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Developing rating curves in a small Iowa watershed to evaluate nutrient loading in streams

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DEVELOPING RATING CURVES IN A SMALL IOWA

WATERSHED TO EVALUATE NUTRIENT

LOADING IN STREAMS

An Abstract of a Thesis

Submitted

in Partial Fulfillment

of the Requirements for the Degree

Master of Science

Jennifer Mary Shepeck

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ABSTRACT

Dry Run Creek, a tributary to the Cedar River in northeast Iowa, is a watershed under high pressure from the surrounding region. With its headwaters located in farm fields and urban drainage ditches, it is subject to flash flooding and erosion and is on the DNR's list of impaired waters. Dry Run Creek is similar to other small watersheds across eastern Iowa. As tributaries to the larger rivers that eventually flow into the Mississippi River and then to the Gulf of Mexico, they are significant contributors to the nutrient loading causing the hypoxia in the Gulf. The purpose of this study is to look at methods to examine low cost, simple, and effective ways to assess nutrient loading in a small stream. Rating curves can be developed and employed with water samples to assess nutrients. A rating curve is the relationship between stage (stream depth) and discharge at that location. From May 11, 2011 to August 9, 2011 rating curves were developed for 11 sites in the Dry Run Creek watershed, comparing discharge in m^3/s and gauge height in cm. Various low cost methods that could be duplicated in other small watersheds were employed to develop the rating curves. The average velocity at most sites ranges from 0.2 to 0.4 m/s with an average discharge of 0.1 m^3/s (3.5 cfs). Many methods face challenges, varying from unstable stream banks causing fluctuations in sediment deposits to bent gauges caused by debris during flash flooding. In some sites depths are measured by painting gauges on existing structures. Other difficulties occur where the stream is too wide and deep during high flows. Creating gauges on existing structures eliminates some of the difficulties encountered in various methods and also eliminates changes in the shape of the streambed. Methods demonstrated in this study could be utilized by other researchers to perform additional studies on small watersheds in an effort to understand their role in the nutrients being loaded into the Cedar

River. This can potentially lead to the identification of areas that are high nutrient contributors and allow us to begin to assess ways to remediate the causes.

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This Study by: Jennifer Mary Shepeck

Entitled: DEVELOPING RATING CURVES IN A SMALL IOWA WATERSHED TO EVALUATE NUTRIENT LOADING IN STREAMS

has been approved as meeting the thesis requirement for the

Degree of Master of Science in Environmental Science

Date	Dr. Mohammad Z. Iqbal, Chair, Thesis Committee
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Date	Dr. James C. Walters, Thesis Committee Member
Date	Dr. Michael J. Licari, Dean, Graduate College

DEDICATION

This is dedicated to my family for all their love, support, and patience.

ACKNOWLEDGMENTS

I would like to thank my advisor Dr. Mohammad Iqbal for his support, confidence, and patience during my studies at UNI. I am also thankful to my committee members Dr. Maureen Clayton and Dr. James Walters for their support and encouragement. I am indebted to the University of Northern Iowa, Environmental Programs, and to the National Science Foundation for providing the funding for me during my studies.

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INTRODUCTION

Background

Gulf of Mexico Hypoxia (dead zone) is an issue of significant concern. Eastern Iowa contributes a significant percentage (~8.25 %) of the nitrogen being supplied to the Gulf of Mexico (Powers, 2007). Dry Run Creek in Cedar Falls, IA is one of the many small tributaries that supply the Cedar River (Figure 1).

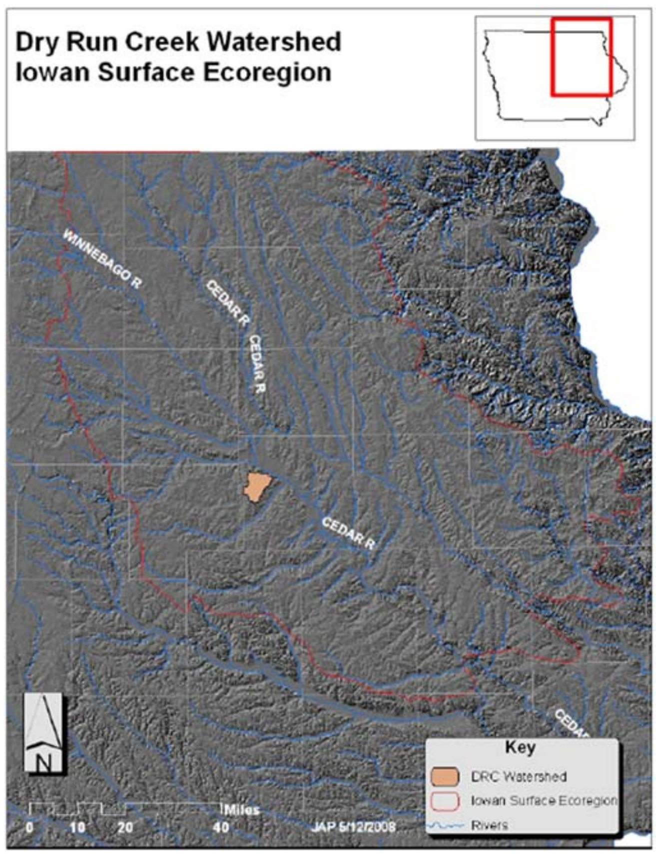

Figure 1. Map showing the location of Dry Run
Creek Watershed within the state of Iowa (Palmer and Buyck, 2011).

The Dry Run Creek watershed has a drainage basin of approximately 35 square miles (15,200 ac). Ephemeral and intermittent branches begin in farm fields (like so many small Iowa watersheds) surrounding Cedar Falls and eventually the stream empties into the Cedar River. A survey conducted by the Iowa Department of Natural Resources (IDNR) in 2002 indicated a lack of aquatic life and a low biotic index. In accordance with the Environmental Protection Agency's Clean Water Act of 1972, section 303d, Dry Run Creek has been cited and placed on the list of impaired waters. The IDNR states that causes of the biological stressors on Dry Run Creek primarily include high amounts of suspended and bedded sediments and storm sewer contamination (Schuppert, 2009). Storm sewer runoff creates a situation of pollutants being expedited directly into the stream without infiltration. Another survey conducted in 2003 by IOWATER (a volunteer water monitoring program through the IDNR) that identified that *E. coli* concentrations and high nitrate levels at several sites in the creek are well above the limit of 10 mg/L set by the EPA for safe drinking water (Lande, 2011). These reports have given the Cedar Falls community concerns about the level of human contact with the stream. The DRC watershed project has created a working partnership between landowners, IDNR, NRCS, University of Northern Iowa and Hawkeye Community College.

One of the goals of this study was to provide discharge (m^3/s) and nutrient load (mg/m^3) data from Dry Run Creek. Gauges were installed and cross-sections measured at eleven sites to develop rating curves and weekly water samples were taken to measure major ions in mg/L. From these data, weekly and annual concentration estimates of nitrate amounts being contributed to the Cedar River were calculated. The significance of this study is that other small watersheds could follow this example and potentially authorities could identify where the highest contributions of nitrate comes from and work on a small scale effort to develop Best Management Practices (BMPs) to reduce contributions.

Developing Rating Curves

Rating curves are developed to estimate the amount of water being discharged at a given site based on a stage (water depth). A 2011 study, performed by Jalbert, Mathevet, and Favre, examined the temporal uncertainty that is associated with discharge rating curves. The most common uncertainties are: i. natural uncertainties (randomness of nature), ii. knowledge uncertainty (lack of understanding in physical processes), and iii. data uncertainties (inaccurate or inadequate measurements and/or samples) (Jalbert et al., 2011). Natural and data uncertainties can often combine to create temporal uncertainties. After the initial uncertainty at stage h_0, the level of uncertainty increases as time passes due to natural variations in the stream bed (Jalbert et al., 2011).

Meybeck and Moatar (2012) observed daily variability in concentrations of various parameters of water chemistry in streams. Rating curves for concentrations of nutrients in the stream are assumed have negligible variations within a 24-hour period (Meybeck & Moatar, 2012). Therefore, linear relationships are often observed between discharge and concentrations. In small and medium sized streams the interannual variability can fluctuate by more than two orders of magnitude (Meybeck & Moatar, 2012).

Nitrate/Nutrient Loading into Streams

Dosskey (2001) identified nonpoint-source pollution (NPS) of streams and lakes, especially in the US, as being mainly caused by agricultural practices. The main problems are declining quality of drinking water, sedimentation, impaired recreation, and declining health of aquatic ecosystems. The main pollutants are sediment, nutrients (mainly nitrogen and phosphorous), pesticides, and pathogenic microbes. Vegetative buffers could reduce NPS by reducing the amount of sheet runoff and loss of sediments from agricultural fields. Riparian buffers of mature forest can retain large amounts of nutrients in the runoff to protect waterways (Dosskey, 2001).

Developing a hydrologic budget for a watershed can be used to estimate nutrient loading into a river. A Hydrologic budget was developed in 2003 by Tavener and Iqbal, using the mass-balance equation (inflow = outflow +/- storage) for the Cedar River watershed in Iowa. This was accomplished by measuring discharge from seven of the major tributaries for the Cedar River. Nutrient load concentrations were measured at each of the tributaries mouths. After data were collected, an average concentration was used to calculate the amount in kilograms of nitrogen and phosphorous discharged during the three month study from each of the tributaries (Tavener & Iqbal, 2003).

Hypoxia in the Gulf of Mexico

In a 2010 study, David, Drinkwater, and McIsaac examined where the sources of nitrate in the Mississippi River Basin (MRB) are located. In order to identify the highest nitrogen contributing areas of the basin, data was collected from all over the MRB. One notable observation is that the total nitrate yield for the entire MRB has increased from approximately 0.18 kg/ha/yr to approximately 20 kg/ha/yr since 1980 when the USDA had performed a Census of Drainage for the MRB (David et al., 2010). Nitrate concentrations in the Ohio, upper Mississippi, lower Mississippi, and Missouri sub-basins during 1997-2006 averaged 5.9, 7.2, 1.1, and 0.8 kg/ha/yr respectively (David et al., 2010). The upper Mississippi and the Ohio sub-basins are by far the greatest contributors and are also draining the Corn Belt of America. The Corn Belt extends from southern Minnesota down through the Des Moines lobe in Iowa and eastward through Illinois, Indiana, and Ohio. The higher the percentage of landuse that is agriculture and heavily drain tiled, the higher the nitrate discharge in the river (David et al., 2010). David et al. (2010) suggested constructed wetlands at the outlets of tile drainage, modified drainage ditches, or denitrification wall or trenches could be adopted to coincide with current farming practices. Any of these processes may cause an increase in nitrous oxide emissions, but with high dividends from corn and soybean production alternative farming practices aren't likely to be adopted (David et al., 2010).

Iowa's Role in the Gulf of Mexico Hypoxia Zone

In a 2011 article, Herringshaw, Stewart, Thompson, and Anderson discuss how Iowa has some of the most highly altered watersheds in the world. Approximately 92% of the land area in Iowa is used to produce row crops and 77% of Iowa's rivers and streams are considered "impaired" or "potentially impaired" (Herringshaw et al., 2011; Zaimes & Schultz, 2011). Nitrate concentrations in the agricultural areas of Iowa are the highest in the United States (Herringshaw et al., 2011). These high nitrate levels are due to exposed soil from mechanical tillage being eroded, excessive amounts of fertilizer being applied, and sediment and nutrient delivery being expedited via tile drainage systems.

Schilling (2007) examined water table depths in three wells located in different land cover types of forest, grass, and corn. In 2011, Zaimes and Schultz examined stream buffers of various land cover types and the effect it has on streambed substrate. Sediment erosion from lack of vegetative cover has greatly impaired stream waters by reducing species richness (Zaimes & Schultz, 2011). Water table fluctuations were present in all cover types, but under corn the daytime water table declines were much more exaggerated than in grass or forest (Schilling, 2007). During and after rain events the water tables underneath grass and corn rapidly rose anywhere from 0.5 to 1.0 m in the span of several hours. Under forested conditions the water table rise was less and often quite delayed (Schilling, 2007).

Litvan, Stewart, Pierce, and Larson (2008) noted in their study that human activities (mainly agriculture) altered most of the stream channels in Iowa to aid in draining the land and keeping the water table lower to grow crops. Channelization and removal of riparian vegetation historically have been practiced. In much of the last century tile drainage has been implemented to further expedite water removal from the land. Agricultural activities and industrialization have caused excess sedimentation and pollution in the streams. Channelization has destroyed much of the riffle, reach, and pool habitats for various organisms. Excessive sediments have coated the bottom of the streams burying gravels and suffocating benthic invertebrates as well as destroying hiding places for them (Litvan et al., 2008).

CHAPTER 2

HYPOTHESIS AND OBJECTIVES

Dry Run Creek, with its headwaters located in farm fields and urban drainage ditches, is a watershed under high pressure from its surrounding community. It is subject to flash flooding and erosion and is on the Iowa DNR's list of impaired waters. The water discharged from Dry Run Creek eventually contributes to Gulf of Mexico Hypoxia, where a significant portion of the nutrients come from tributaries of the Cedar River.

This study investigated discharge and nutrient loading from Dry Run Creek. Various low cost methods were examined to measure discharge and develop rating curves developed on 11 sites around the watershed. Methods demonstrated in this study could be utilized to perform more studies on small watersheds and understand their role in the nutrients being loaded into the Cedar River and possibly identify areas that are amenable to remediation. Objectives of this study were:

1. Develop low cost rating curves at several sites within the Dry Run Creek watershed utilizing a variety of methods.
2. Collect and analyze water samples weekly for nitrate concentrations to observe fluctuations in nitrate discharge.
3. Set the stage for future studies to utilize the rating curves developed for sites in Dry Run Creek and to aid in developing a low cost plan to develop rating curves in many tributary streams of the Cedar River and observe nutrient loading.

CHAPTER 3

STUDY AREA

Dry Run Creek Watershed

The Dry Run Creek watershed is a third order stream and has a drainage basin of approximately 35 square miles (15,248 ac). The main channel of Dry Run Creek, which may also be mentioned as the East Branch of Dry Run Creek, is approximately 22 miles long with a slope of 10.2 feet per mile and a sinuosity of 1.34 (Palmer & Buyck, 2011). Overall, Dry Run Creek has an average slope of 0.3 % and is a dendritic third order watershed. The dominant substrate varies throughout the watershed in proportions of sand and silt depending on the hydrologic segment (Palmer & Buyck, 2011).

A map of the Dry Run Creek Watershed is shown displaying the 11 sites used in this study (Figure 2). Ephemeral and intermittent branches begin in farm fields (like so many small Iowa watersheds) surrounding Cedar Falls and the stream empties into the Cedar River and then eventually into the Mississippi River. The Upper Mississippi River Basin includes an expanse of approximately 190,000 square miles that begins in northern Minnesota at Lake Itasca and ends at the confluence of the Mississippi River and the Ohio River at the southern tip of Illinois. The basin includes large portions of Iowa, Illinois, Minnesota, Wisconsin, and Missouri, as well as parts of Indiana, Michigan, and South Dakota. Within the Upper Mississippi River Basin the highest concentrations of cropland are in northeastern and central Iowa and southern Minnesota where it is greater than 80% of the land use in many counties (UMRBA, 2013).

A survey conducted by the Iowa Department of Natural Resources (IDNR) in 2002 indicated a lack of aquatic life and a low biotic index (IDNR, 2009). In accordance with the Environmental Protection Agency's Clean Water Act of 1972, section 303d, Dry Run Creek has been cited and placed on the list of impaired waters.

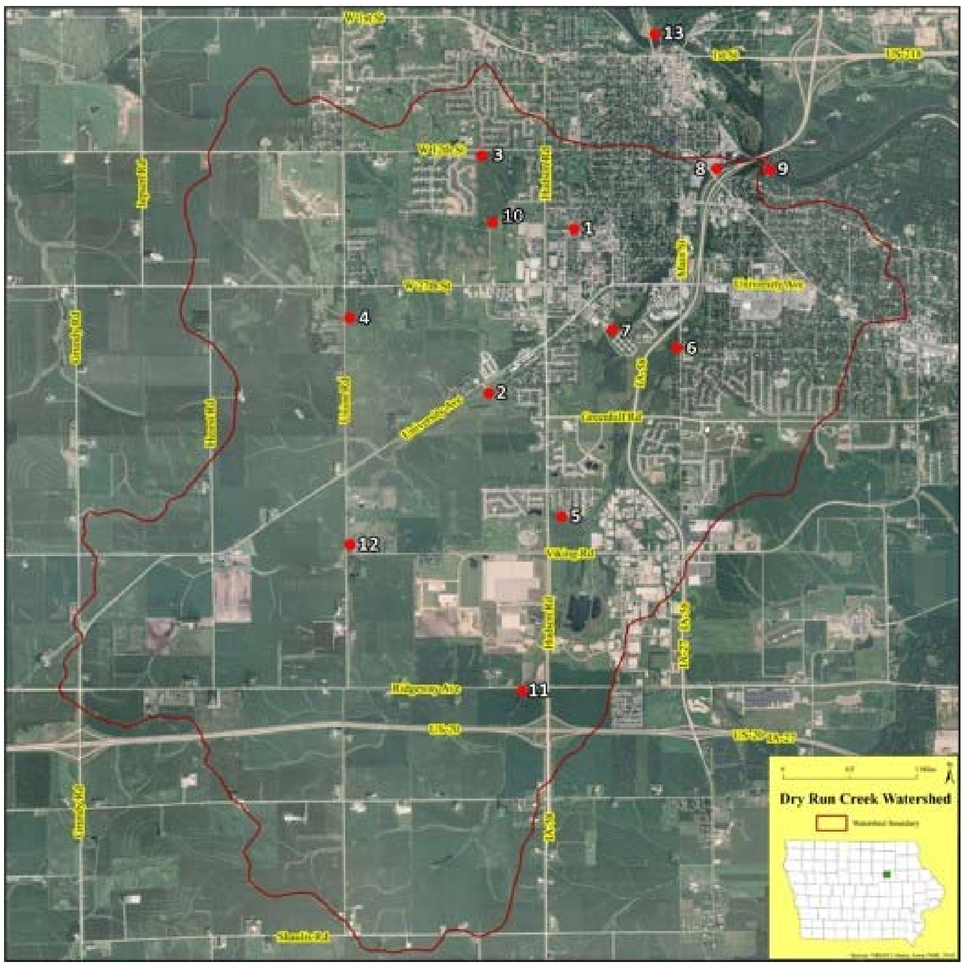

Figure 2. Map delineating Dry Run Creek Watershed and showing sites used.

The IDNR states that causes of the biological stressors on Dry Run Creek include primarily urban runoff and storm sewer contamination. Storm sewer runoff creates a situation of pollutants being expedited directly into the stream without infiltration. Another survey conducted in 2003 by IOWATER that identified that *E. coli* concentrations and high nitrate levels in the creek are well above the limits set by the state of Iowa. Nutrient loading is a significant concern because of the large area of hypoxia in the Gulf of Mexico. Studies have shown that approximately 30% of the nutrients contributed are from Eastern Iowa and that the Cedar River is the largest contributor from Eastern Iowa (Powers, 2007).

