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The Efficacy of Best Management Practices on Peak Discharge and Contaminant Loads in Agricultural Drainage Systems, Blue Earth River Watershed, South-Central Minnesota, USA

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The Efficacy of Best Management Practices on Peak Discharge and Contaminant Loads in Agricultural Drainage Systems, Blue Earth River Watershed, South-Central Minnesota, USA

By

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The efficacy of best management practices on peak discharge and contaminant loads in agricultural drainage systems, Blue Earth River watershed, south-central Minnesota, USA.

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This thesis has been examined and approved by the following members of the student's committee.

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Abstract

Conversion of native land cover to row crop agriculture and anthropogenically modified hydrology, correlates with increases in peak discharge, annual discharge, sediment and nutrient loads in agricultural land-use dominated watersheds within the Mississippi River basin. This results in environmental issues related to turbidity, eutrophication-hypoxia, loss of biodiversity, natural resource degradation, reduction in tourism, and more. In no place is this more obvious than the ever-growing “Dead Zone” in the Gulf of Mexico. The Minnesota River basin, the largest tributary to the Mississippi River in Minnesota, is a disproportionately large contributor of sediment (~80-90%), nitrogen (~56%), and phosphorus (~45%) to the upper Mississippi River watershed above riverine Lake Pepin. More broadly, despite being 1.34% of the surface area of the Mississippi basin, it contributes 5-7% of the nitrate load to the Gulf of Mexico.

Two agricultural drainage basins, approximately 4 km apart in the Le Sueur River watershed, a Minnesota River tributary, provide a unique opportunity to compare County Ditch 57, recently reengineered to include a suite of structural mitigation practices (surge pond and wetland, two-stage ditch, buffer strips, rate control weir), to a lesser modified Little Beauford Ditch (LBD). The efficacy of CD 57 was evaluated over two years (2016-2017), with monitoring stations bounding each mitigation structure. The surge pond and wetland were efficient reducers of peak discharge, sediment and nitrogen loads, during low magnitude events. However, net increases in discharge, sediment and nutrient loads were still consistently observed. LBD exhibited higher peak discharge, sediment, and total phosphorus than CD 57. CD 57 surpassed LBD in nitrogen. Overall, these

results suggest that CD 57 mitigation structures reduce peak discharge, sediment and phosphorous loads/total yields at low-flow events, but are overwhelmed in frequently observed high-magnitude events. This suggests the size/scale of these structures are inefficient for the watershed hydrology. Reduction in peak discharge is promising for limiting peak flows and erosion of bluffs/banks within the knickzone downstream, if similar structures are emplaced throughout the upper watershed. Determining the spatial scale, economic viability, and necessary size of the structures to truly make a broader impact should be the subject of future study.

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Chapter 1: Literature Review

1.1 Introduction

Approximately 12% of the surface of the planet is used for agricultural cultivation (Leff et al., 2004). To maintain production rates it is common practice to apply fertilizers that provide nutrients during crop development to help increase yields. Over the last 55 years, there has been a global 6.78-fold increase in nitrogen fertilizer application and 3.48-fold increase in phosphorus fertilizer application (Tilman, 1999). Furthermore, drainage basins in agricultural regions throughout the world are being modified to help efficiently drain water from the land. These systems have been primarily modified through channelization and the installation of subsurface tile drains to achieve quick and efficient drainage (Blann et al., 2009). However, with such an increase in cultivated lands, fertilizer application, and drainage modification, global waters have been put at jeopardy for a number of water quality issues. Among those issues, eutrophication (accelerated production of aquatic plants) and hypoxia (low dissolved oxygen within a waterbody) are among the most prominent (Petrolia and Gowda, 2006; Alexander et al., 2008; Blann et al., 2009). Such waterbodies include the Black Sea (Rabalais et al., 2002), Northern Adriatic Sea (Diaz, 2001) Seto Inland Sea in Japan (Diaz, 2001), Chesapeake Bay in the United States (Rabalais, 1998), Northeast Pacific Coast of the United States (Grantham et al., 2004), and the Gulf of Mexico (Rabalais et al., 2002; Dodds, 2006b; Petrolia and Gowda, 2006; Rabalais et al., 2007; Porter et al., 2015). These conditions can have vast and negative effects on local aquaculture, fishing, and recreation and are only increasing in size, distribution, and frequency (Diaz, 2001; Donner et al., 2004; Alexander et al., 2008; Hofmann et al., 2011; NOAA, 2017).

In the largest watershed in the United States, the Mississippi-Atchafalaya River Basin (MARB), which encompasses ~40% of the contiguous U.S., ~15% of the basin is used for corn (*Zea mays L.*) and soybean (*Glycine soja*. or *Glycine max)* cultivation, alone (Donner et al., 2004). Over the last 115 years the amount of drained land within the MARB has increased from ~24,000 to ~283,000 km^2 (Mitsch et al., 2001a). Associated with this land use and hydrologic change is an increase in nitrogen and phosphorous loading, with ~70% of the nitrogen and phosphorus load in the MARB originating from agricultural sources (Carpenter et al., 1998; Tilman, 1999; Smith et al., 2003; Donner et al., 2004; Alexander et al., 2008; Galloway et al., 2008; Canfield Jr. et al., 2010). While natural “background” concentrations range from ~0.02-0.5 mg/L for total nitrogen and ~0.006-0.08 mg/L for total phosphorus in the United States (Smith et al., 2003), modern concentrations are closer to ~0.72-7.57 mg/L for total nitrogen and ~0.042-0.990 mg/L for total phosphorus (Goolsby et al., 1999). Agricultural practices involving corn and soybean cultivation are the largest contributors (Donner et al., 2004; Alexander et al., 2008).

The Minnesota River basin (MRB) of southern Minnesota, a tributary watershed to the MARB (Figure 1.1 and Figure 1.2) exhibits greater changes in land use, nutrient concentrations, and hydrologic regimes. The MRB has seen an 80-90% reduction of the native land cover (primarily tall-grass prairies, wetlands, and hardwood deciduous forests) and currently utilizes 78-80% of the basin for row-crop agriculture (Mulla and

Sekely, 2009; Musser et al., 2009; Belmont et al., 2011). In addition, the MRB is a disproportionate contributor of nutrients to the MARB, responsible for 3-7% of the nitrate load deposited in the Gulf of Mexico (Magdalene, 2004; Steil, 2007), despite only representing 1.34% of the drainage area of the MARB. On a more regional scale, drainages within the MRB are a significant source of sediment (~80-90%) and nutrient loading (~45% of phosphorus; ~56% of nitrogen) to Lake Pepin, a riverine lake of the Upper Mississippi River (UMR) (Figure 1.3) (Kelley and Nater, 2000a; Engstrom et al., 2009; Mulla and Sekely, 2009; Belmont et al., 2011; Blumentritt et al., 2013; MPCA, 2013). Given these conditions, ~40% of Minnesota's lakes and streams are currently impaired for "conventional pollutants" under section 303(d) of the Clean Water Act (MPCA, 2016), include turbidity, nitrogen, and phosphorus loading.

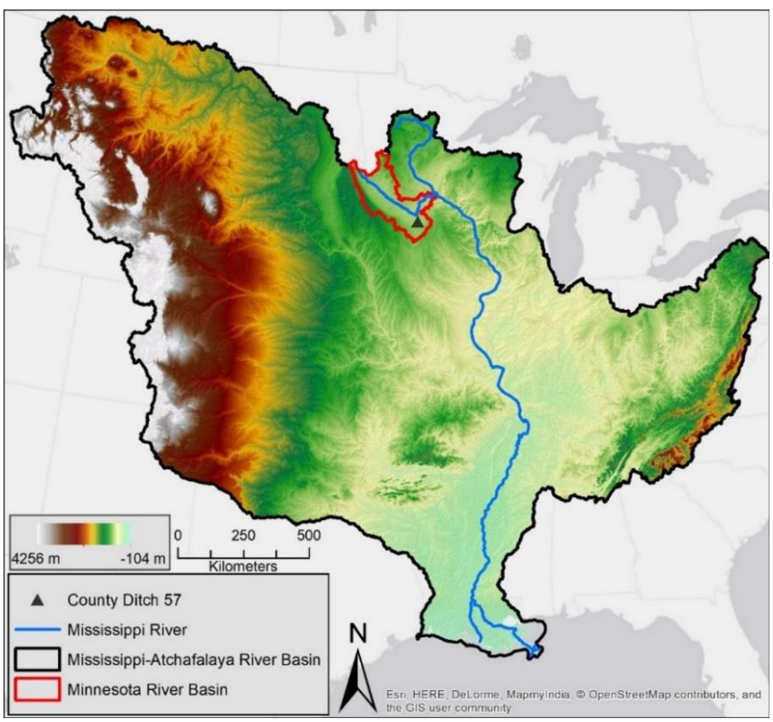


Figure 1.1. Digital elevation map of the Mississippi-Atchafalaya River Basin with the Minnesota River Basin and County Ditch 57 shown.

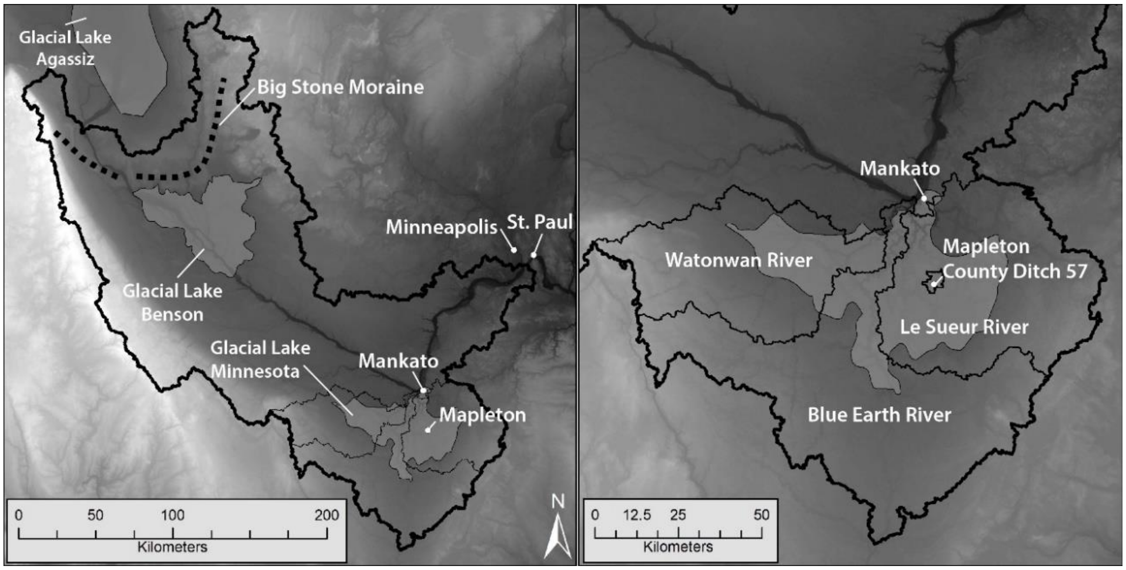


Figure 1.2. Digital elevation map of the Minnesota and Greater Blue Earth River Basins. Prominent glacial features including the Big Stone Moraine, glacial Lake Agassiz, glacial Lake Benson, and glacial Lake Minnesota are included (Leverington and Teller, 2003; Jennings, 2007).

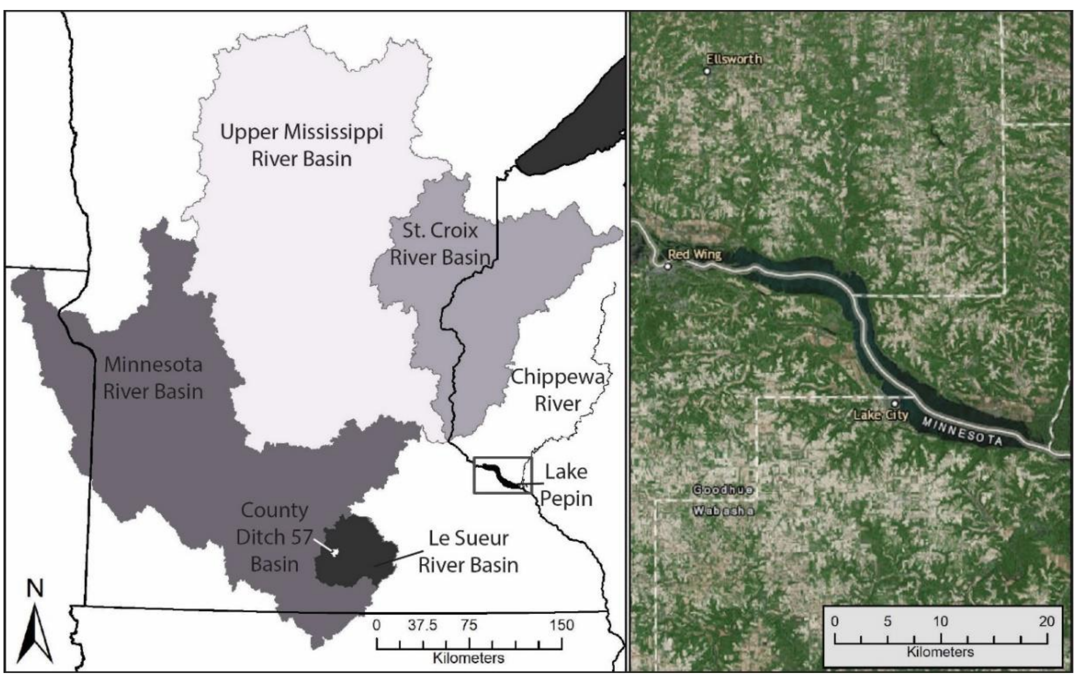


Figure 1.3. Location of Lake Pepin, between Wisconsin and Minnesota, showing the three major contributing basins to the watershed and a satellite image of the lake.

Of all the MRB tributaries, the greater Blue Earth River Basin (GBERB), comprised of the Blue Earth, Le Sueur, and Watonwan Rivers, contributes some of the highest concentrations of sediment, nitrogen, and phosphorus to the MRB and Lake Pepin watersheds continuing into the Mississippi River and Gulf of Mexico (Figure 1.2 and Figure 1.4). The Le Sueur River (LSR) is listed as impaired for turbidity, dissolved oxygen, e coli, and nutrient/eutrophication biological indicators and will be a focus within this study (Belmont et al., 2010; MPCA, 2015a; MPCA, 2016). Land in the LSR is primarily devoted to row crop agriculture, which takes up ~80-84% of the watershed (Gran et al., 2011). Given the land use and hydrologic tendencies of the LSR, and the fact that agricultural watersheds have been identified as regions in which a better understanding of sediment and nutrient loading needs to be developed (Gentry et al., 2000; Borah et al., 2003; Birgand et al., 2007; Herzon and Helenius, 2008; Kröger et al., 2008b; Smith, 2009), the LSR and its tributaries serve as an ideal study area to better understand these issues. A comprehensive analysis of agricultural drainages is imperative for creating better management strategies that reduce downstream sediment and nutrient loading. In addition, current drainage modification practices and best management practices in these watersheds need to be evaluated to determine their effectiveness. Best management practices refer to installed features that have been vetted as a means to reduce specific parameter (i.e. nitrogen, suspended solids, peak discharge) (Miller et al., 2012).

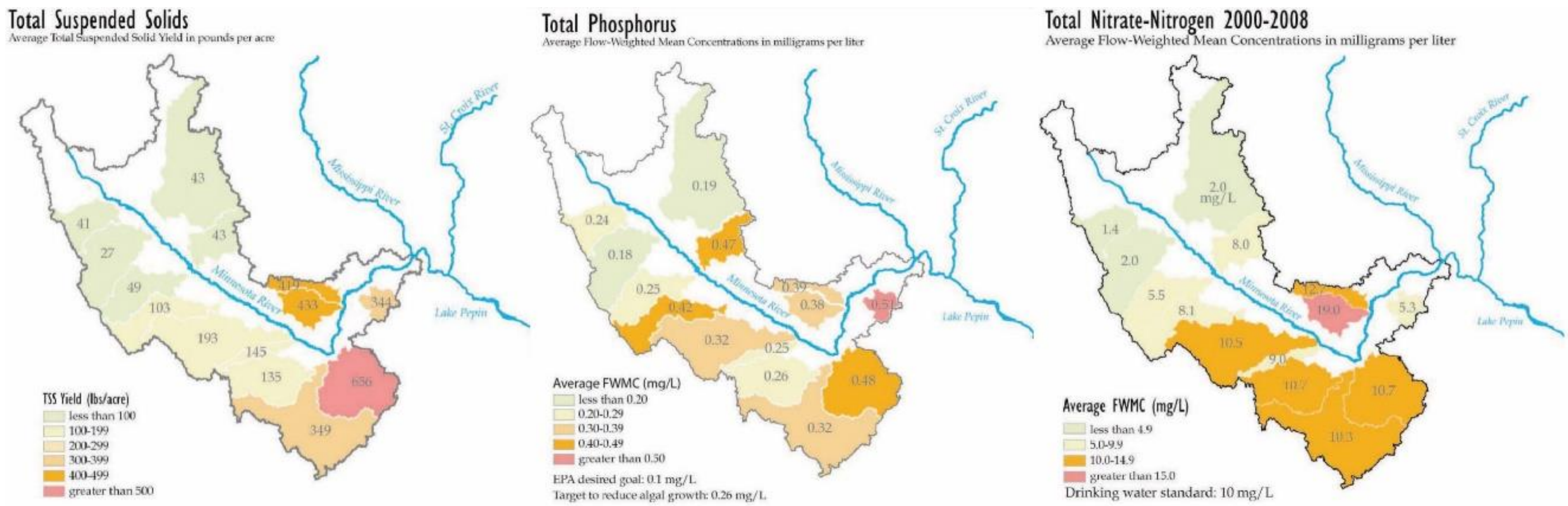


Figure 1.4. Total suspended solids, total phosphorus, and nitrate-N loads for the Minnesota River Basin, from MRBDC (2018). The GBERB, and specifically the LSR, will be of primary focus in this study.

County Ditch (CD) 57 is a 6.6 km drainage ditch flowing into the Cobb River, a tributary of the LSR (Figure 1.5). The Cobb River watershed is located in the southeastern extent of the physiographic region known as the prairie pothole region; which is characterized by fertile soils and abundant wetlands (Lenhart et al., 2012). Attempts to mitigate the influx of total suspended solids, nitrate-N, total phosphorus, and orthophosphates have led to the construction of weirs, a two-stage ditch, a surge pond, and a wetland basin within the CD 57 watershed in 2010-11. These structures are designed to reduce flow velocity to allow suspended solids to settle out and nutrients to be taken up by aquatic and riparian vegetation.

Water quality and flow monitoring stations were positioned upstream and downstream of each mitigation structure to assess their efficiency. This research seeks to better understand the effectiveness of best management practices at reducing sediment and nutrient loads and their impact on water quality within agricultural watersheds. This was accomplished by analyzing drainage tendencies, water quality, and rainfall totals and intensity throughout the year. Furthermore, results from CD 57 were compared to a control watershed, County Ditch 58, (hereafter referred to as Little Beauford Ditch), located in Beauford, MN. Little Beauford Ditch is a 7.3 km drainage ditch that also drains into the Cobb River and is ~4 km northeast and downstream of CD 57. Little Beauford Ditch has been intermittently monitored for almost twenty years and has not yet had any management practices installed within the ditch. Sediment and nutrient loads and discharge from 2016 were compared between the two watersheds to better understand the overall efficiency of management practices in CD 57 and to determine expected outputs typical from headwater agricultural watersheds in the region. This research addresses the following questions:

Question 1*. What are the characteristics of sediment and nutrient loads (total suspended solids, total phosphorus, orthophosphate, and nitrate+nitrite as N) and flow characteristics upstream and downstream of the structural practices (surge pond/wetland, two-stage ditch, rate control weir) during high flow events? How efficiently do the structures reduce loads across each event and in total over the monitoring seasons? How do results in the County Ditch 57 watershed impact the larger regional system?*

Question 2*. How do loads of total suspended solids, total phosphorus, nitrate+nitrite as N, monthly volumetric discharge, and peak discharge in County Ditch 57 compare to Little Beauford Ditch and previous studies in the region? How can result from these two modified agricultural watersheds inform on concerns downstream?*

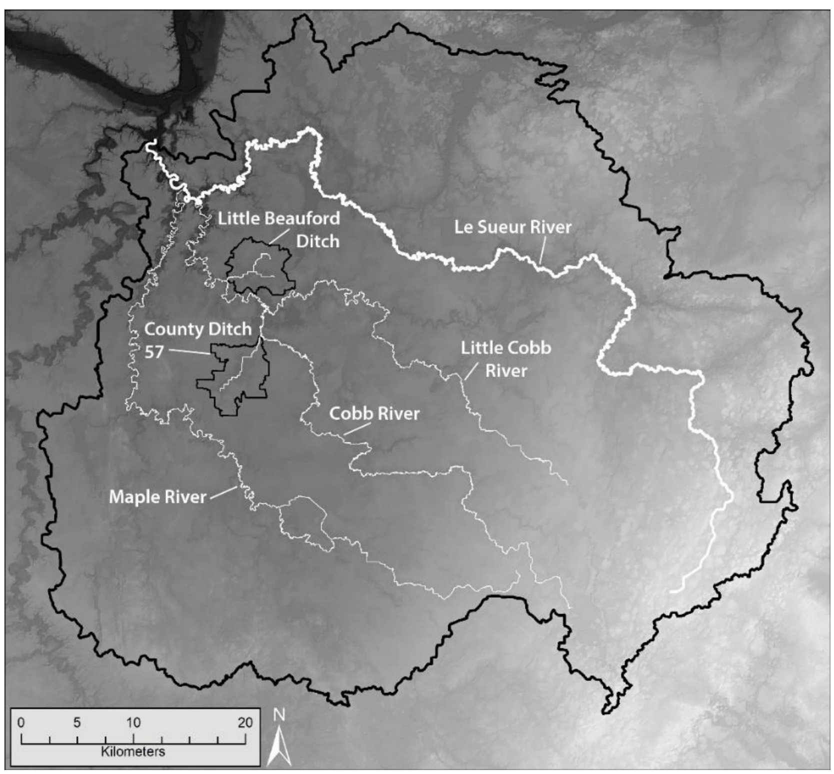


Figure 1.5. Le Sueur River watershed with major rivers, the Maple, Cobb, Little Cobb, and Le Sueur shown. The County Ditch 57 and Little Beauford Ditch watersheds are also shown.

1.2 Geomorphic History of Southern Minnesota

1.2.1 Glacial History of the Minnesota River Valley

To best understand modern drainage issues in southern Minnesota, one must first understand the evolution of the natural landscape before anthropogenic activities drastically altered land use and hydrology in this region (Gran et al., 2009; Belmont et al., 2010; Belmont, 2011; Belmont et al., 2011; Gran et al., 2013; Schottler et al., 2014; Kelly et al., 2017). The Quaternary landscape of southern Minnesota is characterized by landscape response to the advance and retreat of the Des Moines Lobe of the Laurentide Ice Sheet during Late Wisconsinan glaciation (Patterson and Wright Jr., 1998; Gran et al., 2013). In the upper Midwestern United States, the Des Moines Lobe of the Laurentide Ice Sheet reached its maximum extent between ~17.3-16.25 ka (Clayton and Moran, 1982; Bettis III et al., 1996; Lowell et al., 1999). However, starting around 18 ka glaciers were already retreating back across Minnesota (Lepper et al., 2007). Radiocarbon ages from samples collected in the Big Stone Moraine in west-central Minnesota require that glacial activity at the moraine would have ended by ~13.95 ka (Lepper et al., 2007) (Figure 1.6). An aggradational period followed after glacial recession, where 50-60 meters of interbedded glacial tills and glaciofluvial sand and gravel were deposited around present day Mankato, MN (Belmont et al., 2011). The packages of glacial till are described as semiconsolidated to overconsolidated, erodible, and fine to coarse-grained (Belmont et al., 2011; Schottler, 2012) (Figure 1.6). South of Mankato, MN, 1-3 meters of glaciolacustrine silts and clays overlie the till (Jennings, 2007). This package was deposited by proglacial Lake Minnesota, a collective series of proglacial lakes formed during the retreat of the Des Moines Lobe (Figure 1.7) (Matsch and Ojakangas, 1982). Two radiocarbon ages from wood found at the contact of lake sediment and glacial till in the glacial Lake Minnesota basin indicate that the lake is not older than 14.46-13.88 ka and that it still existed in some basins around 12.04-11.27 ka (Jennings et al., 2012). Modern agricultural tillage practices have disturbed much of the upper few meters of the soil, making the collection of other samples even more problematic.

The morphology of the modern Minnesota River valley preserves a record of 65 m of landscape incision (Johnson et al., 1998). This incision primarily resulted from large pulses of glacial meltwater originating from moraine dam failure or moraine dam overflow of glacial Lake Agassiz (GLA) (Upham, 1895a; Upham, 1895b; Fisher, 2003; Fisher, 2004; Breckenridge, 2013; Faulkner et al., 2016). Glacial Lake Agassiz occupied present day Minnesota and North Dakota, USA, and parts of the Canadian provinces of Saskatchewan, Manitoba, Ontario, Quebec, and Nunavut, occupying ~1,500,000 km^2

Figure 1.6. Maximum extent of the Laurentide Ice Sheet during Late Wisconsinan Glaciation (Garrity and Soller, 2009). Map adapted from Faulkner et al. (2016). Data for extent of glacial Lake Agassiz adapted from Leverington and Teller (2003).

from 13.6–8.5 ka (Matsch and Wright Jr., 1967; Fenton et al., 1983; Matsch, 1983; Teller and Leverington, 2004) (Figure 1.2 and Figure 1.6). Initial incision of the Upper Mississippi River, supported by radiocarbon and OSL dates, occurred ~18-16 ka, however the causal mechanism for this incision is unclear (Knox, 1996; Knox, 2007; Loope et al., 2012; Faulkner et al., 2016). The next recorded incision event most likely originated as a large pulse of glacial meltwater when the southern outlet of GLA “catastrophically” drained around 13.4 ka, developing glacial River Warren (the modern Minnesota River valley) as the spillway for future meltwater pulses through the southern outlet (Fisher, 2003; Fisher, 2004). As a result, the modern Minnesota River valley is a 65-70 m deep trench near Mankato, MN (Blumentritt et al., 2009; Gran et al., 2009; Belmont et al., 2011; Gran et al., 2013).

Through time, the primary outlet of GLA changed and occupied various spillways based upon the advance/retreat of lobes of the LIS and isostatic adjustment as the weight of the ice sheet was removed from portions of the landscape (Teller, 2001; Fisher, 2003; Fisher, 2004). A final episode of flow through the southern outlet occurred ~10.7-10.3 ka, based on radiocarbon ages from material below valley bottom alluvial fan (Hudak and Hajic, 2002) and in Big Stone Lake in the Big Stone Moraine, however it is believed this episode did not produce discernible incision in the MRB (Aharon, 2003; Fisher, 2003). Regionally, other glacial meltwater outflows occurred while GLA existed. Examples include glacial Lake Wrenshall, present ~11.9 ka, and glacial Lake Duluth, present ~10.8

Figure 1.7. Bluff featuring exposed glacial tills and glaciofluvial sediment packages near Mankato, MN (photo from Kelly and Belmont, 2018).

ka, though their overall influence on the incision history of the UMR and, more by extension, the MRB is virtually unknown (Breckenridge, 2013; Faulkner et al., 2016). The result of this complex history of episodic and significant incision of the major drainages in the region, especially into underlying highly erodible glacial, glaciofluvial and glaciolacustrine sediments, leaves the UMR and MRB systems as inherently unstable and highly susceptible to erosion and sediment loading (Gran et al., 2009; Belmont, 2011; Belmont et al., 2011; Gran et al., 2013; Schottler et al., 2014). Indeed, the postglacial landscape in the UMR, including the MRB, can generally be characterized by accelerated erosion as tributary streams exist in a state of disequilibrium still responding to incision of the major drainages like the Mississippi and Minnesota River (Mason and Knox, 1997).

The UMR has shown to be particularly susceptible to erosion during changes in flow regimes (Knox, 1985; Knox, 2000). Throughout the Holocene, modal floods varied greatly, coinciding with shifting climates (Knox, 1985; Knox, 2000). In a landscape that is dominantly underlain by erodible sediments, like the UMR, these climatic shifts from warm/dry to cool/wet can destabilize fluvial system and lead to accelerated erosion throughout the landscape. The highly sensitive nature of paleofloods to climate change is associated not only with large climatic shifts, but also with modest climatic shifts (Knox, 2000). The ability to understand the climatic interactions with this geomorphically unstable landscape is particularly pertinent now, given a regional increase in precipitation intensity and total yearly precipitation in southern Minnesota (Novotny and Stefan, 2007; Kelly et al., 2017).

1.2.2 Sediment Budgets and Loading

Measuring sediment, phosphorus, and nitrogen loads and establishing sediment and nutrient budgets throughout the UMR is critical to understand how best to manage environmental issues plaguing the watershed (Beach, 1994; Payne, 1994; Kelley and Nater, 2000a; Thoma et al., 2005; Engstrom, 2009; Mulla and Sekely, 2009; Belmont et al., 2010; Folle, 2010; Hansen et al., 2010; Schottler et al., 2010; Gran et al., 2011; Maalim and Melesse, 2013; Lauer et al., 2017). Much of the UMR is impaired by high suspended sediment loads and elevated trophic states from nutrient loading (Payne, 1994; Magdalene, 2004; Petrolia and Gowda, 2006; James and Larson, 2008; Mulla and Sekely, 2009; Musser et al., 2009; Wilcock, 2009; Belmont et al., 2011; Gran et al., 2011; Schottler et al., 2014; Belmont and Foufoula-Georgiou, 2017; Yuan et al., 2017).

One local example of this is Lake Pepin (Figure 1.3), as Lake Pepin serves as a regional sediment and nutrient sink within the UMR valley. The current understanding of nutrient and sediment loading in Lake Pepin has focused on coring into the sediments underlying the lake to best understand pre- and post-settlement rates of accumulation (Engstrom et al., 2009; Blumentritt et al., 2013). Just after Euro-American settlement (ca. 1860) sediment accumulation rates in the lake were ~152,000 Mg/year, while total phosphorus rates were ~111 Mg/year (Engstrom et al., 2009). Modern sediment accumulation rates (from 1996-2008) range from ~772,000 to 858,000 Mg/year, while total phosphorus accumulation is ~845-920 Mg/year (Engstrom et al., 2009; Blumentritt et al., 2013) (Figure 1.8). This dramatic change correlates to regional increases in modified

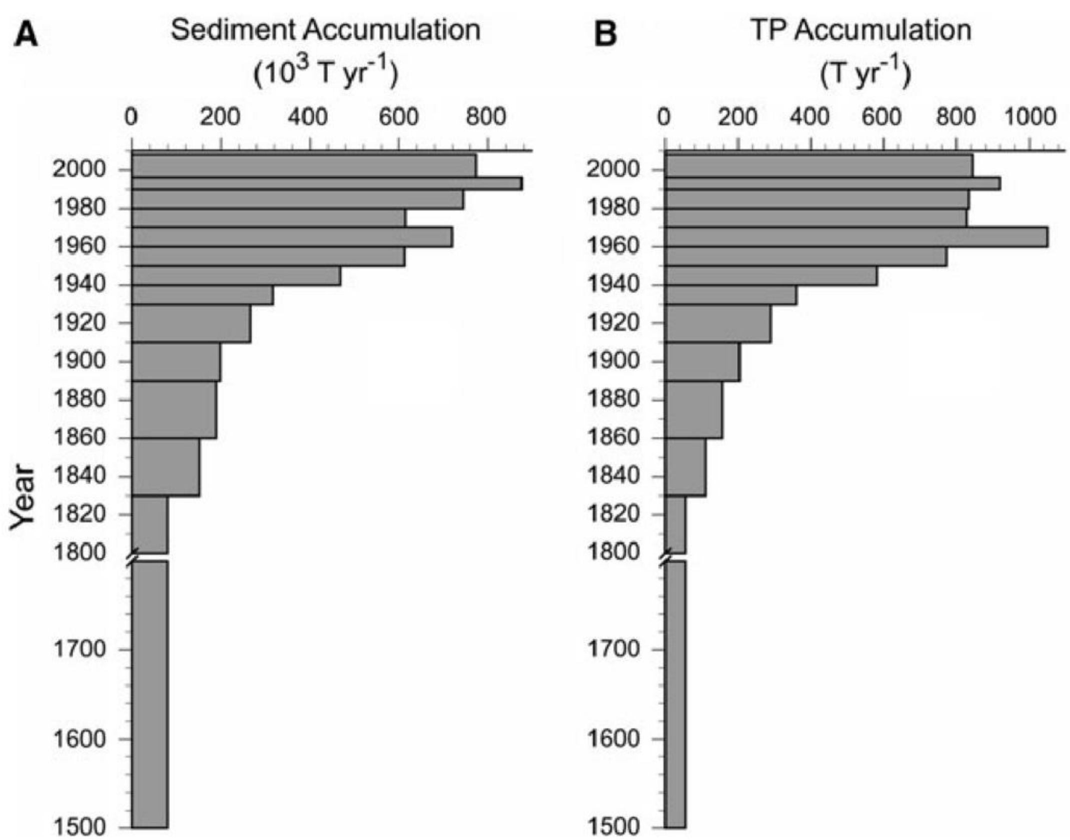


Figure 1.8. Graph denoting sediment and total phosphorus accumulation in Lake Pepin from 1500-2010 (Blumentritt et al., 2013). While changes to wastewater treatment (ca 1970s) helped to reduce phosphorus levels, they remain high from inputs by agricultural watersheds.

agricultural drainages, annual discharge, land use conversion to agriculture, and precipitation totals and intensities (Schottler et al., 2014; Kelly et al., 2017).

In the last 50 years, the UMR watershed that contributes to Lake Pepin has seen significant decreases in phosphorus loading from wastewater treatment facilities and urban areas (Kelley and Nater, 2000a; Kelley et al., 2006; James and Larson, 2008; Engstrom et al., 2009; Mulla and Sekely, 2009; Belmont et al., 2011; Blumentritt et al., 2013). However, there has not been a significant decrease in total phosphorus and agricultural output from livestock and commercial fertilizer applications have increased (Mulla and Sekely, 2009; Blumentritt et al., 2013). In addition, the MRB contributes disproportionate sediment and nutrient loads to the Lake Pepin watershed, with ~85% of sediment accumulation and 45% of the total phosphorus accumulation originating from it (Mulla and Sekely, 2009). Thus, the MRB has been the primary focus of research and mitigation efforts to address environmental impairments (Payne, 1994; Magdalene, 2004; Petrolia and Gowda, 2006; James and Larson, 2008; Mulla and Sekely, 2009; Musser et al., 2009; Wilcock, 2009; Gran et al., 2011; Schottler et al., 2014; Belmont and Foufoula-Georgiou, 2017; Yuan et al., 2017).

Sediment and nutrient accumulation rates can be difficult to reconstruct, however the use of geochemical tracers, or “fingerprinting,” allows for constrained estimates to be developed (Schottler et al., 2010; Willenbring and von Blanckenburg, 2010; Belmont et al., 2011; Gran et al., 2011). Geochemical fingerprinting in the MRB has used a combination of the radioisotopes Cesium-137 (^{137}Cs), Lead-210 (^{210}Pb), and meteoric Beryllium-10 (^{10}Be) to differentiate between various point sources for sediment (Schottler et al., 2010; Belmont et al., 2011; Gran et al., 2011). The radioisotopes ^{10}Be and ^{210}Pb are perpetually produced in the atmosphere and are delivered to the surface by dry (particulate) deposition or during precipitation events (Schottler et al., 2010; Belmont et al., 2011; Gran et al., 2011). However, ^{210}Pb concentrations have been enriched by humans through industrial activities since the mid-1800s (Church, 2010). In comparison, ^{137}Cs is also deposited via atmospheric deposition, similar to ^{10}Be and ^{210}Pb, but the primary source for ^{137}Cs stem from above ground nuclear testing from between ~1955-1963 (Robbins et al., 2000; Schottler et al., 2010).

Depths of penetration in natural systems vary between isotopes, however they primarily occupy the upper portions of the soil column (Willenbring and von Blanckenburg, 2010; Belmont, 2012). When determining source apportionment, concentrations for these isotopes are prominent in upland soils where low gradient surfaces retain more deposition (Walling and Woodward, 1992; Schottler et al., 2010; Belmont et al., 2011; Gran et al., 2011). The isotopes are generally lacking, however, in bluffs, banks, and ravines (near channel sources), where deeper sediment packages are exposed at a more vertical slope (Schottler et al., 2010; Belmont et al., 2011). The half-lives vary greatly between the three isotopes, at 1.4 million years for ^{10}Be, 30 years for ^{137}Cs, and 22.3 years for ^{210}Pb. The differences between the ^{137}Cs and ^{210}Pb isotopes help constrain minimum and maximum ages of sediment deposition (Schottler et al., 2010; Belmont et al., 2011). When developing sediment budgets and source apportionment, sediments derived from upland sources should have much higher concentration of isotopes than near channel sources (Schottler et al., 2010). By comparing minimum and maximum concentrations to overall deposition, for example throughout a sediment core, source apportionment is calculated (Schottler et al., 2010).

This method was applied in the LSR watershed, which exists in a state of disequilibrium following incision by the glacial River Warren (Schottler et al., 2010; Belmont et al., 2011; Gran et al., 2011). Holocene fine sediment budgets for the LSR were primarily supplied by bluff, bank, and ravine erosion and totaled ~55,000 Mg/yr (Belmont et al., 2011). This was almost entirely from the active zone of incision within the watershed, where 60,000 Mg/yr were eroded, but 5,000 Mg/yr were deposited in the floodplain (Belmont, 2011; Gran et al., 2011). Contributions were negligible in uplands below the knickzone and all areas upstream of the knickzone. Comparatively, between 2000-2010, fine sediment budgets for the LSR increased to 225,000 Mg/yr, where sediment budgets below the knickzone were ~170,000 Mg/yr, with the largest source being bluffs (107,000 Mg/yr) and uplands (23,000 Mg/yr) (Belmont et al., 2011). Upstream of the knickzone the opposite was true, where uplands contributed the largest amount of fine sediment (45,000 Mg/yr) and bluffs contributed the second highest (26,000 Mg/yr) (Belmont et al., 2011). As with Lake Pepin, sediment budgets for the LSR correlate to increases in modified agricultural drainages, annual discharge, land use conversion to agriculture, and precipitation totals and intensities (Schottler et al., 2014; Kelly et al., 2017) (Figure 1.9 and Figure 1.10).

These increased budgets can be indicative of channel widening, increased nutrient concentrations through entrainment of floodplain sediments, and increased discharge from subsurface tiling (Belmont et al., 2011; Gran et al., 2011; Schottler et al., 2014). Aside from geochemical fingerprinting, yearly sediment and nutrient budgets can be developed through computer models, like the Soil and Water Assessment Tool (SWAT) in ArcGIS (Folle, 2010) or by frequent water quality sampling where concentrations are coupled with stream discharge to develop loads (Kalkhoff et al., 2016). The SWAT model includes data for hydrology, weather, erosion, soil temperature, crop growth, nutrients, pesticides, and agricultural management practices and generates predicted changes in sediment and nutrient loads with changing conditions within the watershed (Folle, 2010). Models were calibrated from 2000-2006 in Little Beauford Ditch and estimated annual loads of 1,060 kg/ha for total suspended solids, 1.0 kg/ha of total phosphorus, and 18.0 kg/ha of nitrate-N

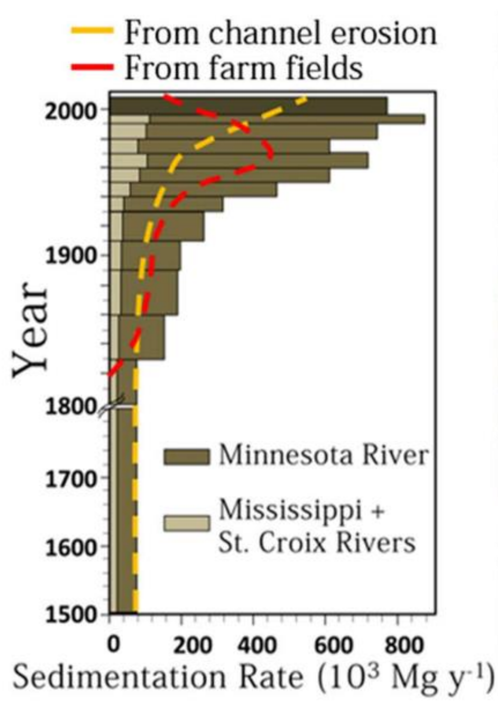


Figure 1.9. Graph showing estimated sedimentation rates from the Minnesota River (dark green) and the combined sedimentation of the Mississippi and St. Croix Rivers (tan) (from Engstrom et al., 2009; modified by Belmont and Foufoula-Georgiou, 2017).

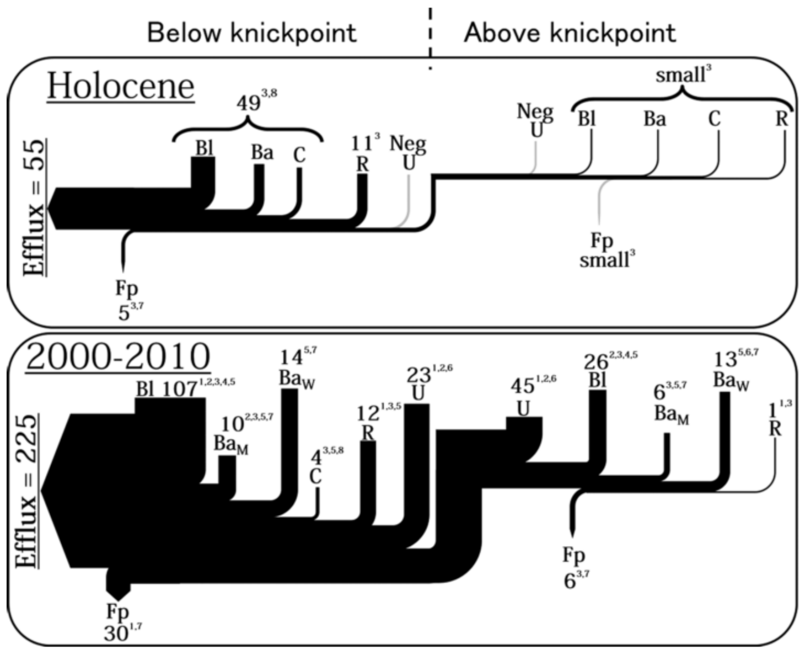


Figure 1.10. Sediment budgets for fine-grained (silt/clay) material for the Le Sueur River. Values given in 10^3 Mg/yr (from Belmont et al., 2011). While Holocene sediment budgets were driven bluff and bank erosion, modern (2000-2010) sediment budgets are driven by bluff erosion below the knickzone and upland erosion above the knickzone.

were produced (Folle, 2010). Finally, recent findings in the Little Cobb River watershed, a tributary of the Cobb River and Le Sueur Rivers, used in situ monitoring to calculate annual exports of 21.3 kg/ha of nitrate-N and 0.51 kg/ha of total phosphorus (Kalkhoff et al., 2016).

A review of yields across the MARB and its six major subbasins help put these numbers in better perspective (Turner and Rabalais, 2004). Annual yields delivered to the Gulf of Mexico ranged between ~340-654 kg/ha for suspended solids, ~0.32-0.45 kg/ha for total phosphorus, and 2.44-3.02 kg/ha for nitrate-N (Turner and Rabalais, 2004). Estimates from the Little Cobb River (Kalkhoff et al., 2016), south fork of the Iowa River (Kalkhoff et al., 2016), and LSR (Folle, 2010) at least double yields averaged across the entire MARB. These studies support the need for further research on loading within agricultural watersheds in the MRB and are particularly useful in the context of this research project. CD 57 and Little Beauford Ditch, subbasins of the LSR, are within close proximity (~4 km) to the Little Cobb River gauging station used in the Kalkhoff et al. (2016) and Folle (2010) studies and share many of the same qualities (Figure 1.11). Similar parameters are being examined in CD 57 and Little Beauford Ditch as were examined in Kalkhoff et al. (2016) and (Folle, 2010) (total suspended solids, nitrate-N, total phosphorus, and average discharge).

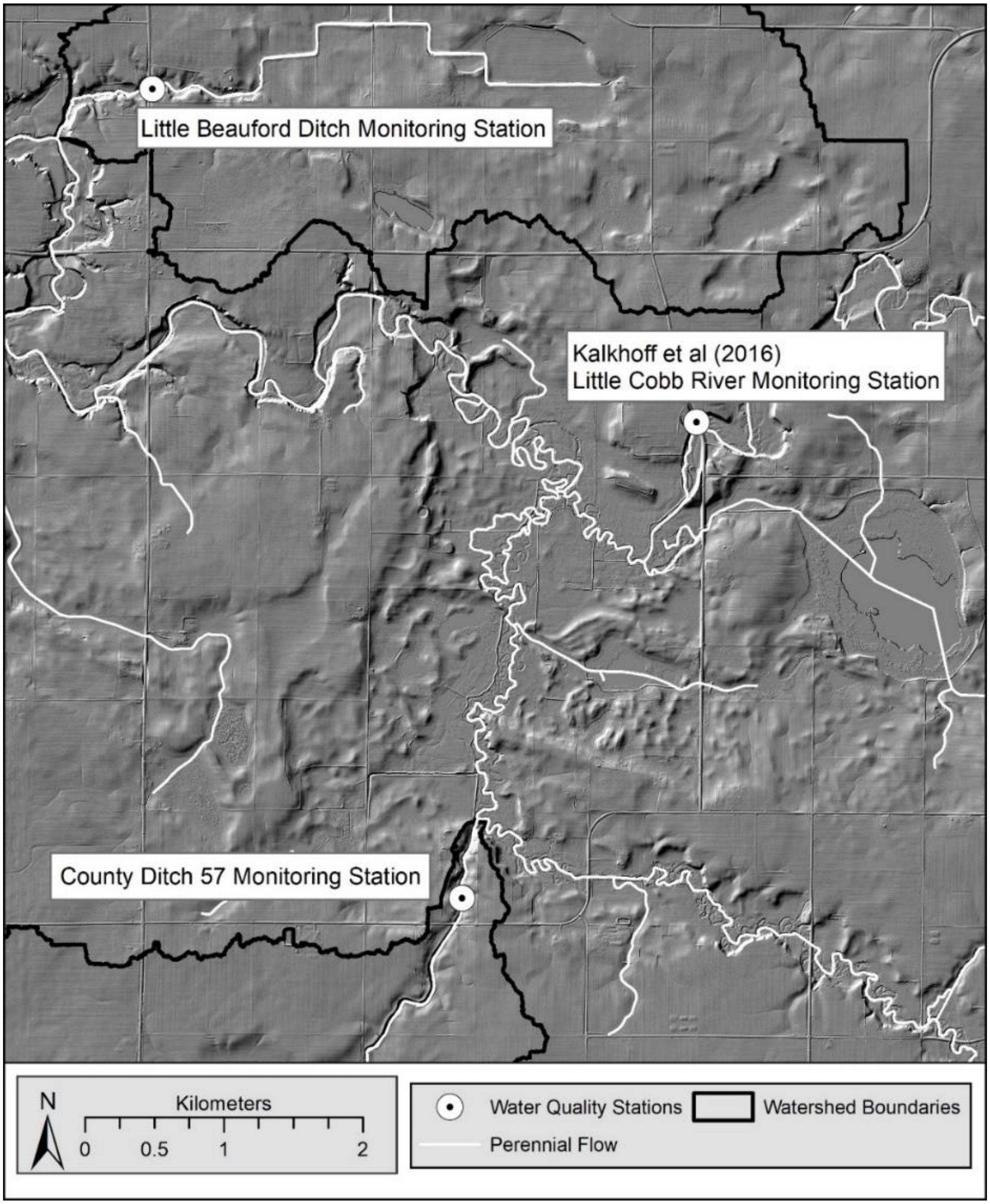


Figure 1.11. Location of the monitoring station from Kalkhoff et al. (2016), in relation to monitoring stations positioned at the mouths of County Ditch 57 and Little Beauford Ditch.

1.2.3 Post-Settlement Climate Shifts

Increases in peak discharge and total discharge have been cited as significant drivers of landscape changes in southern Minnesota, since the mid-1900s (Knox, 2000; Zhang and Schilling, 2006; Novotny and Stefan, 2007; Nangia et al., 2010; Schottler et al., 2014; Gupta et al., 2015; Belmont et al., 2016; Kelly et al., 2017). Increases in total discharge have been observed since the 1940s through the present (Zhang and Schilling, 2006; Novotny and Stefan, 2007; Kelly et al., 2017) and are being attributed to increased precipitation and storm intensity and/or to large scale conversion of land cover to row crop agriculture, which exposes bare soil for much of the year and leads to increases in surface runoff. Intense debate currently exists regarding the driving factor of this increase in annual discharge (Gupta et al., 2015; Belmont et al., 2016; Dingbao, 2016; Foufoula-Georgiou et al., 2016; Gupta et al., 2016a; Gupta et al., 2016b; Gupta et al., 2016c; Gupta et al., 2016d; Gupta et al., 2016e; Schilling, 2016; Schottler et al., 2016). Some argue that it is primarily driven by a changing climate and that the effect of land cover conversion is negligible (Gupta et al., 2015; Gupta et al., 2016a; Gupta et al., 2016b; Gupta et al., 2016c; Gupta et al., 2016d; Gupta et al., 2016e). Others suggest that a combined changing climate, large reduction in native vegetation in favor or row crop agriculture, and a significant increase in soybean cultivation all contribute to this documented increase (Novotny and Stefan, 2007; Schottler et al., 2014; Belmont et al., 2016; Dingbao, 2016; Foufoula-Georgiou et al., 2016; Schilling, 2016; Schottler et al., 2016; Kelly et al., 2017). Differences aside, the general consensus agrees that precipitation and discharge are both increasing across the region.

1.3 Global and National Trends

1.3.1 Altered Hydrologic Regimes

The artificial enhancement of drainage systems through channelization and the development of drainage ditches has been under continued examination to determine its environmental impacts (Pavelis, 1987; Skaggs et al., 1994; Correll, 1998; Birgand et al., 2007; Needelman et al., 2007; Herzon and Helenius, 2008; Blann et al., 2009). Drainage modification is not only isolated to the United States, as at least 34% of northwestern European farmland, 50% of Scottish farmland, 4% of southeastern Asian farmland, and 2% of Iranian farmland are also artificially drained (Abbot and Leeds-Harrison, 1998; Sohrabi et al., 1998; Blann et al., 2009). Furthermore, in poorly drained regions, it has become common practice to install subsurface tile drainage to expand agricultural fields and increase yields (Schottler, 2012; Maalim and Melesse, 2013). Tiling is most frequently used to drain water from natural depressions, increase infiltration rates, lower the water table, and create a more hospitable growing climate for crops (Blann et al., 2009; Schottler et al., 2014). The tile, usually a permeable PVC or ceramic pipe of varying diameter, is buried a meter or two below the surface and plow line, quickly intercepting water and flushing it into a nearby ditch or body of water (Maalim and Melesse, 2013). However, these practices lead to flashier hydrologic systems, increased peak discharge, increased erosivity in larger streams/rivers, and an increase in severe flooding events (Figure 1.12) (EEA, 1996; Knox, 2001; Blann et al., 2009; Schottler et al., 2014). These flashier systems are capable of entraining larger quantities of sediment and nutrients and transporting them downstream (Belmont et al., 2011; Schottler et al., 2014; Kelly et al., 2017).

Estimates of land drained by surface and subsurface drainage are poorly constrained (Sugg, 2007; Naz et al., 2009), however, by 1987 more than 17% of U.S. cropland had been altered by surface or subsurface drainage (Pavelis, 1987; Blann et al., 2009). In the largest watershed in the United States, the MARB, the amount of land artificially drained has increased from ~24,000 to ~280,000 km^2 from 1901-2001 (Mitsch et al., 2001). Similarly, the MRB has seen an increase from ~19% watershed area drained by

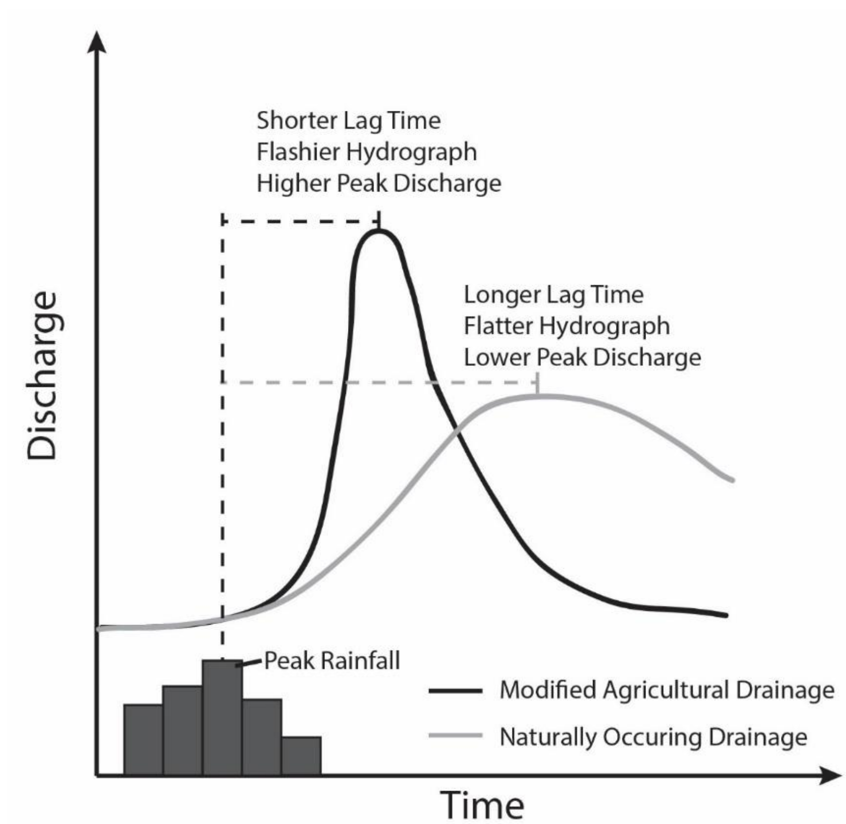


Figure 1.12. Graph showing difference in expected hydrographs between natural drainages and modified agricultural drainages.

tile in 1940 to ~35% in 2012, while the watershed area drained by ditches increased from ~7% in 1940 to ~10% in 2012 (Kelly et al., 2017). In south-central Minnesota, tile drainage networks are particularly dense within the GBERB and LSR watershed. In nineteen watersheds within the LSR, around 71% of the cultivated land is classified as "poorly drained" and has had an estimated 141 meters per hectare of tile drainage installed (Schottler, 2012).

1.3.2 Changes to Land Use and Land Cover

As the population of the world nears 7.5 billion people (Census.gov, 2018), there is continued need for growth in agricultural production rates. Approximately 12% of the planet's land surface is used for agricultural cultivation (Leff et al., 2004). In North America more than 98% of the native prairie and vast forested regions have been replaced with cropland (Blann et al., 2009). Corn and soybeans, for example, account for 28.0% and 23.9% of cropland use in the contiguous United States (Leff et al., 2004; Blann et al., 2009) (Figure 1.13). In the MARB, land use and land cover changes within the basin have resulted in 8.8% of the basin used for corn growth (~284,643 km^2) and 6.1% for soybeans (~197,309 km^2) in 1992 (Donner et al., 2004). In the MRB, ~78% of the landscape (34,236 km^2) is used for agricultural purposes (Musser et al., 2009).

With such a large conversion of land use and land cover to conventional row crop agriculture, the amount of fertilizer used on fields can be problematic. Over the last 55 years there has been a 6.78-fold increase in nitrogen fertilizer application, 3.48-fold increase in phosphorus fertilizer application, 1.68-fold increase in irrigated cropland, and 1.1-fold increase in cultivated land, globally (Tilman, 1999). In the MARB, ~70% of the nitrogen and phosphorus delivered to the Gulf of Mexico originated from agricultural sources (Donner et al., 2004; Alexander et al., 2008). The other 30% is primarily attributed to urban sources (such as wastewater treatment facilities, septic systems, and deposition from power plant and vehicular emissions) and atmospheric deposition (falling to earth as rain, snow, particles, or vapors) (Lawrence et al., 2000; Donner et al., 2004; Alexander et al., 2008; Engstrom et al., 2009; Mulla and Sekely, 2009). Overall, 52% of the nitrogen load and 25% of the phosphorus load deposited in the Gulf of Mexico are attributed to corn and soybean cultivation (Figure 1.14 and Figure 1.15). The quantity of nitrogen per unit area in the MARB has tripled to 4.97 kg/ha over the last forty years

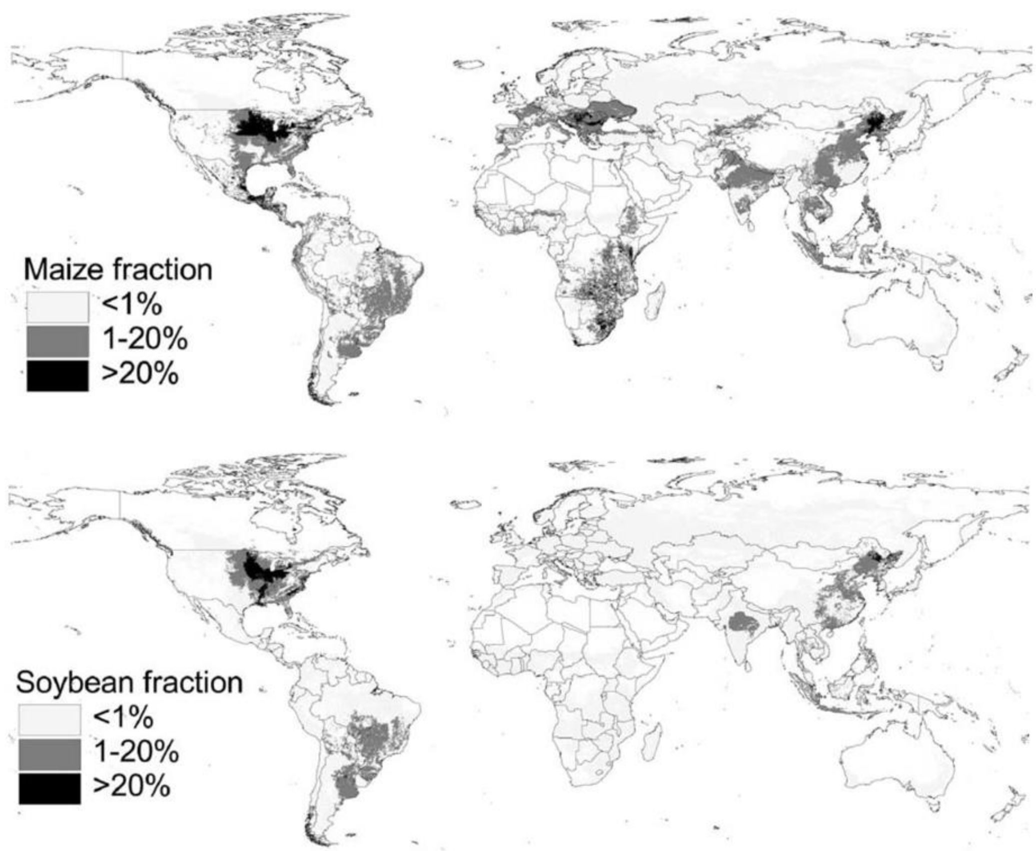


Figure 1.13. Maize (top) and soybean (bottom) coverage throughout the world (Leff et al., 2004).

(Goolsby et al., 2000; Goolsby and Battaglin, 2001; Goolsby et al., 2001). Out of the 4.97 kg/ha, 61% is in the form of nitrate, 37% is in the form of organic nitrogen, and 2% is in the form of ammonium. Such increases result in a variety of environmental and economic implications within the MARB. Two of the most well publicized impacts of excessive nutrient loading are eutrophication and hypoxia, which are the result of accelerated aquatic plant production resulting in low oxygen conditions (Diaz, 2001).

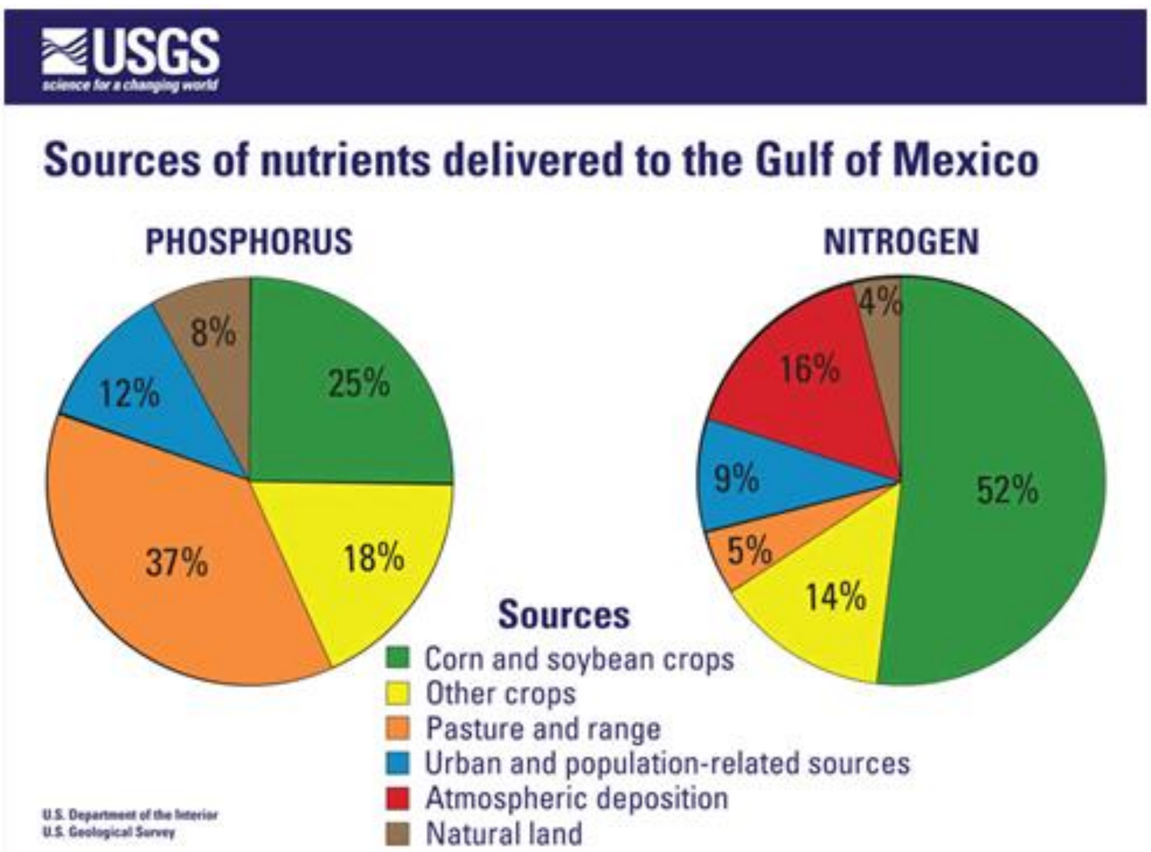


Figure 1.14. Pie charts showing the approximate breakdown of the contributing sources of phosphorus (left) and nitrogen (right) loading to the Gulf of Mexico (from USGS, 2014). These charts were adapted from data by Alexander et al. (2008).

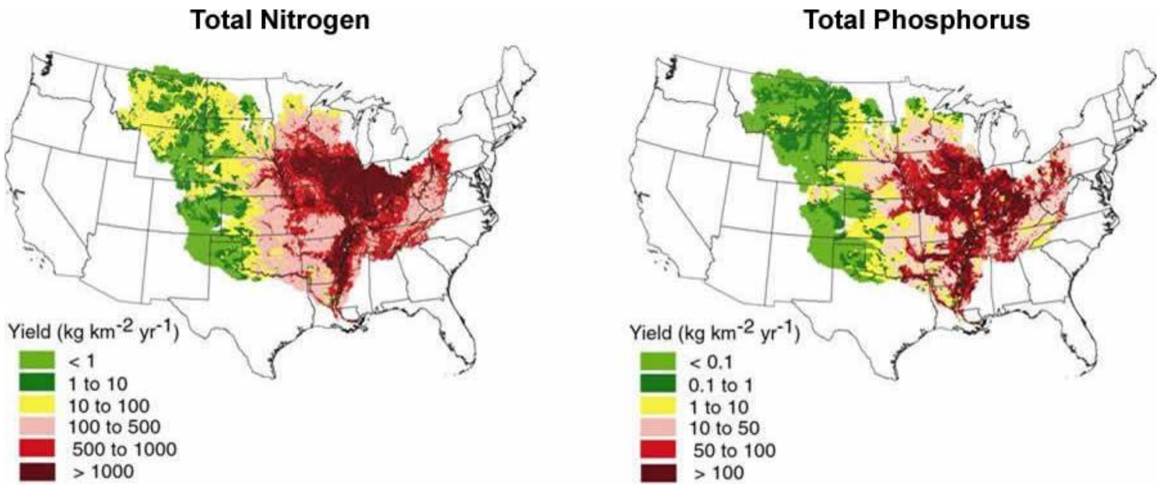


Figure 1.15. Percentage of nutrient load delivered by streams to the Gulf of Mexico from incremental drainages of the MARB (from Alexander et al., 2008).

Land use tendencies in the MRB tend to reflect those in the MARB. The basin, which was originally dominated by tall-grass prairies, wetlands, and deciduous hardwood forests, has undergone an 80-90% reduction in native vegetation (Mulla and Sekely, 2009; Musser et al., 2009; Belmont et al., 2011). Currently, 78-80% of the watershed is used for row-crop agriculture (Mulla and Sekely, 2009; Musser et al., 2009; Belmont et al., 2011). In 2017, 78.5% of the LSR was used for corn and soybean cultivation (USDA, 2018). While basin-wide fertilizer estimates for the MRB or many of its tributaries are not available, estimates for some subbasins do exist. Farmers in the Little Cobb River watershed, a tributary of the Cobb River and part of the LSR watershed, applied ~69 kg/ha of nitrogen per year and ~12 kg/ha of phosphorus per year between 1987-2006 (Kalkhoff et al., 2016). Some farmers within the CD 57 watershed used around ~146 kg/ha of nitrogen fertilizer in 2016-17 growing season (Duncanson, personal communication, 2017).

1.4 Effects of Sediment and Nutrient Loading

Many of the waterbodies within the United States are already considered impaired under Section 303(d) of the Clean Water Act of 1972 for excessive sediment and nutrient loads (Clean Water Act, 2015). Section 303(d) requires individual states to maintain and update a list of impaired waters that require a Total Maximum Daily Load (TMDL) study (Anderson et al., 2017). This list is updated every two years and is presented to the Environmental Protection Agency for approval. In Minnesota, the proposed 2018 draft of the TMDL/impaired waters list includes 2,727 accounts of waters requiring a TMDL study and 5,085 accounts of impaired waters (which include those in the TMDL list). The MRB contains the highest number of impaired waters (1,397 out of 5,085). In all basins, nutrient/eutrophication is the second highest impairment listing (694 out of 5,085) and total suspended solids and turbidity are the sixth highest (371 out of 5,085).

1.4.1 Eutrophication and Hypoxia

Eutrophication and hypoxia are states within waterbodies brought about by accelerated primary production of aquatic flora (Diaz, 2001). Eutrophication is a natural process in which a waterbody moves towards an accelerated trophic state with enhanced plant production capabilities (Anderson et al., 2002; Dodds, 2006a; Dodds, 2006b; Dodds, 2007). This is often seen as an increase in the growth rates of algae, or as algal blooms (Smith, 2003). Eutrophication is commonly tied to increases in nitrogen and phosphorus loading, attributable to contemporary agricultural practices (Anderson et al., 2002; Smith, 2003; Dodds, 2006a; Dodds, 2006b; Dodds, 2007; Kröger and Moore, 2011). Eutrophic states are characterized by poor water quality, toxic algal blooms, low dissolved oxygen concentrations, and decreased ecosystem health (Rabalais et al., 2007). Toxic algal blooms (known as cyanobacteria or blue-green algae) are capable of killing wildlife and poisoning humans through seafood ingestion or prolonged exposure at very low concentrations (Repavich et al., 1990; Anderson et al., 2002). Eutrophic states are often found in agricultural drainage ditches, given high, readily available concentrations of nitrogen and phosphorus throughout the system, but can be found in any other body of water with appropriate conditions (Figure 1.16) (Janse and Van Puijenbroek, 1998; Blann et al., 2009).

Figure 1.16. Eutrophic conditions in surge pond in County Ditch 57, supplied with nutrients by surrounding fields. In lower flow, as seen in the picture, higher residence times are able to remove more nutrients, but this can result in increased plant productivity.

Hypoxia is a state within a waterbody where dissolved oxygen concentrations are below 2 mg/L (Dodds, 2006b; Petrolia and Gowda, 2006). Hypoxic conditions are the result of stratification within a water column because of differing densities of water (such as freshwater over saltwater) or differing temperatures of water, and phytoplankton decomposition (Rabalais et al., 2002). As algal blooms resulting from eutrophication begin to die off, they sink to the bottom of the water column. Once at the bottom, they are decomposed by the microbial community, a process which consumes dissolved oxygen faster than it can be replaced (Dodds, 2006b). The decreased dissolved oxygen concentrations are problematic for benthic organisms that are unable to migrate away from the hypoxic region, such as shrimp, crabs, and bottom dwelling fish, eventually leading to suffocation (Petrolia and Gowda, 2006). Hypoxia does exhibit seasonal characteristics and is most severe from June through August (in the northern hemisphere), following the inundation of nutrient-rich waters from the spring thaw. The Gulf of Mexico and Chesapeake Bay are two of the more famous regions in the contiguous United States that struggle with hypoxic conditions (Figure 1.17) (Mitsch et al., 2001a; Donner et al., 2004; Alexander et al., 2008). As with eutrophication, nutrient-rich waters originating in agricultural regions are the main contributor to hypoxic conditions as they allow eutrophic states to develop resulting in algal growth and subsequent decay (Goolsby and Battaglin, 2001; Mitsch et al., 2001a; Rabalais et al., 2002; Donner et al., 2004; Dodds, 2006b; Rabalais et al., 2007; Alexander et al., 2008; Porter et al., 2015). Such conditions reinforce the need to better understand agricultural field and tile drainage outputs on a more local scale (Petrolia and Gowda, 2006).

Lake Pepin experiences many of the issues associated with excessive sediment and nutrient loading and serves as a local example of these trends in the upper Midwest. Lake Pepin was placed on the Minnesota 303(d) impaired waters list in 2002 for “nutrient impairment” (Heiskary and Wasley, 2011). The Lake Pepin watershed is comprised of the Mississippi River, Minnesota River, and St. Croix River (Figure 1.3). Nutrient and sediment loads from these rivers are not equally proportional, with 75-90% of the sediment load arriving at Lake Pepin derived from the MRB (Kelley and Nater, 2000b; Engstrom et al., 2009; Mulla and Sekely, 2009; Belmont et al., 2011; Blumentritt et al., 2013). As mentioned previously, sediment and phosphorus accumulation in the lake have greatly increased (Engstrom et al., 2009; Mulla and Sekely, 2009; Belmont et al., 2011; Blumentritt et al., 2013). At the current rate of sedimentation the lake would fill in after

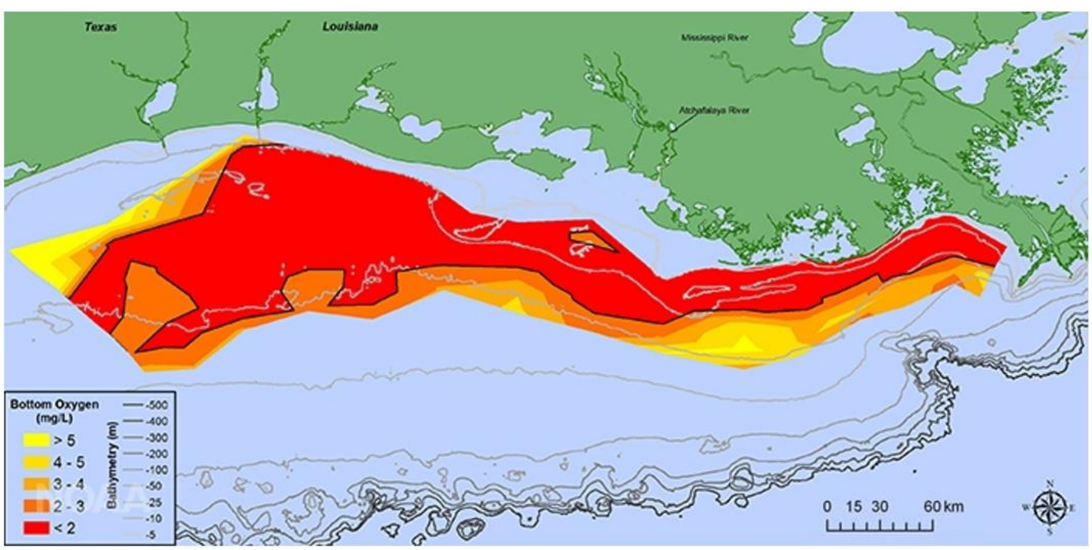


Figure 1.17. Extent of the hypoxic “Dead Zone” in the Gulf of Mexico at the mouth of the Mississippi-Atchafalaya River basin. The hypoxic zone reached a maximum extent of 22,730 km^2, the largest ever recorded. (NOAA, 2017).

approximately 340 years (Engstrom et al., 2009). In comparison, naturally reconstructed presettlement rates indicate that it should take closer to 4,000 years to fill the lake (Engstrom et al., 2009). Lake Pepin is also experiencing nearly five times the natural rate of annual phosphorus accumulation (Blumentritt et al., 2009; Blumentritt et al., 2013). From 1977-1996, approximately 60% of total phosphorus supplied to Lake Pepin originated in the MRB (Mulla and Sekely, 2009). The nutrient load to Lake Pepin has resulted in eutrophication, cyanobacterial blooms, a reduction in recreational visitors, and an update to eutrophication measuring criteria within the state of Minnesota (James et al., 1995; Lung and Larson, 1995; Kelley and Nater, 2000a; James and Larson, 2008; Triplett, 2008; Engstrom et al., 2009; Lafrancois et al., 2009; Heiskary and Wasley, 2011; Blumentritt et al., 2013).

1.4.2 Total Suspended Solids and Turbidity

Total suspended solids are a measure of the suspended organic and inorganic material (silts, clays, plankton, algae, organic debris, and other particulate matter) that have been entrained through turbulence and are generally greater than 2 microns in diameter (Bilotta and Brazier, 2008). Turbidity is a measure of relative clarity within a liquid (usually referred to as cloudiness) and is measured in nephelometric turbidity units (NTU) (Figure 1.18) (Perlman, 2016b). Suspended solids can originate from various sources, including surface runoff, bank slumping, channel scouring, ravine erosion, and organic materials (Gran et al., 2011). Agricultural sources, characterized by exposed soils, tillage practices, and tile drainage, are a primary contributor of suspended solids to streams in the United States (Lee et al., 1985). Total suspended solid concentrations vary seasonally in natural systems. In agricultural systems, excessive loads are common in the early spring when crops are being planted and in late fall after harvest because fields are often bare at these times (Danz et al., 2013). It is estimated that the largest 10% of loading events in a year can account for 73-97% of the annual total suspended solids load, more than half of which can occur in a single event (Danz et al., 2013). In Minnesota, the water quality standard for total suspended solids in Class 2 waters (waters used for aquatic life or recreation) is 65 mg/L and can range between 10-25 NTUs for turbidity, depending on the specific use of the water (Minnesota Office of the Revisor of Statutes 2016).

Total suspended solids and turbidity have widespread effects on ecosystem health, functionality, and water quality (Table 1.1). Dissolved oxygen is largely affected by increased suspended solids loads and higher turbidity (Bilotta and Brazier, 2008).

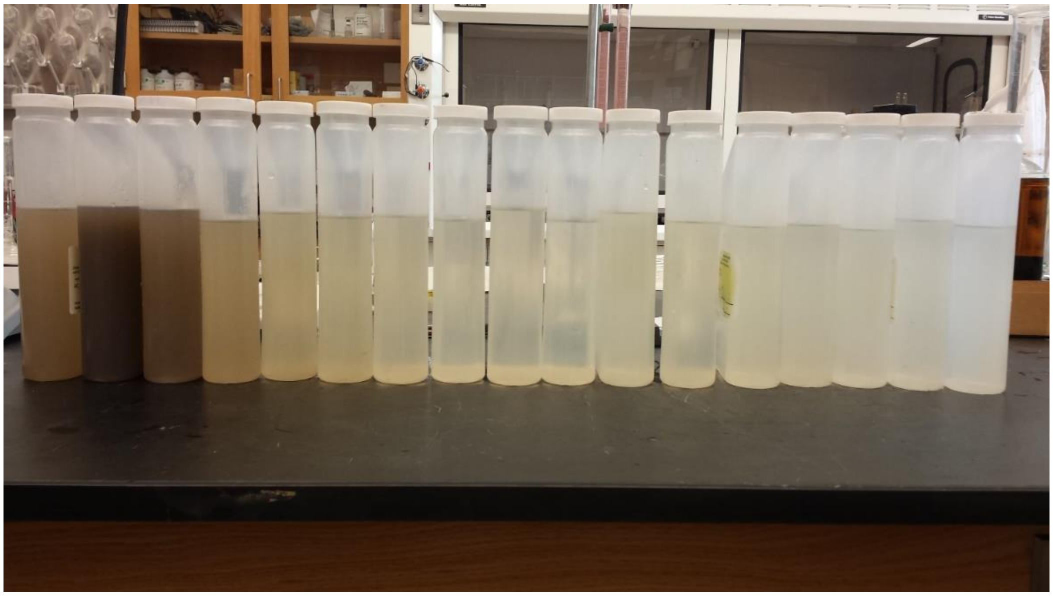


Figure 1.18. Example of water samples with varying degrees of total suspended solids. In this case, the darker bottles towards the left side of the picture have suspended solids concentrations than the bottles towards the right side of the picture. The darker colored bottles are immediately clustered around the peak of a hydrograph encompassing a late May runoff event.

Sediment rich waters retain more heat because of darker colors and more particulate matter absorbing heat, allowing for warmer waters and decreased dissolved oxygen (Dodds, 2007; Garvey et al., 2007; Bilotta and Brazier, 2008; Blann et al., 2009; EPA, 2012). Fish and other invertebrates are at risk where high concentrations of total suspended solids and turbidity exist. Such conditions can clog gills, smother eggs, reduce success rates when feeding, decrease growth rates, decrease activity within certain fish species, and alter the food availability and habitat structure for invertebrates (Gardner, 1981; Kramer, 1987; Murphy, 2007; Verdonschot et al., 2011; EPA, 2012). Plants can also suffer when suspended solids/turbidity rates are high through reduction of sunlight reaching aquatic plant life and prohibiting photosynthesis (Figueroa-Nieves et al., 2006; Chesapeake Bay Program, 2012).

Economically, higher suspended solids can also reduce revenue from tourism and recreational activities because many see the water as aesthetically unappealing (Perlman, 2016b). They are also indicative of severe erosion upstream, which can lead to higher costs for water treatment, reduce the navigability of waterways, and reduce the amount of time a dam or reservoir can be utilized before maintenance is required. (Ryan, 1991; Butcher et al., 1993; Verstraeten and Poesen, 2000; Wood, 2014; Kentucky Water Watch, 2016). Finally, dredging operations may be required to maintain boating and barge operations and may require considerable time, manpower, and resources (Jennings, 2016; Nigbor, 2016; Rogers, 2017).

Table 1.1. Ways in which total suspended solids and turbidity affect humans, the economy, and the environment.

Maximum Levels	Impact	Effect	Author
Suggested ~0.2-5 NTU (Osmond et al., 1995; EPA, 2009; WHO, n.d.). ~6.36 NTU for Aggregate Ecosystem VI for Rivers and Streams (EPA, 2016) < 10 NTU in streams, lakes, or reservoirs designated as trout waters and < 25 NTU for those not designated as trout waters (North Carolina Code, 2002; Minnesota Office of the Revisor of Statutes, 2016) < 50 NTU in streams not designated as trout waters (North Carolina Code, 2002)	Human	Aesthetically unappealing	Perlman (2016b)
		Can provide environment for various levels of protozoa, bacteria, and viruses.	Osmond et al. (1995)
		Can provide environment for various series of waterborne diseases.	Arizona Department of Health Services (2014)
	Economy	Reduce navigability for ships and boats.	Wood (2014)
		Higher costs of water treatment.	Ryan (1991)
		Shorter lifespan for dams and reservoirs	Butcher et al. (1993); Verstraeten and Poesen (2000)
	Environment	Increase in water temperatures and decrease in dissolved oxygen	EPA (2012)
		Decreased photosynthetic processes and plant productivity	Chesapeake Bay Program (2012)
		Indication of increased erosion of stream banks	Kentucky Water Watch (2016)
		Dissolved metals and pathogens can attach to suspended particulates decreasing water quality	Perlman (2016b)
		Can clog fish gills, suffocate benthic organisms and eggs, and affect growth rates	EPA (2012); MDEQ (n.d.)
		Can obscure vision of aquatic life, reducing their ability to locate food	Murphy (2007)

1.4.3 Nutrients – Nitrogen and Phosphorous

Nitrogen and phosphorous are beneficial to plants, but differ in how they are transported, utilized by plants, and how they affect their surroundings. Nitrogen and phosphorus increase plant development and productivity (Dodds, 2006a; Nolte, 2010). Much like total suspended solids, phosphorus and nitrogen concentrations are driven by seasonal runoff events, such as spring snowmelt and storm water runoff (Pionke et al., 1999; Borah et al., 2003; Fink and Mitsch, 2004; Sharpley et al., 2008; Jiang et al., 2010; Corriveau et al., 2013; Danz et al., 2013). As much as 60% of nitrogen fertilizer applied in the spring is washed away and not utilized by crops, instead finding its way into waterbodies downslope/downstream (Smith, 2003; Simpson et al., 2008; Porter et al., 2015). In the Red River of the North, 42-92% of the annual total phosphorus load and 41-81% of the annual total nitrogen load originate during spring snowmelt (Corriveau et al., 2013). Much of this load comes from post-harvest fertilizer application in October-November of the preceding year (Kalkhoff et al., 2016). Between 64-88% of the total phosphorus load originates from the top 10% of loading events throughout the year (Danz et al., 2013). Nutrients like nitrogen and phosphorus are generally considered to be "limiting agents" within a waterbody, meaning that their presence or lack of presence affects primary production of aquatic flora (Correll, 1998). Their role as a limiting agent can reduce biodiversity if there is not enough for flora to consume, but it can also lead to a monoculture, overproduction and degraded conditions in ecosystems with excessive loading (Correll, 1998; Dodds, 2006a; Hoellein et al., 2007).

Nitrogen, while essential for healthy plant growth, is among the most mobile compounds in the soil-plant-atmosphere system and can be difficult to manage or contain (Follett and Delgado, 2002). Nitrogen is readily taken up by aquatic macrophytes and algae throughout the year as a principle source of food (Ehrlich and Slack, 1969; Birgand et al., 2007). The rate of uptake can be subdued if the region is shaded or the current is too fast (Butcher, 1933; Canfield Jr. and Hoyer, 1988; Birgand et al., 2007). Uptake is also affected by the source of the nitrogen. For example, nitrate is much more abundant than ammonia or organic nitrogen, but ammonia is easier for a plant to convert into food (Omernik, 1977; Syrett, 1981; Duda and Finan, 1983; Heathwaite et al., 1996; Birgand et al., 2007). The nitrogen cycle fluctuates seasonally, where summer months exhibit the lowest nitrogen levels in water as crops are utilizing much of the nitrogen as a food source and are removing it from the soil. Nitrogen is highest in the early spring and fall when crops are not utilizing the nitrogen and it is carried off of fields or through decomposing organic matter (Birgand et al., 2007). Concentrations in water also vary with precipitation intensity and annual precipitation within a watershed (Borah et al., 2003). Nitrogen concentrations are heavily regulated in waterbodies and high concentrations can have health repercussions for humans (Table 1.2). The Environmental Protection Agency (EPA) and Minnesota Office of the Revisor (2016) list the maximum safe drinking level for nitrogen concentration at 10 mg/L (Mueller and Helsel, 2013a).

