January 2014

# Removal Efficiency Of Water Quality Pollutants In A Wet Detention Basin In Grand Forks, ND

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REMOVAL EFFICIENCY OF WATER QUALITY POLLUTANTS IN A WET DETENTION BASIN IN GRAND FORKS, ND

by

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Bachelor of Science, University of North Dakota, 2013

A Thesis

Submitted to the Graduate Faculty

of the

University of North Dakota

in partial fulfillment of the requirements

for the degree of

Master of Science

Grand Forks, North Dakota
December
2014

This thesis, submitted by Abbie M. Beaudry in partial fulfillment of the requirements for the Degree of Master of Science from the University of North Dakota, has been read by the Faculty Advisor Committee under whom the work has been done and is hereby approved.

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Date

PERMISSION

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|---|---|
| Title | Removal Efficiency of Water Quality Pollutants in a Wet Detention Basin in Grand Forks, ND |
| Department | Civil Engineering |
| Degree | Master of Science |

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Abbie M. Beaudry
11/20/2014

TABLE OF CONTENTS

LIST OF FIGURES

## LIST OF TABLES

Table Page

## LIST OF ACRONYMS

| | |
|---|---|
| BMP | Best Management Practice |
| COD | Chemical Oxygen Demand |
| CWA | Clean Water Act |
| EMC | Event Mean Concentration |
| IQR | Interquartile Range |
| MEP | Maximum Extent Practicable |
| MRL | Minimum Reporting Limit |
| MS4 | Municipal Separate Storm Sewer System |
| NPDES | National Pollutant Discharge Elimination System |
| POC | Pollutant of Concern |
| QC | Quality Control |
| RPD | Relative Percent Difference |
| SCADA | Supervisory Control and Data Acquisition |
| SWMP | Stormwater Management Plan |
| SWPPP | Stormwater Pollution Prevention Plan |
| TKN | Total Kjeldahl Nitrogen |
| TSS | Total Suspended Solids |

ACKNOWLEDGMENTS

I wish to express my sincere gratitude in the support I received from my graduate advisor, Dr. Yeo Howe Lim for his continuous support in my thesis, graduate, and undergraduate education. I could not have exceeded in this research without his guidance.

I would also like to thank the rest of my thesis committee: Dr. Harvey Gullicks and Dr. Charles Moretti as well as the rest of the UND Civil Engineering Department.

This research would not have been possible without the resources provided by the City of Grand Forks and the North Dakota Water Resources Research Institute. I had the privilege of working for two engineering firms during the summers between my graduate work, both of which helped me in this research. I would like to thank CPS, Ltd. for providing me with the design documents of the project site and AE2S, Ltd. for allowing me to be a part of their water resources group where I learned a substantial amount of information that was applied to this research.

I dedicate my thesis work to my family and friends that motivated me to pursue this graduate degree. A special thanks to my parents Jackie and Tony Beaudry, my "Gram", and to my best friend, Taylor Brown. I would not have made it through this process without their continued love and support.

## ABSTRACT

It is hypothesized that the applied sampling techniques, water quality analysis, and statistical analysis predict pollutant removal efficiencies of the project site. Current practices in urban stormwater runoff are the design of systems that limit the developed peak discharge to less than or equal to the peak discharge of the pre-developed conditions. This is many times accomplished with the installation of stormwater retention, detention, or attenuation facilities that store the generated runoff from the drainage area. These are commonly known as structural Best Management Practices (BMPs). The City of Grand Forks, ND (City) implements BMPs into the stormwater management plans for all new developments. Design of these facilities for water quality is volume based, and considerations for removal efficiency are not currently integrated. The City is interested in determining the pollutant removal efficiency of their current *in-situ* structural BMPs.

This research is used to develop a sampling plan and parameter list for potential future expansion of the project. To determine an accurate sampling plan and parameter list, a baseline study on one operational wet detention pond located within the City was completed to prove the hypothesis. Since this is a baseline study, water quality parameters included the analysis of total suspended solids, nutrients of various forms, heavy metals, bacteria, and other chemical properties used to assess the current quality of stormwater influent and effluent going through the system. The sample collection

includes both single grab samples for instantaneous water quality analysis and manual flow-weighted composite samples for analysis of event mean concentration (EMC). The EMC influent and effluent results are compared to determine intra-event removal efficiency and a statistical analysis is performed to determine if the sample sets are statistically significantly different between the influent and effluent concentrations. Acceptance of the hypothesis is proven for the nutrients, total phosphorus and nitrate as nitrogen, and conductivity. The average removal efficiency of the nutrients is 73 percent for total phosphorus and 40 percent for nitrate as nitrogen. Conductivity was determined to increase between the influent and effluent concentrations. Other analytes that exhibited removal efficiency, but were not proven to be statistically significant, were total suspended solids (TSS) at 76 percent removal, phosphate as orthophosphate at 71 percent removal, and bacteria as *E. Coli* at 83 percent removal. The remaining parameters of ammonia as nitrogen, nitrite as nitrogen, total copper, total lead, total zinc, chloride, pH and dissolved oxygen did not suggest effective removal trends throughout the BMP. Continued analysis of the site is required to better define the statistical difference between the influent and effluent concentrations for these parameters. The removal of the nitrite from the parameter list is suggested based on low to non-detection of the analyte throughout the monitored sampling events. TSS and conductivity were observed to be potential surrogates for total phosphorus and chloride, respectively.

## CHAPTER I

# 1. INTRODUCTION

### 1.1 Background

The hydrology in urban areas is dominated by the presence of impervious surfaces and man-made or hydraulically improved drainage systems. One of the major problems in urban hydrology is the requirement to control peak flows and maximum depths throughout a drainage system. Without control measures, large storm events cause surcharging and flooding of the system that could lead to the impairment of buildings and structures, causing catastrophic damage to a city's infrastructure. Greater impervious percentages lead to increases in runoff quantity and shorter time until the peak discharge occurrence. Urban stormwater conveyance systems generally include overland flows that travel to gutters that lead to inlets connected to a pipe system, which ultimately ends at an outfall. The other major issue with stormwater runoff is water quality. Past engineering practices allowed these system outfalls to be discharged to natural streams and bodies of water, with little attenuation or removal of pollutants.

Regulation of water quality of the nations' surface waters and the discharges of pollutants to these waters first began in 1948 through the Federal Water Pollution Control Act (EPA 2014a). As impacts in water quality became evident over time, the original act was expanded and reorganized into the Clean Water Act (CWA). Within the CWA, discharge of pollutants from point sources was unlawful without an approved National

Pollutant Discharge Elimination System (NPDES) permit. Within this permit program is a specific stormwater program that regulates stormwater discharges from municipal separate storm sewer systems (MS4s), construction activities, and industrial activities. For the purpose of defining which municipalities fall within the NPDES permit requirements, urban areas of the country are categorized as small to large MS4s based on population. The NPDES permit program was originally issued in two phases, with Phase II affecting the research project site within Grand Forks, North Dakota. North Dakota regulates all urbanized areas defined as MS4s through one NPDES permit. Each MS4 is required to show compliance with the permit requirements on an annual basis. Within the requirements are measurable goals that include examples such as public education on stormwater pollution, erosion control during construction, and post-construction runoff control (Pennington et al. 2003).

In the City of Grand Forks (City), post-construction runoff control is generally accomplished through the use of nonstructural and structural best management practices (BMP), with the latter of the two being what is analyzed in this research. The common types of structural BMPs used in the City are wet and dry detention ponds, extended detention ponds, and flow-through devices. The City has an online geographic information system (GIS) portal that includes a database of the different BMPs installed, which includes a description of the BMP type. Based on this portal, it was found that there are roughly 38 wet detention ponds, 14 dry detention ponds, nine swales, and ten flow-through devices that are underground attenuation chambers, hydrodynamic separators, or rain gardens installed throughout the City through 2013 (City of Grand Forks GIS Services 2014). This total continues to increase annually with a BMP required for most new developments that occur within city limits. These structures are designed for water quantity and quality based on the requirements of the North Dakota Pollutant Discharge Elimination System (NDPDES) permit, the City code regarding stormwater, and the City's stormwater manual adopted in 2012 (City of Grand Forks 2013).

Water quality treatment in structural BMPs is design-based in that assessment of the water quality is based on the facilities outlet structure and its ability to provide appropriate detention time for the water quality volume. Water quality volume is the amount of runoff volume designed to be treated by the BMP. This research looks to assess the performance of an *in-situ* wet detention pond by determining the removal efficiency of the BMP for a variety of common stormwater runoff pollutants.

Another area of water quality regulation pertinent to this research is the current effort being taken by the North Dakota Department of Health (NDDH) to create nutrient loading criteria to assess which surface waters require restoration from the harmful effects excess nutrients can have on water bodies. Nutrients are generally classified by nitrogen and phosphorus, with analytes of each being assessed in this study. The NDDH has developed a nutrient loading reduction strategy that is being furthered defined currently through stakeholder groups (NDDH 2014). As progress within the strategy is made, it will be interesting for the City to be able to compare the results of this research with the developed nutrient criteria.

## 1.2 Problem Statement

The City is interested in determining the pollutant removal efficiency of current *in-situ* structural BMPs located throughout its urban watershed. This is a baseline study used to develop a sampling plan and parameter list for potential future expansion of the project and to determine the current removal percentages being exhibited at one of the operational wet detention ponds within the City. Prior to this research there was little to no data collection for performance-based water quality criteria within the region. While this research does not aim to set effluent concentration requirements for the City, it does provide the data to determine a baseline removal percentage goal for parameters found to be statistically proven through this analysis.

## 1.3 Research Hypothesis

Prior to this research, the City did not have a sampling plan to base the analysis on. Instead, this plan was developed throughout the course of the project and will eventually be compiled into a document that will allow future continuation of this research with the resources currently available and with recommendations for improving accuracy through the purchase and installation of devices more suited to measure stormwater flow. The hypothesis being proven through this research is that the developed sampling plan, analytical analysis, and statistical analysis accurately assess the removal efficiency of the studied *in-situ* structural BMP. The hypothesis will be proven as accepted or denied for each individual water quality parameter assessed.

## 1.4 Scope of Work

The original intent of this work was to assess a number of structural BMPs throughout the City to obtain an overview of effectiveness. This would have included the comparison of different BMP types and their measured pollutant removal capabilities to determine which type is best suited for different applications. Through the gathering of the literature, it was deemed that this scope of work was much too large for one individual to complete in the allotted year of research. As knowledge and understanding of the requirements to complete a BMP effectiveness assessment increased, it became apparent that assessing a single structure with more accuracy would be more beneficial than assessing a variety of structures with less accuracy. This accuracy is that pertaining to the requirement of accurate flow measurement, sample collection, water quality analysis, statistical analysis, etc. Assessment of one BMP was also found to be appropriate with the resources already available through the City. The scope of work includes the development of an accurate sampling plan and the assessment of the chosen water quality parameters for removal effectiveness. Parameters exhibiting an increase in concentration over the BMP are identified, as well as those that are not-detected within the influent and effluent. The broad list of parameters for this baseline study is narrowed down based on the results.

### 1.5 Project Site Description

The *in-situ* structural BMP chosen for the project site is a wet detention pond located on the south end of the City in a newly developed area. The site is part of the Highland Point Additions that are still being constructed to date. The delineated drainage area is 0.25 square kilometers in size with a fully developed land use characterization of 44 percent multi-family high density apartments, 33 percent for general business, 15 percent streets and right-of-ways, five percent pond area, and three percent one and two family residential homes (City of Grand Forks 2013). Based on the current development assessment, roughly 70 percent of the drainage area is complete. The pond has two inlet points, one from the west and one from the east. Within the 70 percent developed portion, nearly 70 percent is hydraulically connected to the west inlet, making it the inlet with the greatest influent during precipitation runoff events. The location of the site drainage area relative to the City is given in Figure 1. This figure also depicts the locations of the different rain gages used throughout the project in determining storm event frequency and precipitation for the site during sampled events.


Figure 1. Project site and rain gage location map.

The drainage area delineation is given in Figure 2. The region with parallel and perpendicular cross hatches is the portion of the drainage area that reaches the west inlet, the region with only parallel lines as the pattern is that which reaches the east inlet that is currently developed, and the remaining portion with a dotted hatch pattern represents the undeveloped area that will reach the east inlet in the future. The first two areas make up the portion that currently contributes influent to the wet detention basin.

The pond was designed for water quantity and quality based on the NDPDES permit guidelines for a wet detention pond. The water quantity attenuation was designed more specifically based on a perimeter drainage study (PDS) completed for the City that

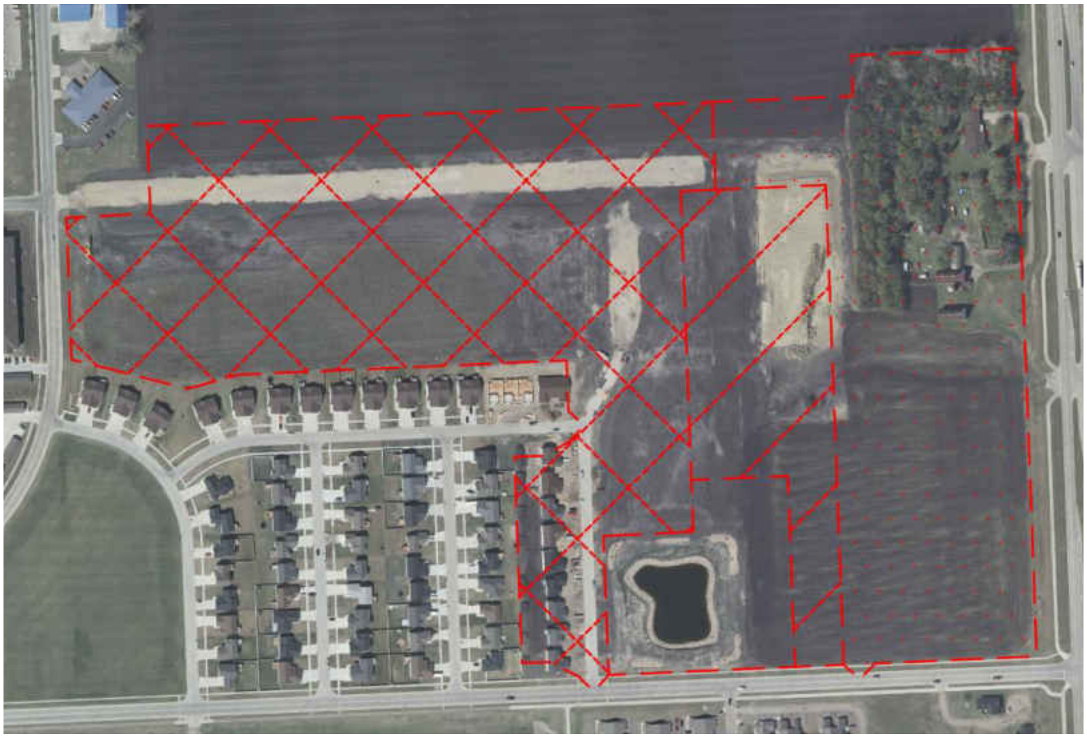


Figure 2. Drainage area delineation.

requires 33,304 cubic meters (27 acre-ft) of storage per quarter section below elevation 254.51 m (835.00 ft) (CPS, Ltd. 2008). The design of the pond is a permanent pool volume of 3873 $m^3$ and a water quality volume of 4590 $m^3$ with a drawdown time of 13.7 hours. These calculations are based on the requirements for wet detention ponds in the NDPDES permit and the PDS. The NDPDES permit requirements are summarized for all typical BMPs installed throughout the state in the literature review of this report. The permanent pool volume is determined by multiplying the area draining to the detention basin by 12595 cubic meters per square kilometer (1800 cubic ft per acre). The water quality volume is determined by multiplying the impervious area, determined to be roughly 64% of the total area based on land use, by 12.7 mm (0.5 in). The detention time must be greater than 12 hours to ensure adequate time for settling and sedimentation to occur within the basin during an event. Table 1 compares the required volumes and detention time to what is actually available based on the design. This shows compliance with the current regulatory requirements imposed on the project BMP.

Table 1. Summary of wet detention basin design.

| | **Required Value** | **Actual Value** |
|---|---|---|
| Permanent Pool Volume ($m^3$) | 3,149 | 3,873 |
| Water Quality Volume ($m^3$) | 2,032 | 4,590 |
| Detention Time (hr) | > 12 | 13.7 |

The pond inlets are 48 inch reinforced concrete pipes (RCP) and the pond outlet is an 18 inch RCP. The outlet structure is designed to control the water quality volume to the specified detention time, with an emergency outfall available for large events that exceed the water quality volume or for the event of a blockage in the main outlet pipe.

The original scope of work included a second project site that is another wet detention basin located in the City. This basin is located in a fully-developed, aged part of the City. The contributing drainage area is 0.50 square kilometers in size with land use classified as single family residential based on the identifications given in City of Grand Forks (2013). The inlet, outlet, and basin details are not given because this site was not used in the BMP analysis within this report. This site is only mentioned in areas of the report related to lessons learned and obstacles that were faced when trying to assess this BMP in the preliminary stages of the research.

### 1.6 Overview

This thesis is arranged to provide a literature review on the pertinent information related to BMP effectiveness studies, to describe the methods used in the process of determining influent and effluent concentrations for each event, and to provide a discussion of the results obtained from the analysis. Chapter 2 contains the literature review on BMPs, water quality and quantity regulations, general BMP monitoring methods, common water quality parameter and statistics applied to stormwater data, and typical effectiveness of wet detention ponds. Chapter 3 provides the methods for forecasting storm events, measuring precipitation and flow, sample collection, water quality analysis, and methods for assessing the results of the collected data. Chapter 4 summarizes all results obtained in the analysis and Chapter 5 goes into a detailed discussion of potential causes of error in the results and the overall assessment of each water quality parameter measured. Lastly, Chapter 6 provides the conclusions of the research.

# CHAPTER II

# 2. LITERATURE REVIEW

## 2.1 Introduction

The literature review serves as a comprehensive background on the assessment of Best Management Practice (BMP) effectiveness on the local level with consideration of current limited resources in monitoring practices and equipment for the project site. It describes the water quality and water quantity regulations pertaining to a BMP assessment on an *in-situ* wet detention pond located within Grand Forks, North Dakota (City). An explanation of general BMP design criteria, monitoring methods, and typical urban runoff pollutants of concern is supported by past studies and literature on similar practices. An overview of potential statistical analysis tools for assessing the collected data aims to prove that BMP effectiveness can be determined from the stormwater data. Finally, previous results of wet detention pond effectiveness studies are described to use as a comparison tool in later sections of the report. The main objective of this literature review is to ascertain that a reasonable plan for future sampling can be established for the City that is adequate for measuring BMP effectiveness.

## 2.2 Best Management Practice Basics

Most water quantity regulations focus on controlling post-development conditions to be equal to or less than the pre-development conditions. This is most commonly accomplished through the use of post-construction structural BMPs to diminish the peak discharge of the increased flow attributed to the increased impervious surfaces of the developed area. To attenuate means to lessen the amount, force, magnitude, or value of a parameter. In BMP utilization, attenuation is accomplished by wet detention ponds and dry detention basins. Retention basins are characterized by a permanent pool that retains some of the storm and detention basins are those that completely drain after an event to the normal pool elevation for a wet basin or to the ground surface for a dry basin (Urbonas 1995).

The size of the BMP is directly related to the water quality volume to be regulated and the maximum design storm that the facility is required to attenuate. The structure has an outlet that may be as simple as an orifice sized to attenuate the water quality volume and have an adequate drawdown time or as complicated as a combination outlet with infiltrating riprap, many orifices, and an overflow grate that ensures the pond is capable of passing larger design storms. Events that produce a stormwater runoff volume greater than the water quality volume will only treat the initial, normally first-flush, portion of the runoff hydrograph, leaving any remaining volume unregulated without adequate drawdown time to allow water quality improvements (Roesner et al. 2001).

The types of BMPs utilized in the City include wet detention basins, dry detention basins, infiltration techniques such as grassed swales, rain gardens, and permeable pavement, and flow-through devices like underground storage chambers or hydrodynamic separators. As of 2013, the City had a reported 71 installed BMPs that are identified in the Grand Forks Geographic Information System (GIS) Engineering Database. Based on this online portal, it was found that there are roughly 38 wet detention ponds, 14 dry detention ponds, nine swales, and ten flow-through devices that are underground attenuation chambers, hydrodynamic separators, or rain gardens installed throughout the City through 2013 (City of Grand Forks GIS Services 2014).The installation of BMPs has continued as a now required practice for all new development within the City, in compliance with the City's Stormwater Management Standards and Design Manual (City of Grand Forks 2013).

Wet detention ponds have primary internal design processes related to evaporation, settling, adsorption, nutrient uptake, and evapotranspiration (Federal Highway Administration 2014). In the City, the intent of the detention time is to allow for the settling process to occur and remove total suspended solids (TSS) through sedimentation. TSS removal is a function of particle density, particle size, and the fluid's viscosity, which in turn is a function of the temperature (Urbonas 1995). Urbonas (1995) described the TSS removal process into two phases: during the storm runoff when settling occurs under turbulent conditions, and during quiescent conditions between events when biological and chemical processes help removed constituents in the water column. The first phase will be the phenomena focused on in this analysis.

The requirements for the physical BMP characteristics that should be collected and reported for different types are summarized in Strecker et al. (2001). The requirements for wet detention ponds are given in Table 2, since the studied BMP is of this type.

## 2.3 Water Quality Regulations

The following sections describe regulations related to water quality at the federal, state, and local level. The governing federal agency is the United States Environmental Protection Agency (EPA). For the project sites analyzed in the research, the governing

Table 2. Parameters to report for wet detention ponds (Strecker et al. 2001).

| **Parameter Type** | **Parameter** |
|---|---|
| Tributary Watershed | Watershed area, average slope, average runoff coefficient, length, soil types, vegetation types<br>Total tributary impervious percent and percent hydraulically connected<br>Details about gutter, sewer, swale, ditches, parking, and roads in watershed<br>Land use types and acreage |
| General Hydrology | Date and start/stop times for monitored storms<br>Runoff volumes<br>Peak 1-hour intensity<br>Design storm recurrence intervals and magnitude<br>Peak flow rate, depth, and Manning's n-value for 2-yr event<br>Average annual values for number of storms, precipitation, snowfall, minimum/maximum temperature |
| Water | Alkalinity, hardness, and pH for each storm<br>Water temperature<br>Sediment settling velocity distribution, when available<br>Facility on- or off-line<br>Bypassed flows during event |
| General Facility | Maintenance type and frequency<br>Monitoring instrument type and location<br>Inlet and outlet dimensions, details, and number |
| Wet Pool | Volume of permanent pool<br>Length of permanent pool<br>Permanent pool surface area<br>Solar radiation, days of sunshine, wind speed, and pan evaporation from weather station |
| Detention Volume | Detention (or surcharge) and flood control volumes<br>Detention basin's surface area and length<br>Brimful and half-brimful emptying time |
| Wetland Plant | Plant species and age of facility, if applicable |

state agency is the North Dakota Department of Health (NDDH), and the regulating local agency is the City. Documents related to each agency are identified as such.

### 2.3.1 Federal Regulations

The first regulatory document related to discharge and water pollution was called the Federal Water Pollution Control Act that was enacted in 1948 (EPA 2014a). In 1972, this document was extensively expanded and reorganized into the Clean Water Act (CWA). The CWA regulates the discharges of pollutants into the waters of the United States (U.S) and regulates the water quality of the countries surface waters (EPA 2014a). This disabled discharge of pollutants from point sources into navigable waters and made it unlawful to do so unless a permit was obtained, which led to the National Pollutant Discharge Elimination System (NPDES) permit program.

In March of 2014, the EPA and the U.S. Army Corps of Engineers (USACE) proposed a new rule to further define the waters of the U.S. to enhance protection of the nation's aquatic and public health and to lessen confusion from past court cases related to discrepancies (Copeland 2014). While the full definition of the waters of the U.S. is lengthy and irrelevant to include in this paper, it is relevant to point out that this new rule would further restrict pollutant discharges and enables more requirements for water quality that have not been previously met. The Congressional Research Service (CRS) report exclaimed that agencies expect the new rule to subject an additional three percent of U.S waters to be CWA jurisdictional (Copeland 2014). It is unknown whether any region of the City would be impacted by this rule if put in place.

Great efforts of opposition have surfaced from farmers, legislators, and other groups fearful that the rule would allow the EPA to have unnecessary jurisdiction of new waters included in the proposal. One movement being led by the American Farm Bureau Federation, called "Ditch the Rule", believes the rule would require unnecessary permitting and mandates for farming procedures (Rodger and Sirekis 2014). On September ninth, 2014 the U.S. House of Representatives passed a bill that would prohibit the USACE and EPA from developing, finalizing, adopting, implementing, applying, administering, or enforcing the proposed rule (113th Congress of the U.S. 2014). The rule's opposition may cause further changes or denial of the proposal.

The NPDES permit program as a whole regulates point sources that discharge pollutants into the waters of the U.S., however, there is also a NPDES stormwater program that specifically regulates stormwater discharges from municipal separate storm sewer systems (MS4s), construction activities, and industrial activities (EPA 2014b). The City is regulated by a MS4 permit, so special attention to that portion of the stormwater program will be mentioned in subsequent sections. The EPA (2014c) issued Phase I of the program in 1990, which required medium and large cities to obtain NPDES permit coverage for stormwater discharges, resulting in approximately 750 Phase I MS4s. Then, in 1999, Phase II of the program was issued and small MS4s were required to obtain NPDES stormwater discharge permits (EPA 2014c). This has resulted in approximately 6,700 Phase II MS4s. The Phase II rule requires that small MS4 owners and operaters must reduce pollutants in stormwater to the maximum extent practicable (MEP).

According to 40 CFR 122.26(b)(8), an MS4 is a conveyance or system of conveyances that is owned or operated by a public body thats purpose is to collect or convey storm water (EPA 2014d). As mentioned previously, MS4s are classified as large, medium, or small, with classifications based on population established by the 1990 census. A large MS4 is one located in an incorporated place or county with a population of at least 250,000, a medium MS4 is one located in an area of population 100,000 to 249,999, and a small MS4 is one that has been designated by a regulating authority or its location is in an "urbanized area" (Water Permits Division of EPA 2012). Other small MS4s are determined on a case-by-case basis even if located outside an urbanized area.

### 2.3.2 State Regulations

The regulating agency of water quality for the state of North Dakota is the NDDH. The legal document that describes the standards of quality of “waters of the state” is the North Dakota Century Code (NDCC), chapter 61-28, titled *Control, prevention, and abatement of pollution of surface waters* (Wax 2014). “Waters of the state” are broader than “waters of the US” and include all waters within the state’s jurisdiction, such as, but not limited to, streams, lakes, ponds, impounding reservoirs, and waterways (Wax, 2014). Small MS4’s within North Dakota are regulated under the North Dakota Pollutant Discharge Elimination System (NDPDES) Permit No. NDR04-0000 (Grossman 2009). There are currently eighteen MS4s regulated under this permit, and each one must develop a separate Stormwater Management Plan (SWMP) to address minimum requirements for controlling pollutants in stormwater runoff (Grossman 2009). These SWMP plans are in place to reduce pollutant discharge to the MEP, to protect water quality, and to satisfy water quality requirements of the CWA (Grossman 2009). These requirements are met by implementing measurable goals that help assess the effectiveness of the stormwater controls.

### 2.3.3 Local Regulations

The City manages stormwater runoff water quality through compliance with the NDPES permit. All new development within city limits is regulated by site-specific Storm Water Pollution Prevention Plan (SWPPP) permits and SWMP plans that are reviewed and accepted by city officials prior to construction. The Phase II program established six elements that the MS4 is required to address: public education and outreach, public participation, illicit discharge detection and elimination, construction site runoff control, post-construction runoff control, and pollution prevention and good housekeeping (Pennington et al. 2003). These objectives are met by nonstructural and structural BMPs. The nonstructural BMPs include publicly available literature that can be accessed directly on the "Stormwater Information" webpage of the City's website (City of Grand Forks 2014). Structural BMPs currently being utilized are various inflitration methods, wet detention ponds, dry detention ponds, and flow-through treatment devices.

### 2.3.4 Current Water Quality Criteria

Water quality standards have been developed for the waters of the state and can be found in the NDDH rules, chapter 33-16-02.1, titled *Standards of quality for waters of the state* (NDDH 2005). The water of the state pertaining to the project site is ultimately the Red River of the North downstream of the site, which has been classified as a Class I stream. While there are numeric criteria in place for surface waters, there are no specific numeric criteria for stormwater runoff point sources, as being analyzed in this research. The current regulating BMP water quality criteria for the state of North Dakota is a design-based approach that focuses on constructing a facility to hold a calculated volume of water based on the contributing watershed and release it over a specified time. There are no performance-based criteria that specify a contaminant percent removal goal or maximum threshold value. The criteria related to post-construction structural BMPs that are addressed in Appendix 1 of the NDR04-0000 permit are summarized in Table 3 (NDDH Division of Water Quality 2009).

### 2.3.5 Water Quality Programs

Throughout the years, different programs and strategies have been developed by agencies concerned with protecting the quality of the waters of the US and individual

Table 3. Post-construction structural BMP water quality design criteria (NDDH Division of Water Quality 2009).

| Method | Water Quality Design Consideration |
|---|---|
| Wet Detention Ponds | 1. Permanent Pool Volume (Vpp) = 1800 cu-ft per acre draining to pond; or the runoff from 2yr-24hr design rainfall event.<br>2. Water Quality Volume (Vwq) = 0.5 inches from impervious area.<br>3. The drawdown time for the Vwq should be a minimum of 12 hours. |
| Dry Detention Ponds (w/ Extended Detention | 1. Extended Detention/ Water Quality Volume (Vwqed) = 1800 cu-ft per acre draining to pond; or the runoff from 2yr-24hr design rainfall event.<br>2. The drawdown time for the Vwqed should be a minimum of 24 hours and not more than 72 hours. |
| Infiltration | 1. Water Quality Volume (Vwq) = 0.5 inches from impervious area.<br>2. The volume captured in rain gardens or passed through biofilters with under drains would be grouped with infiltration for water quality treatment.<br>3. The Vwq should discharge through the soil or filter media within 48 hours. Additional flows that cannot be infiltrated in 48 hours should be routed to bypass the system through a stabilized outlet. |
| Flow-Through Treatment Devices | 1. Size devices to treat the first 0.5 inches of runoff from impervious area. |
| Redevelopment / Retrofit | 1. Where site conditions allow, consider incorporating water quality components or reduction in impervious surface area. The goals to consider are:<br>2. Reducing impervious surface area;<br>3. Implement BMPs or treatment methods to manage a portion of the first 0.5 inches of runoff from the impervious area. |

states. Two programs directly related to this study are the National Urban Runoff Program (NURP) and North Dakota's nutrient reduction strategy. The following sections discuss the purpose and results of these two programs.

#### 2.3.5.1 National Urban Runoff Program

Prior to 1960, there was very little attention given to stormwater pollution by the regulatory and engineering communities because there was little known about its effects on the environment. This led to the formation of NURP. The goal of NURP was to provide cities, states, and other entities with a rational basis on whether urban runoff was causing problems, and if it was, finding control options and developing water quality management plans that consider cost (EPA 1983a). This was a nationwide project that included substantial field monitoring and sampling at 28 sites that were set up to characterize urban runoff flows and pollutant concentrations. The primary water quality statistic chosen to analyze the data was the event mean concentration (EMC) of the individually monitored runoff events (EPA 1983a). Many conclusions were drawn from this program; however, relevant observations to this research included the determination of priority pollutant constituents and the concentrations of these pollutants that were found to negatively impact receiving waters. This includes copper, lead, zinc, coliform bacteria, nutrients, and total suspended solids (TSS). This program yielded an abundance of information related to urban stormwater runoff that is still being focused on today.

#### 2.3.5.2 Nutrient Reduction Strategy

In recent years, the reduction of nutrients, such as nitrogen and phosphorus, in receiving waters has been a major issue. The origin of nutrients in the urban setting has been linked to industrial and municipal point sources, stormwater runoff, and contaminated construction debris. These pollutant sources can travel through stormwater conveyance systems that inevitably discharge to receiving water. The pollution of nutrients in waterways leads to eutrophication and potentially harmful algal blooms, which leads to degradation of wildlife habitat and potential concerns for public health. With these concerns, it becomes apparent that regulations of nutrient loadings are necessary. One of the first documents published by the EPA related to nutrient reduction was the "National Strategy for the Development of Regional Nutrient Criteria," which encompassed the strategy the agency would take to guide states in making the criteria (EPA 1998). A more recent nutrient loading memorandum by the EPA was released in March of 2011, titled "Working in Partnership with States to Address Phosphorus and Nitrogen Pollution through use of a Framework for State Nutrient Reductions," which indicated that development of nutrient loading criteria was best addressed at the state level (Stoner 2011).

In conjunction with the EPA's original push for the states to develop nutrient criteria, Houston Engineering, Inc. and the NDDH published the "State of North Dakota Nutrient Criteria Development Plan" in 2007 (Deutschman and Saunders-Pearce 2007). This plan determined that the EPA's strategic guidance as indicated in the 1998 document was not very applicable to the state of North Dakota and created a more suitable strategy for the state to follow. After the 2011 memorandum, the NDDH created the Nutrient Reduction Strategy Stakeholder Group that is made up of state and surrounding region officials. Within this stakeholder group, there are five workgroups that focus on specific components of the strategy, which include nutrient criteria development, watershed prioritization, agriculture and non-point sources, municipal and industrial point sources, and public education and outreach (NDDH 2014). The four fundamental considerations in the development of this nutrient criteria strategy are to protect the state's water resources and their designated beneficial uses, tailor it to the unique physiographic characteristics and climate of this northern plains state, to be technically and scientifically defensible, and to be based on conceptual models that reflect cause and effect relationships for resource impairment and the loss of beneficial uses (NDDH 2013).

With one of the workgroups being related to municipal and industrial point sources, it is of interest to wonder how, if at all, urban sources to receiving waters will be regulated. Some of the water quality goals of the developing strategy are to “target and prioritize watersheds and BMPs to achieve cost effective water quality improvements … (and) implement water quality monitoring programs that will track our (ND) progress towards our (ND) nutrient reduction goals” (NDDH 2013). Whether the BMPs and monitoring programs will be the responsibility of local officials is unknown, but with the outcome of this research, the City will have a recommended plan to do so.

### 2.4 Water Quantity Regulations

Different sources will describe water quantity regulations in various ways and some require more conservative designs than others. Regardless, the governing document of the site jurisdiction should be the guideline or regulation followed in design. As an example, one source describes that generally, a common drawdown time of water quality volume is 24 hours and the recommended design storm to size the BMP is the storm with a volume just greater than 70 percent to 90 percent of the rainstorms (Roesner et al. 2001). This is a different guideline than what is used in North Dakota and, more specifically, the project site.

In the City, the water quantity is regulated by water quantity volume and detention time requirements for different BMP structures given previously in Table 3 from Appendix 1 of the NDPES Permit No. NDR04-0000, the Letter of Map Revision (LOMR) issued by the Federal Emergency Management Agency (FEMA) that defines 100-year flood water surface profiles for main drainage conveyances in the region, Chapter 15 of the Grand Forks City Code, and recommendations in the Grand Forks Perimeter Drainage Study (PDS) that was completed by CPS, Ltd. for master planning and review of stormwater management plans for undeveloped areas of the city (City of Grand Forks 2013). In general, storms need to be attenuated to the 25-yr design storm with 0.91 m (3 ft) of freeboard, and post-development discharge needs to be less than or equal to the pre-development conditions for the two-, five-, ten-, 25-, and 100-year, Type II, 24-hour design storm.

## 2.5 General BMP Monitoring Methods

This section of the literature review focuses on some of the general methods used to determine when and how BMP monitoring should be conducted. This is not an all-inclusive synopsis, but covers the general methods pertaining to those available for use in this assessment.

### 2.5.1 The "Perfect Storm"

The task of properly sampling a storm event is, in reality, not as simple as it sounds. There are many factors involved in determining whether or not a storm will be adequate to sample. This includes forecasting of the storm frequency based on predictions of the National Weather Service (NWS) or regional news observations. A frequency analysis for the City for events greater than a tenth of an inch between 1994 and 2013 was completed and presented at the ND Water Quality Monitoring Conference in March 2014 (Lim and Beaudry 2014). This analysis was further updated to include events smaller than a tenth of an inch. The analysis is described in section 3.2.1 and the results are given in section 4.2. The operator must also consider the current conditions at the site to determine if a quiescent environment is available. Analysis on the hydraulic characteristics of the BMP and the connecting upstream and downstream conveyance systems is important to understand at what point surcharge or backwater into the structure may occur (Bachmann LeFevre et al. 2010). If this does occur, sampling should be avoided because the BMP is not functioning as it was designed. The aforementioned circumstances are uncontrollable by the operator, and sampling of events must subside until proper conditions are present on site.

The peak flow of the contributing watershed for different design storm events needs to be determined in order to better understand the BMP's response to forecasted and occurring storm events. This can be initially estimated by modeling the stormwater system in software such as the EPA's Storm Water Management Model, Autodesk's Storm and Sanitary Analysis, or more simply using a software package called HydroCAD, which are all computer programs that calculate hydraulic and hydrologic computations, versus completing tedious hand calculations of the same methods. An example of a simple hand calculation is the rational method that utilizes weighted runoff coefficients based on land use (Bachmann LeFevre et al. 2010). The model or hand calculations are calibrated by comparing storms of different intensities and durations to the computed values.

The International Stormwater BMP Database (Int'l BMP Database) created a monitoring and evaluation guidance document that summarizes techniques and methods for developing a monitoring plan based on a given study's limitations. Within this document, the range of storm volumes to be sampled was described as a parameter that depends on the projects' goals, and a suggested minimum precipitation amount of 2.54 mm (0.10 in) for a storm event adequate to be sampled was given (Geosyntec Consultants and Wright Water Engineers, Inc. 2009). If a storm event produced a runoff volume that exceeds the water quality volume the BMP was designed for, is it acceptable to use the determined pollutant concentrations to assess the effectiveness? Should the event concentration only be based on a composite sample up to the water quality volume? The answer to these questions is based on an assumption that the Int'l BMP Database relies on the following definitions of the terms performance and effectiveness as related to stormwater BMP structures. Strecker et al. (2001) defined performance as "a measure of how well a BMP meets its goals for storm water that flows through, or is processed by it" and effectiveness as "a measure of how well a BMP system meets its goals for all storm water flows reaching the BMP site, including flow bypasses." The two terms are used appropriately throughout this report.

De Leon and Lowe (2009) defined a representative storm as one with no maximum, but a 2.54 mm (0.10 in) minimum and typically within the range of 5.08 mm (0.20 in) to 19.1 mm (0.75 in) of rainfall. They suggested six to 24 hour storm duration, an antecedent dry period of 24 hours minimum, an inter-event dry period of six hours, and at least 75 percent capture of the storm hydrograph within the collected samples (De Leon and Lowe 2009).

### 2.5.2 Flow Measurements

The measurement of flow rate over the storm event is one of the most important factors to accurately obtain representative samples of the entire event. This is important for comparing influent and effluent concentrations of the storm in its entirety for the different analyzed parameters. Monitoring stormwater is an expensive task, and flow measurement methods are limited by the project budget. The chosen method for this research is a stage-discharge relationship governed by Manning's equation that is determined from water level measurements taken continuously at five-minute intervals at the BMP inlet and outlet over monitored events.

Uniform flow is the most simply analyzed flow type, but it is not generally one that occurs in the real world. According to the Federal Highway Administration (FHWA), in many applications, the flow is essentially steady and changes in width, depth or direction are so small that the flow can be considered uniform (Brown et al. 2013). The Manning's equation is the most common equation used to solve steady, uniform flow problems. Manning's equation expressed in the discharge form is given below.

$$Q = \left(\frac{K_n}{n}\right) AR^{0.67} S^{0.5}$$

The variables are identified as n equal to Manning's roughness coefficient, or Manning's n-value, A equal to the cross-sectional area of flow, R equal to the hydraulic radius (or the cross-sectional area divided by the wetted perimeter), and S equal to the energy gradeline slope. The variable $K_n$ is equal to 1.0 when R is in meters and 1.49 when R is in feet. These values come from the conversion in which Manning's n maintains the same value for SI or English units (Sturm 2010). The roughness coefficient is a critical parameter in solving Manning's equation and is chosen on the basis of the channel lining. For channels lined with rigid boundaries the n-value is fairly constant, but for grass-lined channels the value can vary significantly depending on the vegetation type and its height relative to the flow depth (Brown et al. 2013).

Stage-discharge relationships based on the Manning's n equation are commonly used in BMP effectiveness studies (Bachmann LeFevre et al. 2010). The study conducted by Bachmann et al. (2010) utilized pressure transducers to determine water depth and determined flow using the measurements and Manning's equation. The researchers found that lower volumes of runoff magnify the effects of pressure sensor instability and therefore suggested the use of a flow control device in the future. There are other applications of pressure transducers that are comparative to their use in this project. For example, the hydrologic monitoring of wetlands over time is applicable to wet detention ponds. Wetland monitoring is completed by the continuous monitoring of water depth that is accomplished at a feasible cost with similar pressure-transducing water level loggers coupled with staff gauges for reference measurements over time (MN Board of Water and Soil Resources 2013). While the water level data in wetlands is generally used for determining the rise and fall of the surface water in the contributing region, the data can be applied to wet detention ponds by measuring the water depth of the inlet and outlet structures to convert it into flow measurements.

A stage-discharge relationship is found by measuring "a sufficient number of discharge measurements and developing a rating curve by plotting the measured discharges against the corresponding stages and drawing a smooth curve of the relation between the two quantities" (Herschy 1995). When a channel is relatively stable, fewer measurements are required to form the relationship. The rating curve can be altered by a number of factors including scour in an unstable channel, growth and decay of aquatic growth, formation of ice cover, variable backwater, rapidly changing discharge, overbank flow, and ponding (Herschy 1995). The factors of concern in this research are potential aquatic growth, variable backwater, and rapidly changing discharge throughout events.

Other flow measurement devices used in BMP studies are flumes and weirs temporarily installed in the inlet and outlet structures (Bachmann LeFevre et al. 2010). Generally, weirs and flumes are structures installed in a channel that determine flow with a stage-discharge relationship developed by calibrated rating equations. Weir design is based on how the obstruction created forces critical depth to occur, which forms the stage-discharge relationship (Sturm 2010). The two main categories of weirs are thin plate and broad-crested. Flumes are flow measurement devices that form a constriction in the channel that can be a narrowing, a hump, or both (Herschy 1995). There are four typical types of flumes commonly used which include rectangular, trapezoidal, u-shaped, and Parshall.

### 2.5.3 Calibration and Sensitivity Analysis

Before utilizing the Manning's n equation to determine the stage-discharge relationship, an analysis on the sensitivity of the inlet and outlet pipe slope, roughness, and zero-flow depth is performed. Design manuals give minimum, typical, and maximum Manning's n values for different pipe materials, however, the roughness actually present in the field may be outside this range. The slope of the energy grade line is dependent on as-built conditions, which can be verified with surveying of the project site. The zero-flow depth is the observed water level after the discharge from an event has completely passed through the system (Bachmann LeFevre et al. 2010). This depth is calculated as accurately as possible to determine runoff versus possible baseflow occurring in the system and is also necessary to compare to the original design of the BMP to determine whether the model needs to be adjusted to better represent *in-situ* characteristics (Bachmann LeFevre et al. 2010). A sensitivity analysis is completed by determining the relative percent difference in flow when one variable within Manning's n equation is altered to a range of values.

### 2.5.4 Sampling Techniques

The two general forms of collecting samples are by automatic or manual sampling. Automatic sampling is completed through the use of an autosampler that takes samples at a specified interval. Two methods of sampling include the discrete sampling method and the composite sampling method. For discrete sampling, samples are collected at a certain interval. The discharge data is downloaded after the event to determine the hydrograph and samples to be analyzed are chosen. For example, a sample at the beginning of the storm, one halfway on the rising limb, one at or near the peak, one halfway on the falling limb, and one near the end may be analyzed to get a sense of the change in concentration of the constituents over the storm (Martin and Smoot 1986). Composite sampling involves the formation of one sample that is the equivalent of a well-mixed sample of the total volume of storm runoff. The amount of each sample used in the composite is directly proportional to the amount of runoff each sample represents based on the runoff hydrograph (Martin and Smoot 1986).

#### 2.5.4.1 Types of Composite Sampling

There are four types of composite samples that are developed on the basis of time, flow volume, or flow rate. The four types of samples are defined in De Leon and Lowe (2009) and compiled in Table 4.

Table 4. Methods for composite sampling (De Leon and Lowe 2009).

| Composite Sampling Method | Description |
|---|---|
| Constant Time / Volume Proportional to Flow Rate | Samples taken at equal time increments and are composited proportional to the flow rate at the time each sample was taken. Sampling completed through manual or autosampling. Manual compositing is usually required. |
| Constant Volume / Constant Flow Volume Increment | Samples of equal volume are taken at equal increments of flow volume and composited. This is most easily used with an autosampler with a flow sensor built into the unit. |
| Constant Time / Volume Proportional to Flow Volume Increment | Samples taken at equal time increments and are composited proportional to the volume of flow since the last sample was taken. Sampling completed through manual or autosampling. Manual compositing is usually required. |
| Constant Time / Constant Volume | Samples of equal volume are taken at equal increments of time and composited to make time-composited average samples. Does not yield a flow-weighted composite. The simplest, yet least useful sampling method available. |

## 2.6 Water Quality Parameters

While there are many parameters that could be sampled in water quality analysis, studies on BMP effectiveness analyses have sought to narrow down the required or common constituents studied to assess the removal efficiency. According Roesner et al. (2001), principle constituents of concern in urban runoff are total suspended solids (TSS), nutrients such as nitrogen and phosphorus, heavy metals like copper, lead and zinc, and coliform bacteria. Roesner et al. (2001) also discussed how these primary parameters were first determined in the EPA's NURP study and report, which was described earlier in more detail. Martin and Smoot (1986) placed constituents into the general categories of heavy metals, dust and soil material, nutrients, pesticides, bacteria, and natural and industrial organic compounds that are believed to be most common in urban runoff. With the large group of constituents that could be tested, the final parameter list should be considerate of budget and feasibility constraints. For instance, pH and dissolved oxygen cannot be sampled while using an autosampler unless a meter for measuring those analytes is a component of the equipment.

The analysis of nutrients can be completed based on different forms of the analytes. In a study completed by Pennington et al. (2003), forms of nitrogen analyzed were total Kjeldahl nitrogen (TKN), nitrate and nitrite, and phosphorus was analyzed as total phosphorus. The chosen forms of the analytes can be based on available existing data, complexity of a testing method, or the cost of a certain test. The required parameters are many times based on what the BMP was designed to store: a certain return period, specific storm duration, or a required detention time (Bachmann LeFevre et al. 2010).

### 2.6.1 Sources of Stormwater Pollution

The common pollutants of concern (POC) in urban runoff are commonly grouped as sediment measured by TSS, nutrients measured in common forms of nitrogen and phosphorus, heavy metals, and bacteria. It is of importance to review typical sources of these POCs in urban stormwater to identify potential sources in the project site.

TSS is a measure of the organic and inorganic particles that stay suspended in water due to their physical and biological properties. The sediment load is dependent on the particle size, stream flow, climate, geology, and vegetation of the contributing drainage system (Strecker 1998). TSS is commonly used as a surrogate for other contaminants due to the ability of fine particulate matter to bind or adsorb to the suspended sediment. TSS has been found to correlate well with total metals and total phosphorus, among others (Kliewer 2006).

Nutrients are necessary for the well-being of natural water systems, however, in excess, can over-stimulate biological growth and create poor, eutrophic water conditions. Nitrogen and phosphorus are the two most common nutrients considered in BMP effectiveness assessment. Sources of nitrogen include lawn fertilizers, atmospheric fallout, nitrite discharges from automobile exhausts, natural sources from organic soil matter, and farm-site fertilizers or animal waste (Strecker 1998). Nitrate and nitrite are the forms of nitrogen associated with inorganic matter. Ammonia has the ability to be toxic to aquatic life. Phosphorus sources are similar to those of nitrogen. It can also be released with the decomposition of plant cells. The forms of phosphorus studied in this analysis are total phosphorus and phosphate as orthophosphate. Orthophosphate indicates the phosphorus that is most immediately biologically available, and total phosphorus includes phosphorus in all forms (Strecker 1998).

Heavy metals commonly associated with urban stormwater runoff are copper, lead, and zinc. Sources of heavy metals include the weathering of exposed soils and mineral deposits, corroding metal surfaces, decomposing paints, and certain corrosion-control compounds (Strecker 1998). Total concentrations of heavy metals are valuable for assessing the overall reduction of the parameter in both soluble and particulate forms.

Bacteria are the pathogenic group most readily encountered in water and wastewater (Mines, Jr. 2014). The bacterium analyzed in this research is *E. Coli* which is associated with gastroenteritis disease.

## 2.7 Water Quality Statistics

There are many statistical approaches that are used to assess the data collected to determine BMP effectiveness. This section describes common methods as suggested by the Int'l BMP Database and by other studies related to BMP effectiveness. Those that are utilized in this study are further described in the methods section of this report. When it comes to determining a statistical approach, consideration must be taken to address that all storm volumes and their associated concentrations are not equal. In wet detention ponds in particular, the effectiveness estimation is complicated by the fact that the outflow for a particular event being measured may have little to no relationship to the inflow from that same event. To compensate for this fact, utilization of a statistical characterization of the inflow and outflow concentrations is the most recommended approach over single storm pollutant loads or removal percentages (Strecker et al. 2001).

Another consideration is the amount of storm events that need to be analyzed to gage the BMP effectiveness. The range of events sampled depends on the amount of events that occur in a season that produce an adequate amount of runoff. In Pennington et al. (2003), two to seven events were typically monitored at each site in a season. Strecker (1998) described an analysis that was completed to utilize a variance-based test with existing storm data to determine how many samples are estimated to be needed to detect a five percent, 20 percent, and 50 percent change in the mean concentration. The test found that a large number of samples would be needed for the five percent to 20 percent difference in concentrations, but for a 50 percent change, two to six events was adequate. The report indicated, however, that there are other examples of literature that found smaller percent differences with fewer required samples (Strecker 1998).

The variability of the number of storm events sampled to assess effectiveness can be seen in almost all studies related to the topic. There is no set number of required storms, and for obvious reasons of not being able to control weather patterns and recognizing all the potential errors in sampling any event. In Luzkow et al. (1981), the effectiveness assessment was based on fourteen monitored events. In Scherger and Davis (1982) seven storms were monitored, and in Ferrara and Witkowski (1983) only three storms were used in the analysis. Obviously, the more monitored events the better, but analysis required within a deadline leads to the necessity to utilize and draw conclusions from the data collected.

### 2.7.1 Statistical Analysis

A common statistical parameter used to represent the flow-proportional average concentration of a given parameter during a storm event is the Event Mean Concentration (EMC), which is the primary focus of the Int'l BMP Database (Geosyntec Consultants and Wright Water Engineers, Inc. 2009). The EMC approach was also used in Pennington et al. (2003) and Strecker et al. (2001). The Int'l BMP Database does not believe percent removal is an accurate measure of BMP effectiveness. Instead, the database suggests analyzing how much the BMP reduces runoff volumes, how much runoff is treated, whether there is a statistical difference in effluent quality compared to influent quality, or how well the BMP reduces peak runoff rates (Wright Water Engineers and Geosyntec Consultants 2007).

Generally, water quality data can be analyzed using nonparametric or parametric tests. The easiest way to decipher the two terms is the fact that parametric statistical procedures rely on assumptions about the shape of the distribution, such as a normal distribution, while nonparametric tests rely on no or few assumptions about the shape or parameters of the data set (Hoskin 2009). Examples of parametric methods include the two-sample t-test that compares means between two independent groups, the paired t-test that compares two quantitative measurements taken from the same individual, and the analysis of variance test (ANOVA) that compares means between three or more independent groups. The nonparametric methods that counterpart these aforementioned methods are the Mann-Whitney test, the Wilcoxon signed-rank test, and the Kruskal-Wallis test (Hoskin 2009). Nonparametric methods are generally used with non-normal data and data with significant gaps between values (Tuppad et al. 2010).

Descriptive parameters for the influent and effluent EMC data sets are also broken down as parametric versus non-parametric. Descriptive statistics include measures of location or central tendency, measures of spread or variability, and measures of skewness or symmetry (Geosyntec Consultants and Wright Water Engineers, Inc. 2009). The parametric and non-parametric statistics associated with these three measures are summarized in Table 5, which is found in (Geosyntec Consultants and Wright Water Engineers, Inc. 2009). Other descriptive statistics such as the ninety-five percent confidence interval for the median or mean are also common in BMP analysis.

Table 5. Common parametric and non-parametric descriptive statistics (Geosyntec Consultants and Wright Water Engineers, Inc. 2009).

| **Statistic Category** | **Parametric** | **Non-Parametric** |
|---|---|---|
| Measures of Location | Mean | Median |
| Measures of Spread | Variance, Standard Deviation | Interquartile Range |
| Measures of Skew | Coefficient of Skewness | Quartile Skew Coefficient |

Once the water quality data are represented as statistical parameters, statistical analysis methods are conducted to determine if an obvious trend or comparison can be made between the influent and effluent concentrations.

In Van Buren et al. (1997), it was found that the log-normal distribution is appropriate for many of the constituents found in urban runoff, which is consistent with the EPA (1983) results. This was further acknowledged in Geosyntec Consultants and Wright Water Engineers, Inc. (2009), which states that water quality data can be easily transformed to normal distribution by simply taking the log of each data point. Prior to this assumption, however, tests of normality are required to determine if the distribution can be analyzed as normal. If normality is not observed, non-parametric statistical methods that do not assume a normal distribution are used.

A component of determining statistical significance is hypothesis testing, which is a common approach for statistical analysis of hydrologic data. Hypothesis testing is used to draw inferences and determine the relevance of the variation in the sample set. McCuen (2005) summarizes performing a statistical analysis of a hypothesis in six steps.

1. Formulate hypotheses expressed using population descriptors;
2. Select the appropriate statistical model that identifies the test statistic;
3. Specify the level of significance;
4. Collect a data sample and compute the test statistic;
5. Find the critical value of the test statistic and define the region of rejection;
6. Make a decision by selecting the appropriate hypothesis.

For hypothesis testing used by the Int'l BMP Database, the hypothesis is rejected if the calculated probability (p-value) is less than the estimated level of significance or (α-value). As an example, for a hypothesis test that states that the medians of the influent and effluent EMCs are equal with α-value equal to 0.05, it can only be rejected if the p-value is less than or equal to 0.05. If the p-value is greater than the α-value, there is not enough statistical evidence to state that the hypothesis is rejected at that confidence.

An analysis of existing Int'l BMP Database data was completed by Fassman (2011) that analyzed flow-weighted composite sample EMCs of total copper, total zinc, and TSS to compare expected effluent water quality from conventional end-of-pipe BMPs. In Fassman (2011) statistical analysis was completed using Kruskal-Wallis tests for the case evaluated of all EMCs considered equally to identify significant differences ($p < 0.05$). Further, Mann-Whitney tests with Bonferroni correction were used to identify specific differences between BMP types (Fassman 2011). The Mann-Whitney test was also used in Strecker et al. (2001) along with the ANOVA and Kolmogorov-Smirnov tests.

