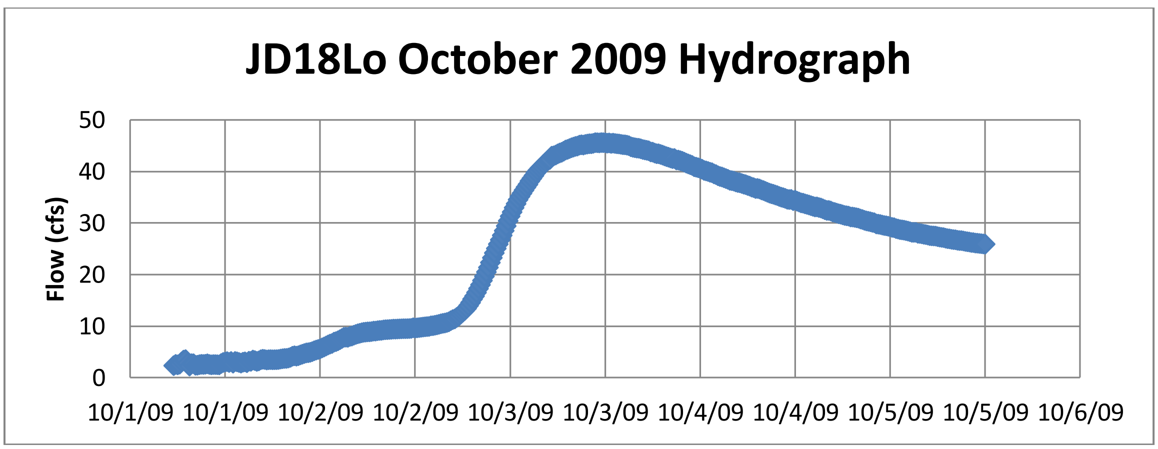

Figure 67. Hydrograph for the October 1, 2009 rainfall event at JD18Lo, Sibley County, Lake Titlow watershed.

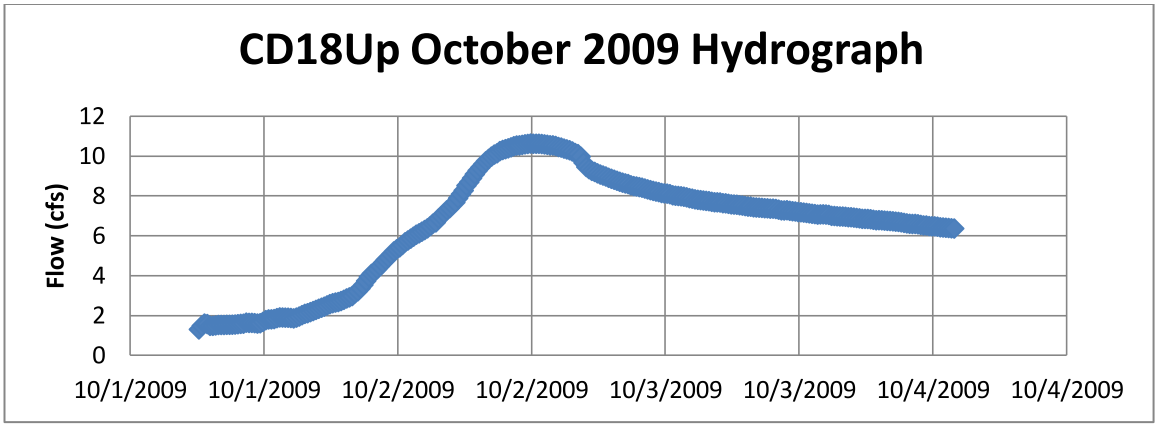

Figure 68. Hydrograph for the October 1, 2009 rainfall event at CD18Up, Sibley County, Lake Titlow watershed.

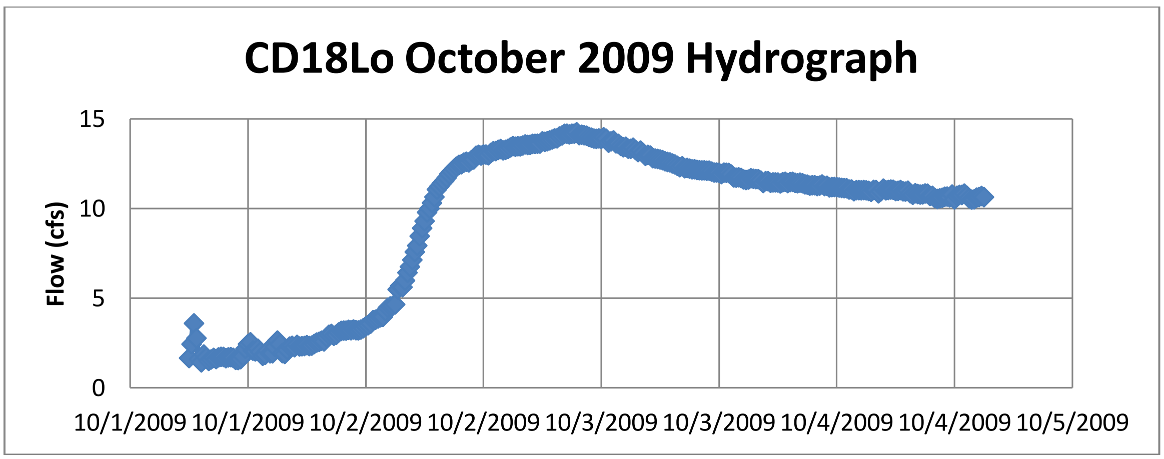

Figure 69. Hydrograph for the October 1, 2009 rainfall event at CD18Lo, Sibley County, Lake Titlow watershed.

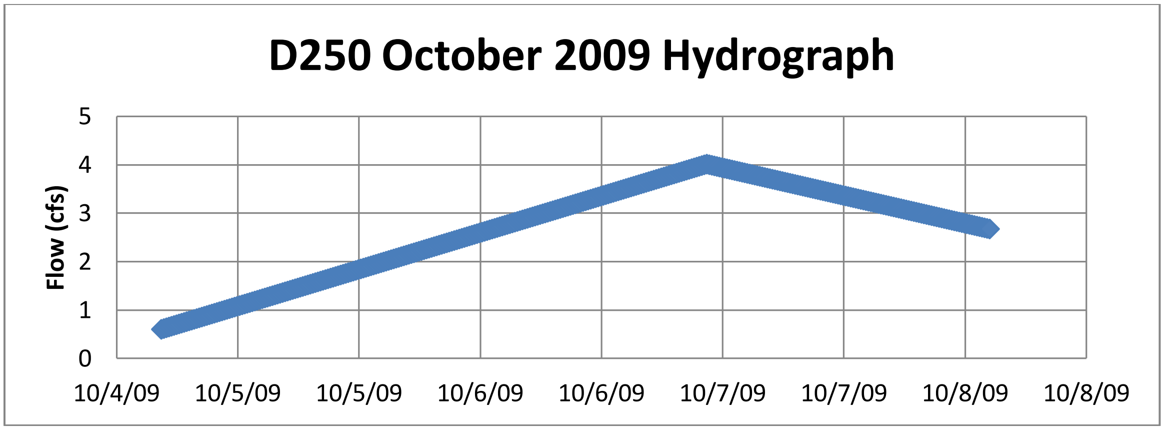

Figure 70. Hydrograph for the October 1, 2009 rainfall event at D250, Sibley County, Lake Titlow watershed.

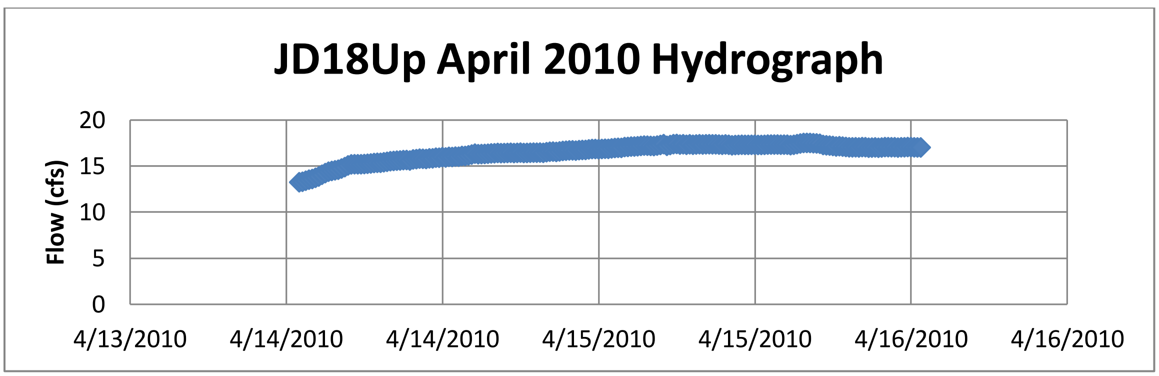

Figure 71. Hydrograph for the April 13, 2010 rainfall event at JD18Up, Sibley County, Lake Titlow watershed.