Table 1.2. Ways in which nitrogen affects humans, the economy, and the environments.

Maximum Levels	Impact	Effect	Author
~2.18 mg/L for Aggregate Ecosystem VI for Rivers and Streams (EPA, 2016) 10 mg/L for human consumption (Mueller and Helsel, 2013a) 90 mg/L for freshwater fish (Osmond et al., 1995)	Human	Fatalities from methemoglobinemia, or "blue baby syndrome" from restriction of oxygen transport in bloodstream	Mueller and Helsel (2013a)
	Economy	Algae can clog water intakes	Perlman (2016a)
		Eutrophication can lead to economic losses of more than $1,000,000 per event and monitoring efforts can cost up to $50,000 annually in affected regions	Corrales and Maclean (1995)
	Environment	Overstimulation of growth of aquatic plants and algae leading to depleted oxygen levels	Perlman (2016a)
		Eutrophic and hypoxic conditions can form given excessive loading	Dodds (2006b)

Phosphorus dynamics within waterbodies pertain mainly to their role as a macronutrient source for plants and are not considered particularly harmful to humans (Table 1.3) (James and Larson, 2008; Bigelow et al., 2009; Oram, 2014). High levels of phosphorus in soil following long-term fertilizer/manure application can lead to mobilization of phosphorus in dissolved or sediment-bound forms, such as orthophosphates, organic phosphate esters, and organic phosphonates (Correll, 1998; Bundy and Sturgul, 2001; Andraski and Bundy, 2003; Ebeling et al., 2003). In the MARB, phosphorus dynamics are primarily driven by agricultural practices. In one study, phosphorus was found to enter into drainage systems merely through exposure to high concentrations of phosphorus-rich agricultural sediment and/or ditch sediment, or through surface runoff (Kröger and Moore, 2011). Many researchers warn that better attention should be paid to phosphorus loading within agricultural drainage systems, suggesting a tendency for them to move from being a sink of phosphorus to a source, through prolonged exposure and eventual oversaturation (Fennessy et al., 1994; Baker et al., 2004; Kröger et al., 2008b; Blann et al., 2009; Baker et al., 2018). Such interactions can greatly change nutrient dynamics and loading within a ditch, creating an environment where the channel and channel banks act more like a source of phosphorus loading when sediments are entrained. High phosphorus concentrations do not necessarily impact humans in the same way high nitrogen concentrations do, but still acts as a limiting factor for macrophyte and algae development and can lead to eutrophic and/or hypoxic conditions (Table 1.2 and Table 1.3). To prevent eutrophication, the Minnesota Office of the Revisor of Statutes (2016) limits the amount of total phosphorus to 30 µg/L.

Table 1.3. Ways in which phosphorus affects humans, the economy, and the environment.

<table>
<tr><th>Maximum Levels</th><th>Impact</th><th>Effect</th><th>Author</th></tr>
<tr><td rowspan="6">0.025 mg/L within lake/reservoir. (EPA, 1986)

0.05 mg/L in stream at a point where it enters a lake/reservoir (EPA, 1986)

~0.07625 mg/L for Aggregate Ecosystem VI for Rivers and Streams (EPA, 2016)

0.1 mg/L in streams that do not discharge directly into a lake/reservoir. (EPA, 1986)</td><td>Human</td><td>Not generally toxic to people/animals unless in extremely high levels (which can lead to digestive issues)</td><td>Oram (2014)</td></tr>
<tr><td rowspan="2">Economy</td><td>Algae can clog water intakes</td><td>Perlman (2016a)</td></tr>
<tr><td>Eutrophication can lead to economic losses of more than $1,000,000 per event and monitoring efforts can cost up to $50,000 annually in affected regions</td><td>Corrales and Maclean (1995)</td></tr>
<tr><td rowspan="3">Environment</td><td>Overstimulation of growth of aquatic plants and algae leading to depleted oxygen levels</td><td>Perlman (2016a)</td></tr>
<tr><td>Eutrophic and hypoxic conditions can form given excessive loading (0.08-0.1 mg/L)</td><td>Dodds (2006a)
Osmond et al. (1995)
Dunne and Leopold (1978)</td></tr>
<tr><td>Bioaccumulation and concentration within fish tissue (>/= 0.001 mg/L)</td><td>EPA (1986)</td></tr>
</table>

1.5 Best Management Practices for Sediment and Nutrient Loading

Best management practices refer to sediment and nutrient mitigation structures and strategies that have been researched and are widely accepted as efficient ways to reduce certain parameters within waterbodies. While a considerable number of reduction strategies and mitigation structures are considered best management practices, focus in this section will be given to the in-channel practices used in the CD 57 watershed to assess their potential efficacy and possible issues associated with them. These include a surge pond, wetland, two-stage ditch, and rate control weir.

1.5.1 Surge Ponds and Wetlands

Surge ponds, ponds designed to control the influx of storm water and slowly drain it, and wetlands, saturated basins filled with aquatic and riparian vegetation, can be used in tandem (as in the CD 57 watershed) or as separate best management practices (Figure 1.19). Their primary purpose is to reduce flow velocity and allow sediment and nutrients to settle out or be taken up by aquatic or riparian vegetation (Kovacic et al., 2000; Hey et al., 2012; Fehling et al., 2014). Research has confirmed the ability of surge ponds and wetlands to reduce peak discharge as well as overall nitrogen, phosphorus, and total suspended solid loading (Fennessy et al., 1994; Kovacic et al., 2000; Verstraeten and Poesen, 2000; Woltemade, 2000; Fink and Mitsch, 2004; Hey et al., 2012; Kröger et al., 2012; Fehling et al., 2014; Roley et al., 2016). However, there is a wide variety of opinions as to how effective these structures can really be.

Figure 1.19. County Ditch 57 surge pond and wetland showing lowest monitored, typical, and highest monitored levels on inundation.

The biggest factor affecting the performance of wetlands is generally residence time, or the amount of time a molecule of water resides in a particular body until moving to the next (Woltemade, 2000; Kröger et al., 2012). Water that is in contact with a wetland or surge pond experiences greater treatment times and the amount of sediment and nutrients has more time to be reduced. However, performance and reported results differ greatly between studied wetlands. For example, wetlands examined in Illinois were capable of removing nitrogen from the water, but did not exhibit evidence of enhanced phosphorus removal (Kovacic et al., 2000) while studied wetlands in Mississippi were found to be capable of reducing the bioavailability of phosphorus through prolonged residence times

(Kröger et al., 2012). Further examples in Maryland, Illinois, and Iowa were capable of removing up to 68% of nitrate-N and 43% of phosphorus (Woltemade, 2000). However, those results varied when comparing wetlands of differing sizes or wetlands that intercepted different percentages of the overall discharge of the watershed. Also, phosphorus tends to be a much harder nutrient to mitigate or reduce because, unlike nitrogen, it exists without a permanent gaseous phase as a pathway for removal (Kröger et al., 2012). Recent research in the MRB has provided local examples of wetland efficiency rates. An average of fifty-three different riverine sites (over 200 in total) were monitored across four years and seven different runoff events of various sizes (Hansen et al., 2018). Wetlands were found to be five times more capable at reducing riverine nitrogen than any other land-based strategies (including cover crops and retiring agricultural land) during moderate to high streamflow conditions (flows with exceedance probabilities between 0-25%) (Hansen et al., 2018). Relationships between wetland connectivity and wetland position were also compared. Wetlands that were ephemeral and only inundated during runoff were most effective during high flow conditions. Also, similar to wetlands in Maryland, Illinois, and Iowa (Woltemade, 2000), wetlands positioned lower in the watershed that intercepted higher percentages of flow were more efficient at reducing nitrate (Hansen et al., 2018).

As beneficial as these structures have the capacity to be there are a number of issues that have been examined regarding how they function. The amount of time that a wetland/surge pond remains effective is still a matter of discussion. There is a point in the “lifespan” of a surge pond/wetland where oversaturation of sediment and nutrients turns it from a sink to a source (Verstraeten and Poesen, 2000; Fink and Mitsch, 2004). In the Illinois example mentioned previously (Kovacic et al., 2000), wetlands were capable of sinking nitrogen but were unable to retain or reduce phosphorus or organic carbon. However, other work has suggested that the amount of time until wetlands start adding more sediment and nutrients is hard to determine and depends primarily on saturation and overall discharge (Fink and Mitsch, 2004). For example, the effectiveness of the Illinois wetlands may be explained by the fact that they were assessed immediately after their construction for a four year period, during a time when the wetlands may have still been capable of reducing sediment and nutrient loads (Kovacic et al., 2000).

High rates of productivity can also result in greenhouse gas production and is a concern as more wetlands are being constructed. While constructed wetlands are designed to remove and take up nutrients moving through a watershed they also allow accelerated growth of aquatic and riparian vegetation (de Klein and van der Werf, 2014; Anderson et al., 2016; Maucieri et al., 2017). Gases of primary concern are carbon dioxide, methane, and nitrous oxide (de Klein and van der Werf, 2014; Anderson et al., 2016; Maucieri et al., 2017). As the vegetation produced in wetlands decays or converts nitrogen to its gaseous form they supply further gases to the atmosphere (de Klein and van der Werf, 2014; Anderson et al., 2016; Maucieri et al., 2017).

Finally, one study examined the economic viability and cost-effectiveness of cover crops, wetlands, and two-stage ditches in the MARB (Roley et al., 2016). Cost-effectiveness was defined as the cost of reducing one transportable kilogram of nitrogen. Wetlands were the most cost-effective option in terms of dollars per kilograms of nitrogen per year removed over both a ten and fifty year timespan. However, higher costs required to construct a wetland reduced cost effectiveness over the ten year interval ($2.91 kilograms of nitrogen per year) compared to the fifty year interval ($2.04 kilograms of nitrogen per year).

1.5.2 Two-Stage Ditches

A two-stage ditch is characterized by wider shoulders, a wider base, and is constructed with flat benches to simulate a natural floodplain (Figure 1.20) (Powell et al., 2007b; Kröger et al., 2013; Mahl et al., 2015; Roley et al., 2016). They are designed with these characteristics to better simulate natural, low-order streams in stable conditions (Ward et al., 2004; D'Ambrosio et al., 2015). When constructed, two-stage ditches are most effective where conventional ditches are unstable, and can sometimes form on their own through bank failure within conventional ditches (Kramer, 2011). Two-stage ditches, though a relatively new practice, have been shown to reduce sediment and nutrient loads and are being considered as a best management practice (Powell et al., 2007a; Powell et al., 2007b; Roley et al., 2012; Kröger et al., 2013; Mahl et al., 2015; Roley et al., 2016).They can facilitate denitrification primarily through uptake by riparian vegetation (Roley et al., 2012). Phosphorus, which is harder to manage than nitrogen (Kröger et al., 2012), is most capably managed when bound with sediment and intercepted by vegetation on the benches, however more focus needs to be given to how efficient this can be (Kröger et al., 2013). Two-stage ditches from Indiana, Michigan, and Ohio were capable of increasing nitrogen removal rates (3-24 times), reducing turbidity (15-82%),

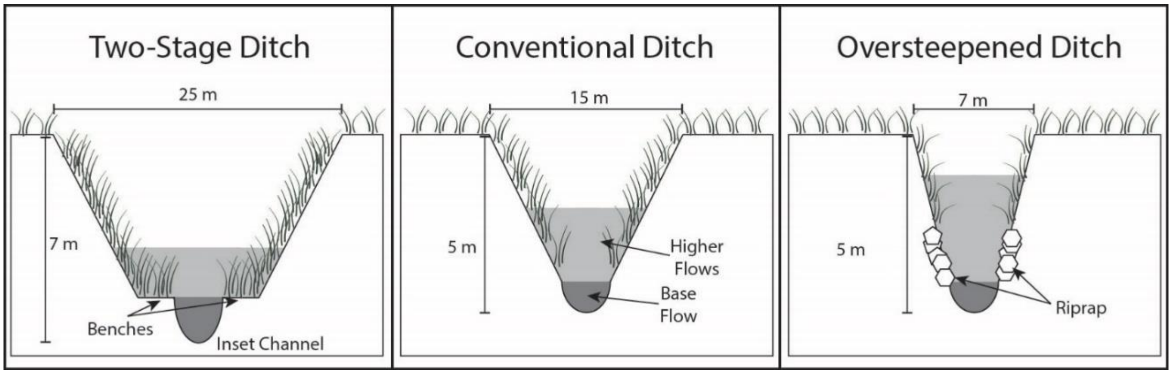


Figure 1.20. Diagram showing the dimensions of a two-stage ditch, conventional ditch, and oversteepened ditch.

and reducing soluble reactive phosphorus (3-53%) during base flow conditions (Mahl et al., 2015). Other two-staged ditches in Ohio were capable of reducing suspended solids (22-50%) and total phosphorus (40-50%) (Hodaj, 2015). Other two-stage ditches in Indiana were able to reduce turbidity, total suspended solids, soluble reactive phosphorus, total phosphorus, nitrate, and ammonium in low flow conditions or with low concentrations, but reduction across all parameters was reduced if residence times were too short (Davis et al., 2015). While these number are highly variable and many local factors determine the efficiency of a two-stage ditch, the reduction rates reported by Mahl et al. (2015), Kröger et al. (2013), Davis et al. (2015), and Hodaj (2015) demonstrate that two-stage ditches can efficiently remove sediment and nutrients.

Geomorphic evaluations of two-stage ditches have confirmed that, aside from improving water quality, they also increase channel stability (Ward et al., 2004; Powell et al., 2007a; Powell et al., 2007b; D'Ambrosio et al., 2015; Davis et al., 2015; Krider et al., 2017). Furthermore, based on their construction, pool-riffle sequences tend to form in two-stage ditches as they would in a natural channel (Powell et al., 2007b; Hodaj, 2015;

Krider et al., 2017). These pool-riffle sequences provide protection and habitat for fish and macroinvertebrates, strengthening the biological integrity of the ditch (Lau et al., 2006; Krider et al., 2017). In Mower County, MN (approximately 100 km southeast of the CD 57 study area) a conventional ditch (Figure 1.20) was converted to a two-stage ditch in 2009 (Krider et al., 2017). After this conversion, the reach was found to have a twelve-fold increase in pool-riffle formation, a 10% increase in bankfull width, and an ~18% increase in bankfull depth, while maintaining channel stability (Krider et al., 2017). A Modified Pfankuch Channel Stability Rating was performed to assess bank and channel erosivity and both metrics were found to be highly stable and at low risk of erosion (Krider et al., 2017). Modified Pfankuch Channel Stability Ratings contain a series of primarily qualitative channel assessments that examine a variety of in situ characteristics and assign a quality rating for the channel (Rosgen, 2008). This increased stability can decrease erosion rates and allow for higher control over sediment budgets, which can also increase denitrification and reduce phosphorus loads (Ward et al., 2004; Powell et al., 2007a; Powell et al., 2007b; D'Ambrosio et al., 2015; Davis et al., 2015; Krider et al., 2017).

Finally, the cost-efficiency study (Roley et al., 2016) that looked at wetlands, two-stage ditches, and cover crops determined that two-stage ditches were the second most cost-effective method over the fifty year interval ($4.61 kilograms of nitrogen per year) and last out of the three methods examined over the ten year interval ($11.63 kilograms of nitrogen per year). The lack of cost-efficiency over the ten year period is attributable to higher startup costs in the first year of installation that are offset by consistent removal capabilities over longer intervals (Roley et al., 2016). For example, an engineering firm in southern Minnesota spends $58.22 per meter more constructing a two-stage ditch than a conventional ditch (Brandel, 2017).

1.5.3 Weirs

Weirs are low-lying “check” dams designed to slow, control, or divert flow (Figure 1.21) (Kröger et al., 2008a; Littlejohn et al., 2014). A preliminary study on low-grade weirs suggest their use an alternative control for drainage mitigation strategies (Kröger et al., 2008a). Low-grade weirs are defined as earthen dams situated in channel that are covered with a woven filtration fabric and covered in riprap (Littlejohn et al., 2014). While this weir design differs from the weir in the CD 57 watershed, weirs, like surge ponds, wetlands, and two-stage ditches, can increase residence times and allow for further reduction on nutrients and sediment (Kröger et al., 2008a; Kröger et al., 2011; Littlejohn et al., 2014). Removal rates of 14% of dissolved inorganic phosphorus and 6% of ammonium and nitrite were observed for low-grade weirs in Mississippi (Littlejohn et al., 2014). While not necessarily listed as a best management practices in Minnesota (Miller et al., 2012), Littlejohn et al. (2014) suggested that weirs could be considered a best management practice, but that additional research was recommended to better understand the dynamics of nitrogen interactions related to weir construction within the water.

Figure 1.21. County Ditch 57 diversionary weir (A) and rate control weir (B). The diversionary in this watershed is designed to slow discharge and allow sediment to settle on the channel bottom. It also diverts water into a surge pond for further treatment. The rate control weir is designed to reduce the amount of water leaving the watershed and also to slow discharge upstream to allow sediment to settle on the channel bottom.

1.6 Ecological Functions within Agricultural Drainage Ditches

While most tend to consider agricultural drainage ditches as merely a way to move water away from fields, they can provide a very unique ecosystem. Herzon and Helenius (2008) provided a comprehensive review of the functional ecosystem of drainage ditches that examined plants, invertebrates, fish, amphibians, birds, mammals, habitat availability, natural water purification, nutrient cycling, and erosion control. Ditches represent a chemically different, slow-flowing system that support a variety of ecological niches, or specialized communities, that larger, faster bodies of water cannot support (Armitage et al., 2003). In northwestern Europe, the biodiversity of invertebrates and other aquatic species in drainage ditches, including uncommon or rare species, was similar to a small lake (Verdonschot et al., 2011). Ditches can serve as a significant habitat for these invertebrates, but the influx of nutrients, common in agricultural drainages, can alter food availability, change habitat structure, and deplete oxygen (Verdonschot et al., 2011). A biological survey and analysis of species richness (overall abundance and diversity) in headwater agricultural drainages west of Lake Erie found that ditches were capable of a high amount of species richness if a balance between management and efficient drainage was maintained (Crail et al., 2011). On the contrary, given the interconnectedness of natural and modified agricultural systems, the conversion of natural drainages to agricultural drainages is a detriment to the many species that inhabit them (Figure 1.22) For example, the reduction of pool and riffle sequences, which are common in natural streams, significantly reduce fish habitat after channelization (Lau et al., 2006). Nutrient inputs and hydrologic modification, both common in agricultural drainage ditches, represent two of the top three threats to 135 organisms, including species of fish, crayfish, dragonflies, damselflies, mussels, and amphibians in the United States alone (Richter et al., 1996; Stein and Flack, 1997; Blann et al., 2009). Furthermore, increases in nutrient loads aid in the development of eutrophic conditions, which alters interactions in the water column through reduced penetration of sunlight, warming temperatures, and dissolved oxygen depletion (Sand-Jensen and Søndergaard, 1981; Bloemendaal and Roelofs, 1988; Janse and Van Puijenbroek, 1998).

Research on fish in ditches has focused on the response of fish communities to changes in water quality, through nutrient loading or increases in turbidity. Increases in turbidity were found to decrease success in feeding rates of bluegills by reducing visibility (Gardner, 1981). Experiments with turbidities of 0 NTU, 60 NTU, 120 NTU, and 190 NTU decreased average three minute feeding success rates from fourteen prey to eleven, ten, and seven, respectively (Gardner, 1981). Water temperature and sediment loads were both potential limiting factors in the abundance of trout, a popular sport fishing species (Halverson, 2008), within streams in southwestern Minnesota (Zimmerman et al., 2003). Additionally, elevated levels of suspended solids and turbidity clog the gills of fish, suffocate benthic organisms and fish eggs, decrease growth rates, and decrease the quantity of dissolved oxygen and fish activity (Kramer, 1987; Murphy, 2007; EPA, 2012).

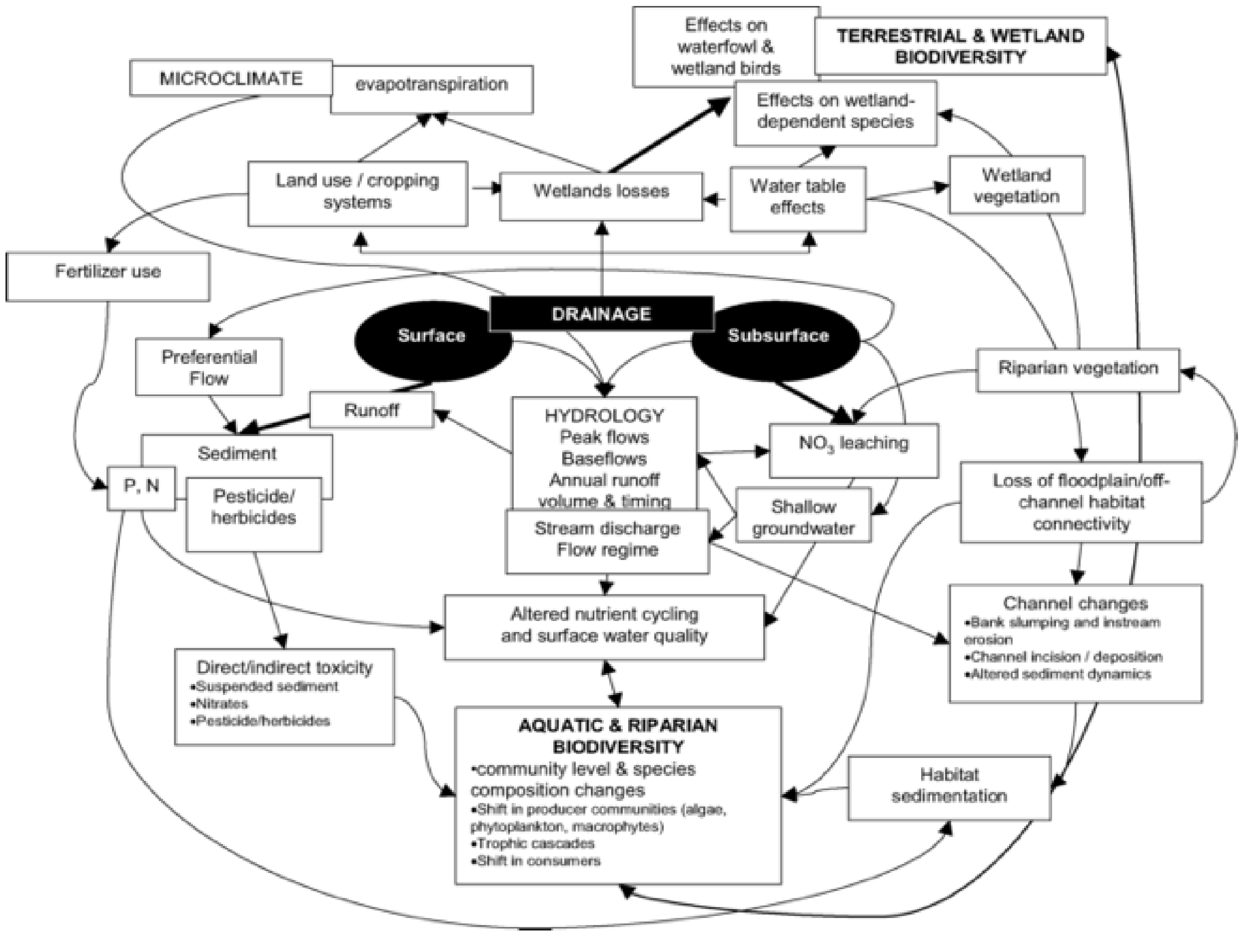


Figure 1.22. Conceptual relationships involving subsurface and surface drainage within an aquatic ecosystem (from Blann et al., 2009). The watersheds examined in this study feature both surface and subsurface drainage interactions.

Chapter 2: Reduction Capabilities of Structural Practices in County Ditch 57, Blue Earth River Watershed

2.1 Introduction

As Earth's population nears as estimated 7.5 billion people it is necessary to improve agricultural yields to meet food demands (Census.gov, 2018). Unfortunately, with increasing yields comes an increasing need for fertilizer application and the modification of agricultural landscapes (Tilman, 1999; Blann et al., 2009). Increases in nitrogen and phosphorus fertilizer stem mainly from agricultural sources and have widespread impact on ecosystem health, as they can serve as a primary food source and growth accelerant for aquatic and riparian vegetation (Alexander et al., 2008; Blann et al., 2009; Canfield Jr. et al., 2010). Global waters are in jeopardy as instances of eutrophication (accelerated production of aquatic plants) and hypoxia (low dissolved oxygen within a waterbody) are increasing in size, distribution, and frequency (Figure 1.16 and Figure 1.17) (Petrolia and Gowda, 2006; Alexander et al., 2008; Blann et al., 2009). These conditions can have vast and negative effects on local aquaculture, fishing, and recreation (Table 1.2 and Table 1.3) (Diaz, 2001; Donner et al., 2004; Alexander et al., 2008; Hofmann et al., 2011; NOAA, 2017).

To help improve crop yields it has become common practice to modify drainages to meet the needs of those in the area (Blann et al., 2009). Drained lands in the Mississippi-Atchafalaya River basin (MARB) of the United States have increased from ~24,000 to ~280,000 km^2 over the last 115 years (Mitsch et al., 2001a). Drainage modifications come generally in the form of ditches (surface) or tile drainage (subsurface) (Armitage et al., 2003; Herzon and Helenius, 2008; Blann et al., 2009). Tiling is primarily used to drain water from natural depressions, increase infiltration rates, lower the water table, and create a more hospitable growing climate for crops (Blann et al., 2009; Schottler et al., 2014). The tile, usually a permeable PVC or ceramic pipe of varying diameter, is buried a meter or two below the surface and plow line, quickly intercepting water and flushing it into a nearby ditch or body of water (Maalim and Melesse, 2013). However, these practices lead to flashier hydrologic systems, increased peak discharge, increased erosivity in larger streams/rivers, and an increase in severe flooding events (Figure 1.12) (EEA, 1996; Knox, 2001; Blann et al., 2009; Schottler et al., 2014). These flashier systems are capable of entraining larger quantities of sediment and nutrients and transporting them downstream (Belmont et al., 2011; Schottler et al., 2014; Kelly et al., 2017).

The Minnesota River basin (MRB) of southern Minnesota is a tributary to the MARB and exhibits greater changes, relative to basin size, in land use, nutrient concentrations, and hydrologic regimes than the MARB (Figure 1.1). Native land cover (primarily tall-grass prairies, wetlands, and hardwood deciduous forests) has been reduced ~80-90% to accommodate a modern basin that uses 78-80% for row-crop agriculture, primarily corn and soybeans (Mulla and Sekely, 2009; Musser et al., 2009; Belmont et al., 2011). In terms of hydrologic changes, the MRB has seen an increase from ~19% watershed area drained by tile in 1940 to ~35% in 2012, while the watershed area drained by ditches increased from ~7% in 1940 to ~10% in 2012 (Kelly et al., 2017). In south-central

Minnesota, tile drainage networks are particularly dense within the greater Blue Earth River basin (GBERB). In nineteen watersheds within the Le Sueur River (LSR) basin, a tributary of the Blue Earth, around 71% of the cultivated land is classified as "poorly drained" and has had an estimated 141 meters per hectare of tile drainage installed (Schottler, 2012). These changes in hydrology and land cover result in a disproportionate contribution of nutrient and sediment loads to the MARB, providing ~3-7% of the nitrate load to the Gulf of Mexico while only comprising 1.34% of the drainage area (Magdalene, 2004; Steil, 2007).

One of the largest contributors to sediment and nutrient loads to the MRB is the GBERB, comprised of the Blue Earth, Le Sueur, and Watonwan Rivers (Figure 1.2). Flow-weighted mean concentrations for total phosphorus for the Watonwan, Blue Earth, and Le Sueur Rivers are around 0.26 mg/L, 0.32 mg/L, and 0.48 mg/L, respectively (MRBDC, 2018). Flow-weighted mean concentrations for nitrate-nitrogen averaged 10.7 mg/L for the Watonwan and Le Sueur, and 10.3 mg/L for the Blue Earth. Comparatively, natural "background" concentrations for nutrients in the Mississippi-Atchafalaya River basin (MARB) ranged from ~0.006-0.08 mg/L for total phosphorus and ~0.02-0.5 mg/L for total nitrogen (Smith et al., 2003), while modern concentrations are closer to ~0.042-0.990 mg/L for total phosphorus and ~0.72-7.57 mg/L for total nitrogen (Goolsby et al., 1999).

Efforts to improve water quality in the GBERB are focusing on implementing best management practices in a variety of landscape positions (Miller et al., 2012). Weirs, surge ponds, wetlands, and two-stage ditches are of particular interest to this study, as they have been employed within the study area. Weirs are low-lying “check” dams that are designed to slow, control, or divert flow (Figure 1.21) (Kröger et al., 2008a; Littlejohn et al., 2014). Weirs are able to increase the residence time of water by slowing or controlling discharge which can allow sediments to settle out and nutrients to be taken up by aquatic and riparian vegetation (Kröger et al., 2008a; Kröger et al., 2011; Littlejohn et al., 2014). While not necessarily listed as a best management practices in Minnesota (Miller et al., 2012), Littlejohn et al. (2014) suggested that weirs could be considered a best management practice, but that additional research was recommended to better understand the dynamics of nitrogen interactions related to weir construction within the water.

Surge ponds and wetlands are used to slow flow velocity while allowing sediment and nutrients to settle out or be taken up by aquatic or riparian vegetation (Figure 1.19) (Kovacic et al., 2000; Hey et al., 2012; Fehling et al., 2014). Surge ponds and wetlands have been shown to reduce peak discharge, nitrogen, phosphorus, and total suspended solids (Fennessy et al., 1994; Kovacic et al., 2000; Verstraeten and Poesen, 2000; Woltemade, 2000; Fink and Mitsch, 2004; Hey et al., 2012; Kröger et al., 2012; Fehling et al., 2014; Roley et al., 2016). However, they are not without issue. Effective reduction has been shown to require sufficient residence times for water moving through the basin (Woltemade, 2000; Kröger et al., 2012). Constructed wetlands have also shown to be contributors to carbon dioxide, methane, and nitrous oxide concentrations because of high primary production rates (de Klein and van der Werf, 2014; Anderson et al., 2016; Maucieri et al., 2017). There is also a point in the “lifespan” of a surge pond or wetland in which the structure becomes too saturated and reduction efficiency slackens or the structure can become a source for sediment and/or nutrients (Verstraeten and Poesen, 2000; Fink and Mitsch, 2004).

Two-stage ditches are characterized by wider shoulders, a wider base, and are constructed with flat benches that act to simulate a natural floodplain (Figure 1.20) (Powell et al., 2007b; Kröger et al., 2013; Mahl et al., 2015; Roley et al., 2016). They are designed with these characteristics to better simulate natural, low-order streams in stable conditions (Ward et al., 2004; D'Ambrosio et al., 2015). When constructed, two-stage ditches are most effective where conventional ditches are unstable, and can sometimes form on their own through bank failure and floodplain widening (Kramer, 2011). Two-stage ditches have been shown to reduce sediment and nutrient loads and are being considered as a best management practice (Powell et al., 2007a; Powell et al., 2007b; Roley et al., 2012; Kröger et al., 2013; Mahl et al., 2015; Roley et al., 2016). Other evaluations of two-stage ditches have supported their ability to increase channel stability, generate pool-riffle sequences that would form naturally, provide protection and habitat for fish and macroinvertebrates, and strengthen the biological integrity of the stream (Ward et al., 2004; Lau et al., 2006; Powell et al., 2007a; Powell et al., 2007b; D'Ambrosio et al., 2015; Davis et al., 2015; Hodaj, 2015; Krider et al., 2017). Two-stage ditches are not without their drawbacks, however. Similar to surge ponds and wetlands, if residence times within the ditches are not prolonged enough the ability to treat the water decreases (Davis et al., 2015). Their width is also much greater than a conventional ditch, which removes more farm land from production. Finally, startup costs for two-stage ditches are generally higher than surge ponds and therefore are not as efficient or cost effective over shorter timescales (1-10 years) as surge ponds tend to be (Roley et al., 2016).

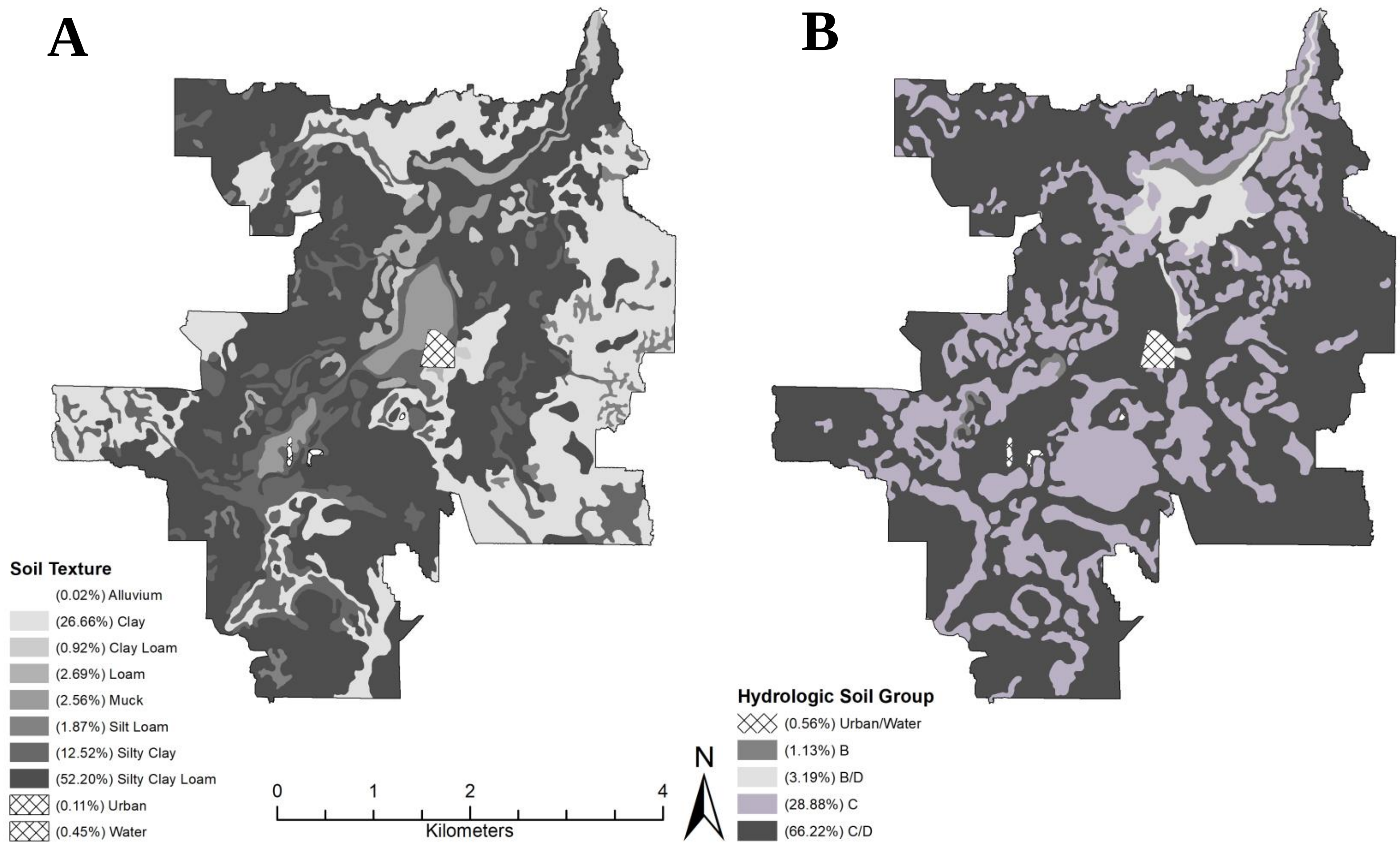
2.2 Study Area and History of County Ditch 57

2.2.1 Study Area

The County Ditch (CD) 57 watershed covers 25.2 km^2 of undulating, upland topography in south-central Blue Earth County, south-central Minnesota (Figure 1.2). The watershed is underlain by glacial till, glaciofluvial sands and gravels, and finer glaciolacustrine sediments deposited as the Des Moines Lobe of the Laurentide Ice Sheet receded and from deposition of glacial Lake Minnesota (Belmont et al., 2011). Modern soils within the watershed are dominantly mollisols (68.13%), rich soils with thick, dark A horizons that formed under grassland or savanna conditions, and vertisols (28.54%), dark soils formed in semi-arid grasslands or savannas that are very clay-rich and crack in the dry season Figure 2.1) (Schaetzl and Anderson, 2005; NRCS, 2016). Hydrologic soil classifications are dominantly C/D soils (66.22%) or C soils (28.88%) (NRCS, 2016). C/D soils are characterized by moderately high runoff potential when saturated and throughflow that is somewhat restricted in drained regions and soils with high runoff potential when saturated and throughflow that is restricted to very restricted in undrained regions (NRCS, 2007). C soils are characterized by moderately high runoff potential when saturated and throughflow that is somewhat restricted (NRCS, 2007). Soil texture throughout the watershed is dominantly silty clay loams (52.20%) and clays (26.66%) (NRCS, 2016). Finally, while 88.33% of the watershed is comprised of soils designated as “Prime Farmland if Drained,” 53.36% and 15.21% of the watershed is designated as “Poorly Drained” or “Very Poorly Drained” (NRCS, 2016).

2.2.2 County Ditch 57 History (1907-2006)

CD 57 was originally constructed between 1907 and 1921 and was primarily a tiled system that connected private tile lines with an open channel (Morrison, 2013). At that time, the open channel portion extended about a quarter of its present-day length (Figure 2.2-2.4). Extensive improvement projects in the 1970s addressed widespread infrastructure failure throughout the system (ISG, 2015a). These improvements included extending the open channel two more miles to the south-southeast and a new open channel in the southern portion of the watershed, both following original locations of tiling (ISG, 2015). Both open channels remained connected by two tile lines which included an existing concrete main line and a supplemental corrugated metal line. The open channel transitioned to a 1.37 m pipe, which was upgraded from the original 1.02 m pipe, immediately west of the city municipal ponds (Brandel, personal communication, 2017). Expansion of the city of Mapleton led to further issues within the CD 57 system, as tile was either abandoned or integrated into the city municipal storm water system (ISG, 2015).


A
B
Soil Texture
(0.02%) Alluvium
(26.66%) Clay
(0.92%) Clay Loam
(2.69%) Loam
(2.56%) Muck
(1.87%) Silt Loam
(12.52%) Silty Clay
(52.20%) Silty Clay Loam
(0.11%) Urban
(0.45%) Water
0
1
2
4
Kilometers
N
Hydrologic Soil Group
(0.56%) Urban/Water
(1.13%) B
(3.19%) B/D
(28.88%) C
(66.22%) C/D

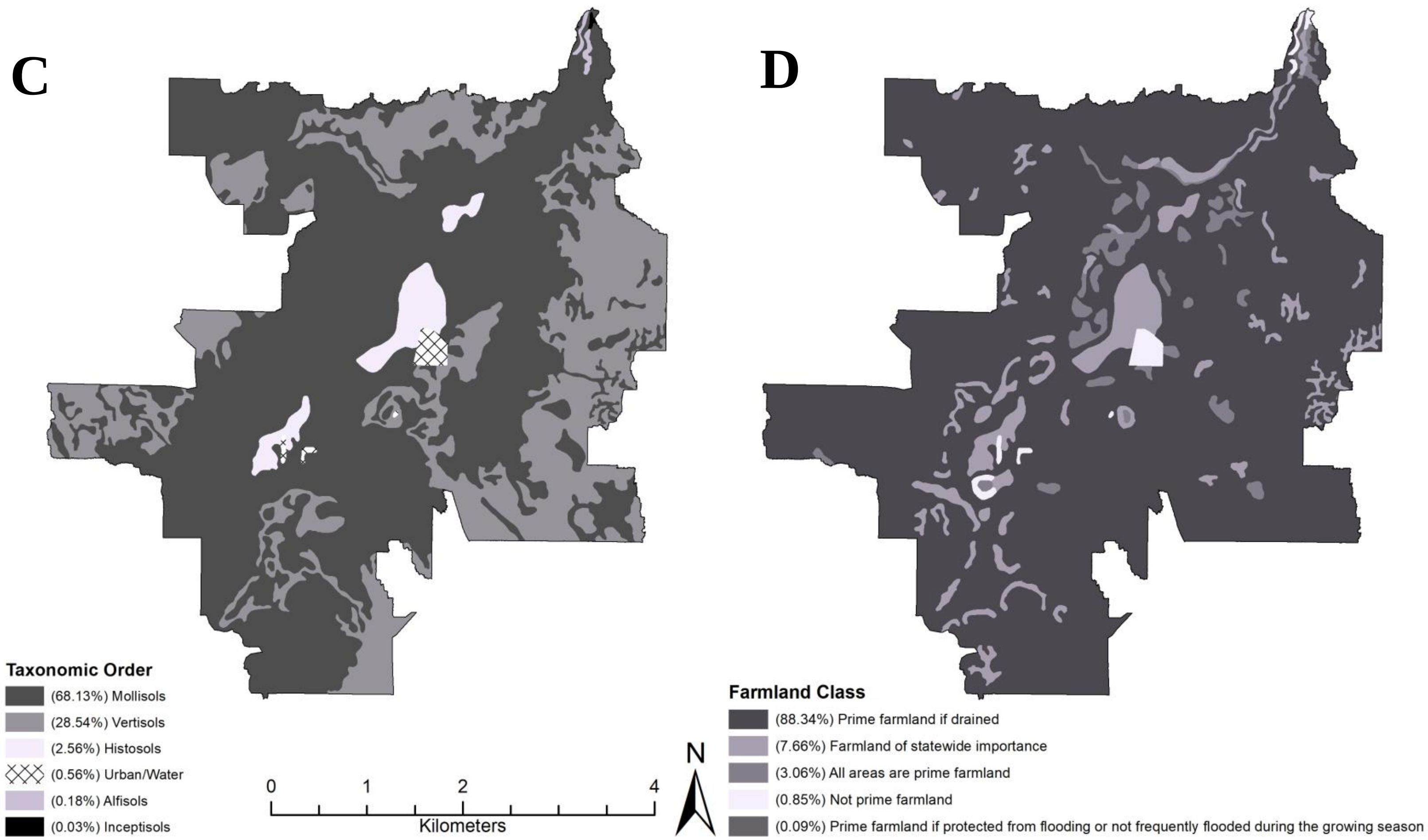


Figure 2.1. A) Taxonomic order map of soils within the CD 57 watershed. Mollisols are the primary taxonomic order throughout CD 57. B) Farmland class map of CD 57 soils. The primary designation is “prime farmland if drained.” C) Soil texture map for the CD 57 watershed. Silty clay loams are the primary soil texture. D) Hydrologic soil group map of the CD 57 watershed. C/D hydrologic soils are the dominant group.

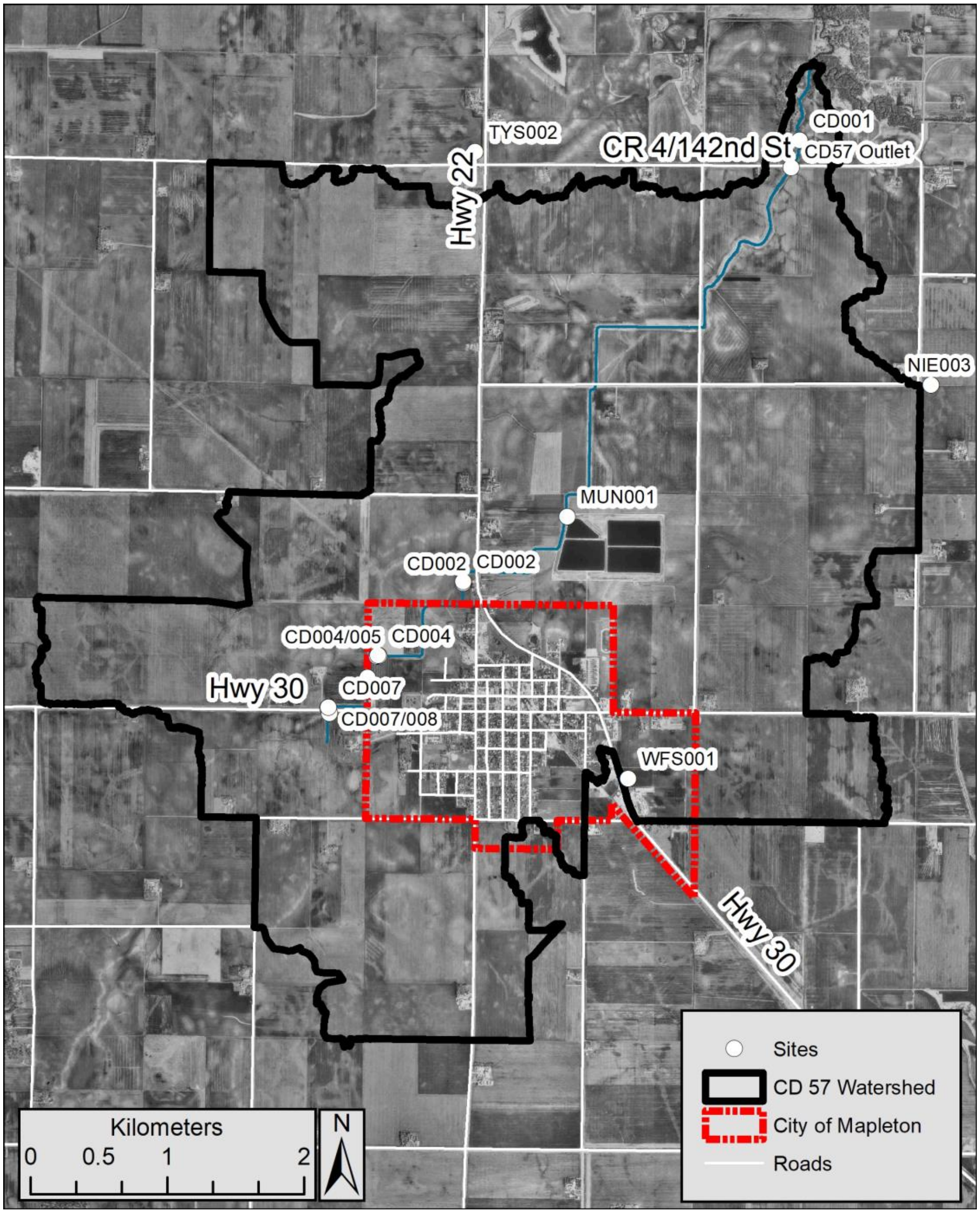


Figure 2.2. Black and white aerial image of the County Ditch 57 watershed.

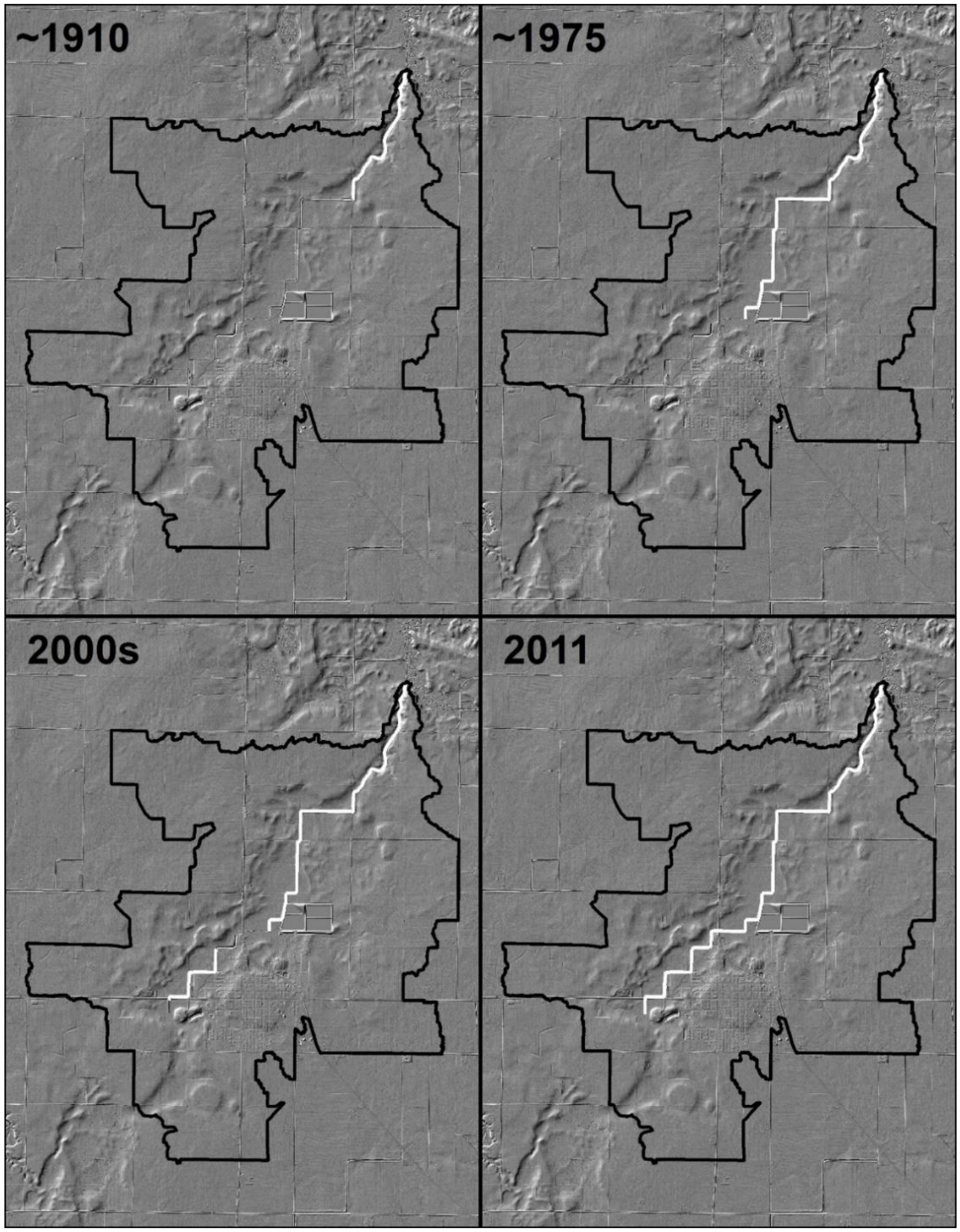


Figure 2.3. Extension of the County Ditch 57 watershed, as shown by channel length, from ~1910 to the present (Morrison, 2013; ISG, 2015a; Brandel, 2017). The original channel drained a wetland that was noted by the original surveyors in the region.

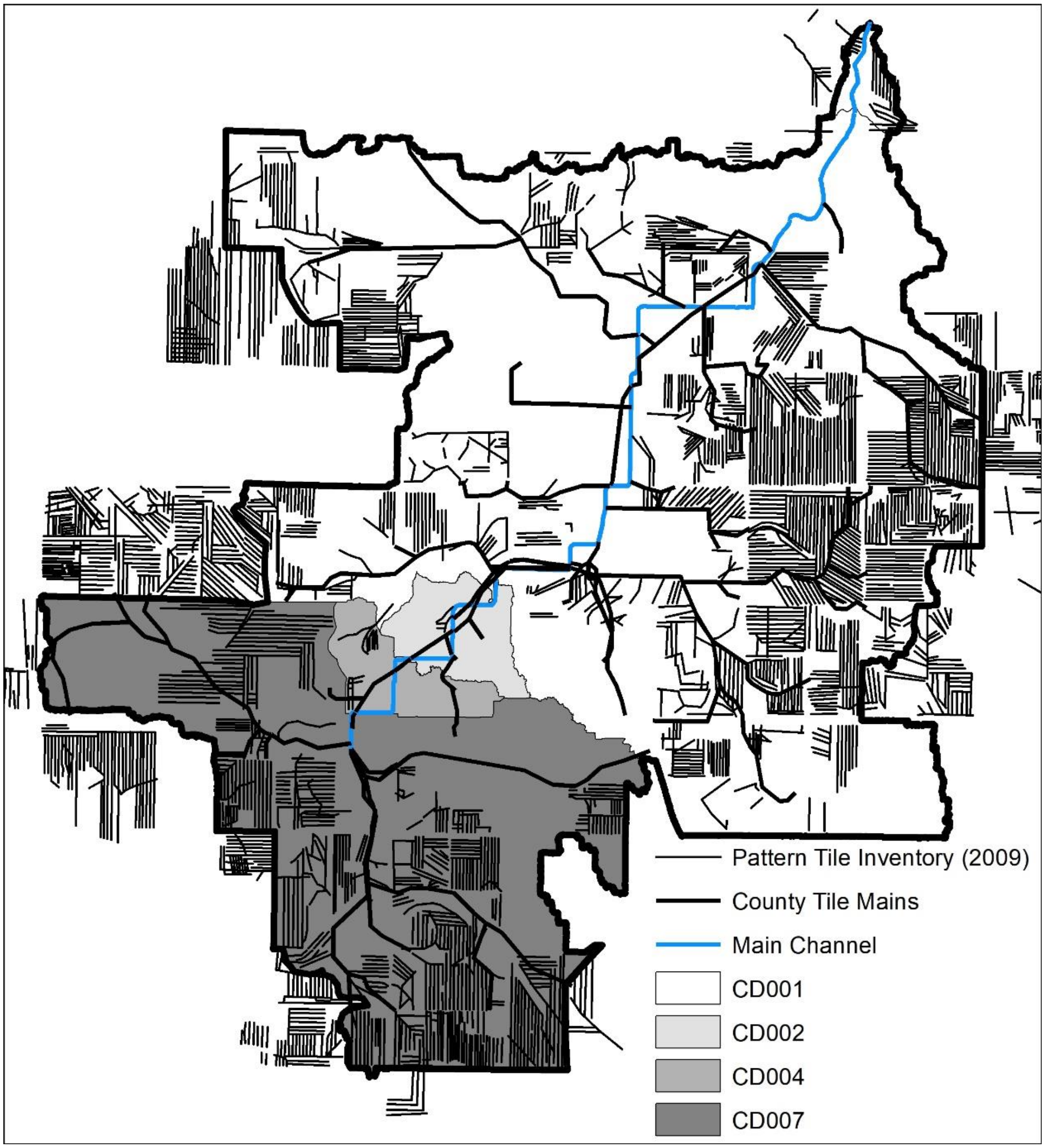


Figure 2.4. Tile map of County Ditch 57. The pattern tile inventory was conducted in 2009 by the MNSU Water Resources Center. Inventory created from aerial imagery, LiDAR, and personal communication.

2.2.3 County Ditch 57 History (2007-2014)

From 2007 to 2014 the Mankato-based engineering firm I+S Group (ISG) handled development, management, and monitoring of the County Ditch 57 watershed. In 2007, in response to decaying and failing infrastructure and significant flooding issues, landowners approached the Blue Earth County Ditch Authority to address their needs. Improvements needed to include changes in the upstream (southern) regions of the watershed to better mitigate flooding while not overloading the capacity of the downstream (northeastern) regions (Morrison, 2013; ISG, 2015b; ISG, 2015a; Brandel, 2017). ISG conducted a feasibility study to determine what would be necessary to improve CD 57 so that all areas saw improvement. The final design included an open channel throughout the system, two surge ponds for added storage in the southern portion of the watershed, named the City Pond and the Klein Pond, the development of a two-stage ditch, buffer strips throughout the watershed, and upsizing many of the culverts throughout the watershed.

The chosen and implemented structural practices were opportunistically distributed within the watershed and included buffer strips, an oversteepened channel reach designed to quickly and efficiently move flow to the surge pond (Figure 1.20), a diversionary weir that channeled water into the surge pond (Klein Pond), which was installed alongside a wetland in a 1.21 hectare basin, a two-stage ditch, and a notched, rate control weir upstream of the mouth of the watershed. These structures were designed to reduce peak discharge while simultaneously reducing sediment and nutrient loads. The project was approved and was awarded a $485,000 grant through the Minnesota Environment and

Natural Resources Trust Fund. With further landowner contributions, funding sufficiently incorporated the desired storage and structural practices within the watershed. Without these funding sources the project would not have been cost effective enough to meet regulatory requirements for drainage projects (ISG, 2015a). Construction began in November 2010 beginning with the two-stage ditch, the over-steepened reach, grading the two storage ponds, constructing the rate control weir, seeding the buffer strips, installing the pipe under County Highway 22, and connecting the two open ditch segments (ISG 2015a). Heavy precipitation in the fall through the spring of 2010-2011 impeded progress, but the project was completed by December 2011.

The economic impact for each of the three main structural practices (Klein Pond, two-stage ditch, and rate-control weir) was recorded and reported in the final reports for the project (ISG, 2015b; ISG, 2015a). The total cost to construct the Klein Pond came to \$148,320, or \$4.57 per cubic meter of storage. The pond can store 32,440 m^3 of water and 4,320 m^3 of sediment. The incremental cost for the two-stage ditch totaled \$26,920, or \$58.22 extra per meter, relative to a conventional ditch construction project (Figure 1.20). The two-stage ditch extends 430 m and has the capacity to store 1,357 m^3 of sediment. The rate control weir near the mouth of the watershed took \$12,500 to construct and led to additional storage capacity of 7,400 m^3 of water.

There were two different stages of monitoring between 2007 and 2014 which included monitoring before and after construction of the structural practices. The preliminary monitoring took place, intermittently, from March to October in 2009-2011. Many of these measurements and samples were recorded during base flow conditions and did not incorporate runoff event samples (ISG, 2015b). Post-installation monitoring was conducted in collaboration with the Minnesota State University, Mankato Department of Civil and Mechanical Engineering and the Department of Chemistry and Geology. Monitoring took place from March to October in 2012-2014. Base flow samples were recorded monthly during this time and increased sampling was carried out following precipitation events of 2.54 cm or greater.

Originally, results reported in 2014 suggested that removal rates comparative to pre-installation were positive (ISG, 2014). The Klein Pond was reported to reduce 77% of the peak discharge (when comparing peak discharge from the pond inlet to the pond outlet), 47% of the total suspended solids load, 63% of the phosphorus load, and 60% of the nitrogen load. This was equated to 195.10 metric tons ($3.68/kg) of total suspended solids, 0.73 metric tons ($974/kg) of phosphorus, and 40.82 metric tons ($17.20/kg) of nitrogen. The two-stage ditch was reportedly reducing 10.5% of the total suspended solids load, 8.0% of the phosphorus load, and 18.9% of the nitrogen load. The equated to 131.5 metric tons ($0.97/kg) of total suspended solids, 0.11 metric tons ($1179/kg) of phosphorus, and 2.72 metric tons ($49.38/kg) of nitrogen. Reductions for the rate control weir were not originally calculated. These numbers were revisited and revised after expressed concern from the Minnesota Department of Agriculture and the Minnesota Department of Natural Resources.

In the final reports (ISG, 2015b; ISG, 2015a), the Klein pond was attributed with annually reducing 28% of the average peak discharge, 25% of the total suspended solids load, 19% of the phosphorus load, and 23% of the nitrogen load. This equated to 104.3

metric tons of total suspended solids, 0.19 metric tons of phosphorus, and 10.4 metric tons of nitrogen. The two-stage ditch was attributed with reducing 5% of the total suspended solids load, 10% of the phosphorus load, and 4% of the nitrogen load. The rate control weir was attributed with annually reducing 6% of the average peak discharge, 6% of the total suspended solids load, 6% of the phosphorus load, and none of the nitrogen load. Loads (in mass) were not provided for the two-stage ditch or rate control weir.

2.2.4 County Ditch 57 History (2015-2018)

Following the initial 2014 reports from ISG regarding the efficiency of the structural practices within CD 57 further observation and research was requested by the Minnesota Department of Agriculture. The goal of this stage of research was to better characterize discharge and contaminant load tendencies within the watershed, while collecting continuous records of conditions throughout the watershed.

Most of the equipment installation took place during the 2015 monitoring season. Site selection followed recommendations outlined by the USGS in Wilde (2005). Naming conventions for the sites were formatted CD00X. Sites CD007, CD006, CD005, CD004, CD003, and CD002 were installed in summer of 2015 (Figure 2.5 and Figure 2.6; Table 2.1 and Table 2.2). CD007 was placed in a 1.22 m concrete culvert under State Highway 30, 237 m downstream of the upstream extent of the open channel. CD006 was placed in a 1.22 m concrete culvert that diverted water from the channel into the surge pond. This culvert is next to the diversionary weir that redirects water into the pond during low flow conditions and allows water pass over it during high flow conditions. CD005 was placed in submerged outlet of the surge pond. CD004 was immediately downstream of CD005 and was placed in a 1.52 m corrugated metal culvert just to the northeast of the surge pond basin. CD003 was installed in what had previously been a county tile main line at the end of the two-stage ditch. This line was thought to have contributed flow at the end of the two-stage ditch. After reviewing the discharge results measured for four and a half months over the 2015 and 2016 monitoring seasons it was determined that there were no significant contributions to flow at the end of the two-stage ditch from this previous county tile main and the site was removed in April 2016. CD002 was placed at the end of the two-stage ditch in a 1.37 m concrete culvert at the beginning of a 560 m subsurface stretch that flows to the east, underneath County Highway 22.

Equipment was installed in four other locations during the 2015 monitoring season. A Vaisala WXT520 weather and telemetry station and YSI 6600V2-4 Multiprobe were installed in the northwest corner of the city municipal ponds, named MUN001. In the 2016 monitoring season the YSI 6600V2-4 Multiprobe had to be removed for extensive repairs and it was not redeployed. Three Onset RG3 Rain Gauges were installed at various locations to provide precipitation measurements across the entirety of the watershed. These sites, named for nearby locations, were referred to as WFS001, TYS002, and NIE003 (Figure 2.5). WFS001 was placed in a parking lot belonging to the company WFS (later the Central Farm Service). This rain gauge was damaged beyond repair and removed following collision with an agricultural weed sprayer in the 2017 monitoring season. TYS002 was placed in the parking lot of the Tyson Fresh Meats hog barn in the northern extent of the watershed. NIE003 was placed on a post along a field boundary, and was named after the landowners.

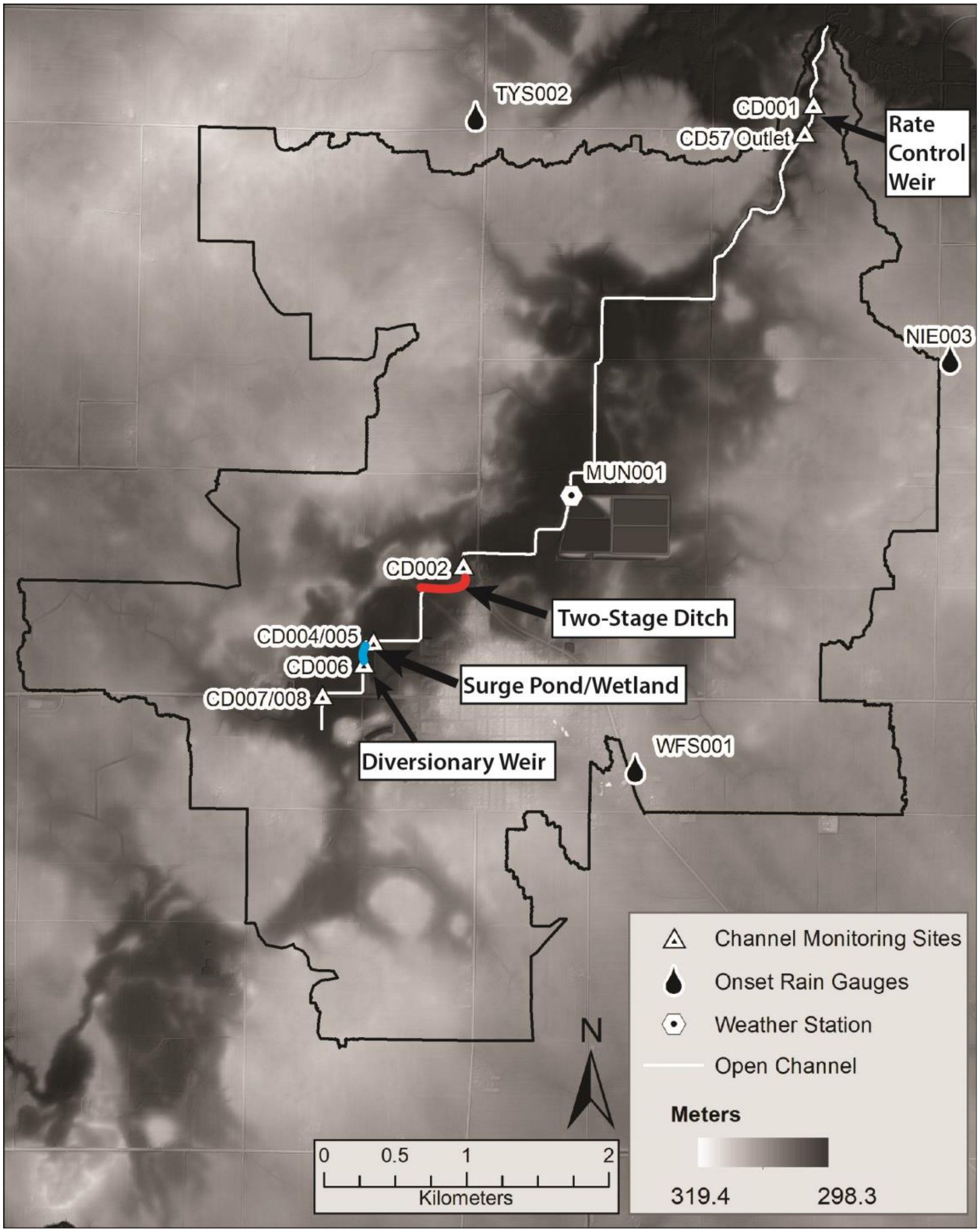


Figure 2.5. Digital elevation map and site map (pictures of sites in Figure 2.7) of the County Ditch 57 watershed. CD001-008 discharge and sampling sites within the ditch. Sites WFS001, TYS002, NIE003 refer to Onset RG3 rain gauging stations. Site MUN001 refers to the Nexsens weather station.

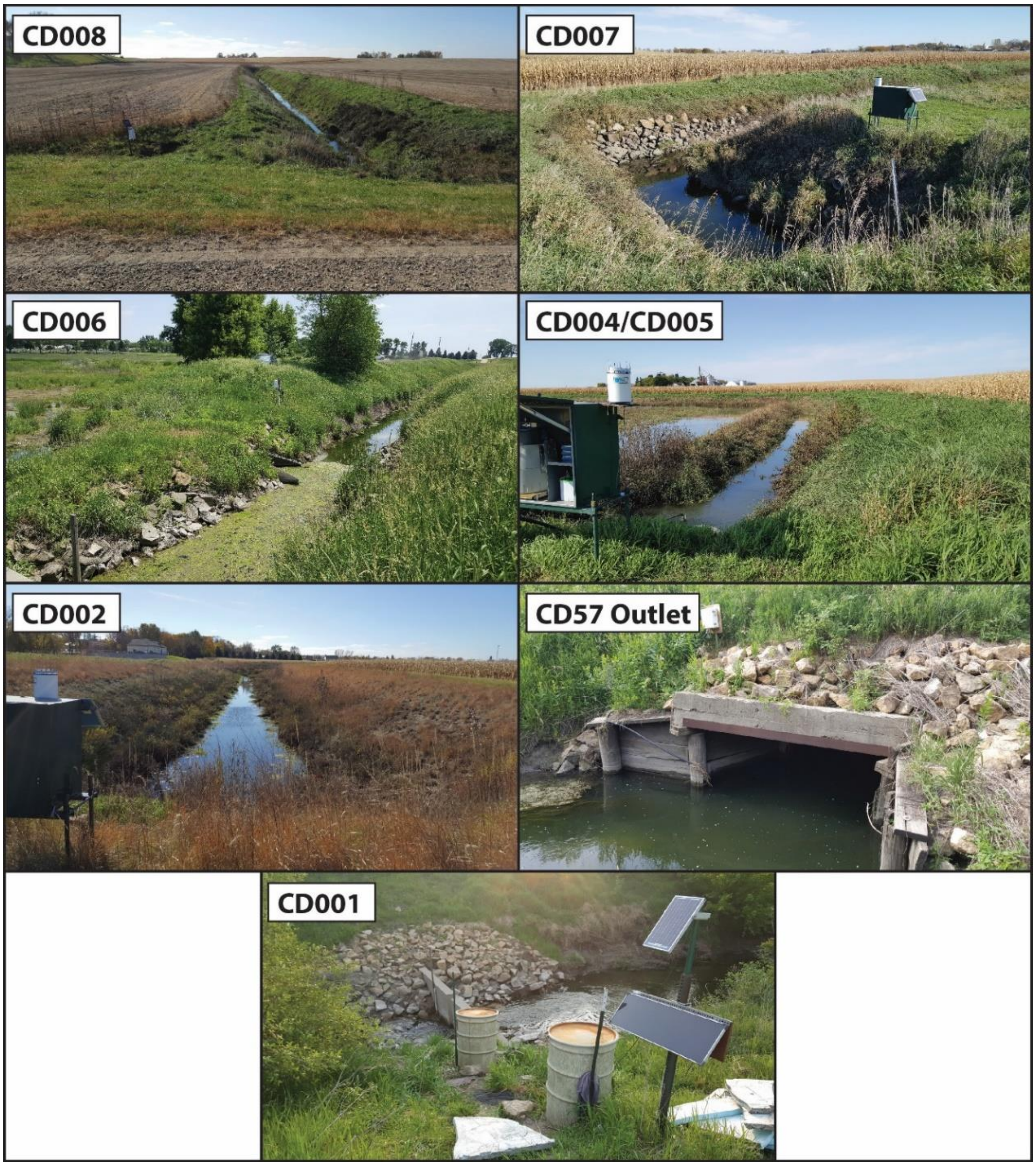


Figure 2.6. Pictures of each of the sites stationed in the ditch (see map in Figure 2.5). CD008 measures discharge from a 1m tile culvert. CD007 is stationed furthest upstream and measures discharge and water quality. CD006 monitors discharge at the surge basin inlet. CD004/005 monitor discharge and water quality from the surge basin. CD002 monitors discharge and water quality from the two-stage ditch. CD57 Outlet validates discharge measurements at the site immediately downstream (CD001). CD001 is the most downstream site in the watershed and monitors discharge and water quality leaving the watershed.

Table 2.1. Equipment distribution across each site.

Site	Isco 6712 Auto Sampler	Isco 750/2150 AV Probe	Isco 720 SPT	Isco 2105ci Modem	Isco 674 Rain Gauge	YSI 600 OMS V2 Sonde	Vaisala WXT520	YSI 6600V2-4 Sonde	Onset RG3 Rain Gauge
MUN001							X	X	
NIE003									X
TYS002									X
WFS001									X
CD008		X							
CD007	X	X			X	X			
CD006		X							
CD005		X							
CD004	X	X	X	X	X	X			
CD002	X	X		X	X				
CD001	X	X	X			X			
CD57 Outlet		X							

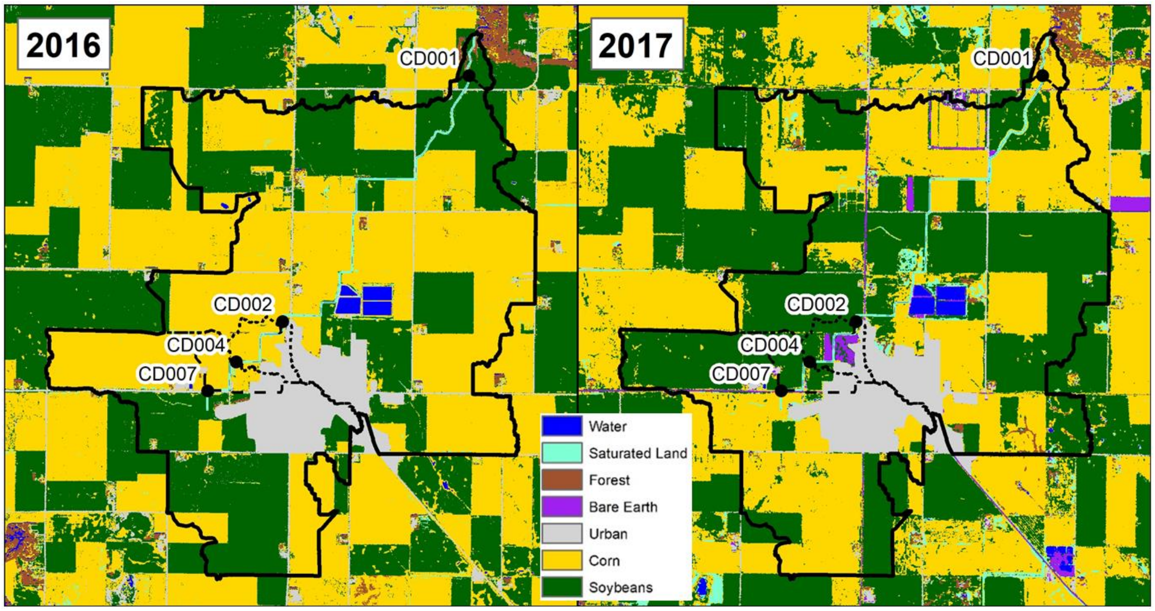
Table 2.2. Monitoring capabilities across each site.

Site	Water Sampling	Velocity (ft/s)	Stage (ft)	Flow Rate (cfs)	Water Temperature (°F)	Specific Conductivity(µS/cm)	Conductivity(µS/cm)	Turbidity (NTU)	Rainfall (in)	Remote Connectivity	pH	Chlorophyll (µg/L)	Dissolved Oxygen (µg/L)	Wind Direction	Wind Speed (mph)	Max Wind Speed (mph)	Relative Humidity (%)	Barometric Pressure (inHg)	PAR (µmol/s/m^2)
MUN001					X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
NIE003									X										
TYS002									X										
WFS001									X										
CD008		X	X	X	X														
CD007	X	X	X	X	X	X	X	X	X										
CD006		X	X	X	X														
CD005		X	X	X	X														
CD004	X	X	X	X	X	X	X	X	X	X									
CD002	X	X	X	X	X				X	X									
CD001	X	X	X	X	X	X	X	X											
CD57 Outlet		X	X	X	X														

Between the 2016 and 2017 monitoring seasons three additional sites were installed. CD001 was installed prior to the start of the 2016 monitoring season in the rate control weir, 620 m upstream from the confluence of CD 57 and the Cobb River. Following an interagency meeting it was determined that another location was required within a 0.91 m tile line that discharged immediately downstream of the CD007 monitoring equipment. Sufficient discharge was observed coming from this tile line, though it was supposed to have been inactive. This station, CD008, is on the south side of State Highway 30 and the tile line runs north, adjacent to the open channel of CD 57. Finally, a monitoring station was placed on the north side of County Road 4, 220 m upstream of CD001. This site was installed to develop better composite samples, following continued issues with intermittent velocity measurements at CD001. This site was installed in March 2017 and was called CD57 Outlet.

Throughout the 2016 and 2017 monitoring seasons, land use was determined by classifying RapidEye (5 m) satellite imagery. Corn and soybeans were the dominant land uses in both years, with more corn throughout the watershed in 2016 and a more even distribution of corn and soybeans in 2017 (Figure 2.7).

Some relatively larger events within the watershed compromised the integrity of certain channel reaches and required attention during the monitoring process. The oversteepened reach, for example, has seen significant bank sloughing related to the peaty nature of the soils leading to widespread instability and increased sediment transport into the ditch (Brandel, personal communication, 2017) (Figure 2.8). In 2015, the rate control weir was bypassed on the north side after eddying flow had cut around the weirs. Fabric, soil, and riprap were installed to secure the bank (Figure 2.9). Further concern, regarding the rate control weir, focused on improper angling of the weir's notch. In high discharge conditions, water directed through the notch flows directly into the downstream banks or eddies along the sides of the channel, resulting in bank undercutting and sluffing (Figure 2.10). Finally, in late September 2016, the largest measured runoff event during the MNSU monitoring project caused considerable flooding and damage throughout the CD 57 system. The main impact was on the downstream end of the box culvert that the CD57 Outlet site was later installed in. Backflow from the Cobb River undercut the banks on the north side of County Road 4. This led to the collapse of a significant portion of the aged wooden box culvert under the road (Figure 2.11). The downstream section of the culvert was completely replaced and the road was repaved.



	2016				2017			
	CD007	CD004	CD002	CD001	CD007	CD004	CD002	CD001
Watershed Size (ha)	685	732	786	2498	685	732	786	2498
Average Slope (Degrees)	1.71	1.78	1.86	1.75	1.71	1.78	1.86	1.75
Water (%)	0.1%	0.1%	0.1%	1.0%	0.1%	0.1%	0.1%	1.0%
Saturated Land (%)	0.7%	1.0%	1.3%	1.4%	0.6%	0.9%	1.3%	2.2%
Forest (%)	0.4%	0.4%	0.4%	0.3%	0.2%	0.2%	0.2%	0.6%
Bare Earth/Other (%)	0.0%	0.0%	0.0%	0.0%	0.9%	0.9%	2.1%	1.5%
Urban (%)	18.5%	18.8%	19.4%	11.1%	16.3%	16.6%	17.3%	9.7%
Corn (%)	35.8%	38.1%	39.8%	53.2%	45.5%	42.8%	40.2%	39.5%
Soybeans (%)	44.5%	41.7%	38.9%	33.0%	36.4%	38.5%	38.9%	45.5%

Figure 2.7. Land use and land cover differences between 2016 and 2017. Overall, 2016 had more corn within the watershed compared to 2017, which was more evenly corn-soybeans.

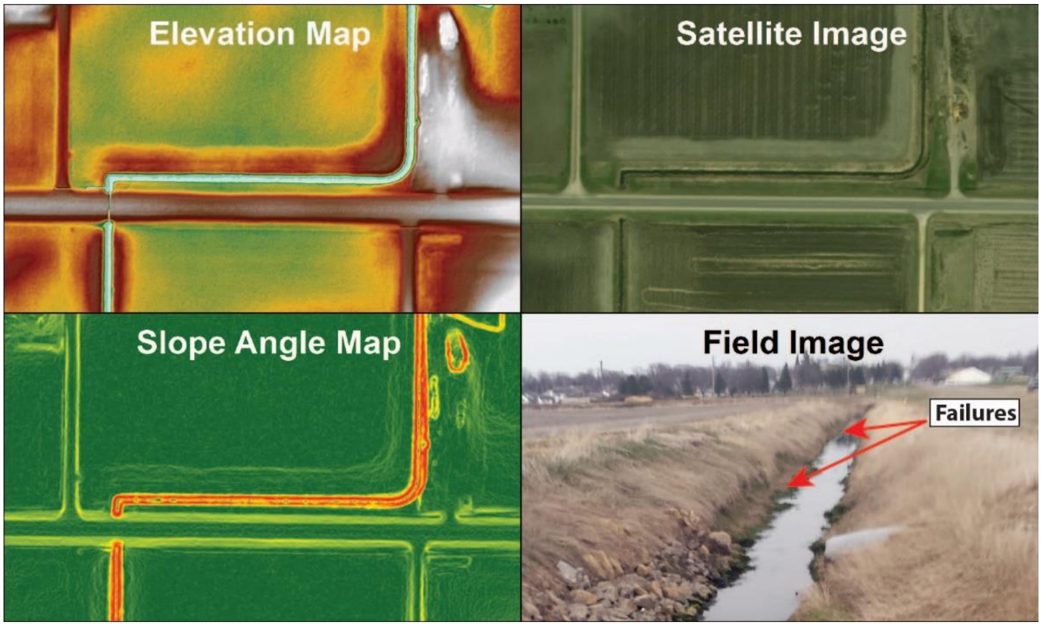


Figure 2.8. Maps showing the oversteepened channel reach within County Ditch 57. This region, between CD007 and CD006, sees increased erosion resulting from steeper banks and insufficient bank armoring.

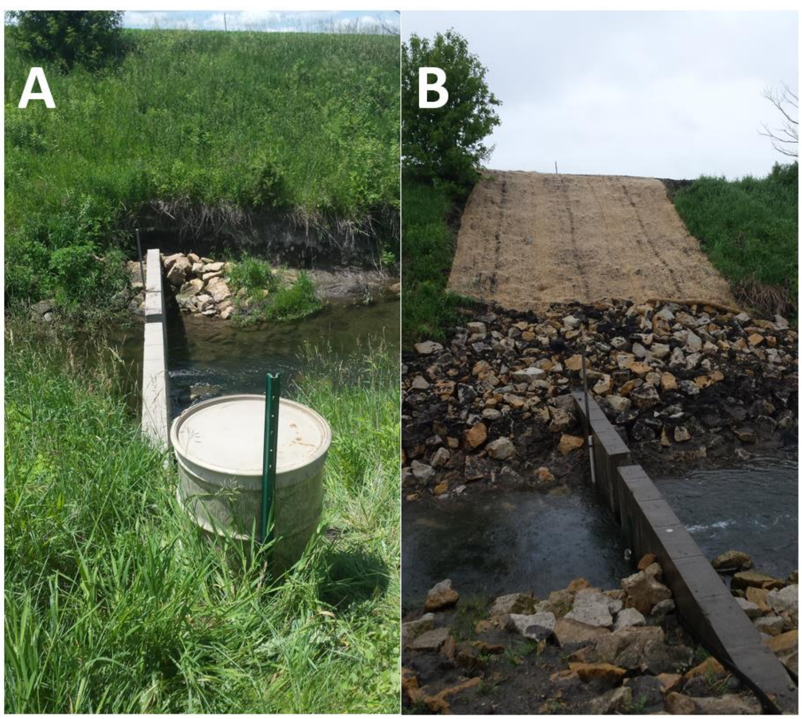


Figure 2.9. Pictures showing bank failure and repairs at CD001. The left image is from June 2015, while the right image is from May 2016.

Figure 2.10. Picture showing bank failure on both sides of the channel, immediately downstream of CD001. A slump can be seen circled on the left side of the image, while the right bank has experienced undercutting and is susceptible to slumping.

Figure 2.11. Picture (October 2016) showing failure of the box culvert under County Road 4, immediately upstream of CD001.

2.3 Methods

2.3.1 Precipitation and Temperature Data

Precipitation and temperature data were collected to better understand the relationship between precipitation and discharge within CD 57. Data were collected by a NexSens iSIC 3100 Data Logger with a Vaisala Weather Transmitter WXT520 rain gauge. This unit collects wind direction, wind speed, maximum wind speed, air temperature, relative humidity, barometric pressure, daily rainfall, rainfall intensity, and sunlight intensity. It was equipped with a YSI 6600 OMS-4 Multi-Parameter Water Quality Sonde for a brief period of time during the 2016 monitoring season and additionally measured water temperature, specific conductivity, conductivity, turbidity, pH, dissolved oxygen, oxygen redox potential, and chlorophyll. Further precipitation data were collected by three Teledyne Isco 674 Tipping Bucket Rain Gauges and three Onset RG3 Hobo Data-Logging Rain Gauges opportunistically dispersed throughout the watershed. The multitude of precipitation measuring sites was used to build isohyetal maps of rainfall throughout the watershed to account for discrepancies in discharge data from site to site, if needed.

2.3.2 Hydrologic Data

Hydrologic data needed to be acquired and accurately represented to calculate loads of the various measured parameters over runoff event and annual intervals. Water levels and velocity were recorded at continuous five minute intervals throughout the monitoring season. This was achieved through the use of Isco 2150 Area Velocity Modules (measuring level, velocity, and discharge), Isco 720 Submerged Probe Flow Modules (level only), and Isco 750 Area Velocity Flow Modules (level, velocity, and discharge). These data were validated through use of an Acoustic Doppler Current Profiler (ADCP) and wading rod nearly once a month by the Minnesota Department of Natural Resources and was supplemented between collections by MNSU personnel at the same locations through the use of a Marsh-McBirney Flo-Mate 2000 Portable Velocity Flow Meter and wading rod. In total, MNDNR ADCP measurements were collected five times in 2015, seven to eight times in 2016 (site-dependent), and six times in 2017, at sites CD001, CD004, and CD007. MNSU Flo-Mate measurements were collected seventeen to twenty-seven times in 2016 and eleven to fourteen times in 2017, at sites CD001, CD002, CD004, and CD007 (Appendix D and Appendix E). Measurements by MNSU varied in 2016 because of high stages and high velocity conditions making data collection hazardous. After each season, level and discharge data were then processed and corrected by a Minnesota Department of Agriculture hydrologist using the software Stream Trac (Forest Technology Services). The output of this data was used to generate loads for the various measured parameters.

