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Determining the Efficacy of a Constructed Wetland as a Water Quality Improvement Strategy in an Urban Environment

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Thesis Committee Chair: Barry Ryan, PhD

An abstract of

A thesis submitted to the Faculty of the
Rollins School of Public Health of Emory University

in partial fulfillment of the requirements for the degree of
Master of Public Health
in Environmental Health

2014

ABSTRACT

The specific aim of this study is to provide empirical evidence determining the efficacy of constructed wetlands in the study site's urban setting as a method for addressing stormwater quality issues. It is hypothesized that the constructed wetlands will improve water quality by lowering total coliform, *E.coli,* and turbidity concentrations and perhaps lower levels of conductivity as well. This study was conducted in the wetlands and lake system in the City of Pine Lake, Georgia. A portion of Snapfinger Creek is diverted through the Eastern (upstream) wetlands. Water flows from the Eastern wetlands to the lake, whose overflow discharges via a drop outlet into a culvert. This culvert also receives stormwater from the southwestern portion of the city, which may contain intrusion from septic tanks and/or leaking sewer pipes. The culvert leads to the Western (downstream) wetlands. The water ultimately discharges into Snapfinger Creek approximately 1000 meters downstream of the initial diversion into the Eastern wetlands. The area of the drainage basin entering the Eastern wetland is approximately 2.7 square miles (7.0 square kilometers). Sample points were designated at 4 strategic locations in the system and collected during the summer months of June – August, 2013 and winter months of December, 2013 – January, 2014. The following parameters were collected and analyzed from each site: total coliform, *E. coli*, turbidity, conductivity, water temperature, air temperature, pH, and dissolved oxygen. Total coliform and *E. coli* concentrations were generally lower and less variable during the winter months. Dissolved oxygen was higher during the winter months, likely due to lower temperature. Statistical analysis of paired data was performed using SAS 9.3. Correlations were calculated by using paired t-Tests of difference between the samples and 2-sided p-values. The effluent from the constructed wetland was determined to be significantly lower than the influent for the following parameters: total coliform, *E. coli*, and conductivity. *E. coli* samples obtained within 48 hours of rain resulted in significantly higher concentrations when compared to those taken during periods of no rain within 48 hours. The hypothesis that constructed wetlands improve water quality is supported by the data collected by this study.

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BACKGROUND and SIGNIFICANCE

Constructed wetlands are a well-regarded option for treating various wastewater streams because of their ability to absorb nutrients and their proven efficacy to reduce industrial pollutants (Mitsch and Gosselink, 1993; EPA 1993). The high pollution removal efficiencies are obtained by maximizing water retention, sediment settling, chemical adsorption, microbial breakdown, plant uptake, and groundwater recharging (Korkusaz et al., 2005). Constructed stormwater wetlands are designed to address the volumes associated with rainfall variability and impervious surface runoff rates. Since the biologically active wetland areas are most efficient under constant regular flow conditions, the stormwater wetland systems require greater use of high volume detention basins and Best Management Practice (BMP) components (Koob et al. 1999).

Since most pollutants are introduced into stormwater during the early part of each runoff event (first flush), it is essential to maximize the capture of the early runoff using various BMP components (Fulcher 1994; Lee and Bang 2000; Lee et al. 2001; Dwight et al. 2002; Li-quing et al. 2007). However, the variability in runoff and uncertainty associated with some pretreatment systems suggests that site-specific BMP and pretreatment elements should be considered (Langeveld et al 2012). Finally, physical and geophysical site limitations, human accessibility and safety requirements, along with political and public considerations also weigh in on the selection of the most suitable BMP, whether it is grass strip, bioretention, bioswale, detention basin, porous pavement, rain garden, retention pond, wetland basin, or other composite feature (International Stormwater 2012; Zarus 2006). Therefore, a stormwater wetlands system that is to be cited into a well-established urban community must be designed for the communities to accept and enjoy (Woolson 2005; Ledbetter 2012). The best solution is a compromise between water quality improvements, flood prevention, aesthetics, and minimization of private property acquisition as well as costs of construction and maintenance.

Australia is often credited for having the first design of constructed wetlands in 1904 (Brix 1994). It was a design adopted by residents themselves. Without a sewerage system until 1880, Southwestern Australian residents would allow their household waste to accumulate to be later disposed into drains that lead to streams, resulting in a high potential for disease transmission (Barker et al. 2011). The 1904 design was simply for residents to "cut a channel leading from the kitchen and wash house into the highest side of the plot and let all the dirty water drain into it. Plant the plot with plants that grow rapidly and require a great deal of water…" (Brix 1994).

This rain-garden design was embraced at that time and has become popular for residents today, with design templates being made available online and through many local organizations (LIDC 2012). These designs are widely accepted and offer one solution for near source capture of the first flush. Having shown some success in reducing household waste contaminants, they could be used for early capture from ruptured sanitary systems.

The rain garden design was seen as one element to be used in the Metropolitan Atlanta area for several reasons. The Metropolitan Atlanta sanitary sewer systems are often located adjacent to streams in creeks. Creeks offer the perfect slope for sewerage to flow and land disturbance is often less difficult for installation of the conveyance pipe. Unfortunately, pipes break or overflow, leading to some of the same problems as historic Melbourne, Australia, resulting in sewerage in the streams. One solution considered for Metropolitan Atlanta was to adapt the Australian solution of trapping sewer overflows in isolated impoundments before they enter other parts of the wetlands systems. An adaptation will allow these impoundments to be isolated during emergencies to minimize the sewerage response and allow the remainder of the wetland system to continue to operate. This philosophy of creating an attractive system where flows could be redirected from areas that need response, repairs, or replanting, along with the need for higher detention in some areas with limited space, was incorporated into the study site's wetlands design.