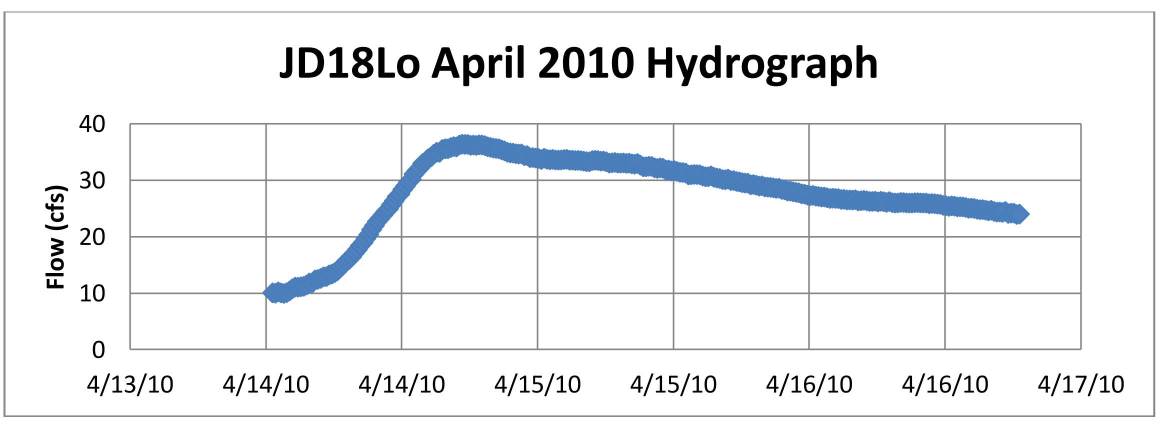

Figure 72. Hydrograph for the April 13, 2010 rainfall event at JD18Lo, Sibley County, Lake Titlow watershed.

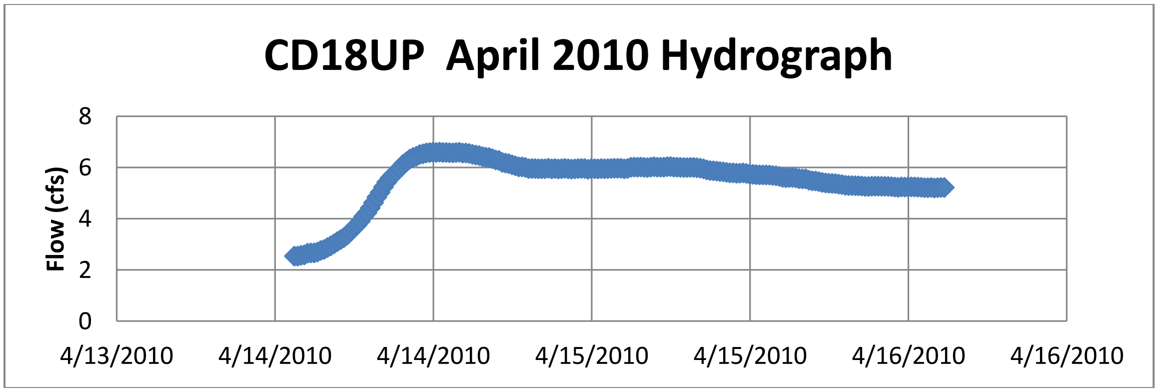

Figure 73. Hydrograph for the April 13, 2010 rainfall event at CD18Up, Sibley County, Lake Titlow watershed.

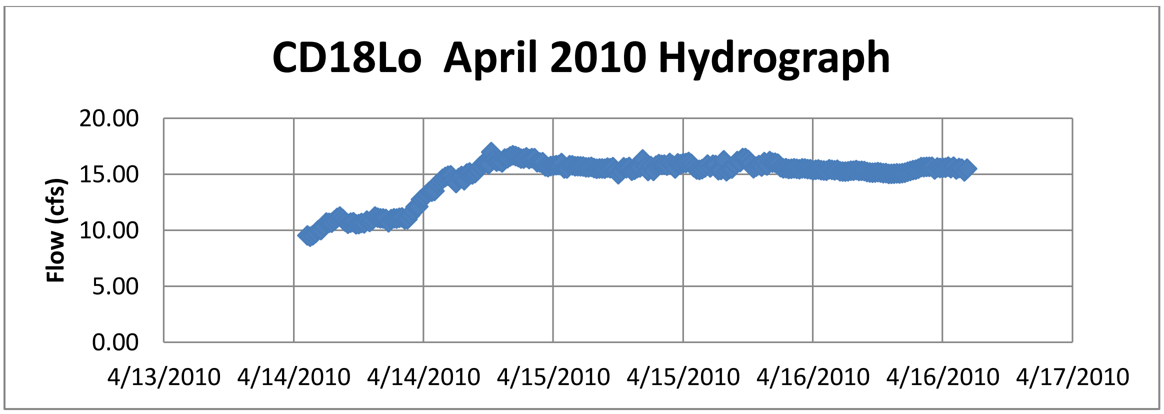

Figure 74. Hydrograph for the April 13, 2010 rainfall event at CD18Lo, Sibley County, Lake Titlow watershed.

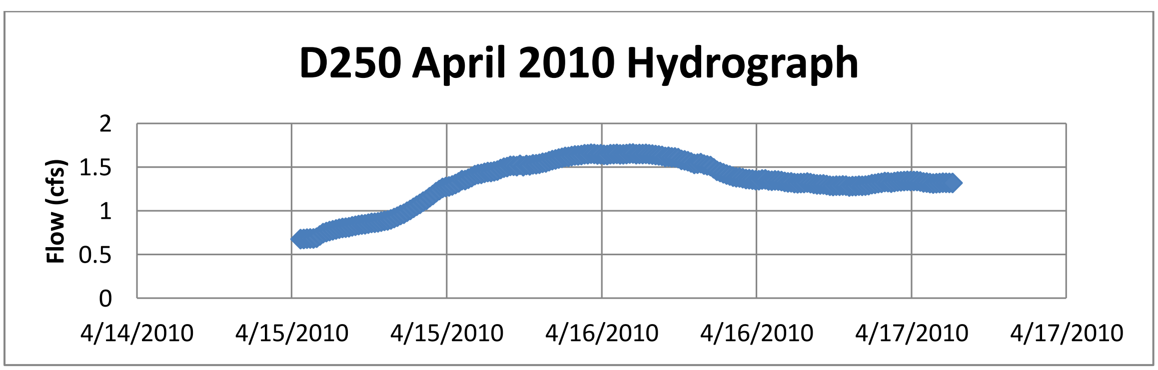

Figure 75. Hydrograph for the April 13, 2010 rainfall event at D250, Sibley County, Lake Titlow watershed.

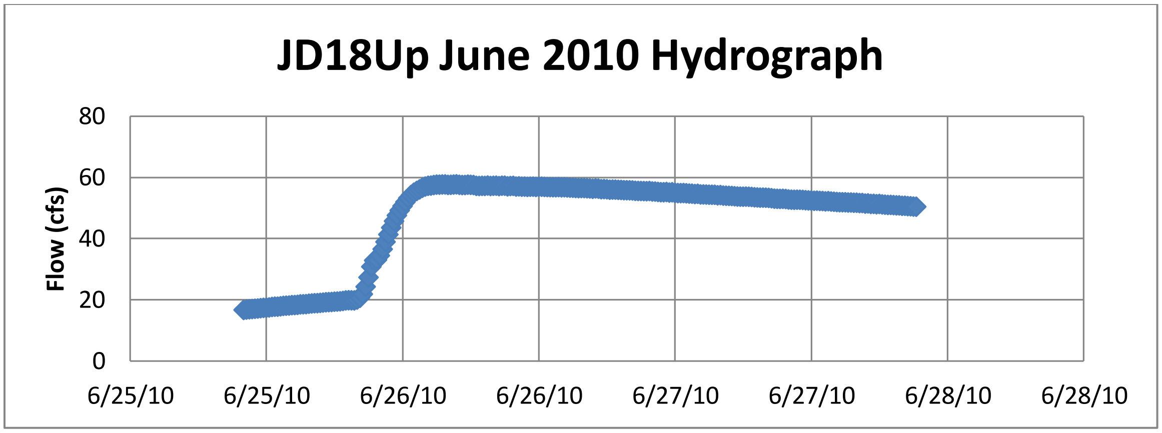

Figure 76. Hydrograph for the June 26, 2010 rainfall event at JD18Up, Sibley County, Lake Titlow watershed.

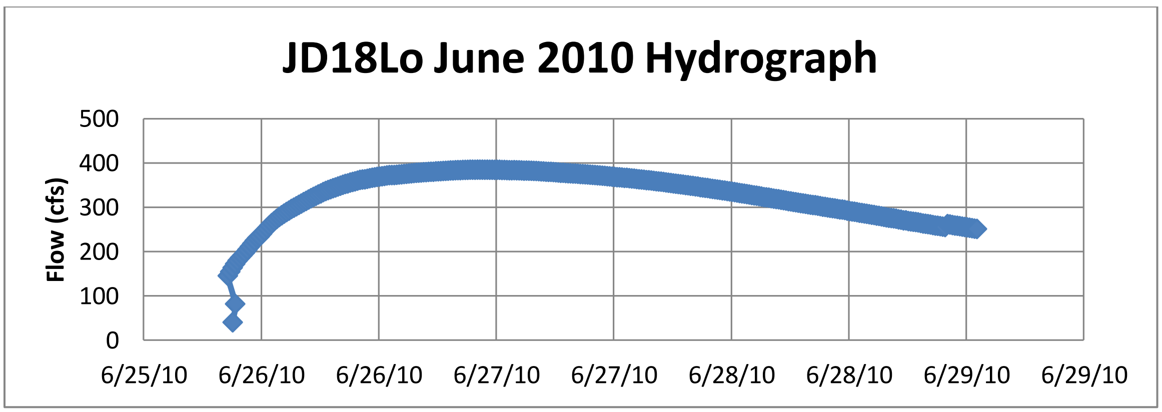

Figure 77. Hydrograph for the June 26, 2010 rainfall event at JD18Lo, Sibley County, Lake Titlow watershed.

