I+S GROUP

WATER QUALITY REPORT PREPARED FOR:
MINNESOTA LEGISLATIVE-CITIZENS COMMISSION ON MINNESOTA RESOURCES

MAPLETON AREA AGRICULTURAL + URBAN RUNOFF ANALYSIS

SOUTHERN MINNESOTA - BLUE EARTH COUNTY DITCH NO. 57 (CD 57)

AUGUST 14, 2015

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND

BLUE EARTH COUNTY

ISG

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SOUTHERN MINNESOTA - BLUE EARTH COUNTY DITCH NO. 57 (CD 57)



PREPARED ON BEHALF OF:
THE BLUE EARTH COUNTY DRAINAGE AUTHORITY

PREPARED BY:
ISG

AUGUST 14, 2015

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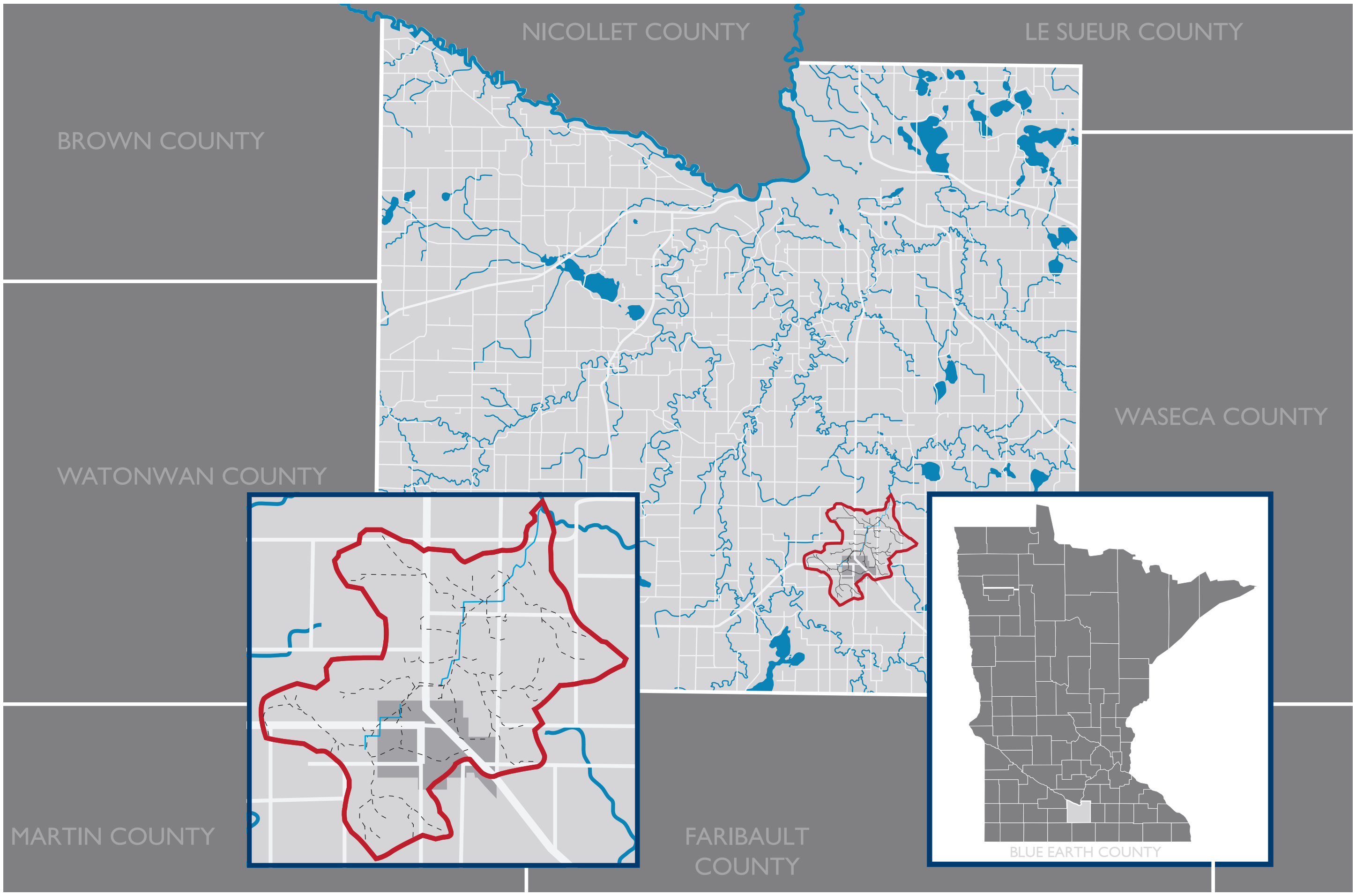


Blue Earth County and DC 57 Location

OVERVIEW AND BACKGROUND

This Water Quality Report supplements the Final Report: Mapleton Area Agricultural and Urban Runoff Analysis and addresses water quality conditions of Blue Earth County Ditch 57 (CD 57). The report outlines and describes the approach used to monitor and analyze water quality parameters before and after the installation of agricultural Best Management Practices (BMPs) within the CD 57 system. These BMPs include buffer strips, surge basins (City Pond, Klein Pond), a two-stage ditch, sediment trap, and weir structures. These practices were designed to reduce peak flow rates and pollutant loading throughout the CD 57 system and improve water quality. The results documented in this report are vital in the ongoing efforts to evaluate potential effectiveness of combining BMPs in small, upland watersheds of the Western Corn Belt Ecoregion.

Water sampling results and other data were used to: 1) determine the effect of storage and peak flow reductions of flooding, 2) determine the effectiveness of BMP's installed, 3) analyze seasonal variations in water quality; and 4) evaluate compliance with water quality standards. These data are available to all interested parties, particularly landowners, drainage authorities, watershed groups, and state agencies. Results and reports are available through Blue Earth County and were provided to the Legislative-Citizens Commission on Minnesota Resources and the Minnesota Environmental and Natural Resources Trust Fund (LCCMR/ENTRF). Project partners for the CD 57 water quality monitoring project include landowners throughout the CD 57 watershed, Blue Earth County Drainage Authority, ISG, Minnesota State University, Mankato (MSU), and Minnesota Valley Testing Laboratories (MVTL).

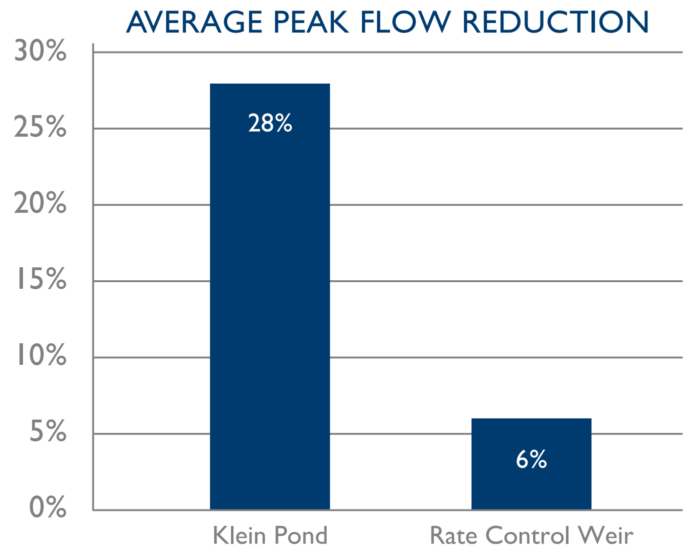


Figure 1 - Average Peak Flow Reductions

Figure 2 - Rate Control Weir Storing Water

PROJECT GOALS

The project's overall goals included improving a nearly century-old drainage system by:

- Increasing drainage capacity while protecting downstream receiving waters
- Improving the water quality of the ditch by reducing soil erosion and nutrient loading by providing storage and treatment practices
- Enhancing ecological value and increasing critical land and habitat
- Providing an innovative demonstration project dealing with Minnesota Drainage Law
- Developing a tool for landowners, land managers planners, and conservationists as a model for future drainage projects

Expected results from the installation of surge basins, native grass buffer strips, a two-stage ditch, sediment trap, and weir structures include: less intense flood events, reduced peak flow rates, and reduced sediment and nutrient loading. Water quality was expected to improve due to less suspended solids in the water column and reduced peak flow rates facilitated by additional storage to the system, a designed self-cleaning system created by the two-stage ditch, and an enhanced habitat for wildlife.

PROJECT RESULTS

This section reviews results of the following data collection: storage and peak flows, average water quality improvements from BMPs, trapped sediment, and perennial baseflows.

STORAGE AND PEAK FLOWS

Storage and peak flow reduction was a major concern for all landowners throughout the CD 57 system. Downstream landowners were fearful of flood damage and crop loss with the upstream improvements to the ditch. Conversely, upstream landowners needed to increase the capacity to prevent their land from routine flooding. This lead to the development of a design that sought to balance storage and peak flow reduction throughout the system through various BMPs.

The City Pond, Klein Pond, and a rate control weir all provided storage and peak flow reduction. The upstream watershed utilized the City and Klein ponds for storage and peak flow reductions while the downstream landowners utilized the rate control weir for storage and peak flow reduction. The average peak flow reductions for the Klein Pond (upstream watershed) and rate control weir (downstream watershed) for the 3 years of monitoring (2012-2014) were compared (*Figure 1*).

The rate control weir provided a total storage of 6 acre-feet. This is equivalent to 3 Olympic sized swimming pools. Peak flow rates were lowered by an average of 6 percent from the upstream ditch section.

The photograph (*Figure 2*) of the rate control weir shows its effectiveness

Figure 3 - Klein Pond Storing Water

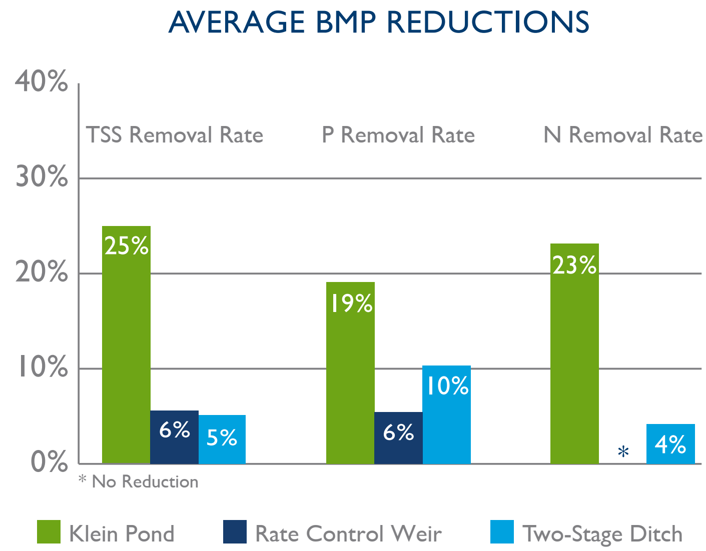


Figure 4 - Average Reductions for TSS, TP and N

at storing water during a rain event.

The Klein Pond provided a total storage of 26.3 acre-feet. This is equivalent to 13 Olympic sized swimming pools. Peak flow rates from the ditch upstream of the pond were reduced by an average of 28 percent. For the watershed area of 1,693 acres at this point, the total storage provided is equivalent to 0.20 inches of rainfall. A photograph (*Figure 3*) shows Klein Pond effectively storing water during a rain event.

AVERAGE BMP REDUCTIONS

Three agricultural BMPs were analyzed through three years of water quality monitoring to determine their overall effectiveness of reducing the loading of total suspended solids (TSS), total phosphorus (TP), and total nitrogen (TN). This analysis included calculating the total loading upstream and downstream of each BMP and determined how much of each parameter was removed. The average TSS, TP and TN reductions for the Klein Pond, two-stage ditch, and rate control weir were compared (*Figure 4*).

Of the three BMPs, the Klein Pond was the most effective at reducing TSS, TP, and TN loading. The two-stage ditch also saw reductions in each of the three parameters, however the reductions were lower than the Klein Pond. The rate control weir also caused reductions in TSS and TP, but did not decrease TN loading.

Three other BMPs were installed to improve water quality and include the City Pond, sediment trap, and buffer strips. Due to monitoring and sampling constraints, the loading for these BMPs could not be analyzed as more monitoring points would be needed to properly measure their effectiveness.

ACCUMULATED SEDIMENT

Sediment loading is a major concern in waterways due in part to the adverse impacts on downstream navigation, potable water supply, and aquatic habitat. Sediment deposits in nearby rivers, lakes, and wetlands where flow velocities are slower, cause the water to back up and results in flooding in the surrounding landscape including agricultural land and residential areas. Sediment also carries nutrient bound particles, most notably phosphorous and nitrogen. These nutrients are linked to poor water quality through algal blooms, oxygen depletion, and hypoxic conditions which do not support aquatic life.

While the main goal of the Klein Pond was to provide storage and reduce peak flow rates, it was also intended to provide a large area to accumulate sediment, thus preventing it from traveling downstream and negatively impacting waterways. To quantify how much sediment accumulated over the three years of post-BMP installation monitoring, a topographic survey was performed in November 2014 to compare the original pond floor to the pond floor after three years of sediment accumulation. This topographic survey revealed substantial sediment accumulation in the pond in some cases reaching nearly 2.5 feet in thickness. A total of 725 cubic yards of sediment had accumulated over three years in the pond, equal to approximately 72 standard dump trucks. This benefits water quality by reducing pollutant loading to downstream waters. *Figure 5* shows the profile of the Klein Pond, which compares the original bottom of the pond and the sediment accumulated in the pond.

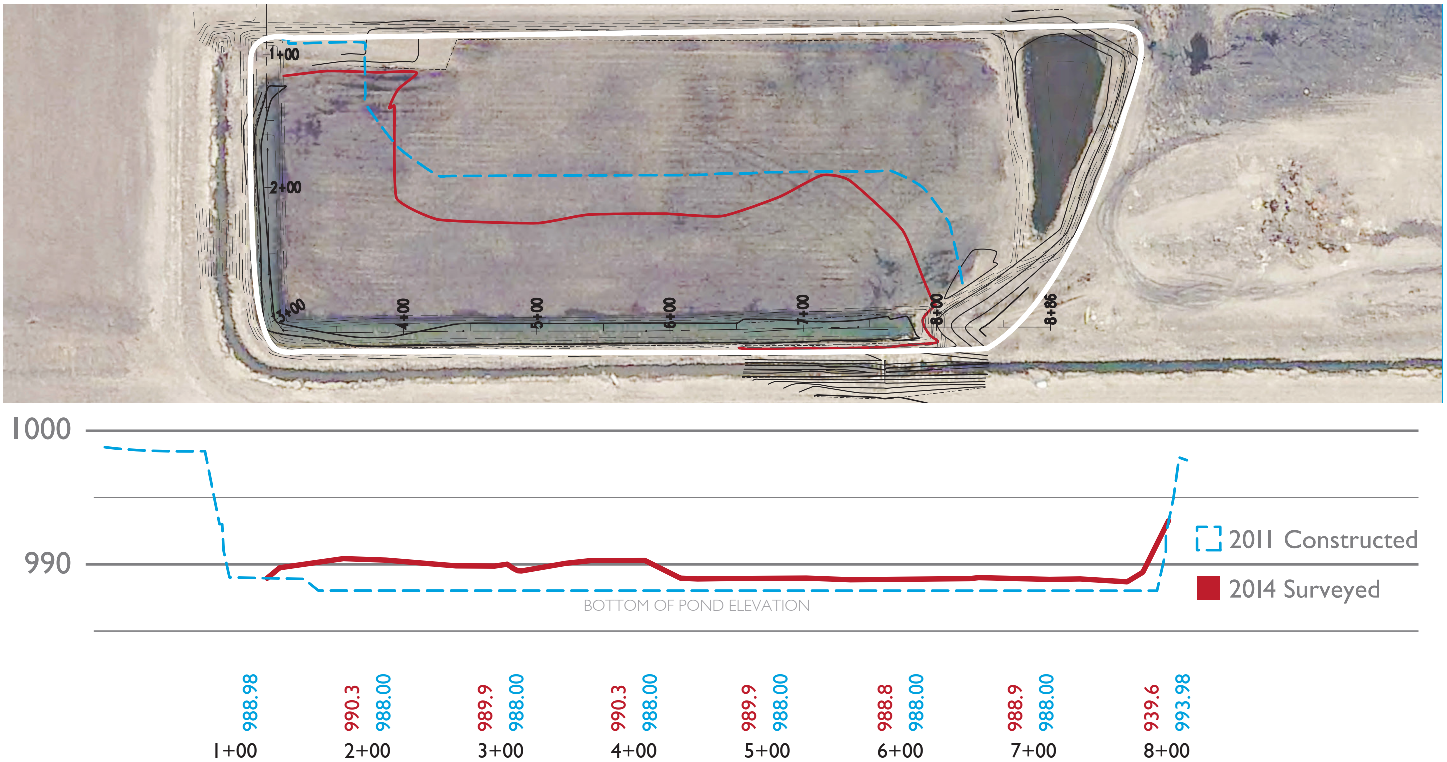


Figure 5 - Accumulated sediment in the Klein Pond

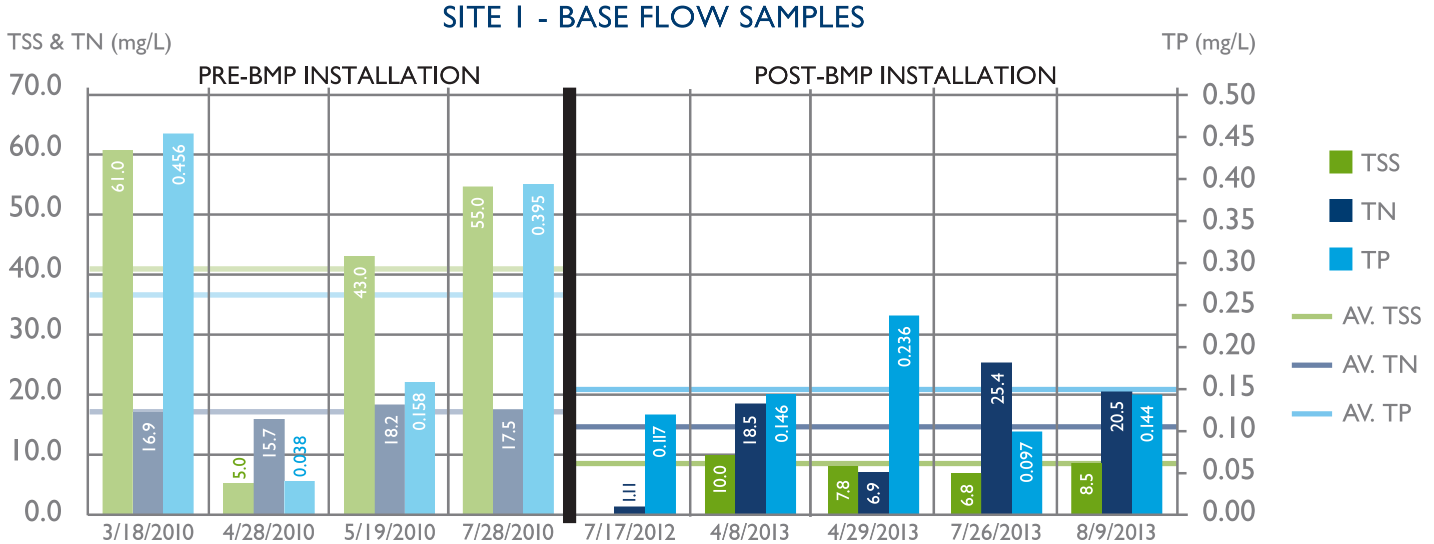


Figure 6 - Pre and Post BMP Installation Low Flow Sample Comparison
(Bars indicate date specific measurements; Lines indicate average measurement)

TSS Reduction = 33% TN Reduction = 3% TP Reduction = 12%

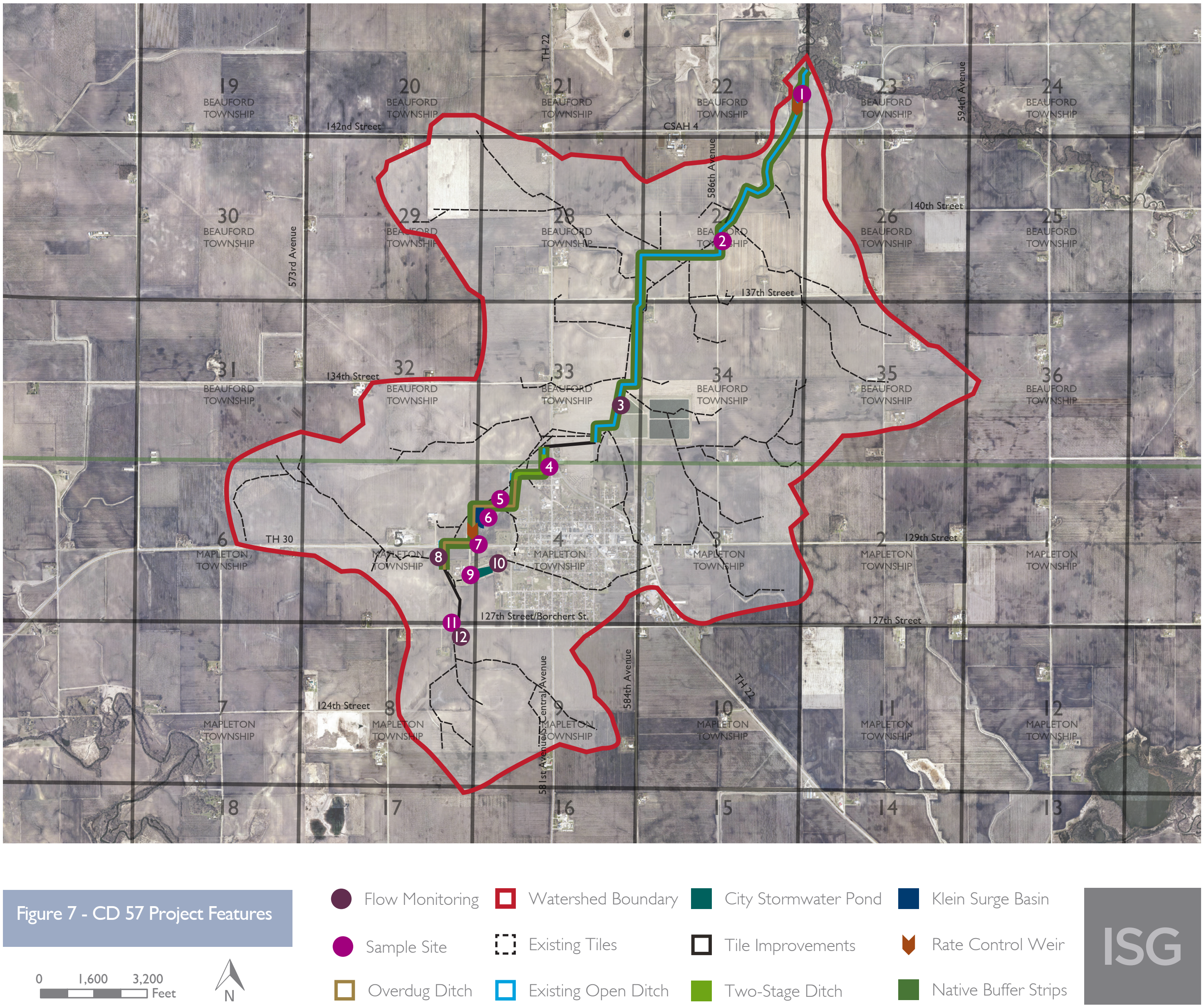


Figure 7 - CD 57 Project Features

PERENNIAL BASEFLOWS

While most of the water quality analyses for CD 57 focused on its function during rain events, it is important to note the condition of the system during low, perennial flows. These flows occur when surface runoff is not present and the flow in the ditch is fed by effluence from subsurface tiling and shallow groundwater. Low flow water quality samples were taken prior to and subsequent to the installation of the BMPs. *Figure 6* compares these samples at the outlet of the CD 57 system (Site 1) for the pre- and post- BMP installation.

The post-BMP installation samples contain lower concentrations of TSS and TP while TN remained nearly the same (*Figure 6*). This can be expected as nitrogen is always present in water despite the passing flow volume. This shows that even during low, perennial baseflows the BMPs prove to be effective at reducing TSS and TP concentrations.

BLUE EARTH COUNTY DITCH 57

This project included six water quality improvement features throughout the 6,041 acre watershed (*Figure 7*). One rod (16.5-foot wide) buffer easements were installed, replacing 17 acres of agricultural land along 4.1 miles of the ditch with native grass buffer strips to improve water quality. A rate control weir was constructed at the outlet of the CD

Figure 8 - Native Grass Buffer Strips Installed

Figure 9 - Klein Pond after 25-Year Rain Event

57 system near the Cobb River, which reduces peak flow rates from the system. The Klein surge basin (Klein Pond) was constructed to store runoff from surrounding farmlands of the upper portion of the watershed. The City of Mapleton's stormwater pond, known in this report as City Pond, was expanded to store runoff from the City and portions of the upper watershed. A two-stage ditch was installed to mimic the conditions that exist within naturally flowing streams that limit in-channel sedimentation. A sediment trap was installed to create in-channel treatment of sediment by over digging portions of the ditch, allowing for sedimentation to occur. Overall, this improvement project provided storage and treatment for agricultural and urban runoff in an effort to improve drainage, water quality, and increase diverse habitat.

BUFFER STRIPS

Buffer strips play an important role along waterways by regulating surface flow, dissipating high water events, and stabilizing stream banks. County ditch systems in southern Minnesota, by design, are usually lacking buffers and therefore, are also lacking the functions that buffer strips provide. One-rod native grass buffer strips (*Figure 8*) were installed adjacent to the ditch along 4.1 miles (17 acres) of CD 57. Areas chosen for the installation of buffer strips include locations where buffer strips were not present, steeper bank slopes occurred, or where a large volume of surface flow occurs, overtopping ditch banks. These native grass buffer strips provide a means to stabilize the sediment and reduce erosion, sediment and nutrient loading, surface flow rates and direction.

KLEIN SURGE BASIN

The Klein surge basin (Klein Pond) covers 4 acres of land and has 26.3 acre-feet of storage. It is located north of Trunk Highway 30 (TH 30), west of the City of Mapleton. This location was chosen to provide adequate storage for the upper half of the watershed (1,700 acres) while protecting the downstream portions of the system from flooding. In general, this pond provides an area where excess water can be stored during high flow periods. The increase in water storage provided by the pond results in decreased peak flow rates and less flooding in CD 57 and downstream rivers (Big Cobb and Le Sueur rivers). With the increased holding capacity, the water has a longer residence time to allow for sedimentation of suspended solids. The pond also removes nutrient bound particles and improves water quality in the system. A photograph (*Figure 9*) shows the Klein Pond after a rain a 25-year rain event in 2013.

CITY POND: CITY OF MAPLETON'S STORMWATER POND EXPANSION

The city stormwater pond existed prior to this project and is owned by the City of Mapleton. The stormwater pond is located south of TH 30, southwest of the City of Mapleton. The city stormwater pond serves as a storage area for the majority of Mapleton's runoff (400 acres) and outlets into a tile in the CD 57 system. The stormwater pond was underutilized for storage during most minor rain events. The CD 57 improvement project expanded the original City stormwater pond into a larger pond by digging the basin deeper and wider, covering an area of 2 acres. The City Pond was designed based on Minnesota Pollution Control Agency's (MPCA) water quality standards which have been well studied for optimum pollutant removals. The outlet was modified to create a retention pond with a maintained water level, provided 11.5 acre-feet of wet storage. This provides additional water treatment and

Figure 10 - Inlet Structures to Klein Pond

Figure 11 - City Pond (Retention Pond) Under Normal Flow Conditions

storage by adding a skimming outlet to prevent suspended solids and debris from entering the CD 57 system. During rain events, the pond has the capacity of 23 acre-feet of storage. The City Pond has a similar purpose to the Klein Pond, but handles primarily municipal stormwater runoff with a small portion of agricultural land. A photograph (*Figure 11*) shows the City Pond under normal flow conditions.

TWO-STAGE DITCH

Two-stage ditches create a low-flow channel within a high-flow channel. Traditional ditches are overly large for low, perennial flows and have no floodplain for large flows (Ward & Mecklenburg 2004). A two-stage ditch allows for a smaller (inner) channel for low perennial flows and a wider (outer) channel (serving as a floodplain) for high flows (Ward & Mecklenburg 2004). The low-flow channel dimensions contain a 2 foot deep, 2 foot wide bottom and 4 foot wide top while the floodplain banks are 10 feet wide. The floodplain banks were planted with native buffers as well as a one-rod buffer strip along the upper banks, allowing for additional filtration and uptake of nutrients and sediment. The inner channel prevents the meandering capability of the ditch, thus attributes higher velocities for baseflows and prevents sediment from depositing in the main channel. This design mimics the conditions that exist within naturally flowing streams that limit in-channel sedimentation.

The two-stage ditch in CD57 includes 1,409 linear feet, treating 2,300 acres of runoff. It is located at the northwest corner of the City of Mapleton, west of Trunk Highway 22 (TH 22). This location was chosen for two reasons. First, new construction of either an open ditch or large tile was required to provide adequate drainage to the system. Since the new tile would be very large, it was more cost effective to construct an open ditch. Second, this location experiences more perennial flows from the City of Mapleton, Klein Pond, City Pond, and several tile branches that enter the ditch just upstream of this location. Therefore, this length of the ditch will more fully support the continuous flow needed to maintain fine sediment throughput and in-channel vegetation. The two-stage ditch is controlled by a 54-inch tile that connects the two-stage ditch to the open ditch on the east side of TH 22. A photograph (*Figure 12*) shows the two-stage ditch looking upstream towards the Klein Pond.

SEDIMENT TRAP

In addition to the two-stage ditch, a sediment trap (in-channel treatment) was constructed. This form of in-channel treatment provides an elongated linear sediment storage basin within the existing ditch channel. This section of ditch was over dug by approximately 3 feet to provide a wet sedimentation basin within the channel. The in-channel treatment includes 5,000 linear feet of ditch beginning south of TH 30 where the City Pond and mainline tile outlets into the open ditch. At this location, 1,600 acres of rural and urban runoff are treating. It then spans northeast through the Klein Pond and ends at the beginning of the two-stage ditch. This location was chosen since the area had historically high sediment transport in the ditch. A photograph (*Figure 13*) shows the overdug ditch downstream of the Klein Pond.