Physical, chemical, and biological processes combine in wetlands to remove contaminants from wastewater. An understanding of these processes is fundamental not only to design wetland systems but to also understand the fate of chemicals once they enter the wetland. Theoretically, wastewater treatment within a constructed wetland occurs as it passes through the wetland medium and the plant rhizosphere. A thin film around each root hair is aerobic due to the leakage of oxygen from the rhizomes, roots, and rootlets. Aerobic and anaerobic micro-organisms facilitate decomposition of organic matter. Microbial nitrification and subsequent denitrification releases nitrogen as gas to the atmosphere. Phosphorus is co-precipitated with iron, aluminum, and calcium compounds located in the root-bed medium (Brix 1994). Suspended solids filter out as they settle in the water column in surface flow wetlands or are physically filtered out by the medium within subsurface flow wetland cells. Harmful bacteria and viruses are reduced by filtration and adsorption by biofilms on the rock media in subsurface flow and vertical flow systems (Brix 1994). Because of the limited greenspace in the study site efforts were made to increase the effective treatment area, by incorporating isolated areas that allowed for treatment beyond the typical rhizosphere, by expanding the root zone and by creating bio-activated filtration areas (Maryland 2000; Christianson et al 2004; Wong 2006).

INTRODUCTION

The City of Pine Lake, GA is located approximately 10 miles east of downtown Atlanta, Georgia. It was established in the late 1930's as a summer retreat centralized around a small lake of approximately 13 acres in area. Following World War II, the weekend residents became full time; Pine Lake is currently the smallest municipality in DeKalb County. The urban lake is partially fed by a portion of Snapfinger Creek, which is diverted to feed the lake while the remainder of the creek flows in a westerly direction parallel to the northern edge of the lake, between a pathway and residential properties. Prior to construction of the wetlands, this diverted water traveled as a canal for approximately 1000 ft; then through an open air corrugated half pipe for 100 ft; leading to an open air concrete flume for 500 ft; and, finally through 200 ft of submerged cast-iron pipe, ultimately reaching the lake. The original lake was constructed during the Depression, using army corps of engineering materials; however, no reference of it being an official project could be found. In addition to Snapfinger Creek the lake is fed by a natural seasonal spring. The overflow of the lake and stormwater from the neighborhood is discharged into Snapfinger Creek. The lake includes a public beach, swimming area, and playground; it remains the focal point of the city. As commercial development of the area surrounding the city greatly expanded, so did its impact on stormwater quality and quantity. The city faced several issues: incised (channelized) creeks, eroded properties with collapsing trees, rapid sedimentation of the lake, increased bacteria and subsequent closing of the public beach, increased area and frequency of flooding, decreased habitat, and decreased quality of life (Zarus, 2012). Snapfinger Creek is one of Georgia's 303(d) listed impaired waters that does not support its designated use of fishing due to fecal coliform bacteria and Biota Impacted Macroinvertebrate Community (Georgia EPD 2012).

Beginning in 2003 and over the course of several years, the city received multiple greenspace and enhancement grants. These awards were used in conjunction with city funds to obtain land upon which to construct wetlands as a "green infrastructure approach to stormwater management" (Scott et al 2013). These constructed wetlands receive drainage from a watershed basin approximately 2.7 square miles in area. A path was included in the construction, which follows along one side of the Eastern wetland, along the northern side of the lake and parallel to Snapfinger Creek, and finally, along the length of the Western wetland. The wetlands were constructed at different depths, creating wetland cells that provide variation in plant habitats. Educational signage was installed throughout the path describing some of the flora and fauna found in the wetlands. Construction of the wetlands was completed in 2012. The specific aim of this study is to provide empirical evidence determining the efficacy of constructed wetlands in this urban setting as a method for addressing stormwater quality issues. It is hypothesized that the constructed wetlands will improve water quality by lowering total coliform, *E.coli,* and turbidity concentrations and perhaps lower levels of conductivity as well.

MATERIALS and METHODS

Study site

The study was conducted in the wetlands and lake system in the City of Pine Lake, Georgia. Rather than flowing through a series of pipes and flumes to feed the lake, a portion of Snapfinger Creek now flows through the Eastern (upstream) wetlands. Water flows from the Eastern wetlands to the lake, whose overflow discharges via a drop outlet into a culvert. This culvert also receives stormwater from the southwestern portion of the city, which may contain intrusion from septic tanks and/or leaking sewer pipes. The culvert, now combined with lake overflow and stormwater, leads to the Western (downstream) wetlands. The water ultimately discharges into Snapfinger Creek approximately 1000 meters downstream of the initial diversion into the Eastern wetlands. The area of the drainage basin entering the Eastern wetland is approximately 2.7 square miles (7.0 square kilometers).

