EVALUATION AND PERFORMANCE OF A CONSTRUCTED WETLAND FOR STORMWATER MANAGEMENT

A Thesis

by

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MASTER OF SCIENCE

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ABSTRACT

The Dickinson Bayou Watershed has several water bodies impaired by high fecal coliform counts and low oxygen levels. Total Maximum Daily Loads (TMDL) were developed to estimate the maximum amounts of *Escherichia coli (E. coli)* the tributaries to Dickinson Bayou could receive and still meet water quality standards. As part of the Dickinson Bayou Watershed Protection Plan, the Clear Creek Independent School District (CCISD) in League City, Texas, together with the Texas Coastal Watershed Program (TCWP-part of TAMU) office, retrofitted a detention pond in the their Education Village into a constructed wetland. This research seeks to evaluate the retrofitted constructed wetland effectiveness in reducing effluent loads of *E. coli* and how it compares to the potential load reduction estimated in the Total Maximum Daily Load (TMDL). Inflow into the wetland was quantified using the SCS Curve Number method and outflow was quantified using the stage-storage curve based on the change of the water level in the wetland. Inflow and outflow water samples were collected using ISCO samplers and tested with 3M™ *E. coli*/ Coliform Petrifilm™. *E. coli* concentrations were analyzed following the methods outlined by the International BMP Database and using the XLSTAT software. The statistical analysis included descriptive statistics and parametric and non-parametric hypothetical testing. The results showed a median *E. coli* inflow concentration of 5,987 CFU/100ml and a median outflow concentration of 1,500 CFU/100ml. The normalized *E. coli* load was calculated to be 2.0 x $10^{10}\frac{CFU}{acre*yr}$. A comparison to similar BMPs using lognormal probability plots showed the Education village compared favorably at high inflow concentrations, but had a higher

minimum achievable concentration. The analysis of BMP performance data is often complex and challenging. Due to the limitations of this study there are a many avenues of further research. First, the influent *E. coli* concentrations were significantly higher than comparable watersheds. Considering the Education Village watershed only contains institutional facilities, high *E. coli* concentrations were not expected. Another possible investigation could involve taking a more detailed hydrograph and pollutograph. Moreover, more studies at other BMPs are needed for a better comparison of treatment performance, especially at detention basins. Finally, while this research highlights the possibility of a loading reduction that is lower than the WPP estimate, more research is needed to confirm that estimate.

DEDICATION

To my wife Thay:

I bet you didn’t think

When we first infatuated

You’d have to wait years

For me to be graduated

So thank you for marrying this geek

I love you to pieces

One day you’ll see

To you I’ll dedicate my thesis

ACKNOWLEDGEMENTS

I would like to thank my committee chair, Dr. Munster, and my committee members, Dr. Jacob, Dr. Jaber, and Dr. Sung, for their guidance and support throughout the course of this research.

I also want to extend my gratitude to the Texas Coastal Watershed Program team, especially Charriss York and Mary Edwards, for their support, time and space; to the teachers and staff at the Education village for their willingness to open the campus wetlands for research and for their initiative and dedication to enhance their impressive natural asset.

Finally, thanks to my mother, father and sister, for their encouragement and to my wife Thay for her support, patience and love.

NOMENCLATURE

APWA	American Public Works Association
ASCE-EWRI	American Society of Civil Engineers – Environmental and Water Resources Institute
BMP	Best Management Practice
CCISD	Clear Creek Independent School District
cfu	Coliform Forming Units
CN	Curve Number
E. coli	*Escherichia coli*
EPA	U.S. Environmental Protection Agency
FHWA	Federal Highway Administration
Ft.	Feet
HRT	Hydraulic Residence Time
I-Plan	Implementation Plan
MPN	Most Probable Number
NH4	Ammonium
NPS	Nonpoint Source
TAMU	Texas A&M University
TCWP	Texas Coastal Watershed Program
TMDL	Total Maximum Daily Load
TFe	Total Iron
TKN	Total Kjeldahl Nitrogen

TN	Total Nitrogen
TP	Total Phosphorus
TPb	Total Lead
TSS	Total Suspended Solids
WERF	Water Environment Research Foundation
WPP	Watershed Protection Plan

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1. INTRODUCTION

Dickinson Bayou

The Dickinson Bayou watershed lies between Houston and Galveston, Texas, and encompasses a total area of 105 square miles. The watershed falls within Galveston and Brazoria Counties and includes portions of Alvin, Dickinson, Friendswood, Kemah, League City, Manvel, San Leon, Santa Fe and Texas City as shown in Figure 1. The total population of the watershed is approximately 75,000 (Dickinson Bayou Watershed Partnership, 2009). The Dickinson Bayou watershed is approximately 50% developed, but there are still significant natural and agricultural areas. Between 2002 and 2008, the amount of developed land has more than doubled due to increased suburbanization and increases in population within the watershed.

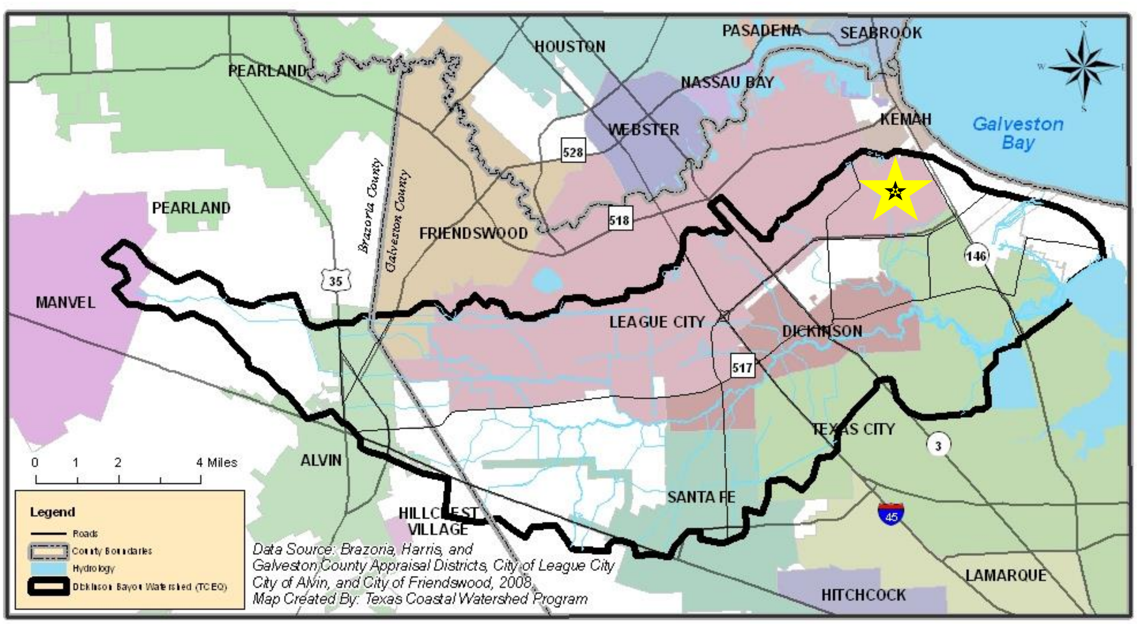


Figure 1 – Project location in relation to the Dickinson Bayou Watershed enclosed in the black boundary (Dickinson Bayou Watershed Partnership, 2009)**.**

Dickinson Bayou is a 22.7 mile long, slow moving coastal stream that drains into Dickinson Bay, and is a sub-bay of the Galveston Bay system. The lower reaches of the bayou from 2.5 miles downstream of FM 517 to Dickinson Bay are tidally influenced (segment No. 1103), as shown in Figure 2. Dickinson Bayou has ten main tributaries: Oak Creek, Algoa Bayou and Hickory Bayou in the portion above tidal influence and Gum Bayou, Bensons Bayou, Giesler Bayou, Bordens Gully, Cedar Creek, Hulen Park Bayou and Arcadia Bayou in the tidal portion (Dickinson Bayou Watershed Partnership, 2009).

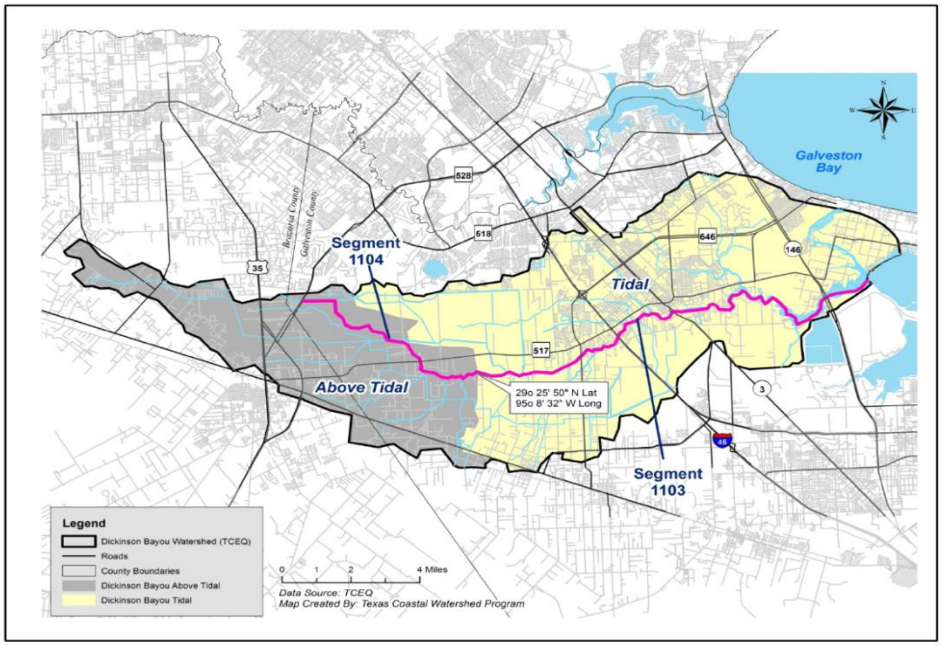


Figure 2 - Dickinson Bayou is divided into tidal (1103) and above tidal segments (1104) (Dickinson Bayou Watershed Partnership, 2009)**.**

Section 303(d) of the federal Clean Water Act requires all states to identify waters that do not meet, or are not expected to meet, applicable water quality standards. States must develop a Total Maximum Daily Loads (TMDL) for each pollutant that contributes to the impairment of a listed water body. The Texas Commission on Environmental Quality (TCEQ) is responsible for ensuring that TMDLs are developed for impaired surface waters in Texas. *Escherichia coli (E. coli)* and *Enterococcus* bacteria have been used as the main bacterial indicator organisms in the state of Texas since 2000 (Dickinson Bayou Watershed Partnership, 2009). The former is used as an indicator in freshwater and the latter in tidal water. TCEQ (Texas Comission on Environmental Quality, 2012) defined the criteria for impairment for contact recreation (e.g. swimming, boating, water skiing, wading) as follows:

- The geometric mean of all *E. coli* samples exceeds 126 colony forming units (cfu) or most probable number (MPN) per 100 mL (1 dL); and/or
- Individual samples exceed 394 cfu or MPN per dL more than 25 percent of the time.
- The geometric mean of all Enterococci samples exceeds 35 cfu or MPN per dL; and/or
- Individual samples exceed 89 cfu or MPN per dL more than 25 percent of the time.

TCEQ first identified *E. coli* impairment for contact recreation use for Dickinson Bayou in the 1996 Texas Water Quality Inventory and 303(d) List. This impairment was expanded in 2002 to include four major tributaries of Dickinson Bayou: Bensons Bayou, Bordens Gully, Giesler Bayou (segments 1103A through 1103C), and Gum Bayou These water bodies remained on the 2008 Texas 303(d) List, with the exception of Gum

Bayou, which was removed from the 303(d) List in 2006 because more recent data indicated the contact recreation use was supported. In 2012, TCEQ adopted TMDLs for five segments of Dickinson Bayou and the above mentioned tributaries shown in Figure 3 (Texas Comission on Environmental Quality, 2012).

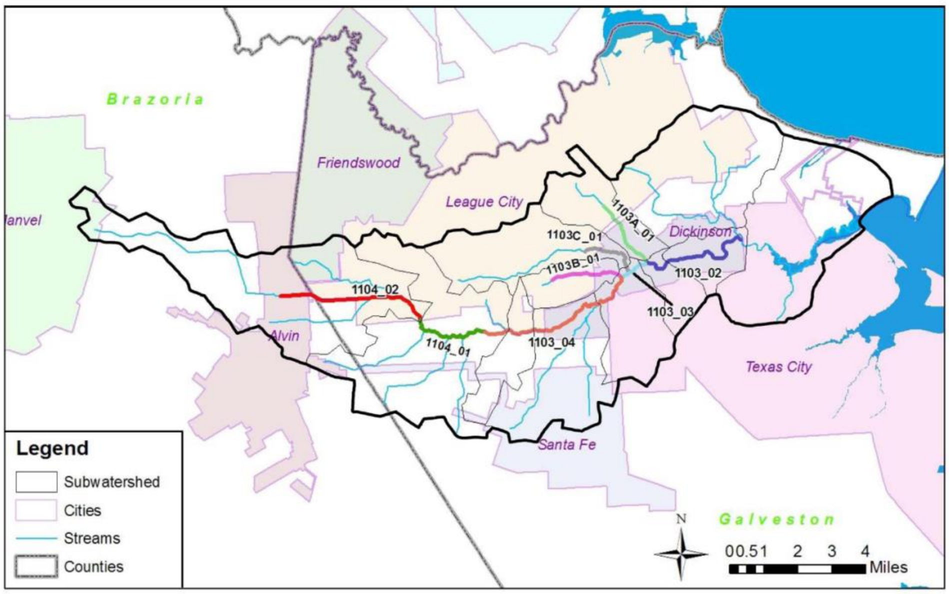


Figure 3 - The Dickinson Bayou watershed, outlined in black, and eight impaired segments, or Assessment Units (AUs) for the project area (Texas Comission on Environmental Quality, 2012)**.**

The Dickinson Bayou Watershed Partnership formally came together in 2004 through a shared interest in preserving and enhancing the natural integrity of the watershed through the coordinated management of natural resources. It comprises of various stakeholders including the Texas Coastal Watershed Program (TCWP), an educational and outreach effort between Texas Sea Grant and Texas A&M AgriLife

Extension Service. Through their efforts, and in coordination with TCEQ and the EPA, The Dickinson Bayou Watershed Protection Plan (WPP) was created. The WPP establishes the baseline conditions and an initial vision for the watershed. It also establishes priorities, creates a detailed plan of management options, and a plan to implement improvement projects. Expected reductions in pollutant loading are detailed for each implementation strategy, as well as the cost and some suggested milestones. The overall short term (~5 years) target for Total Nitrogen (N) and Total Phosphorus (P) is a reduction of 23,394 lbs/yr and 5,816 lbs/yr (5% and 6%), respectively. The long term goal is 267,968 lbs/yr for Total N (32%), and 86,634 for Total P (23%). For bacteria, the short term goal is a reduction of 1.9×10^{15} colonies/yr (15%) and the long term goas is 1.6×10^{16} colonies/yr for bacteria (46%) (Dickinson Bayou Watershed Partnership, 2009)

One major strategy to achieve these goals is to retrofit existing small stormwater detention areas into stormwater wetlands, which provide detention, improve water quality and provide a more natural appearance. For retrofits, a pond would be excavated, re-sculpted, and native wetland plants installed to insure the full benefit of a treatment wetland.

The initial goal of the WPP is for stormwater wetlands to treat approximately 250 acres of developed watershed land, which represents 1.3% of this land use type for the watershed. Using documented median removal rates for total suspended solids and bacteria, the expected load reduction is 1,257 lbs/yr (0.31%) for Total N, 582 lbs/yr

(0.62%) for Total P and 1.2 x 10^{15} colonies/yr (1.1%) for bacteria (Dickinson Bayou Watershed Partnership, 2009).

Education Village Watershed

The Education Village Campus opened in August 2009 and is located within the Clear Creek Independent School District (CCISD). It includes Pre-kindergarten through 12th grade facilities, and playing fields. The campus acts as a distinct watershed of approximately 150 acres as shown in Figure 4. The drainage system transports runoff through a network of curbs, gutters, and storm drains to a constructed wetland, which then discharges into Gum Bayou. Gum Bayou flows into Dickinson Bayou and finally into Dickinson Bay.

Figure 4 – The Education Village watershed (in red) is approximately 150 acres. The wetland area is fenced off (in yellow). *Source*: "Education Village Watershed" 29°30'37.2"N 95°01'29.1"W. Google Earth. 2015.

Education Village Wetland

Original Design

The Education Village Campus was built in 2008 with a storm sewer system that drained to a detention pond designed to store up to 73.19 acre-feet of water with a design water surface elevation of 11 ft. and an outfall flowline of 2.75 ft. (H. F. Scheider III P.E. & PBK Architects, 2008). It incorporated an outlet control structure designed to release water slowly. It is composed of a semicircular weir (Figure 5) with a 12” inlet pipe with trash screen (Figure 6) and a 24” restrictor pipe (Figure 7). In theory, water would flow though the trash screen holes into the control structure pool and through the restrictor pipe. For small storm events, the limiting factor would be the friction losses through the trash screen. For larger events, the concrete weir would be overtopped and the restrictor pipe would limit the flowrate. Additionally, there is an emergency outfall weir made of riprap at a higher elevation. In practice, however, the water table and the water level in Gum bayou maintained a relatively high water elevation in the wetland that prevented it from draining below a certain level. This increased water level was probably unforeseen by the original designers and therefore the water level would stay at the level shown in Figure 5 for extended periods of time at a depth of approximately 3 ft.

Figure 5 – The outlet control structure consists of a semicircular concrete weir and appurtenances designed to release water slowly

Figure 6 – The friction losses though the 12” inlet pipe and trash screen are the limiting factor for small events. The water level is not normally this low. This picture was taken during the wetland retrofit.

Figure 7 – View of the inside of the control structure pool. Water flows though the screen and into a 24” restrictor pipe.

Wetland Retrofit

The detention pond was retrofitted into a wetland in the fall of 2011, with the guidance of the Texas Coastal Watershed Program (TCWP), by an extensive regrading of the site (Figure 8) that created for a wide shallow shelf conducive to the growth of wetland vegetation. The goals were to improve the quality of the site’s runoff, provide a habitat for wildlife, and educational opportunities for students. A comparison of the design documents with the as-built survey show that the regrading was not done exactly as specified.

Figure 8 – Retrofitting the detention pond to a wetland involved regrading to allow for plant growth.

It was calculated that approximately 30% of the water surface area was covered by emergent vegetation at the baseline water level. This percentage varies as the water level rises due to the topography of the wetland, especially when the water overtops the wetland shelves. Emergent vegetation has been limited to the littoral zones at the edge of the wetland while the central area remains a deep pool. The littoral zone (0 to ~1 ft. depth) extends all around the wetland, except the area around the outfall and inlet A where the drop-off is more pronounced and the deep pool (~1 to 3 ft. depth) covers the center and the outfall area. While percent coverage is short of the 50% minimum required for definition as a wetland basin by the BMP Database User’s Guide as shown in Table 1, nevertheless the large littoral zones prevent it from being defined as a retention basin. It is important to keep in mind that the categories of “detention basin” “retention basins” and “wetland basins” exist in a continuum and that each system has unique design characteristics and locations. While the Education Village Wetland can be appropriately classified as a “wetland basin,” its current characteristics fall within the continuum from wetland to retention basin.

Table 1 - BMP definitions (Wright Water Engineers and Geosyntec Consultants, 2010)

Category	Definition
Detention Basins	Dry basins that are designed to completely empty at some time after stormwater runoff ends.
Retention Basins	Wet ponds that have a permanent pool of water, unlike detention basins, which dry out between storms. The permanent pool of water is replaced in part or in total by stormwater during a storm event.
Wetland Basins	A wetland basin is a BMP similar to a retention pond (with a permanent pool of water) with more than 50 percent of its surface covered by emergent wetland vegetation, or similar to a detention basin (no significant permanent pool of water) with most of its bottom covered with wetland vegetation.

The TCWP introduced various kinds of vegetation into the Education Village Wetland shortly after the retrofit through various efforts, including a “floating wetland” (Figure 9) planter that is anchored to the wetland floor. The vegetation introduced by TCWP includes: *Thalia dealbata*, *Nymphea odorata* (American waterlily), *Eleocharis montana* (spikerush), *Eleocharis quadrangulata* (Square-stemmed Spikerush), and *Iris virginica* (blue flag iris), among others. The presence of *Myocastor coypus* (Nutria), however, has made it challenging to maintain since they are notorious for their voracious appetite for wetland plants. Wildlife seen at the wetlands include various species of fish, crabs, rabbits, rodents, frogs, spiders and other insects as well as a large variety of birds. Figures 10 and 11 below show different features of the Education Village Wetlands.

Figure 9 – The floating wetland planter maintains an optimal water level for the vegetation on it even when the water level is low as shown here.

Figure 10 - The Education Village wetland provides wildlife habitat and educational opportunities in addition to stormwater detention and water quality improvement.

Figure 11 – The view from this inlet shows an inlet and the littoral zone that floods after a storm event.

2. LITERATURE REVIEW

A comprehensive review on urban stormwater wetlands was first done by Strecker et al., who documented the performance of 25 natural and constructed wetlands treating runoff (Strecker, Kersnar, Driscoll, & Horner, 1992). The report focused on the comparison of wetland and detention basin treatment performance of solids, various nutrients and metals, including Total Suspended Solids (TSS), Total Lead (TPb) Total Zinc (TZn), Total Nitrogen (TN) and Total Phosphorous (TP) Total Kjehldahl Nitrogen (TKN) and Total Lead (TPb). The results from the selected case studies are shown in Tables 2 - 4.

It is important to note that percent removal, even where the results are statistically significant, often does not provide a useful assessment of treatment performance (see the section below on Percent Removal). Therefore, the results of these early studies that use percent removal only should be carefully evaluated.

Table 2- Results from the Orange County treatment system in Florida (Martin & Smoot, 1986) show that the wetland performed better than the detention basin for three out of the five pollutants studied.

PARAMETER	PERCENT REMOVAL	
	Detention Basin	Wetland
TSS	65	66
TPb	41	75
TZn	37	50
TN	17	30
TP	21	19

Table 3 - Results from the Pittsfield-Ann Arbor swift run system in Michigan (Scherger & Davis, 1982) show that the overall effectiveness of the wetland was greater than that of the detention basin.

