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Effects of Physical Characteristics of Urban Storm Sewersheds on Water Quality in Bloomington, IL

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EFFECTS OF PHYSICAL CHARACTERISTICS OF URBAN STORM SEWERSHEDS ON WATER QUALITY IN BLOOMINGTON, IL

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Increasing urbanization has consequences for surface water quality. Stormwater is a large component of urban water degradation that is poorly understood. Precipitation is quickly transported via underground pipes, from the land to the stream without necessarily following water's natural flow path. Studies have correlated ponds with improved water quality and impervious surface cover with degraded water quality. However, other physical characteristics within a storm sewershed including the presence of sump pumps, area and pipe miles may also affect the stormwater quality. We chose 18 storm sewer systems in Bloomington, Illinois. Using geographic information systems techniques, we delineated the area of these storm sewersheds and determined the physical characteristics of each. In addition, we measured pH, temperature, conductivity, dissolved oxygen, chloride, nitrate, phosphate, and total suspended solids. Relationships and differences among the physical characteristics and water quality were determined using correlation and ANOVA analyses. We found that the presence of a pond significantly lowered total suspended solids and the greater the length of pipe the lower the concentration of nitrate. This research could contribute to how storm sewers are built and retrofitted in the future to decrease the water quality degradation from storm events.

EFFECTS OF PHYSICAL CHARACTERISTICS OF URBAN STORM SEWERSHEDS ON THE WATER QUALITY IN BLOOMINGTON, IL

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EFFECTS OF PHYSICAL CHARACTERISTICS OF URBAN STORM SEWERSHEDS

ON THE WATER QUALITY IN BLOOMINGTON, IL

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CHAPTER I

INTRODUCTION

Literature Review

Increasing urbanization has consequences for surface water quality. The world's urban population continues to rise at a projected annual rate of 1.8% for the next 20 years (Cohen, 2003). In comparison, the global population growth rate is only 1.22% (Cohen, 2003). There are predictable responses of streams to urban development (Walsh et al., 2005a) including increased nutrient and contaminant concentrations (Meyer et al., 2005; Walsh, 2005a).

The majority of contaminants enter streams and rivers as a result of stormwater runoff (Walsh et al., 2005a; EPA, 1999). Rain is relatively pure (Shertzer, et al, 1998) so most contaminants likely come from the surface. The water flows across the surface, enters a storm drain and travels through a pipe to the river. As a result, hydrological processes that take years in a natural watershed may only take hours in cities (Bloschl & Sivapalan, 1995). Hydrographs are most often used during storm events to observe peak flow by plotting stream discharge versus time. In such a hydrography, typically there is a delay between when the storm begins and when increased stream flow is observed. In urban environments this delay is decreased and the peak flow is higher (Walsh et al., 2012).

Run-off occurs when the rate of precipitation exceeds the rate of infiltration. In urban settings there are many surfaces where infiltration possibility is zero (parking lots, roads, sidewalks etc.) making runoff occur immediately (Walsh et al., 2012). Thus, urban environments experience runoff levels eight times more often than undeveloped watersheds (Gallo et al, 2013). This means even small storms that would not normally create runoff will send polluted water to receiving waters (Walsh et al., 2012). In addition, an impervious surface will produce up to sixteen times more runoff than a pervious area (CWP and MDDEWMA, 2000).

Impervious surface cover is strongly correlated with the degradation of urban streams. Additionally, the percentage of impervious surface cover (%ISC) is indirectly related to the time it takes for stormwater runoff to reach the stream (Walsh et al., 2005b; Cantone & Schmidt, 2011). Rivers in watersheds with impervious surface cover greater that 5% have a significantly greater concentration of nitrate and chloride than reference streams (Cunningham et al., 2009). Essentially, higher %ISC increases the efficiency of runoff transportation of contaminants (Hatt et al. 2004). Questions remain about the relationship between water quality and increasing %ISC.

Nitrogen is now more abundant in urban areas than undeveloped ecosystems (Grimm et al., 2005). Increased nutrients are a result of the increased supply and decreased retention (Grimm et al., 2005). In one recent study, watersheds with storm drains had higher concentrations of nutrients than forested watersheds (Kaushal and Belt, 2012).

It is reasonable to expect that a detention or retention pond will improve water quality (Herrmann, 2012). Detention ponds are basins that dry out in between storm events, while a retention pond continuously holds water. Detention ponds and retention ponds, whether intentionally designed to or not, will provide some water quality control measures (Marsalek, 2002). Originally designed to reduce the peak flows during a storm event, ponds will provide treatment through the settling of sediment (Tixier, 2001; Marsalek, 2002). A 2.5-year study by Herrmann (2012) showed nutrient reductions of 43% for nitrogen and 35% for phosphorous.

Infrastructure itself can contribute to changes in water quality in urban stream systems. Concrete ditches and PVC pipes that transport stormwater to rivers may raise pH and contribute calcium and bicarbonate to the stream (Davies et al, 2010). Rainwater collected from a roof that had a pH of 4.8 was raised to 7.9 and bicarbonate went from 0.5 mg/L to 17.3 mg/L after only 100 minutes of concrete contact; all other major ions showed an increase in concentration as well (Davies et al, 2010). If concrete lined pipes and ditches are used to transport stormwater to a stream one might expect changes in some components of the water chemistry.

Storm events are variable and unpredictable. Prior to a storm's occurrence there is no way to determine its exact behavior (Sheng et al., 2008). The frequency and magnitude of previous storms can, of course, affect the available contaminants for later storms. Brodie (2007), for example, found that the load of non-coarse particles during a storm was related to the characteristics of previous storm events. It is often assumed that the highest concentrations will occur in the beginning of the storm in a period called first flush. However, Ren et al. (2008) found that in light rain concentrations varied throughout the event and runoff from road did not always show peak concentrations at the beginning of an event.

One challenge in determining the effect of storm sewersheds is the actual process of delineating the contributing area. Storm sewersheds are a small-scale feature that high resolution elevation data is required. However, fine scale light detection and ranging data (LiDAR) can have a great deal of noise as a result of vegetation and other surface features, which can ultimately result in incorrect drainage paths (Goulden et al., 2014). In addition, most drainage paths are designed to flow along the sides of roads. In an effort to correctly model this in digital elevation models (DEMs), road burning has been used in past. This process lowers the elevation of the road to ensure run-off travels to it (Elgy et al, 1993). Another method used routed determination based on physical characteristics of blocks within the urban landscape and directed flow to the nearest down slope inlet (Green and Cruise, 1995).

Storm sewersheds are different than watersheds. Watersheds are defined as the area in which water drains to a single point. Storm sewersheds have many pour points that are connected by underground outlet. In addition the outlet of the storm sewer system is not necessarily considered a pour point. Given such ambiguities, for this project, we developed a working definition of storm sewershed. A storm sewershed is the land area from which stormwater drains before traveling through a sewer system and discharging to a surface water body.

The purpose of this thesis was to determine what characteristics of storm sewershed affect water quality. The characteristics we expected to change water quality; presence of a retention pond, sewer miles, sewer density, percent impervious surface cover (%ISC) storm sewershed area, presence of sump pumps, and zoning.

Hypotheses

We hypothesized that the presence of a retention or detention pond in a storm sewershed will improve water quality. Ponds increase the amount of time it takes for water to reach receiving waters (Walsh et al., 2005b; Tixier, 2001). The delay allows for settling of solids and nutrient uptake (Herrmann, 2012). Primary indicators used to verify this hypothesis were nutrients and total suspended solids.

We hypothesized that as sewer miles increase, water quality will be more degraded. Almost all stormwater pipes in Bloomington, Illinois, are Portland cement concrete pipe (PCCP) (pers. comm., Kevin Kothe). The more time stormwater is in contact with concrete piping the more ions, such as calcium and bicarbonate, the water will pick up. (Davies et al., 2010). Pipes also connect impervious surfaces leading to greater water quality degradation (Walsh et al., 2005b). Primary indicators used to verify this hypothesis were pH and total suspended solids.

We hypothesized that as sewer density increases water quality will be less degraded. Water picks up pollutants as it travels over the surface (Walsh et al., 2005b). If sewer systems are denser then water will spend less time on the surface. Primary indicators used to verify this hypothesis were nitrate, phosphate, ammonium and total suspended solids.

We hypothesized that as %ISC increases water quality will be more degraded. Percent ISC has been correlated with increased nutrients (Walsh et al, 2005a; Cunningham et al., 2009). Primary indicators used to verify this hypothesis were nitrate, phosphate and chloride concentrations.

Study Area and Project Overview

This study was conducted in Bloomington, Illinois. The City of Bloomington is located approximately 125 miles southwest of Chicago. Immediately north of Bloomington is the Town of Normal. The two municipalities are so close they are locally known as the "Twin Cities." The combined area of the cities is over 90 square kilometers. The combined population of the two cities is approximately 125,000 (US Census, 2010).

A stream, Sugar Creek, flows along the border of Bloomington and Normal (Figure 1). All of the sites in this study drain into Sugar Creek. The storm sewer systems included in this study were primarily owned and maintained by the City of Bloomington (pers. comm., Kevin Kothe). Three systems also had connections with private owners and one system was entirely private. It should also be noted here that some storm sewer lines, whether public or private, may not appear on maps as underground features can be easily overlooked or forgotten.

Geologically, the city of Bloomington is located on an end moraine of the Wisconsin Glaciation. The geology of the area is primarily glacial till of the Wedron Formation composed of pebbly clay till (Weibel and Nelson, 2009). There is also a thin alluvial deposit (Stiff, 2000) along Sugar Creek.

The majority of the storm sewer system in Bloomington was built between 1950 and 1980, making the system, at least in part, slightly older than the national average of 45 years (Chang & Hernandez, 2008). Much of this system requires replacement and expansion. The Municipal Separate Storm Sewer System (MS4) regulates the city of Bloomington with a permit administered by the Illinois Environmental Protection

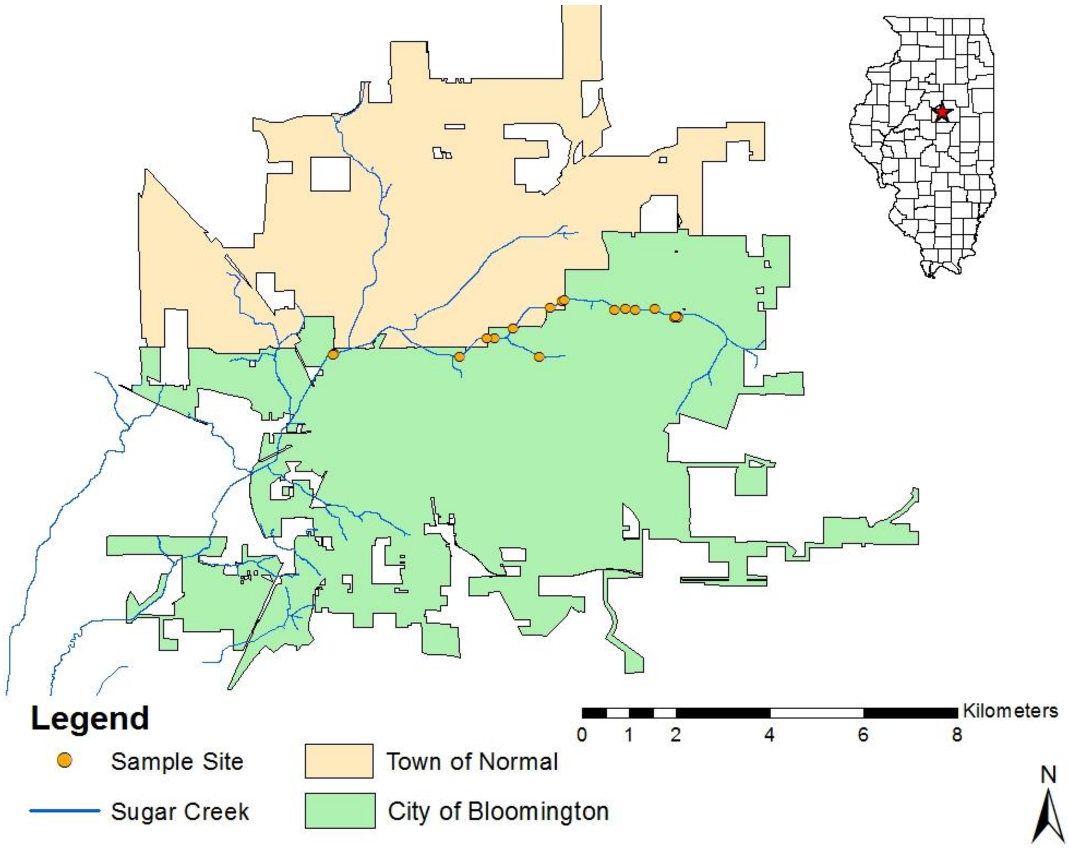

Figure 1. Site Locations. Locations at which storm water sampling took place. Samples were taken at a storm sewer outlet prior to the water reaching the stream

Agency. The city of Bloomington has committed to make efforts over twenty years to improve stormwater quality (City of Bloomington, 2013). The pipes were made of PCC, clay brick or polyvinyl chloride (PVC) (pers. comm., Kevin Kothe) and vary in size at their outlets from 30 cm to 364 cm. The storm sewer system studied is primarily gravity fed; except for sump pumps.

Between the months of May 2014 and February 2015 we sampled eighteen storm sewer systems for water quality during flow events. This study was limited in that only one sample was collected from the outflow of each storm sewershed during each event. We aimed to take a sample near the beginning of each storm event, but it was not possible to know exactly at what point in the hydrograph a sample was taken. However, we assumed that the physical characteristics of each storm sewershed would affect the water quality in a similar manner throughout the entire hydrograph.

CHAPTER II

DETERMINING THE PHYSICAL CHARATERISTICS OF STORM SEWERSHEDS WITH GIS

Introduction

Storm sewer systems are an important aspect of city design; they prevent flooding by quickly transporting runoff to a waterway (City of Bloomington, 2013). Growing concern about the health of urban streams has led scientists to consider the chemical composition of storm runoff (Gallo et al., 2013; Meyer et al., 2005; Walsh et al, 2005a). Runoff water chemistry is dependent on the surfaces over which that water travels (Choe et al, 2002; Chow and Yusop, 2014). If the area that contributes runoff can be categorized then we can understand more about patterns in runoff chemistry and potentially improve water quality as we build new and retrofit existing storm sewers. The purpose of this portion of the project is to explain and critique a method of delineating storm sewersheds using simplified methods and readily available data. This of course, will then allow us to determine the characteristics of those sewersheds.

The path of stormwater through a storm sewer system is different than in an undisturbed watershed (Bloschl & Sivapalan, 1995). Watersheds are defined as the land area over which water flows before draining to a single point. A storm sewershed is the land area over which stormwater drains before traveling through a sewer system and discharging to asurface water body or stream. A storm sewershed is therefore different in that it has multiple pour points that are separate on the land surface but connected via underground pipes. As a result precipitation that lands in one watershed may be transported to another watershed via the underground network (Crimmens, 2006). Natural watersheds have channels that are in constant flux due to erosion and deposition, whereas the channels in urban environments are designed and held constant by city engineers. Undisturbed stream channels and watersheds are connected to the groundwater, but impervious surface cover (ISC) in urban systems reduces the opportunity for storm water to enter the groundwater system (Arden et al., 2014). Once stormwater reaches an impervious surface it is unlikely that it will have another opportunity to infiltrate prior to being discharged to the stream.

In urban environments some land features such as buildings and roads direct stormwater flow. Past studies have manipulated their digital elevation model (DEM) in an effort to obtain the best delineation of the contributing area. One technique called burning forces flow away from buildings and towards roads (Elgy, 1993). Another technique uses breaklines to prevent flow from crossing barriers (Graham, 2012). The downside of using such techniques is that alteration of the DEM for an entire city could take a great deal of an analyst’s time and effort. As technology for generating DEMs advances their sensitivity increases and achieving success with delineating sewersheds with less manipulation becomes more possible. Light detection and ranging (LiDAR)-derived elevation sets have finer resolution that other DEMs. LiDAR data often has cell sizes less than 1 meter while common DEMs may have cells of 5 meters or 10 meters. We chose the finest scale resolution (0.76 m cell size) LiDAR available for our area. However, LiDAR is not without its limitations, it can have a great deal of noise due to the presence of vegetation and other surface features (Goulden et al, 2014). The LiDAR then goes through a filtering process to remove this noise and smooth the landscape. The resulting dataset, called a "bare earth model," has far less error; it represents the topography as if there was no vegetation or structures on the land surface. The small scale of storm sewershed (less than 2 km^2 in most cases) requires fine enough resolution on the DEM to detect subtle changes in topography within a small area.

The primary objective of this portion of the project was to create a model to delineate the boundaries of storm sewersheds using geographic information systems (GIS) and to do so with minimal manipulation of the initial datasets. With such a delineation completed, we then determined for each sewershed the percent impervious surface cover (%ISC), primary zoning, and inlet density. We also observed the presence or absence of ponds and sump pumps in storm sewersheds. We completed this analysis for eighteen storm sewer systems in Bloomington, Illinois, sampled for this study. We used statistical analysis to determine any correlations between physical characteristics.

Study Area

This study was conducted in Bloomington, Illinois. The City of Bloomington is located approximately 125 miles southwest of Chicago. Immediately north of Bloomington is the Town of Normal. The two municipalities are so close they are locally known as the "Twin Cities." The combined area of the cities is over 90 square kilometers. The combined population of the two cities is approximately 125,000 (US Census, 2010).

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The eighteen storm sewersheds we analyzed were chosen in an effort to maximize the variability of their characteristics. We used a combination of aerial imagery and initial data sets to select storm sewer systems to study. Size and shape were the primary criteria utilized in this selection process. We wanted to analyze a range of size of systems and so, we judged the area on the length the pipe in a storm sewer system. Our choices based on shape narrowed down the possible storm sewer systems, we attempted to choose some that were long and skinny and others that were more square-shaped. Our final criteria for selection was a visual determination of zoning, we tried to include several storm sewer systems that drained different zoning classifications. In other words, we chose certain storm sewer systems because they drain residential areas and others because they draining parking lots and commercial areas.

Methodology

Characterization of storms sewersheds is, of course, dependent upon knowing the land area that contributes water to the storm sewer system through a system of inlet drains to underground pipes. It required detailed large scale vector datasets describing the area (e.g. zoning and ISC) in addition to the DEM. Examples of such characteristics include percent ISC and inlet density. The procedure we created to determine and characterize the area contributing to storm sewers was implemented in a GIS environment. Initial data layers included elevation, storm sewer networks, inlets, impervious surface cover, zoning, ponds and aerial imagery (Table 1).

The elevation dataset used was a LiDAR-derived raster dataset with a cell size of 0.76 m. The horizontal accuracy was 1 meter and the vertical accuracy was 0.4 meters. The sewer system and provided inlets had horizontal accuracy of approximately 1.5 m. Additional inlets were generated manually in parts of the city that were built since the inlet layer was created. This was accomplished via interpretation of aerial imagery, which was flown in 2014 with a spatial resolution of 7.5 cm. The LiDAR data set covers

Table 1

Sources and Details of GIS Data Used in this Project

Data	Type	Source	Resolution	Year
McLean County LiDAR	Digital elevation model	Illinois Department of Transportation	0.76 m	2012
ISC	Shapefile	City of Bloomington		2004
Bloomington Zoning	Shapefile	City of Bloomington		2008
Normal Zoning	Shapefile	McGIS		
Inlets	Point file	City of Bloomington		2004
Bloomington Sewer System	Line file	City of Bloomington		2002
Ponds	Shapefile	City of Bloomington		2001
Bloomington Aerial Imagery	Raster	McGIS	7.5 cm	2014
Sample Locations	Point file	Remote Sensing & GPS		2014

Bloomington and the surrounding areas, divided up into 0.76 meter squares, which makes the file size very large. In an effort to reduce the amount of time to process data, we restricted the processing extent to the area surrounding the storm sewer network. The reduced geographic extent for each storm sewershed improved GIS processing time of each attempt from several hours to under a minute in most cases. In cases where we underestimated the contributing area we expanded the processing extent and ran the processes again. We generated a model of the entire process so that it was easily repeatable; we simply changed the input files in order to run it for each storm sewer system.

We used the d8 method (Tribe, 1992) to delineate our storm sewersheds. It used topography and the location of a pour point. The key difference between our methodology and the standard watershed methodology was the location of the pour points. Instead of being located at the mouth or junction of stream, our pour points were located at the inlets to storm sewers. Storm sewer systems in this study included as few as 2 inlets and as many as 463. The first step in the d8 method was to remove any sinks (typically erroneous cells that are completely surrounded by higher cells), and fill those sinks to smooth the topography. Then we determined flow direction for each cell. This process assumes that a cell will contribute water to one of its 8 surrounding cells, specifically the one with the greatest slope downhill. The watershed function was then used to determine which uphill cells contributed water to a selected point called the pour point. The watershed function delineated a contributing area for each inlet, we reclassified the area to be represented as a whole for classification of the physical characteristics.

There is inherent horizontal error in both the DEM and the pour point layer, meaning that the location of the pour point in its layer may not line up with its location on the DEM. To ensure the optimal pour point is chosen another file was created called the flow accumulation. This file is a representation of the number of cells that contribute to each cell. The pour points were then snapped to the highest point of water accumulation (i.e. the cell that has the most cells contributing water to it) within a specified map distance (Figure 2). Snapping the pour points varied among the different storm sewer systems. The original distance threshold allowed for a pour point to snap was 1.5 m, allowing for the same amount of horizontal error that is documented for the inlet layers. Even still, delineating watersheds became an iterative process as some inlet locations produced areas of only a few pixels. Such inaccurate delineations were likely due to the combination of inherent error between the DEM and inlet layers. We extended the snap radius by intervals of 0.76 m until all inlets produced a reasonable area. The furthest snap radius used was 4.5 m (Table 2). Some inlets were compared to the flow accumulation layer and determined they would not create an area.

Once the area of each storm sewershed was delineated, we used a variety of spatial analysis methods to determine the physical characteristics of each sewershed. Originally the watershed function determines the area that contributed to each inlet. The total watershed area was merged through a reclassification so that the total sewershed for each sample point had a value of 1 (Figure 2). Since the impervious surface layer was published in 2004 and construction had taken place, we used the aerial imagery to digitize the new roads and structures manually. The impervious surface layer for the entire city was then converted to a raster and reclassified so that the impervious

Table 2

Various Snap Distances Used to Determine Pour Points

Snap Distance (m)	Number of Storm Sewersheds
1.5	4
2.3	5
3	4
3.8	3
4.5	2

area was also given a value of 1 and the pervious area was given a value of 0. We multiplied the impervious surface layer and the total sewershed area in raster calculator and where the two coincide in the resulting layer yielded a value of 1 sewershed. We then computed the percentage of ISC by dividing the number of cells that were considered impervious by the total number of cells in the storm sewershed. This was then converted to back to a polygon file, and, the resulting shapefile was converted back to raster in order to get the area.

The zoning layer was clipped to the area of the storm sewershed first and then converted to raster. The zoning layer was classified by zoning type, and then the area of each was calculated by multiplying the number of cells by the area of each cell (0.6 m^2). We aggregated different zoning classifications into 4 groups (Table 3): commercial, residential, open space and roads. Roads were not an official zoning classification; rather, roads were the only area of the city that was unzoned. They are considered important in this study because stormwater was directed to roadways to be efficiently transported to the storm sewer. Therefore, the zoning percentage of each storm sewershed was compared to its total area and any cells not assigned a zoning classification were assumed to be a roadway and a percentage of road was calculated as the remaining percentage. Inlet density was calculated by simply dividing the number of inlets in the storm sewer system by the area of the storm sewershed.

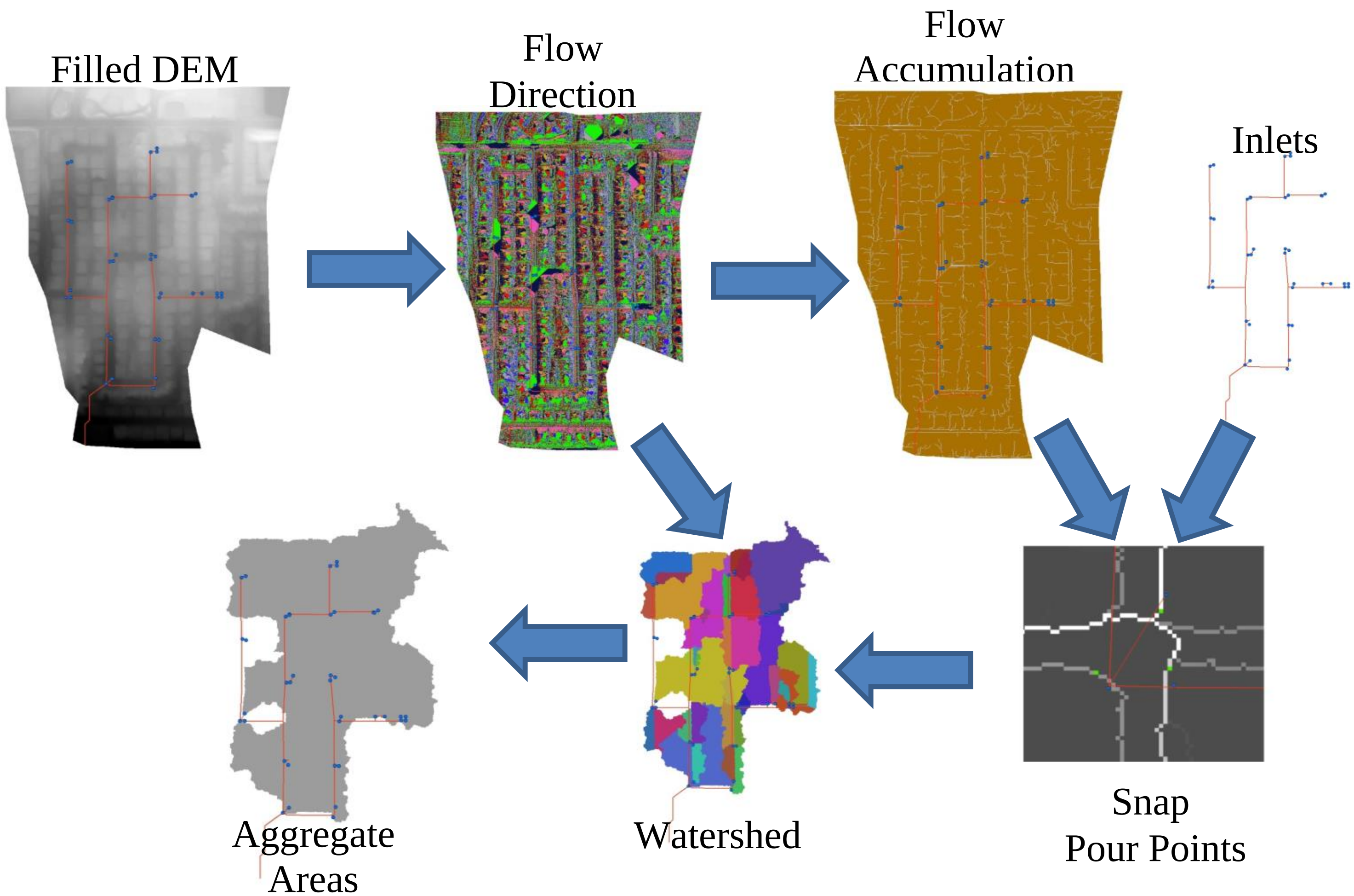

Figure 2. GIS Workflow. The GIS processes used to delineate storm sewersheds starting with a filled DEM and inlet data layers.

Table 3

Zoning Classification Groupings

Zoning Classification	Grouping
M-1, C-1, C-2, C-3, B-1, B-2	Commercial
R-1A, R-1B, R-1C, R-2, R-3A, R-3B	Residential
A, S-5, S-2	Open Space
Unzoned	Road

We considered some features in storm sewer systems based simply on presence or absence. These features did not require the delineation of the storm sewershed; rather they are part the storm sewer system. The most obvious of such features are ponds. There are two types of ponds that may be included in storm sewer system: detention ponds and retention ponds. Detention ponds are designed to be dry between storm events; some are used parks or playing fields. Retention ponds always have water present; they may also have aerators or circulators. Although both pond types will have plant life, they may be clay lined and do not offer an opportunity for infiltration. The City of Bloomington supplied a data layer of the detention and retention ponds (hereafter referred to as ponds), and which allowed us to note those storm sewer systems with a pond present and those that did not. The other common features in our study area are sump pumps. Due to the poor drainage of glacial soils, sump pumps are installed near buildings to draw water away from the foundation to prevent damage. These pumps feed directly into the storm sewer system. The presence or absence of sump pumps was determined from the sewer system layer where they were classified as “tile drainage” (pers. comm., Kevin Kothe).

Statistical analyses were performed in JMP 10.0 software (SAS, 2012). We compared the physical characteristics to determine patterns using linear regression and Tukey-Kramer means test. Data were log transformed to normalize data as necessary to meet assumptions of homogeneity of variance.