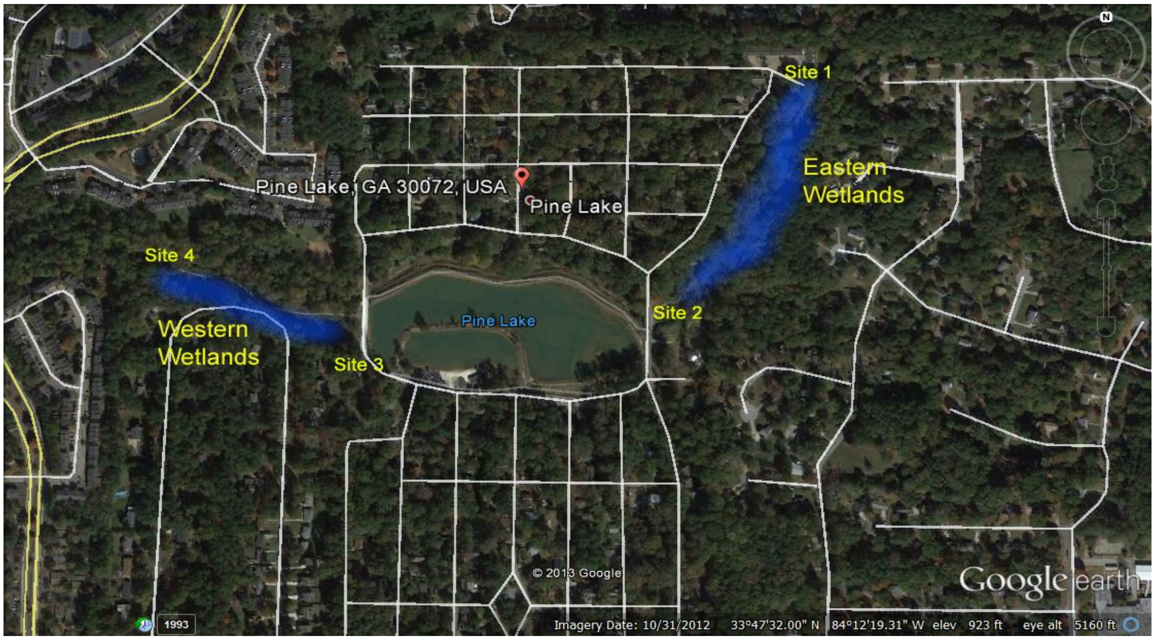


Figure 1. Sample point locations (Google Earth, 2012)

Sample collection

Sample points were designated at 4 strategic locations in the system: 1-Snapfinger Creek diversion, slightly upstream of the Eastern wetlands (influent); 2-effluent of the Eastern wetlands, prior to discharge to the public lake; 3-effluent from the public lake prior to the Western (downstream) wetlands; 4- outfall of the Western wetlands prior to entry into Snapfinger Creek (Figure 1) .

The following field measurements were obtained at each site during each sampling event: turbidity (accuracy ± 2%), conductivity (± 1%), water temperature (± 0.15°C), air temperature, pH (± 0.2 units), and dissolved oxygen (DO_2) (± 0.2mg/L) using a Hydrolab Quanta multi parameter probe and LaMotte 2020 turbidimeter. The LaMotte turbidimeter "meets or exceeds EPA design criteria for NPDWR and NPDES turbidity method 180.1." (O'Dell 1993). These parameters are typically required by regulatory authorities regarding stormwater monitoring and receiving streams. The meters were calibrated per operating manual instructions prior to each sampling event. Samples were taken in order of flow through the system; site 1 was sampled first, etc. Samples were taken at approximately the same time each day of sampling in order to avoid possible confounding from the diurnal cycle and, allow for more accurate comparisons. For example, the total coliform sample obtained at Site 1, the influent of the Eastern wetland, on July 6, 2013 at 14:38 was compared to the total coliform sample obtained at Site 2, the effluent of the Eastern wetland, on July 6, 2014 at 15:15. When possible, samples were obtained in the morning as well as the late afternoon in order to determine if the diurnal cycle may be related to variation in coliform results. Variation related to the diurnal cycle was expected for DO_2 and pH. The initial intention was to collect samples only during times of at least 48 hours of no previous rain. However, the amount of rain was so excessive over the course of collection time; it was not possible to completely avoid rainfall within 48 hours. Samples were collected during the summer months of June – August and winter months of December – January. NOAA ranked Atlanta for the period from July-December of 2013 as the 6th highest out of 7 categories of precipitation (NOAA 2013). The period was one of the top 10 wettest seasons ever recorded for the state (NOAA 2013). During the summer months, 13 sets of samples from the 4 sample sites were obtained. It was decided to focus the remaining limited coliform resources on sampling the Eastern wetland only due to its relative isolation from extraneous sources of water and contaminants, which yielded 17 additional coliform samples at the influent and effluent of the Eastern wetland. Overall, 30 total coliform and *E. coli* sample sets were collected at sample sites 1 and 2 (Eastern wetlands upstream influent and downstream effluent), and 13 were collected at sample sites 3 and 4 (lake and Western wetland effluent). However, field measurements continued at each of the four sample sites for all 30 sampling events because it did not incur the expense of coliform analysis.

Laboratory analysis of Total Coliform and *E. coli* samples, which were collected at each site when the field measurements were obtained, was performed using IDEXX 2000 trays with Colilert snap packs. Total coliform and *E. coli* samples were collected using a Corning® 1700-100 120mL sterile coliform water test sample container with sodium thiosulfate tablet. It is manufactured from pure polypropylene in a sterile environment and sterile-by-process and is typically used to test for the presence of coliform bacteria in drinking water and surface waters. The wide mouthed container has an attached polypropylene snap cap lid to reduce the chance of contamination. It is also leak tight with a locking arrow that assures sterility has not been compromised during transport. The container is graduated and meets EPA requirements per the *Manual for the Certification of Laboratories Analyzing Drinking Water* (EPA 2005). The samples were transported on ice to the university laboratory for processing well within an 8-hour holding time.

Rain data was obtained using U.S. Geological Survey online records for Site Number "02203950 Snapfinger Creek Near Decatur,GA Dekalb County, Georgia; Hydrologic Unit Code 03070103; Latitude 33°45'48", Longitude 84°13'13" NAD27; Drainage area 13.20 square miles; Gage datum 844.6 feet above NAVD88", which includes the study site drainage basin, located approximately 2 miles south and downstream of Pine Lake (USGS 2014).

