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Retrofit of an Existing Flood Control Facility to Improve Pollutant Removal in an Urban Watershed

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Retrofit of an Existing Flood Control Facility to Improve Pollutant Removal in an Urban Watershed

by

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Thesis

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Dedication

To my parents, for their unwavering support of my education and for making my four years at MIT financially possible.

Acknowledgments

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Abstract

Retrofit of an Existing Flood Control Facility to Improve Pollutant Removal in an Urban Watershed

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Levels of bacteria in excess of water quality standards for contact recreational designated use have been documented in Gilleland Creek, located in northeast Travis County, Texas. Stormwater monitoring showed increased bacteria levels after rainfall runoff events in Gilleland Creek, and analysis indicates the bacteria is of a nonpoint source origin. The objective of this research was to modify a flood control basin in an urban area in the upper part of the Gilleland Creek watershed to determine whether it is possible to substantially increase bacteria removal by retaining stormwater in the basin for 24 hours after a storm event. Bacteria reduction was predicted as a result of sedimentation and exposure to sunlight. The outlet of one flood control basin was retrofitted with an automated gate valve to control stormwater outflow and acted as the test basin. Another flood control basin, located approximately ¼ mile from the test basin, was unmodified and acted as the control basin. Stormwater monitoring at the inlet and outlet to both basins over the course of five storm events showed that neither the control nor the test basin exhibited a decrease in *E. coli* concentrations. Both basins were effective in decreasing the concentration of total suspended solids and showed varying performance for the treatment of nutrients. The dataset is limited by the small number of storm events that were sampled, and continued stormwater monitoring would offer additional insight into retrofit performance.

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Chapter 1: Introduction

1.1 BACKGROUND

Many urban areas in the United States were developed prior to the adoption of the Clean Water Act of 1972. In consequence, many receiving waters in these urban areas have been polluted and placed on the states' lists of threatened and impaired water bodies, known as 303(d) lists. 303(d) lists are compiled by each state every two years as a requirement of the Clean Water Act. The water bodies on 303(d) lists lack sufficient pollution controls to maintain water quality standards. As a result, states must establish total maximum daily loads (TMDLs) for the pollutants of concern for each impaired water body and devise a long-term plan to meet these TMDLs.

Stormwater discharges from urban land uses frequently have bacteria concentrations that far exceed contact recreation standards. Levels of bacteria in excess of acceptable standards for contact recreation designated use have been documented for Gilleland Creek in northeast Travis County. As a result, Gilleland Creek is included in Texas Commission on Environmental Quality (TCEQ) 2004 Federal Clean Water Act 303(d) List. In June 2005, Lower Colorado River Authority (LCRA) prepared a study titled, "Assessment of Water Quality Impairment of Gilleland Creek" for the TCEQ to determine the source of bacterial contamination in Gilleland Creek and to perform additional monitoring. This report reviewed historic water quality data and reaffirmed the 303(d) listing of Gilleland Creek for high bacteria concentrations. LCRA stream monitoring also showed increased bacteria levels after rainfall runoff events in Gilleland Creek.

LCRA project staff compared the slopes of load duration curves representing *E. coli* conditions in dry and wet weather to determine whether bacteria concentrations varied in response to runoff events. If the source of bacteria was a point source, different slopes for the dry and wet weather events would be expected as a result of dilution. At all but one site, the slopes of wet and dry weather data were not significantly different, indicating that the bacteria loading to Gilleland Creek is of a nonpoint source origin. Probable nonpoint sources of pollution in the Gilleland Creek watershed include poorly maintained septic systems, storm sewers, agricultural runoff, pet and wildlife waste, and other natural sources. Much of the upper section of the Gilleland Creek watershed where bacteria standards have been routinely exceeded consist of urban areas, similar to those monitored in this study. Consequently, bacteria reduction in stormwater runoff from the test watershed may substantially improve the quality of stormwater runoff discharged to Gilleland Creek.

While there are no standalone facilities in the Gilleland Creek watershed built specifically to address water quality concerns, flood control basins are prevalent throughout the watershed. Flood control basins are integrated into the watershed's stormwater conveyance system in order to mitigate the impacts of increased runoff volume resulting from the additional impervious cover that accompanies urban development. Retrofitting the drainage system to incorporate standalone water quality facilities is prohibitively expensive due to the lack of available space in the built environment and hydraulic constraints associated with the existing system. In addition, current data indicates that many types of water quality facilities do not reduce bacteria concentrations to the degree necessary to meet water quality standards. Managing the geomorphic characteristics of a water body has been used as a strategy to reduce bacteria concentrations in some instances, but with varying degrees of success.

1.2 OBJECTIVE

The objective of this study was to retrofit an existing flood control basin to determine whether it is possible to substantially increase bacteria removal by retaining stormwater in the basin for a significant length of time beyond the end of a storm event. Retaining the stormwater runoff is intended to increase die-off of bacteria and to provide additional removal of suspended solids and nutrients. Reduction in bacteria concentrations entering Gilleland Creek from the flood control basin is predicted as a result of sedimentation and exposure to sunlight.

Monitoring of the modified flood control basin will also provide data needed to determine whether this strategy, which is part of the long-term plan to meet the *E. coli* TMDL established for Gilleland Creek, will reduce pollutant loadings to Gilleland Creek. The goal of the study is to achieve a 50% reduction in *E. coli* levels and a 50% reduction in total phosphorus and total suspended solids in the retrofitted basin outflow. Furthermore, Gilleland Creek is an effluent dominated stream with high levels of nutrients, so eutrophication of Gilleland Creek is a concern. To address this concern, the study will also analyze for a more complete suite of nutrient forms including dissolved phosphorus, Total Kjeldahl Nitrogen (TKN), and nitrate+nitrite to determine the effect of basin retrofit on these additional constituents.

Chapter 2: Literature Review

In a study conducted by the University of Texas for the Texas Department of Transportation (TxDOT), a sedimentation basin in northwest Austin was retrofitted with an automated outlet (Middleton & Barrett, 2008). Middleton and Barrett (2008) modified an extended batch detention basin to provide batch treatment of stormwater runoff in response to a sand filter system that was not meeting total suspended solids (TSS) removal criteria. The study intended to modify the basin outlet, reducing short circuiting in the basin and increasing the residence time of the first flush of stormwater runoff by holding runoff in the basin for an arbitrary length of time before release.

Middleton and Barrett (2008) installed a retrofitted outlet pipe with a butterfly valve powered by an actuator to control the outflow in the sedimentation basin. The stormwater runoff was monitored for heavy metals, chemical oxygen demand (COD), nitrogen, phosphorus, TKN, and TSS. Sampling equipment installed at the inlet and outlet of the basin monitored performance of the valve. Runoff was held in the basin for twelve hours for the purpose of the study, and thirteen storm events were sampled. Statistically significant reductions in the concentration of TSS, total copper, total zinc, total lead, total phosphorus, TKN, nitrate+nitrite, and COD were reported. The study documented a 91% reduction in TSS and a 52% reduction in total phosphorus. The study concluded that the modified outlet reduced loadings discharged in the basin effluent because the first flush runoff had a longer residence time in the basin and received greater treatment.

Middleton and Barrett (2008) did not measure bacteria reduction in the course of their study. However, there are a variety of reasons to expect substantial improvement in bacteria loading and similar results to their study with a modified outlet system. First, bacteria are typically attached to solids, so removal of solids (particularly the smaller fraction) should lead to the reduction of bacteria concentrations. In addition, there was a substantial amount of research conducted in the 1950's on die-off of bacteria in wastewater ponds. Much of this bacteria die-off was associated with exposure to the ultraviolet (UV) radiation in sunlight, which would also be an effective mechanism in the retrofitted flood control basins (Morowitz, 1950). Daylight has a pronounced effect on the mortality of coliform bacteria in water, and the rate of bacteria die-off is proportional to the intensity of radiation it receives (Gameson & Saxon, 1967). Gameson and Saxon's (1967) comparative study of the rate of bacteria die-off in light versus dark conditions estimates that exposure to 43.6 hours of daylight corresponds to a 90% mortality rate of coliform bacteria.

Metcalf and Eddy, Inc. (1991) notes that disinfection of water with ultraviolet light became an established practice during the early 1900s. Light with a wavelength of 254 nanometers is able to penetrate the bacterial cell wall, where it is absorbed by the cell's DNA and RNA. The UV light prevents cell replication and/or causes cell death; the resulting cell die-off is typically modeled with first order decay kinetics. Although 254 nanometers is the ideal wavelength for UV treatment, light in the range of 250-270 nanometers is considered adequate for germicidal impacts (Metcalf and Eddy, Inc., 1991). Finally, Metcalf and Eddy, Inc. (1991) makes the distinction that UV treatment is most effective in waters with low turbidity because shielding via suspended solids is minimized.