RATE CONTROL WEIR

The rate control weir was constructed near the outlet of CD 57, slightly upstream of the confluence with the Big Cobb River, north of County

Figure 12 - Two-Stage Ditch Looking Upstream

Figure 13 - Overdug Ditch Section

Figure 14 - Rate Control Weir After Rain Event

Highway 4. The purpose of this structure is to reduce the peak flow rates from the CD 57 system prior to discharging into the Big Cobb River. The weir reduces peak flow rates by creating a long linear pond within the open ditch, allowing sediment and nutrients to settle out of suspension. The concrete structure spans entirely across the open ditch with an 18-inch opening in the center of the ditch. The weir is 5 feet in height with the top of the weir at an elevation 1 foot lower than the lowest tile invert of the ditch. A photograph (*Figure 14*) shows the rate control weir storing water after a rain event.

MONITORING

THEORY

While water quality monitoring of Minnesota's rivers and stream networks is widespread and has covered many waterways over many years, water quality monitoring of Minnesota's public ditch systems is limited. Monitoring and analysis of an entire ditch system with multiple sample points throughout has not been completed in this region, therefore it is challenging to establish a monitoring scheme.

Although public ditch systems and river networks are different in terms of size, watershed, flow and many other attributes, they do share many similarities. Both rivers and ditches increase their flow as the contributing watershed increases. They both also have point sources that lead to an increase in flow. Both also have drastic changes in water flow rates and water quality during rain events as peak flow rates increase.

Since ditches and rivers share many similarities, the monitoring methods used in rivers were used as a baseline for monitoring the CD 57 system. Most rivers utilize stream gauging stations in which river stage, or depth is measured. The CD 57 system utilized a similar method at determining stage by utilizing data logging devices, which recorded pressure (depth) throughout the system. River monitoring for water chemistry utilizes grab samples with the majority of the samples collected during high flow periods. Sampling is important during high flows since they carry high sediment and nutrient loads (MPCA 2012). The assessment of water chemistry in CD 57 includes grab samples acquired during the peak flow after rain events and periodic baseflow samples. The results are used to compare the water quality prior to and following the implementation of the BMPs.

Several sites were chosen throughout the CD 57 watershed for monitoring. They include 12 sites where stages were recorded and 7 sites where water quality samples were obtained. While all 12 sites contain valuable information, the 7 sites that contain water quality sampling were locations deemed most useful for analysis. These 7 sites were selected based on their proximity to an installed BMP. The locations are either upstream or downstream of each BMP. This allowed for the best analysis to determine how effective each BMP was at reducing sediment and nutrient loading.

Sampling frequency also played a major role in the water chemistry monitoring. The Minnesota Pollution Control Agency (MPCA) uses one-half inch rainfall as a general guidance of a significant rain event to trigger stream monitoring. It was anticipated that infiltration would account for some of the runoff, thus one-inch rain events were chosen to trigger a sampling event for this project with multiple sampling events between 0.5 and 1 inch.

ISG, in conjunction with Minnesota State University's (MSU) departments of Civil and Mechanical Engineering and Chemistry and Geology collected and analyzed six years of water chemistry and stage data with three of these years occurring after the installation of the water quality BMPs. MSUs role over the course of the monitoring included the collection of both water quality and stage data that were subsequently transferred to ISG for analysis. Stage data were calibrated and adjusted based on the barometric pressure and was recorded monthly throughout the monitoring season. Continuously acquired precipitation and temperature data were also collected for all three years via a rain gauge sampler. The rain gauge data were compared to the estimated precipitation amounts listed on Minnesota Climatology Working Group and The Climate Corporation to validate the rainfall. The water quality, stage, and precipitation data were provided to ISG in raw data and calibrated data for use of analysis. ISG then provided a data analysis of the data for each monitoring season.

METHODOLOGY

Parameters

Parameters that were sampled and monitored in the CD 57 system are listed in *Table 1*.

Parameters were selected based on the information they provide on the water's overall quality. Each parameter is further described here:

PARAMETER	HOLDING TIME [1]	LIMIT [2]
Conductivity	N/A	1,000 µmhos/cm
Flow	N/A	N/A
pH	N/A	6.5 to 8.5
Temperature	N/A	≤90°F daily average or ≤5°F above natural, Class 2C waters
Total Dissolved Solids	N/A	500 mg/L
Dissolved Oxygen	N/A	Minimum of 5 mg/L daily average between April 1 - Nov. 30; Minimum of 4 mg/L at all other times
E. coli	6 hour, <24 hours	126 organisms/100mL geometric mean of not less than 5 samples in any calendar month; No more than 10% of all samples taken in a calendar month exceed 1,260 organisms/100mL
Nitrogen (Nitrate+Nitrate)	48 hours	10 mg/L
Ortho-Phosphate	48 hours	N/A
Total Phosphorus	48 hours	12 µg/L, Class 2A waters 30 µg/L, Class 2B, C
Total Suspended Solids	7 days	65 mn/L
Turbidity	24 hours	10 NTU, Class 2A waters 25 NTU, Class 2B, C, D waters

Table 1 - Water Quality Monitoring Parameters

[1](EPA 1997)
[2](Minnesota Office of the Revisor of Statutes 2012 (a))
N/A indicates the paameter is measured in the field immediately

Conductivity: As described by the EPA (1997), conductivity refers to the ability of water to pass an electrical current. Water with higher amounts of inorganic dissolved solids (chloride, nitrate, phosphate, sodium, calcium, aluminum, and other positive and negative ions) has greater conductivity (EPA 1997). Sewage can raise the conductivity due to the presence of chloride, phosphate, and nitrate (MPCA 2004). Streams that support good mixed fisheries have a range between 150 to 500 µmhos/cm (MPCA 2004). Conductivity outside this range could indicate water is not suitable for certain fish and/or macroinvertebrates (MPCA 2004).

Stage: A measurement of depth of water above the bottom of the ditch. This is measured by Onset Data logging devices that record pressure. Pressure is converted to depth by accounting for the water pressure about the data logging device and the air pressure of the ambient air.

Flow: A measurement used to record the water velocity over the area of water at a given time (Teledyne Isco 2009). This will give insight to water level and flow at the time of the sample. Water level loggers are inserted in stilling wells and continuously record mean water level through measuring the amount of pressure that is around the sensor. The water level can be converted to flow with the aid of survey data and a hydrologic/hydraulic model. CD 57 is extensively modeled due to the water quality features that were constructed. If the amount of water within the open channels, tile lines, or ponds is known, then the flow can be calculated based on pressure and water level. Flow is an important focus point for this project since flow aids in transporting nutrients and sediment downstream.

pH: Measures the relative alkalinity or acidity of the sample (EPA 1986). The pH scale ranges from 1 to 14 with low values considered acidic and higher values considered basic (EPA 1986). Because the pH scale is logarithmic, each one-unit change represents a 10-fold change in the acidity/basicity of the sample. Pollution can affect the pH of a waterbody, which can in turn, affect the solubility and availability of nutrients (MPCA 2004). Pollution, therefore, has an indirect influence on how nutrients can be utilized by aquatic biota (MnDNR 2010). Biota may also become stressed when the pH exceeds their tolerances, which can in turn affect the diversity of surface waters (MnDNR 2010). The state of Minnesota defines the range of pH for most Class 2 waters to be between 6.5 and 8.5 (Minnesota Office of the Revisor of Statutes 2012(a)). However, natural waters can exhibit a very broad range of pH values, such that those exceeding the standard range as a result of natural causes (e.g., bogs) may not necessarily be considered an exceedance (MPCA 2004).

Temperature: Measures how hot or cold the water is. It plays an important role in many physiological and chemical processes. As temperature increases, the oxygen levels within the water become lower (EPA 1986). Temperature also has an impact on the rate of photosynthesis, metabolic rates of organisms, and sensitivity of organisms to toxic wastes, parasites, and diseases (EPA 1986). Each organism has an optimal temperature and when the temperature of the surface water changes due to influences by stormwater, groundwater, or other inflows of water, the ability of organisms to persist in that system may be affected (MPCA 2004). Temperature ranges in this area for water are 90 degrees Fahrenheit or 5 degrees Fahrenheit of the natural temperature for that waterbody (Minnesota Office of the Revisor of Statutes 2012(a)).

Total Dissolved Solids: Measures of the amount of particulate solids that are in solution, passing through a 2-micron filter (measured in mg/L) (HCR 2010). Ions often found dissolved in surface water include calcium, magnesium, sodium, iron, manganese, bicarbonate, chloride, sulfate, nitrate, carbonate, and other ion particles that will pass through a filter (HCR 2010). The dissolved solids within the surface water are reflective of the surrounding geology and soils (HCR 2010). Urban and agriculture runoff as well as wastewater and septic system effluent and soil erosion can also contribute to higher amounts of these solids (HCR 2010). Aquatic biota requires a relatively constant concentration of the major dissolved ions in the water such that if dissolved solids become too high or too low, survival, growth and reproduction are affected (Anderson et al. 1996). Dissolved solids can also absorb sunlight and increase the temperature of the surface water, in turn affecting the dissolved oxygen in the water (Anderson et al. 1996). The standard for Class 1B, 1C, 2A, 2B, and 2C waters is 500mg/L (Minnesota Office of the Revisor of Statutes 2012(a)).

Dissolved Oxygen: The amount of oxygen dissolved in the water column (measured in mg/L) (HCR 2010). Water's ability to maintain oxygen in solution is inversely proportional to the temperature of the water (EPA 1986; HCR 2010). For Class 2C waters in Minnesota, the standard minimum daily average is 5 mg/L between April 1 through November 30 and the daily minimum is less than 4.0 mg/L at all other times (Minnesota Office of the Revisor of Statutes 2012(a)). Dissolved oxygen is important for organisms inhabiting the area. Low dissolved oxygen reading can indicate high sediment loads (suspended and dissolved solids) or low productivity (Anderson et al. 1996; Gumbricht 2003). Oxygen is a necessary element to all forms of life. Once oxygen levels drop below 5mg/L, aquatic biota become stressed and oxygen levels below 1 to 2 mg/L for a few hours can lead to fish kills (species dependent) (MPCA 2004).

E. coli: A single species in the fecal coliform group and is used as an indicator of human or animal waste presence (EPA 2010). For Class 2A, B, and C waters in Minnesota, the standard is "not to exceed 126 organisms per 100 milliliters as a geometric mean of not less than five samples representative of conditions within any calendar month, nor shall more than ten percent of all samples taken during any calendar month individually exceed 1,260 organisms per 100 milliliters. The standard applies only between April 1 and October 31 (Minnesota Office of the Revisor of Statutes 2012(a)).

Nitrate + Nitrite: Derived from ammonia when it is broken down by bacteria (Carpenter 1983). Nitrite is formed initially and is then converted to the more stable and less toxic nitrate (Carpenter 1983). Nitrate typically occurs in low natural levels within surface waters; however, it is supplemented with nitrate from human-derived sources (Carpenter 1983). Excessive amounts of nitrate within water bodies are generated from the fertilizer applied to agricultural fields, grass clippings from lawns, and from wastewater discharge or runoff from feedlots (HCR 2010). Once in the water, nitrates can stimulate plant and algae growth, which can deplete the water of dissolved oxygen, adversely impacting fish and other aquatic biota (HCR 2010). Nitrate is regulated to protect human health as well as aquatic environments (MPCA 2004). The MPCA uses the EPA limits of 10 mg/L and 1.0 mg/L for nitrate and nitrite, respectively, in drinking water supplies (MPCA 2004). 10mg/L of total nitrates is the limit for Class 1B, 1C, 2A, 2B, 2C, and 4A waters (Minnesota Office of the Revisor of Statutes 2012(a)).

Ortho-phosphate: The phosphate molecule itself (the biologically available phosphorus) (HCR 2010). It is soluble and can be taken up readily by organisms. Sources of orthophosphate include sewage, runoff from agricultural industries, and fertilizer application on lawns (HCR 2010). Excessive amounts of ortho-phosphate can lead to extensive algal blooms and eutrophication (Carpenter 1983; HCR 2010).

Total Phosphorus: A measure of all forms of phosphorus in the sample (orthophosphate, condensed phosphate, and organic phosphate; biologically available and bound phosphorus) (Carpenter 1983). Phosphorus is a concern because it is in limited supply in surface waters so that even a modest increase can stimulate the growth of plants and algae (Carpenter 1983). Excessive algae growth, death, and decay can reduce the amount of dissolved oxygen available for other aquatic biota, endangering fish and other forms of aquatic life, along with out-competing native vegetation (Carpenter 1983). Sources of phosphorus include agricultural land, lawn fertilizers, erosion containing soil-bound phosphorus, yard waste, runoff from animal feedlots, stormwater, and certain industrial wastewaters (HCR 2010). To prevent eutrophication in Class 2B and C waters in Minnesota, total phosphorus standard limits are 30 μg/L (Minnesota Office of the Revisor of Statutes 2012(a)).

Total Suspended Solids: Consists of silt and clay particles, plankton, algae, fine organic debris, and other particulate matter that will not pass through a 2-micron filter (EPA 1997). These are generated from point (e.g. sanitary wastewater) and non-point sources (e.g. erosion from agriculture) (HCR 2010). Excess suspended solids within the water column decrease water clarity and increase water temperature by absorbing heat from the sun (Anderson et al. 1983; HCR 2010). In turn a raise in temperature affects the amount of oxygen dissolved in the water (EPA 1986). Excess suspended solids can clog the gills of fish, affecting growth rates and disease susceptibility, and smother fish eggs and other benthic biota (Anderson et al.1983). The water quality standard in Minnesota for Class 2 waters is 65 mg/L (Minnesota Office of the Revisor of Statutes 2012(a)).

Turbidity: A measure of water clarity, which is affected by suspended solids (HCR 2010). Suspended solids including clay, silt, inorganic and organic matter, and other compounds within the water column scatter light leading to higher values of turbidity (HCR 2010). Stormwater pollution, construction, active mining, and other similar activities can produce sediment that raises the turbidity of water (HCR 2010). For Class 2A waters in Minnesota, the existing turbidity water quality standard generally has a statewide value of 10 NTU (Nephelometric Turbidity Units) and 25 NTU for Class 2B, C, and D waters (Minnesota Office of the Revisor of Statutes 2012(a)). Turbidity values that exceed the standard can harm aquatic life by affecting foraging, gill function, and spawning beds (MPCA 2004).

The parameters described below were examined and determined to be unnecessary for sample analysis due to the information was either already provided from the above list of parameters or not relevant to the study. These parameters, therefore, will not be sampled or analyzed in this project.

Fecal Coliform: A group of bacteria that are used as an indicator of sewage contamination because they are found in human fecal matter (EPA 1997). Fecal coliform bacteria are not harmful to humans, but when present, may indicate the presence of disease carrying organisms which live in the same environment as the fecal coliform bacteria (EPA 2010). Sources of fecal contamination to surface waters include wastewater treatment plants, on-site septic systems, domestic and wild animal manure, and storm runoff (EPA 2010). In addition to bacteria and other pathogens, human and animal wastes contain high levels of other pollutants such as phosphorus, nitrogen, and oxygen demanding organic material (EPA 2010). A fecal coliform reading is expressed as the number of organisms per 100 mL (#/100mL). Minnesota's water quality standard for fecal coliform bacteria is not more than 200 fecal coliform colonies per 100 mL (Minnesota Office of the Revisor of Statutes 2012(a)). E. coli is one form/species of fecal coliform, therefore, both are not needed. Fecal coliform was eliminated from analysis in the post water quality improvement features monitoring since the local waters had impairments. The Cobb River has an E. coli impairment and CD 57 discharges into the Cobb River (MPCA 2010).

Suspended Volatile Solids: Solids lost on ignition (550°C), which provides a rough estimate as to the amount of organic matter (algae) within the waterbody (HCR 2010). Higher levels of organic matter lead to higher levels of turbidity (HCR 2010). Turbidity and total suspended solids are already being measured, thus suspended volatile solids were eliminated from the monitoring parameter list.

Post-BMP Installation Monitoring Methods

Following installation of the BMPs (fall 2011), all monitoring was performed by MSU's departments of Civil and Mechanical Engineering

Figure 15 - MSU Students Taking Water Quality Grab Samples

Figure 16 - MSU Students Performing Instrumental Readings

and Chemistry and Geology (2012-2014). Water samples in the open ditch were measured and collected from the thalweg. Water grab samples were collected via a sampling rod or taken from the ditch. The container was filled by placing the container in the upstream direction (into the flow) without touching the bottom of the pipe/ditch channel to avoid stirring up sediment and debris (*Figure 15*). The sampling bottles were clean and sterile. Water grab samples were collected for E. coli (in April and October only), nitrogen (nitrate + nitrite), total phosphorus, ortho-phosphate, total dissolved solids, and total suspended solids. After collection, bottles were placed in a cooler with ice to keep samples at or below 4°C and were transported to MSU's laboratory immediately after the sampling event for immediate analysis or transfer to MVTL for further analyses.

Field water quality measurements (pH, temperature, conductivity, dissolved oxygen, turbidity, and transparency tube) were collected and recorded at the site using a variety of instruments including Hanna Instruments HI 98129 and Hydrolab DS5 multi-probe sensors, Hanna HI 9142 Dissolved Oxygen Meter, and LaMotte 2020we/wi and YSI 600OMS turbidmeters. All probes were calibrated the day of sampling, before sampling begins. The probe was held at an intermediate depth in the water column without disturbing substrate materials and remained there until the probe had stabilized the reading. *Figure 16* shows MSU students taking instrument readings for the aforementioned parameters.

Locations

Pre-BMP Installation Monitoring Locations

There were three sites (1, 2A, and 2B) monitored prior to the installation of the water quality BMPs. These sites were used to measure flow and grab samples. Site 1 was located near the outlet of the CD 57 system near the Big Cobb River, corresponding to rate control weir location. Site 2A was located toward the northern end of the existing open ditch immediately upstream of the existing tile, which connected the open ditch sections split by TH 22. This location corresponds to the beginning of the two-stage ditch after its installation. Site 2B was located in the open ditch just north of TH 30. This site is located upstream of the Klein Pond. *Figure 17* shows the 3 pre-BMP installation monitoring locations throughout the CD 57 Watershed.

Post-BMP Installation Monitoring Locations

There are 12 post-BMP installation monitoring locations throughout the CD 57 system (*Figure 18*). These locations are generally located before and after the BMP improvements. Site 1 is located at the outlet of the system in the open ditch while Site 12 is located in a tile main at the upper end of the watershed. Post-installation monitoring Sites 1, 4, and 7 are located relatively close to the location of the pre-installation monitoring Sites 1, 2A, and 2B respectively. The post-installation monitoring locations will provide information on the effectiveness of each water quality BMP. All sample locations have a GPS coordinate to assure samples are taken at the same location throughout monitoring. All 12 locations had data logging devices installed which record stage, or the depth of water throughout the system. Of the 12 locations, 7 were selected as water quality locations for grab samples and instrument readings

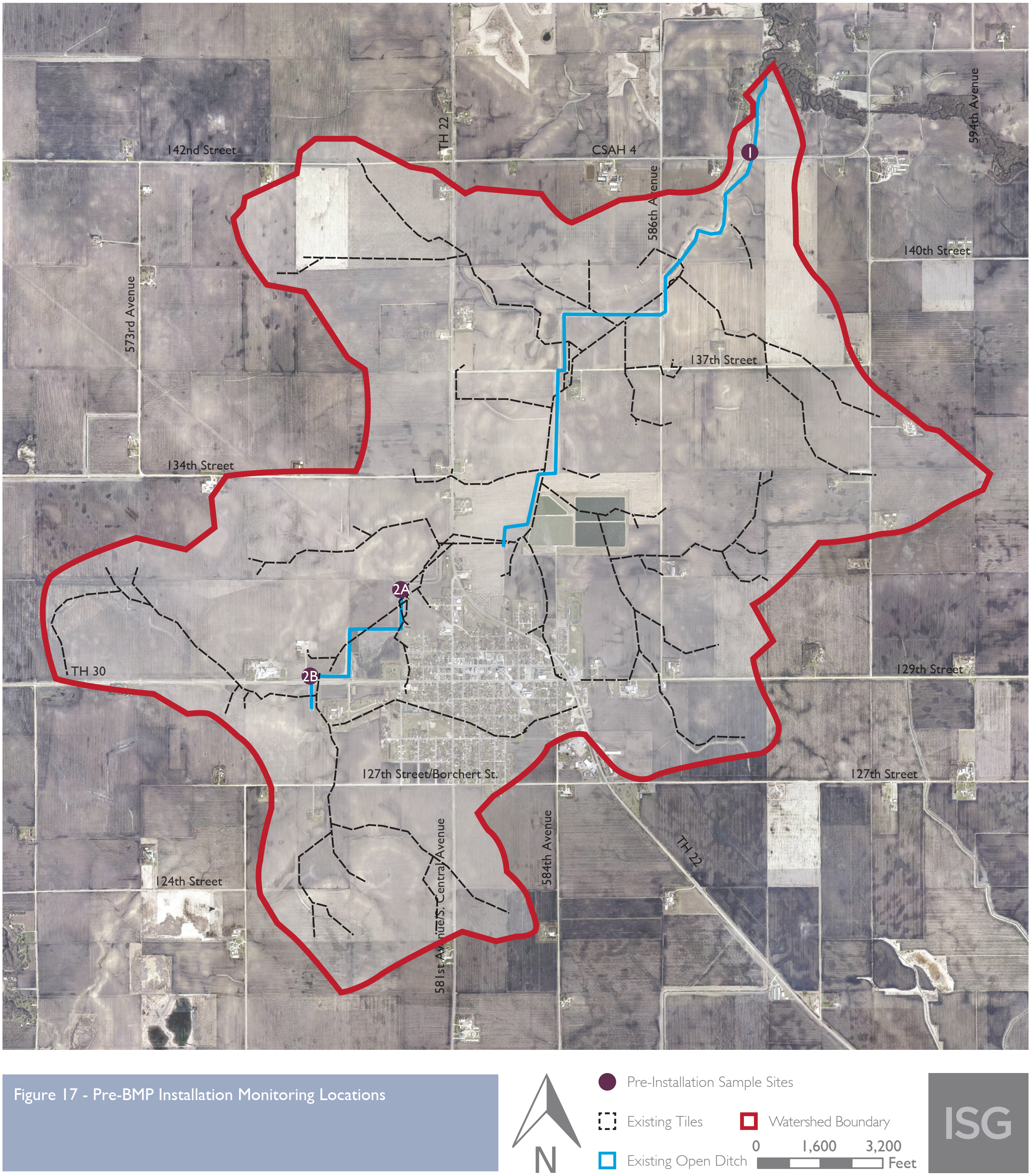


Figure 17 - Pre-BMP Installation Monitoring Locations

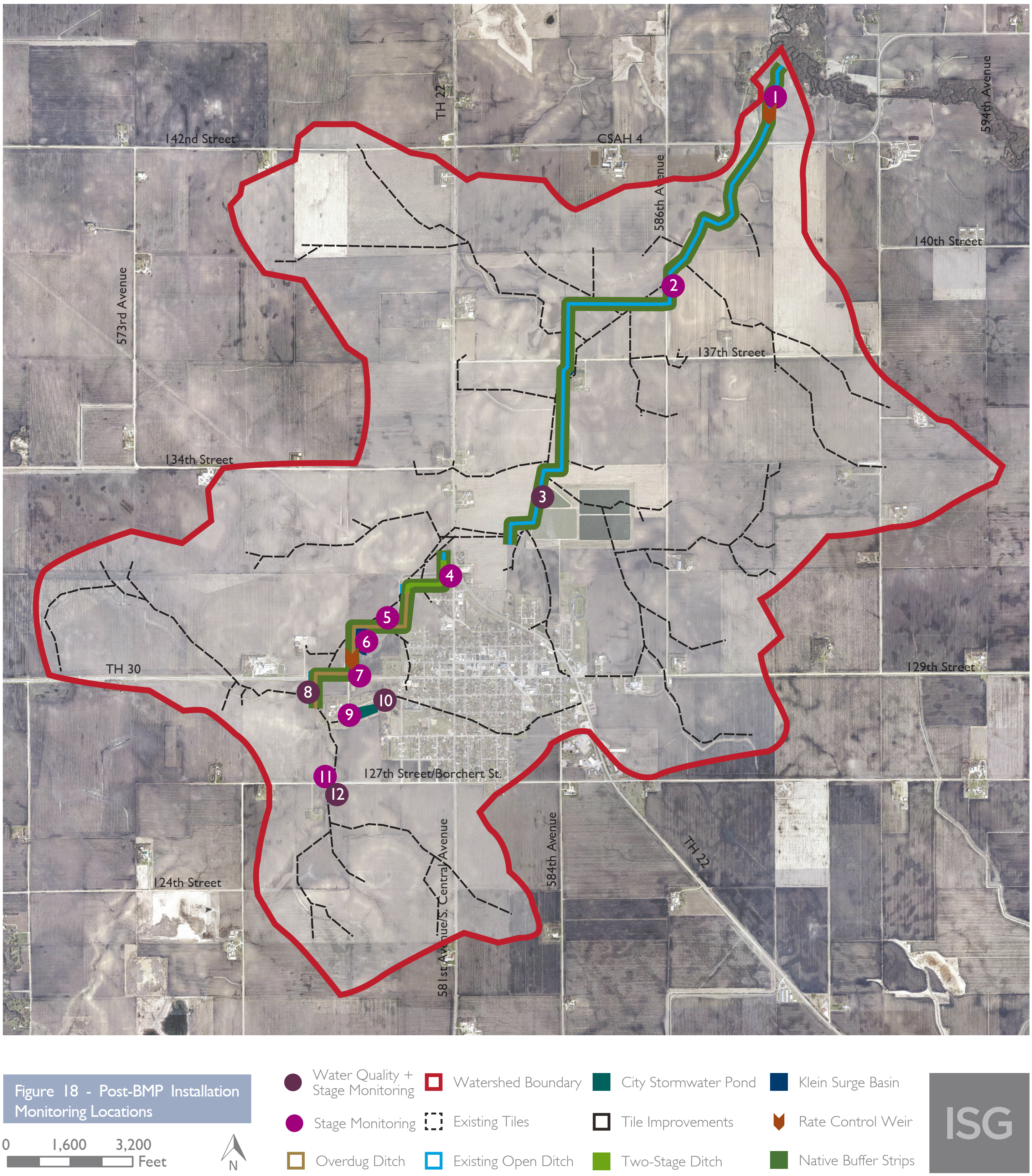


Figure 18 - Post-BMP Installation Monitoring Locations

MONITORING LOCATION ID	WATER QUALITY STRUCTURE/ MONITORING LOCATION	SAMPLING FORM	STAGE MEASURED	WATER QUALITY SAMPLED
1	Rate Control Weir/System Outlet	Concrete Weir	●	●
2	Native Grass Buffer Strips/Downstream Open Ditch	Open Ditch	●	●
3	City Wastewater Ponds	Open Ditch	●	
4	Two-Stage Ditch/End Two-Stage Ditch	Open Ditch	●	●
5	Downstream Klein Pond/Upstream Two-Stage Ditch	Open Ditch	●	●
6	Klein Surge Pond	Sediment Trap in Klein Pond	●	
7	Upstream of Klein Pond	Diversion Weir	●	●
8	Beginning of Open Ditch	Open Ditch	●	●
9	Outlet to the City Stormwater Pond	Manhole	●	●
10	City Stormwater Pond	Middle of City Pond	●	
11	Upper Watershed - Old Tile Main	Road Ditch Drop Intake	●	
12	Upper Watershed - New Tile Main	Road Ditch Drop Intake	●	●

Table 2 - Monitoring Activity Summary

SITE	TOTAL SUSPENDED SOLIDS CONCENTRATION (mg/L)	TOTAL DISSOLVED SOLIDS (mg/L)	TOTAL PHOSPHORUS (mg/L)	ORTHO-PHOSPHORUS (mg/L)	NITRATE (mg/L)	NITRITE (mg/L)
12	13.2	341	0.480	0.134	46.8	0.000
9	110.0	247	0.473	0.236	9.4	0.092
8	6.8	313	0.377	0.221	33.2	0.036
5	14.8	276	0.435	0.295	22.4	0.064
4	14.0	271	0.412	0.314	21.4	0.063
2	32.8	277	0.444	0.283	23.1	0.092
1	30.0	295	0.393	0.301	25.4	0.071

Table 3 - Water Chemistry Grab Sample for July 9, 2013

Frequency

Pre-Installation Monitoring Frequency

Monitoring events occurred from March, or ice-out, through October from 2009 to 2011. The majority of the samples taken were during baseflow conditions. Flow data was collected using pygmy-flow instruments during baseflow conditions since conditions were unsafe in the ditch to use this equipment after rain events.

Post-Installation Monitoring Frequency

Water quality samples were collected from 2012 through 2014 after the BMPs installations were completed. Sampling occurred from March, or after ice-out through October of each year. Baseflow samples of flow and water quality were taken once a month for quality assurance and calibration purposes. Samples were also taken within 24-hours of a 1-inch or greater rainfall event throughout the monitoring season. Stage data were collected in 12 sites throughout the watershed by utilizing Hoboware Data logging devices that record atmospheric and hydrostatic pressure. These pressure data can then be converted to stage (depth), and incorporated into the hydrologic/hydraulic model to develop flowrates.

RESULTS

Results for water chemistry for all sampled rain events were tabulated for each site and parameter. *Tables 3* and *4* show an example of the raw water quality sampling for a July 9, 2013 rain event in which a rain event of 1.29 inches fell for a duration of 1 hour.