Sample processing

Total coliform and *E. coli* analysis was performed using Quanti-Tray®/2000 disposable 97-well trays and Colilert reagent for use with a Quanti-Tray® Sealer, as detailed in Standard Methods for the Examination of Water and Wastewater #9223B Enzyme Substrate Coliform test, 21st Edition. The IDEXX Quanti-Tray® is a relatively simple and quick method by which to obtain accurate counts of coliforms and *E. coli*. It is a semi-automated quantification methods based on the Standard Methods' Most Probable Number (MPN) model. The Quanti-Tray® Sealer 2X automatically distributes the sample/reagent mixture into separate wells. After incubation, the number of positive wells can be converted to an MPN (Dichter, 1990).

IDEXX Quanti-Tray/2000 is designed to give quantitated bacterial counts of 100 mL samples using IDEXX reagent products (Colilert). The chromogenic substrate coliform test utilizes hydrolyzable chromogenic substrates for the detection of enzymes of coliform bacteria. Unlike lactose fermentation methods that permit growth of many aerobic organisms and eliminate or suppress some non-coliforms with inhibitory chemicals, this technique provides nutrients that are more selective and specific for coliform growth. The test can be used in either a multiple-tube or a presence-absence (single 100-mL sample) format. Production of valid results requires strict adherence to quality control procedures. In 1989 EPA published its approval for the use of Colilert in the Federal Register - National Primary Drinking Water Regulations: Analytical Techniques; Coliform Bacteria; Final Rule40 CFR 141 7-17-1989. The initial sample was not diluted prior to addition of the Colilert reagent. Subsequent samples were diluted either 1:5 or 1:10 as noted on the raw data table, Appendix 1. Serial dilutions were not performed for each sample in order to conserve limited supplies; in addition the multiple cells of the Quanti-Tray was designed to serve as serial dilutions. A Colilert 24-hour reagent snap pack was added to the diluted sample and the mixture was poured into a Quanti-Tray/2000. The tray was then sealed using a Quanti-Tray heat sealer and incubated for 24 hours at 37 degrees Celsius. The total coliform count was obtained by counting the number of positive large and small wells, as indicated by a color change from colorless to yellow in relation to the comparator and use of the Most Probable Number (MPN) Table to determine the MPN (Dichter, 1990). The corresponding *E. coli* MPN was determined by the number of large and small wells that fluoresce under ultra violet (UV) light, such that a single IDEXX tray provided both total coliform and *E. coli* MPN of colonies per 100 mL.

Quality control

The Hydrolab Quanta multi parameter probe and LaMotte 2020 turbidimeter were calibrated prior to each use. In addition, each day of coliform samples included a blank sample (distilled water and Colilert reagent) to assure samples were free of contamination. Coliform samples were maintained and transported on ice and were consistently processed within a holding time less than 8 hours. The comparator used for the IDEXX tray and Colilert reagent MPN was distilled water seeded with

Statistical Analysis Methods

The number of individual parameter samples per site location was somewhat low at n=30. Lower sample numbers often result in greater uncertainty as indicated by various measures: potential lack of a normal distribution, less power causing difficulty in rejecting the null in anything but extreme cases, and wider confidence intervals. Normality was determined by adding the normal option to the univariate command in SAS 9.3. This provides a goodness-of-fit test, a formal test to determine whether an empirical distribution follows a normal distribution. The null hypothesis is that it is normally distributed. The p-value for the Kolmogorov-Smirnov test statistic was used to determine whether or not the null was rejected. A p-value ≥0.15 indicated failure to reject the null, i.e. normality was assumed. When normality was assumed, Student's t-Test was used to determine the statistical significance of the particular dataset. When normality could not be assumed, Wilcoxon Signed-Rank Test was used.

Statistical analysis of paired data was performed using SAS 9.3. Associations were calculated by using paired t-Tests of difference between the samples and 2-sided p-values. The distributions were visually plotted as histograms or probability plots and the means procedure was used to determine 95% confidence intervals. Total coliform and *E. coli* values were $\log_{10}$ transformed for normality.

Odds ratio and confidence limits were calculated using Fisher exact or Mid-P Exact 2x2 tables with www.openepi.com. (Sullivan et al 2011). These calculations determined the effect, if any, of 48-hour rainfall on the various parameters. Rainfall within 48 hours defined the exposure and outcomes were designated as either high or low. Current Georgia Environmental Protection Division water quality standards were used to define a parameter value as high or low, when possible: fecal coliform 200 colonies/100 mL in recreational waters (lake) May-October or 500 colonies/100 mL in a free flowing stream (GAEPD 2012). Using the regulatory limitation occasionally resulted in undefined values if there was no value that exceeded the limit. For these occasions the mean was used as the designation; a value above the mean was considered high and a value below the mean was considered low. Fecal coliform is a subset of total coliform and *E. coli* is a subset of fecal coliform; therefore, *E.coli* concentrations should less than or equal to fecal coliform concentrations. If all high values, determined either by regulatory limitation or greater than the mean value, occurred within 48 hours of rain it is not possible to complete a 2x2 table as there will be no value for the exposure +/high concentration group.

RESULTS

The field data, laboratory analytical data, and statistical analysis of the data are contained in the following tables and graphics. The sampling results varied widely during the sampling periods, with total coliform ranging from 189-24,196 colonies/100 mL and *E. coli* ranging from 10-2306. All sampling data collected at each site are reported in tables 1-8 in Appendix A.