Results and Discussion

Delineation of storm sewersheds yields some interesting results, especially when comparing it to the more common task of delineating natural watersheds. Storm sewersheds, of course, differ from natural watersheds in that the latter is delineated in GIS software typically using only one pour point. Storm sewersheds here were generated from multiple pour points, which are connected via an underground pipe network leading to an outlet into a stream. Unlike natural water catchments, storm sewersheds were not always continuous (Figure 3), in that the areas contributing to adjacent pour points may not be adjacent to one another. This was because storm sewersheds occur within natural watersheds and are constructed according to the designs of civil engineers and city officials. Some areas within an urban setting drained directly into the stream rather than through a storm sewer system. In some cases there were instances of this occurring within a storm sewershed between inlets. This also may be a result of the pipe crossing a topographical border (Crimmens, 2006). Figure 3 shows as storm sewershed with three inlets. The two inlets to the north have contributing areas adjoining borders. The third inlet had a separate area that does not join with the others. It is assumed based on the flow accumulation layer that the area between the inlets either flowed contributes to a different storm sewer system.

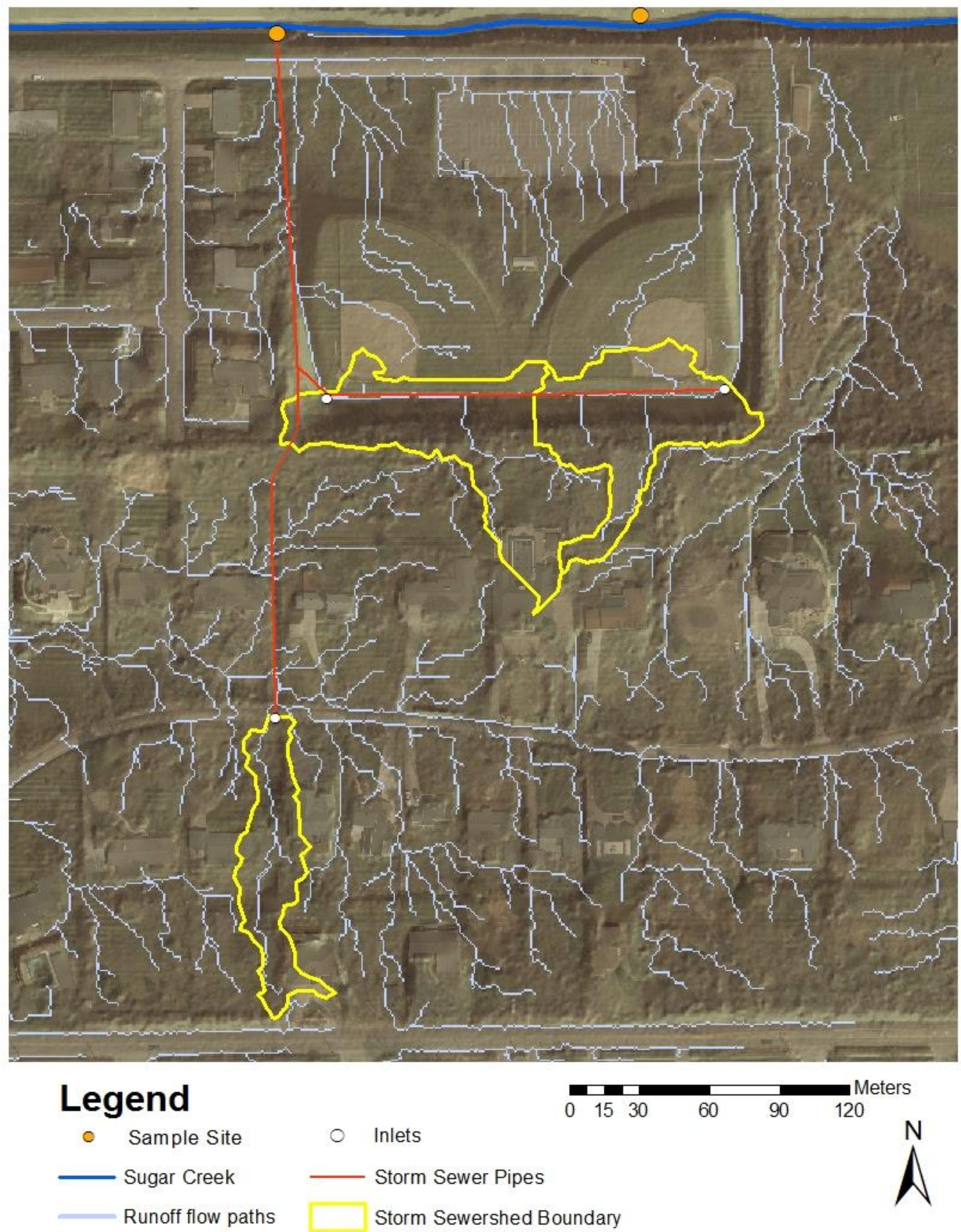

Figure 3. Storm Sewersheds may be Non-Continuous. This storm sewershed demonstrates how it is different than natural watersheds. It is non-continuous (creates more than one polygon) and has multiple pour points. Notice too how the two pour points in the north share a boundary and how the flow lines between the north and south inlets flows to the west.

The shape of the storm sewershed was primarily dictated by two features: the location of the storm sewer inlets and the roads. Storm sewer system networks that were long and skinny had storm sewersheds that were long and skinny (Figure 4). Square-

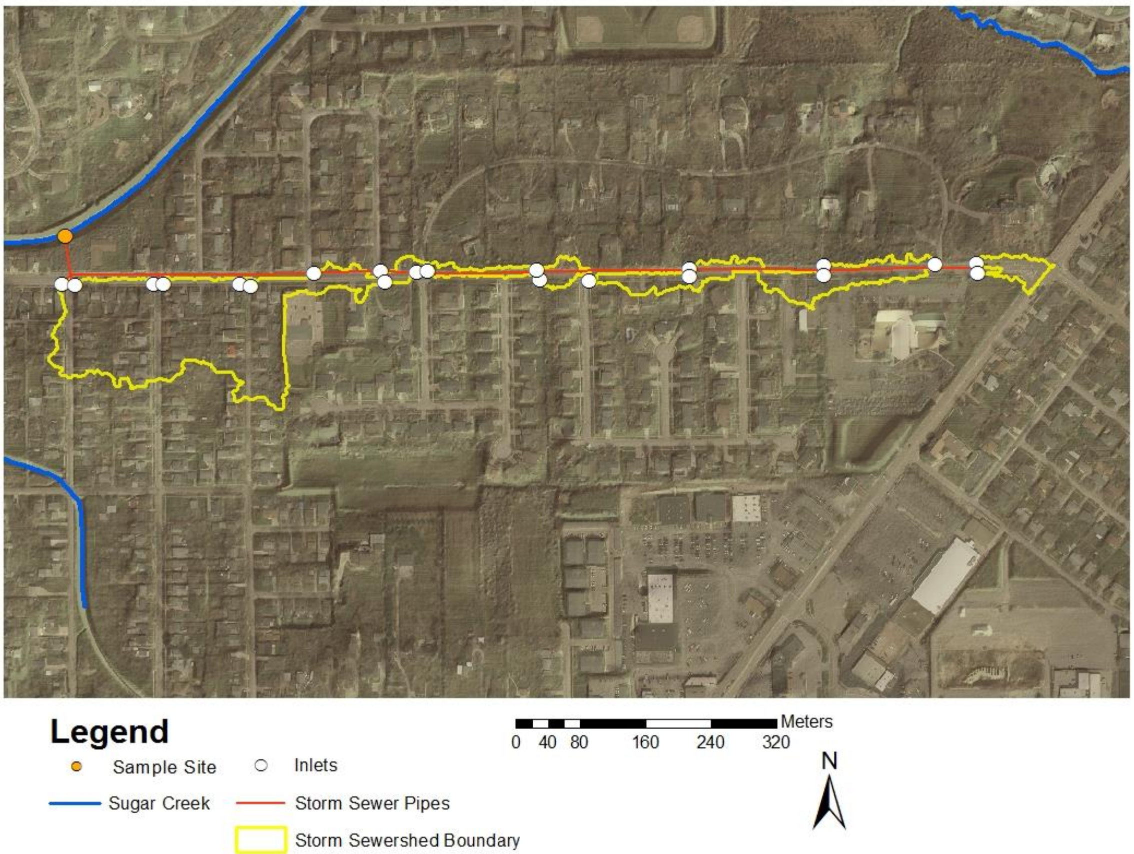

Figure 4. A Long and Skinny Storm Sewershed. This storm sewer system follows a single road, the storm sewershed reflects this shape.

shaped storm sewer system networks had storm sewersheds more square like (Figure 5). Maps, descriptions and photos for all eighteen storm sewersheds are in Appendix A. Roads are raised in the center (also called the crown) so that storm water will be directed to the curb where it will flow to the storm sewer inlets. This is intended to create a boundary for stormwater so that it is directed to the sides of the road, but the difference in

Figure 5. A Square Storm Sewershed. This storm sewer system has many branches. The contributing area generally creates a square-like polygon around it.

elevation was a matter of centimeters, much smaller than the vertical accuracy of the LiDAR which was 0.4 meters. This may be why Figure 6 extended beyond a road to the south making the storm sewershed much larger in area than we expected. At the same time, this may not entirely be due to data error, but rather due to the presence of flood routes. Flow paths such as these are often created intentionally by city engineers to keep water flowing during a large event when inlets may be overburdened. Flood routes allow water to continue moving past such inlets until they reach an available inlet. However, during the average rainfall event it is unlikely that the entire area actually contributes to the storm sewer system in Figure 6. This problem could potentially be fixed by introducing breaklines to prevent flow from extending past a road. Such a fix would lead to a loss of insight into possible flood routes by restricting the flow of water. In fact, we verified with the City of Bloomington that there is a flood route present in this location (pers. comm., Kevin Kothe). It is also worth mentioning that the western boarder of the storm sewershed in Figure 6 does follow the center of a road. However in this case the road in question is large and includes a raised median in the center. This difference creates not only a larger different in the elevation between the center of the road and the curb but also a more abrupt boundary. The larger change in elevation makes the difference closer to the horizontal accuracy of the DEM and the abrupt boundary is significant because the direction of flow is determined by the direction of the steepest slope.

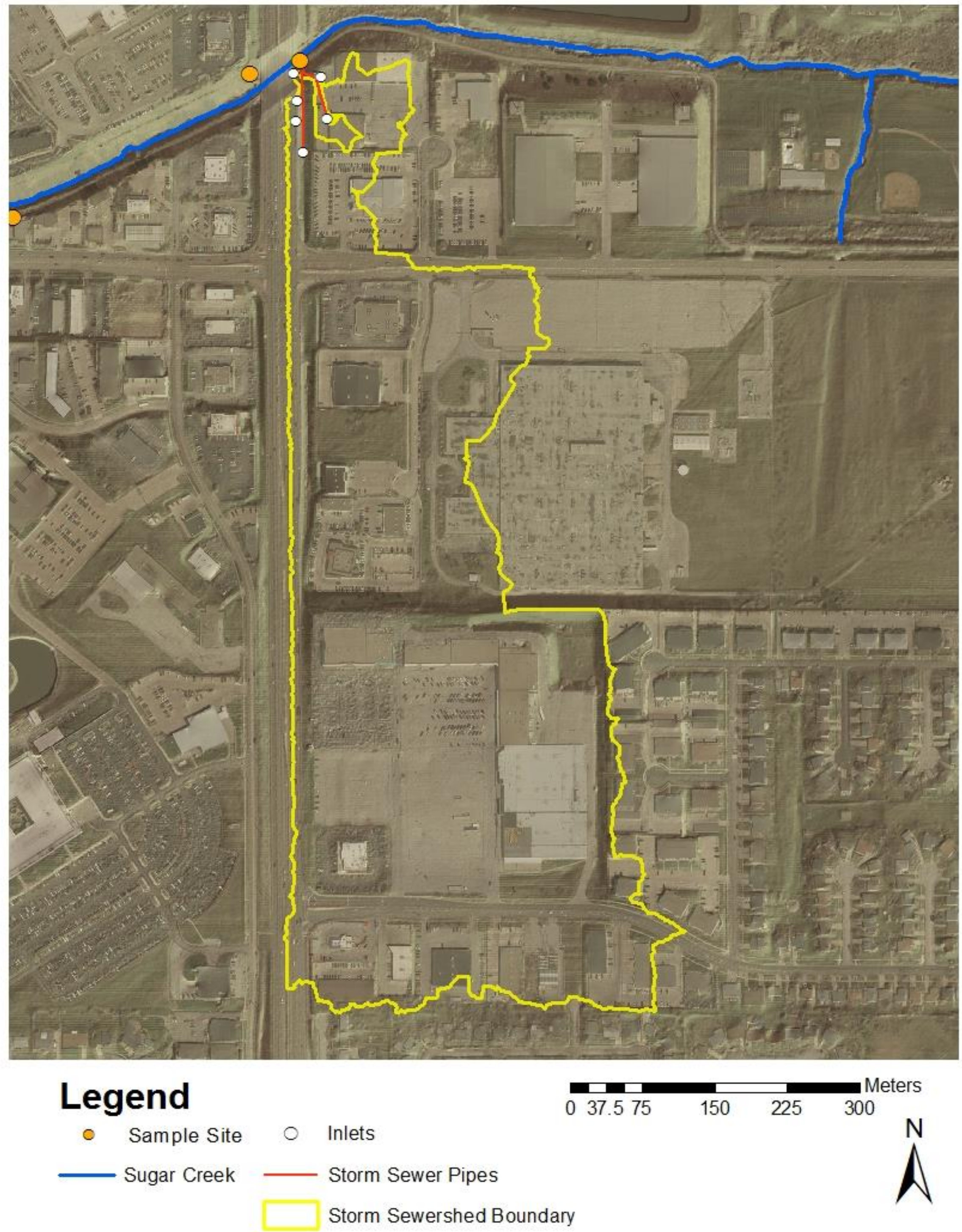

Figure 6. A Storm Sewershed with a Flood Route. This storm sewershed was expected to end along the first east-west road, but it far exceeds it. Its western border also follows the center of a road.

While the area of the storm sewersheds tends to follow the general shape of the storm sewer system we note a few exceptions. The first is illustrated in Figure 7, this storm sewer system presumably drains a parking lot but did not delineate as such. This may be because of discrepancies in the combined horizontal error between the inlet locations (whether from data provided by the city or generated through the aerial photograph) and the LiDAR data. It should be noted that the storm sewer system in Figure 7 was not in the original dataset provided by the City of Bloomington. However, the City of Bloomington was able to provide plans of the property and the storm sewer line was delineated manually based on those plans and aerial imagery. The manual delineation may have caused a greater horizontal error than the other storm sewersheds.

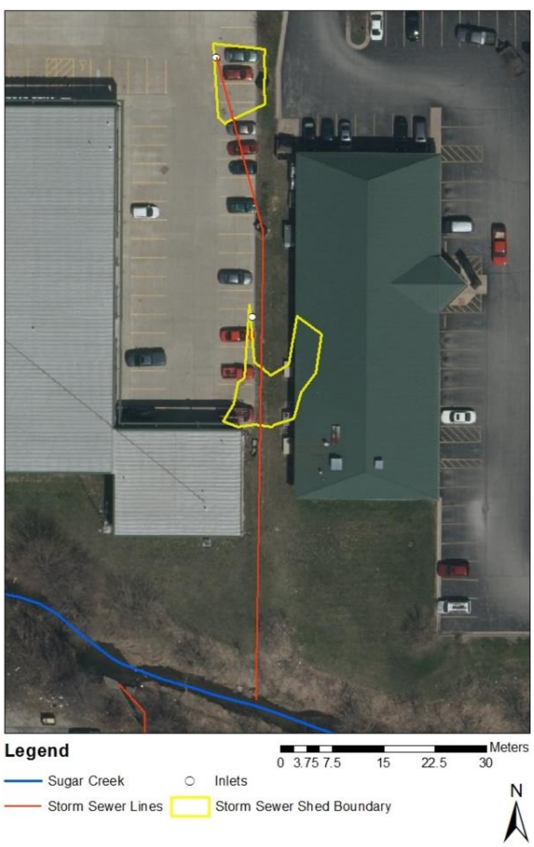

Figure 7. A Storm Sewershed with an Underestimated Area. We expected this storm sewershed (generated by our GIS model) to include the entire parking lot to the west.

A combination of the flow accumulation layer and aerial imagery gave insight to accuracies and errors of this project. Flow accumulation is a data layer that denotes where channels are likely to form based on how many cells contributed water to a single cell. As previously mentioned, storm water was intended to flow along the curb of the road, therefore we should have seen flow accumulation lines align with the curb of the road. Figure 8 shows an example of how this was portrayed as we would expect by our model; indicating that an unaltered LiDAR derived DEM was capable of producing a qualitatively accurate flow model in an urban environment. An example of an error in our model was the flow travelling through a building (Figure 9). This was a limitation of our model as in actuality the storm water would flow around the building. The model allows this type of error because, as mentioned in the introduction, the structures are removed from LiDAR to provide a "bare-earth" model of terrain. The other inaccuracy in Figure 9 is that the flow crosses the road. As previously mentioned the road should act as a boundary. Instead of crossing the road we would have expected the flow path to continue east along the curb up the road until it reached the inlets. In this case the difference in the flow path was outside of our maximum snap pour point distance and these flow paths were excluded from storm sewershed.

There are two possibilities to fix this error. The first would be to use the unfiltered LiDAR although this data set would include a great deal of noise due to the presence of vegetation and would certainly lead to other errors. The other possibility to correct the inaccuracy of the flow path could be fixed with the use of burning. This method would alter the DEM to raise buildings and lower roads (Elgy et al. 1993). In theory flow would then be forced away from buildings and towards roads. This would be a time consuming process as it requires a data layer of just the buildings and another with just roads. If we consider the delineation of the flood routes not to be a limitation, but an indication of the available routes then only one storm sewershed was delineated in serious error and it was generated manually.

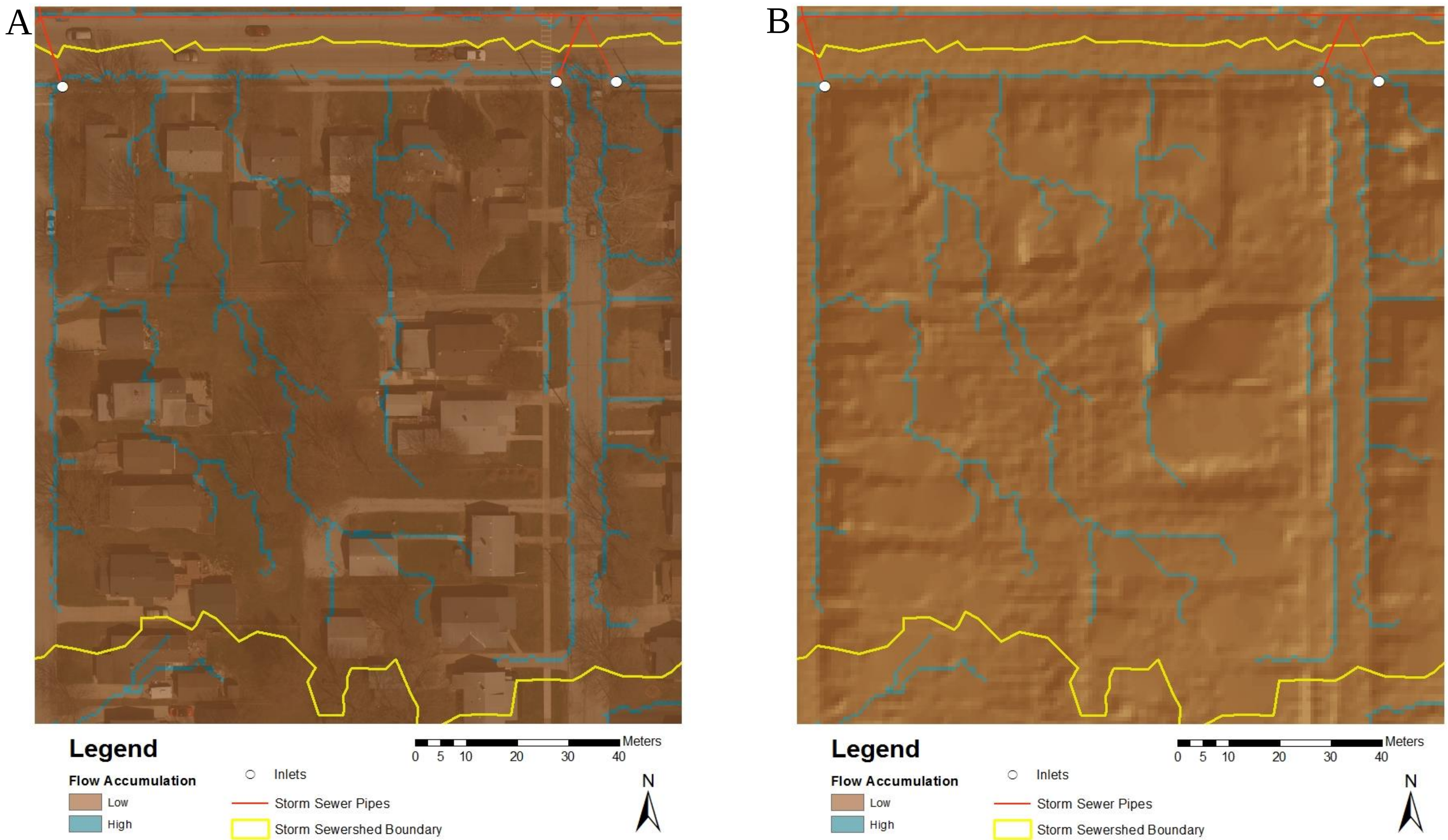

Figure 8. Flow Accumulation Lines Along Road Curbs. An example of how our model represented what is expected based on engieering design. The aerial imagery on the left (A) shows how the flow accumulation is near the curb on the road. The right image (B) is the same area shown in hillshade to express topography

Figure 9. Flow Accumulation Lines Through a Building. The flow line runs north through a building, an error in our model. Additionally, the flow crosses the road and avoids the two pours points and limiting the boundary of our storm sewershed.

The characteristics of the storm sewersheds showed great variation. The %ISC varied from 10-70% among the storm sewersheds. The median %ISC was 30.7%. Of the four zoning classifications we considered, three were the primary classification for at least one storm sewershed: eleven storm sewersheds were dominated by residential zoning, six storm sewersheds had commercial as their primary zoning, and one storm sewershed was dominated by open land. None of the storm sewersheds were dominated by nonresidential or noncommercial roads. Storm sewersheds that had a higher percentage of commercial zoning correlated with those that also had a greater %ISC ($p<0.01$).

The density of inlets ranged from 25 inlets per km^2 to 10,000 inlets per km^2. Although note that the lowest inlet density is likely due to the inclusion of a flood route (Figure 6) and the storm sewershed and the largest inlet density is due to do manual creation of the storm sewer system (Figure 7). Nine of the storm sewersheds had an inlet density between 100-200 inlets per km^2, four had 200-300 inlets per km^2 and two had 400-600 inlets per km^2.

Our analysis showed there are some apparent relationships between physical characteristics. We found that the number of inlets, the length of storm sewer pipe, and amount of impervious surface area were all correlated with the overall area of the storm sewershed ($p<0.0001$, $r^2= 0.912$, $p<0.0001$, $r^2=0.854$, $p<0.0001$, $r^2= 0.943$ respectively) (Figure 10).

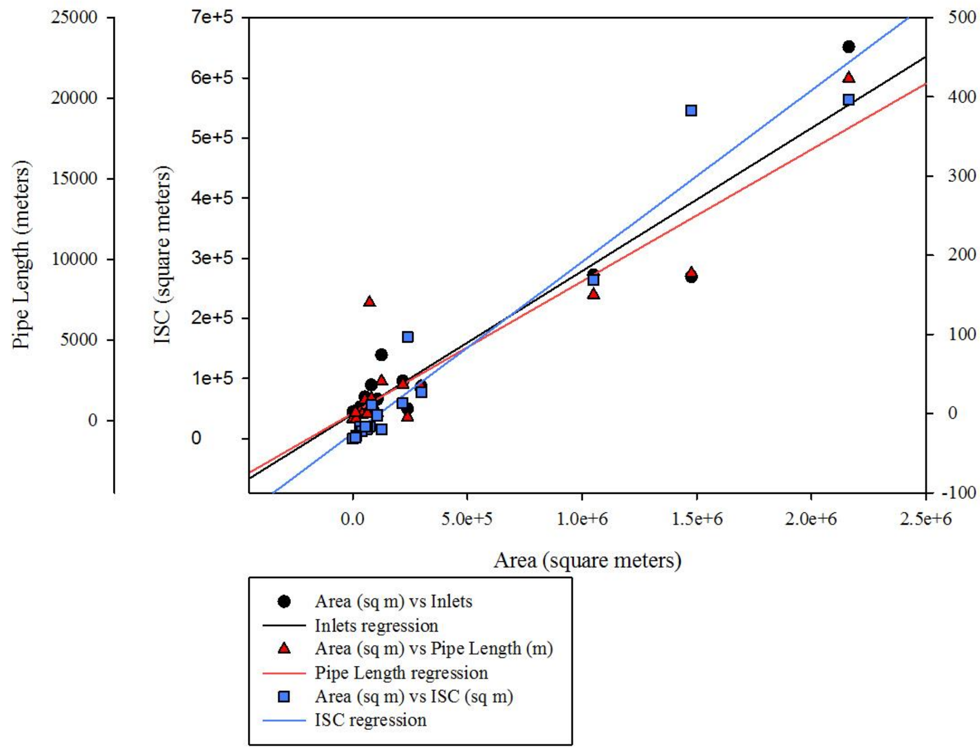

Figure 10. Correlations of Physical Characteristics. Chart with correlations of area to inlet count, pipe length and ISC area. ($p<0.0001$, $r^2= 0.912$, $p<0.0001$, $r^2=0.854$, $p<0.0001$, $r^2= 0.943$ respectively)

Determining the presence or absence of ponds and sump pumps did not require spatial analysis, because they were a feature within of the storm sewer system. Six storm sewersheds had ponds present, 12 storm sewersheds did not have a pond. Ponds were present in significantly larger storm sewersheds ($p<0.0001$). There are 9 storm sewersheds with sump pumps and 9 without sump pumps. They were identified as a category within the sewer layer. Sump pumps were present in storm sewersheds with significantly greater area than storm sewersheds without sump pumps ($p<0.0001$). In addition all 6 of the storm sewersheds with ponds also had sump pumps. Sump pumps are primarily located in the newer (eastern) portion on the city. On occasion sump pumps that are connected to the storm sewer system are not within the boundaries of the storm sewershed (Figure 11). We recognize this but do not consider it a limitation of the study. Sump pumps draw shallow groundwater to keep building foundations dry so they do not act in the same manner as an inlet. However, that water would have infiltrated from the surface. The details of each storm sewershed's characteristics are in Appendix B.

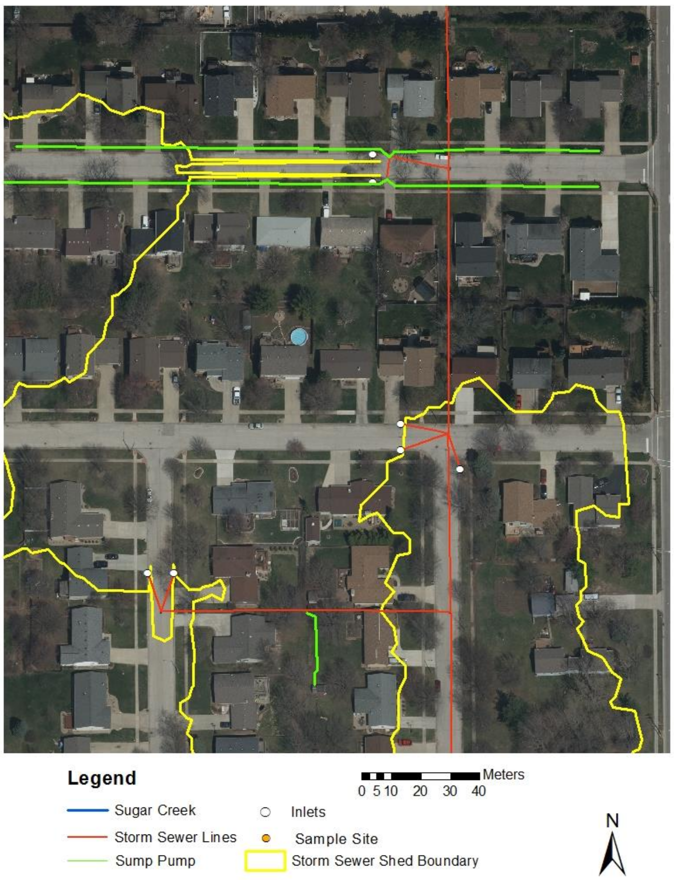

Figure 11. Sump Pumps may be Outside Storm Sewershed Boundaries. An example of how sump pump connection (green) may be located outside of the storm sewershed area (yellow)

Conclusions and Future Work

The main goal of this part of the study was to delineate storm sewersheds using GIS with readily available data. In many ways our model yielded results we expected based on engineering principals but there were some factors that remain limited. The small cell size of LiDAR helped detect some the subtle topographical changes in an urban area in central Illinois. The limiting factor however is the vertical resolution of the DEM. It is possible that when the storm sewershed boundaries exceeded a road it was because the LiDAR did not detect the crown of the road. Another possibility is a flood route is being detected and only a portion of the storm sewershed would contribute water depending on the magnitude of the storm. There was only once instance in our study in which a storm sewershed was obviously grossly underestimated and it was likely due to human error in manual delineation.