Recorded depths via the installed data logging devices were also tabulated for each site, date and time, and depth. This depth was used in conjunction with survey data acquired during site visits to convert

SITE	TEMPERATURE (°C)	pH	DISSOLVED OXYGEN (mg/L)	SPECIFIC CONDUCTIVITY (µS/cm)	TURBIDITY (NTU)	T-TUBE (cm)
12	17.36	6.70	8.47	750.6	5.5	60.0
9	23.15	7.41	7.39	536.8	13.9	28.2
8	19.89	6.83	7.33	665.4	12.7	34.2
5	21.60	6.86	6.73	587.0	26.2	19.1
4	21.59	6.88	6.66	588.1	25.6	26.8
2	20.77	6.73	6.28	592.5	43.6	11.0
1	19.95	6.91	6.91	630.7	38.7	13.0

Table 4 - Sonde Instrument Reading for July 9, 2013

TIME	RECORDED DEPTH	TIME	RECORDED DEPTH	TIME	RECORDED DEPTH
7:00	3.656	9:15	4.479	11:30	6.149
7:05	3.677	9:20	4.545	11:35	6.210
7:10	3.677	9:25	4.646	11:40	6.235
7:15	3.685	9:30	4.693	11:45	6.297
7:20	3.707	9:35	4.764	11:50	6.325
7:25	3.697	9:40	4.821	11:55	6.364
7:30	3.685	9:45	4.899	12:00	6.404
7:35	3.679	9:50	4.967	12:05	6.434
7:40	3.712	9:55	5.046	12:10	6.513
7:45	3.763	10:00	5.105	12:15	6.530
7:50	3.803	10:05	5.162	12:20	6.559
7:55	3.826	10:10	5.241	12:25	6.600
8:00	3.868	10:15	5.300	12:30	6.618
8:05	3.910	10:20	5.368	12:35	6.638
8:10	3.954	10:25	5.427	12:40	6.669
8:15	4.024	10:30	5.475	12:45	6.669
8:20	4.046	10:35	5.556	12:50	6.730
8:25	4.065	10:40	5.615	12:55	6.727
8:30	4.099	10:45	5.662	13:00	6.759
8:35	4.096	10:50	5.744	13:05	6.756
8:40	4.105	10:55	5.744	13:10	6.789
8:45	4.137	11:00	5.789	13:15	6.809
8:50	4.161	11:05	5.871	13:20	6.831
8:55	4.240	11:10	5.930	13:25	6.840
9:00	4.321	11:15	5.990	13:30	6.850
9:05	4.323	11:20	6.050	13:35	6.851
9:10	4.392	11:25	6.099	13:40	6.861

Table 5 - Recorded Depth of Water at Site 1 for July 9, 2013

it to an elevation of the flow line of water. This information was then used to calculate the flow rate, as described in the **Flow Section, Page 19**. *Table 5* shows a portion of recorded depth data for Site 1 on July 9, 2013, during a rain event reflecting an increase in depth.

ANALYSIS

Water chemistry samples were tabulated similarly to *Tables 3 and 4* for all six years of monitoring for the parameters described. Stage data for years 2012 through 2014 was also tabulated in the same format as *Table 5* and was then used to quantify flow. These data were then used for analysis by ISG for various assessments of storage and treatment, BMP reductions, pre- and post-BMP installation watershed hydraulics characterization, seasonal variations, and comparison to MPCA standards.

Compliance with this procedure was maintained and checked a minimum of twice a year throughout the monitoring time period. In addition to adhering to the specific requirements of this Water Quality Sampling and Monitoring Work Plan, the minimum Quality Assurance & Quality Control for this project was as follows:

Water samples

Quality assurances were provided to assure data users that quality control activities were implemented and that data of known quality were being generated. For this project, water quality samples were delivered to MVTL's laboratory in New Ulm, MN and MSU laboratory in Mankato, MN by field technicians. A sample submission sheet, provided by MVTL and MSU, was included for each sample sent to MVTL and MSU for analysis. This submission sheet contained all relevant information about the sample, including collector, date, time, location, and method of preservation (if needed). When samples were forwarded to MVTL, a chain-of-custody was also submitted with the samples. The chain-of-custody references the sample and allows that sample to be traced back to its collection. It documents the possession of the samples

Figure 19 - Photo Validating Data logging device Depth for Water Overtopping of Rate Control Weir

from the time they were collected until the sample analytical results were received. All water samples were maintained as close to sampling conditions as possible. Samples were preserved and stored in a cooler with ice (temperature of around °C) during transport to the MVTL's and MSU's facilities. Samples are transported to MVTL and MSU on the same day as collected to minimize holding times.

Laboratory
Field duplicate samples were taken at 10 percent of all sampling sites to guarantee MSU's and MVTL's data analysis. Blank samples consisting of distilled water were also sent to MVTL and MSU with site identification on the bottle (blind sample) to confirm the accuracy of MVTL's and MSU's data analyses.

Data Logging Devices & Onset Cameras
Data from the Hoboware data logging devices were transferred monthly from 2012 to 2014. At this time, the condition of the staff gauge in which the data logging device was mounted was verified and adjusted if damaged. Also at this time, a manual reading of the water depth was recorded as well as the elevation at which the data logging device was placed. This reading was used to manually adjust the water elevation of the collected data as necessary.

Photos from the onset cameras were also transferred monthly and the cameras were adjusted as necessary. The photos taken of the staff gauge and data logging device were also used to manually adjust the elevation of the collected data as necessary. *Figure 19* shows a photo from the July 9, 2013 rain event at the rate control weir. This photo was used to compare the depth recorded by the data logging device to insure that at this depth, the water level overtopped the weir. This process was used as necessary for all rain events to further insure the depth recorded by the data logging device.

PRECIPITATION

THEORY
Precipitation plays a major role in water quality monitoring and the need for accurate data is essential to determine rainfall, frequency, runoff depth, and surface flow. Most stream and river monitoring uses rain gauge stations that are placed in the surrounding area and are used to interpolate precipitation data throughout the watershed (MPCA 2012). This method is useful for interpolating precipitation on a large watershed scale; however, it may not be as accurate on a small watershed level like the CD 57 System. These rain gauge stations are established by the Minnesota Climatology Working Group through the Minnesota DNR.

Interpolating between nearby rain gauge stations for the CD 57 monitoring was not practical for analysis since the nearest rain gauge stations were over 10 miles away from the watershed. In lieu of using these rain gauge stations, a rain gauge was station was set up in the CD 57 watershed as part of the monitoring. This rain gauge was placed near the middle portion of the watershed in an attempt to depict the precipitation as accurately as possible for the entire watershed.

METHODOLOGY
The rain gauge station is located one half mile west of the Klein Pond that was utilized to measure amount and timing of rainfall to the nearest one hundredth of an inch. This gauge was an Onset® RG3 Data Logging Rain Gauge (*Figure 20*) which provided information on the precipitation of the project area. This rain gauge includes a HOBO® Pendant Event data logging device that records rainfall data to determine rainfall rates, times, and duration. The rain gauge recorded precipitation to the nearest hundredth of an inch for any duration of a rain event. Data from the HOBO® Pendant Event data logging device was downloaded to a computer at the same time stage data was collected.

RESULTS
As mentioned previously, post-BMP installation water quality sampling was based on rain events greater than 1-inch. This monitoring frequency was done for all three years of post-BMP installation water quality monitoring. *Figures 21-23* show the date of the rain events in which water sampling occurred for the 2012, 2013, and 2014 monitoring years.

Based on the rainfall events monitored, 2013 had the most water quality samples (8), followed by 2014 (7), followed by 2012 (4). *Figure 24* shows all water quality monitored events over the 3-year period.

Figure 20 - Onset® RG3 Data Logging Rain Gauge

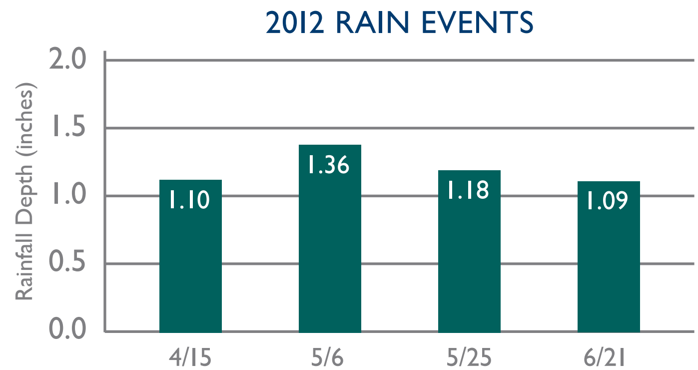


Figure 21 - 2012 Monitored Rain Events

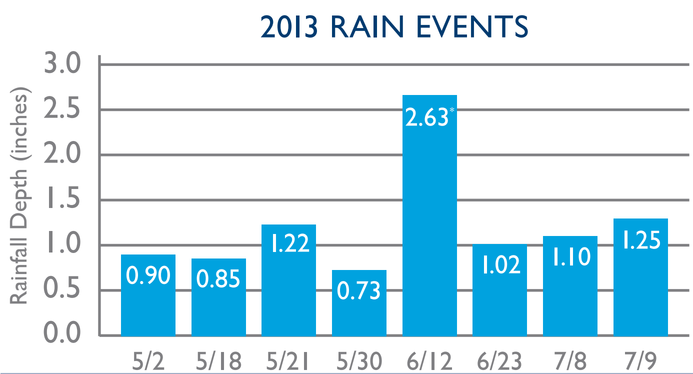


Figure 22 - 2013 Monitored Rain Events
(*NOAA 25-Year Recurrence Interval)

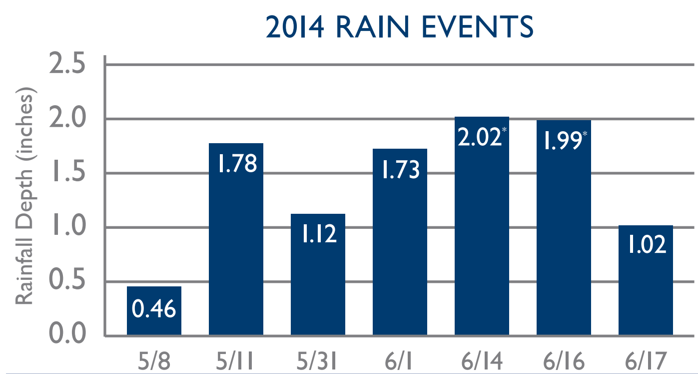


Figure 23 - 2014 Monitored Rain Events
(*NOAA 10-Year Recurrence Interval)

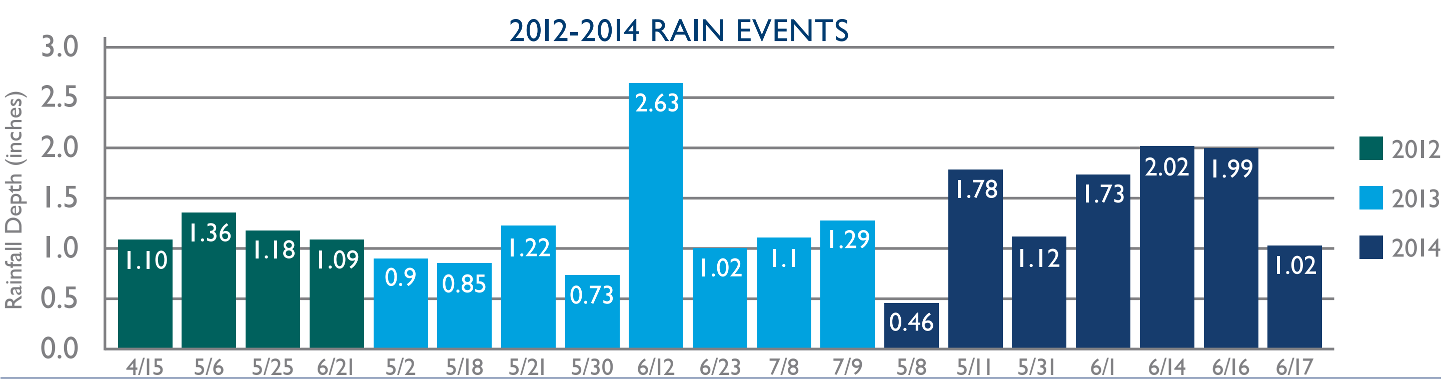


Figure 24 - All Monitored Rain Event

DATE	ONSET® RG3	MN CLIMATOLOGY WORKING GROUP	THE CLIMATE CORPORATION
4/15/12	1.10	1.10	1.11
5/6/12	1.36	1.46	1.56
5/25/12	1.18	1.30	1.24
6/21/12	1.09	1.12	1.08
5/2/13	0.90	0.97	0.79
5/18/13	0.85	0.81	0.80
5/21/13	1.22	0.97	1.20
5/30/13	0.73	0.85	0.64
6/12/13	2.63	2.47	2.67
6/23/13	1.02	0.86	1.19
7/8/13	1.10	1.04	0.97
7/9/13	1.29	1.24	1.21
5/8/14	0.46	0.42	0.58
5/11/14	1.78	1.80	1.70
5/31/14	1.12	1.41	0.95
6/1/14	1.73	1.50	1.76
6/14/14	2.02	1.71	2.05
6/16/14	1.99	2.75	1.94
6/17/14	1.02	0.86	0.99

Table 6 - Rainfall Comparison of Sources Measuring Rainfall

YEAR	DEPTH SAMPLED (in)	TOTAL GROWING SEASON RAINFALL (in)	PERCENT SAMPLED (%)
2012	4.73	13.89	34.0
2013	9.74	21.11	46.1
2014	10.12	20.44	49.5
Total	24.59	55.44	44.4

Table 7 - Sample Rainfall Compared to Growing Season Rainfall

ANALYSIS

In order to validate the precipitation recorded by the Onset rain gauge, a comparison to other records of precipitation generated by radar and state rain gauges was performed. The two other sources used for precipitation comparison are the Minnesota Climatology Working Group and the Climate Corporation. *Table 6* shows this comparison.

Using the rain gauge data for each year, the total rainfall amount for the growing season (April-August) was added and compared to the amount of rainfall that was sampled (1-inch rain events). *Table 7* shows this comparison.

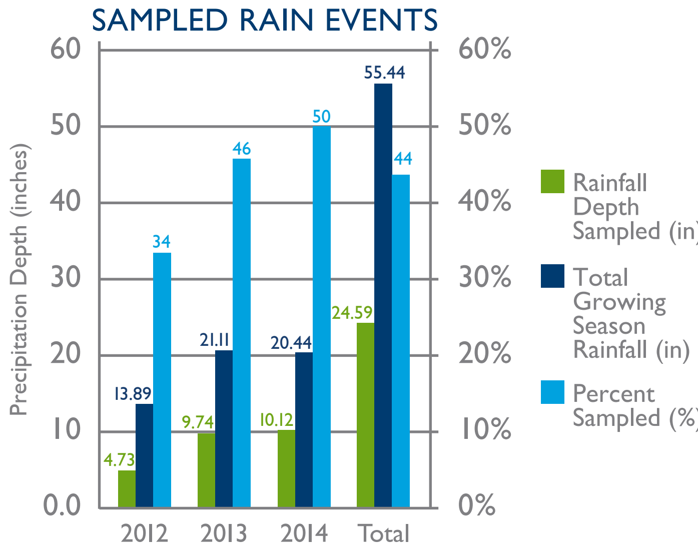


Figure 25 - Sampled Rain Events and Total Precipitation

Figure 25 shows a comparison of all three years of recorded precipitation and sampled events. As shown, overall 44 percent of the rainfall was sampled for water quality analysis.

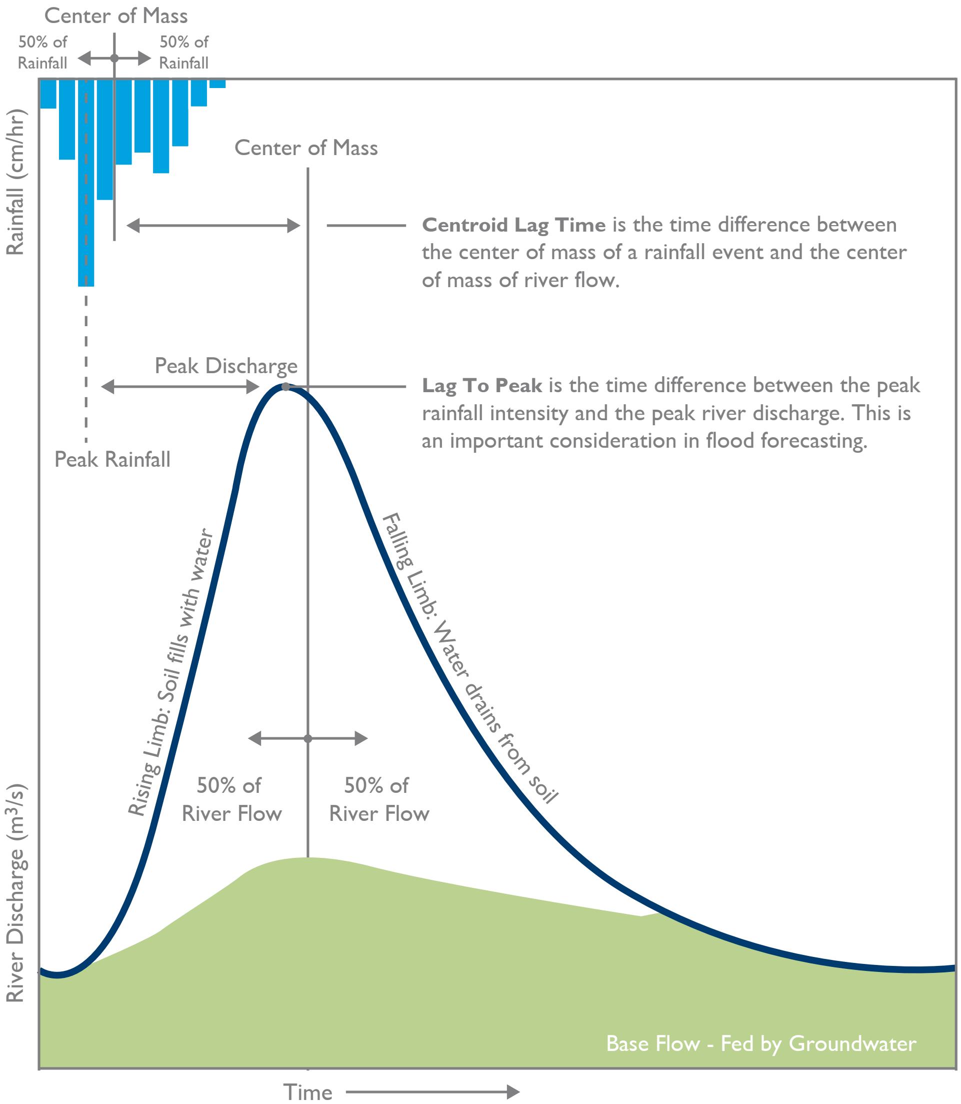
FLOW

THEORY

Flow is defined as the volume of water in either a pipe or open channel that passes a certain point per a unit of time. This is typically referred to as the flow in cubic feet per second (cfs) at a certain point. Flow is a valuable parameter to measure for any monitoring system because it provides the perspective of how much water is moving through the system and is used for the analysis of the following:

- Peak flow rate, or highest flow through the system
- Time and duration of flow
- Comparison to rainfall and runoff
- Total flow volume
- Determine of total loading of water chemistry

Flow for a river, stream, ditch, or tile is often described through a hydrograph. A hydrograph is a graph that compares precipitation, runoff, and time for a rain event. *Figure 26* shows a typical hydrograph.



During a **rainfall event**, the intensity at which precipitation falls on a landscape is often variable. The **peak rainfall**, a measure of the greatest intensity of rainfall, does not necessarily occur in the middle of a rainfall event. Therefore, the peak and the **center of mass** of rainfall (the point at which half of the total rainfall has fallen) often do not correspond.

As precipitation falls across a landscape, some **infiltrates** the soil and some **runs off** and enters river channels causing discharge and river stage to rise. As the soil fills with water, more precipitation enters river channels as runoff, groundwater flow and subsurface stormflow. Stage rises until reaching the **peak**, or maximum discharge resulting from a rainfall event. As water drains from soils and from the landscape, the river stage begins to fall, eventually returning to **base flow**, which reflects normal groundwater discharge to rivers in humid regions.

Figure 26 - Typical Hydrograph - Source: Dunne, Thomas and Leopold

As shown, after rainfall fills the soil profile to a point of saturation, the remainder of the rainfall runs off the landscape. Over time, the discharge risers until the precipitation ends, thus minimizing the runoff from the landscape.

A hydrograph analysis can be used for the following analyses:

- Determining peak flow rates for a rain event
- Determining the duration of a rain event
- Comparing discharge to precipitation
- Determining total volume of runoff for a rain event by calculating the area under the hydrograph curve

METHODOLOGY

Quantifying real time flow values is a difficult process. Real time flow measuring devices are more accurate at quantifying flow because they are physically placed in the line of flow and instantaneously record the flow passing the device. While these devices provide accurate flow data, they are also very expensive and require routine maintenance. Budgeting

Figure 27 - Hobo Data Logging Device (left) and Staff Gague with slotted PVC (behind) for data logging devices

Figure 28 - Camera, Staff Gague, and Data Logging Device Setup for Site 5

for these devices for all the required monitoring locations proved to be infeasible and outside of the project budget. Therefore, alternative methods were used for the CD 57 flow monitoring.

While real time flow measurements were not part of the monitoring of the CD 57 ditch system, real time data logging devices used to measure pressure were installed. These devices recorded stage (depth) measurements and were recorded every five minutes at each monitoring site throughout the watershed. Stage data were obtained at every site using Onset® HOBO U20 Water Level Loggers. Onset® HOBO U20 Water Level Logger Systems were installed in March every year or after ice out and remained deployed through October. A data logging device was stationed above the water level to record the barometric pressure to correct the water levels for atmospheric pressure. For quality assurance and quality control purposes, the water level was manually measured via a calibrated staff gauge when sampling was conducted. *Figure 27* shows the data logging devices and staff gauges used to monitor stage.

To insure the accuracy of the data logging devices, staff gauges with on-site automatic cameras were installed at non-manhole monitoring locations (Sites 1, 2, 3, 4, 5, 6, 7, 8, & 10). The on-site cameras were set to capture pictures every five minutes (the same setting as the water level loggers) so the stage of the ditch can be verified with pictures of the staff gauge and water level from the on-site cameras. ISG also performed yearly topographic surveys of the subject area to identify the horizontal and vertical locations of the monitoring equipment as well as changes to the cross sections of the ditch. *Figure 28* shows the camera, staff gauge, and data logging device setup for Site 5.

Although stage measurements do not directly measure flow rates through the system, depth can be used in conjunction with survey data, a hydrologic/hydraulic model, and Manning's equation for flow to quantify flow. *Equation 1* - Manning's equation for flow is as follows:

Equation 1

$$Q = \frac{1.49}{n} * R^{\frac{2}{3}} * S^{\frac{1}{2}}$$

- Q = flow rate
- n = roughness coefficient of media in which the flow passes over
- A = area of water in which the flow passes
- R = hydraulic radius of the flow area (area/wetted perimeter of flow)
- S = slope of the bed in which the flow passes

The only unknown in this equation from the CD 57 monitoring is flow (Q). Stage data can be used in conjunction with survey data to determine the area of flow (A), wetted perimeter of the flow area, thus hydraulic radius (R), and slope of the bed (S). Therefore, flow was approximated for each monitoring station.

A hydrologic/hydraulic model was also created for this watershed using HydroCAD, software which incorporates modeling of watersheds, open channels, pipe networks, and stormwater ponds. This model was developed using detailed survey, soil, land use, and landscape data from the watershed. The model was then calibrated from various rain events to match runoff hydrographs for elevation. This method was used since elevation depths of the runoff are well documented by the data logging devices.

After the hydrologic/hydraulic model was developed, it was used for:

- Comparing flow rates to those calculated by Manning's equation for flow
- Comparing flow volumes of each rain event
- Comparing runoff amounts for each rain event
- Calculating flow rates and runoffs of rain events where missing data occurred

Flow was also measured monthly via a tracer dye test to ensure accuracy in the calculated flow from measurements from the data logging devices and staff gauges. Methodology described in *Field Techniques for Estimating Water Fluxes between Surface Water and Ground Water* (LaBough & Rosenberry) were used when flow was measured utilizing a tracer dye test. A measuring tape was spread out for 100 meters along the ditch with the flow monitoring location in the middle. A tracer dye (fluorescent salt solution with a higher known conductivity) was dumped into the ditch. The amount of time required for the dye to travel 100 meters was recorded utilizing conductivity meter. Time is recorded when 20, 60, and 80 percent of the dye reaches the 100 meter mark (LaBough & Rosenberry). The velocity was then converted to flow based on the area the dye traveled.

These methods have underlying inconsistencies, primarily due to backwater effects from the Big Cobb River, culvert and field crossings, and added storage through ponds and restricted outlets. Therefore, flow using these methods must be verified by using alternative hydrological methods. These methods include comparing peak flow rates, accumulated flow volumes, and rainfall and runoff amounts. These comparisons are made in the following **Sections: Peak Flows, Flow Volume and Runoff**.

RESULTS

Utilizing Manning's equation, approximate flow rates for all three years were calculated based on the recorded depth from the data logging devices. The following example calculation is from the July 9, 2013 rain event. After rain began to fall and water ran off into the ditch, a depth

Figure 29 - 2.56 Foot Water Depth at Site 2

of 2.56 feet in the ditch was recorded at Site 2. Utilizing this depth and channel geometry from the topographic survey, Manning's equation was used to calculate flow in the trapezoidal channel.
First the wetted perimeter must be calculated using *Equation 2*

Figure 29 shows a cross section of the ditch for the given depth of 2.56 feet.

Equation 2

$$P_w = b + 2\sqrt{((S_s * d)^2 + d^2)}$$

Where

- P_w=wetted perimeter
- b=bottom width of the ditch
- S_s=side slope of ditch bank
- d=depth of water

Inputting the known values results in the following:

$$P_w = 6.47 + 2\sqrt{((1.43 * 2.56)^2 + 2.56^2)} \qquad P_w = 15.43 \text{ ft}$$

TIME	DEPTH IN DITCH-D (ft)	WETTED PERIMETER - P_W (ft)	TOP WIDTH - T (ft)	AREA - A (ft^2)	HYDRAULIC RADIUS - R (ft)	FLOW (cfs)
7:40	2.56	15.43	13.82	25.99	1.68	30.52
7:45	2.60	15.56	13.93	26.52	1.70	31.38
7:50	2.63	15.65	14.00	26.87	1.72	31.95
7:55	2.64	15.70	14.04	27.06	1.72	32.27
8:00	2.66	15.79	14.11	27.41	1.74	32.86
8:05	2.68	15.83	14.15	27.58	1.74	33.14
8:10	2.71	15.95	14.25	28.10	1.76	33.99
8:15	2.74	16.04	14.32	28.45	1.77	34.58
8:20	2.80	16.26	14.50	29.35	1.81	36.09
8:25	2.89	16.56	14.75	30.62	1.85	38.26
8:30	2.98	16.90	15.03	32.08	1.90	40.78
8:35	3.03	17.07	15.17	32.80	1.92	42.05
8:40	3.11	17.33	15.38	33.95	1.96	44.08
8:45	3.22	17.72	15.70	35.66	2.01	47.14
8:50	3.27	17.89	15.84	36.43	2.04	48.55
8:55	3.34	18.14	16.04	37.58	2.07	50.65
9:00	3.44	18.49	16.33	39.20	2.12	53.65
9:05	3.44	18.49	16.33	39.20	2.12	53.65
9:10	3.52	18.80	16.58	40.63	2.16	56.34
9:15	3.59	19.01	16.76	41.64	2.19	58.27
9:20	3.59	19.01	16.75	41.63	2.19	58.24
9:25	3.66	19.26	16.97	42.88	2.23	60.62
9:30	3.72	19.48	17.14	43.93	2.26	62.67

Table 8 - Calculated Flow for July 9, 2013 Rain Event

Next, the top width of the water surface must be calcluated using *Equation 3*.

Equation 3

$$T = b + 2(S_S * d)$$

Inputting the values into *Equation 3* results in the following:

$$T = 6.47 + 2(1.43 * 2.56) \qquad T = 13.82 \text{ ft}$$

area in which the flow passes is calculated using *Equation 4*.

Equation 4

$$A = 0.5 * (b + T) * d$$

Inputting the values into *Equation 4* results in the following:

$$A = 0.5 * (6.47 + 13.81) * 2.56 \qquad A = 25.99 \text{ ft}$$

Next, the hydraulic radius is calculated using *Equation 5*.

Equation 5

$$R = \frac{A}{P_w}$$

Inputting the values into *Equation 5* results in the following:

$$R = \frac{1.49}{15.42} \qquad R = 1.68 \text{ ft}$$

Lastly, assuming an n value of 0.022, using the surveyed bed slope of 0.0002, and using Equation 1 to calculate the flow results in the following:

$$Q = \frac{1.49}{0.022} * 25.96 * 1.63^{\frac{2}{3}} * 0.0002^{\frac{1}{2}} \qquad Q = 30.52 \text{ cfs}$$

This process was repeated for all measured depths and was tabulated in a similar format (*Table 8*) that shows several flow calculations for site 2 during the July 9, 2013 rain event.

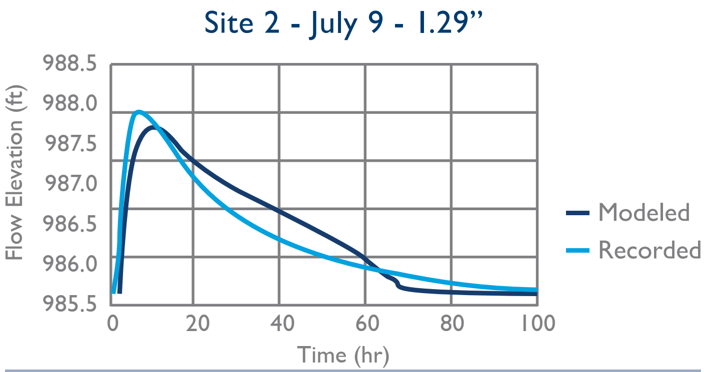


Figure 30 - Elevation Hydrograph for Site 2 of July 9, 2013 Rain Event

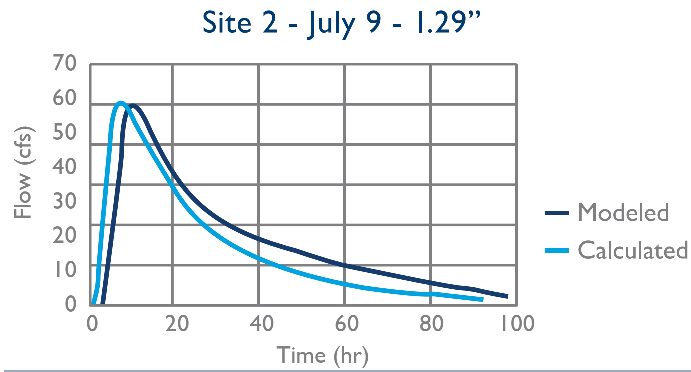


Figure 31 - Hydrograph for SIte 2 of July 9, 2013 Rain Event

This calculated flow data was used to develop a hydrograph for all recorded depths. *Figure 30* shows the recorded elevations from the data logging devices at Site 2 for the July 9, 2013 rain event. Elevations based on the Hydrocad model are also included in *Figure 30*. The modeled elevations are comparable the recorded elevations.

Figure 31 shows the calculated flow based on the recorded depths from the data logging devices and the flows developed through the hydrologic/hydraulic model. While the actual flows may be different than those included in this report, the modeled flows are comparable to those developed using the Manning equation. The similarity of the curves is an artifact of the theory used to develop flow.