### 2.7.2 Graphical Representation

Water quality EMC data is represented graphically by time series scatter plots, box-and-whisker plots, and normal probability plots (Van Buren et al. 1997). Time series scatter plots show the difference in influent and effluent concentration compared by sampling event of the duration of the analysis period. These plots present intra-event relationships between influent and effluent concentrations. In Fassman (2011), EMC probability plots were developed for all analyzed BMP types. The two types of commonly used probability plot distributions are log-normal and normal, with the distribution chosen for the analysis based on the goodness of fit for the given set of data. Probability plots allow succinct analysis of how well the data is represented as a normal distribution and the relationship between two distributions, which is in most cases a comparison of the influent versus the effluent concentration (Geosyntec Consultants and Wright Water Engineers, Inc. 2009).

Box-and-whisker plots show the range of observations for a specific water quality constituent to help visually interpret the degree of spread and skewness plus identify outliers in the data (Tuppad et al. 2010). Box-and-whisker plots along with probability exceedance plots of all parameters were utilized it Tuppad et al. (2010). An example box-and-whisker plot produced by the Minitab statistical software is given in Figure 3. The lower box expresses the range of data within the 25th percentile or first quartile to the median or second quartile. The upper box represents the range of data from the median to the 75th percentile or third quartile, with the total height representing the interquartile range (Geosyntec Consultants and Wright Water Engineers, Inc. 2009). The two lines are drawn from the lower and upper bounds of the boxes to the minimum and maximum data points. In studies where the events monitored are a small number, the box plot may demonstrate quartiles that are inside the 95 percent confidence interval of the median. Caution must be taken when drawing conclusions from small data sets.

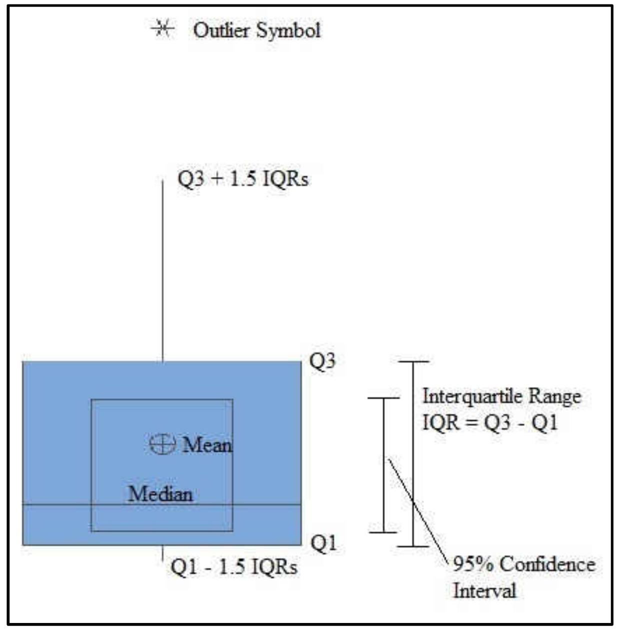



Figure 3. Legend for box-and-whisker plot in Minitab

### 2.7.3 Effluent Probability Method

This section strictly identifies the method that the Int'l BMP Database finds as the most useful approach to quantify BMP efficiency. All content within this section is suggested within the *Urban Stormwater BMP Performance Monitoring Manual* (Geosyntec Consultants and Wright Water Engineers, Inc. 2009). This manual states that the first step in determining BMP efficiency is to determine if the influent and effluent EMCs are statistically different from one another. The standard normal probability plot of both the influent and effluent concentration exceedance probability is assumed to show the best representation of the data for determining BMP effectiveness.

Prior to achieving the probability plots, each BMP study within the database undergoes a statistical analysis for each monitored parameter. The elements contained in this analysis are arithmetic and bootstrap estimates of mean inflow and outflow EMCs, data plots including time series, box-and-whisker, and probability, summary of distributional characteristics, hypothetical test results for non-parametric and parametric analysis, and a test of equal variance. The distributional characteristics or tests of normality, used in the database are the Shapiro-Wilks W-test and Lilliefors test. The non-parametric hypothetical testing is completed using the Mann-Whitney test, and the parametric hypothetical testing is completed with a t-Test on the raw and log-transformed data. Finally, the test of equal variance is completed with the Levene Test on raw and log-transformed data.

## 2.8 Wet Detention Basin Analysis Findings

The BMP type analyzed in this study is a wet detention basin. In order to determine whether the found results are typical of wet detention basins, a synopsis of past study and analysis findings is required. The most recent BMP performance assessment document published by the Int'l BMP Database summarizes the entire data set through parametric and non-parametric descriptive statistics and hypothetical testing. To compare this data to other literature values, the removal efficiencies for the mean and median influent versus effluent concentration data sets are calculated. The statistical results for wet detention basins are summarized in Table 6 (Geosyntec Consultants and Wright Water Engineers, Inc. 2009). Parameters bolded are those that are determined to be statistically significantly different between the influent and effluent data sets, therefore indicating that the data is an acceptable assessment of the BMP effectiveness. Those in italics are not statistically significant. This significance is largely based on the Mann-Whitney test that proves statistical significance when the calculated p-value is less than the assumed α-value of 0.10 for 90 percent confidence. The calculated removal efficiency between the influent and effluent mean and median values for parameters applicable to the project is given in Table 7.

Other sources used to summarize typical wet detention pond removal efficiency are the Minnesota Pollution Control Agency (MPCA), the EPA, and the Center for Watershed Protection (CWP). The CWP published the *National Pollutant Removal Performance Database for Stormwater Treatment Practices* report in 2000. This report summarized the results of many BMPs, but the results presented herein are for wet detention ponds in general and regular wet detention ponds that are defined as ponds serving drainage areas between 0.04 and 1.21 square kilometers (Winer 2000). The removal efficiencies from the three literature sources are summarized in Table 8.

The analysis of the Int'l BMP Database conducted by Fassman (2011) found that detention basins clearly showed the least ability to produce low TSS effluent compared to all other BMP types analyzed. Over 70 percent of the effluent EMCs exceeded the commonly accepted 10 mg/L irreducible TSS concentration (Fassman 2011).

It was previously indicated that log-normal probability distribution is more common than normal distribution for water quality constituents; however, in Van Buren et al. it was found that for pond outflow, the normal distribution had a better fit for all analytes besides total phosphorus. The parameters tested in this analysis that are applicable to those tested herein were TSS, chloride, total phosphorus, ammonia, copper, and zinc (Van Buren et al. 1997).

Table 6. Summary of Int'l BMP Database wet detention basin efficiency results (Geosyntec Consultants and Wright Water Engineers, Inc. 2012).

| | **Count of Studies and EMCs** | | **25th Percentile** | | **Median (95% Conf. Interval)** | | **75th Percentile** | |
|---|---|---|---|---|---|---|---|---|
| **Parameter** | **In** | **Out** | **In** | **Out** | **In** | **Out** | **In** | **Out** |
| **TSS (mg/l)** | 20, 278 | 21, 299 | 24.2 | 11.3 | 66.8 (52.3, 76.1) | 24.2 (19.0, 26.0) | 121.0 | 22.0 |
| *Ammonia-N (mg/l)* | 5, 72 | 6, 94 | 0.04 | 0.04 | 0.09 (0.06, 0.11) | 0.10 (0.07, 0.12) | 0.23 | 0.21 |
| *Nitrate-N (mg/l)* | 7, 104 | 7, 97 | 0.35 | 0.25 | 0.65 (0.50, 0.77) | 0.59 (0.38, 0.63) | 1.0 | 0.93 |
| **Total P (mg/l)** | 18, 250 | 19, 275 | 0.19 | 0.13 | 0.28 (0.25, 0.30) | 0.22 (0.19, 0.24) | 0.51 | 0.36 |
| *Phosphate (mg/l)* | 2, 31 | 2, 31 | 0.28 | 0.22 | 0.53 (0.28, 0.82) | 0.39 (0.24, 0.56) | 1.26 | 1.03 |
| **Total Cu (µg/l)** | 12, 193 | 13, 203 | 4.83 | 2.11 | 10.62 (7.78, 14.00) | 5.67 (4.00, 6.80) | 31.0 | 15.0 |
| *Total Pb (µg/l)* | 12, 193 | 13, 204 | 1.80 | 1.10 | 6.08 (3.86, 8.00) | 3.10 (2.15, 4.30) | 41.0 | 11.0 |
| **Total Zn (µg/l)** | 12, 193 | 14, 212 | 22.0 | 8.0 | 70.0 (40.0, 95.0) | 29.7 (17.1, 38.2) | 230.00 | 72.80 |
| **E. Coli (#/100 ml)** | 3, 32 | 3, 32 | 398 | 60 | 1300 (460, 1990) | 429 (82, 720) | 12600 | 1880 |

Table 7. Removal efficiencies calculated from mean and median, influent and effluent concentrations.

| **Parameter** | **Removal Efficiency Ratio of Mean (%)** | **Removal Efficiency Ratio of Median (%)** |
|---|---|---|
| **TSS (mg/l)** | 63 | 64 |
| *Ammonia-N (mg/l)* | 80 | INCREASE |
| *Nitrate-N (mg/l)* | 22 | 9 |
| **Total P (mg/l)** | 20 | 22 |
| *Phosphate (mg/l)* | 33 | 25 |
| **Total Cu (µg/l)** | 55 | 47 |
| *Total Pb (µg/l)* | 69 | 49 |
| **Total Zn (µg/l)** | 67 | 58 |
| **E. Coli (#/100 ml)** | 86 | 66 |

Table 8. Summary of literature values for removal efficiency of wet detention ponds.

| | **MPCA$^{\alpha}$** | **EPA$^{\beta}$** | **CWP$^{\gamma}$** | |
|---|---|---|---|---|
| **BMP Type** | **Wet Detention Pond** | **Wet Detention Pond** | **Wet Detention Pond** | **Regular Wet Pond** |
| TSS | 84 | 67 | 79 | 80 |
| Total P | 50 | 48 | 49 | 49 |
| Nitrogen | - | 24$^{\beta}$ | 36$^{\gamma}$ | 62$^{\gamma}$ |
| Metals | 60$^{\alpha}$ | 25$^{\beta}$ | 62$^{\gamma}$ | 60$^{\gamma}$ |
| Bacteria | 70 | 65 | 70 | 66 |

$^{\alpha}$ Metals defined as average of zinc and copper (Minnesota Pollution Control Agency 2014).
$^{\beta}$ Nitrogen defined as nitrate as nitrogen, metals constituent inclusion not specified, (EPA 2014).
$^{\gamma}$ Nitrogen defined as nitrate plus nitrite as nitrogen, metals defined as average of zinc and copper (Winer 2000).

# CHAPTER III

# 3. METHODS

## 3.1 Introduction

The methods section of the report describes all techniques utilized in the completion of a sampling event from start to finish. This includes forecasting for adequate storms, precipitation measurements, flow measurements, sampling methods, and water quality analysis methods. Quality control measures for water quality testing are explained. Methods throughout the project course are adapted based on site conditions, more experience with sampling, and increased resource availability as time progresses. The statistical analysis methods applied to the determined water quality data are described. The completed analysis determines if the differences between inflow and outflow data are statistically significant.

## 3.2 Storm Forecasting and Frequency

Storm forecasting is one of the most important factors in best management practice (BMP) analysis due to the necessity for adequate precipitation for runoff generation and fairly steady rainfall intensity to avoid multiple inflow hydrographs within a single sampling event. Forecasting within this project begins with a historical event frequency analysis on publicly available data from local rain gages to determine the likelihood of events of certain cumulative rainfall within a specified annual season. Runoff generation for these typical events and a range of intensities and durations is then completed using hydrologic and hydraulic modeling software. Finally, the frequency analysis and runoff generation estimation is used during live forecasting of precipitation events that have sampling potential. Live forecasting is completed through the use of radar and weather predictions from entities such as the National Weather Service (NWS) and The Weather Channel, LLC (TWC). Details of forecasting methodology are given in subsequent sections.

### 3.2.1 Historical Event Frequency Analysis

A frequency analysis completed on data available from 1994 to 2013 through the National Climatic Data Center (NCDC) online climate database determines the probability of the occurrence of an event of a range of precipitation amounts. The ranges analyzed include less than 2.54 mm (0.10 in), 2.54 mm  to less than 12.7 mm (0.10 in to less than 0.50 in), 12.7 mm to less than 25.4 mm (0.50 in to less than 1.0 in), and greater than 25.4 mm (greater than 1.0 in). Since there is not an active rainfall gage directly at the site location, data for the frequency analysis is developed from two existing sites that have been in operation throughout the analysis period. One site is located at the Grand Forks International Airport, which is 12.1 kilometers from the project site and the other is at the University of North Dakota at the NWS weather station, which is 5.6 kilometers from the project site. The locations relative to the project site are depicted in 5 1. The compiled data are used to extract and organize the monthly data for May through October. Functions within Microsoft Excel complete a count on the number of events within the four ranges. The Quadrant Method determines the missing data at the project site, which weighs the data based on distance from gage to site. Once the missing data are found, the Thiessen Polygon Method weighs the data based on the amount of drainage area from contributing watersheds to the project drainage basin. This method does not allow for effects due to elevation changes, however, the topography of the surrounding area is relatively flat so these effects are minimal (Bedient et al. 2013). The frequency analysis predicts the likelihood of having an event of a certain size occur in a given month. Generally, events expected to be less than 2.54 mm (0.10 in) are not sampled due to not having adequate runoff amounts to obtain sufficient sample aliquots to represent the entire storm.

### 3.2.2 Runoff Estimation through Modeling

Hydrologic and hydraulic modeling is another form of rainfall runoff prediction utilized in the project. A model predicts runoff amounts for various storm durations and intensities to better understand the system's response to precipitation events. The model is created in HydroCAD, which is a computer aided design (CAD) program based on procedures developed by the Soil Conservation Service (SCS), now National Resources Conservation Service (NRCS) (HydroCAD Software Solutions LLC 2011). This model predicts the runoff based on the watershed impervious and pervious characteristics with a specified time of concentration. The model output results are used to develop a duration and intensity table of different storm events to help predict the occurring runoff in forecasted storm events.

Within the model, the areas are broken down into three subcatchments; one for the west inlet, one for the east inlet, and one for the grassed area directly draining to the pond. All of the area draining to the west inlet is considered developed, whether in-progress or fully developed. Based on current total site development, only twenty-one percent of the area draining to the east inlet is completed to date. The remaining area draining to the inlet is assumed to not reach the point of confluence due to not being hydraulically connected.

#### 3.2.2.1 HydroCAD Runoff Parameters

There are different methods built into HydroCAD that are used to generate the runoff to the designed detention pond. The runoff method utilized in this model is the SCS TR-20, which is a model based on the SCS TR-55 that estimates runoff using curve numbers (CN) determined by the subcatchment's soil and cover conditions (NRCS 1986). Impervious areas including rooftops, streets, driveways, permanent pond surface area, etc. are given a CN of 98. Pervious areas are given a CN of 74 based on fully developed urban area grass cover of greater than 75 percent with soils of HSG type C. The impervious and pervious areas are summarized for each subcatchment and calculated based on land use classification and the maximum percent impervious area as defined in the City of Grand Forks (City) Stormwater Management Standards and Design Manual (City of Grand Forks 2013).

Recall that the three subcatchments are divided by the areas draining to the west inlet, east inlet, and area directly draining to the pond. The pipe channel flow determines the time of concentration for the west and east inlets. The pipe channel flow is developed from the as-built pipe network based on the average slope, diameter, and total length of the longest pipe run conveyed to the detention pond. For the area directly draining to the pond, a time of concentration of six minutes is chosen as a conservative estimate.

As with any rainfall runoff estimation, TR-55 has limitations and critical parameters that are necessary to acknowledge before determining if the method is appropriate for the intended use. The critical parameter in TR-55 is the time of concentration. TR-55 is based on four distributions of a 24 hour period, in which Grand Forks is described by the Type II distribution. To analyze different durations of rainfall, the distributions were designed so that for a given cumulative rainfall amount, the most intense hour will approximate the design events' one-hour rainfall volume (NRCS 1986). As stated in (NRCS, 1986), the following lists the limitations and assumptions of utilizing TR-55:

- The methods are based on open and unconfined flow over land and in channels. Hydrograph methods are based on TR-20 output;
- CN values describe average conditions and are less accurate when runoff is less than 13 mm (0.5 in), and if the weighted CN is less than 40 a different method should be used to determine runoff;
- The initial abstraction term is generalized based on agricultural watersheds and needs to be used with caution in urban applications;
- SCS runoff procedures apply only to direct surface runoff.

For the purposes of this method in the project, the SCS TR-55 method is deemed appropriate. The accuracy of this estimate was not required to be high, because the simulation is only an estimate for determining the potential runoff in a forecasted event. The only questionable limitation is the generalized initial abstraction term.

**3.2.2.2 HydroCAD Routing Method**

The detention pond is modeled as a storage area with a specified stage-storage and stage-discharge relationship. The stage-storage curve is developed by the designed pond elevation versus surface area contours from bottom of pond to top ground surface. The stage-discharge relationship is based on the outlet structure configuration, which is an 18 inch reinforced concrete pipe (RCP) culvert with its invert at the pond permanent pool elevation of 251.05 meters above mean sea level (AMSL) and an emergency overflow outlet at elevation 252.22 meters AMSL for precipitation events that have runoff generation above the water quality volume. The pond routing method used in the model is the storage-indication method, which routes the runoff using the specified time span and time increment in the calculation settings. At each point in time, a storage-indication value is calculated based on the current inflow, plus the previous inflow, outflow, and volume in the storage area. Then, the current storage-indication value and storage-indication curve are used to determine the new elevation. Finally, the new elevation, stage-storage and stage-discharge curves are referenced to determine the new storage and discharge, with this process completed for all points in the inflow hydrograph (HydroCAD Software Solutions LLC 2011).

### 3.2.3 Live Forecasting

Forecasting and storm tracking for this project is completed with publicly available radar and precipitation potential estimation data found on sources such as the internet, television, radio, and mobile device applications. Internet and mobile device applications are the most readily used and are both based on the NWS and TWC. The intention of this section is to explain the methods that produce the most favorable results for determining when a sampling event is going to take place.

The first step in determining the next sample date is to view the ten-day outlook. In general, days with greater than 50 percent precipitation chance are flagged as potential events. This ten-day outlook changes on a daily basis, so flagged event dates are updated daily. Once a flagged event approaches, increased attention is made to determine at what part of the day the precipitation is expected to begin and what rainfall amount is expected to fall. Hourly data is observed to be most accurate from TWC due to more frequent updates of the forecast on the internet webpage. Note that the mobile device application does not always update as frequently, therefore the internet site is found to be more accurate. TWC does not predict the amount of rainfall expected to fall, but the NWS gives estimation closer to the event time and date within the detailed forecast and the hourly weather graph. Generally, events expected to produce less than 2.54 mm (0.10 in) of precipitation are not flagged to be sampled. Other descriptive terms used to determine sampling events are the type of precipitation predicted to fall. The NWS describes isolated storms as a precipitation descriptor for a ten percent chance of measurable precipitation, while scattered storms are those that have area coverage of convective weather affecting 30 to 50 percent of a forecast zone (National Weather Service 2009). These events are not preferred for sampling, however, can be sampled if expected to condense or accumulate into large storm cells. Avoid events expected to be severe or have intense wind gusts. Finally, attention is given to the observed amounts of precipitation that have fallen in areas the storm has already passed.

Visual determination of whether an event is going to occur at the project site is found by coupling all of the numeric and descriptive data within these entities with live radar and satellite imagery. TWC has a radar mapping tool that shows past and future weather patterns. This tool visually allows the prediction of isolated or scattered storms developing into steady rainfall events. The NWS uses a composite or base reflectivity map to show areas of potential precipitation. The different map legends are consulted to determine what intensity the color shown on the map is referencing. Generally, radar images with a large width both latitudinally and longitudinally over the project site are highly likely to be considered as sampling events.

### 3.3 Precipitation Measurement

The City has a supervisory control and data acquisition (SCADA) system that is used to monitor its water distribution and wastewater collection system, which includes rain gages at some of the sanitary lift stations. A SCADA system has a control center that performs centralized monitoring and control for field sites over long-distance communication networks (Stouffer et al. 2006). For the City, this control center is located at the Water Treatment Plant (WTP). There are a total of five rain gages connected to the SCADA system, in which three that created a bounding area around the project site are used to determine rainfall amounts for sampling events.

To obtain the data from the SCADA system, the Proficy Historian Microsoft Excel add-in is required. The WTP allows access to this data for use in the project. The three rain gages used to determine the rainfall at the project site are at sanitary lift stations one, 26, and 27, which are respectively located approximately 3.9, 1.4, and 2.6 kilometers away, which create a bounding triangle around the detention pond. The locations are provided in the aerial image presented as Figure 1. To determine the missing data at the site, the same method as indicated in section 3.2.1 is used. This includes distance weighting by the Quadrant Method and drainage area weighting by the Thiesson Polygon Method.

The rain gages are tipping bucket type that consists of a funnel that directs rainfall to one of two small buckets. Once one-hundredth of an inch of rain falls, a rocker mechanism empties the filled bucket and moves the empty bucket underneath the funnel

(Geosyntec Consultants and Wright Water Engineers, Inc. 2009). The data are available as instantaneous, daily, or monthly records, with the instantaneous data being that of a six-minute interval. The rainfall is recorded as a count of one-hundredths of an inch that fall within the six-minute time of concentration interval. The total rainfall for a given event is the sum of the count as one-hundredths of an inch, which is converted to inches by dividing by one hundred. For use in this project the rainfall is converted to millimeters. The most recent calibration of the rain gages is uncertain based on communication with City operators. Due to this uncertainty, comparison to the NWS gages at the Grand Forks University and Grand Forks International Airport is completed to determine potential error.

## 3.4 Flow Measurement

Sampling of stormwater to determine BMP effectiveness begins when the inflow runoff reaches the inlet of the detention pond. As inflow reaches the pond it fills the available storage and gradually discharges from the basin based on the outlet configuration and detention time. In order to capture the inflow and outflow hydrographs, continuous flow measurement is monitored at the inlet and outlet. In many applications, continuous water level measurements are coupled with basic Manning's equation calculations that incorporate the physical characteristics of the inlet and outlet conduit. The following sections describe the methods used to derive flow measurements and indicate methods for calibration of the loggers for depth and barometric compensation.

### 3.4.1 Water Level Measurements

One way to measure water level is to use HOBO Water Level Loggers that record absolute pressure and temperature at a specified interval. The model used in this project is the U20-001-01 that is accurate to a 9 meter depth with a maximum error of ±0.006 m of water. A summary of the HOBO Water Level Logger accuracy for pressure, water level, and temperature measurement is given in Table 9 on the following page**.** The absolute pressure is converted to water level based on either a reference water level measured in the field or barometric pressure readings from a source. If the barometric pressure is left uncompensated, the variations could result in errors of 0.6 or more meters (Onset Computer Corporation 2014). Another consideration is the water density, which varies with temperature. The barometric pressure compensation tool allows the option of adjusting water density based on the recorded temperature, which is utilized in this project. The software required to complete the barometric compensation is HOBOware© Pro and to purge the data from the loggers, a HOBO Waterproof Shuttle is required.

Barometric pressure can be measured using a HOBO Water Level Logger that is deployed above the water surface, rather than in the water with the logger measuring the water depth. During the project, this was not possible until later on when the decision was made to only test one BMP and loggers from the other site became available. Other methods to compensate for barometric pressure include utilizing data from a local weather station, assuming a constant value throughout the storm duration, or taking reference levels during the sampling event. Barometric pressure readings are generally accurate across a 1.6 km or more distance without significantly degrading the accuracy of the compensation (Onset Computer Corporation 2014). Data for barometric pressure at a five minute interval are available from the NWS weather station in Grand Forks upon request. Once these data are obtained it is organized into the appropriate format to be used as a barometric pressure compensation file within HOBOware© Pro.

Table 9. Summary of HOBO Water Level Logger accuracy (Onset Computer Corporation 2014).

| | |
|---|---|
| **Pressure and Water Level Measurement Accuracy** | |
| Operation Range | Pressure: 0 to 207 kPa, Depth: 0 to 9 m |
| Factory Calibrated Range | Pressure: 69 to 145 kPa, Temperature: 0 to 40 °C |
| Water Level Accuracy | Typical Error: ± 0.003 m, Maximum Error: ± 0.006 m |
| Raw Pressure Accuracy | Maximum Error: ± 0.43 kPa |
| Response Time (90%) | <1 second |
| **Temperature Measurement Accuracy** | |
| Operation Range | Temperature: -20 to 50 °C |
| Accuracy | Temperature: ± 0.44 °C from 0 to 50 °C |
| Response Time (90%) | 5 minutes |

Due to not having instantaneous access to the local barometric pressure data during a sampling event, flow weighted composite sampling, which is explained in section 3.5.2, is completed using reference levels that are taken throughout the event. The project includes three sampling events that have a representative composite sample, and the first two events were composited in this manner. The last event has barometric compensation from a logger that was solely deployed for barometric pressure readings. The relative percent difference (RPD) in utilizing the reference levels over actual barometric pressure readings is provided in later sections. RPD is used to determine precision and the equation for calculating the quantity is below.

$$RPD = \frac{(X_1 - X_2) * 100}{(X_1 + X_2)/2}$$

In the RPD equation, $X_1$ is equal to the larger of the two values being compared and $X_2$ is the smaller of the two (EPA 1996).

### 3.4.2 Conversion to Flow

Manning's equation is used to convert the water level measurements to flow, which create the stage-discharge relationship. This equation applies to uniform flow in open channels and is a function of the channel area, hydraulic radius, channel slope, and Manning's n roughness coefficient. Since both the inlet and outlet pipes have circular cross sections, the equations presented herein are Manning's equation modified for circular conduit. Manning's equation is described and given in section 2.5.2.

Manning's n roughness coefficient is based on the material of the channel, which in this case is concrete that has a typical n-value range of 0.011 to 0.015 based on the *in-situ* pipe characteristics (Brown et al. 2013). The minimum value corresponds to a smoother surface. The slope of the channel is based on the upstream and downstream invert elevations, which are determined from site as-built plans. The area and hydraulic radius, area divided by wetted perimeter, can be found with the equations below. In these equations, d is equal to the pipe diameter in meters, and y is equal to the water depth in meters as measured by the water level loggers.

$$A = \frac{(\theta - sin\theta)d^2}{8}$$

$$Wetted\ Perimeter = \frac{\theta d}{2}$$

$$\theta = 2\cos^{-1}\left[1 - 2\left(\frac{y}{d}\right)\right]$$

The limitations to using Manning's equation are that it can only be applied to relatively uniform flow conditions. In conduit flow, Manning's equation cannot be used if the pipe inlet is submerged or backwater is present from downstream features. In this case, the pipe is acting as a submerged culvert and different governing equations would apply to the flow condition. For this reason, sampling events are only completed on those that have unsubmerged conditions at the inlet and outlet to the detention pond.

The stage-discharge curves for the inlet and outlet are not given because the previously given equations for calculating flow of a circular conduit with Manning's equation were used in every measurement taken at the five-minute interval during monitored events. This was found to be more accurate, rather than visually identifying the flow from a stage-discharge curve.

An adjustment that is made before determining the flow is for the zero-flow depth at the outlet. This requirement is not necessary at the inlet because the normal pond water surface elevation (WSEL) is below the inlet invert. At the outlet, however, the WSEL is at or slightly above the outlet invert of 251.05 meters AMSL. For this reason, a WSEL measurement directly before precipitation events is taken to correct all water level measurements before converting to flow. This method allows correction of the outflow hydrograph for zero-flow depth.

Recall that the wet detention pond analyzed in this assessment has two inlets and one outlet. Analysis of the current development progress estimates that roughly 70 percent of the developed drainage area routed to the pond reaches the west inlet. The other 30 percent is area that directly drains to the pond without reaching a storm sewer system and the area that drains to the east inlet. Due to limited water level loggers at the start of the project, loggers were only deployed at the west inlet and detention pond outlet to determine the inflow and outflow hydrographs throughout a sampling event. When determining the total inflow, it is assumed that the difference between inflow and outflow volume is attributed to the thirty percent of drainage area not captured by the west inlet. This is verified with the relative percent difference in the inflow and outflow runoff volumes for each event. For the final sampling event, a water level logger was available to be deployed at the east inlet to determine the inflow volume attributed to that drainage area. This was also used as a comparison to the fact that inflow and outflow volume should generally be equal, with minor losses to infiltration from the poor infiltrating soils beneath the pond, since this pond was designed for detention, not retention.

### 3.4.3 Calibration and Sensitivity Analysis

In order to determine the accuracy of the water level loggers and the conversion to flow, simple calibration and sensitivity analysis techniques are applied.

The calibration of the water level logger’s response to changes in WSEL is tested in a bucket experiment. During this experiment, the loggers are placed in a bucket with a known water depth that is measured to check against the depth measurement recorded by the logger. Since the logger collects data with an internal clock, the time of measurement is also recorded. Changes in WSEL are made throughout the experiment. Accuracy of the logger to adapt to the changes is determined by comparison of the measured water depths to the purged logger data that is compensated for barometric pressure.

A sensitivity analysis for the use of Manning's equation to determine flow at the inlet and outlet is necessary. This includes the determination of the percent difference in the calculated flow when certain variables within the equation are altered. The variables analyzed are Manning's n roughness coefficient and the slope of the conduit. Manning's n was observed for sensitivity between the typical ranges of 0.011 to 0.015 for concrete conduit. The slope of the conduit is altered by plus or minus 20 percent of the as-built plan slope condition. The sensitivity is represented as a RPD.

## 3.5 Stormwater Sampling Methods

There are a variety of ways that stormwater can be collected and proportioned for use in determining BMP effectiveness, however, project resources lead to limitations and the necessity to create a sampling plan with what is currently available without adding extensive cost to the project. This section describes the different methods used in the collection of stormwater samples. The methods changed over the course of the project as more knowledge was gained on proper methods to be able to make a comparison to published literature values and as more resources were made available.

### 3.5.1 Sampling Location

The Int'l BMP Database states that an upstream and downstream sampling location is required to determine whether the BMP provides a measurable and statistically significant change in water quality and whether the effluent concentration is comparable to similar BMPs to assess whether the BMP is achieving typical effluent water quality (Geosyntec Consultants and Wright Water Engineers, Inc. 2009). The chosen sampling locations for this project are the west inlet and detention pond outlet directly within the cross-sectional area of flow being monitored with water level loggers.

### 3.5.2 Sample Collection Techniques

The two types of collection techniques used in this project are grab samples and composite samples. A grab sample is one that is taken at a particular instance and location during a storm event. A composite sample is a compilation of grab samples put together based on either time or flow proportioning. The different methods of composite sampling are given in Table 4. The constant time with volume proportional to flow volume increment is the method used in the project.

Early on in the project before the importance of obtaining an EMC for comparison to other wet detention pond literature values was understood, sampling was only done with single grab samples taken subsequently at the inlet, then at the outlet. During this sampling, the water depth was measured to determine the flow at the sampling instance. With only taking singular grab samples it is possible to measure parameters such as pH and dissolved oxygen, which are not possible with composite sampling because the parameters degrade too rapidly and the available equipment does not have the necessary meters to measure the analytes in the field. The limitations with certain parameters within the baseline study are discussed in later sections.

As the project progressed, further understanding of the importance of composite sampling became evident and the technique was adopted to have data that is comparative to literature values. The composite sampling included manual flow-weighted compositing from autosampler collected aliquots and manual flow-weighted compositing from manual grab sample aliquots.

In mid-August an autosampler became available from the City's Wastewater Treatment Plant (WWTP). The autosampler is a Teledyne ISCO 6700 Full-Size Portable Sampler. While this sampler has the capability to add flow and water quality parameter meters to the analysis, these additional components were not available for use. Since a flow meter was not available to automatically trigger when a sample aliquot was taken, aliquots of the same size were taken at a specified time interval and then manual flow-weighted compositing is completed based on flow volume increments. The amount of water removed from each aliquot is proportional to the volume of flow since the preceding aliquot was sampled. Total volume throughout an event is determined by the area beneath the runoff hydrograph. The area, or total volume, between the aliquots is calculated as a percent of the total runoff volume. Then, to obtain a 2000 mL composite sample for water quality analysis to be completed upon, the volume required from each aliquot is determined by multiplying 2000 by the calculated percent of the total runoff volume. The autosampler was utilized at the detention pond outlet when available for use from the WWTP.

Since there is only one autosampler available, sampling at the inlet during events was completed manually. This method is completed by taking grab samples at intervals over the entire inflow hydrograph duration to obtain an accurate EMC of the influent. The manual flow-weighted compositing is done in the exact same manner as the automatically sampled stormwater aliquots.

### 3.5.3 Sampling Duration and Frequency

Sampling duration was completed over the entire course of the inflow and outflow hydrograph. Since the wet detention pond is designed to detain water for an amount of time to sufficiently allow settling and sedimentation of suspended solids and other pollutants, the outflow hydrograph has a longer duration than the inflow hydrograph. The autosampler is placed at the outlet to continue sampling until the outflow hydrograph falls back down to the zero-flow depth without needing an operator present to collect samples.

The frequency of sampling is not an exact science, but it is important to get samples at the beginning, in the rising limb, at the peak, and in the falling limb of the event. Samples in the beginning of the event represent the first-flush of pollutants that reach the detention pond. The first-flush effect occurs when pollutant concentrations during runoff events peak early and typically before the discharge peak (Tiefenthaler and Schiff 2002). The composite samples do not weight the first-flush aliquots any different but it is still important to capture the samples to ensure peak concentrations of pollutants are included at their proper proportion. The frequency is generally based on the expected duration of the storm event based on the forecast and radar. For instance, the autosampler is only capable of taking 24 samples without having to switch out sampling containers during an event, so the sample aliquots are spaced accordingly to capture the full extent of the detention pond discharge. In both events that utilized the autosampler, sample frequency was at a shorter interval at the onset of the outflow hydrograph and then the interval between samples expanded after the peak discharge was reached. This same method was used for the manual inflow grab samples.

## 3.6 Water Quality Analysis

This project is considered a baseline study on the effectiveness of an *in-situ* post-construction BMP located within an urban drainage basin. Since it is a baseline study, the water quality analysis includes a large amount of parameters. Field measurements include pH and temperature along with reference water levels to compare to the water level logger readout. Measurements completed in the laboratory are total suspended solids (TSS), nutrient analytes that include total phosphorus as phosphate, phosphate as orthophosphate, ammonia as nitrogen, nitrite as nitrogen, and nitrate as nitrogen, bacteria as *E. Coli* as a count per 100 milliliters, chloride, dissolved oxygen, and conductivity. The heavy metals analyzed include total copper, total lead, and total zinc, which are analyzed by Minnesota Valley Testing Laboratories, Inc (MVTL). The preservation and synopsis of the analytical methods of each parameter are described in this section. The detailed analytical procedures are presented in external sources as referenced herein. Quality control measures of the water quality analysis are also discussed.

### 3.6.1 Preservation

Proper preservation of water quality samples is important in analysis to ensure non-degradation of analyte concentrations over time. The preservation techniques adapted herein are compiled from (APHA et al. 2005) and (LaMotte Company 2009a). A summary of preservation techniques and maximum recommended storage times for the determination of the analyte concentrations are given in Table 10.

### 3.6.2 Analytical Methods

This section summarizes the analytical methods and equipment required to complete the water quality analysis for this baseline study. As noted previously, much of the analysis occurs in the laboratory, which is located at the City's WTP. Heavy metals are the only parameters sent for analysis at MVTL. The methods are summarized briefly in Table 11 and discussed in more detail subsequently.

Table 10. Summary of preservation techniques and maximum storage time for determining analytes (APHA et al. 2005) and (LaMotte Company 2009a).

| **Analyte Determination** | **Preservation Technique**$^{\alpha}$ | **Maximum Storage Recommended** |
|---|---|---|
| Ammonia as Nitrogen | Analyze as soon as possible or add $H_2SO_4$ to pH <2, refrigerate | 7 days |
| Bacteria | Analyze as soon as possible | 24 hours |
| Chloride | None required | not stated |
| Conductivity | Refrigerate | 28 days |
| Dissolved Oxygen (Winkler Method) | Titration may be delayed after acidification | 8 hours |
| Nitrate as Nitrogen | Analyze as soon as possible, refrigerate. For extended preservation, add 2 mL of $H_2SO_4$ per liter of sample | 48 hours if no acidification |
| Nitrite as Nitrogen | Analyze as soon as possible, refrigerate | None |
| pH | Analyze immediately | 0.25 hours |
| Phosphate as Orthophosphate | Refrigerate or for extended preservation, add 2 mL of $H_2SO_4$ per liter of sample | 48 hours if no acidification |
| Temperature | Analyze immediately | 0.25 hours |
| Total Copper | Add $HNO_3$ to pH <2 | 6 months |
| Total Lead | Add $HNO_3$ to pH <2 | 6 months |
| Total Phosphorus as Phosphate | Refrigerate or for extended preservation, add 2 mL of $H_2SO_4$ per liter of sample | 28 days if acidified |
| Total Suspended Solids | Refrigerate | 7 days |
| Total Zinc | Add $HNO_3$ to pH <2 | 6 months |

$^{\alpha}$ Refrigerate = storage at 4°C ± 2°C; in the dark; analyze immediately = analyze usually within 15 minute of sample collection

Table 11. Summary of analytical methods used in water quality analysis.

| **Parameter** | **Analytical Method Description** |
|---|---|
| Ammonia as Nitrogen | LaMotte Company Smart 2 Colorimeter reagent kit |
| Bacteria as *E. Coli* | Colilert Test Kit that measures *E. Coli* as a count of multi-wells with fluorescence equal to or greater than the comparator that is then converted to a MPN |
| Chloride | LaMotte Company Smart 2 Colorimeter reagent kit |
| Conductivity | Laboratory analysis with Fisher Scientific AB30 Accumet Basic Conductivity Meter |
| Dissolved Oxygen | Laboratory analysis completed with the Azide Modification Method, or Winkler Test |
| Nitrate as Nitrogen | LaMotte Company Smart 2 Colorimeter reagent kit |
| Nitrite as Nitrogen | LaMotte Company Smart 2 Colorimeter reagent kit |
| pH | Laboratory analysis with Orion model 420A+ pH meter calibrated with Fisher pH standard solutions<br>Field analysis with Oakton pH 300 Series Meter calibrated with Fisher pH standard solutions |
| Phosphate as Orthophosphate | LaMotte Company Smart 2 Colorimeter reagent kit |
| Temperature | Measured with HOBO Water Level Loggers and compared to field measurements with Oakton pH 300 Series Meter |
| Total Copper | Preserved with nitric acid and sent to MVTL for analysis. Metal digestion with EPA Method 200.2. Laboratory analysis with inductively coupled plasma-atomic emission spectrometry |
| Total Lead | Preserved with nitric acid and sent to MVTL for analysis. Metal digestion with EPA Method 200.2. Laboratory analysis with inductively coupled plasma-mass spectrometry |
| Total Phosphorus as Phosphate | LaMotte Company Smart 2 Colorimeter reagent kit. Tuttnauer EZ10 Tabletop Autoclave used for the digestion process |
| Total Suspended Solids | Measurement based on filterable residue in a sample size. The original crucible weight is subtracted from the crucible weight plus filtered residue after an hour long drying period |
| Total Zinc | Preserved with nitric acid and sent to MVTL for analysis. Metal digestion with EPA Method 200.2. Laboratory analysis with inductively coupled plasma-atomic emission spectrometry |
| Water Depth for Flow | Measured with HOBO Water Level Loggers at 5-minute interval and compared to field measurements with handheld device |

The parameters tested in the field are pH, temperature, and reference water levels for comparison to the water level logger output. In the beginning of the project a portable pH meter was not available, so it was tested in the laboratory with an Orion model 420A+ pH meter. Recall that the maximum storage recommendation before measurement for pH is 0.25 hours. Since the Orion meter was not portable, measurement of pH was completed as soon as the samples were brought back to the laboratory, which was generally within one hour of sampling. Measurements of pH with the laboratory meter were only completed on grab samples taken in early parts of the project. Prior to utilization of the meter, daily calibration with Fisher pH standard solutions was completed. The full methodology for calibration and measurement is given in Job (2013).

The pH preservation time presents obvious issues with utilizing the laboratory meter for composite samples considering a 15-minute travel time from site to laboratory and durations of storm events of at least four hours for all sampled events. To compensate for this problem, a portable handheld Oakton pH 300 Series Meter was made available by the WTP to take pH and corresponding temperature measurements in the field. This meter is also calibrated prior to use with Fisher pH standard solutions. When utilizing the autosampler, pH is not measured due to inaccessibility of the sample containers during sampler operation.

Temperature is also measured at a five minute interval throughout the entirety of the sampling event by the water level loggers. The temperature is utilized as both a measured parameter and a compensation tool for pH and the water density throughout the storm duration. Reference water level measurements are taken with each manual grab sample to a sixteenth of inch accuracy with a handheld measuring device. The measurement is converted to millimeters for use in all comparisons. These are utilized for field determination of probable peak discharge occurrence and for comparison to water level logger output.

Simply put, ammonia as nitrogen, chloride, nitrate as nitrogen, nitrite as nitrogen, phosphate as orthophosphate, and total phosphorus as phosphate are determined using a LaMotte Company Smart 2 Colorimeter. This apparatus uses colorimetry to determine the concentration of the analyte being measured. "Colorimetry is defined as the measurement of color and a colorimetric method is any technique used to evaluate an unknown color in reference to known colors" (LaMotte Company 2009b). Within a colorimetric technique, the intensity of the color from the reaction is proportional to the concentration of the sample being tested. The Smart 2 Colorimeter is an EPA-accepted instrument that meets the requirements for instrumentation as found in test procedures that are approved for the National Pollutant Discharge Elimination System (NPDES) compliance monitoring program (LaMotte Company 2009b). Reagent kits for the six analytes measured by colorimetry are used to cause the occurrence of the necessary chemical and physical reactions. These reagent kits are only accurate within certain ranges of concentration, so in some circumstances sample dilution is required. The measured concentration is adjusted by the dilution factor to determine the actual concentration of the sample. Other equipment utilized in these methods are a Tuttnauer EZ10 Tabletop Autoclave as a chemical oxygen demand (COD) reactor to accelerate the digestion process in the procedure for total phosphorus, various sized Serological graduated pipettes and measuring spoons for adding reagents in all methods, and an assortment of glassware for storage and measurement throughout the procedures. The detailed methods for analysis using the LaMotte reagent kits are given in LaMotte Company (2009a).

Bacteria in the form of *E. Coli* is determined using the Colilert Test Kit that determines the most probable number (MPN) based on a count of multi-wells with fluorescence equal to or greater than the comparator. The MPN per 100 milliliters of samples is determined from an IDEXX Quanti-Tray®/2000 MPN Table. The analysis method is given in IDEXX Laboratories, Inc. (2013).

TSS is a measure of the dry weight of filterable (retained) residue in the stormwater sample. To ensure accuracy of this technique, an analytical balance capable of precision to the 0.1 milligram is required. The method also requires the presence of a drying oven set at a range of 103°C to 105°C. TSS measurement at the City's WTP follows the method described in Job (2013).

Dissolved oxygen was only measured in the beginning of the project when singular grab samples were being taken. This was due to the short maximum storage recommendation for the test, similar to the measurement of pH in the laboratory. The method utilized is referred to as the azide modification method, which is more commonly known as the Winkler Test. This method includes the addition of four separate reagents. The initial precipitate is manganous hydroxide that combines with the dissolved oxygen to form a brown precipitate of manganic hydroxide, which is then acidified with sulfuric acid to form manganic sulfate that acts as an oxidizing agent. The iodine from one of the added reagents is freed upon acidification and is then titrated until the proper color change is observed (EPA 1983b). This method is described in APHA et al. (2005).

The final parameter tested in the laboratory is conductivity. The apparatus utilized in this test is a Fisher Scientific AB30 Accumet Basic Conductivity Meter accompanied by a conductivity probe and a temperature compensation probe. This analysis requires the comparison to a conductivity standard, which is required to be within ten percent of the actual for quality control purposes. The measurement is simply determined by allowing the stabilization of the probe reading and recording the value in microsiemens per centimeter (μS/cm), as described in Job (2013).

As previously stated, the heavy metals are sent to MVTL for analysis. The containers for sending the samples are obtained from MVTL prior to the sampling event. The required container is a 500 milliliter plastic bottle that arrives with the necessary amount of nitric acid to add to the sample once it is obtained. The nitric acid preserves the sample and allows for shipment of the samples to the testing lab. With the shipment, a chain of custody form is required to identify the project and samples. A copy of the completed chain of custody form is saved in the project records. The methods used by MVTL are identified in the provided results, which are approved by an environmental laboratory supervisor before being made available. For the metal digestion, EPA Method 200.2 is utilized. Total copper and total zinc are tested using inductively coupled plasma-atomic emission spectrometry and total lead is tested using inductively coupled plasma-mass spectrometry.

Reporting of the water quality data measured in this project based on concentration is given in the units of milligrams per liter (mg/l). Some of the methods provide measurements in parts per million (ppm), which is considered to be equivalent. This previous statement is only true because the specific gravity of the base fluid, being water, is very close to unity. As long as the amount of dissolved solids is less than about one percent, a liter of water weighs approximately one-thousand grams, which is equal to one-million milligrams or one part per million (TETRA Technologies, Inc. 2007).

### 3.6.3 Quality Control

This baseline water quality analysis project requires a degree of quality control (QC) in order to provide data with quality assurance. The internal QC measures taken throughout the project include lab analyst training, proper equipment calibration and documentation, concentration reproducibility through duplicate sample analysis and reference field measurements for comparison to other forms of measurement of the same analyte.

For field measurements, the QC control measures have been mentioned throughout preceding sections. Recall that QC of pH is within calibration of the laboratory and handheld meters utilized throughout analysis. Temperature is measured by both the handheld pH meter and the water level logger, with the RPD given in the project results. The water level derived from the HOBO Water Level Logger is verified with reference water level measurements taken with grab samples and calculated RPD values.

The main QC measures taken in laboratory analysis are equipment calibration and duplicate samples at a frequency of ten percent or one per set of samples, whichever is the greater frequency. Generally, the analysis of each parameter is completed on two samples at a time and at least one duplicate sample is measured. Other specific QC measures for individual analytes are given in the detailed water quality analysis methods provided in the referenced sources. Lab analyst training was provided by the City's Environmental Lab. The heavy metal QC parameters are listed in the MVTL standard operating procedure (SOP) for each analysis (MVTL 2012). QC between samples and duplicates of the sample is represented as a RPD in the results portion of the report. In general, the smaller the RPD, the more precise the measurement is (EPA 1996).

The detection limit, or minimum reporting limit (MRL), is defined as the lowest concentration of a given pollutant that the methods or equipment utilized can detect and report as greater than zero. If the value falls below the MRL, the measurement is too unreliable to include in the data set (EPA 1996). The preassembled LaMotte reagent kits come with a measurement range that provides the range of reliable measurements of the Smart 2 Colorimeter device. The detection limit or measurement range utilized in the project for the constituents tested is summarized in Table 12.

Table 12. Summary of detection limit or measurement range.

| **Parameter** | **MRL** | **Measurement Range** |
|---|---|---|
| Ammonia as Nitrogen[α] | | 0.00 – 1.00 mg/l |
| Chloride[α] | | 0.0 – 30.0 mg/l |
| Conductivity[β] | | 10 – 2000 μS/cm |
| Dissolved Oxygen[β] | | 0.0 – 15.0 mg/l |
| Nitrate as Nitrogen[α] | | 0.00 – 3.00 mg/l |
| Nitrite as Nitrogen[α] | | 0.00 – 0.80 mg/l |
| pH[β] | | -2.00 to 16.00 pH |
| Phosphate as Orthophosphate[α] | | 0.00 – 3.00 mg/l |
| Temperature[β] | | -5.0 to 105 °C |
| Total Copper[γ] | 0.05 | |
| Total Lead[γ] | 0.0010 | |
| Total Phosphorus as Phosphate[α] | | 0.00 – 3.50 mg/l |
| Total Suspended Solids[β] | 5 | |
| Total Zinc[γ] | 0.05 | |

[α] Measurement range from Lamotte Company reagent kit for analyte
[β] MRL or measurement range from WTP equipment manual or analysis method
[γ] MRL from MVTL SOP for analyte

The final form of QC utilized in the project is ethical integrity. As an Engineer in Training, upholding integrity in all practices related to engineering is an expectation. The data obtained in this project was analyzed with this expectation and honesty in mind, and data were in no circumstance falsely represented.

### 3.7 Single-Event Performance

Initial approaches of evaluating BMP performance look at intra-event removal efficiencies between the influent and effluent concentrations. As previously indicated the project began with single grab samples at the inlet and outlet and ended with flow-weighted composite samples of the influent and effluent over the entire storm duration. Due to the difference in these techniques, average removal efficiencies for grab samples and composite samples are calculated separately. For grab samples, the influent and effluent concentrations at a single point in time during an event are determined. Removal efficiency is calculated with the following equation, which is a modified version of the mean concentration method defined in (Geosyntec Consultants and Wright Water Engineers, Inc. 2009).

$$Single\ Instance\ Removal\ (\%) = \left(1 - \frac{outlet\ concentration}{inlet\ concentration}\right) * 100$$

This equation assumes that the removal percentage is only indicative of the flow at the time of the grab sample.. The efficiency ratio method weights the EMCs for all storms equally regardless of the magnitude of the storm and is most useful when the pollutant loads are directly proportional to the storm volume (Geosyntec Consultants and Wright Water Engineers, Inc. 2009). The efficiency ratio as a percentage is calculated with the following equation. Composite sample intra-event removal efficiency is based on a ratio of the effluent and influent EMC

$$Efficiency\ Ratio\ (\%) = \left(1 - \frac{outlet\ EMC}{inlet\ EMC}\right) * 100$$

Average efficiency ratios are then calculated to determine the overall BMP removal efficiency for the given parameter. Limitations in this determination arise when an increase in concentration at the outlet occurs or when the effluent exhibits a non-detectable concentration. Increases in EMCs at the effluent lead to conclusions of poor or non-existent removal of the parameter. If concentration goes from a detectable value to non-detectable, the concentration is assumed to be the MRL or the minimum value of the detection range. For the LaMotte analytical tests the minimum detection range is zero. If the concentration assumptively goes from detectable to zero it is considered one-hundred percent removal, however, this assumption provides provisional conclusions of removal efficiency. To visually represent the influent and effluent EMCs, time series plots of concentration versus date of sampling are presented for each parameter. Again, non-detection is represented as the MRL or minimum value in the detection range.

## 3.8 Statistical Analysis

The efficiency ratio for a parameter gives the preliminary indication of whether the BMP is effectively removing the pollutant. This preliminary conclusion must be paired with statistical evidence that the influent and effluent concentration data sets are significantly different. The methods utilized in this project are based on the Int'l BMP Database effluent probability method with slight modifications for a small sample size. To simplify the statistical analysis, Minitab 17, which is an all-inclusive statistical software package for analyzing data sets, is utilized. This software has the statistical tests performed herein directly built-in for intuitive analysis.

With a small sample size for comparison of influent and effluent data, it is more difficult to draw conclusions on the trends and results of the statistical analysis. Since the sample size obtained for the project is small, both parametric and non-parametric descriptive statistics were identified. For each parameter, the median, mean, standard deviation, first quartile ($25^{th}$ percentile), and third quartile ($75^{th}$ percentile) were summarized. The first and third quartiles identify the interquartile range (IQR). The IQR is then used to determine the confidence interval of the median by the following equation developed on the work of (McGill et al. 1978), where n is the sample size.

$$Confidence\ Interval\ of\ Median = Median\ \pm 1.7\left(\frac{1.25 * IQR}{1.35\sqrt{n}}\right)$$

The extent to which the 95 percent confidence intervals for the influent and effluent EMC distributions overlap is a good indication of whether the medians can be considered statistically different (Geosyntec Consultants and Wright Water Engineers, Inc. 2009).

Further consideration of non-detects is needed in the extended statistical analysis. Non-detection of a parameter concentration is common, which causes bias and misrepresentation of the statistics of the data set. With a small data set, non-detects can cause severe bias. Since this is the case within the project, parameters that have greater than one non-detect are determined to reject the overall project hypothesis of statistical significance between the influent and effluent concentrations. Like the analysis on intra-event efficiency, to perform statistical analysis on non-detects, a common approach is simple substitution of all non-detect values with the analytical procedures MRL or minimum value of the detection range (Geosyntec Consultants and Wright Water Engineers, Inc. 2009). This is the utilized approach in the research.

Before using hypothetical testing to determine statistical significance, the distributional characteristics of the data set are determined using this Ryan-Joiner test, which is similar to the Shapiro-Wilks W-test as used in the Int'l BMP Database effluent probability method. The Ryan-Joiner test is based on the correlation between the sample data and the data expected from a normal distribution (Minitab Inc. 2013). The Ryan-Joiner test determines a coefficient that must be greater than the critical value for the α-value of 0.05 and the sample size. This critical value is approximated in Ryan, Jr. and Joiner (1976) as 0.8781 for the α-value and sample size utilized in this project. The distributional characteristics for the influent and effluent raw and log EMC values are determined with this method.

The next step is a hypothetical test of the statistical significance between the influent and effluent medians with the non-parametric Mann-Whitney test. The assumptions of the Mann-Whitney test require one dependent variable measured at the continuous level, one independent variable that consists of two independent groups, no relationship between the observations in each group, and the distribution for both groups must have the same shape (Lund Research Ltd, 2013). The Ryan-Joiner test allows the comparison of the sample shape between the influent and effluent EMCs, which are the independent groups for the Mann-Whitney test. The Mann-Whitney test was completed with the null hypothesis of "influent and effluent median EMCs are equal" for both 90 and 95 percent significance levels. The null hypothesis is rejected if the calculated p-value is less than or equal to the α-value. Statistical significance between the influent and effluent median EMCs is considered true if the null hypothesis for the Mann-Whitney $\alpha <$

0.10 is rejected. This determination is considered provisional due to other considerations of the comparison of the sample distribution, sample variances, and small sample size.

The final hypothetical test completed on the data is the Levene test that identifies statistical significance between the influent and effluent data sets at the 90 and 95 percent confidence interval. The null hypothesis is that “the two variances are equal”. It is rejected if the calculated p-value is less than or equal to the α-value. The Levene test is completed on both the raw and log-transformed data. Generally, comparison between different data sets requires that the sets have the same variances (Geosyntec Consultants and Wright Water Engineers, Inc. 2009). With this in mind, for this statistical significance analysis, the influent and effluent can be compared as long as the null hypothesis is not rejected.

The final visual representations of the data included in the analysis are lognormal probability plots of concentration versus non-exceedance percentage. Probability plots show how well the EMC data at the influent and effluent fit a normal distribution and the relationship between the two distributions. As indicated previously, water quality observations generally fit on log-normal probability plots (Geosyntec Consultants and Wright Water Engineers, Inc. 2009). The distribution of the data set is visually determined by the relative fit of the points on the extrapolated straight line within the plot. When the influent and effluent distributions are plotted on the same graph, the data sets are observed to have similar variances when the straight lines are generally parallel.

The applied statistical methods and visual representations created for each analyte are summarized in Figure 4 as a flow chart.