In some cases, corrections had to be made to data that was too low quality to use. CD001 had particular issues with this because of highly variable velocities and the location of the probe in the notch of the weir. For 2016, CD001 had to be extrapolated off of data from CD002, scaled by upstream area, and fit to the FloMate recordings. When comparing the 2016 extrapolations to records from 2017 when the data did not need extrapolation the relationship of between average discharges at these two sites was proportional. Furthermore, corrections had to be made when flow rose over the top of rate control weir. These corrections were made by measuring flow across the top of the weir and within the notch of the weir and shifting the hydrographs appropriately.

2.3.3 Water Quality Sampling

Water quality samples were collected to use in combination with discharge data to create loads of the measured parameters. They were collected by a Teledyne Isco 6712 Full-Size Portable Sampler, equipped with twenty-four one liter bottles. The 6712 samplers were programmed to trigger after water levels rose by 10-20% of the current water level. Water levels were monitored with Isco 2150 Area Velocity Modules, Isco 720 Submerged Probe Flow Modules, and Isco 750 Area Velocity Flow Modules and were used to trigger the samplers to initiate sampling (Table 2.1 and Table 2.2). Once sampling initiated, the sampler purged the line, pulled one liter of water, purged the sample line again, and then moved the distributor arm of the sampler to the next bottle. This process repeated every two hours until the twenty-four bottles were filled. Once the program completed, samples were collected within one to two days and brought back to the Minnesota State University, Mankato laboratory to create a discharge-based composite sample. This sample typically represented the duration of the storm hydrograph until conditions returned to base flow. Base flow was approximated by employing the constant-slope method developed by Linsley Jr. et al. (1975) where:

$$D = 0.827A^{0.2} \qquad \text{Equation 1.}$$

Where

D is the number of days between the peak of the storm and the end of overland flow

A is the area of the watershed in square miles

This sample was then sent to certified laboratory, Minnesota Valley Testing Laboratory in New Ulm, MN, within two days of the program finishing, ensuring that the sample was refrigerated until it reached the laboratory to reduce any organic activity (Appendix A and Appendix B). Lab procedures followed USGS protocol 1-3765-85 and EPA protocols 365.1 and 353.2 for TSS, TP and PO_4, and NO_3+NO_2-N, respectively (USGS, 1985; EPA, 1993a; EPA, 1993b). The collection bottle for TP, PO_4, and NO_3+NO_2-N contained 1 ml of sulfuric acid (H_2SO_4) per 500 ml bottle. The rest of the composite sample was used to collect values for specific conductivity (Hach Sension156), dissolved oxygen (Oakton Waterproof Data Meter DO 300 Series), turbidity (Hach 2100P Turbidimeter), pH, and temperature (Oakton pH 6 Acorn series) in the MNSU laboratory. When base flow samples were collected, the Isco 6712 samplers were programmed to immediately fill two one liter bottles, to ensure that all samples were originating under the same sampling conditions. To ensure samples were not being cross contaminated and that the laboratory was consistent in their practices quality assurance samples in the form of duplicates and blanks often accompanied regular sample water (Mueller et al., 1997).

2.3.4 Calculating Loads

After discharge data were finalized for each season it was combined with concentration results to generate approximate loads for each event or for base flow conditions (Appendix D). This was accomplished through the use of a spreadsheet created by the Minnesota Department of Agriculture to generate composite sample loads.

This spreadsheet converted discharge to liters and then multiplied the liters by the parameter concentration (in mg/L) to determine the load of the entire five minute interval. Then, this load was summed to generate a cumulative load for each event, month, or year.

In some instances, it was necessary to fill gaps in data because of equipment malfunctions or improper trigger levels. In the case of base flow conditions, preceding and succeeding base flow concentrations were averaged and input into the load model. Gaps in runoff events were most prominent at sites CD002 and CD001. To develop load ranges that accurately represented in situ conditions a number of approaches were utilized to create an acceptable range. One method compared the cumulative discharge of the event to the total calculated load at the site where the gap existed to develop a best fit relationship. The next two methods used sites CD004 and CD007 to scale their loads to CD002 and CD001, based on discharge. Finally, where possible, a relationship between turbidity and flow-weighted mean concentrations for total suspended solids was developed. This relationship was then used to generate total suspended solids loads based on turbidity readings gathered every fifteen minutes. To ensure that the loads used were accurately representing potential loads, ranges were used in the case of missed runoff events. The minimum and maximum estimates were selected if they fell within one and a half times the interquartile range. The interquartile range was used, as it is a smaller constraint than using the first standard deviation. In larger events, where the estimate fell outside of one and a half times the interquartile range, but within the first standard deviation, the number was used, but noted. This generated annual estimates to compare loads between all sites.

2.3.5 Uncertainty and Possible Errors

Uncertainty and error was considered across the sampling techniques, lab results, and load calculations, to better characterize a range of loads that were possible. Possible error was first calculated for discharge for the final hydrographs compared to the ADCP and Marsh-McBirney FloMate field measurements. Sample duplicates across all sites were then used to determine a range of error for each of the parameters. Minimum and maximum discharges and concentrations were then calculated based on the possible error within the measurement. Finally, loads were calculated using the minimum and maximum values to determine the range of error for each load at each site (Table 2.3). The noticeable higher error ranges from CD001 are based in the discharge error range. Discharge here was collected in an open channel, as opposed to a concrete culvert. Elevated error of total phosphorus and orthophosphate was generated by one duplicate sample that had an elevated total phosphorus and orthophosphate concentration. However, total suspended solids and nitrate+nitrite as nitrogen matched very well within the same sample as the elevated total phosphorus so the values did not seem to be errant.

Table 2.3. Average error calculated from minimum and maximum error ranges of discharge and concentrations, also the percentage of discharge represented by the running autosampler at each site, compared to the total event discharge.

	TSS Avg Load Error	TP Avg Load Error	PO4 Avg Load Error	NO3+NO2 as N Avg Load Error	Percent of Sampled Event Discharge
CD007	±3.26%	±7.47%	±7.47%	±2.33%	87.86%
CD004	±10.16%	±14.37%	±14.37%	±9.23%	77.02%
CD002	±6.01%	±10.22%	±10.22%	±2.66%	61.58%
CD001	±21.49%	±25.70%	±25.70%	±10.35%	45.99%

Finally, cumulative discharge during when the samplers were running was compared to overall event discharge to determine where issues in misrepresented concentrations may exist (Table 2.3). Overall, the samplers at CD007 and CD004 best represented the reported concentrations, representing 87.86% and 77.02%, respectively, of the discharge from all monitored runoff events. Equipment malfunctions/damage at CD002 and CD001 resulted in samplers at those sites representing the least amount of overall storm runoff (61.58% and 45.99%, respectively).

2.3.6 Principal Component Analysis

Principal component analysis is a method of statistical analysis that attempts to simplify complex datasets by developing trends or “components” within the data (Lever et al., 2017). The goal of the analysis is to extract variables that most accurately describe differences between values to provide a list of variables that are impacting the dataset the most. In the CD 57 watershed, principal component analysis was utilized to identify how various factors within the watershed were influencing discharge and loads. Data should be selected so that it did not overlap with other variables. Primary outputs include a correlation matrix, table showing total variance explained by the model, component matrix, and rotated component matrix. The correlation matrix contains Pearson correlation coefficients (r) values that describes the linear relationship between two datasets. The total variance explained table provides eigenvalues, which describe the variance explained by the newly developed components. The component matrix shows how well each variable fits the generated component (trend) in the data. Finally, the rotated component matrix is a final correction that rotates the axes to better fit and explain the trends.

Three different principal component analyses were conducted for this study and were modeled after Meshram and Sharma (2017). The first compared sampleshed size, total discharge, total rainfall, average slope, urban land cover, corn coverage, soybean coverage, and the amount of C/D soils for the entire monitoring period. The second compared peak discharge, total rainfall, sampleshed size, urban land cover, corn coverage, soybean coverage, total suspended solid loads, and nitrate+nitrite as nitrogen loads on an event basis, between the months of July through September for 2016 and 2017. This timespan was selected because corn and soybean vegetation was near or at full canopy coverage by July and crops were not harvested by the end of September, providing a much larger sample size to compare (n=68). The third analysis examined total suspended solid and nitrate+nitrite as nitrogen load differences between upstream and downstream sampling stations, unique watershed size (not overlapping or accumulating with other samplesheds), peak discharge, total rainfall by event, and rainfall intensity by event. This final analysis was conducted to isolate values based on exclusive sampleshed characteristics.

2.4 Results

2.4.1 Precipitation and Temperature Data

The 2016 and 2017 monitoring years provided two very different sampling seasons to assess. In terms of temperature, minimum and average monthly temperatures were warmer than the 1981-2010 climate normals for both 2016 and 2017, while maximum monthly temperatures were only marginally higher in 2016 and cooler in 2017 (Table 2.4) (NOAA, 2018). Precipitation was recorded across seven different locations dispersed throughout the watershed or on the edge of the watershed. Monthly measurements were compared to 1981-2010 climate normal averages and totals gathered by the Minnesota State Climatology Office (MSCO, 2018; NOAA, 2018). Values from the Minnesota State Climatology Office were generated through the interpolation of a network of professional and certified amateur precipitation collection stations (MSCO, 2018). Values from rain gauges stationed throughout the CD 57 watershed were averaged across all active sites (Table 2.4 and Figures 2.12-2.14).

For the first half of the 2016 monitoring season (March-June) the CD 57 watershed experienced climate normal conditions, based on the 1981-2010 climate data and all other comparisons (Table 2.4) (MSCO, 2018; NOAA, 2018). However, the remainder of the monitoring seasons (July-October) saw totals doubling climate normals for those months (Table 2.4). Six different storms brought average rainfall totals of over 40 mm, while a late September storm averaged 95 mm across the watershed, with some stations recording as much as 105 mm of rainfall. This September storm brought the largest single total for an event during both monitoring seasons. A series of mid-August storms recorded the highest rainfall intensities over the duration of the project, with an average of 24 mm of rainfall in approximately 30 minutes and then another 16 mm in approximately 30 minutes, with average rainfall intensities of 48.6 mm/hr and 24.57 mm/hr, respectively.

The 2017 monitoring season more closely resembled climate normal conditions in terms of total precipitation during the monitoring months, but monthly totals exhibited some differences. Rainfall measuring began at the beginning of April for most of the CD 57 watershed. Rainfall totals closely compared to the 1981-2010 rainfall averages from April through August (MSCO, 2018; NOAA, 2018). September rainfall totals were 20-30 mm below average conditions, while October rainfall totals were 90-130 mm above average (Table 2.4) (MSCO, 2018; NOAA, 2018). The 2016 monitoring season exceeded rainfall totals of the 2017 season by up to 335 mm (MSCO, 2018).

Table 2.4. Observed monthly temperatures and precipitation averages for Mapleton, MN with 1981-2010 climate normal averages for Mankato, MN.

	1981-2010 Minimum Temp Mankato (°C)	2016 Minimum Temp Mapleton (°C)	2017 Minimum Temp Mapleton (°C)	1981-2010 Average Temp Mankato (°C)	2016 Average Temp Mapleton (°C)	2017 Average Temp Mapleton (°C)	1981-2010 Maximum Temp Mankato (°C)	2016 Maximum Temp Mapleton (°C)	2017 Maximum Temp Mapleton (°C)
March	-5.6	-0.3	-4.5	-0.2	3.9	0.0	5.3	8.4	4.0
April	1.4	3.9	3.9	7.9	8.8	9.1	14.4	13.8	14.0
May	8.2	9.3	7.9	14.7	15.4	14.1	21.2	20.8	19.5
June	13.7	15.2	14.0	20.0	21.0	20.8	26.3	26.7	26.7
July	16.4	16.8	15.9	22.3	21.8	22.0	28.2	26.5	27.2
August	15.2	15.4	12.9	21.1	20.6	18.2	26.9	25.7	23.0
September	9.6	12.8	11.7	16.1	17.6	17.8	22.7	23.0	23.9
October	2.7	5.2	4.4	9.1	10.6	9.5	15.5	16.0	14.6
Average	**7.7**	**9.8**	**8.3**	**13.9**	**15.0**	**13.9**	**20.1**	**20.1**	**19.1**

	1981-2010 Rainfall Mankato (mm)	2016 Rainfall Mapleton (Averages) (mm)	2016 Rainfall Mapleton (MSCO) (mm)	2016 Rainfall Mapleton (NexSens) (mm)	2017 Rainfall Mapleton (Averages) (mm)	2017 Rainfall Mapleton (MSCO) (mm)	2017 Rainfall Mapleton (NexSens) (mm)
March	49.8	50.7	59.9	71.8		36.8	
April	77.7	69.5	74.9	104.4	79.2	76.7	
May	87.6	67.8	88.6	89.4	86.4	93.2	72.4
June	129.3	84.0	97.3	102.6	106.9	100.1	118.1
July	109.7	152.2	180.3	175.5	121.8	105.7	112.5
August	106.2	185.2	210.3	223.0	93.7	94.2	76.7
September	81.5	187.1	221.2	226.3	63.2	48.8	61.5
October	58.9	68.2	107.7	62.5	187.5	150.1	190.2
Total Rainfall	**700.8**	**864.7**	**1040.4**	**1055.6**	**738.6**	**705.6**	**631.4**

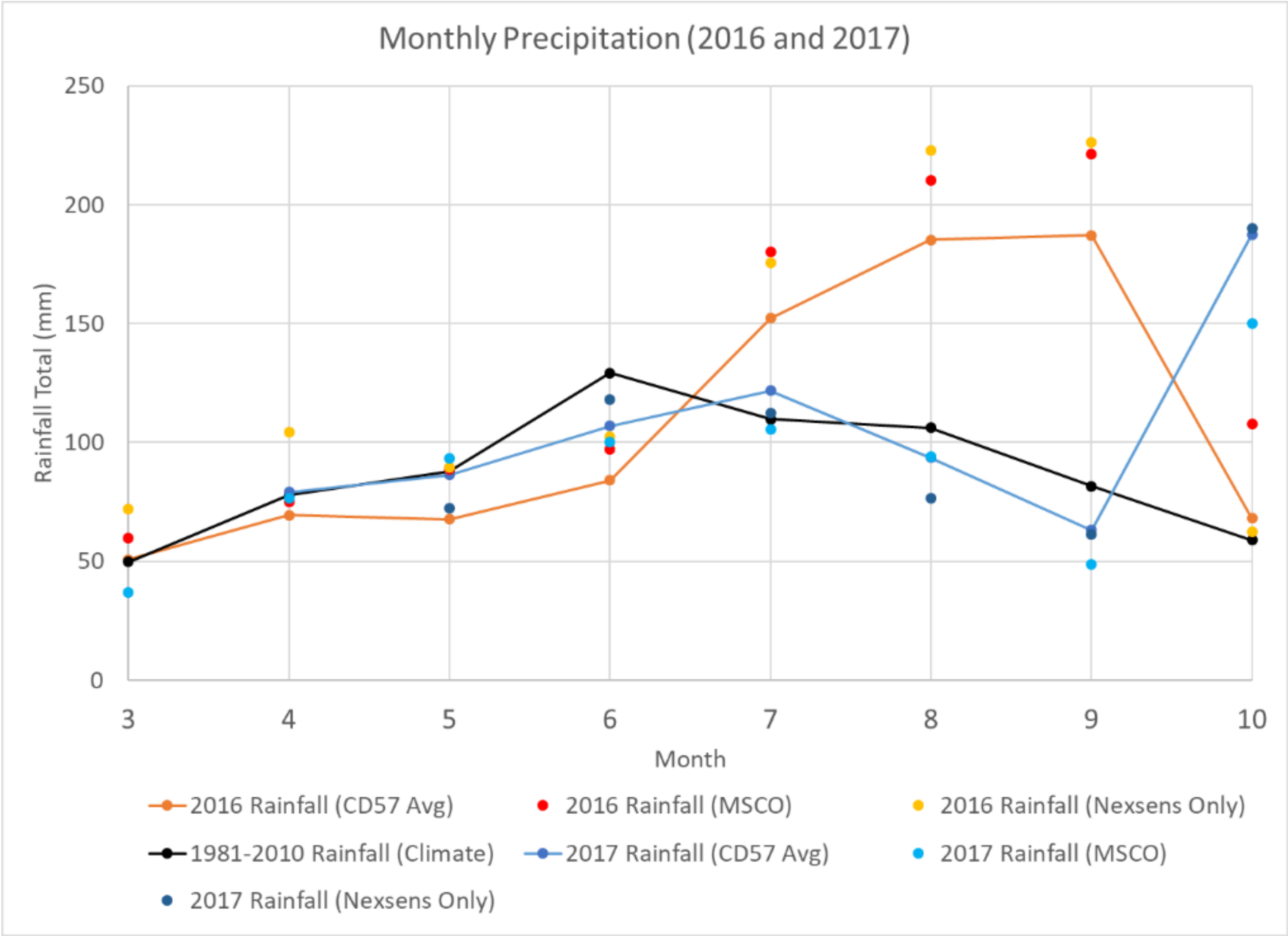


Figure 2.12. Monthly precipitation graph for 2016 and 2017, with climate normal data included.

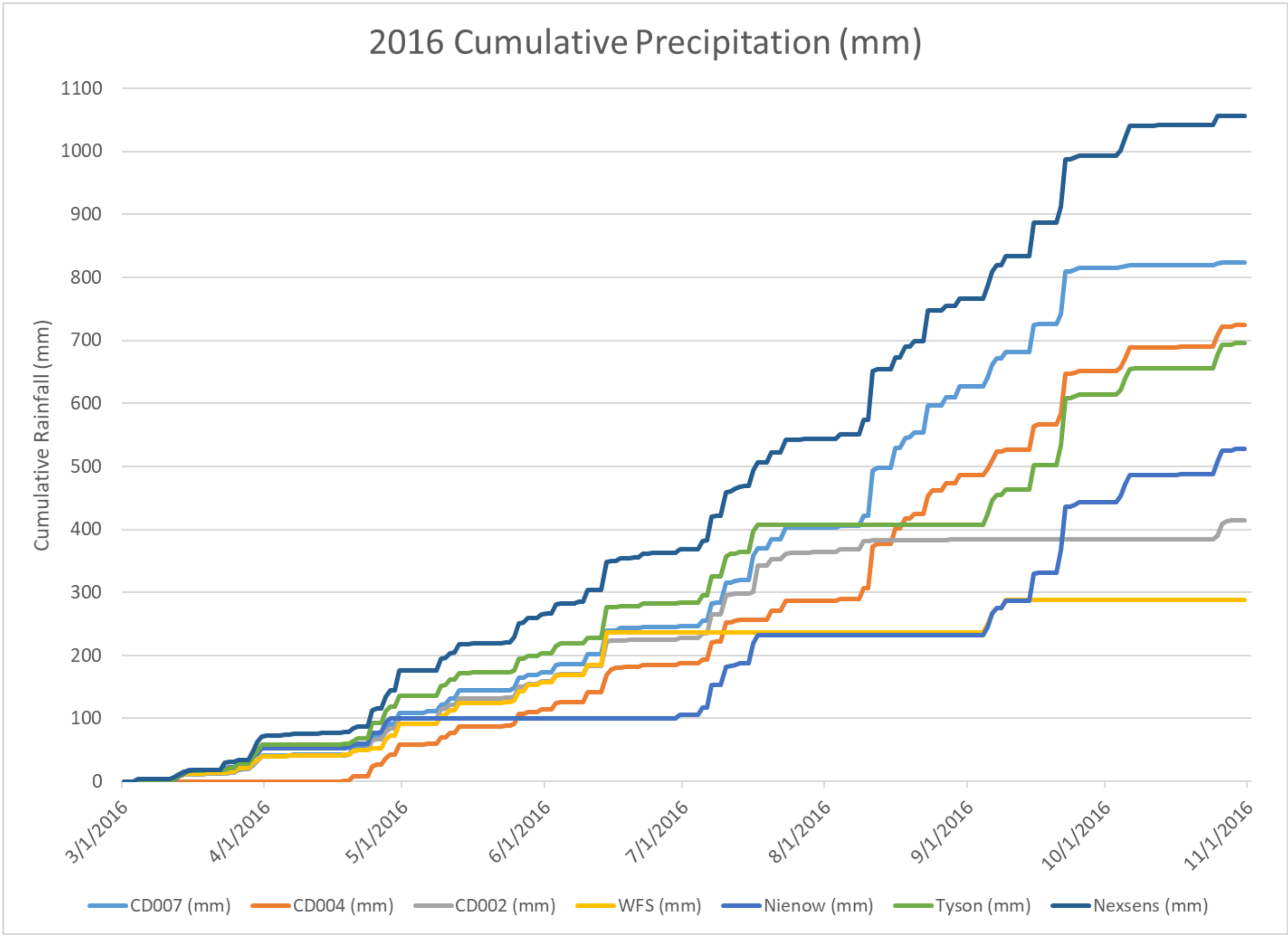


Figure 2.13. 2016 cumulative rainfall totals for each site in the CD 57 watershed.

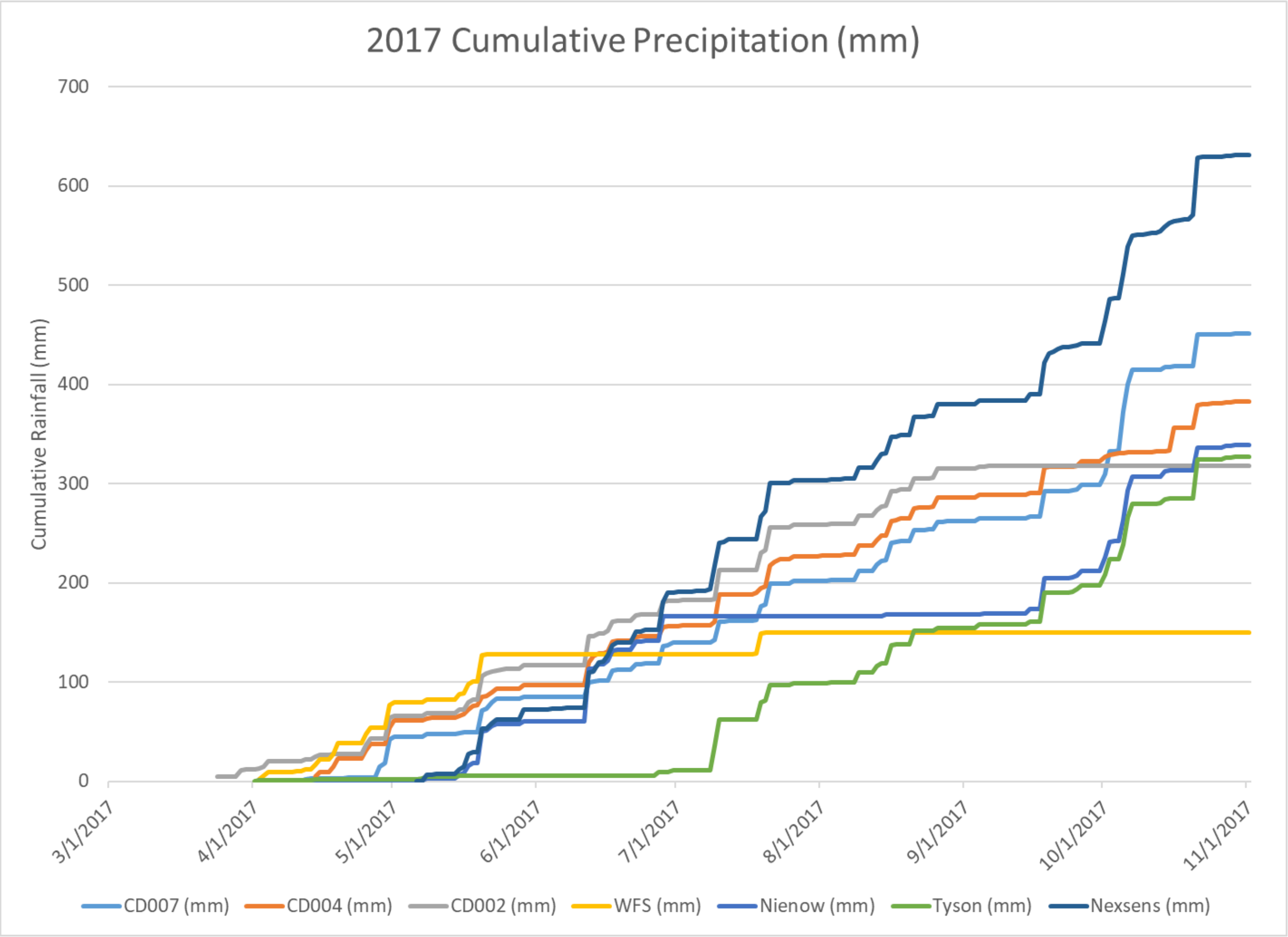


Figure 2.14. 2017 cumulative rainfall totals for each site in the CD 57 watershed.

2.4.2 Hydrologic Data

Monitored discharge for 2016 commenced in early March and continued until early November. This record captured all rainfall during that year except for a series of late November to early December storms totaling ~45 mm over a two and a half week period. Discharge totals from storms ranged by site from 7.4×10^6 liters at CD007, during a runoff event in mid-July, to 1.55×10^9 liters at CD001, during a late September runoff event (Table 2.5). The month of July, while it was the third highest month for rainfall totals that year, was the lowest month for discharge in 2016. September featured the largest storm total during both 2016 and 2017, the most precipitation during a single month, and the highest discharge totals for any month during the project (Table 2.5, Figure 2.15-22, and Figure 2.23).

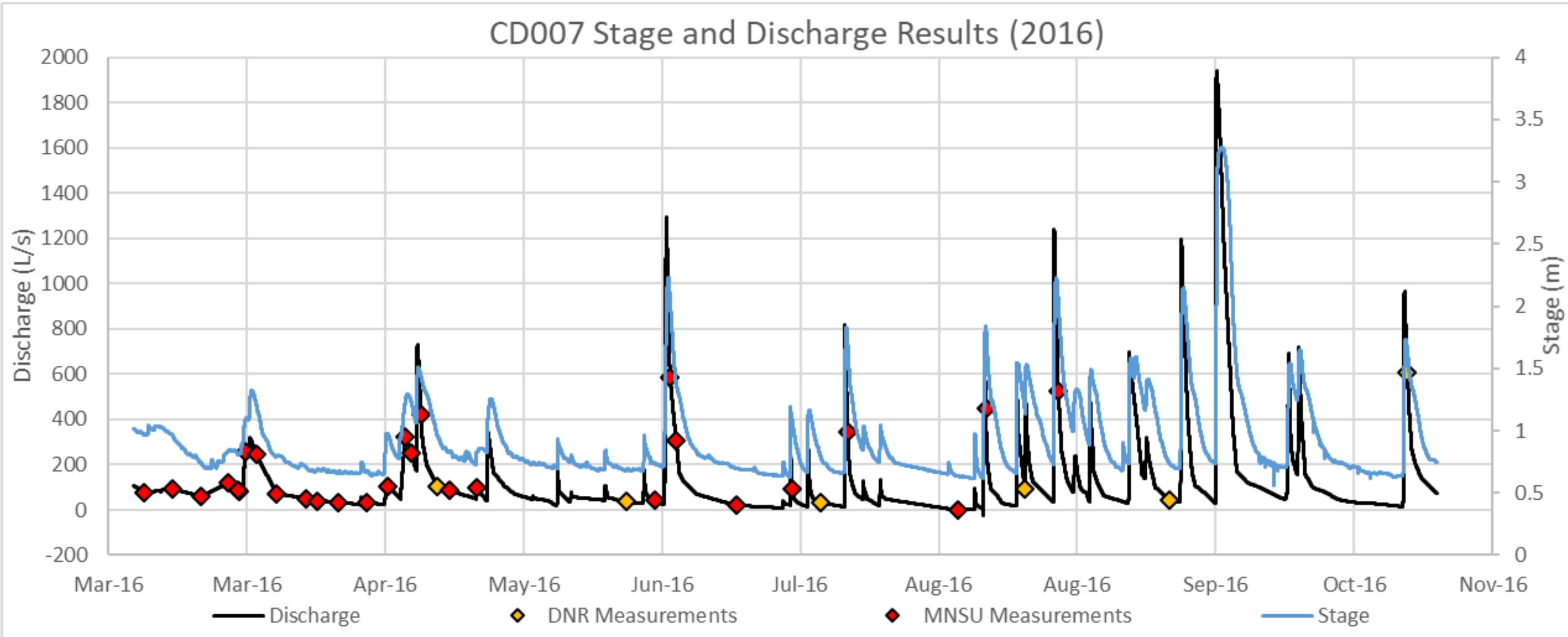


Figure 2.15. Stage and discharge hydrographs for CD007, the most upstream monitoring station, in 2016. The highest peak discharge at this site was recorded in late September (1,940 L/s).

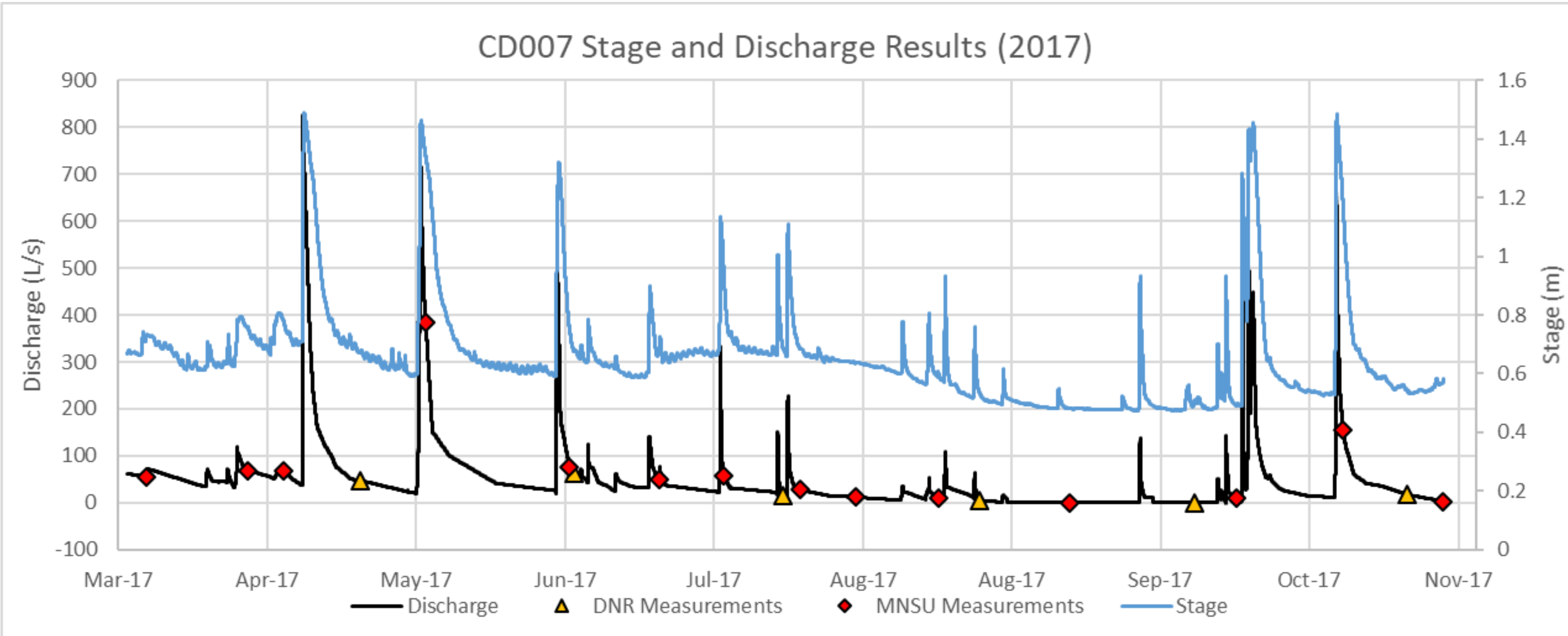


Figure 2.16. Stage and discharge hydrographs for CD007, the most upstream monitoring station, in 2017. In August and September, discharge dropped to 0 L/s. The highest peak discharge was recorded in late April (825 L/s)

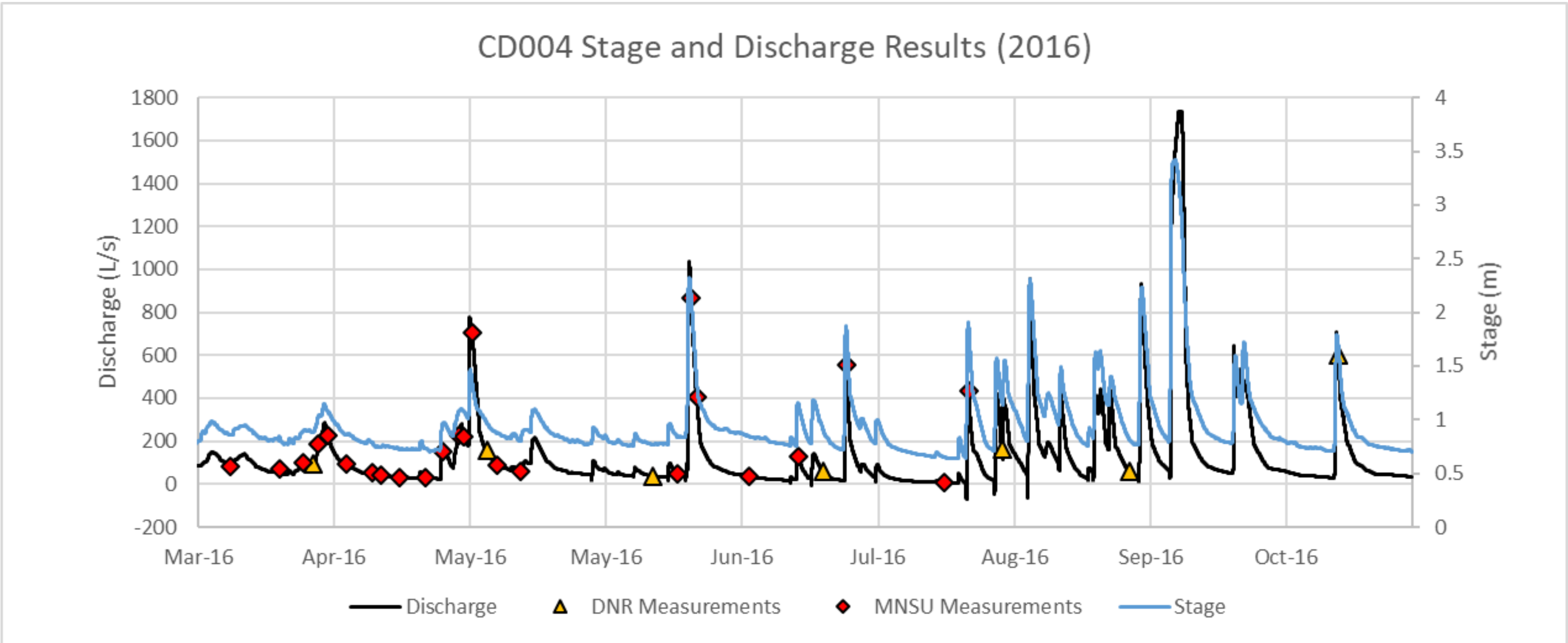


Figure 2.17. Stage and discharge hydrographs for CD004, at the downstream end of the surge basin, in 2016. The highest peak discharge was recorded in late September (1,736 L/s).

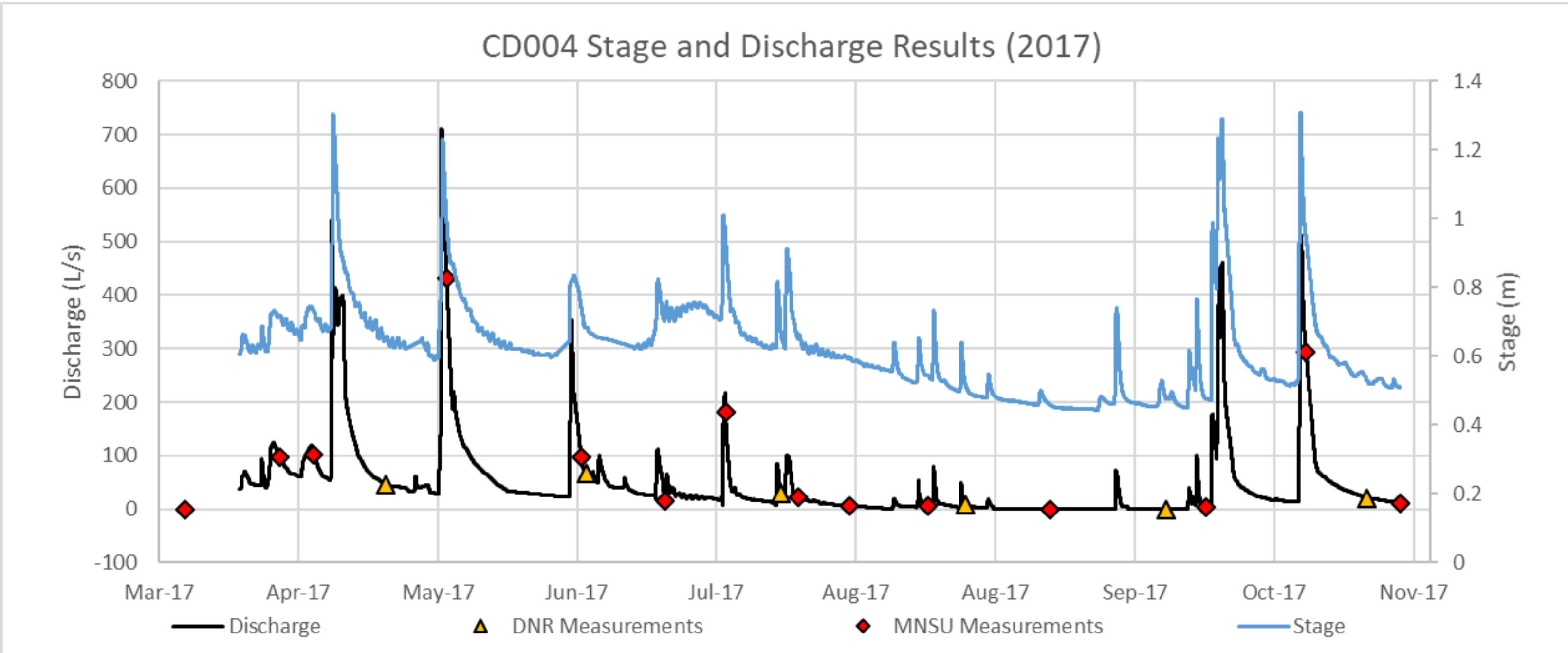


Figure 2.18. Stage and discharge hydrographs for CD004, at the downstream end of the surge basin, in 2017. In August and September, discharge dropped to 0 L/s. The highest peak discharge was recorded in mid-May (710 L/s)

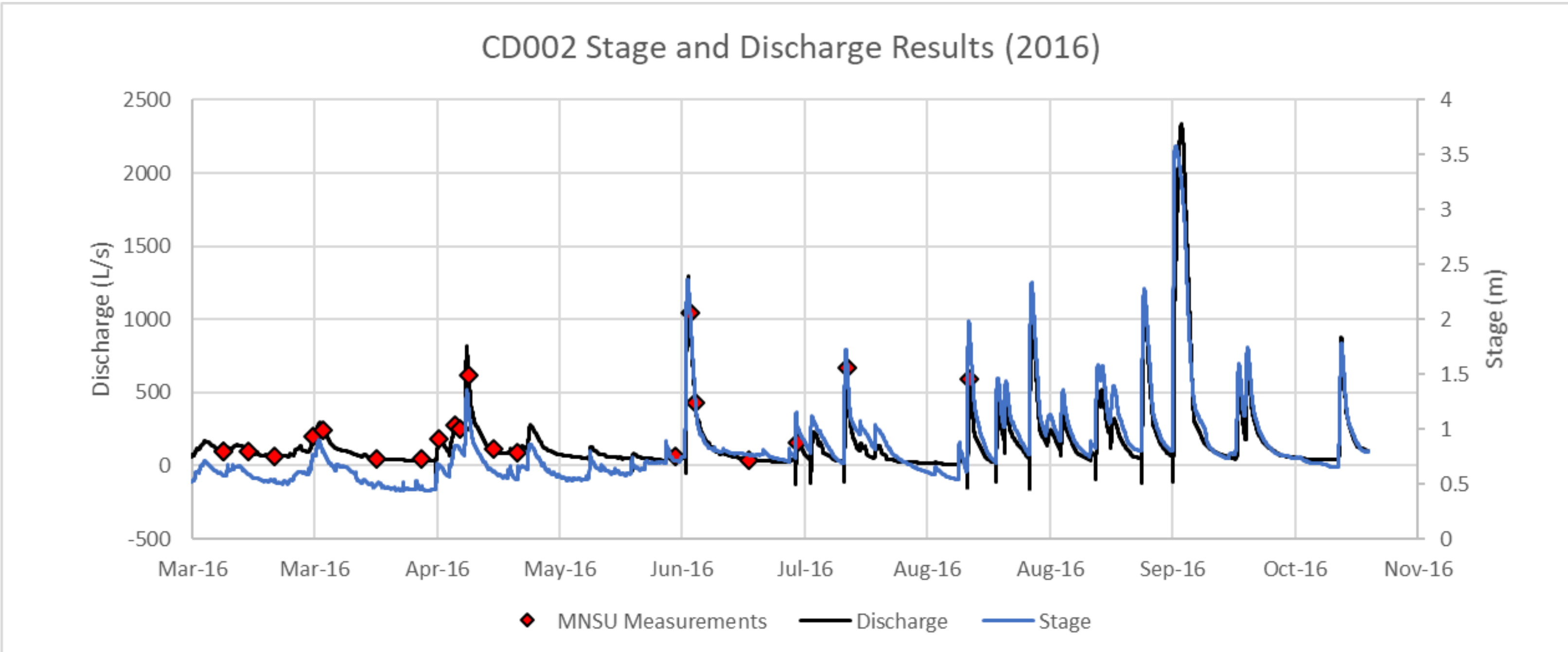


Figure 2.19. Stage and discharge hydrographs for CD002, at the downstream end of the two-stage ditch, in 2016. The highest peak discharge was recorded in late September (2,341 L/s).

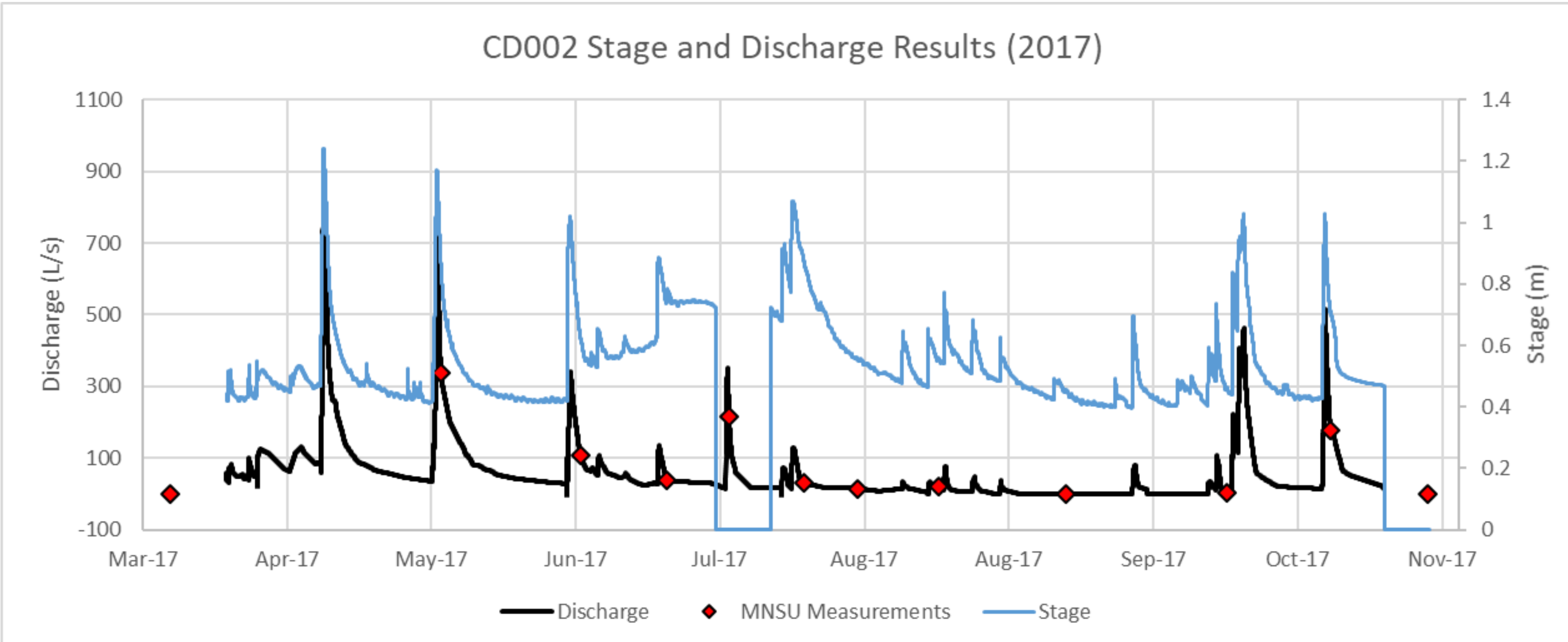


Figure 2.20. Stage and discharge hydrographs for CD002, at the downstream end of the two-stage ditch, in 2017. In August and September, discharge dropped to 0 L/s. The highest peak discharge was recorded in late April (868 L/s). This stage hydrograph features periods during which the area-velocity probe was damaged and can be seen near Jul-17.

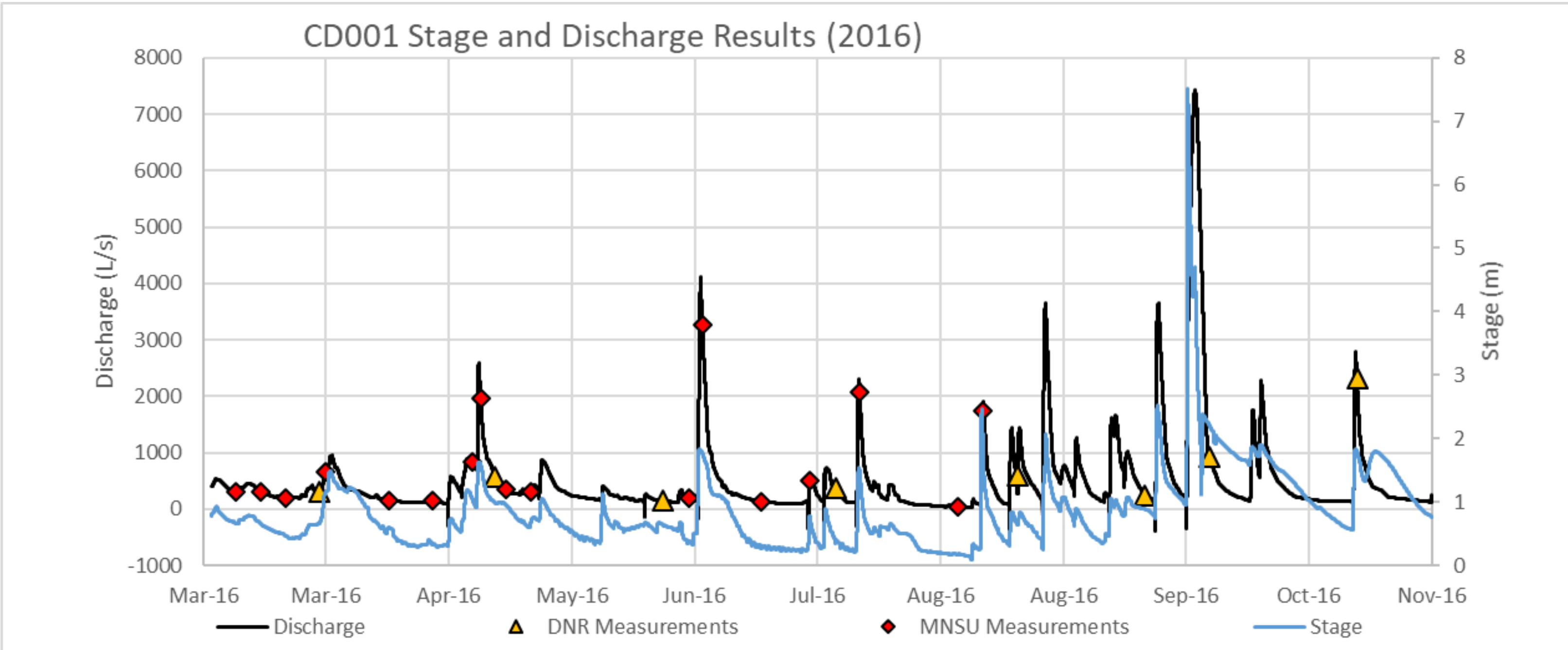


Figure 2.21. Stage and discharge hydrographs for CD001, at the rate control weir, in 2016. The highest peak discharge was recorded in late September (7,439 L/s).

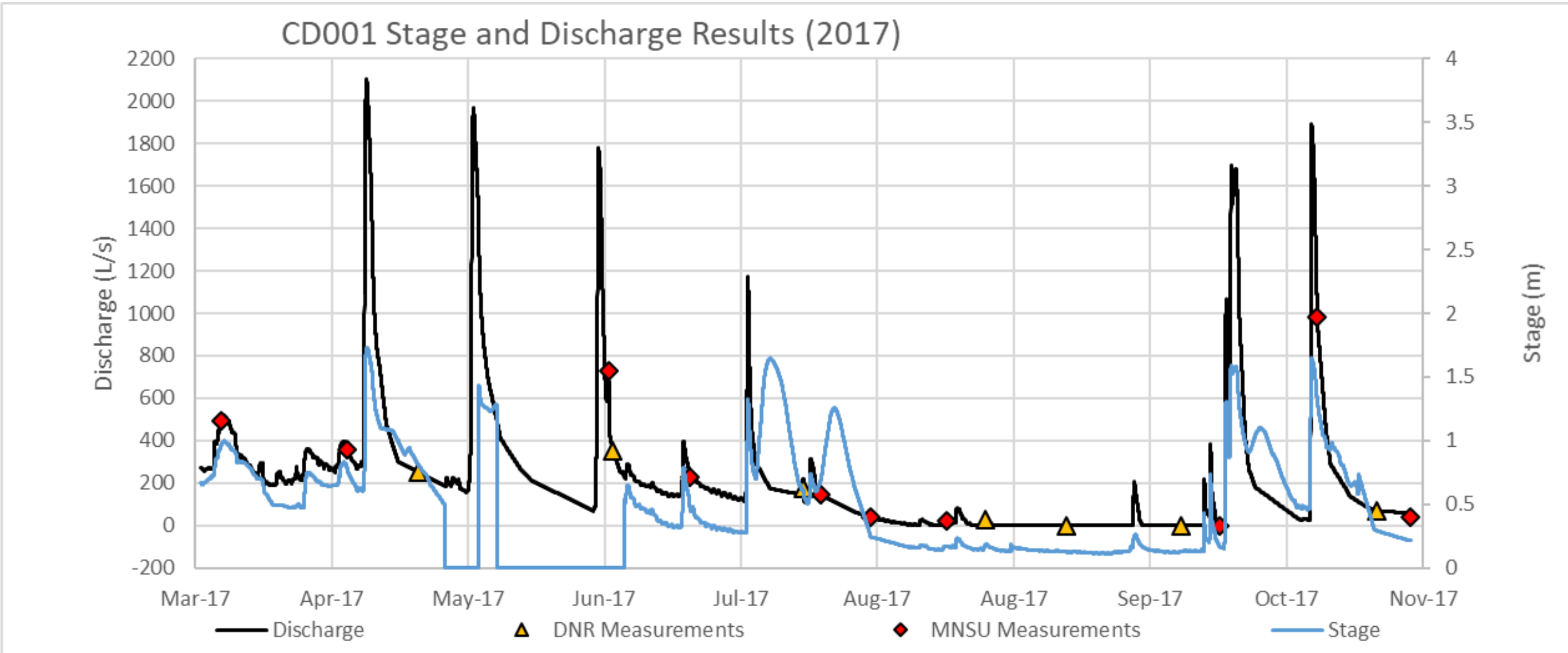


Figure 2.22. Stage and discharge hydrographs for CD001, at the rate control weir, in 2017. In August and September, discharge dropped to 0 L/s. The highest peak discharge was recorded in late April (2,105 L/s). This stage hydrograph features periods where the collection probe was damaged and level data was not collected (~May-June)

Peak discharge values for each event were recorded for each sampling location and compared to determine whether the structural practice could effectively reduce peak discharge (Figure 2.24, Table 2.5, and Table 2.6). In 2016, the surge basin exhibited the highest efficiency rates at reducing peak discharge below the rate of the upstream site 87% of the time (Figure 2.23). The surge basin also effectively delayed the peak from CD007 to CD004 in every runoff event by at least 2 hours and by an average of 9 hours (Table 2.5). Neither the two-stage ditch nor the rate control weir exhibited reduction rates below the upstream site. The two-stage ditch did delay peak rates ~70% of the time, by at least 2.5 hours. However, ~30% of the time, peak rates were measured in the two-stage ditch prior to the surge basin. Peak discharge ranged from 77 L/s, recorded at the downstream end of the surge basin in early June, to 7,439 L/s, interpolated at the rate control weir during late September.

Discharge monitoring started later in 2017 (between late March and early April) because of late season snowfall and below freezing temperatures (Table 2.6). Up to ~43 mm of rainfall was missed from March 1st to April 14th when the last equipment was installed. Discharge totals from storms ranged from 1.91×10^6 liters at CD007, during a runoff event in mid-August, to 2.94×10^8 liters at CD001, during a late April to early May runoff event. Monthly discharge was lowest for all sites in September, which also had the lowest rainfall totals, despite having the third lowest rainfall totals during the monitoring season.

Similar to the 2016 season, the surge basin effectively reduced peak discharge 88% of the time in 2017 (Table 2.6). It also achieved peak discharge delays by at least 0.42 hours and by an average of 3.33 hours. The two-stage ditch effectively reduced peak discharge 41% of the time, while prolonging the peak by at least 0.67 hours and an average of 1.01 hours. Peak discharge was lower at the rate control weir during one August event, while the peak was delayed 65% of the time by at least 0.08 hours and on average 2.42 hours. Peak discharge ranged from 34 L/s in the two-stage ditch in early October, to 2,105 L/s at the rate control weir at the end of April.

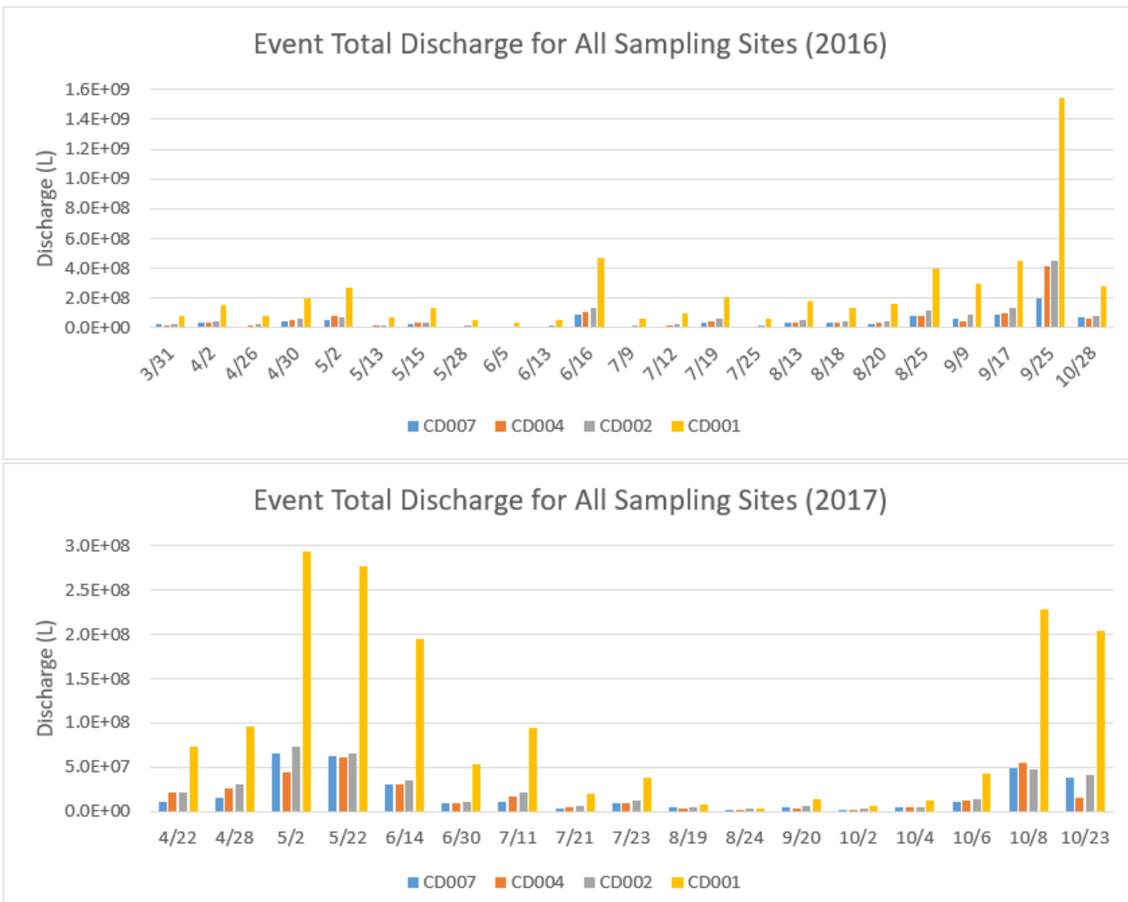


Figure 2.23. Cumulative discharge for all sites from 2016 and 2017. Typically, discharge increased downstream, but in some cases there was loss of discharge after a structural practice.

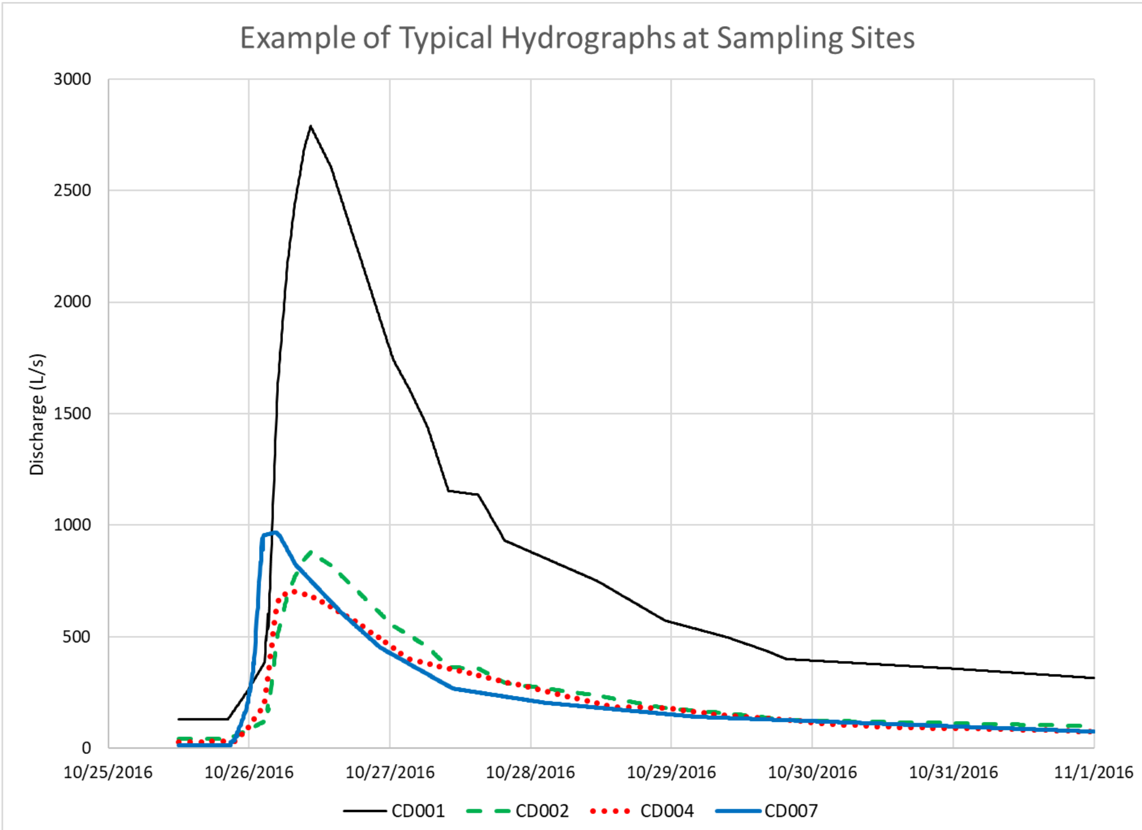


Figure 2.24. Example of typical hydrographs seen from the four water quality monitoring stations in County Ditch 57. This example comes from a late October storm in 2016. CD007, the site furthest upstream, feature flashy discharge. CD004, the site downstream of the surge basin, almost always saw a reduction and elongated peak. CD002, the site downstream of the two-stage ditch, typically saw an increase in discharge rates, but did not always exceed those seen at CD007. CD001, the site at the rate control weir, typically did not see an elongated peak, unless the Cobb River was controlling the local base level.

Table 2.5. Runoff event discharge parameters for the 2016 monitoring season. Peak delay calculations not available for CD001, given required extrapolation of data from CD002 to CD001. Shaded cells signify reductions.

Start Date	End Date	Average Rainfall (mm)	Average Rainfall Intensity (mm/hr)	004-007 Peak Delay (hr)	002-004 Peak Delay (hr)	007 Peak Q (lps)	004 Peak Q (lps)	002 Peak Q (lps)	001 Peak Q (lps)	007 Total Q (liters)	004 Total Q (liters)	002 Total Q (liters)	001 Total Q (liters)
3/29/2016	3/31/2016	16.72	1.32	7.50	-2.25	258	202	221	703	2.29E+07	1.67E+07	2.57E+07	7.95E+07
3/31/2016	4/2/2016	8.00	1.76	12.00	3.67	320	288	299	951	3.23E+07	3.81E+07	4.31E+07	1.55E+08
4/24/2016	4/26/2016	20.79	2.49	6.17	-5.92	109	157	180	572	1.30E+07	2.20E+07	2.27E+07	8.31E+07
4/27/2016	4/30/2016	16.29	1.98	14.33	2.83	323	279	289	920	4.34E+07	5.13E+07	6.33E+07	2.00E+08
4/30/2016	5/2/2016	19.22	1.45	2.00	3.25	732	777	818	2599	5.43E+07	8.19E+07	7.59E+07	2.70E+08
5/11/2016	5/13/2016	12.57	0.84	21.33	-0.75	103	110	136	431	9.03E+06	1.68E+07	2.09E+07	7.02E+07
5/13/2016	5/15/2016	11.35	3.03	19.83	-9.67	345	215	277	880	2.81E+07	3.46E+07	3.73E+07	1.33E+08
5/26/2016	5/28/2016	16.85	5.19	5.33	3.25	170	110	128	407	9.43E+06	1.13E+07	1.53E+07	5.57E+07
6/3/2016	6/5/2016	11.85	1.93	2.33	4.33	109	77	83	263	7.67E+06	7.96E+06	9.66E+06	3.57E+07
6/10/2016	6/13/2016	14.52	15.90	8.17	8.25	178	95	106	336	8.74E+06	1.02E+07	1.44E+07	5.11E+07
6/13/2016	6/16/2016	43.39	3.68	5.33	3.50	1296	1037	1294	4111	9.41E+07	1.06E+08	1.33E+08	4.71E+08
7/7/2016	7/9/2016	30.35	8.74	7.42	0.00	392	128	158	502	1.12E+07	1.26E+07	1.74E+07	6.25E+07
7/10/2016	7/12/2016	32.17	4.75	7.92	-1.92	264	141	232	738	1.30E+07	1.66E+07	2.63E+07	9.69E+07
7/17/2016	7/19/2016	43.69	8.12	8.00	1.83	821	577	723	2298	3.96E+07	4.43E+07	5.94E+07	2.06E+08
7/23/2016	7/25/2016	15.75	3.01	10.58	2.50	136	93	136	431	7.40E+06	9.92E+06	1.90E+07	6.67E+07
8/11/2016	8/13/2016	53.98	6.79	6.25	4.83	679	462	604	1919	3.36E+07	3.55E+07	5.28E+07	1.85E+08
8/17/2016	8/18/2016	24.30	48.60	11.92	-0.17	620	417	455	1447	3.42E+07	3.94E+07	4.10E+07	1.33E+08
8/18/2016	8/20/2016	16.43	24.57	0.33	10.25	486	403	453	1439	2.69E+07	3.50E+07	4.59E+07	1.60E+08
8/23/2016	8/25/2016	43.18	5.10	7.17	5.42	1240	957	1151	3659	7.75E+07	8.42E+07	1.17E+08	3.98E+08
9/6/2016	9/9/2016	21.51	8.03	2.00	28.08	697	519	521	1656	6.13E+07	4.31E+07	8.72E+07	2.97E+08
9/15/2016	9/17/2016	44.04	2.45	8.50	4.75	1195	935	1149	3651	9.33E+07	9.70E+07	1.31E+08	4.50E+08
9/22/2016	9/25/2016	95.05	7.50	52.00	-14.58	1940	1736	2341	7439	1.94E+08	4.14E+08	4.51E+08	1.55E+09
10/25/2016	10/28/2016	31.24	4.26	2.67	3.25	969	707	878	2790	7.22E+07	6.54E+07	8.00E+07	2.80E+08

Table 2.6. Runoff event discharge parameters for the 2017 monitoring season. Shaded cells signify reductions.

Start Date	End Date	Average Rainfall (mm)	Average Rainfall Intensity (mm/hr)	004-007 Peak Delay (hr)	002-004 Peak Delay (hr)	001-002 Peak Delay (hr)	007 Peak Q (lps)	004 Peak Q (lps)	002 Peak Q (lps)	001 Peak Q (lps)	007 Total Q (liters)	004 Total Q (liters)	002 Total Q (liters)	001 Total Q (liters)
04/19/17	04/22/17	5.14	0.82	15.42	-3.83	2.08	119	124	125	360	1.16E+07	2.09E+07	2.13E+07	7.39E+07
04/25/17	04/28/17	11.43	0.82	-11.08	3.92	-5.17	68	118	131	397	1.52E+07	2.54E+07	3.04E+07	9.53E+07
04/30/17	05/02/17	24.32	0.78	0.42	5.33	0.92	825	539	868	2105	6.54E+07	4.41E+07	7.29E+07	2.94E+08
05/19/17	05/22/17	26.88	1.21	1.83	6.08	-0.25	734	710	734	1967	6.25E+07	6.10E+07	6.51E+07	2.76E+08
06/11/17	06/14/17	32.72	6.17	6.00	2.50	-5.00	540	352	342	1778	3.03E+07	3.08E+07	3.53E+07	1.94E+08
06/27/17	06/30/17	17.83	3.24	7.50	-0.75	-0.33	142	113	135	399	9.43E+06	9.87E+06	1.17E+07	5.33E+07
07/09/17	07/11/17	36.27	5.17	10.25	-5.83	0.08	329	218	351	1176	1.09E+07	1.67E+07	2.21E+07	9.52E+07
07/19/17	07/21/17	16.47	23.50	5.17	3.00	7.67	147	83	72	221	4.01E+06	5.25E+06	6.07E+06	2.06E+07
07/21/17	07/23/17	22.05	3.74	6.08	2.50	0.75	229	101	129	316	8.68E+06	9.55E+06	1.19E+07	3.84E+07
08/17/17	08/19/17	15.54	3.17	1.75	3.58	13.00	104	79	77	86	4.98E+06	3.39E+06	4.21E+06	8.35E+06
08/22/17	08/24/17	12.85	3.06	2.08	2.67	22.50	64	48	47	40	1.91E+06	1.97E+06	3.18E+06	3.07E+06
09/18/17	09/20/17	28.96	2.51	0.92	5.58	6.17	137	72	81	209	4.24E+06	4.01E+06	5.82E+06	1.34E+07
10/01/17	10/02/17	16.21	1.31	1.17	3.42	3.42	52	40	34	222	2.02E+06	2.21E+06	2.88E+06	6.36E+06
10/02/17	10/04/17	12.40	2.70	1.58	0.75	1.08	143	101	100	383	4.84E+06	4.41E+06	5.21E+06	1.26E+07
10/05/17	10/06/17	20.12	8.48	2.75	0.67	1.17	480	177	222	1065	1.10E+07	1.23E+07	1.38E+07	4.23E+07
10/06/17	10/08/17	32.92	3.66	2.25	-16.42	-2.58	448	382	407	1700	4.91E+07	5.56E+07	4.79E+07	2.29E+08
10/21/17	10/23/17	35.10	3.85	2.58	4.00	-4.42	757	542	516	1893	3.84E+07	1.50E+07	4.10E+07	2.04E+08

2.4.3 Total Suspended Solids

Loads for total suspended solids in 2016 exhibited variable reduction, depended on the structural practice (Figure 2.25 and Appendix C). However, while the surge basin reduced loads 65% of the time, overall exports during events supplied 22,263 kg more than the upstream station. This is attributable, in part, to the storm in late September, during which 23,004 kg of total suspended solids were added by the surge basin. The next largest instance of suspended solids being added by the pond was 2,620 kg during a runoff event in late April. The largest instance of storage within the surge basin occurred during a late March event, where 1,889 kg were removed. Total event loads and event averages both increased moving downstream while reduction capability decreased. The two-stage ditch reduced loads in 22% of the monitored events, while the rate control weir reduced loads only 9% of the monitored events. The largest addition of suspended solids from the two-stage ditch came during a late August event, where 4,948 kg were added, while the largest storage came during the late April event, where 2,724 kg were stored. Water that moved through the primary treatment region (the surge basin and the two-stage ditch) was reduced during seven events, while net exports totaled 36,025 kg (Figure 2.27). Water leaving the watershed was reduced from the two-stage ditch to the rate control weir on two occasions, with an additional 311,633 kg being added. A series of storms in in mid-May resulted in 3,357 kg of storage, the only instance during 2016. However, this is offset by a mid-June event where 119,247 kg were added by the time it left the watershed.

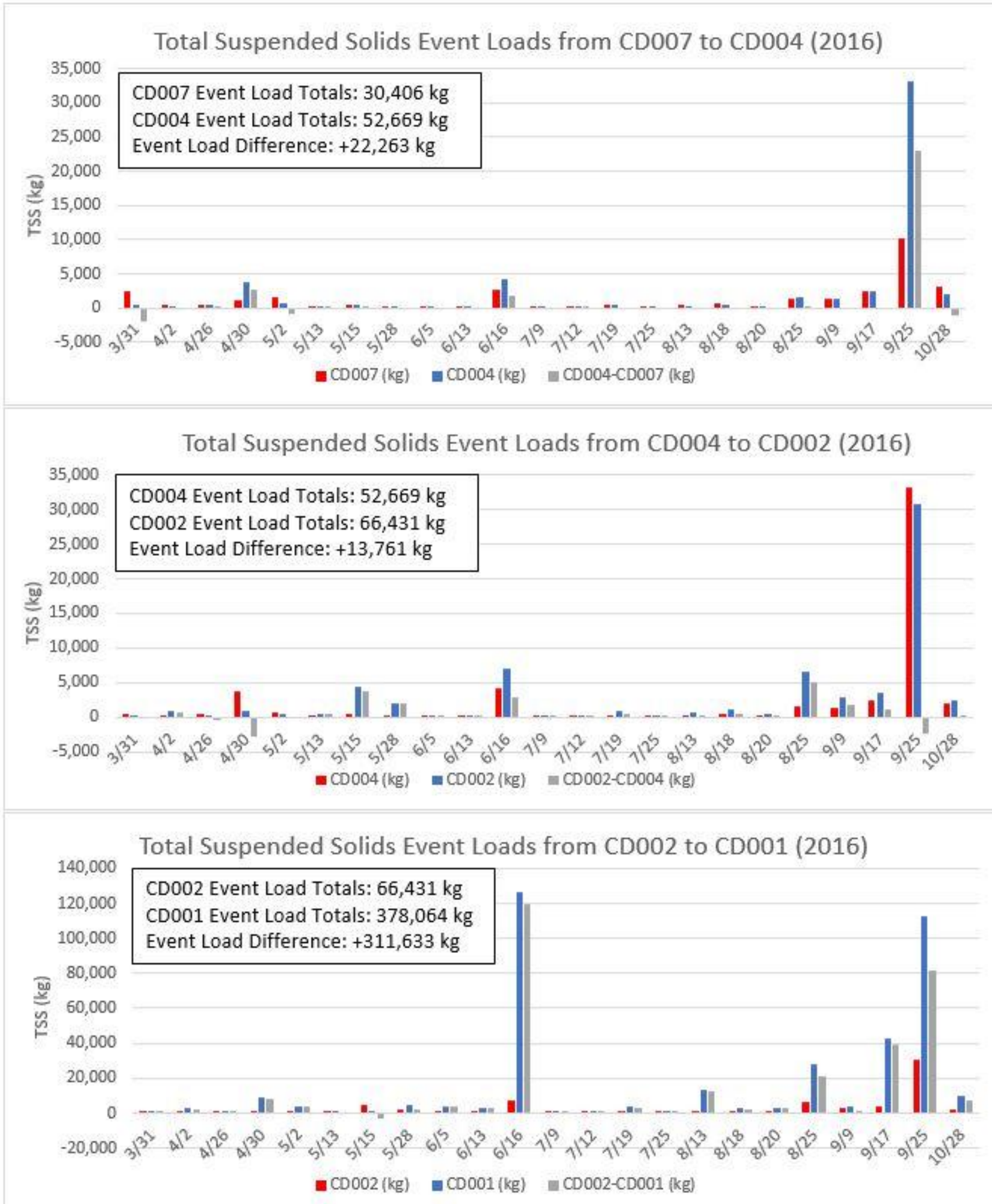


Figure 2.25. Total suspended solid event load comparisons for 2016.

Trends in load reduction for 2017 varied moderately from flow-weighted mean concentrations. The surge basin removed suspended solid loads 82% of the time, while the total load supplied downstream of the surge basin resulted in a net reduction of 1,890 kg of suspended solids (Figure 2.26 and Appendix C). The greatest addition of solids from the surge basin to the downstream watershed was 1,042 kg from a late April event, while the greatest removal of 1,515 kg came from a mid-May event. On average, the surge basin removed 111 kg of sediment during each event. The two-stage ditch reduced suspended solids 12-18% of the time and contributed between 189-563 kg more during each event. The biggest addition from the two-stage ditch was from a late October storm and ranged from 1,882-3,747 kg. The largest removal by the two-stage ditch came during a late April event, where 541 kg of solids were removed, however an early October event ranged from 4-734 kg removed. On average, the two-stage ditch supplied 189-563 kg of suspended solids each event. After the primary treatment region, the load increased by between 1,322-7,685 kg (Figure 2.28). Water leaving the watershed at the rate control weir had reduced suspended solids in 12% of events and exported between 90,380-159,154 kg of suspended solids. Averages of 5,316-9,362 kg of additional sediment were supplied between the rate control weir and the two-stage ditch.

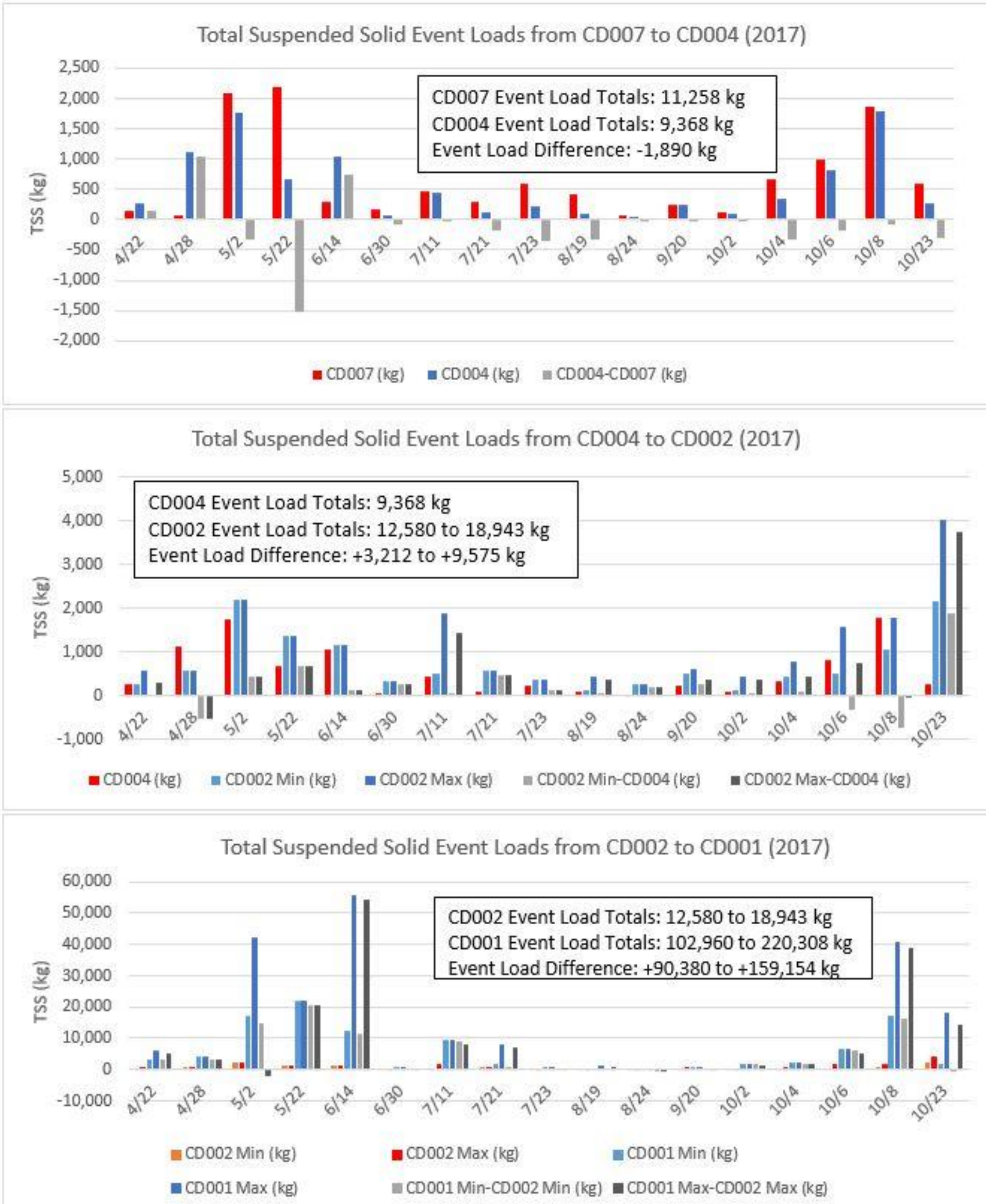


Figure 2.26. Total suspended solid event load comparisons for 2017.

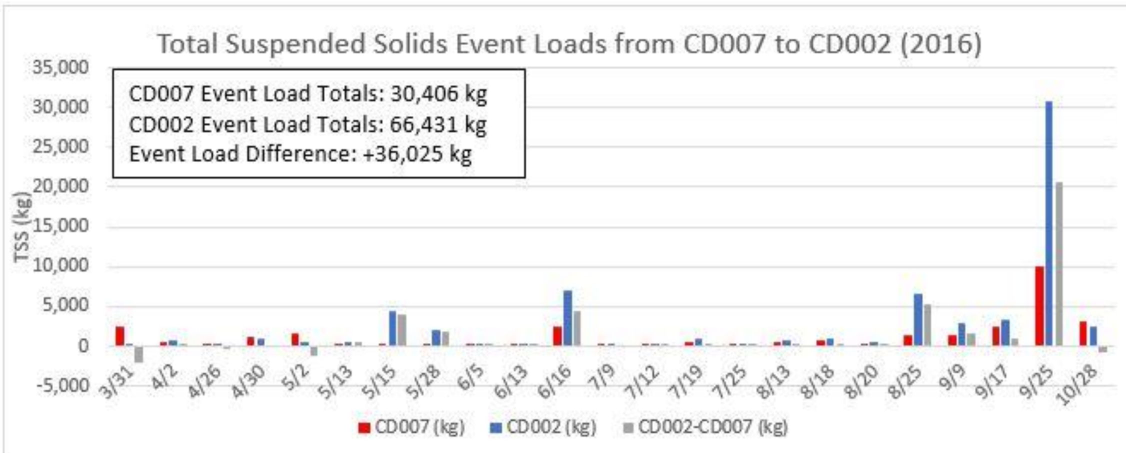


Figure 2.27. CD007 total suspended solid loads compared to CD002 total suspended solid loads for 2016.

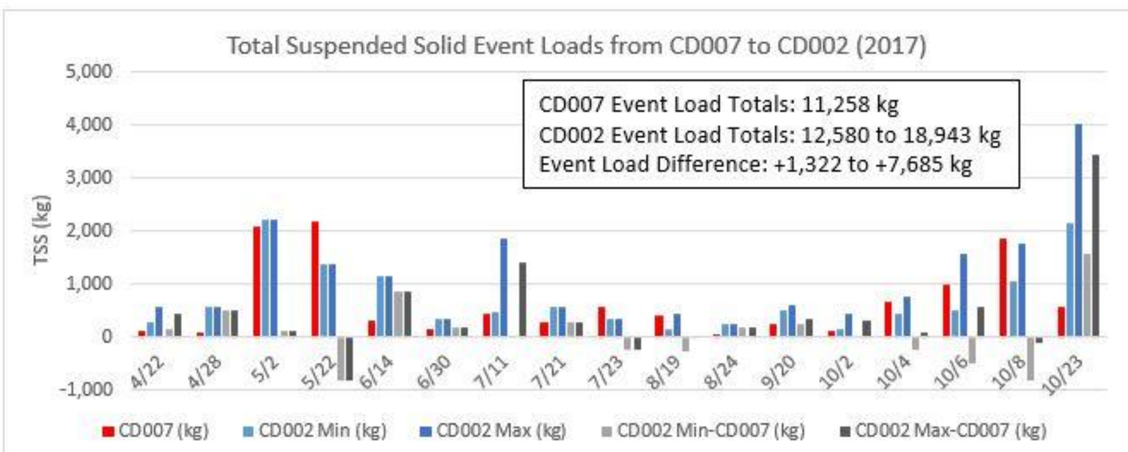


Figure 2.28. CD007 total suspended solid loads compared to CD002 total suspended solid loads for 2017.

2.4.4 Nitrate and Nitrite as N

Load reduction and concentration reduction differed greatly in 2016 (Figure 2.29). The surge basin only reduced loads from events 35% of the time, while providing an additional 1,877 kg (an average of 82 kg per event) of nitrate+nitrite as nitrogen to the downstream watershed. The two-stage ditch reduced loads 13% of the time, while providing a total of 3,178 kg (138 kg per event) to the downstream watershed. Water passing through the primary treatment region were reduced in two events, resulting in an overall addition of ~5,055 kg (Figure 2.31). Loads were never decreased moving through the rate control weir, while 88,900 kg (3,865 kg per event) extra were added. Final loads leaving the rate control weir amounted to 108,216 kg.