ANALYSIS

The above method for calculating flow was used for all rain events in which stage data was recorded. Due to monitoring adjustments and equipment failure, a few rain events did not have recorded stage data. For these locations and events, the hydrologic/hydraulic model was used to simulate the rain event. This model was simulated, calibrated, and tested against recorded data and photos to develop an accurate depiction of the CD 57 system during rain events. An example comparison showing the accuracy of the model is shown for the July 9, 2013 rain event in which a 1 hour, 1.29-inch rain event was recorded (*Figure 31*). This rain event was used as a baseline for calibration of the hydrologic/hydraulic model for the CD 57 system. This event was used since the ditch system was primarily dry and at a slow baseflow condition. It was also chosen since the rain event provided enough precipitation and runoff to accurately calibrate the model. Calibration of the model included comparing water elevations for the recorded data and modeled data. This was verified by a detail topographic survey, calibration of the data logging devices via ambient pressure adjustments, and verification of depth and stage conditions throughout the CD 57 system by utilizing the onset cameras located throughout the watershed.

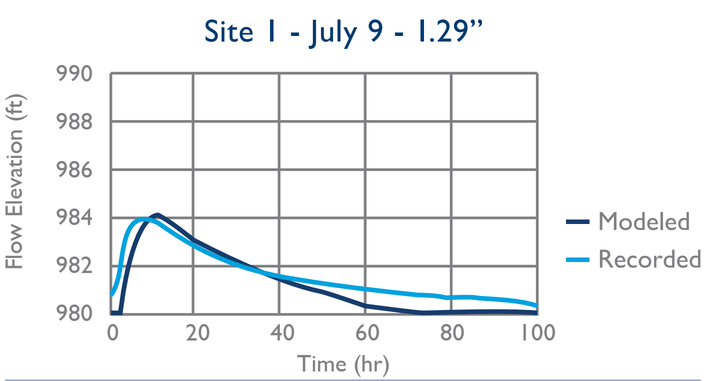


Figure 32 - Elevation Hydrograph for Site 1 of July 9, 2013 Rain Event

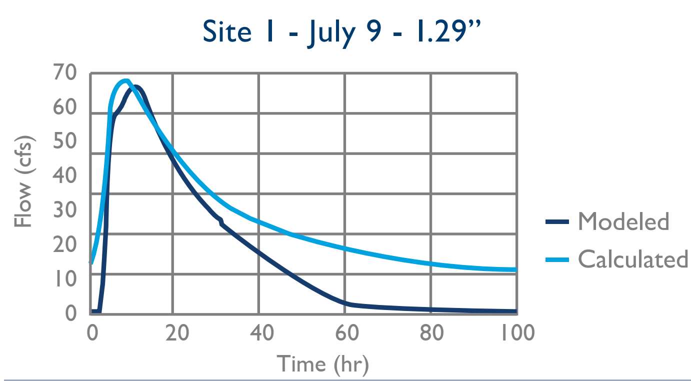


Figure 33 - Hydrograph for Site 1 of July 9, 2013 Rain Event

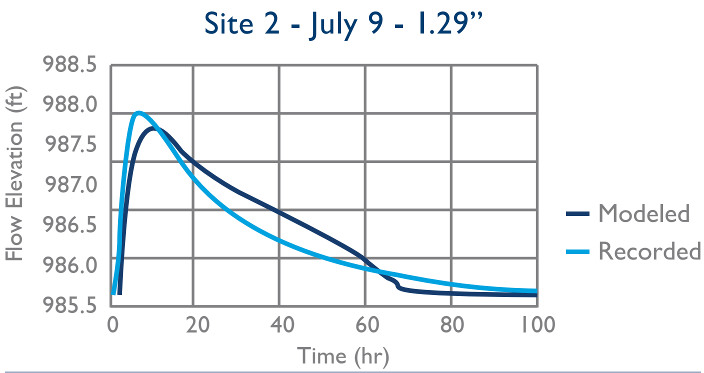


Figure 34 - Elevation Hydrograph for Site 2 of July 9, 2013 Rain Event

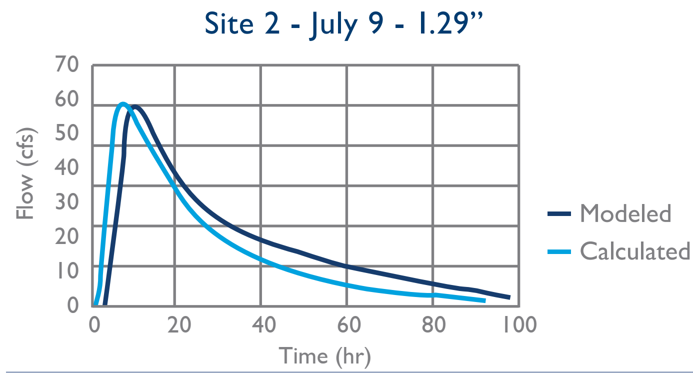


Figure 35 - Hydrograph for Site 2 of July 9, 2013 Rain Event

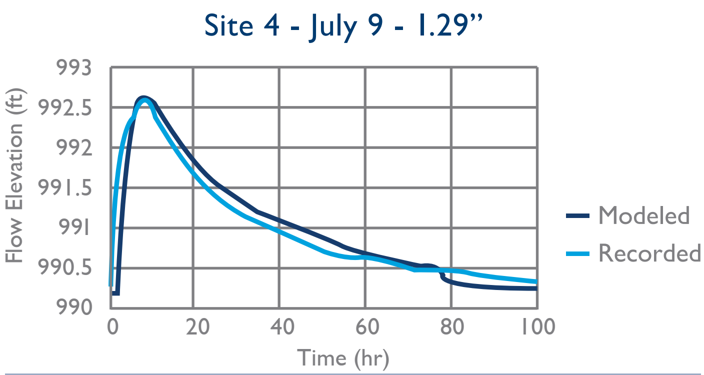


Figure 36 - Elevation Hydrograph for Site 4 of July 9, 2013 Rain Event

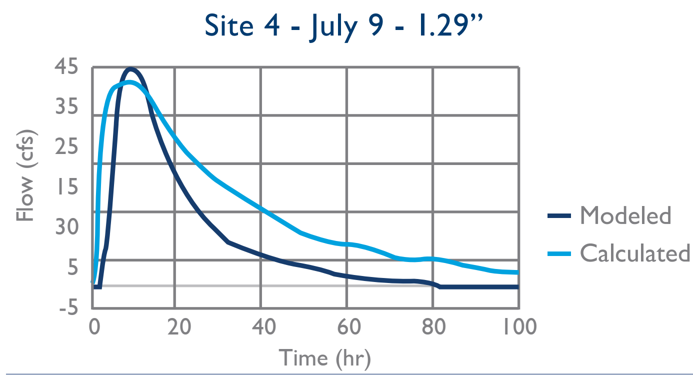


Figure 37 - Hydrograph for Site 4 of July 9, 2013 Rain Event

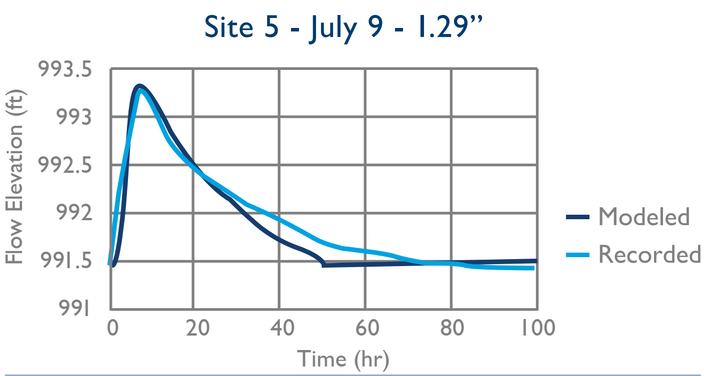


Figure 38 - Elevation Hydrograph for Site 5 of July 9, 2013 Rain Event

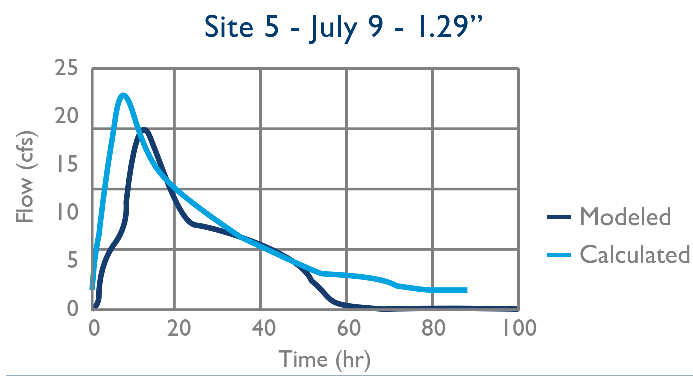


Figure 39 - Hydrograph for Site 5 of July 9, 2013 Rain Event

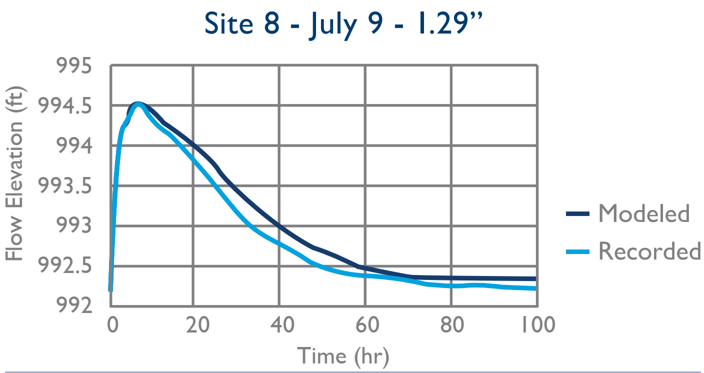


Figure 40 - Elevation Hydrograph for Site 8 of July 9, 2013 Rain Event

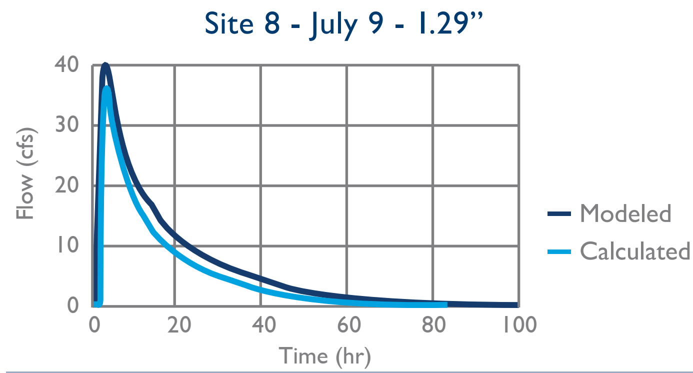


Figure 41 - Hydrograph for Site 8 of July 9, 2013 Rain Event

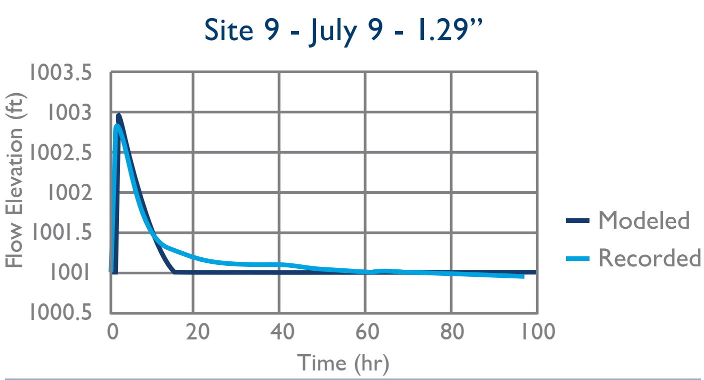


Figure 42 - Elevation Hydrograph for Site 9 of July 9, 2013 Rain Event

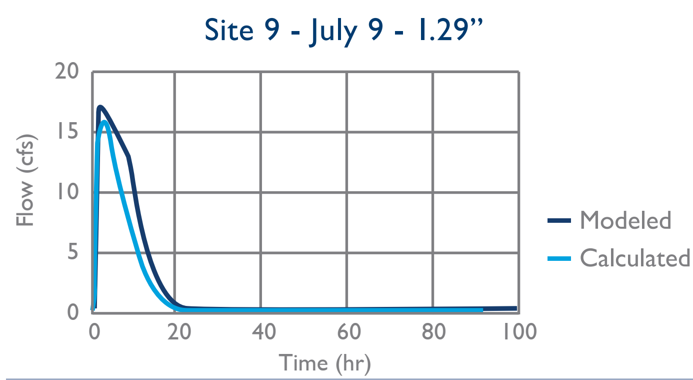


Figure 43 - Hydrograph for Site 9 of July 9, 2013 Rain Event

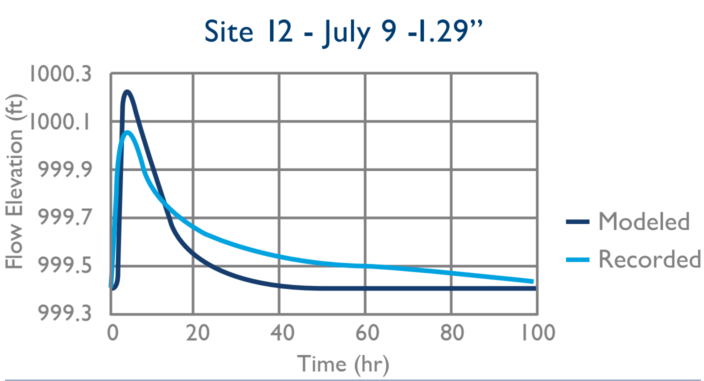


Figure 44 - Elevation Hydrograph for Site 12 of July 9, 2013 Rain Event

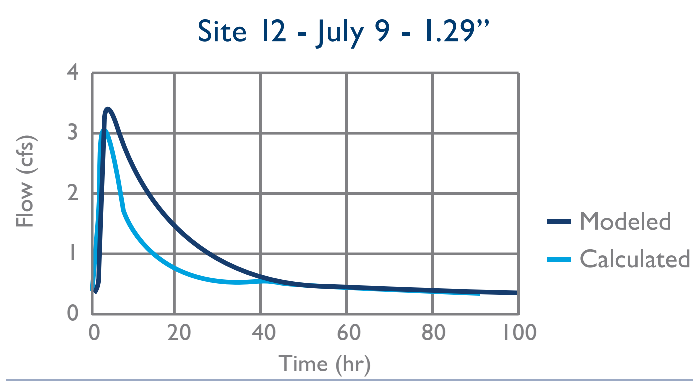


Figure 45 - Hydrograph for Site 12 of July 9, 2013 Rain Event

The previous figures compare the recorded water level elevations and flow rates to those elevations and flow rates that were modeled using the hydrologic/hydraulic model. These figures show the hydrographs or the water quality monitoring sites located throughout the watershed.

The elevation hydrographs and hydrographs (*Figures 32-45*) are very similar for both the modeled and recorded elevations. This proves that the hydrologic/hydraulic model developed for CD 57 accurately depicts the hydrology and hydraulic conditions throughout the watershed. Therefore, using this model for the rain events that were not measured with data logging devices will provide an accurate depiction of the system.

PEAK FLOWS

THEORY

Peak flow rates are defined as the highest volumetric flow rate that passes through a point on a system from a rain event. On a hydrograph, this is the top most point on the hydrograph. Peak flow rates are responsible for the following characteristics of flow in either a river, stream, or any open channel (MPCA, 2012):

- Erosion to ditch banks due to high water flow
- High nutrient loading
- High sediment loading
- Increased flooding to local and downstream waters

Peak flow rates can have damaging effects to both local and global watersheds, thus controlling peak flow rates is essential for improving water quality.

METHODOLOGY

Peak flow rates for the recorded stage depth were determined by using the previously mentioned Manning's equation for flow for the highest recorded depth during a rain event. Peak flow rates for the hydrologic/hydraulic model were taken from the top most point of the simulated hydrograph for the associated rain events.

RESULTS

Using the same July 9, 2013 rain event to for both the calculated and modeled peak flow rates provided similar results (*Figure 46*).

ANALYSIS

The peak flow rates from the model and the recorded peak flow rates calculated using Manning's equation were compared. The peak flow rates for both the modeled and recorded methods are nearly the same throughout the system. This further validates the methodology for computing flow from both the hydrologic/hydraulic model and calculating flow based on Manning's equation for flow.

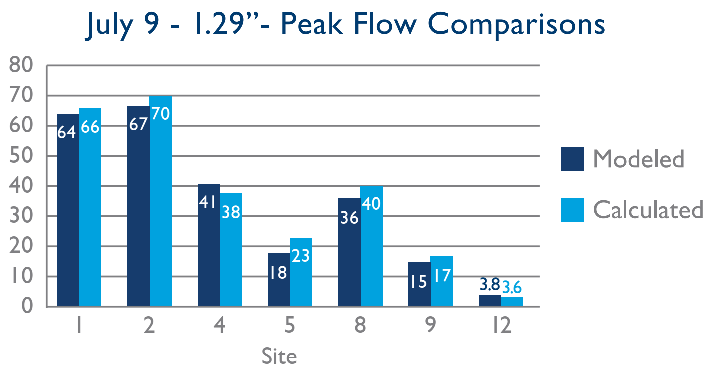


Figure 46 - Peak Flow Rates Comparison for Modeled and Calculated Flow Methods

FLOW VOLUME

THEORY

The total flow volume of a rain event at a given point is defined as the cumulative volume of water that passes through a point for a rain event. It is found by calculating the area under the hydrograph curve. Total flow volumes are used for the following:

- Comparing flow volumes for different monitoring points
- Computing runoff from the watershed
- Computing water chemistry loading of a variety of parameters (i.e. sediment, nutrients, etc.)

As watershed area increases to a stream network, the total flow volume is expected to increase as there is more runoff from a larger contributing watershed. Therefore, total runoff volumes from a rain event are expected to be largest at Site 1 and lower at upstream Sites 9 and 12.

METHODOLOGY

The total flow volume of a rain event is determined by calculating the area under the hydrograph curve. Using the hydrographs for both the modeled and recorded methods of the July 9, 2013 rain event, the total volume of each hydrograph was calculated. For the recorded method, some of the data logging devices contained areas of baseflow and pooled water due to culvert crossing and permanent water due to the overdug ditch. This area under starting and ending points of the hydrograph was subtracted since it does not accurately depict the discharge from the rain event (*Figure 47*).

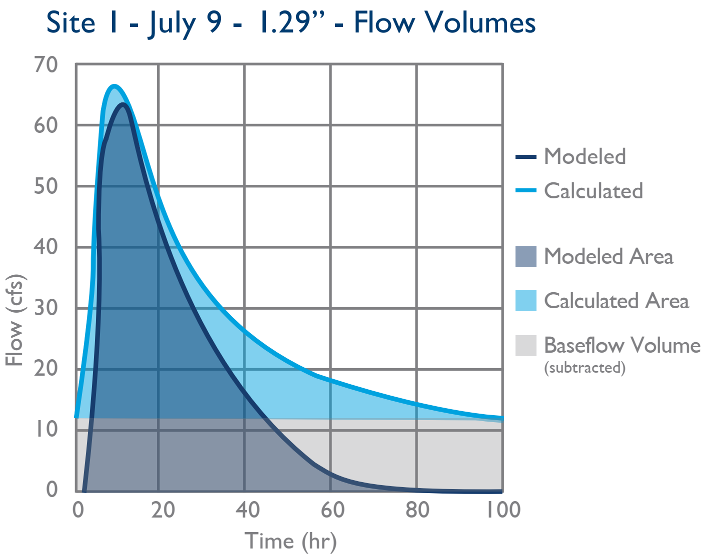


Figure 47 - Total Flow Volume Calculation

RESULTS

Figure 48 shows the total flow volumes calculated for the July 9, 2013 rain event. The total volumes are relatively close for each site for the modeled and recorded methods.

This method can also be used to compare the total flow through the system for each of the monitored years. *Figure 49* compares the total flow through the system for years 2012-2014.

ANALYSIS

The total flow volumes for both the model and the calculated methods for flow provide similar runoff volumes (*Figure 48*). This further validates the methods used in determining flow for the CD 57 system.

The total volume increases from upstream (Site 12) to downstream (Site 1), were as anticipated. Comparing the yearly flow volumes (*Figure 49*) shows that the most flow volume occurred in 2014 while the least amount occurred in 2012. This was expected as the highest rainfall occurred during 2014 while the least amount occurred during 2012.

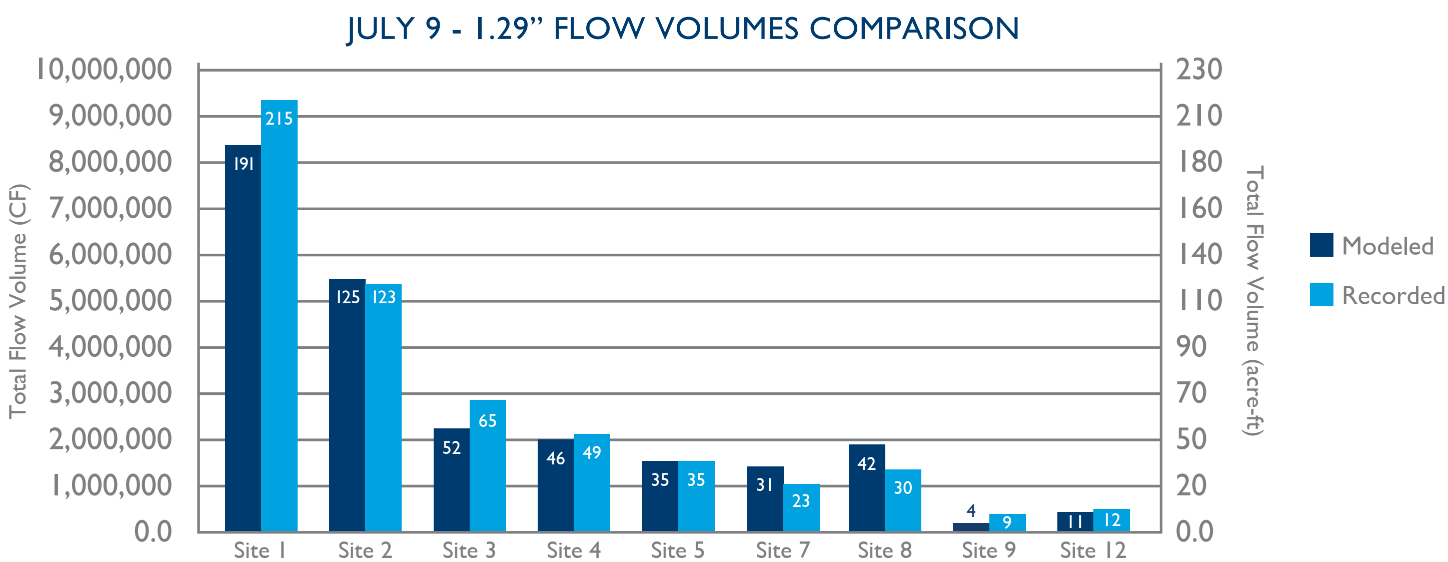


Figure 48 - Total Flow Volume Comparison for July 9, 2013 Rain Event

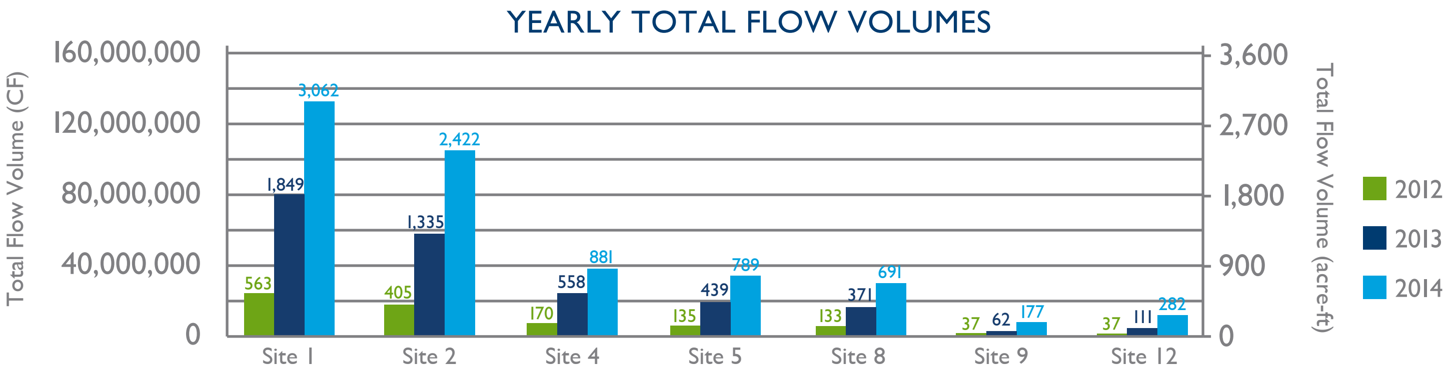


Figure 49 - Yearly Total Flow Volumes

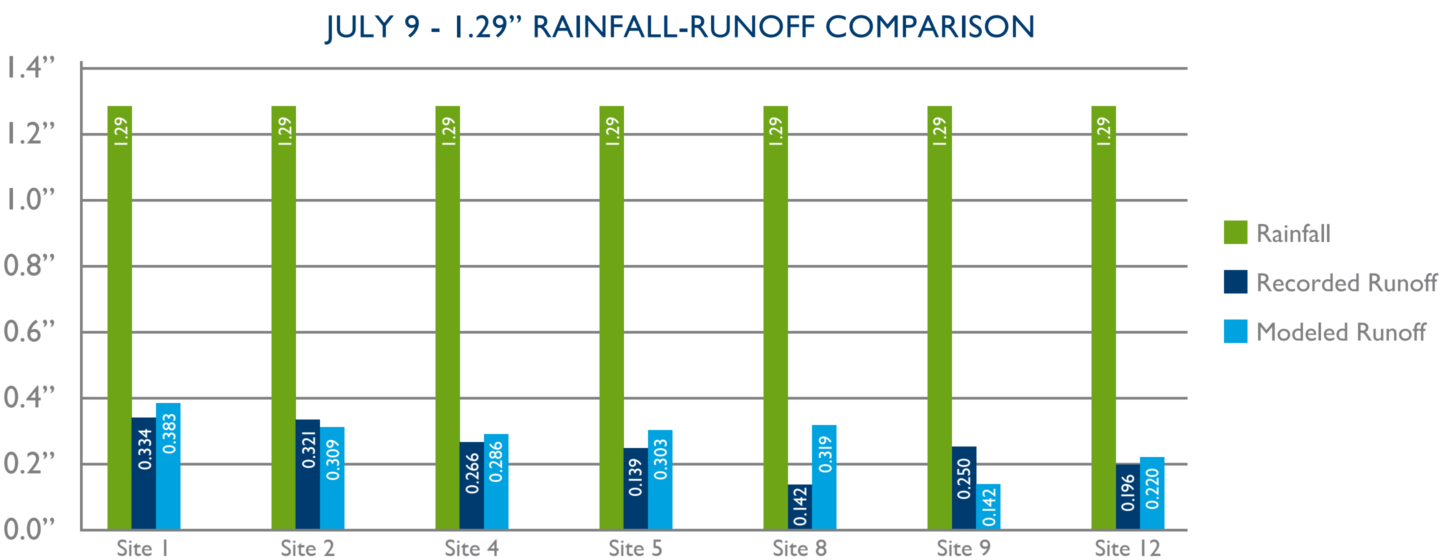


Figure 50 - Rainfall-Runoff Comparison for July 9, 2013 Rain Event

RUNOFF

THEORY

Rainfall and runoff can be directly related to each other in order to validate flow from the CD 57 system. Runoff, precipitation, and infiltration are related by the following equation (Gupta 2008) for direct runoff within a basin.

Equation 6

$$P = R + I$$

Here *P* represents precipitation, *R* represents runoff, and *I* represents infiltration. Runoff is calculated using *Equation 7*.

Equation 7

$$R(in) = \frac{Total\ Flow\ Volume\ ft^3}{Watershed\ Area(acres) * \frac{43560\ ft^2}{1\ acre}} * \frac{12\ in}{1\ ft}$$

Infiltration values are dependent on the soil saturation; therefore, runoff values are also dependent upon the soil conditions. When the soil is saturated, it is expected to have a higher runoff value. When the soil is dry and unsaturated, infiltration values are expected to be higher creating lower runoff values. Following *Equation 7*, runoff values should never exceed the rainfall amount. Since the monitoring for the CD 57 system did not include infiltration, it is to be expected that runoff values would be less than precipitation for monitored rain events.

METHODOLOGY

Using *Equation 7* and the total runoff volumes for the July 9, 2013, 1.29-inch rain event, a rainfall/runoff comparison was completed (*Figure 50*).

RESULTS

This process was repeated and done for the monitored rain events between 2012 and 2014. The results from these calculations were averaged throughout the entire system for each rain event using the flow from Manning's equation. *Figures 51-53* show the rainfall and runoff comparison for the sampled rain events between 2012 and 2014.

Summarizing these three years of rainfall and runoff is shown in *Figure 54*.