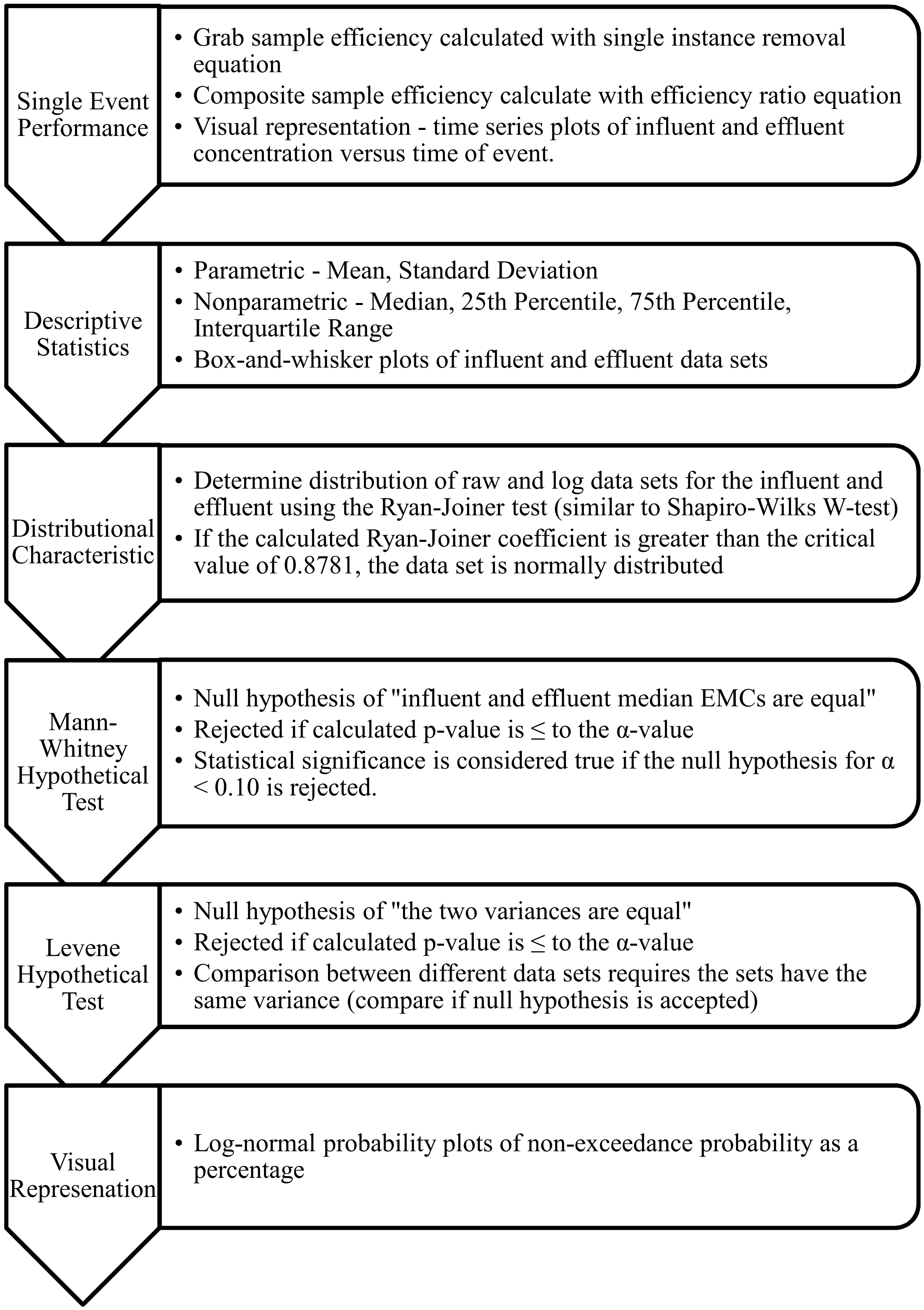



Figure 4. Summary flow-chart of statistical analysis and visual representations.

# CHAPTER IV

# 4. RESULTS

## 4.1 Introduction

This section of the paper summarizes the results of the project that are relevant for defending the hypothesis that the applied sampling plan, analytical methods, and statistical analysis determines the effectiveness of the studied best management practice (BMP). The methods for determining these results are given in the preceding chapter. The data presented within the report is summarized. Detailed results are presented in corresponding appendices as indicated in the subsections.

## 4.2 Storm Forecasting

Storm forecasting to determine events that produce adequate runoff for sampling is completed within the project through historical event frequency analysis and runoff estimation through hydrologic and hydraulic modeling using the software HydroCAD.

The summary of event totals for the frequency analysis period of May through October of 1994 through 2013 is given in Table 13. The frequency analysis results for the entire analysis period based on the less than 2.54 mm (0.1 in), 2.54 mm (0.1 in) to less than 12.7 mm (0.5 in), 12.7 mm (0.5 in) to less than 25.4 mm (1.0 in), and greater than 25.4 mm (1.0 in) ranges are given graphically by Figure 5. This graph shows the relative frequency of the likelihood of total number of event occurrence throughout the entire May through October analysis period for these ranges. As an example, from Figure 5, the relative frequency of the occurrence of 15 to 18 events that are 2.47 to 12.7 mm is 35 percent. The independent monthly frequency analysis, including relative and cumulative frequency, is given in Table 29 of Appendix A. Precipitation data for the frequency analysis were obtained from the National Climatic Data Center (NCDC) online climate database (NOAA 2014).

Table 13. Historic Precipitation Event Summary for May through October of 1994 to 2013.

| Year | < 2.54 mm | >= 2.54 to < 12.7 mm | >= 12.7 to < 25.4 mm | >= 25.4 mm | Total |
|---|---|---|---|---|---|
| 1994 | 28 | 17 | 11 | 3 | 59 |
| 1995 | 29 | 17 | 8 | 6 | 60 |
| 1996 | 23 | 10 | 8 | 2 | 43 |
| 1997 | 22 | 19 | 7 | 3 | 51 |
| 1998 | 30 | 21 | 5 | 6 | 62 |
| 1999 | 27 | 17 | 11 | 2 | 57 |
| 2000 | 32 | 16 | 7 | 2 | 57 |
| 2001 | 25 | 22 | 5 | 6 | 58 |
| 2002 | 34 | 20 | 6 | 5 | 65 |
| 2003 | 31 | 27 | 9 | 2 | 69 |
| 2004 | 30 | 30 | 7 | 3 | 70 |
| 2005 | 27 | 23 | 8 | 4 | 62 |
| 2006 | 30 | 16 | 7 | 1 | 54 |
| 2007 | 30 | 17 | 10 | 5 | 62 |
| 2008 | 33 | 19 | 5 | 7 | 64 |
| 2009 | 30 | 14 | 3 | 3 | 50 |
| 2010 | 31 | 22 | 5 | 8 | 66 |
| 2011 | 24 | 19 | 5 | 4 | 52 |
| 2012 | 33 | 17 | 7 | 1 | 58 |
| 2013 | 28 | 19 | 5 | 5 | 57 |

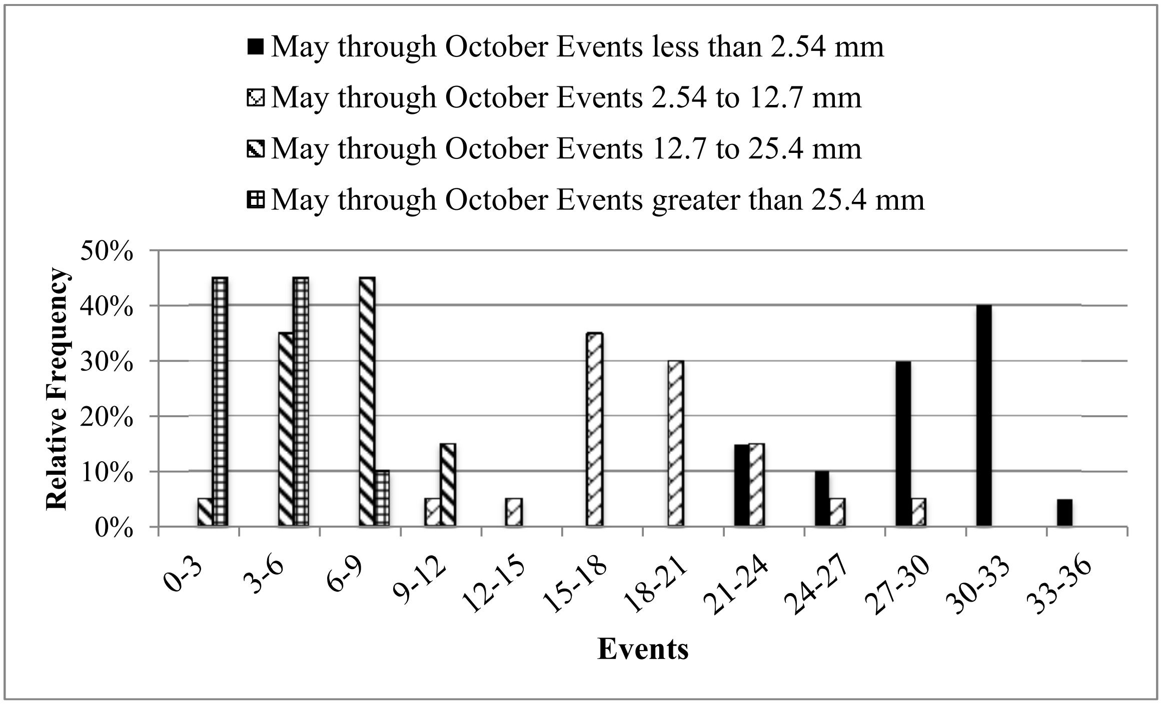



Figure 5. Frequency Analysis Summary of May through October, 1994 to 2013.

The runoff estimation is completed through modeling of the contributing watershed to the wet detention structural BMP. The simulation runoff results for SCS Type-II 24 hour design events of storm durations between four and 24 hours with cumulative rainfall amounts of 2.54 mm (0.10 in), 6.35 mm (0.25 in), 12.7 mm (0.50 in), and 25.4 mm (1.00 in) are given in Table 30 and Table 31 of Appendix A. Table 30 summarizes the peak discharges and Table 31 summarizes the total runoff volume for the simulated events broken down by subwatershed.

### 4.3 Precipitation Measurements

Precipitation data were obtained for each sampling event from the Grand Forks (City) SCADA system that has instantaneous rainfall amounts available through the City's Water Treatment Plant (WTP) historian. Throughout the project analysis period of roughly June through October of 2014, 40 precipitation events of various cumulative amounts were measured by the utilized rain gages. The monthly totals for the same ranges of precipitation analyzed in the frequency analysis are given in Table 14.

Table 14. Summary of 2014 Precipitation events for June through October.

| **Month** | **< 2.54 mm (0.1 in)** | **>= 2.54 to < 12.7 mm (0.1 to 0.5 in)** | **>= 12.7 to < 25.4 mm (0.5 to 1.0 in)** | **>= 25.4 mm (1.0 in)** | **Total** |
|---|---|---|---|---|---|
| June | 1 | 3 | 2 | 5 | **11** |
| July | 4 | 1 | 0 | 2 | **7** |
| August | 4 | 1 | 0 | 2 | **7** |
| September | 3 | 3 | 1 | 1 | **8** |
| October | 4 | 2 | 1 | 0 | **7** |
| **Total** | **16** | **10** | **4** | **10** | **40** |

With the calibration of the rain gages within the SCADA system unknown, the precipitation totals for the sampling events from the SCADA data are compared to the NWS daily precipitation totals from the NCDC online climate database to determine potential error sources. The comparative precipitation totals are given in Table 15 below. The weighted precipitation data for the sampling events at a ten-minute interval are given in Table 32 of Appendix B. These data are used to extrapolate event duration and cumulative rainfall amounts for use in the sampling event summaries**.**

Table 15. SCADA precipitation amounts versus NWS precipitation amounts.

| **Event** | **Grand Forks SCADA Rain Gages** | | | **NWS Rain Gages** | |
|---|---|---|---|---|---|
| | **Gage at 3.9 km distance (mm)** | **Gage at 1.4 km distance (mm)** | **Gage at 2.6 km distance (mm)** | **Gage at 12.1 km distance (mm)** | **Gage at 5.6 km distance (mm)** |
| 06/30/14 | 6.60 | 4.32 | 4.32 | 2.54 | 3.05 |
| 07/01/14 | 1.52 | 1.52 | 1.27 | 2.03 | 1.52 |
| 07/07/14 | 1.02 | 37.3 | 32.0 | 16.0 | 12.7 |
| 09/09/14 | 24.1 | 34.3 | 24.6 | 11.9 | 13.0 |
| 09/28/14 | 5.33 | 4.83 | 6.35 | 4.83 | 5.08 |
| 10/12/14 | 14.2 | 13.0 | 12.2 | 5.08 | 6.35 |

## 4.4 Flow Measurements

The inflow and outflow hydrographs for the composite events are determined by coupling water level measurements within the inlet and outlet conduit with Manning's equation. This equation creates the stage-discharge relationship of the inlet and outlet pipes. The continuous analysis of flow over the storm duration allows for the determination of inflow and outflow volumes. The hydrograph data at the recorded five-minute interval are given in Tables 33 through 38 of Appendix C.

Project resources early on limited the ability to measure influent from the east inlet and for separate deployment of a HOBO Water Level Logger for strictly barometric pressure. With the availability of more loggers later in the project, estimates of previous event influent from the east inlet are deduced and given in Table 16. The east inlet influent data for the final event were used to estimate the amount of effluent contributed by the east inlet drainage area and the drainage area that directly drains to the pond.

Table 16. Estimation of influent amounts based on 10/12/14 results.

| Event | | West Influent | East Influent | Direct Entry to Pond | Effluent |
|---|---|---|---|---|---|
| 10/12/14 | Volume ($m^3$) | 16.3 | 5.79 | 0.35 | 22.4 |
| | % Volume | 72.6 | 25.8 | 1.60 | - |
| 09/09/14 | Volume ($m^3$) | 416 | $214^{\alpha}$ | $11^{\beta}$ | 641 |
| | % Volume | 64.9 | 33.1 | 2.00 | - |
| 09/28/14 | Volume ($m^3$) | 17.8 | $8.83^{\alpha}$ | $0.47^{\beta}$ | 27.1 |
| | % Volume | 65.7 | 32.6 | 1.70 | - |

$$^{\alpha}\,\text{Influent} = \text{Effluent} - \text{West Influent} * \frac{\text{Oct 12th East Influent}}{\text{Oct 12th Effluent} - \text{Oct 12th West Influent}}$$

$$^{\beta}\,\text{Influent} = \text{Effluent} - \text{West Influent} * \frac{\text{Oct 12th Direct Entry to Pond}}{\text{Oct 12th Effluent} - \text{Oct 12th West Influent}}$$

Barometric deployment on site during later events allowed direct barometric compensation. In early events the flow-weighted composites were determined with reference levels and then re-computed with barometric pressure data obtained from the National Weather Service (NWS) to obtain the relative percent difference (RPD) in the original composite. Table 17 summarizes the RPD of the total inflow and outflow volumes between the two methods to show the error in the original composite samples.

Table 17. Summary of barometric compensation differences for composite volumes.

| Event | | Barometric Pressure Compensated Total Volume ($m^3$) | Reference Level Compensated Total Volume ($m^3$) | Relative Percent Difference (%) |
|---|---|---|---|---|
| 09/09/14 | Influent | 416 | 423 | 1.68 |
| | Effluent | 641 | 604 | 5.92 |
| 09/28/14 | Influent | 17.8 | 18.3 | 2.66 |
| | Effluent | 27.1 | 26.0 | 4.15 |
| 10/12/14 | Influent | 16.3 | -[α] | -[α] |
| | Effluent | 22.4 | -[α] | -[α] |

[α] Barometric pressure data immediately available and used for flow-compositing

The water level loggers utilized at the west inlet and outlet of the detention pond were calibrated using a simple bucket calibration test to determine the RPD in logged measurements versus field measurements. The analysis results are given in Table 18. A sensitivity analysis on Manning's n-value for the typical range of 0.011 to 0.015 for reinforced concrete pipe (RCP) and a conduit slope (S) plus or minus 20 percent from the assumed project value based on as-built plans is completed to show the magnitude of the effect that incorrect assumptions has on the measured influent and effluent. Table 19 summarizes the results of this analysis. Details of the sensitivity analysis for the west inlet and outlet conduits are given in Table 39 and Table 40 of Appendix C.

Table 18. Highland Point inlet and outlet water level logger bucket calibration.

| Time | Action | Measured Depth (mm) | Barometric Pressure from NWS (kPa) | Abs Pressure from HOBO Logger (kPa) | Temperature (°C) | Barometric Compensated Water Level (mm) | Water Level Difference, Typical Error (mm) | RPD in Water Level (%) |
|---|---|---|---|---|---|---|---|---|
| **Inlet** | | | | | | | | |
| 15:27 | Deployed | - | | | | | | |
| 15:53 | Measurement | 7.94 | 102.029 | 101.952 | 11.76 | 7.86 | 0.08, 3 | 1.01 |
| 16:06 | Adjust Depth | - | | | | | | |
| 16:53 | Measurement | 52.29 | 102.001 | 101.488 | 11.76 | 52.44 | 0.15, 3 | 0.29 |
| **Outlet** | | | | | | | | |
| 15:27 | Deployed | - | | | | | | |
| 15:53 | Measurement | 7.94 | 102.029 | 101.953 | 11.76 | 7.75 | 0.19, 3 | 2.42 |
| 16:06 | Adjust Depth | - | | | | | | |
| 16:53 | Measurement | 52.29 | 102.001 | 101.486 | 11.76 | 52.54 | 0.25, 3 | 0.48 |

Table 19. Summary of sensitivity analysis.

| **Manning's n** | **n = 0.011** | **n = 0.012** | **n = 0.013** | **n = 0.014** | **n = 0.015** |
|---|---|---|---|---|---|
| Influent Discharge ($m^3/s$) | 0.370 | 0.339 | 0.313 | 0.291 | 0.271 |
| RPD from n = 0.012 (%) | 8.70 | 0.00 | 8.00 | 15.4 | 22.2 |
| Effluent Discharge ($m^3/s$) | 0.170 | 0.156 | 0.144 | 0.134 | 0.125 |
| RPD from n = 0.013 (%) | 16.7 | 8.00 | 0.00 | 7.41 | 14.3 |
| **Conduit Slope (S)** | **-20% S** | **-10% S** | **S** | **+10% S** | **+20% S** |
| Influent Discharge ($m^3/s$) | 0.303 | 0.322 | 0.339 | 0.356 | 0.372 |
| RPD from S = 0.00315 (%) | 11.2 | 5.18 | 0.00 | 4.84 | 9.11 |
| Effluent Discharge ($m^3/s$) | 0.129 | 0.136 | 0.144 | 0.151 | 0.158 |
| RPD from S = 0.00380 (%) | 11.2 | 5.27 | 0.00 | 4.76 | 9.11 |

### 4.5 Stormwater Sampling

As previously mentioned stormwater sampling was completed by single grab samples in the beginning of the project and altered to manual flow-weighted composite samples as the project progressed. The details of the six composited samples throughout the project are given in Table 41 of Appendix D. Within these tables the logger water depth and temperature are compared to the field measured water depth and pH meter temperature to determine the RPD between the measurements. This quality control (QC) check, along with the determined percentage of total flow captured by the composite sample, is summarized in Table 20.

### 4.6 Water Quality Analysis

Tables for the six sample events were created to provide a summary of the general event hydrologic information and water quality analytical results. Different analytes were measured between grab samples and composite samples due to limitations in preservation for the specific parameter. The QC measures conducted on the samples are also summarized in these tables. Event hydrology figures for the composite sample events

Table 20. Quality control summary of composite samples.

| Event | | Flow Captured in Composite (%) | Average Relative Percent Difference in Water Depth (%) | Average Relative Percent Difference in Temperature (%) |
|---|---|---|---|---|
| 09/09/14 | Influent | 99.0 | 5.79 | 1.86 |
| | Effluent | 99.7 | -$^{\alpha}$ | -$^{\alpha}$ |
| 09/28/14 | Influent | 88.8 | 11.1 | 1.43 |
| | Effluent | 90.0 | 3.33 | 1.28 |
| 10/12/14 | Influent | 84.7 | 5.06 | 1.29 |
| | Effluent | 100 | -$^{\alpha}$ | -$^{\alpha}$ |

$^{\alpha}$ Autosampler used for sampling – water depth and temperature were not measured for individual sample aliquots

Table 21. 09/09/14 event hydrologic and analytical results summary.

| **General Information** | |
|---|---|
| Event Date: | 09/09/14 |
| Date of Last Maintenance: | None (online since Summer 2012) |
| Antecedent Conditions: | 130 hours |
| Total Precipitation (mm) | 25.71 |
| Peak Flow, ($m^3$/s) | 0.0707 influent, 0.03585 effluent |
| Total Runoff Volume ($m^3$) | 416 (65%) influent$^{\alpha}$, 641effluent |

$^{\alpha}$ Influent from west inlet only measured, rest of outflow attributed to east inlet

**Analytical**

| Number of Aliquots | Parameter | Concentrations (mg/l) Influent EMC* | Effluent EMC* | MRL or Detection Range | Duplicate RPD* |
|---|---|---|---|---|---|
| Influent: 10 | TSS | 218 | 29.9 | 5 | 4.2% |
| Effluent: 23 | Total P | 1.12 | 0.27 | 0.00 – 1.12 | NA |
| | Phosphate | 1.10 | 0.69 | 0.00 – 3.00 | 9.9% |
| | Ammonia – N | 0.01 | 0.15 | 0.00 – 1.00 | 9.1% |
| | Nitrite – N | ND | ND | 0.00 – 0.80 | ND |
| | Nitrate – N | 0.70 | 0.39 | 0.00 – 3.00 | 15.4% |
| | Chloride | 8.0 | 6.2 | 0.0 – 30.0 | 11.1% |
| | Total Cu | ND | ND | 0.05 | NA |
| | Total Pb | 0.0043 | ND | 0.001 | NA |
| | Total Zn | ND | ND | 0.05 | NA |
| | Conductivity (µS/cm) | 319 | 730 | 10 – 2000 µS/cm | NT |
| | Bacteria (MPN) | 770 | 95 | 0 | NT |

were created to visually represent the watersheds' response to the given event. An example of the event summary table and figure is given in Table 21 and Figure 6. The event summary tables for the remaining events are given in Tables 42 through 47 and Figure 24 through Figure 26 in Appendix E.

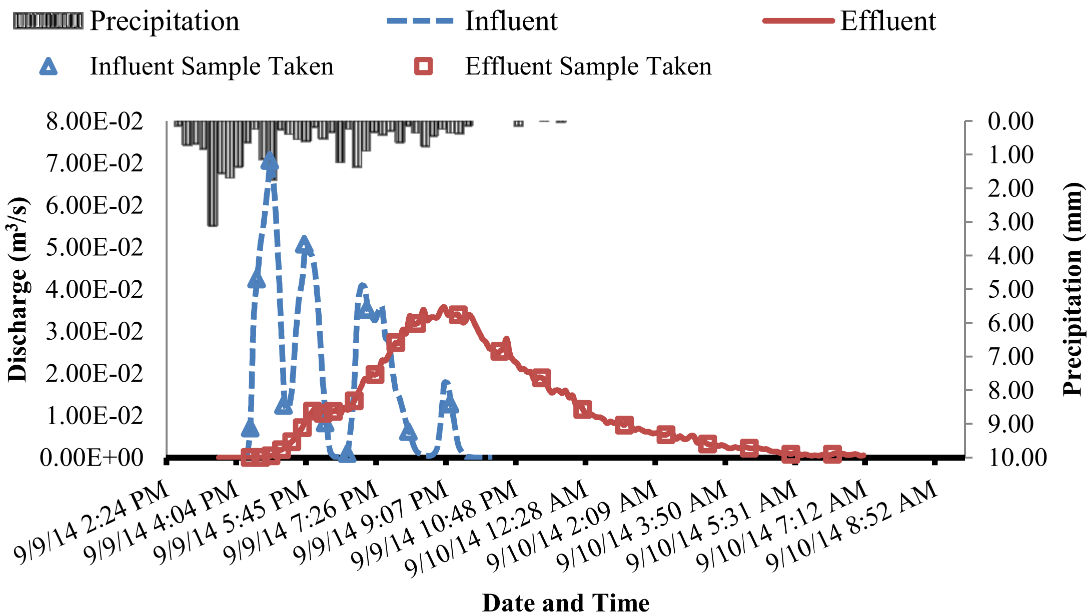



Figure 6. Influent and effluent hydrographs and precipitation hyetograph for 09/09/14 sampling event.

### 4.7 Single Event Performance

The intra-event removal efficiencies for the single grab samples and composite samples are summarized in Table 22. The effluent data are weighted based on the contributing influent percentage from the west inlet to estimate the removal efficiency of only flow that was included in the samples. Refer to Table 16 for these deduced percentages for weighting. In circumstances where the concentration increased between the influent and effluent, no removal percentage was calculated. For events where influent concentration was detected, but effluent concentration was undetected, the provisional removal percentage is considered one-hundred percent. When influent and

Table 22. Summary of intra-event removal percentages.

| | Grab Sample Removal %$^{\alpha}$ | | | Composite Sample Removal %$^{\beta}$ | | |
|---|---|---|---|---|---|---|
| **Parameter** | **06/30/14** | **07/01/14** | **07/07/14** | **09/09/14** | **09/28/14** | **10/12/14** |
| D.O. | INC$^{\gamma}$ | 16 | INC$^{\gamma}$ | NA* | NA* | NA* |
| TSS | 69 | 76 | 83 | 86 | 84 | 59 |
| Total P | 97 | 50 | 50 | 76 | 85 | 58 |
| Phosphate | 100$^{\delta}$ | 100$^{\delta}$ | INC$^{\gamma}$ | 37 | 80 | 95 |
| Ammonia – N | INC$^{\gamma}$ | 40 | INC$^{\gamma}$ | INC$^{\gamma}$ | 66 | 18 |
| Nitrite – N | 100$^{\delta}$ | 100$^{\delta}$ | ND* | ND* | INC$^{\gamma}$ | INC$^{\gamma}$ |
| Nitrate – N | 68 | 69 | 62 | 14 | 64 | 43 |
| Chloride | 66 | 46 | INC$^{\gamma}$ | 23 | INC$^{\gamma}$ | INC$^{\gamma}$ |
| Total Cu | NT* | ND* | NT* | ND* | ND* | ND* |
| Total Pb | NT* | 100$^{\delta}$ | NT* | 100$^{\delta}$ | ND* | 8.3 |
| Total Zn | NT* | ND* | NT* | ND* | ND* | ND* |
| Conductivity | 62 | 43 | 23 | INC$^{\gamma}$ | INC$^{\gamma}$ | INC$^{\gamma}$ |
| Bacteria | 100$^{\delta}$ | 92 | NT* | 88 | 77 | NT* |

$^{\alpha}$ Removal % = [1 – (effluent concentration / influent concentration) * 100]
$^{\beta}$ Removal % = [1 – (effluent EMC / influent EMC) * 100]
$^{\gamma}$ INC. = removal of parameter not observed, effluent concentration greater than influent
$^{\delta}$ Effluent exhibited non-detect (ND), concentration assumed to be MRL or minimum value in detection range
* NA = not applicable to test, ND = not detected in effluent or influent, NT = not tested

effluent concentrations were both undetected, the result is described as ND or not detected. These circumstances are summarized in the table notes. Average removal efficiency for parameters that exhibited the same tendency throughout all monitored events is summarized in Table 23 on the following page. These data are for provisional use only and statistical significance assessment of the parameters is still completed.

Single event performance is visually represented through time series plots of the six sampled events. The grab sample concentrations are only representative of the flow at

Table 23. Provisional average removal percentages for sampled events.

| Parameter | Average Grab Sample Removal % | Average Composite Sample Removal % |
|---|---|---|
| TSS | 76 | 76 |
| Total Phosphorus as Phosphate | 66 | 73 |
| Nitrate – N | 66 | 40 |
| Bacteria | 96 | 83 |

the sampling instance, but the difference in influent and effluent concentration is still used to determine trends. The time series plots for the twelve parameters consistently analyzed throughout the project are given in Figure 7 through Figure 10.

### 4.8 Statistical Analysis

Statistical analysis is completed on the influent and effluent data sets to determine if the two independent groups are significantly different. Hypothesis testing is conducted on all parameters that exhibit a detectable concentration in at least one circumstance between the data sets. If non-detection is observed, the minimum reporting level (MRL) or minimum value of the analytical method detection range is assumed. This is considered the simple substitution technique that is presented in Geosyntec and Wright Water Engineers, Inc (2009). The concentration cannot be assumed to be zero if the result is below the detection limit because the concentration may fall somewhere between zero and the MRL of the method or equipment. The tabular results presented for the statistical analysis include the summary of the descriptive statistics of each data set and the summary of the hypothesis testing calculated p-value versus α-value with null hypothesis either accepted or rejected. Graphically, the lognormal probability of non-exceedance plots and the box-and-whisker plots are presented for parameters that had adequate sample size without non-detects. The descriptive statistics are presented in Table 48 and Table 49 of Appendix F. The critical values of the Ryan-Joiner normality test on the raw and log-transformed data are included, with values above than 0.878 considered accepted.

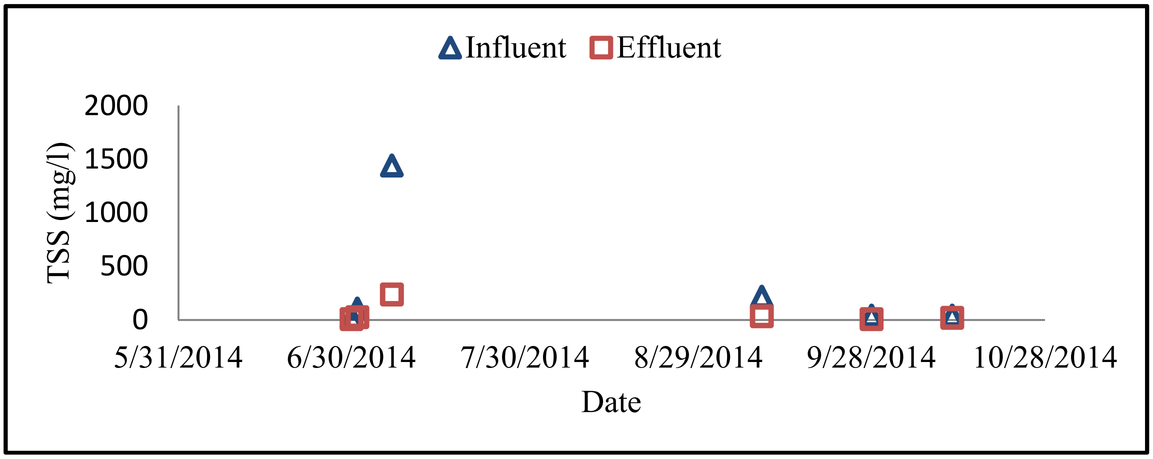
The Mann-Whitney and Levene hypothetical test results are given below in Table 24. For the Mann-Whitney test, a rejected null hypothesis states that the influent and effluent data sets are statistically different. For the Levene test, a rejected null hypothesis indicates that the data do not have similar variances, which would determine that the sets cannot be statistically compared. In summary, to prove statistical significance between the data sets, both data sets need to have the same distribution, the Mann-Whitney null hypothesis needs to be rejected, and the Levene null hypothesis needs to be accepted.

Table 24. Null hypothesis rejected results for statistical analysis of composite samples.

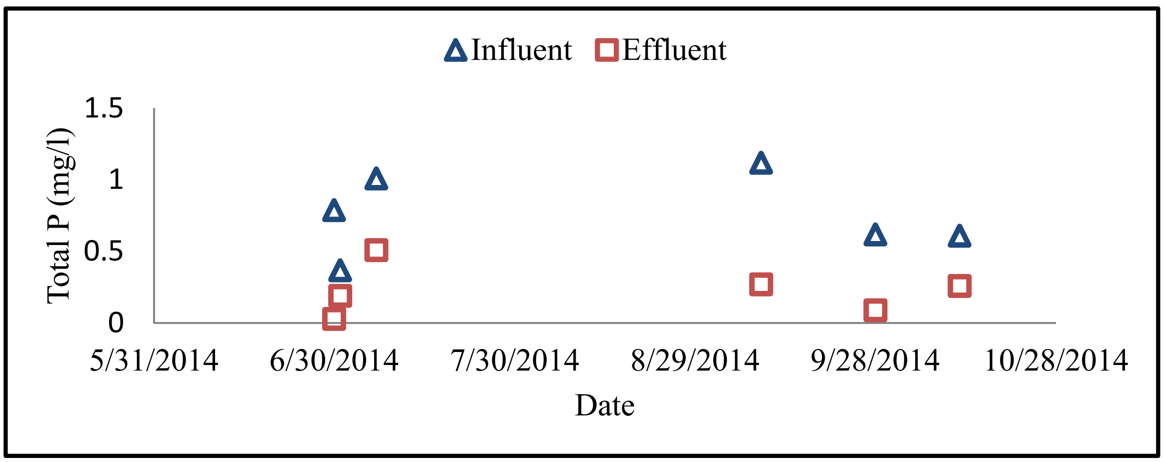
| | **Reject Raw Data Mann-Whitney Null Hypothesis?** | | **Reject Raw Data Levene Null Hypothesis?** | | **Reject Log-Transformed Levene Null Hypothesis?** | |
|---|---|---|---|---|---|---|
| **Parameter** | **$\alpha = 0.05$** | **$\alpha = 0.10$** | **$\alpha = 0.05$** | **$\alpha = 0.10$** | **$\alpha = 0.05$** | **$\alpha = 0.10$** |
| TSS | NO | YES | NO | NO | NO | NO |
| Total P | NO | YES | NO | NO | NO | NO |
| Phosphate | NO | NO | NO | NO | NO | NO |
| Ammonia-N | NO | NO | NO | NO | NO | NO |
| Nitrate-N | NO | YES | NO | NO | NO | NO |
| Chloride | NO | NO | NO | NO | NO | NO |
| Total Pb | NO | NO | NO | NO | NO | NO |
| Conductivity | NO | YES | NO | NO | NO | NO |
| Bacteria | NO | NO | NA[α] | NA[α] | NA[α] | NA[α] |

[α] Minimum sample size for test does not allow hypothetical test on available data set

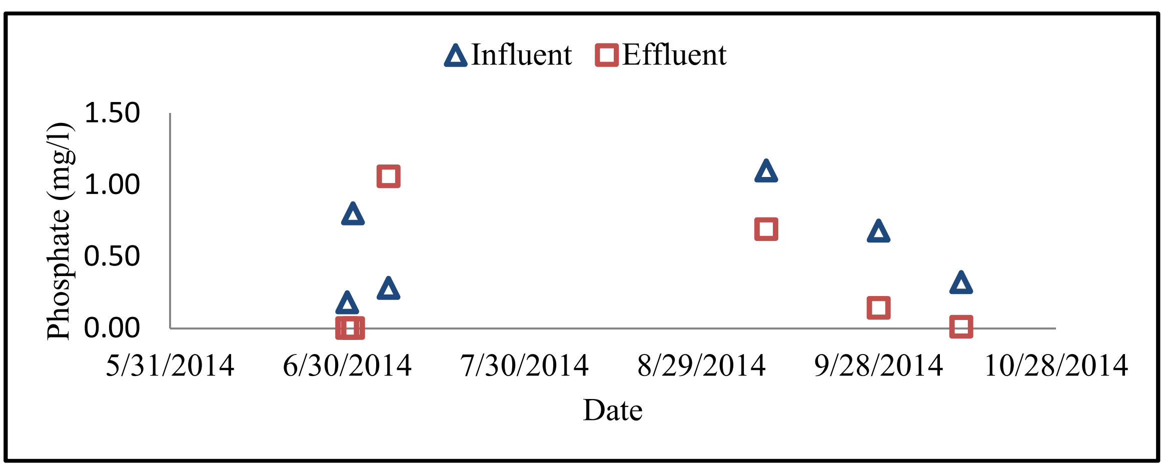
The lognormal probability plots of the applicable data are presented in Figure 11 through Figure 15 and the box-and-whisker plots of the applicable data are presented in Figure 16 through Figure 21.




(a)

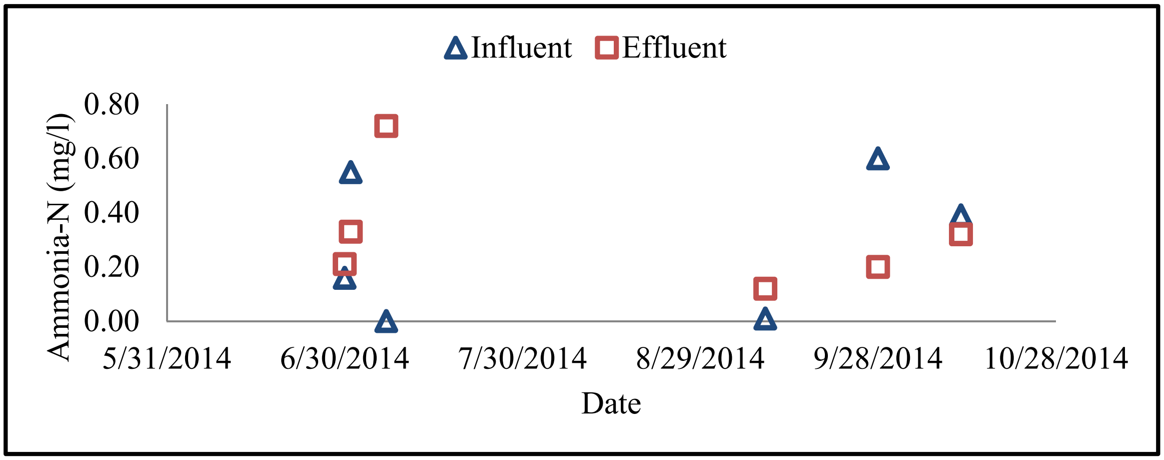



(b)

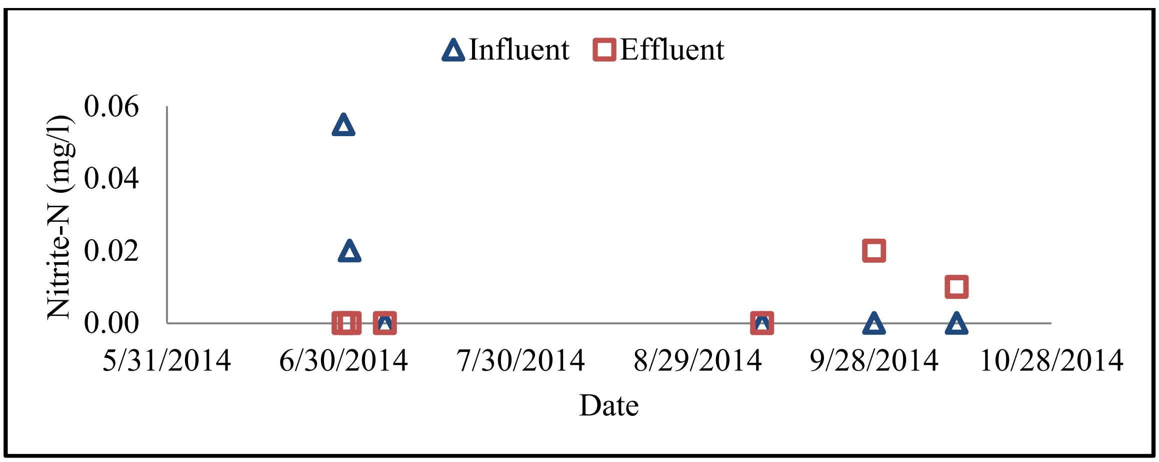



(c)

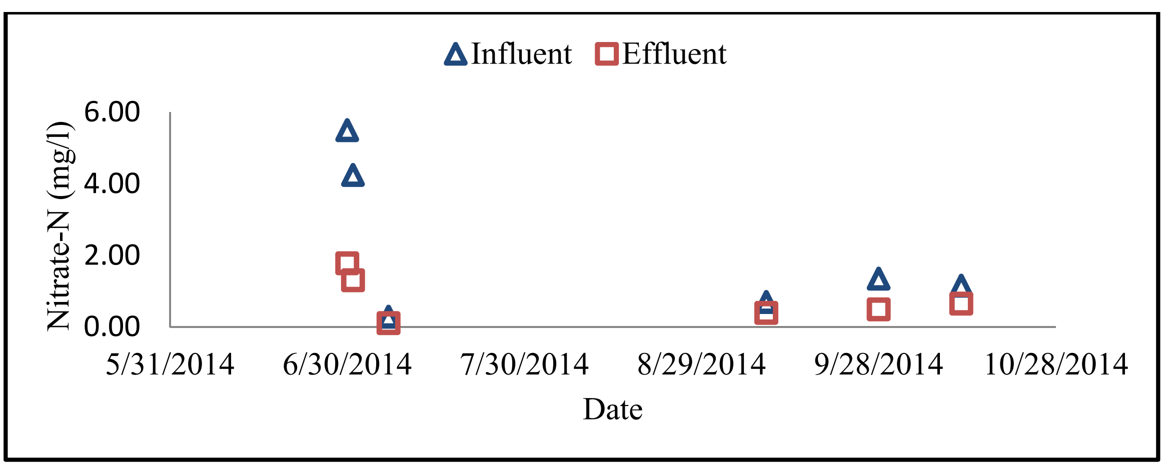
Figure 7. Time series plots for (a) TSS, (b) total phosphorus, and (c) phosphate.




(a)

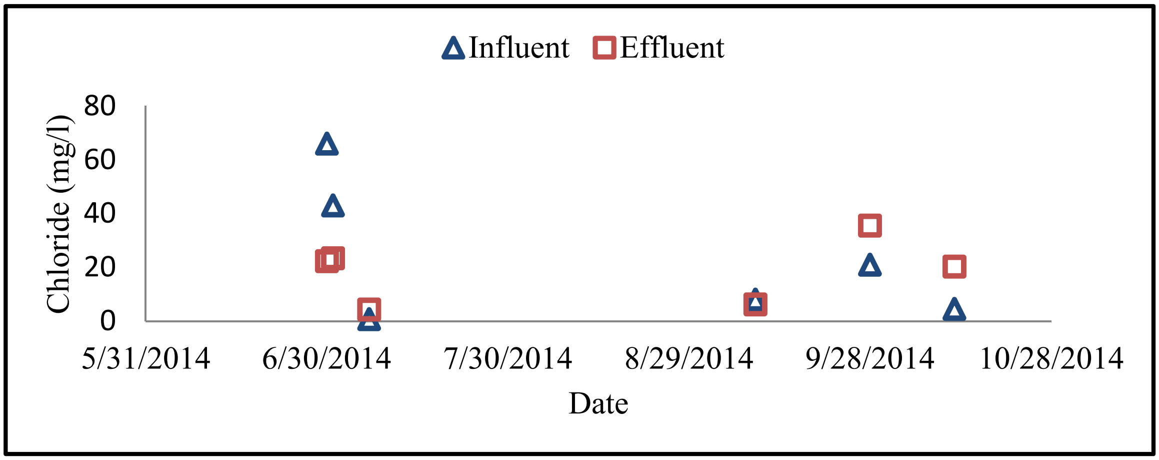



(b)

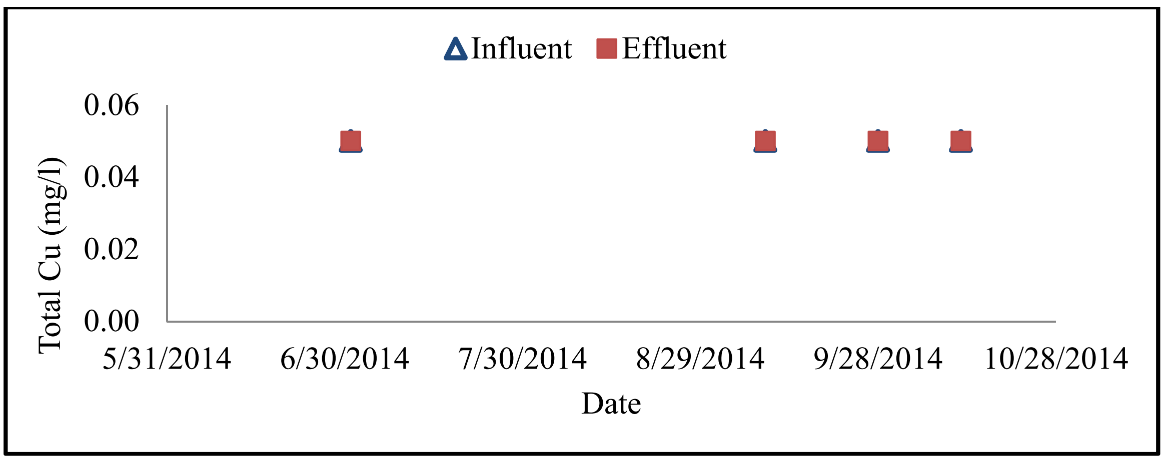



(c)

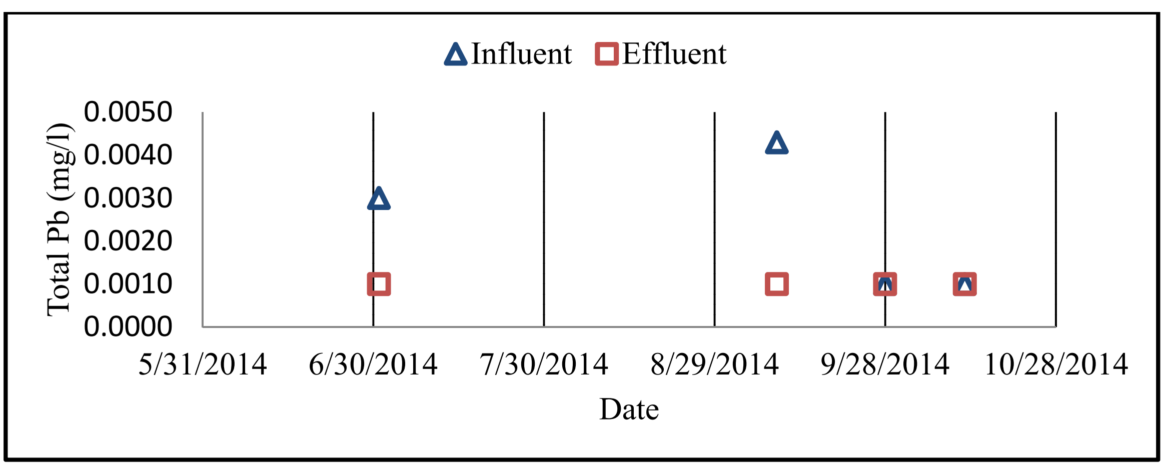
Figure 8. Time series plots for (a) ammonia-n, (b) nitrite-n, (c) nitrate-n




(a)

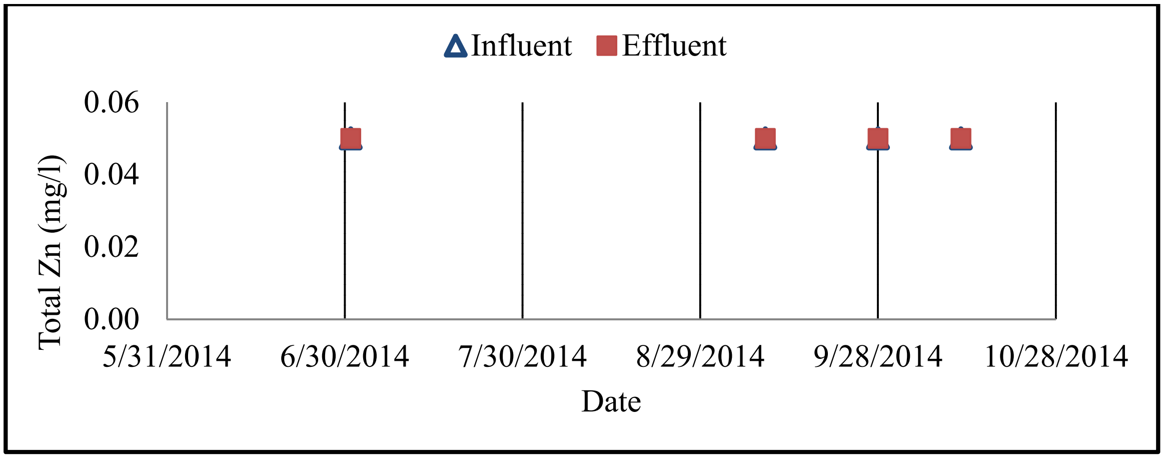



(b)

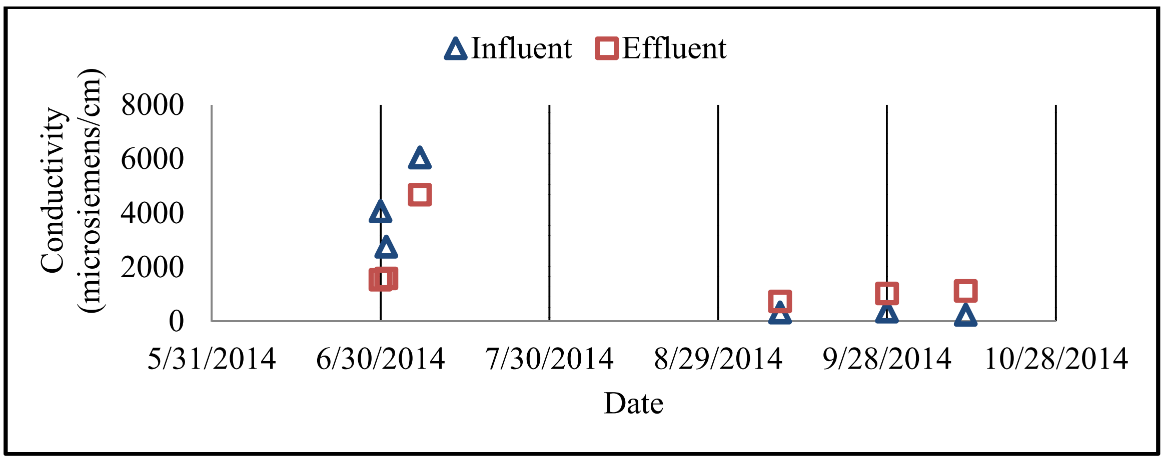



(c)

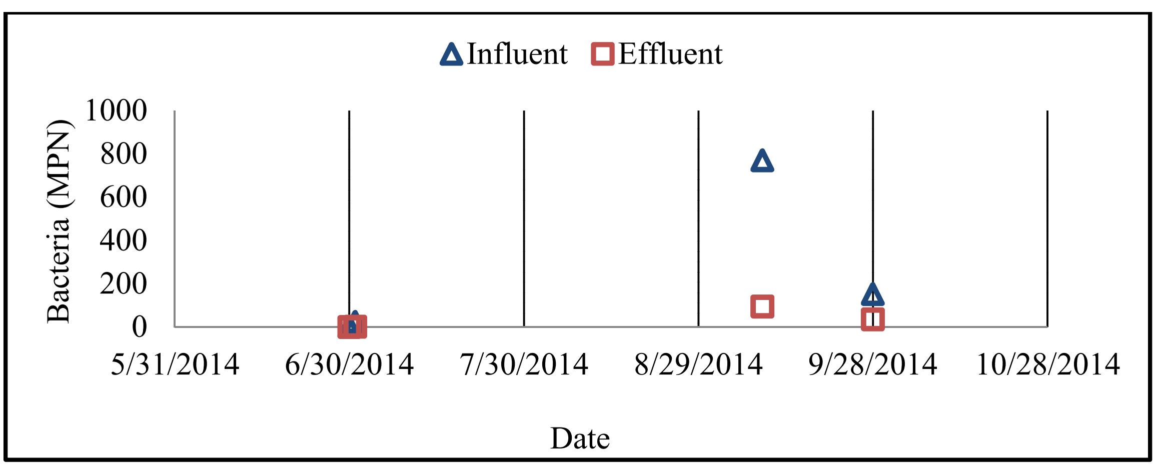
Figure 9. Time series plots for (a) chloride, (b) total copper, and (c) total lead




(a)

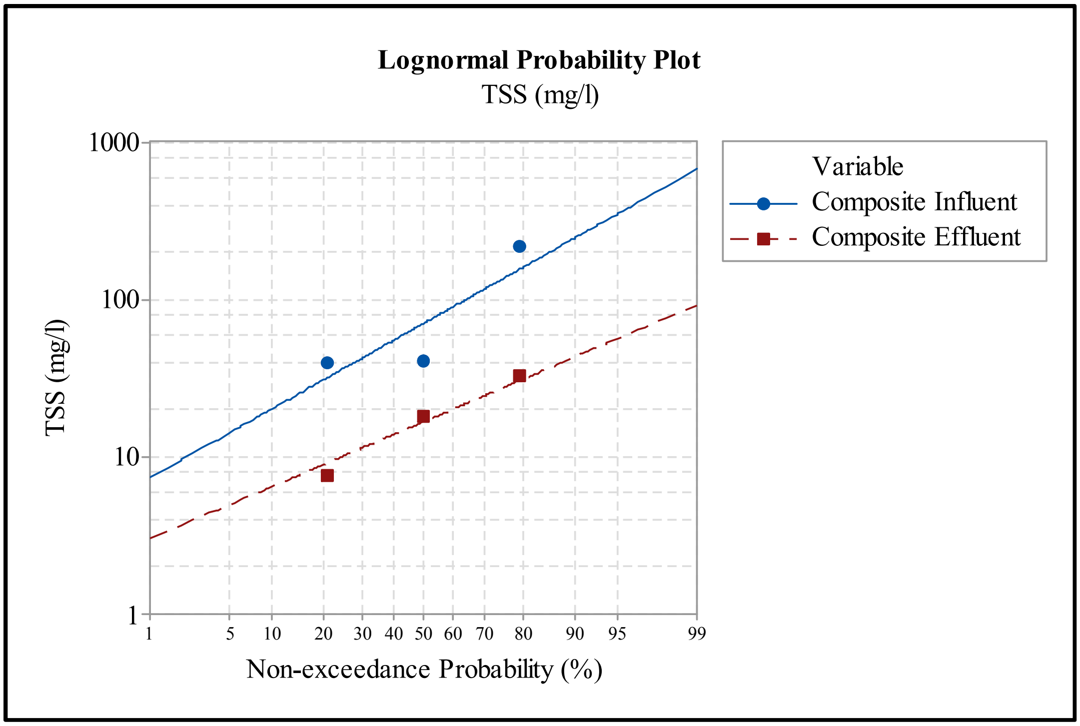



(b)

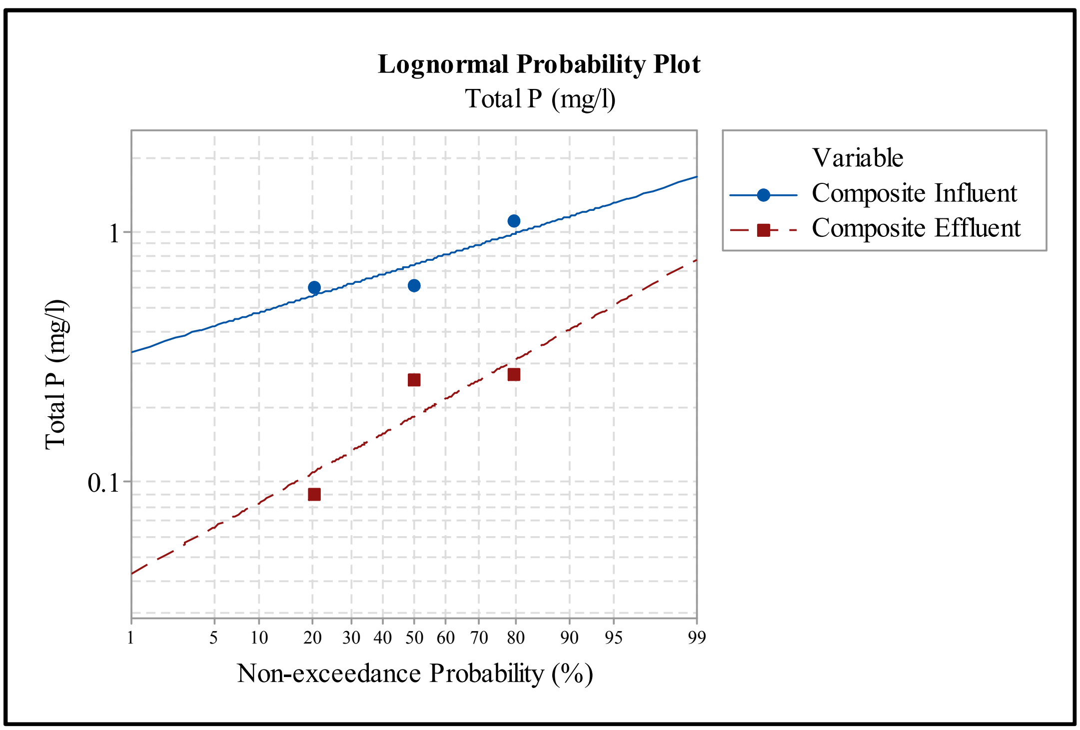



(c)

Figure 10. Time series plots for (a) total zinc, (b) conductivity, and (c) bacteria.