PARAMETER	PERCENT REMOVAL	
	Detention Basin	Wetland
TSS	39	76
TP	23	49
TKN	14	20
TFe	17	62
TPb	61	83

Table 4 - Results from the McCarrons treatment system in Minnesota (Wotzka & Oberts, 1988) show the detention basin proved to be more effective than the wetland in reducing several pollutants.

PARAMETER	PERCENT REMOVAL	
	Detention Basin	Wetland
TSS	91	87
TP	78	36
TN	85	24
TPb	85	68

These three studies featured detention basin-wetland systems in series which gives the first treatment system an advantage due to the fact that higher influent pollutant concentrations result in higher percent removal efficiency than those with cleaner influent. Streker concluded that "due to the physical differences and variability between the treatment systems, it is not reasonable to compare specific performance; however, in general, the detention basins and wetlands appear to function equally well for the parameters reported".

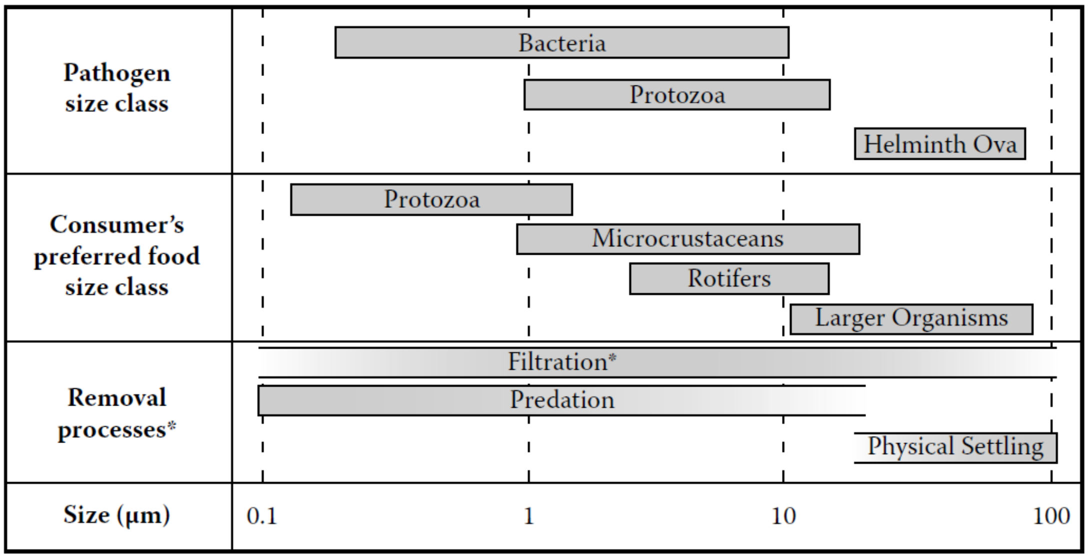
More recently, Carleton et al. compared data from 35 studies on 49 wetland systems used to treat stormwater runoff or runoff-impacted surface waters to identify relevant factors that will aid future design of stormwater treatment wetlands (Carleton, Grizzard, Godrej, & Post, 2001). They concluded that despite the intermittent nature of hydrologic and pollutant inputs from stormwater runoff, their analysis demonstrates that steady-state first-order plug-flow models commonly used to analyze wastewater treatment wetlands can be adapted for use with stormwater wetlands. They also generated first-order removal rate constants for total phosphorus, ammonia, and nitrate, which were comparable to those reported in the literature for wastewater treatment wetlands.

Wong et al. also developed a model to predict the performance of stormwater wetlands, ponds, vegetated swales, sediment basins and biofilters, with a single algorithm (Wong, Fletcher, Duncan, & Jenkins, 2006). The model describes two principal processes: (a) water quality behavior and (b) hydrodynamic behavior. Water quality is described by a first-order kinetic decay model (named the "k–C*" model, after its two parameters, the decay rate, k, and equilibrium concentration, C*). However, since pollutant removal depends on flow behavior, the continuously stirred tank reactor (CSTR) concept is used to account for the hydrodynamics within a treatment device. Where the device has a high degree of turbulence or short-circuiting (such as in a sediment basin), the k–C*model is applied through a small number of CSTRs in series, whereas a well-designed wetland with even flow distribution is modeled by a high number of CSTRs.

Davies and Bavor compared the performances of a constructed wetland and a water pollution control pond in terms of their abilities to reduce stormwater bacterial loads to levels consistent with recreational waters (Davies & Bavor, 2000). Water quality control ponds were defined as having a small range of water level fluctuation in which emergent plants are generally restricted to the edges due to water depth – or wet retention ponds. Concentrations of thermos-tolerant coliforms, enterococci and heterotrophic bacteria were determined in inflow and outflow samples collected from each system over a 6-month period. Bacterial removal was significantly less effective in the water pollution control pond than in the constructed wetland. This was attributed to the inability of the pond system to retain the fine clay particles (<2 mm) to which the bacteria were predominantly adsorbed. Sediment microcosm survival studies showed that the persistence of thermos-tolerant coliforms was greater in the pond sediments than in the wetland sediments, and that predation was a major factor influencing bacterial survival. The key to greater bacterial longevity in the pond sediments appeared to be the adsorption of bacteria to fine particles, which protected them from predators. Bavor et al. expanded on previous efforts by analyzing nutrient loads, as well as bacterial loads (Bavor, Davies, & Sakadevan, 2001). They found removal efficiencies for the wetland although higher than for the pond, but lower than some previously reported values for the treatment of municipal wastewater by constructed wetlands.

The book *Treatment Wetlands* (Kadlec & Wallace, 2009) was the most comprehensive resource available for the understanding of wetland treatment systems. Chapter 12 focuses on pathogens, indicator organisms and removal processes. Because measuring human pathogens is expensive and technically challenging, it has been customary to first look for indicator organisms that are easy to monitor and correlate with populations of pathogenic organisms. The coliform bacteria group has long been used as the first choice among indicator organisms, but *Escherichia coli* is being used more frequently because it can readily be separated from the rest of the fecal group, and because several strains are capable of causing severe human health problems. (Kadlec & Wallace, 2009).

The main pathogen removal processes are: solar disinfection, predation, mortality, settling, and filtration. Solar disinfection is based on UV radiation which is a potent agent for killing bacteria. However, the effect of suspended particles, water depth and the small fraction of UV light in solar radiation lowers inactivation rates. Nematodes, rotifers, and protozoa are the main predators for pathogens. While pathogenic organisms span a wide size range (0.2–100 μm), so do the associated predator/grazing communities (Figure 12). Furtheremore, since many microorganisms are found either associated with particulates or as aggregates of many organisms they become susceptible to physical processes such as settling and filtration. Reintroduction of indicator organisms may originate from many different warm-blooded animals that frequent wetlands consequently, outflow indicator bacteria populations in treatment wetlands cannot be consistently reduced to near zero unless disinfection is used (Kadlec & Wallace, 2009).



*Note: Filtration processes are system dependent.

Figure 12 - Pathogen and predator size chart (Kadlec & Wallace, 2009)

Chapter 14 includes techniques for characterizing incoming flows, concentrations and loads, and the difference in pollutants processes in event-driven wetlands as opposed to continuous- flow systems. Event-driven wetlands are dynamic in all respects, and the principal underlying hydraulics exhibit variable water depths and flows. The behavior is strongly conditioned by the nature of inflow and outflow structures that may be designed to improve detention and treatment. In some instances, the events are separated by inter-event periods of no inflow to the treatment wetland. These periods are important because the wetland will act as a batch reactor during much of these no-inflow durations resulting in highly variable Hydraulic Retention Times (HRT). A typical sequence is, (1) wetland filling with no outflow, (2) flow through with both inflow and outflow, (3) draining with no inflow, and (4) finally, a batch-holding mode with neither inflow nor outflow.

Any water that does not escape the wetland during a particular event will be held until the next event, and possibly longer. Therefore, it is subject to the water quality improvement functions of the wetland for not only the event duration but also the inter-event period. Conversely, water that enters and leaves the wetland during the event is subject to treatment only during the (possibly brief) period of detention during the event. To illustrate this point a hypothetical stormwater wetland event scenario was created. It composed of certain assumed basin, wetland and rainfall parameters. The hypothetical flow, area and stage responses are shown in Figure 13.

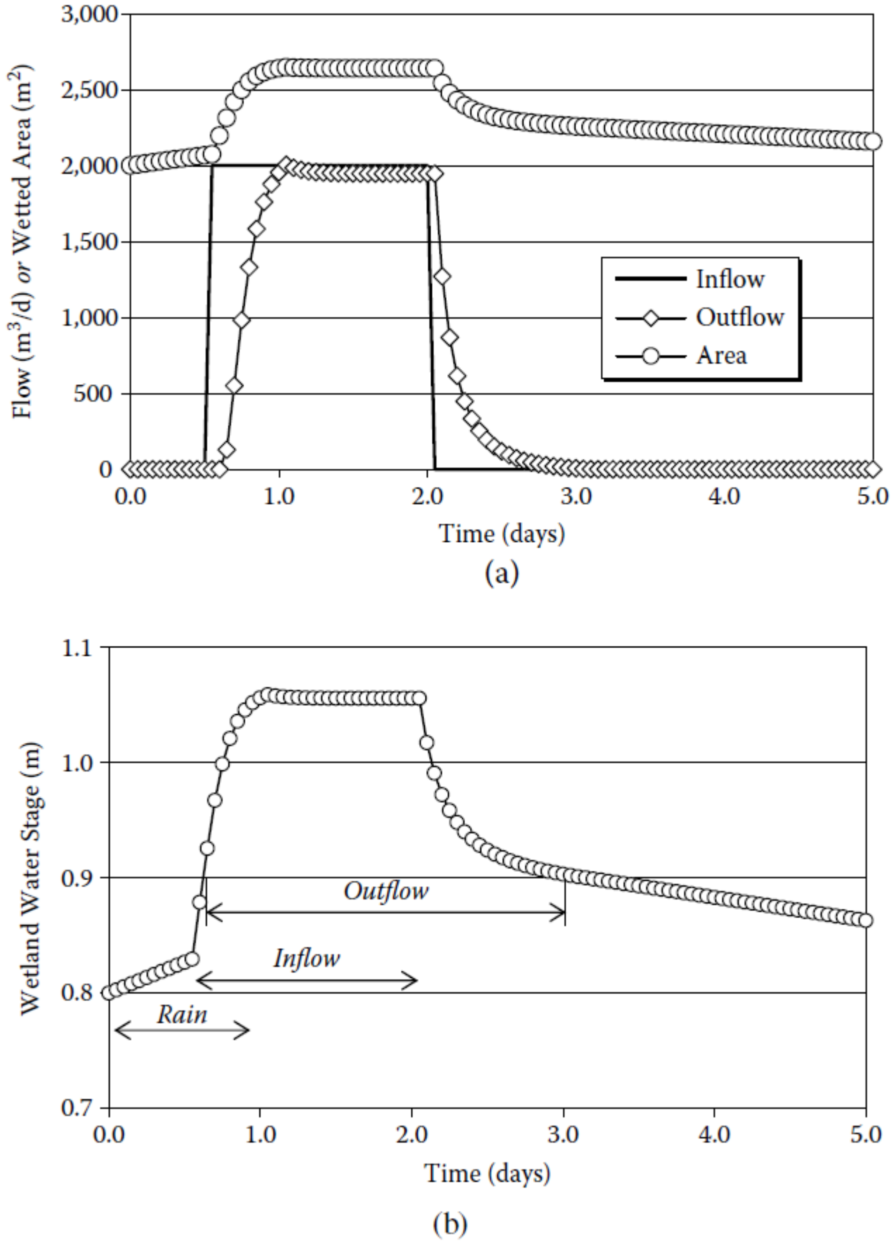


Figure 13 - Response of a hypothetical stormwater wetland to a one-day steady rain. Runoff into the wetland begins after half a day. It is notable that the wetted area in the top figure is not constant, but changes with stage according to the bathymetry of the wetland. (Kadlec & Wallace, 2009).

Concentrations of most parameters in stormwater are time dependent, as are the flows. Stormwater concentrations and loads are episodic due to periods of pollutant deposition, followed by the first flush of runoff after rain, followed by exponential decreases in runoff constituent concentrations as pollutants are washed from the catchment area, and finally, dry conditions and deposition until the next storm event. The time series of concentrations in the inflow to the wetland is called the chemograph or pollutograph.

In some watersheds, the pollutograph is not synchronized with the hydrograph, but instead provides higher concentrations early in the inflow event. This phenomenon is termed first-flush behavior, referring to the surge of pollutants contained in the first water to leave the contributing basin. Of necessity, average concentrations of some sort must be used, of which the flow-weighted concentration is most useful (Kadlec & Wallace, 2009).

The International Stormwater BMP Database Project is a cooperative venture by USEPA, ASCE-EWRI, WERF, FHWA, and APWA which features a database of over 500 Best Management Practices (BMP) studies, performance analysis results, tools for use in BMP performance studies, monitoring guidance and other study-related publications ("International Stormwater Best Management Practice Database," 2014). The database can be accessed at the level of the individual study, by water quality parameter, BMP category, or by location. The Urban Stormwater BMP Performance Monitoring Manual published by the BMP Database was a crucial tool for this project (Wright Water Engineers and Geosyntec Consultants, 2009). It provided monitoring guidance, as well as recommended performance analysis measures for stormwater BMP studies, and a summary of the reporting protocols recommended for BMP studies. The Methods and Analysis sections below were largely based on the manual.

Pollutant Percent Removal

Quantifying the efficiency of BMPs has often centered on examinations and comparisons of “percent removal” defined in a variety of ways. BMPs do not typically function with a uniform percent removal across a wide range of influent water quality concentrations. For example, a BMP that demonstrates a large percent removal under heavily polluted influent conditions may demonstrate poor percent removal where low influent concentrations exist. The decreased efficiency of BMPs receiving low concentration influent has been demonstrated and it has been shown that in some cases there is a minimum concentration achievable through implementation of BMPs for many constituents (Schueler, 2000) and (Minton, 2005). Percent removal alone, even where the results are statistically significant, often does not provide a useful assessment of BMP performance. For a detailed listing of the shortcomings of percent removal see (Wright Water Engineers and Geosyntec Consultants, 2007)

The Effluent Probability Method is recommended instead (See Methodology Section). This approach focuses on whether the BMP can demonstrate a statistical difference in effluent quality compared to influent quality.

E. coli Analysis

Escherichia coli (*E. coli*) is the standard indicator organism of fecal contamination in freshwater. Although Gum Bayou is a tidally influenced reach, *E. coli* was chosen because samples were taken from runoff, not streamflow.

As detailed in Section 3 – Methodology, testing for *E. coli* was performed using 3M Petrifilm™ *E. coli*/Coliform Plates. They were selected because of their cost-effectiveness, and ease of use. Various enumeration experiments have shown very little or no variance between counts obtained through Petrifilm and standard agar counts.(Schraft & Watterworth, 2005). Comparisons to standard method for lactic acid bacteria (Barros, Beatriz, Ortolani, Dora, & Melo, 2006) and Staphylococcus aureus (Silva, Caraviello, Rodrigues, & Ruegg, 2005) have also fared positively. The results are reported in colony forming units per unit volume of sample (CFU/100ml) whereas the multiple tube fermentation method will report the results in most probable number per unit volume of sample (MPN/100ml) (Burton et al., 2013). These two are generally considered interchangeable in the literature (Gronewold & Wolpert, 2008). It is also notable that they are equivalent in the TMDL criteria for impaired streams (see Introduction).

3. OVERVIEW OF RESEARCH STUDY

Objective

The objective of this research was to evaluate the constructed wetland's effectiveness in reducing effluent pollutant loads of *E. coli*. To achieve the objective, the following tasks were completed:

- Hydrologic and hydraulic monitoring at the wetland inlets and outlet.
- Characterization of influent and effluent quality under a variety of storm types
- Comparison of the wetland's *E. coli* treatment performance with similar BMPs (wetland basins, retention ponds, detention basins)

The first two issues were addressed by analyzing the inflow and outflow flowrates and *E. coli* concentration and the last question was answered with the help of the International BMP Database

Data Collection Summary

The Education Village detention pond was built in 2008 and retrofitted into a wetland in 2011 by an extensive regrading of the site. It receives runoff from a 150 acre watershed that is approximately 27% impervious and 73% open space. There are four sub-catchment areas (A though D) that drain using separate storm sewers into the wetland. The wetland area is approximately 6 acres therefore the ratio of wetland area to contributing watershed is .04.

An automatic water sampler was setup at each of the inlets and at the outlet (O) to collect water samples when the wetland water level increased (indicative of a storm event). Three samples per inlet per storm event were obtained to approximate the rising limb, peak, and falling limb of a hypothetical hydrograph. The first was taken immediately when the sensor was triggered, and two more 15 minutes apart since it was not possible to measure flowrate in real time to get an actual hydrograph. The wetland's water level was recorded with a Rugged TROLL pressure sensor adjusted for atmospheric pressure variations with a BaroTROLL pressure sensor. Rainfall data was collected with a Rainwise tipping-bucket rain gauge and data logger.

Water Quality Analysis Summary

The water samples were composited and analyzed using 3M Petrifilm plates. The Event Mean Concentration (EMC) was calculated by multiplying each inlet concentration by its flowrate, adding them together, and then dividing by the total flowrate. The EMC represents the flow-proportional average concentration during a storm event. The bacterial load was calculated by multiplying the *E. coli* concentration by the total flowrate per inlet per storm event. Other parameters were tested for during a certain storm events to determine if their concentrations were high enough to be of concern. They included Ammonia, Nitrate, Phosphorous, Chlorine, TSS, TDS and pH.

Hydrologic and Hydraulic Analysis Summary

The inflows into the wetland were calculated using the SCS Curve Number method with the sub-catchment area for each inlet calculated from the as-built drawings of the storm sewer system. Initial efforts to calculate flowrates for each inlet with water elevation data and Manning's equation were discarded because the water would back up into the culvert causing a "backwater effect".

The change in water volume in the wetland was calculated by inputting the wetland water level from the Rugged TROLL into the stage storage relationship, determined from the as-built survey. This served two purposes:

1. To validate the inflow volume calculated using the SCS Curve Number method.
2. To calculate the outflow by tracking the reduction in volume in the days after a storm event.

Through preliminary measurements it was observed that Gum Bayou rises at a similar rate as the wetland shortly after a storm event. In other words, there is not a measurable head difference between Gum Bayou and the wetland, making the stage-storage relationship the most feasible method to measure outflow. The water depth in the wetland was measured by a pressure sensor set in reference to the datum. The datum was selected to be the invert elevation of the effluent pipe at a mean sea level elevation of 0.463 m. (1.52 ft.).

Statistical Analysis Summary

The *E. coli* concentration data was analyzed following the statistical methods outlined in the BMP Database Monitoring Guide (Wright Water Engineers and Geosyntec Consultants, 2009) and using the XLSTAT analysis software package in Microsoft Excel.

The statistical methods are summarized in two tables. Table 8 shows descriptive statistics including number of observations, measures of location or central tendency (mean and median), measures of spread or variability (standard deviation and interquartile range) and a goodness of fit test (Kolmogorov-Smirnov) on both the normal and lognormal distributions. Table 9 shows hypothesis testing summary including hypothetical test results for non-parametric analysis (Mann-Whitney test), hypothetical test results for parametric analysis (t-Test on raw, log-transformed data) and test of equal variance (Levene Test on raw and log-transformed data). Lastly, plots are used to visualize the data (time series plot, box plot, and probability plot).

4. METHODOLOGY

Data Collection

Site Layout

The Education Village watershed includes an elementary, middle and high school with access roads, parking lots and playing fields, approximately 27% of which is impervious and 73% open space, and totaling about 150 acres. The storm sewer system transports runoff through a network of curbs, gutters and storm drains to the wetland. There are four sub-catchment areas (labeled A though D) that drain into separate storm sewers. These areas were determined by approximating the catchment around storm sewer lines from the as-built drawings as shown in Figures 14 and 15, and summarized in Table 5.

Table 5 – The four sub-catchment areas that drain into the constructed wetland consist mainly of open space and paved surfaces.

Sub-Catchment	**Open space**		**Impervious**		**Total Area**
	Area (sq. ft.)	% of total	Area (sq. ft.)	% of total	(sq. ft.)
A	2,424,000	90%	267,000	10%	2,691,000
B	274,500	30%	643,500	70%	918,000
C	317,500	33%	651,500	67%	969,000
D	1,496,000	95%	86,000	5%	1,582,000
Wetland					269,000

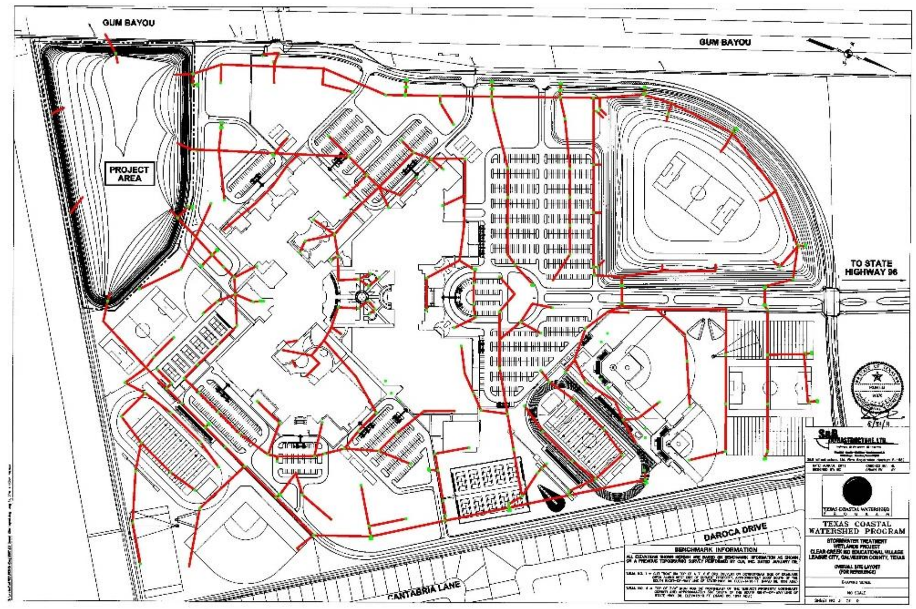


Figure 14 - The network of storm sewers in shown in red and inlets, manholes and outlets are shown in green (Lim Hojin P.E & S&B Infrastructure, 2011).