The 2017 reduction capability matched more closely to the concentration reduction than 2016 (Figure 2.30). The surge basin reduced loads in 71% of events and removed 630 kg (37.1 kg per event). The largest removal in 2017 was by the surge basin during a late October event, where 368.2 kg were stored by the basin. The two-stage ditch reduced loads 29% of the time, while adding 1,142 kg (67.2 kg per event). Loads within the primary treatment region were reduced 41% of the time, but still resulted in a net addition of 511 kg of nitrate+nitrite as nitrogen to the downstream watershed (Figure 2.32). Loads moving through the rate control weir were reduced 18% of the time, but amounted to 13,973 kg more (822 kg per event). Final event loads leaving the watershed at the rate control weir amounted to 18,533, nearly six times less than 2016.

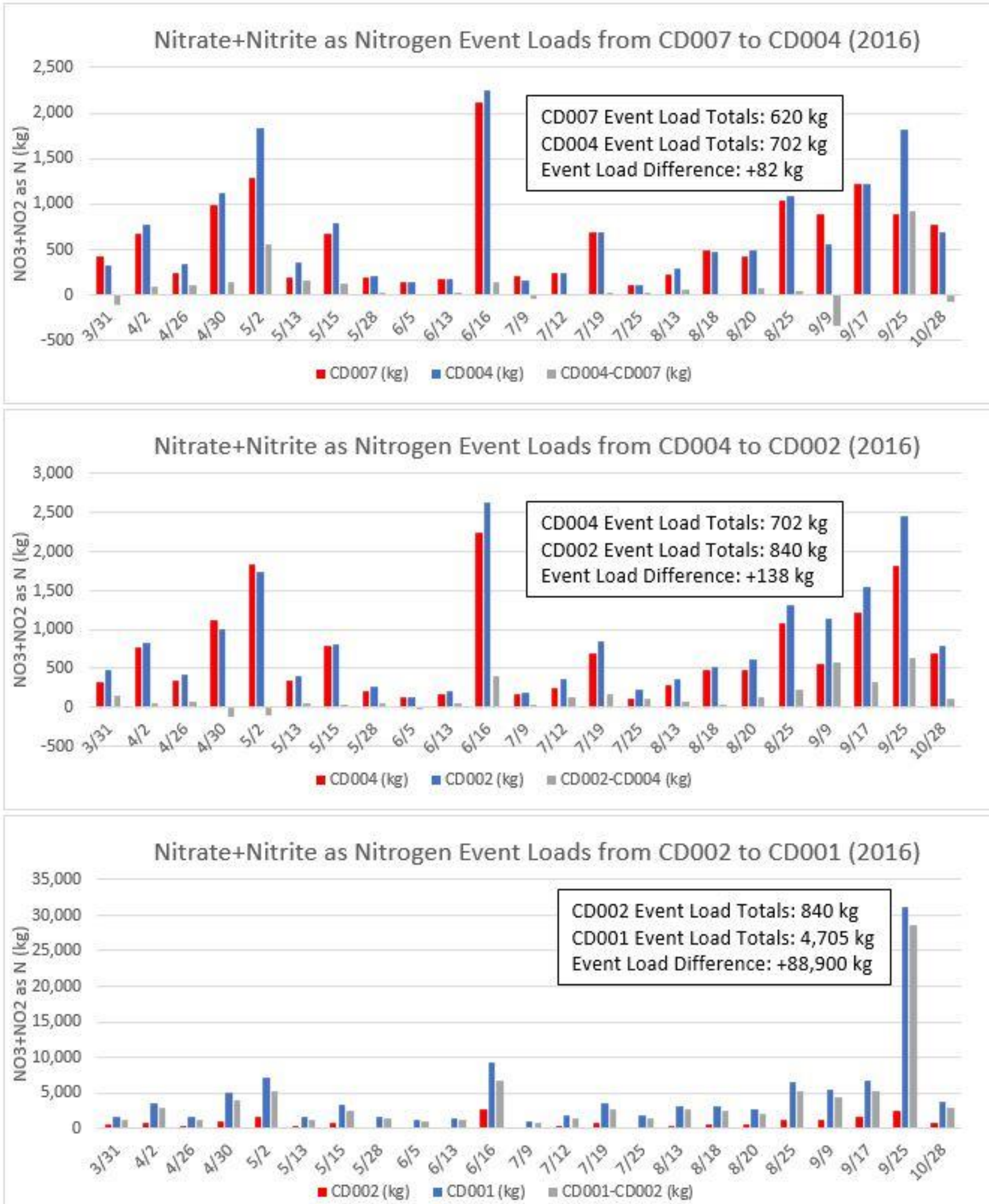


Figure 2.29. Nitrate+nitrite as nitrogen event load comparisons for 2016.

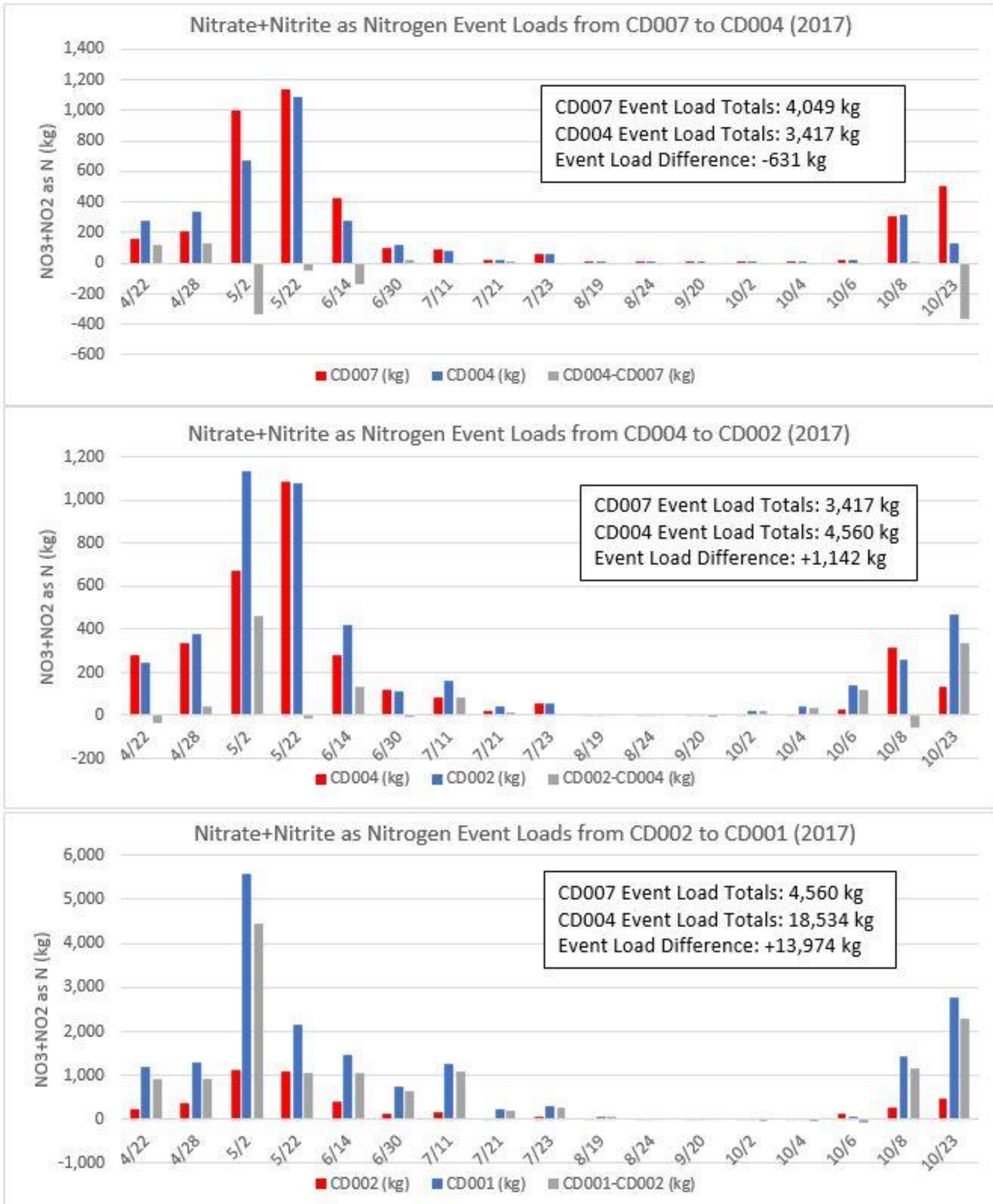


Figure 2.30. Nitrate+nitrite as nitrogen event load comparisons for 2017.

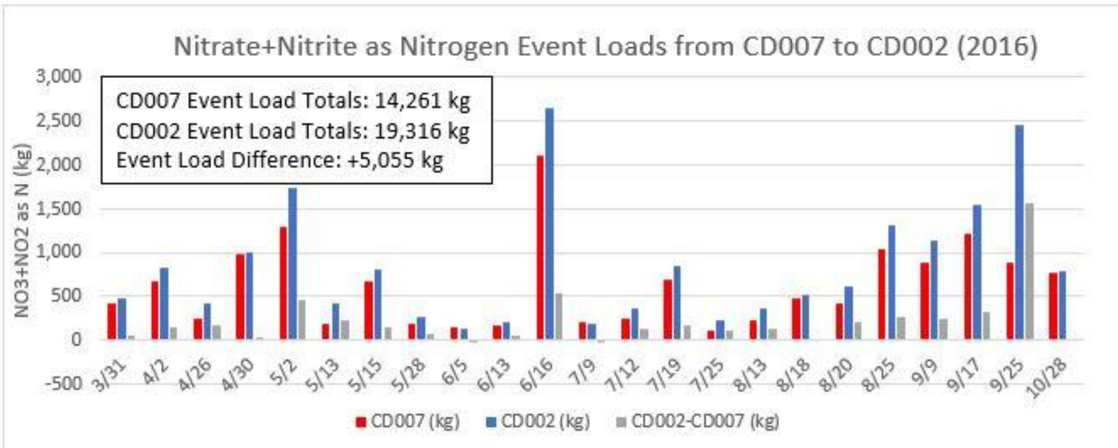


Figure 2.31. CD007 nitrate+nitrite as nitrogen loads compared to CD002 nitrate+nitrite as nitrogen loads for 2016.

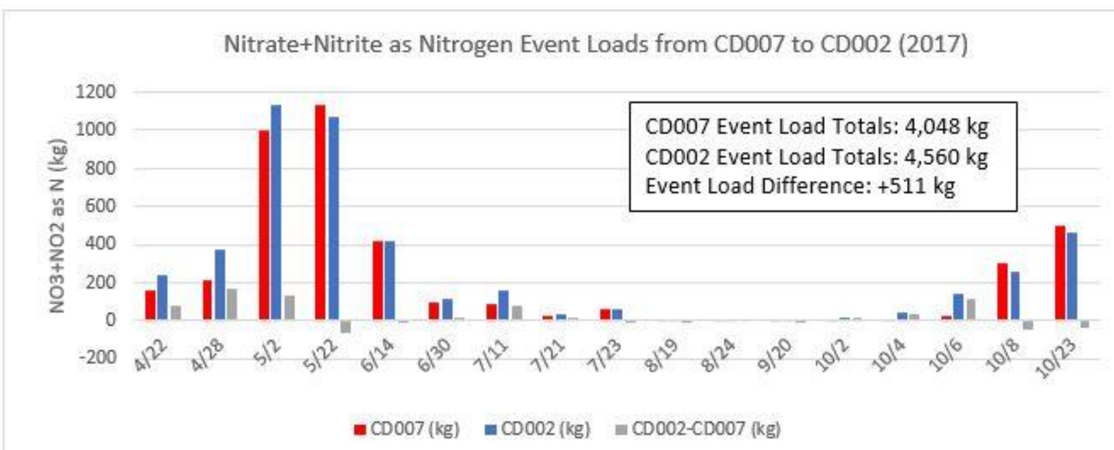


Figure 2.32. CD007 nitrate+nitrite as nitrogen loads compared to CD002 nitrate+nitrite as nitrogen loads for 2017.

2.4.5 Total Phosphorus and Orthophosphate

Total phosphorus and orthophosphate loads for 2016 did not see significant reduction (Figure 2.33 and Figure 2.34). The surge basin reduced loads in 26% of events, resulting in a net addition of 128 kg of total phosphorus downstream. Orthophosphate loads were reduced 9% of events, while still contributed 81 kg more downstream. The two stage ditch and the rate control weir reduced loads only 4% of the time. In comparison to the surge basin, the two-stage ditch contributed another 109 kg of total phosphorus, 16 kg less than the surge basin. The watershed between the rate control weir and two-stage ditch added 1,165 kg of total phosphorus more than the two-stage ditch. The two-stage ditch reduced loads of orthophosphate in 26% of events, the most frequent between the structures, while contributing 47 kg more downstream, nearly half that of the surge basin. The rate control weir never recorded reductions in orthophosphate loads and contributed 613 kg more downstream than the two-stage ditch. Total phosphorus loads after the primary treatment region were reduced in one of the events, and 237 kg were added to the watershed (Figure 2.37).Orthophosphate loads after the primary treatment region were reduced in two events, adding 128 kg to the watershed (Figure 2.37).

Load reductions in 2017 were, overall, more efficient than 2016 (Figure 2.35 and Figure 2.36). The surge basin recorded reductions in 41% of events, while contributing a net addition of 10 kg downstream. Orthophosphate was reduced 24% of events and contributed 4 kg downstream, the lowest out of the structures. The two-stage ditch removed total phosphorus 6-24% of the time, while contributing 22-38 kg downstream. Orthophosphate was reduced 12-24% of the time, adding 10-17 kg downstream. The watershed between the rate control weir and the two-stage ditch reduced loads 6-12% of events, adding 439-670 kg of total phosphorus downstream. Orthophosphates were reduced 12-18% of the time, contributing 209-309 kg to the downstream watershed. Total phosphorus loads within the primary treatment region were reduced 5-18% of the time and resulted in additions of 31-48 kg downstream (Figure 2.37). Orthophosphate loads within the primary treatment region were reduced in 12-17% of events, while contributing 14-21 kg downstream (Figure 2.37).

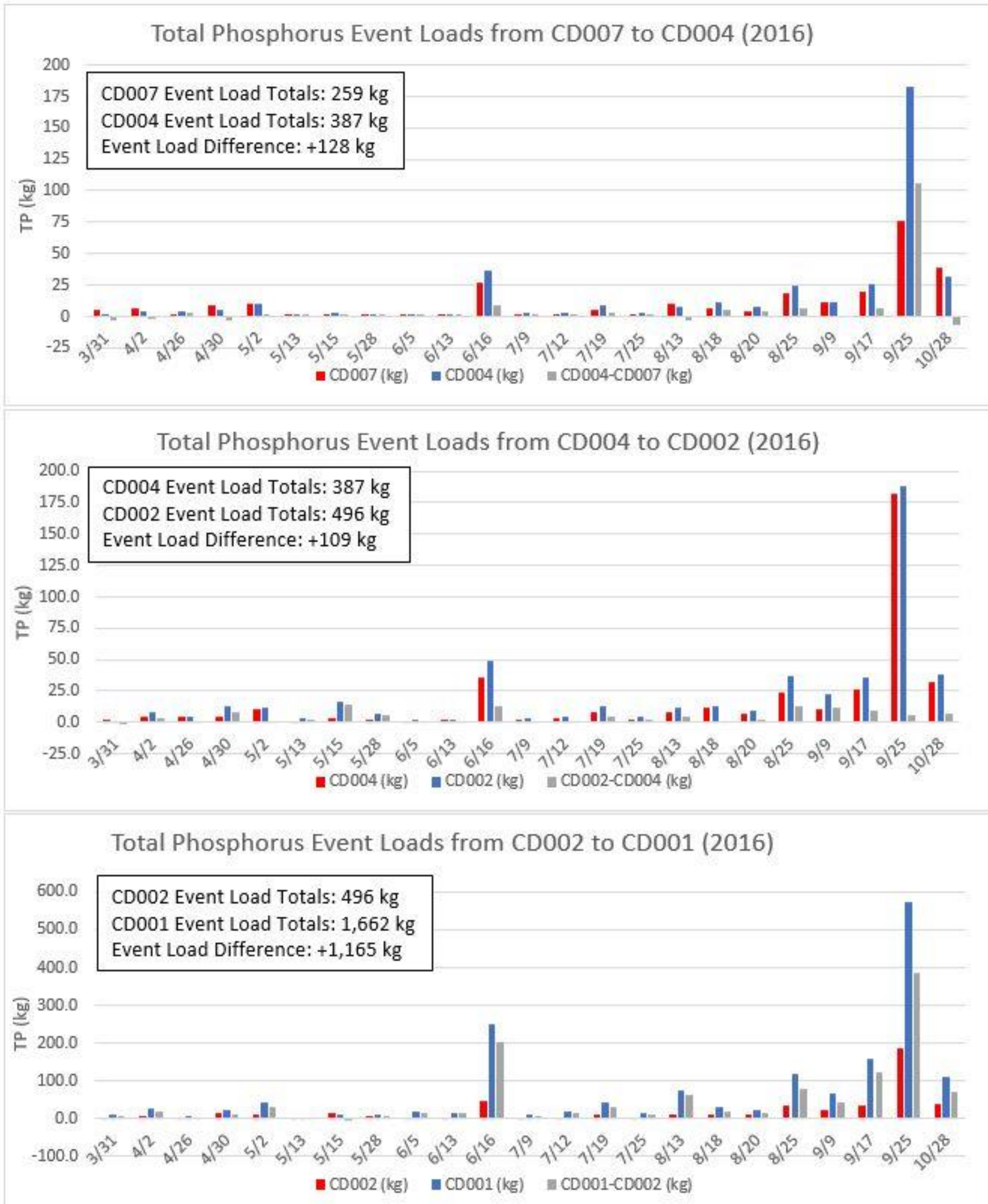


Figure 2.33. Total phosphorus event load comparisons for 2016.

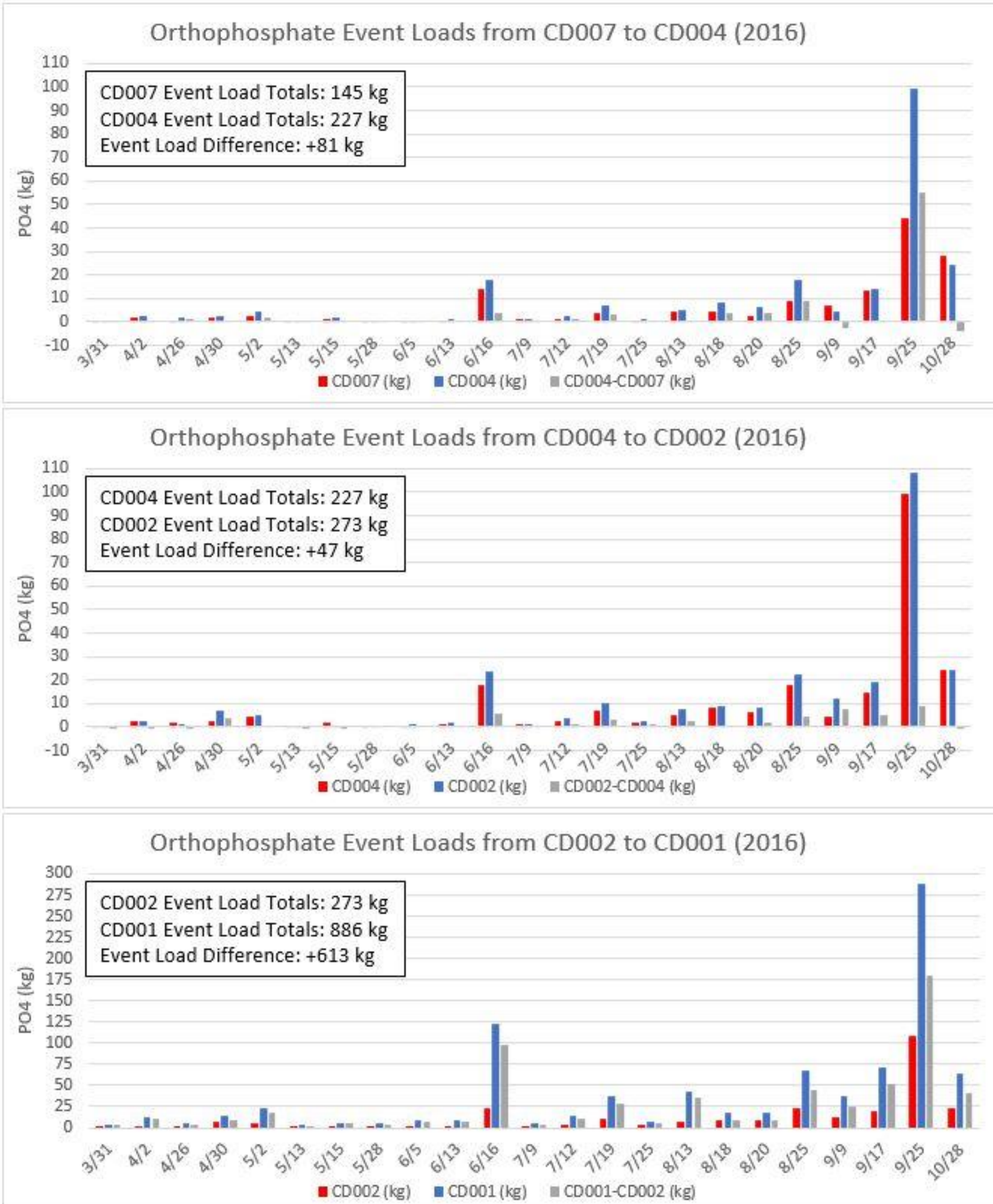


Figure 2.34. Orthophosphate event load comparisons for 2016.

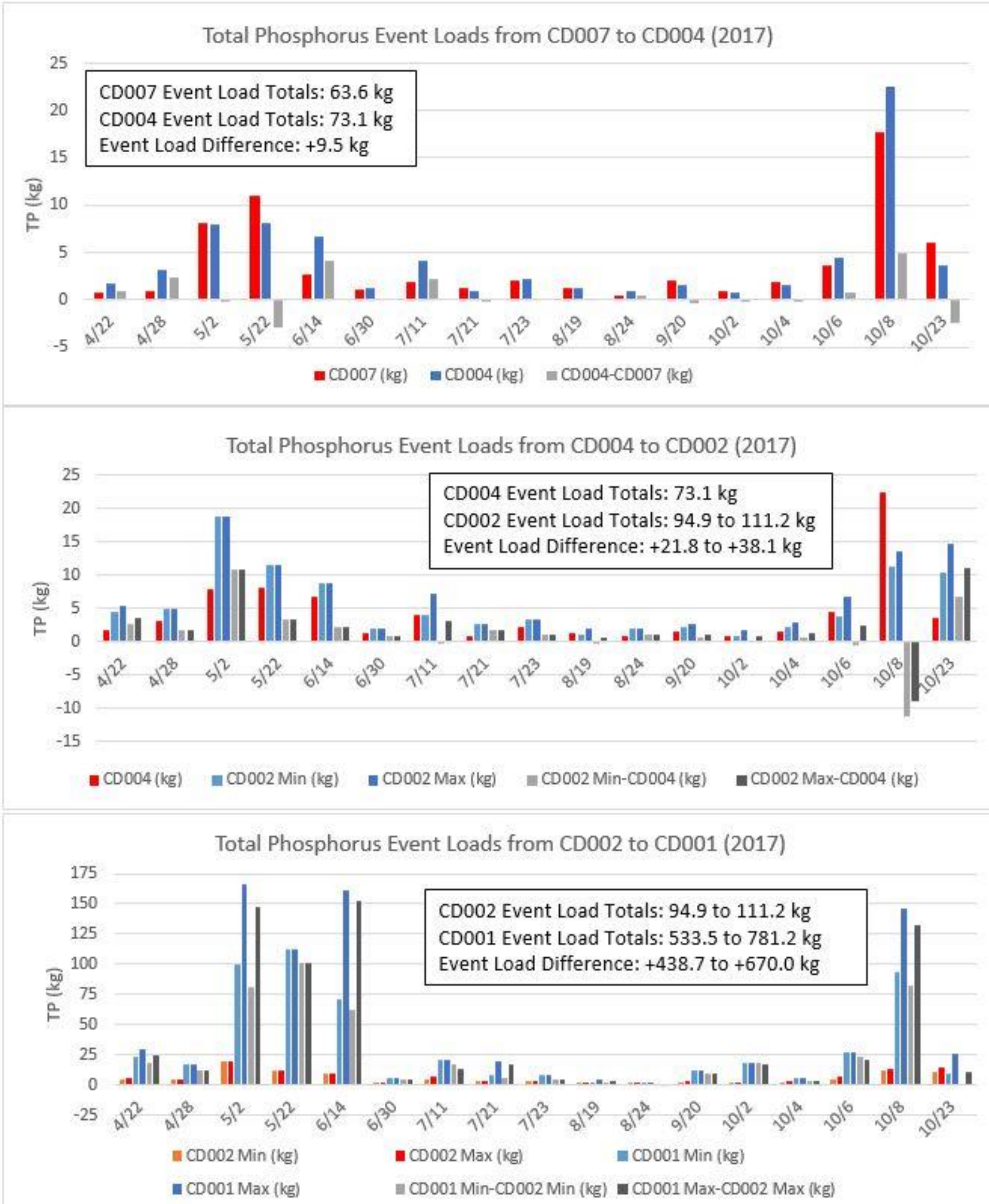


Figure 2.35. Total phosphorus event load comparisons for 2017.

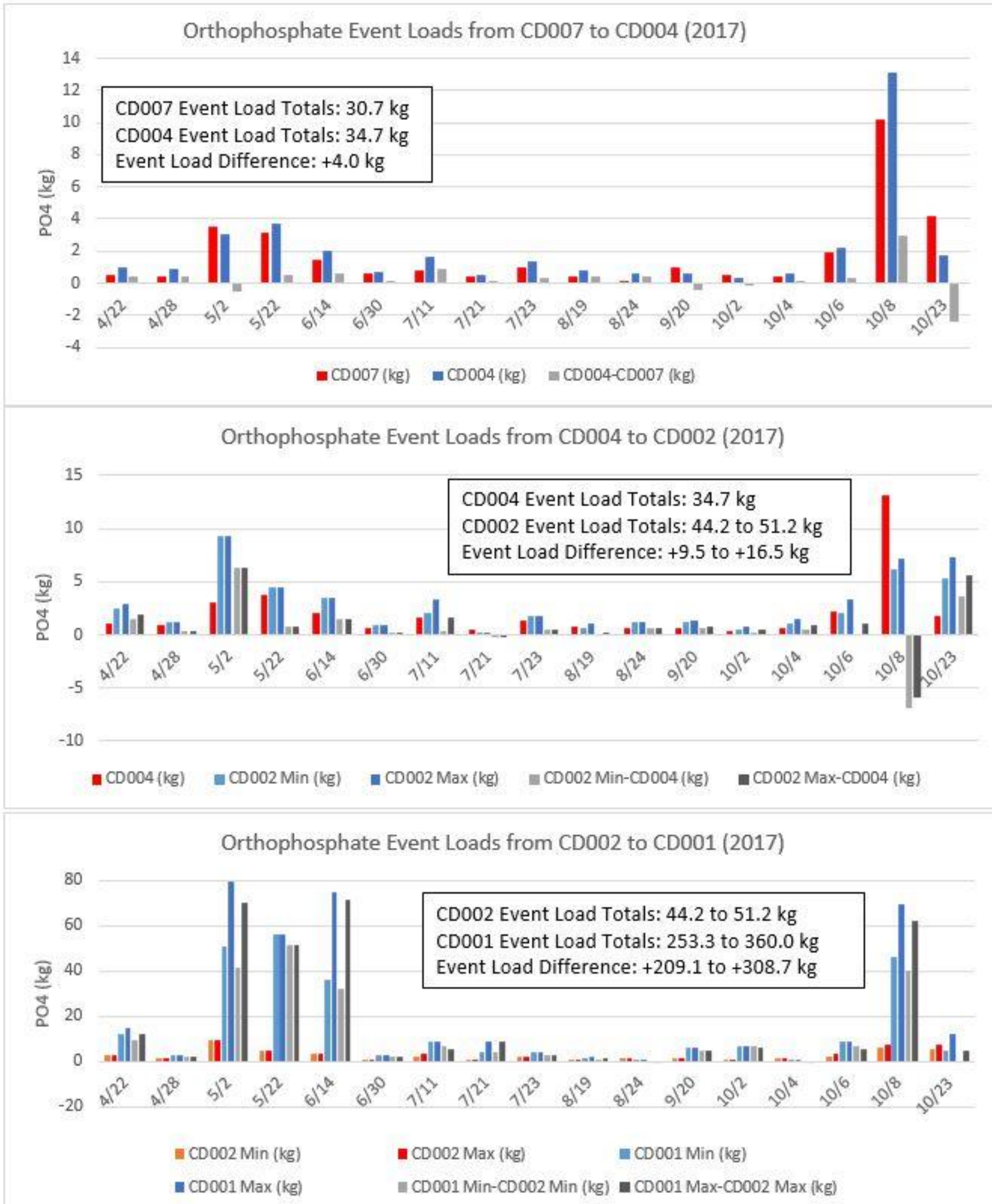


Figure 2.36. Orthophosphate event load comparisons for 2017.

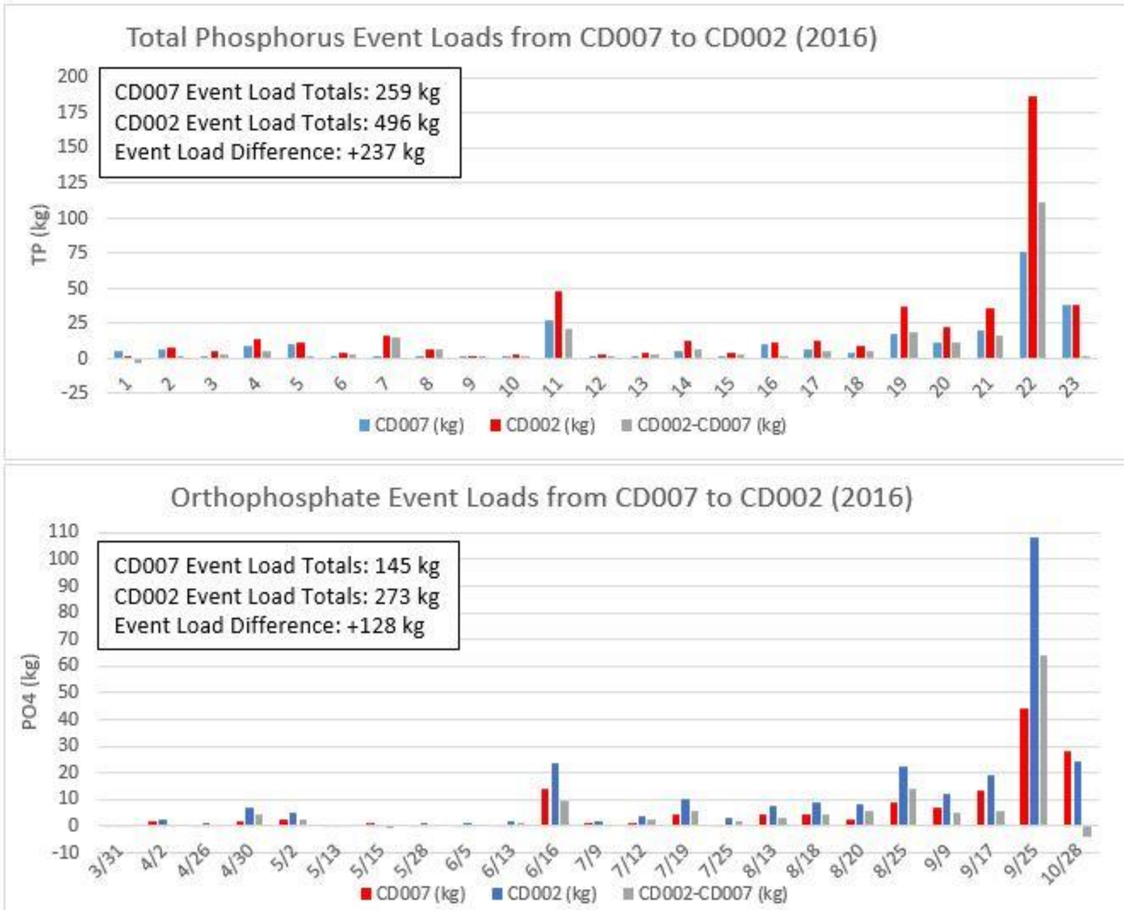


Figure 2.37. Total phosphorus and orthophosphate event load comparisons for 2016.

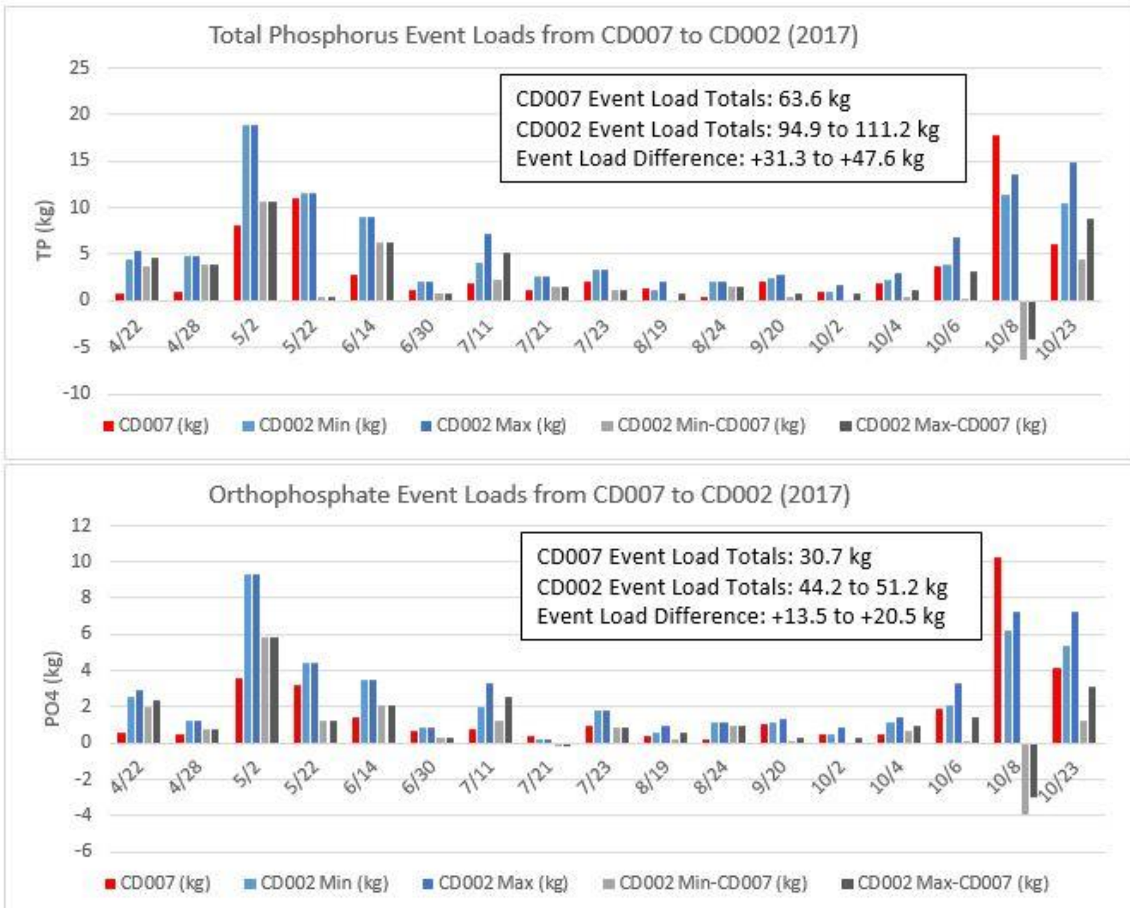


Figure 2.38. Total phosphorus and orthophosphate event load comparisons for 2017.

2.4.6 Principal Component Analysis

Outputs of the principal component analysis included a correlation matrix, total variance explained table, component matrix, and rotated component matrix. The first principal component analysis compared sampleshed size, discharge, rainfall, average slope, C/D hydrologic soils, and urban, corn, and soybean land covers (Tables 2.7 -2.10). It should be noted that rainfall intensity was utilized in previous models, but was removed because it was not a significant factor. The first two components generated eigenvalues higher than 1, accounting for 84.77% of the total variance between the variables (Table 2.8). A third component that was just below an eigenvalue of 1 (0.969) was also included, and raised the explained variance to 97.64% (Table 2.8). The first component in the unrotated component matrix shows very strong (0.80-1.0) positive correlations with urban area, C/D soils, sampleshed size, corn coverage, soybean coverage, and discharge (Table 2.9) (Evans, 1996). The other two variables, total rainfall and average slope, had very weak (0.00-0.19) positive and weak (0.20-0.39) negative correlations. The second component had a single very strong positive correlation with total rainfall, a moderate positive correlation with discharge, weak negative correlation with soybean coverage, and very weak positive and negative correlations with the other variables. The third component also featured a single very strong positive correlation to average slope and very weak positive and negative correlations with the other variables.

The first component of the rotated component matrix is very strongly positively correlated to C/D soils, sampleshed size, urban area, corn coverage, and soybean coverage, strongly (0.60-0.79) positively correlated to discharge, and very weakly negatively correlated to total rainfall and average slope (Table 2.10). The second component is very strongly positively correlated to total rainfall, with strong positive correlation to discharge, weak positive correlation to urban area, and very weak positive and negative correlation with the other variables. Finally, the third component is very strongly positively correlated to average slope, and very weakly positively and negatively correlated to all other variables.

This analysis primarily compared annual watershed parameters like land cover, rainfall, discharge, and slope. The first of the three generated components in the rotated component matrix can be deemed an area component. An increase in the size of the sampleshed correlated very strongly or strongly with C/D soils, urban area, corn coverage, soybean coverage, and discharge. All of those variables increased in hectares or liters as the size of the sampleshed increased. Total rainfall and average slope were independent of sampleshed size and were very weakly negatively correlated to the component. The second component showed very strong and strong positive correlations to rainfall and discharge, respectively, and show that increasing discharge and increasing rainfall are connected. The third component is a component explaining slope and shows that no other compared variable was impacting the slope of the watershed.

The second principal component analysis compared total suspended solid loads, nitrate+nitrite as nitrogen loads, peak discharge, total rainfall, sampleshed size, urban area, corn coverage, and soybean coverage on a runoff event basis between July and September for both 2016 and 2017 (Tables 2.11-2.14). Two components were generated with eigenvalues greater than 1, which accounted for 90.50% of the variance within the components (Table 2.12). The first component in the unrotated component matrix features very strong, positive correlations with urban area, corn coverage, and sampleshed size, strong positive correlations to soybean coverage, peak discharge, total suspended solids loads, and nitrate+nitrite as nitrogen loads, and weak positive correlation with total rainfall (Table 2.13). The second component exhibited strong positive correlations to total suspended solid loads and total rainfall by event, moderate positive correlations to peak discharge and nitrate+nitrite as nitrogen loads, and moderate negative correlations to all other variables (Table 2.13).

The rotated component matrix featured some distinct differences when compared to the unrotated matrix. The first component features very strong positive correlations to sampleshed size, urban area, corn coverage, and soybean coverage, with weak positive correlations to peak discharge and nitrate+nitrite as nitrogen loads, very weak positive correlations to total suspended solids loads, and very weak negative correlation to total rainfall (Table 2.14). The second component was very strongly positively correlated to total suspended solids loads, nitrate+nitrite as nitrogen loads, and peak discharge, strong positive correlations to total rainfall, weak positive correlations to urban area and corn coverage, and very weakly positively correlated to sampleshed size and soybean coverage (Table 2.14).

The second principal component analysis compared sites by land use, rainfall, discharge parameters, and total suspended solid loads. The first of the two components in the rotated component matrix is positively correlated to all variables except total rainfall, but given very strong correlations to urban area, corn coverage, sampleshed size, C/D soils, and soybeans, this component can be deemed an area component, similar to the annual parameters component analysis. Moderate correlations to peak discharge, total suspended solid loads, and total discharge also support this component, as each of those parameters should increase with area. Total rainfall is independent of size, therefore it is the weakest correlation within the first component. The second component was very strongly positively correlated to discharge, peak discharge, total rainfall and total suspended solid loads. This component shows that as one of those variables increase, the rest tend to as well. As discharge increases, peak discharge and total suspended solid loads should as well, while this is most likely because of increasing total rainfall.

The third analysis attempted to isolate the comparison to unique differences between samplesheds (Tables 2.15-2.18). It explained 71.47% of the variance with two generated components (Table 2.16). The first component featured very strong positive correlations to differences in total suspended solid loads, nitrate+nitrite as nitrogen loads, and peak discharge, strong positive correlation to total rainfall, weak positive correlation to unique sampleshed area, and very weak negative correlation to rainfall intensity (Figure 2.17). The second component featured strong positive correlation to unique sampleshed size, weak positive correlation to rainfall intensity and differences in nitrate+nitrite as nitrogen loads, very weak positive correlation to differences in total suspended solid loads, weak negative correlation to peak discharge, and moderate negative correlation to total rainfall.

The first component of the rotated component matrix featured very strong positive correlation to differences in total suspended solid loads, differences in nitrate+nitrite as nitrogen loads, peak discharge, and total rainfall, weak positive correlation to unique sampleshed area, and very weak negative correlation to rainfall intensity (Figure 2.18). The second component featured strong positive correlation to unique sampleshed area, weak positive correlation to rainfall intensity and differences in nitrate+nitrite as nitrogen loads, very weak positive correlation to differences in total suspended solid loads, weak negative correlation to peak discharge, and moderate negative correlation to total rainfall.

The third component analysis helped to determine which compared values were not contributing to changes in the compared parameters. The first component featured strong relationships between differences in total suspended solid loads, nitrate+nitrite as nitrogen loads, peak discharge, and total rainfall by event, and could be deemed a reduction component. Reductions in peak discharge, total suspended solids, and nitrate+nitrite as nitrogen loads were more likely to occur together and these differences would relate to the amount of rain falling on the watershed. The second component feature weaker relationships with unique sampleshed size and rainfall intensity correlating more strongly than the other variables. However, rainfall intensity did not correlate strongly within the component and unique sampleshed size did not relate to any other variables, suggesting that both of these variables were ineffective and did not contribute to differences in loads.

The first two component analyses suggest that there is a weak relationship between land use and in-channel parameters. In both rotated component matrices the discharge/rainfall relationship is best explained by the second component, and only weakly correlates to land use tendencies within the watershed. However, when examining the components that explain in-channel parameters it is interesting to note that corn and urban coverage are the most highly correlated of the “size” variables. This is true in both the annual and event-based component analyses. Soybean coverage, on the other hand, is very weakly negatively correlated in the annual analysis and very weakly positively correlated in the event analysis, suggesting that soybean cultivation in the watershed has no effect on in-channel tendencies. The third component analysis helps single out parameters that played more (i.e. peak discharge or total rainfall) or less (i.e. unique sampleshed size or rainfall intensity) of a role in changing loads.

Table 2.7. Correlation matrix for the first principal component analysis that examined annual parameters for both years.

Correlation Matrix[a]

		Sampleshed (Hect)	Discharge (Liters)	Total Rainfall (mm)	Avg Slope (Degrees)	Urban Area (Hect)	Corn (Hect)	Soybeans (Hect)	C/D Soils (Hect)
Correlation	Sampleshed (Hect)	1.000	.763	.019	-.200	.975	.973	.965	1.000
	Discharge (Liters)	.763	1.000	.540	-.119	.866	.862	.600	.763
	Total Rainfall (mm)	.019	.540	1.000	-.014	.191	.091	-.071	.018
	Avg Slope (Degrees)	-.200	-.119	-.014	1.000	-.081	-.197	-.196	-.199
	Urban Area (Hect)	.975	.866	.191	-.081	1.000	.977	.909	.975
	Corn (Hect)	.973	.862	.091	-.197	.977	1.000	.881	.973
	Soybeans (Hect)	.965	.600	-.071	-.196	.909	.881	1.000	.966
	C/D Soils (Hect)	1.000	.763	.018	-.199	.975	.973	.966	1.000

a. This matrix is not positive definite.

Table 2.8. Total variance explained showing how well the generated components were able to explain the variables.

Total Variance Explained

	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
Component	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	5.558	69.475	69.475	5.558	69.475	69.475	5.375	67.187	67.187
2	1.284	16.050	85.526	1.284	16.050	85.526	1.407	17.584	84.772
3	.969	12.118	97.644	.969	12.118	97.644	1.030	12.872	97.644
4	.188	2.345	99.989						
5	.001	.010	99.999						
6	8.568E-5	.001	100.000						
7	4.864E-6	6.080E-5	100.000						
8	1.799E-15	2.249E-14	100.000						

Extraction Method: Principal Component Analysis.

Table 2.9. Component matrix showing the three generated components used to explain and clump variables.

Component Matrix[a]

	Component		
	1	2	3
Urban Area (Hect)	.991	.054	.122
C/D Soils (Hect)	.988	-.146	.031
Sampleshed (Hect)	.988	-.145	.030
Corn (Hect)	.987	-.032	.017
Soybeans (Hect)	.926	-.272	.037
Discharge (Liters)	.852	.469	-.011
Total Rainfall (mm)	.157	.959	-.137
Avg Slope (Degrees)	-.209	.155	.965

Extraction Method: Principal Component Analysis.

a. 3 components extracted.

Table 2.10. Rotated component matrix showing how well the variables are explained when the axes are rotated to better fit the variables.

Rotated Component Matrix[a]

	Component		
	1	2	3
C/D Soils (Hect)	.994	.025	-.098
Sampleshed (Hect)	.994	.025	-.099
Urban Area (Hect)	.978	.208	.022
Corn (Hect)	.973	.137	-.094
Soybeans (Hect)	.954	-.110	-.104
Discharge (Liters)	.759	.607	-.031
Total Rainfall (mm)	-.014	.981	-.006
Avg Slope (Degrees)	-.102	-.012	.995

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.[a]

a. Rotation converged in 4 iterations.

Table 2.11. Correlation matrix for the second principal component analysis that focused on events from July to September of both years.

Correlation Matrix

		TSS (kg)	NO3+NO2 as N (kg)	Peak Discharge (L/s)	Total Event Rainfall (mm)	Sampleshed (ha)	Urban (ha)	Corn (ha)	Soybeans (ha)
Correlation	TSS (kg)	1.000	.929	.913	.618	.319	.358	.361	.242
	NO3+NO2 as N (kg)	.929	1.000	.903	.462	.398	.445	.458	.294
	Peak Discharge (L/s)	.913	.903	1.000	.656	.427	.494	.494	.312
	Total Event Rainfall (mm)	.618	.462	.656	1.000	.000	.065	.028	-.038
	Sampleshed (ha)	.319	.398	.427	.000	1.000	.979	.978	.964
	Urban (ha)	.358	.445	.494	.065	.979	1.000	.980	.910
	Corn (ha)	.361	.458	.494	.028	.978	.980	1.000	.888
	Soybeans (ha)	.242	.294	.312	-.038	.964	.910	.888	1.000

Table 2.12. Total variance explained showing how well the generated components were able to explain the variables.

Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	4.868	60.854	60.854	4.868	60.854	60.854	3.991	49.887	49.887
2	2.372	29.649	90.503	2.372	29.649	90.503	3.249	40.616	90.503
3	.511	6.391	96.893						
4	.139	1.741	98.635						
5	.048	.606	99.240						
6	.043	.539	99.780						
7	.018	.220	100.000						
8	3.267E-5	.000	100.000						

Extraction Method: Principal Component Analysis.

Table 2.13. Component matrix showing the two generated components used to explain and clump variables.

Component Matrix[a]

	Component	
	1	2
Urban (ha)	.898	-.405
Corn (ha)	.895	-.408
Sampleshed (ha)	.878	-.474
Soybeans (ha)	.799	-.531
Peak Discharge (L/s)	.797	.562
NO3+NO2 as N (kg)	.761	.531
TSS (kg)	.716	.643
Total Event Rainfall (mm)	.354	.724

Extraction Method: Principal Component Analysis.

a. 2 components extracted.

Table 2.14. Rotated component matrix showing how well the variables are explained when the axes are rotated to better fit the variables.

Rotated Component Matrix[a]

	Component	
	1	2
Sampleshed (ha)	.988	.138
Urban (ha)	.963	.207
Corn (ha)	.962	.202
Soybeans (ha)	.958	.046
TSS (kg)	.196	.942
Peak Discharge (L/s)	.309	.925
NO3+NO2 as N (kg)	.298	.878
Total Event Rainfall (mm)	-.144	.793

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization.

a. Rotation converged in 3 iterations.

Table 2.15. Correlation matrix for the third principal component analysis that focused on event differences from July to September of both years.

Correlation Matrix

		Peak Discharge (L/s)	Sampleshed Split (ha)	TSS Differences (kg)	NO3+NO2 Differences (kg)	Total Event Rainfall (mm)	Rainfall Intensity (mm/hr)
Correlation	Peak Discharge (L/s)	1.000	.099	.648	.567	.841	-.003
	Sampleshed Split (ha)	.099	1.000	.347	.388	.000	.000
	TSS Differences (kg)	.648	.347	1.000	.919	.561	-.077
	NO3+NO2 Differences (kg)	.567	.388	.919	1.000	.480	-.022
	Total Event Rainfall (mm)	.841	.000	.561	.480	1.000	-.177
	Rainfall Intensity (mm/hr)	-.003	.000	-.077	-.022	-.177	1.000

Table 2.16. Total variance explained showing how well the generated components were able to explain the variables.

Total Variance Explained

	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
Component	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	3.107	51.776	51.776	3.107	51.776	51.776	3.106	51.763	51.763
2	1.181	19.689	71.465	1.181	19.689	71.465	1.182	19.702	71.465
3	.988	16.474	87.939						
4	.516	8.607	96.547						
5	.134	2.238	98.785						
6	.073	1.215	100.000						

Extraction Method: Principal Component Analysis.

Table 2.17. Component matrix showing the two generated components used to explain and clump variables.

Component Matrix[a]

	Component 1	Component 2
TSS Differences (kg)	.918	.178
NO3+NO2 Differences (kg)	.877	.283
Peak Discharge (L/s)	.852	-.307
Total Event Rainfall (mm)	.794	-.484
Sampleshed Split (ha)	.353	.779
Rainfall Intensity (mm/hr)	-.111	.368

Extraction Method: Principal Component Analysis.

a. 2 components extracted.

Table 2.18. Rotated component matrix showing how well the variables are explained when the axes are rotated to better fit the variables.

Rotated Component Matrix[a]

	Component 1	Component 2
TSS Differences (kg)	.915	.196
NO3+NO2 Differences (kg)	.871	.300
Peak Discharge (L/s)	.858	-.289
Total Event Rainfall (mm)	.803	-.468
Sampleshed Split (ha)	.337	.786
Rainfall Intensity (mm/hr)	-.118	.365

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization.

a. Rotation converged in 3 iterations.

2.5 Discussion

2.5.1 Discharge, Precipitation, Loads and Yields

The efficacy of the structural practices in the CD 57 watershed at reducing peak discharge, sediment loads, and nutrient loads varied throughout the monitoring extent. As a whole, peak discharge and contaminant loads were little altered, though individual structures may have had increased capacity for reduction. The two monitored years represented quite different hydrologic regimes (Table 2.4 and Table 2.5). The 2016 monitoring season was far wetter than 2017, with nearly 300 mm more rainfall (Table 2.4). This difference was consistent across discharge totals and peak discharge, with ~2.5-3.0 times more annual discharge at each site in 2016, compared to 2017. However, it is not unlikely that similar years will become more common as increases in total precipitation, precipitation intensity, and total discharge are recorded across southern Minnesota (Novotny and Stefan, 2007; Schottler et al., 2014; Gupta et al., 2015; Kelly et al., 2017).

Although 2016 may represent a wetter year, compared to a typical climate year, it shows that the structural practices were capable of regularly exporting sediment and nutrient loads. Peak discharge was consistently reduced within the surge basin, however this did not translate to reduced loads, overall. Comparatively, 2017 represented a more climate normal year in terms of total rainfall, but net export or no change (within the range of error) in loads was observed throughout the structures. In 2017, peak discharge was reduced with greater frequency within both the surge basin and two-stage ditch, but this did result in an improved ability to reduced overall loads. This suggests that reducing peak discharge, one of the main goals of the structural practices, does not result in improving load reduction, and that other forces are driving loads throughout the watershed.

In the case of the CD 57 surge basin, peak discharge, total suspended solids, and nitrate+nitrite as nitrogen loads saw the most consistent reduction. In 2017, nitrate+nitrite as nitrogen loads were reduced most often in the surge basin, where lengthier residence times allowed for greater removal by riparian and aquatic vegetation. However, total phosphorus and orthophosphate loads were less likely to be reduced throughout the surge basin. This supports findings in Kröger et al. (2012) that suggest that phosphorus is not as easy to mitigate as nitrogen, as it does not exist in a gaseous state. Furthermore, Hansen et al. (2018) suggests that wetland/basin placement can be a key factor in mitigation efficiency. When placed further downstream, in a location that captures more of the watershed, wetlands were shown to be more efficient at reducing nutrients than if they were placed further upstream (Hansen et al., 2018). The CD 57 surge basin is near the top of the watershed and, therefore, does not treat as much water as it could if it had been placed further downstream. While the upper portion of the watershed features the majority of the structural practices, a section of open channel exists for nearly 4 km that is only treated by buffer strips. This could serve as a prime location for further structural practices while serving to add temporary storage in the middle portion of the watershed and alleviating pressure on the rate control weir downstream. Finally, the surge basin (1.21 ha in size) is positioned to treat water from 732 ha. Throughout the monitoring project, the diversionary weir that redirects water into the surge basin was overtopped on eleven separate occasions. This would suggest that the pond is undersized for the amount of water it is required to treat. A previous wetland, mapped by the first surveyors in the region, did exist and was ~135 ha in size. A wetland this size would most likely be able to help mitigate peak discharges loads to a higher degree, but the wetland has been drained and the open channel of the ditch now runs through where the wetland used to be.

The two-stage ditch was also highly variable in its ability to reduce the measured parameters. It never reduced peak discharge in 2016 and did so less than half of the time in 2017. It did not consistently reduce total suspended solid loads during events in either year, only reducing them 12-22% of the time. The two-stage ditch did not generate considerable reduction in any of the other parameters during runoff event periods in either year. Residence times can be key to reducing sediment and nutrients within these structures (Woltemade, 2000; Kröger et al., 2012). Given lengthier residence times during base flow conditions, it would appear that the two-stage ditch is more capable at reducing the measured parameters, however load transport is not occurring in elevated levels during base flow. While more time in the two-stage ditch may lower loads, to a degree, it does not currently impact loads throughout the season.

It should be noted that two-stage ditch in the CD 57 watershed does not exhibit the typical characteristics of other two-stage ditches in the region (MNDNR, 2016). As described previously, a two-stage ditch is characterized by wider shoulders, a wider base, and is constructed with flat benches that simulate a natural floodplain (Figure 1.20) (Powell et al., 2007b; Kröger et al., 2013; Mahl et al., 2015; Roley et al., 2016). Based on an unpublished 2014 Minnesota Department of Natural Resources geomorphic survey of the CD 57 two-stage ditch, they concluded that the channel is oversized, the bench is too narrow, it lacks sinuosity, and it does not feature an effective floodplain (MNDNR, 2016). With time, a more stable floodplain and channel could form, but until then the structure does not exhibit the correct characteristics of a two-stage ditch. In their report, they also note up to a meter of fine sediments on top of the hard bottom of the channel. This suggests that much of the sediment moving through the two-stage ditch is being temporarily stored within the channel, instead of being deposited on a floodplain. Load reductions through the two-stage ditch are most likely attributable by an undersized culvert (1.4 m) that constricts flow and results in ponding that extends upstream, potentially as far as the surge basin.

2.5.2 Flow-Weighted Mean Concentrations vs. Loads/Yeilds

Flow-weighted mean concentrations and loads for each of the parameters featured key differences between them (Figures 2.39-2.42). In 2016 and 2017, reduced concentrations did not necessarily lead to reduced loads. While a number of parameters saw consistent average reductions in flow-weighted mean concentrations during event runoff, positive exports were frequently observed. Loads may have been reduced during individual events, but not enough to result in a net reduction. In 2017, the surge basin potentially resulted in net reductions of total suspended solid loads and nitrate+nitrite as nitrogen loads, similar to concentration reductions. This reduction is most likely in the form of temporary storage within the basin. The MNDNR (2016) report notes the presence of a source of sediment and nutrients in the form of fine-grained muck throughout the channel bottom. This sediment is easily disturbed, mobilized, and entrained and may be a primary settling location for temporarily stored sediments.

While the 2016 monitoring season exhibited multiple parameters with reduced concentration averages, the net export from every site is most likely a product of the entrainment of this temporarily stored sediment package. As the sediment is remobilized, decayed organic matter, silts, and clays are also mobilized. The larger storms from the 2016 monitoring season were able to entrain and move increased quantities of the measured parameters, scouring the channel, and resulting in the net export, rather than net reduction. Noted increases in peak discharge, total discharge, and precipitation since the 1940s would suggest that this trend will continue (Knox, 2000; Zhang and Schilling, 2006; Novotny and Stefan, 2007; Nangia et al., 2010; Schottler et al., 2014; Gupta et al., 2015; Belmont et al., 2016; Kelly et al., 2017). Furthermore, increases in erosivity given flashier hydrologic regimes (Schottler et al., 2014) would have a higher capability to further incise and entrain temporarily store sediments and nutrients.

Relatively larger runoff events, like the mid-June, mid-August, and late September events in 2016 and the mid-July and early October events in 2017, dominated loads across most of the parameters. For example, in all instances where the surge basin reduced total suspended solid loads in 2016, net reduction totaled -5,570 kg. However, the late September storm resulted in a net export of 23,004 kg of total suspended solids, completely offsetting any stored sediments. This was similar for all other parameters within the surge basin and leaving the watershed at the rate control weir. This varied in the two-stage ditch, with some total suspended load storage during the September event, but followed the previous trend for all other parameters. In 2017, these trends were not consistent. The largest event, a late April to early May event, did not export nearly as much as the September 2016 event and the 2017 watershed was not nearly as saturated as the 2016 watershed. Therefore, water was more likely to be contained within the main channel and did not scour as often or mobilize temporary sediment and nutrients stored on the banks or in the channel as often. These differences between years shows that CD 57 can be overwhelmed by larger runoff events and that concentration reduction does not translate to load reduction over longer (multi-event or multi-annual) temporal scales.

One other factor to consider is tile influence within the samplesheds (Figure 2.39 and Figure 2.40). While tiles were not directly monitored for water quality, their overall impact on each sampleshed should be considered. Tile is densely laid within the southern and eastern portions of the watershed, but exists throughout the entire watershed. Tile lines are typically larger contributors to forms of nitrogen, such as nitrate+nitrite, within watersheds (Blann et al., 2009). The CD001 and CD007 watersheds consistently exhibit higher event and annual concentrations, yields, and loads for nitrate+nitrite as nitrogen. These samplesheds feature densely tiled regions draining agricultural fields. When comparing tile drainage location to the parameters assessed in the study, nitrate+nitrite as nitrogen does not exhibit trends of increasing concentrations, loads, or yields that most of the other parameters do. Previous work within the watershed alluded to increased concentrations of nitrate+nitrite as nitrogen downstream of where tile discharged into the watershed (ISG, 2015b) and this is consistent with concentration results from this study.

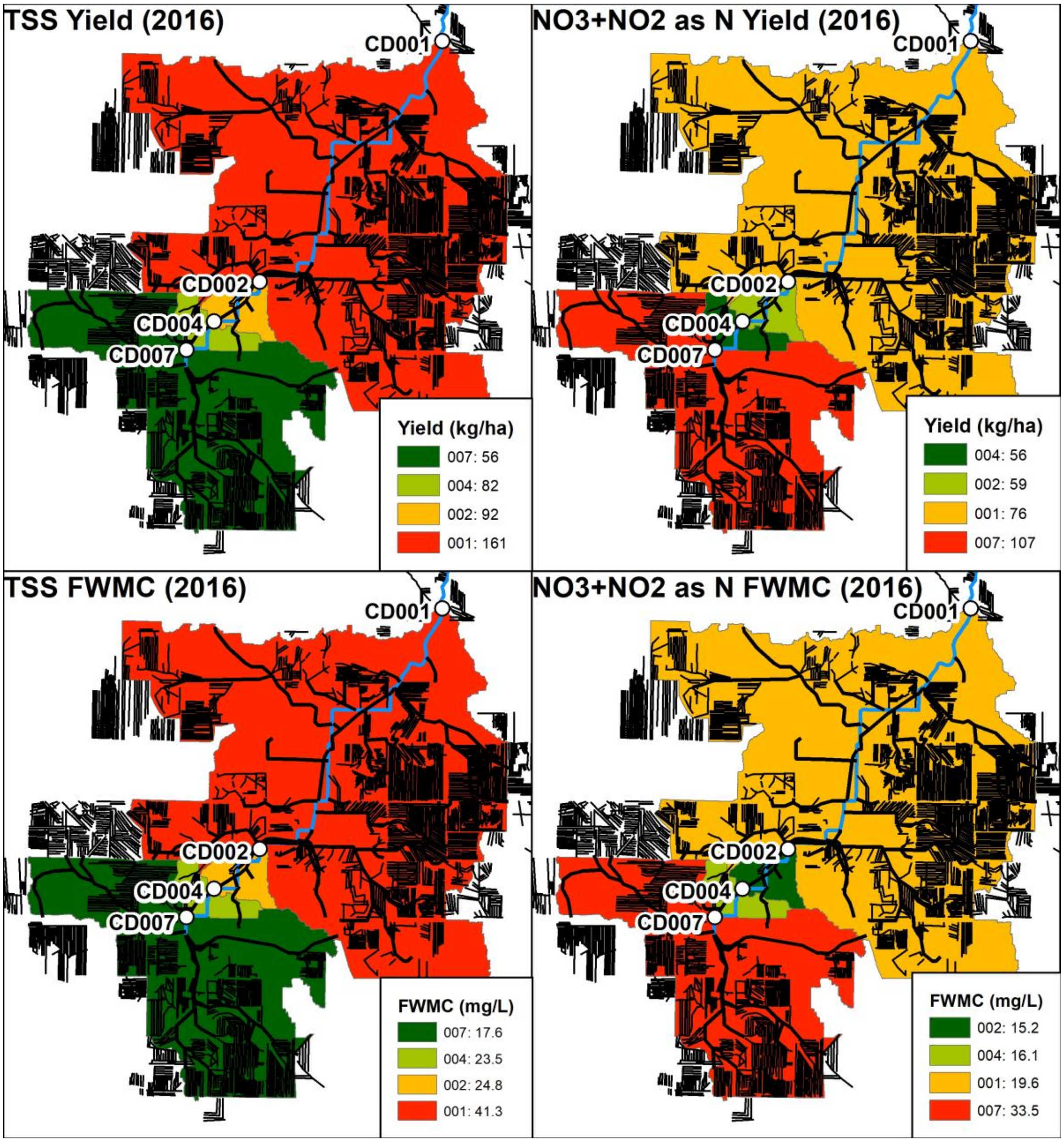


Figure 2.39. Annual yields and concentrations with county main and pattern tile (2016) Total suspended solid concentrations and yields increased downstream, while nitrate+nitrite as nitrogen concentrations and yields were highest in the CD007 and CD001 watersheds.

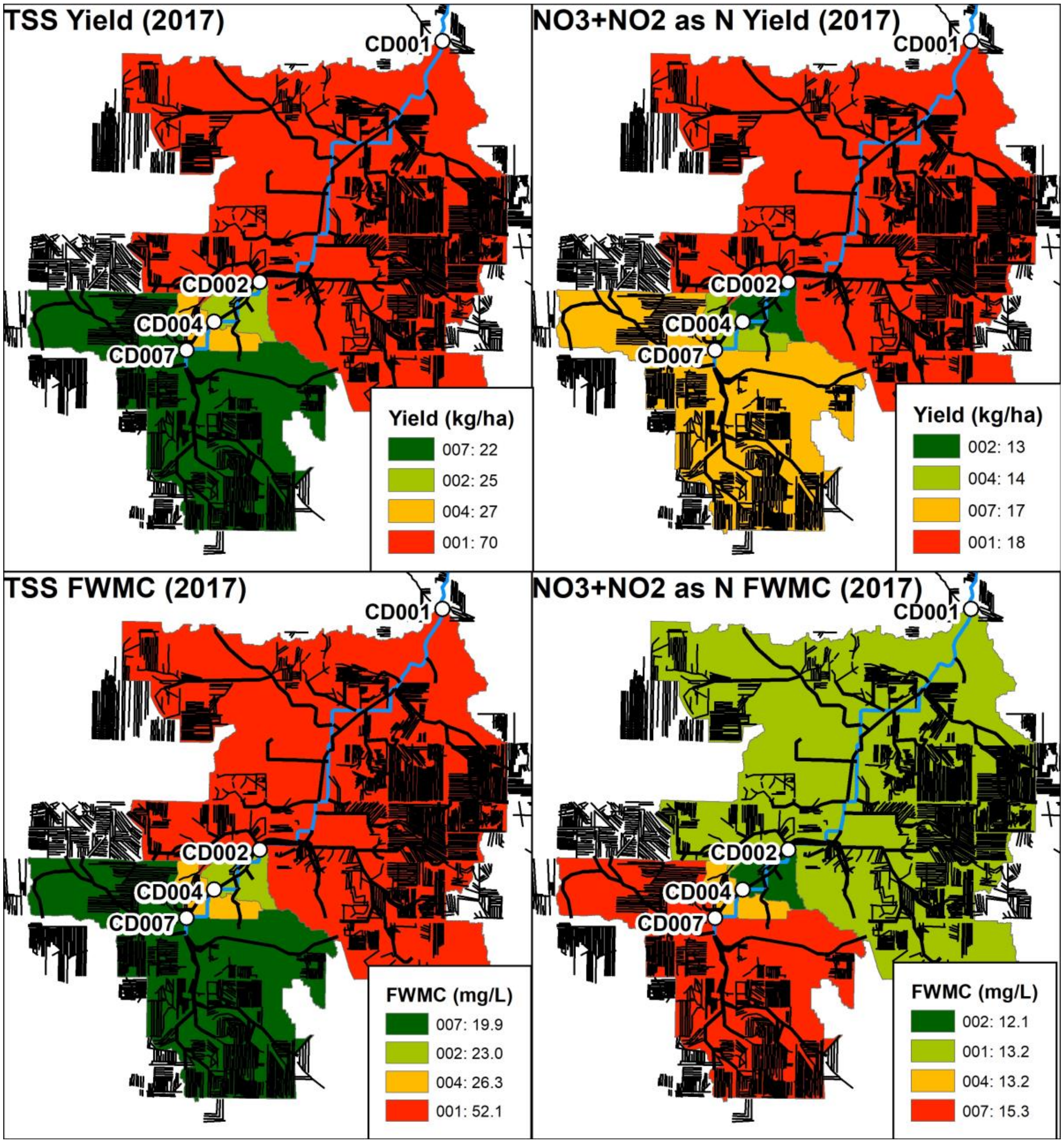


Figure 2.40. Annual yields and concentrations with county main and pattern tile (2017). Similar to 2016, total suspended solid yields and concentrations tended to increase downstream, with the exception of elevated levels within the CD004 watershed, downstream of the surge basin. Unlike 2016, however, the upper portions of the watershed (CD004 and CD007, above the surge basin) featured the highest concentrations, while the CD007 and CD001 watersheds exhibited the highest yields.

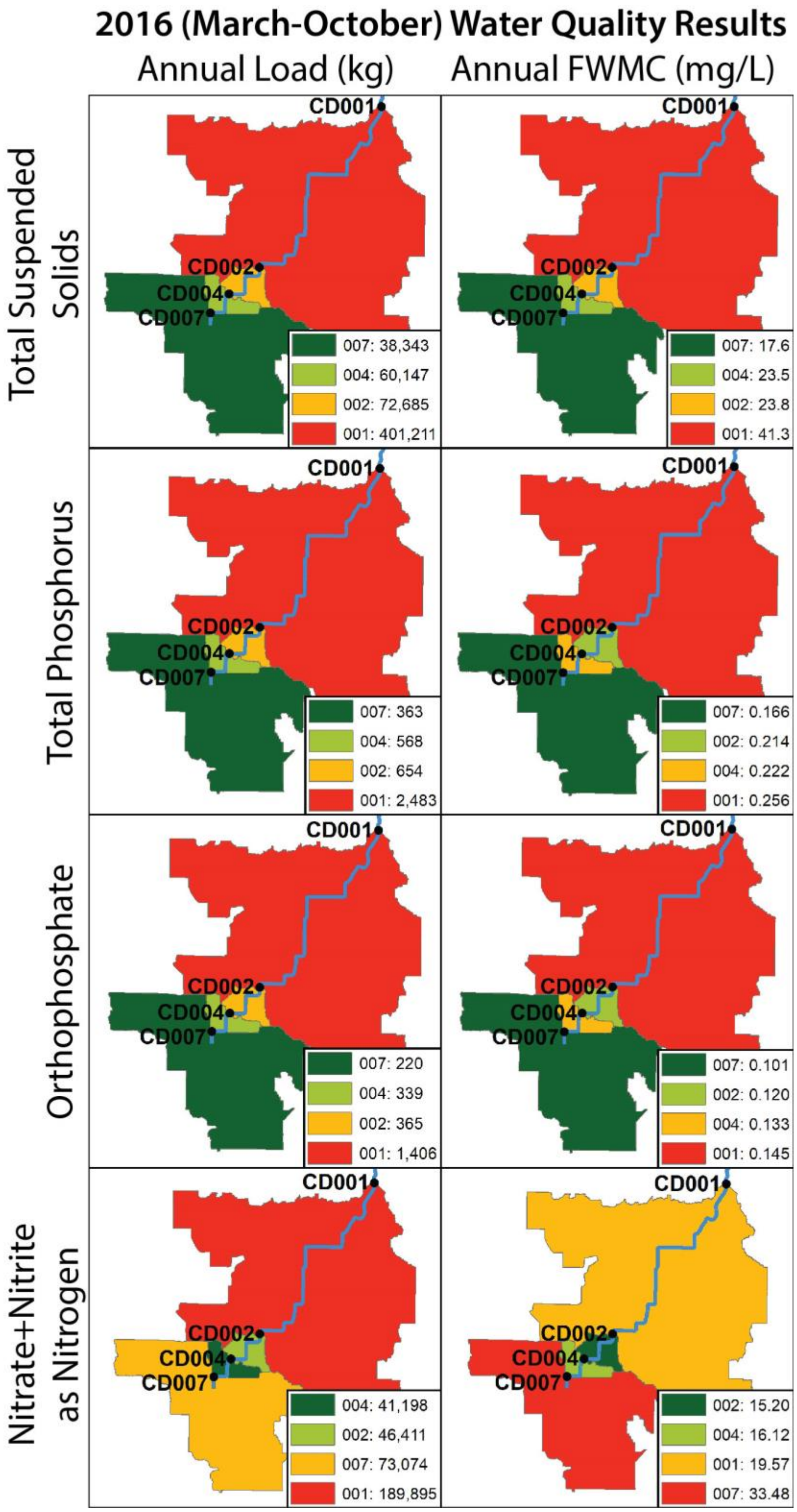


Figure 2.41. Annual water quality results for each sampleshed in the CD 57 watershed for 2016.

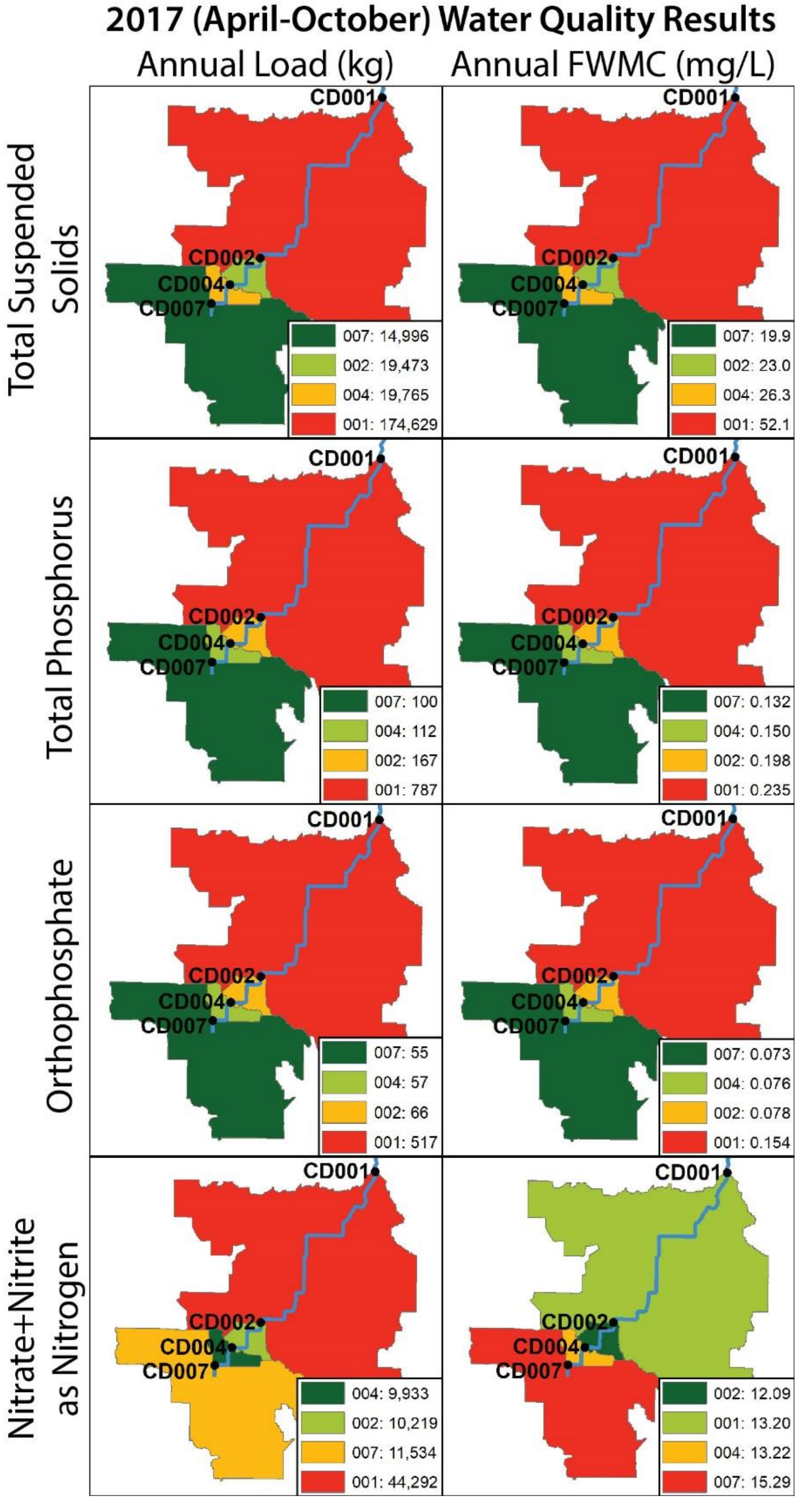


Figure 2.42.Annual water quality results for each sampleshed in the CD 57 watershed for 2017.

2.5.3 Economic and Management Implications

The total cost to reengineer CD 57 was ~$1,311,600 in 2010-11, $485,000 of which came from funds set aside by taxpayers of Minnesota. The total cost to construct the surge basin came to $148,320, or $4.57 per cubic meter of storage (ISG, 2015a). The incremental cost for the two-stage ditch totaled $26,920, or $58.22 extra per meter, relative to a conventional ditch construction project (ISG, 2015a). These structures were designed primarily to reduce peak discharge. While peak discharge may have been reduced within the pond, it did not impact the overall water quality downstream. This suggest that the surge basin is not cost-effective and that the cost to maintain and clean the pond could readily outweigh its benefits. The two-stage ditch, which is not characteristic of a two-stage ditch, would need extensive alterations to meet the required conditions or would need to be left alone and uncleaned so it could build a floodplain. This suggests that the two-stage ditch is also cost-ineffective and that the cost to fix/clean the ditch would quickly outweigh any benefits. With ~70 similar projects planned by a single engineering firm, as of 2015 (ISG, 2015a), the observed tendencies of the CD 57 structural practices suggest that current structural practices in the area need to be reevaluated to determine their cost-effectiveness.

A primary option to achieve the potentially desired reductions would be to upscale the various structural practices so that they could better handle larger discharges, more sediment, and more nutrients (Hansen et al., 2018). However, such increases require more land potentially removed from agricultural use and would also require considerably more funding, to a point where the cost could potentially exceeds what landowners are able to support. As mentioned, a considerable number of other projects are planned for south-central Minnesota. This could result in hundreds of millions of dollars in required funding to achieve the desired results. Also, it is difficult to say whether the current plan for distribution and scale of these structures is sufficient to meet the needs for peak discharge and contaminant reduction where concern is the greatest, within the GBERB. For the LSR, which struggles with flashy flows and increased sediment loads, primarily from bluff erosion, increased storage in the uplands may be a preferable option (MPCA, 2015b). Decreases in peak discharge, which the CD 57 surge basin has shown itself capable of achieving to a degree, would help to release water more slowly to the downstream watersheds and could help reduce bluff erosion. However, in the case of CD 57, the placement of the pond and the length of open channel between the two-stage ditch and the rate control weir consistently allow discharge to increase again. A series of surge basins, positioned throughout the watershed, could potentially help to mitigate this issue, but cost and landowner collaboration would have to be considered (Mitchell, 2015).

2.5.4 Future Considerations

The structural practices of CD 57 have the potential for influence over a much longer time period than the structures may last. These structures may exist as sinks of sediment and nutrients currently, but will most likely continue to be a source of elevated sediments and nutrients over an extended time. The sediment and nutrients stored in the surge basin or two-stage ditch will continue to be stored there until it is either manually cleaned and the sediment removed or it is remobilized during runoff events. While it is stored in those structures there is a potential for nutrient uptake, but there is also a potential for the nutrients to move into the groundwater supply and cause further concern elsewhere. However, while it is difficult to estimate how long such a supply could last in the soil and groundwater, it is a factor that should be considered when implementing practices like those seen in CD 57. Anthropogenic influences to hydrology, land use, and climate need to be considered in the present and the future to determine whether the current suite of best management practices really is the best. Managing current and future water quality issues from county ditches to the regional rivers will depend on the ability to install appropriate practices for in the most effective ways.

2.6 Conclusion

The 2016 and 2017 monitoring seasons provided very different examples of how the structures within County Ditch 57 could perform. Over runoff event conditions, the surge basin in the CD 57 watershed was capable of removing the most nutrient and sediment from the watershed. It was also the most capable at reducing peak discharge. The two-stage ditch could see increased ability to reduce peak discharge and loads, but it does not currently exhibit the characteristics of a typical two-stage ditch and lacks many of the features that make them more successful. With a multitude of water quality improvement projects being constructed across southern Minnesota and across the Midwest, the results from these two years of monitoring help to show positive and negative aspects of each of the examined structures. This project can help inform watershed management practices, provide examples for potential structural efficiency in similar watersheds, and serve as a case study for typical modified agricultural drainages in this region of the world.

Chapter 3: Comparing Modified Agricultural Drainages in the Greater Blue Earth River Basin

3.1 Background

3.1.1 Regional Characteristics

Modified agricultural drainages, watersheds that have been reengineered to effectively control the flow of water, has seen widespread increases over the last century to maintain high crop yields (Pavelis, 1987; Skaggs et al., 1994; Mitsch et al., 2001b; Needelman et al., 2007; Herzon and Helenius, 2008; Blann et al., 2009; Schottler et al., 2014; Kelly et al., 2017). The amount of drained lands in the Mississippi-Atchafalaya River basin (MARB) of the United States has increased from approximately 24,000 to 280,000 km^2 over the last 115 years (Mitsch et al., 2001b). This increase matches well with increases in erosivity, sediment loads, nutrient loads, and poor water quality conditions such as eutrophication and hypoxia (Carpenter et al., 1998; Goolsby et al., 1999; Tilman, 1999; Goolsby et al., 2000; Lawrence et al., 2000; Goolsby and Battaglin, 2001; Goolsby et al., 2001; Smith et al., 2003; Alexander et al., 2008; Schottler et al., 2014).

The Minnesota River basin (MRB) of southern Minnesota, a tributary to the MARB, (Figure 1.2) has experienced increases in suspended sediment loads, nutrient loads, and annual discharge (Payne, 1994; Magdalene, 2004; Petrolia and Gowda, 2006; James and Larson, 2008; Mulla and Sekely, 2009; Musser et al., 2009; Wilcock, 2009; Belmont et al., 2011; Gran et al., 2011; Schottler et al., 2014; Belmont and Foufoula-Georgiou, 2017; Yuan et al., 2017). The MRB has seen an 80-90% reduction of the native land cover (primarily tall-grass prairies, wetlands, and hardwood deciduous forests) and the modern basin has 78-80% in row-crop agriculture (Mulla and Sekely, 2009; Musser et al., 2009; Belmont et al., 2011). Nationally, the MRB is a disproportionate contributor of nutrients to the MARB, responsible for 3-7% of the nitrate load deposited in the Gulf of Mexico (Magdalene, 2004; Steil, 2007), while only representing 1.34% of the drainage area of the MARB. On a more regional scale, watersheds within the MRB are a significant source of sediment (~80-90%) and nutrient loading (~45% of phosphorus; ~56% of nitrogen) to Lake Pepin, a riverine lake of the Upper Mississippi River (UMR) (Figure 1.3) (Kelley and Nater, 2000a; Engstrom et al., 2009; Mulla and Sekely, 2009; Belmont et al., 2011; Blumentritt et al., 2013; MPCA, 2013). Given these trends, ~40% of Minnesota's lakes and streams are currently impaired for "conventional pollutants" under section 303(d) of the Clean Water Act (MPCA, 2016), include turbidity, nitrogen, and phosphorus loading.

The Greater Blue Earth River basin (GBERB), which is comprised of the Blue Earth, Watonwan, and Le Sueur Rivers, is one of the biggest contributors to sediment (~44%), nitrogen (~63%), and phosphorus (~37%) loads in the MRB, to Lake Pepin, and to the Upper Mississippi River watershed (Figure 1.2 and Figure 1.4) (Mulla and Mallawatantri, 2002). The Le Sueur River (LSR), which makes up ~7% of the area of the MRB, was shown to contribute 24-30% of the total suspended solid load to the MRB (MPCA, 2007b; Gran et al., 2011). The LSR and other rivers of the GBERB are listed as impaired for turbidity, dissolved oxygen, e coli, and nutrient/eutrophication biological indicators (MPCA, 2016).

3.1.2 A Landscape Primed For Erosion

Geomorphic events in the GBERB primed the landscape for increased sediment loads. The top 1-3 meters of the subsurface are dominantly glaciolacustrine silts and clays (Matsch and Ojakangas, 1982; Jennings, 2007; Jennings et al., 2012). This sediment was deposited by a series of proglacial lakes, collectively named glacial Lake Minnesota, somewhere between ~14.46-11.27 ka (thousand years before the present) (Matsch and Ojakangas, 1982; Jennings, 2007; Jennings et al., 2012). These estimates are based on radiocarbon ages from buried wood found at a contact between till and lake sediments (Jennings, 2007; Jennings et al., 2012). Beneath the glaciolacustrine sediment lies interbedded glacial till and glaciofluvial sediment that reach a depth of 50-60 meters near Mankato, MN (Figure 1.2).