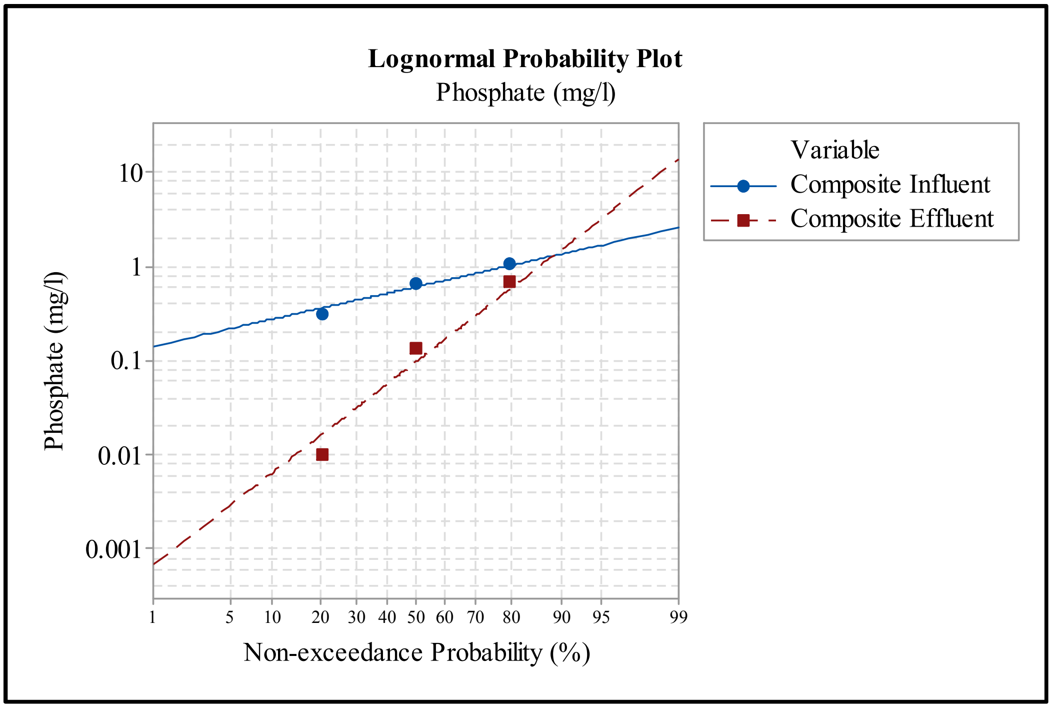



(a)

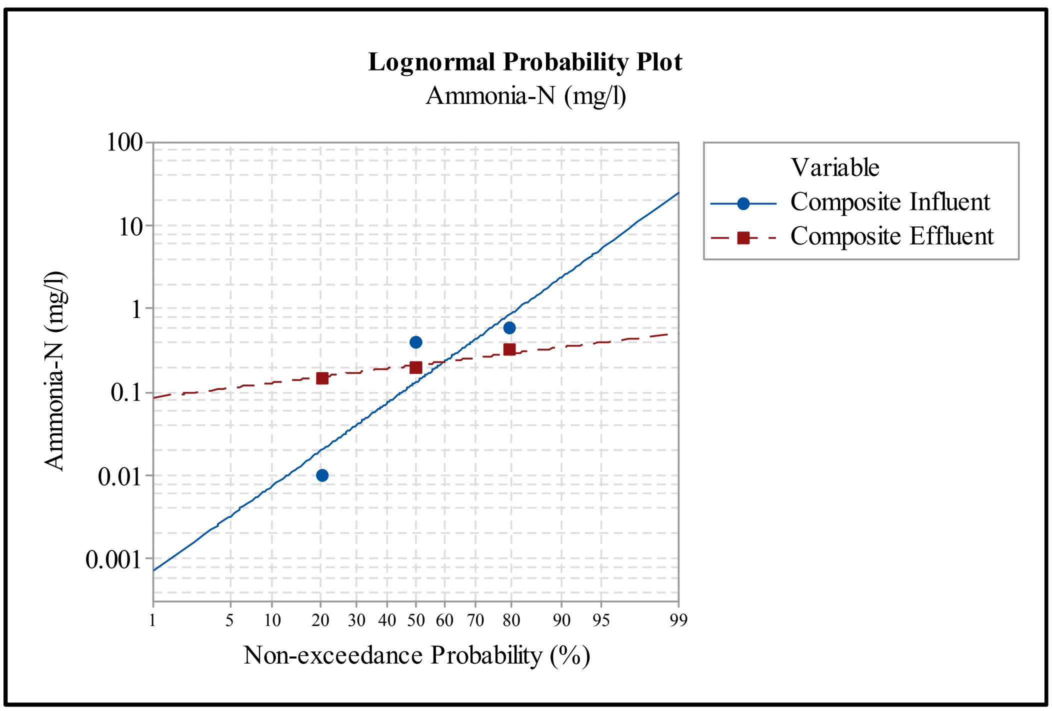



(b)

Figure 11. Lognormal probability plots for (a) TSS, and (b) total phosphorus

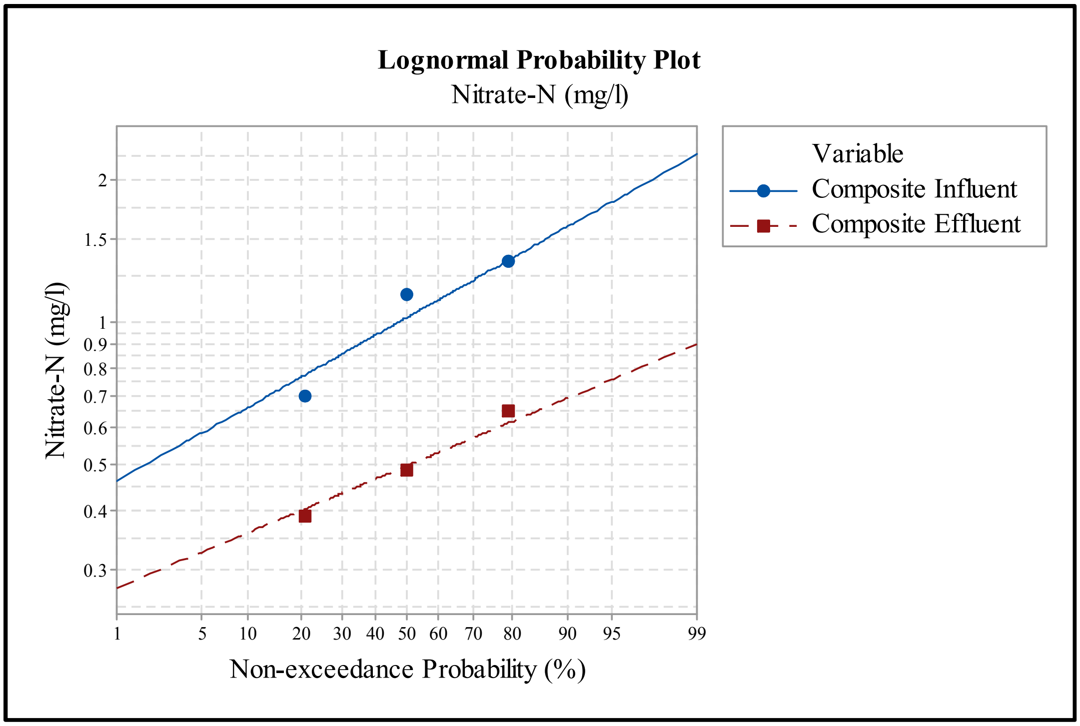



(a)

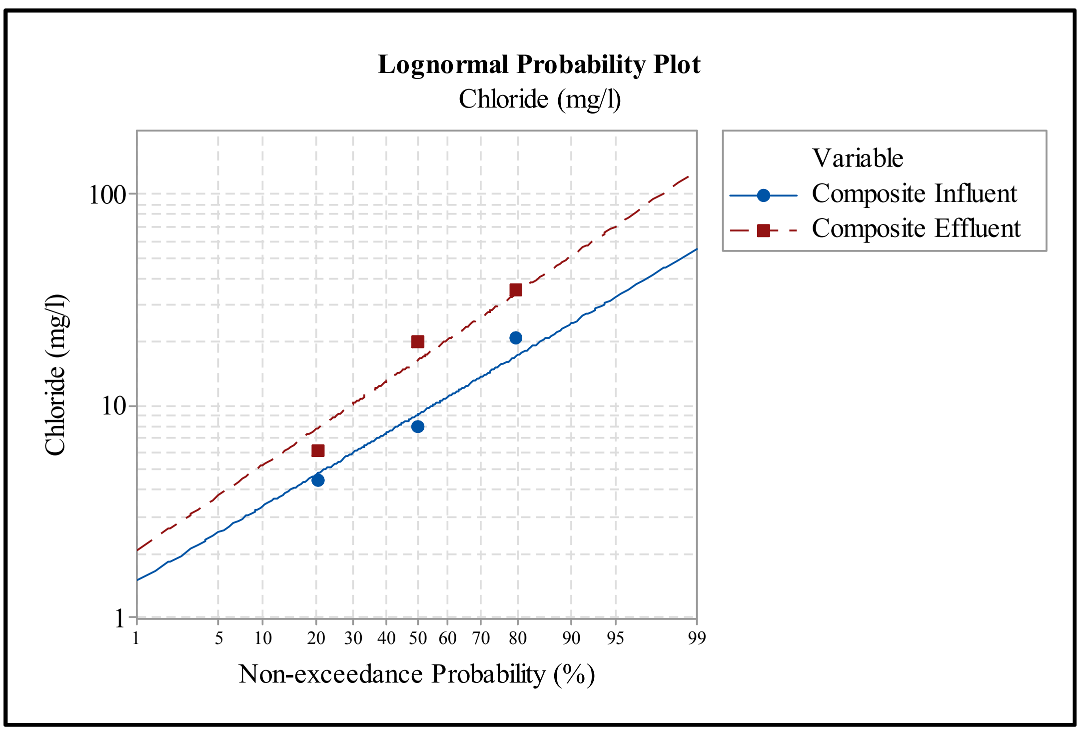



(b)

Figure 12. Lognormal probability plots for (a) phosphate as orthophosphate, and (b) ammonia-n.

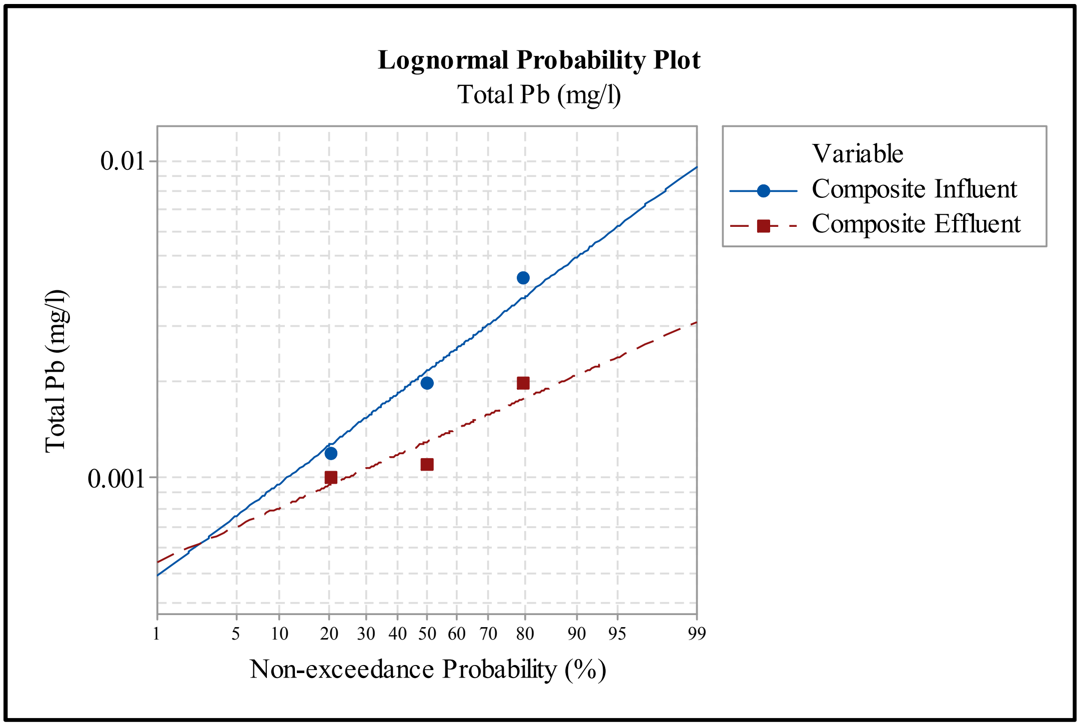



(a)

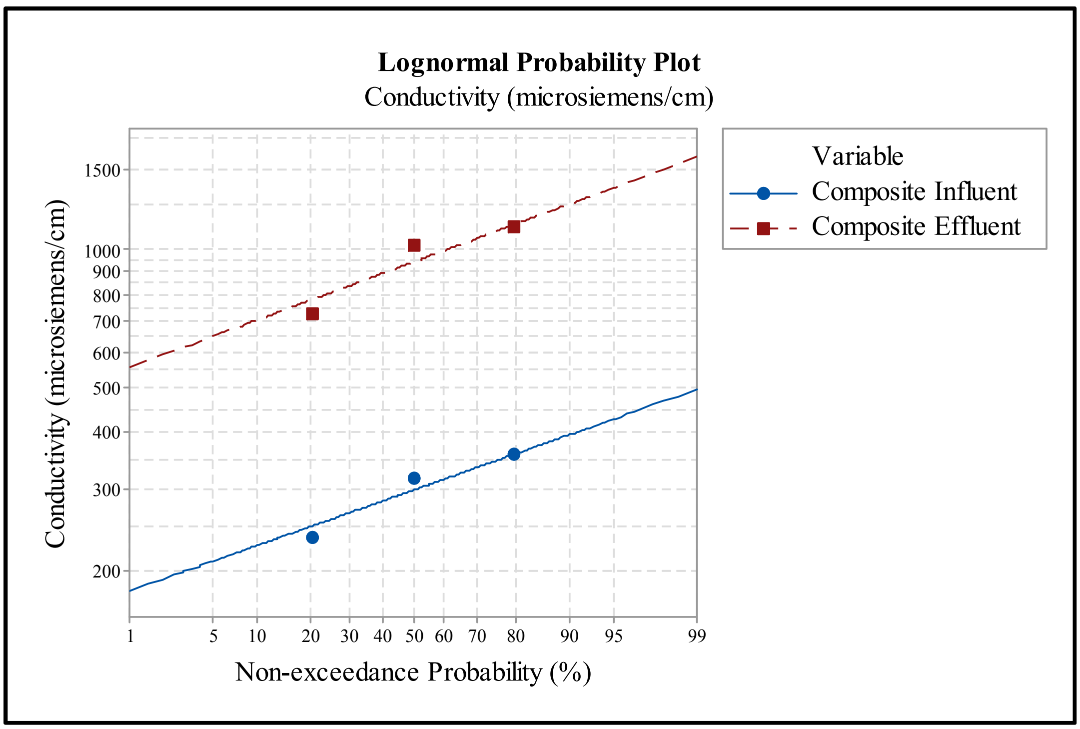



(b)

Figure 13. Lognormal probability plots for (a) nitrate-n, and (b) chloride.




(a)




(b)

Figure 14. Lognormal probability plots for (a) total lead, and (b) conductivity.

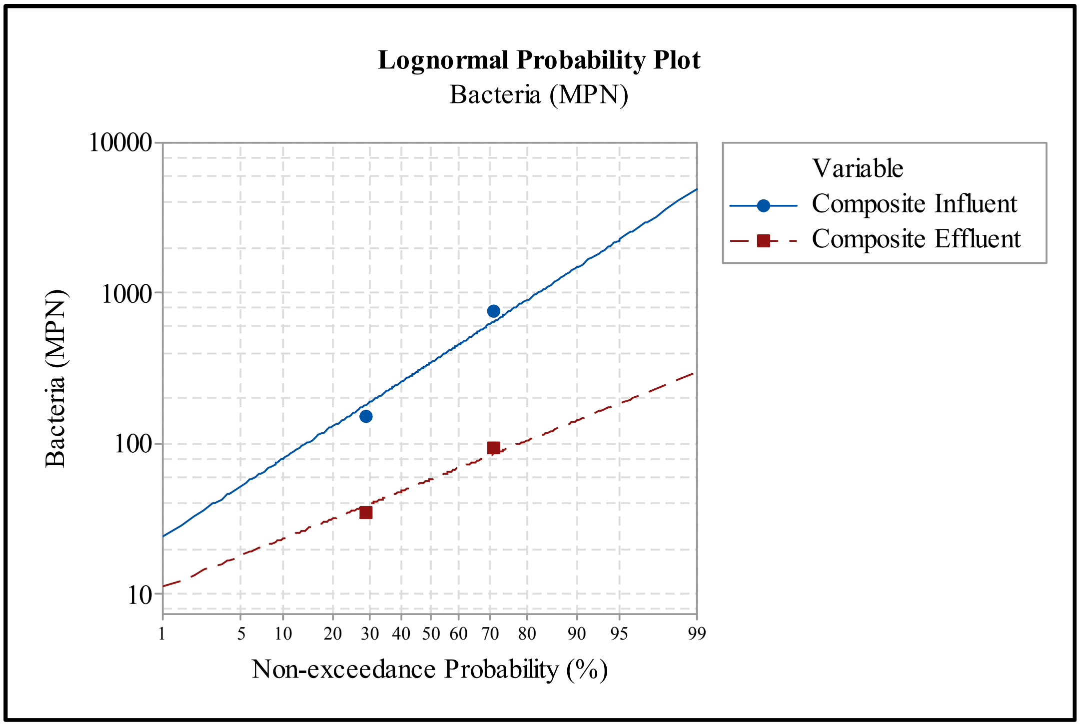



Figure 15. Lognormal probability plots for bacteria as *E. Coli*.

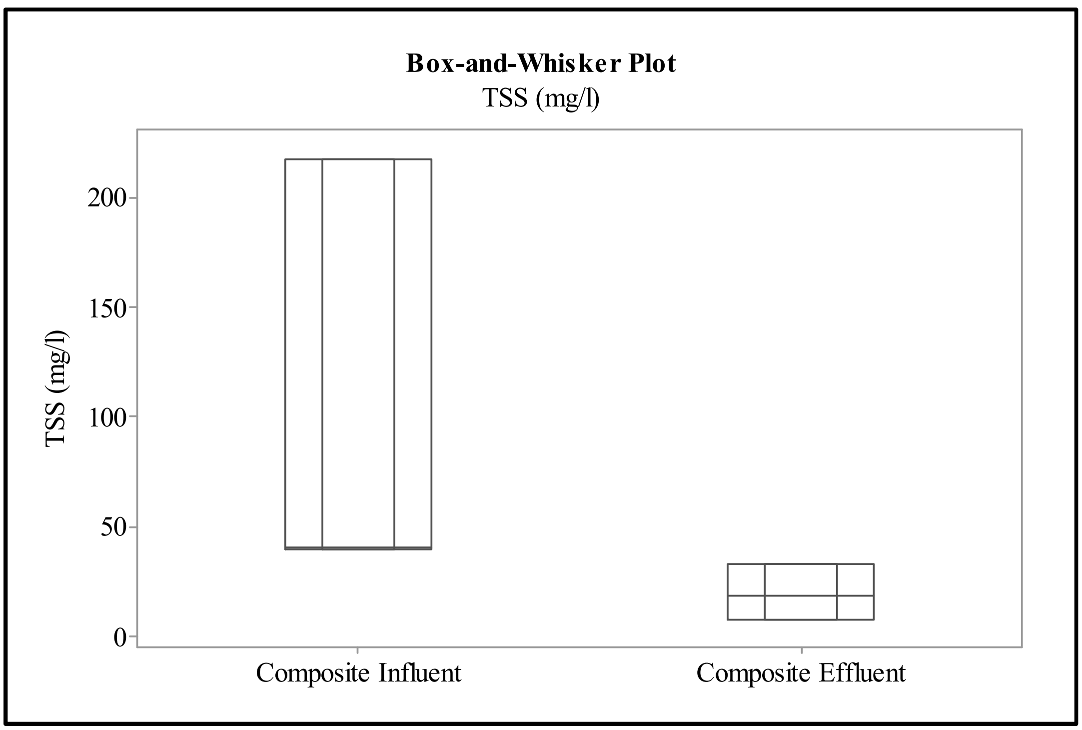
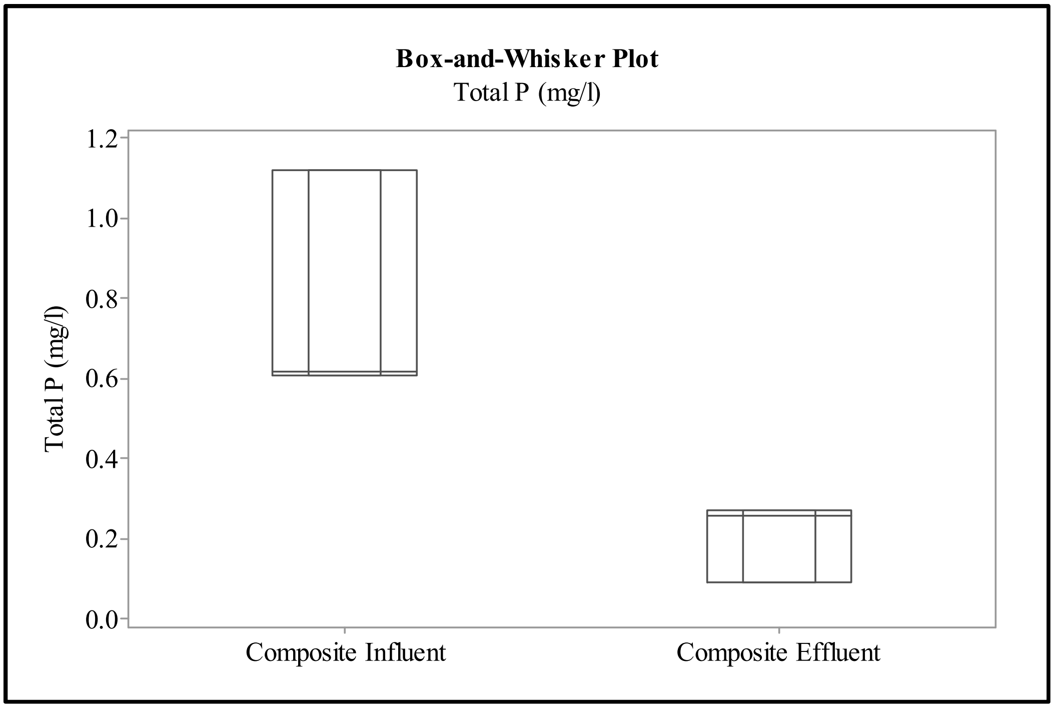
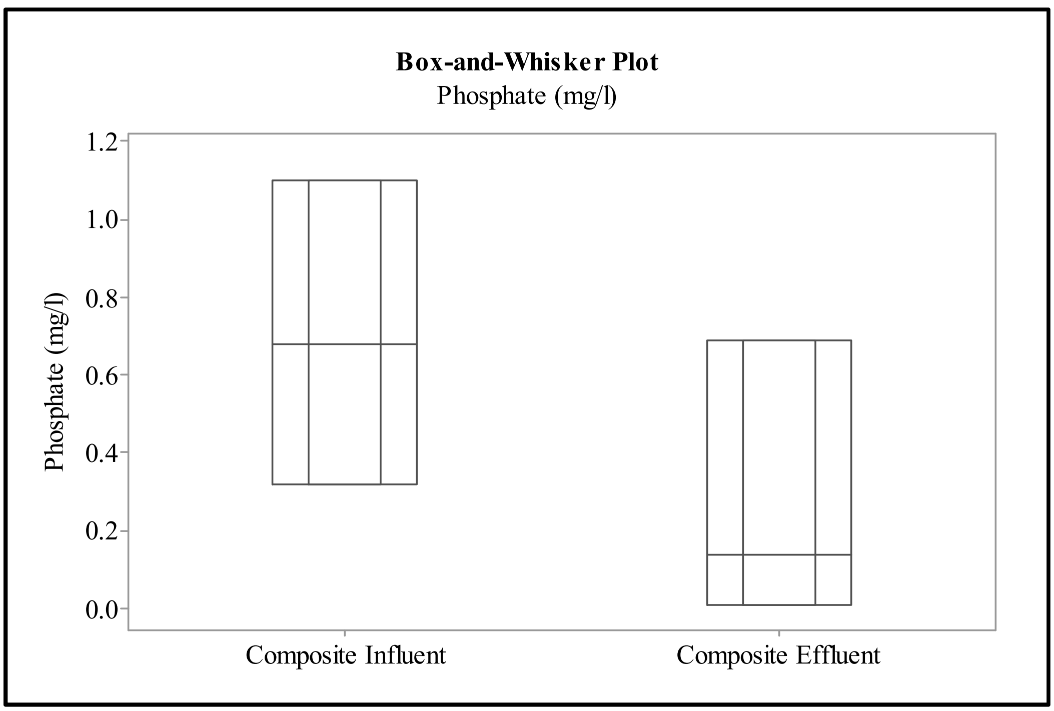



Figure 16. Box-and-whisker plots for TSS.

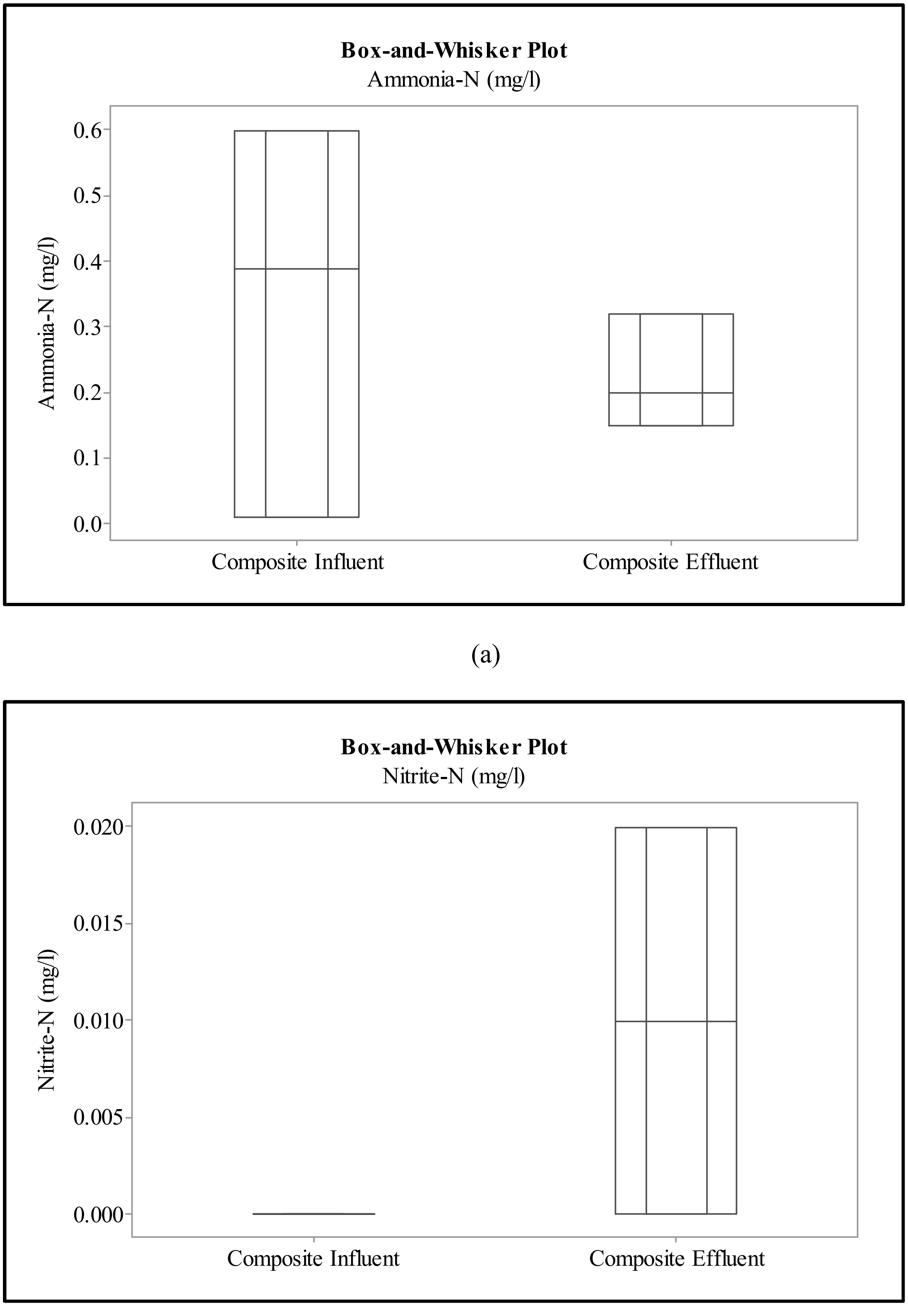



(a)




(b)

Figure 17. Box-and whisker plots for (a) total phosphorus, (b) phosphate as orthophosphate.

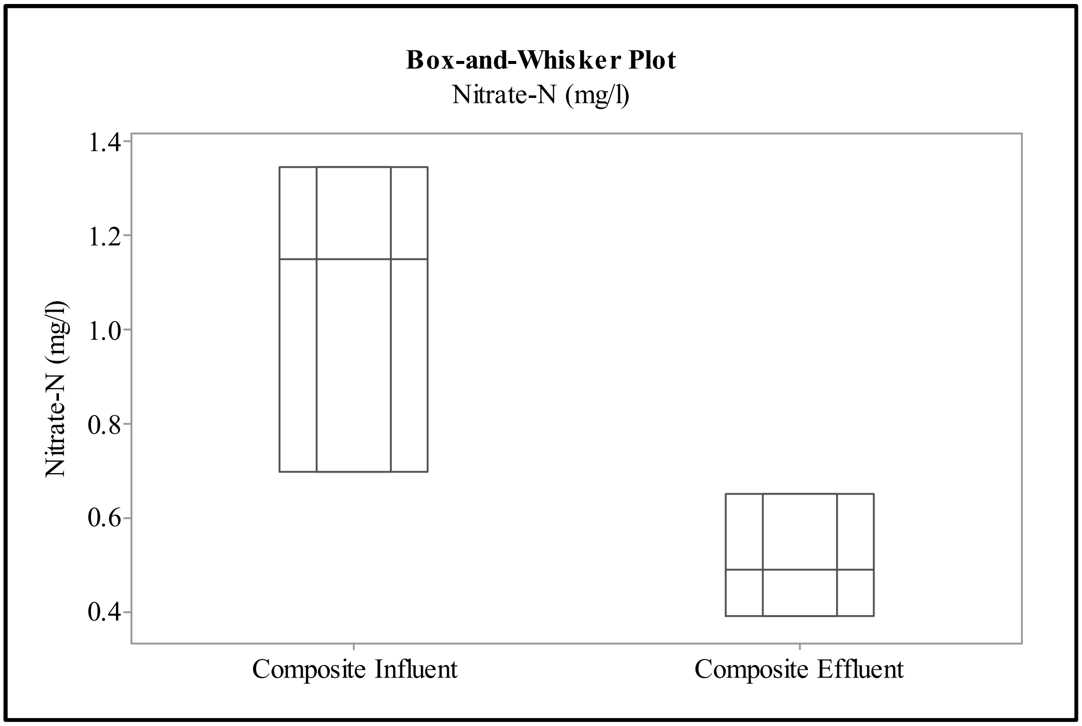



(a)

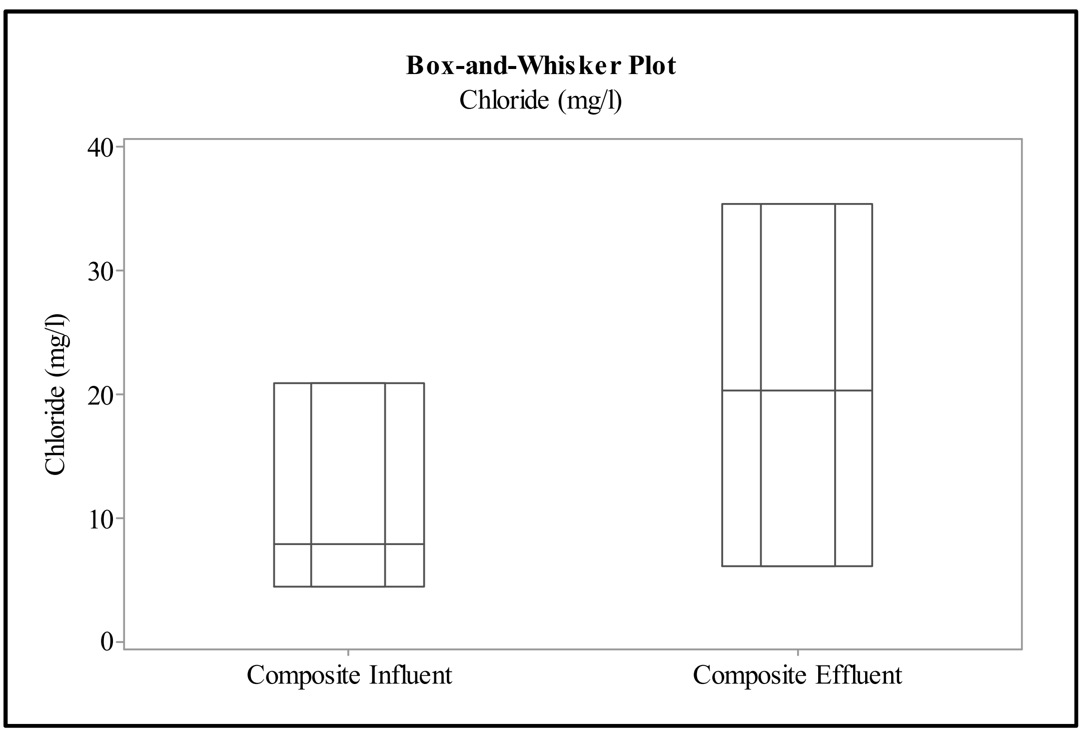


(b)

Figure 18. Box-and-whisker for (a) ammonia-n, and (b) nitrite-n.

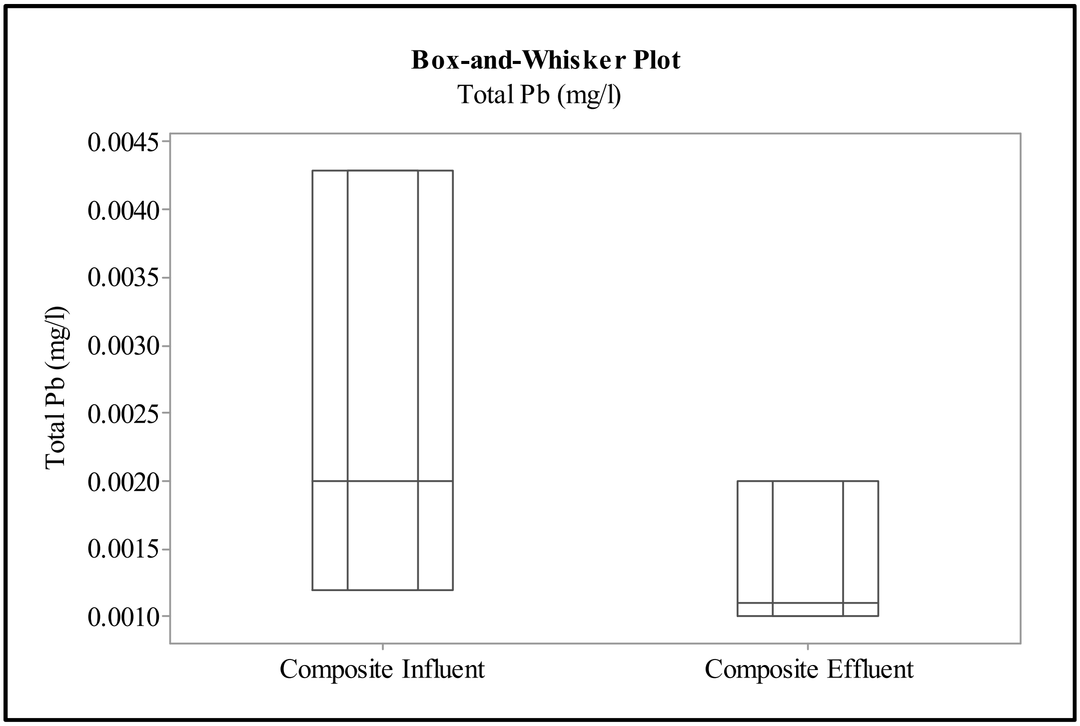



(a)

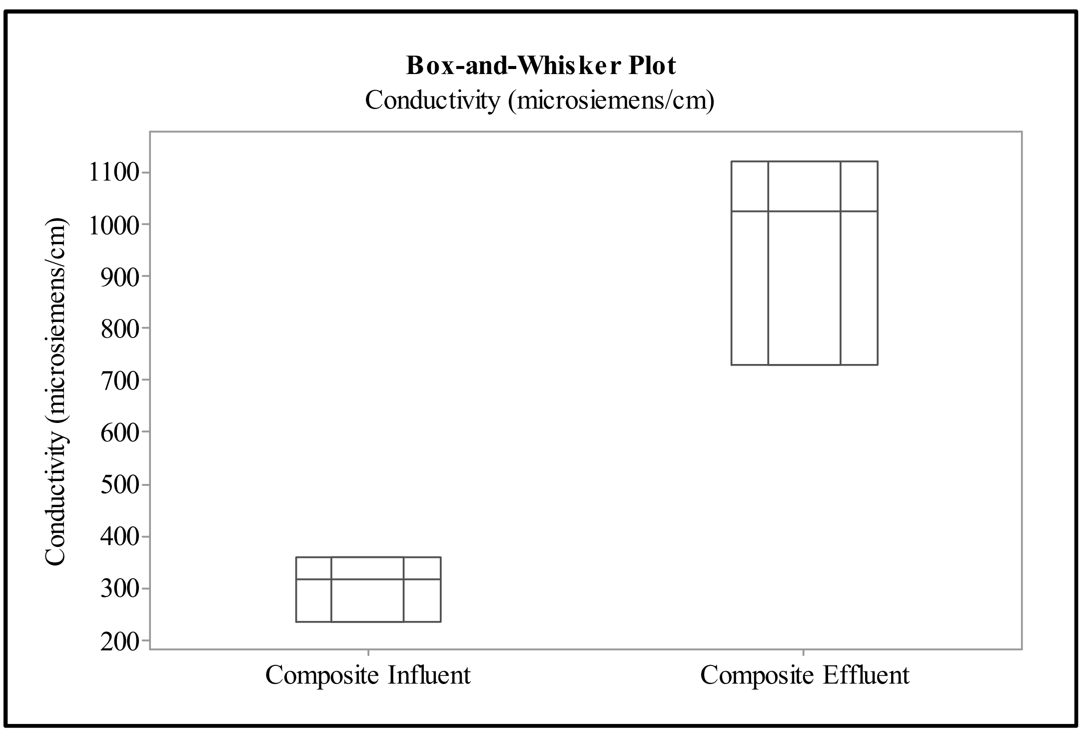



(b)

Figure 19. Box-and-whisker plots for (a) nitrate-n, and (b) chloride.




(a)




(b)

Figure 20. Box-and-whisker plots for (a) total lead, and (b) conductivity.

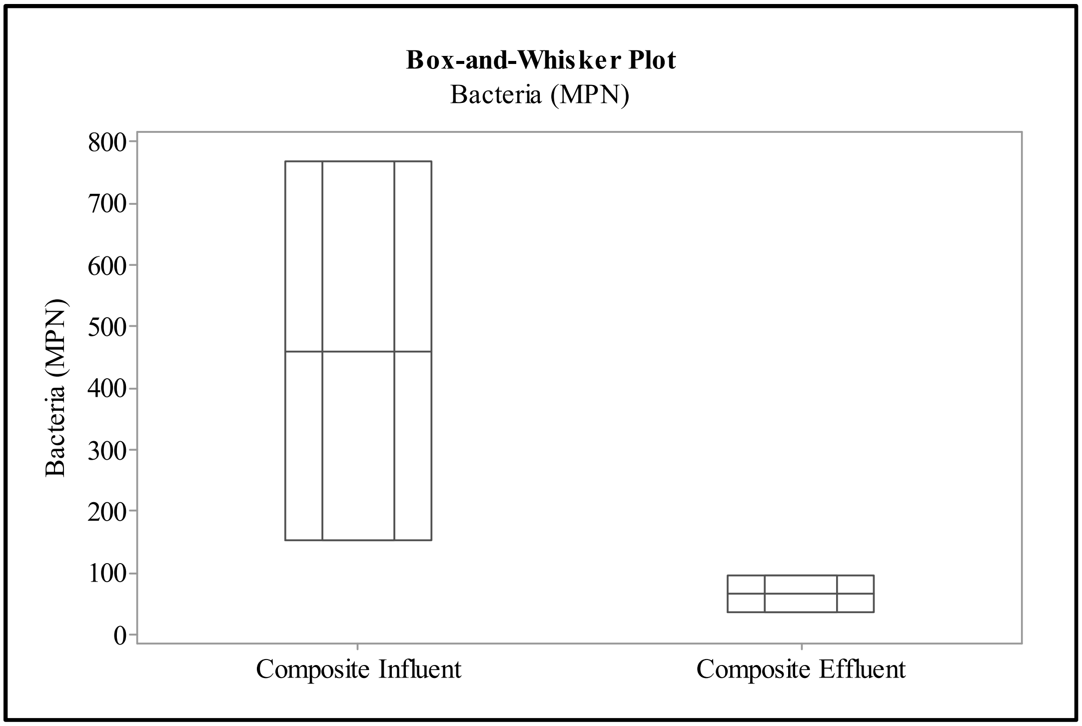



Figure 21. Box-and-whisker plot for bacteria as *E. Coli*.

CHAPTER V

# 5. DISCUSSION

## 5.1 Introduction

This section discusses the results of the project to determine to what extent the overall objectives were accomplished and which hypotheses are accepted. The main objective of this project is to determine if the sampling techniques, analytical methods, and applied statistical analysis have the ability to determine the removal efficiency of the water quality parameters in question. The constituents are analyzed independently, so assessment of the wet detention pond removal efficiency is broken down by individual parameter. This assessment allows for recommendations of potential parameters to remove from the tested parameter list for future continuation of the project based on non-detection or inability to measure due to limitations with preservation of the sample for certain analytical methods and equipment.

The sampling techniques for precipitation and flow measurement were compared to reference values and field checks to identify differences between the equipment and personnel capabilities. These comparisons were used to identify errors. Likewise, quality control (QC) measures for the analytical methods were used to ensure precision of measured influent and effluent concentration. Recommendations for improvement of precision of these measurements are included within this section. The statistical analysis method applied to the composite sample data is a method widely used by the

International Stormwater BMP Database (Int'l BMP Database). The method was slightly modified to compensate for the small sample size. This modification simply avoided using statistical tests better suited for large sample sizes.

## 5.2 Sampling Plan Techniques

The sampling plan for the project includes the methods used for storm forecasting, precipitation measurement, flow measurement, and sample collection throughout a given storm event. A discussion on the techniques used is presented in subsequent sections.

### 5.2.1 Storm Forecasting

The frequency analysis completed on 20 years of historical data presented a preliminary estimation on the number of events that could be expected throughout the project analysis period. While the range of annual precipitation events throughout the 20 years spanned between 43 and 70, the analysis still gives good indication that an appropriate amount of events will occur that are adequate in size for producing stormwater runoff. The frequency analysis was coupled with preliminary estimation of runoff through hydrologic and hydraulic modeling of the site at the current progress with development of the drainage area. This led to the notion that an adequate sampling event is one whose cumulative rainfall is expected to be at least 2.54 mm.

The reality of forecasting a precipitation event is that it can change in an instant. Positive changes occur when storms strengthen or produce greater rainfall than anticipated by meteorologists. Of the 40 events that occurred throughout the analysis period, 40 percent exhibited precipitation amounts of less than 2.54 mm. Another 25 percent were storms greater than 25.4 mm (1 in) that tended to be too dangerous to sample due to wind gusts, lightning, poor visibility, etc. With a team of samplers and analysts available, these events would be some of the best to sample since they would produce larger amounts of runoff. The sample size obtained for the analysis is relatively small compared to the number of events that occurred. The major factors that affected the monitoring of more events were the learning curve that developed over the course of the project toward increases in subject knowledge, the fact that sampling and analysis was being completed by a single person, and the previously mentioned safety concerns. To obtain more samples, a team of trained analysts and equipment for automatic sampling at all inlet and outlet points is necessary.

An improvement to the preliminary runoff estimation from modeling would be calibration of the model with actual monitored influent and effluent volumes. For the purposes of this baseline study, however, this calibration is deemed unnecessary. If proper calibration is completed, the model can theoretically be used to determine the influent and effluent volumes from measured precipitation data. Improved compositing of the samples would require an autosampler with a coupled flow meter to allow the equipment to obtain the necessary sample aliquots without needing an operator on site. In this project, monitoring of the influent and effluent was completed through the onsite water level measurements, so calibration of the model was not completed.

### 5.2.2 Precipitation Measurement

The precipitation data used in the project is compiled from local sources of rain gages linked to the City of Grand Forks (City) municipal supervisory control and data acquisition (SCADA) system. The variability of storms based on distance from the project site is prevalent, which was observed in Table 15 by the variations in recorded precipitation amounts for the monitored events. Comparison of the data between the three SCADA rain gages and the two National Weather Service (NWS) rain gages is difficult due to the variation in distance the gages are from each other. More accurate comparison of the gages would require calibration of all units. This is a recommendation for future use of this sampling plan. Further, errors in distance from the project site or calibration of existing rain gages could be eliminated with the addition of a rain gage directly on site. Temporary rain gages are commonly installed for BMP effectiveness assessment to ensure that the precipitation amounts of the event are accurately measured (Geosyntec Consultants and Wright Water Engineers, Inc. 2009).

**5.2.3 Flow Measurement**

The measurement of the influent and effluent flow throughout the composite sampling events is the most susceptible parameter to error due to the amount of variables considered in the measurement. One project limitation contributing to sources of error in flow measurement is resource availability. At the onset of the project, there was not enough knowledge about what equipment was necessary for accurate flow measurement of the BMP studied. This led to changes in measured quantities over time as the necessary equipment became available. The last composite sampling event was able to capture the full influent and effluent volumes as well as determine on site barometric pressure compensation for proper compositing of the sample aliquots. The results found within this event were used to estimate the contributing influent amounts of the two inlets and direct pond inflow from the surrounding drainage area. The first and second composite sampling events captured the west inlet influent and total effluent volumes. This estimation has the potential for error. As a comparison, the amount of runoff found to be contributed by the west inlet during preliminary modeling in HydroCAD was as much as 78 percent for events between 2.54 and 12.7 mm in cumulative precipitation, while the calculated average west inlet contribution was 68 percent. Since calibration of the model was not completed, the comparison can only be provisional. Factors not accounted for in the modeling, such as exact representation of the current watershed development and stormwater confluence through the storm sewer network, contribute to potential errors in the runoff distribution.

The methods of calculation of relative percent difference (RPD) between the barometric compensation and reference level compensation are given previously. The RPD gives a sense or magnitude of the precision of the two compared measurements. The RPD ranged from 1.7 percent to 5.9 percent for the four volumes requiring adjustment. These values are not extremely significant, but could have been avoided if barometric pressure was directly measured on site for all monitored events. It was observed that the larger volumes of effluent or influent had greater RPD percentages.

A few flow measurement variables that cause potential error are the water level, the Manning's n-value, and the slope of the flow channel. To ensure proper deployment and measurement of water depth with water level loggers, the inlet and outlet loggers were calibrated by a simple bucket calibration test. The calculated RPD percentages ranged from 0.29 percent to 1.01 percent, with increased error in smaller depths. The error is relatively small. The sensitivity of the Manning's n-value and the channel slope is very apparent based on the RPD between calculated discharges found when adjusting the n-value to other typical values for reinforced concrete pipe and slope to values between plus or minus 20 percent of the site as-built slope determination. If an inaccurate n-value is paired with an inaccurate slope value the error is increasingly magnified. To compensate for these potential error sources, Manning's n could be verified with more advanced modeling calibrated with known flow amounts. It is also recommended that the slope of the conduit be verified in the field with surveying equipment. Water level and temperature RPD were calculated for every manual grab sample taken for the composited events. The error in the water level was relatively high (up to 18 percent), while temperature RPD ranged from 0.28 percent to 3.43 percent, which is comparatively less. The lower temperature RPD provides argument that the main source of error is not the water density compensation that is automatically compensated for in the water level logger software. It is estimated that the largest source of error is small water depths experienced throughout some of the monitored events. Other error is attributed to the poor lighting on site that caused reduced visibility of instrumentation while obtaining field measurements at night.

Further recommendations for increased accuracy of flow measurement include better placement of the deployed water level logger and the installation of a temporary flow measurement device. Based on the bucket calibration results, less error was found with greater depth. The development of a stilling well within the inlet and outlet structure to cause an increase in the amount of head measured by the logger would allow compensation for very small water depths throughout the monitoring event. The installation of a flow measurement device would also cause an increase in head on the upstream side, making for an adequate region of logger deployment. The extent of different flow measurement devices that could be utilized at the inlet and outlet pipes is outside the scope of this project. Generally, examples of temporary devices are pre-fabricated flumes and weirs that are sized for the conduit diameter and flow capacity.

### 5.2.4 Sample Collection

The availability of an autosampler in later parts of the project allowed for greater simplicity in the collection of composite samples. Limitations of the equipment included not having the optional meters such as flow or pH that could have been used to enhance project output. Without these meters it made it impossible to measure pH of the sample aliquots collected with the autosampler due to the need to measure the parameter within 15 minutes of collection. The same is true for dissolved oxygen. The autosampler allowed continued sample collection without an operator present after precipitation events were finished. This allowed the sampling of the entire outflow hydrograph as the detention pond digressed to normal pool elevation or zero-flow depth. The main recommendation with sample collection is to deploy autosamplers at every sampling point that have the capability of monitoring flow to create automatic flow-weighted composite samples.

## 5.3 Water Quality Analysis

The analytical methods used to determine the pollutant concentrations of the composite samples were assumed to be accurate enough to assess the BMP removal efficiency for this baseline study. As previously indicated, many of the parameters were analyzed by a colorimetric device that is EPA approved for monitoring analysis for compliance with National Pollutant Discharge Elimination System (NPDES) permit measurable goals. The precision of the analytical methods is measured through duplicate sample analysis that determines RPD. QC early on in the project was not completed at the typical frequency of one per sample set or ten percent of the sample set; therefore, data from the single grab sample events are taken with caution. For this reason, the grab sample influent and effluent concentrations were not included in the data sets determined for statistical significance. The results are presented herein and used as provisional comparison to the results obtained by the composite sampling events. Literature values are generally based on event mean concentrations (EMCs), giving another reason for using only the composite samples in the statistical analysis. The RPD for all analytical results are given in Tables 42 through 47 in Appendix E. High RPD causes error in the determined concentration, which leads to error in the calculated efficiency ratio. For the composite sample events monitored, retesting of the sample was completed in some circumstances due to high variability in the original versus duplicate results.

### 5.4 Single Event Removal Efficiency

The parameters analyzed in this assessment are categorized as chemical properties to describe the total sample make-up, total suspended solids (TSS), nutrients, heavy metals, and bacteria. The following sections discuss the results of the intra-storm analysis of the assessed water quality parameters. This gives a preliminary sense of what parameters were proven to exhibit removal within the BMP and what parameters can be ruled-out for future continuation of this sampling plan. For comparison to literature review values for average intra-event removal efficiency, Table 25 was organized from the literature values given in section 2.8 for wet detention ponds. This table shows the literature values for removal efficiency versus the calculated averages.

The intra-event efficiency is visually presented by the time series plots given for each parameter. Non-detects are shown as a concentration value equal to the minimum reporting limit (MRL) or minimum value within the analytical procedure detection range. These plots also show indication of the variability in event concentrations and the differences in influent and effluent concentrations. The single event analysis, as well as the statistical analysis, considered all storms equal and did not account for the event precipitation magnitude.

Table 25. Calculated removal efficiency versus literature values.

| Parameter | MPCA$^{\alpha}$ | EPA$^{\beta}$ | CWP$^{\gamma}$ | Average Grab Sample | Average Composite Sample |
|---|---|---|---|---|---|
| TSS | 84 | 67 | 79 | 76 | 76 |
| Total P | 50 | 48 | 49 | 66 | 73 |
| Nitrate-N | - | 24$^{\beta}$ | - | 66 | 40 |
| Metals | 60$^{\alpha}$ | 25$^{\beta}$ | 62$^{\gamma}$ | NA$^{\delta}$ | NA$^{\delta}$ |
| Bacteria | 70 | 65 | 70 | 96 | 83 |

$^{\alpha}$ Metals defined as average of zinc and copper (Minnesota Pollution Control Agency 2014).
$^{\beta}$ Nitrogen defined as nitrate as nitrogen, metals constituent inclusion not specified, (EPA 2014e).
$^{\gamma}$ Metals defined as average of zinc and copper (Winer 2000).
$^{\delta}$ Zinc and copper were not detected in any sampling event

### 5.4.1 Chemical Properties

It has been explained throughout that some of the original chemical properties included in the parameter list were deemed inappropriate due to limitations with measuring the parameters within the time constraints of the analytical test. This included pH and dissolved oxygen. If portable pH and dissolved oxygen meters are available in future monitoring, grab samples paired with the autosamplers could be used to assess these chemical properties. Further, a meter as a component of the autosampler would give automatic determination of these parameters for every aliquot collected.