Experiments conducted in the graduate program at The University of Texas at Austin using water and sediment collected from Gilleland Creek indicate that a substantial amount of bacteria is associated with sediment (Sejkora, 2010). The geometric mean initial concentration of *E. coli* in samples that contained Gilleland Creek streambed sediments added to Gilleland Creek stream water was three times greater than that in the Gilleland Creek stream water without sediments. In addition, the maximum initial concentration of *E. coli* in the samples with sediment was almost five times greater than the maximum concentration observed in the samples containing just stream water. Sediment resuspension experiments demonstrated that the concentration of *E. coli* in inland stream water can increase up to three fold when the sonicated sediments are resuspended. As such, stream bed sediments can be considered a nonpoint source of pollution in a catchment. These results indicate that the resuspension of sediment can cause inland streams to exceed surface water quality standards.

Sejkora (2010) also showed an increase in *E. coli* concentrations in an inland stream as a result of stormwater runoff flushing bacteria into the water body. Wet weather observations demonstrated that nonpoint sources of pollution in the watershed were sufficient to cause *E. coli* concentrations in excess of of the contact recreation surface water standards in the receiving water body. Finally, results of persistence reactor-based studies demonstrated that *E. coli* populations followed first-order decay kinetics in warm shady conditions, and that as much as 95% of *E. coli* were deactivated in two days in a water column in which there were no resuspended sediments.

The International Stormwater Best Management Practices (BMP) Database issued a pollutant category summary report on fecal indicator bacteria most recently in December 2010 (Wright Water Engineers, Inc.; Geosyntec Consultants, 2010). In response to the Environmental Protection Agency (EPA) establishing ambient water quality criteria for bacteria in 1986, the report summarizes and evaluates stormwater best management practices aimed at meeting the EPA primary contact criteria for *E. coli*, set at 126 colony-forming units per 100 milliliters (CFU/100mL) based on the calculation of a geometric mean. The report first highlights the fact that bacteria may survive longer in sediments or organic litter than in the water column itself. As such, organic litter and sediments can be a source of bacteria, so BMPs that only address bacteria in the water column may not be wholly effective in reducing the bacteria load to the receiving water body. Although some natural die-off of bacteria occurs as a result of exposure to sunlight and water temperature variations, among other environmental factors, natural inactivation of bacteria cannot be relied upon as a method to meet primary contact criteria. At a broad level, BMP designs that "maximize exposure to sunlight, provide habitat enabling predation by other microbes, provide surfaces for sorption, provide filtration, and/or allow sedimentation should reduce bacteria concentrations in the water column" (Wright Water Engineers, Inc.; Geosyntec Consultants, 2010).

Within the International Stormwater BMP Database report, the stormwater best management practices under evaluation for effectiveness in meeting bacteria water quality standards included biofilters, bioretention, detention basins, filters, manufactured devices, retention ponds, wetlands, porous pavement, infiltration trenches, green roofs, and maintenance practices. Detention basins and biofilters did not reduce effluent bacteria concentrations, while bioretention, filters, and retention ponds reduced effluent bacteria concentrations to some degree. Overall, with the exception of retention ponds, none of the BMP effluent concentrations met the contact recreation standard the majority of the time. Retention ponds demonstrated the best performance among all BMPs; effluent concentrations from retention ponds met the contact recreation standard two-thirds of the time. The report concludes that "the majority of conventional stormwater BMPs in the BMP Database do not appear to be effective at reducing fecal indicator bacteria concentrations to primary contact stream standards, which is the ultimate target of TMDLs" (Wright Water Engineers, Inc.; Geosyntec Consultants, 2010).

Kinnaman, et al. (2012) studied the effect of sediments on the decay rates of coliform bacteria and investigated the required detention times to address bacteria in stormwater BMPs. A microcosm study included the comparison of seven different water, sediment, and bacteria initial conditions that were monitored at a constant 30 degrees Celsius under daytime sunlight conditions. After seven days of monitoring, the final concentration of fecal indicator bacteria was measured, and a first order decay rate constant was calculated. Using a water quality standard of 300 most probable number per deciliter (MPN/dL), none of the microcosms studied met this standard for fecal indicator bacteria. Assuming a detention pond depth of 3 meters, a first flush depth of 1 inch of runoff from the drainage area, and initial fecal indicator bacteria concentrations from 1,000 to 10,000 MPN/dL, results showed that the time needed to decrease fecal indicator bacteria to 330 MPN/dL via sedimentation was between 24 and 73 hours (Kinnaman, Surbeck, & Usner, 2012).

Chapter 3: Materials and Methods

This chapter addresses the location of the research sites, the type and installation of monitoring equipment, sampling procedures, and laboratory analysis.

3.1 SITE CHARACTERISTICS

The study included the monitoring of two flood control basins in the Gilleland Creek watershed, Pon Court basin and Copperhead Drive basin. Pon Court basin is located in a residential subdivision at the end of Pon Court cul-de-sac in Pflugerville, Texas. Copperhead Drive basin is located in a residential subdivision at the intersection of Copperhead Drive and Tortoise Street in Pflugerville, Texas. Pon Court basin collects stormwater runoff from an area of approximately 24 acres, and Copperhead Drive basin collects runoff from an area of approximately 38 acres. There is a significant and similar amount of impervious cover in both residential subdivisions, including streets, sidewalks, driveways, and rooftops.

Pon Court basin and Copperhead Drive basin were selected for the study for a number of reasons. First, the basins are relatively close in proximity (approximately one quarter mile apart) and serve different portions of the same residential development. As a result, the sites have virtually identical land uses. In addition, the spillways for both basin facilities discharge to Gilleland Creek. The relative proximity of Pon Court basin and Copperhead Drive basin can be seen in Figure 1 below.

Figure 1. Location of Pon Court and Copperhead Drive Stormwater Detention Basins in Pflugerville, Texas (Google Maps, 2014).

One of the basins, Pon Court, acted as the test site for the study, and its outlet pipe was retrofitted with an automated valve, which allowed all of the stormwater runoff from the contributing watershed to remain in the basin for any desired length of time after a rain event. The valve could be remotely opened after a period of time (24 hours for the purpose of this study), allowing the runoff to discharge to Gilleland Creek. The second basin, Copperhead Drive, acted as the control site, and its outlet was not modified. Thus, Copperhead Drive basin was used to evaluate the bacteria concentrations in a standard flood control basin.

The two basins selected for monitoring had not had adequate maintenance in many years, so both basins needed to be rehabilitated. The rehabilitation consisted of removal of trees, trash, debris, and accumulated sediment. Figure 2 shows both Pon Court basin and Copperhead Drive basin before and after rehabilitation. In addition, the basin outlets were modified to eliminate standing water.

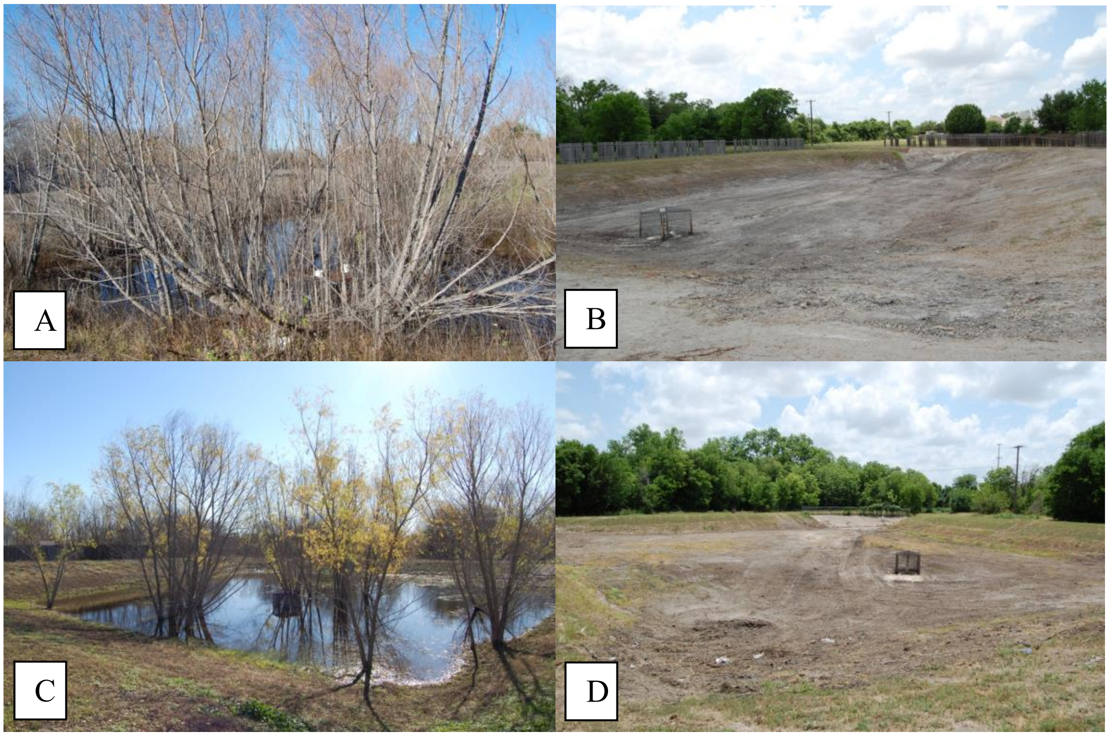


Figure 2. Pon Court and Copperhead Drive Basins, respectively, Before (A, C) and After (B, D) Rehabilitation.