Much has been done to quantify erosion rates and determine source apportionment above and below a documented knickzone throughout the GBERB (Thoma et al., 2005; Gran et al., 2009; Belmont et al., 2010; Schottler et al., 2010; Belmont, 2011; Belmont et al., 2011; Gran et al., 2011; Gran et al., 2013; Bevis, 2015). This knickzone originated from the initial carving of the modern Minnesota River valley by the glacial River Warren, which served as the southern outlet for glacial Lake Agassiz around ~13.4 ka and 10.3 ka (Gran et al., 2009; Gran et al., 2011; Gran et al., 2013). This work has been aided by geochemical fingerprinting, which uses radioisotopic tracers, in this case Cesium-137 (^{137}Cs), Lead-210 (^{210}Pb), and meteoric Beryllium-10 (^{10}Be), to differentiate between various point sources for sediment (Schottler et al., 2010; Belmont et al., 2011; Gran et al., 2011). These isotopes exist naturally in the atmosphere to a degree, though increased levels of ^{137}Cs exist following above ground nuclear testing between ~1955 and 1963 (Robbins et al., 2000; Schottler et al., 2010). Depths of penetration in natural systems vary between isotopes, however they primarily occupy the top few meters of the soil column (Willenbring and von Blanckenburg, 2010; Belmont, 2012). Concentrations for these isotopes are prominent in upland soils where low gradient surfaces retain more deposition (Walling and Woodward, 1992; Schottler et al., 2010; Belmont et al., 2011; Gran et al., 2011). The isotopes are generally lacking, however, in bluffs, banks, and ravines (near channel sources), where deeper sediment packages are exposed at a more vertical slope (Schottler et al., 2010; Belmont et al., 2011).

Geochemical fingerprinting was used in the LSR watershed, which exists in a state of disequilibrium following incision by the glacial River Warren (Table 3.1) (Schottler et al., 2010; Belmont et al., 2011; Gran et al., 2011). Holocene fine sediment budgets for the LSR were primarily supplied by bluff, bank, and ravine erosion and totaled ~55,000 Mg/yr (Belmont et al., 2011). This was almost entirely from the active zone of incision within the watershed, where 60,000 Mg/yr were eroded, but 5,000 Mg/yr were deposited in the floodplain (Belmont, 2011; Gran et al., 2011). Contributions were negligible in uplands below the knickzone and all areas upstream of the knickzone. By comparison, fine-sediment budgets for 2000-2010 show 225,000 Mg/yr exported, where sediment budgets below the knickzone were ~170,000 Mg/yr, with the largest source being bluffs (107,000 Mg/yr) and uplands (23,000 Mg/yr) (Belmont et al., 2011). Upstream of the knickzone the opposite was observed, where uplands contributed the largest amount of fine sediment (45,000 Mg/yr) and bluffs contributed the second highest

Table 3.1. Source of sediment loads in the Le Sueur River (modified from Belmont et. al, 2011).

	Holocene		2000-2010	
	Below Knickpoint	Above Knickpoint	Below Knickpoint	Above Knickpoint
Floodplains	-5	Small	-30	-6
Bluffs			107	26
Banks	49		24	19
Channels		Small	4	
Ravines	11		12	1
Uplands	Negligible		23	45
Totals	55	Small	140	85
Overall Total	~55		~225	

*Values are provided in 10^3 Mg/yr. Estimated floodplain deposition is shown as a negative number.

(26,000 Mg/yr) (Belmont et al., 2011). As with Lake Pepin, sediment budgets for the LSR correlate to increases in modified agricultural drainages, annual discharge, land use conversion to agriculture, and precipitation totals and intensities (Schottler et al., 2014; Kelly et al., 2017) (Figure 1.9 and Figure 1.10).

Rates of sediment loading in the LSR coincide with increases in peak discharge and total discharge throughout southern Minnesota. These increases have been observed since the 1940s and continue through the present (Zhang and Schilling, 2006; Novotny and Stefan, 2007; Kelly et al., 2017). They are being attributed to increased precipitation and storm intensity and/or to large scale conversion of land cover to row crop agriculture, which exposes bare soil for much of the year and leads to increases in surface runoff. Intense debate currently exists regarding the driving factor of this increase in annual discharge (Gupta et al., 2015; Belmont et al., 2016; Dingbao, 2016; Foufoula-Georgiou et al., 2016; Gupta et al., 2016a; Gupta et al., 2016b; Gupta et al., 2016c; Gupta et al., 2016d; Gupta et al., 2016e; Schilling, 2016; Schottler et al., 2016). While a clear consensus has not yet been reached for the driving mechanism behind this shift, a general consensus agrees that both precipitation and discharge are increasing across the region. This increase, coupled with increases in peak discharge and greater erosivity (Schottler et al., 2014), highlight the need for further research across southern Minnesota to assess the impact of small, headwater watersheds as contributors to discharge and sediment loads.

3.2 Study Area

County Ditch (CD) 57 and Little Beauford Ditch (LBD) are both tributaries to the Big Cobb River watershed and part of the larger LSR and Blue Earth River watersheds (Figure 1.5 and Figure 3.1). LBD is located ~4 km northeast and downstream of the CD 57 watershed. Both watersheds have served as the focus for water quality monitoring projects in recent decades. LBD has been monitored, intermittently from 1994-2017 by the Minnesota Department of Agriculture, Minnesota Department of Natural Resources, Minnesota Pollution Control Agency, United States Geological Survey, and the Minnesota State University, Mankato Water Resources Center. CD 57 has been the focus of monitoring from 2010-2018, by Minnesota State University, Mankato researchers to assess the efficacy of a suite of structural practices that have been installed to help primarily reduce peak discharge, and also total suspended solids, total phosphorus, orthophosphate, and nitrate+nitrite as nitrogen. The watershed was reengineered from 2010-11 to include a surge pond/wetland basin, two-stage ditch, buffer strips along the

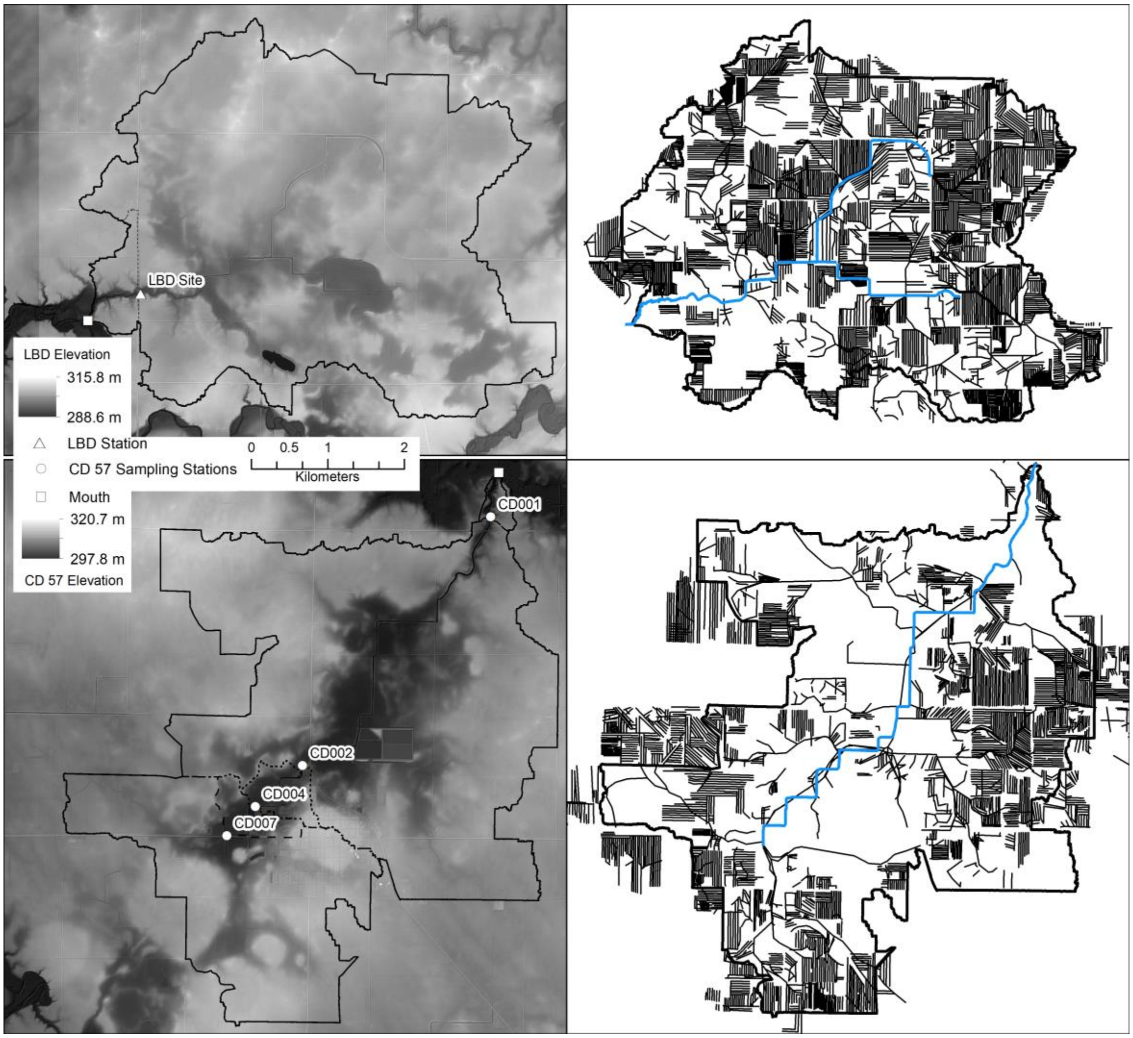


Figure 3.1. Digital elevation map (left) and tile map (right) of County Ditch 86 (Little Beauford Ditch) and County Ditch 57. The inventory used to create the tile map was generated in 2009 and incorporated landowner communication, LiDAR, and aerial imagery interpretation.

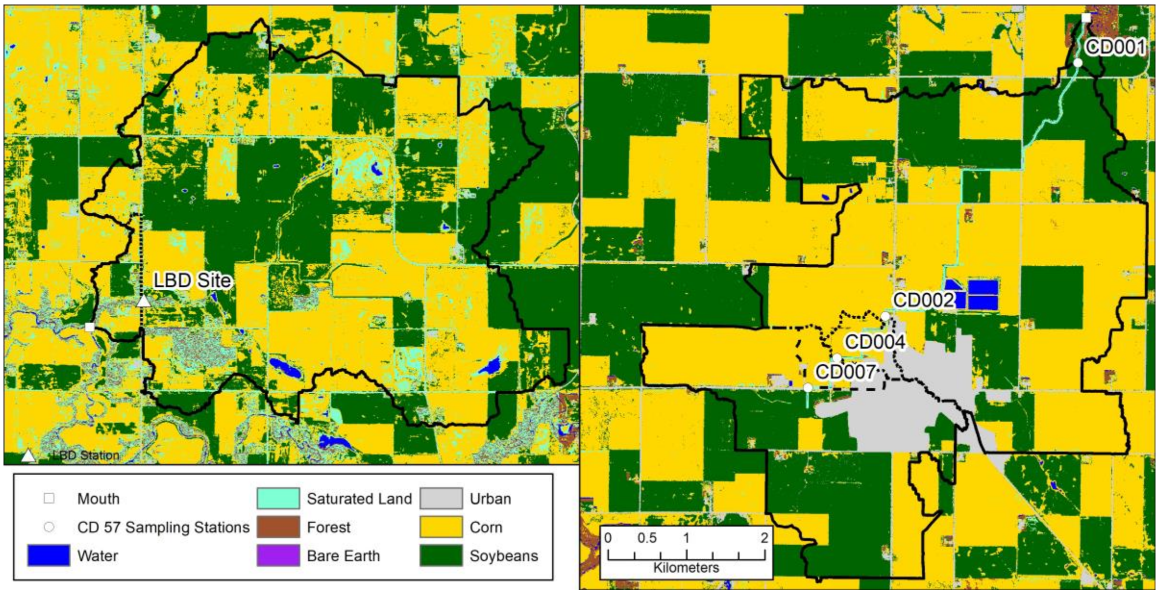
extent of the open channel, and a rate control weir just upstream of the confluence of CD 57and the Big Cobb River. While LBD has a small pond and wetland in place within the watershed, it has not been the subject of a basin-wide reengineering project like CD 57.

Surge basins, such as the one in CD 57, are designed to reduce flow velocity and create a larger wetted perimeter reduce peak discharge, settle out sediment, and allow nutrients to be taken up by aquatic and riparian vegetation (Fennessy et al., 1994; Kovacic et al., 2000; Verstraeten and Poesen, 2000; Woltemade, 2000; Fink and Mitsch, 2004; Hey et al., 2012; Kröger et al., 2012; Fehling et al., 2014; Roley et al., 2016). Increased residence times have been touted as a primary factor in surge basins efficiency (Woltemade, 2000; Kröger et al., 2012). However, varying landscapes, basin location within the watershed, and basin size can all impact how effectively they can function (Kovacic et al., 2000; Woltemade, 2000; Fink and Mitsch, 2004; Kröger et al., 2012; Hansen et al., 2018). It is also of note that there is a potential for surge basins to fluctuate between being a sink and source for sediment and nutrient loads, based on flow conditions. (Verstraeten and Poesen, 2000; Fink and Mitsch, 2004). Furthermore, given high rates of plant productivity, surge basins can be contributors to greenhouse gases like carbon dioxide, methane, and nitrous oxide (de Klein and van der Werf, 2014; Anderson et al., 2016; Maucieri et al., 2017).

Two-stage ditches have emerged as a promising best management practices in recent years and act to simulate low-order streams with active meandering and floodplains (Figure 1.20) (Powell et al., 2007a; Powell et al., 2007b; Roley et al., 2012; Kröger et al., 2013; Mahl et al., 2015; Roley et al., 2016). When properly constructed, two-stage ditches feature pool-riffle sequences, active lateral migration, overbank sedimentation, and greater channel stability (Ward et al., 2004; Powell et al., 2007a; Powell et al., 2007b; D'Ambrosio et al., 2015; Davis et al., 2015; Krider et al., 2017). Two-stage ditches can also form in conventional ditches if the channel is unstable and left to form without interference (Kramer, 2011). Their ability to reduce sediment and nutrient concentrations is typically dependent on residence times within the channel (Davis et al., 2015).

Weirs, low-lying check dams, also serve to reduce flow velocity, increase residence times, allow sediments to settle out, and allow vegetation to take up nutrients (Kröger et al., 2008a; Kröger et al., 2011; Littlejohn et al., 2014). Although they are not listed as a best management practices in Minnesota (Miller et al., 2012) they do show potential but more research is needed (Littlejohn et al., 2014).

Agricultural watersheds have been identified as regions in need of better management of sediment and nutrients (Gentry et al., 2000; Borah et al., 2003; Birgand et al., 2007; Herzon and Helenius, 2008; Kröger et al., 2008b; Smith, 2009). Given a myriad of water quality concerns within the GBERB (MPCA, 2007a; Belmont et al., 2011; Gran et al., 2011; MPCA, 2013; MPCA, 2015a; MPCA, 2016), CD 57 and LBD serve as case studies for typical modified agricultural watersheds within the region. Similar hydrology, land use tendencies (Figure 3.2), size, and proximity to one another provide a unique opportunity to compare a watershed redesigned with a suite of structural practices to reduce peak discharge and contaminant loads to one that has not undergone a similar transformation. Further assessment of other watersheds throughout the GBERB aims to understand how flow-weighted mean concentrations and yields from regional watersheds compare to CD 57 and LBD. This research investigates the characteristics of hydrologically modified headwater drainages within larger fluvial systems and how the implementation of structural practices could help mitigate peak discharges, sediment loads, and nutrient loads, using CD 57 and LBD (in 2016) as case studies to better understand such systems. In CD 57, the station located at the outlet of the watershed (CD001) will be compared to a similarly positioned station in LBD (Figure 3.1).



	LBD Monitoring Station Watershed (2016)	CD001 Monitoring Station Watershed (2016)	LBD Watershed (2016)	CD 57 Watershed (2016)
Watershed Size (Ha)	2085	2498	2152	2517
Average Slope (Degrees)	1.90	1.75	1.95	1.78
Water (%)	0.5%	1.0%	1.1%	1.0%
Saturated Land (%)	9.0%	1.4%	12.1%	1.4%
Forest (%)	1.2%	0.3%	1.2%	0.4%
Urban (%)	1.1%	11.1%	1.1%	11.0%
Corn (%)	50.1%	53.2%	47.2%	52.8%
Soybeans (%)	38.4%	33.0%	37.3%	33.3%
Mollisols (%)	94.0%	64.1%	94.0%	68.1%
C/D Soils (%)	85.0%	68.1%	85.0%	66.2%

Figure 3.2. Land use and land cover map (2016) of County Ditch 86 (Little Beauford Ditch) and County Ditch 57. Land used for corn and soybeans were dominant within both watersheds. Urban lands make up more of the CD 57 watershed because of the city of Mapleton, MN, while only the small township of Beauford, MN is within the LBD watershed.

3.3 Methods

3.3.1 Precipitation Data

Precipitation data were collected at CD 57 and LBD to compare total precipitation across each watershed with discharge results. In CD 57, rainfall was measured by a NexSens iSIC 3100 Data Logger with a Vaisala Weather Transmitter WXT520 rain gauge. This unit collects wind direction, wind speed, maximum wind speed, air temperature, relative humidity, barometric pressure, daily rainfall, rainfall intensity, and sunlight intensity. Further precipitation data were collected by three Teledyne Isco 674 Tipping Bucket Rain Gauges and three Onset RG3 Hobo Data-Logging Rain Gauges opportunistically dispersed throughout the watershed. These data were averaged across the watershed to determine total rainfall for the year. Precipitation data for LBD were collected using a Campbell TE525 tipping bucket rain gauge stationed at the sampling location. Monthly averages were compared to 1981-2010 climate normal averages from Mankato, MN and totals gathered by the Minnesota State Climatology Office (MSCO, 2018; NOAA, 2018). Values from the Minnesota State Climatology Office were generated through the interpolation of a network of professional and certified amateur precipitation collection stations (MSCO, 2018).

3.3.2 Hydrology

Water level and velocity data were recorded at continuous five minute intervals through the monitoring season at CD 57 site CD001, located near the mouth of the watershed (Figure 3.1). Isco 720 Submerged Probe Flow Modules (level only) and Isco 750 Area Velocity Flow Modules (level, velocity, and discharge) were stationed in the rate control weir to monitor flow conditions. Water levels at LBD were collected at fifteen minute intervals through use of a Campbell CS650 Pressure Transducer. Both sites were corrected and validated with measurements by an Acoustic Doppler Current Profiler (ADCP) and wading rod approximately once a month by the Minnesota Department of Natural Resources. Measurements from CD 57 were corrected and validated further through use of a Marsh-McBirney Flo-Mate 2000 Portable Velocity Flow Meter and wading rod. After each season, level and discharge data were then processed and corrected by a Minnesota Department of Agriculture hydrologist using the software Stream Trac (Forest Technology Services). The output of this data were used to generate loads for the various measured parameters.

In some cases, corrections had to be made to data that were too low quality to use or if an event was missed. CD001 had particular issues with this because of highly variable velocities and the location of the probe in the notch of the weir. For 2016, CD001 had to be extrapolated off of data from an upstream site, scaled by sampleshed area, and fit to the FloMate recordings. When comparing the 2016 extrapolations to records from 2017 when the data did not need extrapolation the relationship between average discharges at these two sites was proportional. Furthermore, corrections had to be made when flow rose over the top of rate control weir. These corrections were made by measuring flow across the top of the weir and within the notch of the weir and shifting the hydrographs appropriately.

3.3.3 Water Quality Sampling

Water quality samples for CD 57 were collected by a Teledyne Isco 6712 Full-Size Portable Sampler, equipped with twenty-four one liter bottles. The 6712 sampler was programmed to trigger after water levels rose by 10-20% of the current water level. Samples were collected within one to two days and brought back to the Minnesota State University, Mankato laboratory to create a discharge-based composite sample. This typically represented the duration of the storm hydrograph until conditions returned to base flow. Base flow was approximated by employing the constant-slope method developed by Linsley Jr. et al. (1975) where:

$$D = 0.827A^{0.2}$$

Where

D is the number of days between the peak of the storm and the end of overland flow

A is the area of the watershed in square miles

This sample was then sent to certified laboratory, Minnesota Valley Testing Laboratory in New Ulm, MN, within two days of the program finishing, ensuring that the sample was refrigerated until it reached the laboratory to reduce any organic activity. At the lab, procedures followed USGS protocol 1-3765-85 and EPA protocols 365.1 and 353.2 for TSS, TP and PO_4, and NO_3+NO_2-N, respectively (USGS, 1985; EPA, 1993a; EPA, 1993b). The collection bottle for TP, PO_4, and NO_3+NO_2-N contained 1 ml of sulfuric acid (H_2SO_4) per 500 ml bottle.

Water quality samples at LBD were also collected by an Isco 6712 Full-Size Portable Sampler. This sampler was equipped with a 9.5 liter jar that collected up to 96 pulses of water, based on a developed relationship between water levels and flow. Sample durations represented as little as two days and as much as two weeks of water, encompassing both storm runoff and base flow periods, therefore it is not possible to compare CD 57 and LBD by single events and they will be compared monthly. This method captured 79% of the flow volume for the year. These samples were collected and processed at a certified laboratory to determine concentrations for nitrate+nitrite as nitrogen, total phosphorus, orthophosphate, total suspended solids, and total Kjeldahl nitrogen.

3.3.4 Load Calculations

After discharge data were finalized for each season it was combined with concentration results to generate loads for runoff event and base flow conditions. This was accomplished through the use of a spreadsheet created by the Minnesota Department of Agriculture to generate composite sample loads. This spreadsheet converted discharge to liters and then multiplied the liters by the parameter concentration (in mg/L) to determine the load of the entire five or fifteen minute interval. Then, this load was totaled to generate a cumulative load for each event, month, or year.

In some instances, it was necessary to fill gaps in data because of equipment malfunctions or improper trigger levels. In the case of CD 57 base flow conditions, preceding and succeeding base flow concentrations were averaged and input into the model. In the case of a missed event, it was necessary to develop a range of values to encompass all possible conditions, utilizing a number of approaches were utilized to create an acceptable range. One method compared the cumulative discharge of the event to the total calculated load at the site where the gap existed to develop a best fit relationship. The next two methods used two upstream sites to scale their loads the outlet site, based on discharge. Finally, where possible, a relationship between turbidity and flow-weighted mean concentrations for total suspended solids was developed. This relationship was then used to generate total suspended solids loads based on turbidity readings gathered every fifteen minutes. To ensure that the loads used were accurately representing potential loads, ranges were used in the case of missed runoff events. The minimum and maximum estimates were selected if they fell within one and a half times the interquartile range. The interquartile range was used, as it is a smaller constraint than using the first standard deviation. In larger events, where the estimate fell outside of one and a half times the interquartile range, but within the first standard deviation, the number was used, but noted. This generated event and annual estimates to compare loads between CD 57 and LBD. In 2016, five of the twenty-three events were missed and estimates were developed for these events.

3.4 Results and Discussion

3.4.1 Precipitation

Precipitation in both CD 57 and LBD in the 2016 monitoring year exceeded climate normal averages (~700 mm) by up to 400 mm (NOAA, 2018). Overall, LBD saw ~70 mm more rainfall that CD 57 (MSCO, 2018). While May, June, and October exhibited normal climate conditions July-September experienced 2-3 times the average rainfall for

Table 3.2. Monthly precipitation values for May-October for County Ditch 57 and Little Beauford Ditch in the 2016 monitoring year, compared to the 1981-2010 climate normal values from Mankato, MN.

	1981-2010 Rainfall Mankato (mm)	2016 Rainfall Mapleton (Averages) (mm)	2016 Rainfall Mapleton (NexSens) (mm)	2016 Rainfall Mapleton (MSCO) (mm)	2016 Rainfall Beauford (MSCO) (mm)	2016 Rainfall Beauford (Campbell) (mm)
May	87.6	67.8	89.4	88.6	97.0	94.0
June	129.3	84.0	102.6	97.3	100.6	110.7
July	109.7	152.2	175.5	180.3	176.5	156.2
August	106.2	185.2	223.0	210.3	241.6	231.6
September	81.5	187.1	226.3	221.2	256.3	205.0
October	58.9	68.2	62.5	107.7	98.3	81.3
Total Rainfall (mm)	**573.3**	**744.5**	**879.3**	**905.5**	**970.3**	**878.8**

each month (Table 3.3). The largest storm during the 2016 monitoring season was recorded in late September, with rainfall averaging 95-105 mm across the CD 57 and LBD watersheds. In total, six storms in CD 57 and four storms in LBD brought rainfall totals over 40 mm. A series of mid-August storms brought the highest rainfall intensities in CD 57 during the 2016 season with an average of 24 mm of rainfall in approximately 30 minutes and then another 16 mm in approximately 30 minutes, with average rainfall intensities of 48.6 mm/hr and 24.57 mm/hr, respectively. An early August storm in LBD brought the highest rainfall intensity, with 43 mm of rain falling over the course of 45 minutes (57 mm/hr).

3.4.2 Hydrology

Increased rainfall totals resulted in increased monthly discharge across both watersheds. The CD 57 watershed discharged ~7.09x10^8 liters more than LBD overall in 2016, however July and August were both higher in LBD (Table 3.4 and Figure 3.3). Discharge was greatest in September for both sites, as a result of the late September storm that supplied ~95-105 mm of water across both watersheds. Monthly peak discharge was higher for LBD in all months except April and October. The highest peak discharge for CD 57 and LBD came during the September storm, where CD 57 peaked at ~7,439 L/s at the rate control weir and LBD peaked at 7,538 L/s (Table 3.5). Overall, peak discharge at CD 57 averaged 2,181 L/s while averaging 2,357 L/s at LBD.

The structural practices within the CD 57 watershed were designed to control discharge by slowing velocities and adding more storage capacity. Average discharge at CD 57 was 553 L/s compared to 510 L/s at LBD over the same monitoring period. Even though more water flowed through CD 57, peak discharge rates were almost always smaller than at LBD. This supports the desired impact of the structural practices in the CD 57 watershed to reduce peak discharge. As water is temporarily stored in the two-stage ditch, surge basin, or behind the rate control weir it releases water through the watershed more slowly than in LBD. However, in cases where water exceeds the height of the rate control weir, higher peak discharges can still be observed, as in the case of the 6/14, 7/17. And 9/22 events (Table 3.5).

Table 3.3. Hydrologic parameters of discharge and peak discharge for the CD 57 and LBD from April to October in 2015. April represents a partial month, starting on the 4/21. Peak discharge was not always from the same event, but rather represents the monthly peak discharge from each site. Shaded cells denote the smaller value.

Month	LBD Total Q (Liters)	CD 57 Total Q (Liters)	LBD Peak Q (lps)	CD 57 Peak Q (lps)	LBD Peak Time	CD001 Peak Time
April	174,473,279	372,464,309	762	2,599	4/28/16 12:00	4/30/16 20:15
May	767,757,219	1,115,668,934	1,323	880	5/26/16 5:45	5/13/16 13:00
June	988,233,226	1,036,943,599	5,327	4,111	6/14/16 19:30	6/14/16 20:25
July	765,417,660	745,569,424	2,547	2,298	7/17/16 7:45	7/17/16 1:10
August	1,513,672,808	1,427,622,358	6,306	3,659	8/11/16 6:45	8/23/16 21:00
September	3,076,753,419	3,236,596,987	7,546	7,439	9/22/16 0:15	9/22/16 6:10
October	1,241,730,796	1,301,846,772	2,534	2,790	10/5/16 6:45	10/26/16 4:35
All	**8,528,038,408**	**9,236,712,383**	**3,764**	**3,397**		
	Total	Total	Average	Average		

Table 3.4. A selection of comparable peak discharge measurement from runoff events in 2016. Shaded cells denote the smaller value.

LBD Peak Time	CD 57 Peak Time	LBD Peak Discharge (lps)	CD 57 Peak Discharge (lps)
4/28/2016 12:00	4/29/2016 8:15	762	920
5/1/2016 8:00	5/1/2016 1:30	499	2599
5/12/2016 0:15	5/12/2016 8:10	571	431
5/26/2016 5:45	5/26/2016 12:15	1323	407
6/11/2016 1:30	6/11/2016 10:55	497	336
6/14/2016 19:30	6/15/2016 5:15	5327	4111
7/7/2016 11:00	7/7/2016 11:50	1249	502
7/10/2016 16:30	7/10/2016 17:15	1106	738
7/17/2016 7:45	7/17/2016 11:00	2547	2298
8/11/2016 6:45	8/11/2016 16:30	6306	1919
8/19/2016 6:15	8/19/2016 4:20	502	1439
8/24/2016 2:15	8/24/2016 9:35	2687	3659
9/6/2016 15:30	9/7/2016 16:05	1701	1656
9/15/2016 23:45	9/16/2016 10:00	3732	3651
9/23/2016 0:15	9/23/2016 19:35	7546	7439
10/26/2016 8:45	10/26/2016 10:30	1354	2790

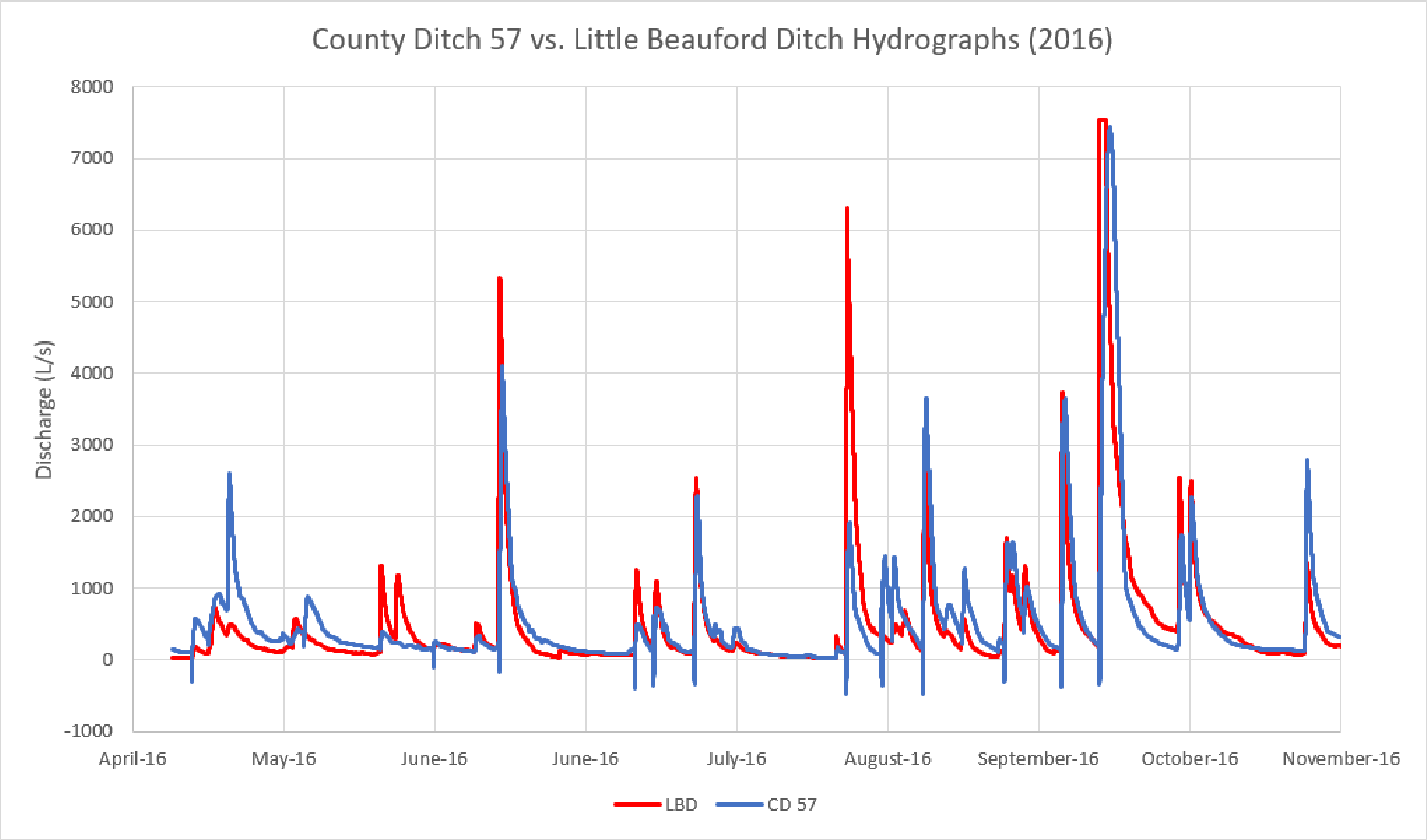


Figure 3.3. Hydrograph comparison between County Ditch 57 and Little Beauford Ditch in 2016. While more water was discharged from CD 57 at the rate control weir than at the LBD watershed, higher peaks were still observed in LBD.

3.4.3 Flow-Weighted Mean Concentrations

Flow-weighted mean concentrations for total suspended solids were higher at LBD than at CD 57 during every month monitored (Table 3.6). Total averages for suspended solids over the duration of the monitoring period were 109 mg/L at LBD and 42 mg/L at CD 57. Highest concentrations in LBD were observed from May-July, with June featuring the highest monthly average in LBD (263 mg/L). June also featured the highest monthly total in CD 57, though May and July were among the lowest observed averages. Overall, heightened discharge and heightened concentrations at LBD would suggest that the CD 57 structural practices are helping reduce sediment concentrations.

Total phosphorus concentrations were also dominantly higher in the LBD watershed, for all months except April and May. Late April through October flow-weighted mean concentrations at LBD averaged 0.379 mg/L, while averaging 0.240 mg/L at CD 57 (Table 3.6). Both of these concentrations far exceed the Minnesota Office of the Revisor of Statutes (2016) limit on total phosphorus for preventing the development of eutrophic conditions at 0.030 mg/L. Concentrations at levels seen in LBD and CD 57 pose threats to the development of eutrophic conditions within their respective waterbodies. However, lower concentrations of total phosphorus at CD 57, along with lower concentrations of total suspended solids, would suggest that sediment-bound phosphorus is settling out with suspended solids, increasing residence times and uptake by vegetation.

The largest difference in flow-weighted mean concentrations between the two ditches is seen in nitrate+nitrite as nitrogen concentrations. CD 57, while generally lower in both total suspended solids and total phosphorus, far exceeds average values seen in LBD for

Table 3.5. Flow-weighted mean concentrations for total suspended solids (TSS), total phosphorus (TP), and nitrate+nitrite as nitrogen (NO3+NO2). Shaded cells denote smaller values.

Month	LBD TSS FWMC (mg/L)	CD 57 TSS FWMC (mg/L)	LBD TP FWMC (mg/L)	CD 57 TP FWMC (mg/L)	LBD NO3+NO2 FWMC (mg/L)	CD 57 NO3+NO2 FWMC (mg/L)
April	55	29	0.148	0.160	19.00	22.74
May	171	13	0.212	0.227	19.56	21.11
June	263	131	0.438	0.326	15.04	21.40
July	121	10	0.309	0.173	14.37	17.70
August	84	34	0.462	0.232	9.96	15.61
September	91	50	0.378	0.280	4.95	17.24
October	24	9	0.409	0.151	8.41	13.92
Total Avg	**109**	**42**	**0.379**	**0.240**	**9.96**	**17.72**
Standard Level	N/A		0.025-0.100 (Dependent on use)		10.00 (for Human Consumption)	

nitrate+nitrite as nitrogen concentrations by nearly double (17.72 mg/L vs. 9.96 mg/L). While concentrations at LBD tended to decrease through the growing season, as more vegetation was taking up nitrate+nitrite as nitrogen, CD 57 observed similar trends, but maintained much higher concentrations overall. During the months of April through July in LBD and April through October in CD 57, concentrations exceeded EPA maximum contaminant for human consumption (10 mg/L) and posed threats to the development of eutrophic conditions within their respective watersheds (Mueller and Helsel, 2013b).

While it is not possible to directly compare LBD and CD 57 on an event basis, a small subset (n=11) of events offer some comparable concentrations (Table 3.7). It is of interest to note that, while most of the LBD samples were composed of base flow and event runoff, concentrations of total suspended solids and total phosphorus are almost always higher at LBD. However, when comparing nitrate+nitrite as nitrogen, flow-weighted mean concentrations at CD 57 far exceed those seen at LBD. These high concentrations are not apparent before the rate control weir site in the CD 57 watershed. Average concentrations across all runoff events over the course of the monitoring season (March-October 2016) from the CD 57 two-stage ditch were the lowest in the top half of the watershed (14.72 mg/L), while flow-weighted mean concentrations jumped to 21.36 mg/L at the rate control weir (Appendix C). This increase could be stemming from excess application of manure/fertilizer farther downstream of the two-stage ditch, after the major in-channel hydrology-based structural practices within the watershed.

Table 3.6. Subset of events during the 2016 monitoring year, where concentrations between CD 57 and LBD were comparable to one another, based on similar collection times.

CD 57 Event Start Time	CD 57 Event End Time	CD 57 Event Duration	LBD Event Start Time	LBD Event End Time	LBD Event Duration	Time Overlapped	LBD TSS FWMC (mg/L)	CD 57 TSS FWMC (mg/L)	LBD TP FWMC (mg/L)	CD 57 TP FWMC (mg/L)	LBD NO3+NO2 FWMC (mg/L)	CD 57 NO3+NO2 FWMC (mg/L)
4/27/16 12:45	4/30/16 15:05	74:20:00	4/27/16 8:08	4/29/16 13:32	53:24:00	48:47:00	64	46	0.173	0.116	19.00	25.00
4/30/16 15:10	5/2/16 15:15	48:05:00	4/29/16 16:08	5/4/16 2:32	106:24:00	48:05:00	32	15	0.086	0.152	19.00	26.21
5/11/16 4:00	5/13/16 10:15	54:15:00	5/5/16 11:38	5/13/16 7:26	187:48:00	51:26:00	65	8	0.113	0.070	20.00	23.81
5/13/16 10:20	5/15/16 12:55	50:35:00	5/13/16 11:08	5/23/16 11:20	240:12:00	49:47:00	34	7	0.082	0.077	20.00	25.41
5/26/16 2:20	5/28/16 2:00	47:40:00	5/25/16 13:32	5/28/16 16:23	74:51:00	47:40:00	400	76	0.429	0.231	19.00	28.91
6/13/16 18:40	6/16/16 19:00	72:20:00	6/14/16 15:05	6/15/16 18:08	27:03:00	27:03:00	430	268	0.696	0.530	9.90	19.81
8/11/16 6:00	8/13/16 6:15	48:15:00	8/11/16 11:23	8/15/16 12:32	97:09:00	42:52:00	73	72	0.397	0.399	7.30	16.70
8/18/16 17:10	8/20/16 18:05	48:55:00	8/15/16 16:05	8/23/16 20:26	196:21:00	48:55:00	56	19	0.712	0.155	12.00	17.30
8/23/16 20:50	8/25/16 23:20	50:30:00	8/25/16 11:47	9/2/16 4:14	184:27:00	38:57:00	39	69	0.260	0.293	13.00	16.50
9/6/16 9:50	9/9/16 5:50	68:00:00	9/2/16 11:53	9/9/16 5:50	161:57:00	68:00:00	83	13	0.308	0.226	11.00	18.51
10/25/16 20:30	10/28/16 0:15	51:45:00	10/25/16 14:23	11/1/16 11:59	165:36:00	51:45:00	44	34	0.586	0.389	10.00	13.30

The watershed of the two-stage ditch does not seem to be where the majority of the concentration is coming from, suggesting that the urban influence of the city of Mapleton is not a dominant factor. There are a series of municipal water treatment ponds in the CD 57 watershed, downstream of the two-stage ditch monitoring station. Water from these ponds is released a few times each year. These ponds could also be contributing to the increase in nitrate flow-weighed mean concentrations, but when examining composite samples that were concurrent with the discharging of the ponds there seems to be no discernible increase that elevates these nitrate+nitrite as nitrogen flow-weighted mean concentrations above proximal runoff event flow-weighted mean concentrations at the rate control weir. Unpublished flow-weighted mean concentrations from a previous study within CD 57 (2013-14) and flow-weighted mean concentrations from this study suggest that the watershed between the rate control weir and the two-stage ditch, which is dominantly tiled and used for row crop agriculture, is the source of elevated levels leaving the watershed. The eastern portion of the watershed, which features dense pattern tile throughout, discharges downstream of the two-stage ditch and should be examined further to understand its influence on loads of nitrate+nitrite as nitrogen (Figure 3.1).

3.4.4 Loads and Yields

Loads during the 2016 monitoring season closely mirrored trends in concentrations between CD 57 and LBD (Table 3.8). Total suspended solid loads are higher at LBD than CD 57 for every month except April, when discharge at CD 57 doubled that of LBD. However, concentrations in LBD (55 mg/L) still exceeded concentrations from CD 57

Table 3.7. Monthly load (kg) totals for total suspended solids, total phosphorus, and nitrate+nitrite as nitrogen for LBD and CD 57 in 2016. Shaded cells denote smaller values.

Month	LBD TSS (kg)	CD 57 TSS (kg)	LBD TP (kg)	CD 57 TP (kg)	LBD NO3+NO2 (kg)	CD 57 NO3+NO2 (kg)
April	9,585	10,717	25.9	59.5	3,316	8,472
May	131,639	14,475	162.8	253.8	15,025	23,561
June	259,864	136,231	433.0	338.0	14,866	22,198
July	92,946	7,563	236.5	129.2	11,001	13,200
August	126,754	49,037	700.0	332.0	15,076	22,290
September	278,601	161,094	1,164.5	906.0	15,240	55,829
October	30,255	11,832	508.2	196.7	10,452	18,128
All	**929,643**	**390,948**	**3,230.9**	**2,215.2**	**84,975**	**163,678**
	Total	Total	Total	Total	Total	Total

(29 mg/L). During the extent of the monitoring season, total suspended solid loads from LBD more than doubled those from CD 57.

Total phosphorus loads and nitrate+nitrite as nitrogen loads both follow the same trend as the flow-weighted mean concentrations. Total phosphorus was higher from CD 57 in April and May, but higher for LBD the rest of the year. Nitrate+nitrite as nitrogen was higher in every month for CD 57, with exports of nearly double from the CD 57 watershed. The largest monthly total for nitrate+nitrite as nitrogen was exported in September, with CD 57 loads greater than triple those calculated from LBD.

Yields for the two watersheds also exhibited trends similar to those seen in loads and flow-weighted concentrations (Table 3.9). September featured the highest yields across all nutrient and sediment parameters in both watersheds. Total suspended solids in LBD totaled 445 kg/ha over the monitoring period, while CD 57 totaled 157 kg/ha (Table 3.9).

Table 3.8. Yields for total suspended solids, total phosphorus, and nitrate+nitrite as nitrogen for 2016. Shaded cells denote smaller values.

Month	LBD TSS Yield (kg/ha)	CD 57 TSS Yield (kg/ha)	LBD TP Yield (kg/ha)	CD 57 TP Yield (kg/ha)	LBD NO3+NO2 Yield (kg/ha)	CD 57 NO3+NO2 Yield (kg/ha)
April	5	4	0.012	0.024	1.59	3.39
May	63	6	0.078	0.102	7.20	9.43
June	125	55	0.208	0.135	7.12	8.89
July	45	3	0.113	0.052	5.27	5.29
August	61	20	0.335	0.133	7.22	8.92
September	134	65	0.558	0.363	7.30	22.35
October	14	5	0.244	0.079	5.01	7.26
All	**445**	**157**	**1.548**	**0.887**	**40.72**	**65.54**
	Total	Total	Total	Total	Total	Total

Total phosphorus amounted to 1.548 kg/ha in LBD with 36% of the yield being supplied in September (0.558 kg/ha). CD 57 transported much less total phosphorus in terms of yields, with 0.887 kg/ha leaving the watershed and 41% of that occurring in September. Nitrate+nitrite as nitrogen yields closely mirrored load trends, with CD 57 transporting 160% more than LBD. A third of the CD 57 yield, and over half of the LBD monitored total yield, occurred during September, with 22.35 kg/ha of nitrate+nitrite as nitrogen being transported out of the watershed. The main contributor to this load was the late September 2016 storm, where 12.45 kg/ha were transported out of the CD 57 watershed, compared to LBD, which transported ~5.00 kg/ha.

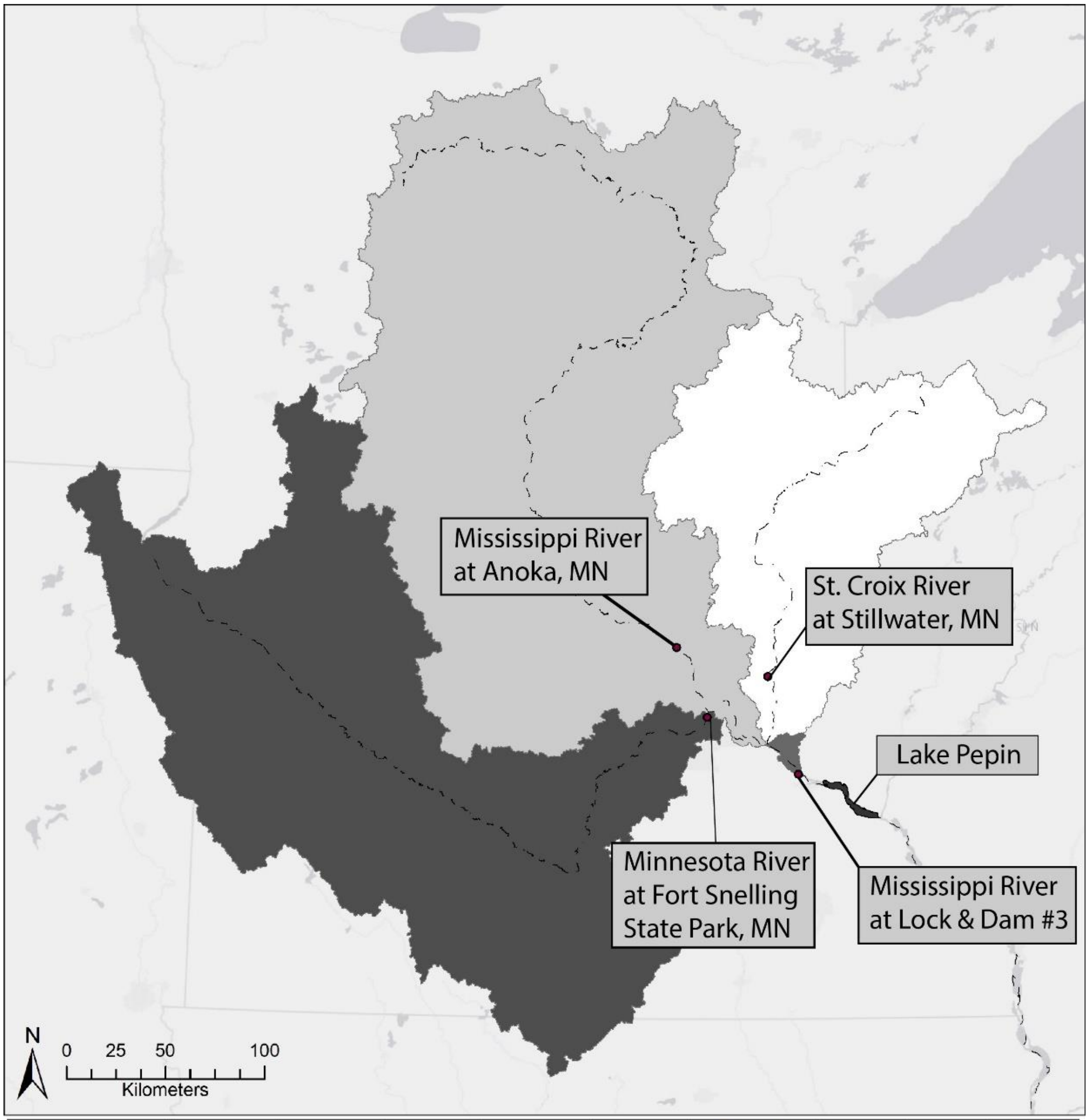
3.4.5 Comparing County Ditch 57 to Little Beauford Ditch

The location, size, and monitoring extent of the CD 57 and LBD watersheds provided a unique opportunity to compare two proximal, hydrologically modified, agricultural watersheds. However, differences between the watersheds may make them less comparable than desired. The monitoring station of CD 57 is stationed in the rate control weir at the outlet of the watershed. This base level of this station (CD001) is primarily controlled by the stage of the Big Cobb River, subjecting it to potential issues in backflowing water. The LBD station is position on the upstream side of a culvert that has a small drop on its downstream extent, reducing the possibility that the LBD monitoring station is influenced by backflow. While the LBD and CD 57 watersheds do exhibit similar land use and land cover tendencies, soil characteristics, and drainage modifications, there seem to be some substantial differences between them. Unfortunately, without full-scale monitoring of both of the watersheds (in-channel and tile) it would be difficult to say where the biggest differences in hydrology and water quality stem from. Even though they are similar in many ways, key differences exist that make the ability to compare these two watersheds somewhat questionable and more data and more concurrent years of monitoring would be needed to rectify this concern.

3.4.6 Regional Comparisons

The 2016 monitoring season for the CD 57 and LBD watersheds serve as a case study for agricultural watersheds within the GBERB. However, while they provide a strong context for nutrient and sediment transport within headwater agricultural systems, they also represent an atypically wet year. To better assess these watersheds and their contribution to the GBERB and MRB it is necessary to examine other proximal watersheds of varying size to understand typical flow-weighted mean concentrations throughout the region. CD 57 and LBD are also part of larger projects that span more than just one year. LBD has been intermittently monitored for a wide array of sediment, nutrient, and chemical parameters, with measurements from 1994-2016. CD 57 was monitored at four different locations from 2016-17, to assess the efficacy of structural practices within the watershed. A final year of monitoring in CD 57 will culminate in 2018. To better understand how these watersheds function across more averaged time scales, flow-weighted mean concentrations and yield data from CD 57 (2016-17) and LBD (2009-15) will be compared to a number of regional watersheds within the UMR and MRB. Data from a series of MPCA monitoring projects will be utilized to provide a holistic context to the region.

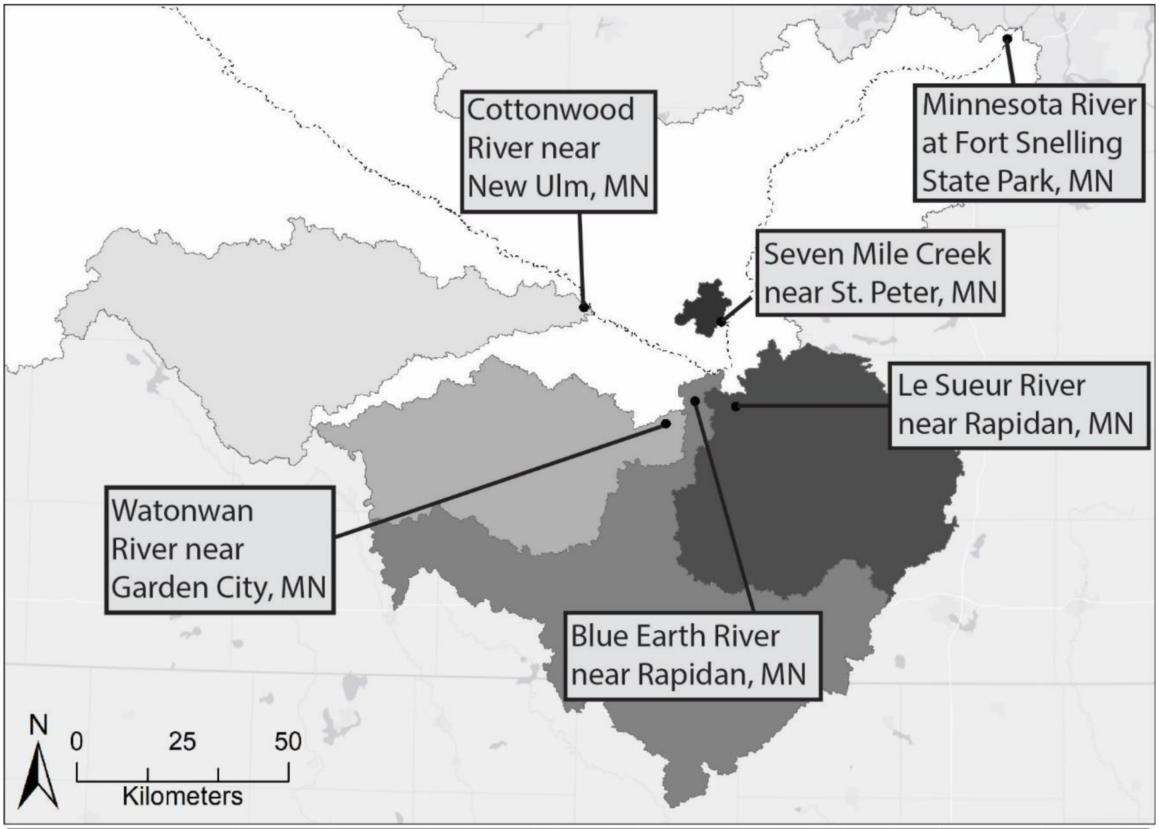
Of the three major watersheds above Lake Pepin, the UMR, MRB, and St. Croix, the MRB maintains the highest annual flow-weighted mean concentrations and yields of total suspended solids, total phosphorus, and nitrate+nitrite as nitrogen (Figure 3.4). Total suspended solid concentrations and yields almost triple the next highest watershed, which is the Mississippi River at Lock and Dam #3, after water from all three major basins have converged (MPCA, 2018). The same trend continues for total phosphorus and nitrate+nitrite as nitrogen, which both nearly double values seen at Lock and Dam #3. Given such elevated concentrations and yields, it is clear from these results and previous research in the basin (Kelley and Nater, 2000b; Magdalene, 2004; MPCA, 2007b; Steil, 2007; Engstrom et al., 2009; Mulla and Sekely, 2009; Belmont et al., 2011; Blumentritt et al., 2013; MPCA, 2013), that conditions within the MRB are contributing far more to flow-weighted mean concentrations and yields of total suspended solids, total phosphorus, and nitrate+nitrite as nitrogen than the UMR and St. Croix Rivers.



Site Name	Years Monitored	Basin Size (ha)	Annual Discharge (m3)	Annual TSS FWMC (mg/L)	Annual TP FWMC (mg/L)	Annual NO3+NO2 as N FWMC (mg/L)	Annual TSS Yield (kg/ha)	Annual TP Yield (kg/ha)	Annual NO3NO2 Yield (kg/ha)
Mississippi River Lock & Dam #3	2007-15	12,069,355	2.11E+10	35	0.130	2.46	61	0.233	4.42
Mississippi River at Anoka, MN	2007-15	4,938,708	8.73E+09	16	0.108	1.18	29	0.195	2.09
Minnesota River at Fort Snelling	2007-15	4,377,084	6.75E+09	100	0.235	5.80	138	0.356	8.85
St Croix River at Stillwater, MN	2007-15	1,828,574	4.64E+09	8	0.051	0.29	20	0.130	0.74

Figure 3.4. Regional scale watersheds of the Upper Mississippi River, above the riverine Lake Pepin (MPCA, 2018).

It has been well documented that the GBERB is among the largest contributor to nutrient and sediment flow-weighted mean concentrations and yields within the MRB (Belmont et al., 2010; Folle, 2010; Belmont et al., 2011; Gran et al., 2011; Maalim and Melesse, 2013; MPCA, 2014; Bevis, 2015; MPCA, 2015a; Kalkhoff et al., 2016; Baker et al., 2018). Within the GBERB, the Blue Earth, Le Sueur, and Watonwan each contribute flow-weighted mean concentrations or yields that exceed those from the MRB at its outlet (MPCA, 2018). While the Blue Earth and Watonwan both exhibit elevated values similar to the other regional watersheds examined, the LSR is the dominant contributor across all parameters within the watershed. Total phosphorus and nitrate+nitrite as nitrogen flow-weighted mean concentrations and yields within the LSR are the highest of all regional watersheds, with the exception of Seven Mile Creek, a ravine near St. Peter, MN (Figure 3.5). Flow-weighted mean concentrations of total suspended solids in the LSR (256 mg/L) are greater than flow-weighted mean concentrations of the Blue Earth and Watonwan, while yields in the LSR are the highest from all examined watersheds except for Seven Mile Creek. Elevated suspended solids throughout the GBERB support the need for ongoing research focusing on quantifying erosion rates and developing source apportionment within the basin (Belmont et al., 2010; Belmont et al., 2011; Gran et al., 2011; Kelly et al., 2017; Treat, 2017; Baker et al., 2018; Kelly and Belmont, 2018).



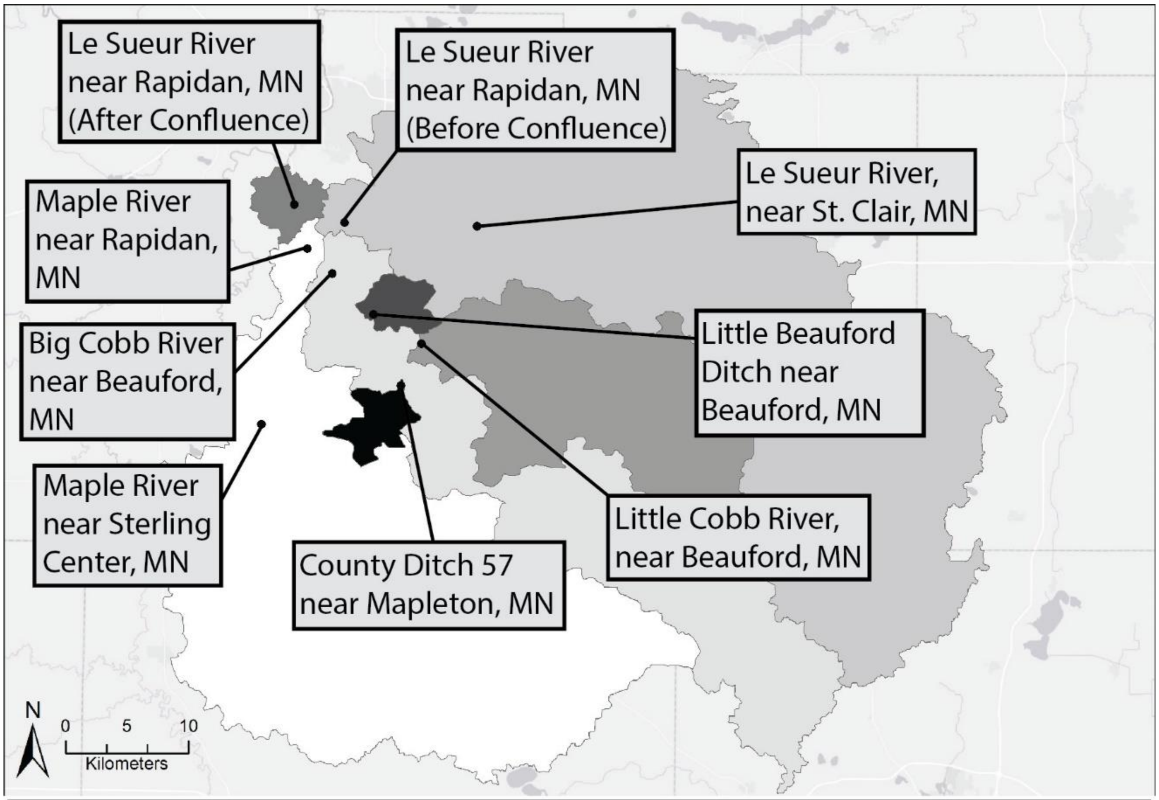
Site Name	Year	Basin Size (ha)	Annual Discharge (m3)	Annual TSS FWMC (mg/L)	Annual TP FWMC (mg/L)	Annual NO3NO2 FWMC (mg/L)	Annual TSS Yield (kg/ha)	Annual TP Yield (kg/ha)	Annual NO3NO2 Yield (kg/ha)
Minnesota River at Fort Snelling State	2007-15	4,377,084	6.75E+09	100	0.235	5.80	138	0.356	8.85
Blue Earth River near Rapidan, MN	2007-15	624,188	1.20E+09	170	0.273	9.30	340	0.530	16.72
Cottonwood River near New Ulm	2007-15	336,699	5.15E+08	188	0.292	7.62	309	0.479	12.31
Le Sueur River near Rapidan, MN66	2007-15	287,489	7.24E+08	256	0.380	9.50	713	1.027	23.09
Watonwan River near Garden City, CSAH13	2007-15	220,408	3.72E+08	86	0.252	9.16	138	0.424	15.00
Seven Mile Creek near St. Peter	2014-15	9,365	1.29E+07	545	0.343	21.00	857	0.488	29.65

Figure 3.5. Closer look at select basins in the southern extent of the Minnesota River watershed (MPCA, 2018).

Finally, focusing on the major watersheds of the greater LSR, the Maple, and Cobb, and Le Sueur, provide further insight to loading tendencies within the watershed and region (Figure 3.6). The knickzone within the LSR is documented roughly 30-40 km upstream of the mouth of the watershed within the three major tributaries (Belmont et al., 2010; Belmont et al., 2011; Gran et al., 2011). Suspended sediment loads downstream of the knickzone are dominated by bluff erosion which consistutes 107,000 Mg of the overall 225,000 Mg (~48%) of fine-grained sediment exported from the LSR, annually averaged over 2000-2010 (Belmont et al., 2011; Gran et al., 2011). Upstream of the knickzone, upland erosion is the dominant transport mechanism, supplying 45,000 Mg (20%) to the overall load (Belmont et al., 2011; Gran et al., 2011).

The two LSR stations near Rapidan, the Maple River near Rapidan, and the Big Cobb near Beauford are within the knickzone (Figure 3.6). The LSR at St. Clair, Maple at Sterling Center, Little Cobb near Beauford, CD 57, and LBD are above the knickzone, and would represent upland topography (Figure 3.6). When comparing the sites within the knickzone to those above the knickzone, it is clear that annual flow-weighted mean concentrations and yields for suspended solids are much higher within the knickzone (Figure 3.7). The Big Cobb site, which is situated near the upstream extent of the knickzone, averages total suspended solid flow-weighted mean concentrations of 120 mg/L. By the time water reaches the mouth of the LSR, concentrations double to 256 mg/L. Yields follow a similar trend and range from 254 kg/ha in the Big Cobb to 713 kg/ha at the mouth of the LSR. The main stem of the LSR, before the confluences with the Maple and Cobb Rivers, exhibits the highest flow-weighted mean concentrations (283 mg/L) and yields(662 kg/ha) of all the major watersheds of the LSR. Above the knickzone, the LSR contributes the highest total suspended solid flow-weighted mean concentrations (130 mg/L). The Little Cobb contributes similar flow-weighted mean concentrations (122 mg/L) to its downstream counterpart at the mouth of the Big Cobb (120 mg/L) (Kalkhoff et al., 2016). The Maple River at Sterling Center, CD 57, and LBD featured the lowest of the total suspended solid flow-weighted mean concentrations, with concentrations in the Maple at 66 mg/L, CD 57 between 28-63 mg/L, and LBD at 73 mg/L. Yields were not provided for the Little Cobb, but based on flow-weighted mean concentrations and average annual discharge yields would be ~247 kg/ha (Kalkhoff et al., 2016). Yields at CD 57 were between 100-119 kg/ha and yields at LBD were 142 kg/ha (MPCA, 2018). Differences in sediment sources agree with previous SWAT modeling within the watershed that locations further downstream, below the knickzone, are contributing larger flow-weighted mean concentrations (Folle, 2010).

Annual total phosphorus flow-weighted mean concentrations did exhibit some differences from upstream of the knickzone to downstream of it (Figure 3.6 and Figure 3.7). The highest concentration (0.380 mg/L) was observed at the mouth of the LSR, while the other sites in the knickzone ranged from 0.284-0.379 mg/L. Sites above the knickzone ranged from 0.187 mg/L (the minimum extent of the CD 57 range), to 0.314 mg/L at LBD. Yields exhibited similar tendencies to concentrations, however the Little Cobb produced the smallest yields (0.510 kg/ha) with CD 57 producing the next smallest yields (0.611-0.635 kg/ha). The highest yields were recorded at the mouth of the LSR, where yields averaged 1.027 kg/ha.



Site Name	Year	Basin Size (ha)	Annual Discharge (m3)	Annual TSS FWMC (mg/L)	Annual TP FWMC (mg/L)	Annual NO3NO2 FWMC (mg/L)	Annual TSS Yield (kg/ha)	Annual TP Yield (kg/ha)	Annual NO3NO2 Yield (kg/ha)
Le Sueur River near Rapidan, MN (After Confluence)	2007-15	287,489	7.24E+08	256	0.380	9.50	713	1.027	23.09
Le Sueur River near Rapidan, MN (Before Confluence)	2007-15	115,629	2.41E+08	283	0.356	9.79	662	0.818	19.72
Le Sueur River near St. Clair, MN	2007-12	91,438	1.88E+08	130	0.259	10.00	270	0.568	18.61
Maple River near Rapidan, MN	2007-15	87,542	1.80E+08	234	0.379	9.68	586	0.869	18.14
Maple River near Sterling Center, MN	2007-15	82,103	1.70E+08	66	0.287	9.90	129	0.638	18.83
Big Cobb River near Beauford, MN	2007-15	78,995	1.63E+08	120	0.284	10.46	254	0.617	19.30
Little Cobb River near Beauford, MN	1997-99, 2002-07	32,100	6.49E+07	122	0.200	7.48	N/A	0.510	21.29
County Ditch 57 near Mapleton, MN (Minimum)	2016-17 (March-October)	2,498	7.44E+06	28	0.187	13.35	100	0.611	46.88
County Ditch 57 near Mapleton, MN(Maximum)				63	0.271		119	0.635	
Little Beauford Ditch near Beauford, MN	2009-15	2,085	4.11E+06	73	0.314	14.42	142	0.684	25.75

Figure 3.6. Map of the Le Sueur River watershed, its three major watersheds (the Le Sueur, Maple, and Cobb), County Ditch 57, and Little Beauford Ditch (MPCA, 2018).

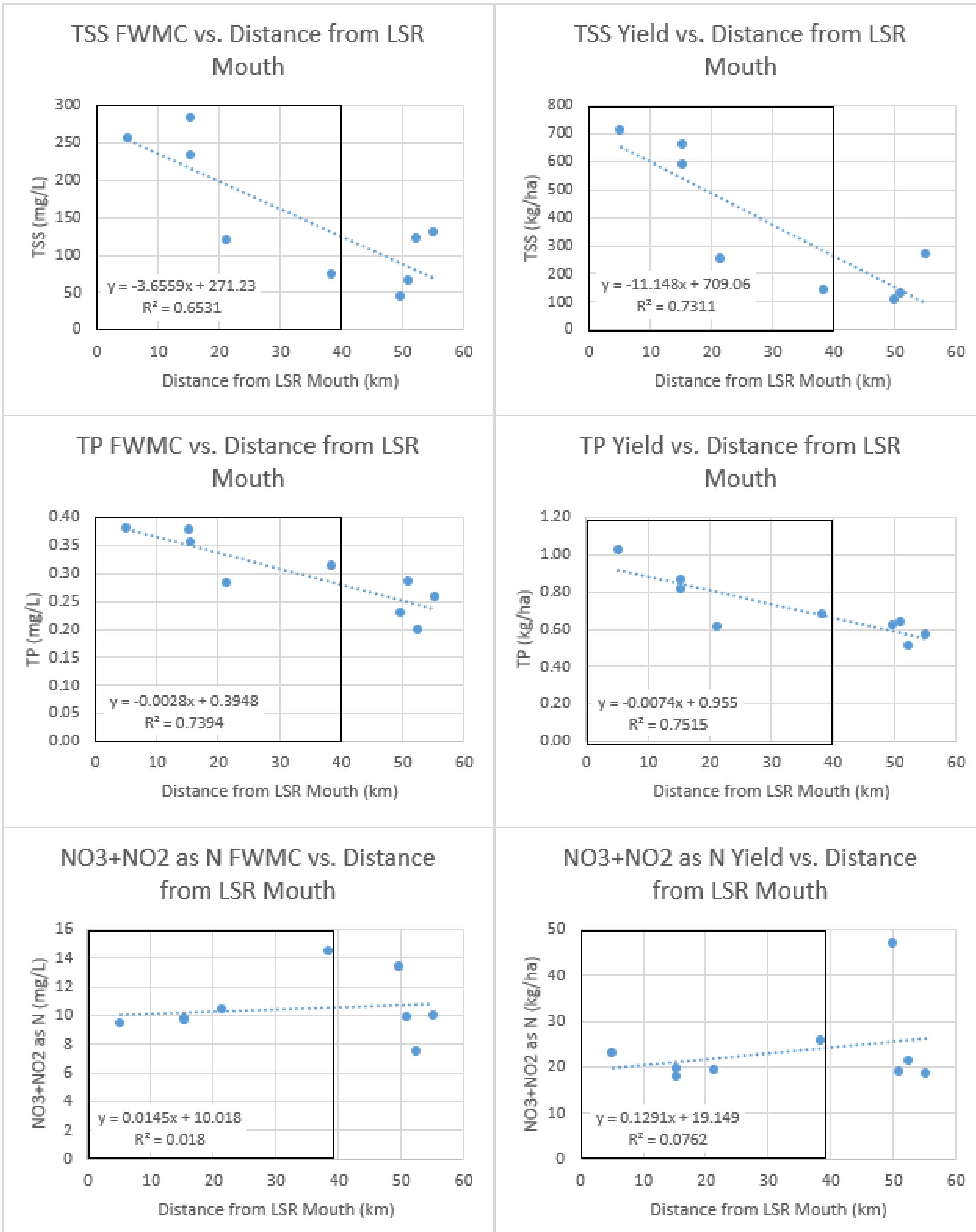


Figure 3.7. Flow-weighted mean concentrations and yields for total suspended solids (TSS), total phosphorus (TP), and nitrate+nitrite as nitrogen (NO3+NO2 as N) of the monitoring stations in Figure 3.6, compared to distance from the mouth of the LSR. The black box denotes the region that is potentially within the knickzone (30-40 km upstream from the mouth of the LSR.

Finally, annual nitrate+nitrite as nitrogen flow-weighted mean concentrations tended to follow different trends than all other parameters examined. The larger suppliers of nitrate+nitrite as nitrogen in terms of flow-weighted mean concentrations and yields were the smaller watersheds, such as CD 57, LBD, and Seven Mile Creek (Figure 3.5-3.7). The largest flow-weighted mean concentrations within the knickzone came from the Big Cobb (10.46 mg/L) and the LSR before the confluence (9.79 mg/L). Above the knickzone, flow-weighted mean concentrations at CD 57 and LBD were much higher than the surrounding watersheds, at 13.35 mg/L and 14.42 mg/L, respectfully. The LSR near St. Clair (10.00 mg/L) and Maple River near Sterling Center (9.90 mg/L) exhibited higher averages than their downstream counterparts, however the relationship was not as strong as seen in total suspended solids and total phosphorus (Figure 3.7). The largest observed yields came from the 2016-17 monitoring seasons at CD 57, where average yields were 46.88 kg/ha. Yields at LBD were the next highest, at 25.75 kg/ha, which represented seven years of data from 2009-15. LBD yields during the 2016 monitoring season were not included in those averages, but 40.72 kg/ha were recorded. This is supported by the previous SWAT model, which denotes larger concentrations of nitrate+nitrite as nitrogen originating from uplands within the LSR (Folle, 2010).

Average nitrogen applications in the Little Cobb watershed were approximated based on county-level estimates. The Little Cobb applies an estimated 121 kg/ha of nitrogen, typically during the fall, with over 60% in the form of fertilizer and animal manure (Kalkhoff et al., 2016). In CD 57, nitrogen application in the upper third of the watershed averaged ~146 kg/ha (Duncanson, personal communication, 2017). If rates of atmospheric nitrogen deposition at CD 57 are similar to those in the Little Cobb, an additional 5.4 kg/ha can be added (Kalkhoff et al., 2016). If application rates are considered constant across the CD 57 watershed then it is possible that up to 30% of the nitrogen applied to fields is seen in exported loads, compared to ~19% in the Little Cobb.

3.4.7 Watershed-Scale Geomorphic and Hydrologic Considerations

County Ditch 57 and Little Beauford Ditch may not be the largest contributors to discharge, sediment loads, or nutrient loads. However, there are ~120 HUC-08 watersheds in the LSR that are similar in size to CD 57 and LBD. The LSR is primarily struggling with erosion of bluffs in the downstream reaches of the river, below the knickzone. If best management practices were distributed within each of those 120 watersheds, then there is a much greater potential to achieve the desired effects of peak discharge reduction downstream (MPCA, 2015b). However, that could end up costing billions of dollars and would require significant external funding to alleviate pressure on the landowners. The CD 57 project cost ~$1,300,000 in 2010-11. As mentioned in the previous chapter, the surge basin that was constructed (~1.21 ha) is a fraction of the size of the original wetland (~136 ha). Wetland placement and distribution has been shown to be large factors in the effectiveness of a wetland to reduce nitrate loads a watershed scale (Hansen et al., 2018). However, further construction and distribution of wetlands throughout the watershed would allow for better control of discharge and peak discharge, while providing more opportunity for sediment and nutrient removal. This, in turn, would help to decrease peak discharge in the larger watersheds downstream. The CD 57 surge pond and wetland are located in the upper reaches of the system and have the potential to be overwhelmed when runoff is sufficient enough (~40-50 mm rainfall). The surge basin in CD 57 would need to be upsized to better handle high magnitude flow events. If the basin was upsized to even a tenth of the size of the original wetland the cost for the basin alone would be ~$1,650,000, exceeding the final cost of the original project by ~$350,000. To expand similar practices to the 120 HUC-08 watersheds of the LSR would require an enormous amount of money.

Finally, the knickzone in the LSR is not static. Eventually, it will move past LBD and CD 57 and increased incision will begin within the watersheds. Present management decisions need to account for a future landscape. Increases in erosivity are already well documented originating from agricultural watersheds (Schottler et al., 2014). Current hydrologic modification will exacerbate an already incising watershed (the LSR). Better controlling water within the headwater watersheds, like CD 57 and LBD, would best serve watersheds downstream and help protect them from increased bluff erosion and rapid incision. As precipitation, precipitation intensity, and total discharge are increasing throughout the region (Knox, 2000; Zhang and Schilling, 2006; Novotny and Stefan, 2007; Nangia et al., 2010; Schottler et al., 2014; Gupta et al., 2015; Belmont et al., 2016; Kelly et al., 2017) it will be increasingly necessary to manage water where it was originally stored, within headwater, upland basins.

3.5 Conclusion

Overall, the LSR watershed dominates flow-weighted mean concentrations and yields for total suspended solids, total phosphorus, and nitrate+nitrite as nitrogen in watersheds examined within the Upper Mississippi River above Lake Pepin. Within the LSR, the largest sediment supply originates from rivers that encompass the knickzone moving through the watershed. These regions are shown to be dominated by bluff erosion, while regions upstream of the knickzone are eroding upland farm fields (Belmont et al., 2010; Belmont et al., 2011; Gran et al., 2011; Kelly et al., 2017; Kelly and Belmont, 2018). Above the knickzone modified agricultural watersheds contribute smaller amounts of total phosphorus than watersheds downstream, but contribute disproportionate concentrations of nitrate+nitrite as nitrogen.

CD 57 and LBD do contribute to the overall suspended solids and total phosphorus, however these contributions are far exceeded by those from within the knickzone. Nitrate+nitrite as nitrogen contributions are higher coming from CD 57 and LBD, which could be attributed to higher local application of nitrogen to meet the demands of row crops like corn and soybeans. Furthermore, when comparing CD 57 and LBD it is apparent that total suspended solids and total phosphorus are less at CD 57, despite higher monitored discharge. Given the suite of structural practices employed within the CD 57 watershed (surge basin, two-stage ditch, buffer strips, and a rate control weir) it would appear that appear that they can help reduce peak discharge and sediment, but have variable efficiency reducing nutrients. However, while flow-weighted mean concentrations are often reduced, loads are dominated by larger precipitation events in the season, where previous or future storage is almost always exceeded by exported loads.

These two modified agricultural watersheds serve as valuable case studies for similar watersheds throughout the region. Implications for future drainage management can be drawn by focusing more attention on the discharge, sediment, and nutrient tendencies observed within these basins. Efforts exerted here could help protect downstream landowners while still maintaining a more natural system.