Landform Regions

Dry Run Creek is located in western Black Hawk County nearly in the middle of the Iowan Surface ecoregion. This region has two major northwest-to-southeast trending stream valleys. In the northern portions of the region the glacial drift and limestone bedrock are relatively thin, creating a karst zone with sinkholes and sags. Pre-Illinoian glacial till (deposited 600,000+ years before present) provided the base for this erosional landscape. The Iowan Surface ecoregion is also referred to as the Iowan Erosional Surface due to all the evidence of alluvial and wind erosion. Soils are composed of wind-deposited Wisconsinan loess over Pre-Illinoian glacial till. Over most of the Iowan Surface the "Iowan pebble band", areas where tills and paleosols have been eroded and a residual lag of stone is deposited, is covered by layers of discontinuous loess and loam deposits (Anderson, 1998).

Climate

Climatic data is provided by NOAA (Cogil, 2010) using data collected at the Waterloo Municipal Airport located approximately seven miles east of the watershed. The average temperature in winter is 18.4 °F with an average low of 9.4 °F. During the summer months the average temperature is 70.8 °F with an average high temperature of 82 °F. The growing season for plants is typically from April through September. The average precipitation is 33.72 inches of which approximately 60% falls between May and September. The average snowfall is 31.8 inches and on average 69 days per year have at least one inch of snow on the ground. The average mid-afternoon relative humidity is approximately 60%. Prevailing winds are from the northwest from December to April and from the south the rest of the year. March and April have the highest average wind speed of 12-13 miles per hour (Cogil, 2010).

During the study period (May 11- August 9, 2011), the average temperature was 71 °F with an average high temperature of 81 °F. The total precipitation for the study period was 10.67 inches (Weather Underground, 2014). Temperatures were average with the areas climate and the precipitation appears to be a bit lower than average.

Land Use

According to the Iowa Department of Natural Resources in a 2011 publication there has been a 200%+ increase in urbanization of the watershed. Row crops with narrow riparian strips in the upper reaches of Dry Run Creek make up approximately 55% of the land use and grazed grasslands make up 4% (Palmer & Buyck, 2011). While studying Dry Run Creek it was observed that the headwaters of the watershed are almost entirely unnatural, many beginning as draintile outlets (Figure 3).

Figure 3. Since this photo was taken looking upstream the farmer has row-cropped what used to be the greenway and ephemeral headwaters for Dry Run Creek.

The central and lower regions of the watershed are primarily urban, making up approximately 22% of the land use (Figure 4). More than 9% of the watershed is considered impervious (Palmer & Buyck, 2011). Drainage from the impervious surfaces is expedited to Dry Run Creek via storm drains (Figure 5). Approximately 36% of the watershed in total was considered urban in 2009 and every year that percentage is growing (Schuppert, 2009). There has been an over 200% increase in urban areas in the last decade (Palmer & Buyck, 2011).

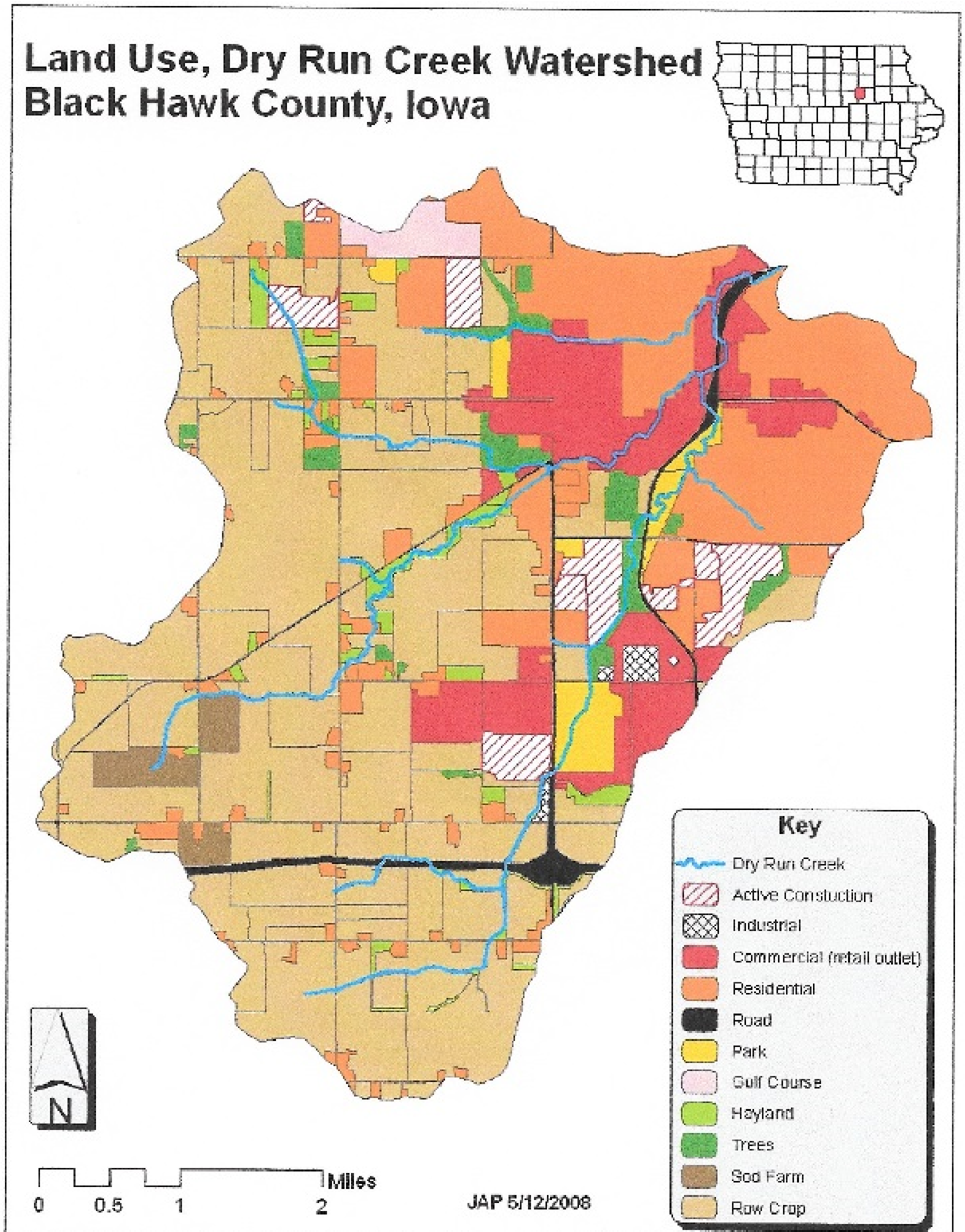

Figure 2-6 Land uses in the Dry Run Creek watershed based on 2006 aerial photography

Figure 4. Land use map of the Dry Run Creek Watershed (Palmer and Buyck, 2011)

Figure 5. Photo taken in 2009 of a storm drain emptying into Dry Run Creek just downstream of Site 6 near the Cedar Falls dog park.

CHAPTER 4

MATERIALS AND METHODS

Sampling Sites

Site 1

Site 1 (Figure 6) is located just to the west of Campus Street to the north of the University of Northern Iowa's "Towers" dormitories (Figure 2). An existing stream gauge from a previous stream study is utilized in this study and measurements are converted to centimeters from feet. To the right of the stream (when looking upstream at this site and other sites) is a large paved parking lot for Price Lab School that drains directly into the stream. To the left of the stream (when looking upstream at this site and at all other sites) there is a large parking lot for students. A portion of this parking lot drains into a small catchment area before entering the stream.

Figure 6. Photo of Site 1

<u>Site 2</u>

Site 2 (Figure 7) is located just to the south of University Avenue and to the west of Hudson Road in Cedar Falls, IA (Figure 2). A constructed stream gauge for this study, measuring in centimeters, was installed along a run in the stream. To the right of the stream is an area of overgrown grass and University Avenue. To the left of the stream are row crops up to the bank of the stream. Just downstream of the gauge is a makeshift road with a concrete pad to allow for farm machinery to cross. After rain events this section of stream is extremely turbid and there is an extreme influx of sediment on the base of the stream. Muskrats were often seen at this site.

Figure 7. Photo of Site 2

Site 3

Site 3 (Figure 8) is located just to the south of the intersection of W 12th Street and Barnett Drive in Cedar Falls, IA (Figure 2). A constructed stream gauge for this study, measuring in centimeters, was installed along a run in the stream. To the right of the stream is a thin strip of riparian zone and row crops. To the left of the stream there is a very thin strip of riparian zone, an area of overgrown grass, and then a residential development. This site often had garbage debris in and around the stream.

Figure 8. Photo of Site 3

Site 4

Site 4 (Figure 9) is located at the outlet of the square culvert underneath North Union Road in Cedar Falls, IA (Figure 2). A stream gauge was painted directly on the concrete of the square culvert for this study, measuring in centimeters. To the right of the stream is a narrow strip of riparian zone and row crops. To the left of the stream there is a narrow strip of riparian zone and row crops. Downstream of this site individuals have constructed a dam creating a deep pool.

Figure 9. Photo of Site 4.

Site 5

Site 5 (Figure 10) is located in the Viking Hills subdivision to the south of where Fjord Drive terminates in Cedar Falls, IA (Figure 2). A constructed stream gauge for this study, measuring in centimeters, was installed along a run in the stream. To the right of the stream is residential housing. To the left of the stream are row crops. Children often play in this portion of the stream and move rocks.

Site 5 was selected for ease of access. In other studies this section of stream was accessed downstream but due to neighborhood development a new locale was needed. This site was chosen due to a road ending ~30yds from the steam-bank and a trail leading down to the stream next to a storm water drain.

Figure 10. Photo of Site 5.

Site 6

Site 6 (Figure 11) is located west of Main Street and south of Highway 58 in Cedar Falls, IA (Figure 2). A constructed stream gauge for this study, measuring in centimeters, was installed along a run in the stream. To the right of the stream is a riparian zone and Highway 58. To the left of the stream there is a riparian zone with a paved bike trail running through. Site 6 is just upstream of the Main Street Bridge and the off-leash dog park.

During rain events this portion, just as most of the watershed, experiences flash flooding and large amounts of debris traveling downstream. After one storm event this gauge was twisted and bent over causing the gauge to need to be replaced.

Figure 11. Photo of Site 6.

Site 7

Site 7 (Figure 12) is located on the University of Northern Iowa campus in Cedar Falls, IA on the north side of the non-traditional student housing complex next to the on-campus testing wells. (Figure 2). A permanent stream gauge measuring in feet was installed along a run in the stream; the measurements are converted to centimeters for this study. To the right of the stream is a thin strip of riparian zone, mowed grass, and buildings. To the left of the stream there is a narrow strip of riparian zone, mowed grass, and then the non-traditional student housing complex and parking lot. Next to the site is a foot bridge connecting student housing to campus.

Figure 12. Photo of Site 7.

Site 8

Site 8 (Figure 13) is located along Waterloo Road near the overpass of Highway 58 next to Cedar Falls Utilities in Cedar Falls, IA (Figure 2). A stream gauge was painted directly on the concrete of the square culvert for this study, measuring in centimeters. To the right of the stream there is a very thin strip of riparian zone and Cedar Falls Utilities. To the left of the stream is a paved bike path and Highway 58. This site is just upstream of the confluence with the Cedar River and is often utilized in studies to represent the total flow of Dry Run Creek.

Figure 13. Photo of Site 8.

Site 9

There is no Site 9.

Site 10

Site 10 (Figure 14) is located north of W 27th Street in Cedar Falls, IA to the west of the UNI-Dome along a dirt access road (Figure 2). There is no stream gauge installed at this site. A measurement in centimeters was taken using the ruler on the velocity meter. The site is at the outlet of a circular metal culvert where the access road crosses the stream. To the right of the stream there is a tall grass riparian zone and then a residential area. To the left of the stream is a tall grass riparian zone and practice fields on the west side of the UNI-Dome. This site has recently undergone a bank stability project by the NRCS and large blocks line the streambanks.

Site 10 was chosen to represent a stream section upstream of the newly developed UNI wetlands. The towers site off of Campus St. is just downstream of the wetlands. In addition, both of those sites have undergone streambank stabilization projects in recent years. At site 10 the gauge location is the mouth of a round culvert that the stream passes through because of a class c road. The advantage to this site is that it is permanent until the road structure is changed someday. The metal culvert won’t change shape as a natural streambed would and therefore it has the advantage of long-term data sets at this site. To measure discharge at this site the velocity meter was used to take 3 velocity measurements that were then averaged out and utilized to estimate discharge.

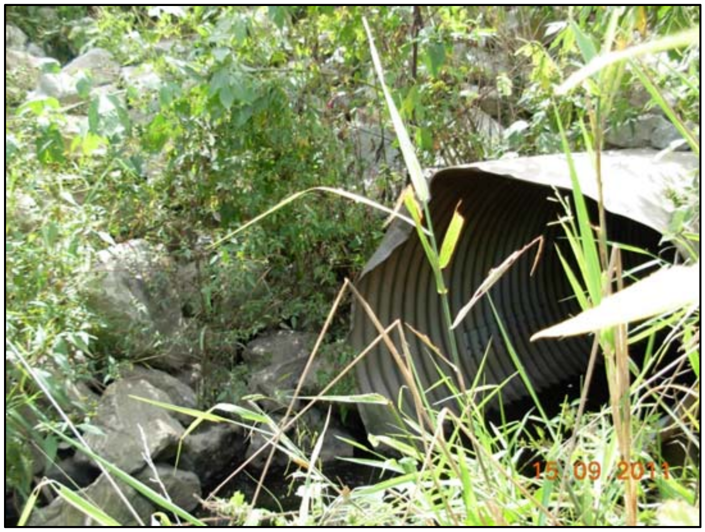

Figure 14. Photo of Site 10.

Site 11

Site 11 (Figure 15) is located along Ridgeway Avenue just west of Hudson Road in Cedar Falls, IA (Figure 2). There is no stream gauge installed at this site. Measurements were taken using a depth sensor measuring from the bridge base down. To the right and left of the stream there is a very thin strip of riparian zone and row crops.

Figure 15. Photo of Site 11.

Site 12

Site 12 (Figure 16) is located along Union Road near its intersection with Viking Road in Cedar Falls, IA (Figure 2). A constructed stream gauge for this study, measuring in centimeters, was installed along a run in the stream. To the right of the stream there is a very thin strip of riparian zone and row crops. To the left of the stream are a very thin strip of riparian zone and the backyard of a home. Upstream of this site is surrounded by row crops with minimal grassed riparian zones. This section of stream has an influx of sediment after rain events but not to the degree as site 2. Frogs were often seen at this site as well as once a mink.

Figure 16. Photo of Site 12.

Sampling Methods

Gauge Selection

For the study period (May 11- August 9, 2011), the location and type of gauge utilized at each site depended on the site. Sites 2, 3, 5, 6, and 12 gauges were created by painting metal fence posts (Figure 17) and installing them in the stream channels. These gauges are very inexpensive, costing less than $20 per site for materials. Existing concrete structures were utilized at sites 4 and 8 by painting gauges on them. These sites are even less expensive than the constructed gauges because they only cost involved is the paint. This is assuming that the person developing the site has a meter stick to use to mark increments to paint.

Figure 17. Photo of painted fence post gauge mid-construction.

At sites 1 and 7 existing stream gauges were employed and gauge readings were converted to metric units. Site 10 is a circular culvert and discharge was measured using the velocity meter by taking 3 velocity measurements that were then averaged out and utilized to estimate discharge. Site 11 depths were measured from the bridge down to the stream bed using a depth sensor.

At each site a cross-sectional area was diagramed at the gauges (Figure 18). Cross-sectional areas of each site can be viewed in Appendix E. A flow meter was used to obtain velocities in m/s at 3-4 locations at each site. Discharge (Q) was calculated as cross-sectional area (A) times velocity (V) (Q=A*V).

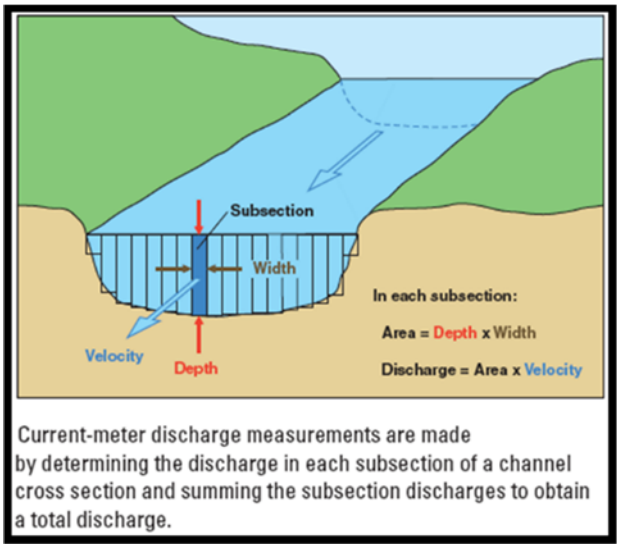

Figure 18. Drawing is from: USGS Water Science for Schools (2014). Shows basic method for determining stream discharge.

Rating Curve

A rating curve is the relationship between stage (stream depth) and discharge at that location. Rating curves were developed for each site comparing discharge in m^3/s and gauge height in cm. Rating curves allow for a reliable rough estimate of average discharge at a given point at a certain depth. To develop a rating curve several depth and velocity measurements must be made over a span of time at various depths and flow regimes. This can be quite hazardous at high flows and this is reflected a few times at sites 1 and 6. However, more modern methods of developing rating curves with LiDAR, salt slug injections, or acoustic meters can be expensive and unrealistic for small watersheds. Developing rating curves on small watersheds can be extremely useful in determining sediment and nutrient discharges (Nathanson et al., 2012).

Laboratory Analysis

Water samples were taken at each site in the study for analysis in the laboratory. Water samples were stored at 4 ^{o}C until samples could be prepared and subjected to analysis. Each sample was prepared and analyzed by an ion chromatograph located in the UNI Hydrology Lab. Chloride, Nitrate, and Sulfate concentrations were measured in mg/L. Sulfate and Chloride concentrations are not going to be discussed in this project and Nitrate concentrations will be discussed briefly. Some of the water samples were collected by a lab assistant and some were collected by the individual conducting this study.

The concentrations of dissolved chloride, nitrate, and sulfate in water were determined with a Dionex® (Model DX-120) ion chromatograph under suppressed conductivity. Ion elution was accomplished using a CO_3-HCO_3 solution. Before analyzing the samples, de-ionized water was injected to verify the stability of the machine. Flow rate was set at 1.95 mL/min. Known standards of the target ions (5, 25, 50 ppm) were used for machine calibration, and a separate 25 ppm standard solution was used to check the validity of calibration. The unknown samples were poured into 5 mL plastic vials fitted with 20 micron filter caps and then loaded into an AS40 automated sampler for injection into the system. The samples flowed from the injection loop first to the guard column (AG14) and then to the anion exchange column (AS14), and finally to the ASRS 300 (4 mm) suppressor to complete the cycle. The peak retention times were 1.74 minutes for chloride, 2.60 minutes for nitrate, and 4.02 minutes for sulfate. Sample scan, data acquisition, and statistical analysis were done by a Chromatography Management System (CMS) software called "Chromeleon" (released from Dionex) remotely from a computer work station. The analytical margin of error was ± 0.5 ppm.

CHAPTER 5

RESULTS AND DISCUSSION

Precipitation

The total precipitation during the study period (May 11- August 9, 2011) was 10.67 inches (Weather Underground, 2014). Figure 19 shows the dates and amounts of rainfall during the study period.