We acknowledge there are some limitations of this study but we would also argue that our methodology provides insight into urban stormwater drainage areas. Future work could involve field verification of a specific storm sewershed or sampling of significant locations. For example, locations in which inlets do not produce a contributing area or where a flow path flows through a house. Field verifications could give insight into how often the methodology is accurate.

Storm sewershed were found to have variation in their characteristics. Some characteristics are related to another characteristic, others are indicative of the use within the storm sewershed. These variations may become important as we continue to analyze their effects on water quality.

Future studies could manipulate the DEM to force flow away from buildings and towards roads in an effort to reduce error. Other manipulation that could be used would be introducing breaklines at known boundaries such as roads. However, it is important to consider the time and effort that may be put into creating the necessary layers and if the manipulations will bias the results.

Possible Applications

There are several possibilities to use this methodology in practice. The first would be a simple verification of drainage patterns in an urban area. Essentially, the model could be used to confirm if the drainage paths and areas the engineers design continue to hold. As time passes, flow paths may be disturbed or altered within the addition of new infrastructure. This methodology could allow verification of drainage old drainage paths with minimal field work.

This methodology could be used to model drainage patterns for storm sewer systems that haven't been installed yet. Analyst could create several different layouts of storm sewer pipes, inlets to optimize drainage. It could also be used as cost analysis tool, to determine what layout will drain the intended area for the least amount of money. In addition, the methodology could be used to determine optimal placement of a feature such as a detention pond in a proposed or existing system. As storm sewer systems are updated and retrofitted the drainage patterns will be affected, and this methodology could be used to determine what those changes might be.

One of the key differences between storm sewersheds and watershed is the underground component that allows stormwater to cross topographic lines. This methodology could be used to determine where instances of this take place and preventing the occurrence of topographic cross.

CHAPTER III

EFFECTS OF PHYSICAL CHARACTERISTICS OF URBAN STORM SEWERSHEDS ON THE WATER QUALITY

Introduction

There are predictable hydraulic responses to urban development (Walsh et al., 2005a). Due to the increase in the percentage of impervious surface cover (%ISC), runoff occurs eight times more often in urban areas than forested areas (Gallo et al., 2013). Storm sewer systems efficiently transport runoff to the stream in an effort to prevent flooding and damage. Storm water travels over the land surface and eventually drains to a storm drain which discharges to a stream (Figure 12).

Changes in the urban landscape alter the hydraulic response. Decreased retention of storm water increases the peak discharge level (Bloschl & Sivapalan, 1995; Cantone & Schmidt, 2011). As a result, the majority of contaminants enter streams and rivers as a result of stormwater runoff (Walsh et al., 2005b; EPA, 1999). Watersheds with storm drains have high concentrations of nutrients (Kaushal and Belt, 2012). And it has been consistently shown that urban settings will have more degraded water resources than forested streams (Walsh et al, 2005a, Cunningham et al., 2009, Kaushal and Belt, 2012).

Features of storm sewer systems affect water quality. Detention ponds, whether intentionally designed to or not, will provide some water quality control (Marsalek, 2002; Herrmann, 2012). Originally designed to reduce the peak flows during a storm, ponds

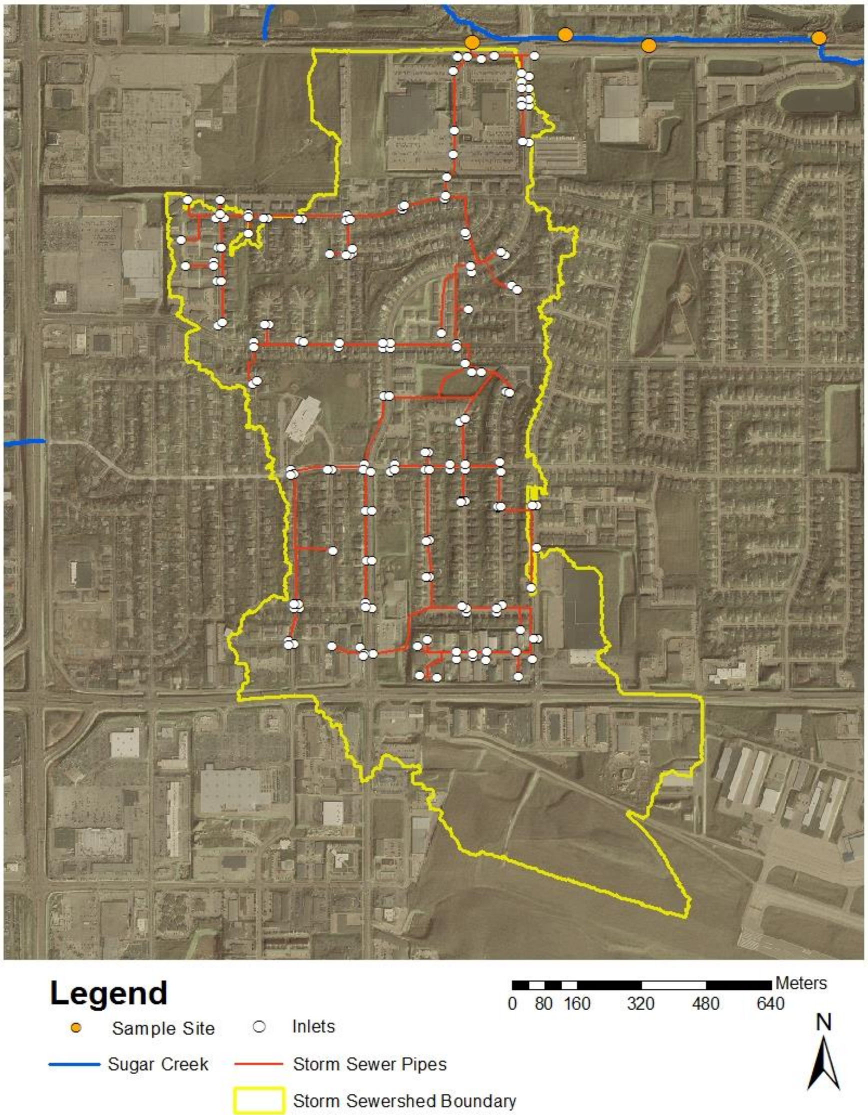

Figure 12. An Example of a Storm Sewer System. The red lines are the storm water pipes the white dots are the inlets. The yellow line outlines the storm sewershed. The blue line is the stream the water it discharges to and the orange dot indicates our sampling site

will provide treatment through the settling of sediment (Tixier et al, 2001; Marsalek, 2002). Ponds can reduce nutrients in stormwater by 43% for nitrogen and 35% for phosphorous (Herrmann, 2012). Concrete ditches and pipes that transport stormwater to river also can alter chemistry. In one study it was found that rain water collected from a roof had a pH of 4.8 that increased to 7.9 after 100 minutes of being in contact with concrete (Davies et al, 2010). In short, stormwater quality is dependent on the land surface it travels over (Gallo et al, 2013; Choe et al, 2002; Chow and Yusop, 2014). Questions remain, however, about how the differences in physical characteristics among urban storm sewersheds affect water quality.

In this part of the study we address the question: what physical characteristics of urban storm sewersheds affect storm water quality? The characteristics we predicted would have the greatest impact on water quality were: presence of a retention pond, inlet density, and %ISC. Other characteristics we considered were storm sewershed area, presence of sump pumps and zoning. We monitored the water quality of storm water at the outlets of eighteen different storm sewer systems in Bloomington, IL during seven storm events between May 2014 and February 2015. We expected that the presence of a retention or detention pond in a stormwater sewershed and high storm inlet density would improve water quality. We predicted that as sewer miles and %ISC increase, water quality would be more degraded.

Study Region and Study Period Overview

This study was conducted in Bloomington, Illinois. The City of Bloomington is located approximately 125 miles southwest of Chicago. Immediately north of Bloomington is the Town of Normal. The two municipalities are so close they are locally known as the "Twin Cities." The combined area of the cities is over 90 square kilometers. The combined population of the two cities is approximately 125,000 (US Census, 2010).

A stream, Sugar Creek, flows along the border of Bloomington and Normal (Figure 1). All of the sites in this study drain into Sugar Creek. The storm sewer systems included in this study were primarily owned and maintained by the City of Bloomington. Three systems also had connections with private owners and one system was entirely private. It should also be noted here that some storm sewer lines, whether public or private, may not appear on maps as underground features can be easily overlooked or forgotten.

Geologically, the city of Bloomington is located on an end moraine of the Wisconsin Glaciation. The geology of the area is primarily glacial till of the Wedron Formation composed of pebbly clay till (Weibel and Nelson, 2009). There is also a thin alluvial deposit (Stiff, 2000) along Sugar Creek.

The majority of the storm sewer system in Bloomington was built between 1950 and 1980, making the system, at least in part, slightly older than the national average of 45 years (Chang & Hernandez, 2008). Much of this system requires replacement and expansion. The Municipal Separate Storm Sewer System (MS4) regulates the city of Bloomington with a permit administered by the Illinois Environmental Protection Agency. The city of Bloomington has committed to make efforts over twenty years to improve stormwater quality (City of Bloomington, 2013). The pipes were made of PCC, clay brick or polyvinyl chloride (PVC) (pers. comm., Kevin Kothe) and vary in size at their outlets from 30 cm to 364 cm. The storm sewer system studied is primarily gravity fed; except for sump pumps.

Between the months of May 2014 and February 2015 eighteen storm sewer systems were sampled for water quality during flow events. This study is limited in that only one sample was collected from the outflow of each storm sewershed during each event. We aimed to take a sample near the beginning of each storm event, but it was not possible to know exactly at what point in the hydrograph a sample was taken. However, we assumed that relationships across the storm sewersheds would remain constant no matter what point on the hydrograph sample collection took place.

Methods

Storm Sewershed Characterization

We measured stormwater quality from eighteen storm sewersheds within the city of Bloomington (Figure 1). For each storm sewershed we considered the following characteristics area, storm sewer density, sewer miles, number of inlets, inlet density and %ISC, primary zoning classification, presence or absence of a retention or detention pond and presence or absence of sump pumps (Table 4).

The storm sewersheds were delineated in ArcCatalog 10.2 using Model Builder. Storm drain inlets were used as pour points and contributing area was determined by topography. We used a 0.76 m LiDAR dataset flown in 2012 as the elevation layer (ILDOT, 2012). Storm sewer miles were calculated for each storm sewershed from the storm sewer system layer provided by the City of Bloomington (City of Bloomington, 2002). Area, storm sewer density, and percent impervious surface cover and primary zoning classification were derived in ArcMap 10.2 from the storm sewershed results in combination with data layers provided by the City of Bloomington (See Chapter 2).

Table 4

A Summary of Physical Characteristics of the Storm Sewersheds in this Study

Characteristics	Number of Storm Sewersheds
Ponds	
Present	6
Absent	12
Sump Pumps	
Present	9
Absent	9
Primary Zoning	
Commercial	6
Residential	11
Other	1
Percent Impervious Surface	
<15%	2
15-30%	6
30-40%	6
40-75%	4
Pipe Diameter (cm)	
30-40	4
40-70	6
70-100	2
100-150	3
150+	3

Storm sewer density was calculated by dividing the number of storm sewer miles in a storm sewershed by its total area. Percent impervious surface cover was extracted for each storm sewershed from the City of Bloomington's data layer and manual digitization using our delineated area. This result was divided by the storm sewershed's total area.

Each storm sewershed had several zoning classifications (residential, commercial, open space/parkland). Component parts of the watershed for zoning was determined using the same method as %ISC. Roads in the city of Bloomington were not assigned a zoning classification, however they are considered important in this study because stormwater was directed to roadways to be efficiently transported to the storm sewer. Therefore, the zoning percentage of each storm sewershed was compared to its total area and any cells not assigned a zoning classification were assumed to be a roadway and a percentage of road was calculated as the remaining percentage.

Precipitation and Discharge

Daily precipitation totals were downloaded from the National Climatic Data Center. We assumed even precipitation for all storm sewersheds. For six events, storm sewer flow was driven by rainfall. An average precipitation value was calculated from the five surrounding weather stations: US1ILMCL017, US1ILMCL018, USC0011076, US1ILMCL023, USC00110764. For one event (Feb 2015), flow was derived from snowmelt. The snow depth was recorded for the sampling date as an average from the same five stations. Conditions surrounding snowmelt-driven flow events can be very different than those of rainfall events based on the snow temperature, snow density, heat flux etc. (Garen and Marks, 2005). Therefore, we treated this snowmelt event separately and did not combine it with the rainfall-driven events.

Water depth measurements of the stormwater were taken at the time of sampling. Depth measurements were unavailable for the June 8th and December 15th sampling events. Manning's equation was used to determine instantaneous discharge (Q_t, Ls^{-1}):

$$Q_t = A\frac{1000}{n}R^{\frac{2}{3}}s^{\frac{1}{2}}$$

Where *A* is the cross sectional area based on depth and pipe diameter, *n* is the hydraulic radius and *s* is the energy slope. Most study sites are reinforced concrete and an *n* value of 0.012 was chosen (ACPA, 2012). Slope (*s*) was determined with a Brunton compass at the pipe outlet.

Stormwater Collection and Analysis

We collected manual grab samples from the outlets of each storm sewer system. Details of each storm sewershed locations and site description are available in Appendix C. Samples were collected in 1L HPDE Nalgene bottles as well as *in situ* measurements with an YSI ProPlus for pH, dissolved oxygen, temperature and specific conductivity. Samples were collected during six distinct storm events and one snowmelt event (Table 5). One sample was associated with each storm sewershed during each storm event.

Sampling from all storm sewers was completed within approximately a 3-hour time frame for each event. Samples were placed in a dark chilled cooler (~4^{o}C) and taken to the laboratory for processing. Storm sewers were not always sampled in the same order. In some cases we worked east to west and in other west to east. The direction primarily depended on the size of the storm. The storm sewer systems in the west are

Table 5

Precipitation Magnitude When Samples Were Taken

Sample Date	Precipitation (mm)
5/9/14	6.5
6/8/14	45.9
6/10/14	4.0
7/25/14	ND
9/15/14	ND
12/15/14	0.7
2/7/15*	13.5

ND = Non-Detection

*The February 2015 precipitation measurement is the depth of snow recorded on the sampling date small and carry less water. When storms were large, we would visit the large sites first in case of flooding. For small events, we would visit small locations first before the storm sewers dried up.

We used pre-combusted 1.5µm glass fiber filters (Whatman 934-AH) to filter samples for total suspended solid (TSS) and volatile suspended solids (VSS) analysis using the loss ignition method (ASTM, 2000). A second filtration at 1µm (Pall Corporation A/E) with another glass fiber filter was used prepare samples for nutrient analysis. Chloride concentrations were determined on a Dionex ISC 1100 ion chromatograph. Ammonia, nitrate, and dissolved reactive phosphorous (DRP) were determined by Latchat QuikChem 8500 flow injection analysis. Total phosphorus was determined by digestion followed by Latchat QuikChem 8500 flow injection analysis for dissolved reactive phosphorus.

Statistical Analysis

Statistical analyses were performed in JMP 10.0 software (SAS, 2012). We compared solute concentrations, solute loads, and specific conductivity across sites, primary zoning, primary land cover, dates, presence or absence of ponds and presence or absence of sump pumps using an ANOVA followed by a post-hoc Tukey-Kramer means test. Data were log transformed to normalize data as necessary to meet assumptions of homogeneity of variance. We used pairwise correlations to identify correlation among solute concentrations, solute loads and specific conductivity against area, percent impervious surface cover, storm sewer pipe miles, storm sewer pipe density, and inlet density.

Storm sewershed areas ranged from 184.7 m^2 to over 2 km^2. The derived area was positively correlated with the number of inlets ($p<0.0001$) and length of storm sewer pipe ($p<0.005$). Unlike natural water catchments, storm sewersheds were not always continuous (see Figure 3). Sources of error included overestimation based on flood routes and underestimation based on sinks and horizontal error between elevation data and inlet data (see Chapter 2).

Results

Our samples had a high degree of variability. Factors such as the season (Table 6), precipitation (Table 7) both affected the concentrations of our parameters but we were unable to account for such variation due to limitations in the project.

Concentrations

Storm sewersheds with a pond present had significantly better water quality than storm sewersheds without ponds. The storm sewersheds with ponds had significantly lower specific conductivity ($p<0.05$), TSS ($p<0.0005$), VSS ($p<0.005$), DRP ($p<0.05$), nitrate ($p<0.05$) (Figure 13). The percentage of organic matter was higher in the storm sewersheds with a pond ($p<0.05$).

Table 6

Mean Concentrations by Precipitation Magnitude.

	Less than <1mm	Medium Precipitation	High Precipitation	Snowmelt
pH	7.96 (7.75-8.17)	7.80 (7.72-7.87)	7.64 (7.2-8.02)	7.21 (6.79-7.63)
Specific Conductivity (µS/cm)	398 (311-510)	815 (665-1000)	1224 (967-1549)	3550 (2505-5030)
Dissolved Oxygen (%)	102 (97-108)	86 (81-91)	85 (80-90)	85 (80-90)
Total Suspended Solids (mg/L)	18.08 (12.95-25.24)	10.06 (7.41-13.66)	3.57 (2.28-5.58)	99.80 (49.84-199.84)
Total Suspended Solids (mg/s)	2.28 (0.87-5.96)	0.71 (0.16-3.16)		3.5 (0.44-27.71)
Volatile Suspended Solids (mg/L)	6.18 (4.70-8.12)	3.75(2.87-4.88)	1.23 (0.82-1.85)	31.65 (16.73-59.88)
Volatile Suspended Solids (mg/s)	0.79 (0.30-2.11)	0.33 (0.08-1.34)		1.17 (0.15-9.36)
Percent Organics	34.37 (30.67-38.56)	39.11 (35.13-43.56)	34.47 (25.87-45.93)	31.71 (27.67-36-35)
Total Phosphorous (µg/L)	79.18 (63.46-98.79)	42.68 (30.81-59.11)	34.83 (23.81-50.95)	126.10 (88.57-179.54)
Total Phosphorous (µg/s)	11.90 (3.99-35.42)	6.12 (1.06-35.34)		4.32 (0.51-36.51)
Dissolved Reactive Phosphorous (µg/L)	55.09 (39.96-75.94)	15.59 (11.30-21.51)	8.06 (4.52-14.37)	30.81 (20.76-45.72)
Dissolved Reactive Phosphorous (µg/s)	8.05 (2.62-24.75)	1.31 (0.31-5.61)		0.99 (0.10-9.63)
Ammonia (mg/L)	0.120 (0.100-0.145)	0.054 (0.038-0.077)	0.022 (0.015-0.030)	0.140 (0.092-0.213)
Ammonia (mg/s)	0.019 (0.006-0.058)	0.004 (0.001-0.018)		0.004 (<0.0001-0.047)
Nitrate (mg/L)	0.78 (0.65-0.94)	0.91 (0.72-1.16)	1.40 (0.76-2.58)	0.63 (0.5-0.79)
Nitrate (mg/s)	0.10 (0.03-0.29)	0.08 (0.02-0.32)		0.02 (<0.01-0.21)
Chloride (mg/L)	76.91 (60.23-98.20)	145.74 (114.35-185.75)	174.62 (124.47-246.98)	1356.40 (931.22-1975.74)
Chloride (mg/s)	10.37 (3.38-31.83)	12.45 (3.15-49.18)		46.96 (5.59-394-30)

(95% Confidence Interval)

Table 7

Mean Concentrations by Season

	Spring	Summer	Fall	Winter
pH	7.84 (7.73-7.96)	7.70(7.50-7.89)	8.22 (7.91-8.54)	7.41 (7.18-7.64)
Temperature (°C)	15.4 (14.4-16.4)	18.5 (17.9-19.0)	16.5 (16.2-16.9)	6.2 (5.2-7.2)
Specific Conductivity (µS/cm)	1014 (795-1296)	763 (618-942)	294 (190-455)	1292 (823-2027)
Dissolved Oxygen (%)	85 (76-97)	93 (88-99)	86 (82-89)	114 (109-119)
Total Suspended Solids (mg/L)	12.11 (8.38-17.50)	7.28 (5.35-9.90)	13.63 (7.40-25.09)	56.56 (34.65-91.33)
Total Suspended Solids (mg/s)	0.69 (0.06-8.32)	0.97 (0.30-3.11)	3.48 (0.77-15.69)	3.39 (0.57-20.14)
Volatile Suspended Solids (mg/L)	4.57 (3.27-6.37)	2.77 (2.09-3.68)	4.02 (2.67-6.05)	17.94 (11.58-27.77)
Volatile Suspended Solids (mg/s)	0.27 (0.02-3.18)	0.45 (0.14-1.39)	1.04 (0.23-4.76)	1.16 (0.19-7.01)
Percent Organics	38 (32-45)	38 (34-43)	30 (23-38)	33 (30-36)
Total Phosphorous (µg/L)		46.75 (36.79-59.41)	65.72 (47.72-90.51)	109.42 (86.52-138.38)
Total Phosphorous (µg/s)		6.82 (1.99-23.40)	16.91 (3.28-87.15)	4.44 (0.69-28.52)
Dissolved Reactive Phosphorous (µg/L)	17.23 (10.77-27.58)	17.00 (11.52-25.10)	45.54 (25.92-80.00)	46.81 (34.50-63.52)
Dissolved Reactive Phosphorous (µg/s)	0.85 (0.07-9.76)	2.73 (0.81-9.24)	14.63 (2.48-86.46)	1.26 (0.17-9.36)
Ammonia (mg/L)	0.065 (0.036-0.120)	0.049 (0.037-0.065)	0.106 (0.076-0.147)	0.131 (0.101-0.169)
Ammonia (mg/s)	0.003 (<0.001-0.003)	0.008 (0.002-0.027)	0.036 (0.006-0.217)	0.005 (0.001-0.037)
Nitrate (mg/L)	0.99 (0.70-1.40)	1.11 (0.85-1.46)	0.51 (0.39-0.67)	0.71 (0.61-0.82)
Nitrate (mg/s)	0.06 (0.01-0.56)	0.10 (0.03-0.33)	0.13 (0.02-0.64)	0.03 (<0.01-0.18)
Chloride (mg/L)	209.07 (150.39-290.67)	131.35 (107.14-161.03)	40.63 (29.58-55.81)	371.70 (223.45-618.32)
Chloride (mg/s)	11.81 (1.12-124.57)	12.28 (3.66-41.24)	11.51 (2.25-59.03)	34.03 (4.62-250.66)

(95% Confidence Interval)

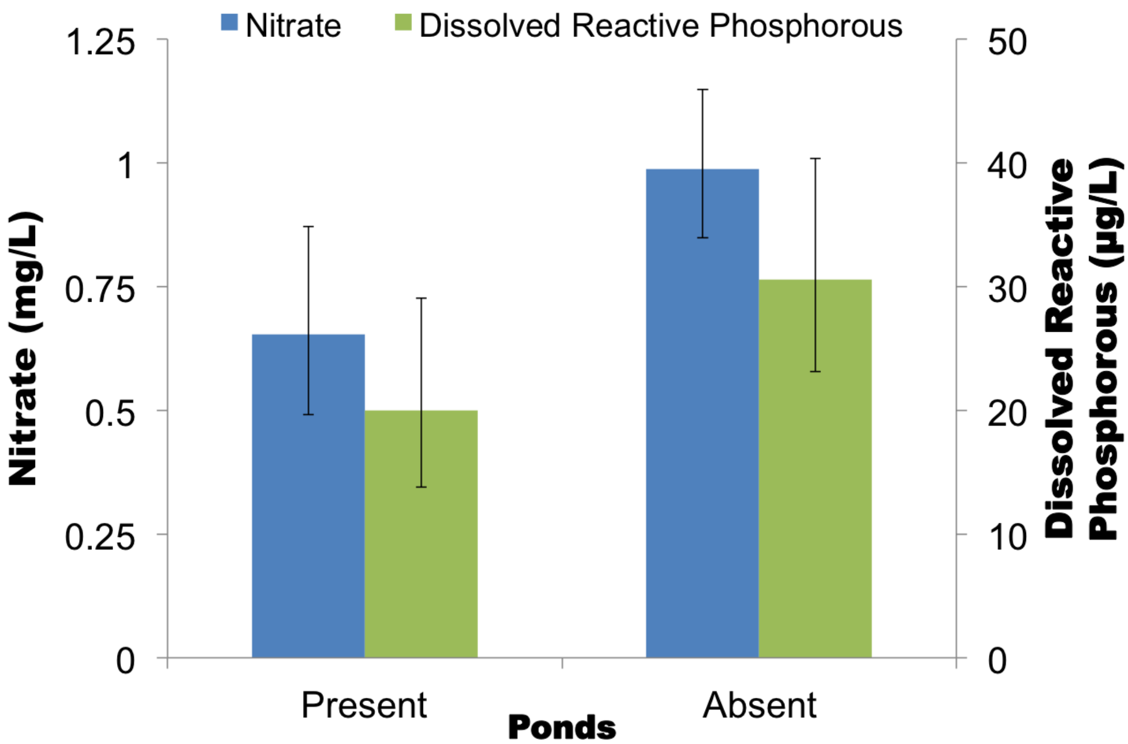

Figure 13. Storm Sewersheds with Ponds had Better Stormwater Quality. The concentration of nitrate (blue) and DRP (green) were lower in storm sewersheds with ponds than storm sewersheds without ponds ($p<0.01$ and $p<0.05$ respectively). Error bars are the 95% confidence interval.

The percent impervious surface cover varied from 10-70% among the storm sewersheds and as the percentage increased the water quality was more degraded. Chloride concentration increased as %ISC increased ($p<0.05$, $r^2=0.03$) (Figure 14).

The nine storm sewersheds with sump pumps had significantly different water quality. The percentage of organic matter was higher in storm sewersheds with sump pumps present ($p<0.005$). Storm sewersheds with sump pumps also had significantly lower chloride concentrations ($p<0.0001$).

The percentage of some zoning classification had an impact on water quality. As the percentage of commercial area increased within a storm sewershed the water quality became less degraded. The TSS, VSS, and total phosphorous concentrations decreased as

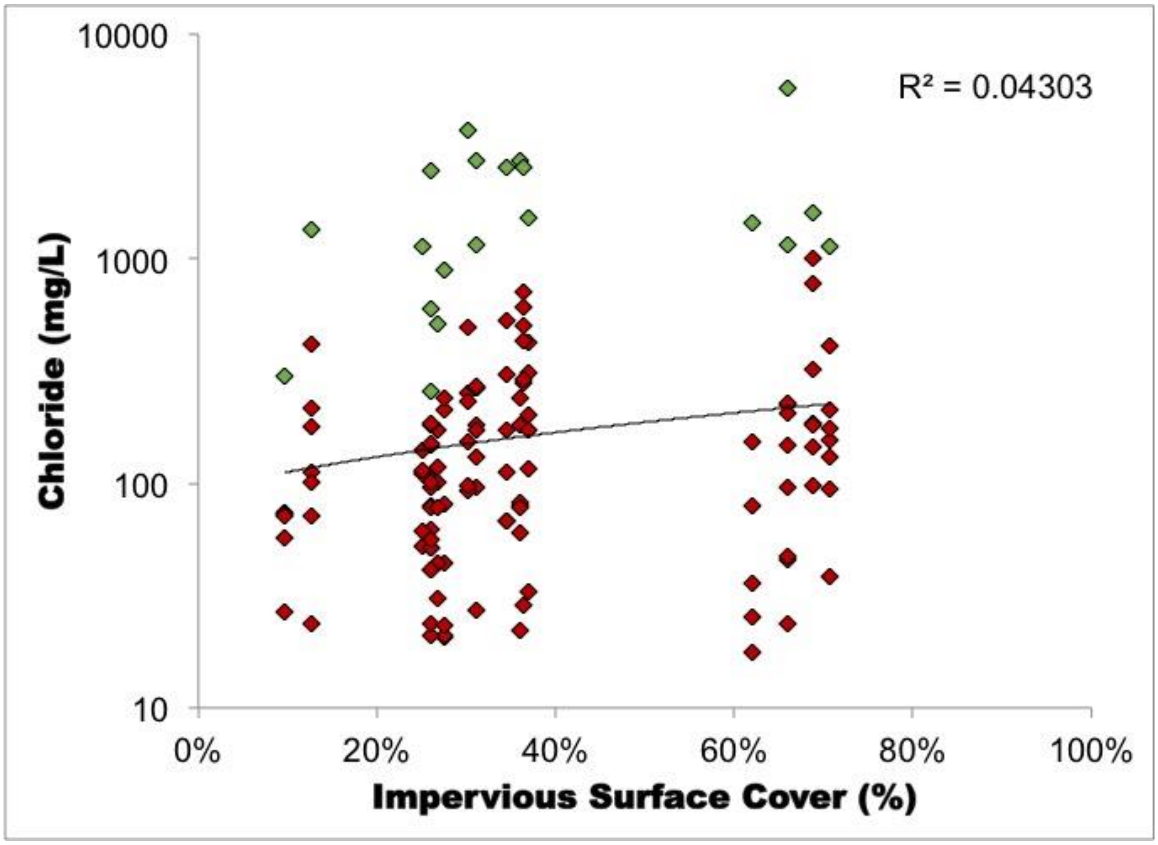

Figure 14. Chloride Concentrations were Positively Correlated with Impervious Surface Cover. When the snowmelt (Feb 2015) was excluded the chloride concentrations decreased as the %ISC increased ($p<0.05$). The green data points are from the excluded snowfall event for reference.

the percentage of commercial area increased ($p<0.05$, $r^2=0.04$; $p<0.0005$, $r^2=0.055$ and $p<0.05$, $r^2=0.047$ respectively). The percentage of residential area had a negative impact on water quality. As the percent of residential area increased the VSS increased ($p<0.05$, $r^2=0.049$).