Water quality monitoring equipment was installed to collect influent and effluent stormwater runoff samples from both basins. In general, only storms exceeding 0.25 inches of precipitation provided a sufficient sample volume for analysis. If the basins contained water from a previous storm event, no sampling occurred.

3.2 EQUIPMENT AND PROGRAMMING

The first step in field construction of the outlet control structure at Pon Court basin consisted of excavating to a depth of twelve inches in front of the existing concrete pad at the basin outlet and pouring a new concrete slab. The new slab was underlain with wire mesh for reinforcement and keyed into the existing concrete slab with concrete anchors. The structure housing the actuated gate valve was mounted onto the new concrete pad with L-brackets and concrete anchors. The control structure that was installed is commonly used in agricultural applications. More detailed information regarding the structure can be obtained from http://www.agridrain.com/watercontrolproductsinline.asp. Figure 3 shows a rendering of the structure.

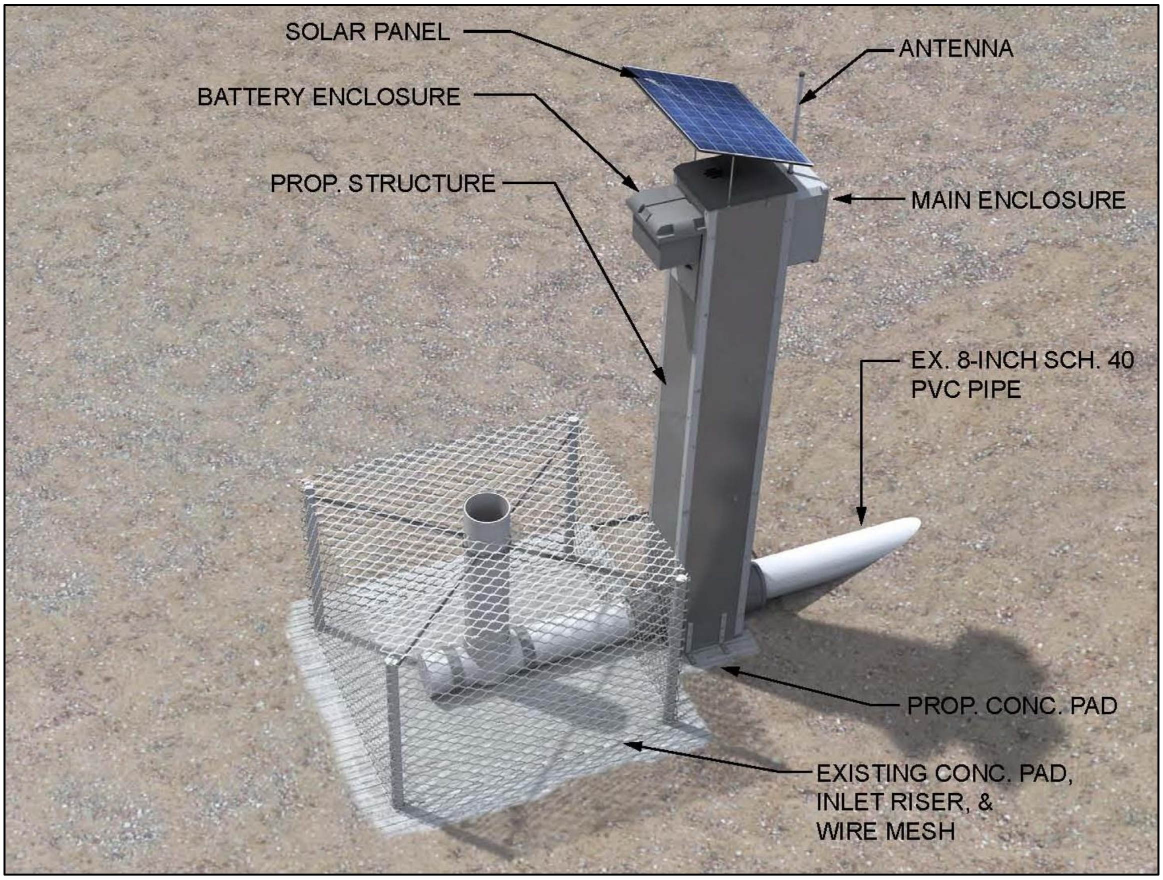
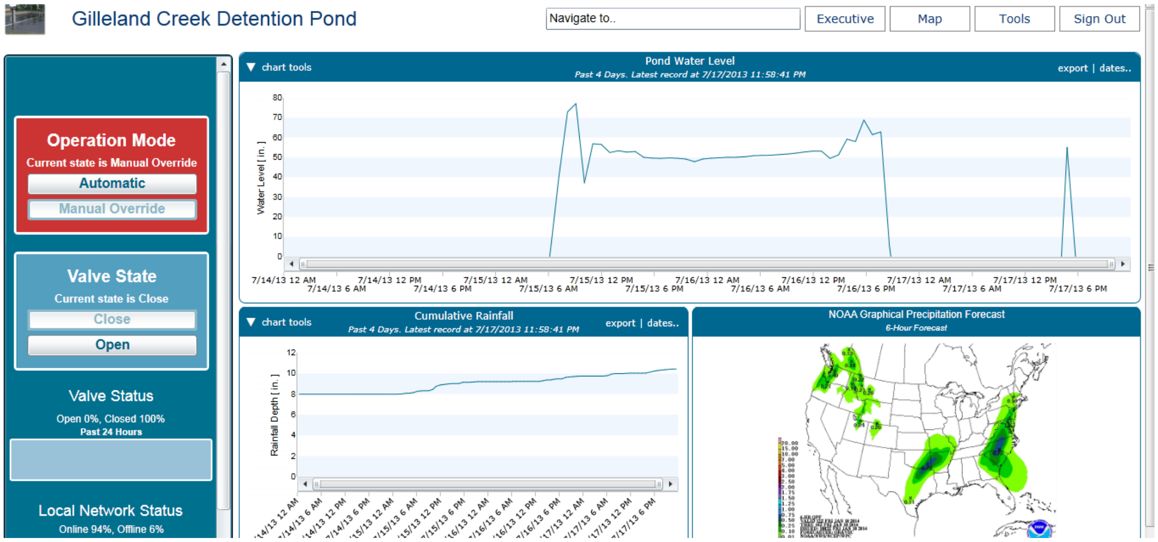


Figure 3. Rendering of the Automated Gate Valve System.

A PVC union was installed to connect the actuated outlet structure to the outlet pipe. An ultrasonic level sensor was mounted externally near the top of the valve structure to record water level readings in the basin. The ultrasonic water level sensor was replaced with a submersible pressure transducer in August 2013 in order to achieve steadier and more reliable water level readings. A battery enclosure was mounted onto the structure, as was a main enclosure housing the electronic components of the setup. A solar panel was mounted near the top of the structure, oriented and angled to capture maximum sunlight and positioned to shade the battery and main enclosures. Electrical cable was run between the solar panel, battery enclosure, main enclosure, water level sensor, and valve actuator. A grounding rod, grounding cables, and corresponding connections to equipment were installed. The existing riser pipe on the basin outlet was capped with PVC, and the holes on the riser pipe were plugged with heavy duty waterproof electrical tape. Figure 4 shows the field installation of the automated gate valve structure at Pon Court basin.

Figure 4. Valve Outlet Structure Installed at Pon Court Detention Basin.