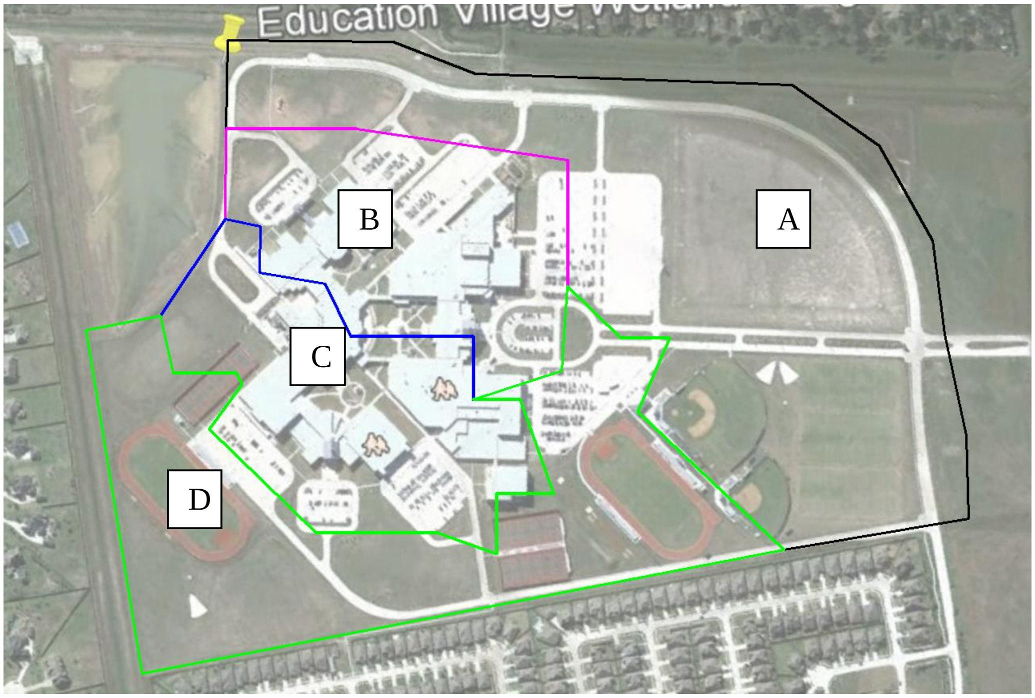


Figure 15 -- The Education Village watershed was subdivided into four catchment areas (A-D). Each sub-catchment had an independent outfall into the wetland. ***Source*****: "Education Village Watershed" 29°30'37.2"N 95°01'29.1"W. (Modified from Google Earth, 2015.)**

Soils

According to the USDA web soil survey ("Web Soil Survey - Home," 2015), the predominant soil type is Bernard clay loam with Mocarey-Leton complex at the northern edge as shown in Figure 16 and Table 6. They are both classified by the Unified Soil Classification System (USCS) as Lean Clays (CL)

Figure 16 – The predominant soil at the Education Village is Bernard Clay Loam, with Mocarey-Leton complex at the northern edge.

Table 6 - Soils at the Education Village ("Web Soil Survey - Home," 2015).

Galveston County, Texas (TX167)			
Map Unit Symbol	**Map Unit Name**	**Acres in AOI**	**Percent of AOI**
Be	Bernard clay loam	140.5	80.3%
LaA	Lake Charles clay, 0 to 1 percent slopes	0.2	0.1%
Lx	Leton-Lake Charles complex	1.8	1.0%
Md	Mocarey-Leton complex	32.3	18.5%
Totals for Area of Interest		**174.9**	**100.0%**

Field Equipment

ISCO Samplers

Five ISCO Portable Samplers model 2700 and 6712 were used to collect water samples. They were powered by solar panels and 12V batteries for remote operation. The samplers were activated with a Liquid Level Actuator (LLA) when stormwater runoff caused the water level to rise above the mean wetland water level elevation (4.5 ft.) and activate a water level sensor. It is shown in Figure 17

Figure 17 – The ISCO portable water samplers were used to collect samples for analysis

Rain Gauges

One Rainwise RainLogger 2.0 tipping-bucket rain gauge with data logger was used to obtain precipitation data in 60 minute intervals. It was mounted on the lid of

ISCO "C" as shown in Figure 18. Before the digital rain gauge was purchased a simple plastic rain gauge was used to measure total precipitation per event.

Figure 18 – The Rainwise RainLogger 2.0 was used to collect rainfall data.

Water Level Measurement

One Rugged TROLL 100, a non-vented (absolute) pressure sensor, was used to record water depth in 10 minute intervals. One BaroTROLL was used to record atmospheric pressure fluctuations. They are shown in Figure 19. Using the included

Winsitu software the raw data from the Rugged TROLL was downloaded and corrected using the BaroTROLL barometric data.

Figure 19 – The Rugged TROLL 100 and BaroTROLL were used to collect water surface elevation data.

Equipment Setup

The inlet ISCO samplers were labeled A, B, C and D and the outlet sampler was labeled O. They were set up adjacent to the storm sewer manhole closest the wetland as shown in Figure 20.

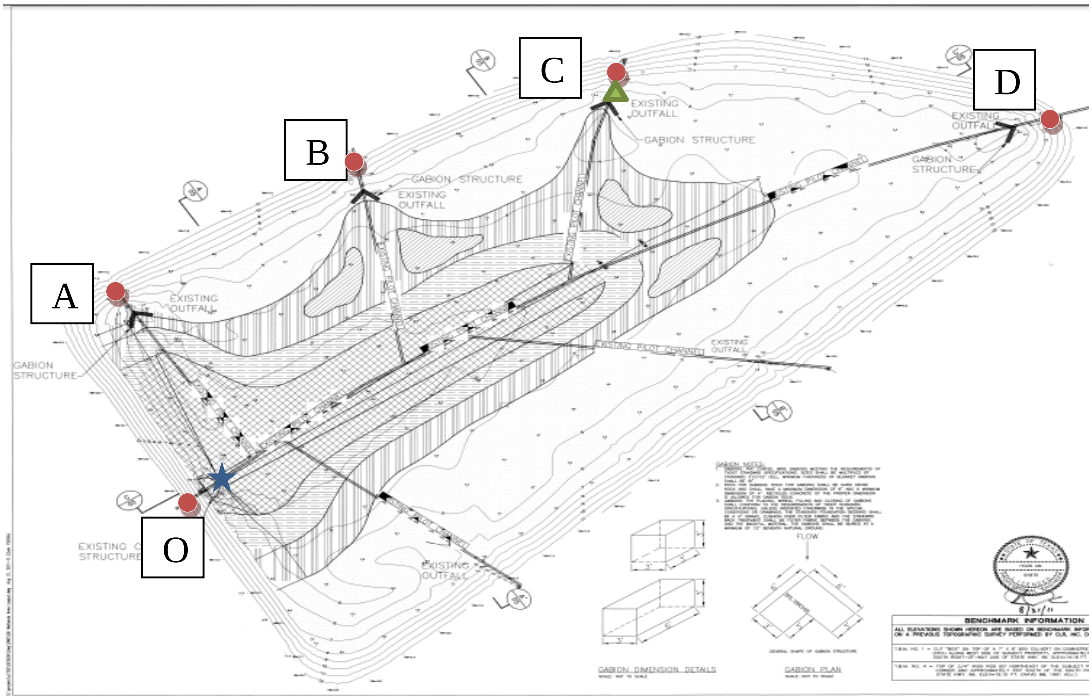


Figure 20 – The four inlets (A, B, C and D) and one outlet (O) where ISCO samplers were installed are shown as circles. The Rugged TROLL used for measuring water level is shown as a star. The location of the rain gauge is shown as a triangle.

All samplers were equipped with a suction hose with a perforated filter tip with 1.3 cm (½ in) diameter perforations that allowed a water sample to be obtained without plugging. They also included a Liquid Level Actuator (LLA) that triggered the sampler when in contact with water. Both the hose and the LLA were lowered though one of the manhole lid holes and securely fastened at the bottom. The samplers had twenty four 1-liter bottles (labeled from 1 to 24) and were programmed to obtain a 200 ml sample every 5 minutes after being triggered for a total of 120 minutes. The bottles selected for analysis were no. 1 (immediately after being triggered) No. 4 and No. 7 (15 minutes apart). This was done to approximate the rising limb, peak, and falling limb of a hypothetical hydrograph since it was not possible to measure flowrate in real time to get an actual hydrograph. The three samples were combined into one bottle before analysis. After the analysis, the bottles were washed and disinfected with methanol before being placed back in the samplers.

The Rugged TROLL was installed at the outlet control structure in the wetland because it was the deepest point of the wetland yet it was still accessible. It consisted of a perforated PVC pipe that is used to regulate flow (See Figure 6). A hook was installed at the top of the pipe and the TROLL was set to hang from it via a rope. It allowed the Rugged Toll to be securely fastened yet easily accessible to retrieve the data. The BaroTROLL was placed in the nearby instrument shelter to get an accurate reading of the atmospheric pressure.

The digital rain gauge was set up on the lid of ISCO “C”. This allowed it to be elevated and note be influenced by nearby vegetation. The manual rain gauge was placed in an adjacent clearing.

Storm Event Sampling Procedure

1. An email weather alert from weather.com and wunderground.com on expected precipitation was received if actual precipitation exceeded 6.35 mm (0.25 in) at nearby weather stations. It was assumed that this would to be as significant enough rainfall event that would produce runoff.
2. Within 24 hours the water samples were collected, put in an ice-filled chest and transported to the TCWP lab for analysis.

3. The rain gage and Rugged TROLL log data were downloaded as well before leaving the site.
4. The bottles were washed, disinfected and returned to their corresponding sampler.

Field Issues

A significant challenge in data collection was related to ISCO sampler reliability. Since all inflow samplers needed to collect a sample successfully for an inflow concentration to be calculated, a failure in one prohibited the calculation of an overall average inflow concentration. Some of these setbacks included a failure of the Liquid Level Actuator (LLA) for ISCO "A", a broken distributor arm on ISCO "C", a broken solar panel, and a few samples missed for unknown reasons. These issues precluded collection of more data at the start of the study.

Hydrologic and Hydraulic Analysis

Inflow – Manning's Equation

Initially, inlet flowrates were intended to be calculated by measuring the water level at each of the inlet culverts. The geometry, material and slope of the culvert would also be inputted into Manning's equation and the discharge equation (below) to calculate the instantaneous flowrate.

$$\boldsymbol{V = \frac{k}{n} R_h^{2/3} S^{1/2}} \qquad \textbf{(1)}$$

V is the cross-sectional average velocity;

n is the Manning coefficient;

Rh is the hydraulic radius;

S is the slope of the hydraulic grade line;

k is a conversion factor between SI and English units.

$$\boldsymbol{Q = V * A} \qquad \textbf{(2)}$$

Q is discharge;

V is the average velocity;

A is the cross-sectional area

However, this method proved to be unsuccessful due to the influence of backwater effect on the slope of the hydraulic grade line (S) as the wetland water level rises. The backwater effect happens when the level of a receiving water body influences the conditions of flow upstream as shown in Figure 21. In this case, the outlet control structure causes the water to back up into the inlet culvers thus varying the slope of the hydraulic grade line (S) for each rain event. While it is possible to take the backwater effect into account for streams in specific situations (single reaches in steady flow conditions), Manning's equation proved unsuitable for this site.

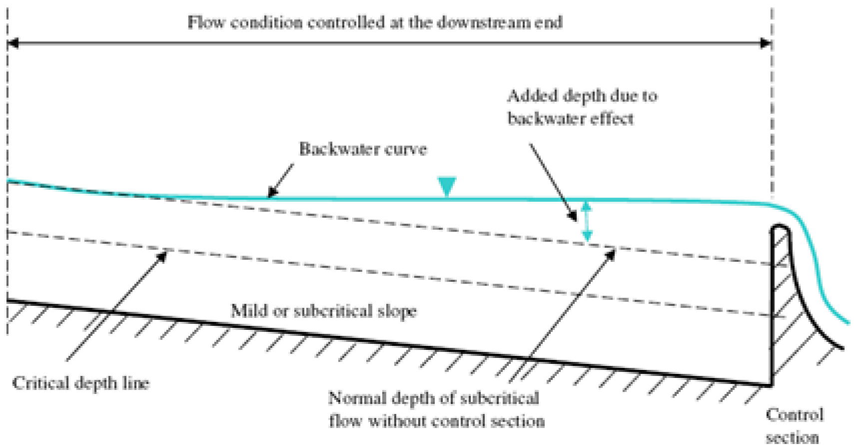


Figure 21 - The backwater effect that influences flow conditions upstream due to an obstruction (Crowder, 2009)

Inflow – SCS Runoff Curve Number Method

The precipitation data served as the main method for calculating inlet flowrates by using the SCS Runoff Curve Number method (Novotny, 1995). It allows for an estimation of the flowrate in each individual inlet, which is necessary to calculate pollutant mass loads.

The composite curve numbers were calculated using the appropriate land area and land use, hydrologic soil group and corrected for antecedent moisture condition (AMC) as given in the procedure below.

The procedure for obtaining runoff using the SCS curve number method is described below. The values used are summarized in Table 7.

1. Select Hydrologic soil group, which for the Bernard Clay Loam soil and Mocarey-Leton complex at the Education Village it is Group D

2. Select the appropriate Curve Number (CN_{II}) for average antecedent moisture condition based on the soil type, the type of cover and its condition.
3. Correct Curve Number for antecedent moisture condition (CN_I for AMC I-Dry and CN_{III} for AMC III-Wet). For most calculations AMC I was chosen, but if there had been any precipitation in the previous 3 days AMC II was used. If the precipitation previous 3 days had been greater than 2.5 cm (1 inch), AMC III was chosen. Furthermore, this was only done for the open space CN, since paved surfaces are minimally affected by AMC.

$$CN_I = 4.2 * \frac{CN_{II}}{10-0.058*CN_{II}} \quad \textbf{(3)}$$

$$CN_{III} = 23 * \frac{CN_{II}}{10+0.13*CN_{II}} \quad \textbf{(4)}$$

4. Calculate the composite CN to take into account both open space and paved areas

$$Composite\ CN = \frac{Area*CN+Area*CN}{Total\ Area} \quad \textbf{(5)}$$

5. Calculate the S Value.

$$S = \left(\frac{1000}{CN}\right) - 10 \quad \textbf{(6)}$$

6. Calculate runoff depth in “watershed” inches.

$$Q = \frac{(P-0.2*S)^2}{P+0.8*S} \quad \textbf{(7)}$$

Table 7 –A curve number was selected for each sub-catchment area (USDA 1986). Then composite values and S values were calculated.

	Open space (Hydro group D)				Pavement		Total Area	Composite CN			S Values		
Inlet	Area (sq. ft.)	CN_{II}	CN_{I}	CN_{III}	Area (sq. ft.)	CN	(sq. ft.)	CN_{II}	CN_{I}	CN_{III}	CN_{II}	CN_{I}	CN_{III}
A	2,424,000	80	63	90	267,000	98	2,691,000	81.8	66.2	91.0	2.23	5.11	0.99
B	274,500	80	63	90	643,500	98	918,000	92.6	87.4	95.7	0.80	1.44	0.45
C	317,500	80	63	90	651,500	98	969,000	92.1	86.4	95.4	0.86	1.57	0.48
D	1,496,000	80	63	90	86,000	98	1,582,000	81.0	64.6	90.6	2.35	5.48	1.04
Wetland							269,098						
Total							6,429,098						

The resulting equation is an exponential relationship between rainfall (P) and runoff (Q). The curve number equation was used to calculate the total volume of water flowing into the wetland for each inlet as follows. The runoff depth from the curve number equation was then multiplied by the total area to obtain the total estimated volume for each rainfall event. The calculated volumes can be found in Appendix B

The amount of precipitation that fell on the wetland was simply calculated by multiplying the precipitation depth (in meters) by the open water wetland area (m^2). Although the open water wetland area varies with water level, it is small compared to the watershed area so an average value of 269,098 sq. ft. was assumed.

Inflow – Stage-Storage Relationship

A stage-storage relationship defines the relationship between the depth of water and storage volume in a water body. The volume of storage can be calculated by using a formula expressed as a function of storage depth. This relationship between storage volume and depth defines the stage-storage curve (*ConnDOT Drainage Manual*, 2000).

To determine a stage-storage rating curve, an AutoCAD Civil 3D model (Figure 22) of the wetland was created using the as-built topographical survey. The model was created by plotting the points in the survey in an x-y coordinate system and giving them an elevation value (z). AutoCAD then created a surface by joining those points. With it, the volume in the wetland was calculated at various levels of stage (Figure 23). The abscissa and the ordinate were then flipped to have stage be the independent variable (Figure 24).

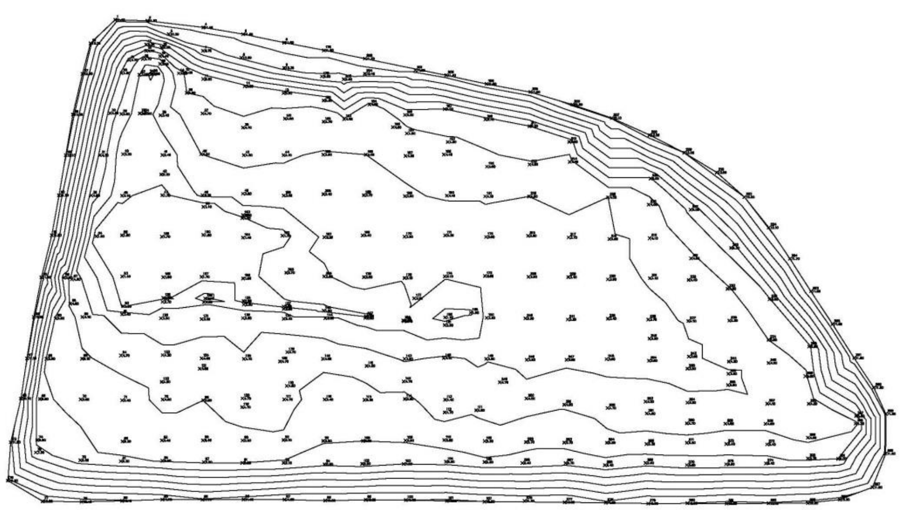


Figure 22 - The AutoCAD model created a surface from the elevation points on the as-built topographical survey (shown) and then plotted the contour lines (shown).

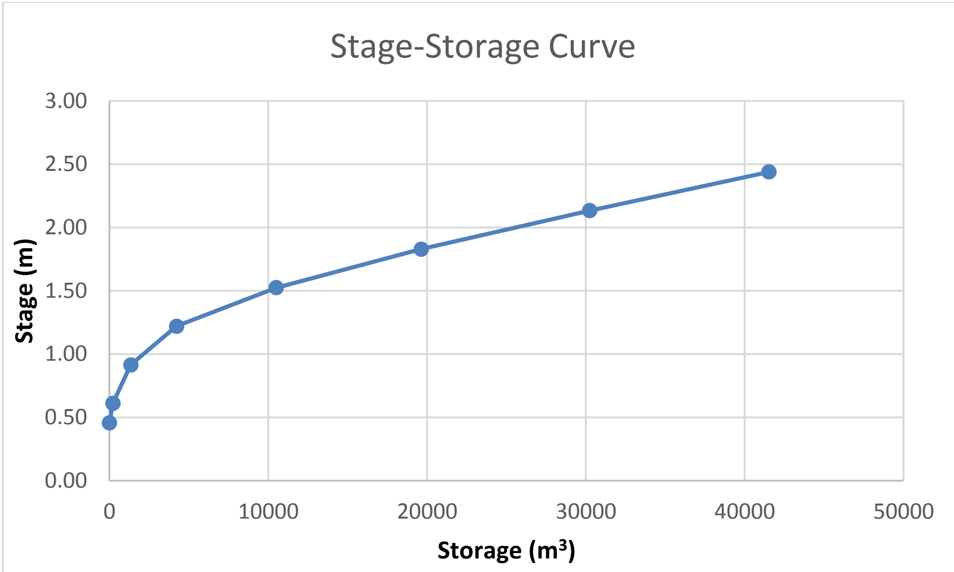


Figure 23 - The volume in the wetland was calculated at various levels of stage.

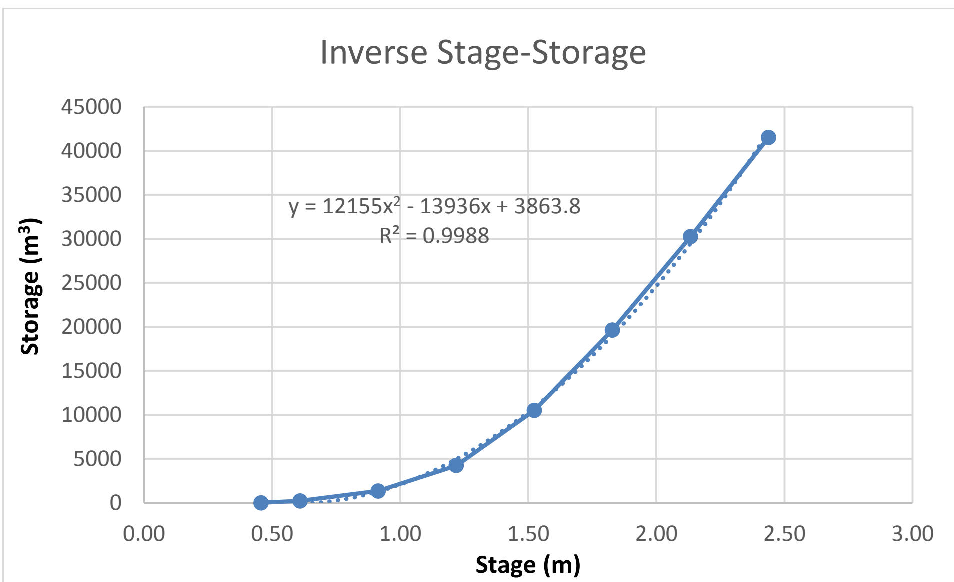


Figure 24 - A polynomial trendline equation was obtained from the inverse stage-storage curve. An R value of 0.9988 indicates a good fit.

Lastly, a polynomial regression trend line was calculated in excel to obtain the equation that relates the water level (stage) to the volume (storage) in the wetland as shown below. It has a coefficient of determination (R^2) of 0.9988, indicating an excellent fit.

$$\boldsymbol{V = 12155 * d^2 - 13936 * d + 3863.8} \quad \textbf{(8)}$$

D is the water depth

V is the volume in the wetland.