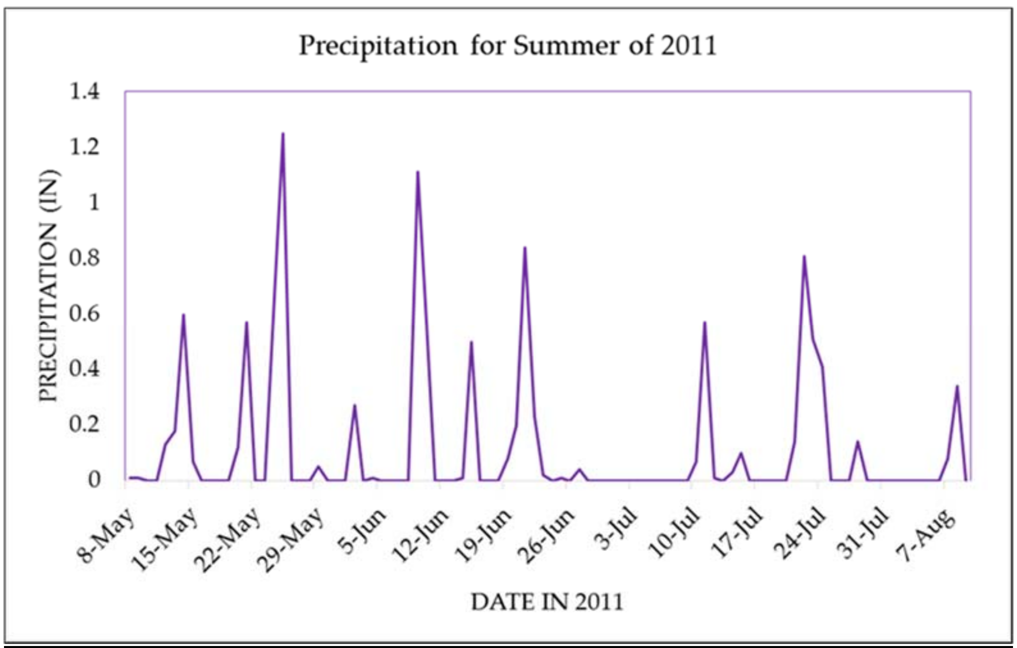

Figure 19: Precipitation for Waterloo, IA May 8- August 8, 2011
(Weather Underground, 2014)

Site 1

Rating Curve

During the study period (May 11- August 9, 2011), the highest gauge height occurred on July 24 at 36.6 cm with a discharge of 0.48 m^3/s. The lowest observed gauge height occurred on May 18 at 29.9 cm with a discharge of 0.31 m^3/s. A gauge height of 30.5 cm occurred on multiple dates (June 13 and 28, July 8, 11, and 26, and August 4 and 9) with discharge ranging from 0.31 m^3/s to 0.38 m^3/s with a mean discharge of 0.335 m^3/s (Figure 20) (Appendix A). The discharge should be the same for the same gauge height at this location. It is possible that the variation in discharge readings could be due to inaccuracy of the flow meter being used. The range in flow is fairly small. Discharge at this section of stream is likely not to fall below 0.3 m^3/s due to the University discharging water from their cooling system in the buildings on the north side of campus. This stream section is stable because of the amount of streambank restoration that has been performed upstream and at the site. This site may be highly useful in follow-up studies for the filtration effectiveness of nitrates in the constructed wetlands located upstream when compared with studies at site 10 that is located upstream of the wetlands.

Discharge

There appears to be a perennial flow on this stream section of approximately 0.31 m^3/s (Figure 21) (Appendix B). A good part of this flow could be a result from the constructed wetlands upstream or the discharge of cooling waters from the dormitories adjacent to the stream.

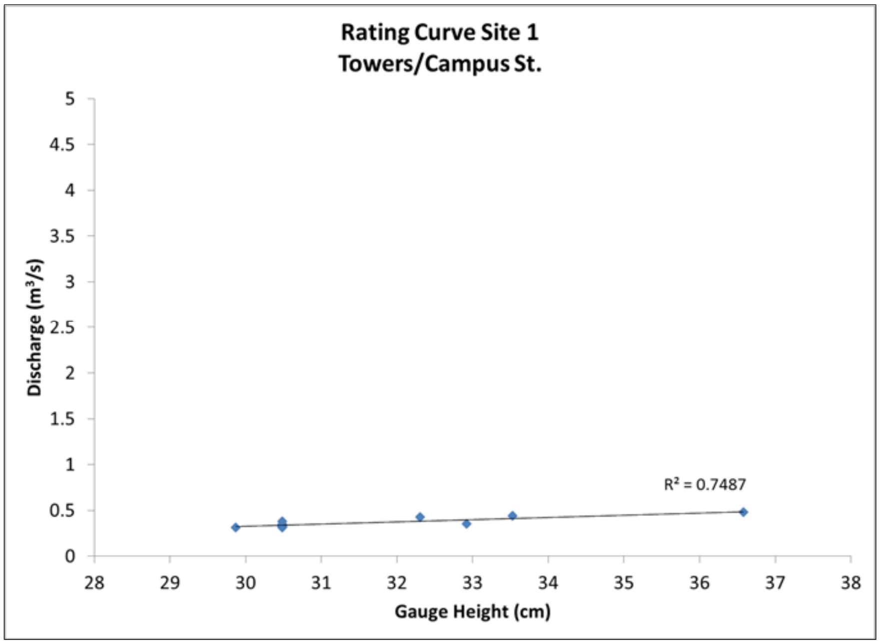

Figure 20: Site 1 Rating Curve.

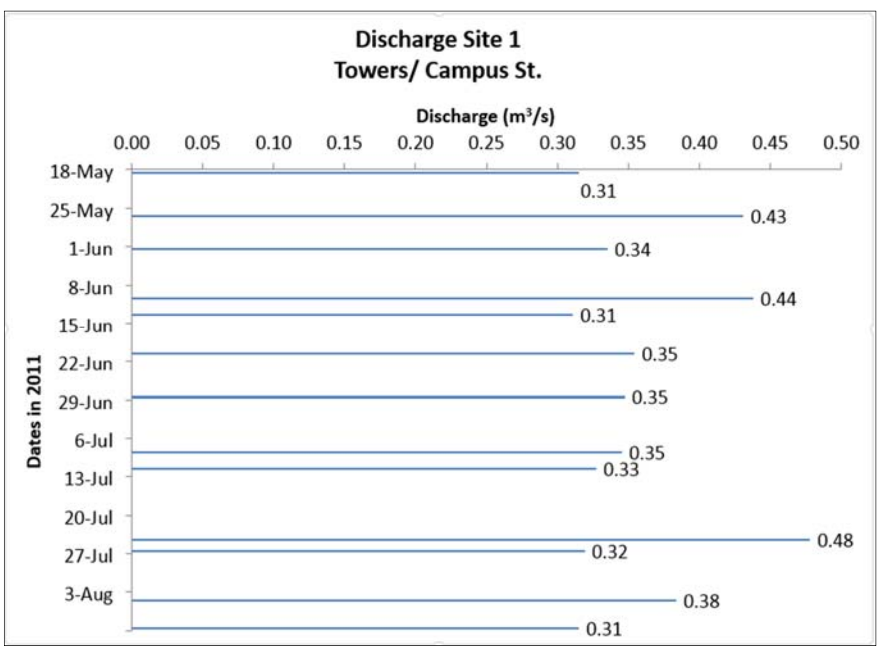

Figure 21: Site 1 Discharge.

Site 2

Rating Curve

During the study period (May 11- August 9, 2011), the highest gauge height occurred on June 13 at 40 cm with a discharge of 0.24 m^3/s. The lowest observed gauge height occurred on August 4 at 26.5 cm with a discharge of 0.02 m^3/s (Figure 22). This site is the most unstable site due to its constant change in the amount of organic sediments, mainly silts, on the streambed. Every week the stream gauge needed to be recalibrated for depth based on the amount of sediments being conveyed through the channel. In order to create a rating curve for this site all depth measurements had a correction factor figured in that changed each week due to organic sediment depth (Appendix A). A correction factor was made to accommodate the changing depth to the bottom of the streambed on the gauge. This site is unsuitable for further studies using the gauge and calculated rating curve.

Discharge

Discharge at site 2 fluctuates rapidly depending on precipitation and there is a general trend of decreasing flow as summer progresses. A gradual decline in overland flow from the adjacent crop fields occurs as summer progresses and the drain tiles have less flow to add to the creek (Figure 23) (Appendix B).

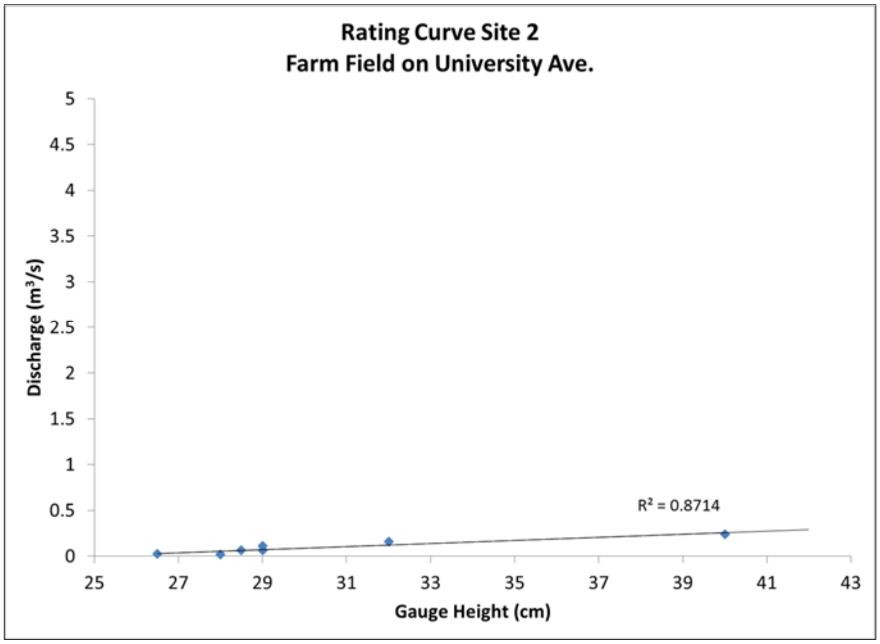

Figure 22: Site 2 Rating Curve.

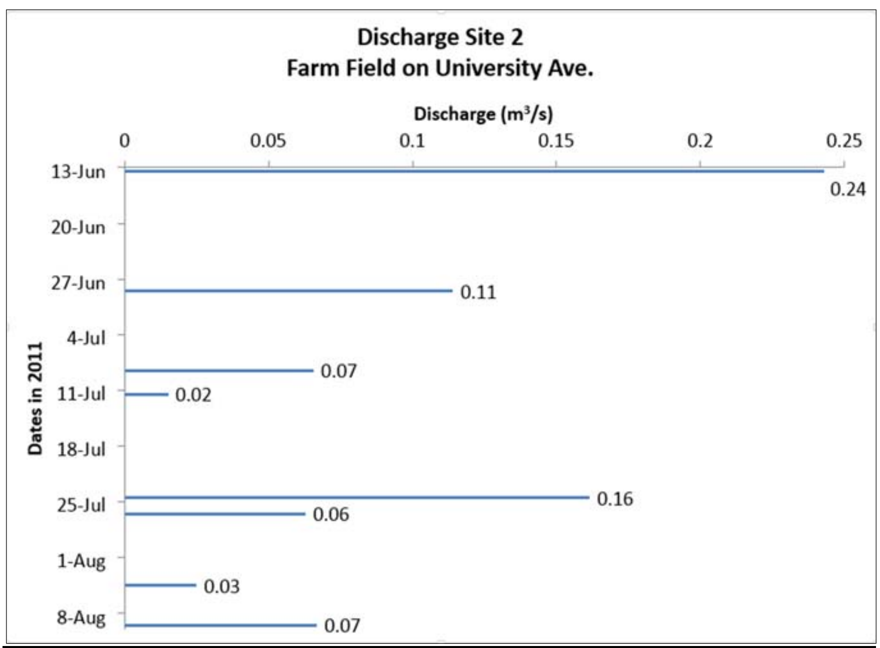

Figure 23: Site 2 Discharge.

Site 3

Rating Curve

During the study period (May 11- August 9, 2011), the highest gauge height occurred on July 24 at 30 cm with a discharge of 0.06 m^3/s. The lowest observed gauge height occurred on July 11 at 24 cm with a discharge of 0.01 m^3/s (Figure 24). This site often had garbage debris due to its proximity to a busy residential area and street. The headwaters in this area have been altered into drainage ditches in a neighborhood (Appendix A). This site could be used to examine fertilizer runoff from the residential area located upstream.

Discharge

Site 3 is missing discharge data from early July that would coincide with nitrate data so there is a gap in the discharge graph. There doesn't appear to be any base flow at this site. In drier conditions flow was close to nothing (Figure 25) (Appendix B).

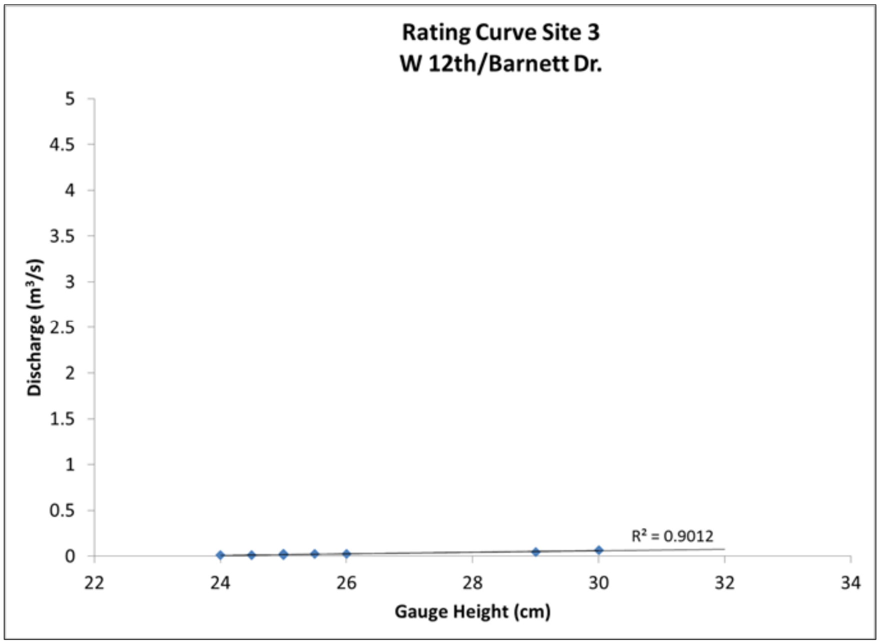

Figure 24: Site 3 Rating Curve.

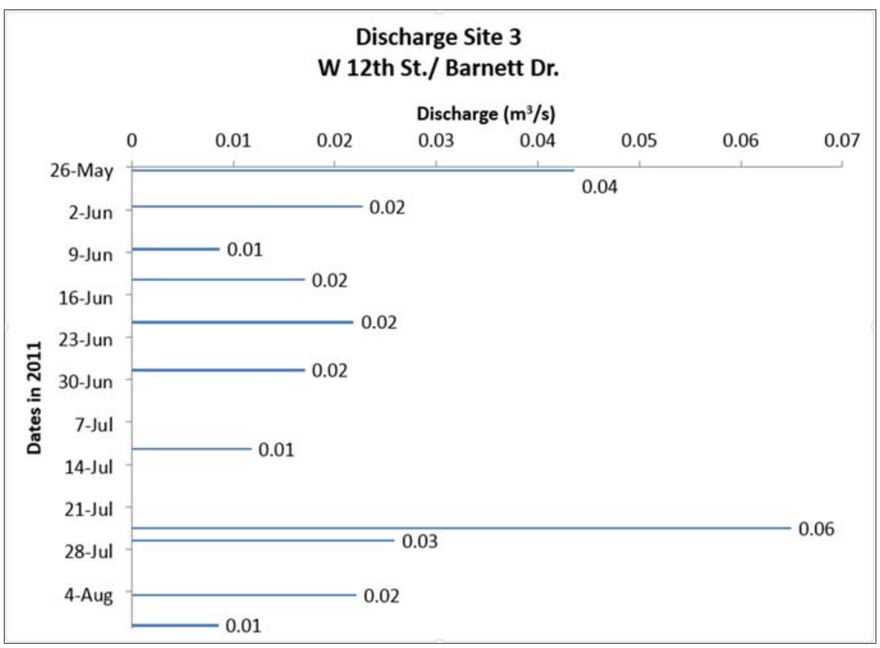

Figure 25: Site 3 Discharge.

Site 4

Rating Curve

During the study period (May 11- August 9, 2011), the highest gauge height occurred on May 26 at 12 cm with a discharge of 0.22 m^3/s. The lowest observed gauge height occurred on August 9 at 1.0 cm with a discharge of 0.02 m^3/s (Figure 26). Site 4 is one of the most stable sites and this site would be an excellent candidate for a permanent gauge to be installed for future studies. This is because it is located in a cement culvert running underneath Union Rd. (Appendix A).

Discharge

Much like site 3, in drier conditions there is no flow in this site. This site is near the headwaters of this branch and is mainly fed by drain tiles from agricultural fields (Figure 27) (Appendix B).

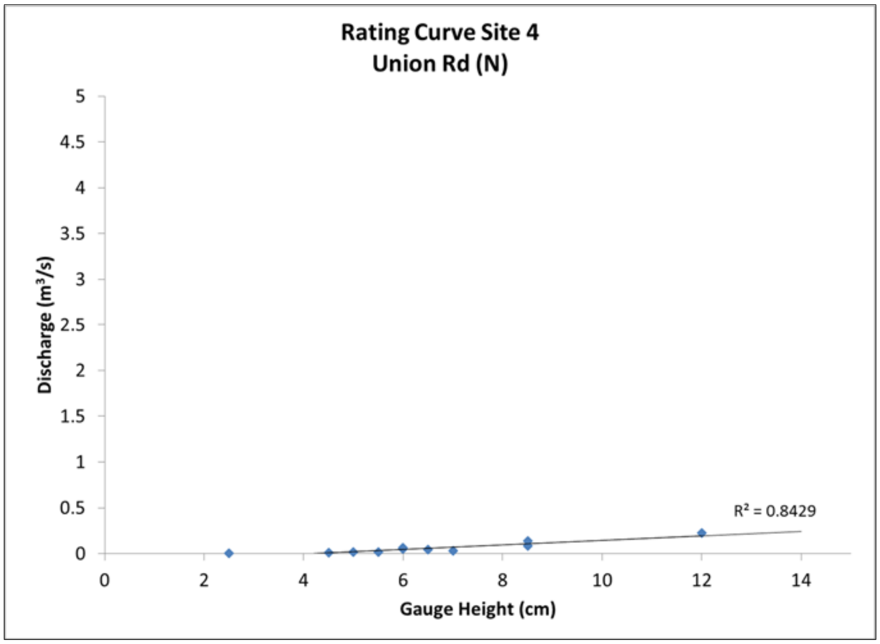

Figure 26: Site 4 Rating Curve.