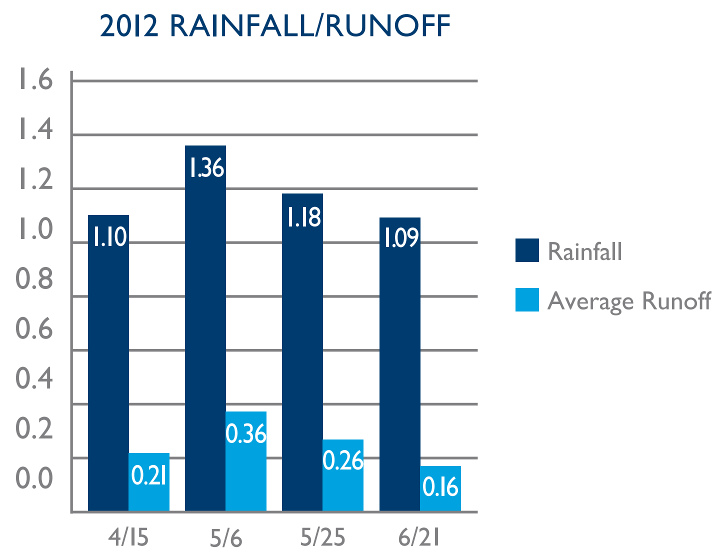


Figure 51 - 2012 Rainfall and Runoff Comparison

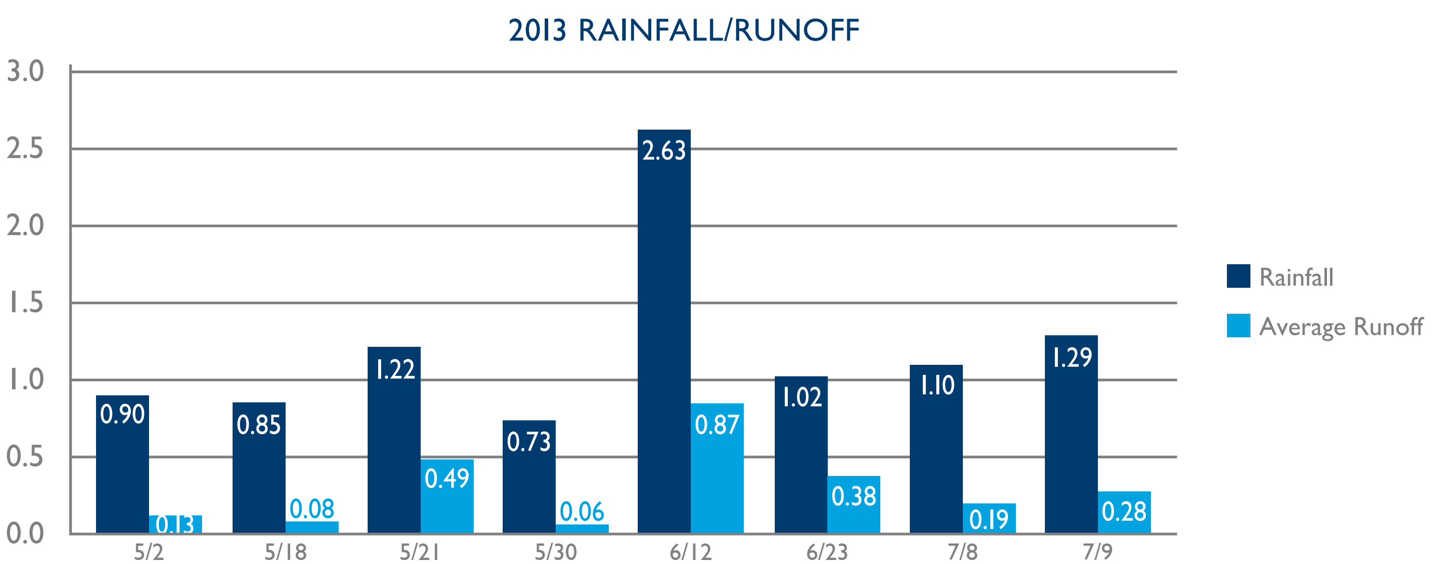


Figure 52 - 2013 Rainfall and Runoff Comparison

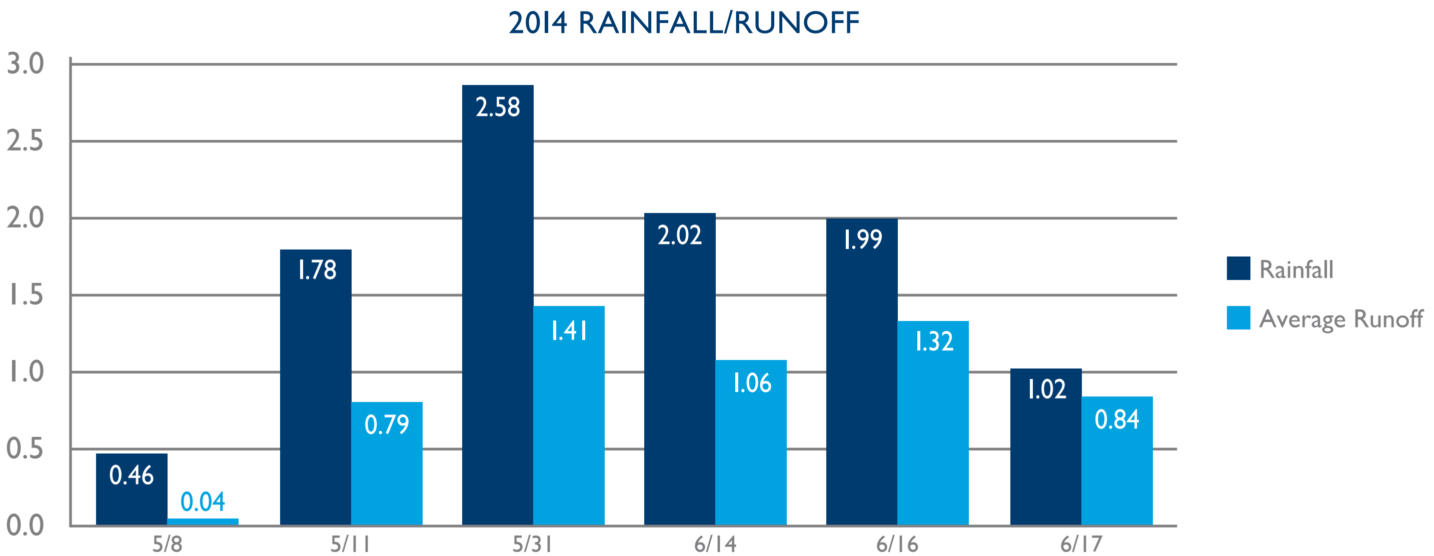


Figure 53 - 2014 Rainfall and Runoff Comparison

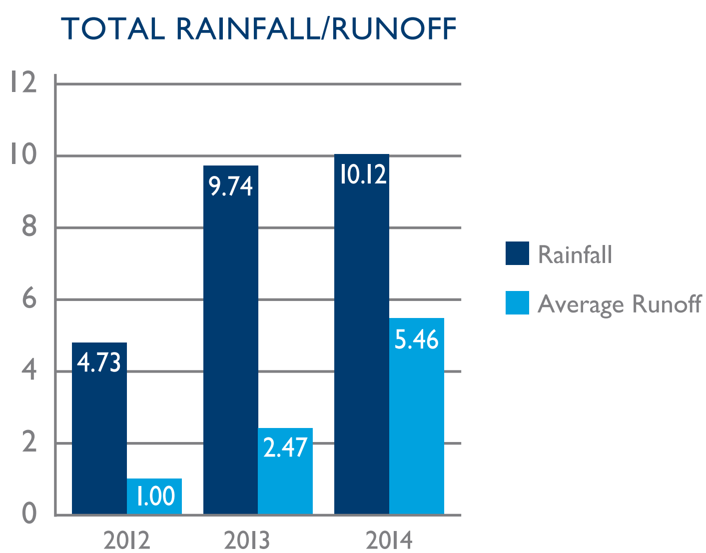


Figure 54 - Total Yearly Rainfall and Runoff Comparison

ANALYSIS

The runoff depths for both the modeled and calculated methods are similar and are less than the rainfall depth. As expected, the runoff depths are less than the rainfall depths, validating the flow data used in this analysis.

The three post-BMP installation monitoring seasons included both high and low rainfall levels (*Figure 54*). Very dry conditions occurred in 2012, with very little runoff and high infiltration throughout watershed. Of the monitored events in 2012, only one inch of runoff was recorded. The low amount of runoff in 2012 was as expected due to overly dry conditions, with the majority of the rainfall being infiltrated.

Moderate rainfall throughout the 2013 growing season provided a more typical season with 2.47 inches of runoff recorded and sampled. A 2.63-inch rainfall event within two hours occurred in 2013, which is equivalent to a NOAA 25-year rain event. In general, this accurately depicts the runoff for 2013 as little flooding occurred throughout the year.

Multiple heavy rainfall events and a few back to back rain events made 2014 a very wet year. There were many times where the entire CD 57 system was full of water and restricting flow throughout the watershed. The wet conditions lead to a large amount of runoff (53% of rainfall) and high flow volumes. For the majority of June 2014, there was significant flooding throughout the watershed. The rainfall runoff comparison for 2014 accurately depicts flow conditions for CD 57. With a 2.02 and a 1.99 inch rain event in two consecutive days, both were considered NOAA 10-year rain events.

RAIN EVENT	HYDROLOGIC/HYDRAULIC MODEL	RECORDED
4/15/2012	●	
5/6/2012	●	
5/25/2012	●	
6/21/2012	●	●
5/2/2013		●
5/18/2013		●
5/21/2013		●
5/30/2013		●
6/12/2013		●
6/23/2013		●
7/8/2013		●
7/9/2013		●
5/8/2014		●
5/11/2014	●	●
5/31/2014		●
6/1/2014		●
6/14/2014		●
6/16/2014		●
6//2014		●

Table10 - Flow Method Used for Analysis

FLOW SUMMARY

The two methods used for quantifying flow (hydrologic/hydraulic modeling and calculating based on recorded elevations) provide very similar results for flow, peak flow, total flow volume, and runoff depths. These methods were used to further validate the hydrologic/hydraulic model used for the CD 57 system. The calculated method of flow was used for analysis while the model was used as a reference and for validation purposes. However, there were multiple occurrences where the equipment used to record flow either malfunctioned, was not installed early enough, or was damaged. For these frequencies, the hydrologic/hydraulic model was used to simulate the sampled rain event. In some instances, both methods were used as some sites functioned properly while others did not. Each sampled rain event was documented along with the method used for measuring flow for analysis (*Table 10*).

LOADING

THEORY

To analyze the effectiveness of each BMP, the total loading of TSS, TN and TP are combined for upstream of the BMP, and downstream of the BMP. The total loading for each parameter was determined using the following equation.

Equation 8

$$Loading = \sum C_i * V_i$$

Where:

- Loading is the total amount of either TSS, TN, or TP (kg)
- Ci is the concentration of either TSS, TN, or TP at each site (mg/L)
- Vi is the total volume of flow at each site (L)

METHODOLOGY

The rate control weir loading will consist of the concentration of each parameter sampled from Site 1 and the total volume from upstream of the weir (Site 2). The total loading at Site 2 will consist of the concentration of each parameter at Site 2 and the total volume and Site 2. The total volume used for the loading is the same at each site since between Sites 1 and 2, 891 acres of runoff is added to CD 57 which contains untreated water and adds more sediment and nutrients to the system. This will properly analyze the loading of the water that travels downstream from Site 2 to Site 1, thus determining the rate control weir's impact on the loading in the water. *Figure 55* shows the watershed differences between Site 1 and Site 2.

Like the rate control weir, the two-stage ditch total loading is based on the same volume for the upstream point (Site 5) and downstream point (Site 4). Since 542 acres of untreated runoff is added to the end of the two-stage ditch near Site 4, it is inaccurate to incorporate this volume into analyzing the two-stage ditch effectiveness. *Figure 56* shows the watershed differences for the beginning of the two-stage ditch and the end of the two-stage ditch.

The Klein Pond is comprised of three sub watersheds upstream. Each watershed has its own sampling point and flow point to calculate the loading. *Figure 57* shows how the total loading upstream of the pond was determined. As shown, for the upstream tile watershed, Site 12 was used for both flow volume and concentrations. For the City Pond watershed, the outlet of the pond (Site 9) will also be used for flow volume and concentrations. For the western watershed, Site 8 will be used for the flow volume while Site 7 will be used for concentrations. At this point, the watershed area is the same as it is at Site 8. Also, at Site 7, flow rates are affected by the diversion weir, backwater from the pond, and inlet culvert. Site 8 provides a more accurate depiction of flow than Site 7 due to these circumstances.

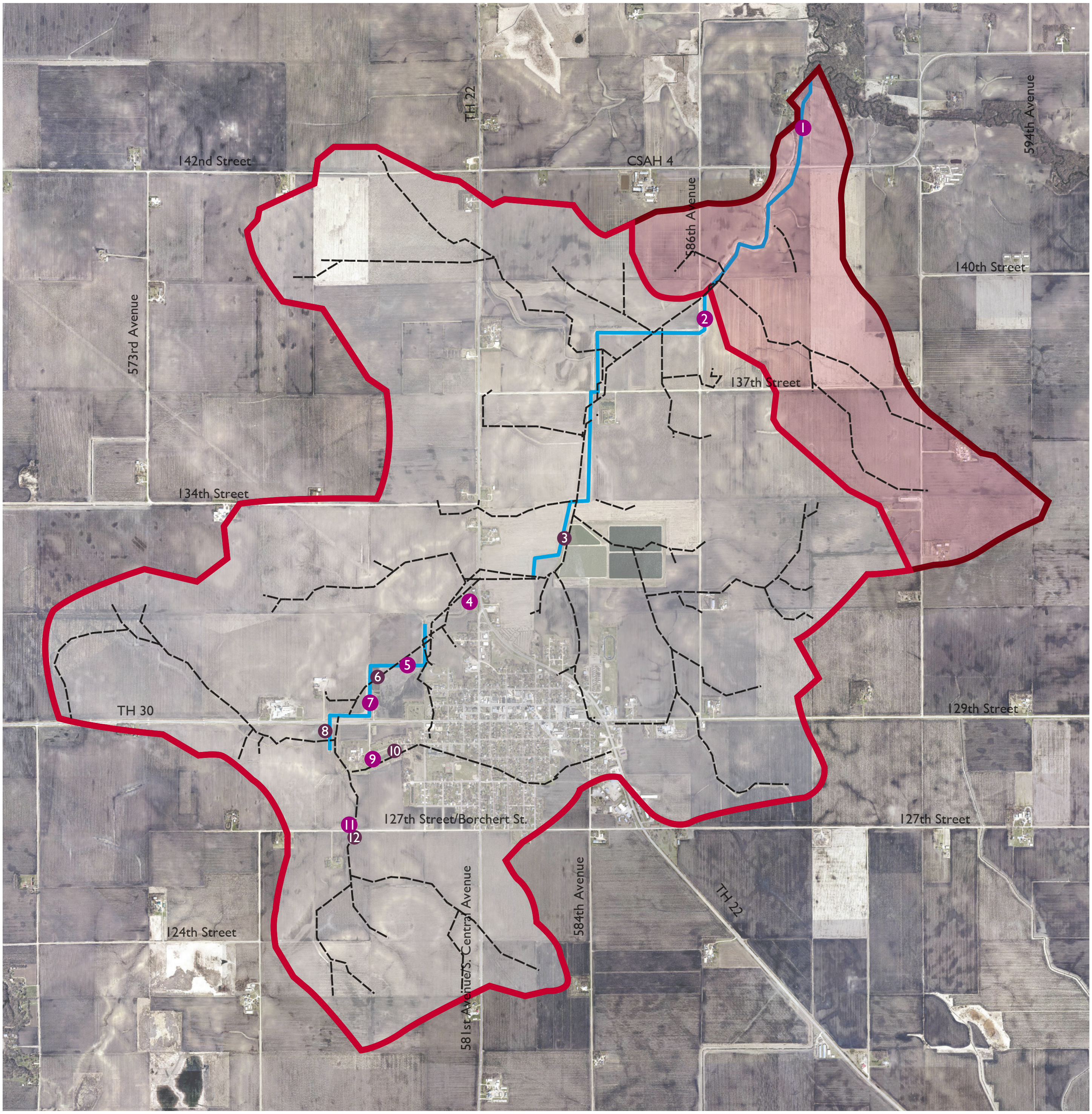


Figure 55 - Watershed Differences for Site 1 and Site 2

N

Stage
Water Quality + Stage
Existing Tiles
Site 2 Watershed
Site 1 Added Watershed
Existing Open Ditch

0 1,600 3,200 Feet

ISG

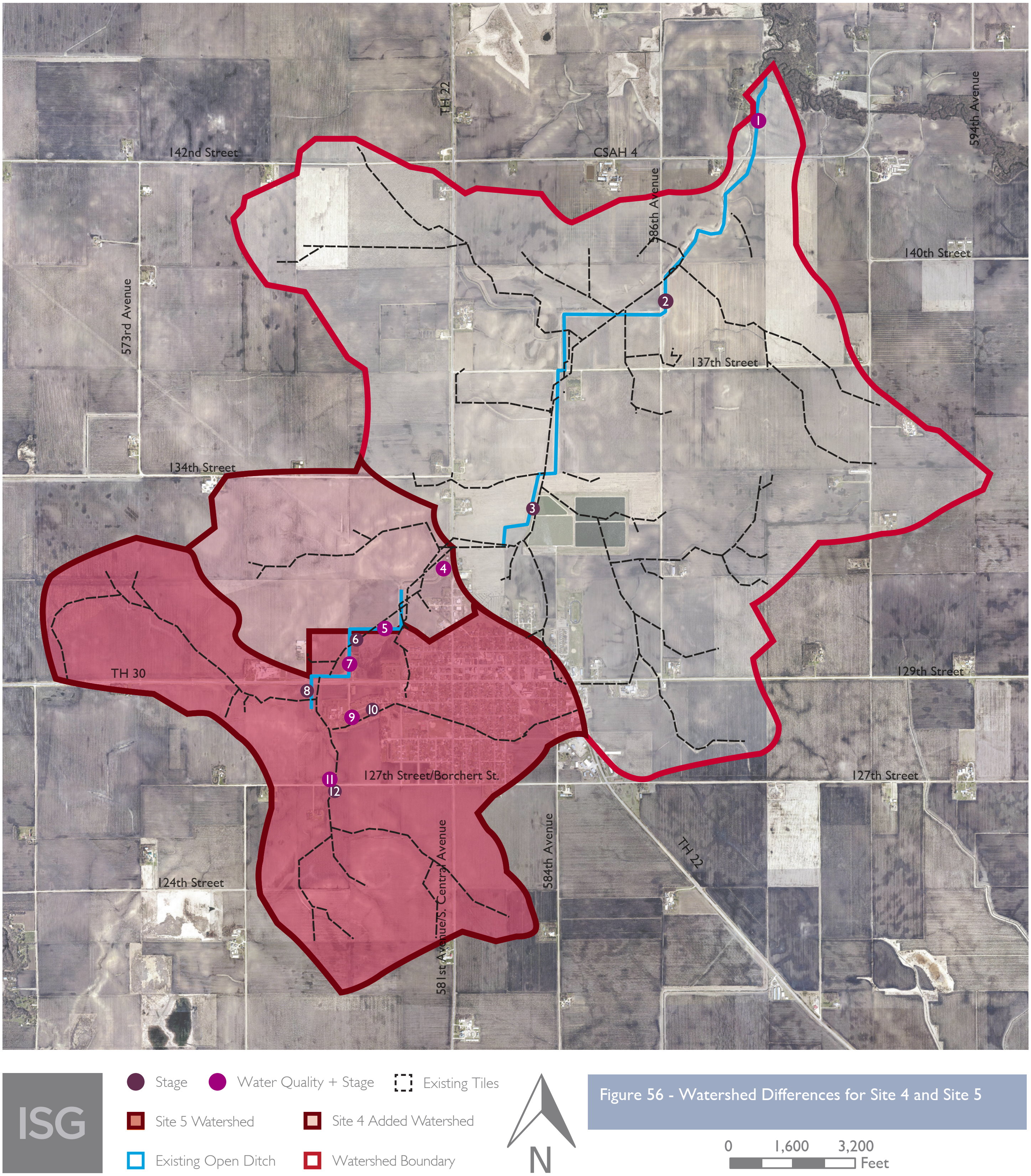


Figure 56 - Watershed Differences for Site 4 and Site 5

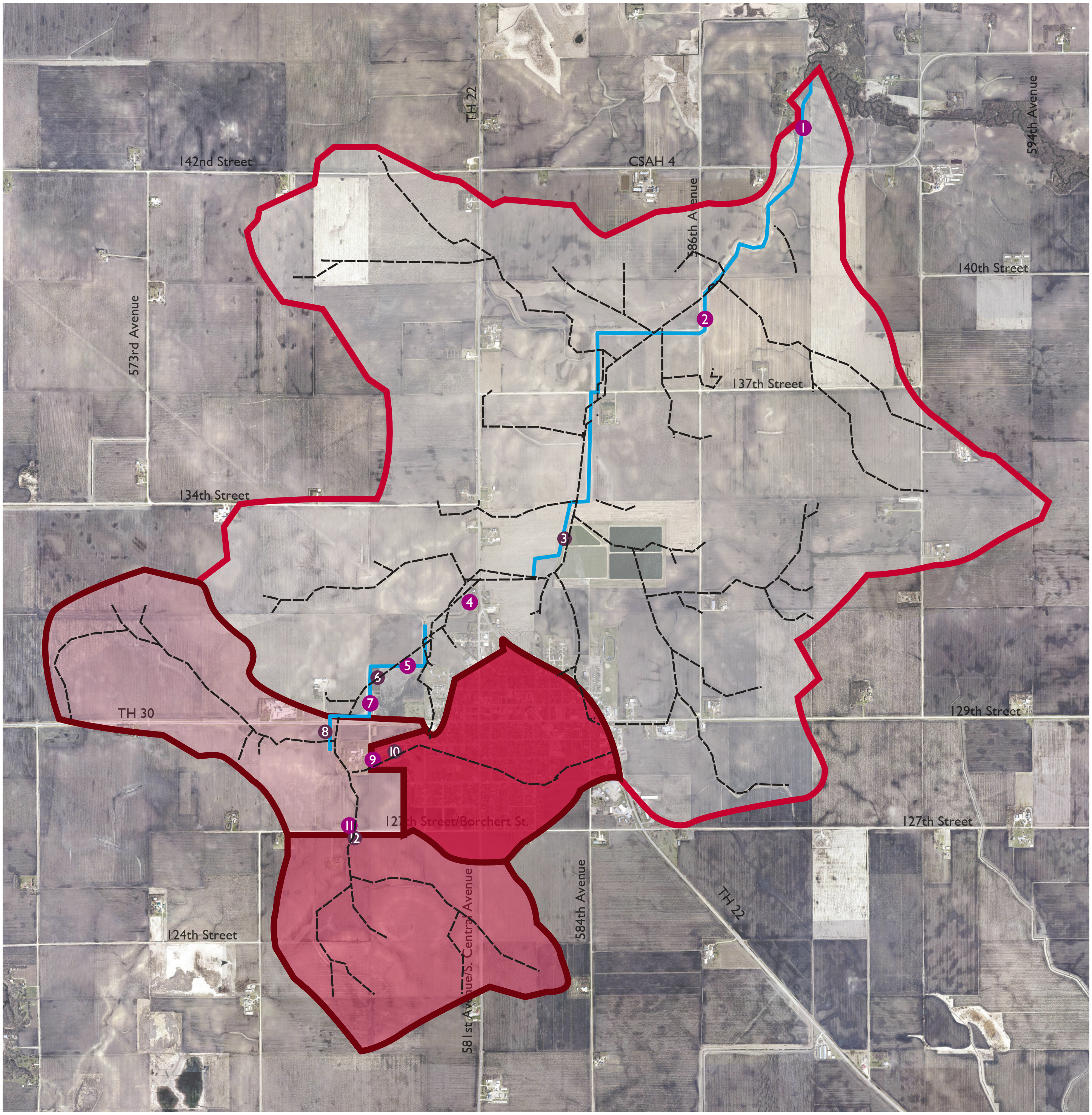


Figure 57 - Watershed Differences for Klein Pond

STATION	TSS (mg/L)	TP (mg/L)	TN (mg/L)
Site 12	13.2	0.4810	46.8
Site 9	110.0	0.4730	9.5
Site 7	6.8	0.3769	33.2
Site 5	14.8	0.4346	22.5
Site 4	14.0	0.4128	21.4
Site 2	32.8	0.4442	23.3
Site 1	30.0	0.3929	25.5

Table 11 - Raw Water Quality Concentrations from July 9, 2013 Rain Event

STATION	FLOW VOLUME (ft^3)	FLOW VOLUME (L)
Site 12	419,762	11,886,313
Site 9	370,311	10,497,361
Site 7	805,192	22,800,473
Site 5	1,558,868	44,142,165
Site 4	1,558,868	44,142,165
Site 2	5,997,151	169,820,118
Site 1	5,997,151	169,820,118

Table 12 - Flow Volumes for July 9, 2013 Rain Event

STATION	TOTAL VOLUME (L)	TSS (mg/L)	TP (mg/L)	TN (mg/L)	TOTAL TSS (kg)	TOTAL TP (kg)	TOTAL N (kg)
Site 12	11,886,313	13.2	0.4810	46.8	157	5.71	556
Site 9	10,497,361	110.0	0.4730	9.5	1,155	4.97	100
Site 7	22,800,473	6.8	0.3769	33.2	154	8.59	758
Site 5	44,142,165	14.8	0.4346	22.5	654	19.19	992
Site 4	44,142,165	14.0	0.4128	21.4	618	18.20	947
Site 2	169,820,118	32.8	0.4442	23.3	5,570	75.44	3,955
Site 1	169,820,118	30.0	0.3929	25.5	5,095	66.73	4,326

Table 13 - Total Loading Determination for July 9, 2013 Rain Event

RESULTS

Sample Rain Event Analysis

The data in *Table 11* is a sample of the water quality analysis for the CD 57 system following the above methodology. This sample is from the same July 9, 2013 rain event used previously for analysis in which a 1-hour, 1.29-inch rainfall event occurred. Raw water quality concentrations for TSS, TP, and TN for this event are shown for each station in *Table 11*.

Using the same approach for flow data for stations 5, 4, 2, and 1, flow volumes were tabulated as shown in *Table 12*.

The raw water quality data and flow volumes from each of the above listed rain event can be combined to determine a total loading of TSS, TP, and TN. This can be done by multiplying the raw concentrations of TSS, TP, and TN by the total volume for each rain event at each location. *Table 13* summarizes the total loading for each parameter and each site for the July 9, 2013 rain event.

The total loading upstream of each BMP was compared to the total loading downstream of the BMP. For the Klein Pond, the total loading upstream included Sites 12, 9, and 8 and 7 while the downstream loading included Site 5. For the two-stage ditch, the total upstream loading included Site 5 while the downstream included Site 4. For the rate control weir, the total upstream loading includes Site 2 while the downstream includes Site 1. *Table 14* summarizes the total loading upstream and downstream of each BMP.

STATION	TOTAL TSS LOADING (kg)	TOTAL P LOADING (kg)	TOTAL N LOADING (kg)
Upstream Klein Pond	1,465	19.27	1,415
Downstream Klein Pond/ Upstream Two-Stage Ditch	654	19.20	992
Downstream Two-Stage Ditch	618	18.20	947
Upstream Rate Control Weir	5,570	75.44	3,955
Downstream Rate Control Weir	5,095	66.73	4,326

Table 14 - July 9, 2013 Total Loading Summary

Figure 58 shows the total loading results for the July 9, 2013 rain event.

The total loading removed by each BMP is the difference between the upstream and downstream loading of each BMP. *Figure 59* shows the removed amounts of TSS, TP, and TN for each BMP during the July 9, 2013 rain event.

Accumulated Loading

The total accumulated loading for TSS, TP, and TN was determined for each year. *Figures 60-62* show the total accumulated loading for TSS, TP and TN for years 2012 to 2014. Since the Klein Pond had significantly more total loading, two separate axis were used to show the results.

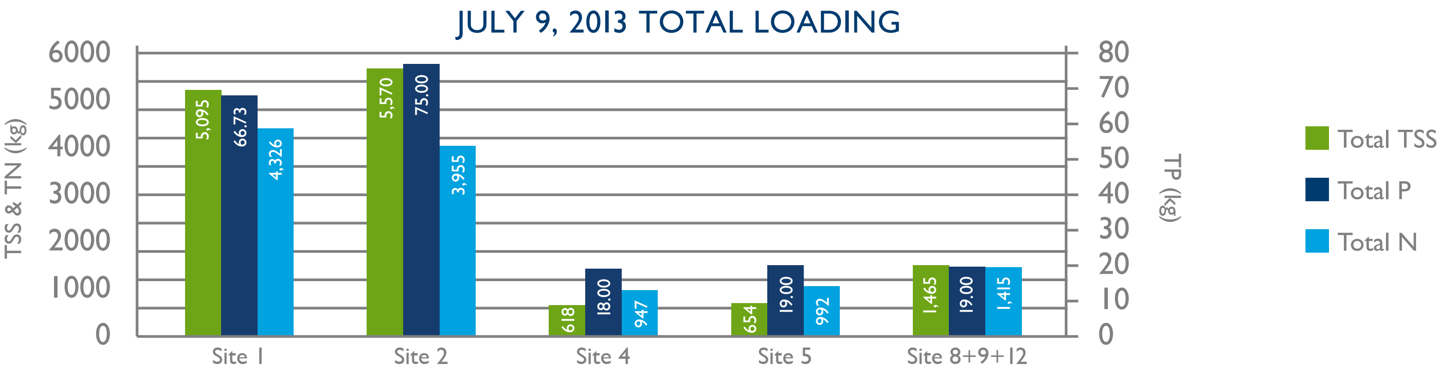


Figure 58 - July 9, 2013 Rain Event Total Loading

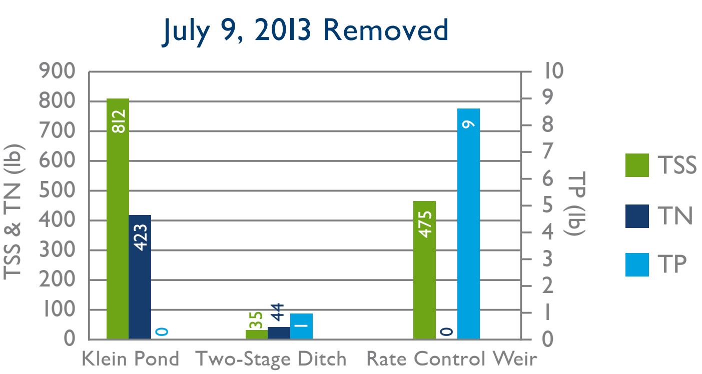


Figure 59 - July 9, 2013 Rain Event Total Loading Removed

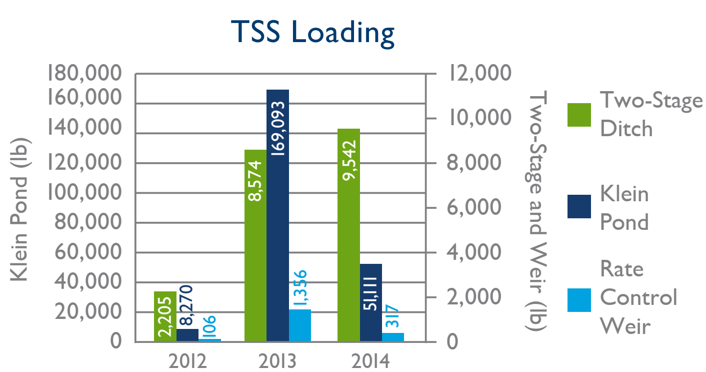


Figure 60 - Total Loading by Year for TSS

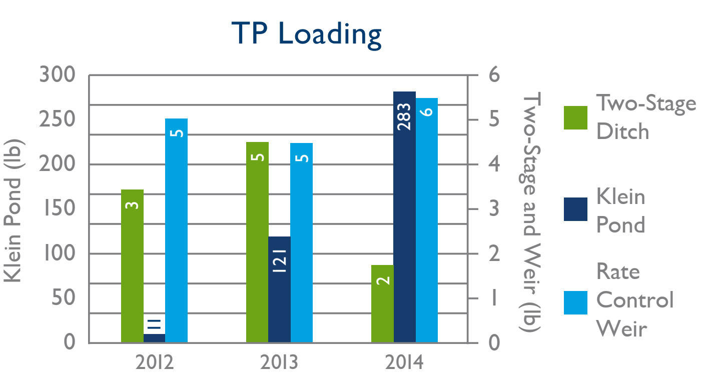


Figure 61 - Total Loading by Year for TP

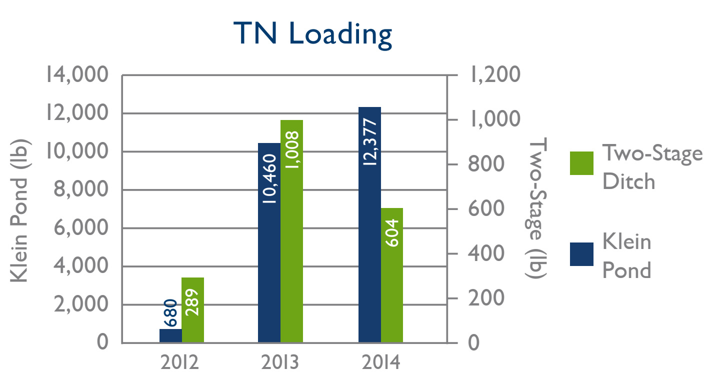


Figure 62 - Total Loading by Year for TN

ANALYSIS

The total loading for each parameter increases for each site moving downstream (*Figure 58*). This is as expected since as the ditch moves downstream, the watershed area and flow increase. However, it is noticeable that after the water passes a BMP, the total loading decreases, thus showing that the BMPs are reducing the loading of TSS, TP, and TN (*Figure 58*).