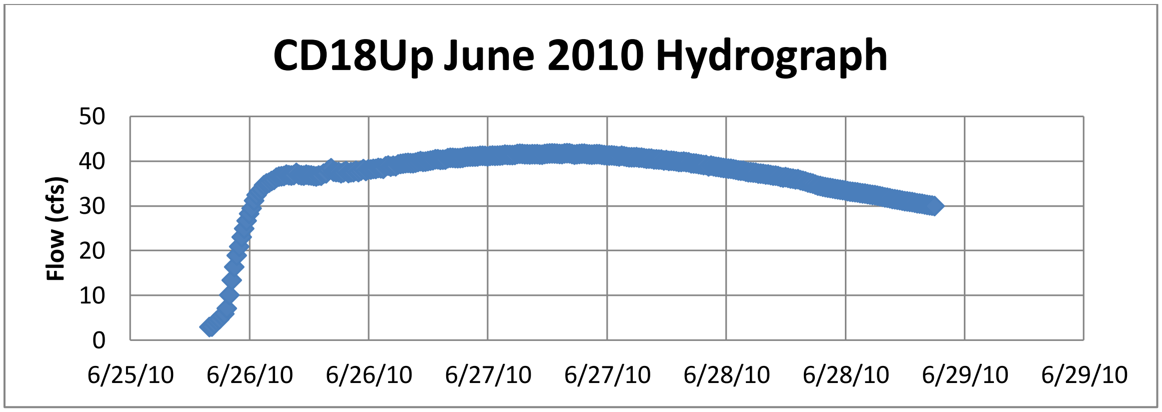

Figure 78. Hydrograph for the June 26, 2010 rainfall event at CD18Up, Sibley County, Lake Titlow watershed.

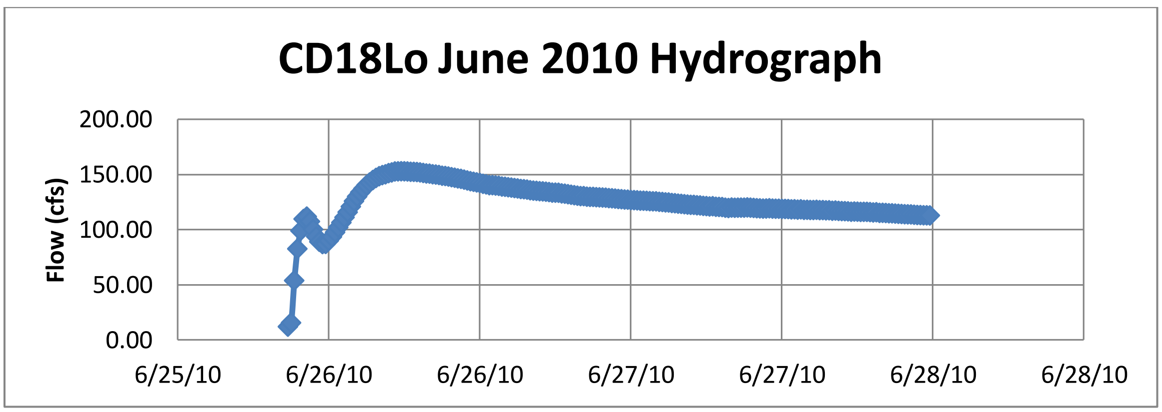

Figure 79. Hydrograph for the June 26, 2010 rainfall event at CD18Lo, Sibley County, Lake Titlow watershed.

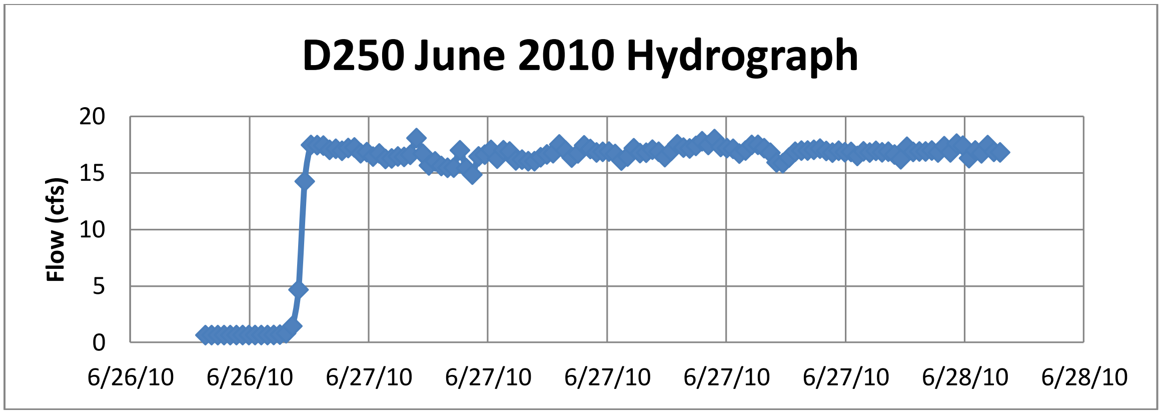

Figure 80. Hydrograph for the June 26, 2010 rainfall event at D250, Sibley County, Lake Titlow watershed.

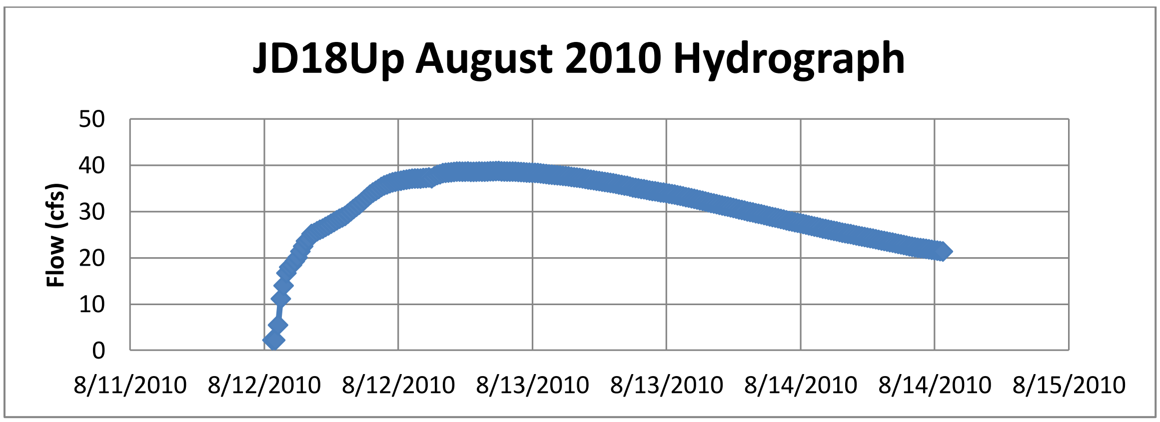

Figure 81. Hydrograph for the August 13, 2010 rainfall event at JD18Up, Sibley County, Lake Titlow watershed.

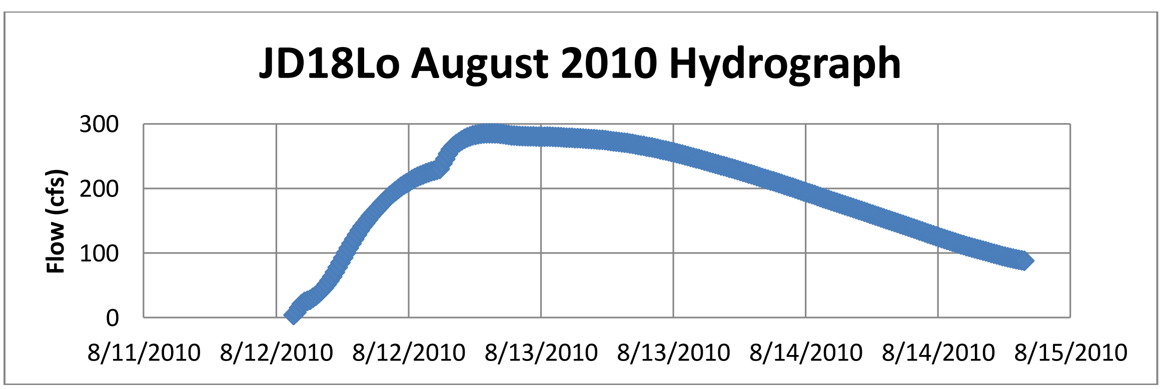

Figure 82. Hydrograph for the August 13, 2010 rainfall event at JD18Lo, Sibley County, Lake Titlow watershed.

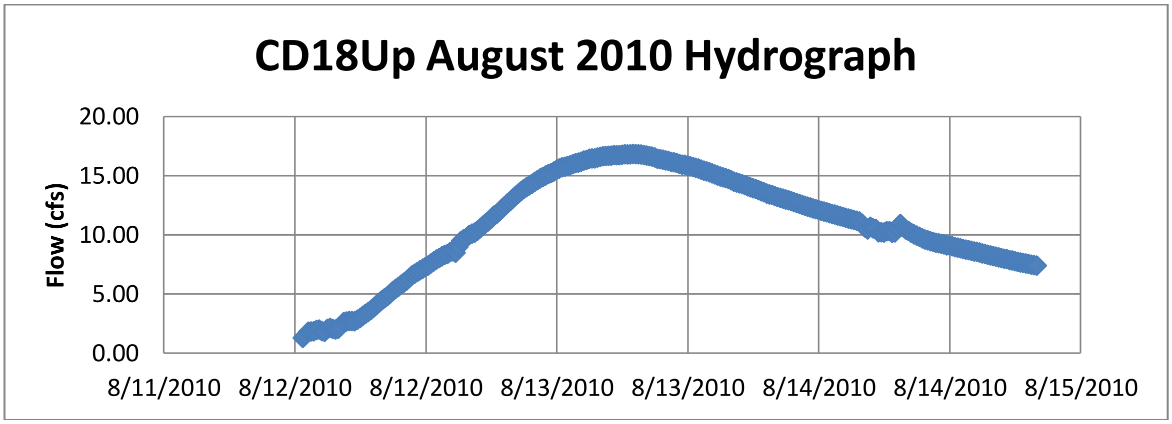

Figure 83. Hydrograph for the August 13, 2010 rainfall event at CD18Up, Sibley County, Lake Titlow watershed.