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Appendices

Appendix A. 2016 Water Quality Reports from MVTL

Minnesota Valley Testing Laboratories Water Quality Results **2016**										
Site	Sample Type	Date Sampled	Date Analyzed	Parameter	Attn	Result	Unit	Method RL	Method Reference	Comments
CD007	Base	3/22/2016	3/23/2016	TSS	<	2	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Base	3/22/2016	3/24/2016	PO4		0.036	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Base	3/22/2016	3/28/2016	NO2/NO3	~	22.40	mg/L as N	0.05	353.2	Sample diluted due to result above calibration of linear range, samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Base	3/22/2016	3/29/2016	TP		0.036	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Base	3/22/2016	3/23/2016	TSS		15	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Base	3/22/2016	3/24/2016	PO4		0.047	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Base	3/22/2016	3/28/2016	NO2/NO3	~	22.10	mg/L as N	0.05	353.2	Sample diluted due to result above calibration of linear range, samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Base	3/22/2016	3/29/2016	TP		0.039	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis

CD002	Base	3/22/2016	3/23/2016	TSS	<	2	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Base	3/22/2016	3/24/2016	PO4		0.024	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Base	3/22/2016	3/28/2016	NO2/NO3	~	20.80	mg/L as N	0.05	353.2	Sample diluted due to result above calibration of linear range, samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Base	3/22/2016	3/29/2016	TP		0.024	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Base	3/22/2016	3/23/2016	TSS		2	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Base	3/22/2016	3/24/2016	PO4		0.019	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Base	3/22/2016	3/28/2016	NO2/NO3	~	24.10	mg/L as N	0.05	353.2	Sample diluted due to result above calibration of linear range, samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Base	3/22/2016	3/29/2016	TP		0.023	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	3/30/2016	3/31/2016	TSS		102	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	3/30/2016	3/31/2016	PO4		0.031	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis

CD007	Composite	3/30/2016	4/1/2016	NO2/NO3		18.70	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	3/30/2016	4/5/2016	TP		0.229	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	3/30/2016	3/31/2016	TSS		27	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	3/30/2016	3/31/2016	PO4		0.048	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	3/30/2016	4/1/2016	NO2/NO3		19.60	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	3/30/2016	4/5/2016	TP		0.118	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	3/30/2016	3/31/2016	TSS		7	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	3/30/2016	3/31/2016	PO4		0.028	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	3/30/2016	4/1/2016	NO2/NO3		18.70	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	3/30/2016	4/5/2016	TP		0.055	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	3/30/2016	3/31/2016	TSS		15	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	3/30/2016	3/31/2016	PO4		0.035	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis

CD001	Composite	3/30/2016	4/1/2016	NO2/NO3	~	20.40	mg/L as N	0.05	353.2	Sample diluted due to result above calibration of linear range, samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	3/30/2016	4/5/2016	TP		0.099	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001DUP	Composite	3/30/2016	3/31/2016	TSS		15	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001DUP	Composite	3/30/2016	3/31/2016	PO4		0.069	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001DUP	Composite	3/30/2016	4/1/2016	NO2/NO3	~	20.30	mg/L as N	0.05	353.2	Sample diluted due to result above calibration of linear range, samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001DUP	Composite	3/30/2016	4/5/2016	TP		0.158	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	4/1/2016	4/5/2016	TSS		16	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	4/1/2016	4/5/2016	PO4	*	0.051	mg/L	0.005	EPA 365.1	Holding time exceeded, samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	4/1/2016	4/8/2016	NO2/NO3	~	20.80	mg/L as N	0.05	353.2	Sample diluted due to result above calibration of linear range, samples filtered in lab for soluble ortho phosphorus prior to analysis

CD007	Composite	4/1/2016	4/12/2016	TP		0.198	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	4/1/2016	4/5/2016	TSS		6	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	4/1/2016	4/5/2016	PO4	*	0.066	mg/L	0.005	EPA 365.1	Holding time exceeded, samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	4/1/2016	4/8/2016	NO2/NO3	~	20.10	mg/L as N	0.05	353.2	Sample diluted due to result above calibration of linear range, samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	4/1/2016	4/12/2016	TP		0.110	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	4/1/2016	4/5/2016	TSS		19	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	4/1/2016	4/5/2016	PO4	*	0.057	mg/L	0.005	EPA 365.1	Holding time exceeded, samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	4/1/2016	4/8/2016	NO2/NO3		19.20	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	4/1/2016	4/12/2016	TP		0.180	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	4/1/2016	4/5/2016	TSS		20	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	4/1/2016	4/5/2016	PO4	*	0.081	mg/L	0.005	EPA 365.1	Holding time exceeded, samples filtered in lab for

										soluble ortho phosphorus prior to analysis
CD001	Composite	4/1/2016	4/8/2016	NO2/NO3	~	23.50	mg/L as N	0.05	353.2	Sample diluted due to result above calibration of linear range, samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	4/1/2016	4/12/2016	TP		0.181	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Base	4/12/2016	4/13/2016	TSS		6	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Base	4/12/2016	4/13/2016	PO4		0.038	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Base	4/12/2016	4/13/2016	NO2/NO3	~	21.60	mg/L as N	0.05	353.2	Sample diluted due to result above calibration of linear range, samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Base	4/12/2016	4/19/2016	TP		0.033	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Base	4/12/2016	4/13/2016	TSS		6	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Base	4/12/2016	4/13/2016	PO4		0.025	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Base	4/12/2016	4/13/2016	NO2/NO3	~	20.60	mg/L as N	0.05	353.2	Sample diluted due to result above calibration of linear range, samples filtered in lab for soluble

										ortho phosphorus prior to analysis
CD004	Base	4/12/2016	4/19/2016	TP		0.045	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Base	4/12/2016	4/13/2016	TSS		5	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Base	4/12/2016	4/13/2016	PO4		0.020	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Base	4/12/2016	4/13/2016	NO2/NO3	~	19.90	mg/L as N	0.05	353.2	Sample diluted due to result above calibration of linear range, samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Base	4/12/2016	4/19/2016	TP		0.025	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Base	4/12/2016	4/13/2016	TSS		12	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Base	4/12/2016	4/13/2016	PO4		0.308	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Base	4/12/2016	4/13/2016	NO2/NO3		12.00	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Base	4/12/2016	4/19/2016	TP	~	0.550	mg/L	0.005	EPA 365.1	Sample diluted due to result above calibration of linear range, samples filtered in lab for soluble ortho phosphorus prior to analysis

CD007	Composite	4/26/2016	4/27/2016	TSS		29	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	4/26/2016	4/27/2016	PO4		0.062	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	4/26/2016	4/27/2016	NO2/NO3		19.00	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	4/26/2016	5/2/2016	TP		0.156	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	4/26/2016	4/27/2016	TSS		21	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	4/26/2016	4/27/2016	PO4		0.078	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	4/26/2016	4/27/2016	NO2/NO3		15.80	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	4/26/2016	5/2/2016	TP		0.201	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004 DUP	Composite	4/26/2016	4/27/2016	TSS		43	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004 DUP	Composite	4/26/2016	4/27/2016	PO4		0.082	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004 DUP	Composite	4/26/2016	4/27/2016	NO2/NO3		15.30	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004 DUP	Composite	4/26/2016	5/2/2016	TP		0.215	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis

CD002	Composite	4/26/2016	4/27/2016	TSS		4	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	4/26/2016	4/27/2016	PO4		0.043	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	4/26/2016	4/27/2016	NO2/NO3		18.60	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	4/26/2016	5/2/2016	TP		0.210	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	4/26/2016	4/27/2016	TSS		4	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	4/26/2016	4/27/2016	PO4		0.059	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	4/26/2016	4/27/2016	NO2/NO3	~	20.70	mg/L as N	0.05	353.2	Sample diluted due to result above calibration of linear range, samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	4/26/2016	5/2/2016	TP		0.091	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	4/28/2016	4/29/2016	TSS		42	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	4/28/2016	4/29/2016	PO4		0.047	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	4/28/2016	5/2/2016	NO2/NO3	~	20.60	mg/L as N	0.05	353.2	Sample diluted due to result above calibration of linear range, samples filtered in lab for soluble

										ortho phosphorus prior to analysis
CD007	Composite	4/28/2016	5/3/2016	TP		0.366	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	4/28/2016	4/29/2016	TSS		11	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	4/28/2016	4/29/2016	PO4		0.060	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	4/28/2016	5/2/2016	NO2/NO3		19.10	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	4/28/2016	5/3/2016	TP		0.114	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004 DUP	Composite	4/28/2016	4/29/2016	TSS		9	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004 DUP	Composite	4/28/2016	4/29/2016	PO4		0.056	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004 DUP	Composite	4/28/2016	5/2/2016	NO2/NO3		19.30	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004 DUP	Composite	4/28/2016	5/3/2016	TP		0.119	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	4/28/2016	4/29/2016	TSS		36	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	4/28/2016	4/29/2016	PO4		0.032	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis

CD002	Composite	4/28/2016	5/2/2016	NO2/NO3		16.80	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	4/28/2016	5/3/2016	TP		0.237	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	4/28/2016	4/29/2016	TSS		12	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	4/28/2016	4/29/2016	PO4		0.091	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	4/28/2016	5/2/2016	NO2/NO3	~	22.50	mg/L as N	0.05	353.2	Sample diluted due to result above calibration of linear range, samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	4/28/2016	5/3/2016	TP		0.152	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	4/29/2016	5/3/2016	TSS		16	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	4/29/2016	5/4/2016	PO4	*	0.046	mg/L	0.005	EPA 365.1	Holding time exceeded, samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	4/29/2016	5/4/2016	NO2/NO3	~	23.60	mg/L as N	0.05	353.2	Sample diluted due to result above calibration of linear range, samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	4/29/2016	5/10/2016	TP		0.109	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis

CD004	Composite	4/29/2016	5/3/2016	TSS		93	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	4/29/2016	5/4/2016	PO4	*	0.051	mg/L	0.005	EPA 365.1	Holding time exceeded, samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	4/29/2016	5/4/2016	NO2/NO3	~	22.90	mg/L as N	0.05	353.2	Sample diluted due to result above calibration of linear range, samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	4/29/2016	5/10/2016	TP		0.078	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	4/29/2016	5/3/2016	TSS		9	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	4/29/2016	5/4/2016	PO4	*	0.030	mg/L	0.005	EPA 365.1	Holding time exceeded, samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	4/29/2016	5/4/2016	NO2/NO3	~	22.40	mg/L as N	0.05	353.2	Sample diluted due to result above calibration of linear range, samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	4/29/2016	5/10/2016	TP		0.075	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	4/29/2016	5/3/2016	TSS		71	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	4/29/2016	5/4/2016	PO4	*	0.063	mg/L	0.005	EPA 365.1	Holding time exceeded, samples filtered in lab for

										soluble ortho phosphorus prior to analysis
CD001	Composite	4/29/2016	5/4/2016	NO2/NO3	~	26.80	mg/L as N	0.05	353.2	Sample diluted due to result above calibration of linear range, samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	4/29/2016	5/10/2016	TP		0.090	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	5/2/2016	5/3/2016	TSS		30	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	5/2/2016	5/4/2016	PO4		0.048	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	5/2/2016	5/4/2016	NO2/NO3	~	23.60	mg/L as N	0.05	353.2	Sample diluted due to result above calibration of linear range, samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	5/2/2016	5/10/2016	TP		0.178	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	5/2/2016	5/3/2016	TSS		8	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	5/2/2016	5/4/2016	PO4		0.054	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	5/2/2016	5/4/2016	NO2/NO3	~	22.40	mg/L as N	0.05	353.2	Sample diluted due to result above calibration of linear range, samples filtered in lab for soluble

										ortho phosphorus prior to analysis
CD004	Composite	5/2/2016	5/10/2016	TP		0.124	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	5/2/2016	5/3/2016	TSS		6	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	5/2/2016	5/4/2016	PO4		0.063	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	5/2/2016	5/4/2016	NO2/NO3	~	22.90	mg/L as N	0.05	353.2	Sample diluted due to result above calibration of linear range, samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	5/2/2016	5/10/2016	TP		0.146	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	5/2/2016	5/3/2016	TSS		15	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	5/2/2016	5/4/2016	PO4		0.083	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	5/2/2016	5/4/2016	NO2/NO3	~	26.20	mg/L as N	0.05	353.2	Sample diluted due to result above calibration of linear range, samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	5/2/2016	5/10/2016	TP		0.152	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis

CD007	Composite	5/13/2016	5/13/2016	TSS		10	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	5/13/2016	5/13/2016	PO4		0.035	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	5/13/2016	5/18/2016	NO2/NO3		21.30	mg/L as N	0.05	353.2	Sample diluted due to result above calibration of linear range, samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	5/13/2016	5/17/2016	TP	~	0.068	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	5/13/2016	5/13/2016	TSS		6	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	5/13/2016	5/13/2016	PO4		0.042	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	5/13/2016	5/18/2016	NO2/NO3		20.80	mg/L as N	0.05	353.2	Sample diluted due to result above calibration of linear range, samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	5/13/2016	5/17/2016	TP		0.069	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	5/13/2016	5/13/2016	TSS	~	27	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	5/13/2016	5/13/2016	PO4		0.029	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis

CD002	Composite	5/13/2016	5/18/2016	NO2/NO3		19.70	mg/L as N	0.05	353.2	Sample diluted due to result above calibration of linear range, samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	5/13/2016	5/17/2016	TP		0.174	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002 DUP	Composite	5/13/2016	5/13/2016	TSS		27	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002 DUP	Composite	5/13/2016	5/13/2016	PO4	~	0.028	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002 DUP	Composite	5/13/2016	5/18/2016	NO2/NO3		19.90	mg/L as N	0.05	353.2	Sample diluted due to result above calibration of linear range, samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002 DUP	Composite	5/13/2016	5/17/2016	TP		0.148	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	5/13/2016	5/13/2016	TSS		8	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	5/13/2016	5/13/2016	PO4		0.043	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	5/13/2016	5/18/2016	NO2/NO3	~	23.80	mg/L as N	0.05	353.2	Sample diluted due to result above calibration of linear range, samples filtered in lab for soluble ortho phosphorus prior to analysis

CD001	Composite	5/13/2016	5/17/2016	TP		0.070	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	5/15/2016	5/17/2016	TSS		13	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	5/15/2016	5/17/2016	PO4		0.040	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	5/15/2016	5/18/2016	NO2/NO3	~	23.70	mg/L as N	0.05	353.2	Sample diluted due to result above calibration of linear range, samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	5/15/2016	5/24/2016	TP		0.071	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	5/15/2016	5/17/2016	TSS		14	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	5/15/2016	5/17/2016	PO4		0.045	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	5/15/2016	5/18/2016	NO2/NO3	~	22.60	mg/L as N	0.05	353.2	Sample diluted due to result above calibration of linear range, samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	5/15/2016	5/24/2016	TP		0.082	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	5/15/2016	5/17/2016	TSS		115	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis

CD002	Composite	5/15/2016	5/17/2016	PO4		0.020	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	5/15/2016	5/18/2016	NO2/NO3	~	21.90	mg/L as N	0.05	353.2	Sample diluted due to result above calibration of linear range, samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	5/15/2016	5/24/2016	TP		0.446	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	5/15/2016	5/17/2016	TSS		7	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	5/15/2016	5/17/2016	PO4		0.047	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	5/15/2016	5/18/2016	NO2/NO3	~	25.40	mg/L as N	0.05	353.2	Sample diluted due to result above calibration of linear range, samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	5/15/2016	5/24/2016	TP		0.077	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	5/27/2016	6/8/2016	TSS		18	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	5/27/2016	5/27/2016	PO4		0.038	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	5/27/2016	6/1/2016	NO2/NO3		19.60	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis

CD007	Composite	5/27/2016	6/7/2016	TP		0.114	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	5/27/2016	6/8/2016	TSS		14	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	5/27/2016	5/27/2016	PO4		0.068	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	5/27/2016	6/1/2016	NO2/NO3		18.30	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	5/27/2016	6/7/2016	TP		0.140	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	5/27/2016	6/8/2016	TSS		135	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	5/27/2016	5/27/2016	PO4		0.058	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	5/27/2016	6/1/2016	NO2/NO3		16.90	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	5/27/2016	6/7/2016	TP		0.462	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	5/27/2016	6/8/2016	TSS		77	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	5/27/2016	5/27/2016	PO4		0.087	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	5/27/2016	6/1/2016	NO2/NO3		29.60	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis

CD001	Composite	5/27/2016	6/7/2016	TP		0.235	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001 DUP	Composite	5/27/2016	6/8/2016	TSS		74	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001 DUP	Composite	5/27/2016	5/27/2016	PO4		0.102	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001 DUP	Composite	5/27/2016	6/1/2016	NO2/NO3		28.20	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001 DUP	Composite	5/27/2016	6/7/2016	TP		0.226	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	6/5/2016	6/7/2016	TSS		9	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	6/5/2016	6/8/2016	NO2/NO3		19.000	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	6/5/2016	6/14/2016	TP		0.10	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	6/5/2016	6/7/2016	TSS		7.000	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	6/5/2016	6/8/2016	NO2/NO3		18	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	6/5/2016	6/14/2016	TP		0.123	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	6/13/2016	6/14/2016	TSS		27.00	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis

CD007	Composite	6/13/2016	6/14/2016	PO4		0.066	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	6/13/2016	6/14/2016	NO2/NO3		19	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	6/13/2016	6/21/2016	TP		0.199	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	6/13/2016	6/14/2016	TSS		15.00	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	6/13/2016	6/14/2016	PO4		0.097	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	6/13/2016	6/14/2016	NO2/NO3		17	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	6/13/2016	6/21/2016	TP		0.182	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	6/13/2016	6/14/2016	TSS		23.00	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	6/13/2016	6/14/2016	PO4		0.120	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	6/13/2016	6/14/2016	NO2/NO3		15	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	6/13/2016	6/21/2016	TP		0.181	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	6/16/2016	6/19/2016	TSS		27.00	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis

CD007	Composite	6/16/2016	6/17/2016	PO4		0.149	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	6/16/2016	6/22/2016	NO2/NO3	~	22	mg/L as N	0.05	353.2	Sample diluted due to result above calibration of linear range, samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	6/16/2016	6/21/2016	TP		0.286	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007 DUP	Composite	6/16/2016	6/19/2016	TSS		31.00	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007 DUP	Composite	6/16/2016	6/17/2016	PO4		0.142	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007 DUP	Composite	6/16/2016	6/22/2016	NO2/NO3	~	22	mg/L as N	0.05	353.2	Sample diluted due to result above calibration of linear range, samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007 DUP	Composite	6/16/2016	6/21/2016	TP		0.280	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	6/16/2016	6/19/2016	TSS		40.00	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	6/16/2016	6/17/2016	PO4		0.169	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	6/16/2016	6/22/2016	NO2/NO3	~	21	mg/L as N	0.05	353.2	Sample diluted due to result above calibration of linear range, samples filtered in lab for soluble

										ortho phosphorus prior to analysis
CD004	Composite	6/16/2016	6/21/2016	TP		0.340	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	6/16/2016	6/19/2016	TSS		53.00	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	6/16/2016	6/17/2016	PO4		0.179	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	6/16/2016	6/22/2016	NO2/NO3	~	20	mg/L as N	0.05	353.2	Sample diluted due to result above calibration of linear range, samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	6/16/2016	6/21/2016	TP		0.364	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	6/16/2016	6/19/2016	TSS		268.00	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	6/16/2016	6/17/2016	PO4		0.259	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	6/16/2016	6/22/2016	NO2/NO3	~	20	mg/L as N	0.05	353.2	Sample diluted due to result above calibration of linear range, samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	6/16/2016	6/21/2016	TP		0.530	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis

CD007	Base	6/29/2016	6/28/2016	TSS		9.00	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Base	6/29/2016	6/28/2016	PO4		0.045	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Base	6/29/2016	7/1/2016	NO2/NO3	~	25	mg/L as N	0.05	353.2	Sample diluted due to result above calibration of linear range, samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Base	6/29/2016	7/12/2016	TP		0.075	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Base	6/29/2016	6/28/2016	TSS		5.00	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Base	6/29/2016	6/28/2016	PO4		0.061	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Base	6/29/2016	7/1/2016	NO2/NO3	~	23	mg/L as N	0.05	353.2	Sample diluted due to result above calibration of linear range, samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Base	6/29/2016	7/12/2016	TP		0.127	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Base	6/29/2016	6/28/2016	TSS		4.00	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Base	6/29/2016	6/28/2016	PO4		0.067	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis

CD002	Base	6/29/2016	7/1/2016	NO2/NO3	~	20	mg/L as N	0.05	353.2	Sample diluted due to result above calibration of linear range, samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Base	6/29/2016	7/12/2016	TP		0.123	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Base	6/29/2016	6/28/2016	TSS		5.00	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Base	6/29/2016	6/28/2016	PO4		0.028	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Base	6/29/2016	7/1/2016	NO2/NO3	~	23	mg/L as N	0.05	353.2	Sample diluted due to result above calibration of linear range, samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Base	6/29/2016	7/12/2016	TP		0.058	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	7/11/2016	7/12/2016	TSS		28.00	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	7/11/2016	7/11/2016	PO4		0.088	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	7/11/2016	7/13/2016	NO2/NO3		18	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	7/11/2016	7/19/2016	TP		0.150	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis

CD004	Composite	7/11/2016	7/12/2016	TSS		7.00	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	7/11/2016	7/11/2016	PO4		0.114	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	7/11/2016	7/13/2016	NO2/NO3		13	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	7/11/2016	7/19/2016	TP		0.184	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	7/11/2016	7/12/2016	TSS		9.00	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	7/11/2016	7/11/2016	PO4		0.087	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	7/11/2016	7/13/2016	NO2/NO3		11	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	7/11/2016	7/19/2016	TP		0.165	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	7/11/2016	7/12/2016	TSS		9.00	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	7/11/2016	7/11/2016	PO4		0.090	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	7/11/2016	7/13/2016	NO2/NO3		16	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	7/11/2016	7/19/2016	TP		0.157	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis

CD007	Composite	7/12/2016	7/19/2016	TSS		4.00	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	7/12/2016	7/19/2016	PO4	*	0.100	mg/L	0.005	EPA 365.1	Holding Time Exceeded. Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	7/12/2016	7/20/2016	NO2/NO3		19	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	7/12/2016	7/26/2016	TP		0.154	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	7/12/2016	7/19/2016	TSS		4.00	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	7/12/2016	7/19/2016	PO4	*	0.138	mg/L	0.005	EPA 365.1	Holding Time Exceeded. Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	7/12/2016	7/20/2016	NO2/NO3		15	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	7/12/2016	7/26/2016	TP		0.175	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	7/12/2016	7/19/2016	TSS		5.00	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	7/12/2016	7/19/2016	PO4	*	0.133	mg/L	0.005	EPA 365.1	Holding Time Exceeded. Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	7/12/2016	7/20/2016	NO2/NO3		14	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis

CD002	Composite	7/12/2016	7/26/2016	TP		0.164	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	7/12/2016	7/19/2016	TSS		11.00	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	7/12/2016	7/19/2016	PO4	*	0.141	mg/L	0.005	EPA 365.1	Holding Time Exceeded. Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	7/12/2016	7/20/2016	NO2/NO3		18	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	7/12/2016	7/26/2016	TP		0.186	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	7/19/2016	7/20/2016	TSS		13.00	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	7/19/2016	7/20/2016	PO4		0.103	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	7/19/2016	7/26/2016	NO2/NO3		17	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	7/19/2016	7/27/2016	TP		0.140	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007 DUP	Composite	7/19/2016	7/20/2016	TSS		12.00	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007 DUP	Composite	7/19/2016	7/20/2016	PO4		0.111	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007 DUP	Composite	7/19/2016	7/26/2016	NO2/NO3		17	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis

CD007 DUP	Composite	7/19/2016	7/27/2016	TP		0.139	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	7/19/2016	7/20/2016	TSS		8.00	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	7/19/2016	7/20/2016	PO4		0.156	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	7/19/2016	7/26/2016	NO2/NO3		16	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	7/19/2016	7/27/2016	TP		0.186	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	7/19/2016	7/20/2016	TSS		14.00	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	7/19/2016	7/20/2016	PO4		0.167	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	7/19/2016	7/26/2016	NO2/NO3		14	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	7/19/2016	7/27/2016	TP		0.208	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	7/19/2016	7/20/2016	TSS		17.00	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	7/19/2016	7/20/2016	PO4		0.185	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	7/19/2016	7/26/2016	NO2/NO3		17	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis

CD001	Composite	7/19/2016	7/27/2016	TP		0.212	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	7/25/2016	7/26/2016	TSS		10.00	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	7/25/2016	7/25/2016	PO4		0.105	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	7/25/2016	7/26/2016	NO2/NO3		15	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	7/25/2016	8/4/2016	TP		0.149	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	7/25/2016	7/26/2016	TSS		3.00	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	7/25/2016	7/25/2016	PO4		0.155	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	7/25/2016	7/26/2016	NO2/NO3		12	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	7/25/2016	8/4/2016	TP		0.233	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	7/25/2016	7/26/2016	TSS		8.00	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	7/25/2016	7/25/2016	PO4		0.148	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	7/25/2016	7/26/2016	NO2/NO3		12	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis

CD002	Composite	7/25/2016	8/4/2016	TP		0.218	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Base	8/7/2016	8/9/2016	TSS		7.00	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Base	8/7/2016	8/9/2016	PO4		0.112	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Base	8/7/2016	8/9/2016	NO2/NO3	~	20	mg/L as N	0.05	353.2	Sample diluted due to result above calibration of linear range, samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Base	8/7/2016	8/16/2016	TP		0.138	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Base	8/7/2016	8/9/2016	TSS		8.00	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Base	8/7/2016	8/9/2016	PO4		0.089	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Base	8/7/2016	8/9/2016	NO2/NO3		11	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Base	8/7/2016	8/16/2016	TP		0.138	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Base	8/7/2016	8/9/2016	TSS		5.00	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Base	8/7/2016	8/9/2016	PO4		0.091	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis

CD002	Base	8/7/2016	8/9/2016	NO2/NO3		8	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Base	8/7/2016	8/16/2016	TP		0.143	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Base	8/7/2016	8/9/2016	TSS		5.00	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Base	8/7/2016	8/9/2016	PO4		0.146	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Base	8/7/2016	8/9/2016	NO2/NO3		11	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Base	8/7/2016	8/16/2016	TP		0.219	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD0099	Blank	8/7/2016	8/9/2016	TSS	<	2.00	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD0099	Blank	8/7/2016	8/9/2016	PO4	<	0.005	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD0099	Blank	8/7/2016	8/9/2016	NO2/NO3	<	0	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD0099	Blank	8/7/2016	8/16/2016	TP	<	0.005	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	8/11/2016	8/12/2016	TSS		16.00	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	8/11/2016	8/12/2016	PO4		0.139	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis

CD007	Composite	8/11/2016	8/16/2016	NO2/NO3		7	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	8/11/2016	8/16/2016	TP		0.315	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	8/11/2016	8/12/2016	TSS		8.00	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	8/11/2016	8/12/2016	PO4		0.135	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	8/11/2016	8/16/2016	NO2/NO3		8	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	8/11/2016	8/16/2016	TP		0.210	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	8/11/2016	8/12/2016	TSS		12.00	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	8/11/2016	8/12/2016	PO4		0.144	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	8/11/2016	8/16/2016	NO2/NO3		7	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	8/11/2016	8/16/2016	TP		0.219	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Base	8/14/2016	8/16/2016	TSS		13.00	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Base	8/14/2016	8/15/2016	PO4		0.130	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis

CD007	Base	8/14/2016	8/16/2016	NO2/NO3		11	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Base	8/14/2016	8/23/2016	TP		0.233	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Base	8/14/2016	8/16/2016	TSS		13.00	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Base	8/14/2016	8/15/2016	PO4		0.245	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Base	8/14/2016	8/16/2016	NO2/NO3		9	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Base	8/14/2016	8/23/2016	TP		0.345	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Base	8/14/2016	8/16/2016	TSS		25.00	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Base	8/14/2016	8/15/2016	PO4		0.213	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Base	8/14/2016	8/16/2016	NO2/NO3		11	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Base	8/14/2016	8/23/2016	TP		0.324	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Base	8/14/2016	8/16/2016	TSS		72.00	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Base	8/14/2016	8/15/2016	PO4		0.233	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis

CD001	Base	8/14/2016	8/16/2016	NO2/NO3		17	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Base	8/14/2016	8/23/2016	TP		0.399	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	8/18/2016	8/19/2016	TSS		19.00	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	8/18/2016	8/19/2016	PO4		0.127	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	8/18/2016	8/24/2016	NO2/NO3		14	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	8/18/2016	8/25/2016	TP		0.193	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	8/18/2016	8/19/2016	TSS		12.00	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	8/18/2016	8/19/2016	PO4		0.209	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	8/18/2016	8/24/2016	NO2/NO3		12	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	8/18/2016	8/25/2016	TP		0.293	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	8/18/2016	8/19/2016	TSS		25.00	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	8/18/2016	8/19/2016	PO4		0.210	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis

CD002	Composite	8/18/2016	8/24/2016	NO2/NO3		12	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	8/18/2016	8/25/2016	TP		0.301	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	8/22/2016	8/23/2016	TSS		12.00	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	8/22/2016	8/23/2016	PO4		0.102	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	8/22/2016	8/24/2016	NO2/NO3		15	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	8/22/2016	8/30/2016	TP		0.135	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	8/22/2016	8/23/2016	TSS		9.00	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	8/22/2016	8/23/2016	PO4		0.180	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	8/22/2016	8/24/2016	NO2/NO3		14	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	8/22/2016	8/30/2016	TP		0.206	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	8/22/2016	8/23/2016	TSS		12.00	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	8/22/2016	8/23/2016	PO4		0.181	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis

CD002	Composite	8/22/2016	8/24/2016	NO2/NO3		14	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	8/22/2016	8/30/2016	TP		0.205	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	8/22/2016	8/23/2016	TSS		19.00	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	8/22/2016	8/23/2016	PO4		0.112	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	8/22/2016	8/24/2016	NO2/NO3		17	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	8/22/2016	8/30/2016	TP		0.155	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	8/25/2016	8/26/2016	TSS		17.00	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	8/25/2016	8/26/2016	PO4		0.114	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	8/25/2016	8/31/2016	NO2/NO3		13	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	8/25/2016	8/30/2016	TP		0.232	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007 DUP	Composite	8/25/2016	8/26/2016	TSS		16.00	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007 DUP	Composite	8/25/2016	8/26/2016	PO4		0.139	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis

CD007 DUP	Composite	8/25/2016	8/31/2016	NO2/NO3		13	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007 DUP	Composite	8/25/2016	8/30/2016	TP		0.230	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	8/25/2016	8/26/2016	TSS		19.00	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	8/25/2016	8/26/2016	PO4		0.213	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	8/25/2016	8/31/2016	NO2/NO3		13	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	8/25/2016	8/30/2016	TP		0.286	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	8/25/2016	8/26/2016	TSS		56.00	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	8/25/2016	8/26/2016	PO4		0.193	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	8/25/2016	8/31/2016	NO2/NO3		11	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	8/25/2016	8/30/2016	TP		0.312	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	8/25/2016	8/26/2016	TSS		69.00	mg/L	1.005	EPA 365.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	8/25/2016	8/26/2016	PO4		0.170	mg/L	2.005	EPA 365.3	Samples filtered in lab for soluble ortho phosphorus prior to analysis

CD001	Composite	8/25/2016	8/31/2016	NO2/NO3		17	mg/L	3.005	EPA 365.4	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	8/25/2016	8/30/2016	TP		0.293	mg/L	4.005	EPA 365.5	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	9/8/2016	9/9/2016	TSS		23.00	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	9/8/2016	9/9/2016	PO4		0.116	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	9/8/2016	9/16/2016	NO2/NO3		15	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	9/8/2016	9/13/2016	TP		0.184	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	9/8/2016	9/9/2016	TSS		29.00	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	9/8/2016	9/9/2016	PO4		0.104	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	9/8/2016	9/16/2016	NO2/NO3		13	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	9/8/2016	9/13/2016	TP		0.251	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	9/8/2016	9/9/2016	TSS		34.00	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	9/8/2016	9/9/2016	PO4		0.137	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis

CD002	Composite	9/8/2016	9/16/2016	NO2/NO3		13	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	9/8/2016	9/13/2016	TP		0.262	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	9/8/2016	9/9/2016	TSS		13.00	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	9/8/2016	9/9/2016	PO4		0.126	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	9/8/2016	9/16/2016	NO2/NO3		19	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	9/8/2016	9/13/2016	TP		0.226	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	9/18/2016	9/20/2016	TSS		27.00	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	9/18/2016	9/20/2016	PO4		0.146	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	9/18/2016	9/21/2016	NO2/NO3		13	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	9/18/2016	9/27/2016	TP		0.214	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	9/18/2016	9/20/2016	TSS		24.00	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	9/18/2016	9/20/2016	PO4		0.148	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis

CD004	Composite	9/18/2016	9/21/2016	NO2/NO3		13	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	9/18/2016	9/27/2016	TP		0.269	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	9/18/2016	9/20/2016	TSS		26.00	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	9/18/2016	9/20/2016	PO4		0.147	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	9/18/2016	9/21/2016	NO2/NO3		12	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	9/18/2016	9/27/2016	TP		0.271	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002 DUP	Composite	9/18/2016	9/20/2016	TSS		27.00	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002 DUP	Composite	9/18/2016	9/20/2016	PO4		0.149	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002 DUP	Composite	9/18/2016	9/21/2016	NO2/NO3		12	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002 DUP	Composite	9/18/2016	9/27/2016	TP		0.278	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	9/18/2016	9/20/2016	TP		94.00	mg/L	1.005	EPA 365.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	9/18/2016	9/20/2016	TP		0.159	mg/L	2.005	EPA 365.3	Samples filtered in lab for soluble ortho phosphorus prior to analysis

CD001	Composite	9/18/2016	9/21/2016	TP		15	mg/L	3.005	EPA 365.4	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	9/18/2016	9/27/2016	TP		0.353	mg/L	4.005	EPA 365.5	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	9/25/2016	9/27/2016	TSS		52.00	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	9/25/2016	9/27/2016	PO4		0.227	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	9/25/2016	9/28/2016	NO2/NO3		5	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	9/25/2016	9/4/2016	TP	~	0.389	mg/L	0.005	EPA 365.1	Sample diluted due to result above calibration of linear range, samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	9/25/2016	9/27/2016	TSS		80.00	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	9/25/2016	9/27/2016	PO4		0.240	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	9/25/2016	9/28/2016	NO2/NO3		4	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	9/25/2016	9/4/2016	TP	~	0.440	mg/L	0.005	EPA 365.1	Sample diluted due to result above calibration of linear range, samples filtered in lab for soluble ortho phosphorus prior to analysis

CD002	Composite	9/25/2016	9/27/2016	TSS		68.00	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	9/25/2016	9/27/2016	PO4		0.240	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	9/25/2016	9/28/2016	NO2/NO3		5	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	9/25/2016	9/4/2016	TP	~	0.415	mg/L	0.005	EPA 365.1	Sample diluted due to result above calibration of linear range, samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	9/25/2016	9/27/2016	TSS		534.00	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	9/25/2016	9/27/2016	PO4		0.322	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	9/25/2016	9/28/2016	NO2/NO3		7	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	9/25/2016	9/4/2016	TP	~	0.809	mg/L	0.005	EPA 365.1	Sample diluted due to result above calibration of linear range, samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Base	10/20/2016	10/21/2016	TSS		3.00	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Base	10/20/2016	10/21/2016	PO4		0.044	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis

CD007	Base	10/20/2016	10/28/2016	NO2/NO3		14	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Base	10/20/2016	10/25/2016	TP		0.057	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Base	10/20/2016	10/21/2016	TSS		3.00	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Base	10/20/2016	10/21/2016	PO4		0.045	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Base	10/20/2016	10/28/2016	NO2/NO3		13	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Base	10/20/2016	10/25/2016	TP		0.084	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Base	10/20/2016	10/21/2016	TSS		2.00	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Base	10/20/2016	10/21/2016	PO4		0.044	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Base	10/20/2016	10/28/2016	NO2/NO3		12	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Base	10/20/2016	10/25/2016	TP		0.086	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Base	10/20/2016	10/21/2016	TSS	<	2.00	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Base	10/20/2016	10/21/2016	PO4		0.062	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis

CD001	Base	10/20/2016	10/28/2016	NO2/NO3		14	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Base	10/20/2016	10/25/2016	TP		0.074	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	10/28/2016	11/1/2016	TSS		44.00	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	10/28/2016	11/2/2016	PO4	*	0.387	mg/L	0.005	EPA 365.1	Holding time exceeded, samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	10/28/2016	11/2/2016	NO2/NO3		11	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	10/28/2016	11/8/2016	TP	~	0.530	mg/L	0.005	EPA 365.1	Sample diluted due to result above calibration of linear range, samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	10/28/2016	11/1/2016	TSS		32.00	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	10/28/2016	11/2/2016	PO4	*	0.369	mg/L	0.005	EPA 365.1	Holding time exceeded, samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	10/28/2016	11/2/2016	NO2/NO3		11	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	10/28/2016	11/8/2016	TP	~	0.490	mg/L	0.005	EPA 365.1	Sample diluted due to result above calibration of linear range, samples filtered in lab for soluble ortho phosphorus prior to analysis

CD002	Composite	10/28/2016	11/1/2016	TSS		30.00	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	10/28/2016	11/2/2016	PO4	*	0.300	mg/L	0.005	EPA 365.1	Holding time exceeded, samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	10/28/2016	11/2/2016	NO2/NO3		10	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	10/28/2016	11/8/2016	TP	~	0.480	mg/L	0.005	EPA 365.1	Sample diluted due to result above calibration of linear range, samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	10/28/2016	11/1/2016	TSS		34.00	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	10/28/2016	11/2/2016	PO4	*	0.230	mg/L	0.005	EPA 365.1	Holding time exceeded, samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	10/28/2016	11/2/2016	NO2/NO3		13	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	10/28/2016	11/8/2016	TP	~	0.389	mg/L	0.005	EPA 365.1	Sample diluted due to result above calibration of linear range, samples filtered in lab for soluble ortho phosphorus prior to analysis

Appendix B. 2017 Water Quality Reports from MVTL

Minnesota Valley Testing Laboratories Water Quality Results **2017**

Site	Sample Type	Date Sampled	Date Analyzed	Parameter	Attn	Result	Unit	Method RL	Method Reference	Comments
CD007	Base	4/4/2017	4/5/2017	TSS		5	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Base	4/4/2017	4/5/2017	PO4		0.038	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Base	4/4/2017	4/7/2017	NO2/NO3		12.30	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Base	4/4/2017	4/11/2017	TP		0.053	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Base	4/4/2017	4/5/2017	TSS		5	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Base	4/4/2017	4/5/2017	PO4		0.036	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Base	4/4/2017	4/7/2017	NO2/NO3		11.20	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Base	4/4/2017	4/11/2017	TP		0.061	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Base	4/4/2017	4/5/2017	TSS		3	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Base	4/4/2017	4/5/2017	PO4		0.027	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Base	4/4/2017	4/7/2017	NO2/NO3		7.08	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Base	4/4/2017	4/11/2017	TP		0.298	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis

CD001	Base	4/4/2017	4/5/2017	TSS		9	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Base	4/4/2017	4/5/2017	PO4		0.179	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Base	4/4/2017	4/7/2017	NO2/NO3		9.99	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Base	4/4/2017	4/11/2017	TP		0.056	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	4/22/2017	4/26/2017	TSS		12	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	4/22/2017	4/24/2017	PO4		0.048	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	4/22/2017	5/2/2017	NO2/NO3		13.90	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	4/22/2017	4/25/2017	TP		0.064	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	4/22/2017	4/26/2017	TSS		13	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	4/22/2017	4/24/2017	PO4		0.048	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	4/22/2017	5/2/2017	NO2/NO3		13.30	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	4/22/2017	4/25/2017	TP		0.082	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis

CD007	Composite	4/28/2017	4/28/2017	TSS		5	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	4/28/2017	4/28/2017	PO4		0.030	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	4/28/2017	5/2/2017	NO2/NO3		13.80	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	4/28/2017	5/2/2017	TP		0.059	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	4/28/2017	4/28/2017	TSS		44	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	4/28/2017	4/28/2017	PO4		0.033	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	4/28/2017	5/2/2017	NO2/NO3		13.20	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	4/28/2017	5/2/2017	TP		0.126	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	4/28/2017	4/28/2017	TSS		19	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	4/28/2017	4/28/2017	PO4		0.041	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	4/28/2017	5/2/2017	NO2/NO3		12.40	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	4/28/2017	5/2/2017	TP		0.160	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis

CD001	Composite	4/28/2017	4/28/2017	TSS		42	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	4/28/2017	4/28/2017	PO4		0.032	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	4/28/2017	5/2/2017	NO2/NO3		13.50	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	4/28/2017	5/2/2017	TP		0.174	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	5/2/2017	5/3/2017	TSS		32	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	5/2/2017	5/3/2017	PO4		0.054	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	5/2/2017	5/10/2017	NO2/NO3		15.30	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	5/2/2017	5/9/2017	TP		0.123	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	5/2/2017	5/3/2017	TSS		40	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	5/2/2017	5/3/2017	PO4		0.068	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	5/2/2017	5/10/2017	NO2/NO3		15.20	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	5/2/2017	5/9/2017	TP		0.179	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis

CD002 RISE	Composite	5/2/2017	5/3/2017	TSS		116	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002 RISE	Composite	5/2/2017	5/3/2017	PO4		0.049	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002 RISE	Composite	5/2/2017	5/10/2017	NO2/NO3		10.00	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002 RISE	Composite	5/2/2017	5/9/2017	TP		0.432	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	5/22/2017	5/23/2017	TSS		35	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	5/22/2017	5/22/2017	PO4		0.051	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	5/22/2017	5/24/2017	NO2/NO3		18.20	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	5/22/2017	5/30/2017	TP		0.176	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	5/22/2017	5/23/2017	TSS		11	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	5/22/2017	5/22/2017	PO4		0.061	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	5/22/2017	5/24/2017	NO2/NO3		17.80	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	5/22/2017	5/30/2017	TP		0.133	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis

CD002	Composite	5/22/2017	5/23/2017	TSS		21	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	5/22/2017	5/22/2017	PO4		0.068	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	5/22/2017	5/24/2017	NO2/NO3		16.50	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	5/22/2017	5/30/2017	TP		0.176	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	5/22/2017	5/23/2017	TSS		48	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	5/22/2017	5/22/2017	PO4		0.052	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	5/22/2017	5/24/2017	NO2/NO3		12.20	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	5/22/2017	5/30/2017	TP	-	0.490	mg/L	0.005	EPA 365.1	Sample diluted due to result above calibration of linear range, samples filtered in lab for soluble ortho phosphorus prior to analysis
CD0099	Composite	5/22/2017	5/23/2017	TSS	<	2	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD0099	Composite	5/22/2017	5/22/2017	PO4	<	0.005	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD0099	Composite	5/22/2017	5/24/2017	NO2/NO3	<	0.05	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis

CD0099	Composite	5/22/2017	5/30/2017	TP	<	0.005	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Base	6/2/2017	6/2/2017	TSS		4	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Base	6/2/2017	6/2/2017	PO4		0.023	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Base	6/2/2017	6/6/2017	NO2/NO3		14.70	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Base	6/2/2017	6/6/2017	TP		0.042	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Base	6/2/2017	6/2/2017	TSS		4	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Base	6/2/2017	6/2/2017	PO4		0.016	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Base	6/2/2017	6/6/2017	NO2/NO3		14.10	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Base	6/2/2017	6/6/2017	TP		0.034	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Base	6/2/2017	6/2/2017	TSS		2	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Base	6/2/2017	6/2/2017	PO4		0.019	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Base	6/2/2017	6/6/2017	NO2/NO3		13.40	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis

CD002	Base	6/2/2017	6/6/2017	TP		0.034	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Base	6/2/2017	6/2/2017	TSS		2	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Base	6/2/2017	6/2/2017	PO4		0.010	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Base	6/2/2017	6/6/2017	NO2/NO3		14.50	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Base	6/2/2017	6/6/2017	TP		0.019	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	6/14/2017	6/15/2017	TSS		10	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	6/14/2017	6/15/2017	PO4		0.047	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	6/14/2017	6/16/2017	NO2/NO3		13.90	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	6/14/2017	6/20/2017	TP		0.089	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	6/14/2017	6/15/2017	TSS		5	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	6/14/2017	6/15/2017	PO4		0.044	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	6/14/2017	6/16/2017	NO2/NO3		13.60	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis

CD004	Composite	6/14/2017	6/20/2017	TP		0.086	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	6/14/2017	6/15/2017	TSS		33	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	6/14/2017	6/15/2017	PO4		0.099	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	6/14/2017	6/16/2017	NO2/NO3		11.80	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	6/14/2017	6/20/2017	TP		0.253	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	6/14/2017	6/15/2017	TSS		12	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	6/14/2017	6/15/2017	PO4		0.057	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	6/14/2017	6/16/2017	NO2/NO3		17.10	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	6/14/2017	6/20/2017	TP	-	0.085	mg/L	0.005	EPA 365.1	Sample diluted due to result above calibration of linear range, samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	6/29/2017	6/30/2017	TSS		17	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	6/29/2017	6/30/2017	PO4		0.066	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis

CD007	Composite	6/29/2017	7/7/2017	NO2/NO3		10.20	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	6/29/2017	7/5/2017	TP		0.121	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	6/29/2017	6/30/2017	TSS		7	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	6/29/2017	6/30/2017	PO4		0.067	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	6/29/2017	7/7/2017	NO2/NO3		12.00	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	6/29/2017	7/5/2017	TP		0.124	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	6/29/2017	6/30/2017	TSS		30	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	6/29/2017	6/30/2017	PO4		0.077	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	6/29/2017	7/7/2017	NO2/NO3		9.78	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	6/29/2017	7/5/2017	TP		0.171	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	6/29/2017	6/30/2017	TSS		14	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	6/29/2017	6/30/2017	PO4		0.050	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis

CD001	Composite	6/29/2017	7/7/2017	NO2/NO3		14.10	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	6/29/2017	7/5/2017	TP		0.112	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	7/11/2017	7/13/2017	TSS		42	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	7/11/2017	7/13/2017	PO4		0.072	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	7/11/2017	7/21/2017	NO2/NO3		7.76	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	7/11/2017	7/18/2017	TP		0.178	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007 DUP	Composite	7/11/2017	7/13/2017	TSS		45	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007 DUP	Composite	7/11/2017	7/13/2017	PO4		0.070	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007 DUP	Composite	7/11/2017	7/21/2017	NO2/NO3		7.84	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007 DUP	Composite	7/11/2017	7/18/2017	TP		0.172	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	7/11/2017	7/13/2017	TSS		20	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	7/11/2017	7/13/2017	PO4		0.098	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis

CD004	Composite	7/11/2017	7/21/2017	NO2/NO3		6.32	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	7/11/2017	7/18/2017	TP		0.191	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	7/11/2017	7/13/2017	TSS		21	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	7/11/2017	7/13/2017	PO4		0.075	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	7/11/2017	7/21/2017	NO2/NO3		5.97	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	7/11/2017	7/18/2017	TP		0.165	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	7/11/2017	7/13/2017	TSS		102	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	7/11/2017	7/13/2017	PO4		0.092	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	7/11/2017	7/21/2017	NO2/NO3		13.20	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	7/11/2017	7/18/2017	TP		0.214	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	7/20/2017	7/25/2017	TSS		74	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	7/20/2017	7/21/2017	PO4		0.095	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis

CD007	Composite	7/20/2017	7/26/2017	NO2/NO3		5.51	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	7/20/2017	7/25/2017	TP		0.293	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	7/20/2017	7/25/2017	TSS		21	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	7/20/2017	7/21/2017	PO4		0.092	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	7/20/2017	7/26/2017	NO2/NO3		4.46	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	7/20/2017	7/25/2017	TP		0.185	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	7/20/2017	7/25/2017	TSS		97	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	7/20/2017	7/21/2017	PO4		0.040	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	7/20/2017	7/26/2017	NO2/NO3		6.35	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	7/20/2017	7/25/2017	TP		0.440	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	7/20/2017	7/25/2017	TSS		20	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	7/20/2017	7/21/2017	PO4		0.084	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis

CD001	Composite	7/20/2017	7/26/2017	NO2/NO3		9.66	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	7/20/2017	7/25/2017	TP		0.127	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	7/23/2017	7/25/2017	TSS		67	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	7/23/2017	7/25/2017	PO4		0.110	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	7/23/2017	7/26/2017	NO2/NO3		6.98	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	7/23/2017	8/1/2017	TP		0.234	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	7/23/2017	7/25/2017	TSS		24	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	7/23/2017	7/25/2017	PO4		0.138	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	7/23/2017	7/26/2017	NO2/NO3		5.80	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	7/23/2017	8/1/2017	TP		0.231	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	7/23/2017	7/25/2017	TSS		30	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	7/23/2017	7/25/2017	PO4		0.151	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis

CD002	Composite	7/23/2017	7/26/2017	NO2/NO3		4.81	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	7/23/2017	8/1/2017	TP		0.273	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	7/23/2017	7/25/2017	TSS		20	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	7/23/2017	7/25/2017	PO4		0.113	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	7/23/2017	7/26/2017	NO2/NO3		8.01	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Composite	7/23/2017	8/1/2017	TP		0.195	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Base	8/1/2017	8/2/2017	TSS		4	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Base	8/1/2017	8/2/2017	PO4		0.070	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Base	8/1/2017	8/4/2017	NO2/NO3		11.50	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Base	8/1/2017	8/8/2017	TP		0.088	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Base	8/1/2017	8/2/2017	TSS		8	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Base	8/1/2017	8/2/2017	PO4		0.069	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis

CD004	Base	8/1/2017	8/4/2017	NO2/NO3		8.44	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Base	8/1/2017	8/8/2017	TP		0.101	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Base	8/1/2017	8/2/2017	TSS		94	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Base	8/1/2017	8/2/2017	PO4		0.041	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Base	8/1/2017	8/4/2017	NO2/NO3		4.22	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Base	8/1/2017	8/8/2017	TP		0.204	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Base	8/1/2017	8/2/2017	TSS		6	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Base	8/1/2017	8/2/2017	PO4		0.079	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Base	8/1/2017	8/4/2017	NO2/NO3		7.15	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD001	Base	8/1/2017	8/8/2017	TP		0.106	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	8/17/2017	8/18/2017	TSS		83	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	8/17/2017	8/18/2017	PO4		0.075	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis

CD007	Composite	8/17/2017	8/23/2017	NO2/NO3		1.93	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	8/17/2017	8/22/2017	TP		0.248	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	8/17/2017	8/18/2017	TSS		27	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	8/17/2017	8/18/2017	PO4		0.226	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	8/17/2017	8/23/2017	NO2/NO3		1.94	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	8/17/2017	8/22/2017	TP		0.373	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	8/17/2017	8/18/2017	TSS		173	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	8/17/2017	8/18/2017	PO4		0.237	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	8/17/2017	8/23/2017	NO2/NO3		1.98	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	8/17/2017	8/22/2017	TP		0.498	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	8/23/2017	8/24/2017	TSS		37	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	8/23/2017	8/24/2017	PO4		0.084	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis

CD007	Composite	8/23/2017	8/25/2017	NO2/NO3		2.38	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD007	Composite	8/23/2017	8/29/2017	TP		0.242	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	8/23/2017	8/24/2017	TSS		19	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	8/23/2017	8/24/2017	PO4		0.291	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	8/23/2017	8/25/2017	NO2/NO3		2.17	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004	Composite	8/23/2017	8/29/2017	TP		0.463	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004 DUP	Composite	8/23/2017	8/24/2017	TSS		18	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004 DUP	Composite	8/23/2017	8/24/2017	PO4		0.245	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004 DUP	Composite	8/23/2017	8/25/2017	NO2/NO3		2.17	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD004 DUP	Composite	8/23/2017	8/29/2017	TP		0.452	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	8/23/2017	8/24/2017	TSS		79	mg/L	2	USGS 1-3765-85	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	8/23/2017	8/24/2017	PO4		0.360	mg/L	0.005	EPA 365.1	Samples filtered in lab for soluble ortho phosphorus prior to analysis

CD002	Composite	8/23/2017	8/25/2017	NO2/NO3		1.99	mg/L as N	0.05	353.2	Samples filtered in lab for soluble ortho phosphorus prior to analysis
CD002	Composite	8/23/2017	8/29/2017	TP	-	0.630	mg/L	0.005	EPA 365.1	Sample diluted due to result above calibration of linear range, samples filtered in lab for soluble ortho phosphorus prior to analysis

Appendix C. Load, yield, and flow-weighted mean concentrations for County Ditch 57 in 2016 and 2017.

Start Date	End Date	007 TSS Load (kg)	004 TSS Load (kg)	002 TSS Load (kg)	001 TSS Load (kg)	004-007 TSS Load (kg)	002-004 TSS Load (kg)	001-002 TSS Load (kg)
3/29/2016	3/31/2016	2340	451	180	1193	-1889	-271	1013
3/31/2016	4/2/2016	517	229	820	3104	-288	591	2285
4/24/2016	4/26/2016	377	462	91	332	85	-372	242
4/27/2016	4/30/2016	1062	3682	959	9243	2620	-2724	8285
4/30/2016	5/2/2016	1631	655	455	4058	-976	-200	3602
5/11/2016	5/13/2016	90	101	563	562	10	463	-1
5/13/2016	5/15/2016	366	485	4288	931	120	3803	-3357
5/26/2016	5/28/2016	170	159	2066	4207	-11	1907	2141
6/3/2016	6/5/2016	69	56	129	4072	-13	73	3943
6/10/2016	6/13/2016	236	153	332	3105	-83	179	2774
6/13/2016	6/16/2016	2542	4239	7029	126276	1697	2791	119247
7/7/2016	7/9/2016	315	88	156	563	-226	68	407
7/10/2016	7/12/2016	52	66	132	1067	14	65	935
7/17/2016	7/19/2016	515	354	832	3506	-160	477	2674
7/23/2016	7/25/2016	74	30	152	860	-44	122	708
8/11/2016	8/13/2016	538	284	634	13325	-254	349	12691
8/17/2016	8/18/2016	651	472	1025	3168	-178	553	2143
8/18/2016	8/20/2016	323	315	551	3043	-8	236	2491
8/23/2016	8/25/2016	1318	1601	6549	27501	283	4948	20953
9/6/2016	9/9/2016	1410	1250	2966	3866	-160	1716	899
9/15/2016	9/17/2016	2521	2328	3418	42358	-193	1090	38939
9/22/2016	9/25/2016	10112	33116	30704	112183	23004	-2412	81479
10/25/2016	10/28/2016	3178	2092	2400	9541	-1086	308	7141
Total Load (kg)		**30406**	**52669**	**66431**	**378064**	**22263**	**13761**	**311633**
Events Average (kg)		**1322**	**2290**	**2888**	**16438**	**968**	**598**	**13549**
Times Reduced (%)						**65%**	**22%**	**9%**

Total suspended solid loads for sampling sites in 2016.

Start Date	End Date	007 TSS Yield (kg/ha)	004 TSS Yield (kg/ha)	002 TSS Yield (kg/ha)	001 TSS Yield (kg/ha)	004-007 TSS Yield (kg/ha)	002-004 TSS Yield (kg/ha)	001-002 TSS Yield (kg/ha)
3/29/2016	3/31/2016	3.42	0.62	0.23	0.48	-2.80	-0.39	0.25
3/31/2016	4/2/2016	0.76	0.31	1.04	1.24	-0.44	0.73	0.20
4/24/2016	4/26/2016	0.55	0.63	0.12	0.13	0.08	-0.52	0.02
4/27/2016	4/30/2016	1.55	5.03	1.22	3.70	3.48	-3.81	2.48
4/30/2016	5/2/2016	2.38	0.89	0.58	1.62	-1.49	-0.32	1.05
5/11/2016	5/13/2016	0.13	0.14	0.72	0.23	0.01	0.58	-0.49
5/13/2016	5/15/2016	0.53	0.66	5.46	0.37	0.13	4.79	-5.08
5/26/2016	5/28/2016	0.25	0.22	2.63	1.68	-0.03	2.41	-0.94
6/3/2016	6/5/2016	0.10	0.08	0.16	1.63	-0.02	0.09	1.47
6/10/2016	6/13/2016	0.34	0.21	0.42	1.24	-0.14	0.21	0.82
6/13/2016	6/16/2016	3.71	5.79	8.94	50.56	2.07	3.16	41.62
7/7/2016	7/9/2016	0.46	0.12	0.20	0.23	-0.34	0.08	0.03
7/10/2016	7/12/2016	0.08	0.09	0.17	0.43	0.01	0.08	0.26
7/17/2016	7/19/2016	0.75	0.48	1.06	1.40	-0.27	0.57	0.35
7/23/2016	7/25/2016	0.11	0.04	0.19	0.34	-0.07	0.15	0.15
8/11/2016	8/13/2016	0.79	0.39	0.81	5.34	-0.40	0.42	4.53
8/17/2016	8/18/2016	0.95	0.65	1.30	1.27	-0.31	0.66	-0.04
8/18/2016	8/20/2016	0.47	0.43	0.70	1.22	-0.04	0.27	0.52
8/23/2016	8/25/2016	1.92	2.19	8.33	11.01	0.26	6.15	2.68
9/6/2016	9/9/2016	2.06	1.71	3.77	1.55	-0.35	2.07	-2.23
9/15/2016	9/17/2016	3.68	3.18	4.35	16.96	-0.50	1.17	12.61
9/22/2016	9/25/2016	14.77	45.22	39.07	44.92	30.45	-6.15	5.85
10/25/2016	10/28/2016	4.64	2.86	3.05	3.82	-1.79	0.20	0.77
Events Average (kg/hect)		**1.93**	**3.13**	**3.68**	**6.58**	**1.20**	**0.55**	**2.91**
Times Reduced (%)						**65%**	**22%**	**22%**

Total suspended solid yields for sampling sites in 2016.

Start Date	End Date	007 TSS (mg/L)	004 TSS (mg/L)	002 TSS (mg/L)	001 TSS (mg/L)	004-007 TSS (mg/L)	002-004 TSS (mg/L)	001-002 TSS (mg/L)
3/29/2016	3/31/2016	102	27	7	15	-75	-20	8
3/31/2016	4/2/2016	16	6	19	20	-10	13	1
4/24/2016	4/26/2016	29	21	4	4	-8	-17	0
4/27/2016	4/30/2016	24	72	15	46	47	-57	31
4/30/2016	5/2/2016	30	8	6	15	-22	-2	9
5/11/2016	5/13/2016	10	6	27	8	-4	21	-19
5/13/2016	5/15/2016	13	14	115	7	1	101	-108
5/26/2016	5/28/2016	18	14	135	76	-4	121	-59
6/3/2016	6/5/2016	9	7	13	114	-2	6	101
6/10/2016	6/13/2016	27	15	23	61	-12	8	38
6/13/2016	6/16/2016	27	40	53	268	13	13	215
7/7/2016	7/9/2016	28	7	9	9	-21	2	0
7/10/2016	7/12/2016	4	4	5	11	0	1	6
7/17/2016	7/19/2016	13	8	14	17	-5	6	3
7/23/2016	7/25/2016	10	3	8	13	-7	5	5
8/11/2016	8/13/2016	16	8	12	72	-8	4	60
8/17/2016	8/18/2016	19	12	25	24	-7	13	-1
8/18/2016	8/20/2016	12	9	12	19	-3	3	7
8/23/2016	8/25/2016	17	19	56	69	2	37	13
9/6/2016	9/9/2016	23	29	34	13	6	5	-21
9/15/2016	9/17/2016	27	24	26	94	-3	2	68
9/22/2016	9/25/2016	52	80	68	72	28	-12	4
10/25/2016	10/28/2016	44	32	30	34	-12	-2	4
Events Average (mg/L)		**25**	**20**	**31**	**47**	**-5**	**11**	**16**
Times Reduced (%)						**70%**	**26%**	**22%**

Total suspended solid flow-weighted mean concentrations for sampling sites in 2016.

Start Date	End Date	007 TP Load (kg)	004 TP Load (kg)	002 TP Load (kg)	001 TP Load (kg)	004-007 TP Load (kg)	002-004 TP Load (kg)	001-002 TP Load (kg)
3/29/2016	3/31/2016	5.253	1.972	1.415	10.224	-3.281	-0.557	8.809
3/31/2016	4/2/2016	6.398	4.194	7.768	28.096	-2.204	3.574	20.328
4/24/2016	4/26/2016	2.031	4.426	4.771	7.563	2.395	0.345	2.792
4/27/2016	4/30/2016	8.361	4.880	13.269	23.238	-3.481	8.389	9.969
4/30/2016	5/2/2016	9.676	10.154	11.082	41.117	0.478	0.928	30.035
5/11/2016	5/13/2016	0.614	1.158	3.631	4.917	0.543	2.474	1.286
5/13/2016	5/15/2016	1.996	2.842	16.629	10.242	0.845	13.787	-6.387
5/26/2016	5/28/2016	1.075	1.587	7.069	12.843	0.511	5.483	5.773
6/3/2016	6/5/2016	0.790	0.979	2.034	17.450	0.189	1.054	15.416
6/10/2016	6/13/2016	1.740	1.856	2.610	16.299	0.116	0.754	13.689
6/13/2016	6/16/2016	26.927	36.028	48.277	249.725	9.101	12.249	201.448
7/7/2016	7/9/2016	1.686	2.323	2.865	9.823	0.637	0.542	6.958
7/10/2016	7/12/2016	1.997	2.900	4.314	18.037	0.903	1.414	13.723
7/17/2016	7/19/2016	5.545	8.242	12.354	43.716	2.697	4.113	31.362
7/23/2016	7/25/2016	1.104	2.311	4.146	13.959	1.208	1.834	9.814
8/11/2016	8/13/2016	10.590	7.462	11.562	73.842	-3.128	4.100	62.280
8/17/2016	8/18/2016	6.611	11.536	12.346	32.398	4.925	0.810	20.052
8/18/2016	8/20/2016	3.638	7.211	9.420	24.821	3.573	2.209	15.402
8/23/2016	8/25/2016	17.983	24.102	36.486	116.781	6.119	12.384	80.295
9/6/2016	9/9/2016	11.278	10.820	22.858	67.200	-0.458	12.038	44.342
9/15/2016	9/17/2016	19.982	26.094	35.631	159.067	6.112	9.537	123.436
9/22/2016	9/25/2016	75.645	182.135	187.383	571.129	106.490	5.248	383.746
10/25/2016	10/28/2016	38.280	32.037	38.403	109.162	-6.243	6.366	70.758
Total Load (kg)		**259**	**387**	**496**	**1662**	**128**	**109**	**1165**
Events Average (mg/L)		**11.270**	**16.837**	**21.579**	**72.246**	**5.567**	**4.742**	**50.666**
Times Reduced (%)						**26%**	**4%**	**4%**

Total phosphorus loads for sampling sites in 2016.

Start Date	End Date	007 TP Yield (kg/ha)	004 TP Yield (kg/ha)	002 TP Yield (kg/ha)	001 TP Yield (kg/ha)	004-007 TP Yield (kg/ha)	002-004 TP Yield (kg/ha)	001-002 TP Yield (kg/ha)
3/29/2016	3/31/2016	0.008	0.003	0.002	0.004	-0.005	-0.001	0.002
3/31/2016	4/2/2016	0.009	0.006	0.010	0.011	-0.004	0.004	0.001
4/24/2016	4/26/2016	0.003	0.006	0.006	0.003	0.003	0.000	-0.003
4/27/2016	4/30/2016	0.012	0.007	0.017	0.009	-0.006	0.010	-0.008
4/30/2016	5/2/2016	0.014	0.014	0.014	0.016	0.000	0.000	0.002
5/11/2016	5/13/2016	0.001	0.002	0.005	0.002	0.001	0.003	-0.003
5/13/2016	5/15/2016	0.003	0.004	0.021	0.004	0.001	0.017	-0.017
5/26/2016	5/28/2016	0.002	0.002	0.009	0.005	0.001	0.007	-0.004
6/3/2016	6/5/2016	0.001	0.001	0.003	0.007	0.000	0.001	0.004
6/10/2016	6/13/2016	0.003	0.003	0.003	0.007	0.000	0.001	0.003
6/13/2016	6/16/2016	0.039	0.049	0.061	0.100	0.010	0.012	0.039
7/7/2016	7/9/2016	0.002	0.003	0.004	0.004	0.001	0.000	0.000
7/10/2016	7/12/2016	0.003	0.004	0.005	0.007	0.001	0.002	0.002
7/17/2016	7/19/2016	0.008	0.011	0.016	0.018	0.003	0.004	0.002
7/23/2016	7/25/2016	0.002	0.003	0.005	0.006	0.002	0.002	0.000
8/11/2016	8/13/2016	0.015	0.010	0.015	0.030	-0.005	0.005	0.015
8/17/2016	8/18/2016	0.010	0.016	0.016	0.013	0.006	0.000	-0.003
8/18/2016	8/20/2016	0.005	0.010	0.012	0.010	0.005	0.002	-0.002
8/23/2016	8/25/2016	0.026	0.033	0.046	0.047	0.007	0.014	0.000
9/6/2016	9/9/2016	0.016	0.015	0.029	0.027	-0.002	0.014	-0.002
9/15/2016	9/17/2016	0.029	0.036	0.045	0.064	0.006	0.010	0.018
9/22/2016	9/25/2016	0.110	0.249	0.238	0.229	0.138	-0.010	-0.010
10/25/2016	10/28/2016	0.056	0.044	0.049	0.044	-0.012	0.005	-0.005
Events Average (mg/L)		**0.016**	**0.023**	**0.027**	**0.029**	**0.007**	**0.004**	**0.001**
Times Reduced (%)						**35%**	**13%**	**43%**

Total phosphorus yields for sampling sites in 2016.

Start Date	End Date	007 TP (mg/L)	004 TP (mg/L)	002 TP (mg/L)	001 TP (mg/L	004-007 TP (mg/L)	002-004 TP (mg/L)	001-002 TP (mg/L)
3/29/2016	3/31/2016	0.229	0.118	0.055	0.129	-0.111	-0.063	0.074
3/31/2016	4/2/2016	0.198	0.110	0.180	0.181	-0.088	0.070	0.001
4/24/2016	4/26/2016	0.156	0.201	0.210	0.091	0.045	0.009	-0.119
4/27/2016	4/30/2016	0.192	0.095	0.210	0.116	-0.097	0.115	-0.093
4/30/2016	5/2/2016	0.178	0.124	0.146	0.152	-0.054	0.022	0.006
5/11/2016	5/13/2016	0.068	0.069	0.174	0.070	0.001	0.105	-0.104
5/13/2016	5/15/2016	0.071	0.082	0.446	0.077	0.011	0.364	-0.369
5/26/2016	5/28/2016	0.114	0.140	0.462	0.231	0.026	0.322	-0.231
6/3/2016	6/5/2016	0.103	0.123	0.210	0.488	0.020	0.087	0.278
6/10/2016	6/13/2016	0.199	0.182	0.181	0.319	-0.017	-0.001	0.138
6/13/2016	6/16/2016	0.286	0.340	0.364	0.530	0.054	0.024	0.166
7/7/2016	7/9/2016	0.150	0.184	0.165	0.157	0.034	-0.019	-0.008
7/10/2016	7/12/2016	0.154	0.175	0.164	0.186	0.021	-0.011	0.022
7/17/2016	7/19/2016	0.140	0.186	0.208	0.212	0.046	0.022	0.004
7/23/2016	7/25/2016	0.149	0.233	0.218	0.209	0.084	-0.015	-0.009
8/11/2016	8/13/2016	0.315	0.210	0.219	0.399	-0.105	0.009	0.180
8/17/2016	8/18/2016	0.193	0.293	0.301	0.243	0.100	0.008	-0.058
8/18/2016	8/20/2016	0.135	0.206	0.205	0.155	0.071	-0.001	-0.050
8/23/2016	8/25/2016	0.232	0.286	0.312	0.293	0.054	0.026	-0.019
9/6/2016	9/9/2016	0.184	0.251	0.262	0.226	0.067	0.011	-0.036
9/15/2016	9/17/2016	0.214	0.269	0.271	0.353	0.055	0.002	0.082
9/22/2016	9/25/2016	0.389	0.440	0.415	0.369	0.051	-0.025	-0.046
10/25/2016	10/28/2016	0.530	0.490	0.480	0.389	-0.040	-0.010	-0.091
Events Average (mg/L)		**0.199**	**0.209**	**0.255**	**0.242**	**0.010**	**0.046**	**-0.012**
Times Reduced (%)						**30%**	**35%**	**57%**

Total phosphorus flow-weighted mean concentrations for sampling sites in 2016.

Start Date	End Date	007 PO4 Load (kg)	004 PO4 Load (kg)	002 PO4 Load (kg)	001 PO4 Load (kg)	004-007 PO4 Load (kg)	002-004 PO4 Load (kg)	001-002 PO4 Load (kg)
3/29/2016	3/31/2016	0.711	0.802	0.721	4.137	0.091	-0.082	3.417
3/31/2016	4/2/2016	1.648	2.516	2.460	12.573	0.868	-0.057	10.113
4/24/2016	4/26/2016	0.807	1.718	0.977	4.904	0.910	-0.741	3.927
4/27/2016	4/30/2016	2.012	2.737	6.702	14.969	0.725	3.965	8.267
4/30/2016	5/2/2016	2.609	4.422	4.782	22.452	1.812	0.360	17.670
5/11/2016	5/13/2016	0.316	0.705	0.605	3.021	0.389	-0.099	2.416
5/13/2016	5/15/2016	1.125	1.560	0.746	6.251	0.435	-0.814	5.506
5/26/2016	5/28/2016	0.358	0.771	0.888	5.315	0.412	0.117	4.428
6/3/2016	6/5/2016	0.465	0.559	1.146	8.513	0.095	0.587	7.366
6/10/2016	6/13/2016	0.577	0.989	1.731	8.449	0.412	0.741	6.718
6/13/2016	6/16/2016	14.028	17.908	23.741	122.035	3.880	5.832	98.295
7/7/2016	7/9/2016	0.989	1.439	1.511	5.631	0.450	0.071	4.120
7/10/2016	7/12/2016	1.297	2.287	3.498	13.673	0.990	1.212	10.175
7/17/2016	7/19/2016	4.079	6.912	9.919	38.149	2.833	3.007	28.230
7/23/2016	7/25/2016	0.778	1.538	2.815	7.878	0.760	1.277	5.064
8/11/2016	8/13/2016	4.673	4.797	7.603	43.121	0.124	2.806	35.518
8/17/2016	8/18/2016	4.350	8.229	8.613	17.673	3.878	0.385	9.060
8/18/2016	8/20/2016	2.749	6.301	8.317	17.935	3.552	2.016	9.618
8/23/2016	8/25/2016	8.837	17.950	22.570	67.757	9.113	4.620	45.187
9/6/2016	9/9/2016	7.110	4.483	11.952	37.466	-2.627	7.469	25.513
9/15/2016	9/17/2016	13.632	14.357	19.328	71.648	0.724	4.971	52.320
9/22/2016	9/25/2016	44.143	99.347	108.366	288.090	55.204	9.020	179.724
10/25/2016	10/28/2016	27.952	24.126	24.002	64.543	-3.826	-0.124	40.541
Total Load (kg)		**145**	**226**	**273**	**886**	**81**	**47**	**613**
Events Average (mg/L)		**6.315**	**9.846**	**11.869**	**38.530**	**3.531**	**2.023**	**26.661**
Times Reduced (%)						**9%**	**26%**	**0%**

Orthophosphate loads for sampling sites in 2016.

Start Date	End Date	007 PO4 Yield (kg/ha)	004 PO4 Yield (kg/ha)	002 PO4 Yield (kg/ha)	001 PO4 Yield (kg/ha)	004-007 PO4 Yield (kg/ha)	002-004 PO4 Yield (kg/ha)	001-002 PO4 Yield (kg/ha)
3/29/2016	3/31/2016	0.001	0.001	0.001	0.002	0.000	0.000	0.001
3/31/2016	4/2/2016	0.002	0.003	0.003	0.005	0.001	0.000	0.002
4/24/2016	4/26/2016	0.001	0.002	0.001	0.002	0.001	-0.001	0.001
4/27/2016	4/30/2016	0.003	0.004	0.009	0.006	0.001	0.005	-0.003
4/30/2016	5/2/2016	0.004	0.006	0.006	0.009	0.002	0.000	0.003
5/11/2016	5/13/2016	0.000	0.001	0.001	0.001	0.001	0.000	0.000
5/13/2016	5/15/2016	0.002	0.002	0.001	0.003	0.000	-0.001	0.002
5/26/2016	5/28/2016	0.001	0.001	0.001	0.002	0.001	0.000	0.001
6/3/2016	6/5/2016	0.001	0.001	0.001	0.003	0.000	0.001	0.002
6/10/2016	6/13/2016	0.001	0.001	0.002	0.003	0.001	0.001	0.001
6/13/2016	6/16/2016	0.020	0.024	0.030	0.049	0.004	0.006	0.019
7/7/2016	7/9/2016	0.001	0.002	0.002	0.002	0.001	0.000	0.000
7/10/2016	7/12/2016	0.002	0.003	0.004	0.005	0.001	0.001	0.001
7/17/2016	7/19/2016	0.006	0.009	0.013	0.015	0.003	0.003	0.003
7/23/2016	7/25/2016	0.001	0.002	0.004	0.003	0.001	0.001	0.000
8/11/2016	8/13/2016	0.007	0.007	0.010	0.017	0.000	0.003	0.008
8/17/2016	8/18/2016	0.006	0.011	0.011	0.007	0.005	0.000	-0.004
8/18/2016	8/20/2016	0.004	0.009	0.011	0.007	0.005	0.002	-0.003
8/23/2016	8/25/2016	0.013	0.025	0.029	0.027	0.012	0.004	-0.002
9/6/2016	9/9/2016	0.010	0.006	0.015	0.015	-0.004	0.009	0.000
9/15/2016	9/17/2016	0.020	0.020	0.025	0.029	0.000	0.005	0.004
9/22/2016	9/25/2016	0.064	0.136	0.138	0.115	0.071	0.002	-0.023
10/25/2016	10/28/2016	0.041	0.033	0.031	0.026	-0.008	-0.002	-0.005
Events Average (mg/L)		**0.009**	**0.013**	**0.015**	**0.015**	**0.004**	**0.002**	**0.000**
Times Reduced (%)						**17%**	**35%**	**35%**

Orthophosphate yields for sampling sites in 2016.

Start Date	End Date	007 PO4 (mg/L)	004 PO4 (mg/L)	002 PO4 (mg/L)	001 PO4 (mg/L)	004-007 PO4 (mg/L)	002-004 PO4 (mg/L)	001-002 PO4 (mg/L)
3/29/2016	3/31/2016	0.031	0.048	0.028	0.052	0.017	-0.020	0.024
3/31/2016	4/2/2016	0.051	0.066	0.057	0.081	0.015	-0.009	0.024
4/24/2016	4/26/2016	0.062	0.078	0.043	0.059	0.016	-0.035	0.016
4/27/2016	4/30/2016	0.046	0.053	0.106	0.075	0.007	0.053	-0.031
4/30/2016	5/2/2016	0.048	0.054	0.063	0.083	0.006	0.009	0.020
5/11/2016	5/13/2016	0.035	0.042	0.029	0.043	0.007	-0.013	0.014
5/13/2016	5/15/2016	0.040	0.045	0.020	0.047	0.005	-0.025	0.027
5/26/2016	5/28/2016	0.038	0.068	0.058	0.095	0.030	-0.010	0.037
6/3/2016	6/5/2016	0.061	0.070	0.119	0.238	0.010	0.048	0.120
6/10/2016	6/13/2016	0.066	0.097	0.120	0.165	0.031	0.023	0.045
6/13/2016	6/16/2016	0.149	0.169	0.179	0.259	0.020	0.010	0.080
7/7/2016	7/9/2016	0.088	0.114	0.087	0.090	0.026	-0.027	0.003
7/10/2016	7/12/2016	0.100	0.138	0.133	0.141	0.038	-0.005	0.008
7/17/2016	7/19/2016	0.103	0.156	0.167	0.185	0.053	0.011	0.018
7/23/2016	7/25/2016	0.105	0.155	0.148	0.118	0.050	-0.007	-0.030
8/11/2016	8/13/2016	0.139	0.135	0.144	0.233	-0.004	0.009	0.089
8/17/2016	8/18/2016	0.127	0.209	0.210	0.133	0.082	0.001	-0.077
8/18/2016	8/20/2016	0.102	0.180	0.181	0.112	0.078	0.001	-0.069
8/23/2016	8/25/2016	0.114	0.213	0.193	0.170	0.099	-0.020	-0.023
9/6/2016	9/9/2016	0.116	0.104	0.137	0.126	-0.012	0.033	-0.011
9/15/2016	9/17/2016	0.146	0.148	0.147	0.159	0.002	-0.001	0.012
9/22/2016	9/25/2016	0.227	0.240	0.240	0.186	0.013	0.000	-0.054
10/25/2016	10/28/2016	0.387	0.369	0.300	0.230	-0.018	-0.069	-0.070
Events Average (mg/L)		**0.104**	**0.128**	**0.126**	**0.134**	**0.025**	**-0.002**	**0.008**
Times Reduced (%)						**13%**	**52%**	**35%**

Orthophosphate flow-weighted mean concentrations for sampling sites in 2016.

Start Date	End Date	007 NO3+NO2 Load (kg)	004 NO3+NO2 Load (kg)	002 NO3+NO2 Load (kg)	001 NO3+NO2 Load (kg)	004-007 NO3+NO2 Load (kg)	002-004 NO3+NO2 Load (kg)	001-002 NO3+NO2 Load (kg)
3/29/2016	3/31/2016	429	328	481	1623	-101	154	1142
3/31/2016	4/2/2016	672	766	829	3648	94	62	2819
4/24/2016	4/26/2016	247	348	423	1720	101	75	1298
4/27/2016	4/30/2016	983	1125	1008	5003	142	-117	3994
4/30/2016	5/2/2016	1283	1834	1738	7087	551	-96	5349
5/11/2016	5/13/2016	192	349	411	1672	157	62	1261
5/13/2016	5/15/2016	666	783	817	3378	117	33	2562
5/26/2016	5/28/2016	185	207	259	1610	23	51	1352
6/3/2016	6/5/2016	146	140	139	1129	-6	-1	990
6/10/2016	6/13/2016	165	169	216	1437	4	47	1221
6/13/2016	6/16/2016	2109	2246	2639	9329	138	393	6690
7/7/2016	7/9/2016	205	163	194	1007	-42	32	813
7/10/2016	7/12/2016	245	242	366	1755	-3	124	1390
7/17/2016	7/19/2016	685	696	855	3506	11	160	2650
7/23/2016	7/25/2016	109	115	226	1749	6	111	1523
8/11/2016	8/13/2016	230	294	364	3091	65	70	2727
8/17/2016	8/18/2016	486	476	509	3076	-10	32	2567
8/18/2016	8/20/2016	415	487	620	2770	72	134	2150
8/23/2016	8/25/2016	1039	1087	1310	6576	48	223	5267
9/6/2016	9/9/2016	889	552	1134	5501	-337	582	4367
9/15/2016	9/17/2016	1223	1222	1538	6714	-1	316	5176
9/22/2016	9/25/2016	893	1821	2452	31101	929	630	28650
10/25/2016	10/28/2016	766	687	788	3732	-79	102	2944
Total Load (kg)		**14261**	**16138**	**19316**	**108216**	**1877**	**3178**	**88900**
Events Average (mg/L)		**620**	**702**	**840**	**4705**	**82**	**138**	**3865**
Times Reduced (%)						**35%**	**13%**	**0%**

Nitrate+nitrite as nitrogen loads for sampling sites in 2016.

Start Date	End Date	007 NO3+NO2 Yield (kg/ha)	004 NO3+NO2 Yield (kg/ha)	002 NO3+NO2 Yield (kg/ha)	001 NO3+NO2 Yield (kg/ha)	004-007 NO3+NO2 Yield (kg/ha)	002-004 NO3+NO2 Yield (kg/ha)	001-002 NO3+NO2 Yield (kg/ha)
3/29/2016	3/31/2016	0.63	0.45	0.61	0.65	-0.18	0.17	0.04
3/31/2016	4/2/2016	0.98	1.05	1.05	1.46	0.06	0.01	0.41
4/24/2016	4/26/2016	0.36	0.48	0.54	0.69	0.11	0.06	0.15
4/27/2016	4/30/2016	1.44	1.54	1.28	2.00	0.10	-0.25	0.72
4/30/2016	5/2/2016	1.87	2.50	2.21	2.84	0.63	-0.29	0.63
5/11/2016	5/13/2016	0.28	0.48	0.52	0.67	0.20	0.05	0.15
5/13/2016	5/15/2016	0.97	1.07	1.04	1.35	0.10	-0.03	0.31
5/26/2016	5/28/2016	0.27	0.28	0.33	0.64	0.01	0.05	0.32
6/3/2016	6/5/2016	0.21	0.19	0.18	0.45	-0.02	-0.01	0.28
6/10/2016	6/13/2016	0.24	0.23	0.28	0.58	-0.01	0.04	0.30
6/13/2016	6/16/2016	3.08	3.07	3.36	3.74	-0.01	0.29	0.38
7/7/2016	7/9/2016	0.30	0.22	0.25	0.40	-0.08	0.03	0.16
7/10/2016	7/12/2016	0.36	0.33	0.47	0.70	-0.03	0.13	0.24
7/17/2016	7/19/2016	1.00	0.95	1.09	1.40	-0.05	0.14	0.32
7/23/2016	7/25/2016	0.16	0.16	0.29	0.70	0.00	0.13	0.41
8/11/2016	8/13/2016	0.34	0.40	0.46	1.24	0.07	0.06	0.77
8/17/2016	8/18/2016	0.71	0.65	0.65	1.23	-0.06	0.00	0.58
8/18/2016	8/20/2016	0.61	0.66	0.79	1.11	0.06	0.12	0.32
8/23/2016	8/25/2016	1.52	1.48	1.67	2.63	-0.03	0.18	0.97
9/6/2016	9/9/2016	1.30	0.75	1.44	2.20	-0.54	0.69	0.76
9/15/2016	9/17/2016	1.79	1.67	1.96	2.69	-0.12	0.29	0.73
9/22/2016	9/25/2016	1.30	2.49	3.12	12.45	1.18	0.63	9.33
10/25/2016	10/28/2016	1.12	0.94	1.00	1.49	-0.18	0.07	0.49
Events Average (mg/L)		**0.91**	**0.96**	**1.07**	**1.88**	**0.05**	**0.11**	**0.82**
Times Reduced (%)						**57%**	**22%**	**0%**

Nitrate+nitrite as nitrogen yields for sampling sites in 2016.

Start Date	End Date	007 NO3+NO2 as N (mg/L)	004 NO3+NO2 as N (mg/L)	002 NO3+NO2 as N (mg/L)	001 NO3+NO2 as N (mg/L)	004-007 NO3+NO2 as N (mg/L)	002-004 NO3+NO2 as N (mg/L)	001-002 NO3+NO2 as N (mg/L)
3/29/2016	3/31/2016	18.70	19.60	18.70	20.41	0.90	-0.90	1.71
3/31/2016	4/2/2016	20.80	20.10	19.20	23.51	-0.70	-0.90	4.31
4/24/2016	4/26/2016	19.00	15.80	18.60	20.71	-3.20	2.80	2.11
4/27/2016	4/30/2016	22.63	21.92	15.92	25.00	-0.71	-5.99	9.07
4/30/2016	5/2/2016	23.60	22.40	22.90	26.21	-1.20	0.50	3.31
5/11/2016	5/13/2016	21.30	20.80	19.70	23.81	-0.50	-1.10	4.11
5/13/2016	5/15/2016	23.70	22.60	21.90	25.41	-1.10	-0.70	3.51
5/26/2016	5/28/2016	19.60	18.30	16.90	28.91	-1.30	-1.40	12.01
6/3/2016	6/5/2016	19.00	17.60	14.37	31.60	-1.40	-3.23	17.23
6/10/2016	6/13/2016	18.90	16.60	15.00	28.10	-2.30	-1.60	13.10
6/13/2016	6/16/2016	22.40	21.20	19.90	19.81	-1.20	-1.30	-0.09
7/7/2016	7/9/2016	18.20	12.90	11.20	16.10	-5.30	-1.70	4.90
7/10/2016	7/12/2016	18.90	14.60	13.90	18.11	-4.30	-0.70	4.21
7/17/2016	7/19/2016	17.30	15.70	14.40	17.00	-1.60	-1.30	2.60
7/23/2016	7/25/2016	14.70	11.60	11.90	26.21	-3.10	0.30	14.31
8/11/2016	8/13/2016	6.83	8.28	6.89	16.70	1.45	-1.39	9.81
8/17/2016	8/18/2016	14.20	12.10	12.40	23.11	-2.10	0.30	10.71
8/18/2016	8/20/2016	15.40	13.90	13.50	17.30	-1.50	-0.40	3.80
8/23/2016	8/25/2016	13.40	12.90	11.20	16.50	-0.50	-1.70	5.30
9/6/2016	9/9/2016	14.50	12.80	13.00	18.51	-1.70	0.20	5.51
9/15/2016	9/17/2016	13.10	12.60	11.70	14.90	-0.50	-0.90	3.20
9/22/2016	9/25/2016	4.59	4.40	5.43	20.09	-0.19	1.03	14.66
10/25/2016	10/28/2016	10.60	10.50	9.85	13.30	-0.10	-0.65	3.45
Events Average (mg/L)		**17.02**	**15.62**	**14.72**	**21.36**	**-1.40**	**-0.90**	**6.64**
Times Reduced (%)						**91%**	**74%**	**4%**

Nitrate+nitrite as nitrogen flow-weighted mean concentrations for sampling sites in 2016.

Start Date	End Date	007 TSS (mg/L)	004 TSS (mg/L)	002 TSS (mg/L)	001 TSS (mg/L)	004-007 TSS (mg/L)	002-004 TSS (mg/L)	001-002 TSS (mg/L)
3/10/2016	3/30/2016	2	15	2	2	13	-13	0
4/1/2016	4/24/2016	6	6	5	12	0	-1	7
6/16/2016	7/7/2016	9	5	4	5	-4	-1	1
7/24/2016	8/11/2016	7	8	5	5	1	-3	0
9/23/2016	10/25/2016	3	3	2	2	0	-1	0

Start Date	End Date	007 TP (mg/L)	004 TP (mg/L)	002 TP (mg/L)	001 TP (mg/L)	004-007 TP (mg/L)	002-004 TP (mg/L)	001-002 TP (mg/L)
3/10/2016	3/30/2016	0.036	0.039	0.024	0.023	0.003	-0.015	-0.001
4/1/2016	4/24/2016	0.033	0.045	0.025	0.550	0.012	-0.020	0.525
6/16/2016	7/7/2016	0.075	0.127	0.123	0.058	0.052	-0.004	-0.065
7/24/2016	8/11/2016	0.138	0.138	0.143	0.219	0.000	0.005	0.076
9/23/2016	10/25/2016	0.057	0.084	0.086	0.074	0.027	0.002	-0.012

Start Date	End Date	007 PO4 (mg/L)	004 PO4 (mg/L)	002 PO4 (mg/L)	001 PO4 (mg/L)	004-007 PO4 (mg/L)	002-004 PO4 (mg/L)	001-002 PO4 (mg/L)
3/10/2016	3/30/2016	0.036	0.047	0.024	0.019	0.011	-0.023	-0.005
4/1/2016	4/24/2016	0.038	0.025	0.020	0.308	-0.013	-0.005	0.288
6/16/2016	7/7/2016	0.045	0.061	0.067	0.028	0.016	0.006	-0.039
7/24/2016	8/11/2016	0.112	0.089	0.091	0.146	-0.023	0.002	0.055
9/23/2016	10/25/2016	0.044	0.045	0.044	0.062	0.001	-0.001	0.018

Start Date	End Date	007 NO3+NO2 as N (mg/L)	004 NO3+NO2 as N (mg/L)	002 NO3+NO2 as N (mg/L)	001 NO3+NO2 as N (mg/L)	004-007 NO3+NO2 as N (mg/L)	002-004 NO3+NO2 as N (mg/L)	001-002 NO3+NO2 as N (mg/L)
3/10/2016	3/30/2016	22.40	22.10	20.80	24.11	-0.30	-1.30	3.31
4/1/2016	4/24/2016	21.60	20.60	19.90	12.00	-1.00	-0.70	-7.90
6/16/2016	7/7/2016	24.50	22.80	20.30	22.71	-1.70	-2.50	2.41
7/24/2016	8/11/2016	20.00	11.20	7.72	10.50	-8.80	-3.48	2.78
9/23/2016	10/25/2016	14.00	11.00	12.40	14.40	-3.00	1.40	2.00

Base flow flow-weighted mean concentrations for total suspended solids, total phosphorus, orthophosphates, and nitrate+nitrite as nitrogen for 2016.

Start Date	End Date	007 TSS Load (kg)	004 TSS Load (kg)	002 TSS Min Load (kg)	002 TSS Max Load (kg)	001 Min TSS Load (kg)	001 Max TSS Load (kg)	004-007 TSS Load (kg)	002 Min-004 TSS Load (kg)	002 Max-004 TSS Load (kg)	001 Min-002 Min TSS Load (kg)	001 Max-002 Max TSS Load (kg)
04/19/17	04/22/17	139	271	282	574	3,400	5,875	133	10	303	3,118	5,301
04/25/17	04/28/17	76	1,118	578	578	4,006	4,006	1,042	-541	-541	3,428	3,428
04/30/17	05/02/17	2,094	1,766	2,206	2,206	17,054	42,212	-328	439	439	14,848	-2,206
05/19/17	05/22/17	2,187	672	1,368	1,368	22,033	22,033	-1,515	696	696	20,665	20,665
06/11/17	06/14/17	303	1,045	1,164	1,164	12,485	55,584	743	119	119	11,321	54,419
06/27/17	06/30/17	160	69	350	350	746	746	-91	281	281	396	396
07/09/17	07/11/17	459	432	493	1,877	9,712	9,712	-28	61	1,446	9,219	7,835
07/19/17	07/21/17	297	110	589	589	1,610	7,830	-186	478	478	1,021	7,241
07/21/17	07/23/17	582	229	357	357	769	769	-353	128	128	412	412
08/17/17	08/19/17	413	91	141	448	280	1,161	-322	50	357	139	713
08/22/17	08/24/17	71	38	252	252	91	208	-33	214	214	-161	-44
09/18/17	09/20/17	250	240	507	608	645	645	-10	267	367	138	38
10/01/17	10/02/17	119	84	142	444	1,795	1,795	-35	58	359	1,652	1,351
10/02/17	10/04/17	667	344	452	774	2,311	2,311	-323	108	429	1,859	1,538
10/05/17	10/06/17	993	809	504	1,566	6,772	6,772	-184	-306	756	6,268	5,206
10/06/17	10/08/17	1,866	1,779	1,045	1,775	17,362	40,577	-87	-734	-4	16,316	38,802
10/21/17	10/23/17	580	268	2,150	4,015	1,889	18,073	-313	1,882	3,747	-260	14,059
Total Load (kg)		**11,258**	**9,368**	**12,580**	**18,943**	**102,960**	**220,308**	**-1890**	**3,212**	**9,575**	**90,380**	**159,154**
Events Average (kg)		**662**	**551**	**740**	**1,114**	**6,056**	**12,959**	**-111**	**189**	**563**	**5,316**	**9,362**
Times Reduced (%)								**82%**	**18%**	**12%**	**12%**	**12%**

Total suspended solid loads for sampling sites in 2017.