The Klein pond was most effective at reducing TSS and TN while the rate control weir was most effective at removing TP (*Figure 59*) for the July 9, 2013 rain event. The rate control weir did not see a reduction in TN for this rain event and for all sampled rain events. This is due to a large volume of water drained through county tiles is added, likely carrying the high concentrations of nitrogen. Nitrogen is always present in water. Unless a high retention time occurs on this water, the loading is not expected to be reduced when compared to the rate control weir.

The Klein Pond removed the most sediment in 2013 (*Figure 60*). This was expected as flow rates were closer to average when compared to the very low flows of 2012, and high flows and flooding of 2014. Like the Klein Pond, the rate control weir had the highest TSS removals for 2013, as the flow rates were more typical than the other two years. Also shown is that the two-stage ditch was more effective at removing sediment during 2014 than the other years. This is likely due to the outer benches of the two-stage ditch acting as a floodplain more often than the previous two years since there was more flow and flooding. This validates the effectiveness of the benches.

The Klein Pond was more effective at removing TP during 2014 than the other two years (*Figure 59*). This is contrary to the removals of TSS for the Klein Pond and may be due to the large flooding that occurred in the agricultural fields when more phosphorus bound soil particles had the opportunity to be removed. The two-stage ditch saw the highest removals for TP and TN during 2013 when flow were more average. This shows that the two-stage ditch is most effective at removing nutrients during average flows.

Topographic Survey

In November of 2014, a topographic survey was completed of the Klein Pond to compare the analytical data of accumulated sediment to what physically was occurring in the pond. The topographic survey compared the ground surface elevation of 2014 to the constructed elevation of the pond in 2012. From this survey, there was a volume difference of 725 cubic yards of material in the Klein Pond from the as-built to the 2014 survey. This was the amount of sediment that has accumulated in the pond and proves the effectiveness of the Klein Pond in removing sediment from the ditch.

To compare this value to what was monitored; the accumulated loading for TSS in the Klein Pond was used to approximate the volume of sediment in the pond. This was done by using and the wet density of

YEAR	TOTAL TSS (lb)	APPROXIMATED SEDIMENT (CY)
2012	8,270	5
2013	169,100	50
2014	51,200	15
Total	288,600	70

Table 15 - Total Accumulated Sediment in Klein Pond

YEAR	TOTAL TSS (lb)	APPROXIMATED SEDIMENT (CY)
2012	17,000	5
2013	713,200	205
2014	309,300	90
Total	1,024,200	300

Table 16 - Total Accumulated Sediment in Klein Pond based on site 7 Loading

sediment and multiplying that by the total accumulated TSS volume for each year. The wet density of sediment for the Klein Pond was sampled and analyzed to be 130 lb/ft3. *Table 15* summarizes the total sediment removed each year by the Klein Pond.

By adding up the 2012, 2013, and 2014 analytical TSS removals based on flow data and TSS concentrations, a total of 70 cubic yards of estimated sediment was removed. This number is less than the actual surveyed volume; however, multiple ambiguities need to be considered. First, the analytical data for TSS removed was taken for rain events larger than 1 inch, which is roughly 40 percent of the rainfall that occurred from 2012 to 2014. Therefore, it is likely that more sediment accumulated than what was sampled from 2012 to 2014. Second, the grab samples were taken after the 1 inch rain events during the peak flow of the system. Studies have shown that TSS concentrations are much higher prior to, rather than at the peak flow, suggesting that the TSS grab samples performed in this monitoring may not have been the highest concentration of each rain event. This suggests that it is possible that even more TSS would have been removed based on the analytical analysis. Third, Site 7 was sampled near the pond which contained already clean water. Therefore, the concentration is likely higher entering the pond than what was sampled. Fourth, during the 25 year event of 2013, a 20 foot portion of the ditch upstream of the Klein Pond completely washed away and the sampling for this event occurred at a later time. Accounting for these items, it is very likely that the method used to determine the total accumulated sediment in the pond is an accurate depiction of its removal potential, based on the 2014 topographic survey.

Another method for determining the total accumulated sediment is based on the water chemistry data from Site 7, which is immediately upstream of the pond and is considered part of the pond due to the geometry and hydrology of the ditch. The total loading at Klein Pond was calculated for three years (*Table 16*).

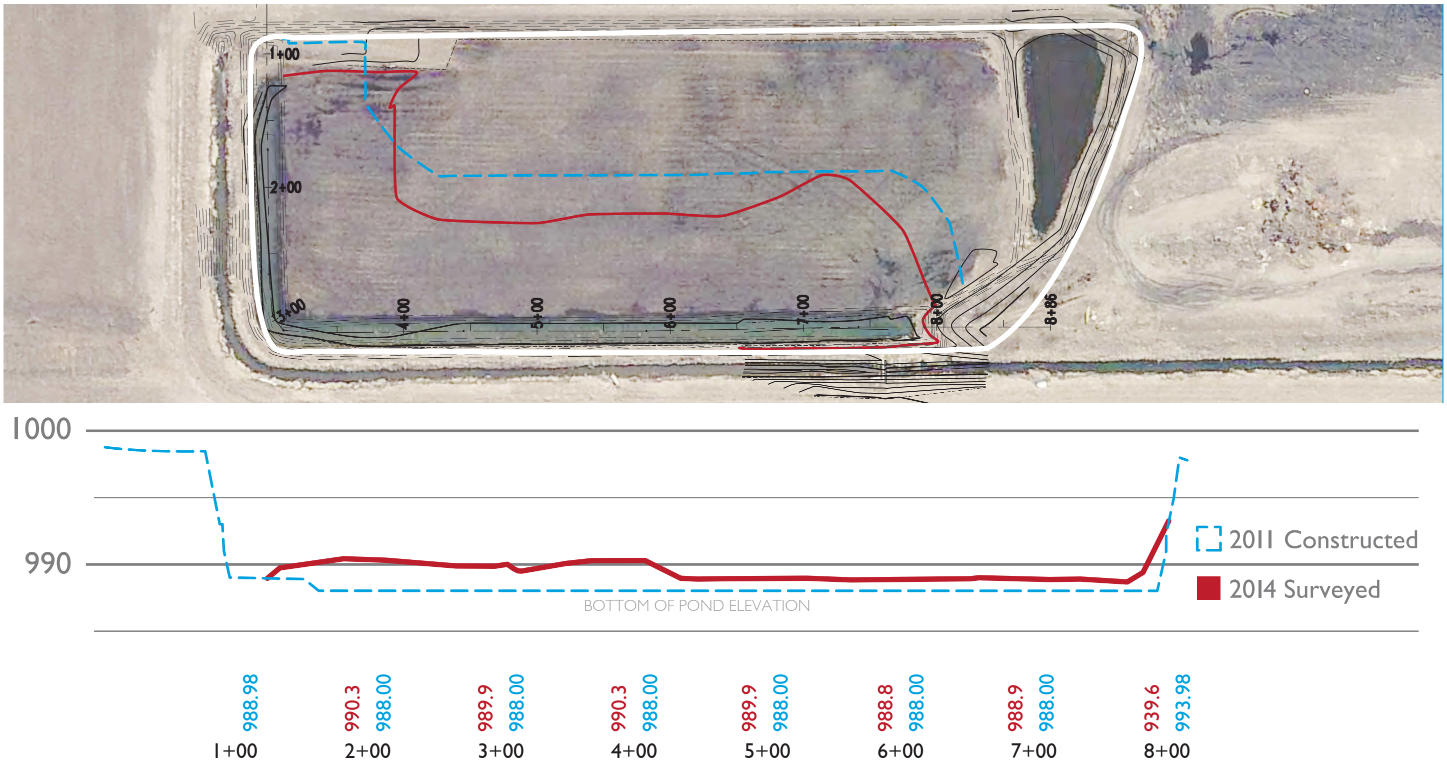


Figure 63 - Klein Pond Profile

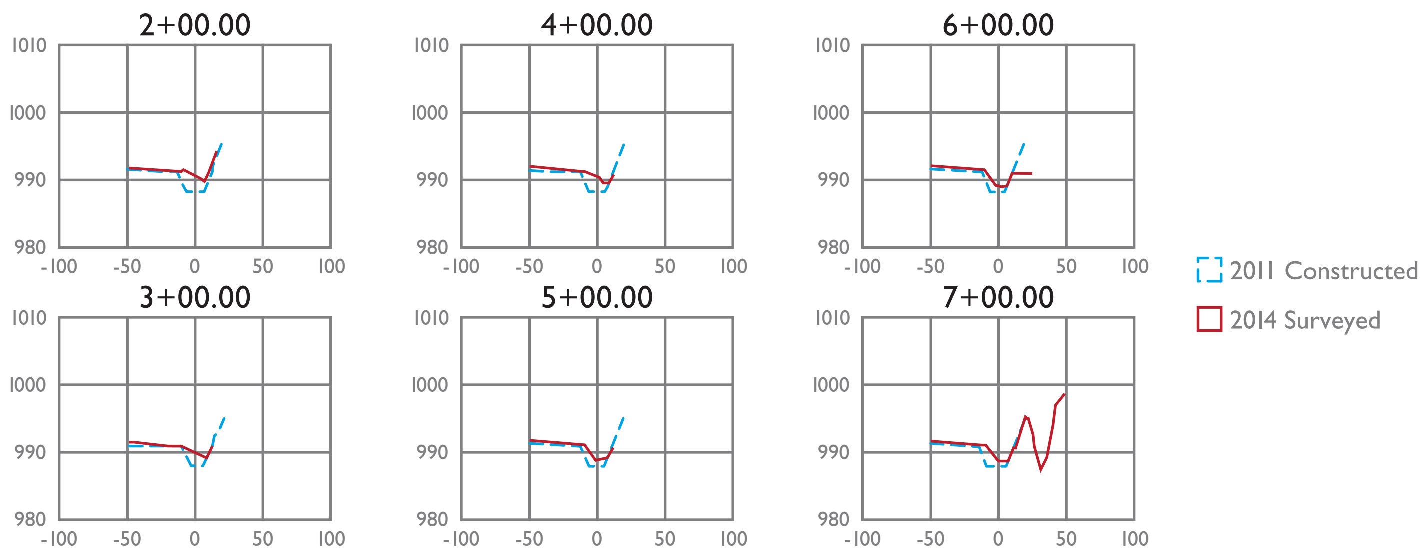


Figure 64 - Klein Pond Cross Sections

STATION	TOTAL TSS LOADING (kg)	TOTAL P LOADING (kg)	TOTAL N LOADING (kg)	PEAK FLOW RATE (cfs)
Upstream Klein Pond	1,465	19.27	1415	28
Downstream Klein Pond/ Upstream Two-Stage Ditch	654	19.20	992	22
Downstream Two-Stage Ditch	618	18.20	947	30
Upstream Rate Control Weir	5,570	75.44	3,955	75
Downstream Rate Control Weir	5,095	66.73	4,326	67

Table 15 - July 9, 2013 Total Loading and Peak Flow Summary

REDUCTIONS

THEORY

In recent years, more emphasis has been put on drainage and water quality in regards to sediment and nutrient loading (MPCA, 2012). Higher concentrations of these have been linked to poor water quality in downstream waters including eutrophication in streams, rivers, and lakes which in turn leads to algal blooms, oxygen depletion, and poor wildlife habitat for fish and waterfowl. Hypoxia and low oxygen conditions have also been linked to poor downstream water quality from these concentrations. Therefore, reducing the loading of sediment, phosphorus, and nitrogen is a key component impacting water quality.

Quantifying BMPs effectiveness in reducing these parameters helps to prove the effectiveness of each BMP in terms of its impact on water quality. It is challenging to visualize the physical amount of reduction for TSS, TP, and TN. Therefore, representing the reduction by a percentage is easier to quantify. *Equation 9* describes the calculation for determining the percent reduction of a BMP.

Equation 9

$$\text{Parameter Reduction}\,(\%) = \frac{\text{Influent Loading - Effluent Loading}}{\text{Influent Loading}} * 100\%$$

Similarly, the peak flow reduction for the rate control weir and Klein Pond can be calculated using *Equation 10*. Peak flow reduction for the two-stage ditch was not considered since its design and function is not to reduce peak flows.

Equation 10

$$\text{Peak Flow Reduction}\,(\%) = \frac{\text{Inlet Peak Flow Rate} - \text{Outlet Peak Flow Rate}}{\text{Inlet Peak Flow Rate}} * 100\%$$

METHODOLOGY

Parameter reductions were determined using *Equation 9* for each sampled rain event from 2012 to 2014 for TSS, TP, and TN. Peak flow reductions were determined using *Equation 10*.

The total loading and peak flow rates from the July 9, 2013 rain event were documented for five key stations (*Table 15*).

Calculating the percent reduction of TSS, TP, and TN for the Klein Pond is as follows using *Equation 9*.

$$\text{TSS Reduction}\,(\%) = \frac{1465\text{ kg} - 654\text{ kg}}{1465\text{ kg}} * 100\% = 55\%$$

$$\text{TP Reduction}\,(\%) = \frac{19.27\text{ kg} - 19.20\text{ kg}}{19.27\text{ kg}} * 100\% = 1\%$$

$$\text{TN Reduction}\,(\%) = \frac{1415\text{ kg} - 922\text{ kg}}{1415\text{ kg}} * 100\% = 30\%$$

Similarly for peak flow rate reduction for the Klein Pond using *Equation 10* results in the following.

$$\text{Peak Flow Reduction}\,(\%) = \frac{28\text{ cfs} - 22\text{ cfs}}{28} * 100\% = 21\%$$

This process was repeated for all four parameters for each sampled rain event from 2012 to 2014.

RESULTS

The percent reduction in TSS, TP, TN and Peak Flow were tabulated for each BMP for the July 9 rain event (*Table 16*). Each BMP and the associated reduction (%) for the July 9, 2013 1.29-inch rain event were tabulated to determine their effectiveness (*Figure 65*). The average reductions during three separate years for the Klein Pond, Two-Stage Ditch, and Rate Control Weir were measured to determine their effectiveness (*Figures 66-68*). Combining these three years of water quality monitoring, the overall average reductions for each BMP was determined (*Figure 69*).

BMP	TSS PERCENT REDUCTION (%)	TP PERCENT REDUCTION (%)	TN PERCENT REDUCTION (%)	PEAK FLOW REDUCTION (%)
Klein Pond	55	1	30	21
Two-Stage Ditch	5	5	4	no reduction
Rate Control Weir	9	12	0	11

Table 16 - July 9, 2013 Total Loading and Peak Flow Summary

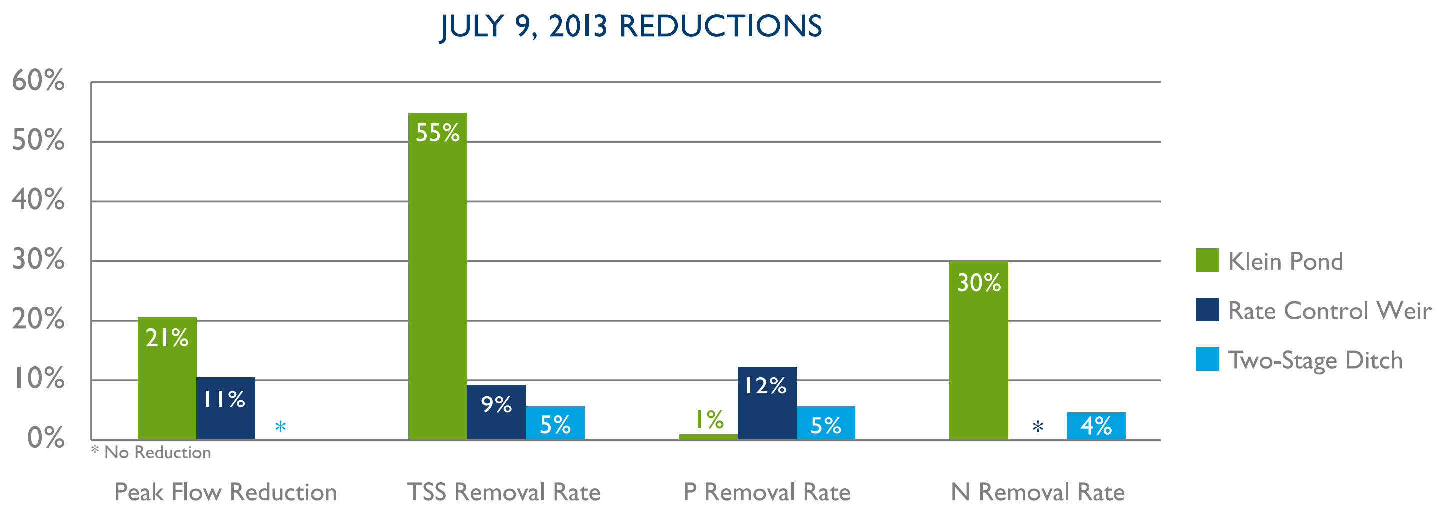


Figure 65 - 2014 Rainfall and Runoff Comparison

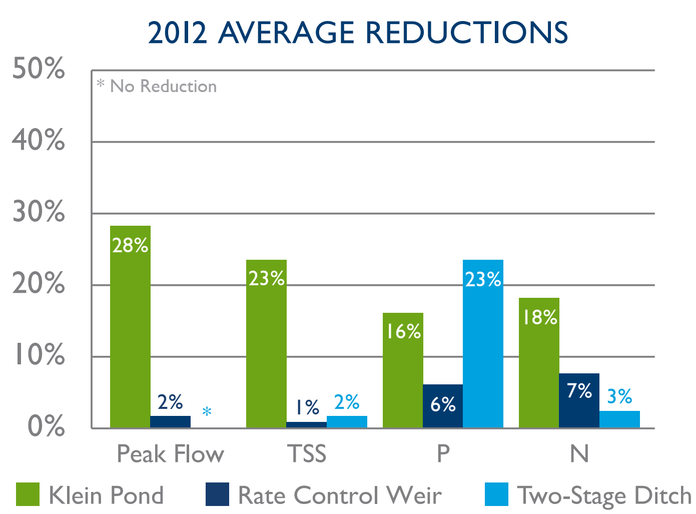


Figure 66 - 2012 Average Reductions from BMPs

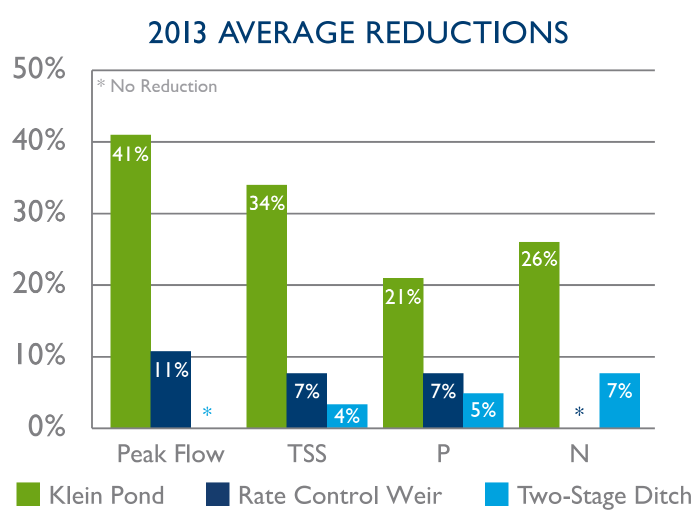


Figure 67 - 2013 Average Reductions from BMPs

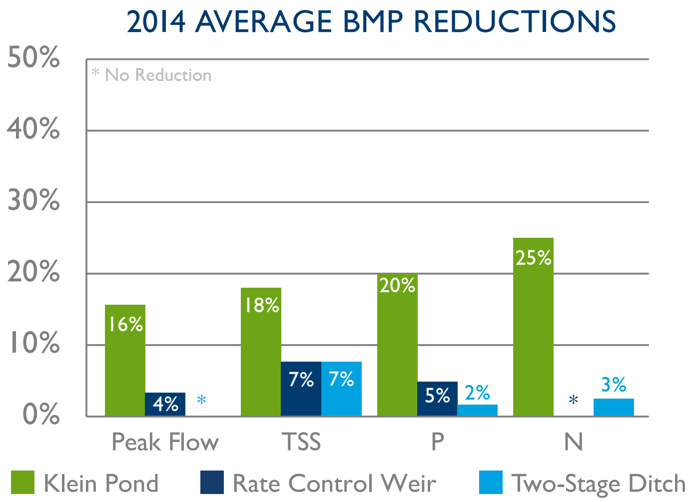


Figure 68 - 2014 Average Reductions from BMPs

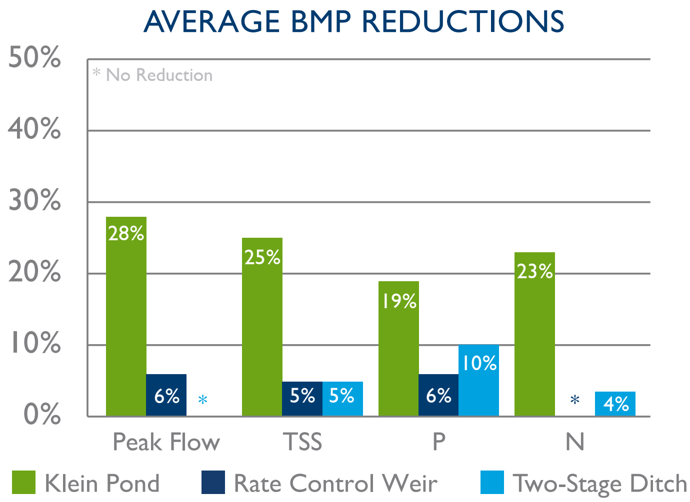


Figure 69 - Three Year Average Reductions from BMPs

ANALYSIS

The above methodology shows how effectiveness was determined for each BMP analyzed. This includes determining the load reduction for the parameters of TSS, TP and TN before and after each BMP. This is related to water quality as it shows the percentage of how much of each pollutant is reduced.

The three year averages for overall effectiveness of the three BMPs analyzed resulted in reductions of all three pollutants. Based on percent reductions, the most effective BMP was the Klein Pond, followed by the two-stage ditch and rate control weir. This can in turn be linked to peak flow reduction and storage. The Klein Pond has the most storage in the entire system at 26.3 acre-feet while the rate control weir provides 6.0 acre-feet of storage. The two-stage ditch does provide storage for a length 1,409 feet of the ditch, however it has a large (54 inch) outlet which does not reduce the flow as effectively as the rate control weir and Klein Pond. The two-stage ditch received added flows from a large watershed with untreated water, yet it still reduced pollutant loading.

While the rate control weir was designed to reduce peak flow rates, it also reduced TSS and TP loading. This had a benefit on the water quality of the system and further suggests that lowering peak flow rates has a positive effect on improving water quality.

The two-stage ditch were lower when compared to Klein Pond for the percent reductions in TSS, TP, and TN. This may or may not be an accurate depiction of the water quality benefits of a two-stage ditch. The two-stage ditch was located immediately downstream of the Klein Pond, thus it was receiving water that was already treated for TSS, TP, and TN. Also, a county tile branch line discharges into the end of the two-stage ditch, draining an area of 500 acres. The water draining into this point does not flow across the entire length of the two-stage ditch, thus may not have the potential to remove sediment and nutrients. However, with all these considerations and ambiguities, it is a major benefit to this system that the two-stage ditch did show notable water quality benefits.

The results for the analysis show that individually the BMPs are effective. While it was anticipated that these BMPs would improve water quality, there was not prior data indicating the extent of their effectiveness. The water quality goal was to reduce pollutant loading and this analysis showed that the BMPs substantially reduced pollutant loading, exceeding expectations. The approach of combining multiple BMPs in a drainage system can maximize the potential benefits of treating agricultural run-off while still increasing the capacity of the system.

CITY RUNOFF

THEORY

All watersheds have vary in terms of soils, hydrology, land cover, and many more parameters. The CD 57 watershed is consistent in soils, topography, and land cover, however a small portion of the watershed is occupied by the City of Mapleton. This portion of the watershed contains impervious surfaces which lead to urban runoff. Urban runoff typically contains more runoff due to the lower infiltration rates and impervious surfaces. It also primarily contains inorganic solids in the

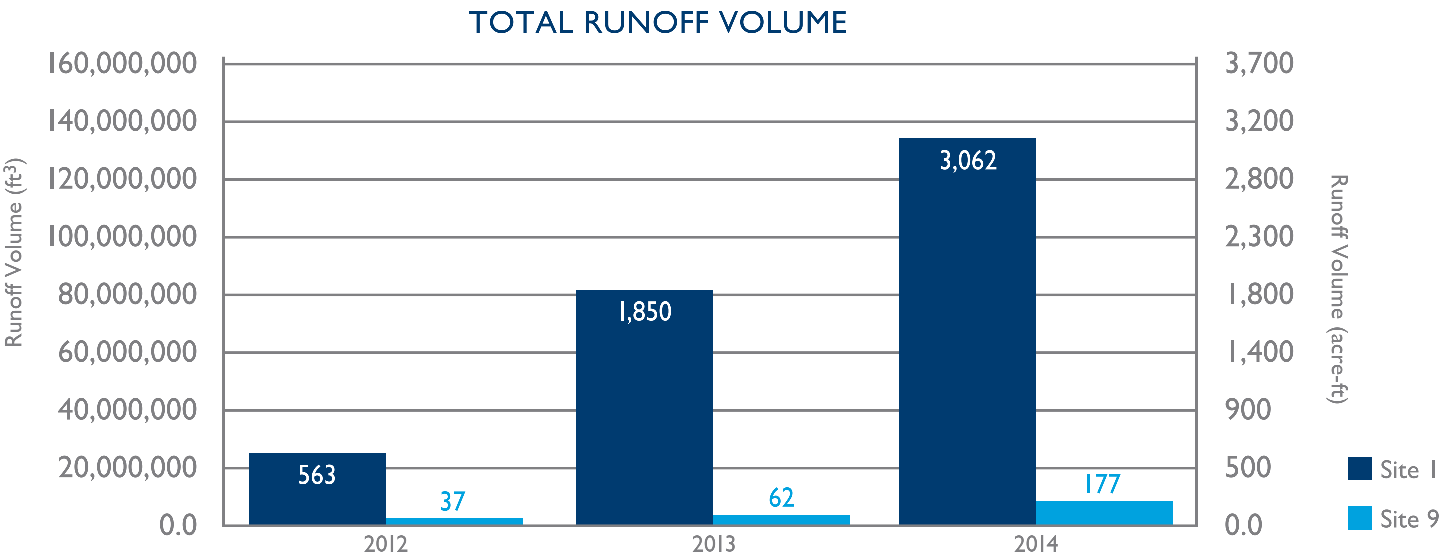


Figure 70 - Urban Runoff and Total Runoff Comparison

runoff such as grit, sand, and gravel.

Flow from urban runoff is primarily routed through storm sewers such as catch basins, manholes, and underground pipe networks. It is typically contained through detention and retention ponds, in which the runoff is stored and released slowly to reduce flooding.

Urban runoff from the City of Mapleton includes 425 acres and is routed through a storm sewer system. The City of Mapleton discharges to the CD 57 system in three locations. Two small stormwater ponds serving a small residential development in the northwest portion of the City discharge to the open ditch to the east of TH 22. The majority of urban runoff (400 acres) is routed through the City Pond and outlets into the open ditch south of TH 30. As part of a routine maintenance, the City of Mapleton discharges treated wastewater from the treatment lagoons to the open ditch twice a year in the east of TH 22.

METHODOLOGY

While the majority the water quality sampling and analysis dealt with agricultural runoff, it is important to compare the runoff from the urban and rural landscapes. Monitoring of urban runoff was limited, but included monitoring stage and water chemistry at the outlet of the pond in a storm manhole. Do to the limited monitoring, the best way to analyze the urban runoff is by comparing the percentage of total volume of runoff and total loading impact that the city runoff has on the entire watershed runoff. This was done by utilizing the flow volume (**Section 9**) and loading (**Section 12**) methods presented previously for Site 9 and Site 1, corresponding to the City Pond and watershed outlet.

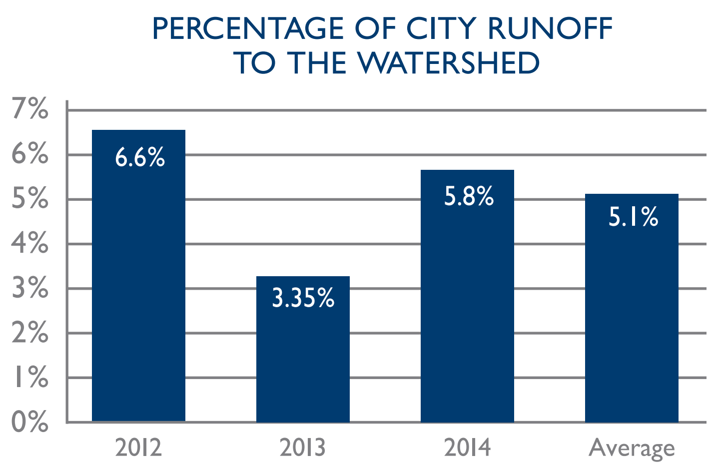


Figure 71 - Urban Runoff and Total Runoff Comparison as Percentage

RESULTS

The total runoff for all three years of monitoring is shown for the City runoff and the runoff from the entire watershed (*Figure 70*). Site 1 contains the flow volume from the entire watershed while Site 9 contains flow volume from the City runoff.