At the onset of event monitoring, pH and dissolved oxygen values were determined for single grab samples. The pH was lower in the influent than effluent for the first two events and opposite in the final event. The grab sample event influent and effluent pH measurements are summarized in Figure 22. Dissolved oxygen was found to be higher at the outlet for two events and only decreased by 16 percent for the third. These trends for dissolved oxygen are summarized in Figure 23. Low levels of dissolved oxygen cause favorable conditions for eutrophication (an oxygen-deficient condition) to occur, so an increase in concentration between the influent and effluent presents a positive correlation of improved water quality. The values determined for dissolved oxygen are relatively high. Typically, in urban runoff it is 5.0 mg/l or greater (EPA 1999), with the determined results much greater than this value considering a measurement range of 0.0 to 15.0 mg/l for the Winkler Test. Also, if the dissolved oxygen was actually at this magnitude the pH measurements would have also been elevated. This indicates that there is potential discrepancy in the results for dissolved oxygen and since QC measures were not completed for the analyte, they cannot be verified or validated.

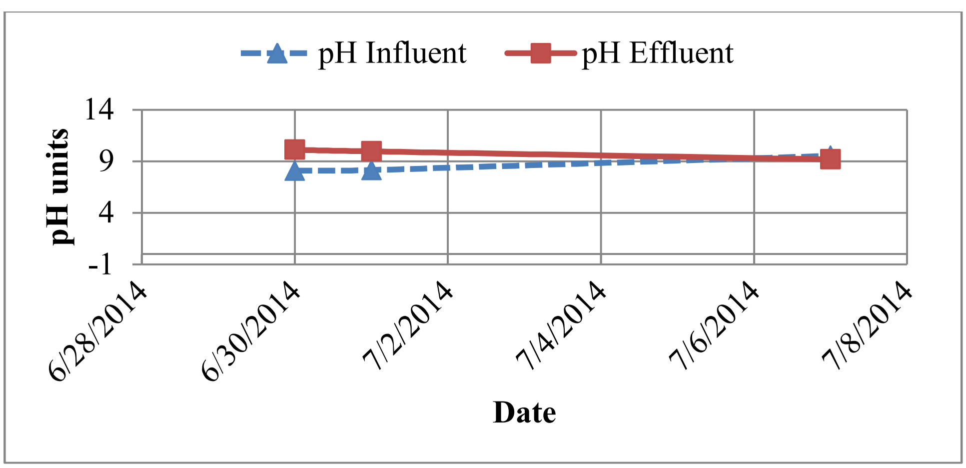



Figure 22. Summary of pH measurements for grab sample events.

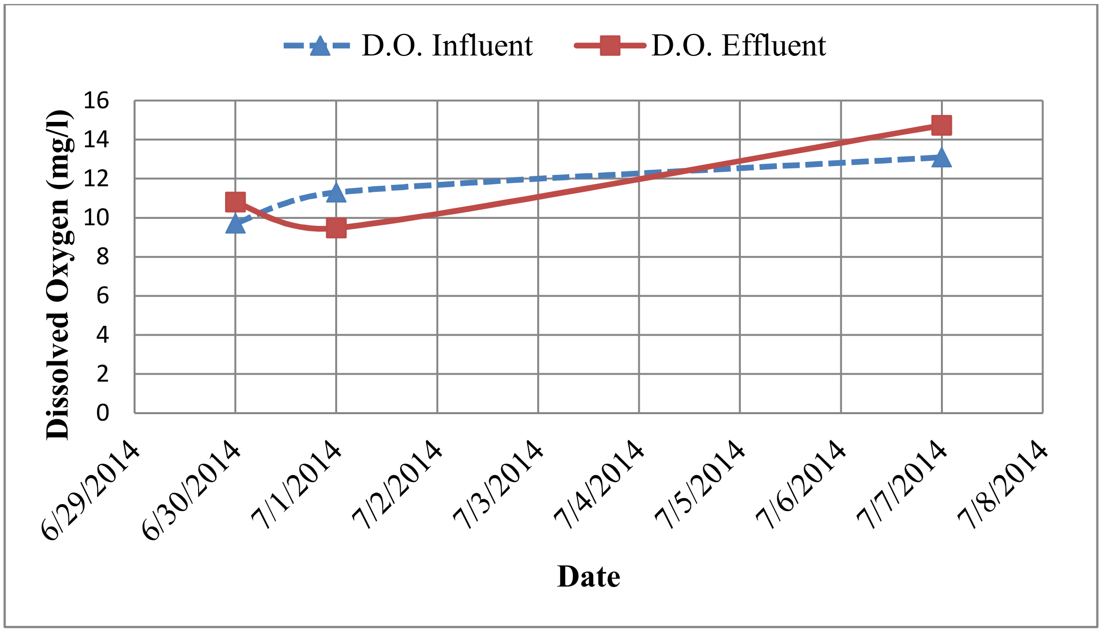



Figure 23. Summary of trend for dissolved oxygen.

Another chemical property evaluated is conductivity. Conductivity is a measure of electrical current within the water. Conductivity in water is affected by the presence of inorganic dissolved ions that carry a negative or positive charge (EPA 2012). The conductivity was found to decrease for all grab samples, but increase for all composite samples. The trends of individually assessed ions that contribute to the conductivity measurements are discussed in subsequent sections. An analyte that is directly proportional to conductivity is chloride, which was also analyzed in the project. The correlation between the two parameters is summarized in Table 26. It can be seen that the removal percentages in the first two grab samples between chloride and conductivity are well correlated. Also, for the last two composite samples increases in effluent chloride were paired with increases in conductivity. For the other two events, low removal efficiency of one parameter was coupled with an increase in concentration of the effluent in the other parameter. The increase in conductivity and chloride of the effluent is potentially due to evaporation that occurs between storm events. As evaporation of water within the permanent pool occurs, the chloride remains dissolved and the loss of volume leads to a greater concentration of the analyte. When an event large enough to create runoff occurs, the influent mixes with the permanent pool and causes the effluent to be comprised of the concentrated chloride. This is one potential explanation for the effluent concentration being greater than the influent for chloride, and in turn, conductivity as well.

Table 26. Comparison of chloride and conductivity for intra-event results.

| | Grab Sample Removal % | | | Composite Sample Removal % | | |
|---|---|---|---|---|---|---|
| **Parameter** | **06/30/14** | **07/01/14** | **07/07/14** | **09/09/14** | **09/28/14** | **10/12/14** |
| Chloride | 66 | 46 | INC$^{\alpha}$ | 23 | INC$^{\alpha}$ | INC$^{\alpha}$ |
| Conductivity | 62 | 43 | 23 | INC$^{\alpha}$ | INC$^{\alpha}$ | INC$^{\alpha}$ |

$^{\alpha}$ INC. = removal of parameter not observed, effluent concentration greater than influent

### 5.4.2 Total Suspended Solids

TSS for all six monitored events resulted in lower effluent concentrations than influent. Wet detention ponds are designed based on the principles of settling and sedimentation, making this result common for the type of BMP. The magnitude of the removal efficiency is 76 percent for both grab samples and composite samples. This finding is within the typical range of 67 to 84 percent based on the literature values compiled in Table 25. TSS of the influent is compared with event precipitation rainfall amounts to determine if a trend can be seen with larger events producing larger suspended solids concentrations. Table 27 summarizes these results. Generally, smaller events exhibited lower concentrations and the largest events had the largest TSS concentration. This shows that heavier rainfall amounts cause greater sediment movement and erosion throughout the contributing watershed.

Table 27. TSS concentration of influent versus event precipitation magnitude.

| | Event Date | | | | | |
|---|---|---|---|---|---|---|
| | **6/30/14** | **7/01/14** | **7/07/14** | **9/09/14** | **9/28/14** | **10/12/14** |
| Influent TSS (mg/l) | 25 | 1.36 | 1442 | 218 | 40.3 | 41 |
| Precipitation (mm) | 4.81 | 25 | 25.95 | 25.71 | 5.94 | 12.72 |

### 5.4.3 Nutrients

The nutrients included in this analysis are ammonia, nitrite, and nitrate all represented as nitrogen, phosphate as orthophosphate, and total phosphorus as phosphate. Total phosphorus was measured in the analytical procedures as total phosphorus as phosphate.

The nitrogen analytes exhibited variable findings between the grab and composite samples. Effluent ammonia concentration was found to be greater than the influent concentration in two grab samples and one composite sample. Removal efficiency of the remaining samples varied between 18 and 66 percent, causing difficulty in determining the actual removal efficiency for this parameter. Nitrite exhibited effluent concentrations below detection range for four events. For two of the grab samples, a provisional complete removal was found due to influent concentrations that decreased to below detection in the effluent. The final grab sample and one composite sample were determined as undetected in both the influent and effluent. For the final two composite samples, nitrite exhibited an increase in effluent concentration versus the influent. The high variation in the results leads to a lack of conclusion on whether the detention pond is capable at removing nitrite. Very little nitrite is usually found in stormwater according to (EPA 1999). With the low detection of nitrite and typically low values found in stormwater, this parameter is recommended to be removed from the list of tested parameters. To continue compensation of the parameter in the future, an analysis method that measures nitrate and nitrite as a combined concentration is recommended. Nitrate demonstrated efficiency in removal in all six monitored events. This efficiency ranged from 14 percent to 69 percent, with the average grab sample efficiency equal to 66 percent and the average composite sample efficiency equal to 40 percent. Both observations are above the typical removal efficiency of 24 percent as indicated by EPA (2014).

The phosphorus analytes showed more consistent data among the sample sets compared to nitrogen constituents. Total phosphorus removal was observed in all six monitored events. Grab samples averaged 66 percent removal, while composite samples averaged 73 percent removal. Typical removal efficiency is on average 49 percent based on literature values given in Table 25. The removal efficiency found in the studied BMP is above average for both grab samples and composite samples. Removal efficiency for phosphate as orthophosphate was found to be variable within the grab samples. In two events the effluent concentration was below detection, so a provisional one-hundred percent removal was calculated. The final grab sample event showed an increase in concentration between the influent and effluent. For the composite samples, all three events showed removal efficiency, with an average of 71 percent between the intra-event results. A literature value to compare removal of phosphate as orthophosphate in detention ponds was not found. Recall that total phosphorus concentration is the summation of the organic and inorganic phosphorus. Organic phosphorus is not typically abundant in water, and phosphorus is mostly comprised of inorganic phosphate species that include orthophosphates and condensed phosphates (Mines Jr. 2014). Total phosphorus tends to correlate well with TSS because it is mostly insoluble particulate material or a substance that adsorbs to sediment (Kliewer 2006). With that being said, TSS could be used as a surrogate for total phosphorus removal. Orthophosphate is the portion of phosphate immediately biologically available. Therefore, its measurement is necessary in the continuation of this project to determine if degradation is occurring in a BMP over time. If orthophosphate concentrations are initially high or rise over the course of an analysis, more biological growth would be likely observed, leading to poor water quality.

### 5.4.4 Heavy Metals

The heavy metals included in the analysis are total copper, total lead, and total zinc. Analysis of these parameters was completed by Minnesota Valley Testing Laboratory (MVTL). Four of the six sample sets were analyzed for metals which included one grab sample and all three composite samples. The results indicated that total copper and total zinc were not detected in any of the analyzed influent and effluent samples. Typically, the removal efficiency for the average of zinc and copper is near 60 percent. With no detection of either parameter throughout the analysis period, it cannot be determined whether the wet detention pond exhibits any removal of these constituents. Total lead was detected in the influent sample in two events, with the first effluent concentration falling below detection and the second just above the MRL. This ascertains that total lead was successfully reduced throughout the BMP.

### 5.4.5 Bacteria

Bacteria in the form of *E. Coli* is determined based on a count per 100 ml of sample. Four of the monitored events were tested for bacteria removal. Results indicate a

96 percent removal in the grab samples and 83 percent removal in the composite samples. Literature values give a typical range between 65 percent and 70 percent for wet detention ponds. With the small sample size it is difficult to determine the certainty in the obtained results. The results indicate above average removal of bacteria within the studied detention pond.

### 5.5 Statistical Analysis

While the aforementioned results and discussion provide insight on parameters that exhibited positive or negative trends in water quality improvement, statistical analysis to determine whether the composite sample data is significantly different between the influent and effluent concentration is required. The analysis methods used were previously described in section 3.8. Statistically significant difference is obtained when the following three conditions are met:

1. The Ryan-Joiner test calculated coefficient is greater than the critical value for both the influent and effluent for either normal or lognormal distribution. This ensures that the sample sets have the same shape as required for the Mann-Whitney test.
2. The Mann-Whitney null hypothesis is rejected for at least the 90 percent confidence interval. Visual representation is given in the box-and-whisker plots.
3. The Levene test null hypothesis is accepted for both the influent and effluent data sets. This is visually presented by the straight lines within the lognormal probability plots being parallel to one another.

Statistical analysis was only performed on the composite sample data. The single event efficiency results led to visible trends in reduction or increase in concentration at the effluent for TSS, total phosphorus, phosphate as orthophosphate, nitrate, conductivity, and bacteria. The other parameters were either found to commonly exhibit non-detection, had results near the MRL, or had variable results. Three parameters met the conditions for concluding 90 percent statistical significance that the influent and effluent data sets are different. This includes total phosphorus, nitrate, and conductivity. Total phosphorus and nitrate were found to exhibit confidence in removal efficiency, while conductivity shows confidence in higher effluent concentration than influent. The TSS, phosphate as orthophosphate, and bacteria removal results are still preliminarily acceptable, just not statistically proven with the sample set collected thus far. A greater sample size would help better indicate the significance of these analytes. A final comparison to the Int'l BMP Database is made to further support the obtained results. The parameters highlighted in bold represent those found to be statistically significantly different and those italicized were not. The removal efficiency ratio of the mean observed influent and effluent concentrations was calculated using the same formula used in the single event removal efficiency analysis. Project results for total phosphorus are significantly greater efficiency ratios compared to the database results. The other parameters show relative comparison. This is summarized in Table 28.

Table 28. Comparison of project removal efficiency results to Int'l BMP Database removal efficiency results (Geosyntec Consultants and Wright Water Engineers, Inc. 2012).

| **Project Results** | | **Int'l BMP Database Results** | |
|---|---|---|---|
| *TSS* | 76 | **TSS** | 63 |
| **Nitrate-N** | 40 | *Nitrate-N* | 22 |
| **Total P** | 73 | **Total P** | 20 |
| *E. Coli* | 83 | **E. Coli** | 86 |

Non-detection of concentrations causes skew in the statistical analysis and replacement with the MRL or minimum value in the detection range must be taken provisionally. The heavy metals tested did not show significant levels of concentration and in most cases were not detected.

For continuation of this project at this particular site, and potentially other relatively new BMPs, it is recommended that monitoring of heavy metals continues, even though high concentrations of the pollutants were not observed. To save on project expenses, the frequency of these tests could be limited. It would be pertinent to analyze the parameters at the project onset and intermittently. Events with high runoff volumes should be targeted. If a spike in the pollutants is noticed after an event, it would be useful to determine any potential point-sources from areas of vehicular corrosion or exhaust, or from aging storm sewer infrastructure corrosion. For analysis of a BMP in a fully-developed, aging drainage area, greater concentrations of heavy metals are likely and analysis of the pollutants should be included. Nitrite was frequently undetected or just above detection limit within the drainage basin, as common in stormwater, so its inclusion in future monitoring is not necessary. Removal efficiency of the nutrients was effectively gaged by the measurement of nitrate and total phosphorus. Project cost can be decreased by not including other analyte forms of nitrogen. Another alternative would be to measure nitrate and nitrite together as a total concentration. Recall that total phosphorus tends to be removed with observed TSS removal, making TSS a potential surrogate for assessing total phosphorus removal. To save on project cost, this assumption could be made. Orthophosphate should be included in further analysis because it identifies biologically available phosphate, which indicates the state of the basin's potential biologic growth. It is also recommended that pH and dissolved oxygen meters become part of the project resources to ensure that the analytes are measured for both the influent and effluent accurately. These parameters give preliminary determination of the overall chemical conditions present in the sample.

### 5.6 Lessons Learned

This project required the determination of a sampling and analytical plan that would accurately describe the removal efficiency of the wet detention pond being studied. Throughout this process there were many lessons learned that enabled increased expertise in the subject over time. This required adaptation and changes made to the plan as trial-and-error produced more accurate results. The obstacles that were overcome are easily summarized by five important lessons learned. These five lessons are briefly discussed so that similar roadblocks are not faced by the next analyst. Many of the lessons learned dealt with the second BMP that was part of the original scope of work that was deemed inappropriate to include in the final analysis due to the many complexities of the site that were never made stable. This second site is left out of the majority of the report. Refer to the introductory sections for a brief site description.

The first lesson learned is that preparedness is essential for the execution of a sampling plan. Much of the literature review was done throughout the sampling season, which leads to the need to adapt the methods over time as new knowledge is gained to better the assessment. It would be beneficial to write a sampling plan prior to its execution, but this would require someone knowledgeable in the subject matter at the project onset to accomplish this.

The second and third lessons correlate with each other. The first of which is assistance with sampling. The City provided the necessary equipment and material resources to complete the sampling. Personnel to help with the sampling were not hired or available through other sources, so the entire project was completed by a single analyst. It is highly recommended that a team of trained individuals make up the sample collection team. Another team should be available for the analytical assessment in the laboratory. Precipitation events are obviously variable and the expectation of one person on call at all times is unreasonable. Instead, the trained team can be broken down into smaller groups that are on call at different periods of time. The minimum number of individuals present during sampling should be two to increase sample collection accuracy and ensure safety for the collectors.

Safety is the third lesson learned. Storm events can be dangerous due to wind gusts, poor visibility, and lightning. Having a collection partner available in all events is recommended to ensure the well-being and safety of the analysts. Safety was a great concern at the second BMP that was located next to the Red River of the North in the City's Greenway, which is a park and recreation area that closes after nightfall. There are no street lights located within this park, so sampling at this location would be difficult, especially during heavy rainfall events. Sampling was attempted at this location a few times, but was unsuccessful due to the safety concerns.

The fourth lesson learned is the need for QC within the analysis to ensure the obtained results are representative of the sample. QC pairs with the need for proper preservation of the samples to stop degradation of analyte concentrations. If the preservation of the samples for specific analytes was better understood at the project onset, the resources for measuring analytes such as pH and dissolved oxygen could have been obtained. Other QC control measures dealt with the measurement of flow. The biggest error in flow measurement occurred at the second BMP that was not included in the final analysis. At this site, a broad-crested weir to control the flow at the outlet was designed, constructed, and installed by the project analyst. Problems arose during some of the massive precipitation events that occurred during the sampling season that caused erosion and failure of the structure walls. The structure was made out of plywood because it was only to be temporary and in-place for the project duration. The weight of the detained water within the detention area and above the weir crest caused further failure in the device. To correct these issues, a cast-in-place reinforced concrete structure would be necessary. This site was part of the U.S. Army Corps of Engineers flood protection program, so any permanent alteration to the outlet structure would need approval and analysis for potential impacts to the existing drainage area. For this reason, the structure was made temporary by request of the City.

The final lesson learned is the need for the "perfect storm" to accurately obtain composite samples. Much time was wasted waiting for precipitation events to begin when weather forecasting was not accurate. Also, many events were missed due to not having the team of samplers that is necessary for such a variable underlying principle. This principle being that BMP effectiveness cannot be assessed without precipitation events that produce runoff.

## CHAPTER VI

# 6. CONCLUSION

The overall goal of this project was to accurately assess the water quality of an *in-situ* structural best management practice (BMP) located in Grand Forks, North Dakota (City). Interest in this research stemmed from the current national awareness and concern with water quality in natural waterways, along with the City's desire to perform a baseline analysis on the effectiveness of installed BMPs. The City falls within the ND National Pollutant Discharge Elimination System (NDPDES) permit because it is considered a municipal separate storm sewer system (MS4). Within this permit, it is required that the MS4 determines and implements measurable goals pertaining to the prevention of pollution. While BMP effectiveness assessment is not a necessary measurable goal, it is one that, if monitored, can provide beneficial information on expected pollutant contribution from the watershed that it serves, which can then be used to estimate the contribution elsewhere. Another current issue that led to the research is the ND Nutrient Reduction Strategy that is being developed by the ND Department of Health (NDDH). This strategy is intending to develop nutrient loading criteria that will be set to determine waterways that require mitigation and restoration. The City can use the results within to compare the effluent concentrations with the developed criteria.

The pollutant removal effectiveness of the studied wet detention pond was determined on an independent water quality parameter basis. This was conducted to determine which parameters were proven to accept the hypothesis, which rejected it, and which were deemed unnecessary for consideration based on effectively estimating the parameter with another analyte or non-detection of the parameter throughout the sampling period. The hypothesis is that the sampling plan techniques, analytical methods, and applied statistical analysis accurately assess the BMP pollutant removal effectiveness.

A summary of the project findings for the thirteen original water quality parameters monitored in this baseline study is presented henceforth. Acceptance of the hypothesis is proven for total phosphorus, nitrate as nitrogen, and conductivity. The nutrient analytes were determined to exhibit on average 73 percent removal of total phosphorus and 40 percent removal of nitrate as nitrogen. Conductivity was found to increase throughout the BMP, with effluent concentrations greater than the influent. Other analytes that exhibited removal efficiency, but were not proven to be statistically significant, were total suspended solids (TSS) at 76 percent removal, phosphate as orthophosphate at 71 percent removal, and bacteria as *E. Coli* at 83 percent removal. TSS has been found to be a useful surrogate for total phosphorus (Kliewer 2006). With TSS and total phosphorus also correlating in this research, total phosphorus could be removed from the parameter list for stormwater runoff analysis to decrease project cost.

The remaining parameters of ammonia as nitrogen, nitrite as nitrogen, total copper, total lead, total zinc, chloride, pH and dissolved oxygen did not suggest effective removal trends throughout the BMP. The heavy metals and nitrite were in many instances not detected or close to the detection. The low heavy metal concentrations could be due to the relatively new drainage area reaching the BMP. Higher concentrations would likely be present in older drainage areas, or would increase over time in a new area. Nitrite is typically low in concentration or undetected in stormwater runoff, which was observed herein, so it could be eliminated from the parameter list. Another typical technique of nitrogen analyte analysis is to determine nitrate and nitrite as nitrogen in a singular concentration. This would require the purchase of only one reagent kit versus two separate kits that determine the analytes separately. Ammonia can be a toxic form of nitrogen; therefore, inclusion of the analyte should be continued with future project extension. Chloride concentration was found to correlate well with conductivity, making it a possible parameter for removal. The more easily measured conductivity value could be a potential surrogate for chloride prediction. Dissolved oxygen and pH are recommended to stay included in the analyte list as long as portable meters are available to properly measure the analytes within the short preservation time.

This research provided a sampling plan, water quality analysis, and statistical analysis that were proven to accurately assess the effectiveness of a wet detention pond located in an urban drainage area for three of the parameters analyzed. Further research and continuation of the plan at the same site would enhance the statistical credibility of the measured results and determine potential outliers or errors not able to be addressed in this analysis. Application of other flow measurement devices to better capture the influent and effluent volumes would provide more accuracy in the overall analysis. This sampling plan can also be adapted to other BMPs located both within and outside of the City. Other types of BMPs can be assessed and comparison between the types can lead to cost-benefit analysis for future planning of city infrastructure. Other areas of interest include comparison of the same BMP type in a new urban development versus an old urban development. Finally, analysis of potential point sources for excessive pollutant contribution can be obtained from comparative studies of the same BMP type in the same urban watershed.

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APPENDICES

# Appendix A

## Storm Forecasting Detailed Data

Table 29. Frequency analysis results for 1994 through 2013.

| May Events < 2.54 mm (0.1 in) | | | | | |
|---|---|---|---|---|---|
| **Bin** | **Frequency** | **Cumulative %** | **Class Interval** | **Class Mark** | **Relative Frequency** |
| 1 | 1 | 5.000 | 0-1 | 1 | 0.050 |
| 2 | 0 | 5.000 | 1-2 | 2 | 0.000 |
| 3 | 2 | 15.000 | 2-3 | 3 | 0.100 |
| 4 | 1 | 20.000 | 3-4 | 4 | 0.050 |
| 5 | 4 | 40.000 | 4-5 | 5 | 0.200 |
| 6 | 5 | 65.000 | 5-6 | 6 | 0.250 |
| 7 | 4 | 85.000 | 6-7 | 7 | 0.200 |
| 8 | 0 | 85.000 | 7-8 | 8 | 0.000 |
| 9 | 3 | 100.000 | 8-9 | 9 | 0.150 |
| 10 | 0 | 100.000 | 9-10 | 10 | 0.000 |
| 11 | 0 | 100.000 | 10-11 | 11 | 0.000 |
| 12 | 0 | 100.000 | 11-12 | 12 | 0.000 |
| **May Events 2.54 to 12.7 mm (0.1 to 0.5 in)** | | | | | |
| **Bin** | **Frequency** | **Cumulative %** | **Class Interval** | **Class Mark** | **Relative Frequency** |
| 1 | 4 | 20.000 | 0-1 | 1 | 0.200 |
| 2 | 1 | 25.000 | 1-2 | 2 | 0.050 |
| 3 | 4 | 45.000 | 2-3 | 3 | 0.200 |
| 4 | 3 | 60.000 | 3-4 | 4 | 0.150 |
| 5 | 4 | 80.000 | 4-5 | 5 | 0.200 |
| 6 | 0 | 80.000 | 5-6 | 6 | 0.000 |
| 7 | 4 | 100.000 | 6-7 | 7 | 0.200 |
| 8 | 0 | 100.000 | 7-8 | 8 | 0.000 |
| 9 | 0 | 100.000 | 8-9 | 9 | 0.000 |
| 10 | 0 | 100.000 | 9-10 | 10 | 0.000 |
| 11 | 0 | 100.000 | 10-11 | 11 | 0.000 |
| 12 | 0 | 100.000 | 11-12 | 12 | 0.000 |
| **May Events 12.7 to 25.4 mm (0.5 to 1.0 in)** | | | | | |
| **Bin** | **Frequency** | **Cumulative %** | **Class Interval** | **Class Mark** | **Relative Frequency** |
| 1 | 11 | 55.000 | 0-1 | 1 | 0.550 |
| 2 | 4 | 75.000 | 1-2 | 2 | 0.200 |
| 3 | 3 | 90.000 | 2-3 | 3 | 0.150 |
| 4 | 2 | 100.000 | 3-4 | 4 | 0.100 |
| 5 | 0 | 100.000 | 4-5 | 5 | 0.000 |
| 6 | 0 | 100.000 | 5-6 | 6 | 0.000 |
| 7 | 0 | 100.000 | 6-7 | 7 | 0.000 |
| 8 | 0 | 100.000 | 7-8 | 8 | 0.000 |
| 9 | 0 | 100.000 | 8-9 | 9 | 0.000 |
| 10 | 0 | 100.000 | 9-10 | 10 | 0.000 |
| 11 | 0 | 100.000 | 10-11 | 11 | 0.000 |
| 12 | 0 | 100.000 | 11-12 | 12 | 0.000 |

Table 29 continued.

| Bin | Frequency | Cumulative % | Class Interval | Class Mark | Relative Frequency |
|---|---|---|---|---|---|
| **May Events greater than 25.4 mm (1.0 in)** | | | | | |
| **Bin** | **Frequency** | **Cumulative %** | **Class Interval** | **Class Mark** | **Relative Frequency** |
| 1 | 16 | 80.000 | 0-1 | 1 | 0.800 |
| 2 | 4 | 100.000 | 1-2 | 2 | 0.200 |
| 3 | 0 | 100.000 | 2-3 | 3 | 0.000 |
| 4 | 0 | 100.000 | 3-4 | 4 | 0.000 |
| 5 | 0 | 100.000 | 4-5 | 5 | 0.000 |
| 6 | 0 | 100.000 | 5-6 | 6 | 0.000 |
| 7 | 0 | 100.000 | 6-7 | 7 | 0.000 |
| 8 | 0 | 100.000 | 7-8 | 8 | 0.000 |
| 9 | 0 | 100.000 | 8-9 | 9 | 0.000 |
| 10 | 0 | 100.000 | 9-10 | 10 | 0.000 |
| 11 | 0 | 100.000 | 10-11 | 11 | 0.000 |
| 12 | 0 | 100.000 | 11-12 | 12 | 0.000 |
| **June Events < 2.54 mm (0.1 in)** | | | | | |
| **Bin** | **Frequency** | **Cumulative %** | **Class Interval** | **Class Mark** | **Relative Frequency** |
| 1 | 0 | 0.000 | 0-1 | 1 | 0.000 |
| 2 | 0 | 0.000 | 1-2 | 2 | 0.000 |
| 3 | 1 | 5.000 | 2-3 | 3 | 0.050 |
| 4 | 4 | 25.000 | 3-4 | 4 | 0.200 |
| 5 | 4 | 45.000 | 4-5 | 5 | 0.200 |
| 6 | 3 | 60.000 | 5-6 | 6 | 0.150 |
| 7 | 6 | 90.000 | 6-7 | 7 | 0.300 |
| 8 | 2 | 100.000 | 7-8 | 8 | 0.100 |
| 9 | 0 | 100.000 | 8-9 | 9 | 0.000 |
| 10 | 0 | 100.000 | 9-10 | 10 | 0.000 |
| 11 | 0 | 100.000 | 10-11 | 11 | 0.000 |
| 12 | 0 | 100.000 | 11-12 | 12 | 0.000 |
| **June Events 2.54 to 12.7 mm (0.1 to 0.5 in)** | | | | | |
| **Bin** | **Frequency** | **Cumulative %** | **Class Interval** | **Class Mark** | **Relative Frequency** |
| 1 | 2 | 10.000 | 0-1 | 1 | 0.100 |
| 2 | 1 | 15.000 | 1-2 | 2 | 0.050 |
| 3 | 4 | 35.000 | 2-3 | 3 | 0.200 |
| 4 | 5 | 60.000 | 3-4 | 4 | 0.250 |
| 5 | 3 | 75.000 | 4-5 | 5 | 0.150 |
| 6 | 2 | 85.000 | 5-6 | 6 | 0.100 |
| 7 | 2 | 95.000 | 6-7 | 7 | 0.100 |
| 8 | 0 | 95.000 | 7-8 | 8 | 0.000 |
| 9 | 0 | 95.000 | 8-9 | 9 | 0.000 |
| 10 | 1 | 100.000 | 9-10 | 10 | 0.050 |
| 11 | 0 | 100.000 | 10-11 | 11 | 0.000 |
| 12 | 0 | 100.000 | 11-12 | 12 | 0.000 |

Table 29 continued.

| June Events 12.7 to 25.4 mm (0.5 to 1.0 in) | | | | | |
|---|---|---|---|---|---|
| **Bin** | **Frequency** | **Cumulative %** | **Class Interval** | **Class Mark** | **Relative Frequency** |
| 1 | 10 | 50.000 | 0-1 | 1 | 0.500 |
| 2 | 5 | 75.000 | 1-2 | 2 | 0.250 |
| 3 | 3 | 90.000 | 2-3 | 3 | 0.150 |
| 4 | 2 | 100.000 | 3-4 | 4 | 0.100 |
| 5 | 0 | 100.000 | 4-5 | 5 | 0.000 |
| 6 | 0 | 100.000 | 5-6 | 6 | 0.000 |
| 7 | 0 | 100.000 | 6-7 | 7 | 0.000 |
| 8 | 0 | 100.000 | 7-8 | 8 | 0.000 |
| 9 | 0 | 100.000 | 8-9 | 9 | 0.000 |
| 10 | 0 | 100.000 | 9-10 | 10 | 0.000 |
| 11 | 0 | 100.000 | 10-11 | 11 | 0.000 |
| 12 | 0 | 100.000 | 11-12 | 12 | 0.000 |
| **June Events greater than 25.4 mm (1.0 in)** | | | | | |
| **Bin** | **Frequency** | **Cumulative %** | **Class Interval** | **Class Mark** | **Relative Frequency** |
| 1 | 14 | 70.000 | 0-1 | 1 | 0.700 |
| 2 | 5 | 95.000 | 1-2 | 2 | 0.250 |
| 3 | 1 | 100.000 | 2-3 | 3 | 0.050 |
| 4 | 0 | 100.000 | 3-4 | 4 | 0.000 |
| 5 | 0 | 100.000 | 4-5 | 5 | 0.000 |
| 6 | 0 | 100.000 | 5-6 | 6 | 0.000 |
| 7 | 0 | 100.000 | 6-7 | 7 | 0.000 |
| 8 | 0 | 100.000 | 7-8 | 8 | 0.000 |
| 9 | 0 | 100.000 | 8-9 | 9 | 0.000 |
| 10 | 0 | 100.000 | 9-10 | 10 | 0.000 |
| 11 | 0 | 100.000 | 10-11 | 11 | 0.000 |
| 12 | 0 | 100.000 | 11-12 | 12 | 0.000 |
| **July Events < 2.54 mm (0.1 in)** | | | | | |
| **Bin** | **Frequency** | **Cumulative %** | **Class Interval** | **Class Mark** | **Relative Frequency** |
| 1 | 1 | 5.000 | 0-1 | 1 | 0.050 |
| 2 | 1 | 10.000 | 1-2 | 2 | 0.050 |
| 3 | 5 | 35.000 | 2-3 | 3 | 0.250 |
| 4 | 4 | 55.000 | 3-4 | 4 | 0.200 |
| 5 | 3 | 70.000 | 4-5 | 5 | 0.150 |
| 6 | 2 | 80.000 | 5-6 | 6 | 0.100 |
| 7 | 2 | 90.000 | 6-7 | 7 | 0.100 |
| 8 | 1 | 95.000 | 7-8 | 8 | 0.050 |
| 9 | 0 | 95.000 | 8-9 | 9 | 0.000 |
| 10 | 1 | 100.000 | 9-10 | 10 | 0.050 |
| 11 | 0 | 100.000 | 10-11 | 11 | 0.000 |
| 12 | 0 | 100.000 | 11-12 | 12 | 0.000 |

Table 29 continued.

| July Events 2.54 to 12.7 mm (0.1 to 0.5 in) | | | | | |
|---|---|---|---|---|---|
| **Bin** | **Frequency** | **Cumulative %** | **Class Interval** | **Class Mark** | **Relative Frequency** |
| 1 | 1 | 5.000 | 0-1 | 1 | 0.050 |
| 2 | 3 | 20.000 | 1-2 | 2 | 0.150 |
| 3 | 8 | 60.000 | 2-3 | 3 | 0.400 |
| 4 | 2 | 70.000 | 3-4 | 4 | 0.100 |
| 5 | 4 | 90.000 | 4-5 | 5 | 0.200 |
| 6 | 0 | 90.000 | 5-6 | 6 | 0.000 |
| 7 | 2 | 100.000 | 6-7 | 7 | 0.100 |
| 8 | 0 | 100.000 | 7-8 | 8 | 0.000 |
| 9 | 0 | 100.000 | 8-9 | 9 | 0.000 |
| 10 | 0 | 100.000 | 9-10 | 10 | 0.000 |
| 11 | 0 | 100.000 | 10-11 | 11 | 0.000 |
| 12 | 0 | 100.000 | 11-12 | 12 | 0.000 |
| **July Events 12.7 to 25.4 mm (0.5 to 1.0 in)** | | | | | |
| **Bin** | **Frequency** | **Cumulative %** | **Class Interval** | **Class Mark** | **Relative Frequency** |
| 1 | 13 | 65.000 | 0-1 | 1 | 0.650 |
| 2 | 5 | 90.000 | 1-2 | 2 | 0.250 |
| 3 | 1 | 95.000 | 2-3 | 3 | 0.050 |
| 4 | 1 | 100.000 | 3-4 | 4 | 0.050 |
| 5 | 0 | 100.000 | 4-5 | 5 | 0.000 |
| 6 | 0 | 100.000 | 5-6 | 6 | 0.000 |
| 7 | 0 | 100.000 | 6-7 | 7 | 0.000 |
| 8 | 0 | 100.000 | 7-8 | 8 | 0.000 |
| 9 | 0 | 100.000 | 8-9 | 9 | 0.000 |
| 10 | 0 | 100.000 | 9-10 | 10 | 0.000 |
| 11 | 0 | 100.000 | 10-11 | 11 | 0.000 |
| 12 | 0 | 100.000 | 11-12 | 12 | 0.000 |
| **July Events greater than 25.4 mm (1.0 in)** | | | | | |
| **Bin** | **Frequency** | **Cumulative %** | **Class Interval** | **Class Mark** | **Relative Frequency** |
| 1 | 16 | 80.000 | 0-1 | 1 | 0.800 |
| 2 | 2 | 90.000 | 1-2 | 2 | 0.100 |
| 3 | 2 | 100.000 | 2-3 | 3 | 0.100 |
| 4 | 0 | 100.000 | 3-4 | 4 | 0.000 |
| 5 | 0 | 100.000 | 4-5 | 5 | 0.000 |
| 6 | 0 | 100.000 | 5-6 | 6 | 0.000 |
| 7 | 0 | 100.000 | 6-7 | 7 | 0.000 |
| 8 | 0 | 100.000 | 7-8 | 8 | 0.000 |
| 9 | 0 | 100.000 | 8-9 | 9 | 0.000 |
| 10 | 0 | 100.000 | 9-10 | 10 | 0.000 |
| 11 | 0 | 100.000 | 10-11 | 11 | 0.000 |
| 12 | 0 | 100.000 | 11-12 | 12 | 0.000 |

Table 29 continued.

| August Events < 2.54 mm (0.1 in) | | | | | |
|---|---|---|---|---|---|
| Bin | Frequency | Cumulative % | Class Interval | Class Mark | Relative Frequency |
| 1 | 0 | 0.000 | 0-1 | 1 | 0.000 |
| 2 | 2 | 10.000 | 1-2 | 2 | 0.100 |
| 3 | 2 | 20.000 | 2-3 | 3 | 0.100 |
| 4 | 5 | 45.000 | 3-4 | 4 | 0.250 |
| 5 | 5 | 70.000 | 4-5 | 5 | 0.250 |
| 6 | 5 | 95.000 | 5-6 | 6 | 0.250 |
| 7 | 0 | 95.000 | 6-7 | 7 | 0.000 |
| 8 | 0 | 95.000 | 7-8 | 8 | 0.000 |
| 9 | 1 | 100.000 | 8-9 | 9 | 0.050 |
| 10 | 0 | 100.000 | 9-10 | 10 | 0.000 |
| 11 | 0 | 100.000 | 10-11 | 11 | 0.000 |
| 12 | 0 | 100.000 | 11-12 | 12 | 0.000 |
| **August Events 2.54 to 12.7 mm (0.1 to 0.5 in)** | | | | | |
| Bin | Frequency | Cumulative % | Class Interval | Class Mark | Relative Frequency |
| 1 | 3 | 15.000 | 0-1 | 1 | 0.150 |
| 2 | 2 | 25.000 | 1-2 | 2 | 0.100 |
| 3 | 2 | 35.000 | 2-3 | 3 | 0.100 |
| 4 | 10 | 85.000 | 3-4 | 4 | 0.500 |
| 5 | 3 | 100.000 | 4-5 | 5 | 0.150 |
| 6 | 0 | 100.000 | 5-6 | 6 | 0.000 |
| 7 | 0 | 100.000 | 6-7 | 7 | 0.000 |
| 8 | 0 | 100.000 | 7-8 | 8 | 0.000 |
| 9 | 0 | 100.000 | 8-9 | 9 | 0.000 |
| 10 | 0 | 100.000 | 9-10 | 10 | 0.000 |
| 11 | 0 | 100.000 | 10-11 | 11 | 0.000 |
| 12 | 0 | 100.000 | 11-12 | 12 | 0.000 |
| **August Events 12.7 to 25.4 mm (0.5 to 1.0 in)** | | | | | |
| Bin | Frequency | Cumulative % | Class Interval | Class Mark | Relative Frequency |
| 1 | 9 | 45.000 | 0-1 | 1 | 0.450 |
| 2 | 7 | 80.000 | 1-2 | 2 | 0.350 |
| 3 | 3 | 95.000 | 2-3 | 3 | 0.150 |
| 4 | 0 | 95.000 | 3-4 | 4 | 0.000 |
| 5 | 1 | 100.000 | 4-5 | 5 | 0.050 |
| 6 | 0 | 100.000 | 5-6 | 6 | 0.000 |
| 7 | 0 | 100.000 | 6-7 | 7 | 0.000 |
| 8 | 0 | 100.000 | 7-8 | 8 | 0.000 |
| 9 | 0 | 100.000 | 8-9 | 9 | 0.000 |
| 10 | 0 | 100.000 | 9-10 | 10 | 0.000 |
| 11 | 0 | 100.000 | 10-11 | 11 | 0.000 |
| 12 | 0 | 100.000 | 11-12 | 12 | 0.000 |

Table 29 continued.

| Bin | Frequency | Cumulative % | Class Interval | Class Mark | Relative Frequency |
|---|---|---|---|---|---|
| **August Events greater than 25.4 mm (1.0 in)** | | | | | |
| **Bin** | **Frequency** | **Cumulative %** | **Class Interval** | **Class Mark** | **Relative Frequency** |
| 1 | 16 | 80.000 | 0-1 | 1 | 0.800 |
| 2 | 4 | 100.000 | 1-2 | 2 | 0.200 |
| 3 | 0 | 100.000 | 2-3 | 3 | 0.000 |
| 4 | 0 | 100.000 | 3-4 | 4 | 0.000 |
| 5 | 0 | 100.000 | 4-5 | 5 | 0.000 |
| 6 | 0 | 100.000 | 5-6 | 6 | 0.000 |
| 7 | 0 | 100.000 | 6-7 | 7 | 0.000 |
| 8 | 0 | 100.000 | 7-8 | 8 | 0.000 |
| 9 | 0 | 100.000 | 8-9 | 9 | 0.000 |
| 10 | 0 | 100.000 | 9-10 | 10 | 0.000 |
| 11 | 0 | 100.000 | 10-11 | 11 | 0.000 |
| 12 | 0 | 100.000 | 11-12 | 12 | 0.000 |
| **September Events < 2.54 mm (0.1 in)** | | | | | |
| **Bin** | **Frequency** | **Cumulative %** | **Class Interval** | **Class Mark** | **Relative Frequency** |
| 1 | 2 | 10.000 | 0-1 | 1 | 0.100 |
| 2 | 1 | 15.000 | 1-2 | 2 | 0.050 |
| 3 | 1 | 20.000 | 2-3 | 3 | 0.050 |
| 4 | 7 | 55.000 | 3-4 | 4 | 0.350 |
| 5 | 2 | 65.000 | 4-5 | 5 | 0.100 |
| 6 | 2 | 75.000 | 5-6 | 6 | 0.100 |
| 7 | 3 | 90.000 | 6-7 | 7 | 0.150 |
| 8 | 0 | 90.000 | 7-8 | 8 | 0.000 |
| 9 | 2 | 100.000 | 8-9 | 9 | 0.100 |
| 10 | 0 | 100.000 | 9-10 | 10 | 0.000 |
| 11 | 0 | 100.000 | 10-11 | 11 | 0.000 |
| 12 | 0 | 100.000 | 11-12 | 12 | 0.000 |
| **September Events 2.54 to 12.7 mm (0.1 to 0.5 in)** | | | | | |
| **Bin** | **Frequency** | **Cumulative %** | **Class Interval** | **Class Mark** | **Relative Frequency** |
| 1 | 4 | 20.000 | 0-1 | 1 | 0.200 |
| 2 | 4 | 40.000 | 1-2 | 2 | 0.200 |
| 3 | 3 | 55.000 | 2-3 | 3 | 0.150 |
| 4 | 6 | 85.000 | 3-4 | 4 | 0.300 |
| 5 | 1 | 90.000 | 4-5 | 5 | 0.050 |
| 6 | 2 | 100.000 | 5-6 | 6 | 0.100 |
| 7 | 0 | 100.000 | 6-7 | 7 | 0.000 |
| 8 | 0 | 100.000 | 7-8 | 8 | 0.000 |
| 9 | 0 | 100.000 | 8-9 | 9 | 0.000 |
| 10 | 0 | 100.000 | 9-10 | 10 | 0.000 |
| 11 | 0 | 100.000 | 10-11 | 11 | 0.000 |
| 12 | 0 | 100.000 | 11-12 | 12 | 0.000 |

Table 29 continued.

| September Events 12.7 to 25.4 mm (0.5 to 1.0 in) | | | | | |
|---|---|---|---|---|---|
| **Bin** | **Frequency** | **Cumulative %** | **Class Interval** | **Class Mark** | **Relative Frequency** |
| 1 | 16 | 80.000 | 0-1 | 1 | 0.800 |
| 2 | 4 | 100.000 | 1-2 | 2 | 0.200 |
| 3 | 0 | 100.000 | 2-3 | 3 | 0.000 |
| 4 | 0 | 100.000 | 3-4 | 4 | 0.000 |
| 5 | 0 | 100.000 | 4-5 | 5 | 0.000 |
| 6 | 0 | 100.000 | 5-6 | 6 | 0.000 |
| 7 | 0 | 100.000 | 6-7 | 7 | 0.000 |
| 8 | 0 | 100.000 | 7-8 | 8 | 0.000 |
| 9 | 0 | 100.000 | 8-9 | 9 | 0.000 |
| 10 | 0 | 100.000 | 9-10 | 10 | 0.000 |
| 11 | 0 | 100.000 | 10-11 | 11 | 0.000 |
| 12 | 0 | 100.000 | 11-12 | 12 | 0.000 |
| **September Events greater than 25.4 mm (1.0 in)** | | | | | |
| **Bin** | **Frequency** | **Cumulative %** | **Class Interval** | **Class Mark** | **Relative Frequency** |
| 1 | 17 | 85.000 | 0-1 | 1 | 0.850 |
| 2 | 2 | 95.000 | 1-2 | 2 | 0.100 |
| 3 | 1 | 100.000 | 2-3 | 3 | 0.050 |
| 4 | 0 | 100.000 | 3-4 | 4 | 0.000 |
| 5 | 0 | 100.000 | 4-5 | 5 | 0.000 |
| 6 | 0 | 100.000 | 5-6 | 6 | 0.000 |
| 7 | 0 | 100.000 | 6-7 | 7 | 0.000 |
| 8 | 0 | 100.000 | 7-8 | 8 | 0.000 |
| 9 | 0 | 100.000 | 8-9 | 9 | 0.000 |
| 10 | 0 | 100.000 | 9-10 | 10 | 0.000 |
| 11 | 0 | 100.000 | 10-11 | 11 | 0.000 |
| 12 | 0 | 100.000 | 11-12 | 12 | 0.000 |
| **October Events < 2.54 mm (0.1 in)** | | | | | |
| **Bin** | **Frequency** | **Cumulative %** | **Class Interval** | **Class Mark** | **Relative Frequency** |
| 1 | 0 | 0.000 | 0-1 | 1 | 0.000 |
| 2 | 2 | 10.000 | 1-2 | 2 | 0.100 |
| 3 | 3 | 25.000 | 2-3 | 3 | 0.150 |
| 4 | 3 | 40.000 | 3-4 | 4 | 0.150 |
| 5 | 4 | 60.000 | 4-5 | 5 | 0.200 |
| 6 | 4 | 80.000 | 5-6 | 6 | 0.200 |
| 7 | 0 | 80.000 | 6-7 | 7 | 0.000 |
| 8 | 3 | 95.000 | 7-8 | 8 | 0.150 |
| 9 | 1 | 100.000 | 8-9 | 9 | 0.050 |
| 10 | 0 | 100.000 | 9-10 | 10 | 0.000 |
| 11 | 0 | 100.000 | 10-11 | 11 | 0.000 |
| 12 | 0 | 100.000 | 11-12 | 12 | 0.000 |

Table 29 continued.

| October Events 2.54 to 12.7 mm (0.1 to 0.5 in) | | | | | |
|---|---|---|---|---|---|
| **Bin** | **Frequency** | **Cumulative %** | **Class Interval** | **Class Mark** | **Relative Frequency** |
| 1 | 8 | 40.000 | 0-1 | 1 | 0.400 |
| 2 | 2 | 50.000 | 1-2 | 2 | 0.100 |
| 3 | 3 | 65.000 | 2-3 | 3 | 0.150 |
| 4 | 4 | 85.000 | 3-4 | 4 | 0.200 |
| 5 | 2 | 95.000 | 4-5 | 5 | 0.100 |
| 6 | 0 | 95.000 | 5-6 | 6 | 0.000 |
| 7 | 1 | 100.000 | 6-7 | 7 | 0.050 |
| 8 | 0 | 100.000 | 7-8 | 8 | 0.000 |
| 9 | 0 | 100.000 | 8-9 | 9 | 0.000 |
| 10 | 0 | 100.000 | 9-10 | 10 | 0.000 |
| 11 | 0 | 100.000 | 10-11 | 11 | 0.000 |
| 12 | 0 | 100.000 | 11-12 | 12 | 0.000 |
| **October Events 12.7 to 25.4 mm (0.5 to 1.0 in)** | | | | | |
| **Bin** | **Frequency** | **Cumulative %** | **Class Interval** | **Class Mark** | **Relative Frequency** |
| 1 | 12 | 60.000 | 0-1 | 1 | 0.600 |
| 2 | 6 | 90.000 | 1-2 | 2 | 0.300 |
| 3 | 2 | 100.000 | 2-3 | 3 | 0.100 |
| 4 | 0 | 100.000 | 3-4 | 4 | 0.000 |
| 5 | 0 | 100.000 | 4-5 | 5 | 0.000 |
| 6 | 0 | 100.000 | 5-6 | 6 | 0.000 |
| 7 | 0 | 100.000 | 6-7 | 7 | 0.000 |
| 8 | 0 | 100.000 | 7-8 | 8 | 0.000 |
| 9 | 0 | 100.000 | 8-9 | 9 | 0.000 |
| 10 | 0 | 100.000 | 9-10 | 10 | 0.000 |
| 11 | 0 | 100.000 | 10-11 | 11 | 0.000 |
| 12 | 0 | 100.000 | 11-12 | 12 | 0.000 |
| **October Events greater than 25.4 mm (1.0 in)** | | | | | |
| **Bin** | **Frequency** | **Cumulative %** | **Class Interval** | **Class Mark** | **Relative Frequency** |
| 1 | 17 | 85.000 | 0-1 | 1 | 0.850 |
| 2 | 2 | 95.000 | 1-2 | 2 | 0.100 |
| 3 | 1 | 100.000 | 2-3 | 3 | 0.050 |
| 4 | 0 | 100.000 | 3-4 | 4 | 0.000 |
| 5 | 0 | 100.000 | 4-5 | 5 | 0.000 |
| 6 | 0 | 100.000 | 5-6 | 6 | 0.000 |
| 7 | 0 | 100.000 | 6-7 | 7 | 0.000 |
| 8 | 0 | 100.000 | 7-8 | 8 | 0.000 |
| 9 | 0 | 100.000 | 8-9 | 9 | 0.000 |
| 10 | 0 | 100.000 | 9-10 | 10 | 0.000 |
| 11 | 0 | 100.000 | 10-11 | 11 | 0.000 |
| 12 | 0 | 100.000 | 11-12 | 12 | 0.000 |

Table 29 continued.

| May through October Events < 2.54 mm (0.1 in) | | | | | |
|---|---|---|---|---|---|
| **Bin** | **Frequency** | **Cumulative %** | **Class Interval** | **Class Mark** | **Relative Frequency** |
| 3 | 0 | 0.000 | 0-3 | 1.5 | 0.000 |
| 6 | 0 | 0.000 | 3-6 | 4.5 | 0.000 |
| 9 | 0 | 0.000 | 6-9 | 7.5 | 0.000 |
| 12 | 0 | 0.000 | 9-12 | 10.5 | 0.000 |
| 15 | 0 | 0.000 | 12-15 | 13.5 | 0.000 |
| 18 | 0 | 0.000 | 15-18 | 16.5 | 0.000 |
| 21 | 0 | 0.000 | 18-21 | 19.5 | 0.000 |
| 24 | 3 | 15.000 | 21-24 | 22.5 | 0.150 |
| 27 | 2 | 25.000 | 24-27 | 25.5 | 0.100 |
| 30 | 6 | 55.000 | 27-30 | 28.5 | 0.300 |
| 33 | 8 | 95.000 | 30-33 | 31.5 | 0.400 |
| 36 | 1 | 100.000 | 33-36 | 34.5 | 0.050 |
| **May through October Events 2.54 to 12.7 mm (0.1 to 0.5 in)** | | | | | |
| **Bin** | **Frequency** | **Cumulative %** | **Class Interval** | **Class Mark** | **Relative Frequency** |
| 3 | 0 | 0.000 | 0-3 | 1.5 | 0.000 |
| 6 | 0 | 0.000 | 3-6 | 4.5 | 0.000 |
| 9 | 0 | 0.000 | 6-9 | 7.5 | 0.000 |
| 12 | 1 | 5.000 | 9-12 | 10.5 | 0.050 |
| 15 | 1 | 10.000 | 12-15 | 13.5 | 0.050 |
| 18 | 7 | 45.000 | 15-18 | 16.5 | 0.350 |
| 21 | 6 | 75.000 | 18-21 | 19.5 | 0.300 |
| 24 | 3 | 90.000 | 21-24 | 22.5 | 0.150 |
| 27 | 1 | 95.000 | 24-27 | 25.5 | 0.050 |
| 30 | 1 | 100.000 | 27-30 | 28.5 | 0.050 |
| 33 | 0 | 100.000 | 30-33 | 31.5 | 0.000 |
| 36 | 0 | 100.000 | 33-36 | 34.5 | 0.000 |
| **May through October Events 12.7 to 25.4 mm (0.5 to 1.0 in)** | | | | | |
| **Bin** | **Frequency** | **Cumulative %** | **Class Interval** | **Class Mark** | **Relative Frequency** |
| 3 | 1 | 5.000 | 0-3 | 1.5 | 0.050 |
| 6 | 7 | 40.000 | 3-6 | 4.5 | 0.350 |
| 9 | 9 | 85.000 | 6-9 | 7.5 | 0.450 |
| 12 | 3 | 100.000 | 9-12 | 10.5 | 0.150 |
| 15 | 0 | 100.000 | 12-15 | 13.5 | 0.000 |
| 18 | 0 | 100.000 | 15-18 | 16.5 | 0.000 |
| 21 | 0 | 100.000 | 18-21 | 19.5 | 0.000 |
| 24 | 0 | 100.000 | 21-24 | 22.5 | 0.000 |
| 27 | 0 | 100.000 | 24-27 | 25.5 | 0.000 |
| 30 | 0 | 100.000 | 27-30 | 28.5 | 0.000 |
| 33 | 0 | 100.000 | 30-33 | 31.5 | 0.000 |
| 36 | 0 | 100.000 | 33-36 | 34.5 | 0.000 |

Table 29 continued.

| May through October Events greater than 25.4 mm (1.0 in) | | | | | |
|---|---|---|---|---|---|
| **Bin** | **Frequency** | **Cumulative %** | **Class Interval** | **Class Mark** | **Relative Frequency** |
| 3 | 9 | 45.000 | 0-3 | 1.5 | 0.450 |
| 6 | 9 | 90.000 | 3-6 | 4.5 | 0.450 |
| 9 | 2 | 100.000 | 6-9 | 7.5 | 0.100 |
| 12 | 0 | 100.000 | 9-12 | 10.5 | 0.000 |
| 15 | 0 | 100.000 | 12-15 | 13.5 | 0.000 |
| 18 | 0 | 100.000 | 15-18 | 16.5 | 0.000 |
| 21 | 0 | 100.000 | 18-21 | 19.5 | 0.000 |
| 24 | 0 | 100.000 | 21-24 | 22.5 | 0.000 |
| 27 | 0 | 100.000 | 24-27 | 25.5 | 0.000 |
| 30 | 0 | 100.000 | 27-30 | 28.5 | 0.000 |
| 33 | 0 | 100.000 | 30-33 | 31.5 | 0.000 |
| 36 | 0 | 100.000 | 33-36 | 34.5 | 0.000 |