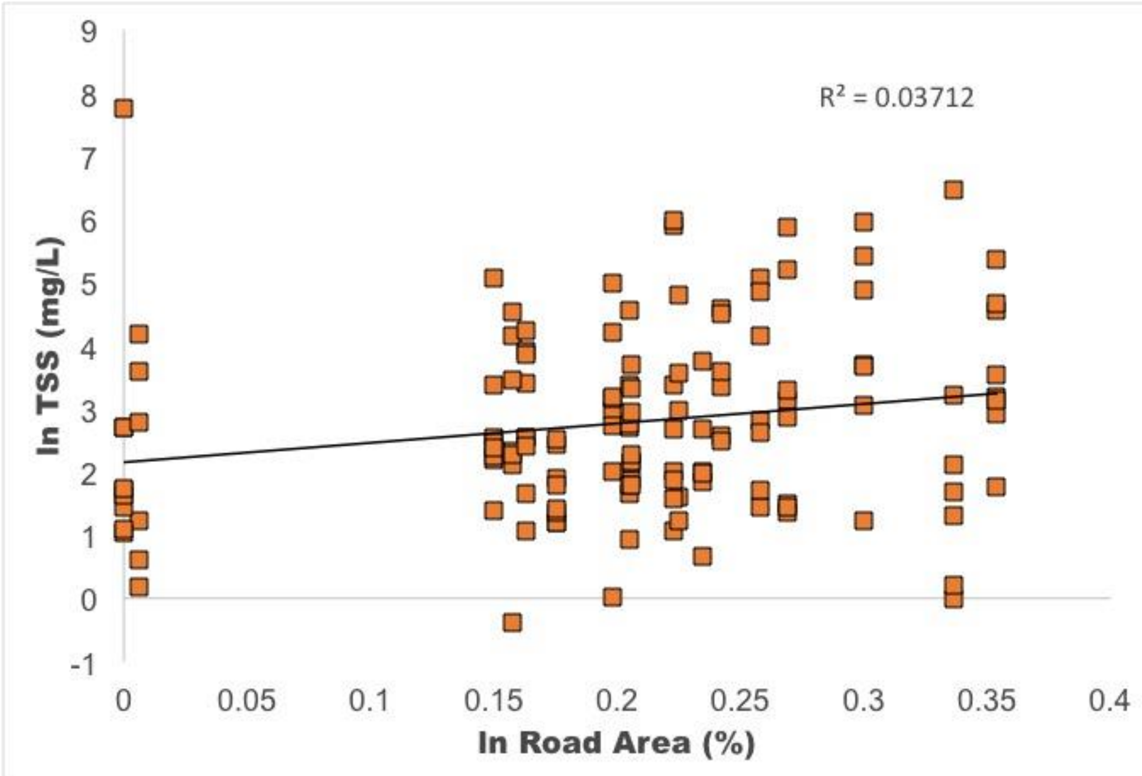

Figure 15. Total Suspended Solid Concentrations were Positively Correlated with Percent Road Area. As the percent of road increased the total suspended solids concentration also increased ($p<0.05$)

The percentage of road area within a storm sewershed had a significant impact on water quality. Roads are designed to be the surface conduits for storm water until it reaches an inlet. Thus, they are where the flow of runoff is likely to be the strongest, especially along the curb. The percentage of road within the storm sewersheds ranged from 0-42% with a median of 23%. As the percentage of road area increased within the storm sewershed, TSS and VSS increased ($p<0.05$, $r^2=0.053$ and $p<0.0005$, $r^2=0.030$ respectively) (Figure 15).

The layout of the pipes in a storm sewer system has a significant impact on water quality. The length of the pipe within a storm sewershed showed trends with pH and dissolved oxygen. As the pipe length increased pH decreased ($p<0.05$, $r^2=0.05$), which is contrary to findings by Davies et al. (2010). The percentage of dissolved oxygen also decreased ($p<0.05$, $r^2=0.04$) as the pipe length increased. Increasing pipe density had a beneficial impact on water quality. The greater the density of the pipes, the lower the concentrations of TSS ($p<0.05$, $r^2=0.039$) and VSS ($p<0.05$, $r^2=0.033$).

The nine storm sewer sheds with sump pumps had significantly better water quality than those without sump pump (Figure 16). Concentrations of chloride were significantly lower in storm sewer sheds with chloride, this may be due to dilution by the subsurface water that sump pumps contribute.

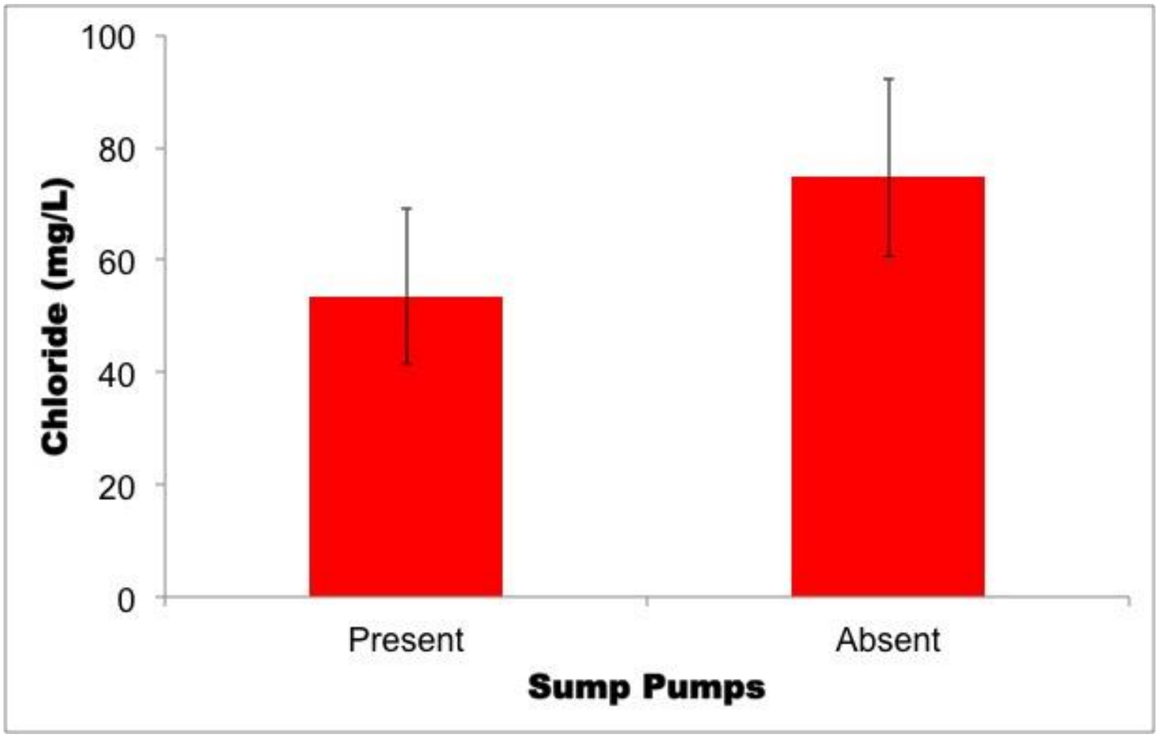

Figure 16. Storm Sewersheds with Sump Pumps had Better Stormwater Quality. The concentration of chloride was significantly lower in storm sewer sheds with sump pumps present. Error bars are 95% confidence interval.

Mass Flux

The area of the storm sewershed had a significant effect on the chemical mass flux. The greater the area the more mass per time will enter the stream for the following:

TSS ($p<0.0005$, $r^2=0.225$), VSS ($p<0.0005$, $r^2=0.269$), DRP ($p<0.005$, $r^2=0.229$), ammonia ($p<0.005$, $r^2=0.255$), nitrate ($p<0.05$, $r^2=0.188$), total phosphorous ($p<0.0005$, $r^2=0315$) and chloride ($p<0.0005$, $r^2=0.169$). Other physical characteristics including pipe length and the presence of a pond or sump pumps have similar relationships. The similarities only occurred for mass flux, not concentrations. However, we suspect that these relationships are artifacts of the storm sewershed area. Pipe length was directly related to the area of storm sewershed size ($p<0.0001$, $r^2=0.854$; Chapter 2). Sump pumps and ponds also occur in larger storm sewersheds.

Increased %ISC increased the mass flux of some contaminants from storm sewersheds. The greater the %ISC, the more nitrate ($p<0.05$, $r^2=0.06$) and chloride ($p<0.05$, $r^2=0.05$) exited the system per second.

Zoning classifications had an impact on the mass flux of contaminants from storm sewersheds. The greater the percentage of commercial zoning in a storm sewershed the more nitrate leaves the system ($p<0.05$, $r^2=0.068$). The storm sewersheds with higher residential zoning have a lower mass of nitrate leaving the system per second ($p<0.05$, $r^2=0.061$). The greater the percentage of road in the storm sewershed, the lower the mass flux of the following: DRP ($p<0.05$, $r^2=0.066$), nitrate ($p<0.05$, $r^2=0.081$), total phosphorous ($p<0.0005$, $r^2=0.072$) and chloride ($p<0.0001$, $r^2=0.077$).

Discussion

The size of the storm sewer system does represent the magnitude of the mass flux of solutes. Miller et al. (2014) reported that in a peri-urban catchment the size of the storm sewershed was a determining factor in the scale runoff response and the volume of water does not appear to offer dilution especially since stormwater concentrations are so variable. Therefore larger storm sewersheds output a greater mass per time. The large storm sewersheds are also constantly flowing due to a combination of sump pumps and ponds. Only in rare cases do small storm sewersheds have large mass flux (for example chloride) during the snowmelt event.

Our findings suggest that the presence of a pond significantly improves storm water quality. These findings are consistent with literature documenting changes in water quality after flowing through a pond (Herrman, 2012; Marsalek, 2002; Tixier, 2001). The observation of reduced solute concentrations measured in this study demonstrated that some treatment likely occurs within ponds.

Treatment within ponds was likely a factor of their discharge control properties and flora present within each system. The original purpose of pond was to slow storm water flow, this process in turn allows for suspended solids to settle out (Welty, 2009). The increase in % organic matter was likely also result of this process. Organic matter may have been less likely to settle out even in slower moving waters. It would also be possible that organic matter was picked up in ponds, especially retention ponds where phytoplankton can grow. The reduction of levels in other parameters is likely due in part to the settling of solids on which these parameters were absorbed (Tixier, 2011). Flora in the pond area may also react with the nutrients in the stormwater (Herrman, 2012).

Parking lots appear to contribute large amounts of chloride. If the road salt spread on roads was the primary contributor of chloride, then percentage of road area would also be correlated with chloride. However, businesses may distribute more road salt than is necessary to prevent slippery surfaces in an effort to prevent liability for injury. The frequency of use of an impervious surface could have affected chemistry just as physical characteristics did (Gallo et al. 2013). A catchment may have high %ISC but if it is not used often that may affect the particulates present on the surface and how they move. This is why we may not see significance with all parameters in relation to %ISC. This is not to say that the water quality is not degraded. Rather it is simply that as impervious surface cover varies throughout an urban area it does not necessarily change the water quality.

Storm sewersheds with high %ISC have higher mass flux of nitrate and chloride either due to increased supply or increased transportation. In the case of chloride it is most likely an increase in supply since road salt is only placed on impervious surfaces. Nitrate however is primarily spread on pervious surfaces as fertilizer. If runoff over pervious surface is the source then the increase in %ISC simply aids in the transportation of nitrate to the storm sewer (Hatt et al., 2004, Hale et al., 2014).

Our study suggests that the higher the percentage of road, the more degraded the water quality. Road were important to storm water management because they are the conduits for the storm water. A greater percentage of roads could lead to stronger flow of runoff before it gets to the storm sewer inlet. Like water accumulated at the curb of the road, debris may have accumulated there as well. Higher flows would lead to the possibility of more solids becoming suspended, and increased debris would increase the availability of solids to be picked up.

The decrease in pH relative to increasing pipe length is contrary to previous literature (Davies et al. 2010). The calcium and bicarbonate in the cement of the pipes should increase the pH with more contact. However, Davies et al. (2010) did state that this effect is reduced as the pipes age and degrade. Perhaps the age of the Bloomington system is such that it does not raise the pH and some other factor is lowering the pH with extended contact with the pipes.

We observed better water quality with denser pipe systems, probably because water spent less time on the surface. In other words, the denser the piping system the shorter the distance the water would have to travel on the surface and less opportunity to be pick up solids and with less power to pick up the larger particles. Pipe density did not seem to have significance with nutrients (Hale et al. 2014). Although it is curious that inlet density did not show the same relationships as pipe density. It is possible that there were inlets missing from the data set. There were inlets within a storm sewer system that contribute to other systems when flood routes were present (see Chapter 2). These inlets were not incorporated in our calculations.

The availability of all suspended solids and total phosphorous was less in commercial areas. The decrease in total phosphorous may have been due to its tendency to be attached to solids (Wang et al., 2011), so as the concentrations of solids decreased total phosphorous also decreased. Residential areas had lower VSS suggesting a greater availability of organic matter. Mass flux of nitrate is affected by zoning in the opposite manner than suspended solids were, in that commercial area had higher mass flux of nitrate and residential areas had lower mass flux of nitrate. These mixed relationships may again be dependent on the type and degree of use (Gallo et al. 2013) or dependent on the fact that solids are available throughout the year and at a relatively constant rate (Brodie, 2007) but nitrate was seasonal (Shertzer et al., 1998). Additionally, Kim et al. (2014) suggest that peak concentrations occur at different points in the hydrograph for commercial and residential catchments. If this is the case, our study would be insufficient to make conclusions on the differences in water quality among different zoning percentages since we collected only one grab sample.

Sump pumps appeared to have a diluting effect on conservative ions. Sump pumps draw water from the subsurface (primarily around residential houses), which appears to have minimal amounts chloride in it. The likely source of most chloride comes from road salt spread on impervious surfaces (Kelly, 2008) and subsurface water comes from pervious surfaces. Therefore the sump pumps are likely diluting the chloride. This is supported by O’Reilly et al. (2012), who suggested that chloride concentrations in the subsurface are impacted by preferential flow. It could also suggest that other parameters such as nitrate and DRP percolated through the subsurface since sump pumps were not correlated with those solutes.

Conclusions and Implications

Our findings suggest that characteristics of storm sewersheds do affect water quality (Table 8). Ponds, sump pumps and higher pipe density improved water quality. Water quality was more degraded by higher %ISC. The presence of each zoning classification had mixed effects on storm water quality.

Urban areas would likely benefit if ponds were built part of storm sewer systems for the purpose of improving water quality in addition to reducing flow. The ponds reduce the peak flow, beautify the area and improve the water quality. Denser storm sewer design could be considered for new and retrofitted storm sewer systems. Other storm sewershed characteristics are unlikely to be easily incorporated in the storm sewershed design. Impervious surface cover and zoning both change over the years as the urban landscape changes and develops. However, whenever any physical characteristics can be considered when designing and building a storm sewer system, water quality could be improved.

Table 8

Results of Our a priori *Hypotheses*

Physical Characteristic	*A priori* Hypothesis	Conclusion
Ponds	Presence would improve water quality	Presence improved water quality
Denser Storm Sewer Pipe Layout	Positive relationship with water quality	Positive relationship with water quality
Storm sewer pipe length	Negative Relationship with water quality	Inconclusive
%ISC	Negative relationship with water quality	Negative relationship with water quality

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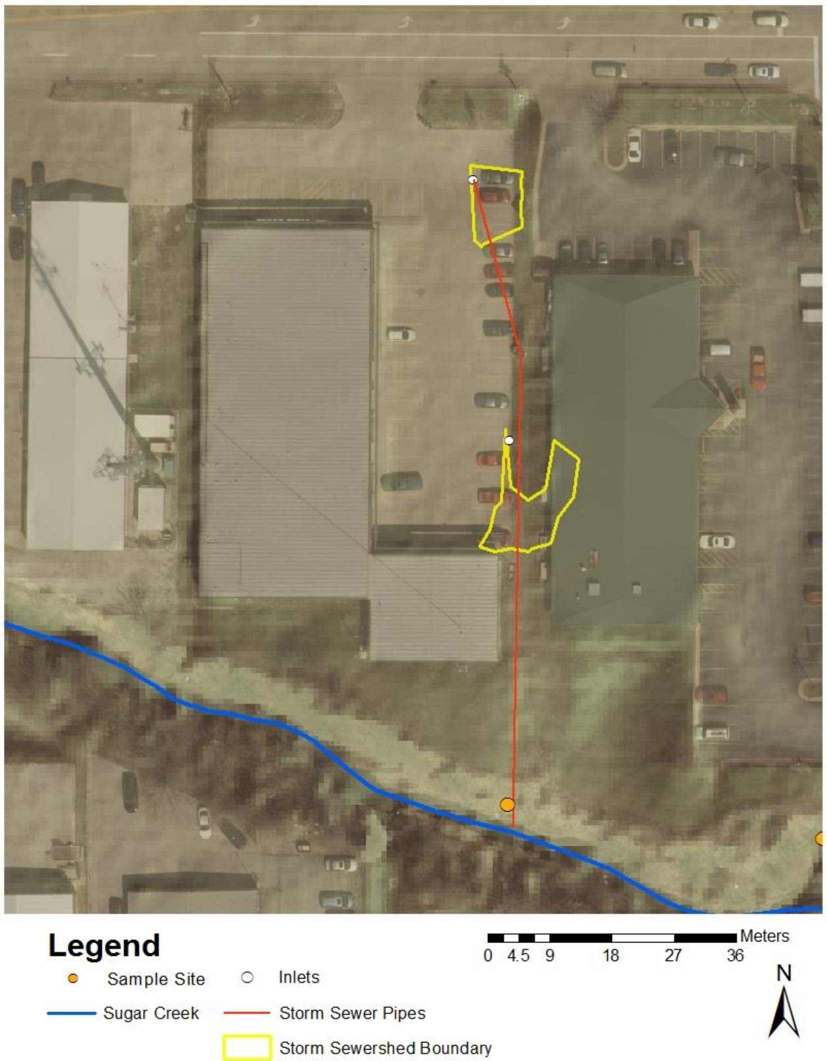
APPENDIX A

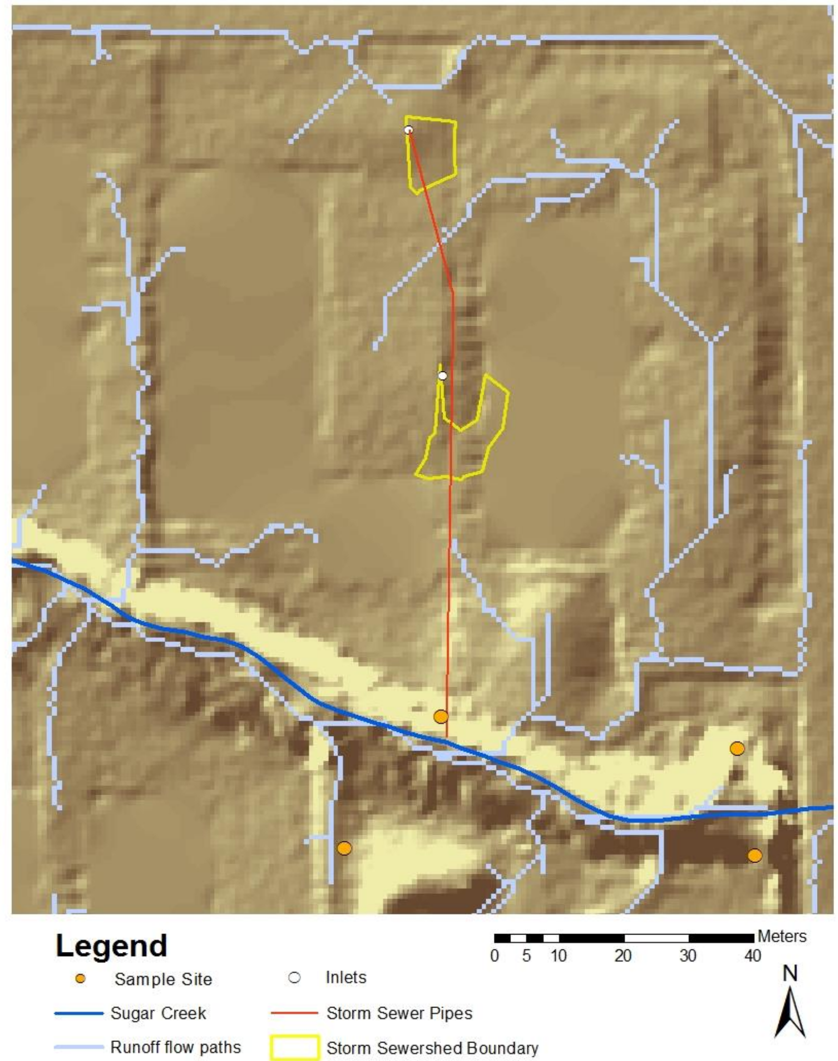
STORM SEWERSHED MAPS, LOCATIONS AND DESCRIPTONS

Parking Lot at Airport Street

B_C_Airport

This is a private sewer system. It drains a parking lot on the corner or General Electric Road and Airport Road. It has a 12 inch diameter pipe at its outlet. The outlet is located on the north side of the stream. There are broken slabs of concrete in front of the outlet

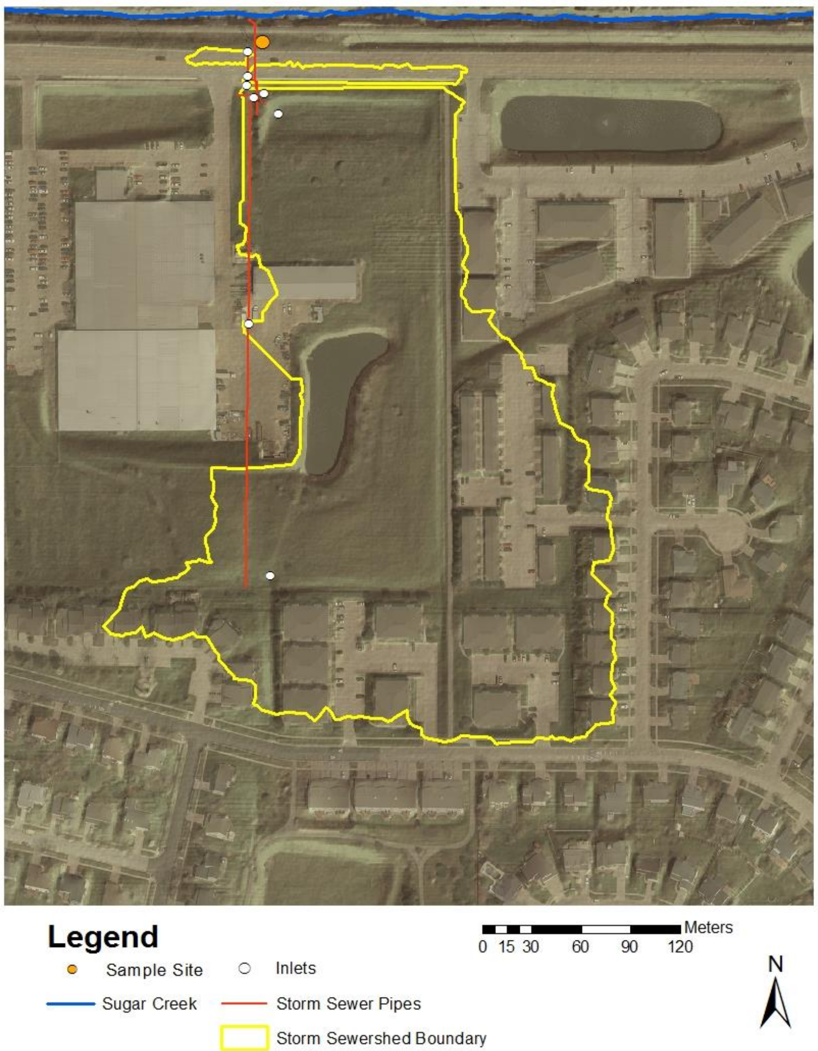

Legend
Sample Site
Inlets
Sugar Creek
Storm Sewer Pipes
Storm Sewershed Boundary
Meters
0 4.5 9 18 27 36
N

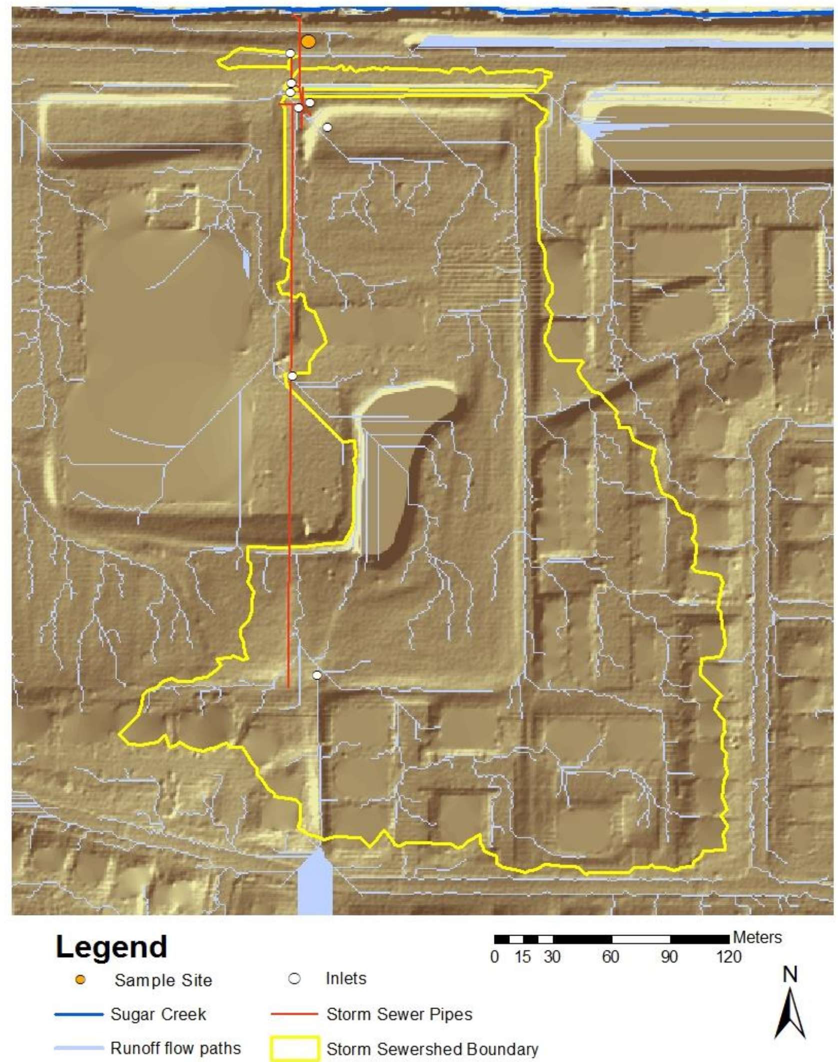

Legend
Sample Site
Inlets
Sugar Creek
Storm Sewer Pipes
Runoff flow paths
Storm Sewershed Boundary
Meters
0 5 10 20 30 40
N

Commercial Drainage on General Electric Street

B_C_GE

This is a public sewer system. It drains a commercial lot south of General Electric Road. The outlet has a 48 inch diameter. I access this location from Hedgewood Park on the north end of Sugar Creek. This is a private park that I accessed with permission from the homeowner’s association. I crossed Sugar Creek from the park and B_C_GE is located upstream. I walked upstream passed two sets of riprap. It is the most downstream outlet in a set of two. The outlet’s tongue has a large amount of sediment accumulated.