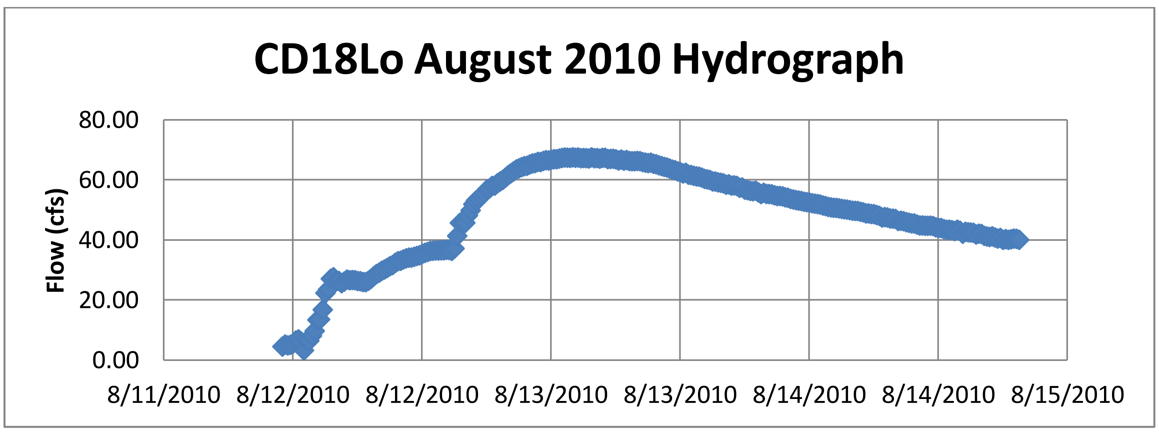

Figure 84. Hydrograph for the August 13, 2010 rainfall event at CD18Lo, Sibley County, Lake Titlow watershed.

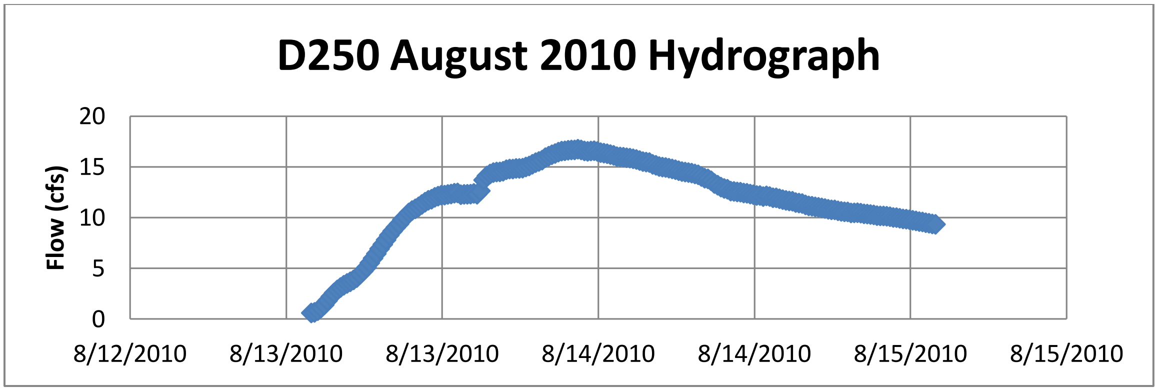

Figure 85. Hydrograph for the August 13, 2010 rainfall event at D250, Sibley County, Lake Titlow watershed.

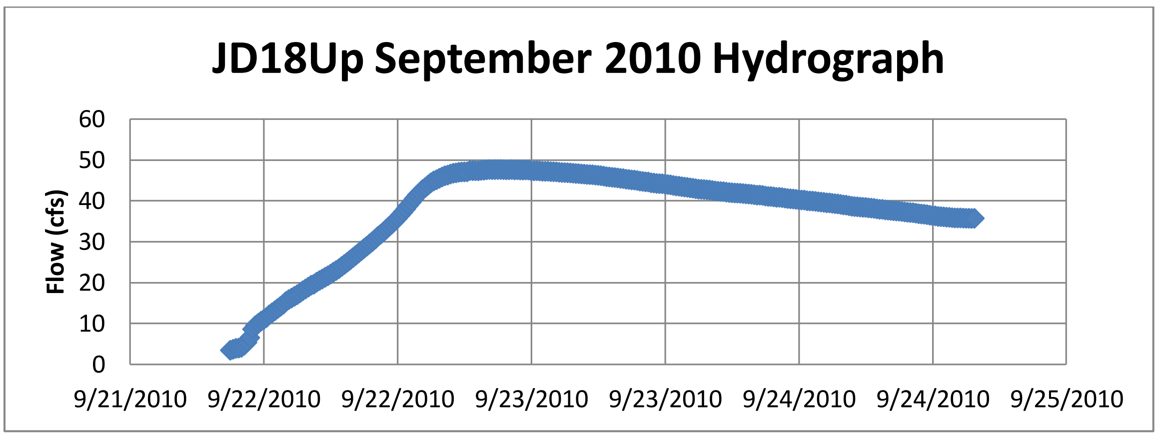

Figure 86. Hydrograph for the September 24, 2010 rainfall event at JD18Up, Sibley County, Lake Titlow watershed.

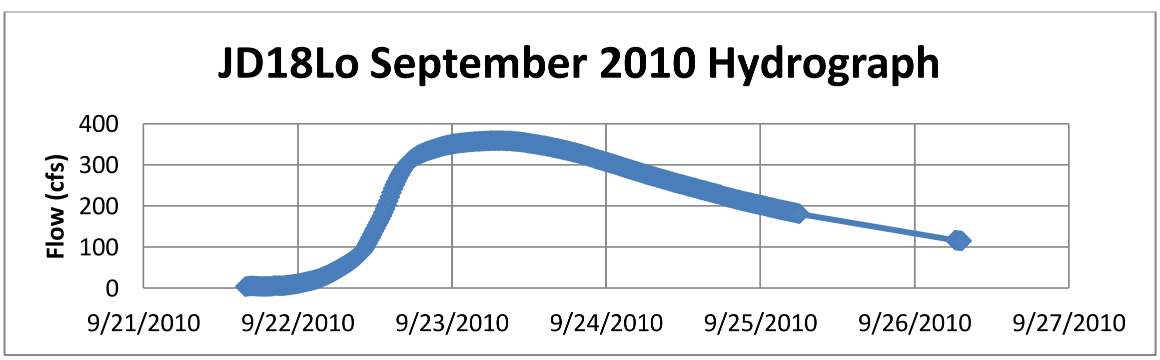

Figure 87. Hydrograph for the September 24, 2010 rainfall event at JD18Lo, Sibley County, Lake Titlow watershed.

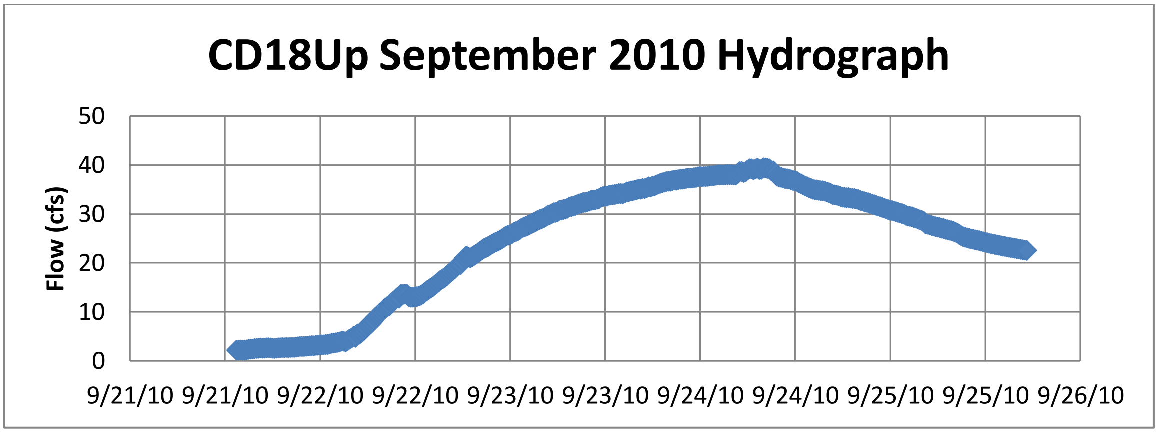

Figure 88. Hydrograph for the September 24, 2010 rainfall event at CD18Up, Sibley County, Lake Titlow watershed.

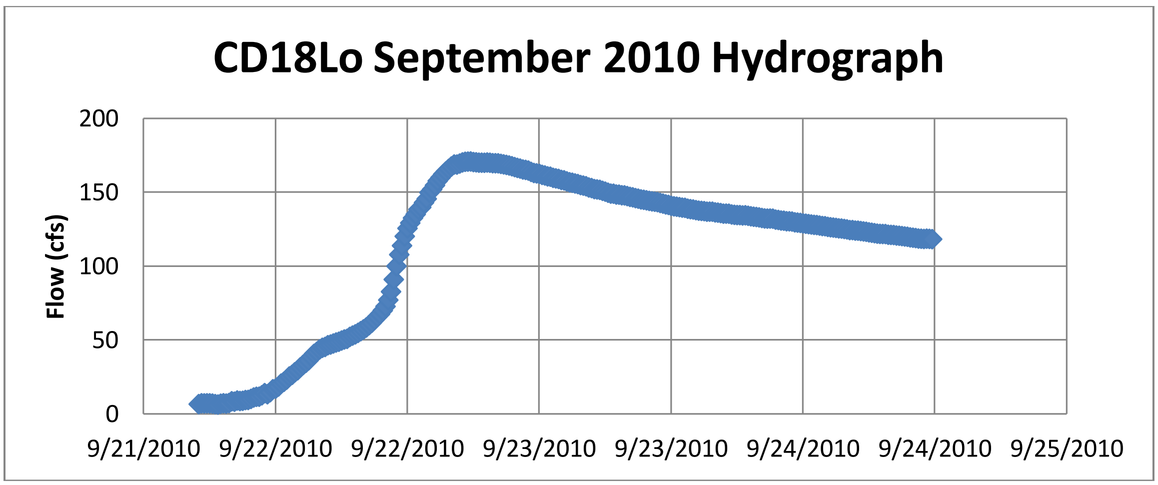

Figure 89. Hydrograph for the September 24, 2010 rainfall event at CD18Lo, Sibley County, Lake Titlow watershed.