The water level obtained from the Rugged TROLL was used to determine the volume of water in the wetland before and after each rain event. The net volume increase in the wetland was then determined by subtracting the volume before the rain event from the volume after the rain event, at the maximum water level recorded in the wetland. A table with the calculated volumes can be found in Appendix B.

Outflow – Stage-Storage Relationship

Through preliminary measurements it was observed that Gum Bayou rises at a similar rate as the wetland shortly after a storm event. It was determined that outflow happens over a period of days, whereas inflow happens within hours; therefore average daily flowrates were calculated. The peak flowrate was determined by calculating the change in volume during the first 24 hours after the water level peaked. The flowrate for subsequent days was calculated until it fell below 10% of the peak flowrate. The process is explained below:

1. The peak water level in the wetland was determined from the Rugged TROLL data. It marked the starting point for the outflow calculations. Outflow before this point was assumed to be negligible

2. The water level after 24 hours was determined and inputted into the stage-storage relationship to determine the change in volume. This was defined as the peak flowrate.
3. The water level change at 24 hour intervals was determined and inputted into the stage-storage relationship to determine daily outflow.
4. The calculations continued until the calculated outflow was less than 10% of the peak outflow.
5. The average daily outflows were added to obtain a cumulative outflow volume per rain event.

The spreadsheet with the calculated flowrates can be found in Appendix A

Evapotranspiration and Infiltration

Evaluating the wetland's hydrology and water quality during the inter-storm periods was beyond the scope of this study so it was determined that estimating evapotranspiration & infiltration was not necessary.

Water Quality Analysis

E. coli *Concentration*

3M™ Petrifilm™ *E. coli*/Coliform Plates were used to identify both *E. coli* and other gram negative coliform (non-*E. coli*) bacteria with confirmed results within 24-48 hours. They have been determined to be comparable to mHPC agar using the membrane filtration procedure according to the Standard Methods for the Examination of Water and Wastewater.

Escherichia Coli is the standard indicator organism of fecal contamination in freshwater. 3M™ Petrifilm™ *E. coli*/Coliform Plates (Figure 25) were traditionally used in the food industry, but have proven to be accurate and publishable for water samples (Schraft & Watterworth, 2005). The method involves three steps:

- Inoculate - Lift the top film and add sample.
- Incubate – This can take from 24 to 48 hours.
- Enumerate - Confirmed coliforms are red and blue colonies with associated gas bubbles. Confirmed *E. coli* coliforms are blue colonies with associated gas bubbles.

Figure 25 - 3M Petrifilm plates were used to measure *E. coli* (blue) and other coliforms (red).

Validation

To validate the sampling procedure and analysis, a set of samples were split and analyzed with 3M Petrifilm Plates and also sent to a local environmental laboratory that is approved by the National Environmental Laboratory Accreditation Program (NELAP). The laboratory used IDEXX Colilet™ 18 which is ISO Standard 9308-2:2012. It is also EPA-approved and included in Standard Methods for Examination of Water and Wastewater. The results showed good general agreement and are summarized in Appendix C.

Other Parameters

The following parameters were measured sporadically to determine if concentrations were high enough to be of concern.

Total Coliforms

As explained above 3M Petrifilm Plates were used to measure Total Coliforms. In general the total coliform concentration was an order of magnitude higher than *E. coli*.

Total Suspended Solids (TSS)

Section 2540 of the Standard Methods for the Examination of Water and Wastewater was followed to determine TSS. The values ranged from 5 mg/l to 60 mg/l for inflow and 15 mg/l to 50 mg/l for outflow.

Total Dissolved Solids (TDS)

A conductivity probe was used to measure conductivity to approximate TDS. The values ranged from 35 µS to 283 µS for inflow and 181 µS to 331 µS for outflow.

Nitrogen-Ammonia

The Nitrogen-Ammonia was determined using a Hach testing kit. The procedure involved adding a reagent that added color to the sample according to the ammonia concentration. The sample was then compared to a continuous color gradient wheel and the matching color determined the sample's concentration. The values ranged from 0 to 0.4 mg/l for inflow and were below the detection limit for the outflow.

Nitrogen-Nitrate

The Nitrogen-Nitrate was determined using a Hach testing kit. The procedure involved adding a reagent that added color to the sample according to the nitrate concentration. The sample was then compared to a continuous color gradient wheel and the matching color determined the sample's concentration. The concentrations were below the detection limit for all the samples.

Phosphorous

The Nitrogen-Ammonia was determined using a Hach testing kit. The procedure involved adding a reagent that added color to the sample according to the ammonia concentration. The sample was then compared to a continuous color gradient wheel and the matching color determined the sample's concentration. The values ranged from 0 to 0.8 mg/l for inflow and were below the detection limit for the outflow.

pH

A probe was used to measure pH. The values ranged from 7.1 to 7.6 for inflow and 7.1 to 7.6 for outflow.

Statistical Analysis

The concentration data was analyzed following the statistical methods outlined in the BMP Database Monitoring Guide using the XLSTAT analysis software package in Microsoft Excel.

Descriptive Statistics

Descriptive statistics include measures of location or central tendency (mean and median) and measures of spread or variability (standard deviation and interquartile range).

Parametric Statistics

Parametric statistics operate under the assumption that data arise from a single statistical distribution. The specific distribution to which the data are modeled is often chosen by scientific judgment, graphical means, and goodness-of-fit tests The one sample Kolmogorov-Smirnov (K-S) test was used to determine if the data fits well to the normal and lognormal distributions.

Non-Parametric Statistics

Non-parametric statistics are fundamentally based on the ranks of the data with no need to assume an underlying distribution. Non-parametric statistics do not depend on the magnitude of the data and are therefore resistant to the occurrence of a few extreme values (i.e., high or low values relative to other data points do not significantly alter the statistic). The data median is the most basic example of a non-parametric statistic. The Mann-Whitney Test is a non-parametric test to determine if the null hypothesis that the inflow and outflow median EMC's are equal should be rejected.

Hypothesis Testing

The t-Test is a parametric test to determine if the null hypothesis that the inflow and outflow mean EMC's are equal should be rejected. It was performed on raw and log-transformed data. The Levene Test is a parametric test to determine if the null hypothesis that the two variances are equal should be rejected. It was performed on raw and log-transformed data. All hypothesis tests were performed at a 90% and 95% confidence levels.

Data Plots

Box Plots

Box plots (or box and whisker plots) provide a schematic representation of the central tendency and spread of the data. A standard boxplot consists of two boxes and two lines.

The lower box expresses the range of data from the 25th percentile (1st quartile or Q1) to the median of the data (50th percentile, 2nd quartile, Q2). An upper box represents the spread of the data from the median to the 75th percentile (3rd quartile or Q3). The total height of the two boxes is known as the interquartile range (Q3 – Q1). The confidence interval about the median is the point at which the box's "sides" stop slanting and become a straight vertical line. A "step" is 1.5 times the interquartile range. Two lines are drawn from the lower and upper bounds of the boxes to the minimum and maximum data points (respectively) within one step of the limits of the box. Asterisks or other point symbols are sometimes used to represent outlying data points.

Figure 26 shows a sample boxplot with each characteristic visually displayed.

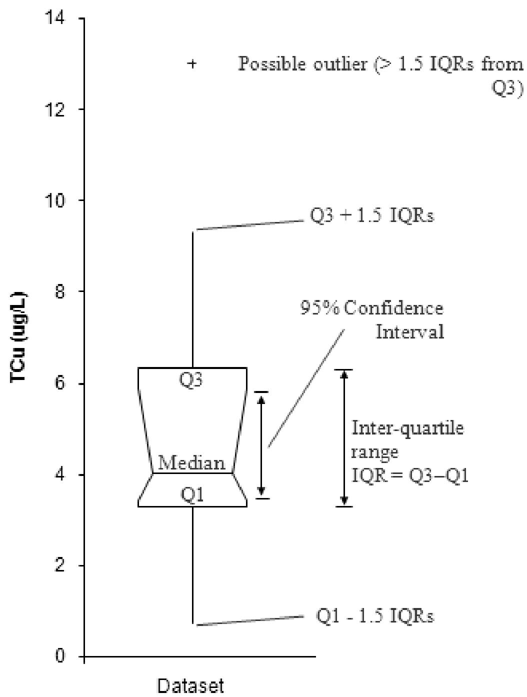


Figure 26 –Box plots show nonparametric statistics including the median, the inter-quartile range and the confidence interval. This is a sample plot that includes labels (Wright Water Engineers and Geosyntec Consultants, 2009)

Time Series Plot

Time series plots simply display the linear inflow and outflow pollutant concentration over the dates the sample were taken. They are provided to give an indication of the number of samples collected over the course of the study, which events had paired samples, and the relative difference between influent and effluent concentrations. Time series plots are helpful in determining seasonal variations.

Lognormal Probability Plot

Lognormal Probability plots are constructed by ranking the sample data and then calculating the plotting position for each data point with the following formula (Helsel, Hirsch, & Gotway, 2002):

$$\boldsymbol{p = \frac{i - 0.4}{N + .02}} \qquad \textbf{(9)}$$

i: rank of the data point

N: number of data points

p: plotting position

The ranked data are placed on the x-axis and the corresponding plotting positions, or percent less than (i.e., percentage of total data points below the value on the x-axis), are placed on the y-axis. This produces a sample approximation of the cumulative distribution function (CDF) where the probability of a random sample value being less than or equal to an observation can be directly determined. Conversely, the percent of data points exceeding a water quality threshold (i.e., percent exceedance) can be simply computed as one minus the percentage of data points less than the value on the x-axis. Probability plots were chosen for graphical analysis of the water quality concentration data because of the plot's ability to quickly and succinctly relay information about the following:

1. How well data, or transformed data, at each monitoring station are represented by the normal distribution.

2. The mean and standard deviation of the normal distribution and the value of any specific quantile. The slope of the normal approximation is an indication of the magnitude of

the standard deviation (straight line); the x-intercept demonstrates the log mean concentration.

3. The relationship between two distributions across the range of quantiles.
4. The presence of any significant outliers.
5. The width of the 95 percent confidence interval of the normal approximation.

5. RESULTS

Calculated Inflows and Outflows

Each storm event where there was successful data collection is plotted below. Figure 27 shows total precipitation in inches, total inflow volume in cubic meters as calculated by the SCS Curve Number method and total inflow volume as calculated by the Stage-Storage method. Figures 28 and 29 show the daily outflow as calculated by the Stage-Storage method. The data tables are shown in Appendix B.

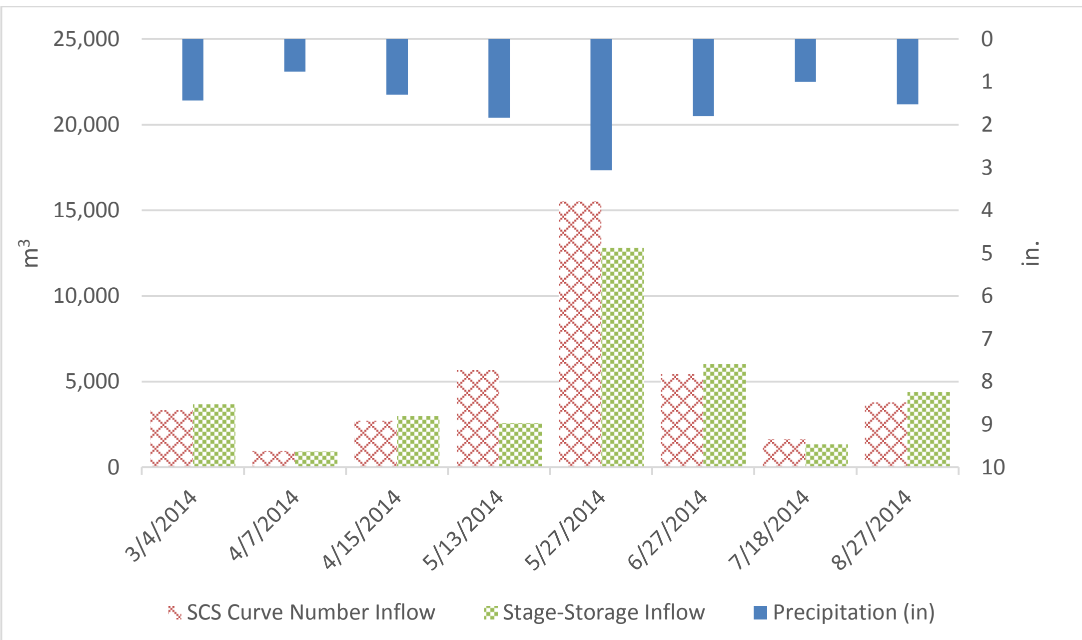


Figure 27 - Inflows by the SCS CN (hatched) and Stage Storage (dotted) methods showed a strong agreement. Precipitation (solid) was plotted on a secondary axis.

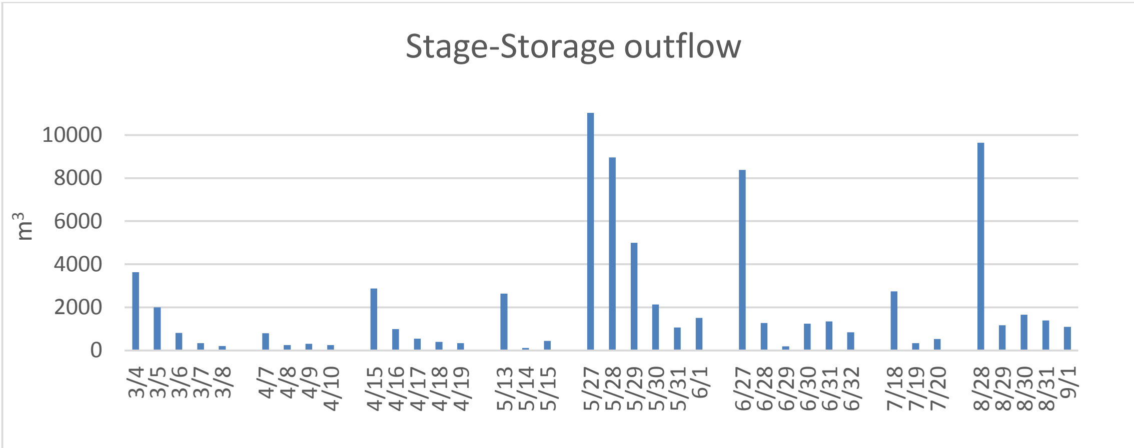


Figure 28 – After a storm event, the highest flowrates occurred within 24 hours, but there was continued outflow for 3-5 days.

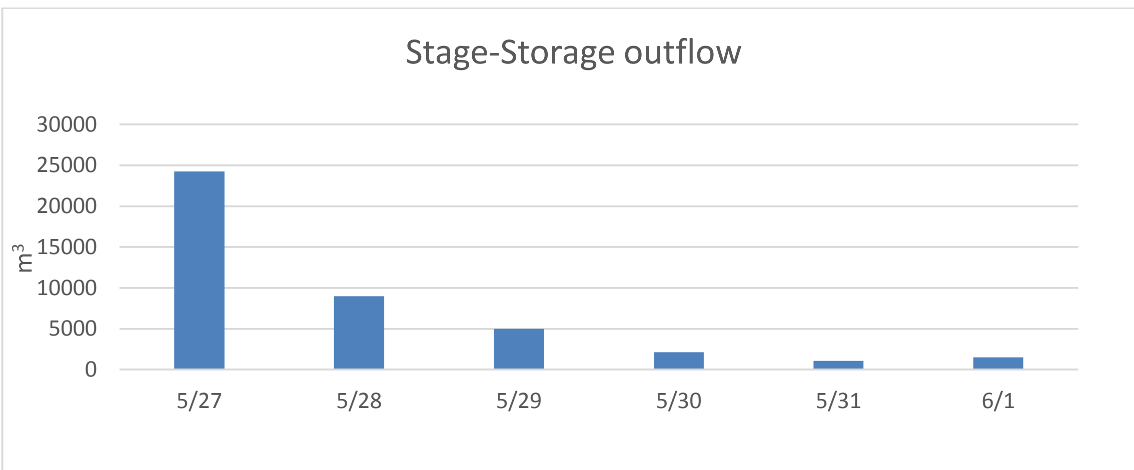


Figure 29 - Daily outflow volumes for the 5/27/14 rain event are shown in detail.

E. coli

E. coli *Concentrations*

The following results were calculated with Microsoft Excel with the addition of the XLSTAT statistical analysis software. The detailed output from XLSTAT can be found in Appendix D. Figure 30 shows a time series plot of raw *E. coli* concentrations. Inflow concentrations were not available in the early stages of the study due to equipment difficulties. All inflow samplers need to successfully collect a sample for an inflow concentration to be calculated. Figure 31 shows a the time series plot of the log transformed data.

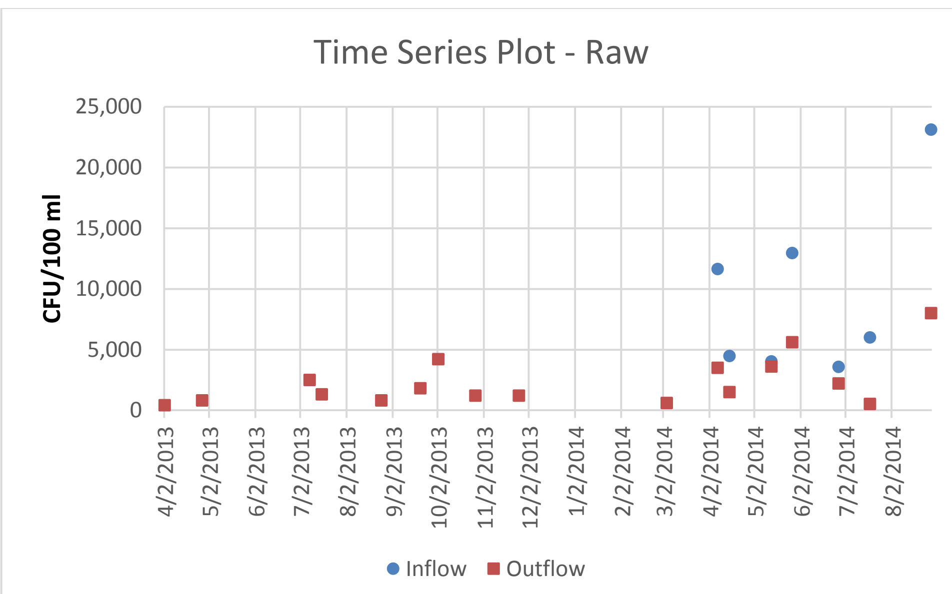


Figure 30 –Time series plot of raw *E. coli* concentrations. All inflow samplers were repaired by April 2014.

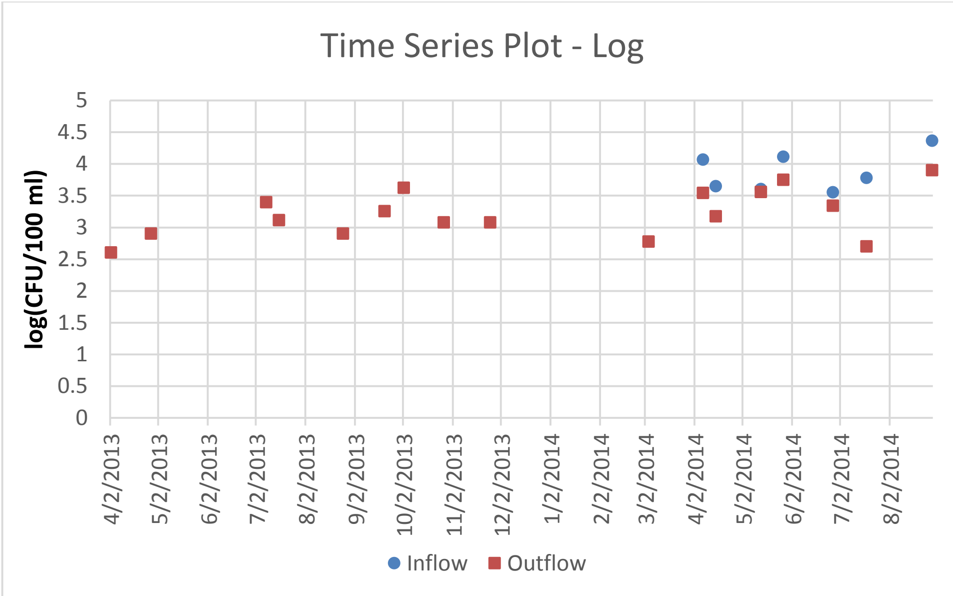


Figure 31 –Time series plot of log transformed *E. coli* concentrations.

Table 8 provides a summary of descriptive statistics for *E. coli* concentrations. It is notable that both the median and the mean concentration were lower in the outflow than in the inflow with the median difference being statistically significant at $\alpha<0.10$. However, it should also be noted that the sample size is relatively small with 7 inflow observations and 17 outflow observations. A graphical interpretation of this table can be seen in the Notched Box-and-Whisker Plot shown in Figure 32. Table 9 provides a summary of Hypothesis Testing. The following null hypotheses were rejected at 90% and 95% confidence levels for raw and log transformed data:

- The inflow and outflow median EMC's are equal
- The inflow and outflow mean EMC's are equal
- The two variances are equal

Table 8 – Summary of descriptive statistics for *E. coli* concentrations for all samples.

Performance Metric	Inflow	Outflow	Comparison
No. of observations	7	17	-
Median (CFU/100ml)	5,987	1,500	Decreased
Mean (CFU/100ml)	9,386	2,335	Decreased
Standard deviation (CFU/100ml)	7,116	2,072	-
1st Quartile (CFU/100ml)	4,246	800	Decreased
3rd Quartile (CFU/100ml)	12,277	3,500	Decreased
Well-fit to normal distribution?	Yes	Yes	-
Well-fit to lognormal distribution?	Yes	Yes	-
***Statistically Significant Difference in Median (Mann-Whitney α<0.10)?**			**Yes**

Table 9 – Summary of hypothesis testing for *E. coli* concentrations for all Samples.

Statistical Test	Data	Null Hypothesis	p-value	Reject Null Hypothesis?	
				α=0.05	α=0.10
Mann-Whitney:	Raw	The inflow and outflow median EMC's are equal	0.002	Yes	Yes
t-Test: (Assume Unequal Variance)	Raw	The inflow and outflow mean EMC's are equal	0.039	Yes	Yes
	Log	The inflow and outflow mean EMC's are equal	0.001	Yes	Yes
Levene (Raw Data):	Raw	The two variances are equal	0.001	Yes	Yes
	Log	The two variances are equal	0.569	No	No

Table 10 and Table 11 are similar to Table 8 and Table 9, but they only include paired data. Paired data only includes outflow concentrations collected at the same time as inflow concentrations.