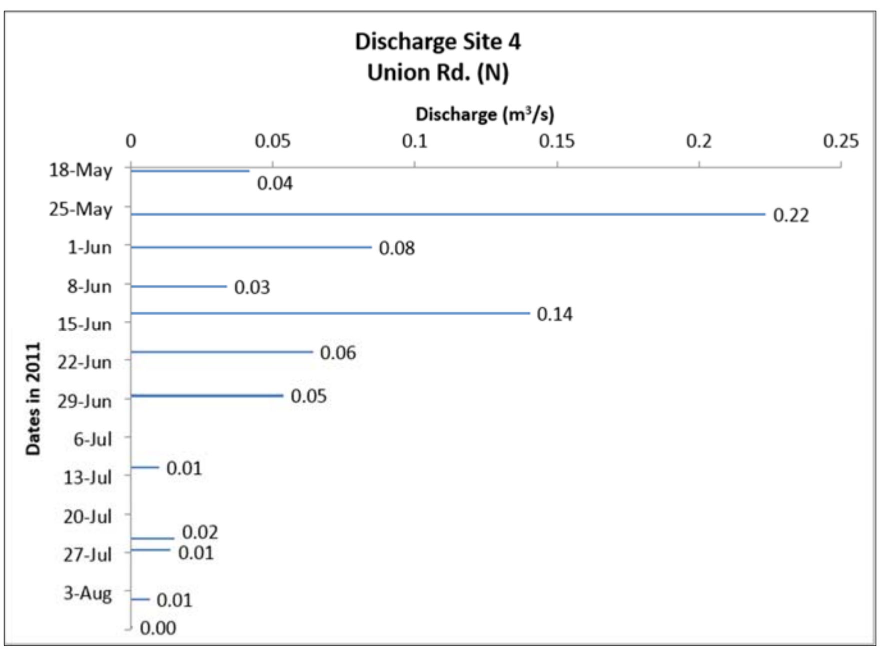

Figure 27: Site 4 Discharge.

Site 5

Rating Curve

The highest gauge height in this site occurred on May 26 at 20 cm with a discharge of 0.16 m^3/s. The lowest observed gauge height occurred on July 11 at 10 cm with a discharge of 0.04 m^3/s (Figure 28). The gauge at this site is vulnerable because it is located in a residential area and there is evidence (a make-shift bridge and other signs) that children often play in this stream section. This site is useful because it is just downstream of the catchment pond for a residential area (Appendix A). Studies could be done in examining the ability of the catchment pond on slowing the influx of discharge during rain events and the ponds ability to precipitate out sediments and fertilizer before entering the creek.

Discharge

Site 5 displays expected fluctuations in flow based on precipitation. It is downstream of a residential retention pond and during drier periods flow decreases to almost none (Figure 29) (Appendix B).

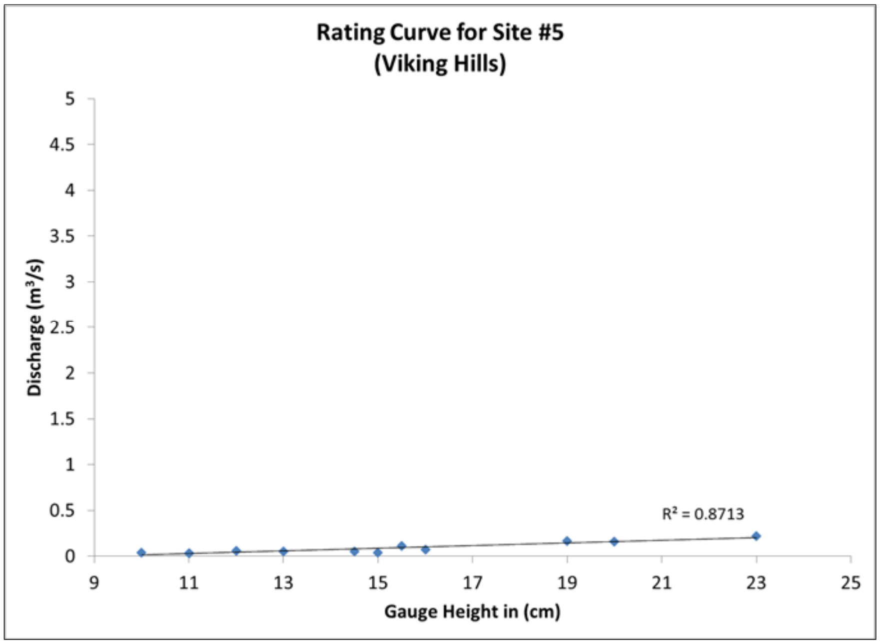

Figure 28: Site 5 Rating Curve.

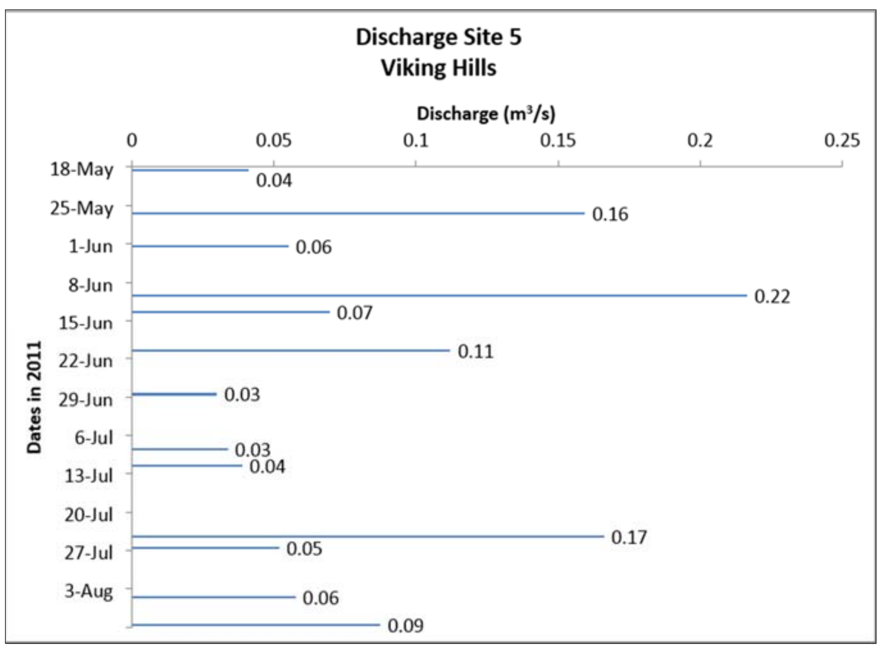

Figure 29: Site 5 Discharge.

Site 6

Rating Curve

The highest gauge height at this site occurred on May 26 at 59 cm with a discharge of 1.93 m^3/s. The lowest observed gauge height occurred on August 4 at 17.5 cm with a discharge of 0.35 m^3/s (Figure 30). During periods of low flow portions of the channel are dry along the right bank. During rain events between July 21-23, debris bent the gauge at this site and a new gauge had to be installed. July 25 measurements were eliminated due to being an outlier at 12.5 cm with a discharge of 1.3 m^3/s. This site represents all of the East Branch of Dry Run Creek (Appendix A). This site's gauge was damaged during a rain event by debris and stands a high risk of vandalism due to its proximity to a well-used bike path.

Discharge

Site 6 readily fluctuates in flow based on precipitation. It is fed by several small ephemeral tributaries and has a low base flow of approximately 0.5 m^3/s (Figure 31). After large rain events flow is too high to safely obtain velocity readings across the stream, therefore, peak flows are not measured accurately. Discharge was calculated based on velocity measurements taken near shore (Appendix B).

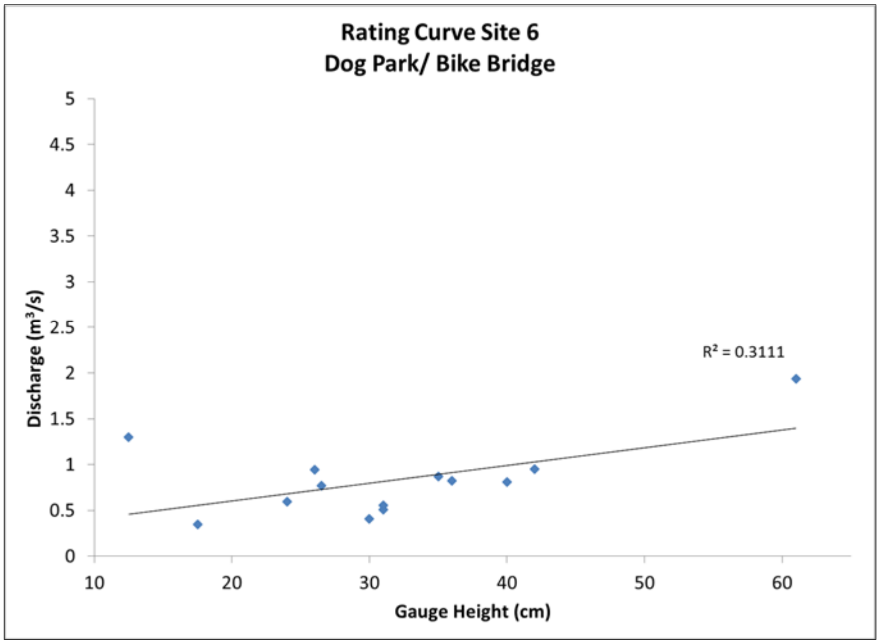

Figure 30: Site 6 Rating Curve.

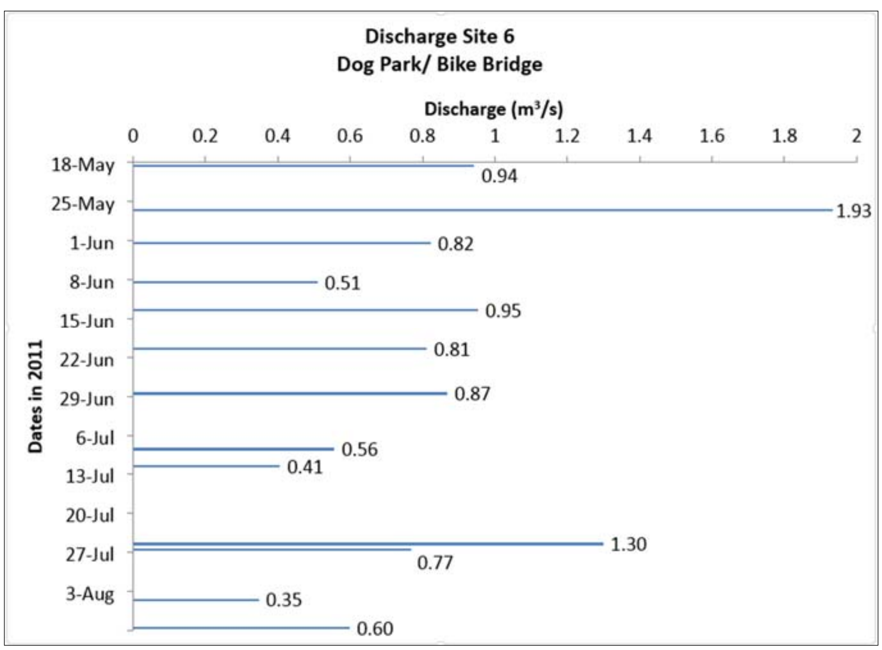

Figure 31: Site 6 Discharge.

Site 7

Rating Curve

The highest gauge height at this site occurred on June 10 at 72 cm with a discharge of 1.1 m^3/s. The lowest observed gauge height occurred on August 4 at 18 cm with a discharge of 0.17 m^3/s (Figure 32). Along the left bank approximately 1 m of the streambed is dry during periods of low flow (Appendix A). This gauge will be highly useful in several studies and classroom exercises because it is located at an established site for hydrological education.

Discharge

During periods of high flow, this site is too deep and turbulent to safely take velocity measurements across the stream. Therefore, high peak flows were calculated based on velocity measurements taken near shore. Base flow is quite low in this stream section, sometimes being almost dry (Figure 33) (Appendix B).

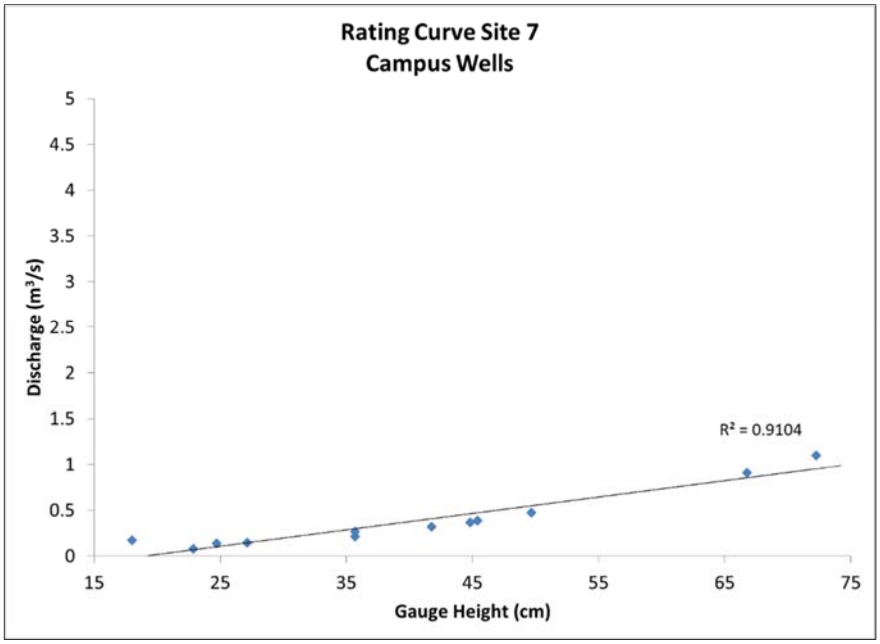

Figure 32: Site 7 Rating Curve.

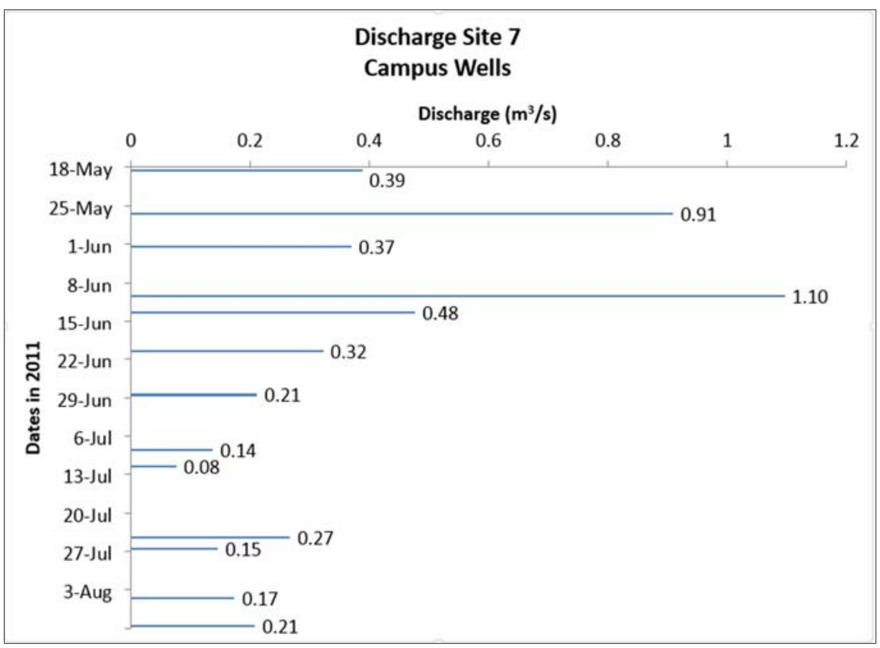

Figure 33: Site 7 Discharge.

Site 8

Rating Curve

The highest gauge height at this site occurred on June 20 at 38 cm with a discharge of 4.6 m^3/s. The discharge rate for this date is not accurate because there were no velocity measurements taken from mid-stream due to the water being too deep and rapid to wade into. May 26 and June 28 velocities are inaccurate as well due to the water being too deep and turbid. The lowest observed gauge height occurred on August 4 at 0.0 cm with a discharge of 0.98 m^3/s (Figure 34). On this date, 3.5 m of the streambed was dry on the right bank of the stream, making the stream narrower in periods of low flow. The gauge at this site will need to be repainted often due to it wearing off during periods of higher flow. This site represents the entire watershed and is located just upstream of the confluence with the Cedar River (Appendix A). Site 8 is extremely important because it is located just upstream of the confluence with the Cedar River. This site however does change in total stream width depending on discharge and is unsafe to enter during high flow. Further work needs to be performed on this site to develop a reliable or more valid rating curve. Equipment to measure from the bridge above needs to be utilized.

Discharge

Site 8 represents the entire discharge of Dry Run Creek flowing into the Cedar River. Its base flow is approximately 1.0 m^3/s (Figure 35). During peak flows it is too deep and fast to safely take velocity measurements across the stream. Therefore, discharge is based on velocity measurements taken near shore (Appendix B).

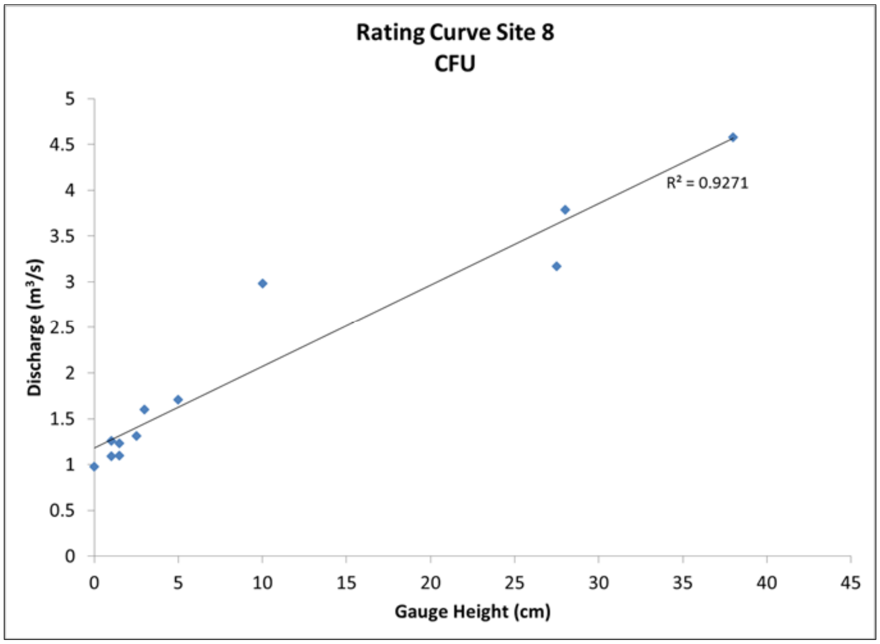

Figure 34: Site 8 Rating Curve.

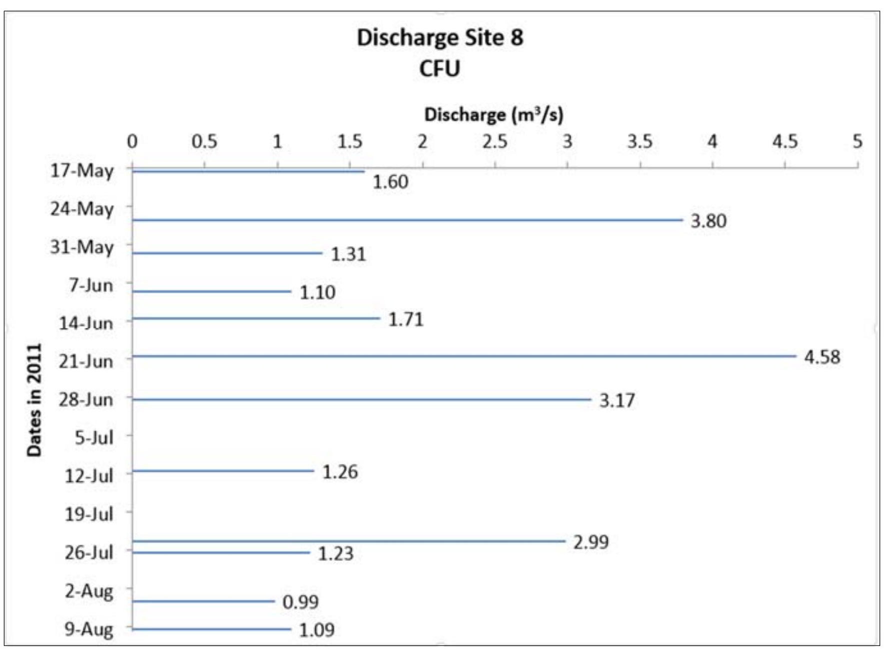

Figure 35: Site 8 Discharge.