Start Date	End Date	007 TSS Yield (kg/ha)	004 TSS Yield (kg/ha)	002 TSS Yield (kg/ha)	002 TSS Yield (kg/ha)	001 TSS Yield (kg/ha)	001 TSS Yield (kg/ha)	004-007 TSS Yield (kg/ha)	002-004 TSS Yield (kg/ha)	002-004 TSS Yield (kg/ha)	001-002 TSS Yield (kg/ha)	001-002 TSS Yield (kg/ha)
04/19/17	04/22/17	0.203	0.371	0.359	0.731	1.361	2.352	0.168	-0.012	0.360	1.003	1.622
04/25/17	04/28/17	0.111	1.527	0.735	0.735	1.604	1.604	1.416	-0.792	-0.792	0.869	0.869
04/30/17	05/02/17	3.059	2.412	2.807	2.807	6.828	16.901	-0.647	0.395	0.395	4.022	-2205.712
05/19/17	05/22/17	3.195	0.917	1.741	1.741	8.822	8.822	-2.278	0.823	0.823	7.081	7.081
06/11/17	06/14/17	0.442	1.427	1.482	1.482	4.999	22.255	0.985	0.054	0.054	3.517	20.774
06/27/17	06/30/17	0.234	0.094	0.445	0.445	0.299	0.299	-0.140	0.351	0.351	-0.147	-0.147
07/09/17	07/11/17	0.671	0.589	0.627	2.389	3.889	3.889	-0.082	0.038	1.799	3.262	1.500
07/19/17	07/21/17	0.433	0.151	0.749	0.749	0.645	3.135	-0.283	0.598	0.598	-0.104	2.386
07/21/17	07/23/17	0.850	0.313	0.455	0.455	0.308	0.308	-0.537	0.142	0.142	-0.147	-0.147
08/17/17	08/19/17	0.604	0.125	0.179	0.570	0.112	0.465	-0.479	0.055	0.445	-0.067	-0.105
08/22/17	08/24/17	0.103	0.051	0.320	0.320	0.036	0.083	-0.052	0.269	0.269	-0.284	-0.237
09/18/17	09/20/17	0.365	0.328	0.646	0.773	0.258	0.258	-0.037	0.317	0.445	-0.387	-0.515
10/01/17	10/02/17	0.174	0.115	0.181	0.565	0.719	0.719	-0.059	0.066	0.450	0.537	0.154
10/02/17	10/04/17	0.975	0.470	0.575	0.984	0.925	0.925	-0.505	0.105	0.514	0.350	-0.059
10/05/17	10/06/17	1.450	1.105	0.641	1.992	2.711	2.711	-0.345	-0.464	0.887	2.071	0.720
10/06/17	10/08/17	2.726	2.429	1.330	2.258	6.952	16.247	-0.296	-1.099	-0.171	5.621	13.989
10/21/17	10/23/17	0.848	0.366	2.735	5.108	0.756	7.236	-0.482	2.369	4.742	-1.979	2.128
Events Average (mg/L)		**0.967**	**0.752**	**0.942**	**1.418**	**2.425**	**5.189**	**-0.215**	**0.189**	**0.665**	**1.483**	**-126.806**
Times Reduced (%)								**82%**	**24%**	**12%**	**41%**	**41%**

Total suspended solid yields for sampling sites in 2017.

Start Date	End Date	007 TSS (mg/L)	004 TSS (mg/L)	002 Min TSS (mg/L)	002 Max TSS (mg/L)	001 Min TSS (mg/L)	001 Max TSS (mg/L)	004-007 TSS (mg/L)	002 Min-004 TSS (mg/L)	002 Max-004 TSS (mg/L)	001 Min-002 Min TSS (mg/L)	001 Max-002 Max TSS (mg/L)
04/19/17	04/22/17	12	13	13	27	46	80	1	0	14	33	53
04/25/17	04/28/17	5	44	27	27	54	54	39	-17	-17	27	27
04/30/17	05/02/17	32	40	104	104	231	571	8	64	64	127	468
05/19/17	05/22/17	35	11	64	64	298	298	-24	53	53	234	234
06/11/17	06/14/17	10	34	55	55	169	752	24	21	21	114	698
06/27/17	06/30/17	17	7	16	16	10	10	-10	9	9	-6	-6
07/09/17	07/11/17	42	26	23	88	131	131	-16	-3	62	108	43
07/19/17	07/21/17	74	21	28	28	22	106	-53	7	7	-6	78
07/21/17	07/23/17	67	24	17	17	10	10	-43	-7	-7	-6	-6
08/17/17	08/19/17	83	27	7	21	4	16	-56	-20	-6	-3	-5
08/22/17	08/24/17	37	19	12	12	1	3	-18	-7	-7	-11	-9
09/18/17	09/20/17	59	60	24	29	9	9	1	-36	-31	-15	-20
10/01/17	10/02/17	59	38	7	21	24	24	-21	-31	-17	18	3
10/02/17	10/04/17	138	78	21	36	31	31	-60	-57	-42	10	-5
10/05/17	10/06/17	90	66	24	74	92	92	-24	-42	8	68	18
10/06/17	10/08/17	38	32	49	83	235	549	-6	17	51	186	466
10/21/17	10/23/17	15	18	101	189	26	245	3	83	171	-75	56
Events Average (mg/L)		**48**	**33**	**35**	**52**	**82**	**175**	**-15**	**2**	**20**	**47**	**123**
Times Reduced (%)								**65%**	**53%**	**41%**	**41%**	**35%**

Total suspended solid flow-weighted mean concentrations for sampling sites in 2017.

Start Date	End Date	007 TP Load (kg)	004 TP Load (kg)	002 TP Min Load (kg)	002 TP Max Load (kg)	001 Min TP Load (kg)	001 Max TP Load (kg)	004-007 TP Load (kg)	002 Min-004 TP Load (kg)	002 Max-004 TP Load (kg)	001 Min-002 Min TP Load (kg)	001 Max-002 Max TP Load (kg)
04/19/17	04/22/17	0.740	1.712	4.476	5.394	22.975	29.958	0.973	2.764	3.682	18.498	24.564
04/25/17	04/28/17	0.898	3.203	4.866	4.866	16.595	16.595	2.305	1.663	1.663	11.730	11.730
04/30/17	05/02/17	8.050	7.905	18.774	18.774	99.163	165.942	-0.146	10.870	10.870	80.389	147.168
05/19/17	05/22/17	10.998	8.121	11.465	11.465	112.196	112.196	-2.877	3.344	3.344	100.731	100.731
06/11/17	06/14/17	2.694	6.741	8.927	8.927	70.621	161.469	4.047	2.186	2.186	61.694	152.542
06/27/17	06/30/17	1.141	1.224	1.995	1.995	5.970	5.970	0.083	0.771	0.771	3.975	3.975
07/09/17	07/11/17	1.947	4.105	4.102	7.164	20.376	20.376	2.157	-0.002	3.059	16.274	13.212
07/19/17	07/21/17	1.175	0.972	2.670	2.670	8.275	19.642	-0.203	1.698	1.698	5.605	16.971
07/21/17	07/23/17	2.033	2.207	3.251	3.251	7.497	7.497	0.174	1.045	1.045	4.246	4.246
08/17/17	08/19/17	1.235	1.264	1.151	2.002	2.283	4.628	0.028	-0.113	0.738	1.133	2.626
08/22/17	08/24/17	0.462	0.914	2.007	2.007	0.803	1.145	0.452	1.093	1.093	-1.203	-0.861
09/18/17	09/20/17	2.004	1.603	2.338	2.739	12.097	12.097	-0.402	0.735	1.136	9.760	9.359
10/01/17	10/02/17	0.956	0.800	0.924	1.694	18.584	18.584	-0.156	0.125	0.894	17.660	16.891
10/02/17	10/04/17	1.799	1.576	2.213	2.999	5.860	5.860	-0.223	0.637	1.422	3.647	2.861
10/05/17	10/06/17	3.673	4.438	3.907	6.816	27.511	27.511	0.765	-0.531	2.377	23.604	20.695
10/06/17	10/08/17	17.726	22.574	11.371	13.610	93.031	146.000	4.848	-11.203	-8.964	81.659	132.390
10/21/17	10/23/17	6.059	3.690	10.409	14.806	9.695	25.721	-2.369	6.719	11.116	-0.714	10.915
Total Load (kg)		**63.6**	**73.0**	**94.8**	**111.2**	**533.5**	**781.2**	**9.5**	**21.8**	**38.1**	**438.7**	**670.0**
Events Average (kg)		**3.7**	**4.3**	**5.6**	**6.5**	**31.4**	**46.0**	**0.6**	**1.3**	**2.2**	**25.8**	**39.4**
Times Reduced (%)								**41%**	**24%**	**6%**	**12%**	**6%**

Total phosphorus loads for sampling sites in 2017.

Start Date	End Date	007 TP Yield (kg/ha)	004 TP Yield (kg/ha)	002 Min TP Yield (kg/ha)	002 Max TP Yield (kg/ha)	001 Min TP Yield (kg/ha)	001 Max TP Yield (kg/ha)	004-007 TP Yield (kg/ha)	002-004 TP Yield (kg/ha)	002-004 TP Yield (kg/ha)	001-002 TP Yield (kg/ha)	001-002 TP Yield (kg/ha)
04/19/17	04/22/17	0.001	0.002	0.006	0.007	0.009	0.012	0.001	0.003	0.005	0.004	0.005
04/25/17	04/28/17	0.001	0.004	0.006	0.006	0.007	0.007	0.003	0.002	0.002	0.000	0.000
04/30/17	05/02/17	0.012	0.011	0.024	0.024	0.040	0.066	-0.001	0.013	0.013	0.016	0.043
05/19/17	05/22/17	0.016	0.011	0.015	0.015	0.045	0.045	-0.005	0.003	0.003	0.030	0.030
06/11/17	06/14/17	0.004	0.009	0.011	0.011	0.028	0.065	0.005	0.002	0.002	0.017	0.053
06/27/17	06/30/17	0.002	0.002	0.003	0.003	0.002	0.002	0.000	0.001	0.001	0.000	0.000
07/09/17	07/11/17	0.003	0.006	0.005	0.009	0.008	0.008	0.003	0.000	0.004	0.003	-0.001
07/19/17	07/21/17	0.002	0.001	0.003	0.003	0.003	0.008	0.000	0.002	0.002	0.000	0.004
07/21/17	07/23/17	0.003	0.003	0.004	0.004	0.003	0.003	0.000	0.001	0.001	-0.001	-0.001
08/17/17	08/19/17	0.002	0.002	0.001	0.003	0.001	0.002	0.000	0.000	0.001	-0.001	-0.001
08/22/17	08/24/17	0.001	0.001	0.003	0.003	0.000	0.000	0.001	0.001	0.001	-0.002	-0.002
09/18/17	09/20/17	0.003	0.002	0.003	0.003	0.005	0.005	-0.001	0.001	0.001	0.002	0.001
10/01/17	10/02/17	0.001	0.001	0.001	0.002	0.007	0.007	0.000	0.000	0.001	0.006	0.005
10/02/17	10/04/17	0.003	0.002	0.003	0.004	0.002	0.002	0.000	0.001	0.002	0.000	-0.001
10/05/17	10/06/17	0.005	0.006	0.005	0.009	0.011	0.011	0.001	-0.001	0.003	0.006	0.002
10/06/17	10/08/17	0.026	0.031	0.014	0.017	0.037	0.058	0.005	-0.016	-0.014	0.023	0.041
10/21/17	10/23/17	0.009	0.005	0.013	0.019	0.004	0.010	-0.004	0.008	0.014	-0.009	-0.009
Events Average (mg/L)		**0.005**	**0.006**	**0.007**	**0.008**	**0.013**	**0.018**	**0.000**	**0.001**	**0.002**	**0.005**	**0.010**
Times Reduced (%)								**47%**	**24%**	**6%**	**41%**	**41%**

Total phosphorus yields for sampling sites in 2017.

Start Date	End Date	007 TP (mg/L)	004 TP (mg/L)	002 Min TP (mg/L)	002 Max TP (mg/L)	001 Min TP (mg/L	001 Max TP (mg/L)	004-007 TP (mg/L)	002 Min-004 TP (mg/L)	002 Max-004 TP (mg/L)	001 Min-002 Min TP (mg/L)	001 Max-002 Max TP (mg/L)
04/19/17	04/22/17	0.064	0.082	0.210	0.254	0.311	0.405	0.018	0.128	0.172	0.101	0.152
04/25/17	04/28/17	0.059	0.126	0.160	0.160	0.174	0.174	0.067	0.034	0.034	0.014	0.014
04/30/17	05/02/17	0.123	0.179	0.257	0.257	0.338	0.565	0.056	0.078	0.078	0.080	0.308
05/19/17	05/22/17	0.176	0.133	0.176	0.176	0.406	0.406	-0.043	0.043	0.043	0.230	0.230
06/11/17	06/14/17	0.089	0.219	0.253	0.253	0.363	0.831	0.130	0.034	0.034	0.110	0.578
06/27/17	06/30/17	0.121	0.124	0.171	0.171	0.112	0.112	0.003	0.047	0.047	-0.059	-0.059
07/09/17	07/11/17	0.178	0.245	0.185	0.324	0.214	0.214	0.067	-0.060	0.079	0.029	-0.110
07/19/17	07/21/17	0.293	0.185	0.440	0.440	0.402	0.954	-0.108	0.255	0.255	-0.038	0.514
07/21/17	07/23/17	0.234	0.231	0.273	0.273	0.195	0.195	-0.003	0.042	0.042	-0.078	-0.078
08/17/17	08/19/17	0.248	0.373	0.274	0.476	0.274	0.554	0.125	-0.099	0.103	0.000	0.078
08/22/17	08/24/17	0.242	0.463	0.630	0.630	0.262	0.373	0.221	0.167	0.167	-0.369	-0.257
09/18/17	09/20/17	0.473	0.400	0.402	0.471	0.900	0.900	-0.073	0.002	0.071	0.498	0.430
10/01/17	10/02/17	0.473	0.361	0.321	0.588	2.921	2.921	-0.112	-0.040	0.227	2.600	2.333
10/02/17	10/04/17	0.372	0.357	0.425	0.576	0.464	0.464	-0.015	0.068	0.219	0.039	-0.112
10/05/17	10/06/17	0.333	0.362	0.282	0.492	0.650	0.650	0.029	-0.080	0.130	0.368	0.158
10/06/17	10/08/17	0.361	0.406	0.238	0.284	0.406	0.638	0.045	-0.168	-0.122	0.169	0.353
10/21/17	10/23/17	0.158	0.246	0.254	0.362	0.047	0.126	0.088	0.009	0.116	-0.207	-0.236
Events Average (mg/L)		**0.235**	**0.264**	**0.291**	**0.364**	**0.496**	**0.617**	**0.029**	**0.027**	**0.100**	**0.205**	**0.253**
Times Reduced (%)								**35%**	**29%**	**6%**	**29%**	**35%**

Total phosphorus flow-weighted mean concentrations for sampling sites in 2017.

Start Date	End Date	007 PO4 Load (kg)	004 PO4 Load (kg)	002 Min PO4 Load (kg)	002 Max PO4 Load (kg)	001 Min PO4 Load (kg)	001 Max PO4 Load (kg)	004-007 PO4 Load (kg)	002 Min-004 PO4 Load (kg)	002 Max-004 PO4 Load (kg)	001 Min-002 Min PO4 Load (kg)	001 Max-002 Max PO4 Load (kg)
04/19/17	04/22/17	0.555	1.002	2.523	2.918	11.960	14.966	0.447	1.521	1.916	9.437	12.048
04/25/17	04/28/17	0.457	0.839	1.247	1.247	3.052	3.052	0.382	0.408	0.408	1.805	1.805
04/30/17	05/02/17	3.534	3.003	9.356	9.356	50.917	79.665	-0.531	6.353	6.353	41.561	70.309
05/19/17	05/22/17	3.187	3.725	4.430	4.430	56.038	56.038	0.538	0.705	0.705	51.609	51.609
06/11/17	06/14/17	1.423	2.034	3.493	3.493	35.846	74.956	0.611	1.459	1.459	32.353	71.463
06/27/17	06/30/17	0.622	0.661	0.898	0.898	2.665	2.665	0.039	0.237	0.237	1.767	1.767
07/09/17	07/11/17	0.788	1.676	1.979	3.297	8.760	8.760	0.889	0.302	1.620	6.781	5.463
07/19/17	07/21/17	0.381	0.483	0.243	0.243	4.139	9.032	0.102	-0.241	-0.241	3.896	8.790
07/21/17	07/23/17	0.955	1.318	1.798	1.798	4.344	4.344	0.363	0.480	0.480	2.546	2.546
08/17/17	08/19/17	0.374	0.766	0.613	0.980	1.217	2.226	0.392	-0.153	0.214	0.604	1.246
08/22/17	08/24/17	0.160	0.574	1.147	1.147	0.432	0.579	0.414	0.572	0.572	-0.715	-0.567
09/18/17	09/20/17	1.021	0.609	1.169	1.342	5.901	5.901	-0.412	0.560	0.733	4.731	4.559
10/01/17	10/02/17	0.487	0.314	0.479	0.810	6.937	6.937	-0.173	0.164	0.495	6.459	6.128
10/02/17	10/04/17	0.460	0.596	1.099	1.437	0.884	0.884	0.137	0.502	0.841	-0.214	-0.553
10/05/17	10/06/17	1.930	2.219	2.070	3.322	8.888	8.888	0.289	-0.149	1.103	6.818	5.566
10/06/17	10/08/17	10.214	13.122	6.236	7.200	46.461	69.265	2.908	-6.886	-5.922	40.225	62.064
10/21/17	10/23/17	4.135	1.712	5.381	7.273	4.848	11.747	-2.423	3.668	5.561	-0.532	4.474
Total Load (kg)		**30.68**	**34.66**	**44.16**	**51.19**	**253.29**	**359.91**	**3.97**	**9.50**	**16.53**	**209.13**	**308.72**
Events Average (kg)		**1.80**	**2.04**	**2.60**	**3.01**	**14.90**	**21.17**	**0.23**	**0.56**	**0.97**	**12.30**	**18.16**
Times Reduced (%)								**24%**	**24%**	**12%**	**18%**	**12%**

Orthophosphate loads for sampling sites in 2017.

Start Date	End Date	007 PO4 Yield (kg/ha)	004 PO4 Yield (kg/ha)	002 Min PO4 Yield (kg/ha)	002 Max PO4 Yield (kg/ha)	001 Min PO4 Yield (kg/ha)	001 Max PO4 Yield (kg/ha)	004-007 PO4 Yield (kg/ha)	002 Min-004 PO4 Yield (kg/ha)	002 Max-004 PO4 Yield (kg/ha)	001 Min-002 Min PO4 Yield (kg/ha)	001 Max-002 Max PO4 Yield (kg/ha)
04/19/17	04/22/17	0.001	0.001	0.003	0.004	0.005	0.006	0.001	0.003	0.005	0.004	0.005
04/25/17	04/28/17	0.001	0.001	0.002	0.002	0.001	0.001	0.003	0.002	0.002	0.000	0.000
04/30/17	05/02/17	0.005	0.004	0.012	0.012	0.020	0.032	-0.001	0.013	0.013	0.016	0.043
05/19/17	05/22/17	0.005	0.005	0.006	0.006	0.022	0.022	-0.005	0.003	0.003	0.030	0.030
06/11/17	06/14/17	0.002	0.003	0.004	0.004	0.014	0.030	0.005	0.002	0.002	0.017	0.053
06/27/17	06/30/17	0.001	0.001	0.001	0.001	0.001	0.001	0.000	0.001	0.001	0.000	0.000
07/09/17	07/11/17	0.001	0.002	0.003	0.004	0.004	0.004	0.003	0.000	0.004	0.003	-0.001
07/19/17	07/21/17	0.001	0.001	0.000	0.000	0.002	0.004	0.000	0.002	0.002	0.000	0.004
07/21/17	07/23/17	0.001	0.002	0.002	0.002	0.002	0.002	0.000	0.001	0.001	-0.001	-0.001
08/17/17	08/19/17	0.001	0.001	0.001	0.001	0.000	0.001	0.000	0.000	0.001	-0.001	-0.001
08/22/17	08/24/17	0.000	0.001	0.001	0.001	0.000	0.000	0.001	0.001	0.001	-0.002	-0.002
09/18/17	09/20/17	0.001	0.001	0.001	0.002	0.002	0.002	-0.001	0.001	0.001	0.002	0.001
10/01/17	10/02/17	0.001	0.000	0.001	0.001	0.003	0.003	0.000	0.000	0.001	0.006	0.005
10/02/17	10/04/17	0.001	0.001	0.001	0.002	0.000	0.000	0.000	0.001	0.002	0.000	-0.001
10/05/17	10/06/17	0.003	0.003	0.003	0.004	0.004	0.004	0.001	-0.001	0.003	0.006	0.002
10/06/17	10/08/17	0.015	0.018	0.008	0.009	0.019	0.028	0.005	-0.016	-0.014	0.023	0.041
10/21/17	10/23/17	0.006	0.002	0.007	0.009	0.002	0.005	-0.004	0.008	0.014	-0.009	-0.009
Events Average (mg/L)		**0.003**	**0.003**	**0.003**	**0.004**	**0.006**	**0.008**	**0.000**	**0.001**	**0.002**	**0.005**	**0.010**
Times Reduced (%)								**47%**	**24%**	**6%**	**41%**	**41%**

Orthophosphate yields for sampling sites in 2017.

Start Date	End Date	007 PO4 (mg/L)	004 PO4 (mg/L)	002 Min PO4 (mg/L)	002 Max PO4 (mg/L)	001 Min PO4 (mg/L)	001 Max PO4 (mg/L)	004-007 PO4 (mg/L)	002 Min-004 PO4 (mg/L)	002 Max-004 PO4 (mg/L)	001 Min-002 Min PO4 (mg/L)	001 Max-002 Max PO4 (mg/L)
04/19/17	04/22/17	0.048	0.048	0.119	0.137	0.162	0.203	0.000	0.071	0.089	0.043	0.065
04/25/17	04/28/17	0.030	0.033	0.041	0.041	0.032	0.032	0.003	0.008	0.008	-0.009	-0.009
04/30/17	05/02/17	0.054	0.068	0.128	0.128	0.173	0.271	0.014	0.060	0.060	0.045	0.143
05/19/17	05/22/17	0.051	0.061	0.068	0.068	0.203	0.203	0.010	0.007	0.007	0.135	0.135
06/11/17	06/14/17	0.047	0.066	0.099	0.099	0.184	0.386	0.019	0.033	0.033	0.085	0.287
06/27/17	06/30/17	0.066	0.067	0.077	0.077	0.050	0.050	0.001	0.010	0.010	-0.027	-0.027
07/09/17	07/11/17	0.072	0.100	0.089	0.149	0.092	0.092	0.028	-0.011	0.049	0.003	-0.057
07/19/17	07/21/17	0.095	0.092	0.040	0.040	0.201	0.439	-0.003	-0.052	-0.052	0.161	0.399
07/21/17	07/23/17	0.110	0.138	0.151	0.151	0.113	0.113	0.028	0.013	0.013	-0.038	-0.038
08/17/17	08/19/17	0.075	0.226	0.146	0.233	0.146	0.267	0.151	-0.080	0.007	0.000	0.034
08/22/17	08/24/17	0.084	0.291	0.360	0.360	0.141	0.189	0.207	0.069	0.069	-0.220	-0.172
09/18/17	09/20/17	0.241	0.152	0.201	0.231	0.439	0.439	-0.089	0.049	0.079	0.238	0.209
10/01/17	10/02/17	0.241	0.142	0.166	0.281	1.090	1.090	-0.099	0.024	0.139	0.924	0.809
10/02/17	10/04/17	0.095	0.135	0.211	0.276	0.070	0.070	0.040	0.076	0.141	-0.141	-0.206
10/05/17	10/06/17	0.175	0.181	0.149	0.240	0.210	0.210	0.006	-0.032	0.059	0.061	-0.030
10/06/17	10/08/17	0.208	0.236	0.130	0.150	0.203	0.303	0.028	-0.106	-0.086	0.073	0.152
10/21/17	10/23/17	0.108	0.114	0.131	0.178	0.024	0.058	0.006	0.017	0.064	-0.108	-0.120
Events Average (mg/L)		**0.106**	**0.126**	**0.136**	**0.167**	**0.208**	**0.260**	**0.021**	**0.009**	**0.041**	**0.072**	**0.093**
Times Reduced (%)								**18%**	**29%**	**12%**	**35%**	**47%**

Orthophosphate flow-weighted mean concentrations for sampling sites in 2017.

Start Date	End Date	007 NO3+NO2 Load (kg)	004 NO3+NO2 Load (kg)	002 NO3+NO2 Load (kg)	001 NO3+NO2 Load (kg)	004-007 NO3+NO2 Load (kg)	002-004 NO3+NO2 Load (kg)	001-002 NO3+NO2 Load (kg)
04/19/17	04/22/17	161	278	244	1174	117.0	-33.9	930.3
04/25/17	04/28/17	210	336	377	1288	125.5	41.6	910.5
04/30/17	05/02/17	1001	671	1133	5584	-330.2	461.4	4451.1
05/19/17	05/22/17	1137	1087	1075	2140	-50.4	-12.0	1065.5
06/11/17	06/14/17	421	281	416	1470	-140.0	135.6	1053.5
06/27/17	06/30/17	96	118	114	752	22.2	-4.3	637.5
07/09/17	07/11/17	85	81	161	1257	-4.2	80.6	1095.5
07/19/17	07/21/17	22	23	39	240	1.3	15.1	201.4
07/21/17	07/23/17	61	55	57	308	-5.2	1.9	250.7
08/17/17	08/19/17	10	7	8	53	-3.0	1.8	44.9
08/22/17	08/24/17	5	4	6	20	-0.3	2.1	13.3
09/18/17	09/20/17	4	3	3	3	-0.7	-0.2	0.9
10/01/17	10/02/17	2	1	19	1	-0.6	17.7	-18.2
10/02/17	10/04/17	4	3	40	9	-0.7	37.2	-31.3
10/05/17	10/06/17	25	24	141	55	-1.0	116.3	-85.7
10/06/17	10/08/17	305	313	260	1424	7.6	-53.5	1164.7
10/21/17	10/23/17	501	133	467	2757	-368.2	334.7	2289.2
Total Load (kg)		**4049**	**3418**	**4560**	**18534**	**-630.7**	**1142.0**	**13973.7**
Events Average (kg)		**238.16**	**201.06**	**268.23**	**1,090.21**	**-37.1**	**67.2**	**822.0**
Times Reduced (%)						**71%**	**29%**	**18%**

Nitrate+nitrite as nitrogen loads for sampling sites in 2017.

Start Date	End Date	007 NO3+NO2 Yield (kg/ha)	004 NO3+NO2 Yield (kg/ha)	002 NO3+NO2 Yield (kg/ha)	001 NO3+NO2 Yield (kg/ha)	004-007 NO3+NO2 Yield (kg/ha)	002-004 NO3+NO2 Yield (kg/ha)	001-002 NO3+NO2 Yield (kg/ha)
04/19/17	04/22/17	0.23	0.38	0.31	0.47	0.14	-0.07	0.16
04/25/17	04/28/17	0.31	0.46	0.48	0.52	0.15	0.02	0.04
04/30/17	05/02/17	1.46	0.92	1.44	2.24	-0.55	0.52	0.79
05/19/17	05/22/17	1.66	1.48	1.37	0.86	-0.18	-0.12	-0.51
06/11/17	06/14/17	0.61	0.38	0.53	0.59	-0.23	0.15	0.06
06/27/17	06/30/17	0.14	0.16	0.15	0.30	0.02	-0.02	0.16
07/09/17	07/11/17	0.12	0.11	0.21	0.50	-0.01	0.10	0.30
07/19/17	07/21/17	0.03	0.03	0.05	0.10	-0.0003	0.02	0.05
07/21/17	07/23/17	0.09	0.08	0.07	0.12	-0.01	-0.003	0.05
08/17/17	08/19/17	0.01	0.01	0.01	0.02	-0.01	0.00	0.01
08/22/17	08/24/17	0.01	0.01	0.01	0.01	-0.001	0.00	0.000
09/18/17	09/20/17	0.01	0.00	0.00	0.00	-0.001	-0.001	-0.002
10/01/17	10/02/17	0.00	0.00	0.02	0.00	-0.001	0.02	-0.02
10/02/17	10/04/17	0.01	0.00	0.05	0.00	-0.001	0.05	-0.05
10/05/17	10/06/17	0.04	0.03	0.18	0.02	-0.004	0.15	-0.16
10/06/17	10/08/17	0.45	0.43	0.88	0.57	-0.02	0.45	-0.31
10/21/17	10/23/17	0.73	0.18	0.59	1.10	-0.55	0.41	0.51
Events Average (mg/L)		**0.35**	**0.27**	**0.37**	**0.44**	**-0.073**	**0.099**	**0.063**
Times Reduced (%)						**82%**	**29%**	**41%**

Nitrate+nitrite as nitrogen yields for sampling sites in 2017.

Start Date	End Date	007 NO3+NO2 as N (mg/L)	004 NO3+NO2 as N (mg/L)	002 NO3+NO2 as N (mg/L)	001 NO3+NO2 as N (mg/L)	004-007 NO3+NO2 as N (mg/L)	002-004 NO3+NO2 as N (mg/L)	001-002 NO3+NO2 as N (mg/L)
04/19/17	04/22/17	13.90	13.30	11.46	15.89	-0.60	-1.84	4.43
04/25/17	04/28/17	13.80	13.20	12.40	13.50	-0.60	-0.80	1.10
04/30/17	05/02/17	15.30	15.20	15.53	19.01	-0.10	0.33	3.48
05/19/17	05/22/17	18.20	17.80	16.50	7.75	-0.40	-1.30	-8.76
06/11/17	06/14/17	13.90	9.13	11.80	7.56	-4.77	2.68	-4.24
06/27/17	06/30/17	10.20	12.00	9.78	14.10	1.80	-2.22	4.32
07/09/17	07/11/17	7.76	4.82	7.29	13.20	-2.94	2.47	5.91
07/19/17	07/21/17	5.51	4.46	6.35	11.65	-1.05	1.89	5.30
07/21/17	07/23/17	6.98	5.80	4.81	8.01	-1.18	-0.99	3.20
08/17/17	08/19/17	1.93	1.94	1.98	6.38	0.01	0.04	4.40
08/22/17	08/24/17	2.38	2.17	1.99	6.39	-0.21	-0.18	4.40
09/18/17	09/20/17	0.84	0.71	0.45	0.26	-0.13	-0.26	-0.19
10/01/17	10/02/17	0.84	0.51	6.53	0.09	-0.33	6.02	-6.44
10/02/17	10/04/17	0.76	0.68	7.72	0.70	-0.08	7.04	-7.02
10/05/17	10/06/17	2.30	1.99	10.16	1.30	-0.31	8.17	-8.86
10/06/17	10/08/17	6.22	5.63	5.42	6.22	-0.59	-0.21	0.80
10/21/17	10/23/17	13.03	8.82	11.41	13.50	-4.20	2.59	2.09
Events Average (mg/L)		**7.87**	**6.95**	**8.33**	**8.56**	**-0.923**	**1.379**	**0.231**
Times Reduced (%)						**88%**	**47%**	**35%**

Nitrate+nitrite as nitrogen flow-weighted mean concentrations for sampling sites in 2017.

Start Date	End Date	007 TSS (mg/L)	004 TSS (mg/L)	002 TSS (mg/L)	001 TSS (mg/L)	004-007 TSS (mg/L)	002-004 TSS (mg/L)	001-002 TSS (mg/L)
4/1/2017	4/19/2017	5	5	3	9	0	-2	6
5/21/2017	6/12/2017	4	4	2	2	0	-2	0
7/22/2017	8/16/2017	4	8	7	6	4	-1	-1
8/23/2017	9/18/2017	24	36	35	6	12	-1	-29
10/22/2017	11/8/2017	18	68	3	20	50	-65	17

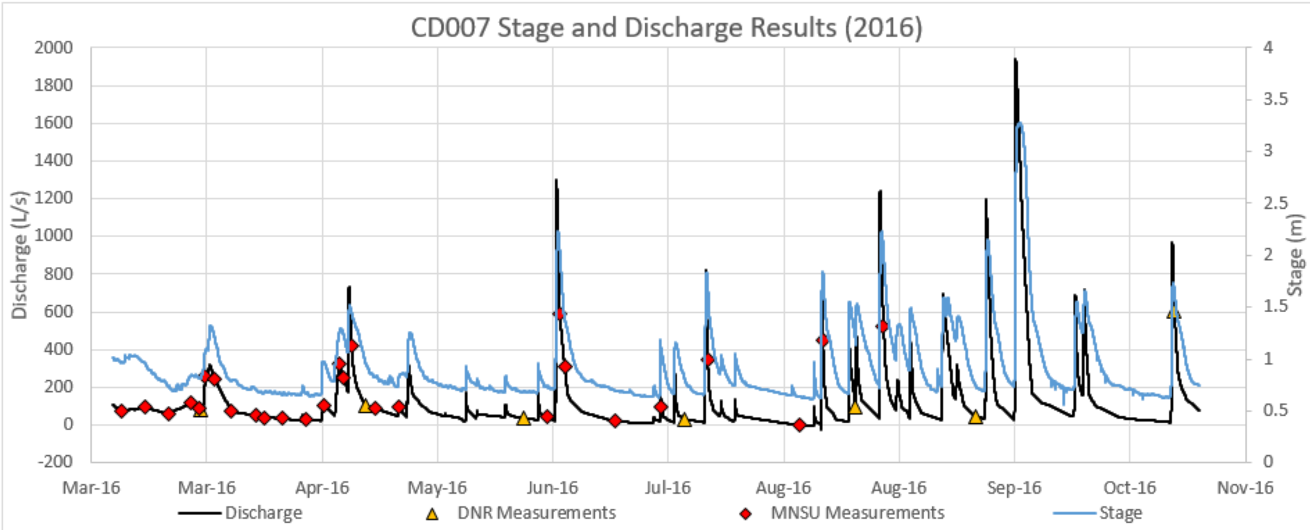
Start Date	End Date	007 TP (mg/L)	004 TP (mg/L)	002 TP (mg/L)	001 TP (mg/L)	004-007 TP (mg/L)	002-004 TP (mg/L)	001-002 TP (mg/L)
4/1/2017	4/19/2017	0.053	0.061	0.298	0.056	0.008	0.237	-0.242
5/21/2017	6/12/2017	0.042	0.034	0.034	0.019	-0.008	0.000	-0.015
7/22/2017	8/16/2017	0.088	0.101	0.124	0.106	0.013	0.023	-0.018
8/23/2017	9/18/2017	0.218	0.184	0.207	0.263	-0.034	0.023	0.056
10/22/2017	11/8/2017	0.083	0.129	0.085	0.005	0.046	-0.044	-0.080

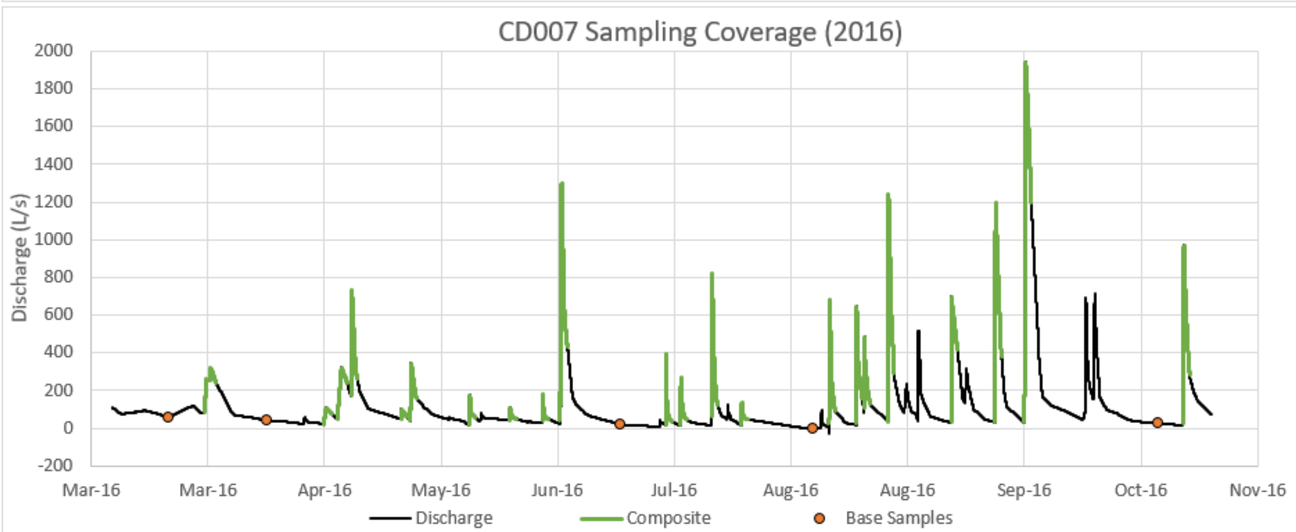
Start Date	End Date	007 PO4 (mg/L)	004 PO4 (mg/L)	002 PO4 (mg/L)	001 PO4 (mg/L)	004-007 PO4 (mg/L)	002-004 PO4 (mg/L)	001-002 PO4 (mg/L)
4/1/2017	4/19/2017	0.038	0.036	0.027	0.179	-0.002	-0.009	0.152
5/21/2017	6/12/2017	0.023	0.016	0.019	0.010	-0.007	0.003	-0.009
7/22/2017	8/16/2017	0.070	0.069	0.041	0.079	-0.001	-0.028	0.038
8/23/2017	9/18/2017	0.119	0.087	0.091	0.146	-0.032	0.004	0.055
10/22/2017	11/8/2017	0.060	0.078	0.057	0.020	0.018	-0.021	-0.037

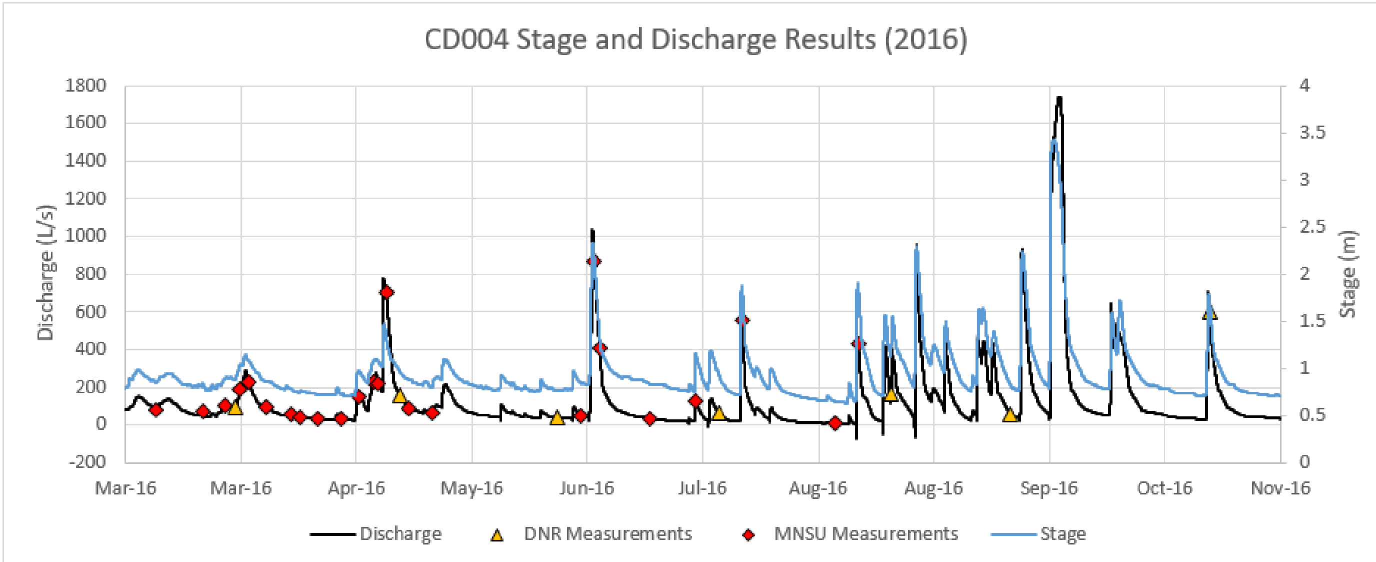
Start Date	End Date	007 NO3+NO2 as N (mg/L)	004 NO3+NO2 as N (mg/L)	002 NO3+NO2 as N (mg/L)	001 NO3+NO2 as N (mg/L)	004-007 NO3+NO2 as N (mg/L)	002-004 NO3+NO2 as N (mg/L)	001-002 NO3+NO2 as N (mg/L)
4/1/2017	4/19/2017	12.30	11.20	7.08	9.99	-1.10	-4.12	2.91
5/21/2017	6/12/2017	14.70	14.10	13.40	14.50	-0.60	-0.70	1.10
7/22/2017	8/16/2017	11.50	8.44	4.22	7.15	-3.06	-4.22	2.93
8/23/2017	9/18/2017	3.53	1.23	0.32	0.05	-2.30	-0.91	-0.27
10/22/2017	11/8/2017	13.40	11.80	12.50	0.05	-1.60	0.70	-12.45

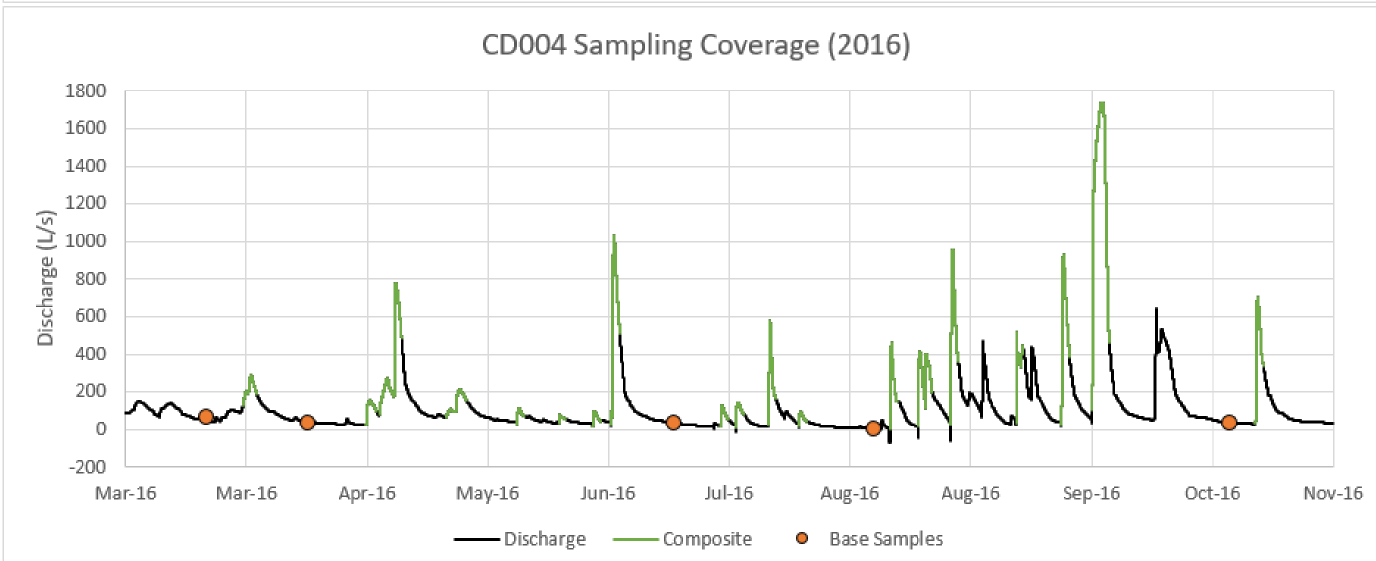
Base flow flow-weighted mean concentrations for total suspended solids, total phosphorus, orthophosphates, and nitrate+nitrite as nitrogen for 2016.

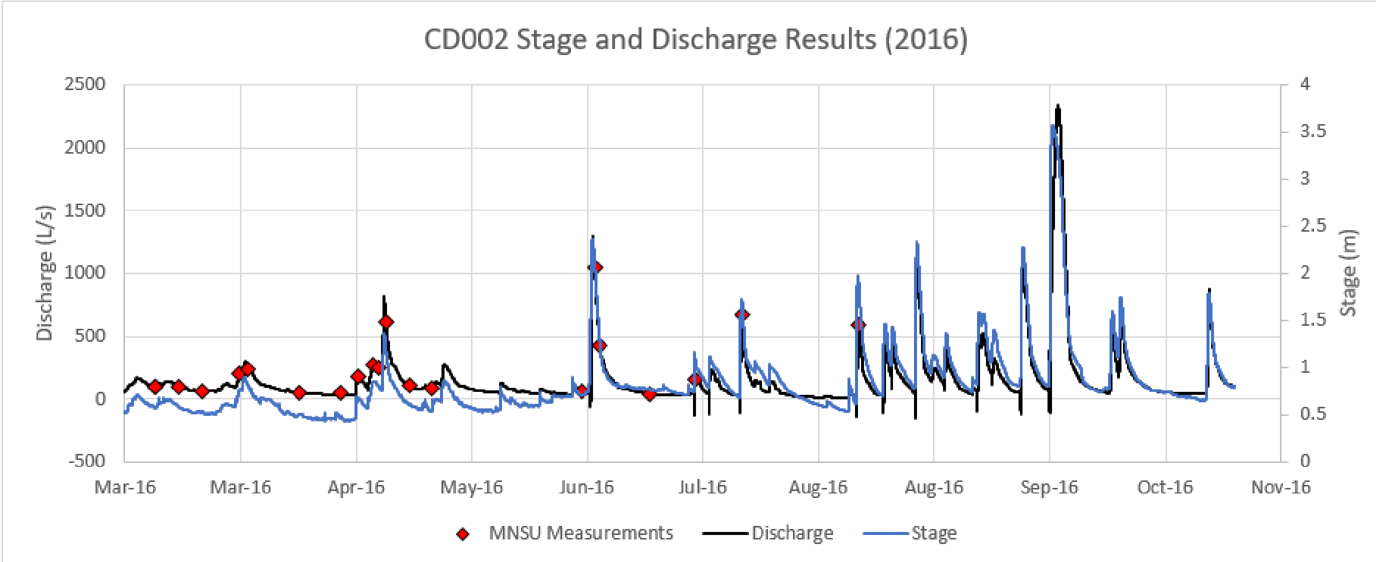
Appendix D. Stage, discharge, and sampling coverage graphs

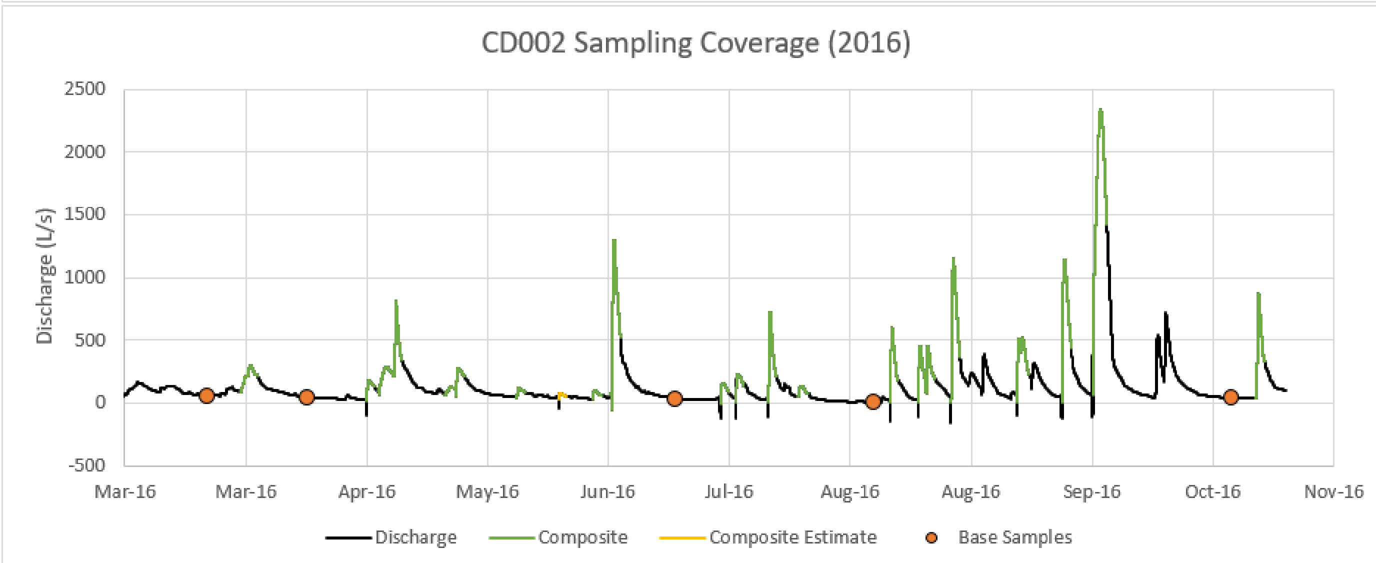


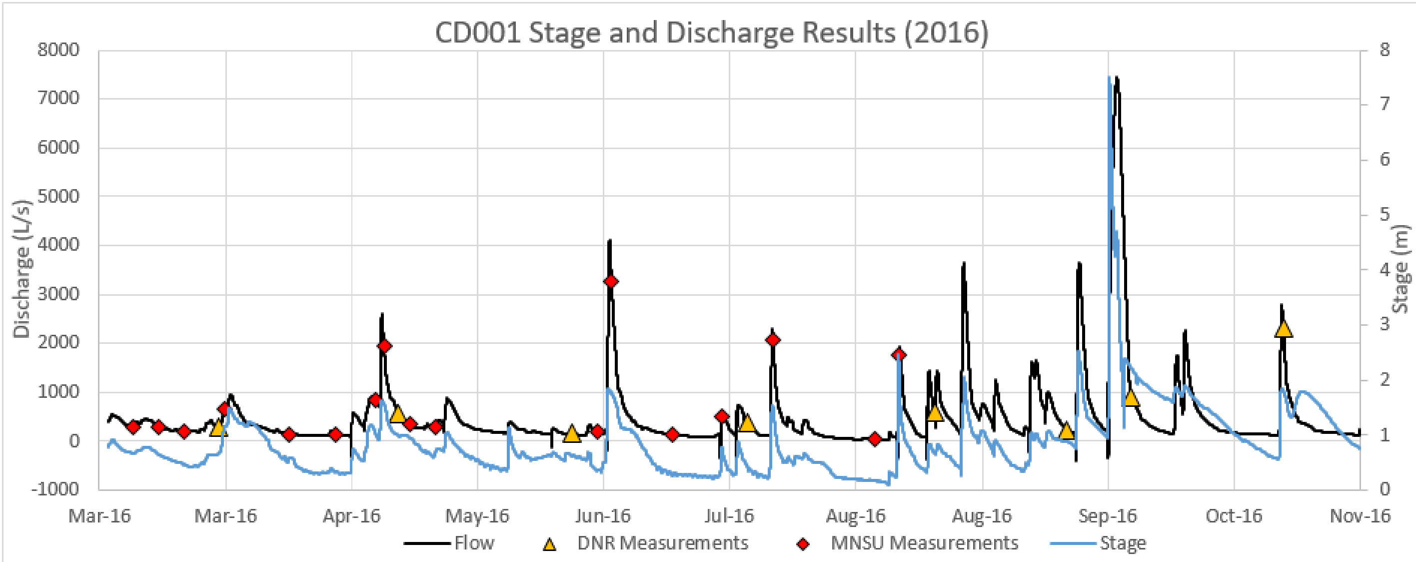


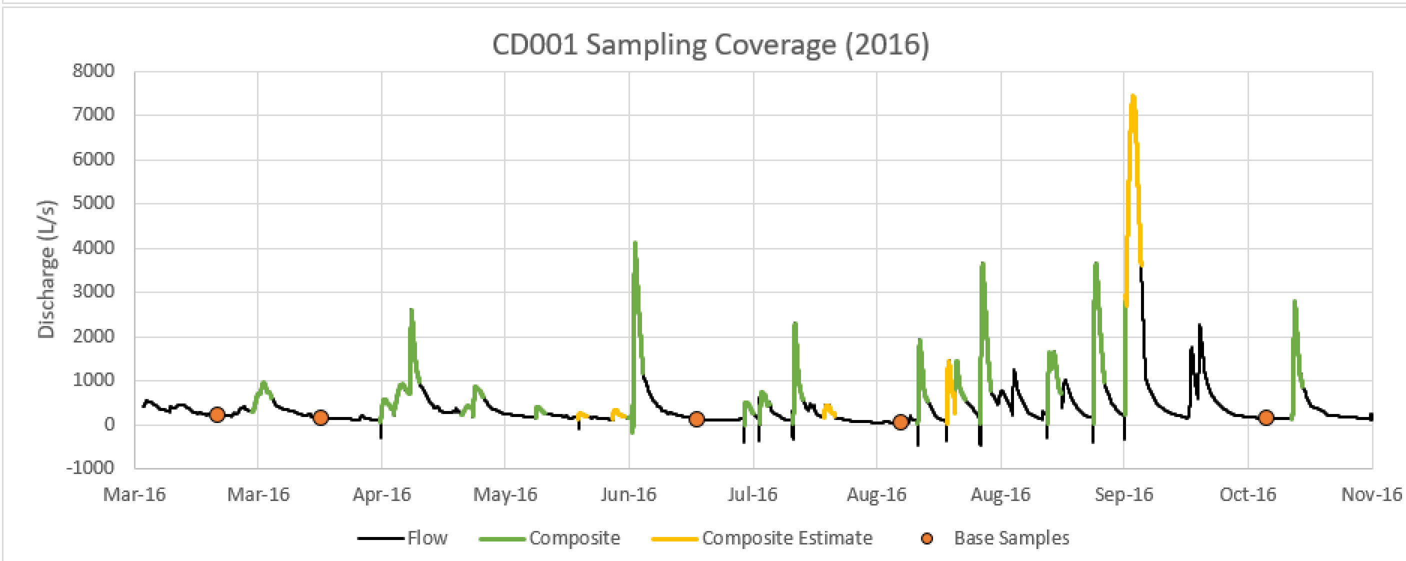

CD004 Stage and Discharge Results (2016)
Discharge (L/s)
Stage (m)
1800
1600
1400
1200
1000
800
600
400
200
0
-200
4
3.5
3
2.5
2
1.5
1
0.5
0
Mar-16
Mar-16
Apr-16
May-16
Jun-16
Jul-16
Aug-16
Aug-16
Sep-16
Oct-16
Nov-16
Discharge
DNR Measurements
MNSU Measurements
Stage

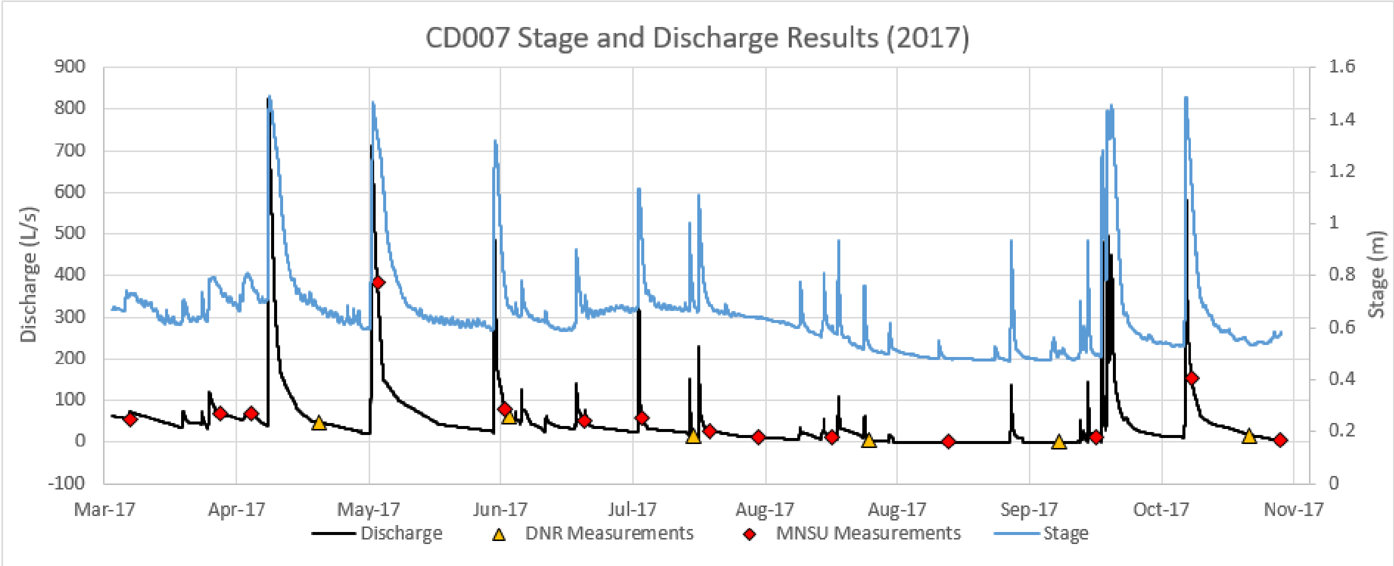

CD004 Sampling Coverage (2016)
Discharge (L/s)
1800
1600
1400
1200
1000
800
600
400
200
0
-200
Mar-16
Mar-16
Apr-16
May-16
Jun-16
Jul-16
Aug-16
Aug-16
Sep-16
Oct-16
Nov-16
Discharge
Composite
Base Samples

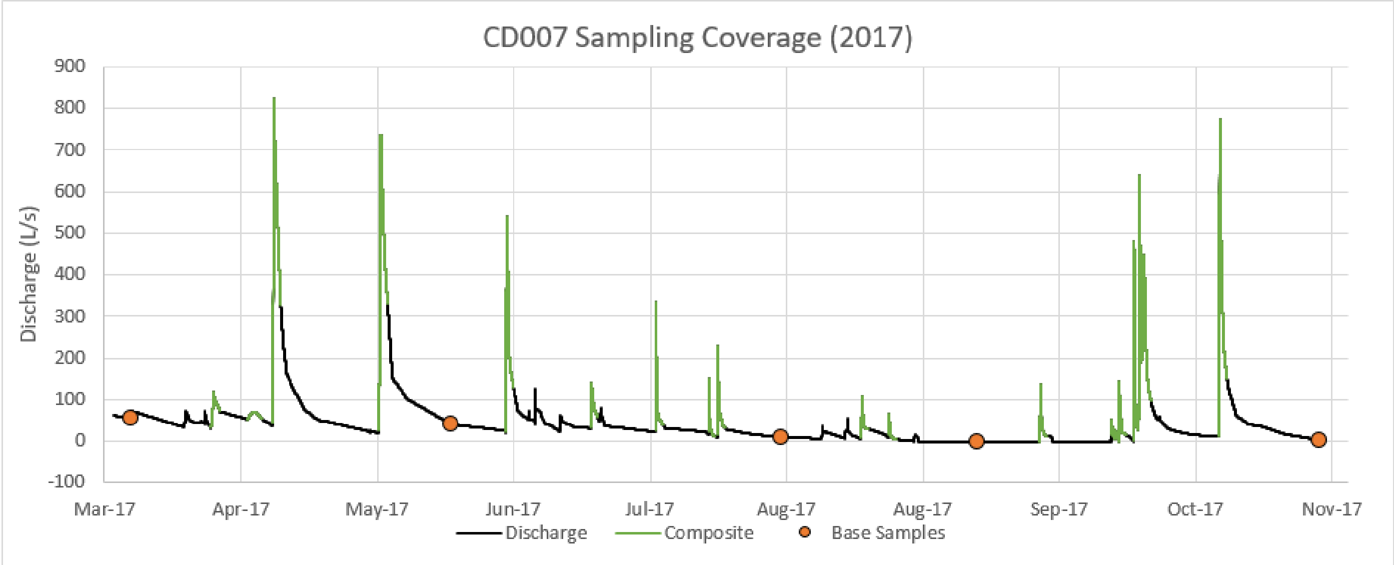

CD002 Stage and Discharge Results (2016)
Discharge (L/s)
Stage (m)
2500
2000
1500
1000
500
0
-500
4
3.5
3
2.5
2
1.5
1
0.5
0
Mar-16
Mar-16
Apr-16
May-16
Jun-16
Jul-16
Aug-16
Aug-16
Sep-16
Oct-16
Nov-16
MNSU Measurements
Discharge
Stage

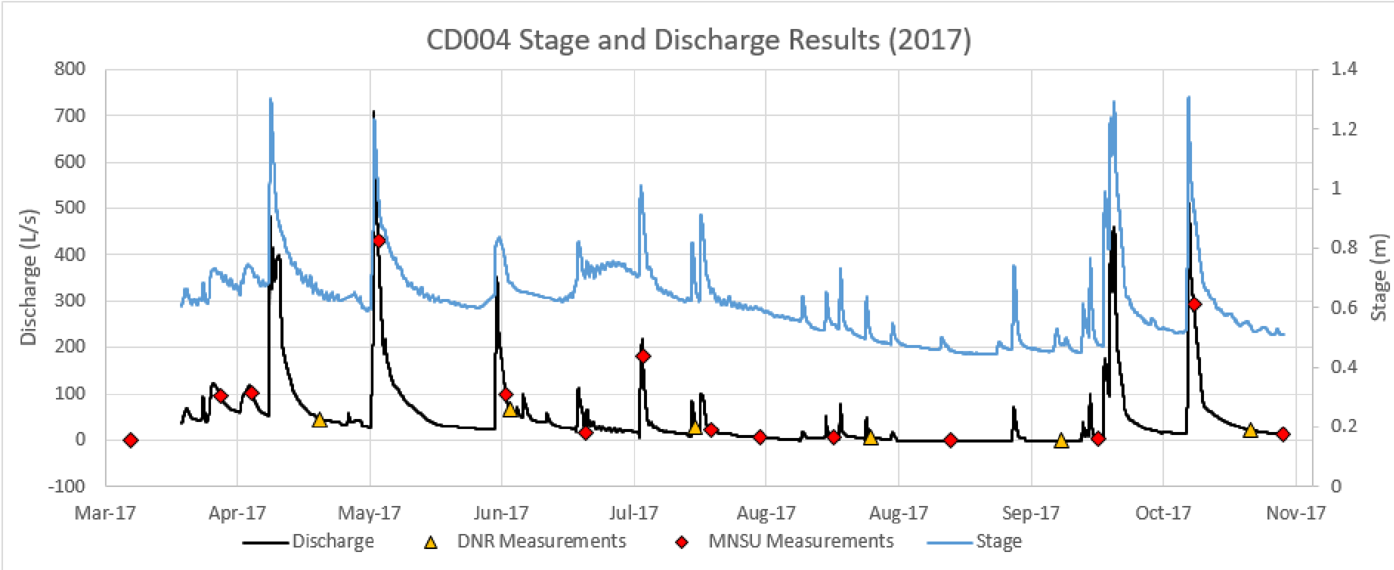

CD002 Sampling Coverage (2016)
Discharge (L/s)
2500
2000
1500
1000
500
0
-500
Mar-16
Mar-16
Apr-16
May-16
Jun-16
Jul-16
Aug-16
Aug-16
Sep-16
Oct-16
Nov-16
Discharge
Composite
Composite Estimate
Base Samples

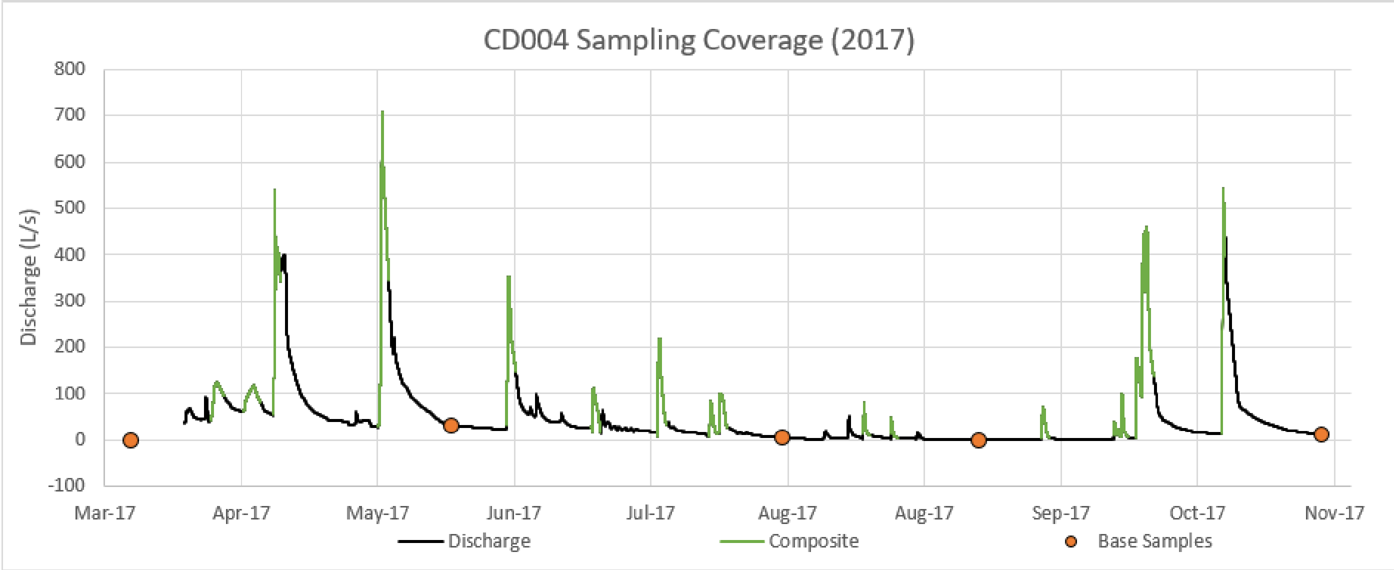

CD001 Stage and Discharge Results (2016)
Discharge (L/s)
Stage (m)
8000
7000
6000
5000
4000
3000
2000
1000
0
-1000
8
7
6
5
4
3
2
1
0
Mar-16
Mar-16
Apr-16
May-16
Jun-16
Jul-16
Aug-16
Aug-16
Sep-16
Oct-16
Nov-16
Flow
DNR Measurements
MNSU Measurements
Stage

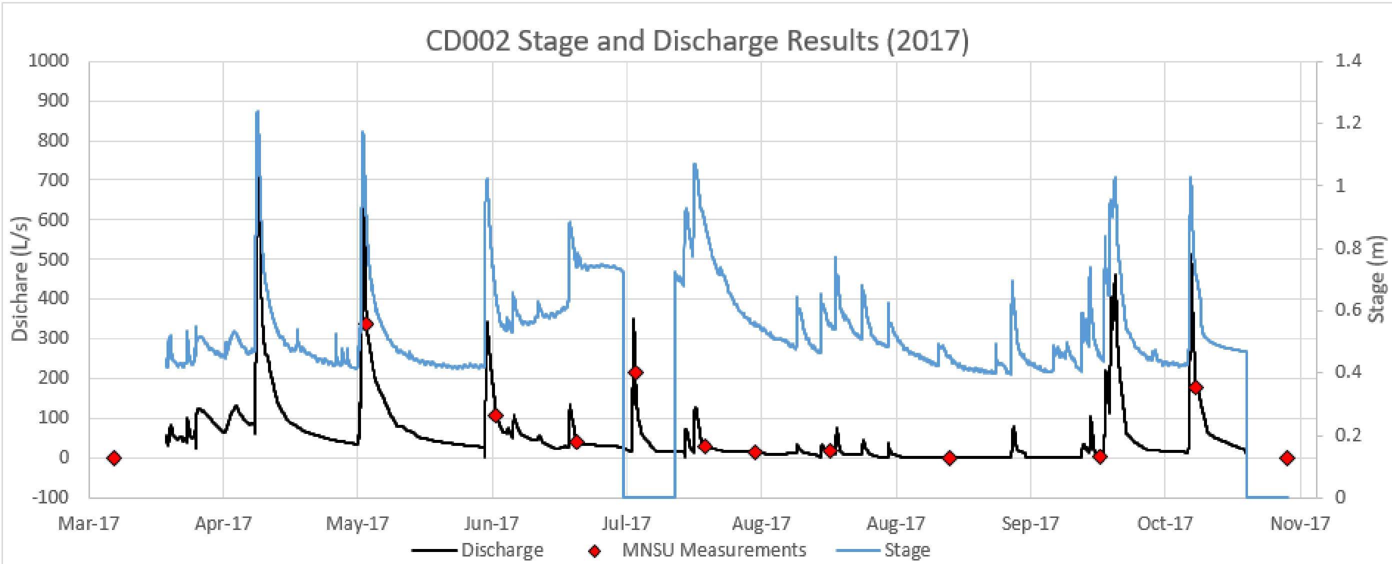

CD001 Sampling Coverage (2016)
Discharge (L/s)
8000
7000
6000
5000
4000
3000
2000
1000
0
-1000
Mar-16
Mar-16
Apr-16
May-16
Jun-16
Jul-16
Aug-16
Aug-16
Sep-16
Oct-16
Nov-16
Flow
Composite
Composite Estimate
Base Samples

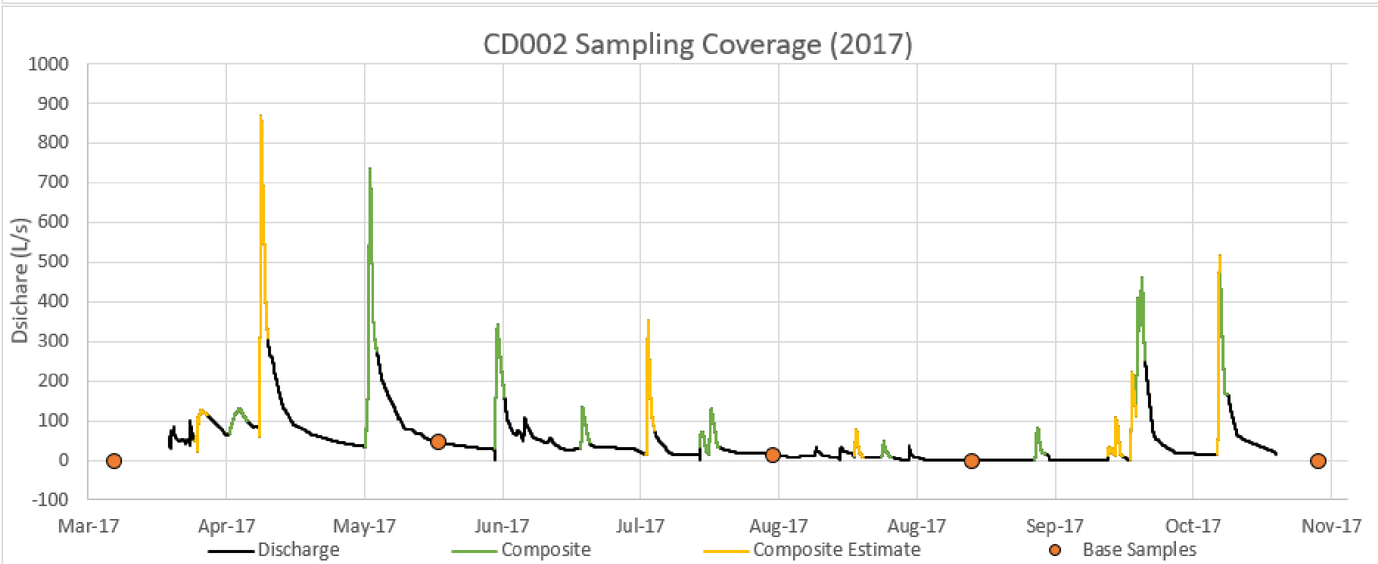

CD007 Stage and Discharge Results (2017)
Discharge (L/s)
Stage (m)
900
800
700
600
500
400
300
200
100
0
-100
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Mar-17
Apr-17
May-17
Jun-17
Jul-17
Aug-17
Aug-17
Sep-17
Oct-17
Nov-17
Discharge
DNR Measurements
MNSU Measurements
Stage

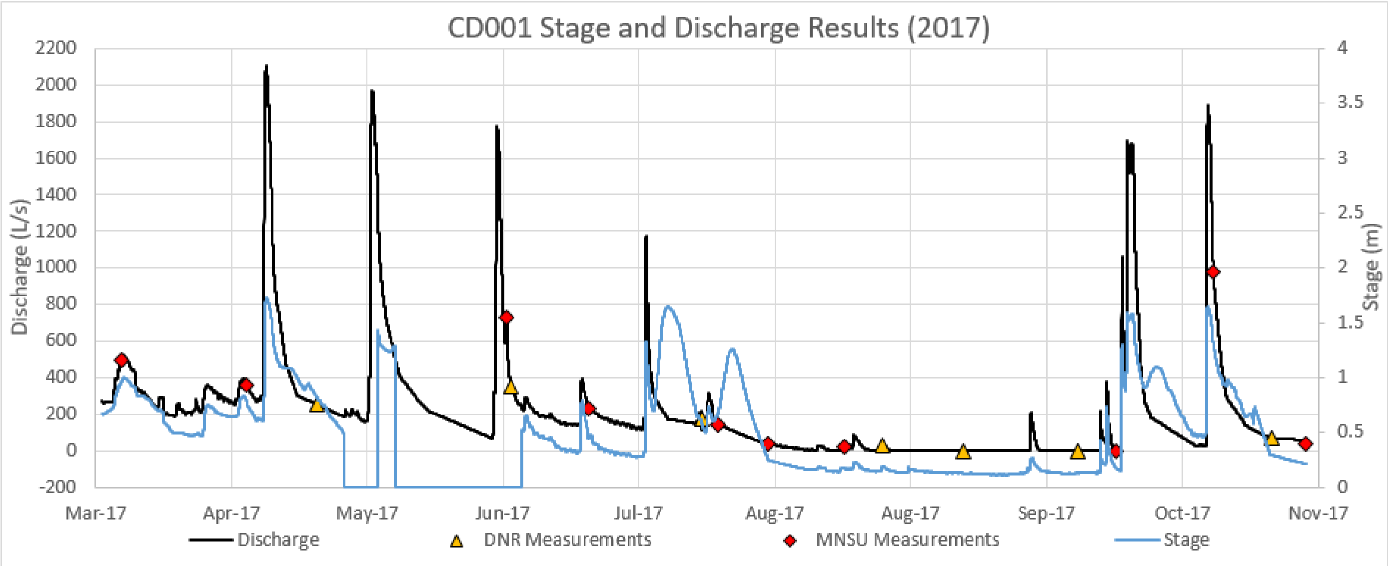

CD007 Sampling Coverage (2017)
Discharge (L/s)
900
800
700
600
500
400
300
200
100
0
-100
Mar-17
Apr-17
May-17
Jun-17
Jul-17
Aug-17
Aug-17
Sep-17
Oct-17
Nov-17
Discharge
Composite
Base Samples


CD004 Stage and Discharge Results (2017)
Discharge (L/s)
Stage (m)
800
700
600
500
400
300
200
100
0
-100
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Mar-17
Apr-17
May-17
Jun-17
Jul-17
Aug-17
Aug-17
Sep-17
Oct-17
Nov-17
Discharge
DNR Measurements
MNSU Measurements
Stage

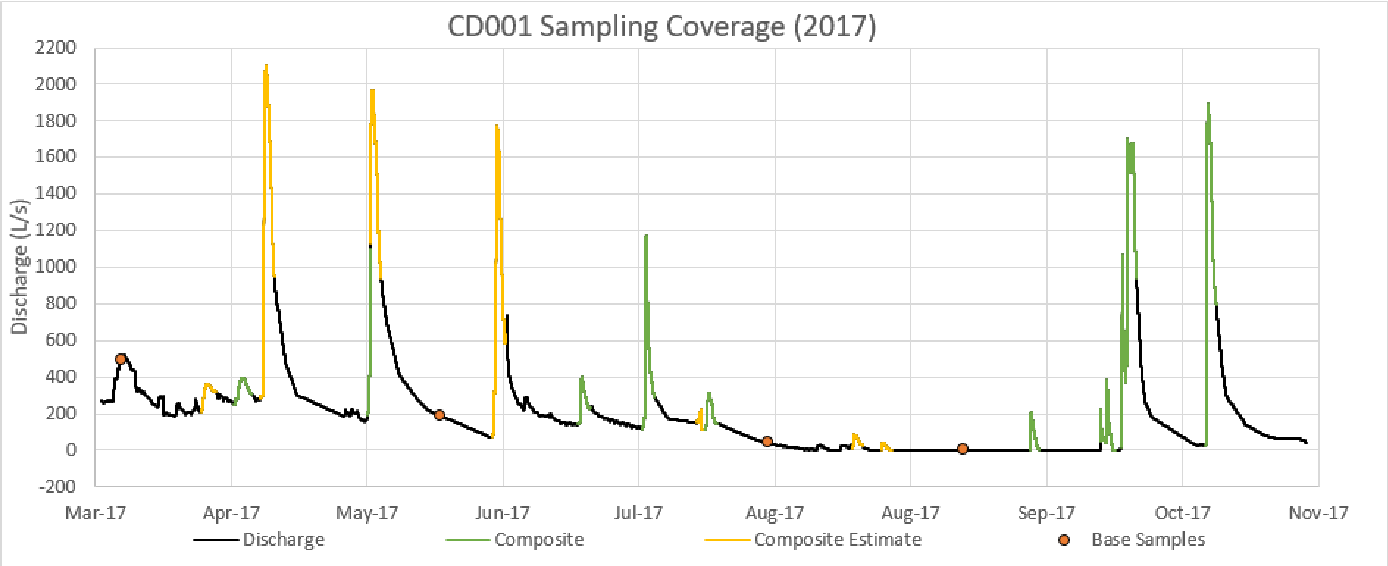

CD004 Sampling Coverage (2017)
Discharge (L/s)
800
700
600
500
400
300
200
100
0
-100
Mar-17
Apr-17
May-17
Jun-17
Jul-17
Aug-17
Aug-17
Sep-17
Oct-17
Nov-17
Discharge
Composite
Base Samples


CD002 Stage and Discharge Results (2017)
Dsichare (L/s)
Stage (m)
1000
900
800
700
600
500
400
300
200
100
0
-100
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Mar-17
Apr-17
May-17
Jun-17
Jul-17
Aug-17
Aug-17
Sep-17
Oct-17
Nov-17
Discharge
MNSU Measurements
Stage


CD002 Sampling Coverage (2017)
Dsichare (L/s)
1000
900
800
700
600
500
400
300
200
100
0
-100
Mar-17
Apr-17
May-17
Jun-17
Jul-17
Aug-17
Aug-17
Sep-17
Oct-17
Nov-17
Discharge
Composite
Composite Estimate
Base Samples

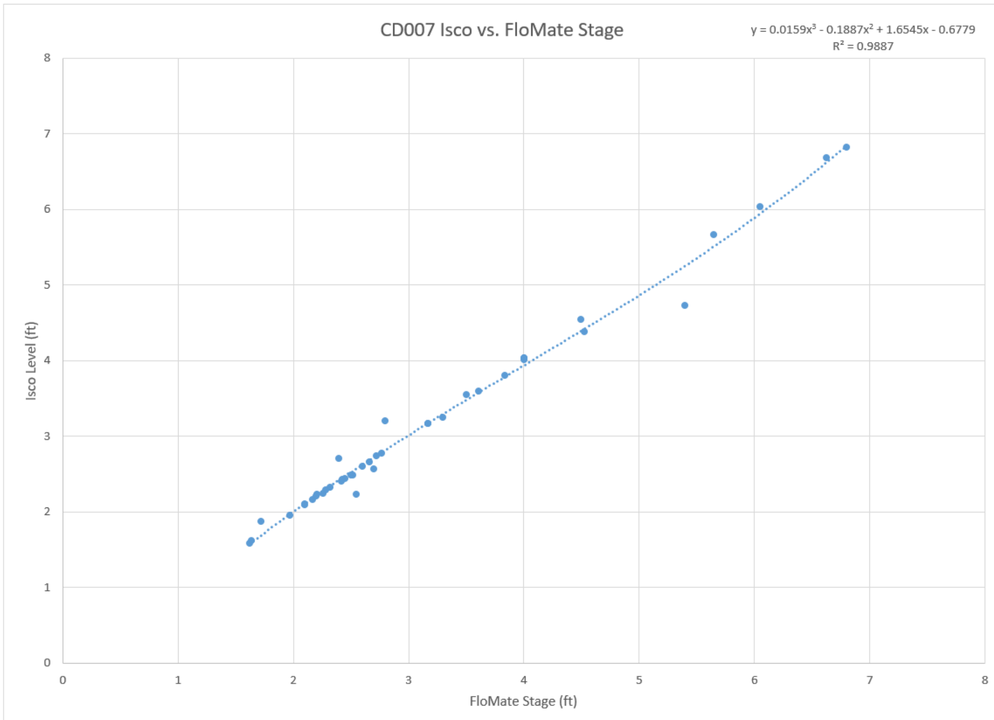


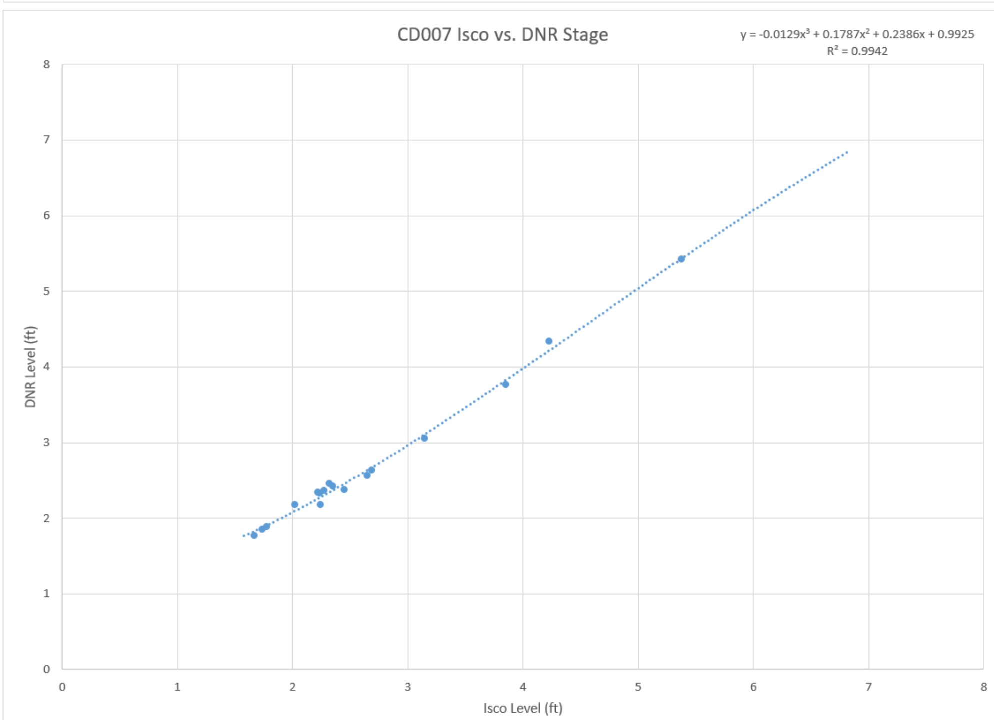
CD001 Stage and Discharge Results (2017)
Discharge (L/s)
Stage (m)
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
-200
4
3.5
3
2.5
2
1.5
1
0.5
0
Mar-17
Apr-17
May-17
Jun-17
Jul-17
Aug-17
Aug-17
Sep-17
Oct-17
Nov-17
Discharge
DNR Measurements
MNSU Measurements
Stage