Table 10 - Summary of descriptive statistics for *E. coli* concentrations for paired samples.

Performance Metric	Inflow	Outflow	Comparison
No. of observations	7	7	-
Median (CFU/100ml)	5,987	3,500	**Decreased**
Mean (CFU/100ml)	9,386	3,557	**Decreased**
Standard deviation (CFU/100ml)	7,116	2,560	-
1st Quartile (CFU/100ml)	4,246	1850	**Decreased**
3rd Quartile (CFU/100ml)	12,277	4,600	**Decreased**
Well-fit to normal distribution?	Yes	Yes	-
Well-fit to lognormal distribution?	Yes	Yes	-
***Statistically Significant Difference in Median (Mann-Whitney α<0.10)?**			**Yes**

Table 11 - Summary of hypothesis testing for *E. coli* concentrations for paired samples.

Statistical Test	Data	Null Hypothesis	p-value	Reject Null Hypothesis?	
				α=0.05	α=0.10
Mann-Whitney:	Raw	The inflow and outflow median EMC's are equal	0.041	Yes	Yes
t-Test: **(Assume Unequal Variance)**	Raw	The inflow and outflow mean EMC's are equal	0.078	No	Yes
	Log	The inflow and outflow mean EMC's are equal	0.037	Yes	Yes
Levene (Raw Data):	Raw	The two variances are equal	0.183	No	No
	Log	The two variances are equal	0.781	No	No

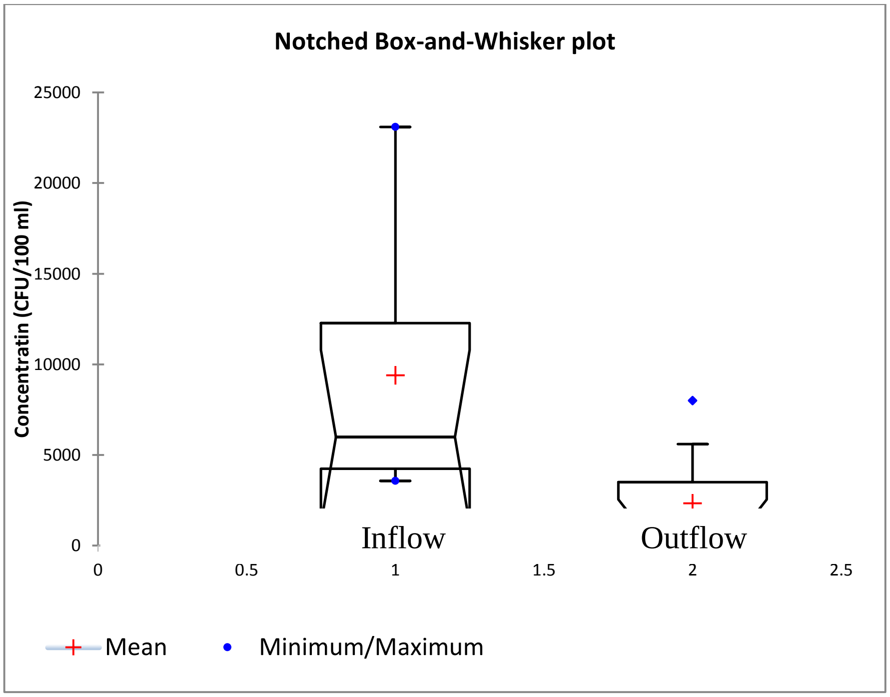


Figure 32 – This *E. coli* concentration box plot summarizes the data in Table 8. Note that quartiles are inside the confidence interval due to the small number of events monitored.

Figure 33 shows the Lognormal Probability Plot for *E. coli* concentrations. Ranked influent and effluent concentrations are plotted on a logarithmic abcissa and the probability of non-exceedance is plotted on the ordinate. A comparison of the influent and effluent probability plots indicates whether there may be differences among all percentiles (not just the median) and whether the influent and effluent data sets are similarly distributed. Probability plots also provide a quick method of identifying the probability that an individual sample would be less than or equal to a particular value.

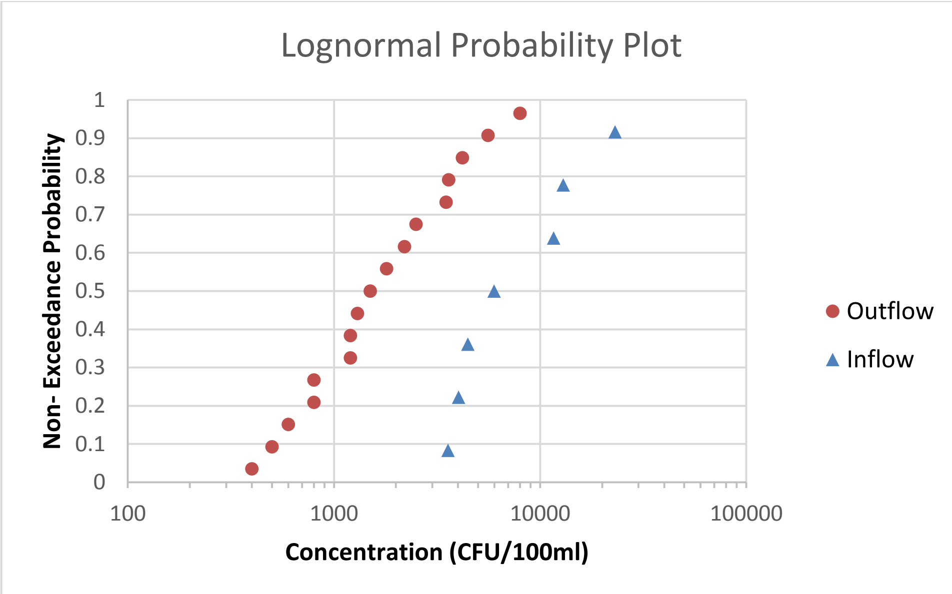


Figure 33 - *E. coli* concentration lognormal probability plot for *E. coli* concentrations. The probability of exceedance for a certain concentration is shown. For example, the probability that an inflow concentration will not exceed 6,000 CFU/100 ml is 0.5.

E. coli *Loading*

The results in Figure 34 show a clear decrease in *E. coli* loading (CFU) from the inlets to the outlet. It is notable that a higher reduction was achieved in the events with higher inflow loading.

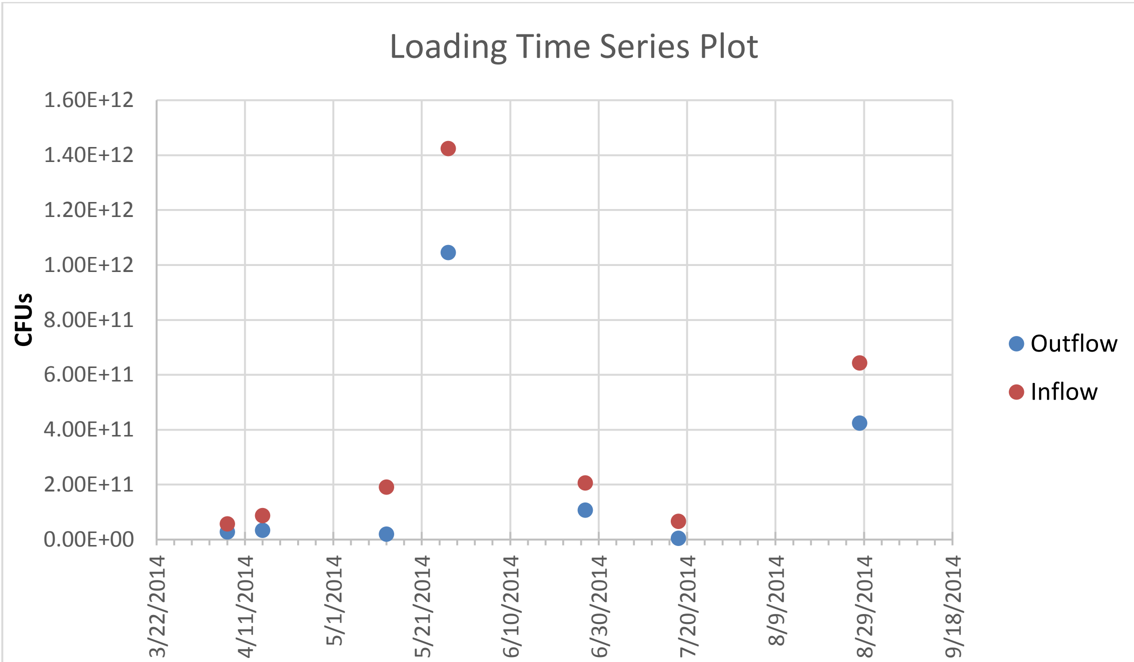


Figure 34 – The *E. coli* CFU loading time series plot shows a significant load reduction for each event. The spread between inflow and outflow increases as loading increases suggesting better treatment efficiency for higher loadings.

The total reduction of *E. coli* loading was calculated to be 1.02 x 10^{12} CFU over the four month study period. Making the assumption that study period was representative of the typical loading reduction throughout the year and normalizing on a per acre basis, it results in an estimate reduction of 2.0 x $10^{10}\frac{\text{CFU}}{\text{acre}*\text{yr}}$. A comparison can then be made to the estimated loading reduction in the Watershed Protection Plan (WPP). As discussed in the introduction, the WPP calculated an expected load reduction of 1.20 x 10^{15} CFU/yr for bacteria for a wetland treating runoff from a 250 acre watershed. Normalized on a per acre basis results in 4.8 x $10^{12}\frac{\text{CFU}}{\text{acre}*\text{yr}}$.

Comparison to Similar BMPs

Results from the BMP database were used to determine how the wetland's *E. coli* treatment performance compares to similar BMPs. The results from the same type of statistical analysis as performed for this study were downloaded for studies on wetland basins, retention ponds and detention basins. A simple comparison of median and mean *E. coli* concentrations among BMPs show a decrease in all of them as shown in Table 12. However, percent reductions were not calculated due to its limitations as explained in the literature review. A more sophisticated evaluation was done by comparing the lognormal probability plots. Although the influent and effluent concentrations in a probability plot are not paired values, the relative position and slope of the two populations are a good indication of the effectiveness of the BMP.

Table 12 – The mean and median summary table shows that for the BMPs compared there is a reduction in mean and median *E. coli* concentrations (except for detention basins).

Performance Metric	Inflow	Outflow	Comparison
Education Village Wetland – All Data	**(CFU/100ml)**	**(CFU/100ml)**	
Median	5,987	1,500	**Decreased**
Mean	9,386	2,335	**Decreased**
Education Village Wetland – Paired Data			
Median	5,987	3,500	**Decreased**
Mean	9,386	3,557	**Decreased**
Wetland Basins			
Median	3,973	727	**Decreased**
Mean	21,748	6,765	**Decreased**
Retention Basins			
Median	3,466	393	**Decreased**
Mean	799,060	352,425	**Decreased**
Detention Basins			
Median	300	230	**Decreased**
Mean	405.67	464.62	**Increased**

Wetland Basins

Figure 35 shows a summary of the basic statistics and the hypothesis testing results for *E. coli* concentrations for the 7 studies available on Wetland Basins. It is notable that the median outflow concentration was 727 MPN/100ml, almost half of the outflow concentration for the Education Village Wetland, although the mean inflow concentration was also lower by two thirds. The lognormal probability plot on Figure 36 shows an even spread form 10% to 95% with the lower and upper ranges becoming very close suggesting there is a minimum concentration achievable. This is a notable difference with the Education Village Wetland, which still provides treatment in the lower concentration range

BASIC STATISTICS

PERFORMANCE METRIC	INFLOW	OUTFLOW	COMPARISON
Number of EMCs:	420	280	--
Percent of Non-Detects:	1%	1%	Increased
Median:	3973	727	Decreased
Mean:	21748	6765.67	Decreased
Standard Deviation:	43847.33	29110.62	Decreased
25th Percentile:	697	100	Decreased
75th Percentile:	17329	2987	Decreased
Well-fit to normal distribution?	No	No	--
Well-fit to lognormal distribution?	No	No	--
*Statistically Significant Difference in Median?	Yes		

HYPOTHESIS TESTING

STATISTICAL TEST	DATA	NULL HYPOTHESIS	p-value	Reject Null Hypothesis	
				a=0.05	a=0.10
Mann-Whitney:	Raw	The medians of the inflow and outflow EMCs are equal.	0	Yes	Yes
t-Test: (Assume Equal Variance)	Raw	The means of the inflow and outflow EMCs are equal.	0	Yes	Yes
	Log	The means of the logs of the inflow and outflow EMCs are equal.	0	Yes	Yes
t-Test: (Assume Unequal Variance)	Raw	The means of the inflow and outflow EMCs are equal.	0	Yes	Yes
	Log	The means of the logs of the inflow and outflow EMCs are equal.	0	Yes	Yes
Levene: (Raw Data)	Raw	The variances of the inflow and outflow EMCs are equal.	0	Yes	Yes
	Log	The variances of the logs of the inflow and outflow EMCs are equal.	0.209	No	No

Figure 35 - Summary of descriptive statistics and hypothesis testing for *E. coli* concentrations on wetland basins from the BMP database. It included 7 different studies on 6 test sites.

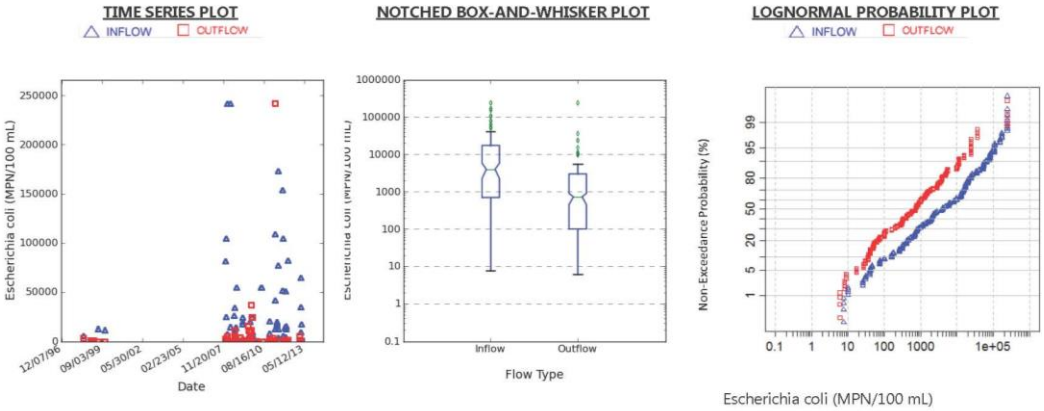


Figure 36 - Summary of plots for *E. coli* concentrations on wetland basins from the BMP database

Retention Basins

Figure 37 shows a summary of the basic statistics and the hypothesis testing results for *E. coli* concentrations for the 5 studies available on Retention Basins. It is notable that the median outflow was 393 MPN/100ml. The lognormal probability plot on Figure 38 shows an even spread form 0% to 60% with the upper range becoming very close. It is hard to tell if it is a statistical irregularity since many of the samples occurred within a short time period (as seen in the time series plot).

BASIC STATISTICS

PERFORMANCE METRIC	INFLOW	OUTFLOW	COMPARISON
Number of EMCs:	348	336	--
Percent of Non-Detects:	0%	1%	Increased
Median:	3466	393	Decreased
Mean:	799060.19	352425.66	Decreased
Standard Deviation:	2567708.94	1422090.43	Decreased
25th Percentile:	651	23	Decreased
75th Percentile:	31000	5225	Decreased
Well-fit to normal distribution?	No	No	--
Well-fit to lognormal distribution?	No	No	--
*Statistically Significant Difference in Median?		Yes	

HYPOTHESIS TESTING

STATISTICAL TEST	DATA	NULL HYPOTHESIS	p-value	Reject Null Hypothesis	
				a=0.05	a=0.10
Mann-Whitney:	Raw	The medians of the inflow and outflow EMCs are equal.	0	Yes	Yes
t-Test: (Assume Equal Variance)	Raw	The means of the inflow and outflow EMCs are equal.	0.005	Yes	Yes
	Log	The means of the logs of the inflow and outflow EMCs are equal.	0	Yes	Yes
t-Test: (Assume Unequal Variance)	Raw	The means of the inflow and outflow EMCs are equal.	0.005	Yes	Yes
	Log	The means of the logs of the inflow and outflow EMCs are equal.	0	Yes	Yes
Levene: (Raw Data)	Raw	The variances of the inflow and outflow EMCs are equal.	0.005	Yes	Yes
	Log	The variances of the logs of the inflow and outflow EMCs are equal.	0	Yes	Yes

Figure 37 - Summary of descriptive statistics and hypothesis testing for *E. coli* concentrations on retention basins from the BMP database. It included 5 different studies on 4 test sites.

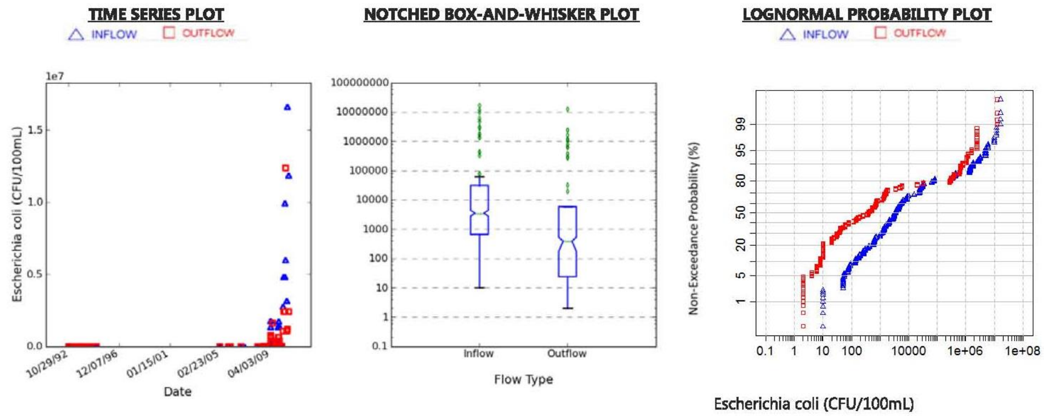


Figure 38 - Summary of plots for *E. coli* concentrations on retention ponds from the BMP database

Detention Basins

Figure 39 shows a summary of the basic statistics and the hypothesis testing results for *E. coli* concentrations for the 7 studies available on Detention Basins. It is notable that the median outflow was 230 MPN/100ml. The lognormal probability plot on Figure 40 shows a wide variation in non-exceedance probability. This can be attributed to the samall sample size, and to the fact that the null hypothesis was not rejected for most of the hypothesis tests.

BASIC STATISTICS

PERFORMANCE METRIC	INFLOW	OUTFLOW	COMPARISON
Number of EMCs:	36	36	--
Percent of Non-Detects:	11%	11%	--
Median:	300	230	Decreased
Mean:	405.67	387.67	Decreased
Standard Deviation:	335.63	464.62	Increased
25th Percentile:	80	4	Decreased
75th Percentile:	800	500	Decreased
Well-fit to normal distribution?	No	No	--
Well-fit to lognormal distribution?	No	No	--
*Statistically Significant Difference in Median?	No		

HYPOTHESIS TESTING

STATISTICAL TEST	DATA	NULL HYPOTHESIS	p-value	Reject Null Hypothesis	
				a=0.05	a=0.10
Mann-Whitney:	Raw	The medians of the inflow and outflow EMCs are equal.	0.369	No	No
t-Test: (Assume Equal Variance)	Raw	The means of the inflow and outflow EMCs are equal.	0.853	No	No
	Log	The means of the logs of the inflow and outflow EMCs are equal.	0.158	No	No
t-Test: (Assume Unequal Variance)	Raw	The means of the inflow and outflow EMCs are equal.	0.853	No	No
	Log	The means of the logs of the inflow and outflow EMCs are equal.	0.158	No	No
Levene: (Raw Data)	Raw	The variances of the inflow and outflow EMCs are equal.	0.416	No	No
	Log	The variances of the logs of the inflow and outflow EMCs are equal.	0.093	No	Yes

Figure 39 - Statistical analysis of *E. coli* on detention basins from the BMP database. It included data from a single study.

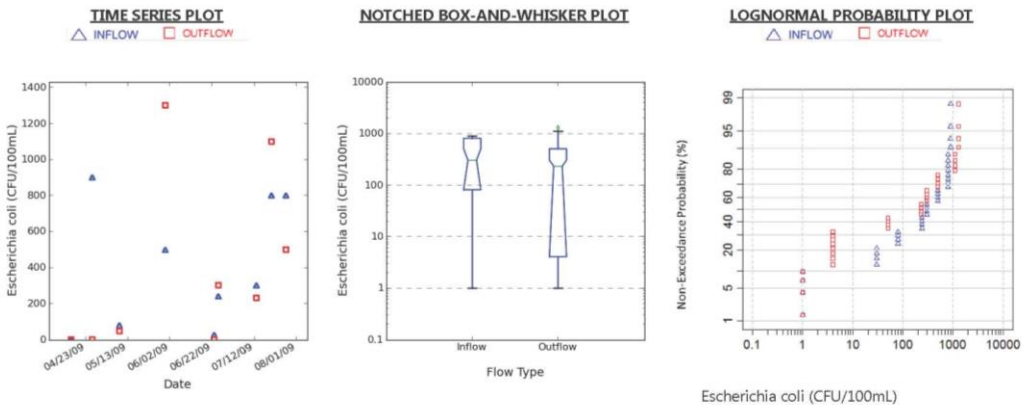


Figure 40 - Summary of plots for *E. coli* concentrations on detention basins from the BMP database

6. DISCUSSION

E. coli Concentrations

The results show that the Education Village Wetland provides significant treatment when comparing the median inflow to outflow *E. coli* concentrations. This was the case when evaluating all samples and only the paired samples. While it's tempting to quantify the reduction in *E. coli* concentrations as a percent removal, there are many drawbacks to that method as discussed in the literature review, therefore lognormal probability plots were created. A comparison of the influent and effluent probability plots indicates whether there may be differences among all percentiles (not just the median) and whether the influent and effluent data sets are similarly distributed.