Site 10

Rating Curve

The highest gauge height at this site occurred on May 26 at 19 cm with a discharge of 0.33 m^3/s. The lowest observed gauge height occurred on June 1 and August 4 at 9 cm with a discharge of 0.13 m^3/s (Figure 36). The gauge at this site is just upstream of the UNI constructed wetlands. This site will be useful for several years because it is a permanent structure and easy to access (Appendix A). This site could be used to compare nitrate concentrations between it and site 1 to observe the filtration of the constructed wetland located between the sites.

Discharge

Site 10 appears to have a base flow of approximately 0.13 m^3/s (Figure 37). This site was gaged at the point of discharge of a primitive road culvert. The entire stream is funneled through a round metal culvert (Appendix B). Discharge is very easily taken and is considered very accurate.

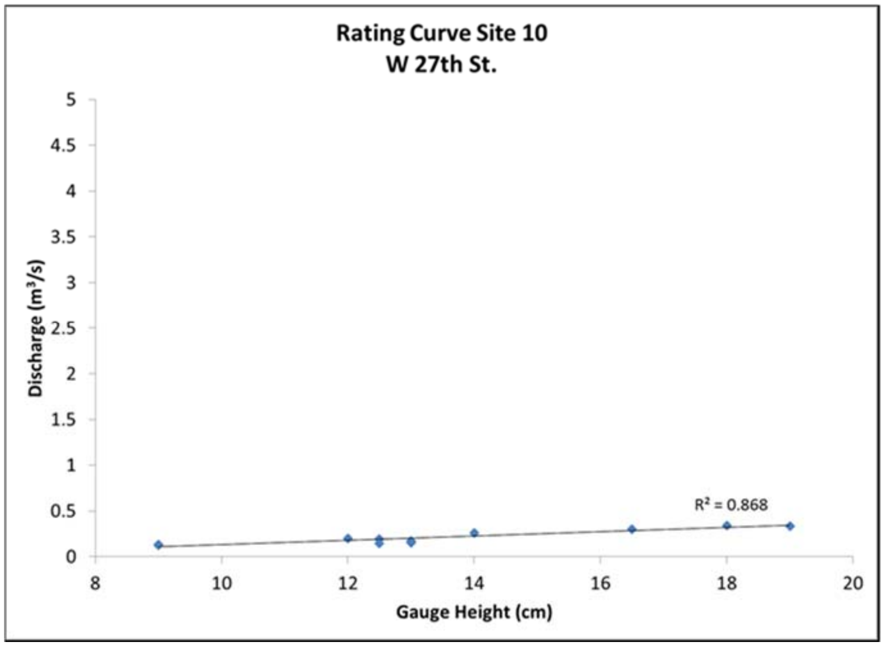

Figure 36: Site 10 Rating Curve.

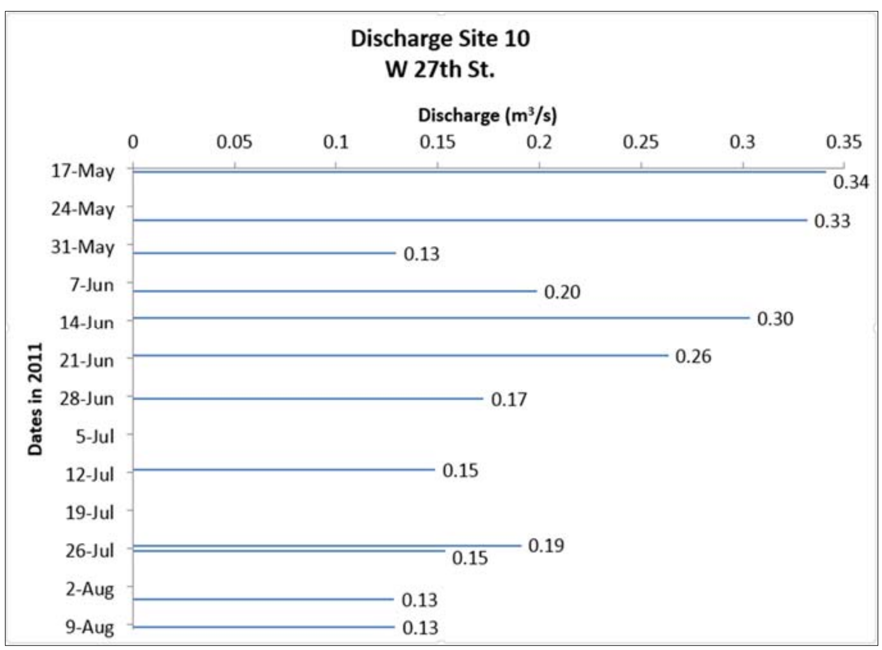

Figure 37: Site 10 Discharge.

Site 11

Rating Curve

The highest gauge height at this site occurred on June 20 and July 25 at 27.5 cm with discharges of 0.79 m^3/s and 1.03 m^3/s respectively. The lowest observed gauge height occurred on August 4 at 17.5 cm with a discharge of 0.08 m^3/s (Figure 38). This site in periods of low flow has dry portions of streambed up to 3 m along the right bank making the stream considerably narrow (Appendix A). This site is located at the divide of urban and rural areas. Upstream is agricultural fields and downstream is industrial and residential.

Discharge

Site 11 is measured from a bridge down and is accessible during all levels of flow. Base flow is extremely low to none at this site (Figure 39) (Appendix B).

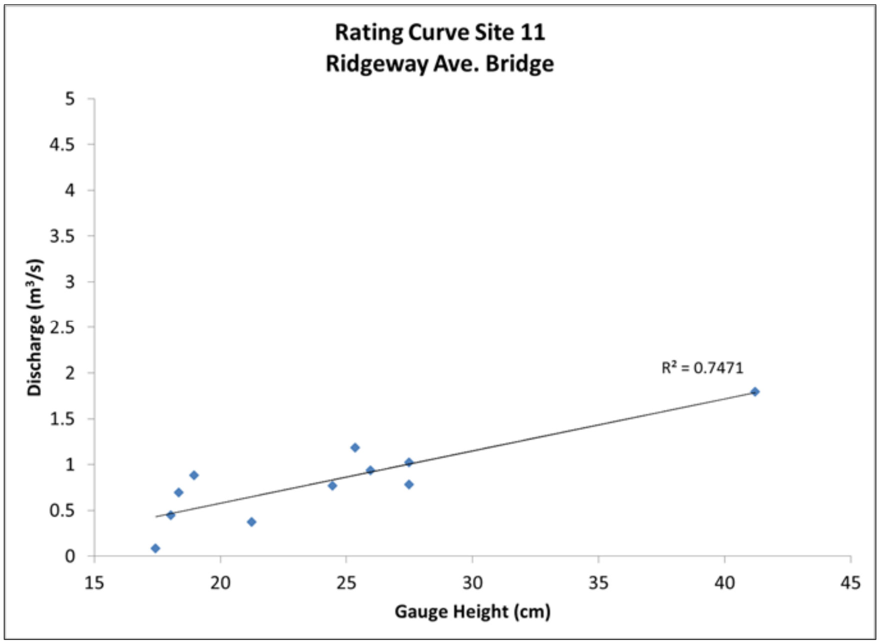

Figure 38: Site 11 Rating Curve.

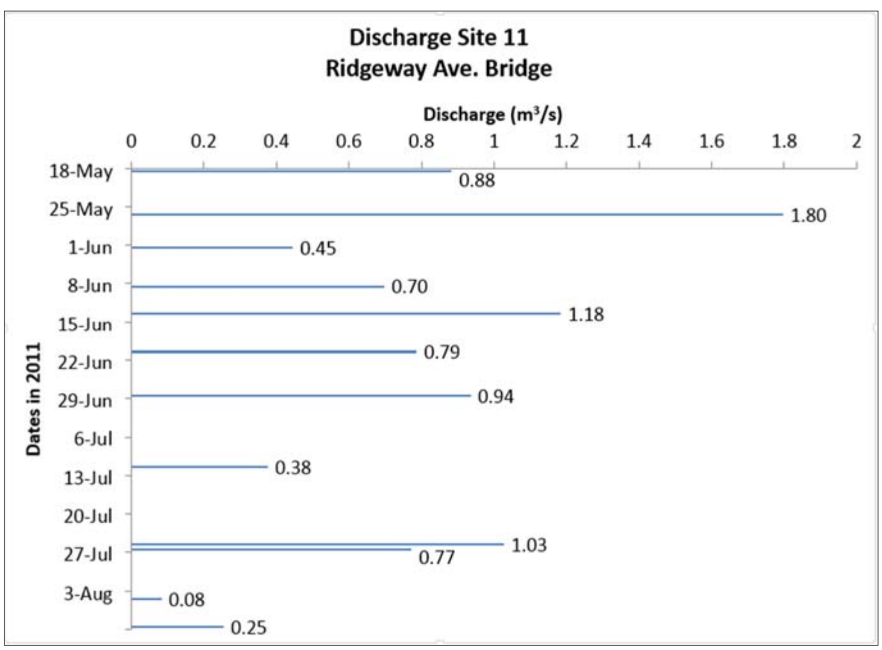

Figure 39: Site 11 Discharge.

Site 12

Rating Curve

The highest gauge height at this site occurred on May 26 at 44 cm with a discharge of 0.43 m^3/s. The lowest observed gauge height occurred on July 11 at 16 cm with a discharge of 0.06 m^3/s (Figure 40). This site during periods of low flow has approximately 1.0 m of dry streambed on the left bank making the stream narrower in low flow (Appendix A).

Discharge

Site 12 has an extremely low to almost no base flow. During periods of drought this stream section along with many others in Dry Run Creek become dry. This stream section shows the expected fluctuations in flow depending upon precipitation events and moisture conditions in the soil (Figure 41) (Appendix B). The headwaters are primarily fed by drain tiles on agricultural fields.

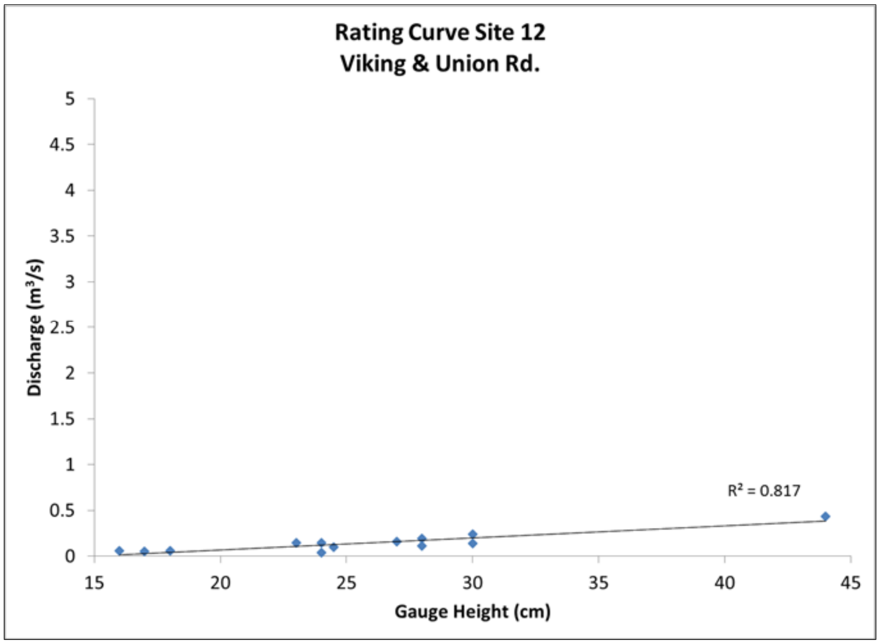

Figure 40: Site 12 Rating Curve.

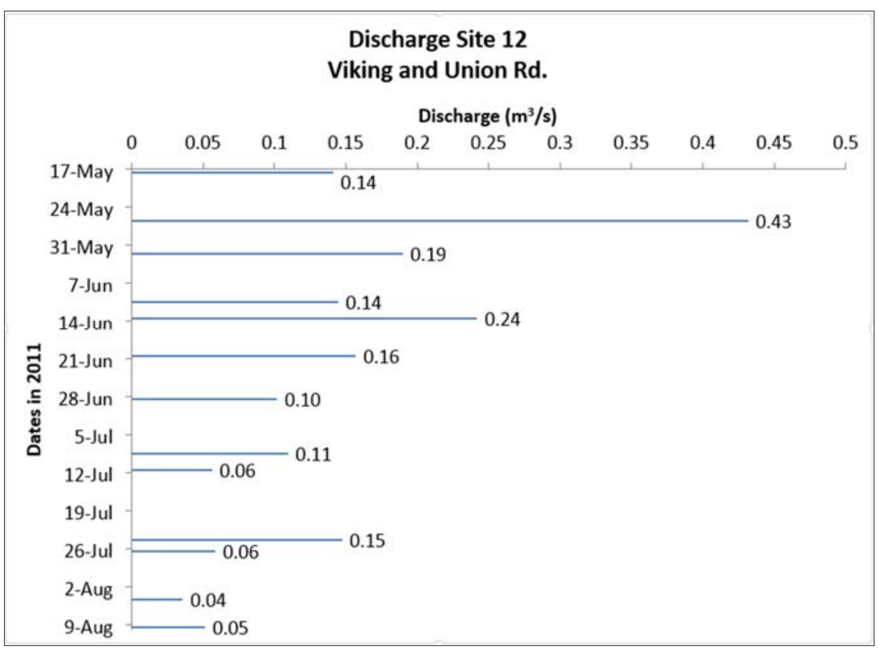

Figure 41: Site 12 Discharge.

Rating Curve Reliability

The rating curves at the various sites vary in reliability. Site 2, located along row crops, is prone to high fluctuations in silt deposits making the gauge unreliable for stream depth. Site 2 is not suitable for using its rating curve. Sites 3, 5, 6, and 12 are all vulnerable to damage in high flow conditions. The stream gauge at site 6, located upstream of the Cedar Falls dog park, was damaged and had to be replaced mid-study from floating debris during a high flow rain event. The instability of the gauges make these sites questionable for use in future studies. However, if a permanent gauge were installed at site 6, it could be useful as it represents the entire flow from the East branch of Dry Run Creek. Sites 1 and 7, located along Campus St. and near the campus wells respectively, have permanent gauges installed and will be excellent for future studies. Sites 4, 8, 10, and 11 all utilize existing structures in some way, making them all very useful for future studies. Site 11 may be the shortest lived of these 4 sites because it may have a change in siltation on the streambed after a major storm event. Sites 4 and 8 can be used long term if a more permanent gauge is installed. These 2 sites had the gauges painted onto the concrete structures and the paint is worn away during higher flow. Sites 4 and 10 are not going to change until their culverts are damaged or destroyed. Site 8 is perhaps the most important site because it is the site that represents the entire flow of Dry Run Creek and is located just before the confluence with the Cedar River. This site requires some work to obtain reliable flow readings during high flows but it has a very stable streambed and will be extremely useful in many future studies.

Nitrates

Nitrates are of concern because of drinking water quality and the health risks associated with high nitrate levels in untreated water. While the city of Cedar Falls doesn't pull drinking water from the stream, other cities downstream along the Cedar River do. Two segments of the Cedar River are considered impaired due to high nitrate levels by the Iowa DNR (Olson, 2010). Known sources for nitrate contamination are from the decay of organic materials, commercial fertilizers, human and animal waste, and the nitrification of ammonia (Lande, 2011).

Looking at nitrate loading instead of just concentration gives a better picture of what is happening in the stream because it incorporates discharge when comparing a site with a high nitrate concentration and a low discharge to a site with a lower nitrate concentration and a higher discharge, the total nitrates might not be directly correlated with concentration. In some watersheds baseflow seems to play an important role in nitrate loading. However, previous studies on Dry Run Creek have shown that there is no baseflow (Rai, 2011). Surface runoff is providing discharge and loading. Rainfall in rural sites show a direct correlation to loading because surface runoff delivers nitrate directly to the stream. In the urban sites precipitation has more of a diluting effect to the nitrate loading. There are no results on nitrate from site 7 because water samples were not taken there.

EPA standards for nitrate concentration for safe drinking water is 10 mg/l as NO_3^--N (Lande, 2011). Only site 1 and site 3 were consistently in compliance with these standards (Appendix C).

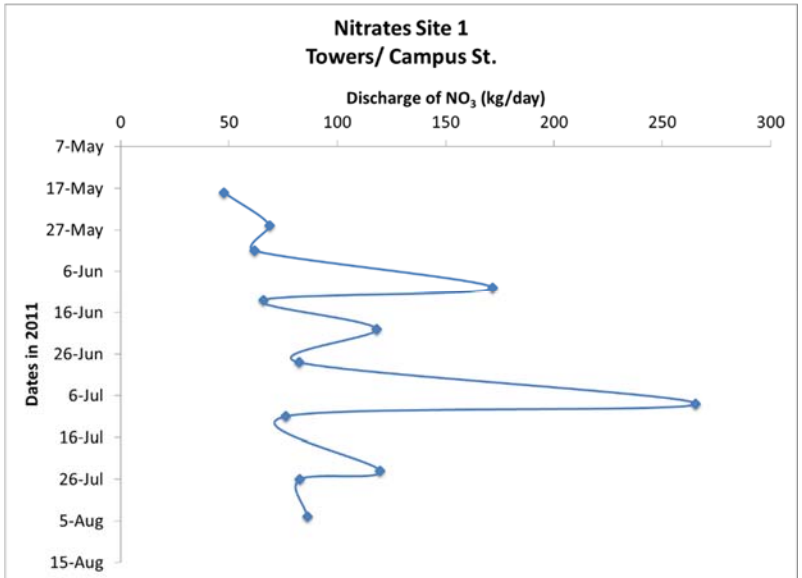

Figure 42: Site 1 nitrate discharges.

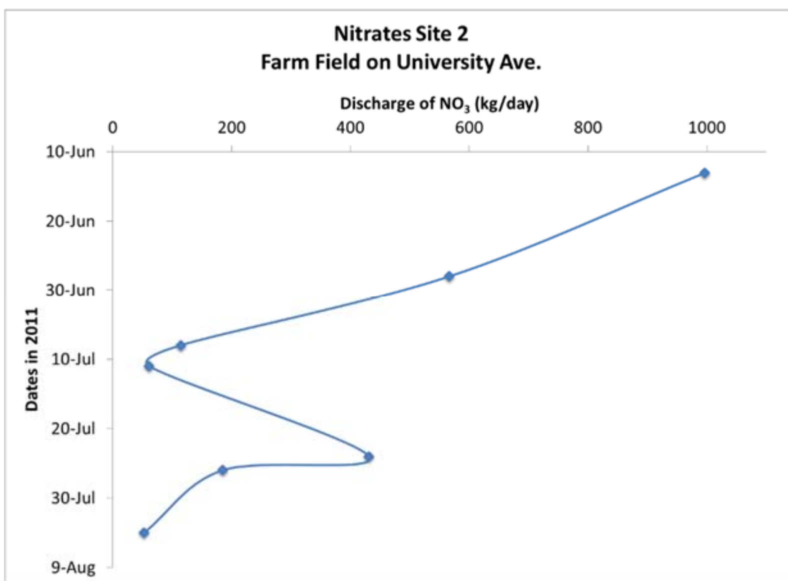

Figure 43: Site 2 nitrate discharges.