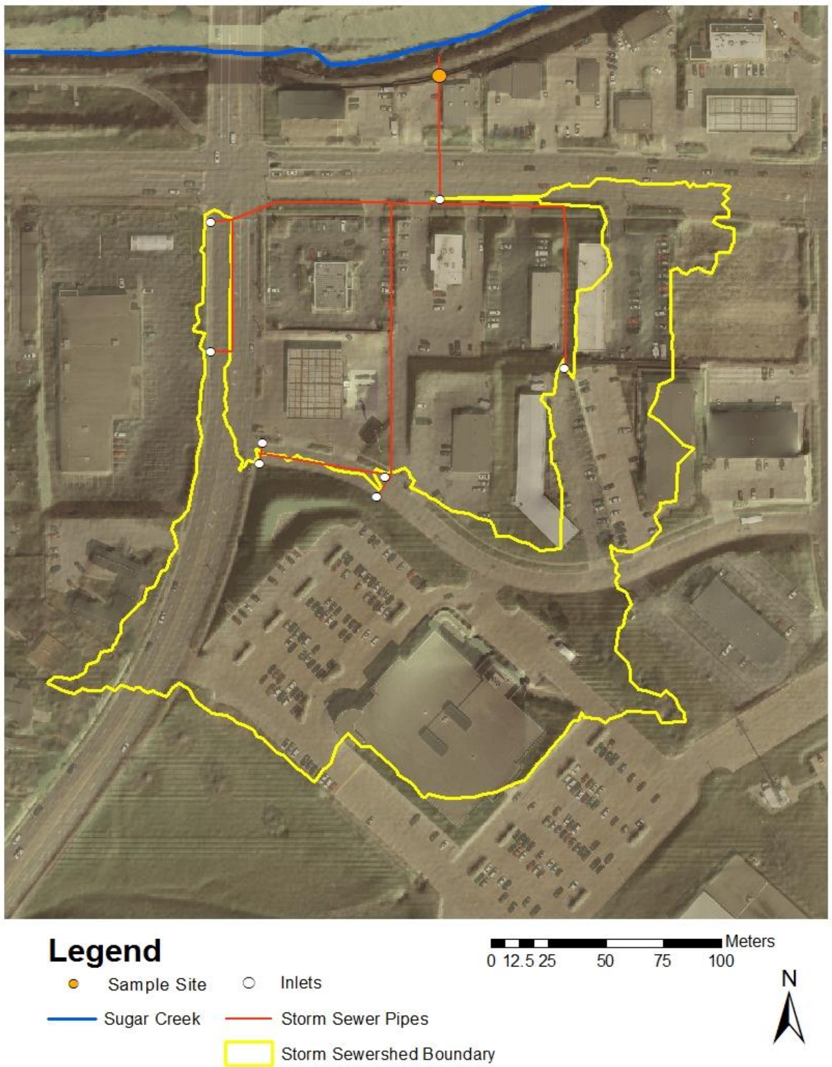

Legend
Sample Site
Inlets
Sugar Creek
Storm Sewer Pipes
Storm Sewershed Boundary
Meters
0 15 30 60 90 120
N

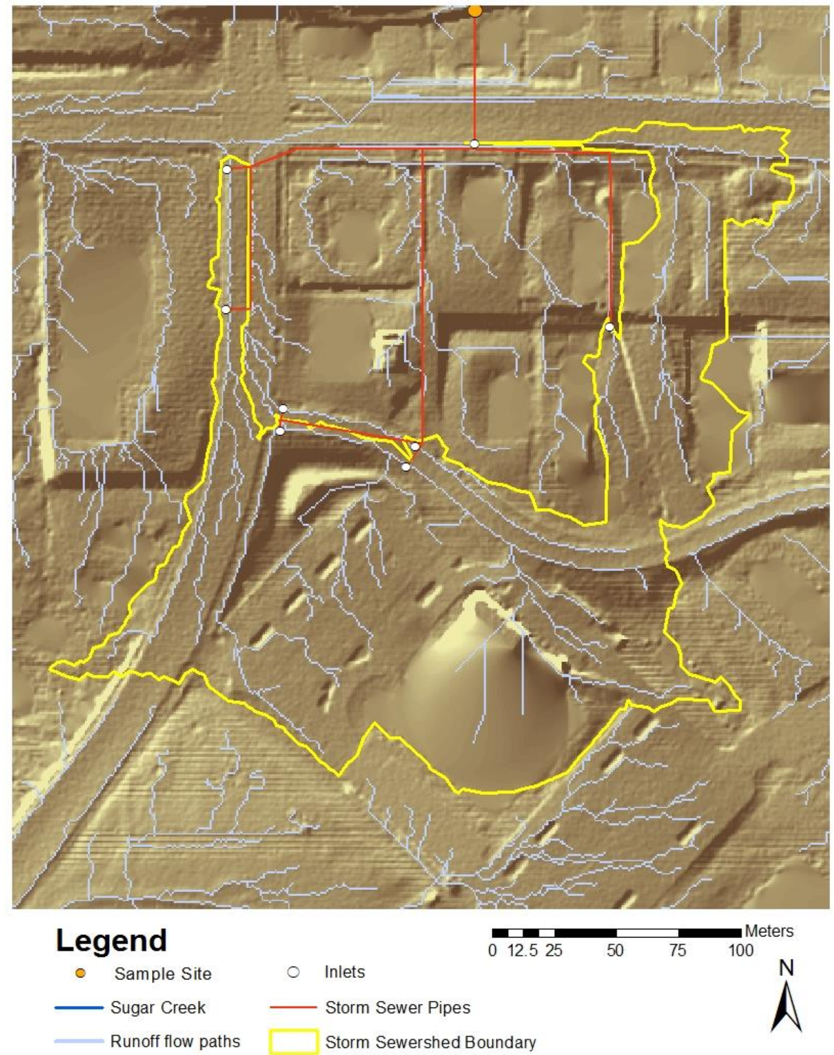

Legend
Sample Site
Inlets
Sugar Creek
Storm Sewer Pipes
Runoff flow paths
Storm Sewershed Boundary
Meters
0 15 30 60 90 120
N

Commercial Drainage on Vernon Street

B_C_GE

Public sewer system, draining commercial parking lots south of Vernon Road. It has an 18 inch diameter outlet pipe. To access this site I parked at Jason’s Deli on Vernon Road. There is access to the constitution trail from there. B_C_Vernon is downstream of the access point. The outlet is located under a fence there is a garbage can immediately before it. The outlet drains to a small gully and there is about a 2 foot drop below the tongue of the outlet.

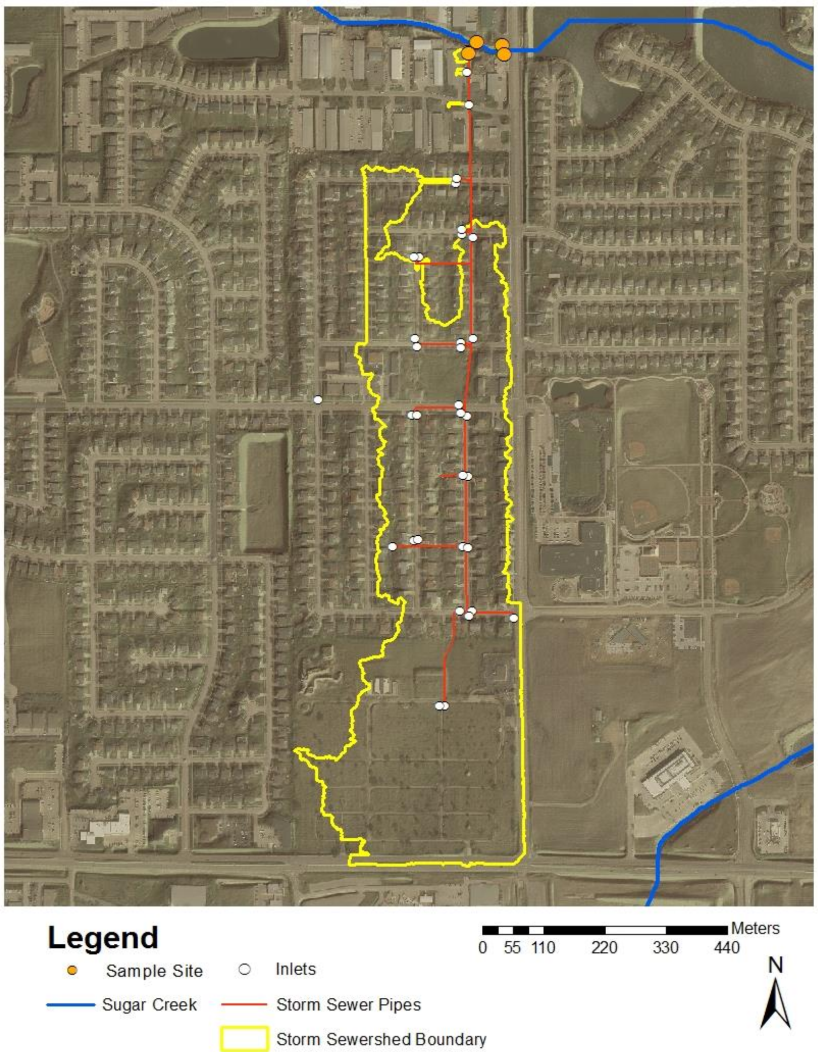

Legend
Sample Site
Inlets
Sugar Creek
Storm Sewer Pipes
Storm Sewershed Boundary
0 12.5 25 50 75 100
Meters
N

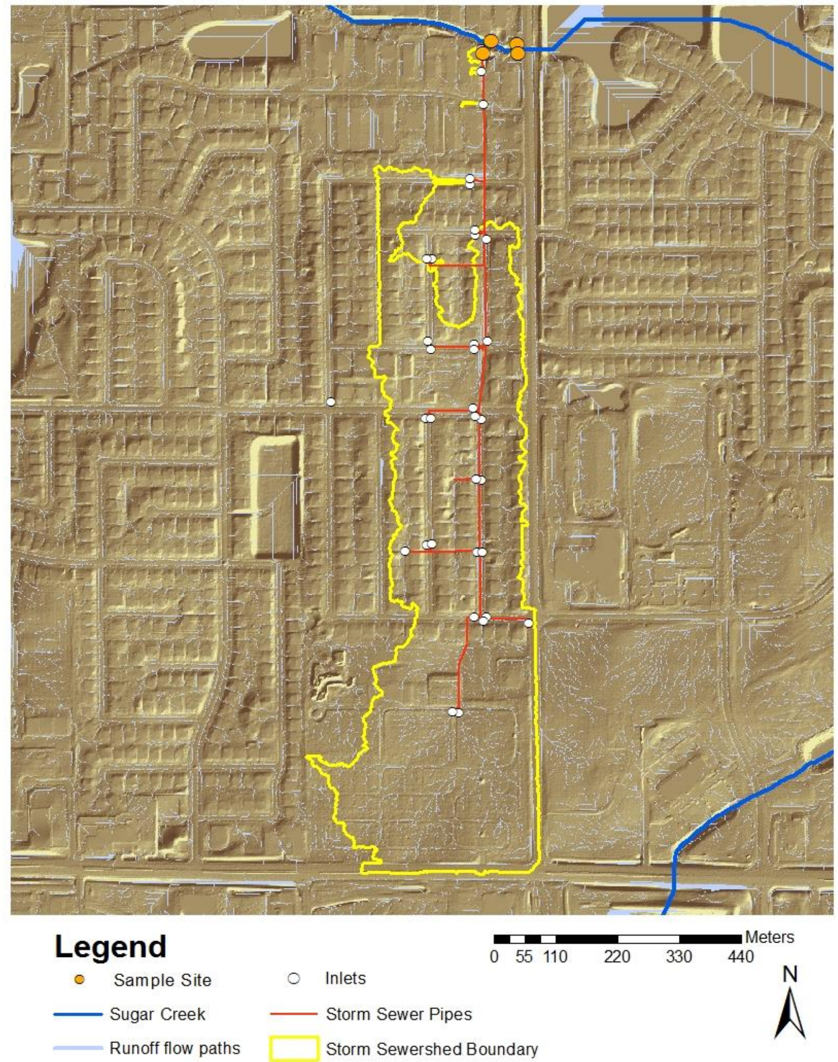

Legend
Sample Site
Inlets
Sugar Creek
Storm Sewer Pipes
Runoff flow paths
Storm Sewershed Boundary
0 12.5 25 50 75 100
Meters
N

Residential and Park Drainage at Airport Street

B_H_Airport

This is a public sewer system draining a residential area south of General Electric Road. It has a 54 diameter outlet pipe. I accessed the site from the corner of General Electric Road and Airport Rd. This is the furthest upstream site from this access location. When walking upstream from B_C_Airport this site is on the left side. It has a very long tongue which is usually raised only a few inches from the stream. This site has tendency to flood during large storm events as shown in the picture.

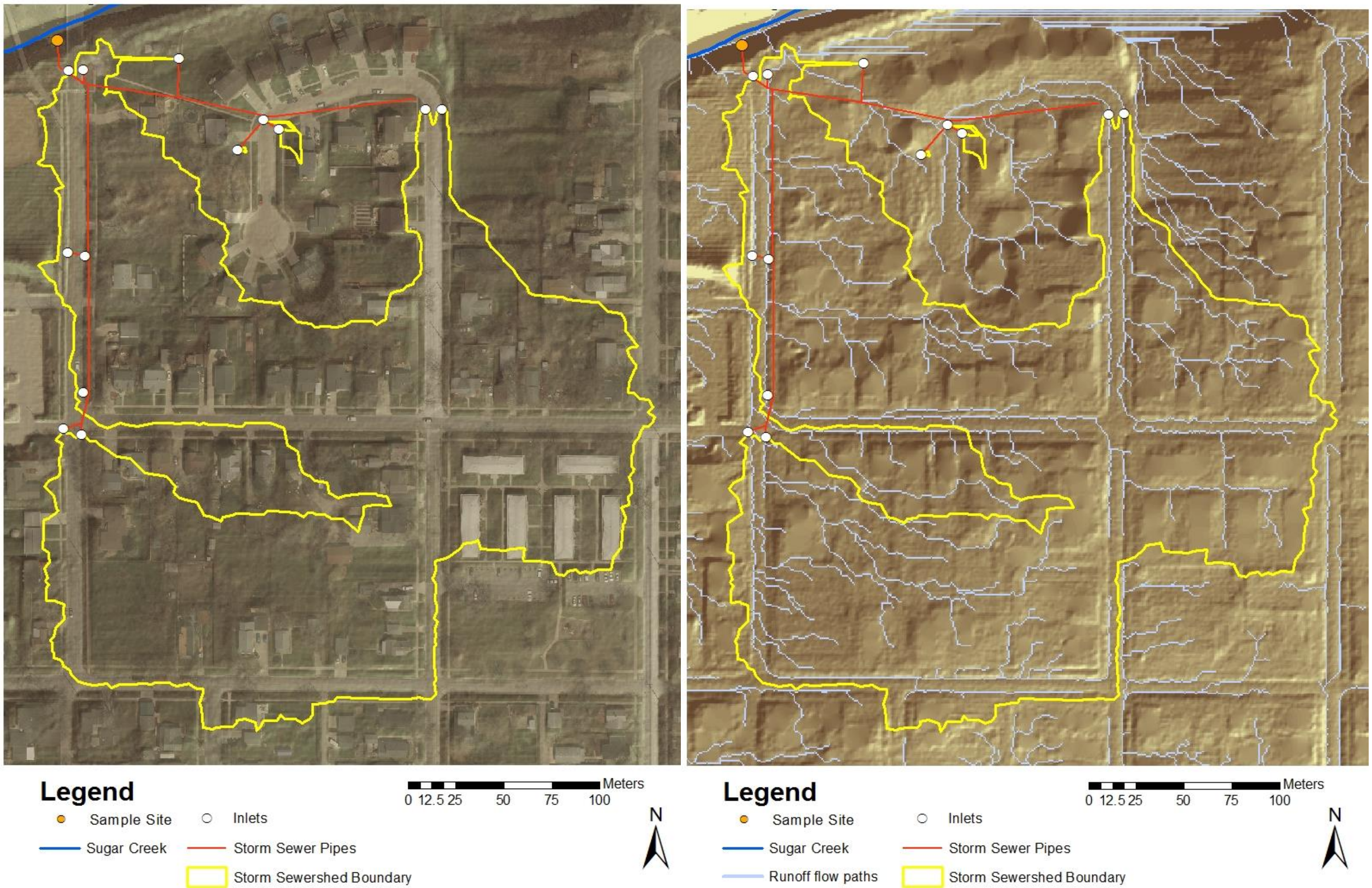

Legend
Sample Site
Inlets
Sugar Creek
Storm Sewer Pipes
Storm Sewershed Boundary
Meters
0 55 110 220 330 440
N


Legend
Sample Site
Inlets
Sugar Creek
Storm Sewer Pipes
Runoff flow paths
Storm Sewershed Boundary
Meters
0 55 110 220 330 440
N

Residential Drainage at White Oak Park

B_H_Cott

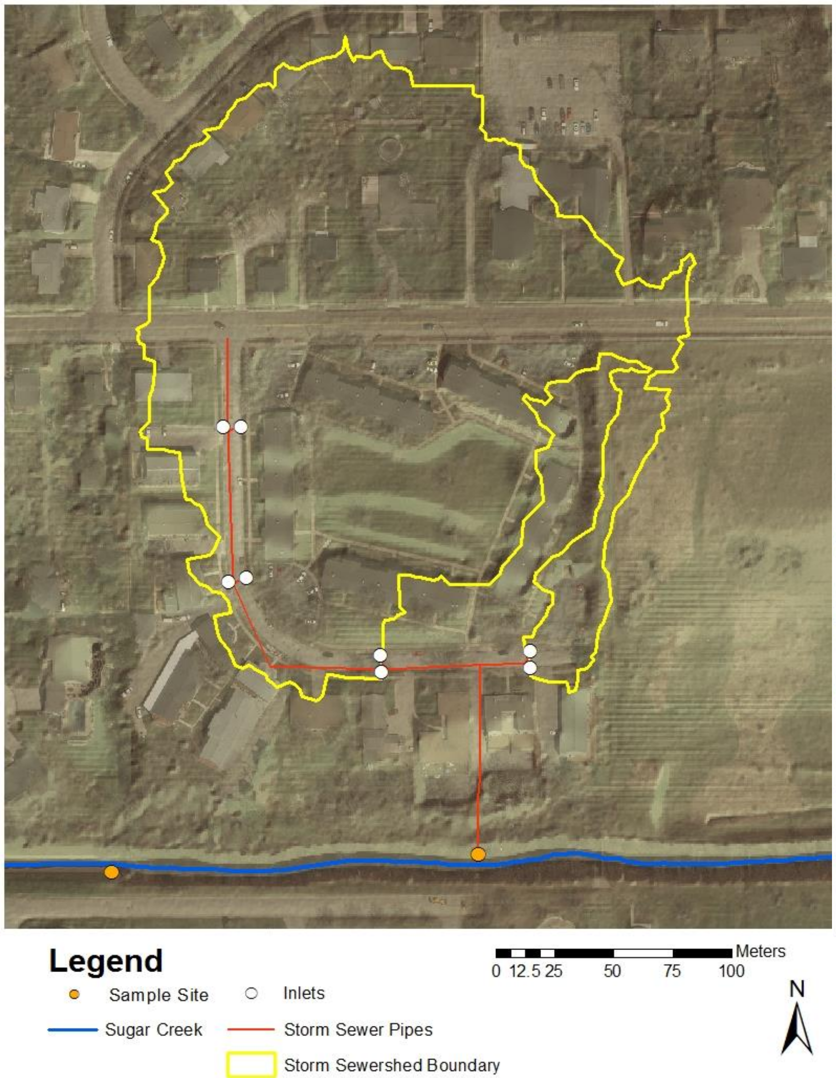
This is a public sewer draining a residential area south of Sugar Creek and east of White Oak Park. I accessed the site from the White Oak Park parking lot on Cottage Street. The outlet is across a foot bridge and slightly to the north. The outlet pipe is 24 inches in diameter. There is a gap between the pipe and the tongue, during low flow conditions water will not travel over tongue.

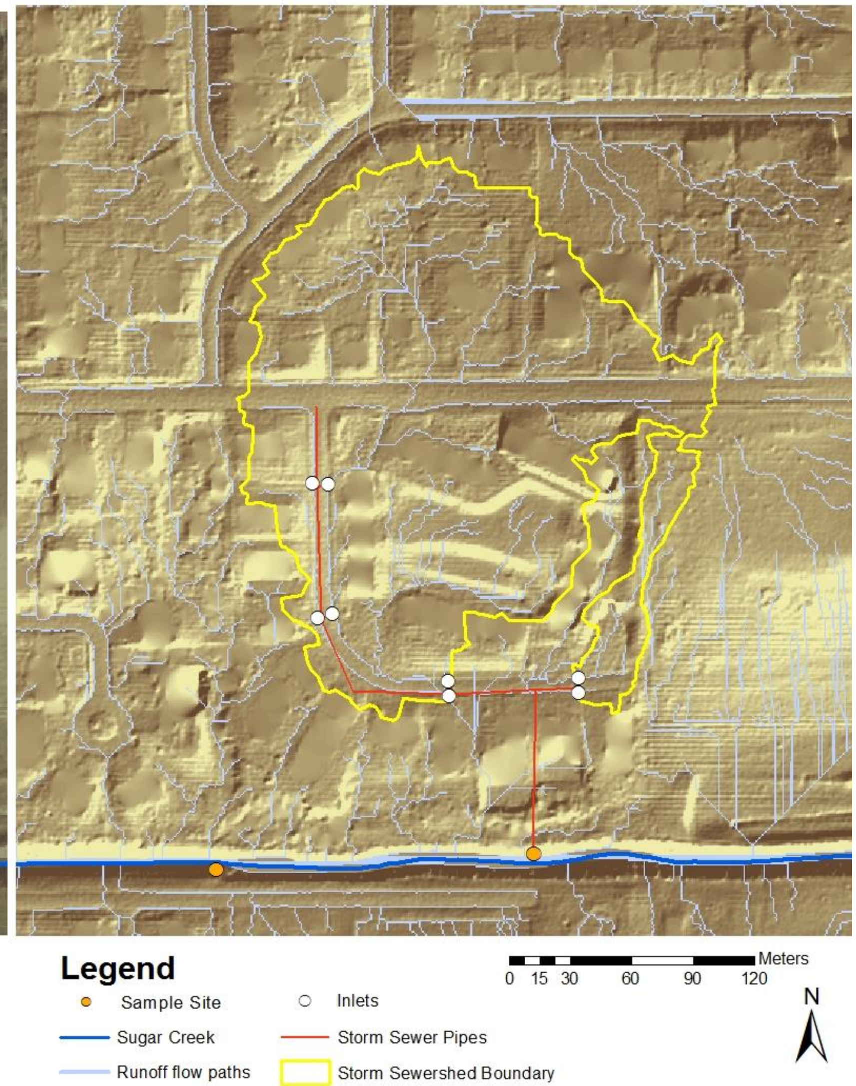

Legend
Sample Site
Inlets
Sugar Creek
Storm Sewer Pipes
Storm Sewershed Boundary
0 12.5 25 50 75 100 Meters
N
Legend
Sample Site
Inlets
Sugar Creek
Storm Sewer Pipes
Runoff flow paths
Storm Sewershed Boundary
0 12.5 25 50 75 100 Meters
N

Apartment Complex Drainage at Ewing Park

B_H_Ew

This is a public sewer draining a residential area north of Sugar Creek and Ewing Park. The pipe diameter throughout the system is 12 inches. I accessed the site from Ewing Park II entrance from Ethel Parkway. From the end of the road the site is upstream, and on the northern bank. It is the only storm sewer outlet in the area with a tongue. Across the stream from the site is another storm sewer pipe that extends several feet over the stream.

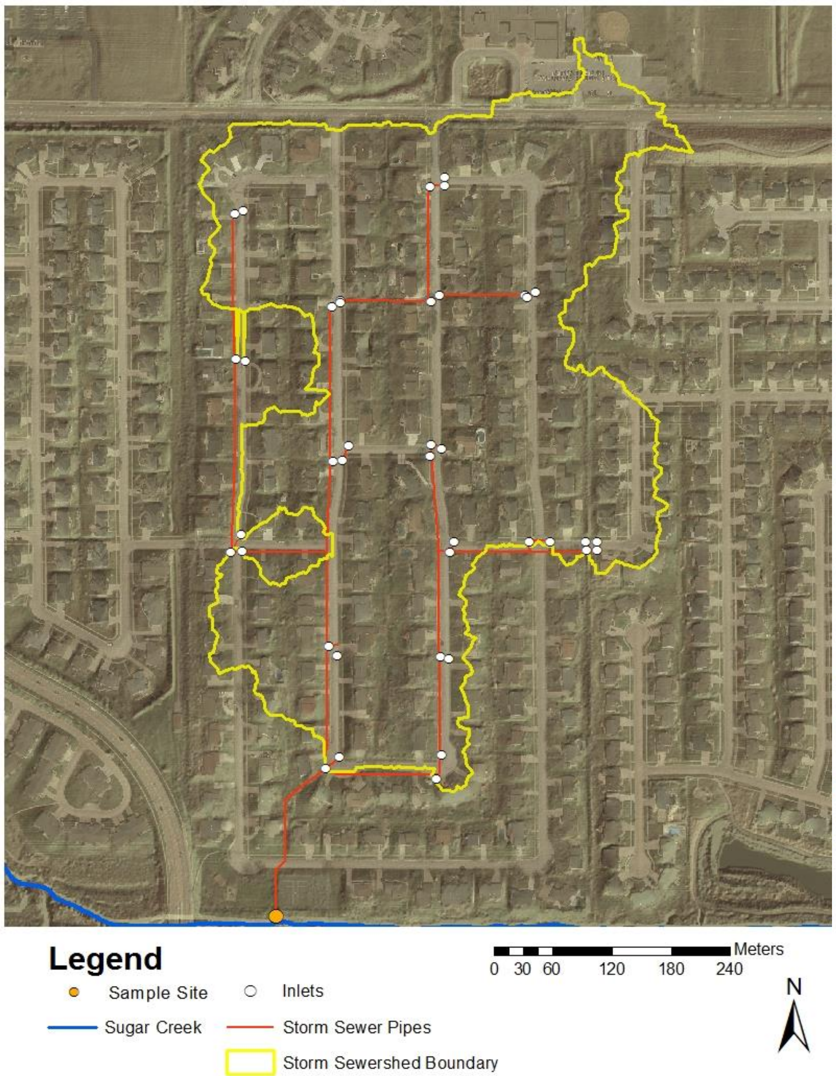

Legend
Sample Site
Inlets
Sugar Creek
Storm Sewer Pipes
Storm Sewershed Boundary
Meters
0 12.5 25 50 75 100
N

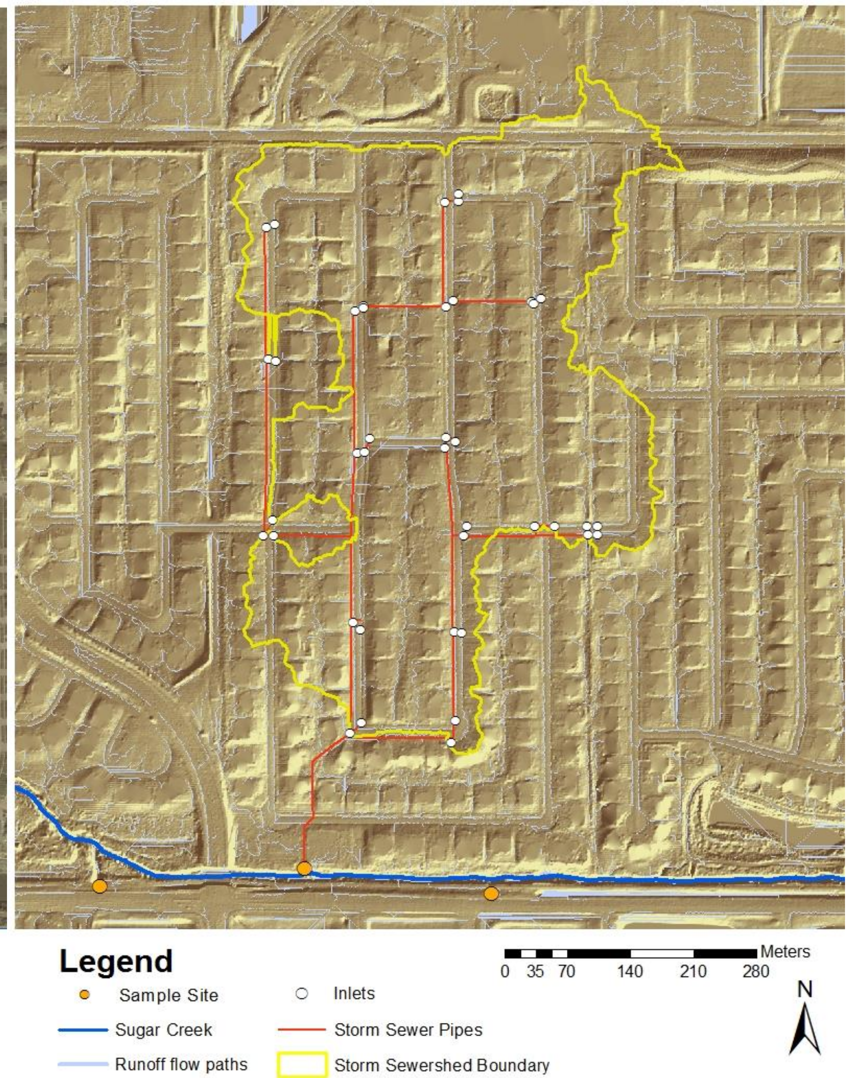

Legend
Sample Site
Inlets
Sugar Creek
Storm Sewer Pipes
Runoff flow paths
Storm Sewershed Boundary
Meters
0 15 30 60 90 120
N

Hedgewood Park

B_H_GE

This is a public storm sewer system draining a residential area north of Sugar Creek. The pipe diameter at the outlet is 42 inches with a grate covering it. The grate is often clogged leaf litter. I accessed this site as well as B_C_GE and B_L_GE from Hedgewood Park. It is a private park run by the Hedgewood Park Homeowner's Association. I gained permission from the HOA. This site is located on the east side of the park near the tennis courts.