Table 30. HydroCAD peak discharge results for various storm durations and cumulative precipitation amounts.

| | 2.54 mm (0.1 in) Event Runoff ($m^3/s$) | | | 6.35 mm (0.25 in) Event Runoff ($m^3/s$) | | | 12.7 mm (0.5 in) Event Runoff ($m^3/s$) | | | 25.4 mm (1.0 in) Event Runoff ($m^3/s$) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Duration (hr)** | **West Inlet** | **East Inlet** | **Pond** | **West Inlet** | **East Inlet** | **Pond** | **West Inlet** | **East Inlet** | **Pond** | **West Inlet** | **East Inlet** | **Pond** |
| 4 | 0.010 | 0.003 | 0.001 | 0.124 | 0.037 | 0.011 | 0.386 | 0.114 | 0.034 | 0.944 | 0.276 | 0.083 |
| 5 | 0.010 | 0.003 | 0.001 | 0.117 | 0.034 | 0.010 | 0.364 | 0.105 | 0.032 | 0.891 | 0.255 | 0.077 |
| 6 | 0.009 | 0.003 | 0.001 | 0.112 | 0.032 | 0.010 | 0.346 | 0.098 | 0.030 | 0.844 | 0.237 | 0.072 |
| 7 | 0.008 | 0.003 | 0.001 | 0.107 | 0.030 | 0.009 | 0.332 | 0.092 | 0.028 | 0.808 | 0.222 | 0.067 |
| 8 | 0.008 | 0.002 | 0.001 | 0.103 | 0.029 | 0.009 | 0.319 | 0.087 | 0.026 | 0.775 | 0.209 | 0.063 |
| 9 | 0.008 | 0.002 | 0.001 | 0.099 | 0.027 | 0.008 | 0.306 | 0.082 | 0.025 | 0.746 | 0.197 | 0.059 |
| 10 | 0.008 | 0.002 | 0.001 | 0.096 | 0.026 | 0.008 | 0.296 | 0.078 | 0.024 | 0.717 | 0.185 | 0.056 |
| 11 | 0.007 | 0.002 | 0.001 | 0.093 | 0.025 | 0.007 | 0.286 | 0.074 | 0.022 | 0.693 | 0.176 | 0.053 |
| 12 | 0.007 | 0.002 | 0.001 | 0.091 | 0.024 | 0.007 | 0.278 | 0.070 | 0.021 | 0.671 | 0.167 | 0.050 |
| 13 | 0.007 | 0.002 | 0.001 | 0.088 | 0.022 | 0.007 | 0.268 | 0.067 | 0.020 | 0.648 | 0.159 | 0.048 |
| 14 | 0.007 | 0.002 | 0.001 | 0.086 | 0.022 | 0.007 | 0.261 | 0.064 | 0.019 | 0.628 | 0.151 | 0.046 |
| 15 | 0.007 | 0.002 | 0.001 | 0.083 | 0.021 | 0.006 | 0.253 | 0.061 | 0.018 | 0.610 | 0.144 | 0.044 |
| 16 | 0.007 | 0.002 | 0.001 | 0.081 | 0.020 | 0.006 | 0.246 | 0.058 | 0.018 | 0.592 | 0.138 | 0.042 |
| 17 | 0.007 | 0.002 | 0.001 | 0.079 | 0.019 | 0.006 | 0.239 | 0.056 | 0.017 | 0.574 | 0.132 | 0.040 |
| 18 | 0.007 | 0.002 | 0.001 | 0.077 | 0.018 | 0.005 | 0.233 | 0.054 | 0.016 | 0.559 | 0.127 | 0.038 |
| 19 | 0.006 | 0.002 | 0.001 | 0.075 | 0.018 | 0.005 | 0.227 | 0.052 | 0.016 | 0.544 | 0.122 | 0.037 |
| 20 | 0.006 | 0.002 | 0.001 | 0.073 | 0.017 | 0.005 | 0.221 | 0.050 | 0.015 | 0.528 | 0.117 | 0.035 |
| 21 | 0.006 | 0.002 | 0.001 | 0.072 | 0.016 | 0.005 | 0.215 | 0.048 | 0.014 | 0.515 | 0.113 | 0.034 |
| 22 | ¯.006 | 0.001 | 0.001 | 0.070 | 0.016 | 0.005 | 0.210 | 0.046 | 0.014 | 0.502 | 0.109 | 0.033 |
| 23 | 0.006 | 0.001 | 0.001 | 0.069 | 0.015 | 0.005 | 0.205 | 0.044 | 0.013 | 0.489 | 0.105 | 0.032 |

Table 31. HydroCAD runoff volume results for various storm durations and cumulative precipitation amounts.

| | 2.54 mm (0.1 in) Event Volume ($m^3$) | | 6.35 mm (0.25 in) Event Volume ($m^3$) | | 12.7 mm (0.5 in) Event Volume ($m^3$) | | 25.4 mm (1.0 in) Event Volume ($m^3$) | |
|---|---|---|---|---|---|---|---|---|
| **Duration (hr)** | **Inflow** | **Outflow** | **Inflow** | **Outflow** | **Inflow** | **Outflow** | **Inflow** | **Outflow** |
| 4 | 27 | 25 | 215 | 202 | 644 | 625 | 1653 | 1632 |
| 5 | 27 | 25 | 215 | 201 | 644 | 625 | 1653 | 1632 |
| 6 | 27 | 25 | 215 | 201 | 644 | 625 | 1653 | 1631 |
| 7 | 27 | 25 | 215 | 201 | 644 | 624 | 1653 | 1631 |
| 8 | 27 | 25 | 215 | 201 | 644 | 624 | 1653 | 1629 |
| 9 | 27 | 25 | 215 | 200 | 644 | 624 | 1653 | 1629 |
| 10 | 27 | 25 | 215 | 200 | 644 | 623 | 1653 | 1628 |
| 11 | 27 | 25 | 215 | 200 | 644 | 623 | 1653 | 1628 |
| 12 | 27 | 25 | 215 | 199 | 644 | 622 | 1653 | 1627 |
| 13 | 27 | 25 | 215 | 199 | 644 | 622 | 1653 | 1627 |
| 14 | 27 | 25 | 215 | 199 | 644 | 620 | 1653 | 1626 |
| 15 | 27 | 25 | 215 | 197 | 644 | 620 | 1653 | 1626 |
| 16 | 27 | 25 | 215 | 197 | 644 | 619 | 1653 | 1624 |
| 17 | 27 | 25 | 215 | 197 | 644 | 619 | 1653 | 1623 |
| 18 | 27 | 25 | 215 | 196 | 644 | 618 | 1653 | 1623 |
| 19 | 27 | 25 | 215 | 196 | 644 | 618 | 1653 | 1622 |
| 20 | 27 | 25 | 215 | 195 | 644 | 617 | 1653 | 1621 |
| 21 | 27 | 25 | 215 | 195 | 644 | 617 | 1653 | 1621 |
| 22 | 27 | 23 | 215 | 194 | 644 | 616 | 1653 | 1620 |
| 23 | 27 | 23 | 215 | 194 | 644 | 614 | 1653 | 1618 |
| 24 | 27 | 23 | 215 | 192 | 644 | 614 | 1653 | 1617 |

Appendix B

Detailed Precipitation Data

Table 32. Summary of Utilized Precipitation Data.

| Date | Event Start and End Point | Time | Precipitation (mm) | Cumulative Precipitation (mm) |
|---|---|---|---|---|
| 06/30/14 | START | 15:00:00 | 0.00 | 0.00 |
| | | 15:10:00 | 0.00 | 0.00 |
| | | 15:20:00 | 0.64 | 0.64 |
| | | 15:30:00 | 0.48 | 1.13 |
| | | 15:40:00 | 0.53 | 1.66 |
| | | 15:50:00 | 0.34 | 2.00 |
| | | 16:00:00 | 0.68 | 2.68 |
| | | 16:10:00 | 0.31 | 2.99 |
| | | 16:20:00 | 0.00 | 2.99 |
| | | 16:30:00 | 0.03 | 3.02 |
| | | 16:40:00 | 0.00 | 3.02 |
| | | 16:50:00 | 0.17 | 3.19 |
| | | 17:00:00 | 0.00 | 3.19 |
| | | 17:10:00 | 0.00 | 3.19 |
| | | 17:20:00 | 0.00 | 3.19 |
| | | 17:30:00 | 0.03 | 3.22 |
| | | 17:40:00 | 0.00 | 3.22 |
| | | 17:50:00 | 0.00 | 3.22 |
| | | 18:00:00 | 0.00 | 3.22 |
| | | 18:10:00 | 0.00 | 3.22 |
| | | 18:20:00 | 0.00 | 3.22 |
| | | 18:30:00 | 0.00 | 3.22 |
| | | 18:40:00 | 1.42 | 4.64 |
| | | 18:50:00 | 0.00 | 4.64 |
| | END | 19:00:00 | 0.17 | **4.81** |
| 07/01/14 | START | 8:40:00 | 0.00 | 0.00 |
| | | 8:50:00 | 0.17 | 0.17 |
| | | 9:00:00 | 0.05 | 0.22 |
| | | 9:10:00 | 0.40 | 0.62 |
| | | 9:20:00 | 0.17 | 0.79 |
| | | 9:30:00 | 0.05 | 0.85 |
| | | 9:40:00 | 0.00 | 0.85 |
| | | 9:50:00 | 0.00 | 0.85 |
| | | 10:00:00 | 0.17 | 1.02 |
| | | 10:10:00 | 0.00 | 1.02 |
| | | 10:20:00 | 0.00 | 1.02 |
| | | 10:30:00 | 0.00 | 1.02 |

Table 32 continued.

| Date | Event Start and End Point | Time | Precipitation (mm) | Cumulative Precipitation (mm) |
|---|---|---|---|---|
| 07/01/14 | | 10:40:00 | 0.00 | 1.02 |
| | | 10:50:00 | 0.00 | 1.02 |
| | | 11:00:00 | 0.00 | 1.02 |
| | | 11:10:00 | 0.00 | 1.02 |
| | | 11:20:00 | 0.00 | 1.02 |
| | | 11:30:00 | 0.00 | 1.02 |
| | | 11:40:00 | 0.00 | 1.02 |
| | | 11:50:00 | 0.00 | 1.02 |
| | | 12:00:00 | .05 | 1.07 |
| | | 12:10:00 | 0.03 | 1.10 |
| | | 12:20:00 | 0.00 | 1.10 |
| | | 12:30:00 | 0.17 | 1.27 |
| | | 12:40:00 | 0.00 | 1.27 |
| | | 12:50:00 | 0.00 | 1.27 |
| | | 13:00:00 | 0.00 | 1.27 |
| | | 13:10:00 | 0.00 | 1.27 |
| | | 13:20:00 | 0.03 | 1.30 |
| | END | 13:30:00 | 0.05 | **1.36** |
| 07/07/14 | START | 18:40:00 | 0.00 | 0.00 |
| | | 18:50:00 | 8.18 | 8.18 |
| | | 19:00:00 | 7.68 | 15.86 |
| | | 19:10:00 | 8.11 | 23.97 |
| | | 19:20:00 | 1.90 | 25.87 |
| | | 19:30:00 | 0.03 | 25.90 |
| | END | 19:40:00 | 0.05 | **25.95** |
| 09/09/14 | START | 15:40:00 | 0.00 | 0.00 |
| | | 15:50:00 | 0.17 | 0.17 |
| | | 16:00:00 | 0.74 | 0.91 |
| | | 16:10:00 | 0.68 | 1.59 |
| | | 16:20:00 | 0.85 | 2.44 |
| | | 16:30:00 | 3.12 | 5.55 |
| | | 16:40:00 | 1.56 | 7.11 |
| | | 16:50:00 | 1.70 | 8.80 |
| | | 17:00:00 | 1.39 | 10.19 |
| | | 17:10:00 | 0.66 | 10.85 |
| | | 17:20:00 | 0.25 | 11.10 |
| | | 17:30:00 | 1.15 | 12.26 |

Table 32 continued.

| Date | Event Start and End Point | Time | Precipitation (mm) | Cumulative Precipitation (mm) |
|---|---|---|---|---|
| 09/09/14 | | 17:40:00 | 1.76 | 14.02 |
| | | 17:50:00 | 0.29 | 14.30 |
| | | 18:00:00 | 0.41 | 14.71 |
| | | 18:10:00 | 0.56 | 15.27 |
| | | 18:20:00 | 0.62 | 15.89 |
| | | 18:30:00 | 0.20 | 16.09 |
| | | 18:40:00 | 0.54 | 16.63 |
| | | 18:50:00 | 0.34 | 16.97 |
| | | 19:00:00 | 1.25 | 18.22 |
| | | 19:10:00 | 0.25 | 18.47 |
| | | 19:20:00 | 1.38 | 19.85 |
| | | 19:30:00 | 0.90 | 20.76 |
| | | 19:40:00 | 0.36 | 21.12 |
| | | 19:50:00 | 0.42 | 21.54 |
| | | 20:00:00 | 0.32 | 21.86 |
| | | 20:10:00 | 0.64 | 22.50 |
| | | 20:20:00 | 0.17 | 22.68 |
| | | 20:30:00 | 0.37 | 23.04 |
| | | 20:40:00 | 0.76 | 23.81 |
| | | 20:50:00 | 0.45 | 24.26 |
| | | 21:00:00 | 0.25 | 24.51 |
| | | 21:10:00 | 0.37 | 24.88 |
| | | 21:20:00 | 0.40 | 25.28 |
| | | 21:30:00 | 0.17 | 25.45 |
| | | 21:40:00 | 0.00 | 25.45 |
| | | 21:50:00 | 0.00 | 25.45 |
| | | 22:00:00 | 0.00 | 25.45 |
| | | 22:10:00 | 0.00 | 25.45 |
| | | 22:20:00 | 0.00 | 25.45 |
| | | 22:30:00 | 0.17 | 25.62 |
| | | 22:40:00 | 0.00 | 25.62 |
| | | 22:50:00 | 0.00 | 25.62 |
| | | 23:00:00 | 0.03 | 25.65 |
| | | 23:10:00 | 0.00 | 25.65 |
| | END | 23:20:00 | 0.05 | **25.71** |
| 09/28/14 | START | 15:30:00 | 0.00 | 0.00 |
| | | 15:40:00 | 0.05 | 0.05 |

Table 32 continued.

| Date | Event Start and End Point | Time | Precipitation (mm) | Cumulative Precipitation (mm) |
|---|---|---|---|---|
| 09/28/14 | | 15:50:00 | 0.00 | 0.05 |
| | | 16:00:00 | 0.00 | 0.05 |
| | | 16:10:00 | 0.00 | 0.05 |
| | | 16:20:00 | 0.00 | 0.05 |
| | | 16:30:00 | 0.00 | 0.05 |
| | | 16:40:00 | 0.00 | 0.05 |
| | | 16:50:00 | 0.17 | 0.22 |
| | | 17:00:00 | 0.28 | 0.50 |
| | | 17:10:00 | 0.37 | 0.87 |
| | | 17:20:00 | 0.25 | 1.12 |
| | | 17:30:00 | 0.00 | 1.12 |
| | | 17:40:00 | 0.59 | 1.71 |
| | | 17:50:00 | 0.57 | 2.28 |
| | | 18:00:00 | 0.48 | 2.76 |
| | | 18:10:00 | 0.09 | 2.84 |
| | | 18:20:00 | 0.64 | 3.49 |
| | | 18:30:00 | 0.03 | 3.52 |
| | | 18:40:00 | 0.73 | 4.25 |
| | | 18:50:00 | 0.03 | 4.28 |
| | | 19:00:00 | 0.45 | 4.73 |
| | | 19:10:00 | 0.45 | 5.18 |
| | | 19:20:00 | 0.51 | 5.69 |
| | | 19:30:00 | 0.20 | 5.89 |
| | END | 19:40:00 | 0.05 | **5.94** |
| 10/12/14 | START | 17:00:00 | 0.00 | 0.00 |
| | | 17:10:00 | 0.14 | 0.14 |
| | | 17:20:00 | 0.53 | 0.67 |
| | | 17:30:00 | 0.05 | 0.73 |
| | | 17:40:00 | 0.00 | 0.73 |
| | | 17:50:00 | 0.17 | 0.90 |
| | | 18:00:00 | 0.00 | 0.90 |
| | | 18:10:00 | 0.00 | 0.90 |
| | | 18:20:00 | 0.00 | 0.90 |
| | | 18:30:00 | 0.00 | 0.90 |
| | | 18:40:00 | 0.00 | 0.90 |
| | | 18:50:00 | 0.76 | 1.66 |
| | | 19:00:00 | 0.28 | 1.94 |

Table 32 continued.

| Date | Event Start and End Point | Time | Precipitation (mm) | Cumulative Precipitation (mm) |
|---|---|---|---|---|
| 10/12/14 | | 19:10:00 | 0.54 | 2.47 |
| | | 19:20:00 | 0.48 | 2.96 |
| | | 19:30:00 | 0.34 | 3.30 |
| | | 19:40:00 | 0.12 | 3.42 |
| | | 19:50:00 | 0.54 | 3.95 |
| | | 20:00:00 | 0.45 | 4.40 |
| | | 20:10:00 | 0.68 | 5.08 |
| | | 20:20:00 | 0.39 | 5.47 |
| | | 20:30:00 | 0.34 | 5.81 |
| | | 20:40:00 | 0.17 | 5.98 |
| | | 20:50:00 | 0.68 | 6.66 |
| | | 21:00:00 | 0.71 | 7.37 |
| | | 21:10:00 | 0.03 | 7.40 |
| | | 21:20:00 | 0.84 | 8.24 |
| | | 21:30:00 | 0.59 | 8.84 |
| | | 21:40:00 | 0.22 | 9.06 |
| | | 21:50:00 | 0.71 | 9.77 |
| | | 22:00:00 | 0.68 | 10.44 |
| | | 22:10:00 | 0.62 | 11.06 |
| | | 22:20:00 | 0.12 | 11.18 |
| | | 22:30:00 | 0.45 | 11.62 |
| | | 22:40:00 | 0.00 | 11.62 |
| | | 22:50:00 | 0.00 | 11.62 |
| | | 23:00:00 | 0.76 | 12.38 |
| | | 23:10:00 | 0.00 | 12.38 |
| | | 23:20:00 | 0.00 | 12.38 |
| | | 23:30:00 | 0.17 | 12.56 |
| | | 23:40:00 | 0.00 | 12.56 |
| | | 23:50:00 | 0.00 | 12.56 |
| 10/13/14 | | 0:00:00 | 0.00 | 12.56 |
| | | 0:10:00 | 0.00 | 12.56 |
| | END | 0:20:00 | 0.17 | **12.72** |

# Appendix C

## Detailed Flow Measurement Data

Table 33. 09/09/14 influent hydrograph data.

| Time | Temperature (°C) | Barometric Compensated Discharge ($m^3/s$) | Barometric Compensated Volume ($m^3$) | Reference Level Compensated Discharge ($m^3/s$) | Reference Level Compensated Volume ($m^3$) |
|---|---|---|---|---|---|
| 9/9/14 16:20 | 13.65 | 0.00E+00 | 0.00 | 0.00E+00 | 0.00 |
| 9/9/14 16:25 | 13.46 | 7.00E-03 | 2.10 | 5.22E-03 | 1.56 |
| 9/9/14 16:30 | 13.75 | 3.32E-02 | 9.96 | 2.94E-02 | 8.83 |
| 9/9/14 16:35 | 13.85 | 4.25E-02 | 12.74 | 3.81E-02 | 11.44 |
| 9/9/14 16:40 | 13.85 | 5.10E-02 | 15.29 | 4.62E-02 | 13.87 |
| 9/9/14 16:45 | 13.65 | 5.65E-02 | 16.95 | 5.42E-02 | 16.27 |
| 9/9/14 16:50 | 13.56 | 6.41E-02 | 19.24 | 6.50E-02 | 19.51 |
| 9/9/14 16:55 | 13.46 | 7.07E-02 | 21.20 | 7.16E-02 | 21.49 |
| 9/9/14 17:00 | 13.46 | 6.23E-02 | 18.70 | 6.29E-02 | 18.88 |
| 9/9/14 17:05 | 13.37 | 4.83E-02 | 14.49 | 4.57E-02 | 13.71 |
| 9/9/14 17:10 | 13.37 | 2.90E-02 | 8.70 | 2.72E-02 | 8.17 |
| 9/9/14 17:15 | 13.27 | 1.24E-02 | 3.73 | 1.12E-02 | 3.35 |
| 9/9/14 17:20 | 13.27 | 1.17E-02 | 3.50 | 1.06E-02 | 3.17 |
| 9/9/14 17:25 | 13.27 | 1.62E-02 | 4.86 | 1.33E-02 | 4.00 |
| 9/9/14 17:30 | 13.27 | 2.78E-02 | 8.34 | 2.38E-02 | 7.15 |
| 9/9/14 17:35 | 13.27 | 3.72E-02 | 11.17 | 3.26E-02 | 9.77 |
| 9/9/14 17:40 | 13.17 | 4.22E-02 | 12.66 | 3.70E-02 | 11.10 |
| 9/9/14 17:45 | 13.17 | 5.07E-02 | 15.21 | 4.25E-02 | 12.74 |
| 9/9/14 17:50 | 13.08 | 4.88E-02 | 14.65 | 4.32E-02 | 12.96 |
| 9/9/14 17:55 | 13.08 | 4.75E-02 | 14.25 | 4.20E-02 | 12.59 |
| 9/9/14 18:00 | 12.98 | 4.17E-02 | 12.52 | 3.65E-02 | 10.96 |
| 9/9/14 18:05 | 12.98 | 3.04E-02 | 9.13 | 2.61E-02 | 7.82 |
| 9/9/14 18:10 | 12.98 | 1.74E-02 | 5.22 | 1.57E-02 | 4.72 |
| 9/9/14 18:15 | 12.98 | 8.20E-03 | 2.46 | 7.10E-03 | 2.13 |
| 9/9/14 18:20 | 12.98 | 1.67E-03 | 0.50 | 1.21E-03 | 0.36 |
| 9/9/14 18:25 | 12.98 | 2.97E-04 | 0.09 | 1.35E-04 | 0.04 |
| 9/9/14 18:30 | 12.98 | 1.35E-04 | 0.04 | 3.86E-05 | 0.01 |
| 9/9/14 18:35 | 12.98 | 0.00E+00 | 0.00 | 0.00E+00 | 0.00 |
| 9/9/14 18:40 | 12.98 | 2.01E-04 | 0.06 | 2.01E-04 | 0.06 |
| 9/9/14 18:45 | 12.88 | 9.62E-04 | 0.29 | 9.62E-04 | 0.29 |
| 9/9/14 18:50 | 12.79 | 6.90E-03 | 2.07 | 6.81E-03 | 2.04 |
| 9/9/14 18:55 | 12.79 | 1.71E-02 | 5.13 | 1.71E-02 | 5.13 |
| 9/9/14 19:00 | 12.79 | 3.59E-02 | 10.76 | 3.59E-02 | 10.76 |
| 9/9/14 19:05 | 12.69 | 4.08E-02 | 12.23 | 4.05E-02 | 12.15 |
| 9/9/14 19:10 | 12.59 | 4.05E-02 | 12.15 | 4.03E-02 | 12.08 |

Table 33 continued.

| Time | Temperature (°C) | Barometric Compensated Discharge ($m^3/s$) | Barometric Compensated Volume ($m^3$) | Reference Level Compensated Discharge ($m^3/s$) | Reference Level Compensated Volume ($m^3$) |
|---|---|---|---|---|---|
| 9/9/14 19:15 | 12.50 | 3.52E-02 | 10.56 | 3.75E-02 | 11.24 |
| 9/9/14 19:20 | 12.40 | 3.36E-02 | 10.09 | 3.59E-02 | 10.76 |
| 9/9/14 19:25 | 12.40 | 3.26E-02 | 9.77 | 3.72E-02 | 11.17 |
| 9/9/14 19:30 | 12.30 | 3.47E-02 | 10.42 | 3.93E-02 | 11.80 |
| 9/9/14 19:35 | 12.30 | 3.59E-02 | 10.76 | 4.08E-02 | 12.23 |
| 9/9/14 19:40 | 12.21 | 2.86E-02 | 8.58 | 3.52E-02 | 10.56 |
| 9/9/14 19:45 | 12.21 | 2.74E-02 | 8.23 | 3.41E-02 | 10.22 |
| 9/9/14 19:50 | 12.11 | 2.12E-02 | 6.35 | 2.68E-02 | 8.05 |
| 9/9/14 19:55 | 12.11 | 1.59E-02 | 4.77 | 2.08E-02 | 6.25 |
| 9/9/14 20:00 | 12.11 | 1.43E-02 | 4.29 | 1.90E-02 | 5.70 |
| 9/9/14 20:05 | 12.11 | 1.14E-02 | 3.42 | 1.56E-02 | 4.68 |
| 9/9/14 20:10 | 12.11 | 8.31E-03 | 2.49 | 1.19E-02 | 3.57 |
| 9/9/14 20:15 | 12.11 | 6.16E-03 | 1.85 | 8.10E-03 | 2.43 |
| 9/9/14 20:20 | 12.11 | 3.18E-03 | 0.95 | 5.47E-03 | 1.64 |
| 9/9/14 20:25 | 12.11 | 1.45E-03 | 0.44 | 3.05E-03 | 0.92 |
| 9/9/14 20:30 | 12.11 | 8.64E-04 | 0.26 | 2.15E-03 | 0.64 |
| 9/9/14 20:35 | 12.11 | 5.54E-04 | 0.17 | 1.17E-03 | 0.35 |
| 9/9/14 20:40 | 12.11 | 4.15E-04 | 0.12 | 1.37E-03 | 0.41 |
| 9/9/14 20:45 | 12.11 | 4.15E-04 | 0.12 | 1.37E-03 | 0.41 |
| 9/9/14 20:50 | 12.11 | 8.64E-04 | 0.26 | 2.15E-03 | 0.64 |
| 9/9/14 20:55 | 12.01 | 2.47E-03 | 0.74 | 4.50E-03 | 1.35 |
| 9/9/14 21:00 | 12.01 | 8.84E-03 | 2.65 | 1.10E-02 | 3.31 |
| 9/9/14 21:05 | 12.11 | 1.77E-02 | 5.32 | 2.08E-02 | 6.25 |
| 9/9/14 21:10 | 12.11 | 1.76E-02 | 5.27 | 2.27E-02 | 6.82 |
| 9/9/14 21:15 | 12.01 | 1.27E-02 | 3.81 | 1.71E-02 | 5.13 |
| 9/9/14 21:20 | 12.01 | 7.59E-03 | 2.28 | 1.10E-02 | 3.31 |
| 9/9/14 21:25 | 11.92 | 3.05E-03 | 0.92 | 6.25E-03 | 1.88 |
| 9/9/14 21:30 | 11.92 | 1.37E-03 | 0.41 | 3.57E-03 | 1.07 |
| 9/9/14 21:35 | 11.92 | 2.63E-04 | 0.08 | 1.49E-03 | 0.45 |
| 9/9/14 21:40 | 11.92 | 1.24E-04 | 0.04 | 7.14E-04 | 0.21 |
| 9/9/14 21:45 | 11.92 | 3.28E-05 | 0.01 | 4.37E-04 | 0.13 |
| 9/9/14 21:50 | 12.01 | 0.00E+00 | 0.00 | 1.03E-04 | 0.03 |
| 9/9/14 21:55 | 12.01 | 0.00E+00 | 0.00 | 1.73E-04 | 0.05 |
| 9/9/14 22:00 | 12.11 | 0.00E+00 | 0.00 | 1.86E-04 | 0.06 |
| 9/9/14 22:05 | 12.11 | 0.00E+00 | 0.00 | 3.28E-05 | 0.01 |

Table 34. 09/09/14 effluent hydrograph data.

| Time | Temperature (°C) | Barometric Compensated Discharge ($m^3/s$) | Barometric Compensated Volume ($m^3$) | Reference Level Compensated Discharge ($m^3/s$) | Reference Level Compensated Volume ($m^3$) |
|---|---|---|---|---|---|
| 9/9/14 15:40 | 17.76 | 0.00E+00 | 0.00 | 0.00E+00 | 0.00 |
| 9/9/14 15:45 | 17.67 | 0.00E+00 | 0.00 | 0.00E+00 | 0.00 |
| 9/9/14 15:50 | 17.67 | 0.00E+00 | 0.00 | 0.00E+00 | 0.00 |
| 9/9/14 15:55 | 17.67 | 0.00E+00 | 0.00 | 0.00E+00 | 0.00 |
| 9/9/14 16:00 | 17.67 | 0.00E+00 | 0.00 | 0.00E+00 | 0.00 |
| 9/9/14 16:05 | 17.67 | 0.00E+00 | 0.00 | 0.00E+00 | 0.00 |
| 9/9/14 16:10 | 17.67 | 0.00E+00 | 0.00 | 0.00E+00 | 0.00 |
| 9/9/14 16:15 | 17.67 | 0.00E+00 | 0.00 | 0.00E+00 | 0.00 |
| 9/9/14 16:20 | 17.67 | 0.00E+00 | 0.00 | 0.00E+00 | 0.00 |
| 9/9/14 16:25 | 17.67 | 0.00E+00 | 0.00 | 0.00E+00 | 0.00 |
| 9/9/14 16:30 | 17.67 | 0.00E+00 | 0.00 | 0.00E+00 | 0.00 |
| 9/9/14 16:35 | 17.67 | 0.00E+00 | 0.00 | 0.00E+00 | 0.00 |
| 9/9/14 16:40 | 17.67 | 5.25E-07 | 0.00 | 0.00E+00 | 0.00 |
| 9/9/14 16:45 | 17.67 | 6.01E-06 | 0.00 | 0.00E+00 | 0.00 |
| 9/9/14 16:50 | 17.67 | 1.56E-04 | 0.05 | 0.00E+00 | 0.00 |
| 9/9/14 16:55 | 17.67 | 3.77E-04 | 0.11 | 3.36E-05 | 0.01 |
| 9/9/14 17:00 | 17.67 | 8.19E-04 | 0.25 | 2.10E-04 | 0.06 |
| 9/9/14 17:05 | 17.67 | 1.61E-03 | 0.48 | 4.44E-04 | 0.13 |
| 9/9/14 17:10 | 17.67 | 1.82E-03 | 0.55 | 5.36E-04 | 0.16 |
| 9/9/14 17:15 | 17.67 | 2.25E-03 | 0.67 | 7.71E-04 | 0.23 |
| 9/9/14 17:20 | 17.57 | 2.95E-03 | 0.89 | 1.19E-03 | 0.36 |
| 9/9/14 17:25 | 17.57 | 3.75E-03 | 1.13 | 1.35E-03 | 0.40 |
| 9/9/14 17:30 | 17.48 | 4.65E-03 | 1.40 | 1.86E-03 | 0.56 |
| 9/9/14 17:35 | 17.48 | 5.98E-03 | 1.79 | 2.77E-03 | 0.83 |
| 9/9/14 17:40 | 17.38 | 7.10E-03 | 2.13 | 3.49E-03 | 1.05 |
| 9/9/14 17:45 | 17.28 | 8.81E-03 | 2.64 | 4.02E-03 | 1.21 |
| 9/9/14 17:50 | 17.28 | 9.64E-03 | 2.89 | 5.33E-03 | 1.60 |
| 9/9/14 17:55 | 17.19 | 1.10E-02 | 3.31 | 6.32E-03 | 1.90 |
| 9/9/14 18:00 | 17.19 | 1.16E-02 | 3.48 | 6.74E-03 | 2.02 |
| 9/9/14 18:05 | 17.09 | 1.10E-02 | 3.31 | 6.25E-03 | 1.88 |
| 9/9/14 18:10 | 17.09 | 1.05E-02 | 3.15 | 6.60E-03 | 1.98 |
| 9/9/14 18:15 | 17.00 | 1.10E-02 | 3.29 | 6.96E-03 | 2.09 |
| 9/9/14 18:20 | 17.00 | 1.10E-02 | 3.29 | 6.96E-03 | 2.09 |
| 9/9/14 18:25 | 16.90 | 1.10E-02 | 3.29 | 6.89E-03 | 2.07 |
| 9/9/14 18:30 | 16.81 | 1.13E-02 | 3.40 | 7.18E-03 | 2.15 |

Table 34 continued.

| Time | Temperature (°C) | Barometric Compensated Discharge ($m^3/s$) | Barometric Compensated Volume ($m^3$) | Reference Level Compensated Discharge ($m^3/s$) | Reference Level Compensated Volume ($m^3$) |
|---|---|---|---|---|---|
| 9/9/14 18:35 | 16.81 | 1.03E-02 | 3.10 | 7.18E-03 | 2.15 |
| 9/9/14 18:40 | 16.81 | 1.18E-02 | 3.54 | 8.40E-03 | 2.52 |
| 9/9/14 18:45 | 16.81 | 1.13E-02 | 3.40 | 8.01E-03 | 2.40 |
| 9/9/14 18:50 | 16.81 | 1.18E-02 | 3.54 | 8.40E-03 | 2.52 |
| 9/9/14 18:55 | 16.81 | 1.34E-02 | 4.03 | 9.81E-03 | 2.94 |
| 9/9/14 19:00 | 16.71 | 1.51E-02 | 4.52 | 1.11E-02 | 3.34 |
| 9/9/14 19:05 | 16.71 | 1.68E-02 | 5.04 | 1.26E-02 | 3.79 |
| 9/9/14 19:10 | 16.71 | 1.86E-02 | 5.59 | 1.42E-02 | 4.27 |
| 9/9/14 19:15 | 16.62 | 1.85E-02 | 5.55 | 1.53E-02 | 4.59 |
| 9/9/14 19:20 | 16.62 | 1.98E-02 | 5.94 | 1.65E-02 | 4.94 |
| 9/9/14 19:25 | 16.62 | 1.97E-02 | 5.90 | 1.77E-02 | 5.31 |
| 9/9/14 19:30 | 16.62 | 2.04E-02 | 6.12 | 1.84E-02 | 5.52 |
| 9/9/14 19:35 | 16.52 | 2.30E-02 | 6.91 | 2.08E-02 | 6.23 |
| 9/9/14 19:40 | 16.52 | 2.30E-02 | 6.91 | 2.21E-02 | 6.64 |
| 9/9/14 19:45 | 16.52 | 2.44E-02 | 7.33 | 2.35E-02 | 7.06 |
| 9/9/14 19:50 | 16.52 | 2.59E-02 | 7.77 | 2.50E-02 | 7.49 |
| 9/9/14 19:55 | 16.43 | 2.73E-02 | 8.18 | 2.63E-02 | 7.89 |
| 9/9/14 20:00 | 16.43 | 2.73E-02 | 8.18 | 2.63E-02 | 7.89 |
| 9/9/14 20:05 | 16.43 | 3.04E-02 | 9.11 | 2.94E-02 | 8.81 |
| 9/9/14 20:10 | 16.43 | 2.95E-02 | 8.85 | 2.85E-02 | 8.56 |
| 9/9/14 20:15 | 16.33 | 3.36E-02 | 10.09 | 3.08E-02 | 9.24 |
| 9/9/14 20:20 | 16.33 | 3.18E-02 | 9.55 | 3.08E-02 | 9.24 |
| 9/9/14 20:25 | 16.24 | 3.18E-02 | 9.55 | 3.05E-02 | 9.16 |
| 9/9/14 20:30 | 16.24 | 3.26E-02 | 9.77 | 3.14E-02 | 9.42 |
| 9/9/14 20:35 | 16.24 | 3.51E-02 | 10.54 | 3.21E-02 | 9.64 |
| 9/9/14 20:40 | 16.14 | 3.26E-02 | 9.77 | 3.12E-02 | 9.37 |
| 9/9/14 20:45 | 16.14 | 3.33E-02 | 10.00 | 3.20E-02 | 9.59 |
| 9/9/14 20:50 | 16.14 | 3.33E-02 | 10.00 | 3.20E-02 | 9.59 |
| 9/9/14 20:55 | 16.05 | 3.33E-02 | 10.00 | 3.18E-02 | 9.55 |
| 9/9/14 21:00 | 16.05 | 3.50E-02 | 10.50 | 3.18E-02 | 9.55 |
| 9/9/14 21:05 | 16.05 | 3.58E-02 | 10.73 | 3.27E-02 | 9.82 |
| 9/9/14 21:10 | 15.95 | 3.39E-02 | 10.18 | 3.24E-02 | 9.73 |
| 9/9/14 21:15 | 15.95 | 3.39E-02 | 10.18 | 3.24E-02 | 9.73 |
| 9/9/14 21:20 | 15.95 | 3.39E-02 | 10.18 | 3.24E-02 | 9.73 |
| 9/9/14 21:25 | 15.95 | 3.39E-02 | 10.18 | 3.42E-02 | 10.27 |

Table 34 continued.

| Time | Temperature (°C) | Barometric Compensated Discharge ($m^3/s$) | Barometric Compensated Volume ($m^3$) | Reference Level Compensated Discharge ($m^3/s$) | Reference Level Compensated Volume ($m^3$) |
|---|---|---|---|---|---|
| 9/9/14 21:30 | 15.86 | 3.23E-02 | 9.68 | 3.24E-02 | 9.73 |
| 9/9/14 21:35 | 15.86 | 3.23E-02 | 9.68 | 3.24E-02 | 9.73 |
| 9/9/14 21:40 | 15.86 | 3.39E-02 | 10.18 | 3.24E-02 | 9.73 |
| 9/9/14 21:45 | 15.86 | 3.32E-02 | 9.95 | 3.15E-02 | 9.46 |
| 9/9/14 21:50 | 15.76 | 3.14E-02 | 9.42 | 2.98E-02 | 8.94 |
| 9/9/14 21:55 | 15.76 | 2.98E-02 | 8.94 | 2.98E-02 | 8.94 |
| 9/9/14 22:00 | 15.76 | 2.82E-02 | 8.47 | 2.82E-02 | 8.47 |
| 9/9/14 22:05 | 15.76 | 2.74E-02 | 8.22 | 2.75E-02 | 8.26 |
| 9/9/14 22:10 | 15.76 | 2.59E-02 | 7.77 | 2.60E-02 | 7.81 |
| 9/9/14 22:15 | 15.66 | 2.59E-02 | 7.77 | 2.59E-02 | 7.77 |
| 9/9/14 22:20 | 15.66 | 2.44E-02 | 7.33 | 2.44E-02 | 7.33 |
| 9/9/14 22:25 | 15.66 | 2.52E-02 | 7.57 | 2.38E-02 | 7.14 |
| 9/9/14 22:30 | 15.66 | 2.59E-02 | 7.77 | 2.44E-02 | 7.33 |
| 9/9/14 22:35 | 15.66 | 2.82E-02 | 8.47 | 2.66E-02 | 7.98 |
| 9/9/14 22:40 | 15.66 | 2.44E-02 | 7.33 | 2.44E-02 | 7.33 |
| 9/9/14 22:45 | 15.66 | 2.30E-02 | 6.91 | 2.30E-02 | 6.91 |
| 9/9/14 22:50 | 15.66 | 2.24E-02 | 6.71 | 2.24E-02 | 6.71 |
| 9/9/14 22:55 | 15.66 | 2.10E-02 | 6.30 | 2.10E-02 | 6.30 |
| 9/9/14 23:00 | 15.66 | 2.10E-02 | 6.30 | 2.10E-02 | 6.30 |
| 9/9/14 23:05 | 15.66 | 2.03E-02 | 6.08 | 2.03E-02 | 6.08 |
| 9/9/14 23:10 | 15.66 | 2.03E-02 | 6.08 | 2.03E-02 | 6.08 |
| 9/9/14 23:15 | 15.66 | 1.84E-02 | 5.52 | 1.84E-02 | 5.52 |
| 9/9/14 23:20 | 15.57 | 1.90E-02 | 5.69 | 1.90E-02 | 5.69 |
| 9/9/14 23:25 | 15.57 | 1.90E-02 | 5.69 | 1.77E-02 | 5.31 |
| 9/9/14 23:30 | 15.57 | 1.84E-02 | 5.52 | 1.70E-02 | 5.11 |
| 9/9/14 23:35 | 15.57 | 1.66E-02 | 4.97 | 1.53E-02 | 4.59 |
| 9/9/14 23:40 | 15.57 | 1.54E-02 | 4.62 | 1.41E-02 | 4.24 |
| 9/9/14 23:45 | 15.57 | 1.59E-02 | 4.78 | 1.47E-02 | 4.40 |
| 9/9/14 23:50 | 15.47 | 1.59E-02 | 4.78 | 1.47E-02 | 4.40 |
| 9/9/14 23:55 | 15.47 | 1.53E-02 | 4.59 | 1.40E-02 | 4.21 |
| 9/10/14 0:00 | 15.47 | 1.59E-02 | 4.78 | 1.47E-02 | 4.40 |
| 9/10/14 0:05 | 15.47 | 1.42E-02 | 4.27 | 1.29E-02 | 3.88 |
| 9/10/14 0:10 | 15.47 | 1.48E-02 | 4.43 | 1.34E-02 | 4.03 |
| 9/10/14 0:15 | 15.47 | 1.25E-02 | 3.76 | 1.14E-02 | 3.42 |
| 9/10/14 0:20 | 15.47 | 1.30E-02 | 3.91 | 1.19E-02 | 3.56 |

Table 34 continued.

| Time | Temperature (°C) | Barometric Compensated Discharge ($m^3/s$) | Barometric Compensated Volume ($m^3$) | Reference Level Compensated Discharge ($m^3/s$) | Reference Level Compensated Volume ($m^3$) |
|---|---|---|---|---|---|
| 9/10/14 0:25 | 15.38 | 1.14E-02 | 3.42 | 1.13E-02 | 3.40 |
| 9/10/14 0:30 | 15.38 | 1.04E-02 | 3.13 | 1.03E-02 | 3.10 |
| 9/10/14 0:35 | 15.38 | 1.04E-02 | 3.13 | 1.03E-02 | 3.10 |
| 9/10/14 0:40 | 15.38 | 9.98E-03 | 2.99 | 9.81E-03 | 2.94 |
| 9/10/14 0:45 | 15.38 | 9.55E-03 | 2.87 | 9.39E-03 | 2.82 |
| 9/10/14 0:50 | 15.38 | 9.55E-03 | 2.87 | 9.39E-03 | 2.82 |
| 9/10/14 0:55 | 15.38 | 9.05E-03 | 2.72 | 8.89E-03 | 2.67 |
| 9/10/14 1:00 | 15.38 | 8.17E-03 | 2.45 | 8.09E-03 | 2.43 |
| 9/10/14 1:05 | 15.28 | 8.56E-03 | 2.57 | 8.40E-03 | 2.52 |
| 9/10/14 1:10 | 15.28 | 8.17E-03 | 2.45 | 8.01E-03 | 2.40 |
| 9/10/14 1:15 | 15.28 | 8.56E-03 | 2.57 | 8.40E-03 | 2.52 |
| 9/10/14 1:20 | 15.28 | 8.17E-03 | 2.45 | 8.01E-03 | 2.40 |
| 9/10/14 1:25 | 15.28 | 7.70E-03 | 2.31 | 7.55E-03 | 2.27 |
| 9/10/14 1:30 | 15.28 | 8.64E-03 | 2.59 | 7.55E-03 | 2.27 |
| 9/10/14 1:35 | 15.28 | 7.33E-03 | 2.20 | 7.18E-03 | 2.15 |
| 9/10/14 1:40 | 15.28 | 6.53E-03 | 1.96 | 6.39E-03 | 1.92 |
| 9/10/14 1:45 | 15.28 | 6.89E-03 | 2.07 | 6.74E-03 | 2.02 |
| 9/10/14 1:50 | 15.28 | 6.53E-03 | 1.96 | 6.39E-03 | 1.92 |
| 9/10/14 1:55 | 15.28 | 6.12E-03 | 1.83 | 5.98E-03 | 1.79 |
| 9/10/14 2:00 | 15.28 | 6.12E-03 | 1.83 | 5.98E-03 | 1.79 |
| 9/10/14 2:05 | 15.19 | 5.71E-03 | 1.71 | 5.58E-03 | 1.68 |
| 9/10/14 2:10 | 15.28 | 5.78E-03 | 1.73 | 5.65E-03 | 1.69 |
| 9/10/14 2:15 | 15.28 | 5.78E-03 | 1.73 | 5.65E-03 | 1.69 |
| 9/10/14 2:20 | 15.19 | 5.39E-03 | 1.62 | 5.26E-03 | 1.58 |
| 9/10/14 2:25 | 15.19 | 5.39E-03 | 1.62 | 5.26E-03 | 1.58 |
| 9/10/14 2:30 | 15.19 | 5.78E-03 | 1.73 | 4.89E-03 | 1.47 |
| 9/10/14 2:35 | 15.19 | 5.45E-03 | 1.64 | 4.59E-03 | 1.38 |
| 9/10/14 2:40 | 15.19 | 4.42E-03 | 1.33 | 4.25E-03 | 1.27 |
| 9/10/14 2:45 | 15.19 | 5.08E-03 | 1.52 | 4.89E-03 | 1.47 |
| 9/10/14 2:50 | 15.19 | 4.42E-03 | 1.33 | 4.25E-03 | 1.27 |
| 9/10/14 2:55 | 15.19 | 4.42E-03 | 1.33 | 4.25E-03 | 1.27 |
| 9/10/14 3:00 | 15.19 | 5.08E-03 | 1.52 | 4.89E-03 | 1.47 |
| 9/10/14 3:05 | 15.19 | 5.08E-03 | 1.52 | 4.89E-03 | 1.47 |
| 9/10/14 3:10 | 15.19 | 3.49E-03 | 1.05 | 3.97E-03 | 1.19 |
| 9/10/14 3:15 | 15.19 | 4.08E-03 | 1.22 | 4.59E-03 | 1.38 |

Table 34 continued.

| Time | Temperature (°C) | Barometric Compensated Discharge ($m^3/s$) | Barometric Compensated Volume ($m^3$) | Reference Level Compensated Discharge ($m^3/s$) | Reference Level Compensated Volume ($m^3$) |
|---|---|---|---|---|---|
| 9/10/14 3:20 | 15.19 | 3.75E-03 | 1.13 | 4.25E-03 | 1.27 |
| 9/10/14 3:25 | 15.09 | 3.19E-03 | 0.96 | 3.60E-03 | 1.08 |
| 9/10/14 3:30 | 15.09 | 2.95E-03 | 0.89 | 3.34E-03 | 1.00 |
| 9/10/14 3:35 | 15.09 | 3.19E-03 | 0.96 | 3.60E-03 | 1.08 |
| 9/10/14 3:40 | 15.09 | 2.68E-03 | 0.80 | 3.09E-03 | 0.93 |
| 9/10/14 3:45 | 15.09 | 2.95E-03 | 0.89 | 2.81E-03 | 0.84 |
| 9/10/14 3:50 | 15.09 | 2.68E-03 | 0.80 | 3.09E-03 | 0.93 |
| 9/10/14 3:55 | 15.09 | 2.21E-03 | 0.66 | 2.54E-03 | 0.76 |
| 9/10/14 4:00 | 15.09 | 2.21E-03 | 0.66 | 2.54E-03 | 0.76 |
| 9/10/14 4:05 | 15.09 | 2.46E-03 | 0.74 | 2.81E-03 | 0.84 |
| 9/10/14 4:10 | 15.09 | 2.21E-03 | 0.66 | 2.54E-03 | 0.76 |
| 9/10/14 4:15 | 15.09 | 2.46E-03 | 0.74 | 2.81E-03 | 0.84 |
| 9/10/14 4:20 | 15.09 | 2.46E-03 | 0.74 | 2.81E-03 | 0.84 |
| 9/10/14 4:25 | 15.09 | 2.21E-03 | 0.66 | 2.54E-03 | 0.76 |
| 9/10/14 4:30 | 15.09 | 2.21E-03 | 0.66 | 2.54E-03 | 0.76 |
| 9/10/14 4:35 | 15.09 | 2.21E-03 | 0.66 | 2.54E-03 | 0.76 |
| 9/10/14 4:40 | 15.00 | 2.21E-03 | 0.66 | 2.54E-03 | 0.76 |
| 9/10/14 4:45 | 15.00 | 1.97E-03 | 0.59 | 2.29E-03 | 0.69 |
| 9/10/14 4:50 | 15.00 | 1.97E-03 | 0.59 | 2.29E-03 | 0.69 |
| 9/10/14 4:55 | 15.00 | 1.57E-03 | 0.47 | 2.29E-03 | 0.69 |
| 9/10/14 5:00 | 15.00 | 1.41E-03 | 0.42 | 2.09E-03 | 0.63 |
| 9/10/14 5:05 | 15.00 | 1.41E-03 | 0.42 | 2.09E-03 | 0.63 |
| 9/10/14 5:10 | 15.00 | 1.05E-03 | 0.32 | 2.09E-03 | 0.63 |
| 9/10/14 5:15 | 15.00 | 1.22E-03 | 0.37 | 2.29E-03 | 0.69 |
| 9/10/14 5:20 | 15.00 | 1.05E-03 | 0.32 | 2.09E-03 | 0.63 |
| 9/10/14 5:25 | 15.00 | 7.71E-04 | 0.23 | 2.09E-03 | 0.63 |
| 9/10/14 5:30 | 15.00 | 1.05E-03 | 0.32 | 2.09E-03 | 0.63 |
| 9/10/14 5:35 | 14.90 | 1.05E-03 | 0.32 | 2.05E-03 | 0.61 |
| 9/10/14 5:40 | 14.90 | 5.36E-04 | 0.16 | 1.64E-03 | 0.49 |
| 9/10/14 5:45 | 14.90 | 7.71E-04 | 0.23 | 2.05E-03 | 0.61 |
| 9/10/14 5:50 | 14.90 | 5.36E-04 | 0.16 | 1.64E-03 | 0.49 |
| 9/10/14 5:55 | 14.90 | 4.27E-04 | 0.13 | 1.82E-03 | 0.55 |
| 9/10/14 6:00 | 14.90 | 5.17E-04 | 0.16 | 2.05E-03 | 0.61 |
| 9/10/14 6:05 | 14.90 | 4.27E-04 | 0.13 | 1.82E-03 | 0.55 |
| 9/10/14 6:10 | 14.80 | 6.16E-04 | 0.18 | 2.21E-03 | 0.66 |

Table 34 continued.

| Time | Temperature (°C) | Barometric Compensated Discharge ($m^3/s$) | Barometric Compensated Volume ($m^3$) | Reference Level Compensated Discharge ($m^3/s$) | Reference Level Compensated Volume ($m^3$) |
|---|---|---|---|---|---|
| 9/10/14 6:15 | 14.80 | 7.48E-04 | 0.22 | 2.46E-03 | 0.74 |
| 9/10/14 6:20 | 14.80 | 5.17E-04 | 0.16 | 2.01E-03 | 0.60 |
| 9/10/14 6:25 | 14.80 | 7.48E-04 | 0.22 | 2.46E-03 | 0.74 |
| 9/10/14 6:30 | 14.80 | 1.02E-03 | 0.31 | 2.46E-03 | 0.74 |
| 9/10/14 6:35 | 14.80 | 7.48E-04 | 0.22 | 2.01E-03 | 0.60 |
| 9/10/14 6:40 | 14.80 | 8.93E-04 | 0.27 | 2.21E-03 | 0.66 |
| 9/10/14 6:45 | 14.80 | 6.16E-04 | 0.18 | 2.21E-03 | 0.66 |
| 9/10/14 6:50 | 14.80 | 6.16E-04 | 0.18 | 2.21E-03 | 0.66 |
| 9/10/14 6:55 | 14.80 | 7.48E-04 | 0.22 | 2.46E-03 | 0.74 |
| 9/10/14 7:00 | 14.80 | 7.48E-04 | 0.22 | 2.46E-03 | 0.74 |
| 9/10/14 7:05 | 14.80 | 4.10E-04 | 0.12 | 2.21E-03 | 0.66 |
| 9/10/14 7:10 | 14.80 | 4.98E-04 | 0.15 | 2.46E-03 | 0.74 |

Table 35. 09/28/14 influent hydrograph data.

| Time | Temperature (°C) | Barometric Compensated Discharge ($m^3/s$) | Barometric Compensated Volume ($m^3$) | Reference Level Compensated Discharge ($m^3/s$) | Reference Level Compensated Volume ($m^3$) |
|---|---|---|---|---|---|
| 9/28/14 16:00 | 13.56 | 0.00E+00 | 0.00 | 0.00E+00 | 0.00 |
| 9/28/14 16:05 | 13.46 | 0.00E+00 | 0.00 | 0.00E+00 | 0.00 |
| 9/28/14 16:10 | 13.46 | 5.47E-06 | 0.00 | 5.47E-07 | 0.00 |
| 9/28/14 16:15 | 13.46 | 6.09E-05 | 0.00 | 2.61E-06 | 0.00 |
| 9/28/14 16:20 | 13.37 | 1.86E-04 | 0.06 | 6.63E-06 | 0.00 |
| 9/28/14 16:25 | 13.37 | 2.03E-04 | 0.06 | 1.27E-05 | 0.00 |
| 9/28/14 16:30 | 13.27 | 2.23E-04 | 0.07 | 2.10E-05 | 0.01 |
| 9/28/14 16:35 | 13.08 | 2.45E-04 | 0.07 | 3.19E-05 | 0.01 |
| 9/28/14 16:40 | 13.08 | 2.67E-04 | 0.08 | 4.50E-05 | 0.01 |
| 9/28/14 16:45 | 13.08 | 2.92E-04 | 0.09 | 6.10E-05 | 0.02 |
| 9/28/14 16:50 | 13.08 | 3.19E-04 | 0.10 | 7.92E-05 | 0.02 |
| 9/28/14 16:55 | 13.08 | 3.47E-04 | 0.10 | 1.00E-04 | 0.03 |
| 9/28/14 17:00 | 13.08 | 3.78E-04 | 0.11 | 1.24E-04 | 0.04 |
| 9/28/14 17:05 | 13.08 | 4.18E-04 | 0.13 | 1.50E-04 | 0.05 |
| 9/28/14 17:10 | 13.27 | 4.75E-04 | 0.14 | 1.79E-04 | 0.05 |
| 9/28/14 17:15 | 13.56 | 5.42E-04 | 0.16 | 2.10E-04 | 0.06 |
| 9/28/14 17:20 | 13.75 | 6.17E-04 | 0.19 | 2.45E-04 | 0.07 |
| 9/28/14 17:25 | 13.85 | 7.02E-04 | 0.21 | 2.86E-04 | 0.09 |
| 9/28/14 17:30 | 13.75 | 7.96E-04 | 0.24 | 3.33E-04 | 0.10 |
| 9/28/14 17:35 | 13.56 | 8.91E-04 | 0.27 | 3.84E-04 | 0.12 |
| 9/28/14 17:40 | 13.56 | 9.85E-04 | 0.30 | 4.38E-04 | 0.13 |
| 9/28/14 17:45 | 13.65 | 1.08E-03 | 0.32 | 4.95E-04 | 0.15 |
| 9/28/14 17:50 | 13.75 | 1.15E-03 | 0.35 | 5.54E-04 | 0.17 |
| 9/28/14 17:55 | 13.75 | 1.22E-03 | 0.37 | 6.11E-04 | 0.18 |
| 9/28/14 18:00 | 13.75 | 1.27E-03 | 0.38 | 6.67E-04 | 0.20 |
| 9/28/14 18:05 | 13.85 | 1.31E-03 | 0.39 | 7.20E-04 | 0.22 |
| 9/28/14 18:10 | 13.85 | 1.34E-03 | 0.40 | 7.69E-04 | 0.23 |
| 9/28/14 18:15 | 13.85 | 1.36E-03 | 0.41 | 8.14E-04 | 0.24 |
| 9/28/14 18:20 | 13.85 | 1.37E-03 | 0.41 | 8.54E-04 | 0.26 |
| 9/28/14 18:25 | 13.75 | 1.38E-03 | 0.41 | 8.90E-04 | 0.27 |
| 9/28/14 18:30 | 13.75 | 1.38E-03 | 0.41 | 9.20E-04 | 0.28 |
| 9/28/14 18:35 | 13.75 | 1.37E-03 | 0.41 | 9.47E-04 | 0.28 |
| 9/28/14 18:40 | 13.75 | 1.36E-03 | 0.41 | 9.72E-04 | 0.29 |
| 9/28/14 18:45 | 13.75 | 1.34E-03 | 0.40 | 9.96E-04 | 0.30 |
| 9/28/14 18:50 | 13.75 | 1.31E-03 | 0.39 | 1.02E-03 | 0.31 |