Once construction and installation of the valve structure were complete, the monitoring and control interface was brought online, which allowed remote viewing of water level and rain gauge data. The online interface also allowed remote operation of the gate valve. OptiRTC, developed by Geosyntec Consultants, acted as the control interface for the structure. Figure 5 below shows a screenshot of the web-based OptiRTC interface for monitoring and operating the control structure.



Gilleland Creek Detention Pond

Operation Mode
Current state is Manual Override

Valve State
Current state is Close

Valve Status
Open 0%, Closed 100%
Past 24 Hours

Local Network Status
Online 94%, Offline 6%

Pond Water Level
Past 4 Days. Latest record at 7/17/2013 11:58:41 PM

Cumulative Rainfall
Past 4 Days. Latest record at 7/17/2013 11:58:41 PM

NOAA Graphical Precipitation Forecast
6-Hour Forecast

Figure 5. Screenshot of the OptiRTC System for Controlling the Gate Valve Structure from a July 2013 Storm Event.

Water quality monitoring equipment was installed at the inlet and outlet to both the retrofitted basin and the control basin to evaluate the bacteria and other constituent concentrations entering and exiting the flood control basins. Figure 6 and Figure 7 show the locations of the inlet pipe and outlet pipe at Pon Court basin and at Copperhead Drive basin.

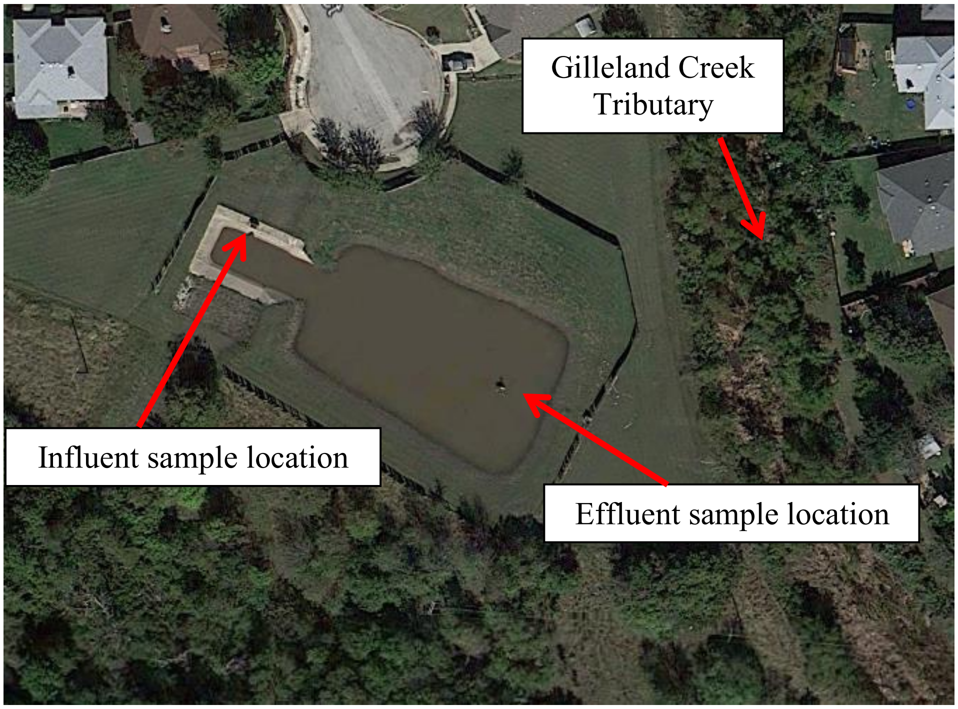


Figure 6. Detailed Site Map of Pon Court Basin (Google Maps, 2014).

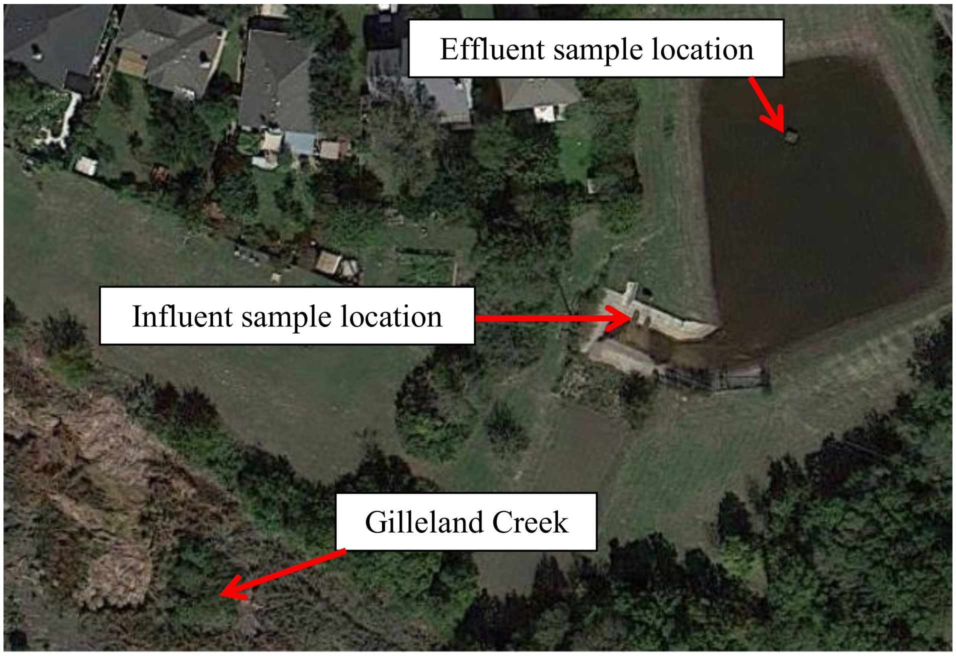


Figure 7. Detailed Map of Copperhead Drive Basin (Google Maps, 2014).

One ISCO Signature Flow Meter and one ISCO 3700 Portable Sampler were installed at the inlet to both the Pon Court test basin and the Copperhead Drive control basin. The ISCO Signature Flow Meter measures flow using an area velocity meter. The area velocity probe installed in each of the detention basin inlet pipes records water level and velocity via an ultrasonic sensor. The ISCO Signature Flow Meter then converts the water level and velocity data into a flow rate based on the dimensions of the pipe (circular pipe with a diameter of 48 inches at both basins). The flow rate data is stored by the ISCO Signature Flow Meter, and this data was downloaded via USB connection to a laptop computer using the ISCO Flowlink software interface.

The ISCO 3700 Portable Sampler is a portable programmable liquid sampler that draws stormwater samples through a Teflon-lined suction tube into a nine liter propylene bottle via a peristaltic pump. A stainless steel strainer is attached to the end of the suction tube to prevent debris from clogging the intake. Figure 8 below shows the sampler intake tube with strainer and area velocity probe in the Pon Court basin inlet. At the Copperhead Drive basin, the area velocity meter probe was installed in one of two 48 inch inlet pipes, while the sampler inlet tube with strainer was installed on the concrete pad slightly downstream from where the flow paths from both inlet pipes merge.

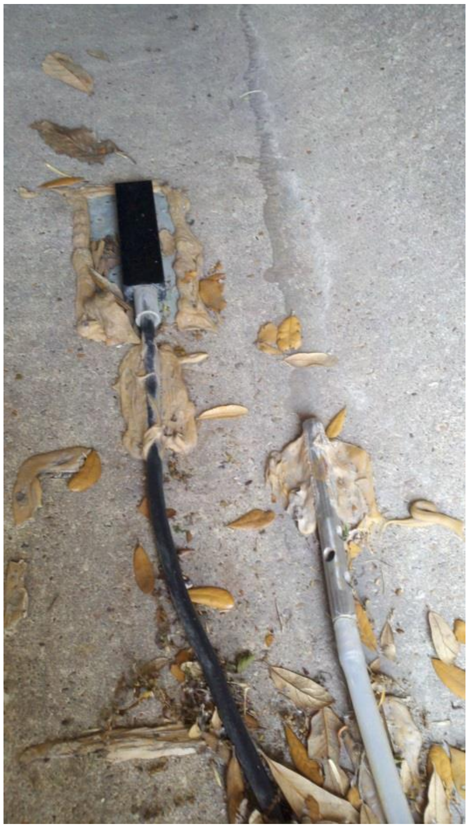


Figure 8. Sampler Tube Intake and Area Velocity Probe at Pon Court Basin Inlet.

One ISCO 4230 Bubbler Flow Meter and one ISCO 3700 Portable Sampler were installed at the outlet of each basin. The ISCO 4230 Bubbler Flow Meter monitors the depth of stormwater runoff in the inlet pipe and calculates a corresponding flow rate in one minute intervals. The level and flow rate data were stored by the bubbler flow meter, and this data was downloaded via USB connection to a laptop computer using the ISCO Flowlink software interface. An ISCO 674 tipping bucket rain gauge was installed near the field box at the Copperhead Drive basin outlet. Rainfall data was sent to the flow meter and subsequently downloaded via ISCO Flowlink.