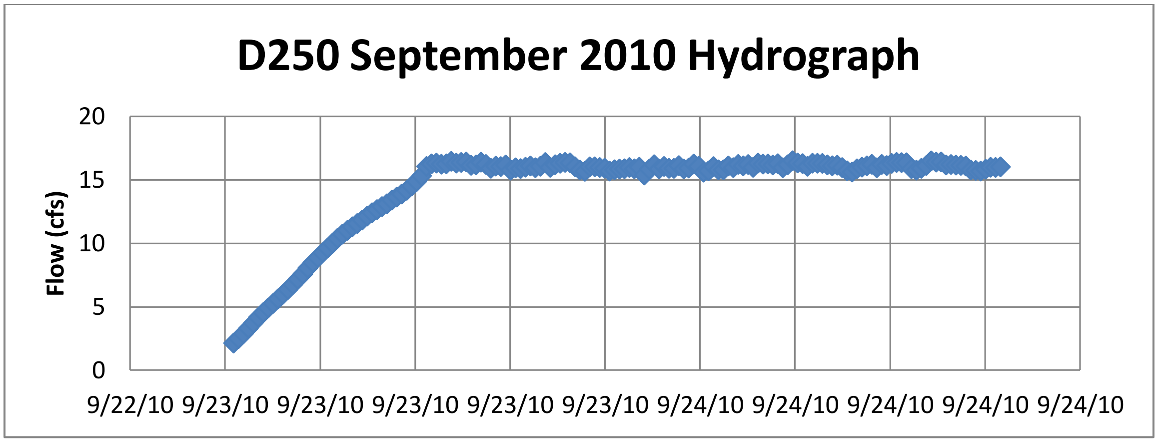

Figure 90. Hydrograph for the September 24, 2010 rainfall event at D250, Sibley County, Lake Titlow watershed.

Appendix 7. Sediment and nutrient loads from the eight precipitation events in 2009 and 2010

This appendix includes TSS, TP, and NOx loads for cumulative, exclusive, and per square mile subshed for each of the precipitation events of this study. Time series graphs depict subshed response for each of the eight precipitation events.

Table 38. Total suspended solids per cumulative drainage for the eight events in this study of the Lake Titlow watershed, Sibley and McLeod Counties, Minnesota.

Site	TSS (kg) 4/26/09	TSS (kg) 6/8/09	TSS (kg) 8/19/09	TSS (kg) 10/1/09	TSS (kg) 4/14/10	TSS (kg) 6/25/10	TSS (kg) 8/12/10	TSS (kg) 9/21/10
JD18Up	77	178	51	266	114	1611	518	960
CD18Up	68	206	31	189	118	632	300	430
JD18Lo	324	662	122	756	555	6169	3202	4845
CD18Lo	113	402	73	269	262	6179	2252	6913
D250	45	59	16	67	54	81	119	102

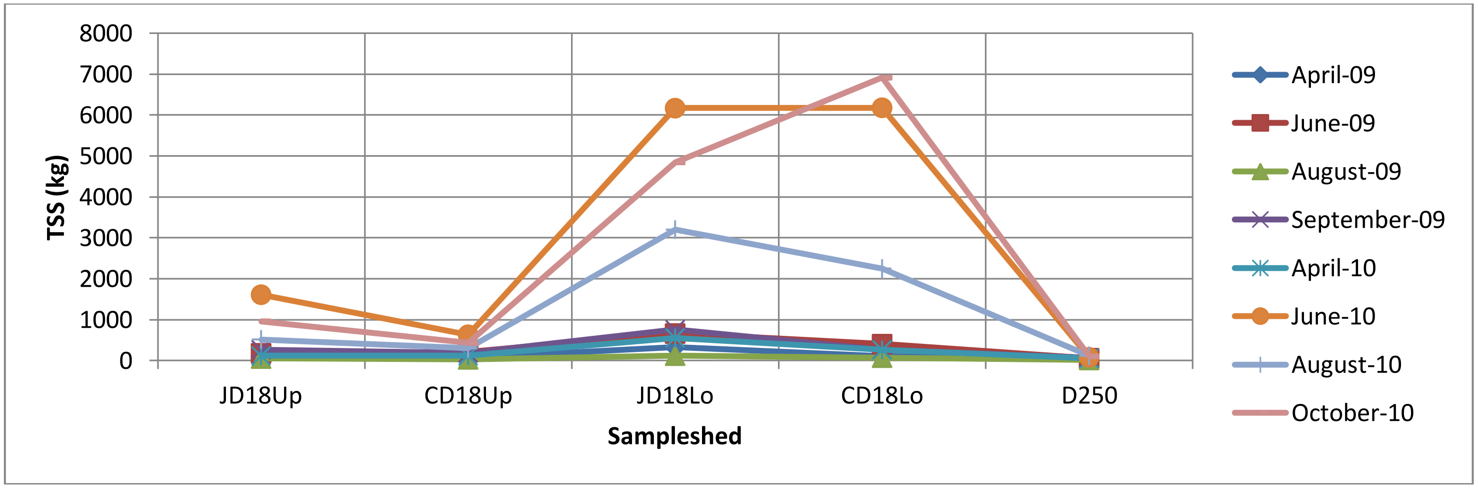

Figure 91. Total suspended solids (TSS) from each subshed for each of the study's precipitation events during 2009 and 2010 in the Lake Titlow watershed, Sibley and McLeod counties, Minnesota. JD18Lo and CD18Lo TSS include amounts from their upland subsheds (JD18Up and CD18Up).

Table 39. Total suspended solids per exclusive drainage for the eight events in this study of the Lake Titlow watershed, Sibley and McLeod Counties, Minnesota.

Site	TSS (kg) 4/26/09	TSS (kg) 6/8/09	TSS (kg) 8/19/09	TSS (kg) 10/1/09	TSS (kg) 4/14/10	TSS (kg) 6/25/10	TSS (kg) 8/12/10	TSS (kg) 9/21/10
JD18Up	77.30	178.10	50.70	265.60	114.18	1610.74	517.65	959.61
CD18Up	67.92	206.28	30.85	188.74	118.15	631.58	300.33	430.13
JD18Lo	246.70	484.00	71.20	489.90	440.77	4558.30	2684.32	3885.50
CD18Lo	44.89	195.42	41.90	80.55	144.27	5547.50	1951.31	6483.32
D250	44.80	59.29	15.76	66.66	54.15	81.16	118.96	102.41

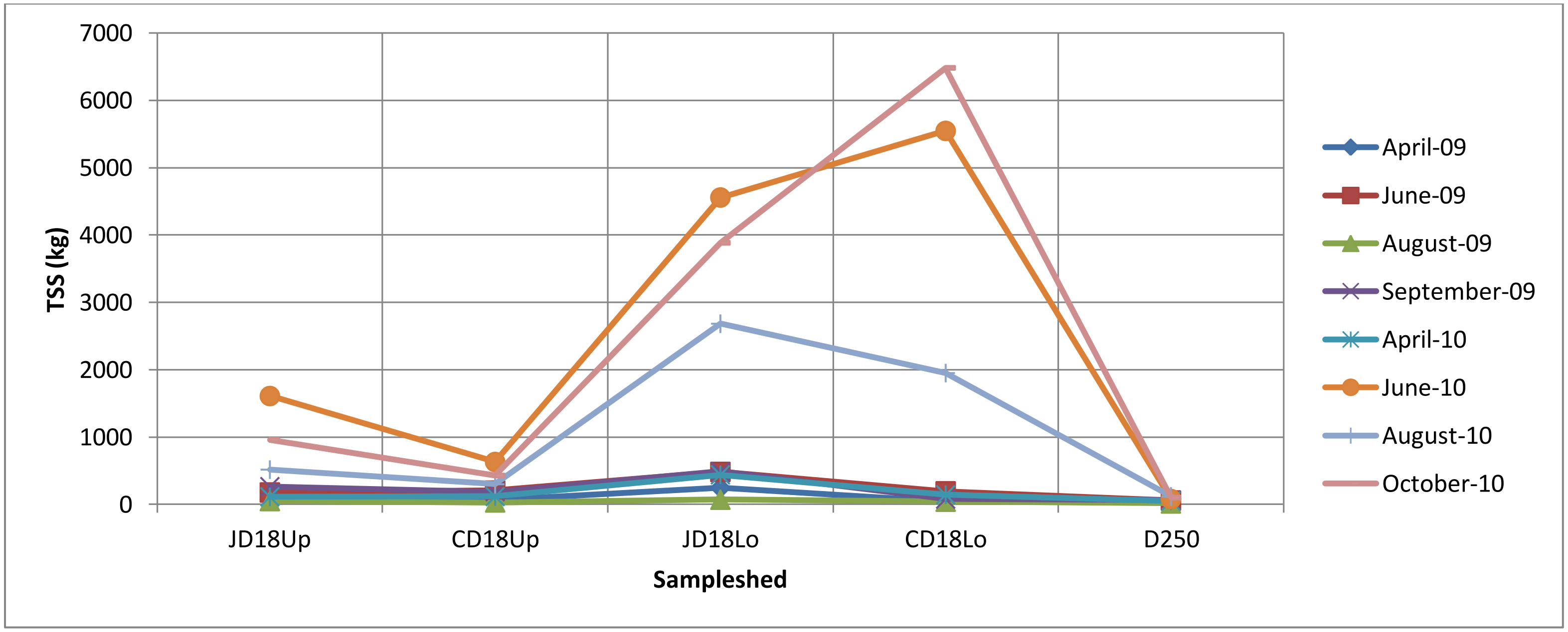

Figure 92. Total suspended solids (TSS) from each sampleshed for each of the study's precipitation events during 2009 and 2010 in the Lake Titlow watershed, Sibley and McLeod counties, Minnesota. TSS amounts are for exclusive samplesheds.