As expressed in a percentage, the urban runoff from the City compared to the entire watershed is shown in *Figure 71*.

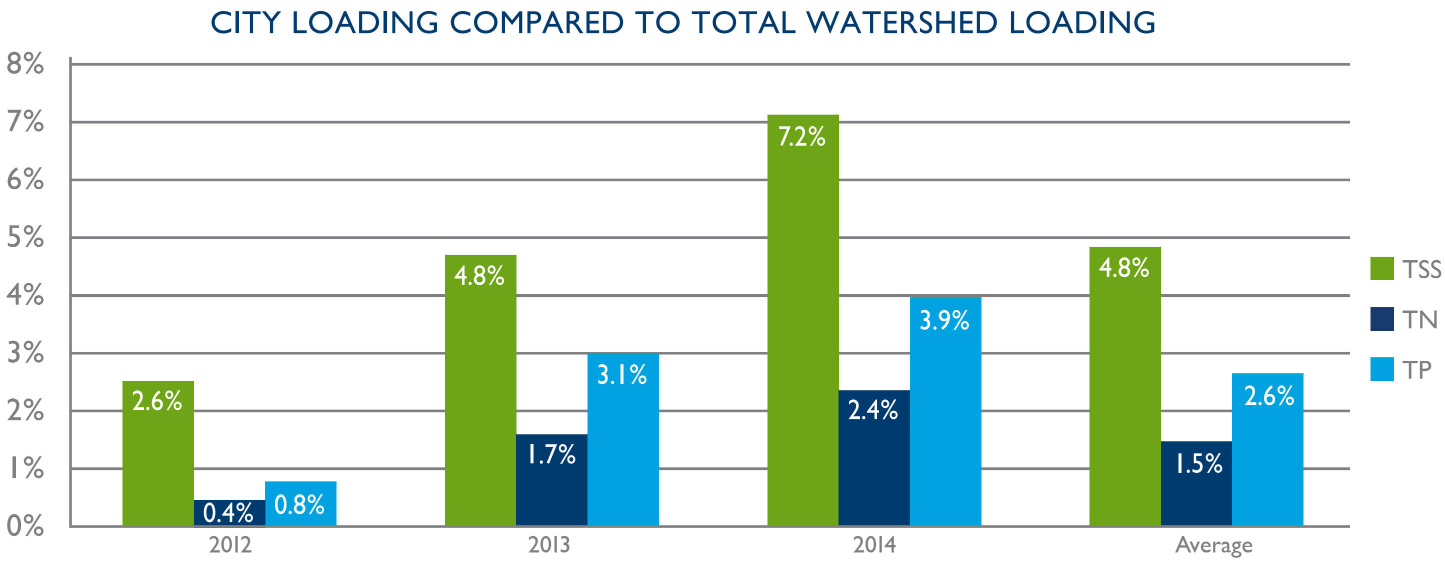


Figure 72 - Urban Loading Compared to Total Watershed Loading

* Does not include wate water treatment pond

The total loading of TSS, TP, and TN for all three years of monitoring is shown for the City runoff and the runoff from the entire watershed (*Figure 72*). The percentage of loading that the City contributes to the entire watershed is broken down by year and averaged.

ANALYSIS

As shown in *Figure 71*, on average the City contributes to only 5 percent of the total runoff to the entire watershed. This is as expected as the City watershed contributes to only 7 percent of the total watershed. The City Pond also stores all of the runoff and slowly releases it overtime. Some of this water is lost through evaporation and evapotranspiration while a portion is retained for the ponds maintained water level.

On average, the City contributes less than 5 percent of the pollutant loading to the watershed (*Figure 72*). The TSS loading contributed the most compared to the entire watershed over TP and TN. This is as expected since the majority of the runoff from urban watersheds contains solids such as grit, sand, and gravel.

The wastewater lagoons discharge directly into the open ditch twice a year. Water quality sampling was not performed at the time of sanitary discharge, therefore an analysis cannot be made on its impacts to the CD 57 system. Wastewater treatment systems are have strict water quality regulations. The City of Mapleton's lagoons have been in place and regulated for more than 25 years.

It is difficult to compare the water quality of the urban runoff to the agricultural runoff as pollutants, monitoring methods, and water quality standards are significantly different. Since urban runoff is part of the CD 57 watershed, there is an impact to water quality. However, to what extent can only be speculated. As shown in the results, the total volume and loading is insignificant compared to the rest of the watershed. A further study including sampling, monitoring, and analysis is needed to fully interpret the impacts that the urban runoff has to the CD 57 watershed.

BASEFLOW DATA COMPARISON

THEORY

River systems in southern Minnesota are comprised of watersheds that are heavily tiled by agriculture and comprised of multiple ditch systems. The geomorphology (soils) are comprised of heavy clay tend to hold water, which drain out over time. Cumulatively, these systems contribute to the baseflows that feed the rivers. Improving water quality during baseflow in ditch systems would improve the overall quality of the river.

While the main function of the ditch during high flows is to effectively drain the landscape for agricultural production, it also serves a function during low flow as an important habitat for wildlife. During low flow a variety of wildlife species including fish, reptiles, birds and small mammals utilize the hydrology effects of a ditch system. Healthy water quality with low pollutant loading is a major contributor to providing optimum conditions for wildlife habitat.

Figure 73 - Pre-BMP Installation Water Quality Grab Sampling (ISG)

Figure 74 - Pre-BMP Installation Flow Sampling (ISG)

METHODOLOGY

While the pre-BMP installation data did not consist of monitoring water chemistry and flow after rain events, it did consist of water quality grab samples of baseflow conditions throughout the system. Baseflow samples were also taken post-BMP installation.

Pre-BMP Installation Monitoring Methods

Water Quality

All pre-BMP installation monitoring was performed by ISG with water quality samples analyzed by Minnesota Valley Testing Labs (MVTL). Water quality samples and flow data were collected from the thalweg (deepest continuous inline within a water channel) of the open water channel. Water quality grab samples were collected for: total suspended solids, fecal coliform, E. coli, nitrogen (nitrate + nitrite), total phosphorus, ortho-phosphate, and suspended volatile solids. Samplings were collected by facing a clean, sterile sampling bottle upstream into the flow to ensure no influence of disturbed water due to wading; facing upside down, and submerging elbow deep water and inverting the bottle until filled (*Figure 73*). Nutrient bottles (nitrogen- nitrates + nitrites, total Kjeldahl nitrogen, and total phosphorus samples) contain 5 mL of 10 percent H2SO4 solution for preservation purposes. The bottles were narrow mouth, high-density polyethylene natural cylinder bottles with plastic and poly-foam 19 lined caps. After collection, bottles were placed in a cooler with ice to keep samples at or below 4°C. Samples were then transported to MVTL in New Ulm, Minnesota within 24 hours for analysis. A chain-of-custody was filled out before and while samples were at MVTL.

Field water quality measurements (pH, temperature, conductivity, and total dissolved solids) were also collected and recorded at the site using a Hanna Instruments HI 98129 multi-probe meter. All probes were calibrated the day of sampling, before sampling began. The probe was held at an intermediate depth in the water column without disturbing substrate materials and remained there until the probe has stabilized the reading.

Flow

For the monitoring period prior to construction, flow measurements were obtained for a cross section of the channel at each of the three monitoring locations. Flow was measured using the Pygmy Flow meter according to methodology described in Harrelson et al. (1994). Flow was measured at the same sampling location (identified by GPS) and was primarily recorded during baseflow conditions due to the hazard of sampling after rain events. To measure flow, a tape was spread from one side of the stream bank to the other. The tape was secured above the surface and pulled taught. The entire distance of the channel was recorded. Depth and velocity are recorded beginning at the edge of the bank where it meets the water (Harrelson et al. 1994). If no water was present at this location, 'no flow' was marked and subsequent measurements were taken at every 10 cm along the tape (Harrelson et al. 1994). The velocity measurements were converted to discharge using the formula provided by the manufacturer. *Figure 74* shows pre-BMP installation flow measurements in the open ditch portion of the system.

Post-BMP Installation Monitoring Methods

Post-BMP installation monitoring methods were described in the **Monitoring Section, Page 8**.

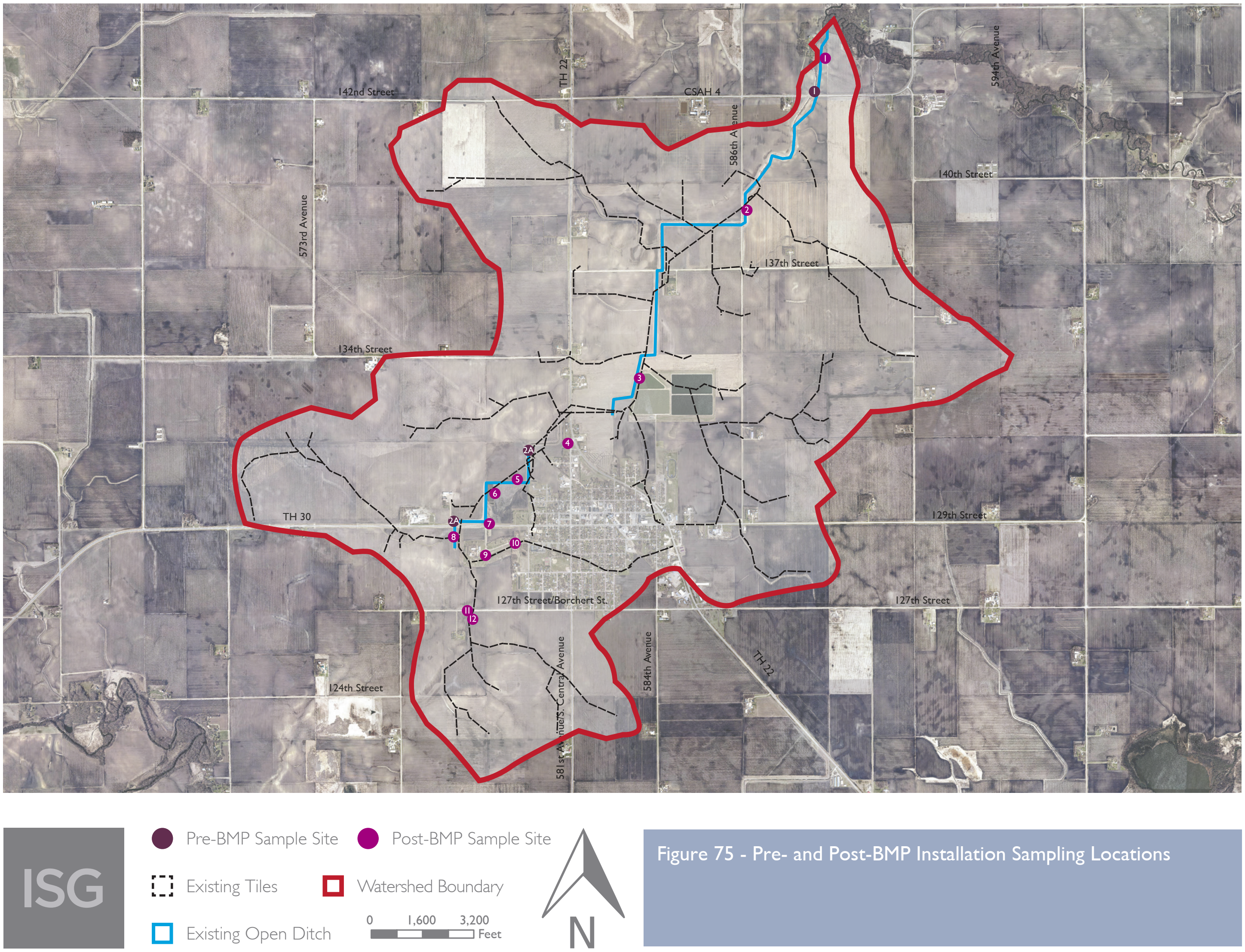


Figure 75 - Pre- and Post-BMP Installation Sampling Locations

PRE-CONSTRUCTION	POST-CONSTRUCTION
3/18/2010	7/17/2012
4/28/2010	7/26/2013
5/19/2010	8/9/2013
7/28/2010	5/22/2014
	7/16/2014

Table 17 - Baseflow Sample Dates

Pre- & Post- BMP Installation Data Comparison

There was limited pre-installation data from rain events, therefore the majority of flow data collected was similar to the post-BMP baseflow. In order to document changes in ditch water quality over time, baseflow samples from both pre-BMP installation and post-BMP installation were compared. Baseflow samples for pre- and post-BMP installation were collected (*Table 17*). These samples did not occur after a rain event and were taken when the stage of the entire ditch was relatively low.

Pre-construction baseflow samples were taken from three sites throughout the CD 57 watershed (sites 1, 2A and 2B). These sites were near the post construction monitoring locations of the rate control weir (1), after two-stage ditch (4), and before the Klein Pond (7). Therefore, these three locations were used to compare pre- and post-BMP installation baseflow water quality. Although flow data was taken for each baseflow sample, an overall volume of TSS, TN, and TP were not compared since no peak in flow rate occurred. The pre- and post-BMP installation sampling locations are identified on a map of the CD 57 system (*Figure 75*).

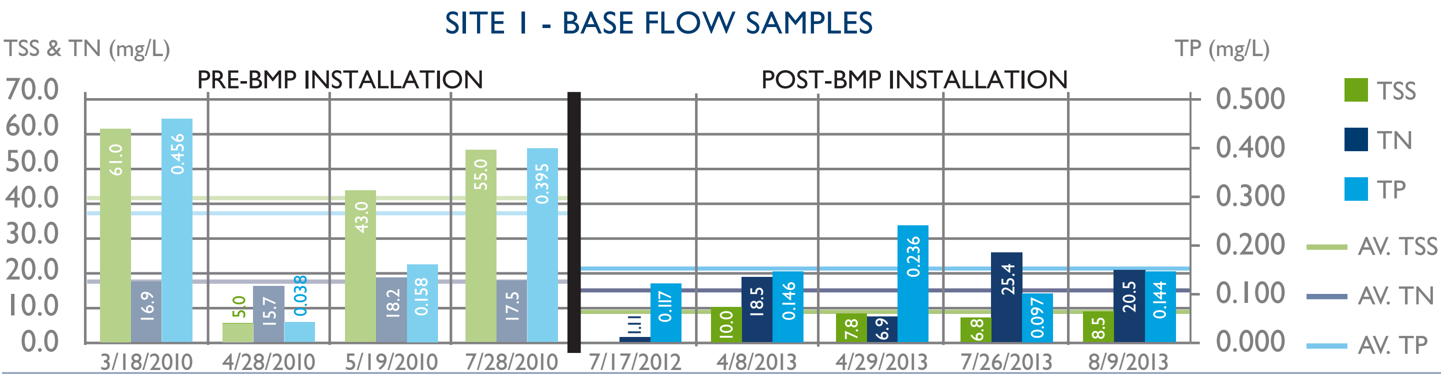


Figure 76 - Rate Control Weir: Site 1 Baseflow Samples

TSS Reduction = 33% TN Reduction = 3% TP Reduction = 12%

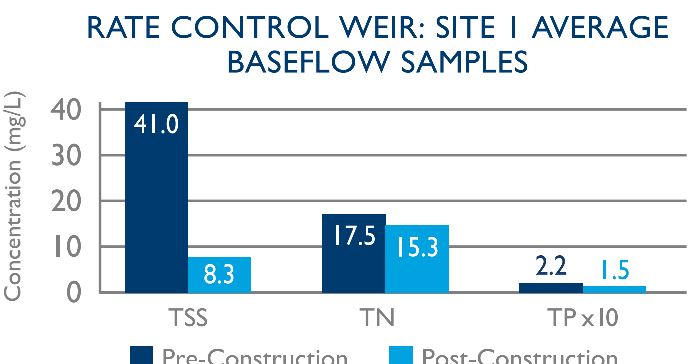


Figure 77 - Rate Control Weir: Site 1 Average Baseflow Samples

RESULTS

Site 1: Rate Control Weir

Both the pre-BMP installation and post-BMP installation baseflow samples at the rate control weir (Site 1) were compared (*Figure 76*). The pre-BMP installation was sampled near the location where the weir was installed while the post-BMP installation was sampled from the weir.

The average baseflow concentrations for TSS, TN, and TP for both the pre- and post-BMP installation samples at the rate control weir were compared (*Figure 77*). This shows the average concentration of each parameter sampled during baseflow events for the pre- and post-monitoring.

Site 4

Both the pre-construction and post-construction baseflow samples at the end of the two-stage ditch were compared (*Figure 78*). The pre-BMP

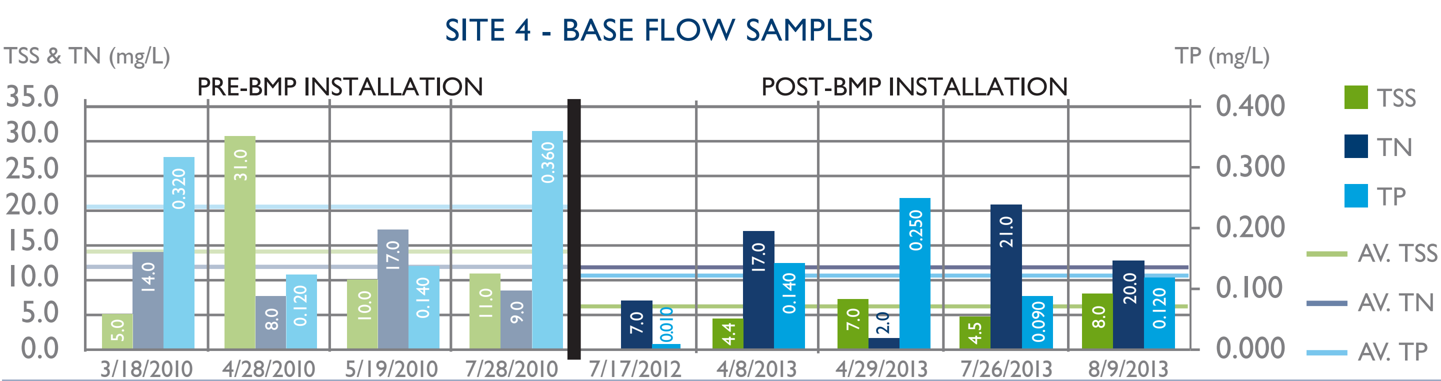


Figure 78 - Two-Stage Ditch: Site 4 Baseflow Samples

TSS Reduction = 9% TN Reduction = 0% TP Reduction = 10%

TWO-STAGE DITCH: SITE 4 AVERAGE BASEFLOW SAMPLES

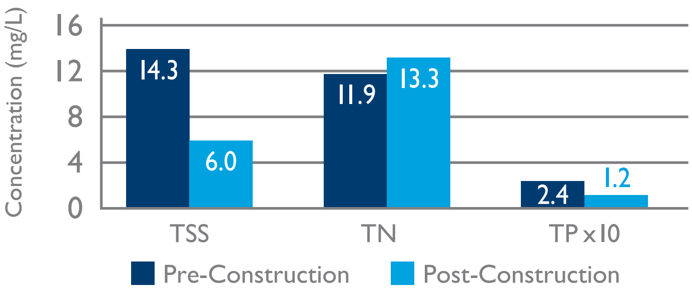


Figure 79 - Two Stage Ditch: Site 4 Average Baseflow Samples

installation was sampled at the end of the existing open ditch while the post-BMP installation was sampled at the end of the two-stage ditch.

The average concentrations for TSS, TN, and TP for both the pre- and post-construction samples at the end of the two-stage ditch (*Figure 79*). This shows the average concentration of each parameter sampled during baseflow events for the pre- and post-monitoring.

Site 7

The pre- and post-construction baseflow samples before the Klein Pond (Site 7) were compared (*Figure 80*). The pre-BMP installation was sampled north of TH 30 while the post-BMP installation was sampled upstream of the Klein Pond.

The average concentrations for TSS, TN, and TP for both the pre- and post-construction samples at the Klein Pond were compared (*Figure 81*). This shows the average concentration of each parameter sampled during baseflow events for the pre- and post-monitoring.

SITE 7 - BASE FLOW SAMPLES

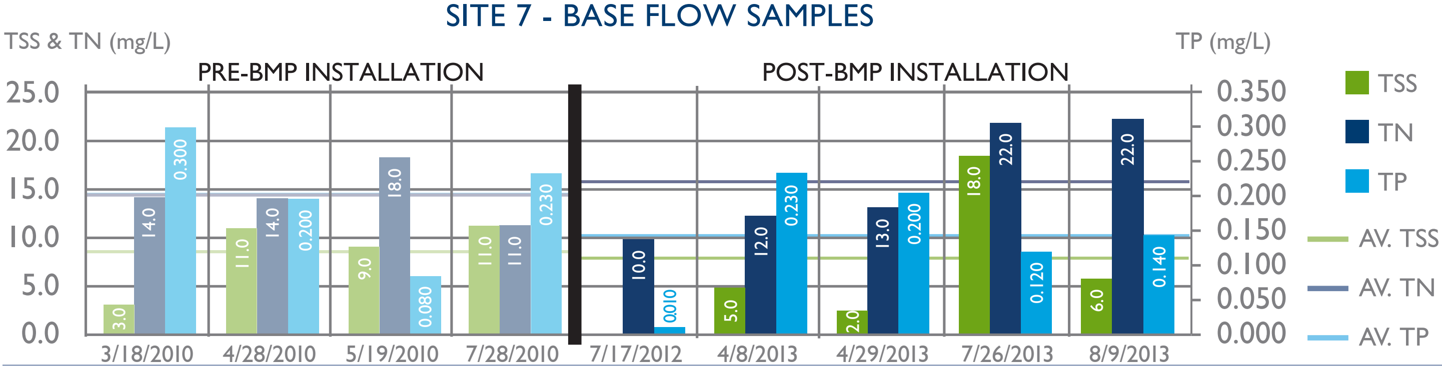


Figure 80 - Klein Pond: Site 7 Baseflow Samples

* No reduction in baseflow

KLEIN POND: SITE 7 AVERAGE BASEFLOW SAMPLES

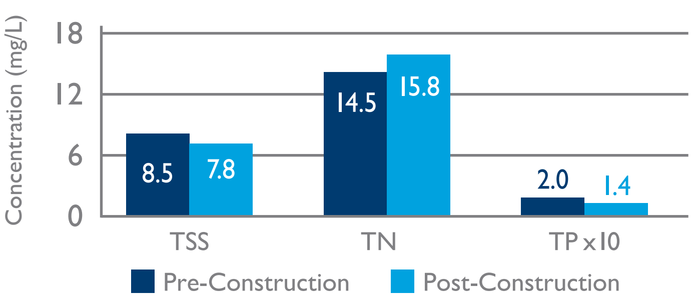


Figure 81 - Klein Pond: Site 7 Average Baseflow Samples

ANALYSIS

The baseflow results for the pre- and post-BMP installation were as anticipated. Sites 1 and 4 were downstream of the series of combined BMPs—considered a treatment train—including the Klein Pond, overdug ditch, two-stage ditch (Site 4), and rate control weir (Site 1). These BMPs were specifically designed to remove sediment from the water flowing through the system. As a result, overall concentrations of TSS and TP were lower for the post-BMP installation versus the pre-BMP installation. The majority of phosphorus traveling through the system is bound to sediment. Therefore, as sediment is removed from the constructed BMPs the concentration of TSS and TP also decreases.

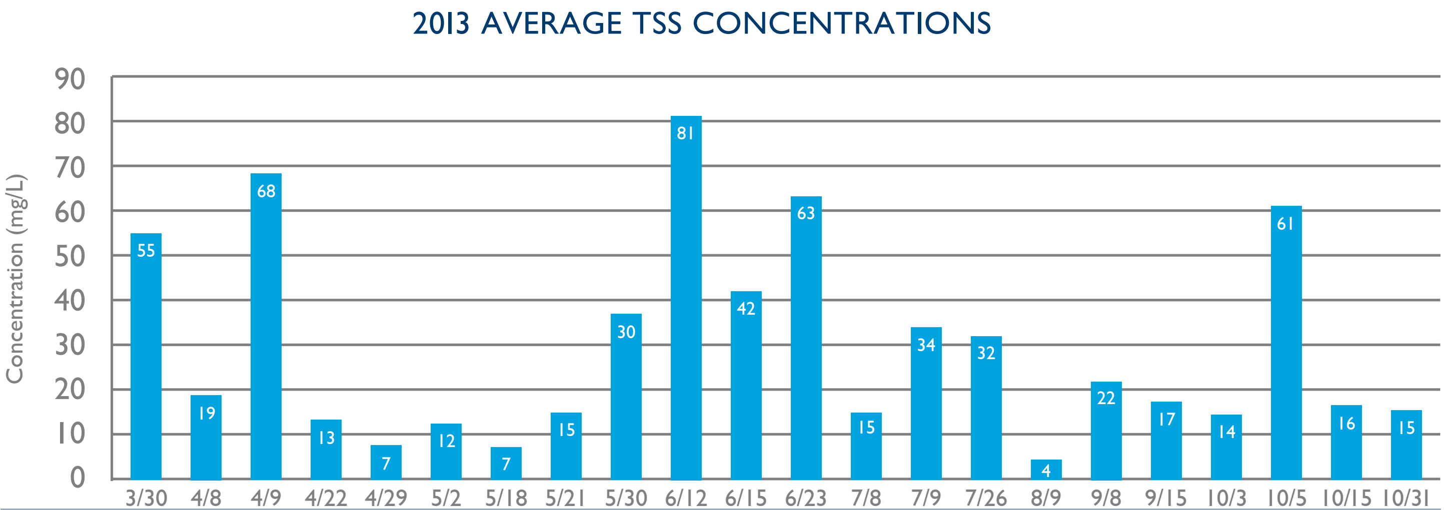


Figure 82 - Average TSS Concentrations for 2013

Nitrogen however, is not primarily attached to sediment particles and is dissolved into each water particle. Therefore, it is always present in drainage water and is expected to remain consistent as it travels downstream. The results shown by the Site 1 and Site 4 comparison supports this theory since the concentrations of both pre- and post-BMP installation samples for nitrogen were relatively consistent (*Figures 76-81*).

The results shown for the Site 7 pre- and post-BMP installation baseflow sampling were also as anticipated. The concentrations for all three parameters were nearly the same on average for this site (*Figure 81*). This sampling site is located before the BMP treatment train, thus the water at this point has not been treated for TSS, TP, and TN. This further supports the fact that the BMPs have a positive benefit for baseflow conditions.

While the major concern for sediment and nutrients in agricultural drainage systems occurs during peak runoff levels where TSS, TP, and TN concentrations are at their highest, it is important to analyze the baseflow conditions as well. The BMPs installed in this system were designed to reduce peak flow rates, thus reduce the loading of nutrients as well. This analysis contains data which supports the fact that these BMPs are both effective during rain events and peak flows, and are also effective during baseflow conditions. TSS and TP concentrations were significantly less during baseflow for the post-BMP installation sampling and thus can be attributed to the BMPs installed.

SEASONAL VARIATIONS

THEORY

It is anticipated that the CD 57 monitoring results had many seasonal variations for the analyzed parameters of TSS, TP, and TN. The beginning months of the growing season (April, May, and June) typically consist of wetter conditions with saturated soil and more flow in the ditch. With the higher runoff throughout the watershed and higher flow rates, it is anticipated the concentrations of these parameters are higher than later in the season when flow rates are lower.

METHODOLOGY

Each of the three monitoring years presented a variety of seasonal variations. Since rainfall varied significantly in depth, duration, and timing, seasonal variations throughout each year will be analyzed separately. For the sampled rain events, concentrations from each sampled site throughout the watershed were averaged. The averages were compared to all other average concentrations for each rain event.

RESULTS

The average TSS concentrations of all water chemistry sample sites for each sampled rain event for 2013 and 2014 were tabulated (*Figures 82-83*). The graphs show the average TSS concentration and the date it was sampled. In 2012, total dissolved solids (TDS) were sampled and not TSS, therefore, 2012 was left out of the analysis.

The average TP concentration of all water chemistry sample sites for each sampled rain event for the years 2012 to 2014 were tabulated (*Figures 84-86*). The graphs show the average TP concentration and the date it was sampled.

The average TP concentration of all water chemistry sample sites for each sampled rain event for the years 2012 to 2014 were tabulated (Figures 87-89). The graphs show the average TN concentration and the date it was sampled.