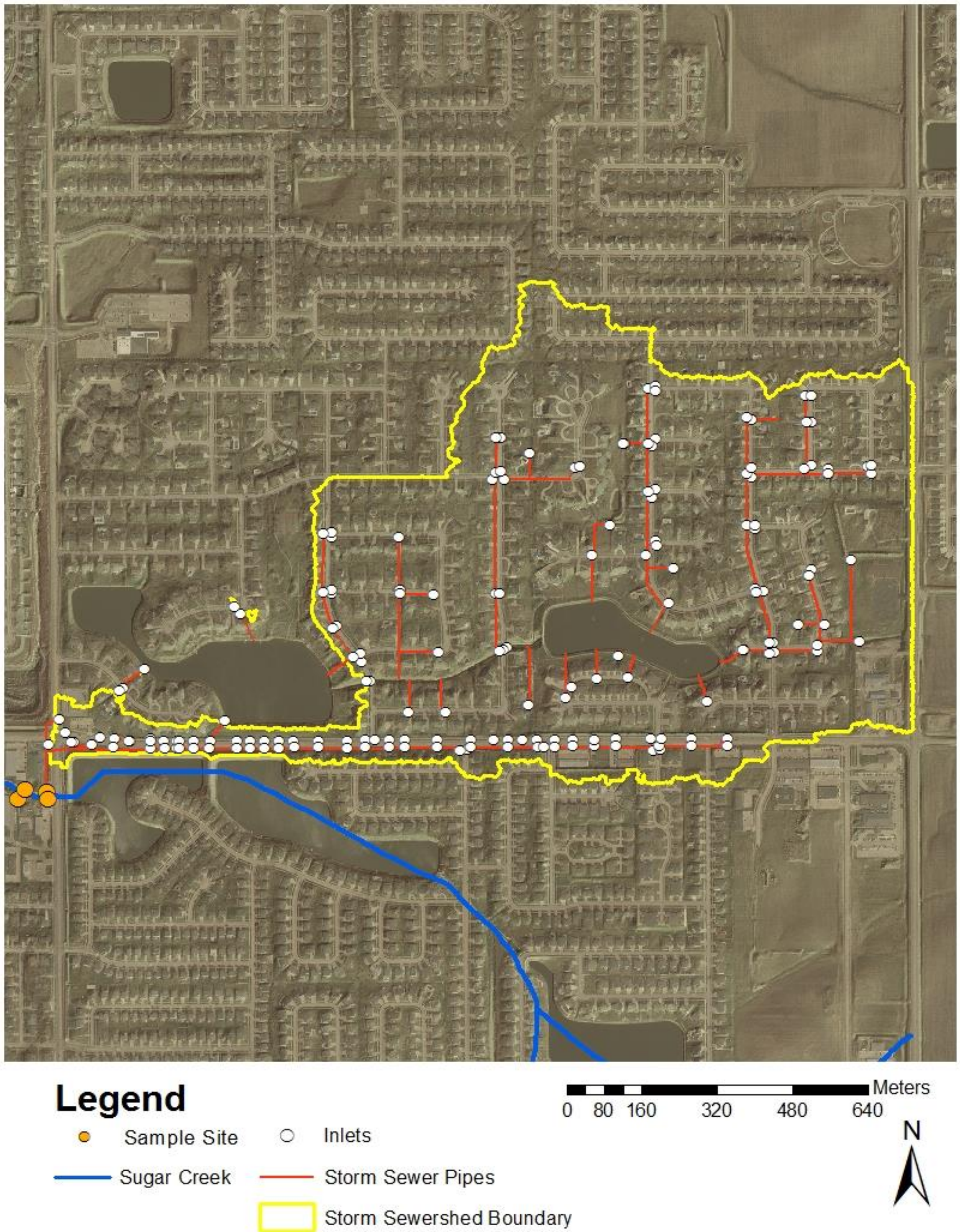

Legend
Sample Site
Inlets
Sugar Creek
Storm Sewer Pipes
Storm Sewershed Boundary
0 30 60 120 180 240
Meters
N

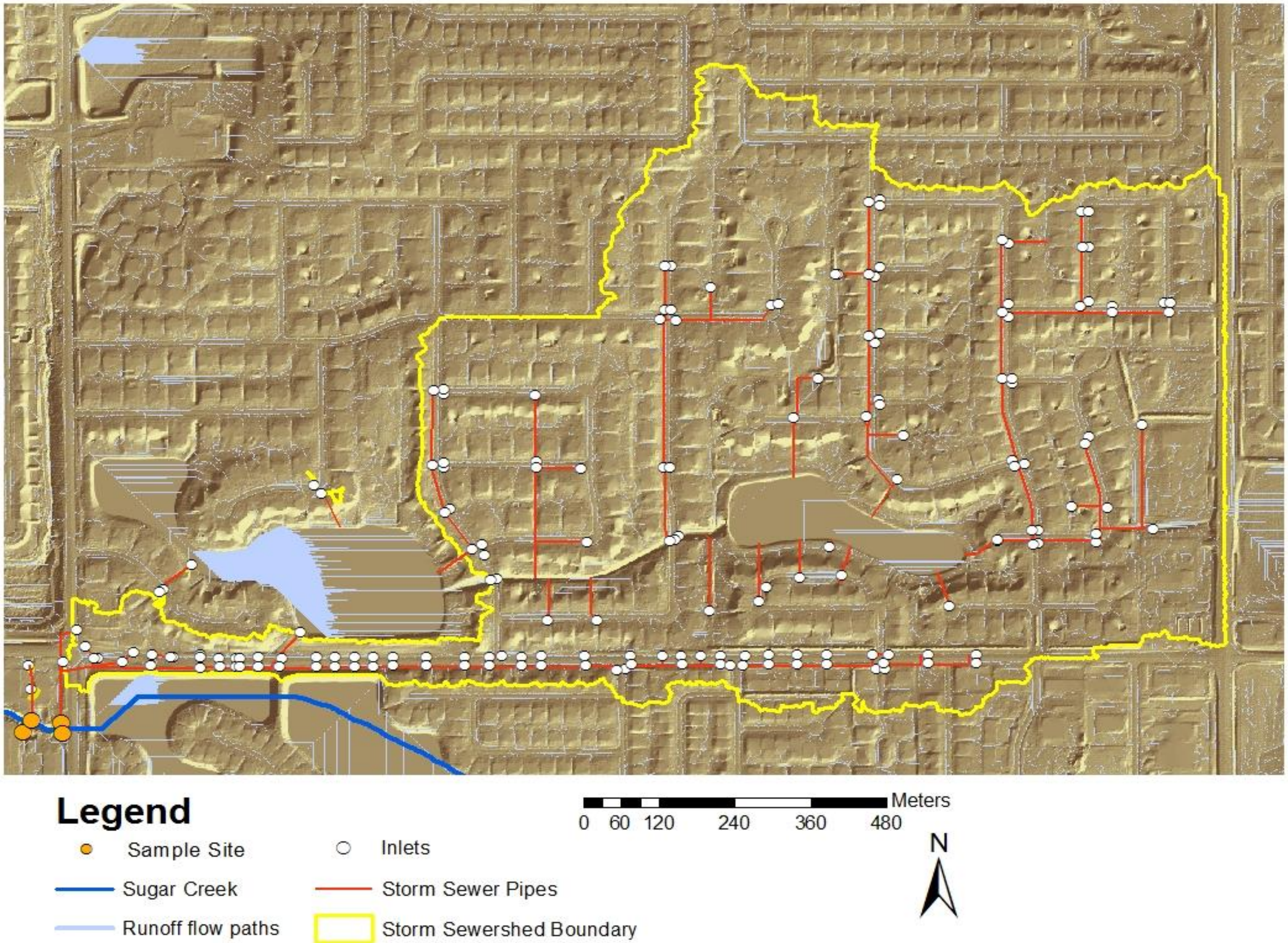

Legend
Sample Site
Inlets
Sugar Creek
Storm Sewer Pipes
Runoff flow paths
Storm Sewershed Boundary
0 35 70 140 210 280
Meters
N

Residential Drainage at G.E. and Airport

B_H_GEAir

This a public storm sewer system draining a residential systems north of Sugar Creek. The outlet pipe is 60 inches. I accessed this pipe from the corner of General Electric Road and Airport Road. It is located on the north side of the stream near a bridge over Airport Road. This site drains a large detention pond and usually has at least six inches of water flowing out.

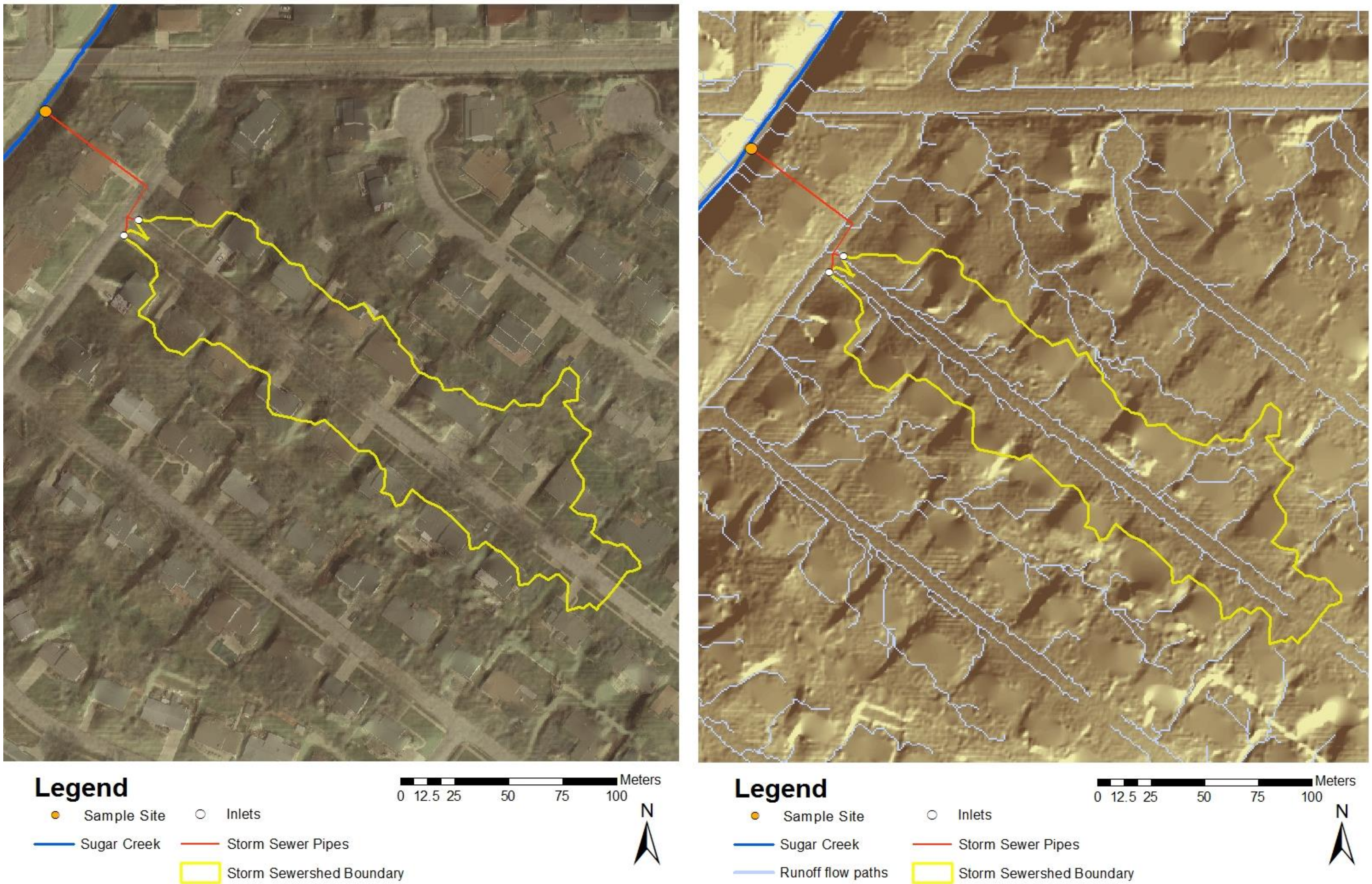

Legend
Sample Site
Inlets
Sugar Creek
Storm Sewer Pipes
Storm Sewershed Boundary
Meters
0 80 160 320 480 640
N


Legend
Sample Site
Inlets
Sugar Creek
Storm Sewer Pipes
Runoff flow paths
Storm Sewershed Boundary
Meters
0 60 120 240 360 480
N

Residential Drainage at Jersey Street

B_H_Jersey

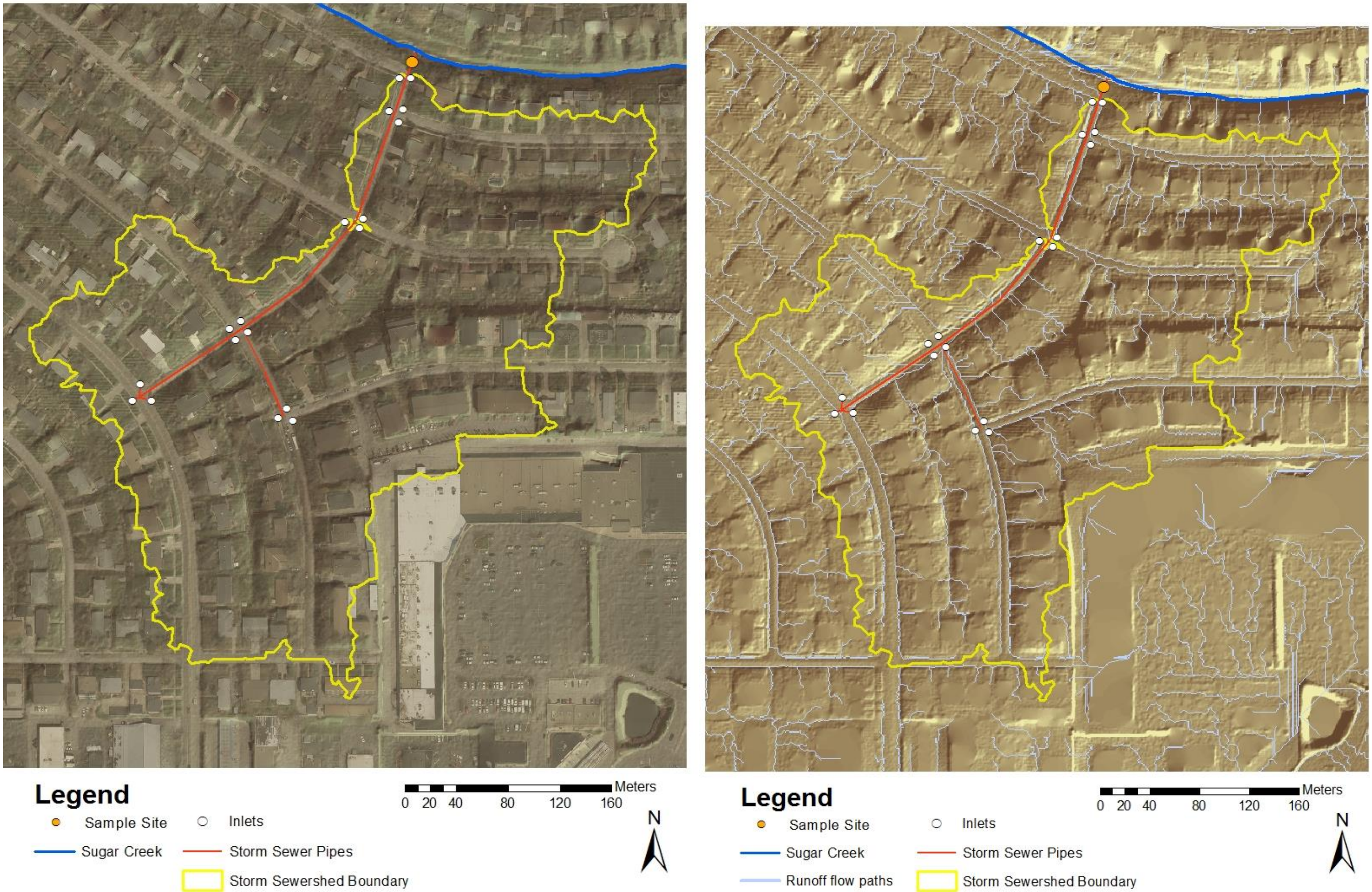
This is a public sewer system. The outlet pipe has a 12 inch diameter draining a road in a residential area south of Sugar Creek off of Jersey St. I accessed this site from Jersey Street on the north side of Ewing Park. This pipe is about 100ft downstream from the bridge. There is no tongue for this storm sewer. The pipe is rusted and ends before the concrete bank, the water will often drain below some of the concrete and in low flow conditions is difficult to sample.


Legend
Sample Site
Inlets
Sugar Creek
Storm Sewer Pipes
Storm Sewershed Boundary
0 12.5 25 50 75 100
Meters
N
Legend
Sample Site
Inlets
Sugar Creek
Storm Sewer Pipes
Runoff flow paths
Storm Sewershed Boundary
0 12.5 25 50 75 100
Meters
N

Residential Drainage at Rowe St

B_H_Rowe

This is a public storm sewer system. The outlet pipe is 15 inch pipe. It drains a residential area south of a tributary of Sugar Creek off of Rowe Street. I accessed this site from Rowe Street, just before Delmar Lane. The pipe is on the south side of the tributary, it has no tongue and sticks out into a small gully.

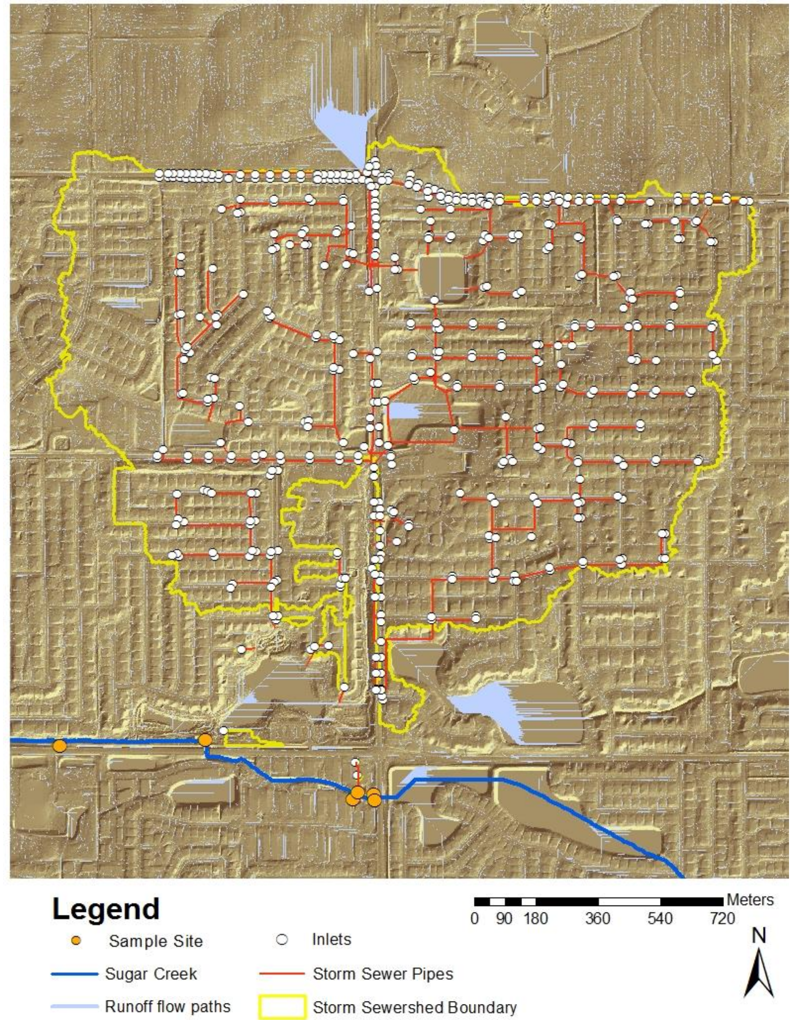

Legend
Sample Site
Inlets
Sugar Creek
Storm Sewer Pipes
Storm Sewershed Boundary
Meters
0 20 40 80 120 160
N
Legend
Sample Site
Inlets
Sugar Creek
Storm Sewer Pipes
Runoff flow paths
Storm Sewershed Boundary
Meters
0 20 40 80 120 160
N

Residential Drainage at Tipton Park

B_H_Tipton

This is a public storm sewer system. There are two outlet pipes each 72 inches in diameter exiting a retention pond from Tipton Park. I accessed this site from Tipton Park, the outlet is past the port-a-potty, and there is a large gully just off the trail. I sampled from the southside outlet pipe.

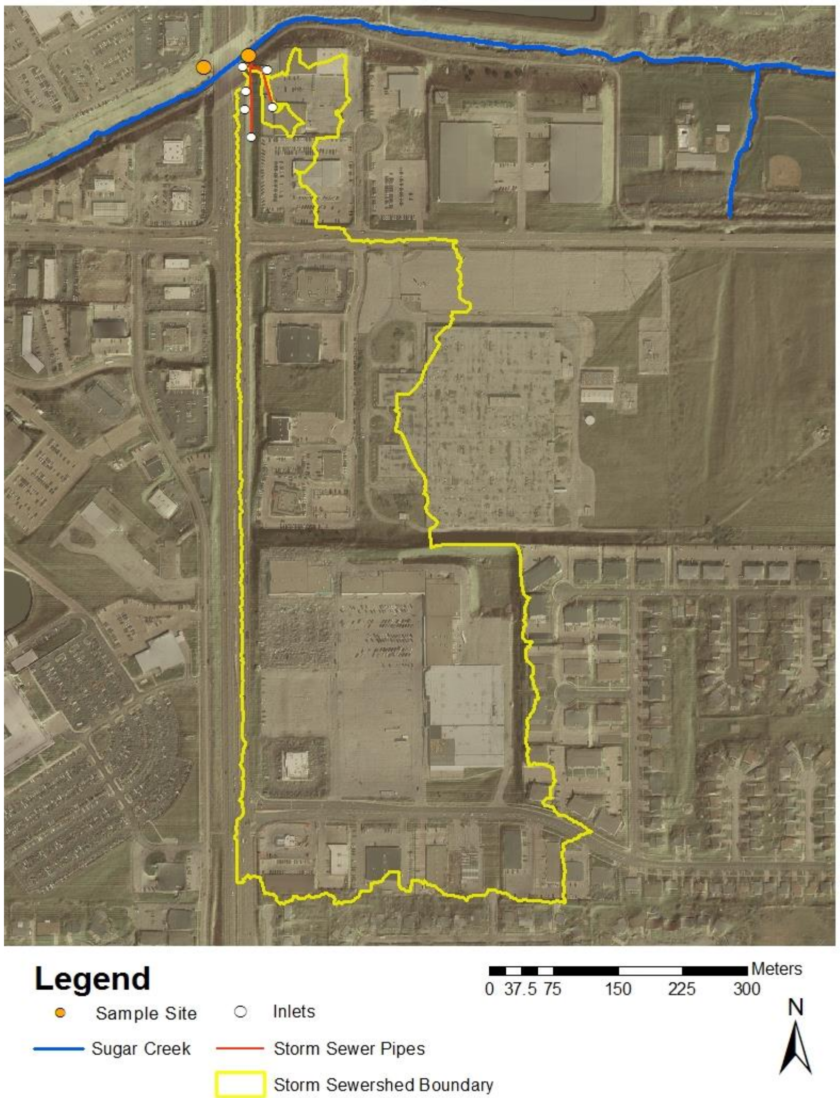

Legend
Sample Site
Inlets
Sugar Creek
Storm Sewer Pipes
Storm Sewershed Boundary
0 90 180 360 540 720
Meters
N

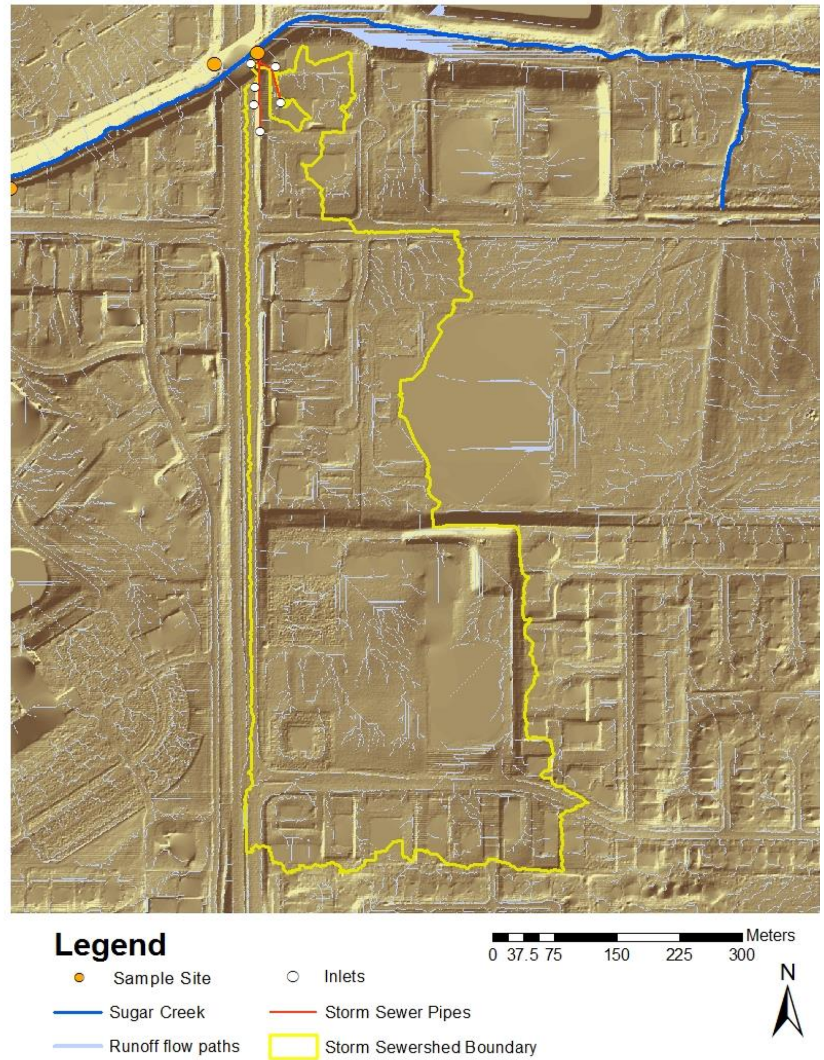

Legend
Sample Site
Inlets
Sugar Creek
Storm Sewer Pipes
Runoff flow paths
Storm Sewershed Boundary
0 90 180 360 540 720
Meters
N

Commercial Drainage at Veteran's Parkway

B_H_Vet

This is a public storm sewer system. The outlet pipe is 24 inches in diameter. The system drains a commercial areas south of Sugar Creek. I accessed this location from Jason's Deli on Vernon St. From this parking lot there is access to the Constitution Trail. This location is upstream from the access point. Immediately after passing under the Veteran's Parkway Bridge this site is located on the south side of the stream. I climbed down to this site using the bricks for the bridge. The site has a metal tongue.