Table 40. Total suspended solids per exclusive drainage per square mile for the eight events in this study of the Lake Titlow watershed, Sibley and McLeod Counties, Minnesota.

Exclusive Drainages Per mi^2	TSS (kg) 4/26/2009	TSS (kg) 6/8/2009	TSS (kg) 8/19/2009	TSS (kg) 10/1/2009	TSS (kg) 4/14/2010	TSS (kg) 6/25/2010	TSS (kg) 8/12/2010	TSS (kg) 9/21/2010
JD18Up	3.90	8.99	2.56	13.41	5.77	81.35	26.14	48.47
CD18Up	7.72	23.44	3.51	21.45	13.43	71.77	34.13	48.88
JD18Lo	21.30	41.80	6.15	42.31	38.06	393.64	231.81	335.54
CD18Lo	5.85	25.45	5.46	10.49	18.79	722.33	254.08	844.18
D250	20.36	26.95	7.17	30.30	24.61	36.89	54.07	46.55

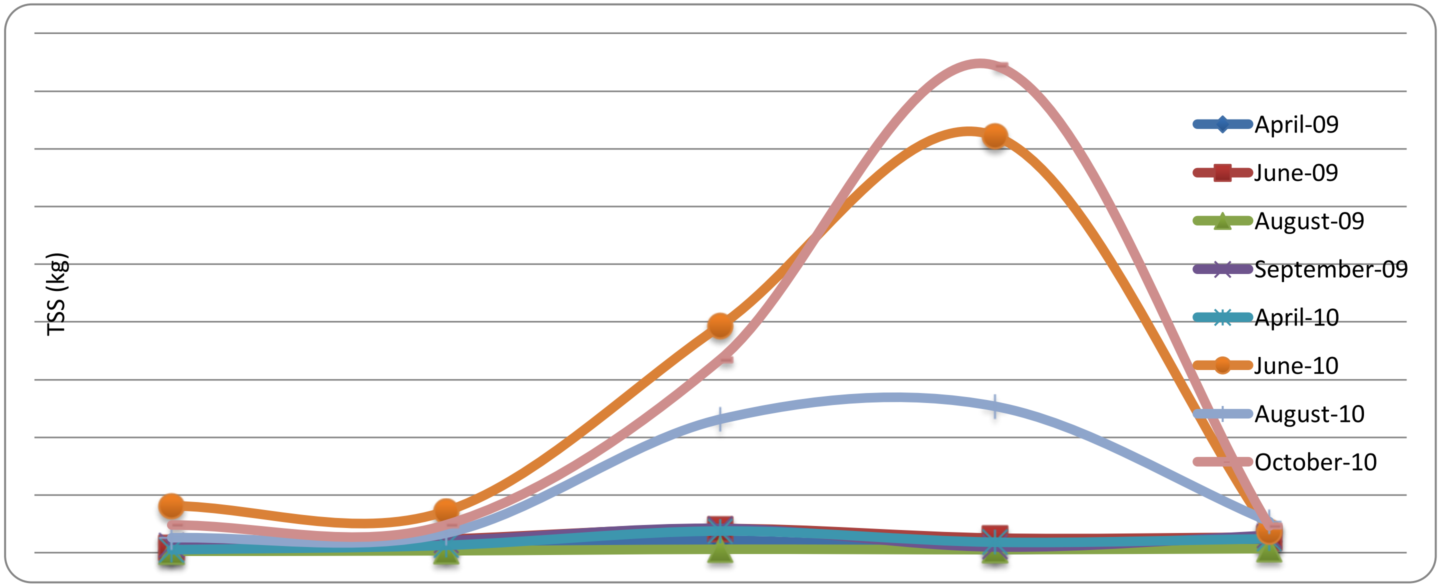

Figure 93. Total suspended solids (TSS) per square mile for each sampleshed for each of the study's precipitation events during 2009 and 2010 in the Lake Titlow watershed, Sibley and McLeod counties, Minnesota.

Table 41. Total phosphorus per cumulative drainage for the eight events in this study of the Lake Titlow watershed, Sibley and McLeod Counties, Minnesota.

Cumulative Drainage	TP (kg) 4/26/09	TP (kg) 6/8/09	TP (kg) 8/19/09	TP (kg) 10/1/09	TP (kg) 4/14/10	TP (kg) 6/25/10	TP (kg) 8/12/10	TP (kg) 9/21/10
JD18Up	0.63	1.87	0.03	2.44	1.36	3.27	2.77	3.36
CD18Up	0.69	1.85	0.04	1.76	1.23	4.90	2.57	3.31
JD18Lo	2.68	3.75	0.51	4.38	3.33	7.15	5.38	6.89
CD18Lo	0.66	2.11	0.38	1.34	1.16	7.34	4.04	8.66
D250	0.92	1.05	0.17	0.80	0.64	0	0	1.12

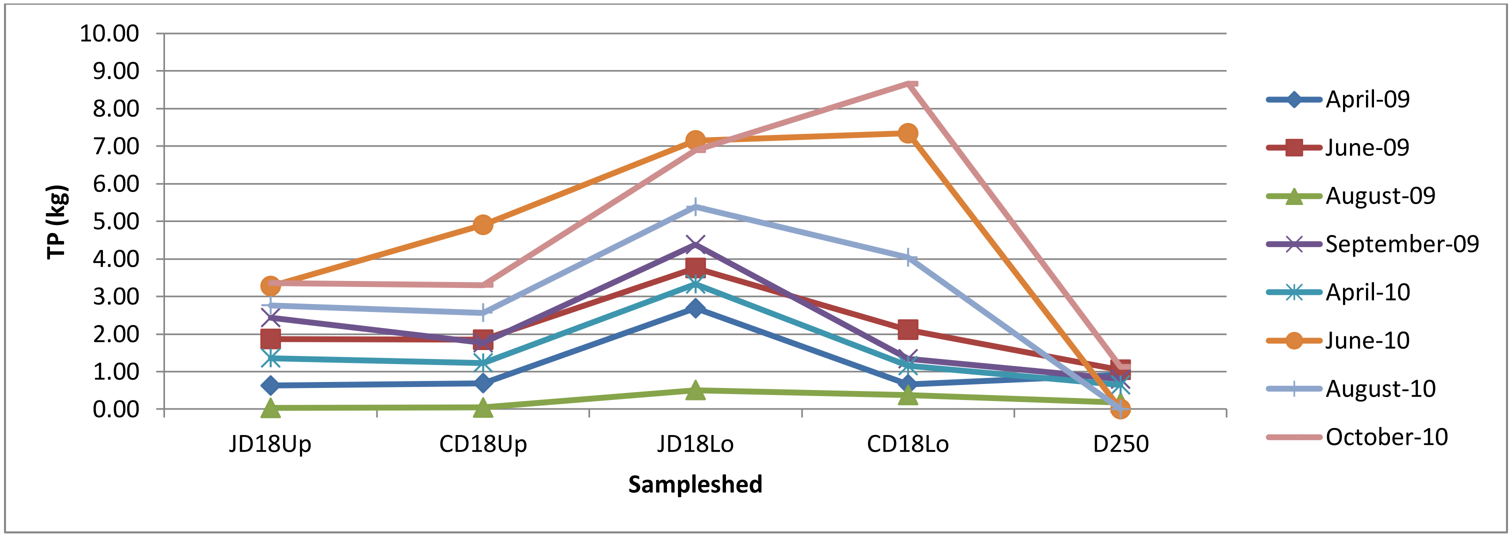

Figure 94. Total phosphorus (TP) from each sampleshed for each of the study's precipitation events during 2009 and 2010 in the Lake Titlow watershed, Sibley and McLeod counties, Minnesota. JD18Lo and CD18Lo TSS include amounts from their upland subsheds (JD18Up and CD18Up).

Table 42. Total phosphorus per exclusive drainage for the eight events in this study of the Lake Titlow watershed, Sibley and McLeod Counties, Minnesota.