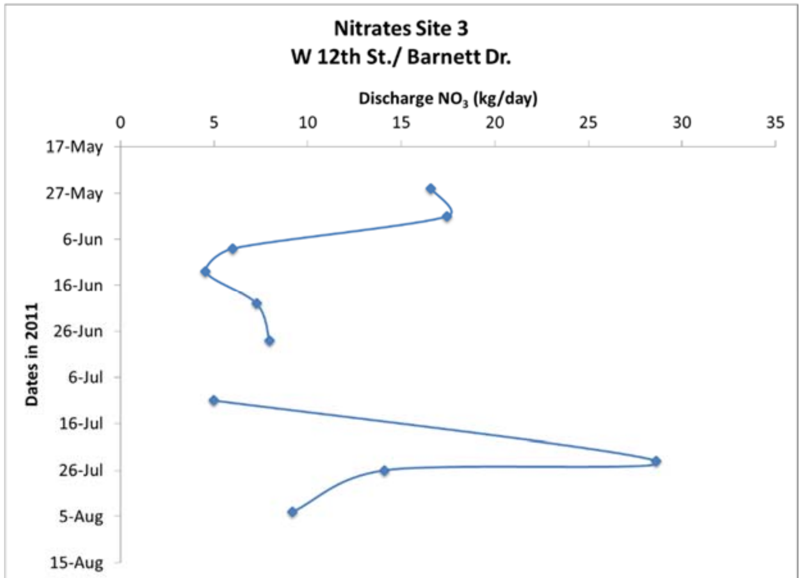

Figure 44: Site 3 nitrate discharges.

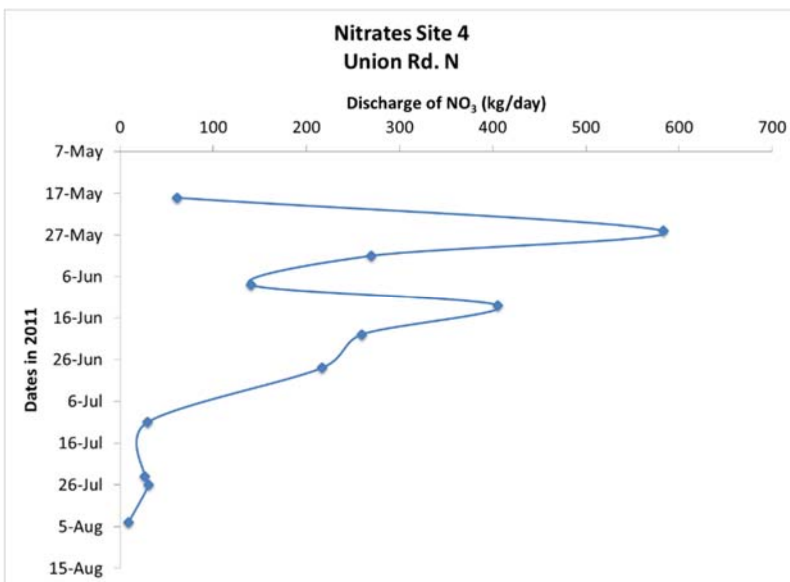

Figure 45: Site 4 nitrate discharges.

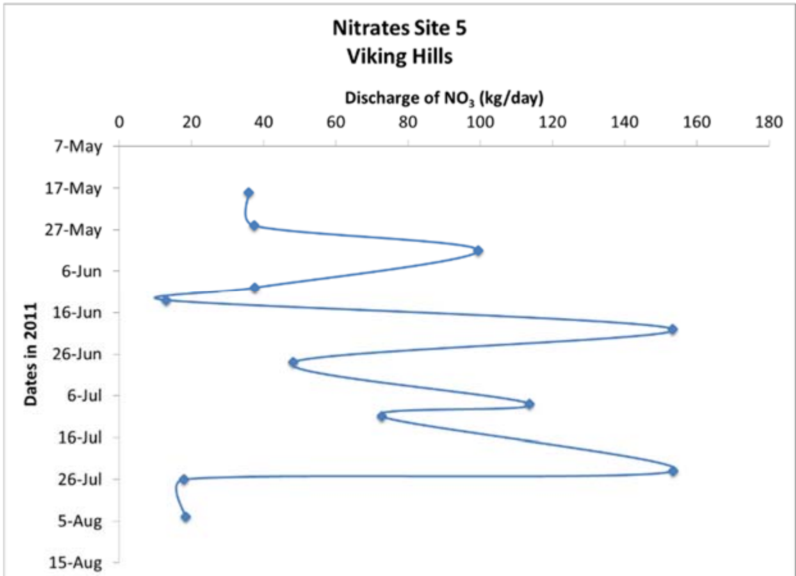

Figure 46: Site 5 nitrate discharges.

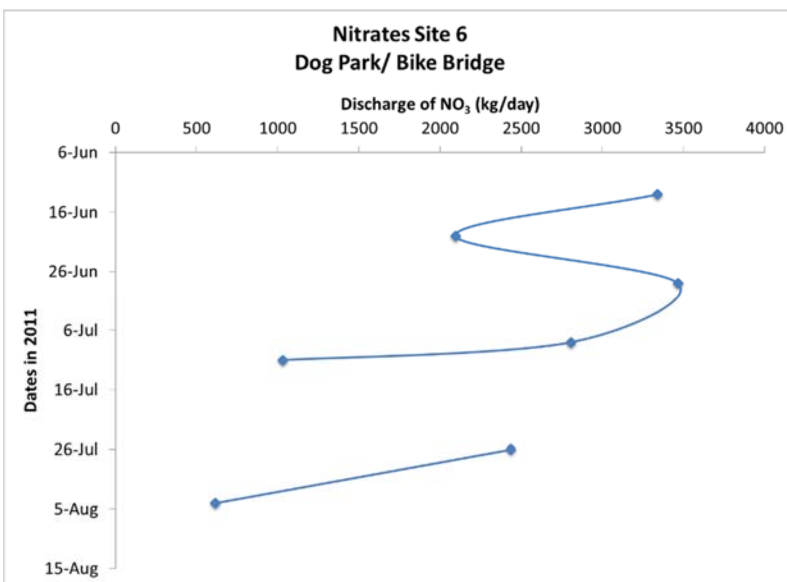

Figure 47: Site 6 nitrate discharges.

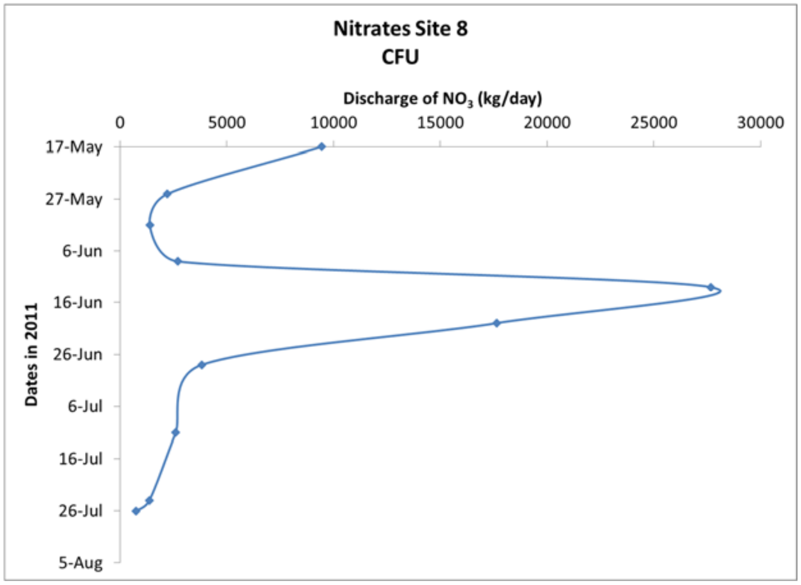

Figure 48: Site 8 nitrate discharges.

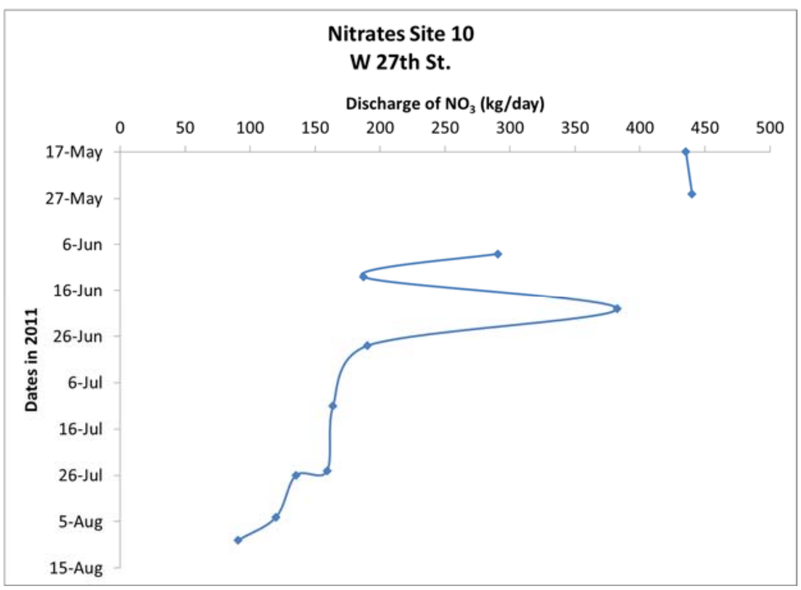

Figure 49: Site 10 nitrate discharges.

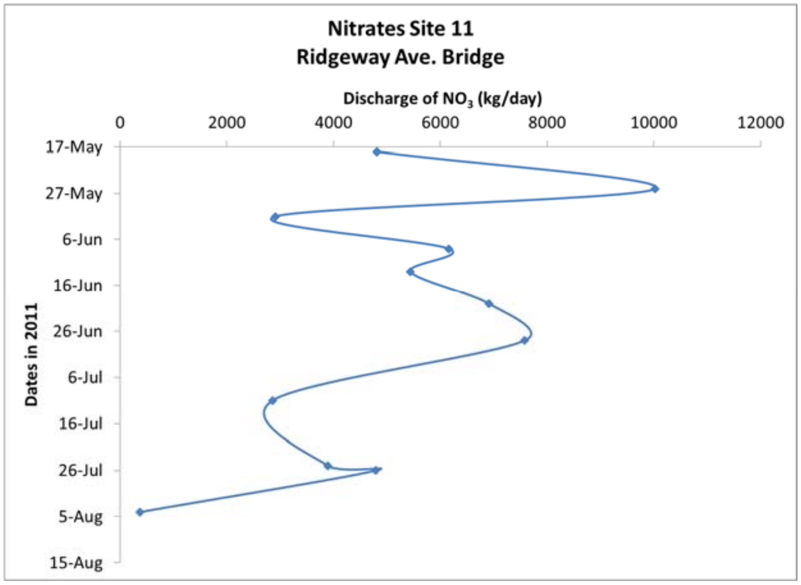

Figure 50: Site 11 nitrate discharges.

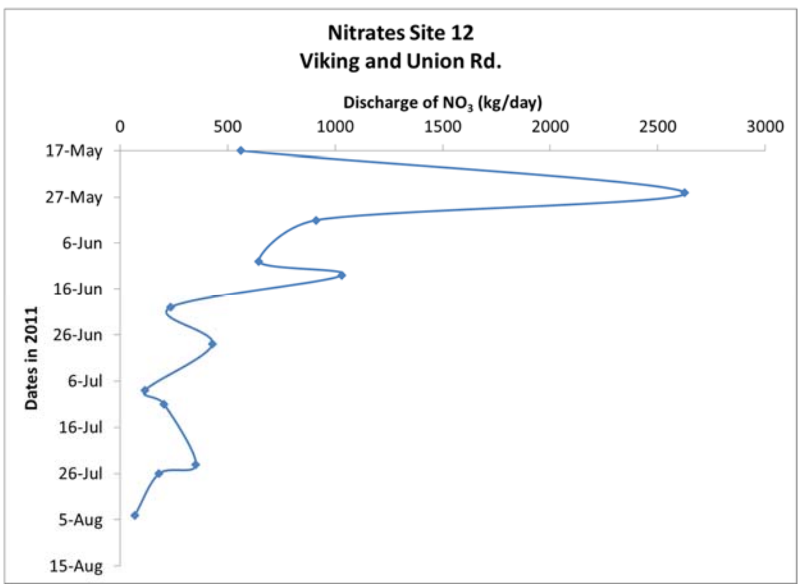

Figure 51: Site 12 nitrate discharges.

Sites 1, 3, 5, 6, and 8 are considered more urban locations and nitrates show different peaks in concentration compared to the more rural locations of sites 2, 4, 10, 11, and 12 (Figure 4). Sites 1, 3, and 5 all have peak nitrate discharges recorded on July 24, 2011 of 119.75 kg/day, 28.62 kg/day, and 153.55 kg/day respectively. Sites 5 and 8 also have peak nitrate discharges on June 20, 2011 of 153.35 kg/day and 27677.01 kg/day respectively. Site 5 peaks twice at basically the same discharge and Site 8 shows the highest discharge of all the sites because it represents the entire watershed. Sites 4, 10, 11, and 12 have their peak nitrate discharge on May 26, 2011 of 583.16 kg/day, 440.08 kg/day, 10024.48 kg/day, and 2625.96 kg/day respectively. Sites 2 and 6 have peak nitrate discharge on June 13, 2011 of 996.50 kg/day and 3339.80 kg/day respectively.

The urban locations show peak nitrate flow during mid-summer and the rural sites show peak flow in late spring to early summer (Figures 42-51). For all sites except site 1 and 3, the lowest nitrate discharges are in August when stream discharges are also the lowest. For sites 1 and 3, which are both urban sites, the lowest nitrate discharges are May 11 and June 13, respectively. Nitrate concentrations in the water are lowest in all the rural sites except site 10 in August as well. Site 10's headwaters are located in a residential neighborhood but then flow through row crop fields and the lowest nitrate concentration occurred in June, the same as the more urban sites. Sites 1, 3, and 5 have their lowest nitrate concentrations occurring in May and June. Site 8, which is considered an urban site but also represents the watershed as a whole, has both the lowest discharge and concentration of recorded nitrates in August when total stream flow is also the lowest.

An interesting observation that was made is that site 1 has a lower nitrate load, at times nearly half the amount, than site 10 which is located upstream of it. There is a constructed wetland in-between the two sites suggesting that the wetland is capturing nitrates. A future study could be performed to examine the extent of the constructed wetland's effectiveness.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

After collecting data and comparing methods of gauges, sites 4 and 8 seem to give the most precise depth measurements because both of these sites utilized existing structures (i.e. bridges). The morphology of these two sites remained the most constant throughout the summer. Sites 1 and 7 employed existing gauges and were the next two most stable sites. Site 2 was the most unstable site and is surrounded by agricultural fields and a minimal riparian zone. Next to this site is also a stream crossing that goes through the stream to access fields. Calculating discharge at this site was challenging due to the aggradations and erosion of the silts on the streambed. However, the rating curve for this site looks similar to other site's rating curves.

Rating curves are only valid for a few years. Instability resulting from sedimentation rates and bank erosion cause a shift in discharge which is characteristic of small streams. Future studies should consider this and rating curves should be reevaluated in 3 to 5 years. Another limitation to this method of evaluating nitrates is that data are only collected once per week. In small systems there can be dramatic variations in relation to rainfall and lines shown in loading graphs are not smooth. The lines are not truly representative of what is happening. More frequent sampling would be recommended in future studies.

One issue that arose with the installed gauges was that during a flash flood event debris twisted and bent a gauge. The posts utilized for the gauges may not be sturdy enough for long term use. The sites where the gauges were painted onto the concrete will require ongoing maintenance due to the flowing water wearing away the paint. Utilizing existing structures appears to be the most reliable and stable gauge sites. They tend to be concrete structures or steel culverts and the morphology at these sites won't change much over longer periods of time. Measuring from the bridge down is also a more stable method for measuring stream depth and is also easily accessed for reduced collection time.

Nitrate concentrations taken from the sites on a weekly basis are calculated into total amounts of N being discharged at the sites and of Dry Run Creek as a whole. Future studies may want to observe nitrates being discharged more frequently than once per week and possibly observe when farmers are making fertilizer applications onto the fields. This could aid in correlating any potential lag times to spikes in nitrate discharges in the streams or whether rain events dictate the nitrate discharge spikes.

The importance of finding low cost methods to develop rating curves is to provide an example of what other investigators can do in their studies of other small watersheds to assess nutrient loads being discharged. Streams in eastern Iowa are major contributors to the nutrients in the Mississippi River that is causing a large area of hypoxia in the Gulf of Mexico. Potentially, if more studies can be done on small watersheds to assess their nutrient loads, specific areas could be targeted to reduce the causes of nutrient loading.