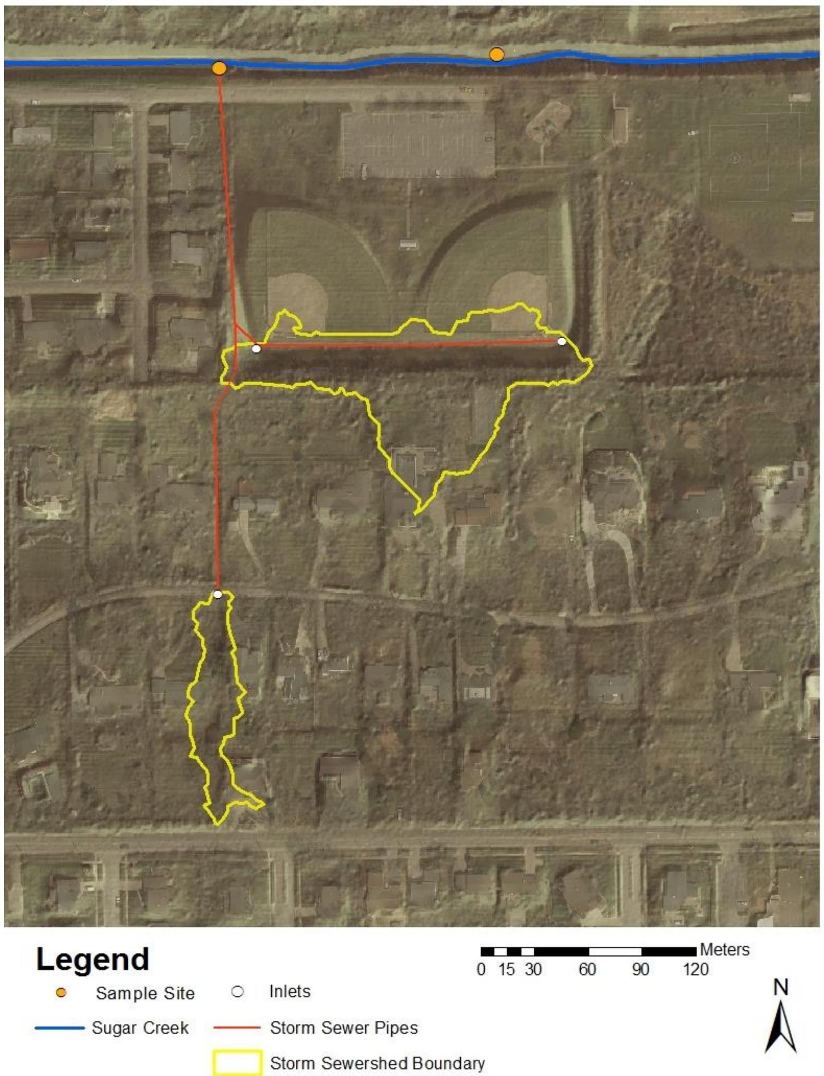

Legend
Sample Site
Inlets
Sugar Creek
Storm Sewer Pipes
Storm Sewershed Boundary
0 37.5 75 150 225 300
Meters
N


Legend
Sample Site
Inlets
Sugar Creek
Storm Sewer Pipes
Runoff flow paths
Storm Sewershed Boundary
0 37.5 75 150 225 300
Meters
N

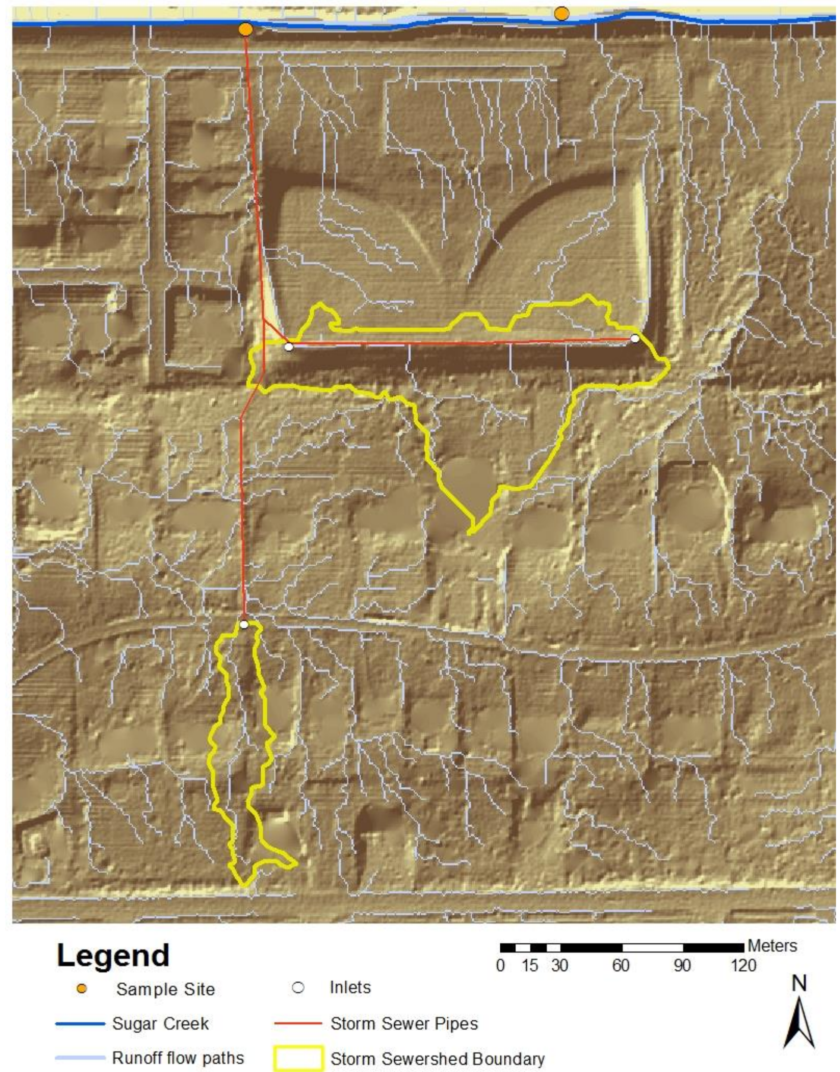
Low Impervious Surface at Ewing Park

B_ISC_EW

This is a public storm sewer system. The outlet pipe is 21 inches in diameter. The system drains the baseball fields of Ewing Park and a residential area to the south. I accessed this site from Ewing Park II off of Ethel Parkway. This site is located on the south side of the stream just after the site becomes cement lined.



Legend
Sample Site
Inlets
Sugar Creek
Storm Sewer Pipes
Storm Sewershed Boundary
Meters
0 15 30 60 90 120
N

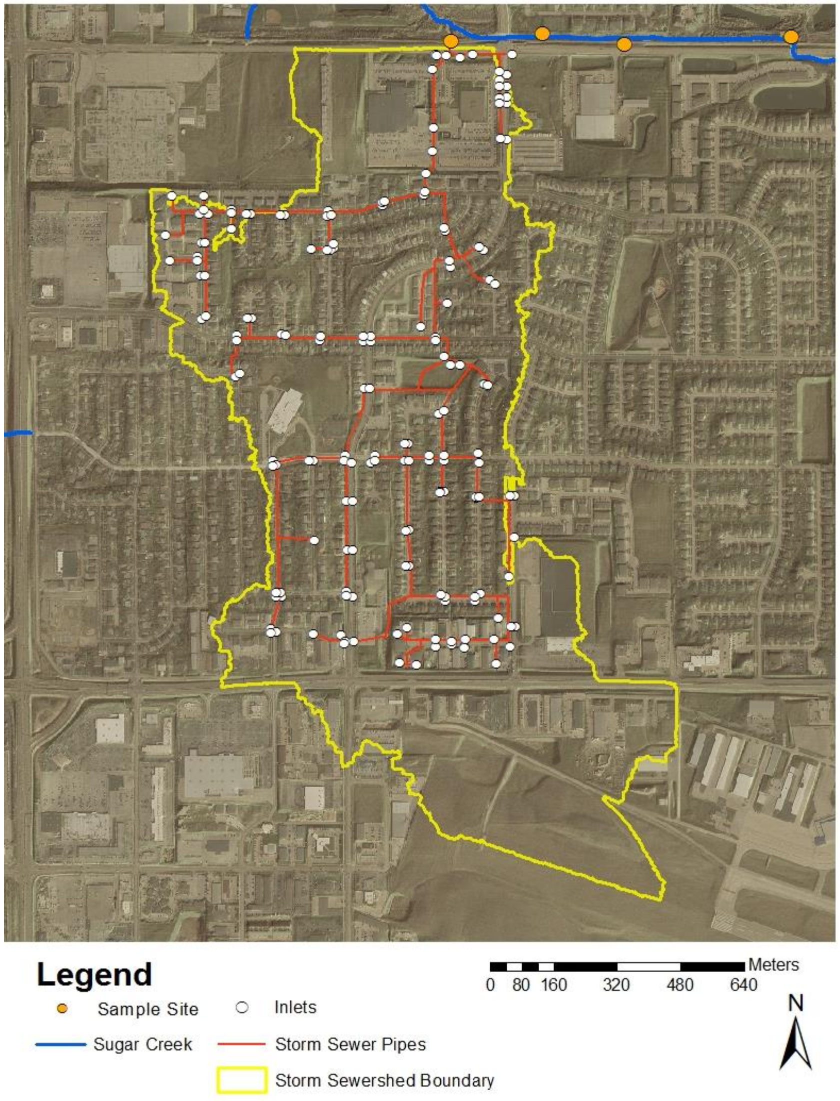


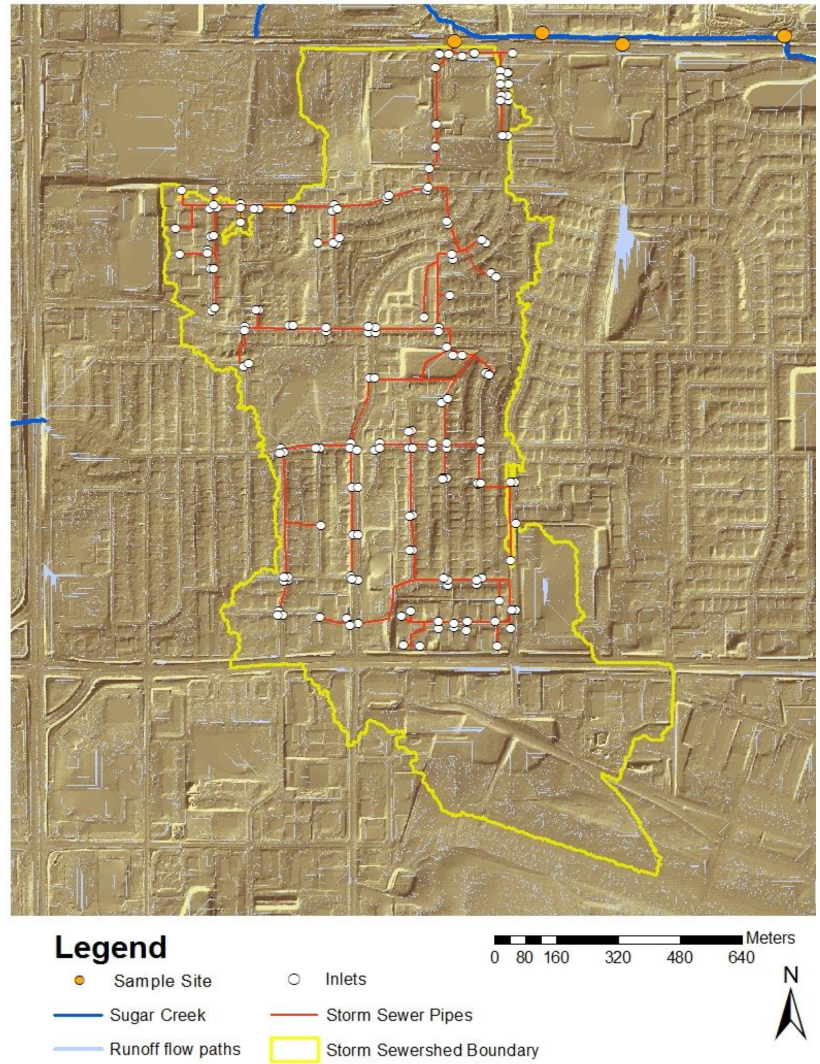
Legend
Sample Site
Inlets
Sugar Creek
Storm Sewer Pipes
Runoff flow paths
Storm Sewershed Boundary
Meters
0 15 30 60 90 120
N

Long Range Drainage at General Electric

B_L_GE

This is a public sewer system. The outlet pipe is 72 inches square. It drains a residential area south of Sugar Creek near the intersection of Hershey Road and General Electric Road. I accessed this site from Hedgewood Park. This site is downstream of the access point. I travel under Hershey Road via the Constitution Trail. At the first fence post I climb into a large gully that the outlet creates. This is a square shaped outlet with no tongue.

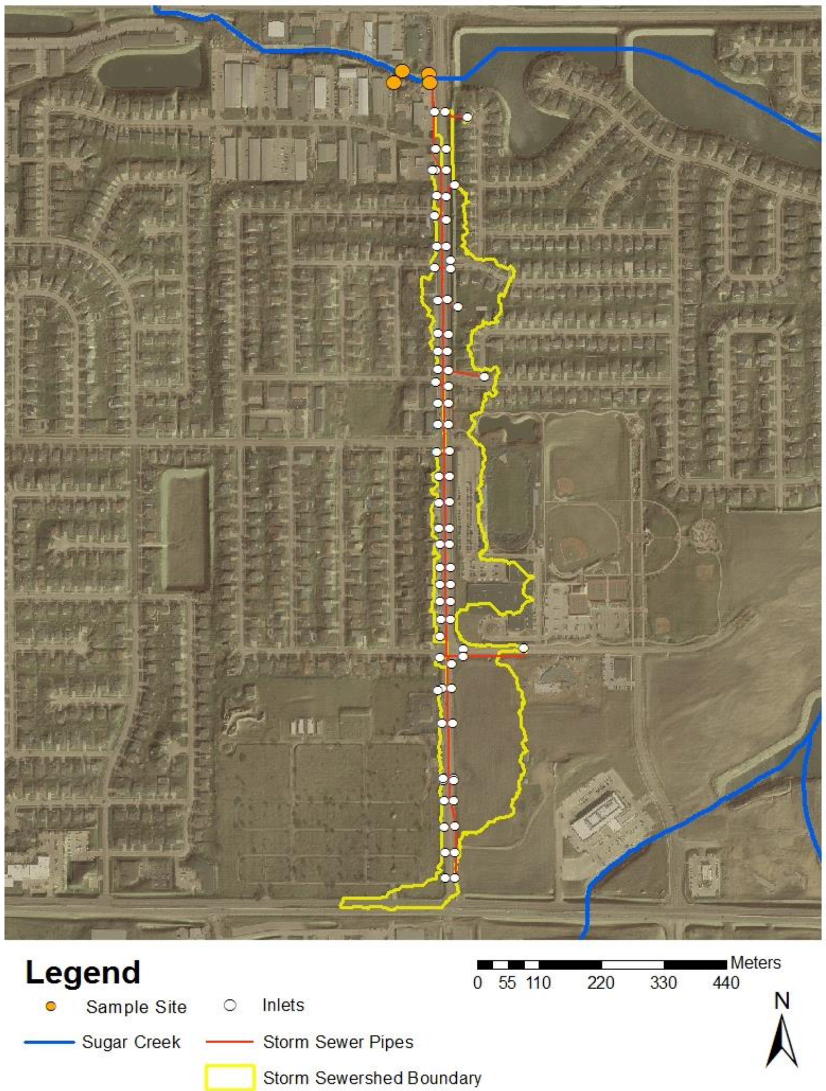

Legend
Sample Site
Inlets
Sugar Creek
Storm Sewer Pipes
Storm Sewershed Boundary
Meters
0 80 160 320 480 640
N

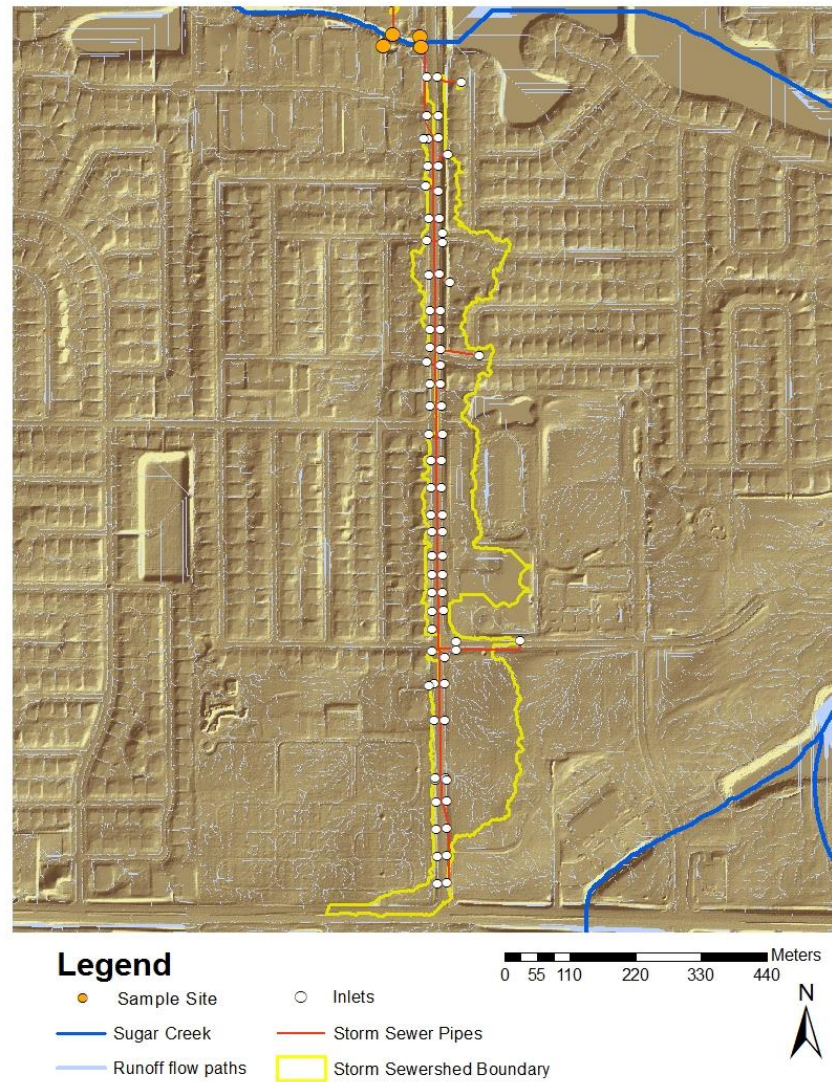

Legend
Sample Site
Inlets
Sugar Creek
Storm Sewer Pipes
Runoff flow paths
Storm Sewershed Boundary
Meters
0 80 160 320 480 640
N

Drainage from Airport Road

B_R_Airport

This is a public sewer system. The outlet pipe is 36 inches in diameter. It drains Airport Road south of General Electric Road. I accessed this site from the corner of Airport Road and General Electric Road. This site is across the stream from B_H_GEAir, on the south end of the bridge.


Legend
Sample Site
Inlets
Sugar Creek
Storm Sewer Pipes
Storm Sewershed Boundary
Meters
0 55 110 220 330 440
N


Legend
Sample Site
Inlets
Sugar Creek
Storm Sewer Pipes
Runoff flow paths
Storm Sewershed Boundary
Meters
0 55 110 220 330 440
N

Drainage from Cottage Street

B_R_Cott

This is a public storm sewer system located on the north side of Sugar Creek. The outlet pipe is 21 inches in diameter. This site drains Cottage Road north of White Oak Park. I accessed this site from White Oak Park. From the parking lot I walk underneath the Cottage Road bridge over Sugar Creek. The outlet is located on the north side. The outlet pipe sticks out a few feet and hangs 5 feet from the ground.

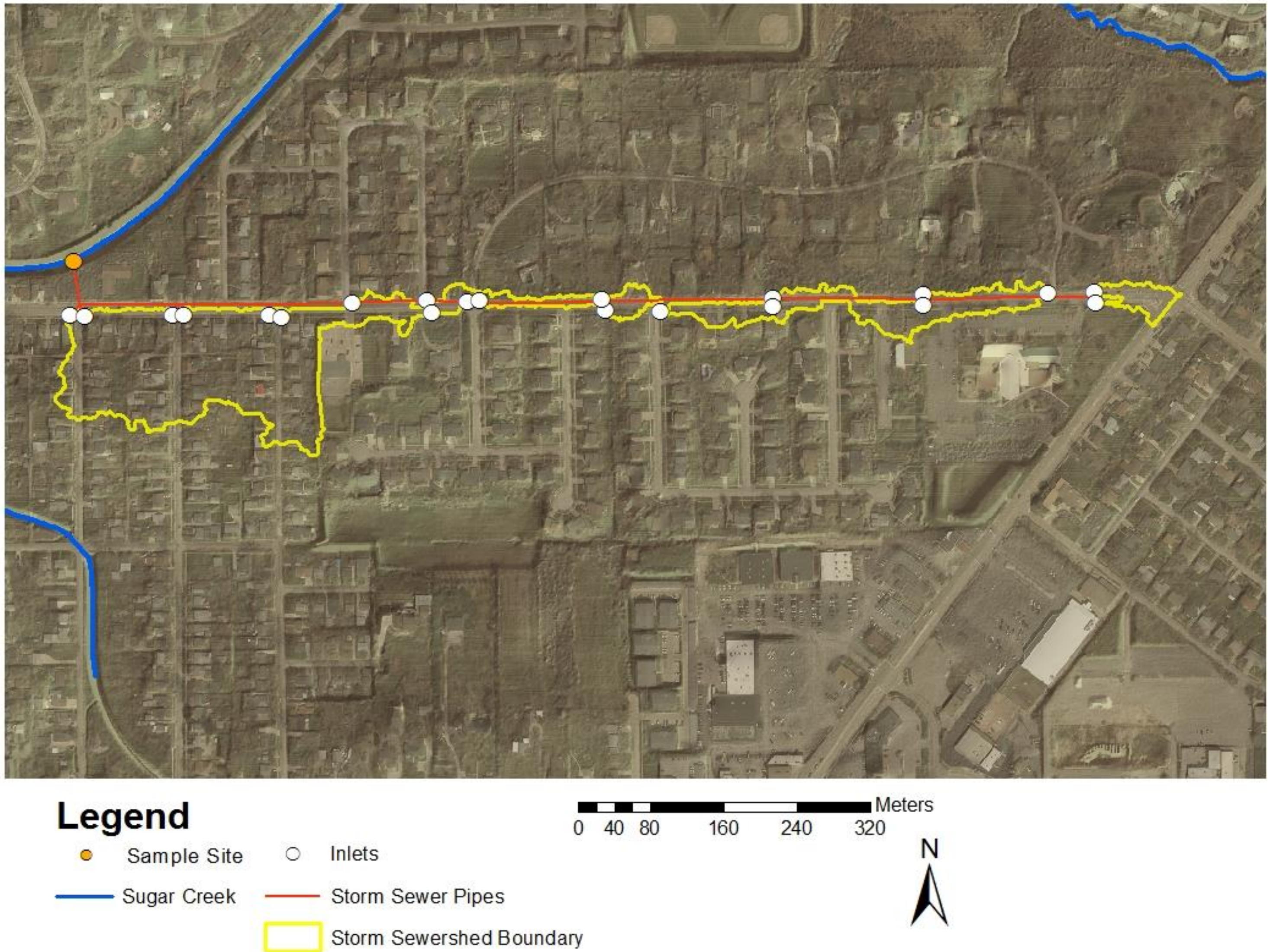

Legend
Sample Site
Inlets
Sugar Creek
Storm Sewer Pipes
Storm Sewershed Boundary
0 45 90 180 270 360
Meters
N

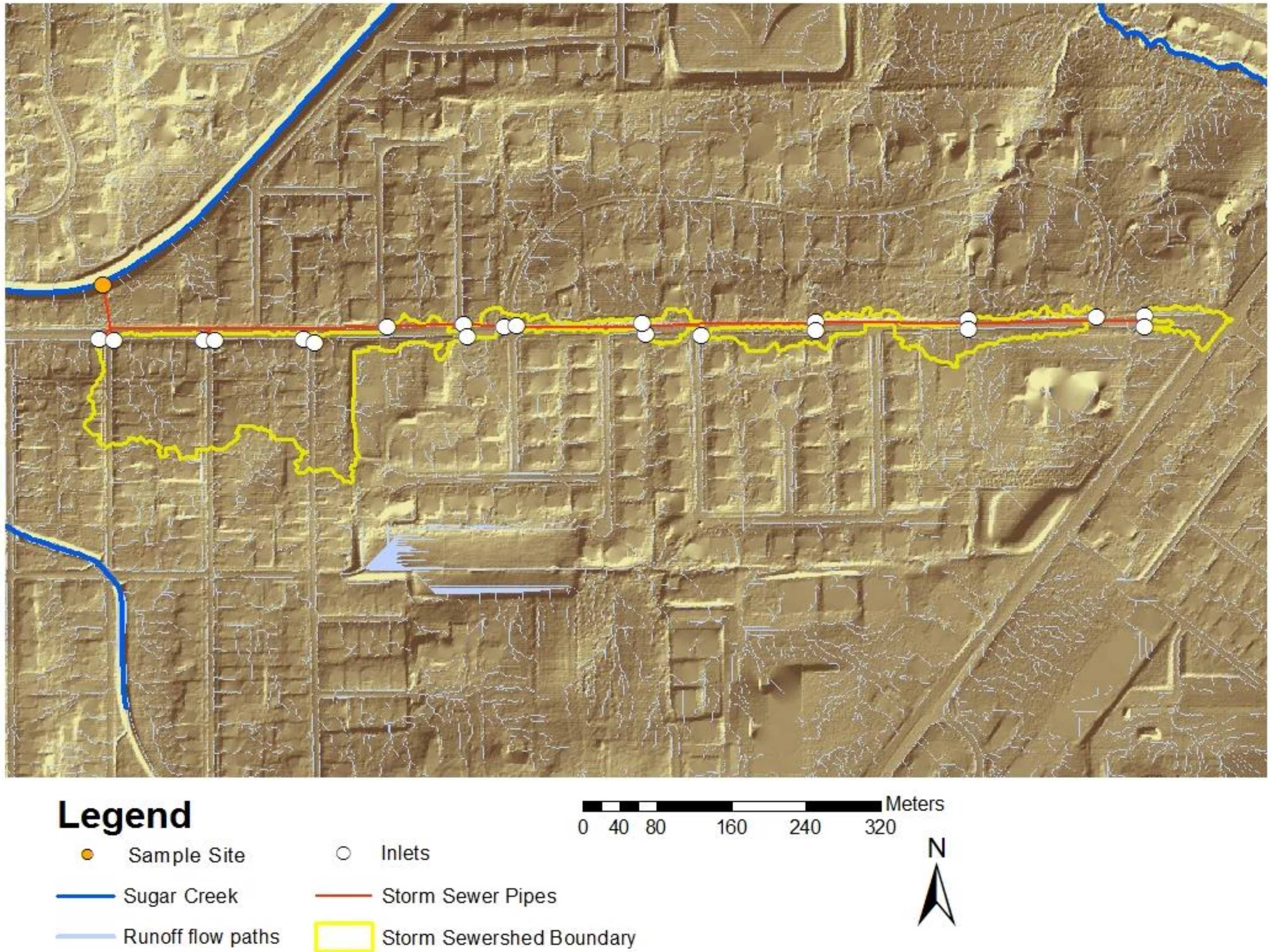

Legend
Sample Site
Inlets
Sugar Creek
Storm Sewer Pipes
Runoff flow paths
Storm Sewershed Boundary
0 45 90 180 270 360
Meters
N

Drainage from Emerson Street

B_R_Emer

This is a public sewer systems located on the south side of Sugar Creek. The outlet pipe is 18 inches. This site drains Emerson St. east of Linden St. I accessed this site from the Bloomington Bible Church parking lot. The outlet is near a big tree on the north side of the parking lot.