Exclusive Drainage	TP (kg) 4/26/2009	TP (kg) 6/8/2009	TP (kg) 8/19/2009	TP (kg) 10/1/2009	TP (kg) 4/14/2010	TP (kg) 6/25/2010	TP (kg) 8/12/2010	TP (kg) 9/21/2010
JD18Up	0.63	1.87	0.03	2.44	1.36	3.27	2.77	3.36
CD18Up	0.69	1.85	0.04	1.76	0.03	4.90	2.57	3.31
JD18Lo	2.06	1.89	0.48	1.94	1.97	3.88	2.62	3.53
CD18Lo	0	0.27	0.33	0	0	2.44	1.47	5.35
D250	0.92	1.05	0.17	0.80	0.64	0	0	1.12

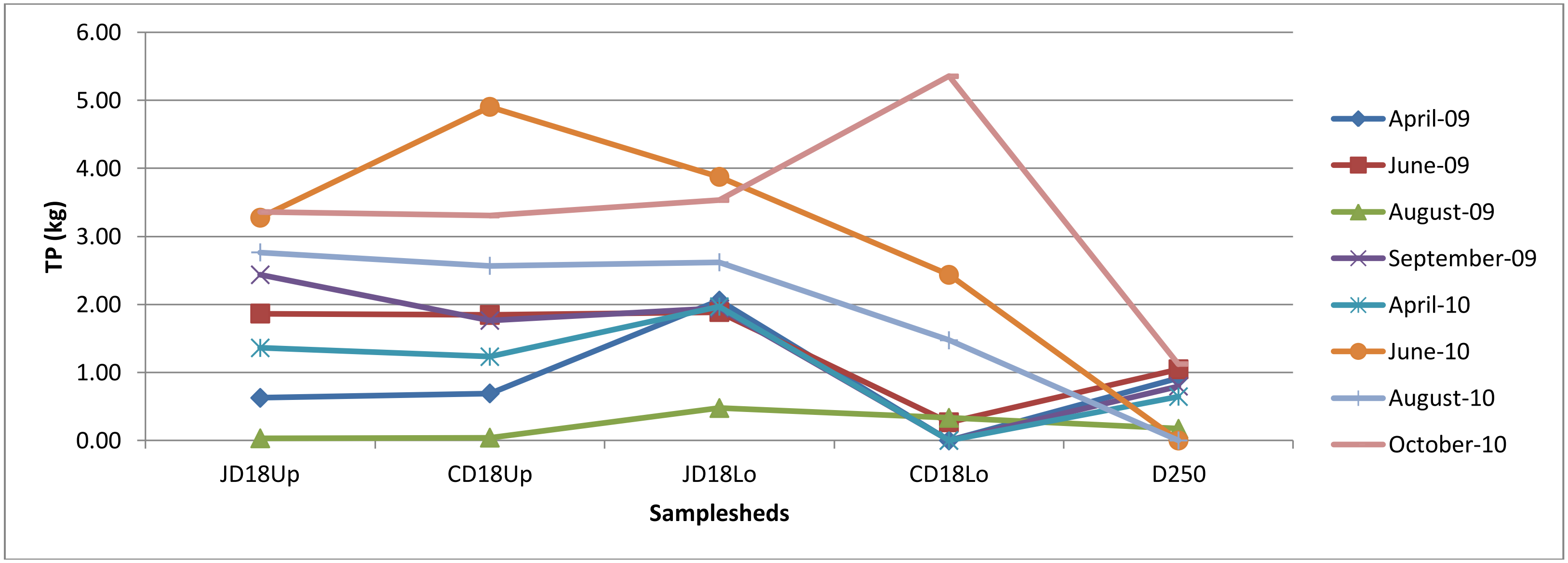

Figure 95. Total phosphorus (TP) from each sampleshed for each of the study's precipitation events during 2009 and 2010 in the Lake Titlow watershed, Sibley and McLeod counties, Minnesota. TP amounts are for exclusive samplesheds.

Table 43. Total phosphorus per exclusive drainage per square mile for the eight events in this study of the Lake Titlow watershed, Sibley and McLeod Counties, Minnesota.

Exclusive Drainage Per mi^2	TP (kg) 4/26/2009	TP (kg) 6/8/2009	TP (kg) 8/19/2009	TP (kg) 10/1/2009	TP (kg) 4/14/2010	TP (kg) 6/25/2010	TP (kg) 8/12/2010	TP (kg) 9/21/2010
JD18Up	0.03	0.09	0.00	0.12	0.07	0.17	0.14	0.17
CD18Up	0.08	0.21	0.00	0.20	0.00	0.56	0.29	0.38
JD18Lo	0.18	0.16	0.04	0.17	0.17	0.33	0.23	0.31
CD18Lo	0.00	0.03	0.04	0	0	0.32	0.19	0.70
D250	0.42	0.48	0.08	0.36	0.29	0	0	0.51

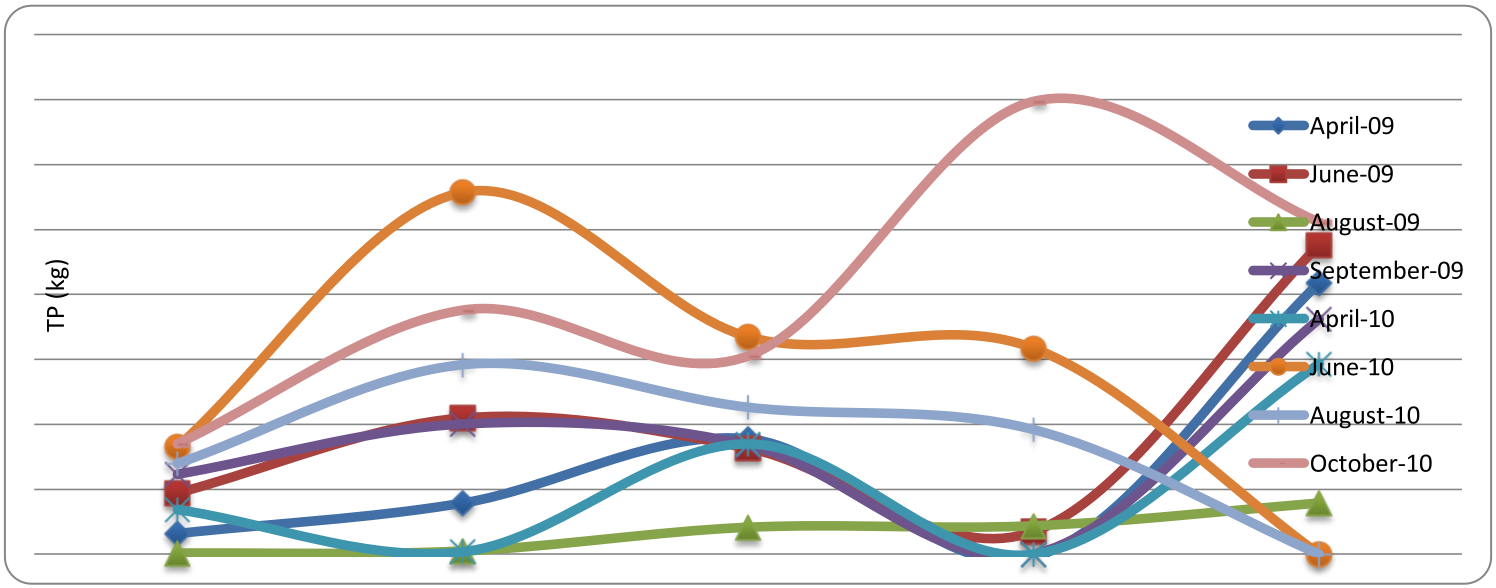

Figure 96. Total phosphorus (TP) per square mile from each sampleshed for each of the study's precipitation events during 2009 and 2010 in the Lake Titlow watershed, Sibley and McLeod counties, Minnesota.

Table 44. Nitrate-nitrite (NOx) per cumulative drainage for the eight events in this study of the Lake Titlow watershed, Sibley and McLeod Counties, Minnesota.

Results per cumulative site	NO3 (kg) 4/26/2009	NO3 (kg) 6/8/2009	NO3 (kg) 8/19/2009	NO3 (kg) 10/1/2009	NO3 (kg) 4/14/2010	NO3 (kg) 6/25/2010	NO3 (kg) 8/12/2010	NO3 (kg) 9/21/2010
JD18Up	200.47	231.79	48.70	193.90	177.10	163.35	154.83	176.26
CD18Up	133.80	109.96	43.50	120.80	224.90	231.21	147.35	172.32
JD18Lo	259.33	274.34	47.51	144.49	243.72	177.12	137.98	178.63
CD18Lo	123.12	340.80	71.18	207.81	154.64	225.93	252.95	276.81
D250	215.32	295.18	54.27	602.09	254.08	75.70	112.13	93.47

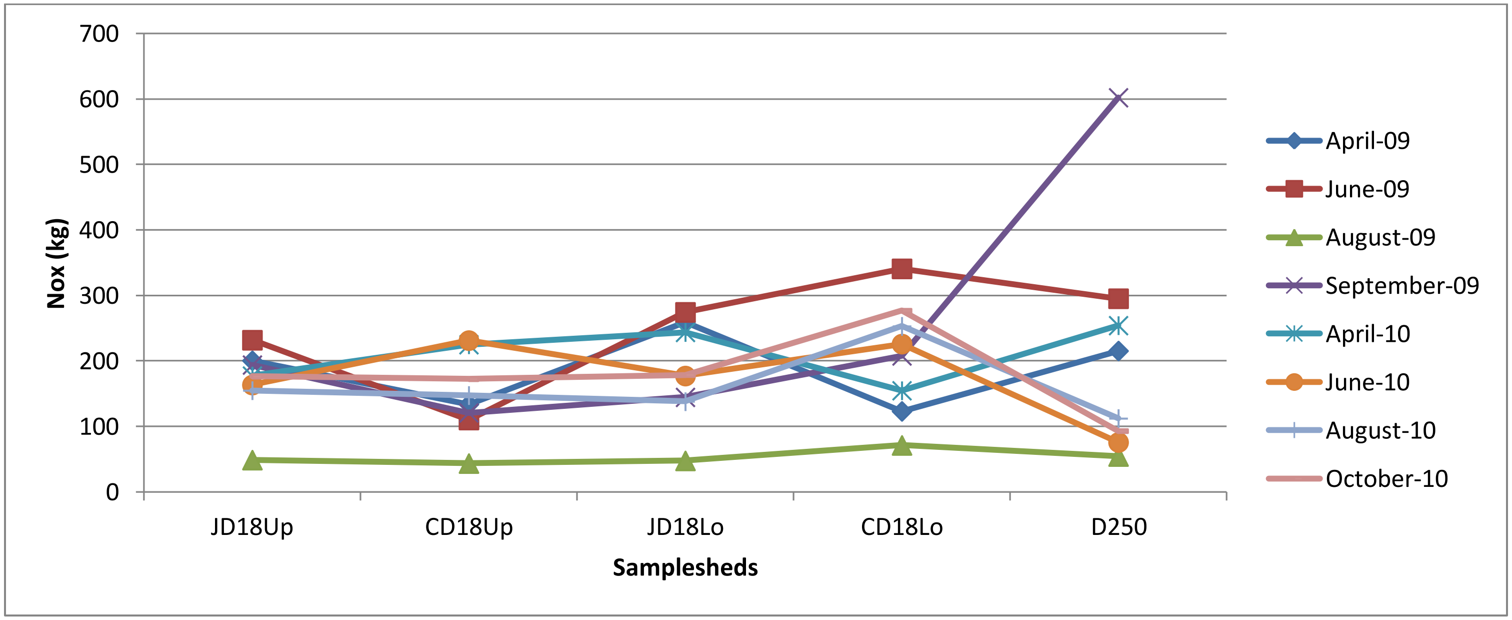

Figure 97. Nitrate-nitrite (NOx) from each sampleshed for each of the study's precipitation events during 2009 and 2010 in the Lake Titlow watershed, Sibley and McLeod counties, Minnesota. JD18Lo and CD18Lo TSS include amounts from their upland subsheds (JD18Up and CD18Up).