Table 35 continued.

| Time | Temperature (°C) | Barometric Compensated Discharge ($m^3/s$) | Barometric Compensated Volume ($m^3$) | Reference Level Compensated Discharge ($m^3/s$) | Reference Level Compensated Volume ($m^3$) |
|---|---|---|---|---|---|
| 9/28/14 18:55 | 13.75 | 1.28E-03 | 0.38 | 1.05E-03 | 0.31 |
| 9/28/14 19:00 | 13.75 | 1.26E-03 | 0.38 | 1.07E-03 | 0.32 |
| 9/28/14 19:05 | 13.65 | 1.24E-03 | 0.37 | 1.10E-03 | 0.33 |
| 9/28/14 19:10 | 13.65 | 1.23E-03 | 0.37 | 1.12E-03 | 0.34 |
| 9/28/14 19:15 | 13.56 | 1.23E-03 | 0.37 | 1.14E-03 | 0.34 |
| 9/28/14 19:20 | 13.56 | 1.23E-03 | 0.37 | 1.17E-03 | 0.35 |
| 9/28/14 19:25 | 13.56 | 1.23E-03 | 0.37 | 1.19E-03 | 0.36 |
| 9/28/14 19:30 | 13.56 | 1.23E-03 | 0.37 | 1.20E-03 | 0.36 |
| 9/28/14 19:35 | 13.56 | 1.22E-03 | 0.37 | 1.22E-03 | 0.37 |
| 9/28/14 19:40 | 13.56 | 1.21E-03 | 0.36 | 1.23E-03 | 0.37 |
| 9/28/14 19:45 | 13.56 | 1.18E-03 | 0.35 | 1.24E-03 | 0.37 |
| 9/28/14 19:50 | 13.56 | 1.15E-03 | 0.34 | 1.24E-03 | 0.37 |
| 9/28/14 19:55 | 13.56 | 1.10E-03 | 0.33 | 1.25E-03 | 0.37 |
| 9/28/14 20:00 | 13.56 | 1.06E-03 | 0.32 | 1.25E-03 | 0.37 |
| 9/28/14 20:05 | 13.56 | 1.02E-03 | 0.30 | 1.25E-03 | 0.37 |
| 9/28/14 20:10 | 13.46 | 9.72E-04 | 0.29 | 1.25E-03 | 0.37 |
| 9/28/14 20:15 | 13.46 | 9.28E-04 | 0.28 | 1.24E-03 | 0.37 |
| 9/28/14 20:20 | 13.46 | 8.84E-04 | 0.27 | 1.24E-03 | 0.37 |
| 9/28/14 20:25 | 13.46 | 8.37E-04 | 0.25 | 1.23E-03 | 0.37 |
| 9/28/14 20:30 | 13.46 | 7.87E-04 | 0.24 | 1.21E-03 | 0.36 |
| 9/28/14 20:35 | 13.46 | 7.33E-04 | 0.22 | 1.20E-03 | 0.36 |
| 9/28/14 20:40 | 13.46 | 6.79E-04 | 0.20 | 1.18E-03 | 0.35 |
| 9/28/14 20:45 | 13.46 | 6.30E-04 | 0.19 | 1.15E-03 | 0.35 |
| 9/28/14 20:50 | 13.46 | 5.90E-04 | 0.18 | 1.13E-03 | 0.34 |
| 9/28/14 20:55 | 13.46 | 5.60E-04 | 0.17 | 1.10E-03 | 0.33 |
| 9/28/14 21:00 | 13.46 | 5.37E-04 | 0.16 | 1.07E-03 | 0.32 |
| 9/28/14 21:05 | 13.46 | 5.22E-04 | 0.16 | 1.06E-03 | 0.32 |
| 9/28/14 21:10 | 13.46 | 5.12E-04 | 0.15 | 1.04E-03 | 0.31 |
| 9/28/14 21:15 | 13.46 | 5.06E-04 | 0.15 | 1.02E-03 | 0.31 |
| 9/28/14 21:20 | 12.88 | 5.04E-04 | 0.15 | 1.00E-03 | 0.30 |
| 9/28/14 21:25 | 12.88 | 5.01E-04 | 0.15 | 9.86E-04 | 0.30 |
| 9/28/14 21:30 | 12.98 | 4.95E-04 | 0.15 | 9.70E-04 | 0.29 |
| 9/28/14 21:35 | 12.98 | 4.78E-04 | 0.14 | 9.53E-04 | 0.29 |
| 9/28/14 21:40 | 13.08 | 4.55E-04 | 0.14 | 9.37E-04 | 0.28 |
| 9/28/14 21:45 | 13.17 | 4.30E-04 | 0.13 | 9.22E-04 | 0.28 |

Table 35 continued.

| Time | Temperature (°C) | Barometric Compensated Discharge ($m^3/s$) | Barometric Compensated Volume ($m^3$) | Reference Level Compensated Discharge ($m^3/s$) | Reference Level Compensated Volume ($m^3$) |
|---|---|---|---|---|---|
| 9/28/14 21:50 | 13.17 | 4.06E-04 | 0.12 | 9.06E-04 | 0.27 |
| 9/28/14 21:55 | 13.17 | 3.83E-04 | 0.11 | 8.92E-04 | 0.27 |
| 9/28/14 22:00 | 13.17 | 3.60E-04 | 0.11 | 8.78E-04 | 0.26 |
| 9/28/14 22:05 | 13.08 | 3.38E-04 | 0.10 | 8.63E-04 | 0.26 |
| 9/28/14 22:10 | 12.98 | 3.18E-04 | 0.10 | 8.50E-04 | 0.26 |
| 9/28/14 22:15 | 12.88 | 2.97E-04 | 0.09 | 8.37E-04 | 0.25 |
| 9/28/14 22:20 | 12.79 | 2.76E-04 | 0.08 | 8.25E-04 | 0.25 |
| 9/28/14 22:25 | 17.76 | 2.56E-04 | 0.08 | 8.12E-04 | 0.24 |
| 9/28/14 22:30 | 19.66 | 2.35E-04 | 0.07 | 8.12E-04 | 0.19 |

Table 36. 09/28/14 effluent hydrograph data.

| Time | Temperature (°C) | Barometric Compensated Discharge ($m^3/s$) | Barometric Compensated Volume ($m^3$) | Reference Level Compensated Discharge ($m^3/s$) | Reference Level Compensated Volume ($m^3$) |
|---|---|---|---|---|---|
| 9/28/14 17:35 | 17.95 | 8.20E-06 | 0.00 | 0.00E+00 | 0.00 |
| 9/28/14 17:40 | 17.95 | 1.27E-05 | 0.00 | 0.00E+00 | 0.00 |
| 9/28/14 17:45 | 17.95 | 1.81E-05 | 0.01 | 0.00E+00 | 0.00 |
| 9/28/14 17:50 | 17.95 | 2.46E-05 | 0.01 | 0.00E+00 | 0.00 |
| 9/28/14 17:55 | 17.95 | 3.22E-05 | 0.01 | 0.00E+00 | 0.00 |
| 9/28/14 18:00 | 17.95 | 4.05E-05 | 0.01 | 0.00E+00 | 0.00 |
| 9/28/14 18:05 | 17.95 | 5.00E-05 | 0.01 | 0.00E+00 | 0.00 |
| 9/28/14 18:10 | 17.95 | 6.04E-05 | 0.02 | 0.00E+00 | 0.00 |
| 9/28/14 18:15 | 17.95 | 7.20E-05 | 0.02 | 3.53E-05 | 0.01 |
| 9/28/14 18:20 | 17.95 | 8.45E-05 | 0.03 | 4.55E-05 | 0.01 |
| 9/28/14 18:25 | 17.95 | 9.79E-05 | 0.03 | 5.67E-05 | 0.02 |
| 9/28/14 18:30 | 17.95 | 1.12E-04 | 0.03 | 6.96E-05 | 0.02 |
| 9/28/14 18:35 | 17.95 | 1.28E-04 | 0.04 | 8.35E-05 | 0.03 |
| 9/28/14 18:40 | 17.86 | 1.44E-04 | 0.04 | 9.87E-05 | 0.03 |
| 9/28/14 18:45 | 17.86 | 1.61E-04 | 0.05 | 1.16E-04 | 0.03 |
| 9/28/14 18:50 | 17.86 | 1.79E-04 | 0.05 | 1.33E-04 | 0.04 |
| 9/28/14 18:55 | 17.86 | 1.99E-04 | 0.06 | 1.52E-04 | 0.05 |
| 9/28/14 19:00 | 17.76 | 2.19E-04 | 0.07 | 1.73E-04 | 0.05 |
| 9/28/14 19:05 | 17.76 | 2.39E-04 | 0.07 | 1.94E-04 | 0.06 |
| 9/28/14 19:10 | 17.76 | 2.61E-04 | 0.08 | 2.17E-04 | 0.07 |
| 9/28/14 19:15 | 17.76 | 2.83E-04 | 0.09 | 2.41E-04 | 0.07 |
| 9/28/14 19:20 | 17.67 | 3.07E-04 | 0.09 | 2.67E-04 | 0.08 |
| 9/28/14 19:25 | 17.67 | 3.31E-04 | 0.10 | 2.93E-04 | 0.09 |
| 9/28/14 19:30 | 17.67 | 3.56E-04 | 0.11 | 3.21E-04 | 0.10 |
| 9/28/14 19:35 | 17.57 | 3.82E-04 | 0.11 | 3.50E-04 | 0.10 |
| 9/28/14 19:40 | 17.57 | 4.09E-04 | 0.12 | 3.80E-04 | 0.11 |
| 9/28/14 19:45 | 17.57 | 4.36E-04 | 0.13 | 4.11E-04 | 0.12 |
| 9/28/14 19:50 | 17.57 | 4.65E-04 | 0.14 | 4.44E-04 | 0.13 |
| 9/28/14 19:55 | 17.48 | 4.94E-04 | 0.15 | 4.77E-04 | 0.14 |
| 9/28/14 20:00 | 17.48 | 5.25E-04 | 0.16 | 5.13E-04 | 0.15 |
| 9/28/14 20:05 | 17.48 | 5.56E-04 | 0.17 | 5.49E-04 | 0.16 |
| 9/28/14 20:10 | 17.38 | 5.88E-04 | 0.18 | 5.88E-04 | 0.18 |
| 9/28/14 20:15 | 17.38 | 6.21E-04 | 0.19 | 6.27E-04 | 0.19 |
| 9/28/14 20:20 | 17.38 | 6.55E-04 | 0.20 | 6.69E-04 | 0.20 |
| 9/28/14 20:25 | 17.38 | 6.90E-04 | 0.21 | 7.12E-04 | 0.21 |

Table 36 continued.

| Time | Temperature (°C) | Barometric Compensated Discharge ($m^3/s$) | Barometric Compensated Volume ($m^3$) | Reference Level Compensated Discharge ($m^3/s$) | Reference Level Compensated Volume ($m^3$) |
|---|---|---|---|---|---|
| 9/28/14 20:30 | 17.28 | 7.25E-04 | 0.22 | 7.58E-04 | 0.23 |
| 9/28/14 20:35 | 17.28 | 7.61E-04 | 0.23 | 8.04E-04 | 0.24 |
| 9/28/14 20:40 | 17.28 | 7.97E-04 | 0.24 | 8.52E-04 | 0.26 |
| 9/28/14 20:45 | 17.28 | 8.32E-04 | 0.25 | 8.86E-04 | 0.27 |
| 9/28/14 20:50 | 17.28 | 8.55E-04 | 0.26 | 9.19E-04 | 0.28 |
| 9/28/14 20:55 | 17.28 | 8.76E-04 | 0.26 | 9.51E-04 | 0.29 |
| 9/28/14 21:00 | 17.28 | 8.95E-04 | 0.27 | 9.81E-04 | 0.29 |
| 9/28/14 21:05 | 17.19 | 9.13E-04 | 0.27 | 1.01E-03 | 0.30 |
| 9/28/14 21:10 | 17.19 | 9.29E-04 | 0.28 | 1.04E-03 | 0.31 |
| 9/28/14 21:15 | 17.19 | 9.44E-04 | 0.28 | 1.06E-03 | 0.32 |
| 9/28/14 21:20 | 17.19 | 9.56E-04 | 0.29 | 1.09E-03 | 0.33 |
| 9/28/14 21:25 | 17.19 | 9.67E-04 | 0.29 | 1.11E-03 | 0.33 |
| 9/28/14 21:30 | 17.19 | 9.76E-04 | 0.29 | 1.13E-03 | 0.34 |
| 9/28/14 21:35 | 17.19 | 9.83E-04 | 0.30 | 1.14E-03 | 0.34 |
| 9/28/14 21:40 | 17.19 | 9.89E-04 | 0.30 | 1.16E-03 | 0.35 |
| 9/28/14 21:45 | 17.19 | 9.93E-04 | 0.30 | 1.17E-03 | 0.35 |
| 9/28/14 21:50 | 17.19 | 9.95E-04 | 0.30 | 1.18E-03 | 0.35 |
| 9/28/14 21:55 | 17.19 | 9.95E-04 | 0.30 | 1.19E-03 | 0.36 |
| 9/28/14 22:00 | 17.09 | 9.94E-04 | 0.30 | 1.19E-03 | 0.36 |
| 9/28/14 22:05 | 17.09 | 9.93E-04 | 0.30 | 1.19E-03 | 0.36 |
| 9/28/14 22:10 | 17.09 | 9.89E-04 | 0.30 | 1.20E-03 | 0.36 |
| 9/28/14 22:15 | 17.09 | 9.85E-04 | 0.30 | 1.19E-03 | 0.36 |
| 9/28/14 22:20 | 17.09 | 9.80E-04 | 0.29 | 1.19E-03 | 0.36 |
| 9/28/14 22:25 | 17.09 | 9.75E-04 | 0.29 | 1.19E-03 | 0.36 |
| 9/28/14 22:30 | 17.09 | 9.69E-04 | 0.29 | 1.18E-03 | 0.35 |
| 9/28/14 22:35 | 17.09 | 9.62E-04 | 0.29 | 1.18E-03 | 0.35 |
| 9/28/14 22:40 | 17.09 | 9.54E-04 | 0.29 | 1.17E-03 | 0.35 |
| 9/28/14 22:45 | 17.00 | 9.47E-04 | 0.28 | 1.16E-03 | 0.35 |
| 9/28/14 22:50 | 17.00 | 9.39E-04 | 0.28 | 1.15E-03 | 0.35 |
| 9/28/14 22:55 | 17.00 | 9.30E-04 | 0.28 | 1.14E-03 | 0.34 |
| 9/28/14 23:00 | 17.00 | 9.22E-04 | 0.28 | 1.13E-03 | 0.34 |
| 9/28/14 23:05 | 17.00 | 9.13E-04 | 0.27 | 1.12E-03 | 0.34 |
| 9/28/14 23:10 | 17.00 | 9.04E-04 | 0.27 | 1.11E-03 | 0.33 |
| 9/28/14 23:15 | 17.00 | 8.94E-04 | 0.27 | 1.09E-03 | 0.33 |
| 9/28/14 23:20 | 17.00 | 8.85E-04 | 0.27 | 1.08E-03 | 0.32 |

Table 36 continued.

| Time | Temperature (°C) | Barometric Compensated Discharge ($m^3/s$) | Barometric Compensated Volume ($m^3$) | Reference Level Compensated Discharge ($m^3/s$) | Reference Level Compensated Volume ($m^3$) |
|---|---|---|---|---|---|
| 9/28/14 23:25 | 17.00 | 8.74E-04 | 0.26 | 1.06E-03 | 0.32 |
| 9/28/14 23:30 | 17.00 | 8.64E-04 | 0.26 | 1.05E-03 | 0.31 |
| 9/28/14 23:35 | 17.00 | 8.53E-04 | 0.26 | 1.03E-03 | 0.31 |
| 9/28/14 23:40 | 16.90 | 8.42E-04 | 0.25 | 1.01E-03 | 0.30 |
| 9/28/14 23:45 | 16.90 | 8.31E-04 | 0.25 | 9.97E-04 | 0.30 |
| 9/28/14 23:50 | 16.90 | 8.19E-04 | 0.25 | 9.80E-04 | 0.29 |
| 9/28/14 23:55 | 16.90 | 8.07E-04 | 0.24 | 9.62E-04 | 0.29 |
| 9/29/14 0:00 | 16.90 | 7.96E-04 | 0.24 | 9.43E-04 | 0.28 |
| 9/29/14 0:05 | 16.90 | 7.84E-04 | 0.24 | 9.25E-04 | 0.28 |
| 9/29/14 0:10 | 16.90 | 7.71E-04 | 0.23 | 9.06E-04 | 0.27 |
| 9/29/14 0:15 | 16.90 | 7.59E-04 | 0.23 | 8.87E-04 | 0.27 |
| 9/29/14 0:20 | 16.90 | 7.46E-04 | 0.22 | 8.68E-04 | 0.26 |
| 9/29/14 0:25 | 16.81 | 7.33E-04 | 0.22 | 8.50E-04 | 0.25 |
| 9/29/14 0:30 | 16.81 | 7.21E-04 | 0.22 | 8.31E-04 | 0.25 |
| 9/29/14 0:35 | 16.81 | 7.08E-04 | 0.21 | 8.13E-04 | 0.24 |
| 9/29/14 0:40 | 16.81 | 6.96E-04 | 0.21 | 7.94E-04 | 0.24 |
| 9/29/14 0:45 | 16.81 | 6.84E-04 | 0.21 | 7.76E-04 | 0.23 |
| 9/29/14 0:50 | 16.81 | 6.72E-04 | 0.20 | 7.58E-04 | 0.23 |
| 9/29/14 0:55 | 16.81 | 6.60E-04 | 0.20 | 7.41E-04 | 0.22 |
| 9/29/14 1:00 | 16.81 | 6.48E-04 | 0.19 | 7.23E-04 | 0.22 |
| 9/29/14 1:05 | 16.81 | 6.37E-04 | 0.19 | 7.06E-04 | 0.21 |
| 9/29/14 1:10 | 16.81 | 6.26E-04 | 0.19 | 6.89E-04 | 0.21 |
| 9/29/14 1:15 | 16.81 | 6.16E-04 | 0.18 | 6.73E-04 | 0.20 |
| 9/29/14 1:20 | 16.71 | 6.06E-04 | 0.18 | 6.57E-04 | 0.20 |
| 9/29/14 1:25 | 16.71 | 5.96E-04 | 0.18 | 6.40E-04 | 0.19 |
| 9/29/14 1:30 | 16.71 | 5.87E-04 | 0.18 | 6.24E-04 | 0.19 |
| 9/29/14 1:35 | 16.71 | 5.78E-04 | 0.17 | 6.08E-04 | 0.18 |
| 9/29/14 1:40 | 16.71 | 5.69E-04 | 0.17 | 5.92E-04 | 0.18 |
| 9/29/14 1:45 | 16.71 | 5.60E-04 | 0.17 | 5.77E-04 | 0.17 |
| 9/29/14 1:50 | 16.71 | 5.51E-04 | 0.17 | 5.61E-04 | 0.17 |
| 9/29/14 1:55 | 16.71 | 5.43E-04 | 0.16 | 5.45E-04 | 0.16 |
| 9/29/14 2:00 | 16.71 | 5.34E-04 | 0.16 | 5.30E-04 | 0.16 |
| 9/29/14 2:05 | 16.71 | 5.25E-04 | 0.16 | 5.14E-04 | 0.15 |
| 9/29/14 2:10 | 16.71 | 5.16E-04 | 0.15 | 4.99E-04 | 0.15 |
| 9/29/14 2:15 | 16.71 | 5.07E-04 | 0.15 | 4.83E-04 | 0.15 |

Table 36 continued.

| Time | Temperature (°C) | Barometric Compensated Discharge ($m^3/s$) | Barometric Compensated Volume ($m^3$) | Reference Level Compensated Discharge ($m^3/s$) | Reference Level Compensated Volume ($m^3$) |
|---|---|---|---|---|---|
| 9/29/14 2:20 | 16.62 | 4.98E-04 | 0.15 | 4.68E-04 | 0.14 |
| 9/29/14 2:25 | 16.62 | 4.88E-04 | 0.15 | 4.53E-04 | 0.14 |
| 9/29/14 2:30 | 16.62 | 4.79E-04 | 0.14 | 4.38E-04 | 0.13 |
| 9/29/14 2:35 | 16.62 | 4.69E-04 | 0.14 | 4.23E-04 | 0.13 |
| 9/29/14 2:40 | 16.62 | 4.59E-04 | 0.14 | 4.09E-04 | 0.12 |
| 9/29/14 2:45 | 16.62 | 4.49E-04 | 0.13 | 3.95E-04 | 0.12 |
| 9/29/14 2:50 | 16.62 | 4.39E-04 | 0.13 | 3.81E-04 | 0.11 |
| 9/29/14 2:55 | 16.62 | 4.29E-04 | 0.13 | 3.67E-04 | 0.11 |
| 9/29/14 3:00 | 16.62 | 4.19E-04 | 0.13 | 3.54E-04 | 0.11 |
| 9/29/14 3:05 | 16.62 | 4.09E-04 | 0.12 | 3.41E-04 | 0.10 |
| 9/29/14 3:10 | 16.52 | 3.98E-04 | 0.12 | 3.29E-04 | 0.10 |
| 9/29/14 3:15 | 16.52 | 3.88E-04 | 0.12 | 3.17E-04 | 0.10 |
| 9/29/14 3:20 | 16.52 | 3.78E-04 | 0.11 | 3.05E-04 | 0.09 |
| 9/29/14 3:25 | 16.52 | 3.69E-04 | 0.11 | 2.94E-04 | 0.09 |
| 9/29/14 3:30 | 16.52 | 3.59E-04 | 0.11 | 2.83E-04 | 0.08 |
| 9/29/14 3:35 | 16.52 | 3.50E-04 | 0.10 | 2.73E-04 | 0.08 |
| 9/29/14 3:40 | 16.52 | 3.41E-04 | 0.10 | 2.63E-04 | 0.08 |
| 9/29/14 3:45 | 16.52 | 3.32E-04 | 0.10 | 2.53E-04 | 0.08 |
| 9/29/14 3:50 | 16.52 | 3.23E-04 | 0.10 | 2.44E-04 | 0.07 |
| 9/29/14 3:55 | 16.52 | 3.15E-04 | 0.09 | 2.36E-04 | 0.07 |
| 9/29/14 4:00 | 16.52 | 3.07E-04 | 0.09 | 2.27E-04 | 0.07 |
| 9/29/14 4:05 | 16.52 | 3.00E-04 | 0.09 | 2.19E-04 | 0.07 |
| 9/29/14 4:10 | 16.52 | 2.93E-04 | 0.09 | 2.12E-04 | 0.06 |
| 9/29/14 4:15 | 16.52 | 2.86E-04 | 0.09 | 2.05E-04 | 0.06 |
| 9/29/14 4:20 | 16.52 | 2.79E-04 | 0.08 | 1.98E-04 | 0.06 |
| 9/29/14 4:25 | 16.52 | 2.73E-04 | 0.08 | 1.91E-04 | 0.06 |
| 9/29/14 4:30 | 16.52 | 2.67E-04 | 0.08 | 1.85E-04 | 0.06 |
| 9/29/14 4:35 | 16.52 | 2.61E-04 | 0.08 | 1.78E-04 | 0.05 |
| 9/29/14 4:40 | 16.43 | 2.54E-04 | 0.08 | 1.72E-04 | 0.05 |
| 9/29/14 4:45 | 16.43 | 2.48E-04 | 0.07 | 1.67E-04 | 0.05 |
| 9/29/14 4:50 | 16.43 | 2.42E-04 | 0.07 | 1.61E-04 | 0.05 |
| 9/29/14 4:55 | 16.43 | 2.36E-04 | 0.07 | 1.55E-04 | 0.05 |
| 9/29/14 5:00 | 16.43 | 2.30E-04 | 0.07 | 1.50E-04 | 0.05 |
| 9/29/14 5:05 | 16.43 | 2.24E-04 | 0.07 | 1.45E-04 | 0.04 |
| 9/29/14 5:10 | 16.43 | 2.18E-04 | 0.07 | 1.40E-04 | 0.04 |

Table 36 continued.

| Time | Temperature (°C) | Barometric Compensated Discharge ($m^3/s$) | Barometric Compensated Volume ($m^3$) | Reference Level Compensated Discharge ($m^3/s$) | Reference Level Compensated Volume ($m^3$) |
|---|---|---|---|---|---|
| 9/29/14 5:15 | 16.43 | 2.12E-04 | 0.06 | 1.35E-04 | 0.04 |
| 9/29/14 5:20 | 16.43 | 2.06E-04 | 0.06 | 1.30E-04 | 0.04 |
| 9/29/14 5:25 | 16.43 | 2.00E-04 | 0.06 | 1.26E-04 | 0.04 |
| 9/29/14 5:30 | 16.43 | 1.94E-04 | 0.06 | 1.22E-04 | 0.04 |
| 9/29/14 5:35 | 16.43 | 1.88E-04 | 0.06 | 1.17E-04 | 0.04 |
| 9/29/14 5:40 | 16.43 | 1.82E-04 | 0.05 | 1.13E-04 | 0.03 |
| 9/29/14 5:45 | 16.43 | 1.76E-04 | 0.05 | 1.09E-04 | 0.03 |
| 9/29/14 5:50 | 16.43 | 1.71E-04 | 0.05 | 1.06E-04 | 0.03 |
| 9/29/14 5:55 | 16.43 | 1.65E-04 | 0.05 | 1.02E-04 | 0.03 |
| 9/29/14 6:00 | 16.33 | 1.60E-04 | 0.05 | 9.93E-05 | 0.03 |
| 9/29/14 6:05 | 16.33 | 1.55E-04 | 0.05 | 9.63E-05 | 0.03 |
| 9/29/14 6:10 | 16.33 | 1.51E-04 | 0.05 | 9.35E-05 | 0.03 |
| 9/29/14 6:15 | 16.33 | 1.47E-04 | 0.04 | 9.09E-05 | 0.03 |
| 9/29/14 6:20 | 16.33 | 1.43E-04 | 0.04 | 8.85E-05 | 0.03 |
| 9/29/14 6:25 | 16.33 | 1.40E-04 | 0.04 | 8.63E-05 | 0.03 |
| 9/29/14 6:30 | 16.33 | 1.37E-04 | 0.04 | 8.43E-05 | 0.03 |
| 9/29/14 6:35 | 16.33 | 1.34E-04 | 0.04 | 8.24E-05 | 0.02 |
| 9/29/14 6:40 | 16.33 | 1.31E-04 | 0.04 | 8.07E-05 | 0.02 |
| 9/29/14 6:45 | 16.33 | 1.29E-04 | 0.04 | 7.90E-05 | 0.02 |
| 9/29/14 6:50 | 16.33 | 1.27E-04 | 0.04 | 7.74E-05 | 0.02 |
| 9/29/14 6:55 | 16.33 | 1.26E-04 | 0.04 | 7.59E-05 | 0.02 |
| 9/29/14 7:00 | 16.33 | 1.24E-04 | 0.04 | 7.44E-05 | 0.02 |
| 9/29/14 7:05 | 16.33 | 1.23E-04 | 0.04 | 7.30E-05 | 0.02 |
| 9/29/14 7:10 | 16.33 | 1.22E-04 | 0.04 | 7.15E-05 | 0.02 |
| 9/29/14 7:15 | 16.33 | 1.21E-04 | 0.04 | 7.01E-05 | 0.02 |
| 9/29/14 7:20 | 16.33 | 1.20E-04 | 0.04 | 6.87E-05 | 0.02 |
| 9/29/14 7:25 | 16.24 | 1.19E-04 | 0.04 | 6.72E-05 | 0.02 |
| 9/29/14 7:30 | 16.24 | 1.18E-04 | 0.04 | 6.57E-05 | 0.02 |
| 9/29/14 7:35 | 16.24 | 1.17E-04 | 0.04 | 6.41E-05 | 0.02 |
| 9/29/14 7:40 | 16.24 | 1.16E-04 | 0.03 | 6.25E-05 | 0.02 |
| 9/29/14 7:45 | 16.24 | 1.15E-04 | 0.03 | 6.09E-05 | 0.02 |
| 9/29/14 7:50 | 16.24 | 1.14E-04 | 0.03 | 5.91E-05 | 0.02 |
| 9/29/14 7:55 | 16.24 | 1.14E-04 | 0.03 | 5.74E-05 | 0.02 |
| 9/29/14 8:00 | 16.24 | 1.13E-04 | 0.03 | 5.56E-05 | 0.02 |
| 9/29/14 8:05 | 16.24 | 1.12E-04 | 0.03 | 5.37E-05 | 0.02 |

Table 36 continued.

| Time | Temperature (°C) | Barometric Compensated Discharge ($m^3/s$) | Barometric Compensated Volume ($m^3$) | Reference Level Compensated Discharge ($m^3/s$) | Reference Level Compensated Volume ($m^3$) |
|---|---|---|---|---|---|
| 9/29/14 8:10 | 16.24 | 1.11E-04 | 0.03 | 5.19E-05 | 0.02 |
| 9/29/14 8:15 | 16.24 | 1.11E-04 | 0.03 | 5.00E-05 | 0.02 |
| 9/29/14 8:20 | 16.24 | 1.10E-04 | 0.03 | 4.82E-05 | 0.01 |
| 9/29/14 8:25 | 16.24 | 1.10E-04 | 0.03 | 4.63E-05 | 0.01 |
| 9/29/14 8:30 | 16.24 | 1.10E-04 | 0.03 | 4.45E-05 | 0.01 |
| 9/29/14 8:35 | 16.24 | 1.09E-04 | 0.03 | 4.26E-05 | 0.01 |
| 9/29/14 8:40 | 16.24 | 1.09E-04 | 0.03 | 4.08E-05 | 0.01 |
| 9/29/14 8:45 | 16.14 | 1.09E-04 | 0.03 | 3.91E-05 | 0.01 |
| 9/29/14 8:50 | 16.14 | 1.09E-04 | 0.03 | 3.73E-05 | 0.01 |
| 9/29/14 8:55 | 16.14 | 1.10E-04 | 0.03 | 3.56E-05 | 0.01 |
| 9/29/14 9:00 | 16.14 | 1.10E-04 | 0.03 | 3.39E-05 | 0.01 |
| 9/29/14 9:05 | 16.14 | 1.11E-04 | 0.03 | 3.22E-05 | 0.01 |
| 9/29/14 9:10 | 16.14 | 1.12E-04 | 0.03 | 3.06E-05 | 0.01 |
| 9/29/14 9:15 | 16.14 | 1.13E-04 | 0.03 | 2.90E-05 | 0.01 |
| 9/29/14 9:20 | 16.14 | 1.14E-04 | 0.03 | 2.75E-05 | 0.01 |
| 9/29/14 9:25 | 16.14 | 1.15E-04 | 0.03 | 2.60E-05 | 0.01 |
| 9/29/14 9:30 | 16.14 | 1.16E-04 | 0.03 | 2.45E-05 | 0.01 |
| 9/29/14 9:35 | 16.14 | 1.17E-04 | 0.04 | 2.30E-05 | 0.01 |
| 9/29/14 9:40 | 16.14 | 1.18E-04 | 0.04 | 2.16E-05 | 0.01 |
| 9/29/14 9:45 | 16.14 | 1.19E-04 | 0.04 | 2.03E-05 | 0.01 |
| 9/29/14 9:50 | 16.14 | 1.21E-04 | 0.04 | 1.90E-05 | 0.01 |
| 9/29/14 9:55 | 16.14 | 1.22E-04 | 0.04 | 1.77E-05 | 0.01 |
| 9/29/14 10:00 | 16.14 | 1.22E-04 | 0.04 | 1.64E-05 | 0.00 |
| 9/29/14 10:05 | 16.14 | 1.23E-04 | 0.04 | 1.52E-05 | 0.00 |
| 9/29/14 10:10 | 16.14 | 1.24E-04 | 0.04 | 1.40E-05 | 0.00 |
| 9/29/14 10:15 | 16.14 | 1.24E-04 | 0.04 | 1.29E-05 | 0.00 |
| 9/29/14 10:20 | 16.14 | 1.25E-04 | 0.04 | 1.18E-05 | 0.00 |
| 9/29/14 10:25 | 16.14 | 1.26E-04 | 0.04 | 1.07E-05 | 0.00 |
| 9/29/14 10:30 | 16.14 | 1.26E-04 | 0.04 | 9.74E-06 | 0.00 |
| 9/29/14 10:35 | 16.14 | 1.27E-04 | 0.04 | 8.80E-06 | 0.00 |
| 9/29/14 10:40 | 16.14 | 1.27E-04 | 0.04 | 7.91E-06 | 0.00 |
| 9/29/14 10:45 | 16.14 | 1.28E-04 | 0.04 | 7.08E-06 | 0.00 |
| 9/29/14 10:50 | 16.14 | 1.29E-04 | 0.04 | 6.30E-06 | 0.00 |
| 9/29/14 10:55 | 16.14 | 1.29E-04 | 0.04 | 0.00E+00 | 0.00 |
| 9/29/14 11:00 | 16.14 | 1.30E-04 | 0.04 | 5.17E-06 | 0.00 |

Table 36 continued.

| Time | Temperature (°C) | Barometric Compensated Discharge ($m^3/s$) | Barometric Compensated Volume ($m^3$) | Reference Level Compensated Discharge ($m^3/s$) | Reference Level Compensated Volume ($m^3$) |
|---|---|---|---|---|---|
| 9/29/14 11:05 | 16.14 | 1.30E-04 | 0.04 | 0.00E+00 | 0.00 |
| 9/29/14 11:10 | 16.14 | 1.31E-04 | 0.04 | 4.24E-06 | 0.00 |
| 9/29/14 11:15 | 16.14 | 1.31E-04 | 0.04 | 3.82E-06 | 0.00 |
| 9/29/14 11:20 | 16.14 | 1.32E-04 | 0.04 | 3.43E-06 | 0.00 |
| 9/29/14 11:25 | 16.14 | 1.33E-04 | 0.04 | 3.06E-06 | 0.00 |
| 9/29/14 11:30 | 16.14 | 1.33E-04 | 0.04 | 0.00E+00 | 0.00 |
| 9/29/14 11:35 | 16.14 | 1.34E-04 | 0.04 | 0.00E+00 | 0.00 |
| 9/29/14 11:40 | 16.14 | 1.34E-04 | 0.04 | 0.00E+00 | 0.00 |
| 9/29/14 11:45 | 16.24 | 1.35E-04 | 0.04 | 0.00E+00 | 0.00 |
| 9/29/14 11:50 | 16.24 | 1.36E-04 | 0.04 | 0.00E+00 | 0.00 |
| 9/29/14 11:55 | 16.24 | 1.36E-04 | 0.04 | 0.00E+00 | 0.00 |
| 9/29/14 12:00 | 16.24 | 1.37E-04 | 0.04 | 0.00E+00 | 0.00 |
| 9/29/14 12:05 | 16.24 | 1.37E-04 | 0.04 | 0.00E+00 | 0.00 |
| 9/29/14 12:10 | 16.24 | 1.38E-04 | 0.04 | 0.00E+00 | 0.00 |
| 9/29/14 12:15 | 16.24 | 1.38E-04 | 0.04 | 0.00E+00 | 0.00 |
| 9/29/14 12:20 | 16.24 | 1.39E-04 | 0.04 | 0.00E+00 | 0.00 |
| 9/29/14 12:25 | 16.24 | 1.39E-04 | 0.04 | 0.00E+00 | 0.00 |
| 9/29/14 12:30 | 16.24 | 1.40E-04 | 0.04 | 0.00E+00 | 0.00 |
| 9/29/14 12:35 | 16.24 | 1.40E-04 | 0.04 | 0.00E+00 | 0.00 |
| 9/29/14 12:40 | 16.24 | 1.41E-04 | 0.04 | 0.00E+00 | 0.00 |
| 9/29/14 12:45 | 16.24 | 1.42E-04 | 0.04 | 0.00E+00 | 0.00 |
| 9/29/14 12:50 | 16.24 | 1.42E-04 | 0.04 | 0.00E+00 | 0.00 |
| 9/29/14 12:55 | 16.24 | 1.43E-04 | 0.04 | 0.00E+00 | 0.00 |
| 9/29/14 13:00 | 16.24 | 1.43E-04 | 0.04 | 0.00E+00 | 0.00 |
| 9/29/14 13:05 | 16.24 | 1.44E-04 | 0.04 | 0.00E+00 | 0.00 |

Table 37. 10/12/14 influent hydrograph data.

| Time | West Influent | | | East Influent | | |
|---|---|---|---|---|---|---|
| | Temp. (°C) | Discharge ($m^3/s$) | Volume ($m^3$) | Temp. (°C) | Discharge ($m^3/s$) | Volume ($m^3$) |
| 10/12/14 17:00 | 11.82 | 0.00E+00 | 0.00 | - | - | - |
| 10/12/14 17:05 | 11.72 | 0.00E+00 | 0.00 | 9.97 | 1.13E-07 | 0.00 |
| 10/12/14 17:10 | 11.72 | 0.00E+00 | 0.00 | 9.87 | 2.95E-07 | 0.00 |
| 10/12/14 17:15 | 11.72 | 2.46E-06 | 0.00 | 9.97 | 5.82E-07 | 0.00 |
| 10/12/14 17:20 | 11.72 | 3.43E-06 | 0.00 | 9.87 | 9.61E-07 | 0.00 |
| 10/12/14 17:25 | 11.72 | 4.56E-06 | 0.00 | 9.87 | 1.46E-06 | 0.00 |
| 10/12/14 17:30 | 11.72 | 5.91E-06 | 0.00 | 9.87 | 2.08E-06 | 0.00 |
| 10/12/14 17:35 | 11.82 | 7.43E-06 | 0.00 | 9.87 | 2.80E-06 | 0.00 |
| 10/12/14 17:40 | 11.92 | 9.20E-06 | 0.00 | 9.87 | 3.65E-06 | 0.00 |
| 10/12/14 17:45 | 11.92 | 1.12E-05 | 0.00 | 9.87 | 4.62E-06 | 0.00 |
| 10/12/14 17:50 | 11.82 | 1.34E-05 | 0.00 | 9.87 | 5.71E-06 | 0.00 |
| 10/12/14 17:55 | 11.63 | 1.58E-05 | 0.00 | 9.87 | 6.94E-06 | 0.00 |
| 10/12/14 18:00 | 11.63 | 1.85E-05 | 0.01 | 9.87 | 8.29E-06 | 0.00 |
| 10/12/14 18:05 | 11.53 | 2.14E-05 | 0.01 | 9.87 | 9.77E-06 | 0.00 |
| 10/12/14 18:10 | 11.43 | 2.44E-05 | 0.01 | 9.87 | 1.14E-05 | 0.00 |
| 10/12/14 18:15 | 11.33 | 2.74E-05 | 0.01 | 9.87 | 1.32E-05 | 0.00 |
| 10/12/14 18:20 | 11.24 | 3.13E-05 | 0.01 | 9.87 | 1.51E-05 | 0.00 |
| 10/12/14 18:25 | 11.14 | 3.58E-05 | 0.01 | 9.97 | 1.71E-05 | 0.01 |
| 10/12/14 18:30 | 11.04 | 4.07E-05 | 0.01 | 9.97 | 1.92E-05 | 0.01 |
| 10/12/14 18:35 | 11.04 | 4.61E-05 | 0.01 | 9.97 | 2.15E-05 | 0.01 |
| 10/12/14 18:40 | 10.94 | 5.21E-05 | 0.02 | 9.97 | 2.38E-05 | 0.01 |
| 10/12/14 18:45 | 10.94 | 5.87E-05 | 0.02 | 9.97 | 2.62E-05 | 0.01 |
| 10/12/14 18:50 | 10.94 | 6.61E-05 | 0.02 | 9.87 | 2.82E-05 | 0.01 |
| 10/12/14 18:55 | 10.94 | 7.45E-05 | 0.02 | 9.87 | 3.01E-05 | 0.01 |
| 10/12/14 19:00 | 10.94 | 8.40E-05 | 0.03 | 9.87 | 3.19E-05 | 0.01 |
| 10/12/14 19:05 | 10.94 | 9.40E-05 | 0.03 | 9.87 | 3.35E-05 | 0.01 |
| 10/12/14 19:10 | 10.94 | 1.04E-04 | 0.03 | 10.06 | 3.52E-05 | 0.01 |
| 10/12/14 19:15 | 10.85 | 1.15E-04 | 0.03 | 10.26 | 3.70E-05 | 0.01 |
| 10/12/14 19:20 | 10.85 | 1.26E-04 | 0.04 | 10.46 | 3.90E-05 | 0.01 |
| 10/12/14 19:25 | 10.85 | 1.35E-04 | 0.04 | 10.46 | 4.15E-05 | 0.01 |
| 10/12/14 19:30 | 10.85 | 1.45E-04 | 0.04 | 10.55 | 4.45E-05 | 0.01 |
| 10/12/14 19:35 | 10.85 | 1.53E-04 | 0.05 | 10.55 | 4.82E-05 | 0.01 |
| 10/12/14 19:40 | 10.85 | 1.60E-04 | 0.05 | 10.55 | 5.27E-05 | 0.02 |
| 10/12/14 19:45 | 10.85 | 1.68E-04 | 0.05 | 10.55 | 5.79E-05 | 0.02 |
| 10/12/14 19:50 | 10.85 | 1.77E-04 | 0.05 | 10.55 | 6.40E-05 | 0.02 |
| 10/12/14 19:55 | 10.85 | 1.86E-04 | 0.06 | 10.55 | 7.10E-05 | 0.02 |

Table 37 continued.

| Time | West Influent | | | East Influent | | |
|---|---|---|---|---|---|---|
| | Temp. (°C) | Discharge ($m^3/s$) | Volume ($m^3$) | Temp. (°C) | Discharge ($m^3/s$) | Volume ($m^3$) |
| 10/12/14 20:00 | 10.94 | 1.97E-04 | 0.06 | 10.55 | 7.90E-05 | 0.02 |
| 10/12/14 20:05 | 10.94 | 2.10E-04 | 0.06 | 10.55 | 8.79E-05 | 0.03 |
| 10/12/14 20:10 | 10.94 | 2.25E-04 | 0.07 | 10.55 | 9.76E-05 | 0.03 |
| 10/12/14 20:15 | 10.94 | 2.42E-04 | 0.07 | 10.55 | 1.08E-04 | 0.03 |
| 10/12/14 20:20 | 11.04 | 2.59E-04 | 0.08 | 10.55 | 1.20E-04 | 0.04 |
| 10/12/14 20:25 | 11.43 | 2.77E-04 | 0.08 | 10.55 | 1.33E-04 | 0.04 |
| 10/12/14 20:30 | 11.72 | 2.94E-04 | 0.09 | 10.55 | 1.47E-04 | 0.04 |
| 10/12/14 20:35 | 11.63 | 3.08E-04 | 0.09 | 10.65 | 1.63E-04 | 0.05 |
| 10/12/14 20:40 | 11.53 | 3.21E-04 | 0.10 | 10.75 | 1.79E-04 | 0.05 |
| 10/12/14 20:45 | 11.53 | 3.32E-04 | 0.10 | 10.85 | 1.97E-04 | 0.06 |
| 10/12/14 20:50 | 11.43 | 3.42E-04 | 0.10 | 10.94 | 2.17E-04 | 0.06 |
| 10/12/14 20:55 | 11.43 | 3.51E-04 | 0.11 | 11.04 | 2.37E-04 | 0.07 |
| 10/12/14 21:00 | 11.43 | 3.59E-04 | 0.11 | 11.14 | 2.58E-04 | 0.08 |
| 10/12/14 21:05 | 11.43 | 3.66E-04 | 0.11 | 11.14 | 2.80E-04 | 0.08 |
| 10/12/14 21:10 | 11.53 | 3.74E-04 | 0.11 | 11.24 | 3.02E-04 | 0.09 |
| 10/12/14 21:15 | 11.53 | 3.80E-04 | 0.11 | 11.24 | 3.24E-04 | 0.10 |
| 10/12/14 21:20 | 11.53 | 3.86E-04 | 0.12 | 11.24 | 3.45E-04 | 0.10 |
| 10/12/14 21:25 | 11.53 | 3.92E-04 | 0.12 | 11.24 | 3.65E-04 | 0.11 |
| 10/12/14 21:30 | 11.53 | 3.99E-04 | 0.12 | 11.24 | 3.83E-04 | 0.11 |
| 10/12/14 21:35 | 11.53 | 4.09E-04 | 0.12 | 11.24 | 4.00E-04 | 0.12 |
| 10/12/14 21:40 | 11.53 | 4.23E-04 | 0.13 | 11.24 | 4.15E-04 | 0.12 |
| 10/12/14 21:45 | 11.53 | 4.42E-04 | 0.13 | 11.24 | 4.27E-04 | 0.13 |
| 10/12/14 21:50 | 11.53 | 4.68E-04 | 0.14 | 11.24 | 4.36E-04 | 0.13 |
| 10/12/14 21:55 | 11.53 | 5.00E-04 | 0.15 | 11.24 | 4.43E-04 | 0.13 |
| 10/12/14 22:00 | 11.53 | 5.39E-04 | 0.16 | 11.24 | 4.47E-04 | 0.13 |
| 10/12/14 22:05 | 11.63 | 5.86E-04 | 0.18 | 11.24 | 4.49E-04 | 0.13 |
| 10/12/14 22:10 | 11.63 | 6.40E-04 | 0.19 | 11.24 | 4.50E-04 | 0.13 |
| 10/12/14 22:15 | 11.63 | 7.02E-04 | 0.21 | 11.24 | 4.50E-04 | 0.13 |
| 10/12/14 22:20 | 11.63 | 7.68E-04 | 0.23 | 11.24 | 4.48E-04 | 0.13 |
| 10/12/14 22:25 | 11.53 | 8.41E-04 | 0.25 | 11.24 | 4.46E-04 | 0.13 |
| 10/12/14 22:30 | 11.53 | 9.20E-04 | 0.28 | 11.24 | 4.44E-04 | 0.13 |
| 10/12/14 22:35 | 11.63 | 1.00E-03 | 0.30 | 11.14 | 4.40E-04 | 0.13 |
| 10/12/14 22:40 | 11.63 | 1.09E-03 | 0.33 | 11.14 | 4.36E-04 | 0.13 |
| 10/12/14 22:45 | 11.63 | 1.17E-03 | 0.35 | 11.14 | 4.31E-04 | 0.13 |
| 10/12/14 22:50 | 11.63 | 1.25E-03 | 0.38 | 11.14 | 4.25E-04 | 0.13 |
| 10/12/14 22:55 | 11.63 | 1.32E-03 | 0.40 | 11.14 | 4.18E-04 | 0.13 |

Table 37 continued.

| Time | West Influent | | | East Influent | | |
|---|---|---|---|---|---|---|
| | Temp. (°C) | Discharge ($m^3$/s) | Volume ($m^3$) | Temp. (°C) | Discharge ($m^3$/s) | Volume ($m^3$) |
| 10/12/14 23:00 | 11.63 | 1.37E-03 | 0.41 | 11.14 | 4.10E-04 | 0.12 |
| 10/12/14 23:05 | 11.63 | 1.40E-03 | 0.42 | 11.14 | 4.01E-04 | 0.12 |
| 10/12/14 23:10 | 11.53 | 1.41E-03 | 0.42 | 11.14 | 3.92E-04 | 0.12 |
| 10/12/14 23:15 | 11.53 | 1.40E-03 | 0.42 | 11.14 | 3.82E-04 | 0.11 |
| 10/12/14 23:20 | 11.43 | 1.37E-03 | 0.41 | 11.14 | 3.71E-04 | 0.11 |
| 10/12/14 23:25 | 11.43 | 1.34E-03 | 0.40 | 11.14 | 3.59E-04 | 0.11 |
| 10/12/14 23:30 | 11.43 | 1.29E-03 | 0.39 | 11.14 | 3.46E-04 | 0.10 |
| 10/12/14 23:35 | 11.43 | 1.23E-03 | 0.37 | 11.14 | 3.33E-04 | 0.10 |
| 10/12/14 23:40 | 11.33 | 1.16E-03 | 0.35 | 11.14 | 3.19E-04 | 0.10 |
| 10/12/14 23:45 | 11.33 | 1.09E-03 | 0.33 | 11.14 | 3.04E-04 | 0.09 |
| 10/12/14 23:50 | 11.33 | 1.02E-03 | 0.30 | 11.14 | 2.89E-04 | 0.09 |
| 10/12/14 23:55 | 11.24 | 9.39E-04 | 0.28 | 11.14 | 2.74E-04 | 0.08 |
| 10/13/14 0:00 | 11.24 | 8.63E-04 | 0.26 | 11.14 | 2.58E-04 | 0.08 |
| 10/13/14 0:05 | 11.24 | 7.94E-04 | 0.24 | 11.14 | 2.41E-04 | 0.07 |
| 10/13/14 0:10 | 11.24 | 7.30E-04 | 0.22 | 11.14 | 2.24E-04 | 0.07 |
| 10/13/14 0:15 | 11.24 | 6.73E-04 | 0.20 | 11.14 | 2.07E-04 | 0.06 |
| 10/13/14 0:20 | 11.24 | 6.21E-04 | 0.19 | 11.14 | 1.91E-04 | 0.06 |
| 10/13/14 0:25 | 11.24 | 5.75E-04 | 0.17 | 11.04 | 1.75E-04 | 0.05 |
| 10/13/14 0:30 | 11.24 | 5.36E-04 | 0.16 | 11.04 | 1.59E-04 | 0.05 |
| 10/13/14 0:35 | 11.24 | 5.03E-04 | 0.15 | 11.04 | 1.44E-04 | 0.04 |
| 10/13/14 0:40 | 11.24 | 4.77E-04 | 0.14 | 11.04 | 1.30E-04 | 0.04 |
| 10/13/14 0:45 | 11.24 | 4.56E-04 | 0.14 | 11.04 | 1.17E-04 | 0.04 |
| 10/13/14 0:50 | 11.24 | 4.38E-04 | 0.13 | 11.04 | 1.06E-04 | 0.03 |
| 10/13/14 0:55 | 11.24 | 4.23E-04 | 0.13 | 11.04 | 9.52E-05 | 0.03 |
| 10/13/14 1:00 | 11.24 | 4.10E-04 | 0.12 | 11.04 | 8.57E-05 | 0.03 |
| 10/13/14 1:05 | 11.24 | 3.99E-04 | 0.12 | 11.04 | 7.71E-05 | 0.02 |
| 10/13/14 1:10 | 11.14 | 3.90E-04 | 0.12 | 11.04 | 6.94E-05 | 0.02 |
| 10/13/14 1:15 | 11.14 | 3.83E-04 | 0.12 | 11.04 | 6.26E-05 | 0.02 |
| 10/13/14 1:20 | 11.14 | 3.79E-04 | 0.11 | 11.04 | 5.65E-05 | 0.02 |
| 10/13/14 1:25 | 11.14 | 3.75E-04 | 0.11 | 11.04 | 5.12E-05 | 0.02 |
| 10/13/14 1:30 | 11.14 | 3.71E-04 | 0.11 | 11.04 | 4.63E-05 | 0.01 |
| 10/13/14 1:35 | 11.14 | 3.66E-04 | 0.11 | 11.04 | 4.20E-05 | 0.01 |
| 10/13/14 1:40 | 11.14 | 3.59E-04 | 0.11 | 11.04 | 3.80E-05 | 0.01 |
| 10/13/14 1:45 | 11.04 | 3.52E-04 | 0.11 | 10.94 | 3.44E-05 | 0.01 |
| 10/13/14 1:50 | 11.04 | 3.44E-04 | 0.10 | 10.94 | 3.16E-05 | 0.01 |
| 10/13/14 1:55 | 11.04 | 3.37E-04 | 0.10 | 10.94 | 2.89E-05 | 0.01 |

Table 37 continued.