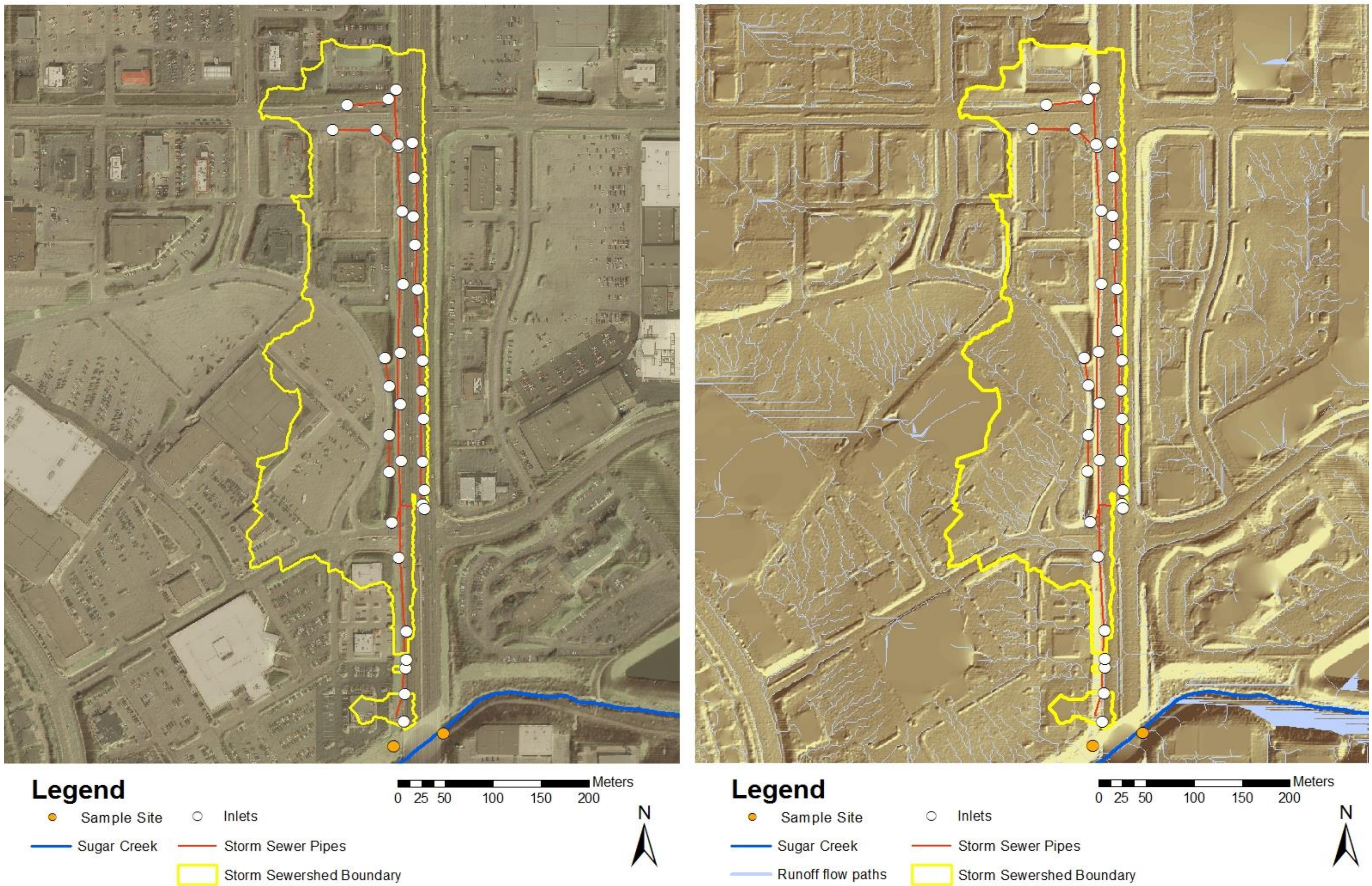

Legend
Sample Site
Inlets
Sugar Creek
Storm Sewer Pipes
Storm Sewershed Boundary
0 40 80 160 240 320
Meters
N


Legend
Sample Site
Inlets
Sugar Creek
Storm Sewer Pipes
Runoff flow paths
Storm Sewershed Boundary
Meters
0 40 80 160 240 320
N

Drainage from Veteran's Parkway

B_R_Vet

This is a public sewer system located on the north side of Sugar Creek. The outlet pipe is 30 inches in diameter. This site drains Veteran's Parkway north of IAA drive. To access this site I parked at Jason's Deli and walked down to the constitution trail. Enter the stream at B_H_Vet and walk down stream under the Veteran's Parkway bridge. Immediately after the bridge climb the riprap to the north and the outlet will be at the top there the Hampton Inn and Suites Sign


Legend
Sample Site
Inlets
Sugar Creek
Storm Sewer Pipes
Storm Sewershed Boundary
Meters
0 25 50 100 150 200
N
Legend
Sample Site
Inlets
Sugar Creek
Storm Sewer Pipes
Runoff flow paths
Storm Sewershed Boundary
Meters
0 25 50 100 150 200
N

APPENDIX B

STORM SEWERSHED CHARACTERISTICS

Site	Inlets (counts)	Inlet Density (per km^2)	Pipe Diameter (cm)	Max. Snap Distance (m)	Pipe length (meters)	Pipe Density (m/sq m)	Area (m^2)
B_C_Airport	2	10826	30	1.5	94	5.13E-01	184
B_C_GE	8	109	121	3.8	7297	1.00E-01	72872
B_C_Vernon	8	248	45	4.6	552	1.72E-02	32166
B_H_Airport	34	113	137	3.0	2099	7.03E-03	298462
B_H_Cott	13	213	60	1.5	467	7.67E-03	60977
B_H_EW	8	196	30	2.3	363	8.90E-03	40810
B_H_GE	41	187	106	3.8	2224	1.02E-02	218408
B_H_GEAir	175	166	182	1.5	7794	7.42E-03	1050242
B_H_Jersey	2	140	30	1.5	90	6.38E-03	14205
B_H_Rowe	18	167	38	2.3	456	4.26E-03	107269
B_H_Tipton	463	214	364	3.0	21236	9.82E-03	2162726
B_H_Vet	6	25	60	1.6	184	7.72E-04	238756
B_ISC_EW	3	241	53	3.0	483	3.90E-02	12401
B_L_GE	173	117	182	2.3	9135	6.19E-03	1476493
B_R_Airport	74	590	91	3.8	2425	1.93E-02	125397
B_R_Cott	8	125	53	2.3	427	6.68E-03	63939
B_R_Emer	21	394	45	3	1271	2.39E-02	53176
B_R_Vet	36	442	76	2.3	1359	1.67E-02	81337

Site	Pond	Sump Pump	ISC Edited	ISC (sq m)	%ISC	% Com	% Res	% Open	% Road
B_C_Airport	No	No	Yes	122	66.0%	100.0%	0.0%	0.0%	0.0%
B_C_GE	Yes	No	Yes	20097	27.6%	51.7%	8.3%	0.0%	40.0%
B_C_Vernon	Yes	Yes	Yes	19948	62.0%	73.6%	0.0%	0.0%	26.4%
B_H_Airport	No	Yes	No	77467	26.0%	0.8%	38.9%	43.2%	17.0%
B_H_Cott	No	Yes	No	15851	26.0%	0.0%	61.1%	11.5%	27.4%
B_H_EW	No	No	No	12704	31.1%	0.0%	40.9%	4.0%	11.1%
B_H_GE	No	Yes	No	58567	26.8%	0.0%	72.3%	2.5%	25.2%
B_H_GEAir	Yes	Yes	Yes	263678	25.1%	3.7%	73.3%	0.2%	22.8%
B_H_Jersey	No	No	No	4905	34.5%	0.0%	70.6%	0.0%	29.4%
B_H_Rowe	No	Yes	No	38719	36.1%	1.5%	73.5%	0.0%	25.0%
B_H_Tipton	Yes	Yes	Yes	563683	26.1%	0.0%	72.7%	8.2%	19.1%
B_H_Vet	Yes	No	No	168906	70.7%	82.2%	1.6%	0.0%	16.2%
B_ISC_EW	No	Yes	Yes	1193	9.6%	0.0%	51.1%	48.3%	0.6%
B_L_GE	Yes	Yes	No	545820	37.0%	22.8%	42.6%	11.8%	22.8%
B_R_Airport	No	No	No	15977	12.7%	33.8%	18.7%	25.7%	21.9%
B_R_Cott	No	No	Yes	19350	30.3%	0.0%	5.1%	0.0%	19.6%
B_R_Emer	No	No	No	19358	36.4%	0.0%	57.0%	0.6%	42.5%
B_R_Vet	No	No	No	55952	68.8%				33.0%

APPENDIX C

RAW CHEMISTY DATA

Sample ID	Date	Time	Depth (in)	pH	Temp (ºC)	SPC (µS/cm)	DO (mg/L)	DO (%)	TSS (mg/L)	VSS (mg/L)	PO_4^- (µg/L-P)	NH_3 (mg/L-N)	NO_3^- (mg/L-N)	TP (mg/L-P)	Cl^- (mg/L)
B_C_Airport	5/9/14	10:48	<0.125	8.51	17.5	1119	9.14	95.51	14.81	3.05	97.9	0.0551	1.91		223.6
B_C_GE	5/9/14	10:10	0.25	7.51	17.8	536.5	4.70	36.52	24.95	13.56	123	0.04	2.03	276	80.262
B_C_Vernon	5/9/14	12:57	<0.125	7.76	18.1	584	8.09	85.61	7.39	4.55	7.15	0.225	0.458		79.504
B_H_Airport	5/9/14	10:56	0.625	7.85	14.1	635	8.42	81.91	8.23	2.33	10.5	0.122	1.58		107.08
B_H_Cott	5/9/14	14:00													
B_H_EW	5/9/14	13:24	<0.125	7.77	14.4	713	9.69	94.81	12.88	4.18	67.2	0.0767	1.08		182.48
B_H_GE	5/9/14	10:00	0.875	7.89	15.7	766	8.13	81.87	120.96	26.54	11	0.0571	1.39		171.52
B_H_GEAir	5/9/14	11:06	2.5	7.72	15.3	738	8.47	84.53	6.48	4.10	4.38	0.0247	0.289		140.77
B_H_Jersey	5/9/14	12:52	<0.125	7.82	14.7	2054	9.36	92.22	16.59	7.23	19.2	0.0631	0.868		530.61
B_H_Rowe	5/9/14	13:09	0.125	7.93	14.8	946	10.14	100.1	7.53	3.87	11.8	0.0192	1.28		182.65
B_H_Tipton	5/9/14	11:29	0.75	8.06	20.4	891	8.00	88.69	11.54	7.15	10.1	0.0116	0.143		183.27
B_H_Vet	5/9/14	12:32	0.125	7.84	14.2	1587	10.38	101.1	9.07	3.07	9.2	0.0374	1.11		411.05
B_ISC_EW	5/9/14	13:36	0.125	7.90	12.7	872	10.21	96.23	3.40	1.38	6.09	0.0177	1.68		74.254
B_L_GE	5/9/14	10:20	0.5	7.57	15.3	1075	8.85	88.32	14.80	4.61	13.7	0.0667	1.14		310.75
B_R_Airport	5/9/14	11:15		7.77	13.6	927	8.00	76.92	7.45	2.34	23.6	0.297	1.51		214.75
B_R_Cott	5/9/14	15:18	<0.125	7.69	15.2	1211	10.44	103.9	21.48	7.89	14.6	0.109	1.57		254.51
B_R_Emer	5/9/14	13:49	0.625	8.00	15.9	1484	7.99	80.79	18.60	7.83	15.7	0.104	1.36		503.8
B_R_Vet	5/9/14	12:14	<0.125	7.81	13.1	3362	10.37	98.67	4.45	2.23	6.96	0.0117	1.58		998.5
DUP B_C_Airport	5/9/14	10:48							14.96	3.32	20.1	2.42	0.331		228.13
DUP B_H_EW	5/9/14	13:24							12.82	4.07	79.7	0.0815	1.19		171.26

Sample ID	Date	Time	Depth (in)	pH	Temp (°C)	SPC (µS/cm)	DO (mg/L)	DO (%)	TSS (mg/L)	VSS (mg/L)	PO_4^{3-} (µg/L-P)	NH_3 (mg/L-N)	NO_3^- (mg/L-N)	TP (mg/L-P)	Cl^- (mg/L)
B_C_Airport	6/8/14	8:38		8.57	19.2	907	8.62	93.29	4.20	1.23	1.69	0.0218	3.45	164	146.87
B_C_GE	6/9/14	6/9/2014 7:28		7.25	16.9	1322	7.47	77.09	8.21	1.39	6.04	0.03	0.06	48.7	212.09
B_C_Vernon	6/8/14	7:51		7.85	16.7	899	8.43	86.64	6.32	4.34	11.7	0.0282	0.262	29.5	153.35
B_H_Airport	6/9/14	6/9/2014 8:06		6.48	14.9	1024	9.18	90.8	0.68	0.24	11.8	0.0298	1.93	20.1	148.02
B_H_Cott	6/8/14	5:52	<0.125	8.06	17.6	766	7.56	79.16	13.23	2.58	1.65	0.0104	2.19	47.3	62.46
B_H_EW	6/8/14	5:54		7.8	16.8	1648	8.27	85.17	2.95	1.03	123	0.02	1.19	254	266.89
B_H_GE	6/8/14	9:54		7.66	15.7	992	9.08	91.44	5.00	1.82	4.48	0.0106	8.89	21.4	118.49
B_H_GEAir	6/8/14	9:02		8.32	23	602	8.37	97.55	8.44	5.15	2.27	0.0193	4.84	24.9	112.58
B_H_Jersey	6/8/14	7:28		7.74	15.8	1339	8.68	87.59	4.22	1.28	10.4	0.0159	0.142	60.9	112.5
B_H_Rowe	6/8/14	7:14		7.82	16.2	1339	9.7	98.68	2.89	1.25	6.84	0.0076	4.67	14.2	79.098
B_H_Tipton	6/8/14	9:35		8.02	21.3	576	5.27	59.48	3.32	2.15	9.93	0.0094	2.79	35.9	104.22
B_H_Vet	6/8/14	8:21		7.91	17.3	1497	7.22	75.21	29.11	1.41	7.05	0.0101	4.73	33.3	213.34
B_ISC_EW	6/8/14	7:00		7.82	14.6	800	9.7	95.38	1.21	0.53	4.01	0.0396	1.16	11	56.761
B_L_GE	6/8/14	10:35		7.89	17.3	1110	7.87	81.98	2.51	1.14	8.01	0.0325	2.43	12.8	201.59
B_R_Airport	6/8/14	7:59		5.03	17.5	1892	7.67	80.15	1.01	0.33	4.82	0.0265	1.15	19.9	416.96
B_R_Cott	6/8/14	6:02		7.74	16.4	2609	8.27	84.47	3.38	-0.36	179	0.0175	1.16	19.6	499.45
B_R_Emer	6/8/14	6:34		7.86	18	2388	8.32	87.86	5.78	2.75	5.83	0.168	1.99	34.8	613.96
B_R_Vet	6/8/14	8:14		7.74	16.3	2819	8.98	91.54	3.95	1.35	36.4	0.0615	0.273	104	776.36
DUP_ B_C_GE	6/8/14	7:28							0.60	0.29	6.23	0.0158	0.596	29.8	237.71
DUP_ B_H_Rowe	6/8/14	7:14							2.81	1.22	2.51	0.0175	5.63	37.1	82.744

Sample ID	Date	Time	Depth (in)	pH	Temp (ºC)	SPC (µS/cm)	DO (mg/L)	DO (%)	TSS (mg/L)	VSS (mg/L)	PO_4^{-} (µg/L-P)	NH_3 (mg/L-N)	NO_3^{-} (mg/L-N)	TP (mg/L-P)	Cl^- (mg/L)
B_C_Airport	6/10/14	8:44	<0.125	8.33	19.5	639	8	87.15	2.84	1.03	8.27	0.0402	1.23	25.9	96.51
B_C_GE	6/10/14	9:45	<.25	7.7	18.8	254.3	7.49	80.45	0.99	0.59	11.9	0.0895	1.4	35.7	43.91
B_C_Vernon	6/10/14	10:59	<0.125	7.84	18.1	211.1	8.66	91.64		1.32	7.31	0.029	0.961	33.6	25.42
B_H_Airport	6/10/14	8:50	1.0	7.7	17.1	504.7	8.04	83.4	10.29	2.56	11.8	0.0739	0.73	45.1	78.74
B_H_Cott	6/10/14	12:53	<0.125	7.78	17.8	465.8	7.53	79.18	28.91	9.97	13.3	0.0216	3.58	54.3	51.64
B_H_EW	6/10/14	12:03	0.25	7.63	17.7	604	8.32	87.3	5.21	2.60	17	0.0509	0.762	28.3	130.60
B_H_GE	6/10/14	9:34	1.25	7.56	17.2	3661.1	8.09	84.1		1.80	82.2	0.0227	0.681	56.8	44.09
B_H_GEAir	6/10/14	8:35	3.0	8.14	22.1	585	8.31	95.19	8.78	4.85	103	0.356	2.06	150	109.31
B_H_Jersey	6/10/14	11:37	<.25	7.49	17.5	755	7.8	81.5	5.54	2.36	14.8	0.0363	0.457	40	171.42
B_H_Rowe	6/10/14	11:49	1	7.64	18.2	497.1	7.94	84.2	6.50	2.75	12.8	0.0276	1.43	57.2	77.49
B_H_Tipton	6/10/14	10:23	1.3	7.75	21.1	491.8	5.84	65.62	3.34	2.16	11.1	0.177	0.473	26.7	78.68
B_H_Vet	6/10/14	11:11	0.75	7.61	18.3	497.5	7.48	79.49	4.07	1.30	10.09	0.0146	0.222	19.2	95.02
B_ISC_EW	6/10/14	12:15	0.75	7.55	14.6	881	10.06	98.92	1.84	1.05	97.9	0.0233	0.709	21.1	72.94
B_L_GE	6/10/14	9:59	1.0	7.93	18	846	8.58	90.6	5.23	2.11	1.79	0.0175	0.131	29.9	171.26
B_R_Airport	6/10/14	8:30	0.25	7.97	18.8	617	7.39	79.38	19.66	5.41	8.86	0.0458	1.82	25.4	112.05
B_R_Cott	6/10/14	12:42	0.5	7.8	17.7	1418	8.77	92.03	40.14	9.71	17.9	0.0204	0.936	35.7	233.51
B_R_Emer	6/10/14	12:28		7.7	18.2	1227	8.36	88.65	24.26	9.54	4	0.123	0.733	80.8	279.50
B_R_Vet	6/10/14	11:18	<0.25	7.53	18.1	813	8.91	94.29	22.83	9.89		0.114	0.712	20.2	144.42
DUP_ B_R_Emer	6/10/14	12:28							22.95	8.88	12.1	0.0232	0.942	23.1	292.31
DUP_ B_R_Vet	6/10/14	11:18							17.52	8.38	14.8	0.0612	1.36	134	186.10

Sample ID	Date	Time	Depth (in)	pH	Temp (ºC)	SPC (µS/cm)	DO (mg/L)	DO (%)	TSS (mg/L)	VSS (mg/L)	$PO_4^{=}$ (µg/L-P)	NH_3 (mg/L-N)	$NO_3^{=}$ (mg/L-N)	TP (mg/L-P)	Cl^- (mg/L)
B_C_Airport	7/25/14	15:08	<0.1		21.6	1050	11.85	134.51	5.52	2.38	132	0.0439	1.69	31.1	205.01
B_C_GE	7/25/14	15:52	0.1		19.5	155.8	10.94	119.17	3.67	1.79	13	0.0748	0.441	215	20.80
B_C_Vernon	7/25/14	14:11	<0.1		19.4	385.2	9.7	105.43	14.45	9.30	33	0.0504	1.78	25.5	35.99
B_H_Airport	7/25/14	15:15	0.2		19.6	1102	10.9	118.87	9.67	2.25				580	184.21
B_H_Cott	7/25/14		0.3			244.7			36.83	16.14	5.39	0.126	7.65	148	41.06
B_H_EW	7/25/14	13:22	0.4		20.2	467.7	10.31	113.8	30.24	10.43	206	0.236	0.791	178	96.23
B_H_GE	7/25/14	15:43	0.1		19.1	676	13.59	146.76	3.4	2.63	12.5	0.0512	0.616	20.1	101.63
B_H_GEAir	7/25/14	15:23	1.8		20.1	660	10.75	118.52	9.69	3.05	137	0.152	2.07	438	114.95
B_H_Jersey	7/25/14	13:53			20.5	355.5	9.09	101							
B_H_Rowe	7/25/14	13:43	0.2		23	644	10.27	119.7	14.42	5.69	429	0.34	1.3	42.4	60.11
B_H_Tipton	7/25/14	14:51	0.4		18.9	831	12.72	136.77	3.86	3.07	8.56	0.0935	0.156	62.8	151.24
B_H_Vet	7/25/14	14:28	<0.1						9.39	3.11	12.6	0.0963	1.38	43.7	156.63
B_ISC_EW	7/25/14	13:43	0.2		19.5	1727	8.86	96.51							
B_L_GE	7/25/14	16:01	0.1		21.2	941	11.93	134.35	6.00	4.17	9.36	0.128	1.59	80.7	423.94
B_R_Airport	7/25/14	15:26							15.29	4.54	58.6	0.139	1.78	49.1	179.57
B_R_Cott	7/25/14		1.4			502			131.67	33.43	317	0.198	0.846	311	92.64
B_R_Emer	7/25/14	13:15	0.1		20.5		11.21	124.56	95.75	26.67	152	0.383	1.81	198	714.46
B_R_Vet	7/25/14	14:21			19.6	1275			27.16	17.16	40.2	0.234	0.794	68.1	323.30
DUP_ B_H_Vet	7/25/14	14:28	<0.2		19.4	48.3	11.28		12.61	3.61	680	0.453	0.974	19	175.80
DUP_ B_R_Airport	7/25/14	15:26							23.36	6.50	24.8	0.134	1.9	19.5	101.54

Sample ID	Date	Time	Depth (in)	pH	Temp (°C)	SPC (µS/cm)	DO (mg/L)	DO (%)	TSS (mg/L)	VSS (mg/L)	PO_4^{3-} (µg/L -P)	NH_3 (mg/L -N)	NO_3^{-} (mg/L -N)	TP (mg/ L-P)	Cl^- (mg/L)
B_C_Airport	9/14/14	10:05	0.2	7.87	16.1	125.5	9.58	97.26	3.00	1.26	6.93	0.289	1.2	38.2	23.70
B_C_GE	9/14/14	11:10	0.3	7.99	15.2	1036	9.06	90.24	1.22	1.01	31.9	0.107	0.269	37.8	21.05
B_C_Vernon	9/14/14	11:24	0.1	7.77	17.2	156	7.7	80.04	1.94	1.47	36	0.0229	0.649	32.4	17.81
B_H_Airport	9/14/14	10:00	1	7.67	16.2	243.6	8.59	87.39	31.75	7.64	104	0.135	0.635	87.8	41.43
B_H_Cott	9/14/14	12:55	0.1	8.25	17.3	163	8.15	84.9	12.15	3.53	167	0.0584	0.873	181	20.95
B_H_EW	9/14/14	12:20	0.4	8.72	16.6	135.5	9.41	96.51	11.16	4.23	68.8	0.0851	0.336	70.8	27.12
B_H_GE	9/14/14	9:25	0.9	8.72	15.3	59.7	8.8	87.82	19.45	5.62	67.8	0.161	0.337	68.1	78.16
B_H_GEAir	9/14/14	10:12	6	7.7	17	290.6	8.94	92.55	5.95	2.14	88.7	0.0633	0.326	95.9	52.04
B_H_Jersey	9/14/14	11:50	1	9.7	16.2	1466.9	7.71	78.43	158.18	12.95				25.6	67.62
B_H_Rowe	9/14/14	12:03	3	9.26	16.3	109	8.8	89.7	4.79	1.66	91.5	0.0781	0.348	91.3	22.26
B_H_Tipton	9/14/14	10:30	3	7.62	16.7	461.5	6.77	69.58	12.48	4.63	24.6	0.272	0.922	48.3	51.59
B_H_Vet	9/14/14	11:36	0.1	7.62	17.7	601	7.98	83.74	11.84	2.47	76.1	0.0882	0.545	59.4	130.01
B_ISC_EW	9/14/14	12:27	0.2	8.33	16	268.5	8.94	90.58	65.14	16.29	214	0.192	0.786	270	26.74
B_L_GE	9/14/14	10:45	3	8.07	15.6	175.4	8.07	81.11	15.97	4.42	109	0.0769	0.325	133	32.93
B_R_Airport	9/14/14	10:10	2.5	7.95	16.3	115.9	8.93	91.03	24.24	5.44	86.2	0.0552	0.295	98.5	23.79
B_R_Cott	9/14/14	12:49	0.8	8.24	16.6	568	8.3	85.13	38.93	10.53	37.3	0.0846	0.321	61.5	98.00
B_R_Emer	9/14/14	12:37	0.9	8.35	17.5	155.2	8.73	91.22	34.48	11.61	77.4	0.0588	0.287	105	28.73
B_R_Vet	9/14/14	11:30	0.1	7.43	17.7	891	8.83	92.65	4.26	1.58	12.4	0.101	0.963	13.6	183.27
DUP_ B_H_Jersey	9/14/14	11:50	1	9.7	16.2	1466.9	7.71	78.43	128.93	13.03	1.72	0.29	1.19	51.7	67.64
DUP_ B_H_Tipton	9/14/14	10:30	3	7.62	16.7	461.5	6.77	69.58	6.66	1.96	26.6	0.269		61	23.88

Sample ID	Date	Time	Depth (in)	pH	Temp (°C)	SPC (µS/cm)	DO (mg/L)	DO (%)	TSS (mg/L)	VSS (mg/L)	PO_4^{3-} (µg/L-P)	NH_3 (mg/L-N)	NO_3^- (mg/L-N)	TP (mg/L-P)	Cl^- (mg/L)
B_C_Airport	12/15/14	12:51		7.88	7.7	279.3	14.22	119.2	5.12	1.41	65.8	0.0504	0.579	54.1	45.68
B_C_GE	12/15/14	13:33		7.83	8.3	137.5	10.95	93.11	5.38	2.47	22.2	0.326	0.423	74.2	23.43
B_C_Vernon	12/15/14	12:20	0.2	8.04	8.1	155.4	14.5	122.78	7.17	4.21	58.6	0.0967	0.725	22.3	
B_H_Airport	12/15/14	12:54		7.88	9.4	312.9	13.16	114.93	63.17	16.42	137	0.082	0.651	181	56.18
B_H_Cott	12/15/14	10:51	<0.1	7.26	8.5	418.2	14.18	121.2	98.76	32.88	254	0.239	1.06	350	95.90
B_H_EW	12/15/14	11:41		7.58	9.7	964	12.6	110.82	69.07	20.21	127	0.209	1.27	144	263.68
B_H_GE	12/15/14	13:30		7.83	9.7	190.1	12.01	105.63		4.50	70.9	0.131	0.598	81.5	30.93
B_H_GEAir	12/15/14	12:58	6	7.58	7.3	350.6	12.94	107.39	40.67	16.07	68.3	0.0642	0.496	109	60.82
B_H_Jersey	12/15/14			7.41	9.8	1161	16.37	144.36	13.94	5.19	76.2	0.0595	1.59	85.7	304.67
B_H_Rowe	12/15/14	11:52		7.69	9.4	870	14.94	130.48	29.21	11.95	136	0.224	1.38	181	239.43
B_H_Tipton	12/15/14	13:11		7.4	5.7	727.45	11.07	88.28	6.06	3.25	3.71	0.231	0.507	28.3	101.56
B_H_Vet	12/15/14	12:34		7.84	8.7	182.5	14.51	124.66	10.95	4.45	50.5	0.127	0.621	45.8	38.24
B_ISC_EW	12/15/14	11:32		7.55	9.2	854	11.95	103.91	36.82	7.86	43.9	0.0269	1.59	51.7	71.00
B_L_GE	12/15/14								29.20	10.75	52.6	0.118	0.956	73.7	115.55
B_R_Airport	12/15/14								148.31	34.15	135	0.0701	0.698	184	71.28
B_R_Cott	12/15/14	10:58	0.3	7.27	8.7	780	10.6	91.07	223.92	57.67	115	0.22	0.848	182	151.79
B_R_Emer	12/15/14	11:18		7.3	9.5	1251	13.9	121.72	106.87	37.60	162	0.116	0.805	198	430.73
B_R_Vet	12/15/14	12:30		7.79	8.8	364.4	14.54	125.13	183.60	62.80	62.8	0.373	0.606	101	97.00
DUP_ B_C_Airport	12/15/14								5.67	1.93	68.2	0.0537	0.593	65.7	47.65
DUP_ B_H_EW	12/15/14								50.56	17.56	124	0.21	1.28	145	271.13

Sample ID	Date	Time	Depth (in)	pH	Temp (ºC)	SPC (µS/cm)	DO (mg/L)	DO (%)	TSS (mg/L)	VSS (mg/L)	PO_4^{-} (µg/L-P)	NH_3 (mg/L-N)	NO_3^{-} (mg/L-N)	TP (mg/L-P)	Cl^{-} (mg/L)
B_C_Airport	2/7/15	13:15	0.4	7.05	1.3	14244	15.71	133.6	2358.75	789.00	59.1	0.181	0.352	434	5796.40
B_C_GE	2/7/15	14:15	4.1	7.55	4.3	2438	15.35	131	640.50	140.80	21.9	0.35	0.37	91.2	893.94
B_C_Vernon	2/7/15	12:51		7.55	1.9	3867	18.45	143	43.27	12.80	53.3	0.358	0.381	178	1434.56
B_H_Airport	2/7/15	13:25	4.2	7.63	4.9	1935	12.77	105.7	92.00	28.50	64.6	0.241	0.803	101	599.31
B_H_Cott	2/7/15	11:30	0.4	4.12	3	6737	14.4	110.2	90.29	32.76	12.7	0.0409	1.34	204	2477.08
B_H_EW	2/7/15	12:08	1.2	7.31	6.3	3177	12.82	106.9	47.74	18.53	50.1	0.183	0.792	95.5	1157.46
B_H_GE	2/7/15	14:06	4.9	7.58	3.5	1509	15.18	117.3	35.58	12.47	45.3	0.312	0.516	65.2	515.43
B_H_GEAir	2/7/15	13:34	4.8	7.42	3	3161	13.55	102.2	28.00	9.26	25.3	0.133	0.444	66	1125.04
B_H_Jersey	2/7/15	12:35	0.8	7.38	5.1	6478	13.18	114.7	64.67	22.81	79	0.313	0.58	127	2538.44
B_H_Rowe	2/7/15	12:24	0.6	7.24	2.8	7518	13.59	107.8	363.50	120.67	12	0.049	1.08	414	2748.25
B_H_Tipton	2/7/15	13:51	3.7	7.55	3.7	1122	16.8	128.8	4.08	2.81	3.83	0.0286	0.823	20.1	256.58
B_H_Vet	2/7/15	13:05		7.5	3	3135	13.15	99.6	160.65	21.48	56.7	0.365	0.421	97	1143.83
B_ISC_EW	2/7/15	12:16	0.2	7.36	6.1	1263	12.97	107	16.41	5.41	42.5	0.116	1.25	55.7	297.66
B_L_GE	2/7/15	14:22	1.4	7.37	4.1	4044	14.44	115	96.89	30.42	60.4	0.288	0.501	121	1523.87
B_R_Airport	2/7/15	13:40	2	7.48	4.5	3603	14.8	126	67.27	20.82	78.6	0.22	0.543	114	1352.47
B_R_Cott	2/7/15	11:35	0.7						382.36	124.82	17.9	0.0456	0.487	312	3706.72
B_R_Emer	2/7/15	11:59	0.8	6.98	4.6	6350	13.8	112.6	216.92	66.33	11.4	0.0304	1.47	214	2537.75
B_R_Vet	2/7/15	13:00	0.6	7.51	4.5	4231	13.37	106.7	359.50	96.50	73.1	0.293	0.328	174	1602.65
DUP_ B_H_GEAir	2/7/15								19.05	6.47	24.8	0.185	0.494	290	1155.12
DUP_ B_H_Rowe	2/7/15								397.45	121.45	11.9	0.0582	1.14	65.3	2743.14