All equipment was placed in tamper resistant field boxes for security. Figure 9 below shows the completed field installation of water quality monitoring equipment at the outlet to Pon Court basin. The power for each set of monitoring equipment was drawn from a deep cycle marine battery which maintained charge via a connection to a solar panel mounted on the top of each field box.

Figure 9. Water Quality Monitoring Equipment at Pon Court Basin Outlet.

Rating curves for the control basin and test basin were developed and used to program the flow meters. A composite sampling regime, consisting of a mixture of a number of individual stormwater runoff sample aliquots was used at Pon Court inlet and Copperhead Drive inlet and outlet. The aliquots were collected at specific intervals of flow during the storm events and combined to form a single sample for laboratory analysis. The samplers were programmed to take equal volume aliquots (300mL). Flow-weighted sample pacing was determined after observing the runoff volume for the first several rain events prior to beginning the monitoring period. At least eight aliquots must have been collected to ensure representativeness of the sample, so the sample pacing was set as the volume of runoff from a 0.25 inch storm divided by eight. Sample collection ended at either the end of stormwater runoff or when 28 individual aliquots had been collected.

The runoff coefficient was determined by dividing the measure runoff volume, obtained from flow meters installed at the sites, by the rainfall depth, measured at a rainfall gauge at the Pon Court site.

3.3 COMPOSITE VERSUS GRAB SAMPLING

The two principal methods for collection of stormwater samples for water quality analysis are grab sampling and composite sampling. Grab samples are collected instantaneously and provide a snapshot of the water quality at an instant in time. A composite sample is a mixture of a number of individual sample aliquots collected at specific intervals of time or flow during a storm event and combined to form a single sample for laboratory analysis.

Beginning with the October 2013 storm events, the sample from Pon Court outlet was collected via grab sampling rather than composite sampling. This change in sampling protocol presented three distinct advantages to the study. First, grab sampling extended the monitoring period for the project. Due to Lower Colorado River Authority Environmental Laboratory Services (LCRA ELS) hours of operation and detention basin drainage time, only storm events that occurred from mid-morning on Sundays to mid-day on Wednesdays could be sampled. Grab sampling extended the monitoring period so that storm events occurring up to mid-day on Thursday could be sampled. Second, grab sampling eliminated potential interference from consecutive storm events. That is, if it began raining while the Pon Court detention basin was draining and a composite sample was being collected, the water submitted for analysis would contain a mix of water that had been held in the pond for 24 hours and new runoff. Alternately, grab sample collection could be timed to avoid any such interfering storm events. Third, grab sampling reduced the number of site visits required to complete Pon Court outlet sampling after a storm event. In a composite sampling regime, one trip must be made to Pon court to activate the automated sampler once the gate valve is opened. A second trip must be made several hours or up to a full day later, after the basin has drained, to collect the composite sample. Grab sampling could be completed in one trip immediately after the gate valve was opened.

The grab sampling protocol for Pon Court outlet was approved by TCEQ after comparative sampling in May 2013 showed equivalent analytical results between composite and grab sampling. The analytical results presented in Table 1 show that the effluent concentration of bacteria in both the composite and grab samples were an order of magnitude lower than the influent concentration of bacteria. The influent concentration is one order of magnitude above the primary contact recreation water quality standard for bacteria (399 MPN/100mL for a single sample), while the effluent concentrations in both the composite and grab samples meet the bacteria water quality standard. As is evident in the analytical results, the grab and composite samples from the Pon Court detention basin outlet show comparable removal percentages across all constituents.

Table 1. Analytical Results for Composite and Grab Sampling Comparison at Pon Court Basin Outlet.

	E. Coli (MPN)	TKN (mg/L)	Nitrate/Nitrite as N (mg/L)	Total P (mg/L)	Dissolved P (mg/L)	TSS (mg/L)
Pon Inlet	1940	2.06	0.596	0.295	0.107	174
Pon Outlet Grab	187	0.935	0.0467	0.179	0.129	4.84
Percent Removal	90.4%	54.6%	92.2%	39.3%	-	97.2%
Pon Outlet Composite	222	0.900	0.0343	0.182	0.121	3.49
Percent Removal	88.6%	56.3%	94.2%	38.3%	-	98.0%

The analytical results confirm previous findings that water in a detention basin that has been allowed to settle for 24 hours prior to discharge has a relatively uniform bacteria concentration.

3.4 SAMPLING PROCEDURE

Prior to each anticipated storm event, a clean sample bottle was placed in each sampler (Pon Court inlet, Copperhead Drive inlet, and Copperhead Drive outlet) and then surrounded by ice. Per EPA specifications, the samples needed to remain below 6 degrees Celsius throughout the sampling process. The samplers were turned on, and the flow meters were triggered such that the samplers were inhibited until the flow meters registered 25 millimeters of water in the inlet and outlet pipes. All inlets, outlets, sample intake lines, and strainers were checked for, and cleared of debris.

After each storm event, lids were placed on the collected sample bottles and the sample bottles were placed in coolers filled with ice. The samples were transported to Lower Colorado River Authority Environmental Laboratory Services (LCRA ELS) in Austin, TX for analysis. After a 24 hour holding period, the Pon Court outlet gate valve was opened via the OptiRTC interface, and as soon as flow began through the outlet pipe, four sample bottles were filled manually. These sample bottles were placed on ice and then transported to the LCRA ELS for analysis. If the samples were collected outside of LCRA ELS business hours, the samples were stored in the 4 degree Celsius cooler at The

University of Texas at Austin Center for Research in Water Resources until LCRA ELS opened for sample reception.

LCRA ELS analyzed all stormwater samples for the parameters listed in Table 2. Table 2 also details the Environmental Protection Agency (EPA) laboratory method for analysis of each parameter. The Practical Quantification Limit (PQL) represents the minimal limit at which concentrations can be accurately quantified. For the purposes of this study, the EPA specified that the bacteriological analysis of each stormwater sample had to occur within twenty-four hours of the first aliquot of sample collection.

Table 2. Parameters Selected for Stormwater Analysis.

Parameter	**Units**	**Practical Quantification Limit**	**Method**
Nitrate/Nitrite as N	mg/L	0.02	SM4500 NO3H
Total Kjeldahl Nitrogen (TKN)	mg/L	0.2	EPA 351.2
Total Phosphorus	mg/L	0.02	EPA 365.4
Dissolved P	mg/L	0.02	EPA 365.4
E. coli	MPN/100mL	1	SM 9223B
Residue, Total Nonfilterable	mg/L	1	SM 2540 D

Chapter 4: Results and Discussion

This chapter presents and discusses the results of the stormwater monitoring at Pon Court basin and Copperhead Drive basin. The discussion includes an analysis of the concentrations of constituents for each storm that was monitored. The concentrations of constituents at the two basins are compared to each other, and the concentrations of constituents at the two basins are compared to the recreational contact standard.

4.1 STORMWATER MONITORING EVENTS

With the installation and programming of all field equipment complete, the period of stormwater monitoring began in March 2013 and ended in March 2014. The first several rain events during the stormwater monitoring period were used to determine the hydraulic and drainage characteristics of the detention basins. These rain events were also used as a means to identify any equipment failures and as a trial run for sample collection. Beginning in May 2013, two paired stormwater runoff samples were collected during storm events at the two detention basins. Over the course of the study, five storms were sampled and analyzed at Pon Court basin, and four storms were sampled and analyzed at Copperhead Drive basin.

In general, following each storm event, samples were collected from Pon Court inlet, Copperhead Drive inlet, and Copperhead Drive outlet and immediately submitted to the LCRA laboratory. After a 24 hour holding window, a sample was collected from Pon Court outlet as the gate valve was opened, and this sample was immediately submitted to the LCRA laboratory. Table 3 below summarizes the sample collection dates and locations, as well as the corresponding rainfall depths, for the storm events that were sampled.

Table 3. Summary of Sample Collection Dates and Locations for Storm Events.