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APPENDIX A

GAUGE AND VELOCITY DATA

Site 1

Date	Gauge Ht.	Gauge Ht.	Correction Factor	Corrected Gauge Ht.	Area	Velocity				Average Velocity	Discharge
					A	V1	V2	V3	V4	Avg V	Q
	ft	cm	cm	m	m^2	m/s	m/s	m/s	m/s	m/s	m^3/s
11-May	0.98	29.870	0	0.299	1.180						
18-May	0.98	29.870	0	0.299	1.180	0.27	0.32	0.21		0.267	0.315
26-May	1.06	32.309	0	0.323	1.306	0.28	0.45	0.26		0.330	0.431
1-Jun	1	30.480	0	0.305	1.211	0.29	0.35	0.19		0.277	0.335
10-Jun	1.1	33.528	0	0.335	1.368	0.21	0.42	0.41	0.24	0.320	0.438
13-Jun	1	30.480	0	0.305	1.211	0.35	0.28	0.14		0.257	0.311
20-Jun	1.08	32.918	0	0.329	1.337	0.3	0.41	0.22	0.13	0.265	0.354
28-Jun	1	30.480	0	0.305	1.211	0.33	0.43	0.1		0.287	0.347
8-Jul	1	30.480	0	0.305	1.211	0.36	0.35	0.3	0.13	0.285	0.345
11-Jul	1	30.480	0	0.305	1.211	0.35	0.35	0.11		0.270	0.327
24-Jul	1.2	36.576	0	0.366	1.525	0.38	0.43	0.13		0.313	0.478
26-Jul	1	30.480	0	0.305	1.211	0.31	0.35	0.13		0.263	0.319
4-Aug	1	30.480	0	0.305	1.211	0.28	0.45	0.22		0.317	0.384
9-Aug	1	30.480	0	0.305	1.211	0.25	0.35	0.18	0.03	0.260	0.315

Site 2

Date	Gauge Ht.	Correction factor	Corrected Gauge Ht.	Area	Velocity			Average Velocity	Discharge
				A	V1	V2	V3	Avg V	Q
	cm	cm	m	m^2	m/s	m/s	m/s	m/s	m^3/s
13-Jun	44.0	-4.0	0.400	1.656	0.180	0.160	0.100	0.147	0.243
28-Jun	44.0	-15.0	0.290	1.180	0.130	0.120	0.040	0.097	0.114
8-Jul	40.0	-11.5	0.285	1.158	0.100	0.060	0.010	0.057	0.066
11-Jul	41.0	-13.0	0.280	1.137	0.020	0.020	0.000	0.013	0.015
24-Jul	46.0	-14.0	0.320	1.310	0.100	0.140	0.130	0.123	0.162
26-Jul	42.0	-13.0	0.290	1.180	0.050	0.060	0.050	0.053	0.063
4-Aug	40.5	-14.0	0.265	1.072	0.020	0.030	0.020	0.023	0.025
9-Aug	42.0	-13.0	0.290	1.180	0.020	0.070	0.080	0.057	0.067

Site 3

Date	Gauge Ht.	Correction factor	Corrected Gauge Ht.	Area	Velocity			Average Velocity	Discharge
				A	V1	V2	V3	Avg V	Q
	cm	cm	m	m^2	m/s	m/s	m/s	m/s	m^3/s
11-May	26	-1	0.25	0.82					
26-May	29	-1	0.28	0.727	0	0.18	0	0.060	0.044
1-Jun	25	-1	0.24	0.851	0	0.07	0.01	0.027	0.023
8-Jun	24.5	-1	0.235	0.8665	0	0.03	0	0.010	0.009
13-Jun	25	-1	0.24	0.851	0	0.06	0	0.020	0.017
20-Jun	26	-1	0.25	0.82	0	0.08	0	0.027	0.022
28-Jun	25	-1	0.24	0.851	0	0.06	0	0.020	0.017
11-Jul	24	-1	0.23	0.882	0	0.04	0	0.013	0.012
24-Jul	30	-1	0.29	0.696	0	0.13	0.15	0.093	0.065
26-Jul	25.5	-1	0.245	0.8355	0	0.08	0.013	0.031	0.026
4-Aug	25	-1	0.24	0.851	0.026			0.026	0.022
9-Aug	25	-1	0.24	0.851	0	0.01	0.02	0.010	0.009

Site 4

Date	Gauge Ht.	Correction Factor	Corrected Gauge Ht.	Area	Velocity				Average Velocity	Discharge
				A	V1	V2	V3	V4	Avg V	Q
	cm	cm	m	m	m^2	m/s	m/s	m/s	m/s	m^3/s
18-May	6.5	0	0.065	0.196	0.21	0.22	0.35		0.213	0.042
26-May	12	0	0.12	0.362	0.69	0.47	0.55		0.617	0.223
1-Jun	8.5	0	0.085	0.257	0.4	0.19	0.4		0.330	0.085
8-Jun	7	0	0.07	0.211	0.13	0.22	0.27		0.160	0.034
13-Jun	8.5	0	0.085	0.257	0.62	0.4	0.46		0.547	0.140
20-Jun	6	0	0.06	0.181	0.16	0.34	0.1	0.4	0.353	0.064
28-Jun	6	0	0.06	0.181	0.32	0.25	0.34		0.297	0.054
11-Jul	4.5	0	0.045	0.136	0.07	0.08	0.03		0.073	0.010
24-Jul	5.5	0	0.055	0.166	0.08	0.12	0.2		0.093	0.016
26-Jul	5	0	0.05	0.151	0.09	0.1	0.14		0.093	0.014
4-Aug	2.5	0	0.025	0.076	0.07	0.12	0.15		0.087	0.007
9-Aug	1	0	0.01	0.030	0.02	0.02	0.02		0.020	0.001

Site 5

Date	Gauge Ht.	Correction factor	Corrected Gauge Ht.	Area	Velocity			Average Velocity	Discharge
				A	V1	V2	V3	Avg V	Q
	cm	cm	m	m^2	m/s	m/s	m/s	m/s	m^3/s
11-May	14	-3	0.11	0.993	0				
18-May	15	-3	0.12	0.950	0	0.07	0.06	0.043	0.041
26-May	20	-3	0.17	0.736	0.12	0.32	0.21	0.217	0.159
1-Jun	14.5	-3	0.115	0.972	0	0.07	0.1	0.057	0.055
10-Jun	23	-3	0.2	0.607	0.4	0.57	0.1	0.357	0.216
13-Jun	16	-3	0.13	0.907	0	0.14	0.09	0.077	0.070
20-Jun	15.5	-3	0.125	0.929	0.012	0.21	0.14	0.121	0.112
28-Jun	11	-3	0.08	1.122	0	0.01	0.07	0.027	0.030
8-Jul	11	-3	0.08	1.122	0	0.09	0	0.030	0.034
11-Jul	10	-3	0.07	1.165	0	0.1	0	0.033	0.039
24-Jul	19	-3	0.16	0.779	0.1	0.32	0.22	0.213	0.166
26-Jul	13	-3	0.1	1.036	0.01	0.04	0.1	0.050	0.052
4-Aug	12	-3	0.09	1.079	0.04	0.08	0.04	0.053	0.058
9-Aug	14.5	-3	0.115	0.972	0.04	0.13	0.1	0.090	0.087

Site 6

Date	Gauge Ht.	Correction factor	Corrected Gauge Ht.	Area	Velocity				Average Velocity	Discharge
				A	V1	V2	V3	V4	Avg V	Q
	cm	cm	m	m^2	m/s	m/s	m/s	m/s	m/s	m^3/s
12-May	24	2	0.26	2.3						
18-May	24	2	0.26	2.3	0.46	0.62	0.15		0.410	0.943
26-May	59	2	0.61	2.65	0.73	0.83	0.63		0.730	1.935
1-Jun	34	2	0.36	2.4	0.52	0.55	0.3	0	0.343	0.822
8-Jun	29	2	0.31	2.35	0.3	0.2	0.15		0.217	0.509
13-Jun	40	2	0.42	2.46	0.5	0.6	0.45	0	0.388	0.953
20-Jun	38	2	0.4	2.44	0.04	0.36	0.52	0.41	0.333	0.811
28-Jun	33	2	0.35	2.39	0.43	0.51	0.15		0.363	0.868
8-Jul	29	2	0.31	2.35	0.34	0.24	0.13		0.237	0.556
11-Jul	28	2	0.3	2.34	0.15	0.2	0.17		0.173	0.406
25-Jul	12.5	0	0.125	2.165	0.73	0.34	0.73		0.600	1.299
26-Jul	26.5	0	0.265	2.305	0.37	0.4	0.23	-	0.333	0.768
4-Aug	17.5	0	0.175	2.215	0.2	0.18	0.09		0.157	0.347
9-Aug	25	-1	0.24	2.28	0.38	0.44	0.23	0	0.263	0.599

Site 7

Date	Gauge Ht.	Correction factor	Corrected Gauge Ht.	Gauge Ht.	Area	Velocity				Average Velocity	Discharge
					A	V1	V2	V3	V4	Avg V	Q
	ft	ft	ft	m	m^2	m/s	m/s	m/s	m/s	m/s	m^3/s
18-May	1.26	0.23	1.49	0.454	1.640	0.28	0.29	0.32	0.06	0.238	0.390
26-May	1.96	0.23	2.19	0.668	3.368	0.28	0.28	0.4	0.12	0.270	0.909
1-Jun	1.24	0.23	1.47	0.448	1.591	0.27	0.28	0.31	0.07	0.233	0.370
10-Jun	2.14	0.23	2.37	0.722	3.813	0.21	0.28	0.5	0.16	0.288	1.096
13-Jun	1.4	0.23	1.63	0.497	1.986	0.16	0.35	0.31	0.14	0.240	0.477
20-Jun	1.14	0.23	1.37	0.418	1.344	0.06	0.42	0.4	0.08	0.240	0.322
28-Jun	0.94	0.23	1.17	0.357	0.963	0.23	0.5	0.15		0.220	0.212
8-Jul	0.58	0.23	0.81	0.247	0.277	-	0.46	0.6	0.43	0.497	0.138
11-Jul	0.52	0.23	0.75	0.229	0.163	-	0.35	0.6	0.46	0.470	0.076
24-Jul	0.94	0.23	1.17	0.357	0.963	0.17	0.36	0.4	0.18	0.278	0.267
26-Jul	0.66	0.23	0.89	0.271	0.429	0.27	0.47	0.47	0.15	0.340	0.146
4-Aug	0.36	0.23	0.59	0.180	0.360	0.46	0.53	0.46		0.483	0.174
9-Aug	0.44	0.23	0.67	0.204	0.488	0.42	0.48	0.38		0.427	0.208

Site 8

Date	Gauge Ht.	Correction factor	Corrected Gauge Ht.	Area	Velocity				Average Velocity	Discharge	Comments
				A	V1	V2	V3	V4	Avg V	Q	
	cm	cm	m	m^2	m/s	m/s	m/s	m/s	m/s	m^3/s	
12-May	2.5	0	0.025	2.463							
17-May	3	0	0.03	2.543	0.45	0.85	0.59		0.630	1.602	
26-May	28	0	0.28	6.543	0.3	0.84	0.84	0.34	0.580	3.795	*no measurement from center.
1-Jun	2.5	0	0.025	2.463	0.42	0.6	0.58		0.533	1.314	
8-Jun	1.5	0	0.015	2.303	0.38	0.53	0.68	0.32	0.478	1.100	
13-Jun	5	0	0.05	2.863	0.43	0.66	0.71	0.59	0.598	1.711	
20-Jun	38	0	0.38	8.143	0.15	0.96	0.96	0.18	0.563	4.581	*no measurement from center.
28-Jun	27.5	0	0.275	6.463	0.16	0.84	0.84	0.12	0.490	3.167	*no measurement from center.
11-Jul	1	0	0.01	2.223	0.55	0.5	0.75	0.46	0.565	1.256	
24-Jul	10	0	0.1	3.663	0.7	1.04	0.84	0.68	0.815	2.986	
26-Jul	1.5	0	0.015	2.303	0.39	0.64	0.69	0.41	0.533	1.226	
4-Aug	0	0	0	2.063	0.3	0.45	0.66	0.5	0.478	0.985	**3.5m dry on right bank
9-Aug	1	0	0.01	2.223	0.44	0.51	0.6	0.42	0.493	1.095	

Site 10

Date	Gauge Ht.	Correction factor	Corrected Gauge Ht.	Area	Velocity			Average Velovity	Discharge
				A	V1	V2	V3	Avg V	Q
	cm	cm	m	m^2	m/s	m/s	m/s	m/s	m^3/s
11-May	9.5	0	0.095	0.30					
17-May	18	0	0.18	0.39	0.84	0.88	0.88	0.867	0.341
26-May	19	0	0.19	0.40	0.84	0.8	0.82	0.820	0.332
1-Jun	9	0	0.09	0.29	0.44	0.47	0.41	0.440	0.130
8-Jun	12	0	0.12	0.33	0.78	0.46	0.58	0.607	0.199
13-Jun	16.5	0	0.165	0.38	0.62	0.81	0.8	0.805	0.303
20-Jun	14	0	0.14	0.35	0.81	0.8	0.65	0.753	0.263
28-Jun	13	0	0.13	0.34	0.52	0.5	0.51	0.510	0.173
11-Jul	12.5	0	0.125	0.33	0.42	0.47	0.45	0.447	0.149
25-Jul	12.5	0	0.125	0.33	0.73	0.34	0.65	0.573	0.191
26-Jul	13	0	0.13	0.34	0.43	0.5	0.43	0.453	0.153
4-Aug	9	0	0.09	0.29	0.43	0.48	0.4	0.437	0.129
9-Aug	9.5	0	0.095	0.30	0.37	0.48	0.44	0.430	0.129

Site 11

Date	Gauge Ht.	Gauge Ht.	Correction factor	Corrected Gauge Ht.	Area	Velocity				Average Velocity	Discharge	Comments
					A	V1	V2	V3	V4	Avg V	Q	
	ft	cm	cm	m	m^2	m/s	m/s	m/s	m/s	m/s	m^3/s	
18-May	-10.73	-327.05	346	0.19	2.52	0.13	0.51	0.49	0.27	0.350	0.883	10.78 ft to stream bottom from bridge railing
26-May	-10	-304.8	346	0.41	4.58	0.1	0.31	0.6	0.56	0.393	1.796	
1-Jun	-10.76	-327.965	346	0.18	2.44	0	0.33	0.3	0.1	0.183	0.445	
8-Jun	-10.75	-327.66	346	0.18	2.47	0	0.38	0.51	0.24	0.283	0.697	
13-Jun	-10.52	-320.65	346	0.25	3.11	0.18	0.46	0.55	0.33	0.380	1.183	
20-Jun	-10.45	-318.516	346	0.27	3.31	0.06	0.24	0.34	0.31	0.238	0.786	
28-Jun	-10.5	-320.04	346	0.26	3.17	0.28	0.41	0.36	0.13	0.295	0.935	
11-Jul	-10.655	-324.764	346	0.21	2.73	0.09	0.35	0.1	0.01	0.138	0.376	
25-Jul	-10.45	-318.516	346	0.27	3.31	0.13	0.47	0.47	0.17	0.310	1.026	
26-Jul	-10.55	-321.564	346	0.24	3.03	0.09	0.36	0.43	0.14	0.255	0.773	
4-Aug	-10.78	-328.574	346	0.17	0.66	0	0.25	-	-	0.125	0.083	**3m dry from right bank**
9-Aug	-10.58	-322.478	346	0.24	1.22	0.07	0.32	0.35	0.09	0.208	0.254	

Site 12

Date	Gauge Ht.	Correction factor	Corrected Gauge Ht.	Area	Velocity				Average Velocity	Discharge	Comments
				A	V1	V2	V3	V4	Avg V	Q	
	cm	cm	m	m^2	m/s	m/s	m/s	m/s	m/s	m^3/s	
11-May	20	-6	0.14	0.32							
17-May	30	-6	0.24	0.61	0.13	0.29	0.28		0.233	0.141	
26-May	44	-6	0.38	1.00	0.42	0.51	0.36		0.430	0.432	
1-Jun	28	-6	0.22	0.55	0.33	0.4	0.31		0.347	0.190	
10-Jun	24	-6	0.18	0.43	0.2	0.45	0.35		0.333	0.145	
13-Jun	30	-6	0.24	0.61	0.45	0.5	0.25		0.400	0.242	
20-Jun	27	-6	0.21	0.52	0.29	0.31	0.43	0.18	0.303	0.157	
28-Jun	24.5	-6	0.185	0.45	0.2	0.42	0.29	0	0.228	0.102	
8-Jul	28	-6	0.22	0.55	0	0.38	0.22		0.200	0.110	
11-Jul	16	-6	0.1	0.21	-	0.44	0.38	0	0.273	0.056	
24-Jul	23	-6	0.17	0.41	0.2	0.51	0.38		0.363	0.147	
26-Jul	18	-6	0.12	0.26	-	0.21	0.46		0.223	0.059	
4-Aug	24	-15.5	0.085	0.16	-	0.28	0.16		0.220	0.036	**1m dry on left bank
9-Aug	17	-6	0.11	0.23	0.33	0.32	0.01		0.220	0.052	**1m dry on left bank

APPENDIX B

NITRATES

Site 1

Date	Discharge	Chloride	Nitrate	Sulfate	Nitrate Discharge	Nitrate Discharge
	Q					QN
	m^3/s	mg/L	mg/L	mg/L	mg/s	kg/day
18-May	0.315	9.352	1.756	12.870	552.555	47.741
26-May	0.431	10.196	1.848	18.118	796.323	68.802
1-Jun	0.335	9.707	2.130	16.610	714.009	61.690
10-Jun	0.438	12.640	4.536	17.433	1986.343	171.620
13-Jun	0.311	15.001	2.453	14.965	762.605	65.889
20-Jun	0.354	11.423	3.862	19.227	1368.333	118.224
28-Jun	0.347	9.871	2.746	19.735	953.420	82.375
8-Jul	0.345		8.900		3072.702	265.481
11-Jul	0.327		2.700		883.107	76.300
24-Jul	0.478		2.900		1386.024	119.752
26-Jul	0.319		3.000		957.002	82.685
4-Aug	0.384		2.600		997.381	86.174

Site 2

Date	Discharge	Chloride	Nitrate	Sulfate	Nitrate Discharge	Nitrate Discharge
	Q					QN
	m^3/s	mg/L	mg/L	mg/L	mg/s	kg/day
13-Jun	0.243	13.323	48.058	7.863	11533.992	996.537
28-Jun	0.114	19.867	59.582	13.924	6554.031	566.268
8-Jul	0.066		18.900		1323	114.307
11-Jul	0.015		47.100		706.5	61.042
24-Jul	0.162		31.200		4992	431.309
26-Jul	0.063		35.600		2136	184.550
4-Aug	0.025		24.300		607.5	52.488

Site 3

Date	Discharge	Chloride	Nitrate	Sulfate	Nitrate Discharge	Nitrate Discharge
	Q					QN
	m^3/s	mg/L	mg/L	mg/L	mg/s	kg/day
11-May						
26-May	0.044		4.4		191.928	16.583
1-Jun	0.023		8.9		201.971	17.450
8-Jun	0.009		8		69.320	5.989
13-Jun	0.017	13.044	3.092	14.664	52.619	4.546
20-Jun	0.022	22.747	3.847	18.848	84.121	7.268
28-Jun	0.017	32.163	5.405	23.749	91.995	7.948
11-Jul	0.012		4.9		57.624	4.979
24-Jul	0.065		5.1		331.296	28.624
26-Jul	0.026		6.3		163.173	14.098
4-Aug	0.022		4.8		106.205	9.176

Site 4

Date	Discharge	Chloride	Nitrate	Sulfate	Nitrate Discharge	Nitrate Discharge
	Q					Q N
	m^3/s	mg/L	mg/L	mg/L	mg/s	kg/day
18-May	0.042	8.990	16.892	5.635	707.371	61.117
26-May	0.223	18.172	30.202	12.589	6749.588	583.164
1-Jun	0.085	15.151	36.820	11.199	3119.017	269.483
8-Jun	0.034	15.638	48.124	10.112	1627.750	140.638
13-Jun	0.140	15.789	33.459	10.387	4695.307	405.675
20-Jun	0.064	17.066	46.894	11.699	3002.309	259.400
28-Jun	0.054	19.883	46.639	13.941	2507.099	216.613
11-Jul	0.010		34.200		340.837	29.448
24-Jul	0.016		19.800		306.953	26.521
26-Jul	0.014		25.100		353.743	30.563
4-Aug	0.007		15.900		104.039	8.989

Site 5

Date	Discharge	Chloride	Nitrate	Sulfate	Nitrate Discharge	Nitrate Discharge
	Q					QN
	m^3/s	mg/L	mg/L	mg/L	mg/s	kg/day
11-May						
18-May	0.041	75.032	10.066	23.329	414.497	35.813
26-May	0.159	120.164	2.713	24.683	432.394	37.359
1-Jun	0.055	45.280	20.903	18.425	1151.029	99.449
10-Jun	0.216	82.383	2.011	16.294	435.210	37.602
13-Jun	0.070	38.515	2.148	13.248	149.428	12.911
20-Jun	0.112	38.468	15.836	13.681	1774.877	153.349
28-Jun	0.030	39.335	18.612	16.582	556.854	48.112
8-Jul	0.034		39.100		1316.094	113.711
11-Jul	0.039		21.700		842.625	72.803
24-Jul	0.166		10.700		1777.170	153.547
26-Jul	0.052		4.000		207.226	17.904
4-Aug	0.058		3.700		212.935	18.398