Inflow Concentrations

The inflow concentration mean was 9,386 CFU/100ml. This was significantly higher than expected for an institutional suburban watershed. These high values were independently verified by a local laboratory as explained in the methodology section. While the exact cause behind these high values is unknown, possible factors that affected the inflow concentrations could be a septic sewer overflow, domestic animals or wildlife. There is also some uncertainty in the collection method related to the pollutograph estimation. Using only three samples to estimate the pollutograph might be inadequate. Since there is no way to determine the pollutograph in advance, samples could be under or overestimated. Samples might be overestimated if they were all collected during the first flush effect, or underestimated if they were collected much later. This is particularly relevant for this study since the samplers were activated by a rise in water level and were not flow-paced. Further research is needed to shed light onto the exact cause of these high concentrations.

Outflow Concentrations

The outflow concentration mean was 2,335 CFU/100ml and had a much lower standard deviation than the inflow (2,072 CFU/100ml for outflow vs 7,116 CFU/100ml for inflow). The possible factors that affected the outflow include a large wildlife population and the Hydraulic Retention Time (HRT). While it is expected that most BMPs will reduce *E. coli* concentrations, this is not always the case on BMPs with large wildlife populations which could reintroduce *E. coli* directly to the wetland. Furthermore, most of the measured outflow concentrations were low for storm events where the estimated HRT was high (small storm events and long inter-event periods). In the case of larger events on 5/27 and 8/28, the outflow concentrations were generally higher due to the lower estimated HRT. In these cases the HRT was probably shorter because most of the water in the wetland was replaced by new runoff. Alternatively, there could have been some short-circuiting where some influent water found its way to the outflow faster than expected. Tracer studies and/or hydraulic modelling could be done to further understand the nature of the HRT in this wetland.

Comparison to Similar BMPs

Making a comparison among BMPs is not a simple task due to the myriad of variables that are specific to each site affecting each BMP's performance. The Education Village Wetland's *E. coli* treatment performance was compared to results from similar BMPs from the BMP Database using the lognormal probability plot. The data from the detention ponds was insufficient to be compared since the null hypothesis was not able to be rejected in almost all statistical tests. Comparing the effluent concentration at three different non-exceedance probabilities allows for reasonable comparison of their lognormal probability plots. As shown in Table 13, the concentrations for the Education Village wetland were higher at non- exceedance probabilities of 0.1 and 0.5, but lower at 0.9. This could indicate that the minimum achievable concentration in the Education Village wetland is relatively high. However, the concentrations at high non-exceedance probability are expected to be low.

Table 13 - Non-exceedance probability comparison

Non-Exceedance Probability	Education Village Wetland (CFU/100ml)	Wetland Basins (CFU/100ml)	Retention Basins (CFU/100ml)
0.1	500	9	2
0.5	1,500	900	500
0.9	5,600	10,000	100,000

Retention Ponds provide a better effluent quality at low and medium non-exceedance probabilities (0.1 and 0.5) than the Education Village Wetland and other Wetland Basins. A possible reason for difference in performance is that wetlands had the added loads of wildlife. However, a significant drawback of Retention Ponds is that the quality of the habitat provided for wildlife is generally of lesser quality compared to a wetland basin. In this context, a holistic approach should be taken when deciding whether or not to increase a ponds attractiveness to wildlife as it could be linked to an increase in *E. coli* concentrations. There are many limitations to this approach, but as more research is done, better comparisons can be made.

***E. coli* Loading**

The results also show that the Education Village Wetland provides significantly reduced *E. coli* loads into Gum Bayou. Factors that affected the loading results included the *E. coli* concentrations as discussed in the previous section and uncertainties in the hydrologic and hydraulic analysis.

Hydrologic and Hydraulic Analysis

There is some uncertainty in the calculation of the inflow flowrate due to the inherent imprecision of the Curve Number method. When the Curve Number method results were compared to the Stage Storage method results, there was a 15% difference on average.

The outflow was only calculated with the stage storage method. The main uncertainty with this method was that it did not take into account any flowrate that happened when inflow and outflow are both happening simultaneously, since the water level did not change at that time. This was a minor concern since inflow generally happened in the time scale of hours and outflow continued for days. More accurate measuring methods could yield better results for both inflow and outflow.

Load Comparison to WPP Estimate

The normalized load reduction for the Education Village Wetland was 2.0 x $10^{10}\frac{CFU}{acre*yr}$ while the normalized load reduction estimated on the WPP was 4.8 x $10^{12}\frac{CFU}{acre*yr}$. In other words, the actual load reduction of the wetland on a per acre basis is lower than the estimated reduction on the WPP. This difference of two orders of magnitude is of concern because Dickinson Bayou is regulated under the Total Maximum Daily Load program. Possible causes of this discrepancy are the limitations of this research as outlined in this section. As mentioned above, it is also important to note that the wetland has not been fully vegetated and is thus not acting at its full "treatment capacity" and acting like a retention pond. It is expected that higher vegetation coverage will lead to improved load reductions.

Further Research

As explained above, there are unique challenges in data analysis for event-driven wetlands. Due to the limitations of this study there are many avenues of further research. First, the influent *E. coli* concentrations were significantly higher than comparable BMP. Considering the watershed only contains institutional facilities, high *E. coli* concentrations were not expected. Further research is needed to determine their cause. Another possible investigation could involve taking a more detailed hydrograph and pollutograph. This would reduce the uncertainties that affected this study. Moreover, more studies at other BMPs are needed for a better comparison of treatment performance, especially at detention basins. Finally, while this research highlights the possibility of a loading reduction that is lower than the WPP estimate, more research is needed to confirm that estimate.

7. CONCLUSION

The Dickinson Bayou watershed has seen increasing suburbanization and associated impacts to its water quality. Section 303(d) of the federal Clean Water Act requires all states to identify waters that do not meet applicable water quality standards. TCEQ first identified *E. coli* impairment to the contact recreation use for Dickinson Bayou in 1996, and in 2002 the impairment classification was expanded to include four major tributaries of Dickinson Bayou: Bensons Bayou Bordens Gully, Giesler Bayou and Gum Bayou. While Gum Bayou was then removed from the 303(d) List in 2006, it remains important to monitor and reduce *E. coli* loads. This was the reasoning behind the retrofit of a detention pond into a constructed wetland at the Education Village Campus. The objective of this research was to evaluate the constructed wetland's effectiveness in reducing effluent pollutant loads of *E. coli*. To achieve the objective, the following tasks were completed:

- Hydrologic and hydraulic monitoring at the wetland inlets and outlet
- Characterization of influent and effluent quality under a variety of storm types
- Comparison of the wetland's *E. coli* treatment performance with similar BMPs

The results showed a median *E. coli* inflow concentration of 5,987 CFU/100ml and a median outflow concentration of 1,500 CFU/100ml. The normalized *E. coli* load was calculated to be 2.0 x $10^{10}\frac{CFU}{acre*yr}$. A comparison to similar BMPs using lognormal probability plots showed the Education village compared favorably at high inflow concentrations, but had a higher minimum achievable concentration. The analysis of BMP performance data is often complex and challenging. Due to the limitations of this study there are a few avenues of further research. First, the influent *E. coli* concentrations were significantly higher than comparable BMPs. Considering the watershed only contains institutional facilities, high *E. coli* concentrations were not expected. Another possible investigation could involve taking a more detailed hydrograph and pollutograph. Moreover, more studies at other BMPs are needed for a better comparison of treatment performance, especially at detention basins. Finally, while this research highlights the possibility of a loading reduction that is lower than the WPP estimate, more research is needed to confirm that estimate.

The Dickinson Bayou is impaired for bacteria and dissolved oxygen. It is therefore necessary to identify sources of contamination and apply individually tailored mitigation strategies. This study attempted to provide a better understanding of the hydrology and the water quality of the Education Village Constructed Wetland system which flows into Dickinson bayou. It also helped to quantify the pollutant reduction goals of the Dickinson Bayou WPP. However, more research is needed to overcome the limitations of this study.

REFERENCES

Barros, F., Beatriz, M., Ortolani, T., Dora, B., & Melo, G. D. E. (2006). Comparison of Petrifilm Aerobic Count Plates and Lactic Acid Bacteria, *14*, 249–257.

Bavor, H. J., Davies, C. M., & Sakadevan, K. (2001). Stormwater treatment: do constructed wetlands yield improved pollutant management performance over a detention pond system? *Water Science and Technology : A Journal of the International Association on Water Pollution Research*, *44*(11-12), 565–70. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/11804151

Burton, F., Tchobanoglous, G., Tsuchihashi, R., Stensel, H. D., Eddy, M. &, & Inc. (2013). *Wastewater Engineering: Treatment and Resource Recovery*. McGraw-Hill Education. Retrieved from https://books.google.com/books?id=6KVKMAEACAAJ&pgis=1

Carleton, J. N., Grizzard, T. J., Godrej, a N., & Post, H. E. (2001). Factors affecting the performance of stormwater treatment wetlands. *Water Research*, *35*(6), 1552–62. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/11317903

ConnDOT Drainage Manual. (2000). Retrieved from http://www.ct.gov/dot/cwp/view.asp?a=3200&q=260116

Crowder, R. a. (2009). *Fluvial Design Guide*. The UK Environment Agency. Retrieved from http://evidence.environment-agency.gov.uk/FCERM/en/FluvialDesignGuide.aspx

Davies, C. M., & Bavor, H. J. (2000). The fate of stormwater-associated bacteria in constructed wetland and water pollution control pond systems. *Journal of Applied Microbiology*, *89*(2), 349–360. doi:10.1046/j.1365-2672.2000.01118.x

Dickinson Bayou Watershed Partnership. (2009). Dickinson Bayou Watershed Protection Plan.

Gronewold, A. D., & Wolpert, R. L. (2008). Modeling the relationship between most probable number (MPN) and colony-forming unit (CFU) estimates of fecal coliform concentration. *Water Research*, *42*(13), 3327–34. doi:10.1016/j.watres.2008.04.011

H. F. Scheider III P.E., & PBK Architects. (2008). CCISD As Builts.pdf.

Helsel, D. R., Hirsch, R. M., & Gotway, C. A. (2002). *Statistical Methods in Water Resources*. *Technometrics*. doi:10.2307/1269385

International Stormwater Best Management Practice Database. (2014). Wright Water Engineers; Inc. and Geosyntec Consultants for the Water Envir; the American Society of Civil Engineers (ASCE)/Env; the American Public Works Association (APWA); and U.S. Environmental Protection Agency (EPA). Retrieved from http://www.bmpdatabase.org/

Kadlec, R. H., & Wallace, S. D. (2009). *Treatment Wetlands, Second Edition*. Boca Raton, FL: CRC Press.

Lim Hojin P.E, & S&B Infrastructure. (2011). Stormwater Treatment Wetlands Project CCISD.PDF.

Martin, E. H., & Smoot, J. L. (1986). Constituent-Load Changes in Urban Stormwater Runoff Routed Through a Detention Pond-Wetlands System in Central Florida.

Minton, G. R. (2005). *Stormwater Treatment*. Seattle, WA: Resources Planning Associates.

Novotny, V. (1995). *Nonpoint Pollution and Urban Stormwater Management*. Lancaster, Pennsylvania: Technomic Publishing.

Scherger, D. A., & Davis, J. A. (1982). Control of stormwater runoff pollutant loads by a wetland and retention basin. *International Symposium on Urban Hydrology, Hydraulics*, 109–123.

Schraft, H., & Watterworth, L. a. (2005). Enumeration of heterotrophs, fecal coliforms and Escherichia coli in water: comparison of 3M Petrifilm plates with standard plating procedures. *Journal of Microbiological Methods*, *60*(3), 335–42. doi:10.1016/j.mimet.2004.10.008

Schueler, T. R. (2000). Irreducible Pollutant Concentrations Discharged from Stormwater Practices. *The Practice of Watershed Protection*. Ellicott City, MD: Center for Watershed Protection.

Silva, B. O., Caraviello, D. Z., Rodrigues, a C., & Ruegg, P. L. (2005). Evaluation of Petrifilm for the isolation of Staphylococcus aureus from milk samples. *Journal of Dairy Science*, *88*(8), 3000–3008. doi:10.3168/jds.S0022-0302(05)72980-5

Strecker, E. W., Kersnar, J. M., Driscoll, E. D., & Horner, R. R. (1992). *The use of wetlands for controlling stormwater pollution*.

Texas Comission on Environmental Quality. (2012). Eight Total Maximum Daily Loads for Indicator Bacteria in Dickinson Bayou and Three Tidal Tributaries.

Web Soil Survey - Home. (2015). Retrieved from http://websoilsurvey.sc.egov.usda.gov/

Wong, T. H. F., Fletcher, T. D., Duncan, H. P., & Jenkins, G. a. (2006). Modelling urban stormwater treatment-A unified approach. *Ecological Engineering*, *27*(1), 58–70. doi:10.1016/j.ecoleng.2005.10.014

Wotzka, P., & Oberts, G. (1988). The Water Quality Performance of a Detention Basin - Wetland Treatment System in an Urban Area. *Nonpoint Pollution: Policy, Economy, Management, and Appropriate Technology*.

Wright Water Engineers and Geosyntec Consultants. (2007). *Frequently Asked Questions : Why does the International Stormwater BMP Database Project omit percent removal as a measure of BMP performance?* Retrieved from www.bmpdatabase.org

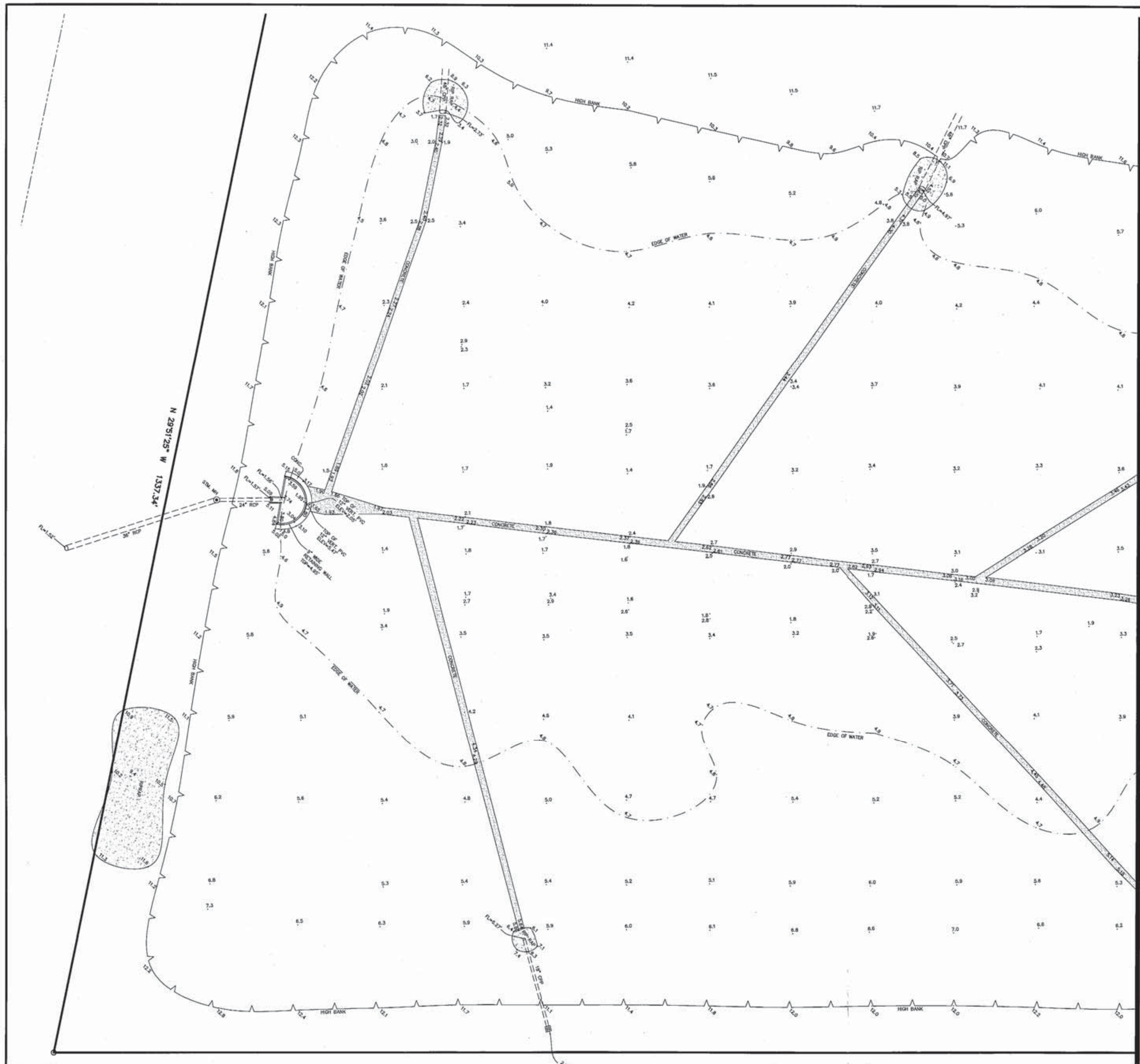
Wright Water Engineers and Geosyntec Consultants. (2009). *BMP Monitoring Manual*. Retrieved from www.bmpdatabase.org

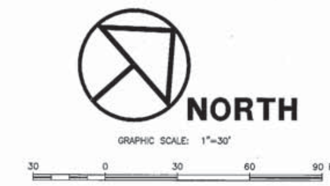
Wright Water Engineers and Geosyntec Consultants. (2010). International Stormwater Best Management Practices (BMP) Database User's Guide for BMP Data Entry Spreadsheets, (August).

APPENDICES

Appendix A - Wetland As-Built Drawings
Appendix B - Calculated Inflow and Outflow Volumes
Appendix C - *E. Coli* Validation Results
Appendix D - XLSTAT Output

Appendix A -Wetland As-Built Drawings





GALVESTON COUNTY, TEXAS

VICINITY MAP

NOT TO SCALE

BENCHMARK INFORMATION

ALL ELEVATIONS SHOWN HEREON ARE BASED ON BENCHMARK INFORMATION AS SHOWN ON A PREVIOUS TOPOGRAPHIC SURVEY PERFORMED BY CLR, INC. DATED JANUARY 09, 2008.
T.B.M. NO. 1 = CUT "BOX" ON TOP OF A 7' X 8' BOX CULVERT ON DOWNSTREAM SIDE OF DRAINAGE DITCH ALONG WEST SIDE OF SUBJECT PROPERTY, APPROXIMATELY 2000' SOUTH OF THE SOUTH RIGHT-OF-WAY LINE OF STATE HWY. 96. ELEV=14.18 FT. (NAVD 88, 1991 ADJ.)
T.B.M. NO. 4 = TOP OF 3/4" IRON ROD 60' NORTHEAST OF THE SUBJECT PROPERTY NORTHEAST CORNER AND APPROXIMATELY 350' SOUTH OF THE SOUTH RIGHT-OF-WAY LINE OF STATE HWY. 96. ELEV=15.10 FT. (NAVD 88, 1991 ADJ.)

GENERAL NOTES

1. SURVEYOR DID NOT ABSTRACT SUBJECT PROPERTY. THIS SURVEY WAS PREPARED WITHOUT THE BENEFIT OF A TITLE COMMITMENT AND WOULD BE SUBJECT TO ANY AND ALL CONDITIONS OR RESTRICTIONS THAT A CURRENT TITLE COMMITMENT OR ABSTRACTORS CERTIFICATE MAY DISCLOSE.
2. BEARINGS WERE BASED ON THE TEXAS STATE PLANE COORDINATE SYSTEM, SOUTH CENTRAL ZONE, (NAD 83).
3. ACCORDING TO THE FEDERAL EMERGENCY MANAGEMENT AGENCY (FEMA), FLOOD INSURANCE RATE MAP (FIRM) FOR GALVESTON COUNTY, TEXAS, MAP NO. 485488 0014D REVISED/DATED SEPTEMBER 22, 1999, THE SUBJECT TRACT APPEARS TO LIE WITHIN UNSHADED ZONE "X". THIS DETERMINATION WAS DONE BY GRAPHIC PLOTTING AND IS APPROXIMATE ONLY, AND HAS NOT BEEN FIELD VERIFIED. THIS FLOOD NOTE DOES NOT IMPLY THAT THE PROPERTY OR STRUCTURES THEREON WILL BE FREE FROM FLOODING OR FLOOD DAMAGE. ON OCCASION FLOODS CAN AND WILL OCCUR AND FLOOD HEIGHTS MAY BE INCREASED BY MAN-MADE OR NATURAL CAUSES. THIS FLOOD NOTE SHALL NOT CREATE LIABILITY ON THE PART OF WINDROSE LAND SERVICES, INC.
4. THIS TOPOGRAPHIC SURVEY DOES NOT IMPLY TO BE A FULL BOUNDARY SURVEY OF THE PARENT TRACT AND SHOULD NOT BE RELIED UPON AS SUCH.
5. READILY VISIBLE IMPROVEMENTS AND UTILITIES WERE LOCATED WITH THIS SURVEY. NO SUBSURFACE PROBING, EXCAVATION OR EXPLORATION WAS PERFORMED BY WINDROSE LAND SERVICES, INC.
6. ENVIRONMENTAL AND DRAINAGE ISSUES ARE BEYOND THE SCOPE OF THIS SURVEY.
7. ELEVATIONS SHOWN TO THE NEAREST TENTH ARE NATURAL GROUND SURFACE ELEVATIONS AND ELEVATIONS SHOWN TO THE NEAREST HUNDREDTH ARE SOLID SURFACE ELEVATIONS.
8. AT THE TIME OF SURVEY (12-29-11) THE DETENTION BASIN CONTAINED WATER AS SHOWN HEREON WHICH VISUALLY OBSTRUCTED STRUCTURES BELOW WATER LEVEL.

SURVEYOR'S CERTIFICATION

TO: S & B INFRASTRUCTURE, LTD.

I DO HEREBY CERTIFY TO THE ABOVE LISTED THAT THIS SURVEY WAS THIS DAY MADE ON THE GROUND AND WAS PERFORMED UNDER MY SUPERVISION. THAT THIS PLAT CORRECTLY REPRESENTS THE FACTS FOUND AT THE TIME OF THIS SURVEY TO THE BEST OF MY KNOWLEDGE.