Sample Collection Date	**Rainfall Depth (inches)**	**Location**
5/13/2013	1.28	Pon Court outlet (grab) Pon Court outlet (automated sampler)
5/15/2013	0.13	Pon Court inlet Copperhead Drive inlet Copperhead Drive outlet
5/16/2013	0.13	Pon Court outlet
7/15/2013	0.55	Pon Court inlet Copperhead Drive inlet Copperhead Drive outlet
7/16/2013	0.55	Pon Court outlet
10/16/2013	0.62	Pon Court inlet
10/17/2013	0.62	Pon Court outlet
10/30/2013	3.24	Copperhead Drive inlet Copperhead Drive outlet
10/31/2013	3.24	Copperhead Drive inlet Copperhead Drive outlet
2/26/2014	0.11	Pon Court inlet Copperhead Drive outlet Copperhead Drive inlet
2/27/2014	0.11	Pon Court outlet

As part of an effort to modify the sampling protocol to allow grab sampling from the Pon Court basin outlet, both a grab sample and an automated sample were collected for analysis from Pon Court basin outlet on May 13, 2013. This comparison sampling followed a storm event that occurred on May 10, 2013, which was a Friday, ruling out the occurrence of a complete round of sampling. Copperhead Drive basin was not sampled during the October 16, 2013 storm event because the basin contained standing water from a previous storm event. Due to heavy rainfall during the October 30-31, 2013 storm event, the monitoring equipment at Pon Court basin was rendered inoperable, so stormwater samples were not collected for analysis from Pon Court basin.

4.2 DETENTION BASIN VOLUME ANALYSIS

The runoff coefficient for Pon Court basin was calculated from preliminary stormwater monitoring data during March 2013 through May 2013, before the stormwater sampling began, and also from storm events during June 2013 through August 2013. For nine storm events, the volume of stormwater runoff was recorded by the bubbler flow meter. This was converted to a runoff depth using the size of the Pon Court basin drainage area. The rainfall amount in inches for each storm event was plotted against the corresponding runoff depth in inches, and a linear regression line of best fit was used to approximate the runoff coefficient. The calculated runoff coefficient for the basin is 0.28, which is in range of the generally accepted runoff coefficient value of 0.35 for urban residential development.

For the purpose of comparing influent and effluent constituent concentrations across each detention basin, the volume entering and exiting each basin must be equivalent. Infiltration is the largest factor that could cause volume loss in the detention basins. Although the City of Pflugerville confirmed that the basins were fully underlain with an impermeable liner upon construction, water level data was used to confirm this assurance.

Figure 10 and Figure 11 show the level versus time data for Pon Court basin following a rain event on March 20, 2013. Figure 10 was developed based on data collected from the OptiRTC water level sensor installed on the outlet control structure, while Figure 11 was developed based on data collected from the bubbler flow meter.

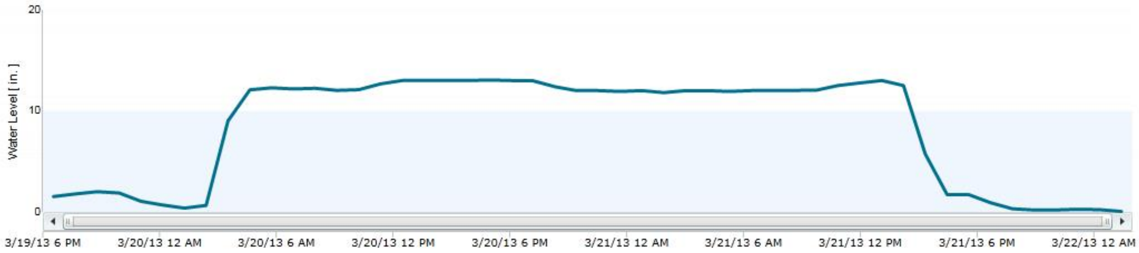


Figure 10. Pon Court Basin OptiRTC Water Level after March 20, 2013 Storm Event.

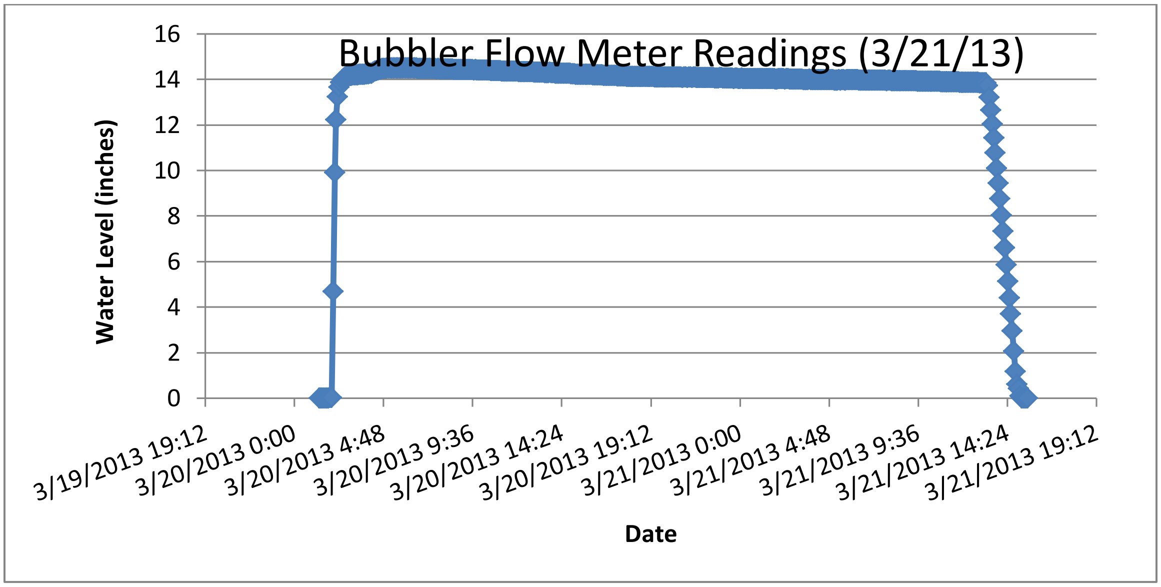


Figure 11. Pon Court Basin Bubbler Flow Meter Water Level after March 20, 2013 Storm Event.

The gate valve on the outlet control structure was closed prior to the rain event and remained closed until March 21, 2013. Based on the OptiRTC readings, the water level in the basin rose from 0 to 13 inches over a period of 10 hours, reaching 13 inches at 12:30pm on March 20, 2013. The water level in Pon Court basin remained nearly constant at 13 inches, only varying by a maximum of 1.2 inches over a period of 2 days. Based on the bubbler flow meter readings, the water level in the basin reached a maximum of 14.51 inches and did not vary by more than 0.49 inches until the gate valve was opened. The water level in the basin began decreasing when the gate valve was opened at approximately 1:00pm on March 21, 2013.

Figure 12 and Figure 13 show the level versus time data for Pon Court basin following a rain event on April 2, 2013. These data sets confirm the consistency of water level readings within the basin while the gate valve was closed.

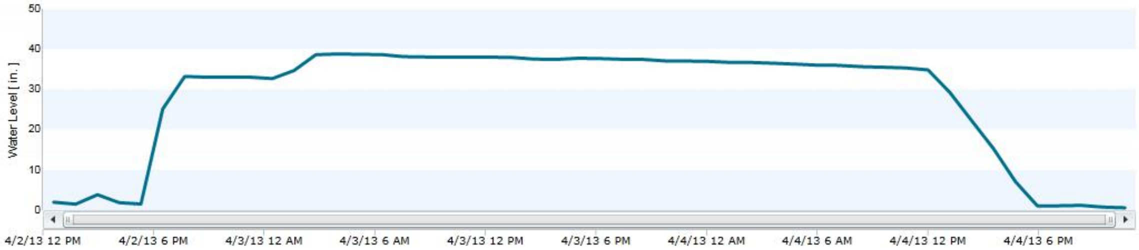


Figure 12. Pon Court Basin OptiRTC Water Level after April 2, 2013 Storm Event.