| Time | West Influent | | | East Influent | | |
|---|---|---|---|---|---|---|
| | Temp. (°C) | Discharge ($m^3/s$) | Volume ($m^3$) | Temp. (°C) | Discharge ($m^3/s$) | Volume ($m^3$) |
| 10/13/14 2:00 | 11.04 | 3.30E-04 | 0.10 | 10.94 | 2.65E-05 | 0.01 |
| 10/13/14 2:05 | 11.04 | 3.23E-04 | 0.10 | 10.94 | 2.42E-05 | 0.01 |
| 10/13/14 2:10 | 11.04 | 3.14E-04 | 0.09 | 10.94 | 2.20E-05 | 0.01 |
| 10/13/14 2:15 | 11.04 | 3.04E-04 | 0.09 | 10.94 | 2.00E-05 | 0.01 |
| 10/13/14 2:20 | 11.14 | 2.93E-04 | 0.09 | 10.94 | 1.81E-05 | 0.01 |
| 10/13/14 2:25 | 11.14 | 2.81E-04 | 0.08 | 10.94 | 1.63E-05 | 0.00 |
| 10/13/14 2:30 | 11.14 | 2.69E-04 | 0.08 | 10.94 | 1.46E-05 | 0.00 |
| 10/13/14 2:35 | 11.14 | 2.57E-04 | 0.08 | 10.85 | 1.31E-05 | 0.00 |
| 10/13/14 2:40 | 11.14 | 2.45E-04 | 0.07 | 10.85 | 1.16E-05 | 0.00 |
| 10/13/14 2:45 | 11.14 | 2.34E-04 | 0.07 | 10.85 | 1.02E-05 | 0.00 |
| 10/13/14 2:50 | 11.14 | 2.22E-04 | 0.07 | 10.85 | 8.95E-06 | 0.00 |
| 10/13/14 2:55 | 11.14 | 2.09E-04 | 0.06 | 10.85 | 7.75E-06 | 0.00 |
| 10/13/14 3:00 | 11.14 | 1.97E-04 | 0.06 | 10.85 | 6.66E-06 | 0.00 |
| 10/13/14 3:05 | 11.24 | 1.86E-04 | 0.06 | 10.85 | 5.64E-06 | 0.00 |
| 10/13/14 3:10 | 11.24 | 1.74E-04 | 0.05 | 10.85 | 4.71E-06 | 0.00 |
| 10/13/14 3:15 | 11.24 | 1.63E-04 | 0.05 | 10.85 | 3.87E-06 | 0.00 |
| 10/13/14 3:20 | 11.24 | 1.53E-04 | 0.05 | 10.85 | 3.12E-06 | 0.00 |
| 10/13/14 3:25 | 11.24 | 1.44E-04 | 0.04 | 10.75 | 2.45E-06 | 0.00 |
| 10/13/14 3:30 | 11.24 | 1.36E-04 | 0.04 | - | - | - |
| 10/13/14 3:35 | 11.24 | 1.30E-04 | 0.04 | - | - | - |
| 10/13/14 3:40 | 11.24 | 1.25E-04 | 0.04 | - | - | - |
| 10/13/14 3:45 | 11.24 | 1.20E-04 | 0.04 | - | - | - |
| 10/13/14 3:50 | 11.24 | 1.17E-04 | 0.03 | - | - | - |
| 10/13/14 3:55 | 11.24 | 1.13E-04 | 0.03 | - | - | - |
| 10/13/14 4:00 | 11.24 | 1.10E-04 | 0.03 | - | - | - |
| 10/13/14 4:05 | 11.24 | 1.06E-04 | 0.03 | - | - | - |
| 10/13/14 4:10 | 11.24 | 1.02E-04 | 0.03 | - | - | - |
| 10/13/14 4:15 | 11.24 | 9.81E-05 | 0.03 | - | - | - |
| 10/13/14 4:20 | 11.24 | 9.36E-05 | 0.03 | - | - | - |
| 10/13/14 4:25 | 11.24 | 8.90E-05 | 0.03 | - | - | - |
| 10/13/14 4:30 | 11.24 | 8.43E-05 | 0.03 | - | - | - |
| 10/13/14 4:35 | 11.24 | 7.95E-05 | 0.02 | - | - | - |
| 10/13/14 4:40 | 11.24 | 7.49E-05 | 0.02 | - | - | - |
| 10/13/14 4:45 | 11.24 | 7.03E-05 | 0.02 | - | - | - |
| 10/13/14 4:50 | 11.24 | 6.60E-05 | 0.02 | - | - | - |
| 10/13/14 4:55 | 11.24 | 6.17E-05 | 0.02 | - | - | - |

Table 37 continued.

| Time | West Influent | | | East Influent | | |
|---|---|---|---|---|---|---|
| | Temp. (°C) | Discharge ($m^3/s$) | Volume ($m^3$) | Temp. (°C) | Discharge ($m^3/s$) | Volume ($m^3$) |
| 10/13/14 5:00 | 11.24 | 5.75E-05 | 0.02 | - | - | - |
| 10/13/14 5:05 | 11.33 | 5.35E-05 | 0.02 | - | - | - |
| 10/13/14 5:10 | 11.33 | 4.98E-05 | 0.01 | - | - | - |
| 10/13/14 5:15 | 11.33 | 4.60E-05 | 0.01 | - | - | - |
| 10/13/14 5:20 | 11.33 | 4.25E-05 | 0.01 | - | - | - |
| 10/13/14 5:25 | 11.33 | 3.91E-05 | 0.01 | - | - | - |

Table 38. 10/12/14 effluent hydrograph data.

| Time | Temp. (°C) | Discharge ($m^3/s$) | Volume ($m^3$) |
|---|---|---|---|
| 10/12/14 20:35 | 9.57 | 5.34E-06 | 0.00 |
| 10/12/14 20:40 | 9.57 | 1.36E-05 | 0.00 |
| 10/12/14 20:45 | 9.57 | 2.64E-05 | 0.01 |
| 10/12/14 20:50 | 9.57 | 4.36E-05 | 0.01 |
| 10/12/14 20:55 | 9.57 | 6.61E-05 | 0.02 |
| 10/12/14 21:00 | 9.57 | 9.32E-05 | 0.03 |
| 10/12/14 21:05 | 9.57 | 1.24E-04 | 0.04 |
| 10/12/14 21:10 | 9.57 | 1.61E-04 | 0.05 |
| 10/12/14 21:15 | 9.57 | 2.02E-04 | 0.06 |
| 10/12/14 21:20 | 9.57 | 2.48E-04 | 0.07 |
| 10/12/14 21:25 | 9.57 | 2.98E-04 | 0.09 |
| 10/12/14 21:30 | 9.57 | 3.53E-04 | 0.11 |
| 10/12/14 21:35 | 9.57 | 4.13E-04 | 0.12 |
| 10/12/14 21:40 | 9.57 | 4.78E-04 | 0.14 |
| 10/12/14 21:45 | 9.67 | 5.47E-04 | 0.16 |
| 10/12/14 21:50 | 9.67 | 6.21E-04 | 0.19 |
| 10/12/14 21:55 | 9.67 | 7.00E-04 | 0.21 |
| 10/12/14 22:00 | 9.67 | 7.83E-04 | 0.23 |
| 10/12/14 22:05 | 9.67 | 8.71E-04 | 0.26 |
| 10/12/14 22:10 | 9.67 | 9.62E-04 | 0.29 |
| 10/12/14 22:15 | 9.67 | 1.06E-03 | 0.32 |
| 10/12/14 22:20 | 9.67 | 1.13E-03 | 0.34 |
| 10/12/14 22:25 | 9.67 | 1.21E-03 | 0.36 |
| 10/12/14 22:30 | 9.67 | 1.28E-03 | 0.38 |
| 10/12/14 22:35 | 9.67 | 1.34E-03 | 0.40 |
| 10/12/14 22:40 | 9.77 | 1.41E-03 | 0.42 |
| 10/12/14 22:45 | 9.77 | 1.46E-03 | 0.44 |
| 10/12/14 22:50 | 9.77 | 1.51E-03 | 0.45 |
| 10/12/14 22:55 | 9.77 | 1.55E-03 | 0.47 |
| 10/12/14 23:00 | 9.67 | 1.59E-03 | 0.48 |
| 10/12/14 23:05 | 9.67 | 1.62E-03 | 0.48 |
| 10/12/14 23:10 | 9.67 | 1.64E-03 | 0.49 |
| 10/12/14 23:15 | 9.67 | 1.65E-03 | 0.50 |
| 10/12/14 23:20 | 9.67 | 1.66E-03 | 0.50 |
| 10/12/14 23:25 | 9.67 | 1.67E-03 | 0.50 |
| 10/12/14 23:30 | 9.67 | 1.66E-03 | 0.50 |
| 10/12/14 23:35 | 9.67 | 1.65E-03 | 0.50 |

Table 38 continued.

| Time | Temp. (°C) | Discharge ($m^3/s$) | Volume ($m^3$) |
|---|---|---|---|
| 10/12/14 23:40 | 9.67 | 1.64E-03 | 0.49 |
| 10/12/14 23:45 | 9.67 | 1.62E-03 | 0.49 |
| 10/12/14 23:50 | 9.67 | 1.60E-03 | 0.48 |
| 10/12/14 23:55 | 9.67 | 1.58E-03 | 0.47 |
| 10/13/14 0:00 | 9.67 | 1.55E-03 | 0.46 |
| 10/13/14 0:05 | 9.67 | 1.52E-03 | 0.46 |
| 10/13/14 0:10 | 9.67 | 1.48E-03 | 0.45 |
| 10/13/14 0:15 | 9.67 | 1.45E-03 | 0.43 |
| 10/13/14 0:20 | 9.67 | 1.41E-03 | 0.42 |
| 10/13/14 0:25 | 9.67 | 1.37E-03 | 0.41 |
| 10/13/14 0:30 | 9.67 | 1.33E-03 | 0.40 |
| 10/13/14 0:35 | 9.67 | 1.29E-03 | 0.39 |
| 10/13/14 0:40 | 9.67 | 1.25E-03 | 0.38 |
| 10/13/14 0:45 | 9.67 | 1.21E-03 | 0.36 |
| 10/13/14 0:50 | 9.67 | 1.17E-03 | 0.35 |
| 10/13/14 0:55 | 9.67 | 1.13E-03 | 0.34 |
| 10/13/14 1:00 | 9.67 | 1.09E-03 | 0.33 |
| 10/13/14 1:05 | 9.67 | 1.04E-03 | 0.31 |
| 10/13/14 1:10 | 9.67 | 1.00E-03 | 0.30 |
| 10/13/14 1:15 | 9.67 | 9.60E-04 | 0.29 |
| 10/13/14 1:20 | 9.67 | 9.17E-04 | 0.28 |
| 10/13/14 1:25 | 9.67 | 8.75E-04 | 0.26 |
| 10/13/14 1:30 | 9.67 | 8.33E-04 | 0.25 |
| 10/13/14 1:35 | 9.67 | 7.92E-04 | 0.24 |
| 10/13/14 1:40 | 9.67 | 7.53E-04 | 0.23 |
| 10/13/14 1:45 | 9.67 | 7.15E-04 | 0.21 |
| 10/13/14 1:50 | 9.67 | 6.78E-04 | 0.20 |
| 10/13/14 1:55 | 9.67 | 6.44E-04 | 0.19 |
| 10/13/14 2:00 | 9.67 | 6.11E-04 | 0.18 |
| 10/13/14 2:05 | 9.67 | 5.80E-04 | 0.17 |
| 10/13/14 2:10 | 9.67 | 5.50E-04 | 0.17 |
| 10/13/14 2:15 | 9.67 | 5.22E-04 | 0.16 |
| 10/13/14 2:20 | 9.67 | 4.96E-04 | 0.15 |
| 10/13/14 2:25 | 9.67 | 4.69E-04 | 0.14 |
| 10/13/14 2:30 | 9.67 | 4.45E-04 | 0.13 |
| 10/13/14 2:35 | 9.67 | 4.21E-04 | 0.13 |
| 10/13/14 2:40 | 9.67 | 3.98E-04 | 0.12 |

Table 38 continued.

| Time | Temp. (°C) | Discharge ($m^3/s$) | Volume ($m^3$) |
|---|---|---|---|
| 10/13/14 2:45 | 9.67 | 3.76E-04 | 0.11 |
| 10/13/14 2:50 | 9.67 | 3.54E-04 | 0.11 |
| 10/13/14 2:55 | 9.67 | 3.34E-04 | 0.10 |
| 10/13/14 3:00 | 9.67 | 3.15E-04 | 0.09 |
| 10/13/14 3:05 | 9.67 | 2.97E-04 | 0.09 |
| 10/13/14 3:10 | 9.67 | 2.80E-04 | 0.08 |
| 10/13/14 3:15 | 9.67 | 2.63E-04 | 0.08 |
| 10/13/14 3:20 | 9.67 | 2.48E-04 | 0.07 |
| 10/13/14 3:25 | 9.77 | 2.33E-04 | 0.07 |
| 10/13/14 3:30 | 9.77 | 2.19E-04 | 0.07 |
| 10/13/14 3:35 | 9.67 | 2.05E-04 | 0.06 |
| 10/13/14 3:40 | 9.67 | 1.92E-04 | 0.06 |
| 10/13/14 3:45 | 9.67 | 1.79E-04 | 0.05 |
| 10/13/14 3:50 | 9.67 | 1.67E-04 | 0.05 |
| 10/13/14 3:55 | 9.67 | 1.54E-04 | 0.05 |
| 10/13/14 4:00 | 9.67 | 1.42E-04 | 0.04 |
| 10/13/14 4:05 | 9.67 | 1.31E-04 | 0.04 |
| 10/13/14 4:10 | 9.67 | 1.20E-04 | 0.04 |
| 10/13/14 4:15 | 9.77 | 1.09E-04 | 0.03 |
| 10/13/14 4:20 | 9.77 | 9.96E-05 | 0.03 |
| 10/13/14 4:25 | 9.77 | 9.05E-05 | 0.03 |
| 10/13/14 4:30 | 9.77 | 8.20E-05 | 0.02 |
| 10/13/14 4:35 | 9.67 | 7.43E-05 | 0.02 |
| 10/13/14 4:40 | 9.67 | 6.73E-05 | 0.02 |
| 10/13/14 4:45 | 9.67 | 6.09E-05 | 0.02 |
| 10/13/14 4:50 | 9.67 | 5.49E-05 | 0.02 |
| 10/13/14 4:55 | 9.67 | 4.94E-05 | 0.01 |
| 10/13/14 5:00 | 9.77 | 4.42E-05 | 0.01 |
| 10/13/14 5:05 | 9.77 | 3.93E-05 | 0.01 |
| 10/13/14 5:10 | 9.77 | 3.46E-05 | 0.01 |
| 10/13/14 2:45 | 9.77 | 3.03E-05 | 0.01 |
| 10/13/14 2:50 | 9.77 | 2.64E-05 | 0.01 |
| 10/13/14 2:55 | 9.77 | 2.30E-05 | 0.01 |
| 10/13/14 3:00 | 9.77 | 2.00E-05 | 0.01 |
| 10/13/14 3:05 | 9.77 | 1.74E-05 | 0.01 |
| 10/13/14 3:10 | 9.77 | 1.50E-05 | 0.00 |
| 10/13/14 3:15 | 9.77 | 1.28E-05 | 0.00 |

Table 38 continued.

| Time | Temp. (°C) | Discharge ($m^3$/s) | Volume ($m^3$) |
|---|---|---|---|
| 10/13/14 3:20 | 9.67 | 2.48E-04 | 0.07 |
| 10/13/14 3:25 | 9.77 | 2.33E-04 | 0.07 |
| 10/13/14 3:30 | 9.77 | 2.19E-04 | 0.07 |
| 10/13/14 3:35 | 9.67 | 2.05E-04 | 0.06 |
| 10/13/14 3:40 | 9.67 | 1.92E-04 | 0.06 |
| 10/13/14 3:45 | 9.67 | 1.79E-04 | 0.05 |
| 10/13/14 3:50 | 9.67 | 1.67E-04 | 0.05 |
| 10/13/14 3:55 | 9.67 | 1.54E-04 | 0.05 |
| 10/13/14 4:00 | 9.67 | 1.42E-04 | 0.04 |
| 10/13/14 4:05 | 9.67 | 1.31E-04 | 0.04 |
| 10/13/14 4:10 | 9.67 | 1.20E-04 | 0.04 |
| 10/13/14 4:15 | 9.77 | 1.09E-04 | 0.03 |
| 10/13/14 4:20 | 9.77 | 9.96E-05 | 0.03 |
| 10/13/14 4:25 | 9.77 | 9.05E-05 | 0.03 |
| 10/13/14 4:30 | 9.77 | 8.20E-05 | 0.02 |
| 10/13/14 4:35 | 9.67 | 7.43E-05 | 0.02 |
| 10/13/14 4:40 | 9.67 | 6.73E-05 | 0.02 |
| 10/13/14 4:45 | 9.67 | 6.09E-05 | 0.02 |
| 10/13/14 4:50 | 9.67 | 5.49E-05 | 0.02 |
| 10/13/14 4:55 | 9.67 | 4.94E-05 | 0.01 |
| 10/13/14 5:00 | 9.77 | 4.42E-05 | 0.01 |
| 10/13/14 5:05 | 9.77 | 3.93E-05 | 0.01 |
| 10/13/14 5:10 | 9.77 | 3.46E-05 | 0.01 |
| 10/13/14 5:15 | 9.77 | 3.03E-05 | 0.01 |
| 10/13/14 5:20 | 9.77 | 2.64E-05 | 0.01 |
| 10/13/14 5:25 | 9.77 | 2.30E-05 | 0.01 |
| 10/13/14 5:30 | 9.77 | 2.00E-05 | 0.01 |
| 10/13/14 5:35 | 9.77 | 1.74E-05 | 0.01 |
| 10/13/14 5:40 | 9.77 | 1.50E-05 | 0.00 |
| 10/13/14 5:45 | 9.77 | 1.28E-05 | 0.00 |
| 10/13/14 5:50 | 9.77 | 1.08E-05 | 0.00 |
| 10/13/14 5:55 | 9.77 | 8.94E-06 | 0.00 |
| 10/13/14 6:00 | 9.77 | 7.30E-06 | 0.00 |
| 10/13/14 6:05 | 9.77 | 5.85E-06 | 0.00 |
| 10/13/14 6:10 | 9.77 | 4.57E-06 | 0.00 |
| 10/13/14 6:15 | 9.77 | 3.46E-06 | 0.00 |
| 10/13/14 6:20 | 9.77 | 2.50E-06 | 0.00 |

Table 38 continued.

| Time | Temp. (°C) | Discharge ($m^3/s$) | Volume ($m^3$) |
|---|---|---|---|
| 10/13/14 6:25 | 9.77 | 1.71E-06 | 0.00 |
| 10/13/14 6:30 | 9.77 | 1.09E-06 | 0.00 |
| 10/13/14 6:35 | 9.77 | 6.12E-07 | 0.00 |
| 10/13/14 6:40 | 9.77 | 2.79E-07 | 0.00 |
| 10/13/14 6:45 | 9.77 | 8.15E-08 | 0.00 |
| 10/13/14 6:50 | 9.77 | 3.27E-09 | 0.00 |
| 10/13/14 6:55 | 9.77 | 5.37E-10 | 0.00 |

Table 39. Influent sensitivity analysis details.

| Governing Equations | | Manning's n-value Constants | Manning's n-value Scenarios | Slope Constants | Slope Scenarios |
|---|---|---|---|---|---|
| Theta, θ (radians) | $2\cos^{-1}(1-2(y/d))$ | d = 1.219 m | n = 0.011 | d = 1.219 m | S = 0.00252 |
| Area, A (sq m) | $(\theta - \sin(\theta))(d^2/8)$ | y = 0.305 m | n = 0.012 | y = 0.305 m | S = 0.00284 |
| Perimeter, P (m) | $\theta d/2$ | S = 0.00315 m/m | n = 0.013 | n = 0.012 | S = 0.00315 |
| Hydraulic Radius, R | A/P | | n = 0.014 | | S = 0.00347 |
| Discharge ($m^3/s$) | $(1.00/n)AR^{2/3}S^{1/2}$ | | n = 0.015 | | S = 0.00378 |
| | **n = 0.011** | **n = 0.012** | **n = 0.013** | **n = 0.014** | **n = 0.015** |
| Theta, θ (radians) | 2.095 | 2.095 | 2.095 | 2.095 | 2.095 |
| Area, A (sq m) | 0.228 | 0.228 | 0.228 | 0.228 | 0.228 |
| Perimeter, P (m) | 1.277 | 1.277 | 1.277 | 1.277 | 1.277 |
| Hydraulic Radius, R | 0.1789 | 0.1789 | 0.1789 | 0.1789 | 0.1789 |
| Discharge ($m^3/s$) | 0.3700 | 0.3392 | 0.3131 | 0.2907 | 0.2713 |
| RPD from 0.012 (%) | 8.70 | 0.00 | 8.00 | 15.4 | 22.2 |
| | **S = 0.00252** | **S = 0.00284** | **S = 0.00315** | **S = 0.00347** | **S = 0.00378** |
| Theta, θ (radians) | 2.095 | 2.095 | 2.095 | 2.095 | 2.095 |
| Area, A (sq m) | 0.228 | 0.228 | 0.228 | 0.228 | 0.228 |
| Perimeter, P (m) | 1.277 | 1.277 | 1.277 | 1.277 | 1.277 |
| Hydraulic Radius, R | 0.1789 | 0.1789 | 0.1789 | 0.1789 | 0.1789 |
| Discharge ($m^3/s$) | 0.3034 | 0.3220 | 0.3392 | 0.3560 | 0.3715 |
| RPD from 0.00315 (%) | 11.2 | 5.18 | 0.00 | 4.84 | 9.11 |

Table 40. Effluent sensitivity analysis details.

| **Governing Equations** | | **Manning's n-value Constants** | **Manning's n-value Scenarios** | **Slope Constants** | **Slope Scenarios** |
|---|---|---|---|---|---|
| Theta, θ (radians) | $2\cos^{-1}(1-2(y/d))$ | d = 0.457 m | n = 0.011 | d = 0.457 m | S = 0.00304 |
| Area, A (sq m) | $(\theta - \sin(\theta))(d^2/8)$ | y = 0.305 m | n = 0.012 | y = 0.305 m | S = 0.00342 |
| Perimeter, P (m) | $\theta d/2$ | S = 0.00380 m/m | n = 0.013 | n = 0.013 | S = 0.00380 |
| Hydraulic Radius, R | A/P | | n = 0.014 | | S = 0.00418 |
| Discharge ($m^3$/s) | $(1.00/n)AR^{2/3}S^{1/2}$ | | n = 0.015 | | S = 0.00456 |
| | **n = 0.011** | **n = 0.012** | **n = 0.013** | **n = 0.014** | **n = 0.015** |
| Theta, θ (radians) | 3.824 | 3.824 | 3.824 | 3.824 | 3.824 |
| Area, A (sq m) | 0.116 | 0.116 | 0.116 | 0.116 | 0.116 |
| Perimeter, P (m) | 0.874 | 0.874 | 0.874 | 0.874 | 0.874 |
| Hydraulic Radius, R | 0.1331 | 0.1331 | 0.1331 | 0.1331 | 0.1331 |
| Discharge ($m^3$/s) | 0.1699 | 0.1558 | 0.1438 | 0.1335 | 0.1246 |
| RPD from 0.012 (%) | 16.7 | 8.00 | 0.00 | 7.41 | 14.3 |
| | **S = 0.00304** | **S = 0.00342** | **S = 0.00380** | **S = 0.00418** | **S = 0.00456** |
| Theta, θ (radians) | 3.824 | 3.824 | 3.824 | 3.824 | 3.824 |
| Area, A (sq m) | 0.116 | 0.116 | 0.116 | 0.116 | 0.116 |
| Perimeter, P (m) | 0.874 | 0.874 | 0.874 | 0.874 | 0.874 |
| Hydraulic Radius, R | 0.1331 | 0.1331 | 0.1331 | 0.1331 | 0.1331 |
| Discharge ($m^3$/s) | 0.1286 | 0.1364 | 0.1438 | 0.1508 | 0.1575 |
| RPD from 0.00315 (%) | 11.2 | 5.27 | 0.00 | 4.76 | 9.11 |

# Appendix D

## Sample Flow-Weighted Composite Details

Table 41. Manual flow-weighted compositing details for all events.

| Time of Sample | Flow Volume Prior to Sample | % of Captured Flow | Required Volume from Sample* | HOBO Water Level Logger Water Depth | Measured Water Depth | RPD in Water Depth | HOBO Water Level Logger Temp. | pH Meter Temp. | RPD in Temp. |
|---|---|---|---|---|---|---|---|---|---|
| | **09/09/14 Influent Composite Sample** | | | | | | | | |
| | **($m^3$)** | **(%)** | **(ml)** | **(mm)** | **(mm)** | **(%)** | **(°C)** | **(°C)** | **(%)** |
| 16:25 | 2.10 | 0.51 | 10 | 47.5 | 44.4 | 6.75 | 13.5 | 13.05 | 3.39 |
| 16:34 | 22.7 | 5.51 | 110 | 111 | 102 | 8.45 | 13.9 | 13.75 | 1.08 |
| 16:53 | 72.7 | 17.6 | 353 | 141 | 133 | 5.84 | 13.5 | 13.05 | 3.39 |
| 17:13 | 45.6 | 11.1 | 221 | 62.2 | 57.2 | 8.38 | 13.3 | 13.15 | 1.13 |
| 17:43 | 55.7 | 13.5 | 271 | 121 | 114 | 5.96 | 13.2 | 13.35 | 1.13 |
| 18:13 | 58.2 | 14.1 | 283 | 51.2 | 47.6 | 7.29 | 13.0 | 13.15 | 1.15 |
| 18:45 | 0.98 | 0.24 | 5 | 18.9 | 19.1 | 1.05 | 12.9 | 12.95 | 0.39 |
| 19:13 | 52.9 | 12.8 | 257 | 102 | 95.3 | 6.79 | 12.5 | 12.75 | 1.98 |
| 20:13 | 81.0 | 19.7 | 393 | 44.8 | 44.5 | 0.67 | 12.1 | 12.45 | 2.85 |
| 21:13 | 20.1 | 4.88 | 98 | 62.8 | 58.7 | 6.75 | 12.0 | 12.25 | 2.06 |
| **Total** | **412** | | **2000** | | | | | | |
| | **09/09/14 Effluent Composite Sample*** | | | | | | | | |
| 16:55 | 0.16 | 0.03 | 1 | 15.4 | - | - | 17.7 | - | - |
| 17:10 | 1.27 | 0.20 | 4 | 32.1 | - | - | 17.7 | - | - |
| 17:25 | 2.69 | 0.42 | 8 | 45.2 | - | - | 17.6 | - | - |
| 17:40 | 5.32 | 0.83 | 17 | 61.4 | - | - | 17.4 | - | - |
| 17:55 | 8.85 | 1.39 | 28 | 76.0 | - | - | 17.2 | - | - |
| 18:10 | 9.95 | 1.56 | 31 | 74.2 | - | - | 17.1 | - | - |
| 18:25 | 9.86 | 1.54 | 31 | 75.7 | - | - | 16.9 | - | - |
| 18:55 | 21.0 | 3.29 | 66 | 83.6 | - | - | 16.8 | - | - |
| 19:25 | 32.5 | 5.09 | 102 | 101 | - | - | 16.6 | - | - |
| 19:55 | 43.2 | 6.77 | 135 | 119 | - | - | 16.4 | - | - |
| 20:25 | 55.3 | 8.66 | 173 | 129 | - | - | 16.2 | - | - |
| 21:25 | 122 | 19.1 | 382 | 133 | - | - | 16.0 | - | - |

Table 41 continued.

| Time of Sample | Flow Volume Prior to Sample | % of Captured Flow | Required Volume from Sample* | HOBO Water Level Logger Water Depth | Measured Water Depth | RPD in Water Depth | HOBO Water Level Logger Temp. | pH Meter Temp. | RPD in Temp. |
|---|---|---|---|---|---|---|---|---|---|
| | **($m^3$)** | **(%)** | **(ml)** | **(mm)** | **(mm)** | **(%)** | **(°C)** | **(°C)** | **(%)** |
| **09/09/14 Effluent Composite Sample Continued*** | | | | | | | | | |
| 22:25 | 105 | 16.4 | 329 | 114 | 116 | 1.74 | 15.7 | - | - |
| 23:25 | 78.9 | 12.4 | 247 | 99.2 | - | - | 15.6 | - | - |
| 0:25 | 53.8 | 8.43 | 169 | 77.2 | - | - | 15.4 | - | - |
| 1:25 | 32.5 | 5.09 | 102 | 63.8 | - | - | 15.3 | - | - |
| 2:25 | 22.9 | 3.58 | 72 | 53.8 | - | - | 15.2 | - | - |
| 3:25 | 16.3 | 2.55 | 51 | 41.9 | - | - | 15.1 | - | - |
| 4:25 | 9.19 | 1.44 | 29 | 35.2 | - | - | 15.1 | - | - |
| 5:25 | 5.72 | 0.89 | 18 | 21.5 | - | - | 15.0 | - | - |
| 6:25 | 2.38 | 0.37 | 7 | 21.2 | - | - | 14.8 | - | - |
| **Total** | **639** | | **2000** | | | | | | |
| * Autosampler used for sampling – water depth and temperature were not measured for individual sample aliquots | | | | | | | | | |
| **09/28/14 Influent Composite Sample** | | | | | | | | | |
| 17:20 | 1.35 | 8.57 | 171 | 15.4 | 14.3 | 7.41 | 13.8 | 14.2 | 2.59 |
| 17:50 | 1.68 | 10.6 | 213 | 20.6 | 17.5 | 16.3 | 13.8 | 13.6 | 1.74 |
| 18:20 | 2.37 | 15.0 | 300 | 22.3 | 23.8 | 6.51 | 13.9 | 13.7 | 1.72 |
| 18:50 | 2.44 | 15.5 | 309 | 21.8 | 23.8 | 8.77 | 13.8 | 13.6 | 1.74 |
| 19:20 | 2.24 | 14.2 | 283 | 21.2 | 25.4 | 18.0 | 13.6 | 13.6 | 0.28 |
| 19:50 | 2.16 | 13.7 | 274 | 20.5 | 19.1 | 7.07 | 13.6 | 13.6 | 0.28 |
| 20:20 | 1.79 | 11.3 | 227 | 18.2 | 15.9 | 13.5 | 13.5 | 13.8 | 1.93 |
| 21:05 | 1.76 | 11.2 | 223 | 14.2 | 12.7 | 11.2 | 13.5 | 13.7 | 1.20 |
| **Total** | **15.8** | | **2000** | | | | | | |
| **09/28/14 Effluent Composite Sample** | | | | | | | | | |
| 17:53 | 0.03 | 0.12 | 2 | 4.90 | 4.76 | 2.90 | 18.0 | 17.9 | 0.33 |
| 18:23 | 0.12 | 0.50 | 10 | 8.21 | 7.94 | 3.34 | 18.0 | 18.1 | 0.77 |

Table 41 continued.

| Time of Sample | Flow Volume Prior to Sample ($m^3$) | % of Captured Flow (%) | Required Volume from Sample* (ml) | HOBO Water Level Logger Water Depth (mm) | Measured Water Depth (mm) | RPD in Water Depth (%) | HOBO Water Level Logger Temp. (°C) | pH Meter Temp. (°C) | RPD in Temp. (%) |
|---|---|---|---|---|---|---|---|---|---|
| **09/28/14 Effluent Composite Sample Continued** | | | | | | | | | |
| 18:53 | 0.28 | 1.14 | 23 | 11.4 | 11.1 | 2.67 | 17.9 | 18.1 | 1.33 |
| 19:26 | 0.49 | 2.02 | 40 | 14.5 | 14.3 | 1.39 | 17.7 | 17.9 | 1.35 |
| 19:53 | 0.76 | 3.14 | 63 | 17.4 | 17.6 | 1.14 | 17.5 | 17.5 | 0.23 |
| 20:23 | 1.09 | 4.48 | 90 | 20.4 | 20.6 | 0.98 | 17.4 | 17.4 | 0.23 |
| 21:08 | 2.28 | 9.35 | 187 | 23.4 | 25.4 | 8.20 | 17.2 | 17.3 | 0.81 |
| 0:02 | 9.49 | 39.0 | 780 | 21.8 | 22.2 | 1.82 | 16.9 | 17.1 | 1.41 |
| 3:00 | 6.38 | 26.2 | 524 | 16.4 | 17.6 | 7.06 | 16.6 | 16.0 | 3.43 |
| 7:00 | 3.41 | 14.0 | 281 | 9.17 | 9.53 | 3.85 | 16.3 | 15.8 | 2.86 |
| **Total** | **24.3** | | **2000** | | | | | | |
| **10/12/14 Influent Composite Sample** | | | | | | | | | |
| 18:30 | 0.08 | 0.59 | 12 | 4.38 | 4.76 | 8.32 | 11.0 | 11.1 | 0.90 |
| 19:00 | 0.11 | 0.83 | 17 | 6.11 | 6.35 | 3.85 | 10.9 | 11.0 | 0.91 |
| 19:30 | 0.22 | 1.56 | 31 | 7.86 | 7.94 | 1.01 | 10.9 | 11.0 | 0.91 |
| 20:00 | 0.31 | 2.26 | 45 | 9.07 | 9.53 | 4.95 | 10.9 | 11.0 | 0.91 |
| 20:30 | 0.45 | 3.27 | 65 | 10.9 | 11.1 | 1.82 | 11.7 | 11.4 | 2.60 |
| 21:00 | 0.60 | 4.37 | 87 | 12.0 | 11.1 | 7.79 | 11.4 | 11.1 | 2.67 |
| 21:30 | 0.69 | 4.98 | 100 | 12.6 | 12.7 | 0.79 | 11.5 | 11.4 | 0.87 |
| 22:30 | 2.17 | 15.7 | 314 | 18.5 | 17.5 | 5.56 | 11.5 | 11.4 | 0.87 |
| 23:30 | 4.62 | 33.4 | 668 | 21.6 | 19.1 | 12.3 | 11.4 | 11.6 | 1.74 |
| 0:30 | 3.07 | 22.2 | 444 | 14.4 | 14.3 | 0.70 | 11.2 | 11.3 | 0.89 |
| 1:30 | 1.50 | 10.9 | 217 | 12.1 | 11.1 | 8.62 | 11.1 | 11.2 | 0.90 |
| **Total** | **13.8** | | **2000** | | | | | | |

Table 41 continued.

| 10/12/14 Effluent Composite Sample* | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Time of Sample** | **Flow Volume Prior to Sample** | **% of Captured Flow** | **Required Volume from Sample*** | **HOBO Water Level Logger Water Depth** | **Measured Water Depth** | **RPD in Water Depth** | **HOBO Water Level Logger Temp.** | **pH Meter Temp.** | **RPD in Temp.** |
| | **($m^3$)** | **(%)** | **(ml)** | **(mm)** | **(mm)** | **(%)** | **(°C)** | **(°C)** | **(%)** |
| 20:51 | 0.03 | 0.12 | 2 | 5.64 | - | - | 9.6 | - | - |
| 21:21 | 0.27 | 1.20 | 24 | 12.6 | - | - | 9.6 | - | - |
| 21:51 | 0.81 | 3.63 | 73 | 19.4 | - | - | 9.7 | - | - |
| 22:21 | 1.65 | 7.37 | 147 | 25.7 | - | - | 9.7 | - | - |
| 22:51 | 2.46 | 11.0 | 220 | 29.4 | 30.2 | 2.70 | 9.8 | - | - |
| 23:51 | 5.87 | 26.2 | 524 | 30.2 | - | - | 9.7 | - | - |
| 0:51 | 4.99 | 22.3 | 445 | 26.1 | - | - | 9.7 | - | - |
| 1:51 | 3.24 | 14.4 | 289 | 20.2 | - | - | 9.7 | - | - |
| 2:51 | 1.76 | 7.85 | 157 | 14.9 | - | - | 9.7 | - | - |
| 3:51 | 0.88 | 3.93 | 79 | 10.5 | - | - | 9.7 | - | - |
| 4:51 | 0.36 | 1.59 | 32 | 6.28 | - | - | 9.7 | - | - |
| 5:51 | 0.10 | 0.43 | 9 | 2.95 | - | - | 9.8 | - | - |
| **Total** | **22.4** | | **2000** | | | | | | |

* Autosampler used for sampling – water depth and temperature were not measured for individual sample aliquots

# Appendix E

## Water Quality Analytical Details

Table 42. 09/09/14 event summary.

| **General Information** | |
|---|---|
| Event Date: | 09/09/14 |
| Date of Last Maintenance: | None (online since Summer 2012) |
| Antecedent Conditions: | 130 hours |
| Total Precipitation (mm) | 25.71 |
| Peak Flow, ($m^3$/s) | 0.0707 influent, 0.03585 effluent |
| Total Runoff Volume ($m^3$) | 416 (65%) influent*, 641effluent |
| * Influent from west inlet only measured, rest of outflow attributed to east inlet | |

**Analytical**

| | | Concentrations (mg/l) | | | |
|---|---|---|---|---|---|
| **Number of Aliquots** | **Parameter** | **Influent EMC*** | **Effluent EMC*** | **MRL or Detection Range** | **Duplicate RPD*** |
| Influent: 10 | TSS | 218 | 29.9 | 5 | 4.2% |
| Effluent: 23 | Total P | 1.12 | 0.27 | 0.00 – 1.12 | NA |
| | Phosphate | 1.10 | 0.69 | 0.00 – 3.00 | 9.9% |
| | Ammonia – N | 0.01 | 0.15 | 0.00 – 1.00 | 9.1% |
| | Nitrite – N | ND | ND | 0.00 – 0.80 | ND |
| | Nitrate – N | 0.70 | 0.39 | 0.00 – 3.00 | 15.4% |
| | Chloride | 8.0 | 6.2 | 0.0 – 30.0 | 11.1% |
| | Total Cu | ND | ND | 0.05 | NA |
| | Total Pb | 0.0043 | ND | 0.001 | NA |
| | Total Zn | ND | ND | 0.05 | NA |
| | Conductivity (µS/cm) | 319 | 730 | 10 – 2000 µS/cm | NT |
| | Bacteria (MPN) | 770 | 95 | 0 | NT |

*NA = not applicable; ND = not detected; NT = no duplicated tested

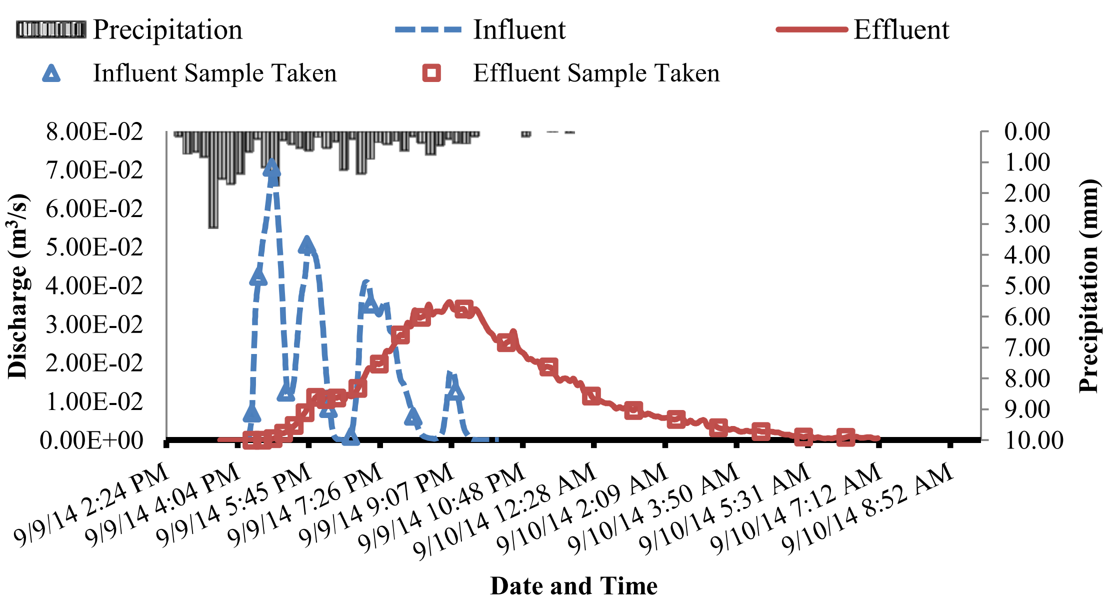


Figure 24. 09/09/14 event summary.

Table 43. 09/28/14 event summary.

| | |
|---|---|
| General Information | |
| Event Date: | 09/28/14 |
| Date of Last Maintenance: | None (online since Summer 2012) |
| Antecedent Conditions: | 192 hours |
| Total Precipitation (mm) | 5.94 |
| Peak Flow, ($m^3$/s) | 0.00138 influent, 0.000995 effluent |
| Total Runoff Volume ($m^3$) | 17.8 (66%) influent*, 27.1 effluent |
| * Influent from west inlet only measured, rest of outflow attributed to east inlet | |

**Analytical**

| | | Concentrations (mg/l) | | | |
|---|---|---|---|---|---|
| **Number of Aliquots** | **Parameter** | **Influent EMC*** | **Effluent EMC*** | **MRL or Detection Range** | **Duplicate RPD*** |
| Influent: 8 | TSS | 40.3 | 6.3 | 5 | 2.96 |
| Effluent: 10 | Total P | 0.62 | 0.09 | 0.00 – 1.12 | 11.8 |
| | Phosphate | 0.68 | 0.14 | 0.00 – 3.00 | 9.09 |
| | Ammonia – N | 0.60 | 0.20 | 0.00 – 1.00 | NT |
| | Nitrite – N | ND | 0.02 | 0.00 – 0.80 | ND |
| | Nitrate – N | 1.35 | 0.49 | 0.00 – 3.00 | 6.90 |
| | Chloride | 21.0 | 35.5 | 0.0 – 30.0 | 7.69 |
| | Total Cu | ND | ND | 0.05 | NA |
| | Total Pb | ND | ND | 0.002 | NA |
| | Total Zn | ND | ND | 0.05 | NA |
| | Conductivity (µS/cm) | 360 | 1028 | 10 – 2000 µS/cm | NT |
| | Bacteria (MPN) | 153 | 35 | 0 | NT |

*NA = not applicable; ND = not detected; NT = no duplicated tested

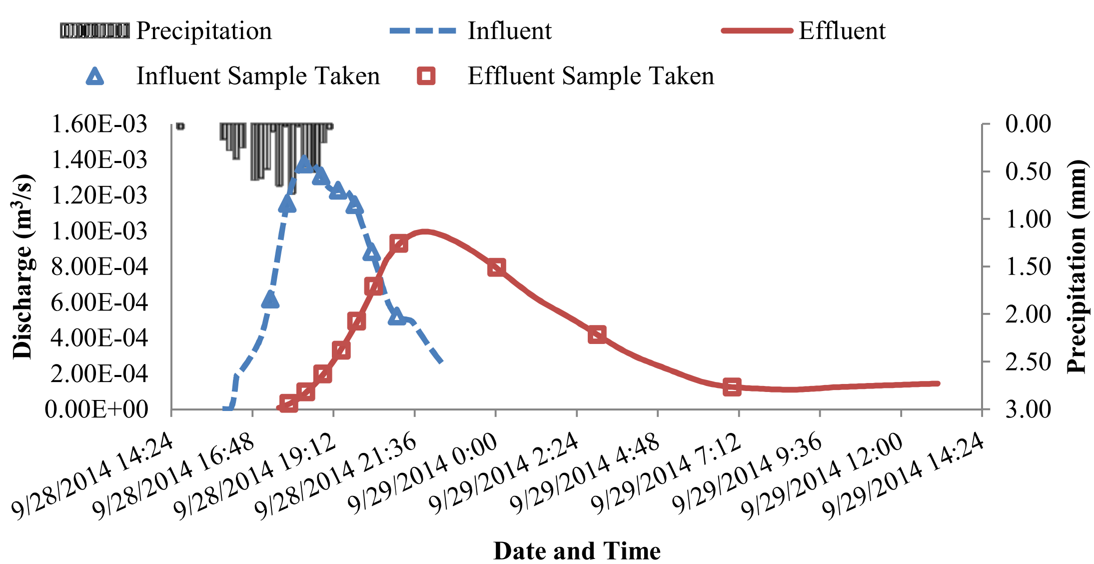


Figure 25. 09/28/14 event summary.

Table 44. 10/12/14 event summary.

| **General Information** | |
|---|---|
| Event Date: | 10/12/14 |
| Date of Last Maintenance: | None (online since Summer 2012) |
| Antecedent Conditions: | 230 hours |
| Total Precipitation (mm) | 12.72 |
| Peak Flow, ($m^3$/s) | 0.00141 west influent, 0.000450 east influent, 0.00167 effluent |
| Total Runoff Volume ($m^3$) | 16.27 (73%) west influent, 5.79 (26%) east influent, 22.41 effluent |

**Analytical**

| | | Concentrations (mg/l) | | | |
|---|---|---|---|---|---|
| **Number of Aliquots** | **Parameter** | **Influent EMC*** | **Effluent EMC*** | **MRL or Detection Range** | **Duplicate RPD*** |
| Influent: 11 | TSS | 41 | 17 | 5 | 9.18 |
| Effluent: 12 | Total P | 0.61 | 0.26 | 0.00 – 1.12 | 2.67 |
| | Phosphate | 0.32 | 0.01 | 0.00 – 3.00 | 0.00 |
| | Ammonia – N | 0.39 | 0.32 | 0.00 – 1.00 | 12.1 |
| | Nitrite – N | ND | 0.01 | 0.00 – 0.80 | ND |
| | Nitrate – N | 1.15 | 0.65 | 0.00 – 3.00 | 5.71 |
| | Chloride | 4.5 | 20.3 | 0.0 – 30.0 | 1.77 |
| | Total Cu | ND | ND | 0.05 | NA |
| | Total Pb | 0.0012 | 0.0011 | 0.001 | NA |
| | Total Zn | ND | ND | 0.05 | NA |
| | Conductivity (µS/cm) | 236 | 1123 | 10 – 2000 µS/cm | NT |
| | Bacteria (MPN) | NT | NT | 0 | NT |

*NA = not applicable; ND = not detected; NT = no duplicated tested

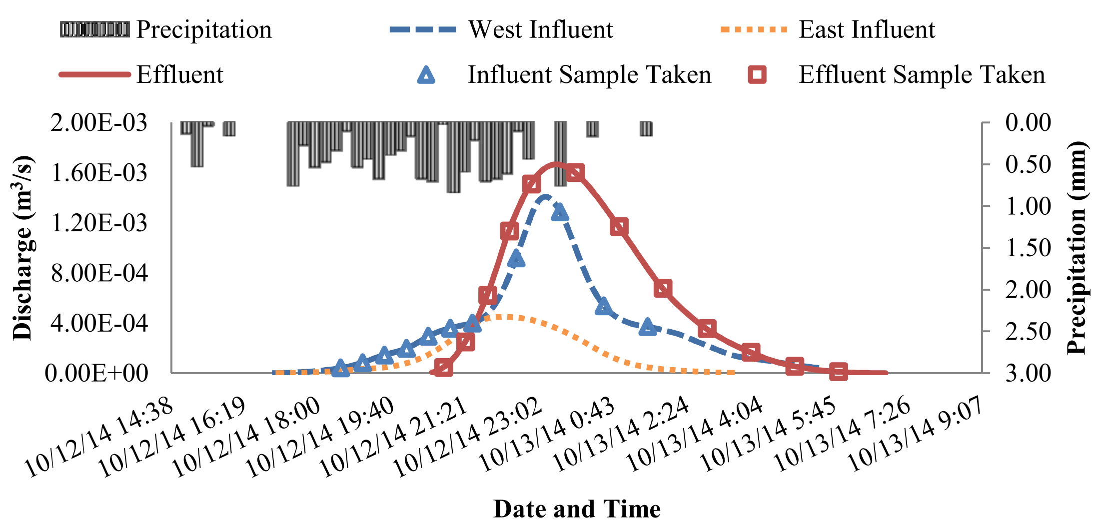


Figure 26. 10/12/14 event summary.

Table 45. 06/30/14 event summary.

| **General Information** | | | | |
|---|---|---|---|---|
| Event Date: | 06/30/14 | | | |
| Date of Last Maintenance: | None (online since Summer 2012) | | | |
| Antecedent Conditions: | 48 hours | | | |
| Total Precipitation (mm): | 4.81 | | | |
| **Analytical** | | | | |
| | **Concentrations (mg/l)** | | | |
| **Parameter** | **Influent*** | **Effluent*** | **MRL or Detection Range** | **Duplicate RPD*** |
| Dissolved Oxygen | 9.7 | 10.8 | 0.0 – 15.0 | NT |
| TSS | 25 | 7.5 | 5 | NT |
| Total P | 0.79 | 0.03 | 0.00 – 1.12 | NT |
| Phosphate | 0.18 | ND | 0.00 – 3.00 | 11.8 |
| Ammonia – N | 0.16 | 0.21 | 0.00 – 1.00 | NT |
| Nitrite – N | 0.055 | ND | 0.00 – 0.80 | NT |
| Nitrate – N | 5.5 | 1.78 | 0.00 – 3.00 | 34.0 |
| Chloride | 66.0 | 22.3 | 0.0 – 30.0 | NT |
| Total Cu | NT | NT | 0.05 | NT |
| Total Pb | NT | NT | 0.001 | NT |
| Total Zn | NT | NT | 0.05 | NT |
| Conductivity (μS/cm) | 236 | 1123 | 10 – 2000 μS/cm | NT |
| Bacteria (MPN) | 2 | ND | 0 | NT |
| pH | 8.09 | 10.11 | -2.00 to 16.00 pH | NT |
| Temp (°C) | 59.2 | 63.1 | -5.0 to 105.0 °C | NT |
| Flow ($m^3/s$) | 0.000148 | 0.00223 | NA | NT |

*NA = Not applicable, ND = not detected, NT = no duplicate tested

Table 46. 07/01/14 event summary.

| **General Information** | | | | |
|---|---|---|---|---|
| Event Date: | 07/01/14 | | | |
| Date of Last Maintenance: | None (online since Summer 2012) | | | |
| Antecedent Conditions: | 14 hours | | | |
| Total Precipitation (mm): | 1.36 | | | |
| **Analytical** | | | | |
| | **Concentrations (mg/l)** | | | |
| **Parameter** | **Influent*** | **Effluent*** | **MRL or Detection Range** | **Duplicate RPD*** |
| Dissolved Oxygen | 11.3 | 9.47 | 0.0 – 15.0 | NT |
| TSS | 106 | 25 | 5 | NT |
| Total P | 0.37 | 0.19 | 0.00 – 1.12 | 11.4 |
| Phosphate | 0.80 | ND | 0.00 – 3.00 | 3.82 |
| Ammonia – N | 0.55 | 0.33 | 0.00 – 1.00 | NT |
| Nitrite – N | 0.02 | ND | 0.00 – 0.80 | NT |
| Nitrate – N | 4.25 | 1.31 | 0.00 – 3.00 | 11.2 |
| Chloride | 43.0 | 23.4 | 0.0 – 30.0 | 8.48 |
| Total Cu | ND | ND | 0.05 | NA |
| Total Pb | 0.003 | ND | 0.001 | NA |
| Total Zn | ND | ND | 0.05 | NA |
| Conductivity (μS/cm) | 2758 | 1584 | 10 – 2000 μS/cm | NT |
| Bacteria (MPN) | 24.3 | 2 | 0 | NT |
| pH | 8.15 | 9.96 | -2.00 to 16.00 pH | NT |
| Temp (°C) | 55.2 | 59.5 | -5.0 to 105.0 °C | NT |
| Flow ($m^3/s$) | 0.0000911 | 0.00506 | NA | NT |

*NA = Not applicable, ND = not detected, NT = no duplicate tested

Table 47. 07/07/14 event summary.

| **General Information** | | | | |
|---|---|---|---|---|
| Event Date: | 07/07/14 | | | |
| Date of Last Maintenance: | None (online since Summer 2012) | | | |
| Antecedent Conditions: | 74 hours | | | |
| Total Precipitation (mm): | 25.95 | | | |
| **Analytical** | | | | |
| | **Concentrations (mg/l)** | | | |
| **Parameter** | **Influent*** | **Effluent*** | **MRL or Detection Range** | **Duplicate RPD*** |
| Dissolved Oxygen | 13.1 | 14.73 | 0.0 – 15.0 | NT |
| TSS | 1442 | 239 | 5 | 3.48 |
| Total P | 1.01 | 0.51 | 0.00 – 1.12 | 17.9 |
| Phosphate | 0.28 | 1.06 | 0.00 – 3.00 | 17.9 |
| Ammonia – N | ND | 0.72 | 0.00 – 1.00 | 5.83 |
| Nitrite – N | ND | ND | 0.00 – 0.80 | ND |
| Nitrate – N | 0.29 | 0.11 | 0.00 – 3.00 | ND |
| Chloride | 0.7 | 4.3 | 0.0 – 30.0 | 3.51 |
| Total Cu | NT | NT | 0.05 | 0.00 |
| Total Pb | NT | NT | 0.001 | NT |
| Total Zn | NT | NT | 0.05 | NT |
| Conductivity (μS/cm) | 6051 | 4680 | 10 – 2000 μS/cm | NT |
| Bacteria (MPN) | NT | NT | 0 | NT |
| pH | 9.53 | 9.18 | -2.00 to 16.00 pH | NT |
| Temp (°C) | 63.1 | 63.3 | -5.0 to 105.0 °C | NT |
| Flow ($m^3/s$) | 0.398 | 0.100 | NA | NT |

*NA = Not applicable, ND = not detected, NT = no duplicate tested

# Appendix F

## Statistical Analysis Details

Table 48. Descriptive statistics summary part 1.

| **Parameter** | **TSS** | | **Total P** | | **Phosphate** | | **Ammonia-N** | | **Nitrite-N** | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Performance Metric** | **In** | **Out** | **In** | **Out** | **In** | **Out** | **In** | **Out** | **In** | **Out** |
| Number of EMCs | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Percent ND | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 100% | 33% |
| Median | 41.0 | 18.4 | 0.62 | 0.26 | 0.68 | 0.14 | 0.39 | 0.20 | NA* | 0.01 |
| Mean | 99.7 | 19.8 | 0.78 | 0.21 | 0.70 | 0.28 | 0.33 | 0.33 | NA* | 0.01 |
| St. Deviation | 102.5 | 12.9 | 0.29 | 0.10 | 0.39 | 0.36 | 0.30 | 0.09 | NA* | 0.01 |
| 1$^{st}$ Quartile | 40.0 | 7.7 | 0.61 | 0.09 | 0.32 | 0.01 | 0.01 | 0.15 | NA* | 0.00 |
| 3$^{rd}$ Quartile | 218.0 | 33.4 | 1.12 | 0.27 | 1.10 | 0.69 | 0.60 | 0.32 | NA* | 0.02 |
| Normal RJ Coefficient | 0.868 | 0.995 | 0.874 | 0.890 | 0.999 | 0.942 | 0.986 | 0.973 | NA* | 1.000 |
| Lognormal RJ Coefficient | 0.872 | 0.994 | 0.878 | 0.881 | 0.992 | 0.990 | 0.910 | 0.990 | NA* | 1.000 |
| Well-fit to normal distribution? | NO | YES | NO | YES | YES | YES | YES | YES | NA* | YES |
| Well-fit to lognormal distribution? | NO | YES | YES | YES | YES | YES | YES | YES | NA* | YES |

* NA = not applicable due to inability to complete statistical analysis on non-detects equal to zero from the minimum value of the analyte detection range

Table 49. Descriptive statistics summary part 2.

| Parameter | Nitrate-N | | Chloride | | Total Pb | | Conductivity | | Bacteria | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Performance Metric** | **In** | **Out** | **In** | **Out** | **In** | **Out** | **In** | **Out** | **In** | **Out** |
| Number of EMCs | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 2 |
| Percent ND | 0% | 0% | 0% | 0% | 33% | 66% | 0% | 0% | 0% | 0% |
| Median | 1.15 | 0.49 | 8.0 | 20.3 | 0.0020 | 0.0010 | 319 | 1028 | 462 | 65 |
| Mean | 1.07 | 0.51 | 11.2 | 20.7 | 0.0025 | 0.0014 | 305 | 960 | 462 | 65 |
| St. Deviation | 0.33 | 0.13 | 8.7 | 14.7 | 0.0016 | 0.0006 | 63.2 | 205 | 436 | 42 |
| $1^{st}$ Quartile | 0.70 | 0.39 | 4.5 | 6.2 | 0.0012 | 0.0010 | 236 | 730 | NA | NA |
| $3^{rd}$ Quartile | 1.35 | 0.65 | 21.0 | 35.5 | 0.0043 | 0.0020 | 360 | 1123 | NA | NA |
| Normal RJ Coefficient | 0.976 | 0.991 | 0.949 | 1.000 | 0.963 | 0.908 | 0.981 | 0.958 | 1.000 | 1.000 |
| Lognormal RJ Coefficient | 0.959 | 0.998 | 0.990 | 0.979 | 0.993 | 0.922 | 0.971 | 0.947 | 1.000 | 1.000 |
| Well-fit to normal distribution? | YES | YES | YES | YES | YES | YES | YES | YES | YES | YES |
| Well-fit to lognormal distribution? | YES | YES | YES | YES | YES | YES | YES | YES | YES | YES |