Table 9: Number of Beach Closures Due to High Fecal Coliform (Geometric Mean >200 col/100mL) based upon DeKalb County Board of Health Sampling

Year	2007	2008	2009	2010	2011	2012	2013
No. of Beach Closings	19	7	6	9	10	4	1

(DeKalb County Board of Health 2013)

Observations can be made from the data in Tables1-8 prior to statistical analysis. Diurnal patterns of pH, DO_2, and temperature are evident on days that were sampled in the morning and late afternoon. Coliform concentrations do not appear to be associated with diurnal changes; however, higher coliform levels are generally preceded by rain within 48 hours. Total coliform and *E. coli* concentrations are lower during the winter months and appear to be less variable. DO_2 is higher during the winter months, likely due to lower temperature. Increased turbidity and conductivity may be associated with rain; although the lake appears to be more stable than the wetlands after rain. This stability is not unexpected as the larger body of water has a much longer retention time allowing for more mixing as well as settling of particulate matter.

The DeKalb County Board of Health, Environmental Health group regularly samples lake water at the public beach. Samples are analyzed by the county's Water and Sewer Division, Public Works Department using the membrane filtration method. Geometric mean is a type of average using the logarithmic value of the data converted back to a base 10 number. It is determined based upon 4 consecutive measurements as an indication of the quality of the water at the lake. Beach closings are prompted by high geometric mean values. Declines in the number of beach closings are notable since completion of the wetlands in 2012.

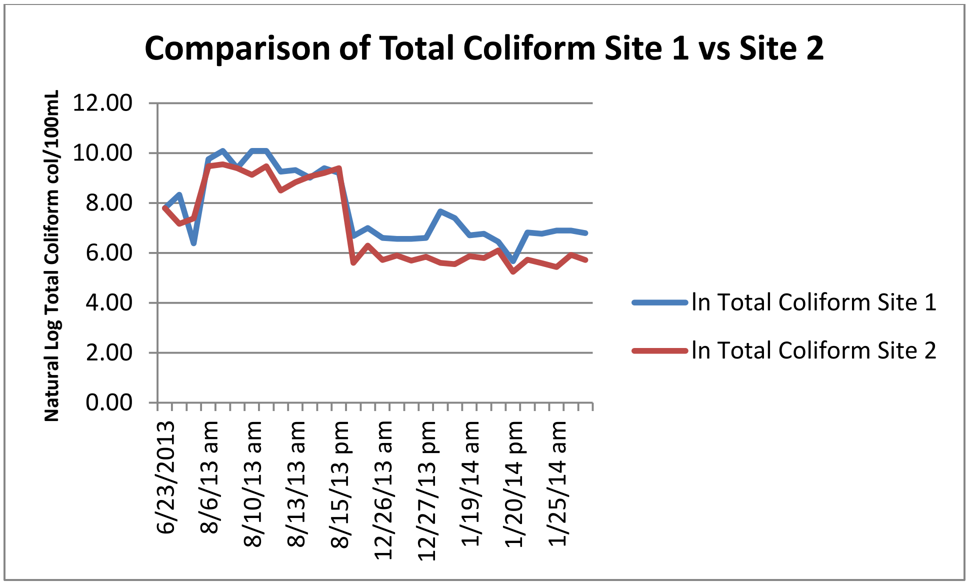


Figure 2. Total Coliform - Eastern Wetland Site 1 / Site 2 (Influent/Effluent)

Mean log difference 0.7 (0.5, 0.9) Kolmogorov-Smirnov >0105 = Normal Distribution; Student's t-Test p<0.0001

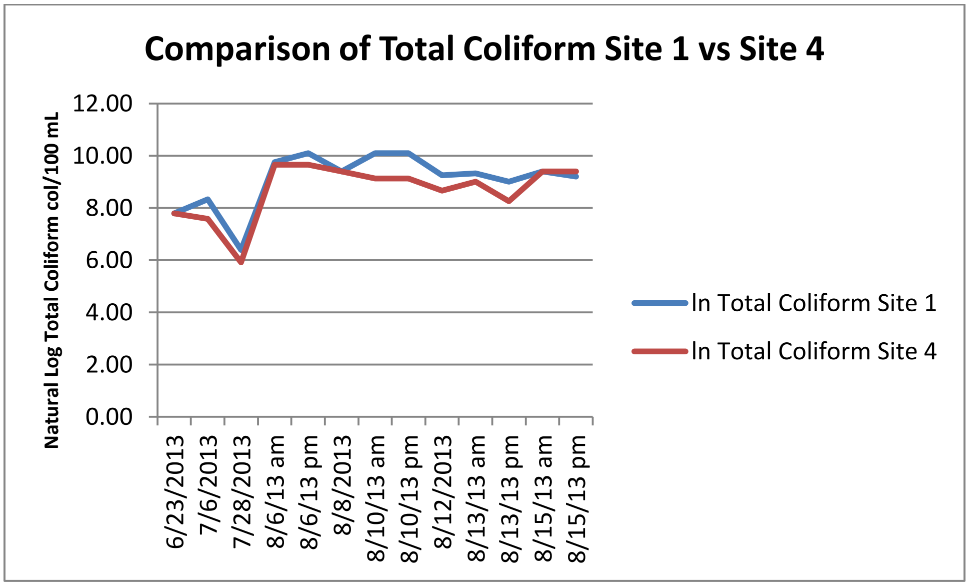


Figure 3. Total Coliform Site 1 vs. Western Wetland Effluent (Site 4)