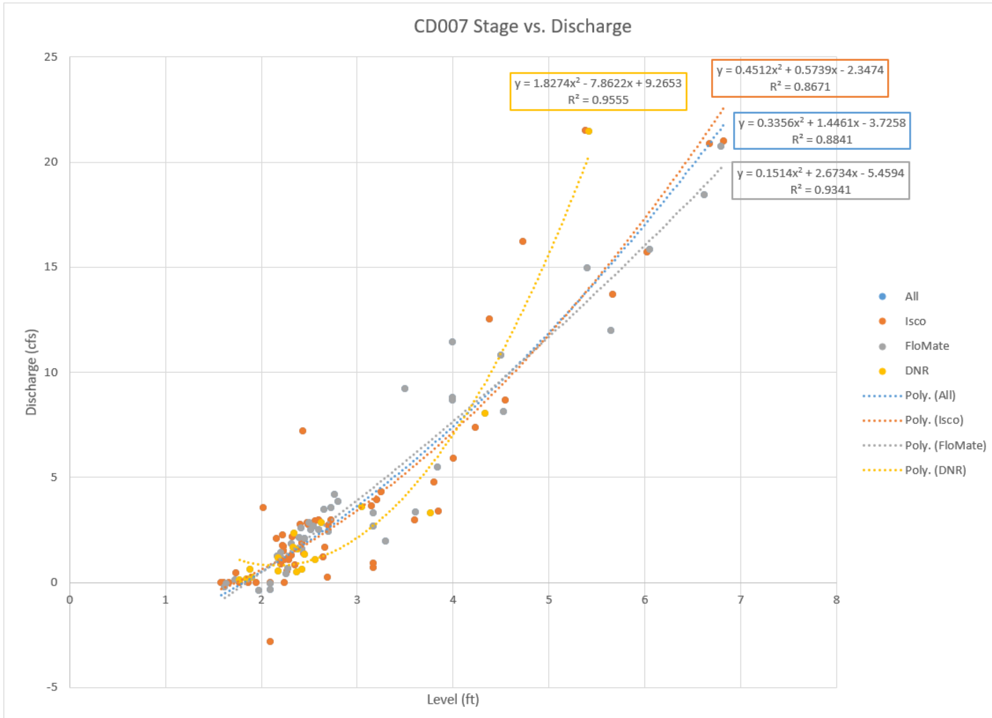


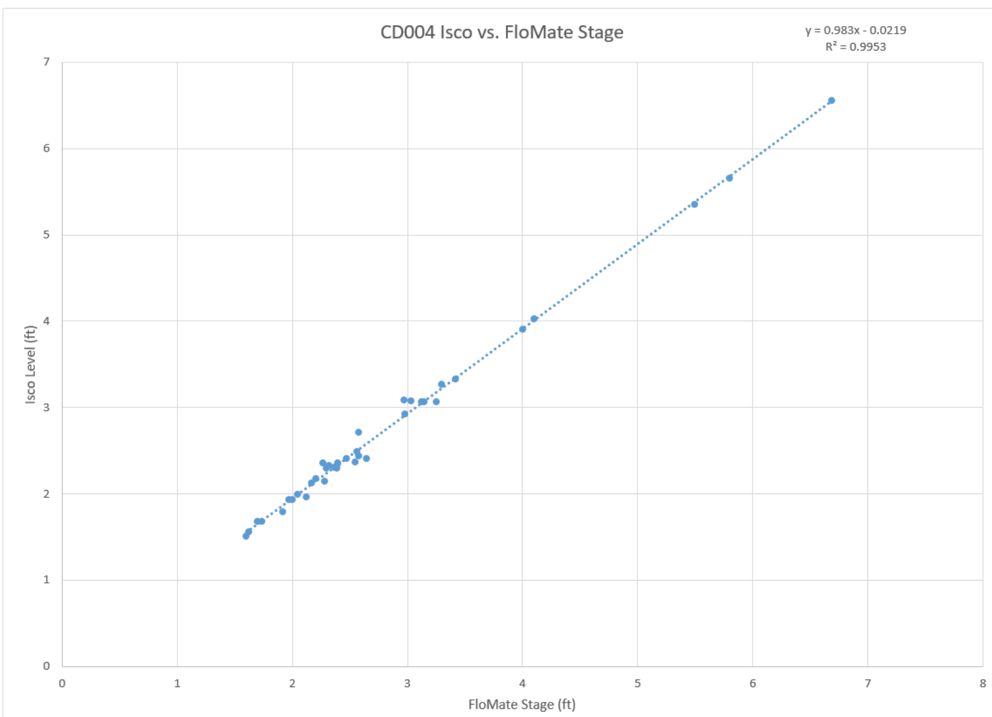
CD001 Sampling Coverage (2017)
Discharge (L/s)
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
-200
Mar-17
Apr-17
May-17
Jun-17
Jul-17
Aug-17
Aug-17
Sep-17
Oct-17
Nov-17
Discharge
Composite
Composite Estimate
Base Samples

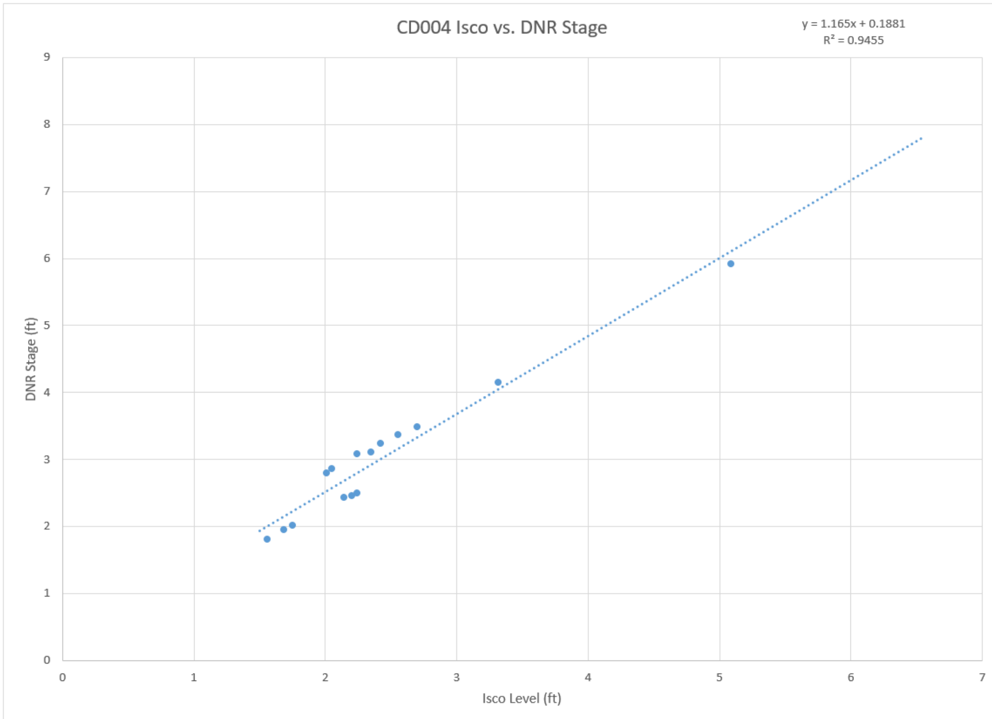
Appendix E. Rating curve stage and discharge comparisons

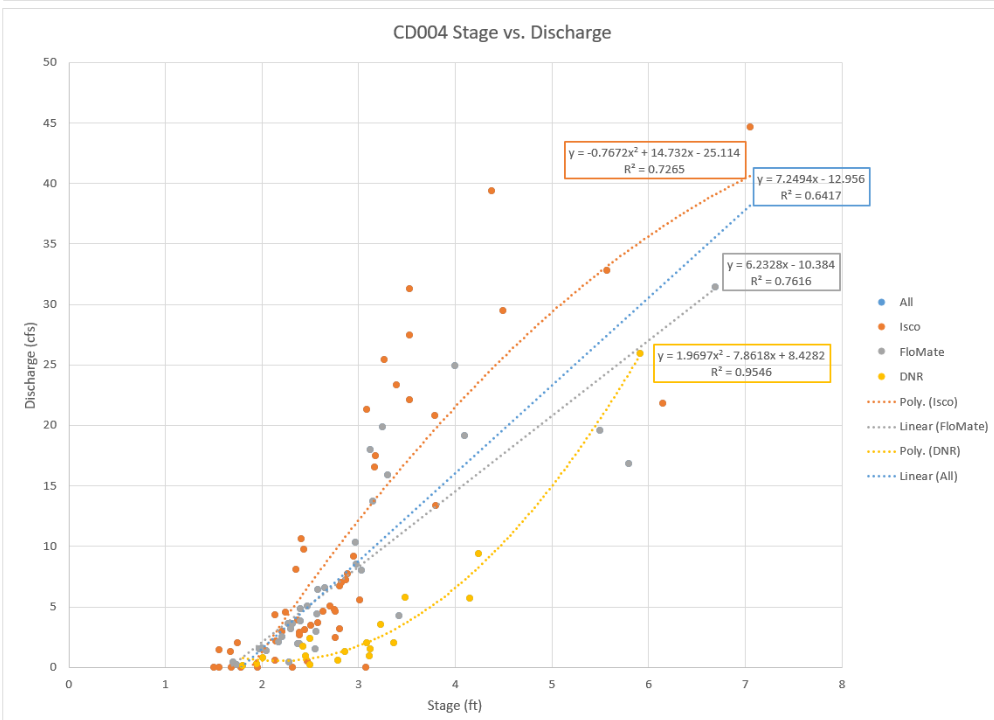


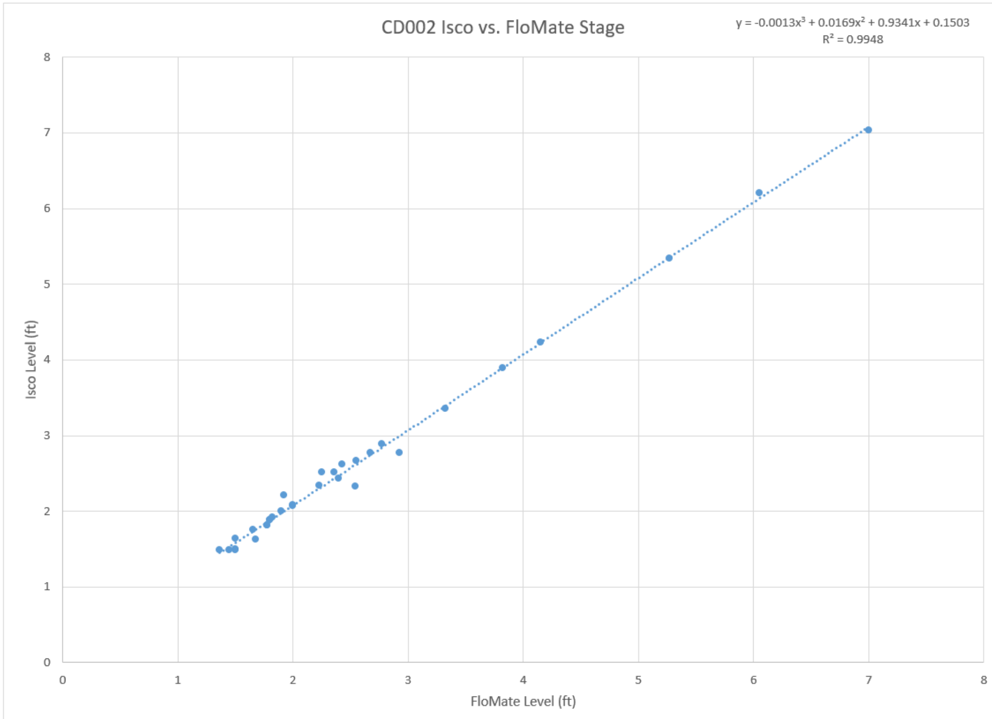


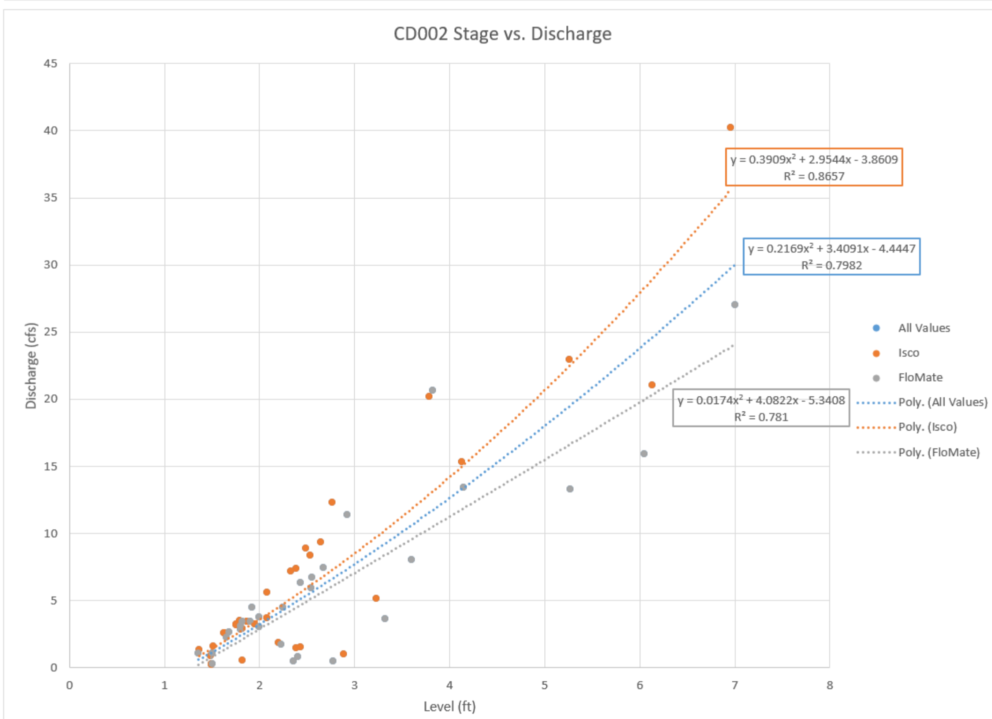

CD007 Stage vs. Discharge
y = 1.8274x² - 7.8622x + 9.2653
R² = 0.9555
y = 0.4512x² + 0.5739x - 2.3474
R² = 0.8671
y = 0.3356x² + 1.4461x - 3.7258
R² = 0.8841
y = 0.1514x² + 2.6734x - 5.4594
R² = 0.9341
Discharge (cfs)
Level (ft)
All
Isco
FloMate
DNR
Poly. (All)
Poly. (Isco)
Poly. (FloMate)
Poly. (DNR)

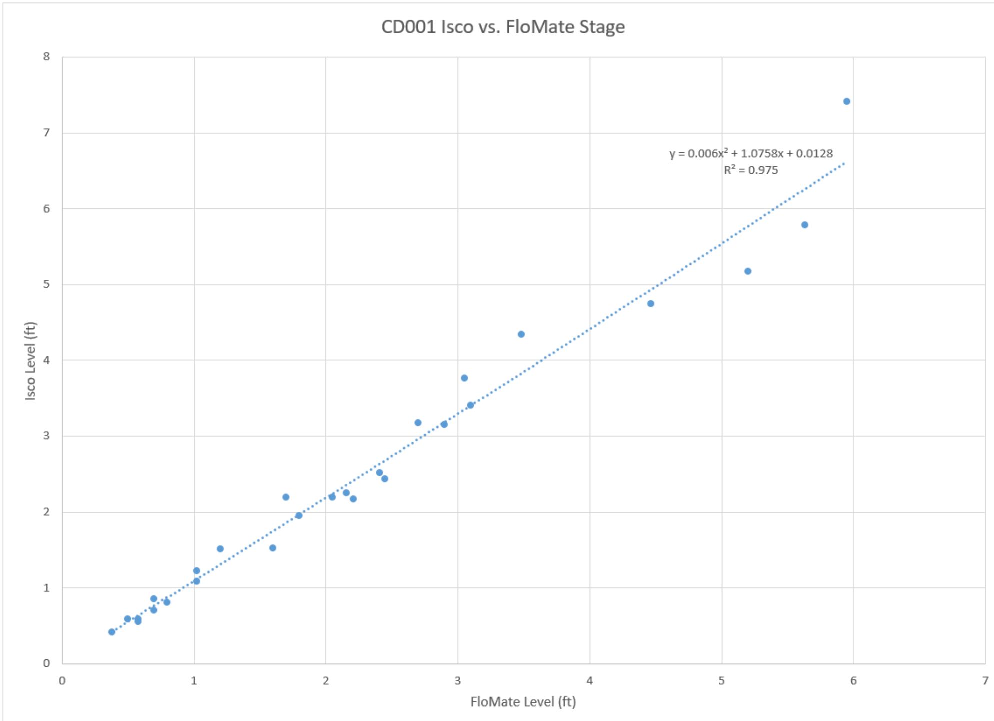

CD004 Isco vs. FloMate Stage
y = 0.983x - 0.0219
R² = 0.9953
Isco Level (ft)
FloMate Stage (ft)

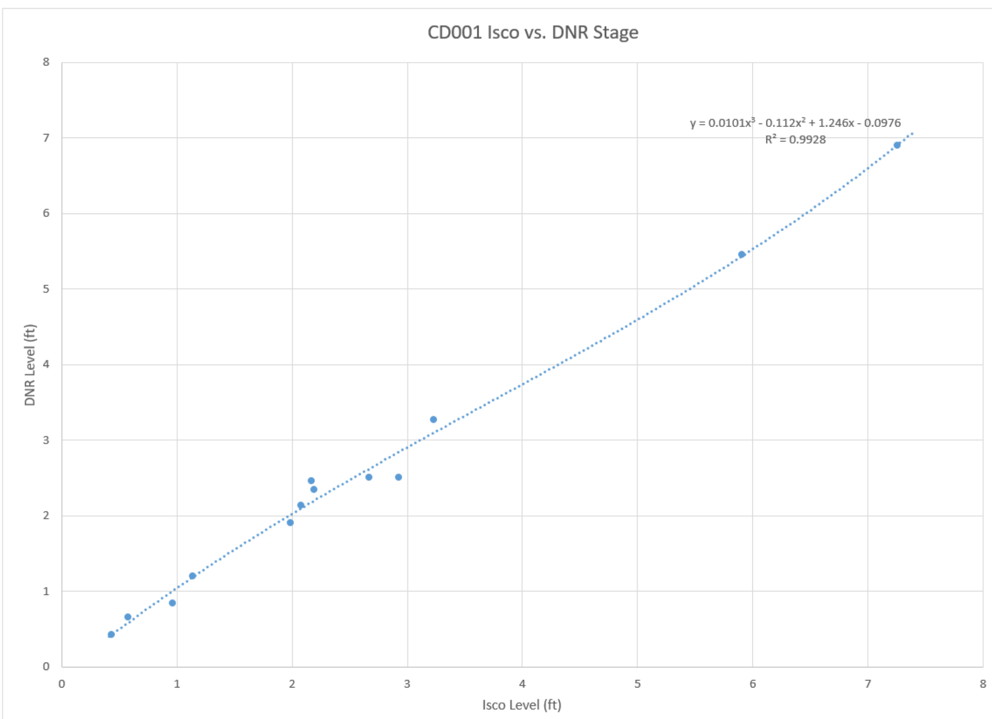

CD004 Isco vs. DNR Stage
y = 1.165x + 0.1881
R² = 0.9455
DNR Stage (ft)
Isco Level (ft)

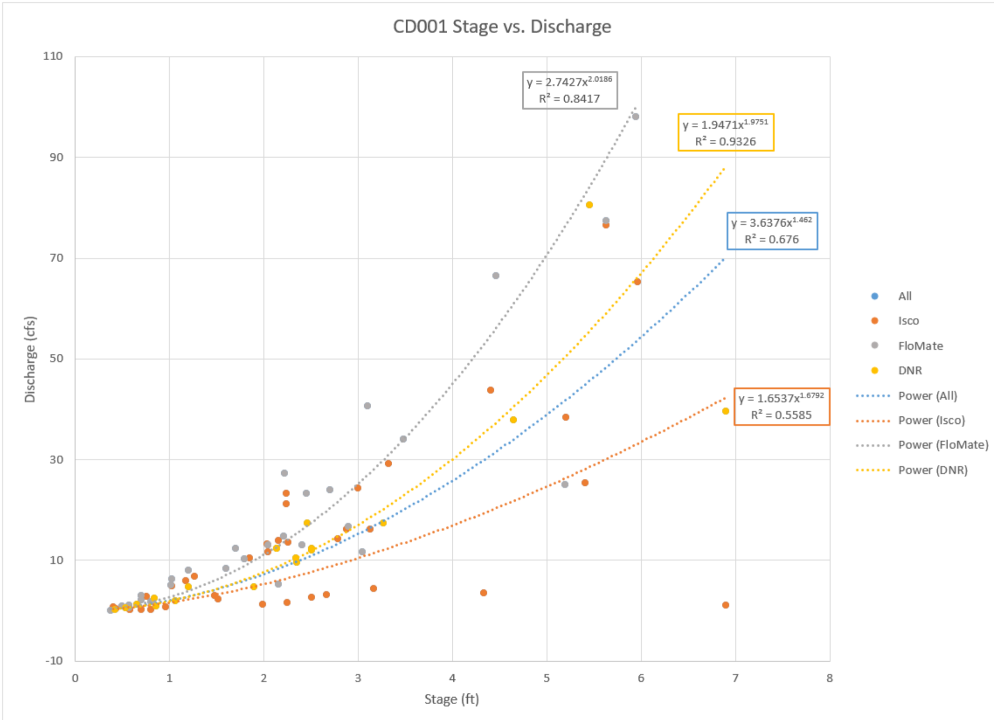

CD004 Stage vs. Discharge
y = -0.7672x² + 14.732x - 25.114
R² = 0.7265
y = 7.2494x - 12.956
R² = 0.6417
y = 6.2328x - 10.384
R² = 0.7616
y = 1.9697x² - 7.8618x + 8.4282
R² = 0.9546
All
Isco
FloMate
DNR
Poly. (Isco)
Linear (FloMate)
Poly. (DNR)
Linear (All)
Discharge (cfs)
Stage (ft)


CD002 Isco vs. FloMate Stage
y = -0.0013x³ + 0.0169x² + 0.9341x + 0.1503
R² = 0.9948
Isco Level (ft)
FloMate Level (ft)

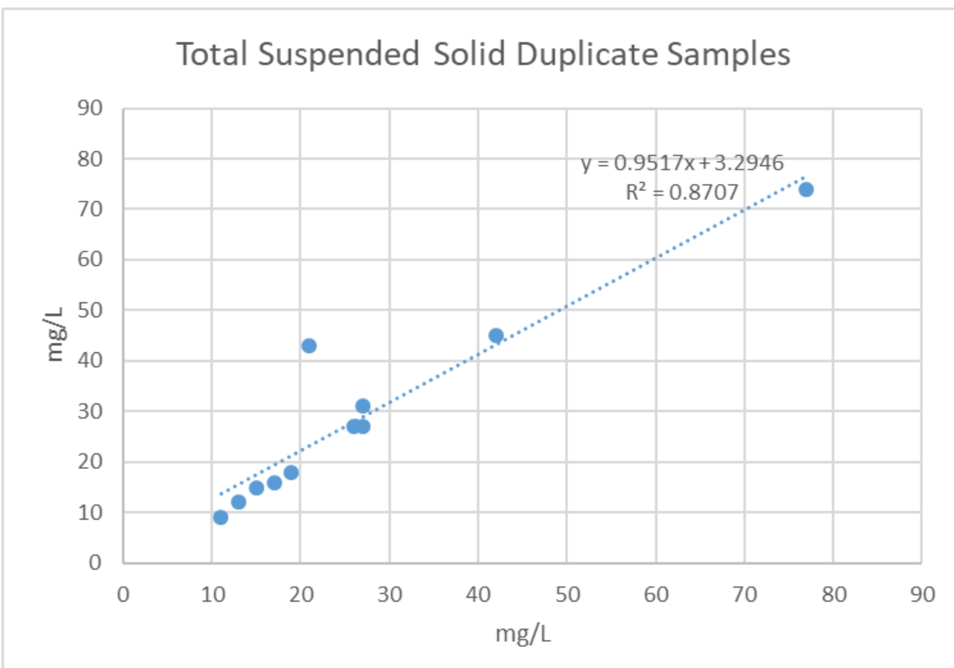

CD002 Stage vs. Discharge
y = 0.3909x² + 2.9544x - 3.8609
R² = 0.8657
y = 0.2169x² + 3.4091x - 4.4447
R² = 0.7982
y = 0.0174x² + 4.0822x - 5.3408
R² = 0.781
All Values
Isco
FloMate
Poly. (All Values)
Poly. (Isco)
Poly. (FloMate)
Discharge (cfs)
Level (ft)

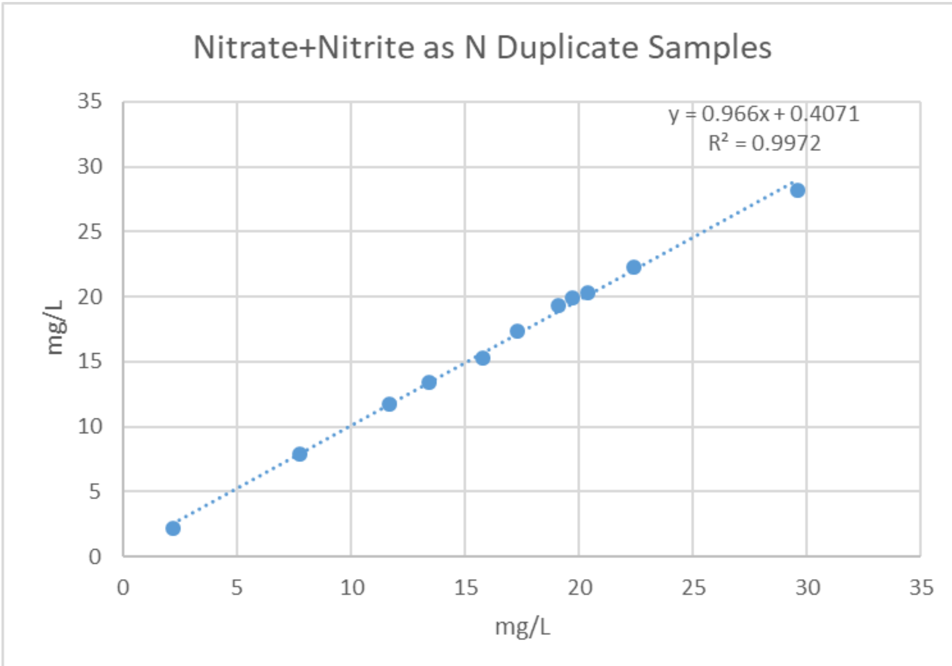

CD001 Isco vs. FloMate Stage
y = 0.006x² + 1.0758x + 0.0128
R² = 0.975
Isco Level (ft)
FloMate Level (ft)

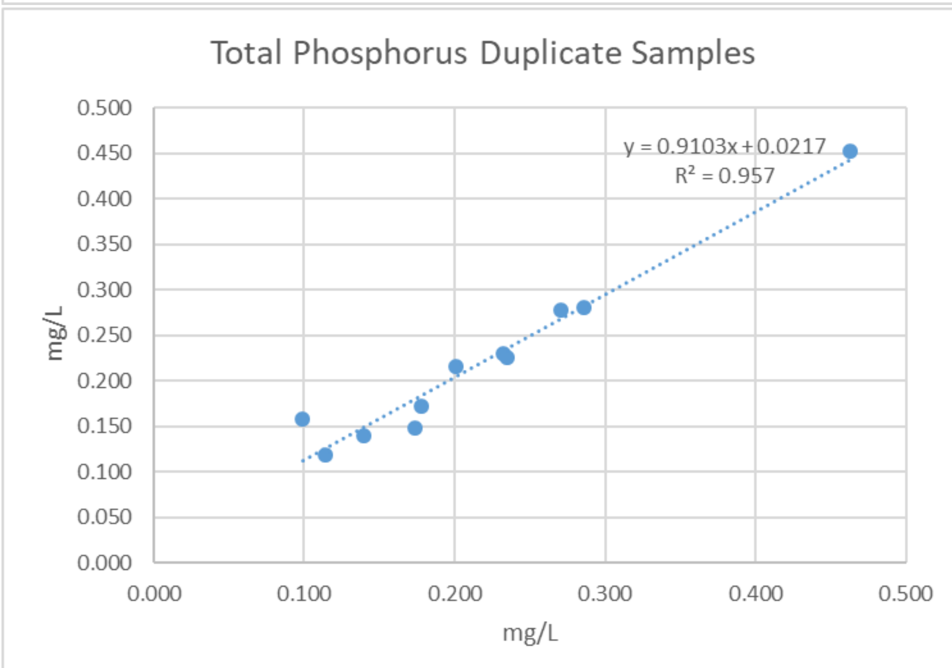

CD001 Isco vs. DNR Stage
y = 0.0101x³ - 0.112x² + 1.246x - 0.0976
R² = 0.9928
DNR Level (ft)
Isco Level (ft)

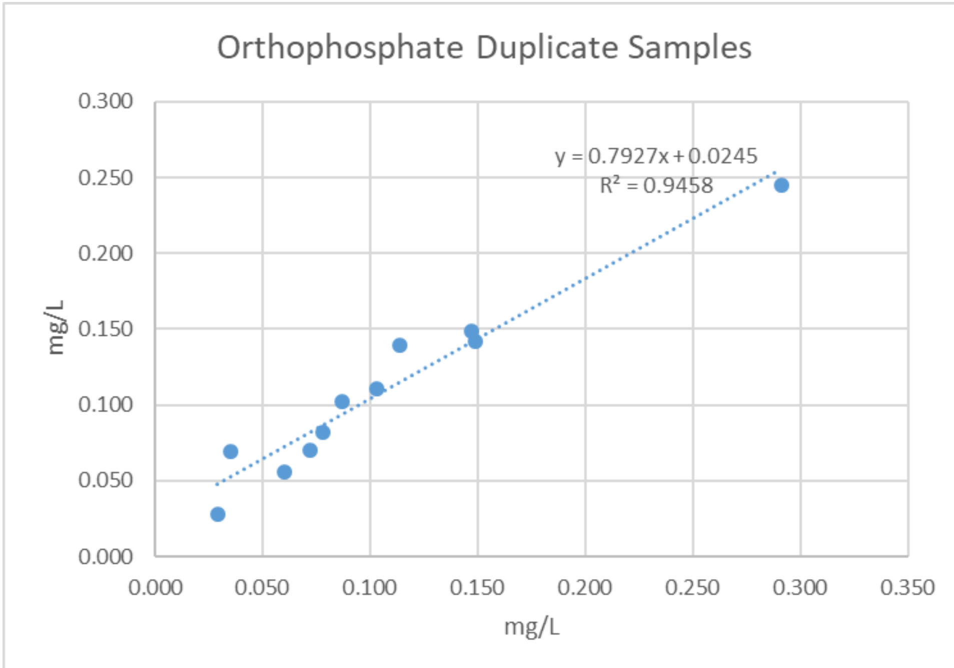


Appendix F. Duplicate sample flow-weighted mean concentration comparison.

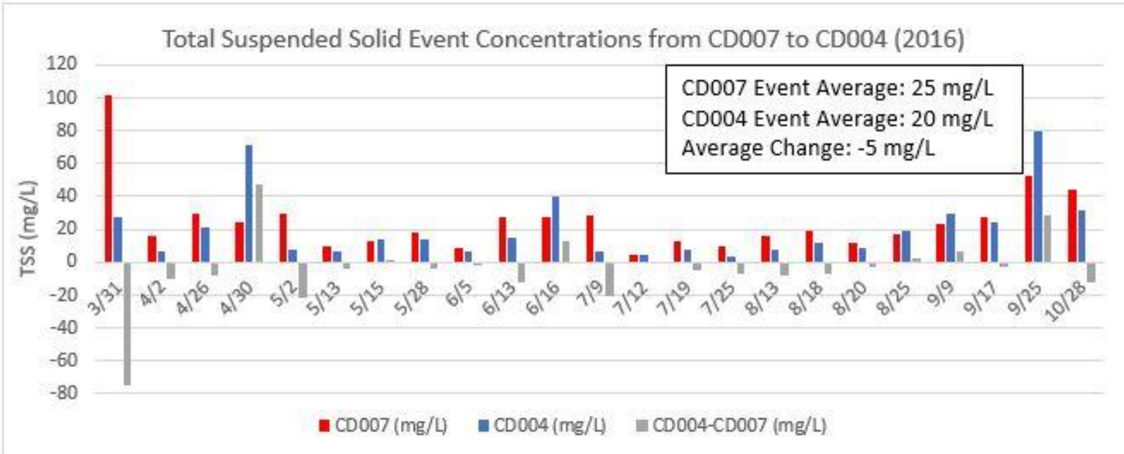


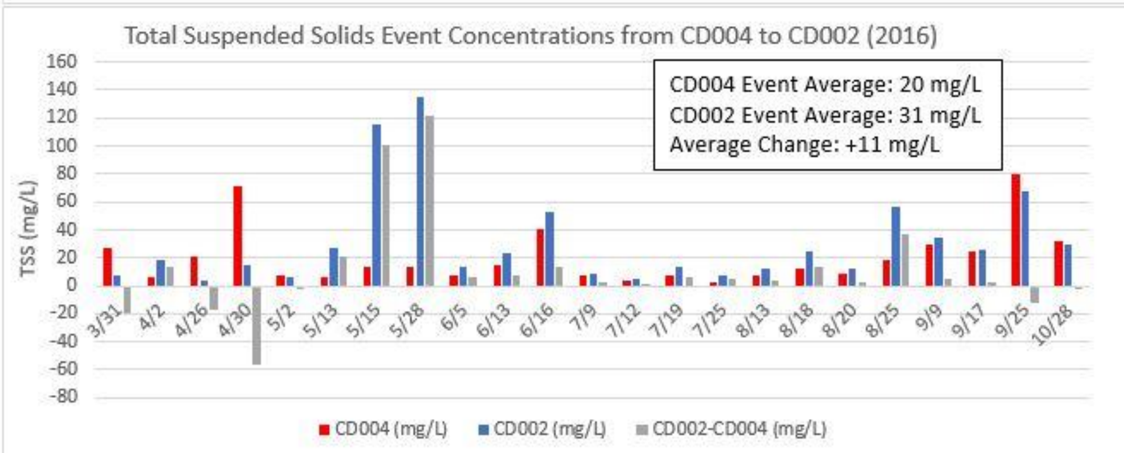

Nitrate+Nitrite as N Duplicate Samples
y = 0.966x + 0.4071
R² = 0.9972
mg/L
mg/L
0
5
10
15
20
25
30
35
0
5
10
15
20
25
30
35

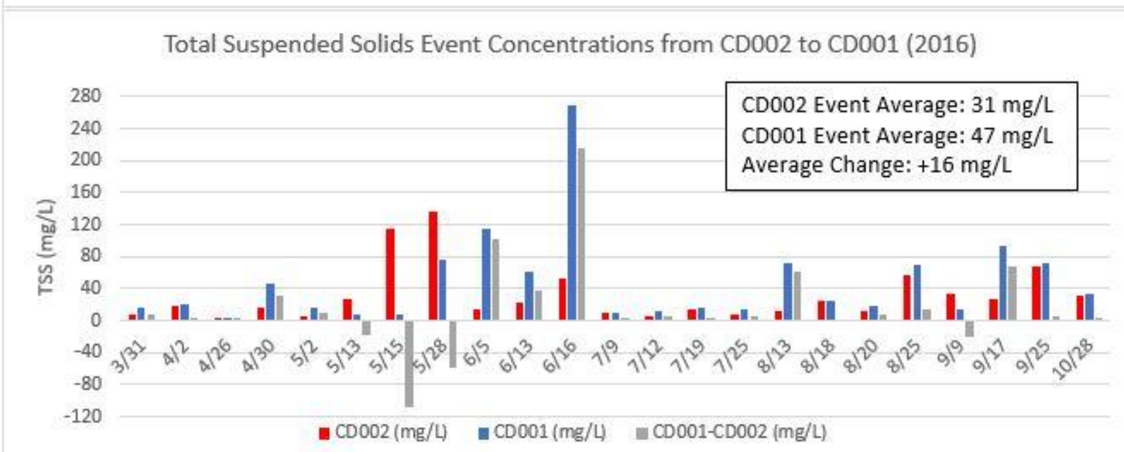

Total Phosphorus Duplicate Samples
y = 0.9103x + 0.0217
R² = 0.957
mg/L
mg/L
0.000
0.050
0.100
0.150
0.200
0.250
0.300
0.350
0.400
0.450
0.500
0.000
0.100
0.200
0.300
0.400
0.500

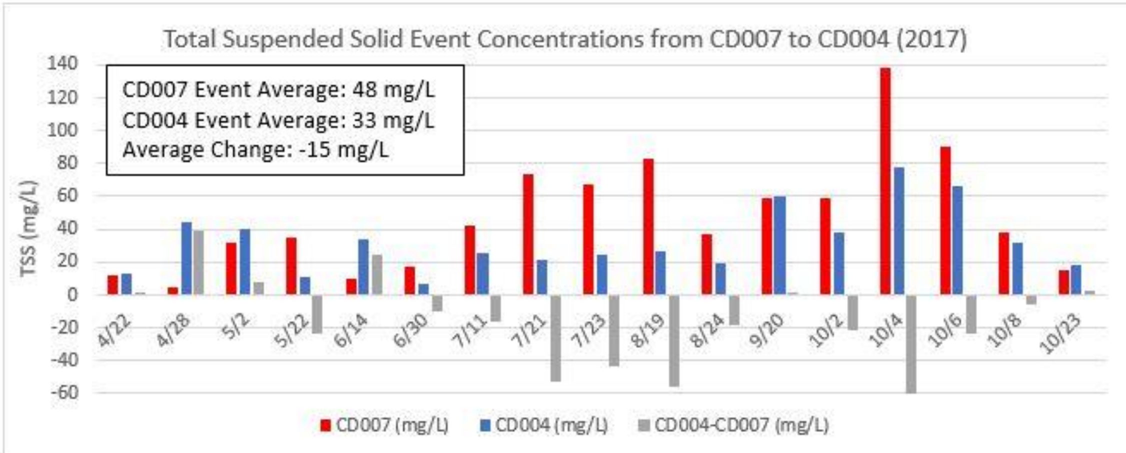


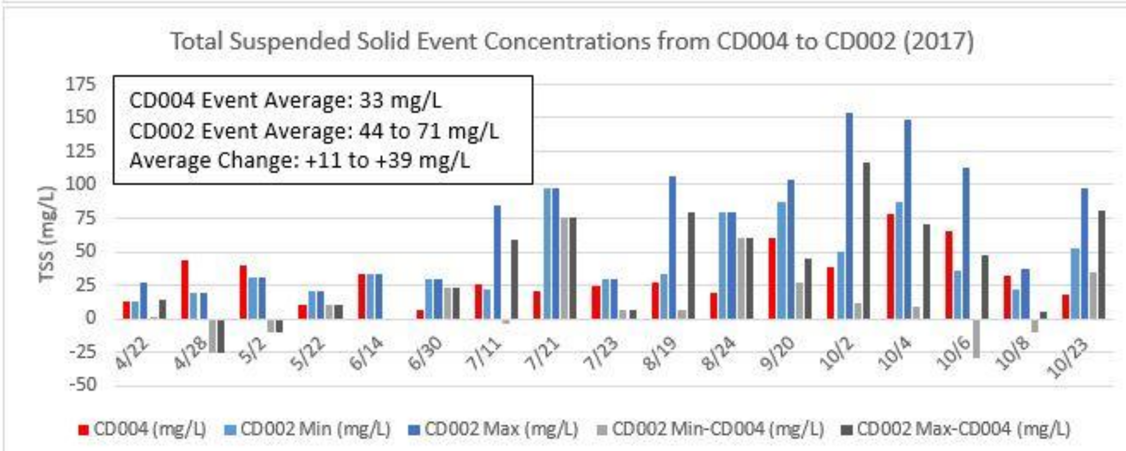
Appendix G. Event concentration comparison graphs.

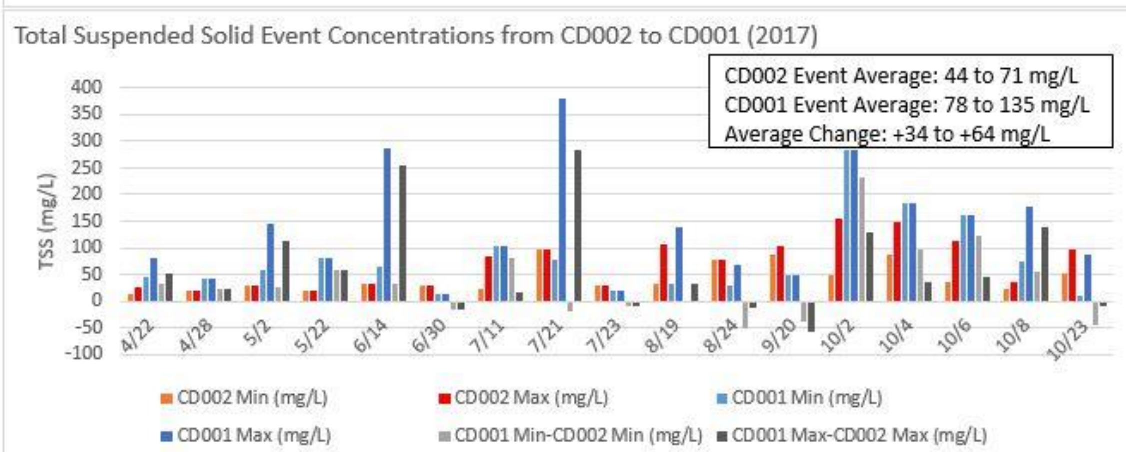

Total Suspended Solid Event Concentrations from CD007 to CD004 (2016)
CD007 Event Average: 25 mg/L
CD004 Event Average: 20 mg/L
Average Change: -5 mg/L
TSS (mg/L)
120
100
80
60
40
20
0
-20
-40
-60
-80
3/31
4/2
4/26
4/30
5/2
5/13
5/15
5/28
6/5
6/13
6/16
7/9
7/12
7/19
7/25
8/13
8/18
8/20
8/25
9/9
9/17
9/25
10/28
CD007 (mg/L)
CD004 (mg/L)
CD004-CD007 (mg/L)

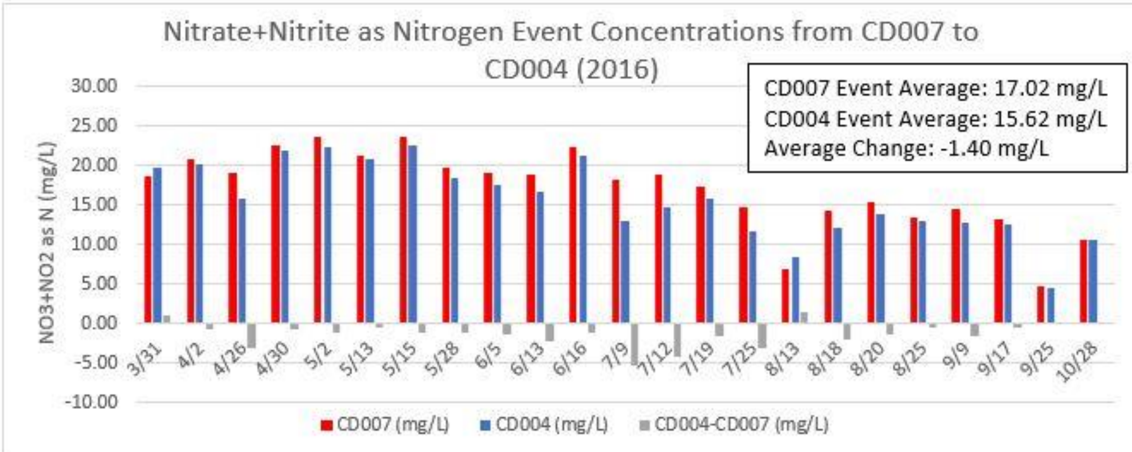

Total Suspended Solids Event Concentrations from CD004 to CD002 (2016)
CD004 Event Average: 20 mg/L
CD002 Event Average: 31 mg/L
Average Change: +11 mg/L
TSS (mg/L)
160
140
120
100
80
60
40
20
0
-20
-40
-60
-80
3/31
4/2
4/26
4/30
5/2
5/13
5/15
5/28
6/5
6/13
6/16
7/9
7/12
7/19
7/25
8/13
8/18
8/20
8/25
9/9
9/17
9/25
10/28
CD004 (mg/L)
CD002 (mg/L)
CD002-CD004 (mg/L)

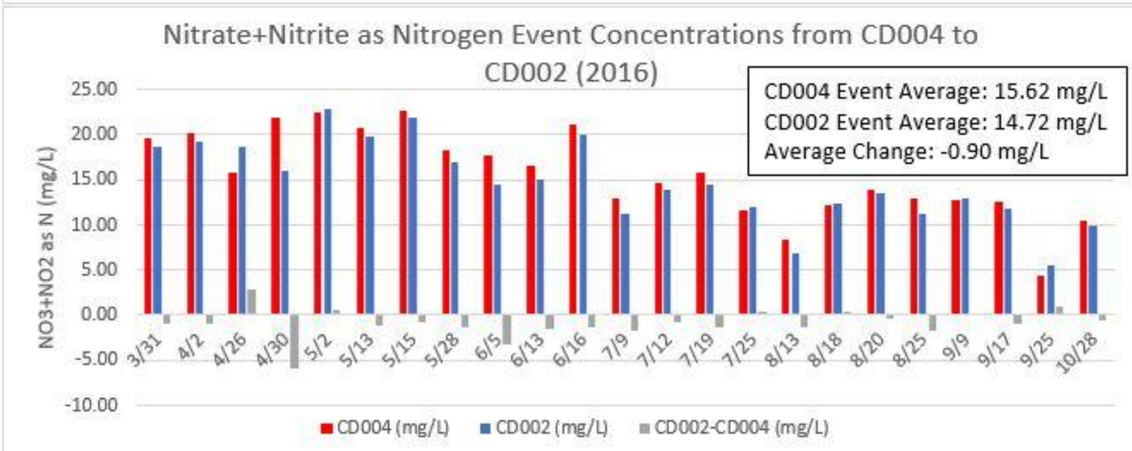

Total Suspended Solids Event Concentrations from CD002 to CD001 (2016)
CD002 Event Average: 31 mg/L
CD001 Event Average: 47 mg/L
Average Change: +16 mg/L
TSS (mg/L)
280
240
200
160
120
80
40
0
-40
-80
-120
3/31
4/2
4/26
4/30
5/2
5/13
5/15
5/28
6/5
6/13
6/16
7/9
7/12
7/19
7/25
8/13
8/18
8/20
8/25
9/9
9/17
9/25
10/28
CD002 (mg/L)
CD001 (mg/L)
CD001-CD002 (mg/L)

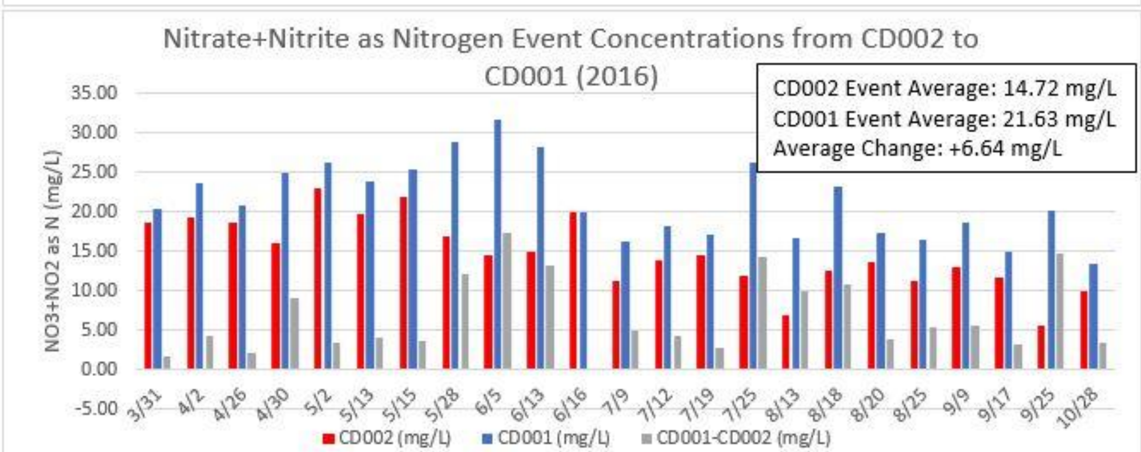

Total Suspended Solid Event Concentrations from CD007 to CD004 (2017)
CD007 Event Average: 48 mg/L
CD004 Event Average: 33 mg/L
Average Change: -15 mg/L
TSS (mg/L)
140
120
100
80
60
40
20
0
-20
-40
-60
4/22
4/28
5/2
5/22
6/14
6/30
7/11
7/21
7/23
8/19
8/24
9/20
10/2
10/4
10/6
10/8
10/23
CD007 (mg/L)
CD004 (mg/L)
CD004-CD007 (mg/L)

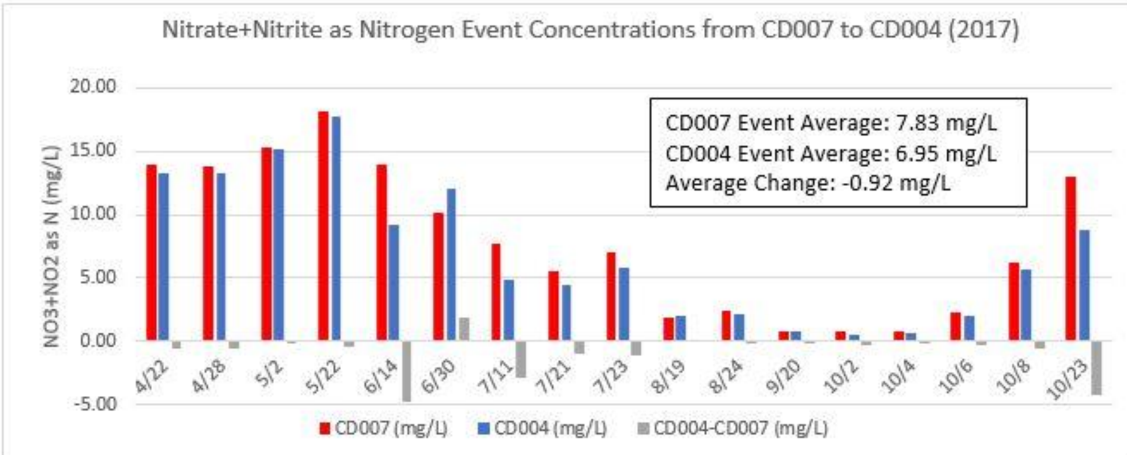

Total Suspended Solid Event Concentrations from CD004 to CD002 (2017)
CD004 Event Average: 33 mg/L
CD002 Event Average: 44 to 71 mg/L
Average Change: +11 to +39 mg/L
TSS (mg/L)
175
150
125
100
75
50
25
0
-25
-50
4/22
4/28
5/2
5/22
6/14
6/30
7/11
7/21
7/23
8/19
8/24
9/20
10/2
10/4
10/6
10/8
10/23
CD004 (mg/L)
CD002 Min (mg/L)
CD002 Max (mg/L)
CD002 Min-CD004 (mg/L)
CD002 Max-CD004 (mg/L)

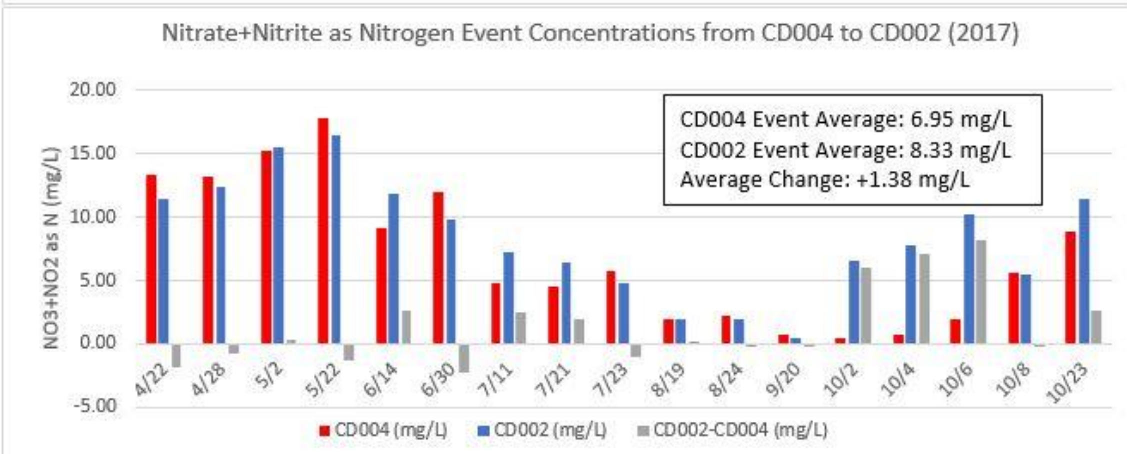

Total Suspended Solid Event Concentrations from CD002 to CD001 (2017)
CD002 Event Average: 44 to 71 mg/L
CD001 Event Average: 78 to 135 mg/L
Average Change: +34 to +64 mg/L
TSS (mg/L)
400
350
300
250
200
150
100
50
0
-50
-100
4/22
4/28
5/2
5/22
6/14
6/30
7/11
7/21
7/23
8/19
8/24
9/20
10/2
10/4
10/6
10/8
10/23
CD002 Min (mg/L)
CD002 Max (mg/L)
CD001 Min (mg/L)
CD001 Max (mg/L)
CD001 Min-CD002 Min (mg/L)
CD001 Max-CD002 Max (mg/L)

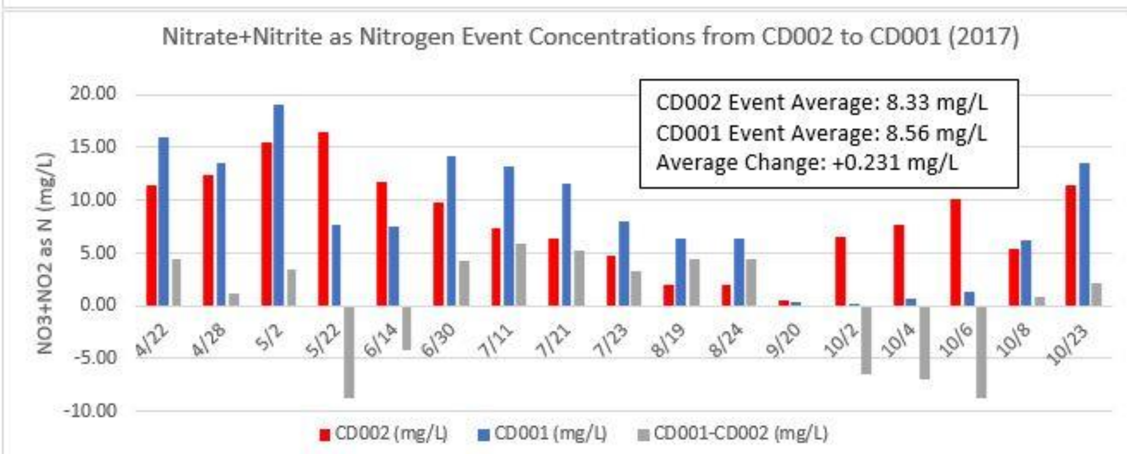

Nitrate+Nitrite as Nitrogen Event Concentrations from CD007 to CD004 (2016)
CD007 Event Average: 17.02 mg/L
CD004 Event Average: 15.62 mg/L
Average Change: -1.40 mg/L
NO3+NO2 as N (mg/L)
30.00
25.00
20.00
15.00
10.00
5.00
0.00
-5.00
-10.00
3/31 4/2 4/26 4/30 5/2 5/13 5/15 5/28 6/5 6/13 6/16 7/9 7/12 7/19 7/25 8/13 8/18 8/20 8/25 9/9 9/17 9/25 10/28
CD007 (mg/L)
CD004 (mg/L)
CD004-CD007 (mg/L)

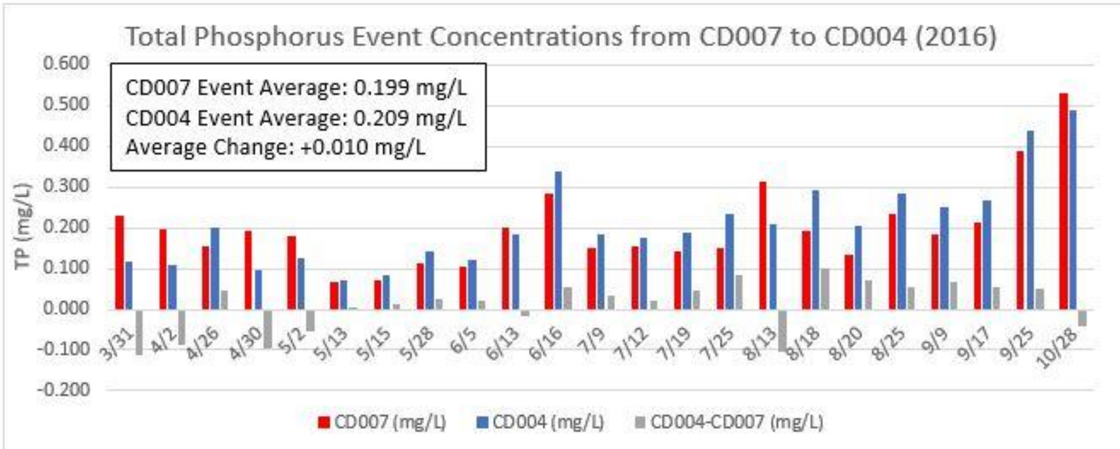

Nitrate+Nitrite as Nitrogen Event Concentrations from CD004 to CD002 (2016)
CD004 Event Average: 15.62 mg/L
CD002 Event Average: 14.72 mg/L
Average Change: -0.90 mg/L
NO3+NO2 as N (mg/L)
25.00
20.00
15.00
10.00
5.00
0.00
-5.00
-10.00
3/31 4/2 4/26 4/30 5/2 5/13 5/15 5/28 6/5 6/13 6/16 7/9 7/12 7/19 7/25 8/13 8/18 8/20 8/25 9/9 9/17 9/25 10/28
CD004 (mg/L)
CD002 (mg/L)
CD002-CD004 (mg/L)

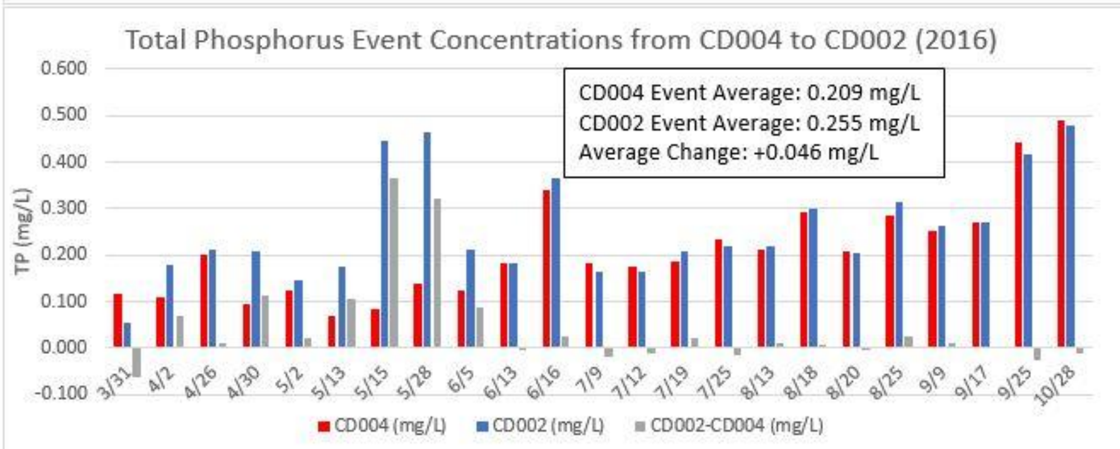

Nitrate+Nitrite as Nitrogen Event Concentrations from CD002 to CD001 (2016)
CD002 Event Average: 14.72 mg/L
CD001 Event Average: 21.63 mg/L
Average Change: +6.64 mg/L
NO3+NO2 as N (mg/L)
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
-5.00
3/31 4/2 4/26 4/30 5/2 5/13 5/15 5/28 6/5 6/13 6/16 7/9 7/12 7/19 7/25 8/13 8/18 8/20 8/25 9/9 9/17 9/25 10/28
CD002 (mg/L)
CD001 (mg/L)
CD001-CD002 (mg/L)

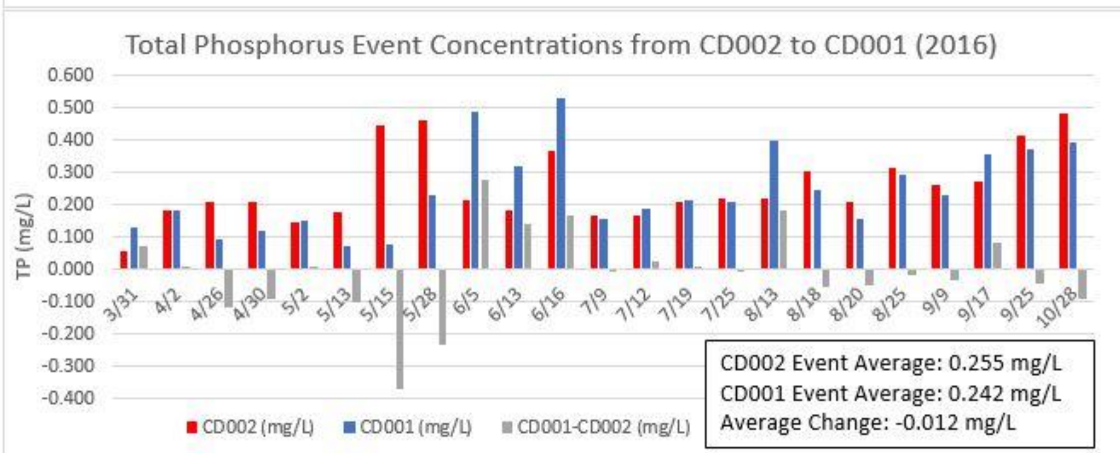

Nitrate+Nitrite as Nitrogen Event Concentrations from CD007 to CD004 (2017)
CD007 Event Average: 7.83 mg/L
CD004 Event Average: 6.95 mg/L
Average Change: -0.92 mg/L
NO3+NO2 as N (mg/L)
20.00
15.00
10.00
5.00
0.00
-5.00
4/22
4/28
5/2
5/22
6/14
6/30
7/11
7/21
7/23
8/19
8/24
9/20
10/2
10/4
10/6
10/8
10/23
CD007 (mg/L)
CD004 (mg/L)
CD004-CD007 (mg/L)

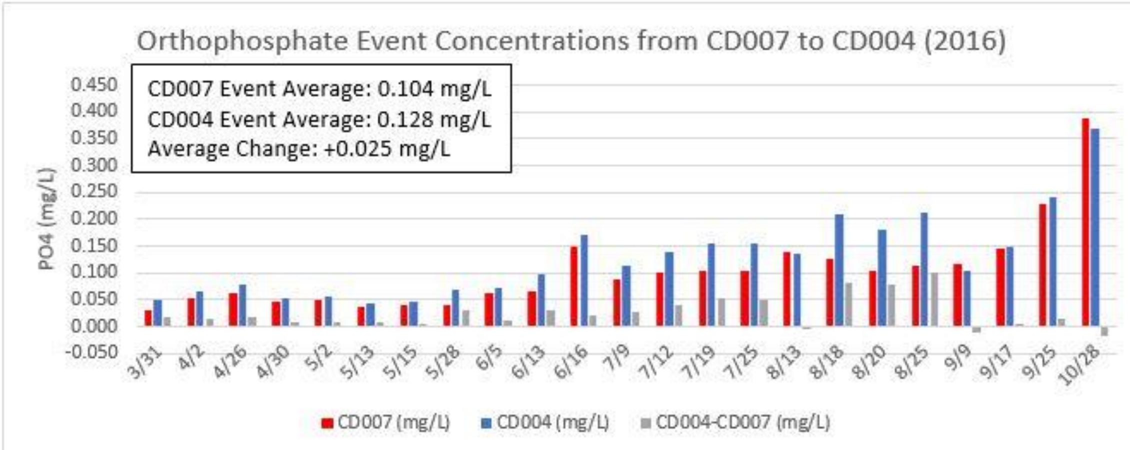

Nitrate+Nitrite as Nitrogen Event Concentrations from CD004 to CD002 (2017)
CD004 Event Average: 6.95 mg/L
CD002 Event Average: 8.33 mg/L
Average Change: +1.38 mg/L
NO3+NO2 as N (mg/L)
20.00
15.00
10.00
5.00
0.00
-5.00
4/22
4/28
5/2
5/22
6/14
6/30
7/11
7/21
7/23
8/19
8/24
9/20
10/2
10/4
10/6
10/8
10/23
CD004 (mg/L)
CD002 (mg/L)
CD002-CD004 (mg/L)

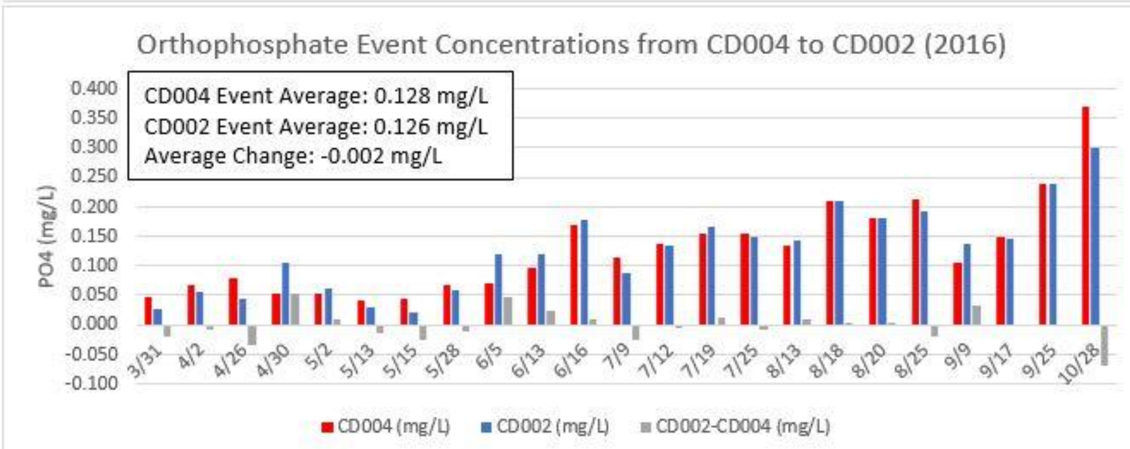

Nitrate+Nitrite as Nitrogen Event Concentrations from CD002 to CD001 (2017)
CD002 Event Average: 8.33 mg/L
CD001 Event Average: 8.56 mg/L
Average Change: +0.231 mg/L
NO3+NO2 as N (mg/L)
20.00
15.00
10.00
5.00
0.00
-5.00
-10.00
4/22
4/28
5/2
5/22
6/14
6/30
7/11
7/21
7/23
8/19
8/24
9/20
10/2
10/4
10/6
10/8
10/23
CD002 (mg/L)
CD001 (mg/L)
CD001-CD002 (mg/L)

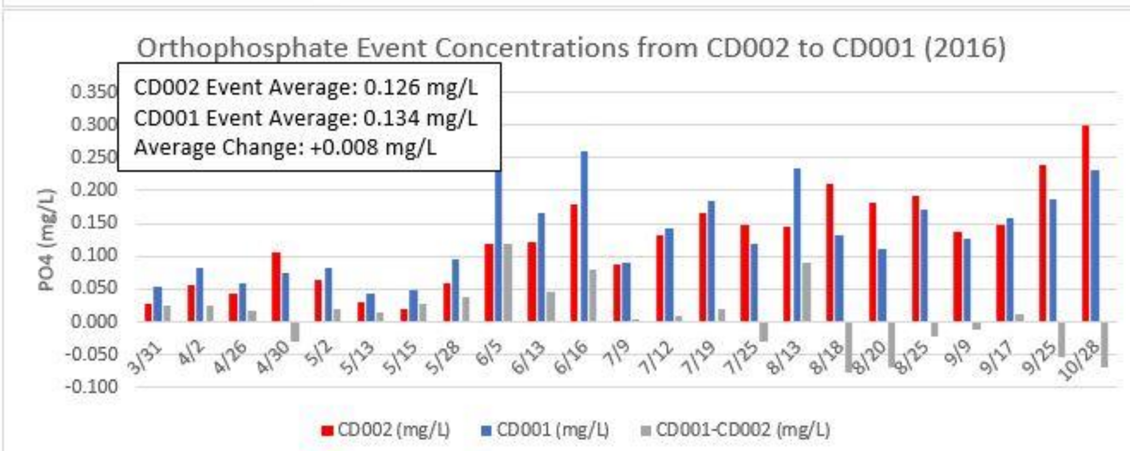

Total Phosphorus Event Concentrations from CD007 to CD004 (2016)
CD007 Event Average: 0.199 mg/L
CD004 Event Average: 0.209 mg/L
Average Change: +0.010 mg/L
TP (mg/L)
CD007 (mg/L)
CD004 (mg/L)
CD004-CD007 (mg/L)

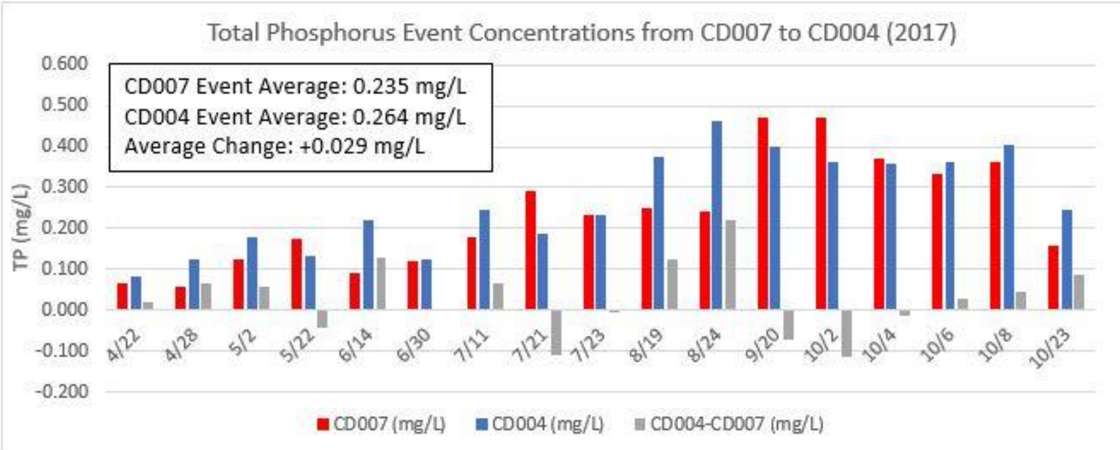

Total Phosphorus Event Concentrations from CD004 to CD002 (2016)
CD004 Event Average: 0.209 mg/L
CD002 Event Average: 0.255 mg/L
Average Change: +0.046 mg/L
TP (mg/L)
CD004 (mg/L)
CD002 (mg/L)
CD002-CD004 (mg/L)

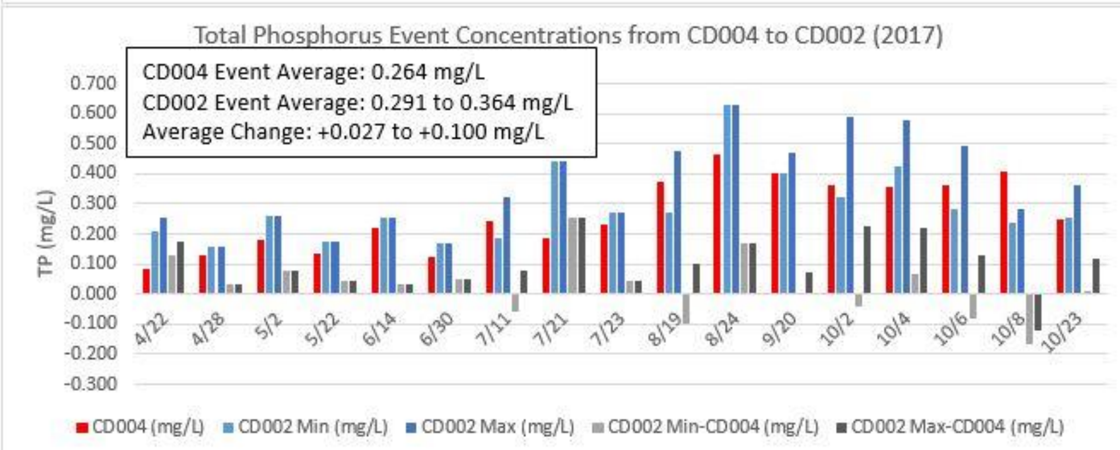

Total Phosphorus Event Concentrations from CD002 to CD001 (2016)
CD002 Event Average: 0.255 mg/L
CD001 Event Average: 0.242 mg/L
Average Change: -0.012 mg/L
TP (mg/L)
CD002 (mg/L)
CD001 (mg/L)
CD001-CD002 (mg/L)

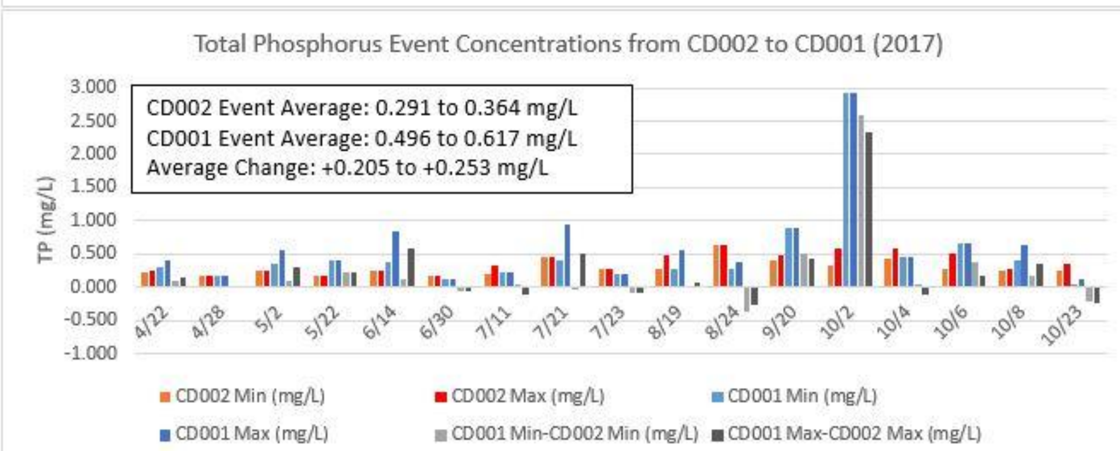

Orthophosphate Event Concentrations from CD007 to CD004 (2016)
CD007 Event Average: 0.104 mg/L
CD004 Event Average: 0.128 mg/L
Average Change: +0.025 mg/L
PO4 (mg/L)
0.450
0.400
0.350
0.300
0.250
0.200
0.150
0.100
0.050
0.000
-0.050
3/31 4/2 4/26 4/30 5/2 5/13 5/15 5/28 6/5 6/13 6/16 7/9 7/12 7/19 7/25 8/13 8/18 8/20 8/25 9/9 9/17 9/25 10/28
CD007 (mg/L)
CD004 (mg/L)
CD004-CD007 (mg/L)

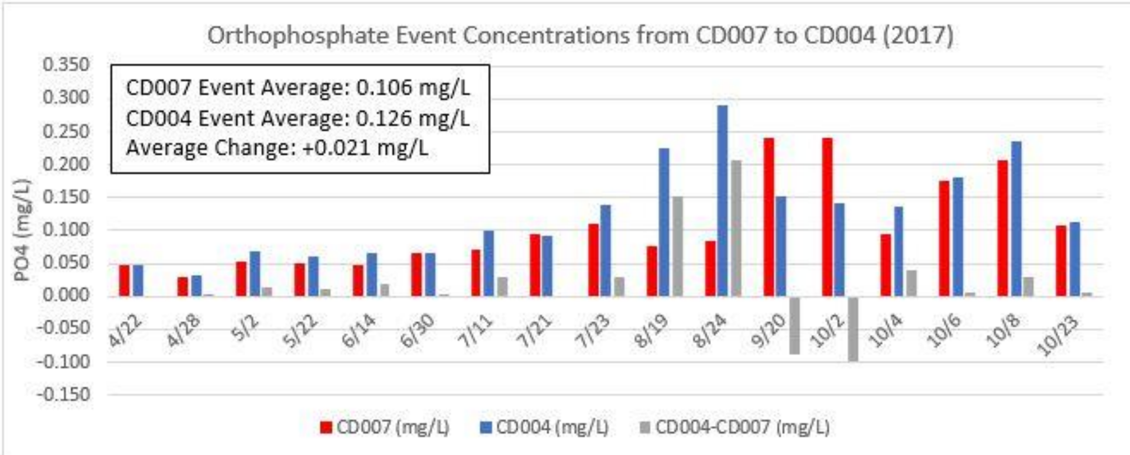

Orthophosphate Event Concentrations from CD004 to CD002 (2016)
CD004 Event Average: 0.128 mg/L
CD002 Event Average: 0.126 mg/L
Average Change: -0.002 mg/L
PO4 (mg/L)
0.400
0.350
0.300
0.250
0.200
0.150
0.100
0.050
0.000
-0.050
-0.100
3/31 4/2 4/26 4/30 5/2 5/13 5/15 5/28 6/5 6/13 6/16 7/9 7/12 7/19 7/25 8/13 8/18 8/20 8/25 9/9 9/17 9/25 10/28
CD004 (mg/L)
CD002 (mg/L)
CD002-CD004 (mg/L)

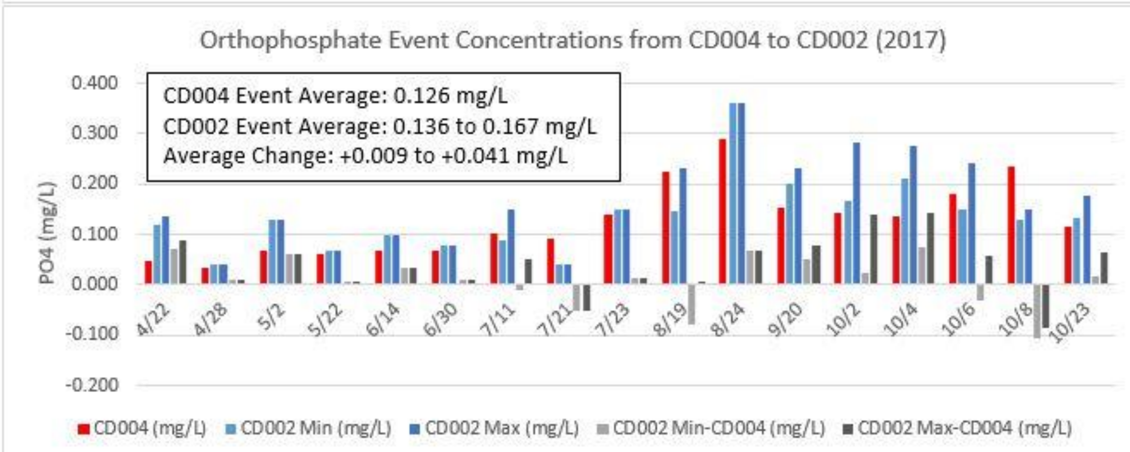

Orthophosphate Event Concentrations from CD002 to CD001 (2016)
CD002 Event Average: 0.126 mg/L
CD001 Event Average: 0.134 mg/L
Average Change: +0.008 mg/L
PO4 (mg/L)
0.350
0.300
0.250
0.200
0.150
0.100
0.050
0.000
-0.050
-0.100
3/31 4/2 4/26 4/30 5/2 5/13 5/15 5/28 6/5 6/13 6/16 7/9 7/12 7/19 7/25 8/13 8/18 8/20 8/25 9/9 9/17 9/25 10/28
CD002 (mg/L)
CD001 (mg/L)
CD001-CD002 (mg/L)

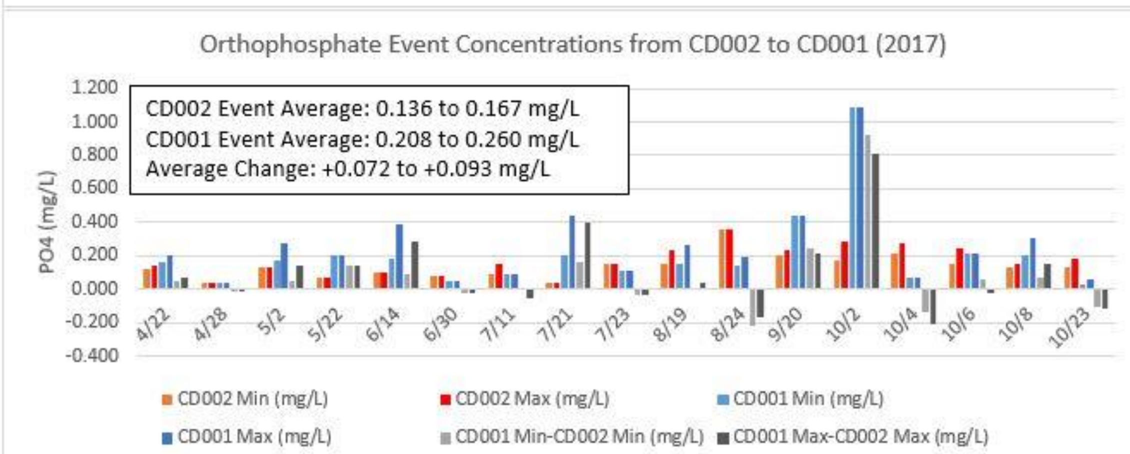

Total Phosphorus Event Concentrations from CD007 to CD004 (2017)
CD007 Event Average: 0.235 mg/L
CD004 Event Average: 0.264 mg/L
Average Change: +0.029 mg/L
TP (mg/L)
0.600
0.500
0.400
0.300
0.200
0.100
0.000
-0.100
-0.200
4/22
4/28
5/2
5/22
6/14
6/30
7/11
7/21
7/23
8/19
8/24
9/20
10/2
10/4
10/6
10/8
10/23
CD007 (mg/L)
CD004 (mg/L)
CD004-CD007 (mg/L)


Total Phosphorus Event Concentrations from CD004 to CD002 (2017)
CD004 Event Average: 0.264 mg/L
CD002 Event Average: 0.291 to 0.364 mg/L
Average Change: +0.027 to +0.100 mg/L
TP (mg/L)
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.000
-0.100
-0.200
-0.300
4/22
4/28
5/2
5/22
6/14
6/30
7/11
7/21
7/23
8/19
8/24
9/20
10/2
10/4
10/6
10/8
10/23
CD004 (mg/L)
CD002 Min (mg/L)
CD002 Max (mg/L)
CD002 Min-CD004 (mg/L)
CD002 Max-CD004 (mg/L)


Total Phosphorus Event Concentrations from CD002 to CD001 (2017)
CD002 Event Average: 0.291 to 0.364 mg/L
CD001 Event Average: 0.496 to 0.617 mg/L
Average Change: +0.205 to +0.253 mg/L
TP (mg/L)
3.000
2.500
2.000
1.500
1.000
0.500
0.000
-0.500
-1.000
4/22
4/28
5/2
5/22
6/14
6/30
7/11
7/21
7/23
8/19
8/24
9/20
10/2
10/4
10/6
10/8
10/23
CD002 Min (mg/L)
CD002 Max (mg/L)
CD001 Min (mg/L)
CD001 Max (mg/L)
CD001 Min-CD002 Min (mg/L)
CD001 Max-CD002 Max (mg/L)


Orthophosphate Event Concentrations from CD007 to CD004 (2017)
CD007 Event Average: 0.106 mg/L
CD004 Event Average: 0.126 mg/L
Average Change: +0.021 mg/L
PO4 (mg/L)
CD007 (mg/L)
CD004 (mg/L)
CD004-CD007 (mg/L)


Orthophosphate Event Concentrations from CD004 to CD002 (2017)
CD004 Event Average: 0.126 mg/L
CD002 Event Average: 0.136 to 0.167 mg/L
Average Change: +0.009 to +0.041 mg/L
PO4 (mg/L)
CD004 (mg/L)
CD002 Min (mg/L)
CD002 Max (mg/L)
CD002 Min-CD004 (mg/L)
CD002 Max-CD004 (mg/L)


Orthophosphate Event Concentrations from CD002 to CD001 (2017)
CD002 Event Average: 0.136 to 0.167 mg/L
CD001 Event Average: 0.208 to 0.260 mg/L
Average Change: +0.072 to +0.093 mg/L
PO4 (mg/L)
CD002 Min (mg/L)
CD002 Max (mg/L)
CD001 Min (mg/L)
CD001 Max (mg/L)
CD001 Min-CD002 Min (mg/L)
CD001 Max-CD002 Max (mg/L)