Site 6

Date	Discharge	Chloride	Nitrate	Sulfate	Nitrate Discharge	Nitrate Discharge
	Q					QN
	m^3/s	mg/L	mg/L	mg/L	mg/s	kg/day
18-May	0.943					
26-May	1.935					
1-Jun	0.822					
8-Jun	0.509					
13-Jun	0.953	34.548	40.551	11.655	38655.050	3339.796
20-Jun	0.811	27.043	29.887	13.985	24247.648	2094.997
28-Jun	0.868	25.234	46.187	23.333	40107.425	3465.282
8-Jul	0.556		58.400		32480.133	2806.284
11-Jul	0.406		29.400		11924.640	1030.289
25-Jul	1.299					
26-Jul	0.768		36.700		28197.833	2436.293
4-Aug	0.347		20.500		7113.842	614.636

Site 8

Date	Discharge	Chloride	Nitrate	Sulfate	Nitrate Discharge	Nitrate Discharge
	Q					QN
	m^3/s	mg/L	mg/L	mg/L	mg/s	kg/day
17-May	1.602		16.400		26276.342	2270.276
26-May	3.795		28.800		109297.613	9443.314
1-Jun	1.314		19.500		25617.280	2213.333
8-Jun	1.100		14.600		16056.759	1387.304
13-Jun	1.711	34.172	18.330	16.482	31358.781	2709.399
20-Jun	4.581	41.304	69.934	17.726	320335.726	27677.007
28-Jun	3.167	53.530	64.462	20.518	204150.041	17638.564
11-Jul	1.256		35.300		44340.612	3831.029
24-Jul	2.986		10.100		30153.631	2605.274
26-Jul	1.226		12.900		15821.257	1366.957
4-Aug	0.985		8.900		8768.084	757.562

Site 10

Date	Discharge	Chloride	Nitrate	Sulfate	Nitrate Discharge	Nitrate Discharge
	Q					QN
	m^3/s	mg/L	mg/L	mg/L	mg/s	kg/day
17-May	0.341	24.312	14.776	23.823	5039.143	435.382
26-May	0.332	19.153	15.356	18.670	5093.498	440.078
1-Jun	0.130					
8-Jun	0.199	21.896	16.921	22.951	3361.980	290.475
13-Jun	0.303	7.933	7.136	4.998	2165.730	187.119
20-Jun	0.263	20.765	16.803	21.273	4423.957	382.230
28-Jun	0.173	14.403	12.763	12.848	2203.323	190.367
11-Jul	0.149	19.819	12.752	22.751	1896.703	163.875
25-Jul	0.191	18.094	9.652	21.926	1842.760	159.214
26-Jul	0.153	18.390	10.196	23.038	1564.656	135.186
4-Aug	0.129	19.534	10.799	25.446	1388.708	119.984
9-Aug	0.129	20.924	8.141	24.930	1050.189	90.736

Site 11

Date	Discharge	Chloride	Nitrate	Sulfate	Nitrate Discharge	Nitrate Discharge
	Q					QN
	m^3/s	mg/L	mg/L	mg/L	mg/s	kg/day
18-May	0.883	27.882	63.089	14.546	55711.626	4813.485
26-May	1.796	28.172	64.588	15.021	116024.122	10024.484
1-Jun	0.445	24.992	75.602	14.028	33647.108	2907.110
8-Jun	0.697	20.021	102.352	12.445	71325.899	6162.558
13-Jun	1.183	26.097	53.232	10.676	62986.938	5442.071
20-Jun	0.786	24.635	101.704	14.509	79970.576	6909.458
28-Jun	0.935	28.269	93.815	15.797	87734.086	7580.225
11-Jul	0.376		87.900		33044.362	2855.033
25-Jul	1.026		43.900		45056.312	3892.865
26-Jul	0.773		71.800		55466.068	4792.268
4-Aug	0.083		52.700		4347.750	375.646

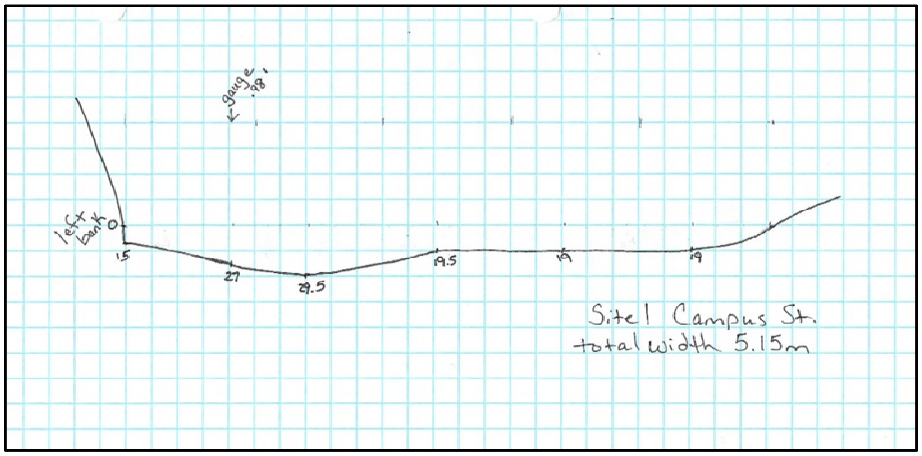
Site 12

Date	Discharge	Chloride	Nitrate	Sulfate	Nitrate Discharge	Nitrate Discharge
	Q					QN
	m^3/s	mg/L	mg/L	mg/L	mg/s	kg/day
17-May	0.141		46.100		6507.783	562.272
26-May	0.432		70.400		30393.088	2625.963
1-Jun	0.190		55.600		10562.517	912.601
10-Jun	0.145		51.600		7464.800	644.959
13-Jun	0.242	12.882	49.325	6.297	11936.553	1031.318
20-Jun	0.157	5.221	17.255	1.465	2711.633	234.285
28-Jun	0.102	15.372	48.757	9.980	4972.076	429.587
8-Jul	0.110		12.300		1348.080	116.474
11-Jul	0.056		42.100		2370.511	204.812
24-Jul	0.147		27.700		4081.087	352.606
26-Jul	0.059		35.700		2096.899	181.172
4-Aug	0.036		22.100		793.722	68.578

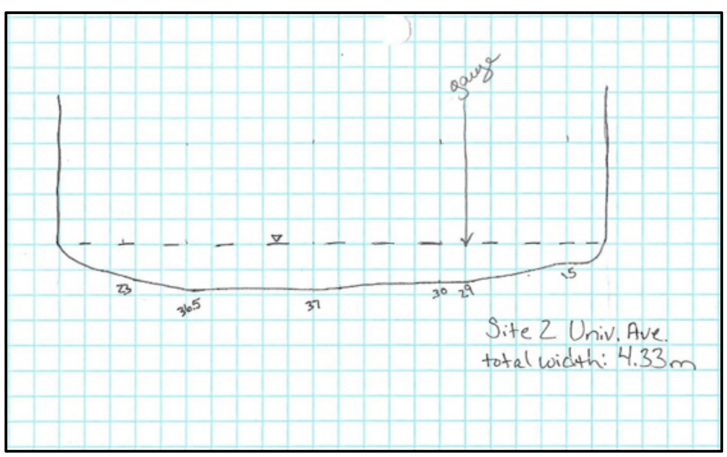
APPENDIX C

STREAMBED PROFILES

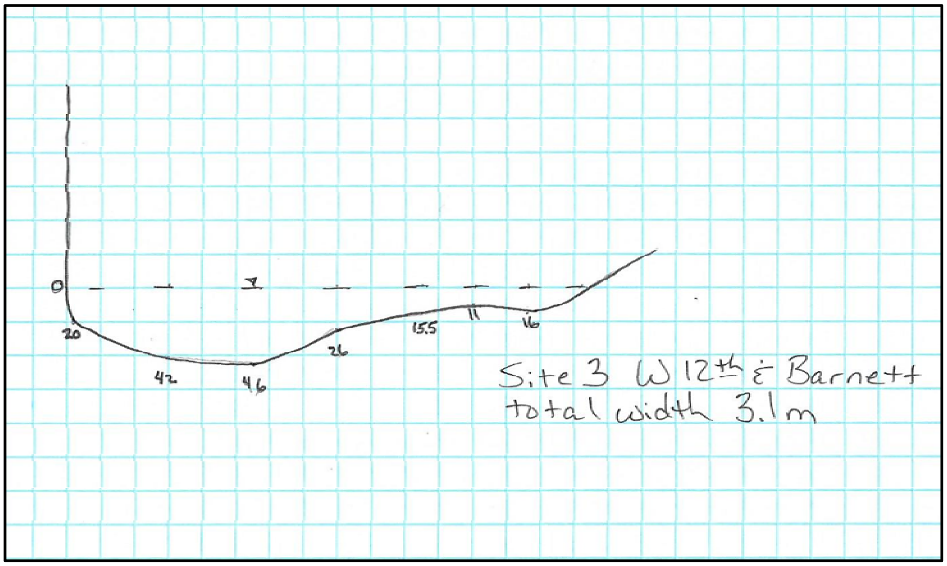
Site 1



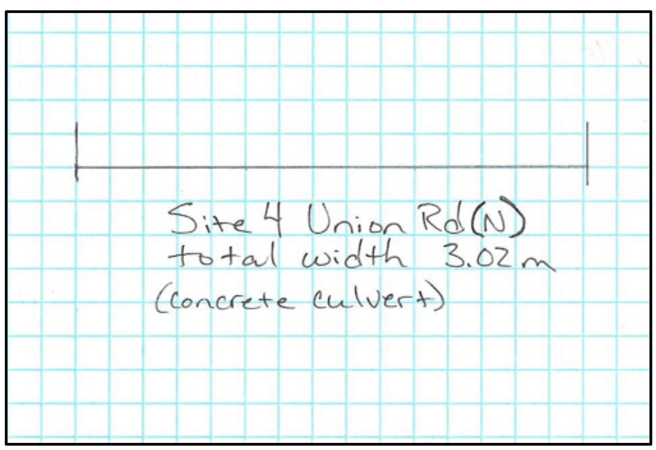
Site 2



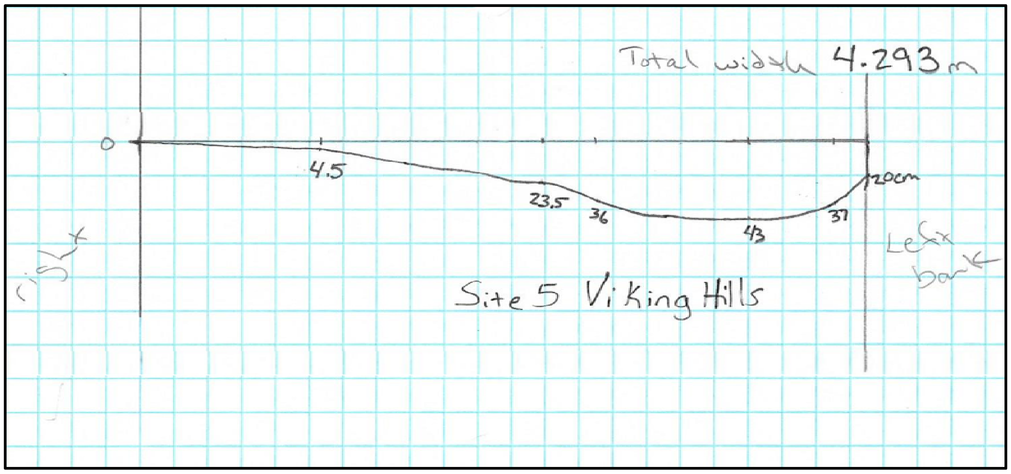
Site 3


0
20
42
46
26
15.5
11
16
Site 3 W 12th & Barnett
total width 3.1m

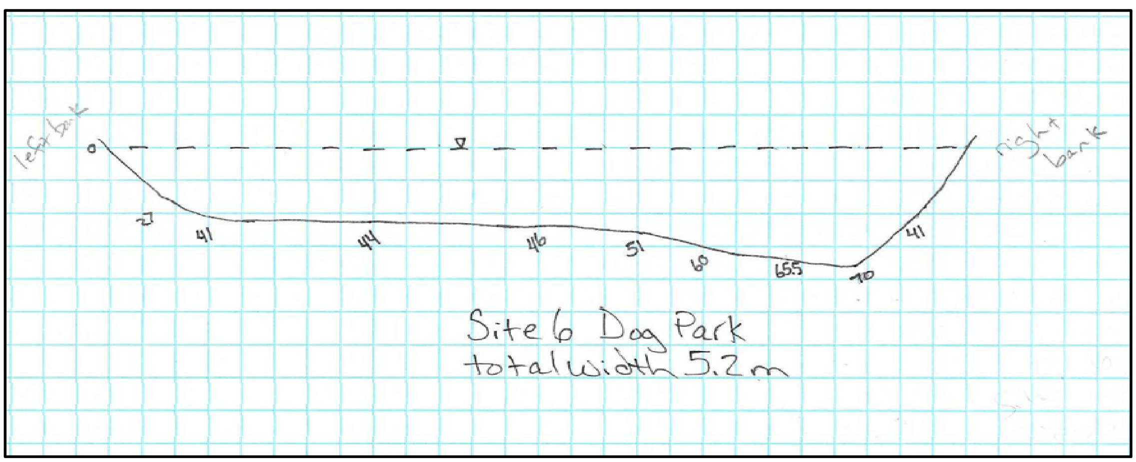
Site 4


Site 4 Union Rd (N)
total width 3.02 m
(concrete culvert)

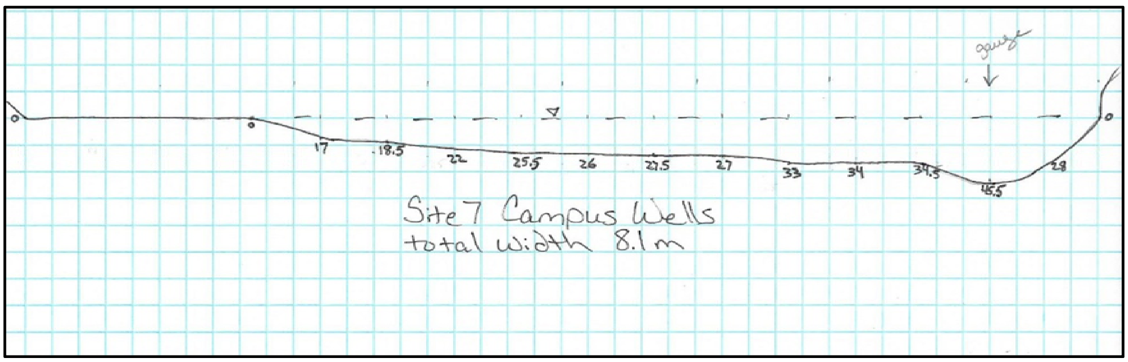
Site 5


Total width 4.293m
0
4.5
23.5
36
43
37
20cm
right
Left bank
Site 5 Viking Hills

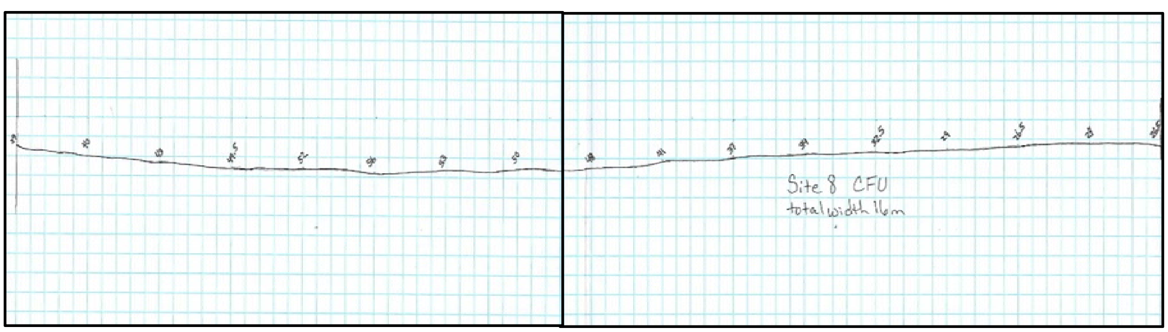
Site 6


left bank
0
27
41
44
46
51
60
65.5
70
41
right bank
Site 6 Dog Park
total width 5.2m

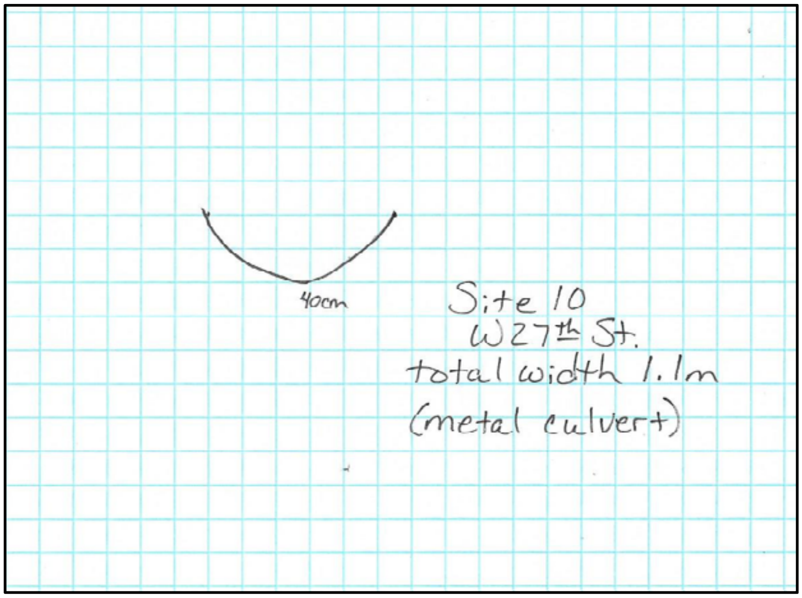
Site 7


gauge
0
0
17
18.5
22
25.5
26
27.5
27
33
34
34.5
45.5
28
0
Site 7 Campus Wells
total width 8.1m

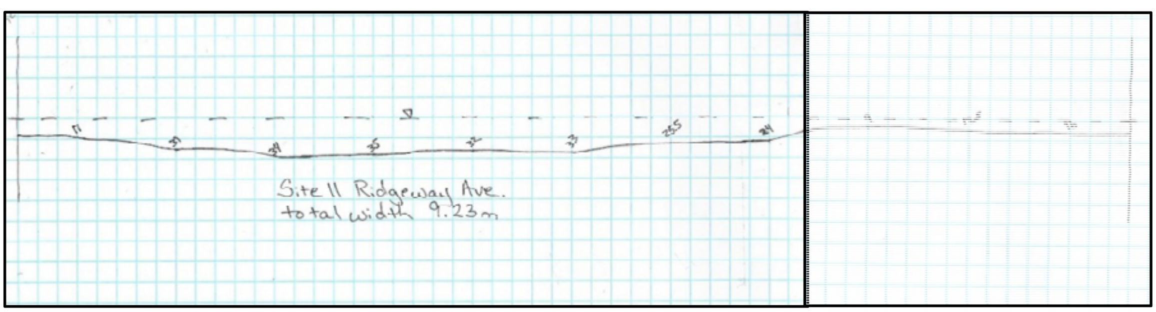
Site 8


Site 8 CFU
total width 16m

Site 10



Site 11



Site 12