Mean Log Difference=0.4 (0.2, 0.6) Kolmogorov-Smirnov >0.15 = Normal Distribution; Student's t-Test p= 0.0033

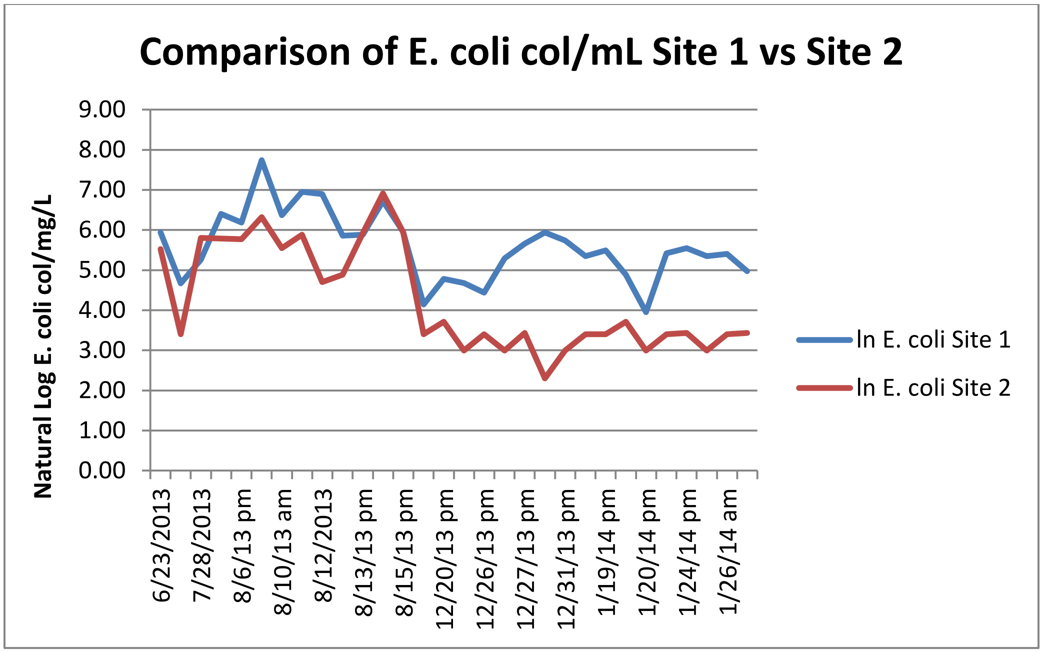


Figure 4. ***E. coli*** **Eastern Wetland Site 1 / Site 2 (Influent/Effluent):**

Mean Log Difference=1.3 (1.0, 1.7) Kolmogorov-Smirnov >0.15 = Normal Distribution; Student's T-Test $p<0.0001$

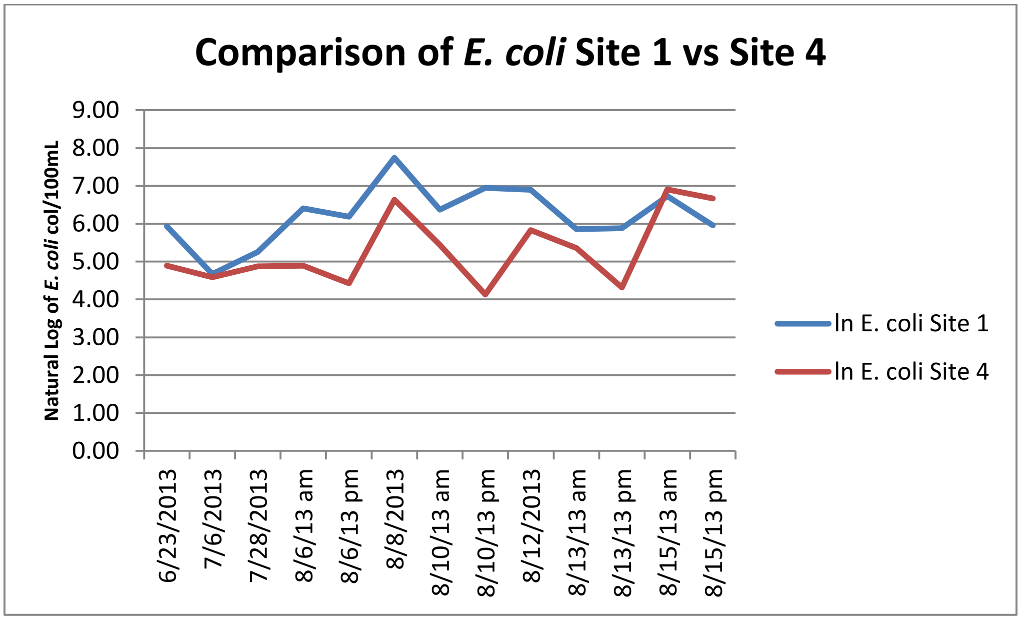


Figure 5. ***E. coli*** **Site 1 vs. Site 4**

Kolmogorov-Smirnov >0.15 = Normal Distribution; Mean Log Difference=0.9 (0.4, 1.5) Student's T-Test $p=0.0038$