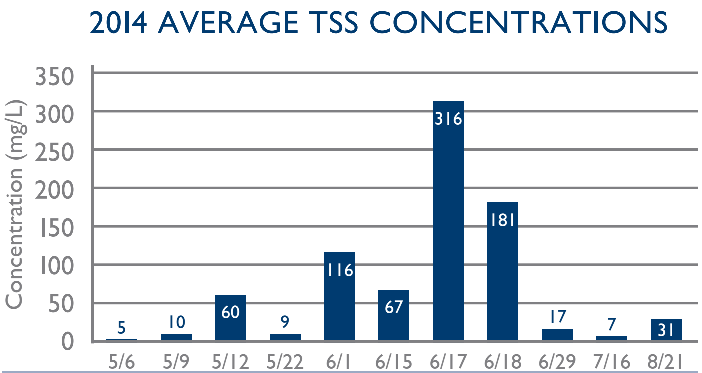


Figure 83 - Average TSS Concentrations in 2014

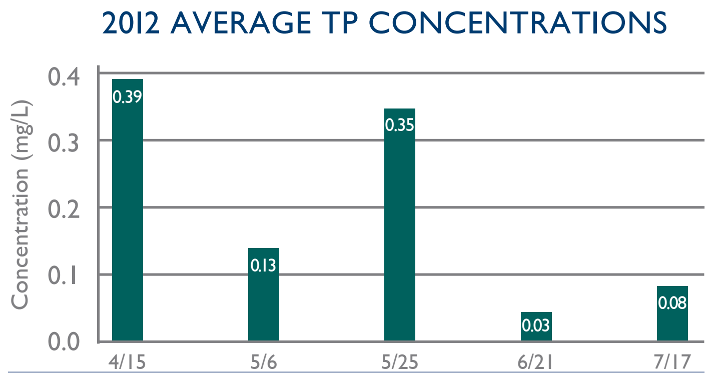


Figure 84 - Average TP Concentrations for 2012

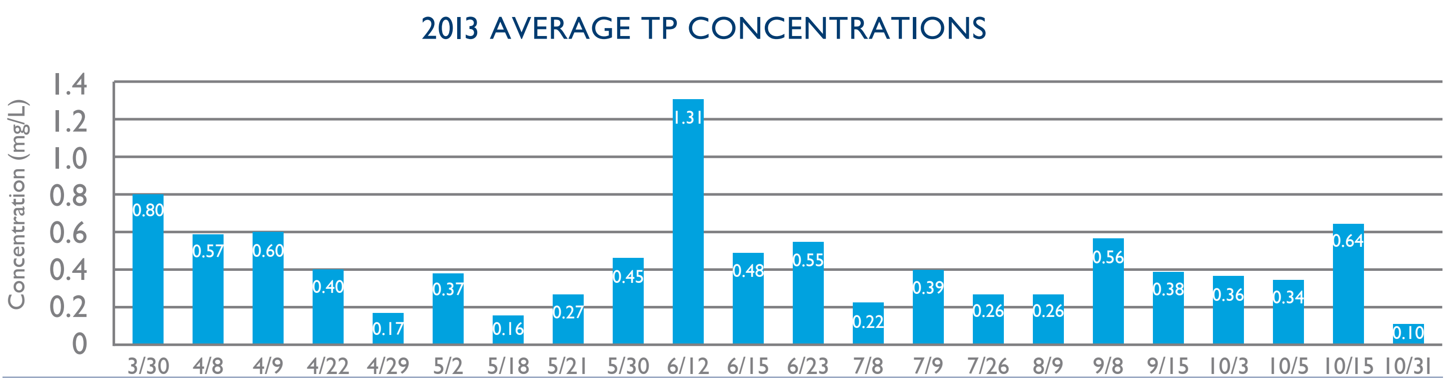


Figure 85 - Average TP Concentrations for July 2013

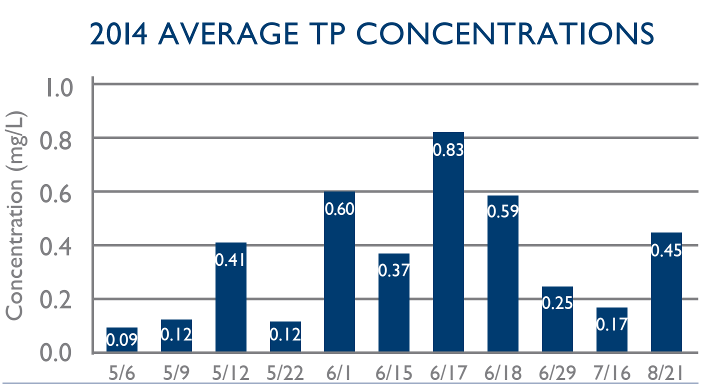


Figure 86 - Average TP Concentrations for 2014

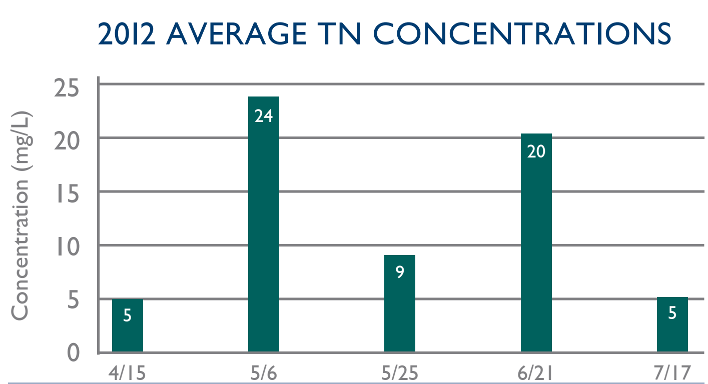


Figure 87 - Average TN Concentrations for 2012

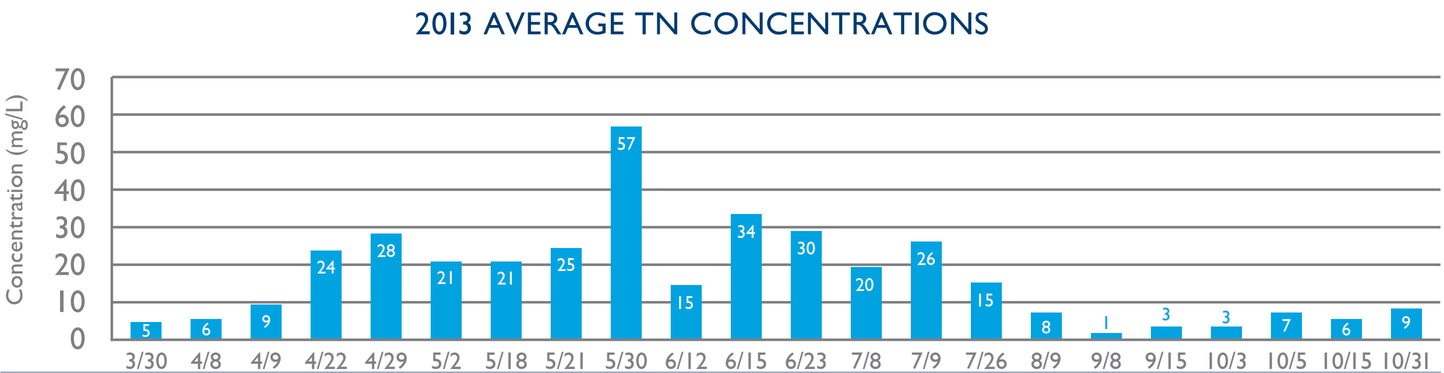


Figure 88 - Average TN Concentrations for 2013

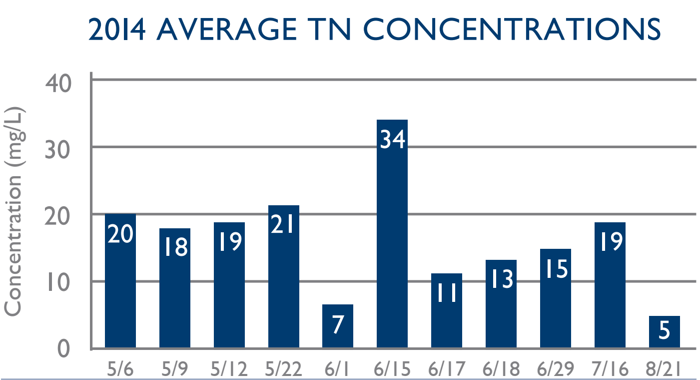


Figure 89 - Average TN Concentrations for 2014

ANALYSIS

In general, TSS concentrations follow the pattern of flow rate throughout the year. In spring and early summer when flow rates are higher, it is expected that TSS concentrations are high since more sediment is traveling through the system. In late summer and early fall as the flow rates decrease and in most cases shut off, TSS concentrations are expected to decrease. Therefore, it is expected that the seasonal variation is TSS follows the variation of flow with higher concentrations in the beginning of the year and tapering off later in the year.

In general, TSS concentrations from 2013 and 2014 followed the expected pattern. In 2013, higher average concentrations of TSS were sampled between mid-May and late July, however some events outside of this range also experienced a higher average TSS concentration. Late March, early April, and late October brought high average concentrations throughout the CD 57 system. This may be caused by the flow conditions of the system. Prior to these samples, the system was at a low or no flow stage. Therefore, with a sudden change in flow, settled sediment may have become suspended in the abrupt change in flow conditions.

The 2014 concentrations for TSS were almost exactly as expected. Flow patterns for this year begin moderately low with a major frequency of rain events in late June. As expected, with the high flows, higher TSS concentrations were recorded. As the year progressed into fall, flow rates diminished and with that, so did TSS concentrations.

Similar to the seasonal pattern of TSS, TP concentrations are also expected follow the same pattern as flow. Therefore, it is expected that average concentrations of TP are higher during spring and early summer when flow patterns are higher and concentrations are expected to diminish during late summer and early fall. The theory behind this is that the phosphorus is primarily bound to sediment as it travels through the system. Therefore, as TSS concentrations decrease, so do TP concentrations.

Average TP concentrations for 2012 gradually decreased throughout the monitoring season for the entire CD 57 system. During early April, high concentrations of TP were recorded and decreased until early May. During May, higher values of TP were recorded, but by the end of May TP values were decreasing and decreased through the rest of the summer. This corresponds to the flow through the system in 2012. After May, no significant rain events were recorded, thus allowing phosphorous bound sediment to remain out of suspension.

The 2013 and 2014 TP concentrations also followed the flow and TSS pattern throughout the year. TP concentrations in spring were relatively high and then peaked in June, corresponding to significant rain events.

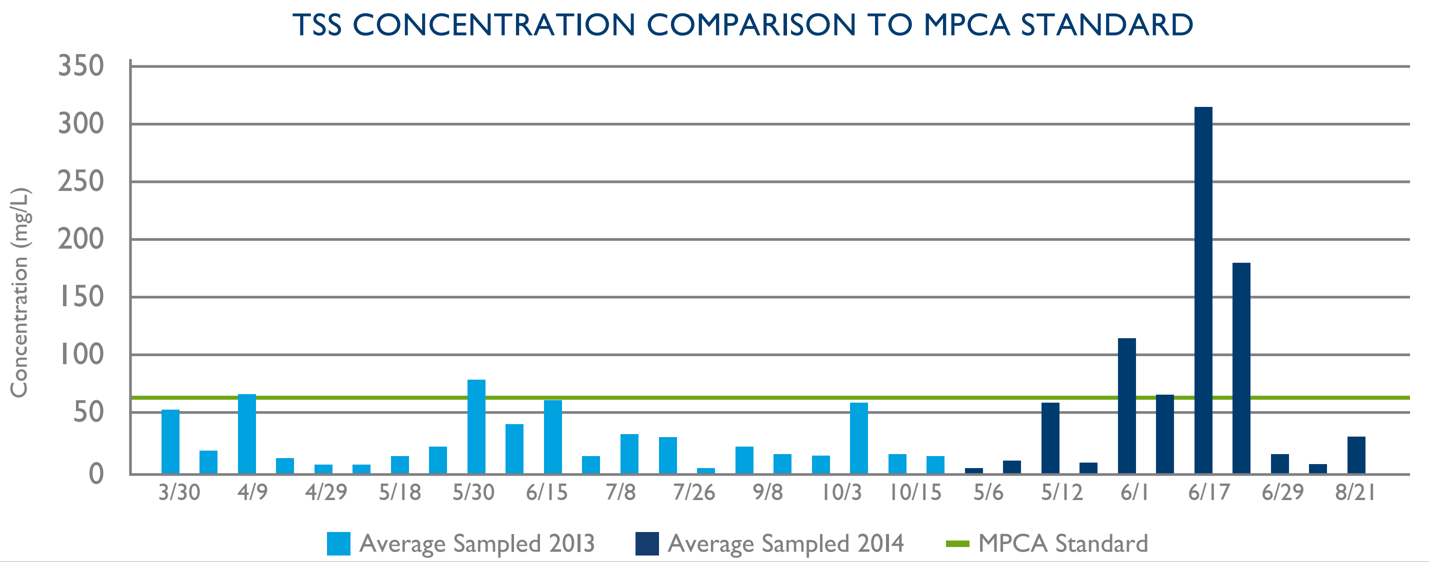


Figure 90 - TSS Concentration Comparison to MPCA Standard

As the year progressed, flows diminished, thus so did TP concentrations.

Among the sampled parameters, TN is expected to have the most notable seasonal variations. This is due to the application of nitrogen to the agricultural fields within the watershed. Nitrogen is always present in drainage water and more specifically leaches through the soil profile and into drainage tiles. It is typically applied in early spring before crops fully take root. As rainfall events occur, the nitrogen leaches into the soil profile. Some of it is consumed by the crop while the rest continues to leach through the soil, eventually into drainage tiles. As the year moves on, crop roots grow and can uptake more nitrogen. Also, with less rainfall and water, less nitrogen leaches to drainage tiles. Therefore, it is expected to have higher concentrations of nitrogen during the spring and early summer while a lower concentration during late summer and fall. *Figures 87-89* support this theory and show the season average concentrations for TN from 2012 to 2014. As expected, in all three years the TN concentrations were higher early in the year due to the bare ground and application of nitrogen, but were significantly lower late in the year as crops began to grow and runoff lessened.

MPCA COMPARISON

THEORY

The MPCA has developed standards for water quality in several different classes of water throughout the state. These standards are developed to classify each waterway for associated impairments for any of these parameters. These standards help develop practices to improve water quality in watershed that contribute to each classified waterway and may help when developing Total Maximum Daily Load (TMDL) or Watershed Restoration and Protection Strategy (WRAPS). For Class 2 waters in Minnesota, the standard concentrations for TSS, TP, and TN are 65 mg/L, 0.30 mg/L, and 10 mg/L respectively (MPCA, 2013).

METHODOLOGY

Similar to the methodology used in **Seasonal Variations Section, Page 49,** for the sampled rain events, the concentrations from each sample site throughout the watershed were averaged for the parameters of TSS, TP, and TN and were tabulated (*Figures 90-91*). Average sampled concentration values for each rain event for the three monitoring seasons were compared to the MPCA standards for the parameters of TSS, TP, and TN.

RESULTS

The average TSS concentrations for each sampled rain event for 2013 and 2014 were compared with the MPCA standard (*Figure 90*). The points on the graph show the average sampled concentration of TSS for rain events while the solid line represents the MPCA Standard.

The average TP concentrations for each sampled rain event were compared to the MPCA standard for 2012 to 2014 (*Figure 91*). The points on the graph show the average sampled concentration of TP for rain events while the solid line represents the MPCA Standard.

The average TN concentrations each sampled rain event for 2012 to 2014 were compared to the MPCA standard (*Figure 92*). The points

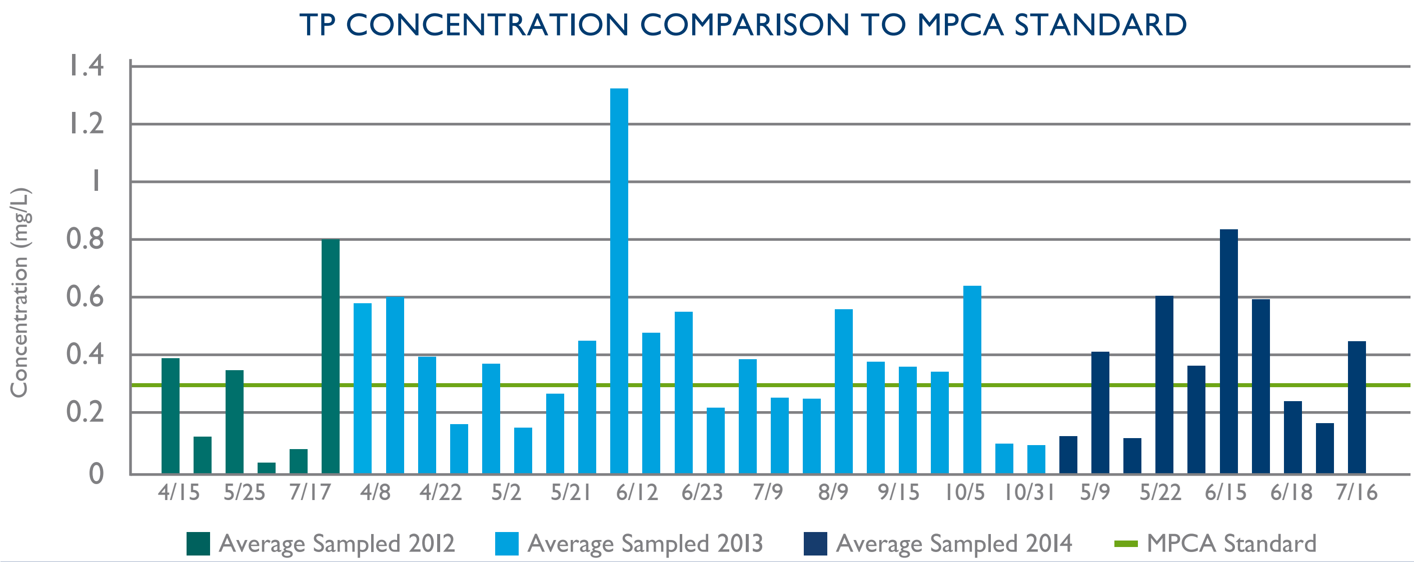


Figure 91 - TP Concentration Comparison to MPCA Standard

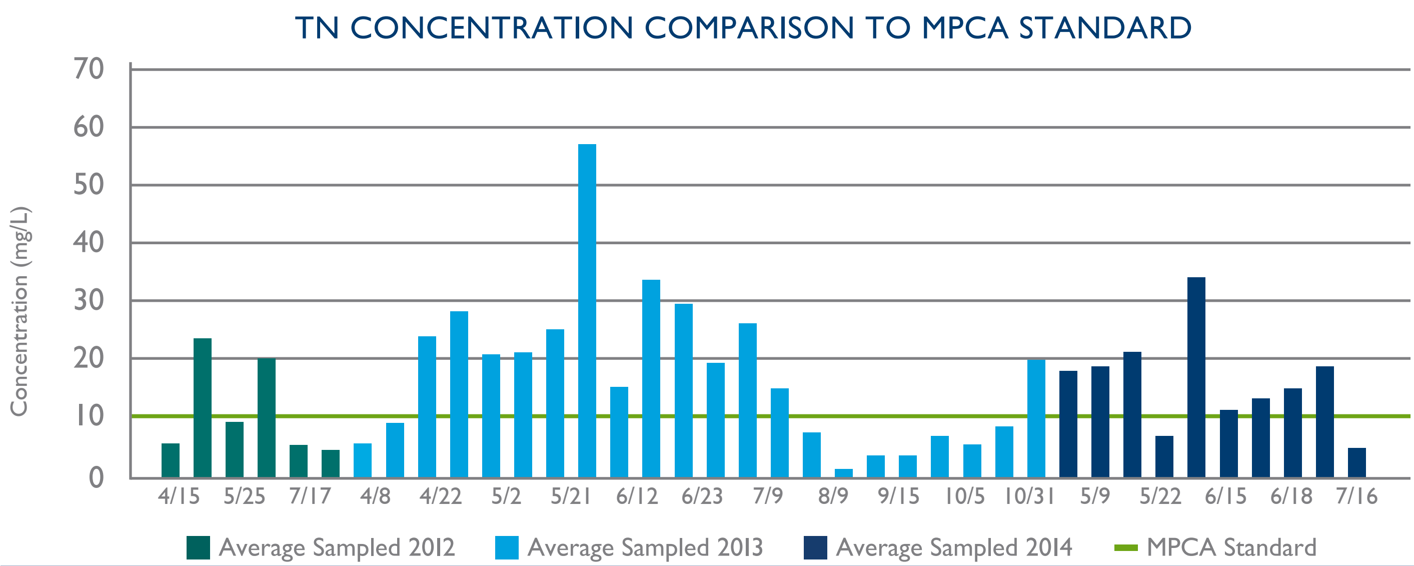


Figure 92 - TN Concentration Comparison to MPCA Standard

on the graph show the average sampled concentration of TN for rain events while the solid line represents the MPCA Standard.

ANALYSIS

The majority of average sampled events for TSS fall within the MPCA standard of 65 mg/L (*Figure 77*). There were a few samples that were outside of this standard. Three of these samples were above the MPCA standard by less than 15 mg/L while three others were much higher than the standard. These three samples occurred during the 2014 monitoring season during the three back to back rain events causing the entire

CD 57 system to fill. This limited the effectiveness of the BMPs until the water receded. Overall, the average sampled TSS concentrations between 2012 and 2014 were in compliance with the MPCA Standard.

Total phosphorus and total nitrogen were not in compliance for the majority of the 2012-2014 sampling period (*Figures 91-92*). TP concentrations were over the 0.30 mg/L MPCA standard concentration during 2013 and 2014. Concentration values during the 2012 season were much closer and in some cases in compliance with the standard. This was likely due to the non-typical low flows during the 2012 season. The higher concentrations during 2013 and 2014 can be attributed to the higher flows for these years.

Total nitrogen concentrations were significantly higher than the MPCA Standard of 10 mg/L during the entirety of the 2012-2014 monitoring seasons. It is unclear why these concentration values were much higher than the standard. One theory can be attributed to high nitrogen applications leaching of nitrates through the soil.

These average concentrations occurred during the peak flow of each rain event when the pollutant loading was at its highest. It can only be speculated how much higher these concentrations would be without the BMPs installed throughout the CD 57 system. Although the majority of the samples revealed TP and TN concentrations higher than the MPCA standards, concentrations of TSS were predominately in compliance with the standard. This is a significant benefit not only to the CD 57 system, but to the downstream receiving waters. High concentrations of sediment (i.e. TSS) have resulted in severe bank erosion, hyper eutrophication in downstream lakes and rivers, sediment accumulation and deposition, and poor water clarity. By reducing TSS concentrations to meet MPCA standards, water quality is improved as CD 57 water enters the receiving waters.

WEATHER CONDITIONS

With only 14 inches of rain throughout the growing season, 2012 was considered a very dry year with limited rainfall events and low flow conditions. The 2013 growing season was considered much more typical as a total of 21 inches of rainfall occurred and was spread relatively evenly throughout April and July. However, 2013 did experience a 2.63-inch rainfall event within 2 hours which is equivalent to a National Oceanic and Atmospheric Administration (NOAA) 25-year rain event.

Considered a very wet year, 2014 experience multiple heavy rainfall events and a few back to back rain events, which primarily occurred in May and June. A total of 21 inches of rain fell with the majority occurring early in the growing season. There were many times where the entire CD 57 system was full of water and restricting flow throughout the watershed. This year also received a 2.02 and a 1.99 inch rain event in back to back days. Both were equivalent to a NOAA 10-year rain event.

SUMMARY

The goal of the water quality portion of the CD 57 project was to design, construct, monitor, and evaluate the BMPs installed. Overall, water quality results of the BMPs proved to be effective at reducing peak flow rates, sediment, nitrogen, and phosphorus loading throughout the CD 57 system.

The Klein Pond, two-stage ditch, and rate control weir all have different functions and were placed in strategic locations throughout the watershed to improve water quality. The Klein Pond was designed to provide storage to the upper half of the CD 57 watershed to improve the drainage capacity while protecting the downstream landowners from flooding. It is functioning as designed and also provides significant water quality benefits to the system by reducing the sediment and nutrient loading. As an alternative to a standard ditch, the two-stage ditch was designed and installed to carry the perennial baseflows. Monitoring results showed that it functions similar to a natural stream and also reduced pollutant loading. Since construction was finished in 2011, the two-stage ditch has experienced very little sloughing or bank erosion, minimizing repair and maintenance costs. The rate control weir was designed to reduce peak flow rates from the system. Monitoring results showed that peak flow rates were indeed reduced and TSS and TP loading was also reduced. Together this combination of BMPs maximized the effectiveness of improving water quality.

An overall goal of the CD 57 project was to provide storage and reduce peak flow rates downstream. This was accomplished while increasing drainage capacity by constructing the Klein Pond and rate control weir. These BMPs stored water during rain events and reduced peak flow rates on average between 6 and 28 percent for the weir and Klein Pond respectively. While providing storage, the Klein Pond also removed over 70 dump truck loads of sediment over the three years of monitoring.

The effectiveness of the Klein Pond, two-stage ditch, and rate control weir were analyzed to determine their reduction of TSS, TP, and TN loading over the three years of monitoring. The Klein Pond was the most effective by reducing the loading of each between 19 and 25 percent. The two-stage ditch and rate control weir reduced the loadings between 4 and 10 percent of each parameter.

The TSS and TP concentrations were more than 30 percent lower during baseflow conditions for post sampling at the outlet of the system (Site 1) and the two-stage ditch (Site 4). The pre- and post- BMP installation sampling concentrations were similar at the beginning of the open ditch upstream (Site 7). At Sites 1 and 4, BMPs were present and concentrations of TSS and TP were lower during the post- monitoring compared to the pre monitoring. At Site 7, no BMPs were installed and the concentrations of TSS, TP, and TN were all similar for both the pre and post monitoring. This shows that the BMPs had a direct impact on water quality during baseflow conditions.

The CD 57 project is now a model for the future of agricultural drainage in the Midwest. This project showed that it is possible to increase drainage capacity while improving water quality. Monitoring the system also provided a baseline of methodology that can be incorporated into future projects relating to monitoring of county ditch systems. With many drainage projects in progress, BMPs can and should be incorporated into these projects to improve drainage capacity, agricultural production, and water quality.

LIMITATIONS

While there were several limitations with the CD 57 monitoring, this project still produced great results and an excellent experience for those involved. The collaboration between Blue Earth County, ISG and MSU was a great opportunity for both parties to develop and adjust methods to produce the best possible outcomes of the monitoring process. As with any research project, several limitations occurred and lessons were learned. The following sections deal with limitations that were experienced with the monitoring of the system.

Monitoring

The first year of post BMP monitoring and sampling was done by MSU's Department of Civil and Mechanical Engineering. There were challenges due to the complex ditch system, inexperience with monitoring equipment and methods, and a learning curve for college students in the first year. In the second year of monitoring, MSU's departments of Chemistry and Geology were added to assist in the sampling of water chemistry. At this time, the Department of Civil and Mechanical Engineering only managed equipment and maintenance. This technique resulted in excellent coordination of monitoring and sampling.

Only 3 BMPs analyzed

The three BMPs that were analyzed included the Klein Pond, two-stage ditch, and rate control weir. Other BMPs were installed in the CD 57 project but were not analyzed. They include native buffer strips, the City Pond, and an overdug ditch.

In order to analyze the BMPs for effectiveness, a sampling point is needed both upstream and downstream of that specific BMP. Native buffer strips were installed throughout the entire length of the open ditch. Therefore it was difficult to install monitoring stations upstream and downstream of this BMP. It was also difficult to sample surface runoff through the buffer strips since flow volumes were very low.

The City Pond also did not have a sampling point upstream of it. There were three different inlet points to the pond, requiring an additional three monitoring stations. Runoff from the City included primarily gravel and grit from the urban streets and impervious surfaces. This project focused on runoff from rural agricultural area, therefore the analysis of the City Pond was left out.

The overdug ditch section began at the beginning of the open ditch, south of TH 30 and spanned through the Klein Pond and ended at the two-stage ditch. It was difficult to analyze this BMP since it was a long segment with a varying watershed and included other BMPs within it.

Only analyzed 3 parameters

While several parameters were sampled for water chemistry, only 3 were included in this analysis. This project was aimed at water quality in an agricultural setting. These main parameters that are linked with rural agricultural runoff are TSS, TP, and TN. These parameters were selected because they also have the most significant impacts on water quality throughout the nation.

Monitoring stage not flow

Monitoring stage provided an accurate depiction of the water depth throughout the CD 57 system, however it didn't provide an accurate depiction of flow through the system. It many cases, backwater and ponding occurred in the ditch, altering flow rates. This was adjusted through hydrographs and photo reviews, however, the process of quantify flow would be much easier and more accurate if real time flow-velocity meters were installed in the ditch. If sufficient funding was available for equipment, data logging devices would have been replaced by flow-velocity meters to monitor flow instead of depth. This would result in more accurate flow readings and would avoid discrepancies with ponding and backwater effects.

Grab Sampling

Grab samples during the peak flow of a rain event were taken assuming that the pollutant loading was highest at this point. While this thesis has been proven in other studies, pollutant loading is not a linear relationship to flow. Rather than one grab sample at the peak flow of the rain event, a real time portable sampler could be installed at each monitoring site. This sampler would take water chemistry samples from the ditch at different intervals of a rain event. This would give more measurements on water chemistry associated with different flows throughout a rain event. Water chemistry could also be tested through a certified testing lab. This would provide a validated water quality analysis of the tested parameters.

Equipment

Equipment used for the monitoring of the CD 57 system experienced many issues over the course of the three years of post- BMP installation. In some instances, the data logging devices experienced internal flaws, which provided missing data or data that was out of range and could not be converted to flow. Onsite cameras provided a good back up for stage data with the staff gauges, however these devices could be easily damaged. In some cases, high winds and heavy rains damaged the cameras beyond recovery. At some monitoring sites, the cameras were tampered with in which the cameras were no longer focused on the staff gauges. Staff gauges were also damaged when large debris flowed through the ditch. Debris including sediment, grass, and trash would collect on the staff gauges and would shift the alignment of the staff gauge and data logging device.

Pre Installation Monitoring Data
It would have been beneficial to do more pre- BMP installation sampling during rain events. This would allow for more analyses on installed BMPs during similar rain events. It would have been best if the same party would have done both the pre and post sampling to insure consistency. Again, sufficient funding would have been required for this approach.

Weather
Weather significantly impacted the monitoring of the CD 57 system. This included damaging monitoring equipment and created unsafe conditions for water chemistry sampling. Timing of weather also impacted installation of the monitoring equipment, as snow and ice conditions damaged equipment. While the weather cannot be predicted or adjusted to fit the monitoring approach, it was, and will continue to be a limitation to monitoring of the CD 57 and similar ditch systems.

The need for future monitoring
With these limitations, it is evident that future monitoring is needed for ditch systems. The approach used in the CD 57 monitoring proved to be an effective method of water quality monitoring, however lessons were learned to further improve the monitoring approach. The next step in monitoring systems is not an easy one as it requires willing landowners, systems with BMPs included in them, and adequate funding for the monitoring.

GOING FORWARD

The results of the CD 57 monitoring showed that all BMPS were effective with the Klein Pond being the most effective BMP for reducing peak flow rates, TSS, TP, and TN loading. This practice took 4 acres of marginal farmland out of production to provide storage and treatment for a large ditch system and reduce flooding. It also increased the drainage capacity, optimizing drainage of agricultural land to enhance conditions for crop production while also protecting water quality. The theory used in urban drainage systems was replicated to store the water, reduce flow rates, and remove sediment from the flowing water. It was the most effective BMP since it stored and treated the largest volume of water.

The Klein Pond was part of a treatment train which was a series of BMPs that were designed to alter the hydraulics of the water to improve water quality. This treatment train included several BMPs designed for different functions as follows:

- Buffer Strips: Control surface runoff by controlling flow rates and trapping sediment
- City Pond: Trap sediment, grit and gravel from urban runoff
- Overdug ditch: Trap sediment passing within the ditch
- Klein Pond: Reduce peak flow rates, provide storage, remove sediment and nutrients
- Two-stage ditch: Provide perennial baseflow area mimicking natural streams to create a self-cleaning system
- Rate control weir: Reduce peak flows at the outlet

While this treatment train was beneficial to the CD 57 system, it is important to develop a specific management plan for each individual watershed. The blanket approach does not fit all agricultural drainage systems. Each BMP is designed for a specific purpose and must be placed in a strategic place in order to optimize its effectiveness. It is important for land managers, watershed groups, and drainage authorities to develop multi-purpose drainage management plans for each individual watershed when repairs and improvements are scheduled. By incorporating these BMPs to ditch systems throughout the Midwest, significant water quality improvements will be seen on both local and national scales.

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