MIKE KURKOWSKI
Registered Professional Land Surveyor
Texas Registration No. 5101

STATE OF TEXAS REGISTERED MIKE KURKOWSKI 5101 PROFESSIONAL LAND SURVEYOR

01/04/12
DATE

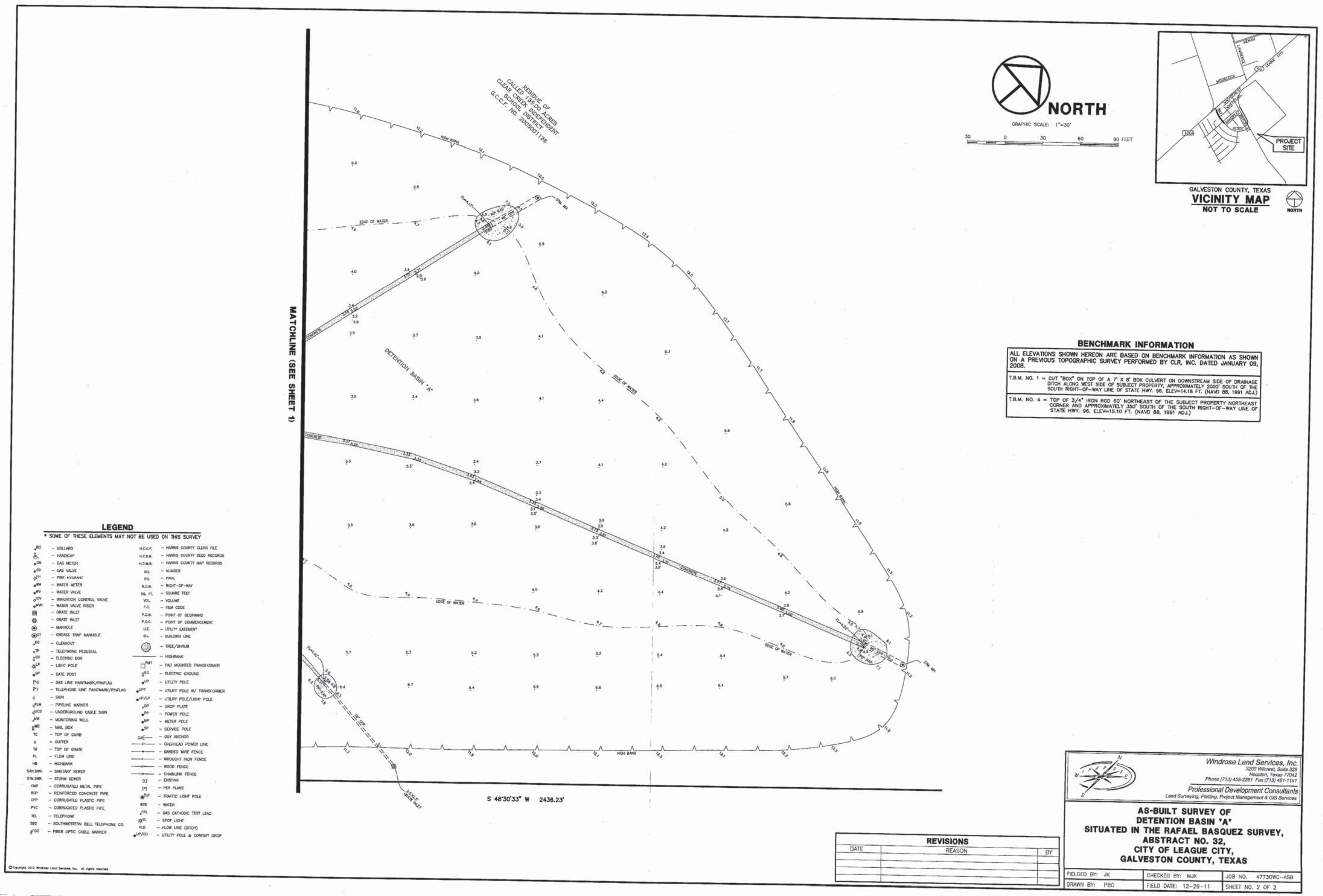
REVISIONS

DATE	REASON	BY

Windrose Land Services, Inc.
3200 Wilcrest, Suite 325
Houston, Texas 77042
Phone (713) 458-2281 Fax (713) 461-1151
Professional Development Consultants
Land Surveying, Platting, Project Management & GIS Services

AS-BUILT SURVEY OF
DETENTION BASIN "A"
SITUATED IN THE RAFAEL BASQUEZ SURVEY,
ABSTRACT NO. 32,
CITY OF LEAGUE CITY,
GALVESTON COUNTY, TEXAS

FIELDED BY: JK	CHECKED BY: MJK	JOB NO. 47730WC-ASB
DRAWN BY: PBC	FIELD DATE: 12-29-11	SHEET NO. 1 OF 2


NORTH
GRAPHIC SCALE: 1"=30'
30 0 30 60 90 FEET
GALVESTON COUNTY, TEXAS
VICINITY MAP
NOT TO SCALE
PROJECT SITE
RESIDUE OF CALLED 135.06 ACRES CLEAR CREEK INDEPENDENT SCHOOL DISTRICT G.C.C.F. NO. 2005001138
MATCHLINE (SEE SHEET 1)
DETENTION BASIN "A"
EDGE OF WATER
HIGH BANK
S 48°30'33" W 2436.23'
BENCHMARK INFORMATION
ALL ELEVATIONS SHOWN HEREON ARE BASED ON BENCHMARK INFORMATION AS SHOWN ON A PREVIOUS TOPOGRAPHIC SURVEY PERFORMED BY CLR, INC. DATED JANUARY 09, 2008.
T.B.M. NO. 1 = CUT "BOX" ON TOP OF A 7' X 8' BOX CULVERT ON DOWNSTREAM SIDE OF DRAINAGE DITCH ALONG WEST SIDE OF SUBJECT PROPERTY, APPROXIMATELY 2000' SOUTH OF THE SOUTH RIGHT-OF-WAY LINE OF STATE HWY. 96. ELEV=14.18 FT. (NAVD 88, 1991 ADJ.)
T.B.M. NO. 4 = TOP OF 3/4" IRON ROD 60' NORTHEAST OF THE SUBJECT PROPERTY NORTHEAST CORNER AND APPROXIMATELY 350' SOUTH OF THE SOUTH RIGHT-OF-WAY LINE OF STATE HWY. 96. ELEV=15.10 FT. (NAVD 88, 1991 ADJ.)
LEGEND
* SOME OF THESE ELEMENTS MAY NOT BE USED ON THIS SURVEY
REVISIONS
DATE
REASON
BY
Windrose Land Services, Inc.
3200 Wilcrest, Suite 325
Houston, Texas 77042
Phone (713) 458-2281 Fax (713) 461-1151
Professional Development Consultants
Land Surveying, Platting, Project Management & GIS Services
AS-BUILT SURVEY OF
DETENTION BASIN "A"
SITUATED IN THE RAFAEL BASQUEZ SURVEY,
ABSTRACT NO. 32,
CITY OF LEAGUE CITY,
GALVESTON COUNTY, TEXAS
FIELDED BY: JK
CHECKED BY: MJK
JOB NO. 47730WC-ASB
DRAWN BY: PBC
FIELD DATE: 12-29-11
SHEET NO. 2 OF 2

Appendix B - Calculated Inflow and Outflow Volumes

Inflow Calculation

			SCS Curve Number Inflow						Stage-Storage Inflow			
Event No.	Start Date	Precipitation (in)	Inlet A Flow (cu. m)	Inlet B Flow (cu. m)	Inlet C Flow (cu. m)	Inlet D Flow (cu. m)	Precip in Wetland (cu. m)	**Total Inflow (cu. m)**	WL - initial (m)	WL - final (m)	**Total Inflow (cu. m)**	Inflow Discrepancy (%)
21	3/4/2014	1.43	192	1097	1060	72	908	3329	0.710	1.140	3677	10%
22	4/7/2014	0.76	0	254	226	0	483	962	0.580	0.850	930	3%
23	4/15/2014	1.3	91	907	870	27	826	2721	0.575	1.070	2999	10%
24	5/13/2014	1.84	718	1747	1720	332	1168	5685	0.500	1.040	2583	55%
25	5/27/2014	3.06	3692	3957	3995	1935	1943	15522	0.570	1.600	12814	17%
28	6/27/2014	1.8	654	1681	1652	300	1143	5429	0.900	1.350	6036	11%
29	7/18/2014	1	1	512	477	6	635	1631	0.750	0.950	1346	17%
32	8/27/2014	1.52	281	1233	1198	114	965	3792	0.650	1.180	4403	16%

Stage-Storage Outflow

		Peak		Day 1		Day 2		Day 3		Day 4		Day 5		
Event No.	Start Date	WL	Volume	WL	Volume out	WL	Volume out	WL	Volume out	WL	Volume out	WL	Volume out	Total Volume
21	3/4/2014	1.13	3637	0.96	1996	0.86	806	0.8	334	0.76	207			3344
22	4/7/2014	0.85	800	0.81	250	0.75	302	0.68	241					792
23	4/15/2014	1.07	2869	0.98	988	0.92	550	0.87	391	0.82	330			2259
24	5/13/2014	1.05	2632	1.04	115	1	434							549
25	5/27/2014	1.99	24266	1.7	8966	1.5	4992	1.4	2131	1.35	1069	1.26	1507	18664
28	6/27/2014	1.41	8379	1.35	1271	1.34	186	1.27	1237	1.18	1342	1.12	841	4877
29	7/18/2014	1.06	2749	1.03	344	0.98	525							869
32	8/28/2014	1.47	9644	1.42	1162	1.33	1652	1.25	1394	1.18	1092			5300

Appendix C - E. Coli Validation Results

EASTEX ENVIRONMENTAL LABORATORY, INC.
P. O. Box 1089
Coldspring, Texas 77331
(936) 653-3249 (800) 525-0508
www.eastexlabs.com *eastexlab@eastex.net*

Derek Morrison -Texas A & M
7138 Coldstream

Pasadena TX 77505

LABORATORY ANALYSIS REPORT

ProjectID: Dickinson Bayou Watershed

Site: A
Sample Number: C1442086-01
SampleType: Grab

Collect Date: 8/28/2014
Collect Time: 11:30 AM
Collector:

Test	*	Result	Units	Tech	Date Time	Method
E coli IDEXX	A	6310	mpn/100ml	KH	8/28/2014 4:00:00 PM	Colilert 18

ProjectID: Dickinson Bayou Watershed

Site: B
Sample Number: C1442086-02
SampleType: Grab

Collect Date: 8/28/2014
Collect Time: 11:40 AM
Collector:

Test	*	Result	Units	Tech	Date Time	Method
E coli IDEXX	A	3360	mpn/100ml	KH	8/28/2014 4:00:00 PM	Colilert 18

ProjectID: Dickinson Bayou Watershed

Site: C
Sample Number: C1442086-03
SampleType: Grab

Collect Date: 8/28/2014
Collect Time: 11:50 AM
Collector:

Test	*	Result	Units	Tech	Date Time	Method
E coli IDEXX	A	46100	mpn/100ml	KH	8/28/2014 4:00:00 PM	Colilert 18

ProjectID: Dickinson Bayou Watershed

Site: D
Sample Number: C1442086-04
SampleType: Grab

Collect Date: 8/28/2014
Collect Time: 12:00 PM
Collector:

Test	*	Result	Units	Tech	Date Time	Method
E coli IDEXX	A	6270	mpn/100ml	KH	8/28/2014 4:00:00 PM	Colilert 18

*NELAC Status:A=Accredited N=Accreditation not offered O=Not Accredited P=Approved
Most current versions applicable for methods listed are being used.

The test results in this report relate only to the samples received and the report shall not be reproduced except in full, without the approval of the laboratory.

EASTEX ENVIRONMENTAL LABORATORY, INC.
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Coldspring, Texas 77331
(936) 653-3249 (800) 525-0508
www.eastexlabs.com *eastexlab@eastex.net*

Derek Morrison -Texas A & M
7138 Coldstream

Pasadena TX 77505

LABORATORY ANALYSIS REPORT

ProjectID: Dickinson Bayou Watershed

Site: O
Sample Number: C1442086-05
SampleType: Grab

Collect Date: 8/28/2014
Collect Time: 12:10 PM
Collector:

Test	*	Result	Units	Tech	Date	Time	Method
E coli IDEXX	A	28510	mpn/100ml	KH	8/28/2014	4:00:00 PM	Colilert 18

C1442086-01	E coli	5	Sample not pulled in appropriate container.
C1442086-02	E coli	5	Sample not pulled in appropriate container.
C1442086-03	E coli	5	Sample not pulled in appropriate container.
C1442086-04	E coli	5	Sample not pulled in appropriate container.
C1442086-05	E coli	5	Sample not pulled in appropriate container.

Daniel Bowen, Quality Assurance Officer

*NELAC Status:A=Accredited N=Accreditation not offered O=Not Accredited P=Approved
Most current versions applicable for methods listed are being used.
The test results in this report relate only to the samples received and the report shall not be reproduced except in full, without the approval of the laboratory.

Appendix D - XLSTAT Output

		E. coli Concentration (CFU/100ml)		Log Concentration (CFU/100ml)	
Event No.	Start Date	Inflow	Outflow	Inflow	Outflow
1	4/2/2013		400		2.6
2	4/27/2013		800		2.9
3	7/8/2013		2500		3.4
4	7/16/2013		1300		3.1
5	8/25/2013		800		2.9
6	9/20/2013		1800		3.3
7	10/2/2013		4200		3.6
8	10/27/2013		1200		3.1
9	11/25/2013		1200		3.1
10	3/4/2014		600		2.8
11	4/7/2014	11621	3500	4.1	3.5
12	4/15/2014	4471	1500	3.7	3.2
13	5/13/2014	4022	3600	3.6	3.6
14	5/27/2014	12934	5600	4.1	3.7
15	6/27/2014	3573	2200	3.6	3.3
16	7/18/2014	5988	500	3.8	2.7
17	8/28/2014	23097	8000	4.4	3.9

Event No.	Start Date	Outflow	Rank	P
1	4/2/2013	400	1	0.034884
2	4/27/2013	800	4	0.209302
3	7/8/2013	2500	12	0.674419
4	7/16/2013	1300	8	0.44186
5	8/25/2013	800	5	0.267442
6	9/20/2013	1800	10	0.55814
7	10/2/2013	4200	15	0.848837
8	10/27/2013	1200	6	0.325581
9	11/25/2013	1200	7	0.383721
10	3/4/2014	600	3	0.151163
11	4/7/2014	3500	13	0.732558
12	4/15/2014	1500	9	0.5
13	5/13/2014	3600	14	0.790698
14	5/27/2014	5600	16	0.906977
15	6/27/2014	2200	11	0.616279
16	7/18/2014	500	2	0.093023
17	8/28/2014	8000	17	0.965116

Event No.	Start Date	Inflow	Rank	P
1	4/7/2014	11621	5	0.638889
2	4/15/2014	4471	3	0.361111
3	5/13/2014	4022	2	0.222222
4	5/27/2014	12934	6	0.777778
5	6/27/2014	3573	1	0.083333
6	7/18/2014	5988	4	0.5
7	8/28/2014	23097	7	0.916667

XLSTAT 2014.3.03 - Two-sample comparison of variances - on 9/13/2014 at 4:33:04 PM
Sample 1: Workbook = 20140913 CN Flowrates & Ecoli.xlsm / Sheet = Clean Data & plots / Range = 'Clean Data & plots'!$D$3:$D$20 / 17 rows and 1 column
Sample 2: Workbook = 20140913 CN Flowrates & Ecoli.xlsm / Sheet = Clean Data & plots / Range = 'Clean Data & plots'!$E$3:$E$20 / 17 rows and 1 column
Significance level (%): 10

Summary statistics

Summary statistics:

Variable	Observations	Obs. with missing dat	bs. without missing da	Minimum	Maximum	Mean	Std. deviation
Inflow	17	10	7	3573.452	23097.139	9386.612	7116.181
Outflow	17	0	17	400.000	8000.000	2335.294	2072.119

Levene's test (Mean) / Two-tailed test:

F (Observed value)	15.365
F (Critical value)	2.949
DF1	1
DF2	22
p-value (one-tailed)	0.001
alpha	0.1

Test interpretation:
H0: The variances are identical.
Ha: At least one of the variances is different from another.

As the computed p-value is lower than the significance level alpha=0.1, one should reject the null hypothesis H0, and accept the alternative hypothesis Ha.

The risk to reject the null hypothesis H0 while it is true is lower than 0.07%.

XLSTAT 2014.3.03 - Two-sample comparison of variances - on 9/13/2014 at 4:31:57 PM
Sample 1: Workbook = 20140913 CN Flowrates & Ecoli.xlsm / Sheet = Clean Data & plots / Range = 'Clean Data & plots'!$D$3:$D$20 / 17 rows and 1 column
Sample 2: Workbook = 20140913 CN Flowrates & Ecoli.xlsm / Sheet = Clean Data & plots / Range = 'Clean Data & plots'!$E$3:$E$20 / 17 rows and 1 column
Significance level (%): 5

Summary statistics

Summary statistics:

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
Inflow	17	10	7	3573.452	23097.139	9386.612	7116.181
Outflow	17	0	17	400.000	8000.000	2335.294	2072.119

Levene's test (Mean) / Two-tailed test:

F (Observed value)	15.365
F (Critical value)	4.301
DF1	1
DF2	22
p-value (one-tailed)	0.001
alpha	0.05

Test interpretation:
H0: The variances are identical.
Ha: At least one of the variances is different from another.

As the computed p-value is lower than the significance level alpha=0.05, one should reject the null hypothesis H0, and accept the alternative hypothesis Ha.

The risk to reject the null hypothesis H0 while it is true is lower than 0.07%.

XLSTAT 2014.3.03 - Two-sample comparison of variances - on 9/13/2014 at 4:31:25 PM
Sample 1: Workbook = 20140913 CN Flowrates & Ecoli.xlsm / Sheet = Clean Data & plots / Range = 'Clean Data & plots'!$G$3:$G$20 / 17 rows and 1 column
Sample 2: Workbook = 20140913 CN Flowrates & Ecoli.xlsm / Sheet = Clean Data & plots / Range = 'Clean Data & plots'!$H$3:$H$20 / 17 rows and 1 column
Significance level (%): 5

Summary statistics

Summary statistics:

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
Inflow	17	10	7	3.553	4.364	3.875	0.308
Outflow	17	0	17	2.602	3.903	3.218	0.377

Levene's test (Mean) / Two-tailed test:

F (Observed value)	0.334
F (Critical value)	4.301
DF1	1
DF2	22
p-value (one-tailed)	0.569
alpha	0.05

Test interpretation:
H0: The variances are identical.
Ha: At least one of the variances is different from another.

As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.

The risk to reject the null hypothesis H0 while it is true is 56.94%.

XLSTAT 2014.3.03 - Two-sample comparison of variances - on 9/13/2014 at 4:30:08 PM
Sample 1: Workbook = 20140913 CN Flowrates & Ecoli.xlsm / Sheet = Clean Data & plots / Range = 'Clean Data & plots'!$G$3:$G$20 / 17 rows and 1 column
Sample 2: Workbook = 20140913 CN Flowrates & Ecoli.xlsm / Sheet = Clean Data & plots / Range = 'Clean Data & plots'!$H$3:$H$20 / 17 rows and 1 column
Significance level (%): 10

Summary statistics

Summary statistics:

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
Inflow	17	10	7	3.553	4.364	3.875	0.308
Outflow	17	0	17	2.602	3.903	3.218	0.377

Levene's test (Mean) / Two-tailed test:

F (Observed value)	0.334
F (Critical value)	2.949
DF1	1
DF2	22
p-value (one-tailed)	0.569
alpha	0.1

Test interpretation:
H0: The variances are identical.
Ha: At least one of the variances is different from another.

As the computed p-value is greater than the significance level alpha=0.1, one cannot reject the null hypothesis H0.

The risk to reject the null hypothesis H0 while it is true is 56.94%.

XLSTAT 2014.3.03 - Two-sample t-test and z-test - on 9/13/2014 at 4:27:09 PM
Sample 1: Workbook = 20140913 CN Flowrates & Ecoli.xlsm / Sheet = Clean Data & plots / Range = 'Clean D
Sample 2: Workbook = 20140913 CN Flowrates & Ecoli.xlsm / Sheet = Clean Data & plots / Range = 'Clean D
Hypothesized difference (D): 0
Significance level (%): 10
Population variances for the t-test:

Summary statistics

Summary statistics:

Variable	)bservation	with missin	thout missi	Minimum	Maximum	Mean	td. deviatio
Inflow	17	10	7	3.553	4.364	3.875	0.308
Outflow	17	0	17	2.602	3.903	3.218	0.377

t-test for two independent samples / Two-tailed test:

90% confidence interval on the difference between the means:
] 0.396, 0.918 [

Difference	0.657
t (Observed value)	4.442
|t| (Critical value)	1.764
DF	14
p-value (Two-tailed)	0.001
alpha	0.1

The number of degrees of freedom is approximated by the Welch-Satterthwaite formula

Test interpretation:
H0: The difference between the means is equal to 0.
Ha: The difference between the means is different from 0.
As the computed p-value is lower than the significance level alpha=0.1, one should reject the null hypothe
accept the alternative hypothesis Ha.
The risk to reject the null hypothesis H0 while it is true is lower than 0.06%.

XLSTAT 2014.3.03 - Two-sample t-test and z-test - on 9/13/2014 at 4:26:29 PM
Sample 1: Workbook = 20140913 CN Flowrates & Ecoli.xlsm / Sheet = Clean Data & plots / Range = 'Clean Data & plots'!$G$3:$G$20 / 17 rows and 1 column
Sample 2: Workbook = 20140913 CN Flowrates & Ecoli.xlsm / Sheet = Clean Data & plots / Range = 'Clean Data & plots'!$H$3:$H$20 / 17 rows and 1 column
Hypothesized difference (D): 0
Significance level (%): 5
Population variances for the t-test:
Summary statistics

Summary statistics:

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
Inflow	17	10	7	3.553	4.364	3.875	0.308
Outflow	17	0	17	2.602	3.903	3.218	0.377

t-test for two independent samples / Two-tailed test:

95% confidence interval on the difference between the means:
] 0.339, 0.975 [

Difference	0.657
t (Observed value)	4.442
|t| (Critical value)	2.148
DF	14
p-value (Two-tailed)	0.001
alpha	0.05

The number of degrees of freedom is approximated by the Welch-Satterthwaite formula

Test interpretation:
H0: The difference between the means is equal to 0.
Ha: The difference between the means is different from 0.