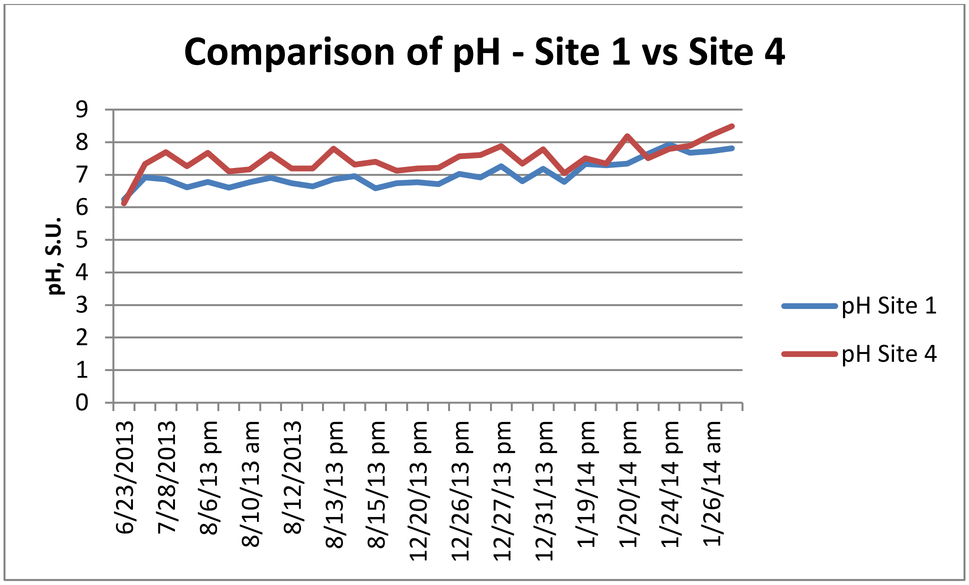


Figure 6. pH Eastern Wetland Influent (Site 1) vs. Western Wetland Effluent (Site 4)

Mean difference of pH Site 1 vs Site 4= -0.5 (-0.6,-0.4) Kolmogorov-Smirnov >0.15 = Normal Distribution; Student's T-Test; p <0.0001

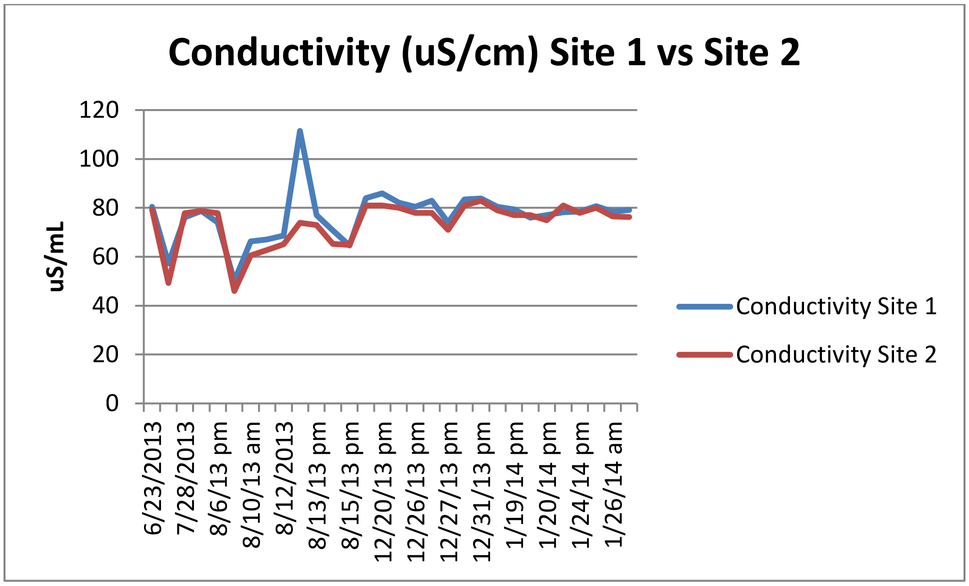


Figure 7. Conductivity – Site 1 vs Site 2

Mean difference of conductivity Site 1 vs Site24= 3.3 uS/cm (0.7, 6.0) Kolmogorov-Smirnov <0.05 = Non-Normal Distribution; Wilcoxon Signed Rank Test; p <0.0001