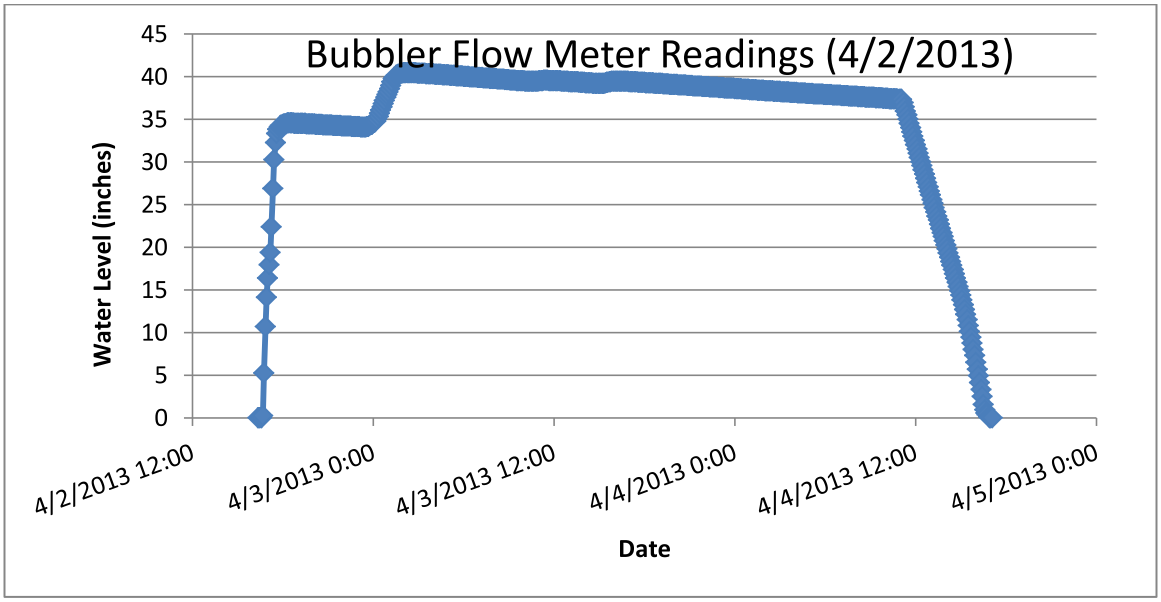


Figure 13. Pon Court Basin Bubbler Flow Meter Water Level after April 2, 2013 Storm Event.

The consistency in water level in Pon Court basin indicates that there is no volume loss occurring in the studied detention basins; infiltration and evaporation are both negligible. Thus, for the purposes of calculation and analysis, the influent runoff volumes are equivalent to the effluent runoff volumes within each detention basin.

4.3 STORMWATER MONITORING RESULTS

Individual constituent concentrations for each stormwater runoff sampling event at each basin can be found in Appendix A. Water quality monitoring results from Pon Court basin and Copperhead Drive basin for all sampled storm events were compiled and are summarized in Table 4 and Table 5 below. The mean, median, range, and standard deviation of influent and effluent concentrations for all constituents at Pon Court basin are presented in Table 4, while the mean, median, range, and standard deviation of influent and effluent concentrations for all constituents at Copperhead Drive basin are presented in Table 5. A comparison of sampling results between the two detention basins is included later in the analysis, as is a statistical comparison of the influent and effluent concentrations within each detention basin.

Table 4. Summary Statistics of Constituent Concentrations at Pon Court Basin.

Constituent	**Influent**	**Effluent**
***E. Coli* (MPN/100mL)**		
Mean	4577.5	2281
Median	3345	291
Standard Deviation	3001.6	3297
Range	1940-9680	109-9220
TKN (mg/L)		
Mean	1.25	0.945
Median	1.2485	0.935
Standard Deviation	0.778	0.432
Range	0.453-2.06	0.353-1.559
Nitrate+Nitrite (mg/L)		
Mean	0.40	0.108
Median	0.422	0.0467
Standard Deviation	0.200	0.131
Range	0.156-0.599	0.0292-0.146
Total P (mg/L)		
Mean	0.21	0.155
Median	0.199	0.165
Standard Deviation	0.114	0.0308
Range	0.0888-0.345	0.0993-0.182
Dissolved P (mg/L)		
Mean	0.09	0.0990
Median	0.0828	0.0910
Standard Deviation	0.037	0.0183
Range	0.0565-0.146	0.0766-0.129
TSS (mg/L)		
Mean	85.6	5.16
Median	70.0	4.84
Standard Deviation	56.2	1.41
Range	28.6-174	3.46-7.83

Table 5. Summary Statistics of Constituent Concentration at Copperhead Drive Basin.

Constituent	**Influent**	**Effluent**
***E. Coli* (MPN/100mL)**		
Mean	29548	6472
Median	8410	6250
Standard Deviation	45502	4757
Range	1920-130000	20-13000
TKN (mg/L)		
Mean	2.045	1.127
Median	1.79	0.898
Standard Deviation	1.028	0.676
Range	1.20-4.26	0.378-2.41
Nitrate+Nitrite (mg/L)		
Mean	0.517	0.66
Median	0.470	0.36
Standard Deviation	0.304	0.57
Range	0.0756-0.946	0.02-1.56
Total P (mg/L)		
Mean	0.327	0.171
Median	0.261	0.148
Standard Deviation	0.178	0.0754
Range	0.195-0.709	0.0966-0.291
Dissolved P (mg/L)		
Mean	0.0805	0.117
Median	0.0767	0.101
Standard Deviation	0.0206	0.0556
Range	0.0571-0.116	0.059-0.197
TSS (mg/L)		
Mean	229.6	12.89
Median	218	10.42
Standard Deviation	135.8	7.77
Range	71.8-400	4.54-20.8

4.4 WATERSHED COMPARISON

To assess the presumed similarity of the drainage areas for the two selected detention basins, the influent concentrations for each constituent were compared across all storms between Pon Court basin and Copperhead Drive basin. A two sample t-test assuming equal variances with a p value of 0.1 was used to compare the mean influent concentrations at each basin. There was no statistically significant difference between the influent *E. coli* (p=0.18), TKN (p=0.14), nitrate+nitrite (p=0.28), total phosphorus (p=0.16), or dissolved phosphorus (p=0.29) concentrations at Pon Court basin and Copperhead Drive basin. Thus, for these five constituents, the assumption that the two drainage areas display similar stormwater runoff characteristics is valid. The p value for TSS was 0.055, indicating that the difference in influent concentrations of TSS between the two basins is statistically significant. The mean influent concentration of TSS at Pon Court basin is 86.5 mg/L in comparison to 229.6 mg/L at Copperhead Drive basin; the stormwater runoff from the Copperhead Drive basin drainage area is carrying more suspended solids into the basin.

4.5 PON COURT BASIN PERFORMANCE

The mean inlet concentrations of all constituents were compared with the mean outlet concentrations of all constituents at Pon Court basin to assess the performance of the retrofitted test basin. A paired two sample t-test for means was performed with a p value of 0.1. The concentrations of *E. coli* (p=0.25), total phosphorus (p=0.13), and dissolved phosphorus (p=0.38) were not significantly different between the inlet and outlet of Pon Court basin. The decrease in concentrations of TKN (p=0.07), nitrate+nitrite (p=0.05), and TSS (p=0.05) between the inlet and outlet of Pon Court basin were statistically significant. Total phosphorus is normally associated with sediments, so it would be expected to show a significant decrease in concentration from inlet to outlet as did the concentration of TSS. The p value for total phosphorus was 0.12, close to the t-test p value of 0.1, and only four storm events were eligible for inclusion in the comparison. Total phosphorus would likely track more closely with TSS with continued stormwater sampling of rain events and a larger dataset. Although data analysis does not indicate that the automated valve resulted in statistically significant reductions in *E. coli* concentrations between the inlet and outlet of Pon Court basin, the dataset is limited by four storm events.

4.6 COPPERHEAD DRIVE BASIN PERFORMANCE

A paired two sample t-test for means was performed with a p value of 0.1 to assess the performance of the control basin in treating stormwater runoff. Between the inlet and outlet of Copperhead Drive basin there was not a statistically significant reduction in the concentration of *E. coli* (p=0.16) or nitrate+nitrite (p=0.17). The reduction in concentrations of TKN (p=0.08), total phosphorus (p=0.09), dissolved phosphorus (p=0.08), and TSS (p=0.008) seen from the inlet to the outlet were statistically significant. Based on the high levels of TSS that Copperhead Drive basin received with each storm event, the 'dirtier' storms that the basin is receiving seem to drive the concentration reductions from inlet to outlet. It should be noted that the Copperhead Drive basin dataset is limited to six pairs of inlet to outlet samples from five distinct storm events.

4.7 EFFLUENT COMPARISON

In order to compare the performance of the retrofitted test basin to the control basin, the average effluent concentration of all constituents across all storm events was calculated for Pon Court basin and Copperhead Drive basin. The average effluents at each basin were then compared using a two sample t-test assuming equal variances with a p value of 0.1. The difference in effluent concentrations of *E. coli* (p=0.06), nitrate+nitrite (p=0.02), and TSS (p=0.02) were statistically significant. For these three constituents, the concentrations in the effluent in Pon Court basin were lower than the Copperhead Drive effluent concentrations. While TKN (p=0.3), total phosphorus (p=0.32), and dissolved phosphorus (p=0.24) concentrations were lower in the Pon Court basin effluent than in the Copperhead Drive basin effluent, these differences were not statistically significant at the chosen p value.