Table 45. Nitrate-nitrite per exclusive drainage for the eight events in this study of the Lake Titlow watershed, Sibley and McLeod Counties, Minnesota.

Results Per Exclusive Drainages	NO3 (kg) 4/26/2009	NO3 (kg) 6/8/2009	NO3 (kg) 8/19/2009	NO3 (kg) 10/1/2009	NO3 (kg) 4/14/2010	NO3 (kg) 6/25/2010	NO3 (kg) 8/12/2010	NO3 (kg) 9/21/2010
JD18Up	200.47	231.79	48.70	193.90	177.10	163.35	154.83	176.26
CD18Up	133.80	109.96	43.50	120.80	224.90	231.21	147.35	172.32
JD18Lo	58.86	42.54	0	0	66.62	13.76	0	2.38
CD18Lo	0	230.85	27.68	87.01	0	0	105.60	104.49
D250	215.32	295.18	54.27	602.09	254.08	75.70	112.13	93.47

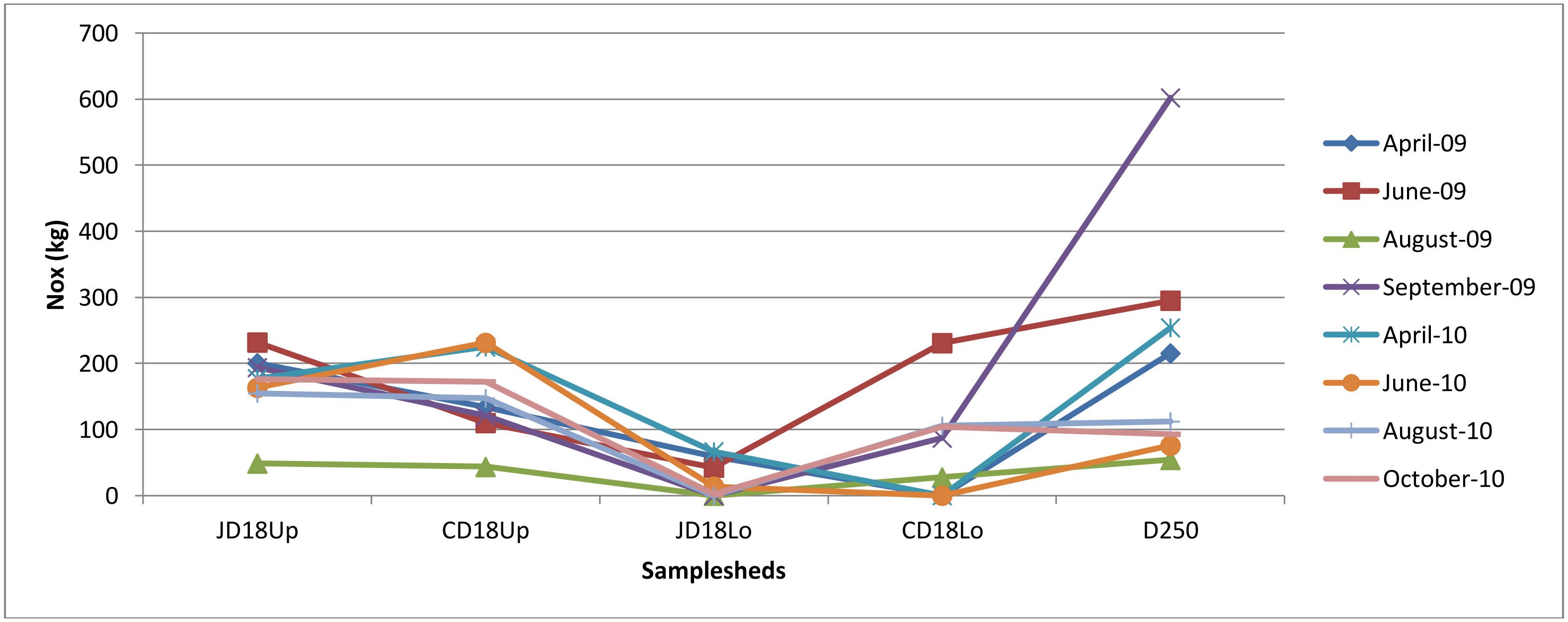

Figure 98. Nitrate-nitrite (NOx) from each sampleshed for each of the study's precipitation events during 2009 and 2010 in the Lake Titlow watershed, Sibley and McLeod counties, Minnesota. NOx amounts are for exclusive samplesheds.

Table 46. Nitrate-nitrite per exclusive drainage per square mile for the eight events in this study of the Lake Titlow watershed, Sibley and McLeod Counties, Minnesota.

Exclusive Drainages Per mi^2	NOx (kg) 4/26/2009	NOx (kg) 6/8/2009	NOx (kg) 8/19/2009	NO3 (kg) 10/1/2009	NO3 (kg) 4/14/2010	NO3 (kg) 6/25/2010	NO3 (kg) 8/12/2010	NO3 (kg) 9/21/2010
JD18Up	10.12	11.71	2.46	9.79	8.94	8.25	7.82	8.90
CD18Up	15.20	12.50	4.94	13.73	25.56	26.27	16.74	19.58
JD18Lo	5.08	3.67	0	0	5.75	1.19	0	0.21
CD18Lo	0	30.06	3.60	11.33	0	0	13.75	13.61
D250	97.87	14.91	24.67	30.41	115.49	3.82	50.97	4.72

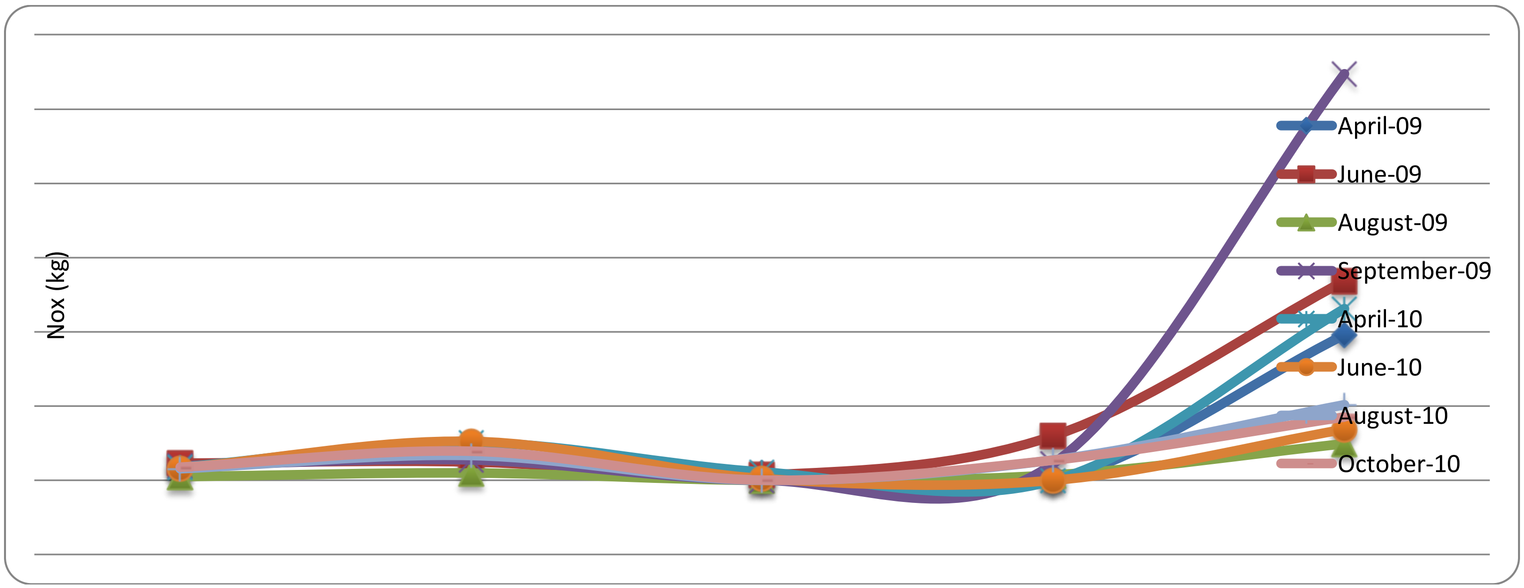

Figure 99. Nitrate-nitrite (NOx) per square mile from each sampleshed for each of the study's precipitation events during 2009 and 2010 in the Lake Titlow watershed, Sibley and McLeod counties, Minnesota.