As the computed p-value is lower than the significance level alpha=0.05, one should reject the null hypothesis H0, and accept the alternative hypothesis Ha.

The risk to reject the null hypothesis H0 while it is true is lower than 0.06%.

XLSTAT 2014.3.03 - Two-sample t-test and z-test - on 9/13/2014 at 4:20:47 PM
Sample 1: Workbook = 20140913 CN Flowrates & Ecoli.xlsm / Sheet = Clean Data & plots / Range = 'Clean Data & plots'!$D$3:$D$20 / 17 rows and 1 column
Sample 2: Workbook = 20140913 CN Flowrates & Ecoli.xlsm / Sheet = Clean Data & plots / Range = 'Clean Data & plots'!$E$3:$E$20 / 17 rows and 1 column
Hypothesized difference (D): 0
Significance level (%): 5
Population variances for the t-test:

Summary statistics

Summary statistics:

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
Inflow	17	10	7	3573.452	23097.139	9386.612	7116.181
Outflow	17	0	17	400.000	8000.000	2335.294	2072.119

t-test for two independent samples / Two-tailed test:

95% confidence interval on the difference between the means:
] 458.821, 13643.814 [

Difference	7051.317
t (Observed value)	2.577
|t| (Critical value)	2.409
DF	6
p-value (Two-tailed)	0.039
alpha	0.05

The number of degrees of freedom is approximated by the Welch-Satterthwaite formula

Test interpretation:
H0: The difference between the means is equal to 0.
Ha: The difference between the means is different from 0.

As the computed p-value is lower than the significance level alpha=0.05, one should reject the null hypothesis H0, and accept the alternative hypothesis Ha.

The risk to reject the null hypothesis H0 while it is true is lower than 3.95%.

XLSTAT 2014.3.03 - Two-sample t-test and z-test - on 9/13/2014 at 4:15:38 PM
Sample 1: Workbook = 20140913 CN Flowrates & Ecoli.xlsm / Sheet = Clean Data & plots / Range = 'Clean Data & plots'!$D$3:$D$20 / 17 rows and 1 column
Sample 2: Workbook = 20140913 CN Flowrates & Ecoli.xlsm / Sheet = Clean Data & plots / Range = 'Clean Data & plots'!$E$3:$E$20 / 17 rows and 1 column
Hypothesized difference (D): 0
Significance level (%): 10
Population variances for the t-test:

Summary statistics

Summary statistics:

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
Inflow	17	10	7	3573.452	23097.139	9386.612	7116.181
Outflow	17	0	17	400.000	8000.000	2335.294	2072.119

t-test for two independent samples / Two-tailed test:

90% confidence interval on the difference between the means:
] 1796.465, 12306.170 [

Difference	7051.317
t (Observed value)	2.577
|t| (Critical value)	1.920
DF	6
p-value (Two-tailed)	0.039
alpha	0.1

The number of degrees of freedom is approximated by the Welch-Satterthwaite formula

Test interpretation:
H0: The difference between the means is equal to 0.
Ha: The difference between the means is different from 0.

As the computed p-value is lower than the significance level alpha=0.1, one should reject the null hypothesis H0, and accept the alternative hypothesis Ha.

The risk to reject the null hypothesis H0 while it is true is lower than 3.95%.

XLSTAT 2014.3.03 - Comparison of two samples (Wilcoxon, Mann-Whitney, ...) - on 9/13/2014 at 4:07:19 PM
Sample 1: Workbook = 20140913 CN Flowrates & Ecoli.xlsm / Sheet = Clean Data & plots / Range = 'Clean Data & plots'!$D$3:$D$20 / 17 rows and 1 column
Sample 2: Workbook = 20140913 CN Flowrates & Ecoli.xlsm / Sheet = Clean Data & plots / Range = 'Clean Data & plots'!$E$3:$E$20 / 17 rows and 1 column
Hypothesized difference (D): 0
Significance level (%): 5
p-value: Asymptotic p-value
Continuity correction: Yes
Summary statistics

Summary statistics:

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
Inflow	17	10	7	3573.452	23097.139	9386.612	7116.181
Outflow	17	0	17	400.000	8000.000	2335.294	2072.119

Mann-Whitney test / Two-tailed test:

U	109.000
Expected value	59.500
Variance (U)	247.701
p-value (Two-tailed)	0.002
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:
H0: The difference of location between the samples is equal to 0.
Ha: The difference of location between the samples is different from 0.

As the computed p-value is lower than the significance level alpha=0.05, one should reject the null hypothesis H0, and accept the alternative hypothesis Ha.

The risk to reject the null hypothesis H0 while it is true is lower than 0.18%.

Ties have been detected in the data and the appropriate corrections have been applied.

XLSTAT 2014.3.03 - Comparison of two samples (Wilcoxon, Mann-Whitney, ...) - on 9/13/2014 at 4:04:22 PM
Sample 1: Workbook = 20140913 CN Flowrates & Ecoli.xlsm / Sheet = Clean Data & plots / Range = 'Clean Data & plots'!$D$3:$D$20 / 17 rows and 1 column
Sample 2: Workbook = 20140913 CN Flowrates & Ecoli.xlsm / Sheet = Clean Data & plots / Range = 'Clean Data & plots'!$E$3:$E$20 / 17 rows and 1 column
Hypothesized difference (D): 0
Significance level (%): 10
p-value: Asymptotic p-value
Continuity correction: Yes

Summary statistics

Summary statistics:

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
Inflow	17	10	7	3573.452	23097.139	9386.612	7116.181
Outflow	17	0	17	400.000	8000.000	2335.294	2072.119

Mann-Whitney test / Two-tailed test:

U	109.000
Expected value	59.500
Variance (U)	247.701
p-value (Two-tailed)	0.002
alpha	0.1

An approximation has been used to compute the p-value.

Test interpretation:
H0: The difference of location between the samples is equal to 0.
Ha: The difference of location between the samples is different from 0.

As the computed p-value is lower than the significance level alpha=0.1, one should reject the null hypothesis H0, and accept the alternative hypothesis Ha.

The risk to reject the null hypothesis H0 while it is true is lower than 0.18%.

Ties have been detected in the data and the appropriate corrections have been applied.

XLSTAT 2014.3.03 - Distribution fitting - on 9/13/2014 at 4:02:57 PM
Data: Workbook = 20140913 CN Flowrates & Ecoli.xlsm / Sheet = Clean Data & plots / Range = 'Clean Data & plots'!$D$3:$E$20 / 17 rows and 2 columns
Significance level (%): 5
Distribution: Normal
Estimation method: Moments

Summary statistics

Summary statistics:

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
Inflow	17	10	7	3573.452	23097.139	9386.612	7116.181
Outflow	17	0	17	400.000	8000.000	2335.294	2072.119

Distribution fitting (Inflow):

Estimated parameters (Inflow):

Parameter	Value
µ	9386.612
sigma	7116.181

Statistics estimated on the input data and computed using the estimated parameters of the Normal distribution (Inflow):

Statistic	Data	Parameters
Mean	9386.612	9386.612
Variance	50640034.677	50640034.677
Skewness (Pearson)	0.842	0.000
Kurtosis (Pearson)	-0.872	0.000

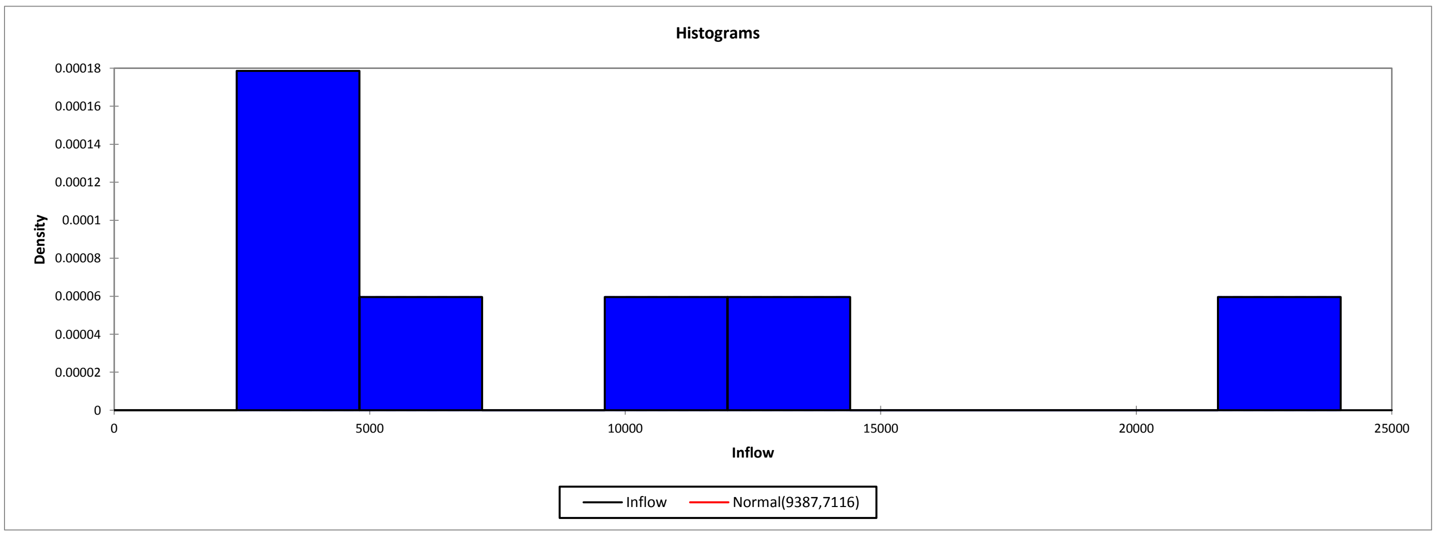
Kolmogorov-Smirnov test (Inflow):

D	0.255
p-value	0.685
alpha	0.05

Test interpretation:
H0: The sample follows a Normal distribution
Ha: The sample does not follow a Normal distribution

As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.

The risk to reject the null hypothesis H0 while it is true is 68.49%.



Descriptive statistics for the intervals (Inflow):

Lower bound	Upper bound	Frequency	Relative frequency	Density (Data)	Density (Distribution)
0	2400	0	0.000	0.000	0.070
2400	4800	3	0.429	0.000	0.097
4800	7200	1	0.143	0.000	0.120
7200	9600	0	0.000	0.000	0.133
9600	12000	1	0.143	0.000	0.131
12000	14400	1	0.143	0.000	0.116
14400	16800	0	0.000	0.000	0.092
16800	19200	0	0.000	0.000	0.065
19200	21600	0	0.000	0.000	0.041
21600	24000	1	0.143	0.000	0.023

Distribution fitting (Outflow):

Estimated parameters (Outflow):

Parameter	Value
µ	2335.294
sigma	2072.119

Statistics estimated on the input data and computed using the estimated parameters of the Normal distribution (Outflow):

Statistic	Data	Parameters
Mean	2335.294	2335.294
Variance	4293676.471	4293676.471
Skewness (Pearson)	1.296	0.000
Kurtosis (Pearson)	0.862	0.000

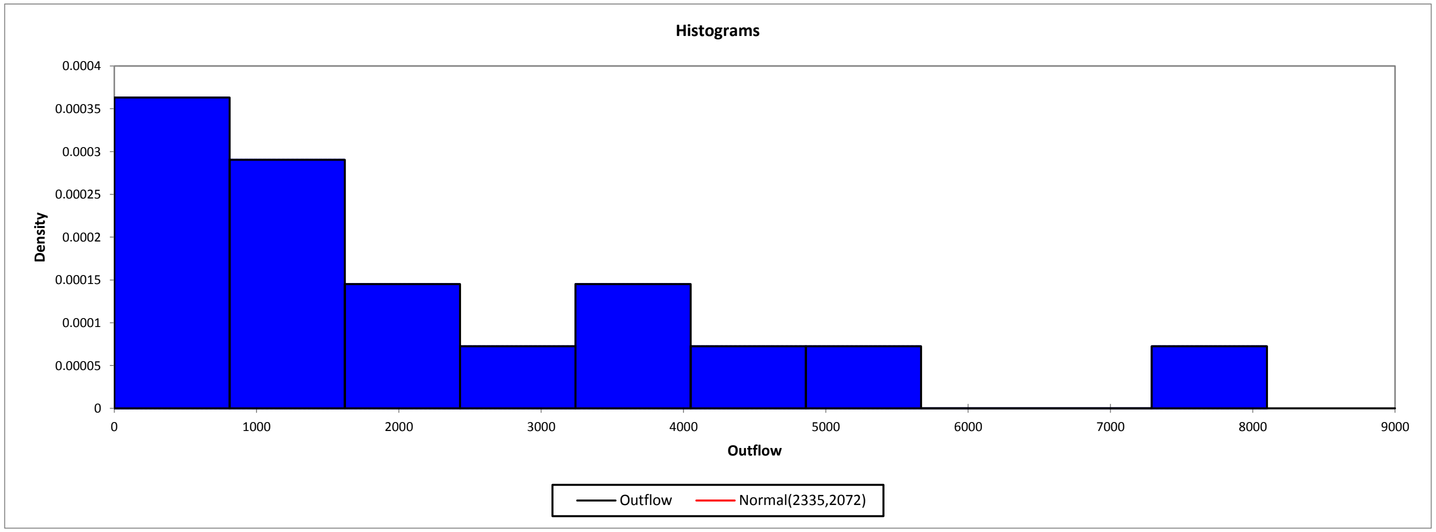
Kolmogorov-Smirnov test (Outflow):

D	0.190
p-value	0.525
alpha	0.05

Test interpretation:
H0: The sample follows a Normal distribution
Ha: The sample does not follow a Normal distribution

As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.

The risk to reject the null hypothesis H0 while it is true is 52.48%.



Descriptive statistics for the intervals (Outflow):

Lower bound	Upper bound	Frequency	Relative frequency	Density (Data)	Density (Distribution)
0	810	5	0.294	0.000	0.101
810	1620	4	0.235	0.000	0.134
1620	2430	2	0.118	0.000	0.153
2430	3240	1	0.059	0.000	0.151
3240	4050	2	0.118	0.000	0.127
4050	4860	1	0.059	0.000	0.092
4860	5670	1	0.059	0.000	0.058
5670	6480	0	0.000	0.000	0.031
6480	7290	0	0.000	0.000	0.014
7290	8100	1	0.059	0.000	0.006

XLSTAT 2014.3.03 - Distribution fitting - on 9/13/2014 at 4:00:56 PM
Data: Workbook = 20140913 CN Flowrates & Ecoli.xlsm / Sheet = Clean Data & plots / Range = 'Clean Data & plots'!$D$3:$E$20 / 17 rows and 2 columns
Significance level (%): 5
Distribution: Log-normal
Estimation method: Moments

Summary statistics

Summary statistics:

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
EMC	17	10	7	3573.452	23097.139	9386.612	7116.181
Outflow	17	0	17	400.000	8000.000	2335.294	2072.119

Distribution fitting (EMC):

Estimated parameters (EMC):

Parameter	Value
µ	8.923
sigma	0.708

Statistics estimated on the input data and computed using the estimated parameters of the Log-normal distribution (EMC):

Statistic	Data	Parameters
Mean	9386.612	9639.289
Variance	50640034.677	60535192.406
Skewness (Pearson)	0.842	2.947
Kurtosis (Pearson)	-0.872	18.630

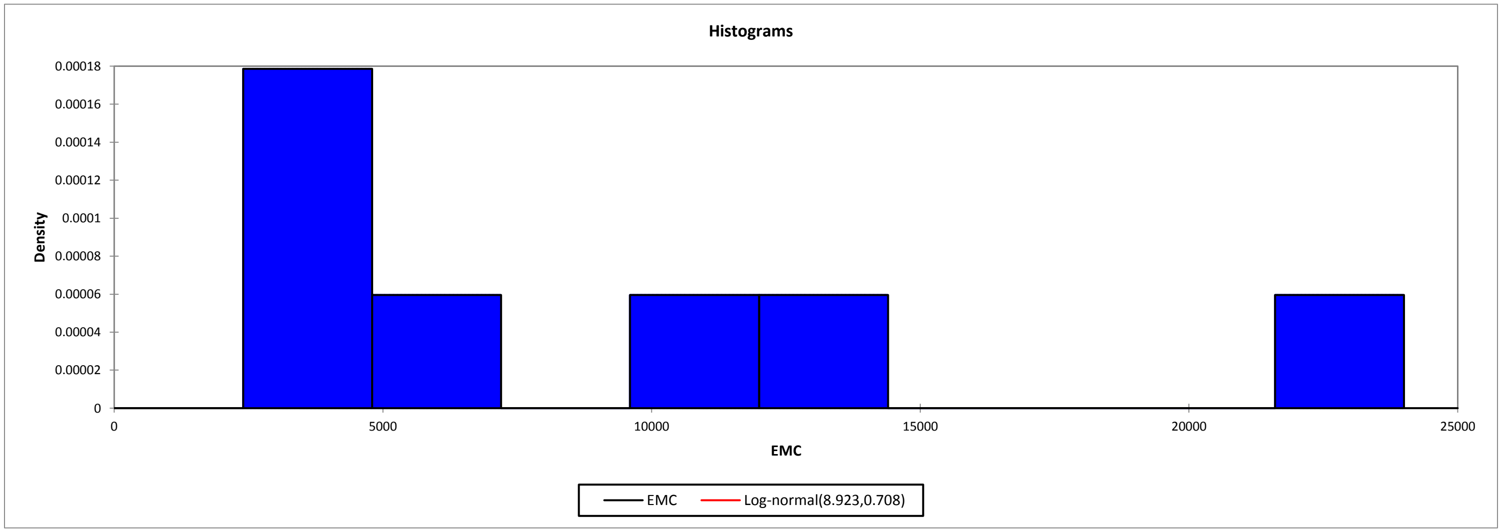
Kolmogorov-Smirnov test (EMC):

D	0.196
p-value	0.922
alpha	0.05

Test interpretation:
H0: The sample follows a Log-normal distribution
Ha: The sample does not follow a Log-normal distribution

As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.

The risk to reject the null hypothesis H0 while it is true is 92.20%.



Descriptive statistics for the intervals (EMC):

Lower bound	Upper bound	Frequency	Relative frequency	Density (Data)	Density (Distribution)
0	2400	0	0.000	0.000	0.054
2400	4800	3	0.429	0.000	0.210
4800	7200	1	0.143	0.000	0.213
7200	9600	0	0.000	0.000	0.159
9600	12000	1	0.143	0.000	0.110
12000	14400	1	0.143	0.000	0.075
14400	16800	0	0.000	0.000	0.051
16800	19200	0	0.000	0.000	0.035
19200	21600	0	0.000	0.000	0.025
21600	24000	1	0.143	0.000	0.017

Distribution fitting (Outflow):

Estimated parameters (Outflow):

Parameter	Value
µ	7.409
sigma	0.869

Statistics estimated on the input data and computed using the estimated parameters of the Log-normal distribution (Outflow):

Statistic	Data	Parameters
Mean	2335.294	2408.237
Variance	4293676.471	6531390.038
Skewness (Pearson)	1.296	4.379
Kurtosis (Pearson)	0.862	47.221

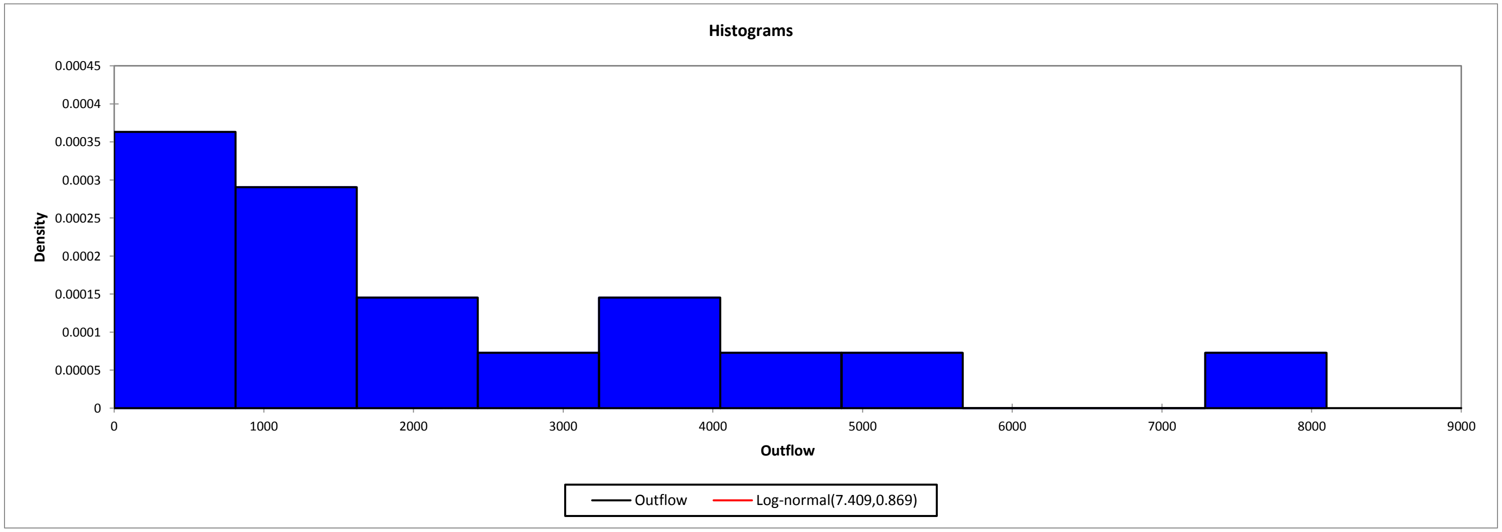
Kolmogorov-Smirnov test (Outflow):

D	0.101
p-value	0.993
alpha	0.05

Test interpretation:
H0: The sample follows a Log-normal distribution
Ha: The sample does not follow a Log-normal distribution

As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.

The risk to reject the null hypothesis H0 while it is true is 99.28%.



Descriptive statistics for the intervals (Outflow):

Lower bound	Upper bound	Frequency	Relative frequency	Density (Data)	Density (Distribution)
0	810	5	0.294	0.000	0.206
810	1620	4	0.235	0.000	0.285
1620	2430	2	0.118	0.000	0.181
2430	3240	1	0.059	0.000	0.109
3240	4050	2	0.118	0.000	0.068
4050	4860	1	0.059	0.000	0.044
4860	5670	1	0.059	0.000	0.029
5670	6480	0	0.000	0.000	0.020
6480	7290	0	0.000	0.000	0.014
7290	8100	1	0.059	0.000	0.010