The water quality criteria for Gilleland Creek specifies that individual effluent samples must not exceed 399 MPN/100mL to meet the primary contact recreation standard for *E. coli*. Although the average effluent *E. coli* concentration from the test basin (2281 MPN/100mL) is less than the control basin (6472 MPN/100mL), it still exceeds the contact recreation standard. At an individual storm level, Pon Court basin effluent met contact recreation standards during two of five storm events (both storm events in May 2013).

Table 6 below shows the average effluent concentrations for all six constituents at Pon Court basin, Copperhead Drive basin, and a typical detention basin. The typical detention basin concentrations are based on performance data collected by the International Stormwater Best Management Practices Database.

Table 6. Average Effluent Concentrations at the Test Basin, Control Basin, and a Typical Detention Basin.

	E. coli	**TKN**	**Nitrate+Nitrite**	**Total P**	**Dissolved P**	**TSS**
	(MPN/100mL)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)
Pon Court Basin	2281	0.945	0.108	0.160	0.098	5.16
Copperhead Drive Basin	6472	1.13	0.657	0.17	0.12	12.9
Typical Detention Basin	429	1.61	0.360	0.22	0.11	24.2

The typical detention basin outperforms the studied basins with respect to effluent *E. coli* concentrations, while the studied basins perform generally as expected with regard to TKN, nitrate+nitrite, total phosphorus, and dissolved phosphorus. Both Pon Court basin and Copperhead Drive basin are more effective at treating TSS than the typical detention basin. It is important to note that the *E. coli* concentrations measured at the outlet to typical detention basins do not meet primary contact recreation water quality standards.

4.8 POLLUTANT LOAD REDUCTION

The goal of the detention basin retrofit was to demonstrate a 50% reduction in *E. coli*, total phosphorus, and TSS concentrations. The difference in the inlet and outlet concentrations of *E. coli* and total phosphorus at Pon Court basin were not statistically significant, so a pollutant load reduction is not calculated. The difference in average TSS concentration between Pon Court basin inlet and outlet was statistically significant, so a load reduction is calculated. The annual rainfall for Pflugerville, TX is 32 inches, and Pon Court basin treats runoff from a residential area of approximately 24 acres. With the calculated runoff coefficient of 0.28, there was a 93% load reduction of TSS at Pon Court basin.

$$Annual\ Runoff = 32\frac{in}{yr} * \frac{1ft}{12in} * 24ac * \frac{44{,}560ft^2}{ac} * .28 * \frac{28.32L}{ft^3} = 22.6 * 10^6 L/yr$$

$$TSS\ load\ at\ inlet = 22.6 * \frac{10^6 L}{yr} * 85.6\frac{mg}{L} = 19.4 * 10^8 mg/yr$$

$$TSS\ load\ at\ outlet = 22.6 * \frac{10^6 L}{yr} * 5.16\frac{mg}{L} = 1.17 * 10^8 mg/yr$$

As discussed in Chapter 2, the stormwater detention basin monitored by Middleton and Barrett (2008) showed statistically significant reductions in the concentrations of TSS, total copper, total zinc, total lead, COD, total phosphorus, nitrate+nitrite, and TKN from inlet to outlet. Like Pon Court detention basin, the basin in

Middleton and Barrett’s (2008) study showed the greatest removal for TSS. The average effluent concentrations of TSS, TKN, total phosphorus, and dissolved phosphorus were on the same order of magnitude and very similar in numerical value between Pon Court basin and the Middleton and Barrett (2008) basin. As a result, it is expected that if Pon Court basin were monitored across thirteen or more storm events, as was the Middleton and Barrett basin, sedimentation and UV exposure (as a result of the installation of the gate valve to increase retention time) would likely show more statistically significant decreases in constituent concentrations from inlet to outlet.

Chapter 5: Conclusions

The sampling protocol for this study was designed to determine whether improved removal of *E. coli*, phosphorus, nitrogen, and total suspended solids would be observed in a modified flood control detention basin as compared to a similar unmodified flood control detention basin. The main objective of this research was to determine whether a retrofitted flood control basin could demonstrate 50% removal of *E. coli*, total phosphorus, and total suspended solids. Over a period of one year, five storms were monitored at Pon Court basin and Copperhead Drive basin. Water quality monitoring of stormwater runoff demonstrated there was no significant reduction in *E. coli* or total phosphorus concentrations between the inlet and outlet of Pon Court test basin after stormwater runoff was retained in the basin for a period of 24 hours. The test basin was effective in reducing concentrations of TKN, nitrate+nitrite, and TSS. While neither the test nor the control basin met the water quality contact recreation standard for *E. coli*, the study is severely limited by the few number of storm events that occurred and could be sampled during the stormwater monitoring period. Continued stormwater monitoring would provide additional data points for evaluation and strengthen the analysis conducted within this study.

Residential areas are significant sources of fecal indicator bacteria in wet weather discharges from residential communities. Furthermore, many urban areas in the United States have stormwater systems that are similar to the Pon Court and Copperhead Drive stormwater detention basins in the Gilleland Creek watershed. In addressing the negative effects of stormwater runoff on local watersheds, retrofitting drainage systems to incorporate standalone water quality facilities is often prohibitively expensive for municipalities. However, in many other parts of Texas and the rest of the United States, where flood control basins are prevalent, modifying these flood control facilities with a simple gate valve structure as installed in this study presents an opportunity to reduce the input of bacteria and other pollutants that are discharged to the local receiving water. The modification of flood control basins in this manner could offer one cost effective method for municipalities to address TMDLs for bacteria and other impairments in urban areas.

Appendix A: Constituent Concentrations for all Storm Events

Table 7. Constituent Concentrations at Pon Court Basin.

Date	**Location**	**Type**	**Rainfall**	***E. coli***	**TKN**	**Nitrate+Nitrite**	**Total P**	**Dissolved P**	**TSS**
			(in)	(MPN/100mL)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)
5/13/2013	Outlet	Grab	1.28	291	1.59	0.0292	0.180	0.0910	5.93
5/13/2013	Outlet	Composite	1.28	109	1.47	0.0595	0.164	0.0834	4.81
5/15/2013	Inlet	Composite	0.13	1940	2.06	0.596	0.295	0.107	174
5/16/2013	Outlet	Grab	0.13	187	0.935	0.0467	0.179	0.129	4.84
5/16/2013	Outlet	Composite	0.13	222	0.900	0.0343	0.182	0.121	3.49
7/15/2013	Inlet	Composite	0.55	3410	0.453	0.248	0.0888	0.0585	28.6
7/16/2013	Outlet	Composite	0.55	768	0.353	0.146	0.0993	0.0766	3.46
10/16/2013	Inlet	Composite	0.62	9680	0.497	0.156	0.103	0.0565	46.7
10/17/2013	Outlet	Grab	0.62	9220	0.431	0.0238	0.117	0.0878	7.83
2/26/2014	Inlet	Composite	0.11	3280	2	0.599	0.345	0.146	93.2
2/27/2014	Outlet	Grab	0.11	5170	0.936	0.413	0.165	0.104	5.75

Table 8. Constituent Concentrations at Copperhead Drive Basin.

Date	**Location**	**Type**	**Rainfall**	***E. coli***	**TKN**	**Nitrate+Nitrite**	**Total P**	**Dissolved P**	**TSS**
			(in)	(MPN/100mL)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)
5/15/2013	Inlet	Composite	0.13	6020	1.89	0.839	0.211	0.116	71.8
5/15/2013	Outlet	Composite	0.13	3640	2.41	1.33	0.291	0.197	20.8
7/15/2013	Inlet	Composite	0.55	4350	1.30	0.946	0.209	0.0814	95.5
7/15/2013	Outlet	Composite	0.55	8860	1.54	1.56	0.249	0.178	12.7
7/16/2013	Inlet	Composite	0.55	10800	1.93	0.302	0.311	0.0571	312
7/16/2013	Outlet	Composite	0.55	11000	0.378	0.304	0.0966	0.0637	25.4
10/30/2013	Inlet	Composite	3.24	1920	1.20	0.367	0.195	0.0719	124
10/30/2013	Outlet	Composite	3.24	<20	0.64	0.342	0.097	0.059	4.54
10/31/2013	Inlet	Composite	3.24	130000	1.690	0.0756	0.328	0.06	374
10/31/2013	Outlet	Composite	3.24	2310	0.785	<0.02	0.175	0.13	8.13
2/26/2014	Inlet	Composite	0.11	>24200	4.26	0.572	0.709	0.0963	400
2/26/2014	Outlet	Composite	0.11	13000	1.01	0.384	0.120	0.072	5.77

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