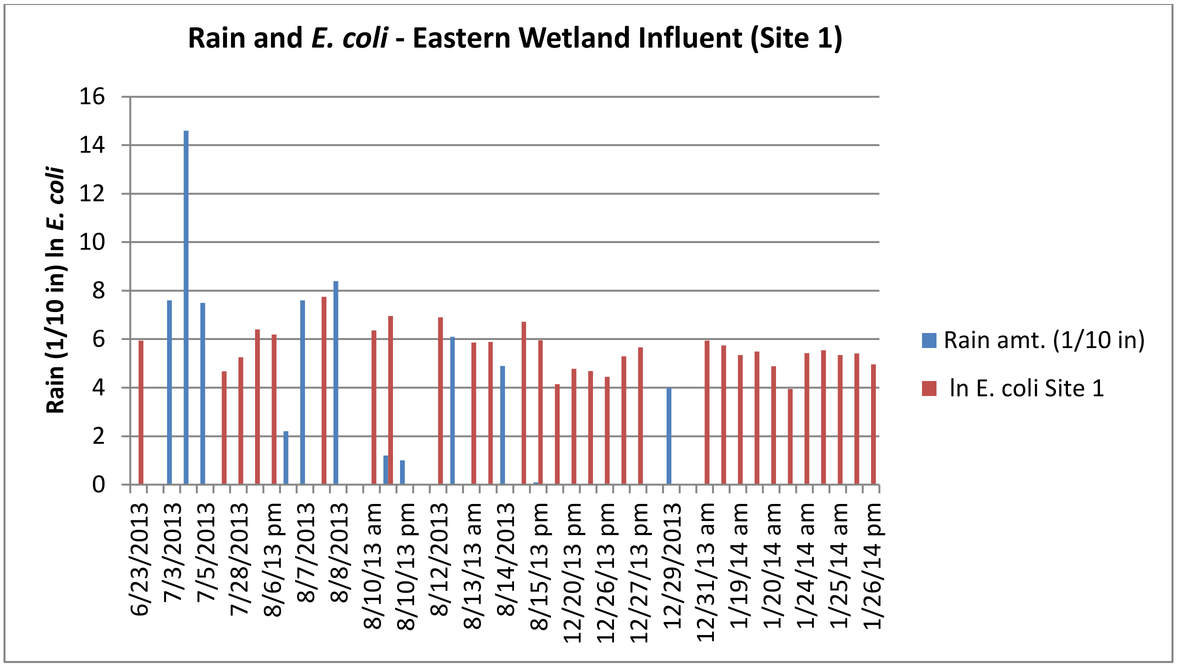


Figure 8. ***E. coli*** **(colonies/100 mL) / Rain (1/10 in.) Site 1**

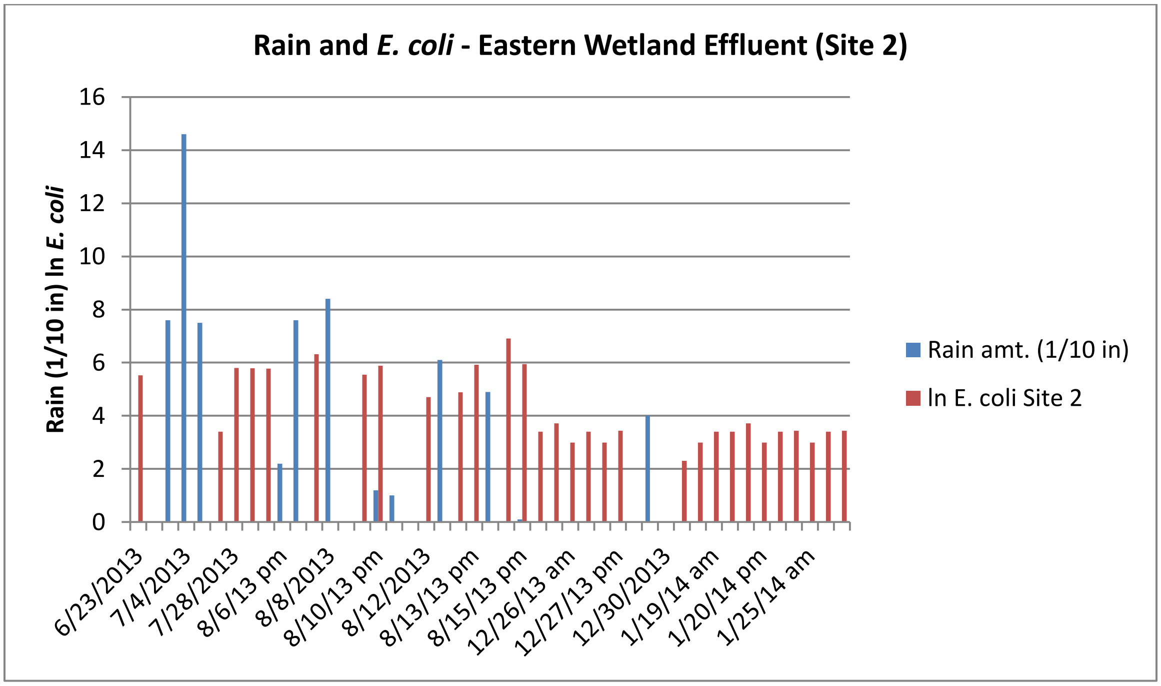


Figure 9. ***E. coli*** **(colonies/100 mL) / Rain (1/10 in.) Site 2**

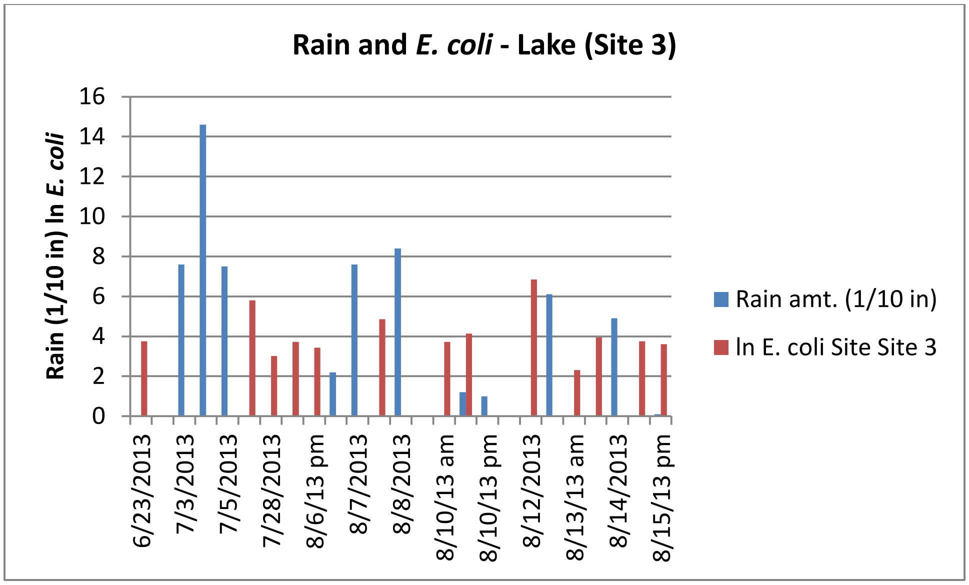


Figure 10. ***E. coli*** **(colonies/100 mL) / Rain (1/10 in.) Site 3**

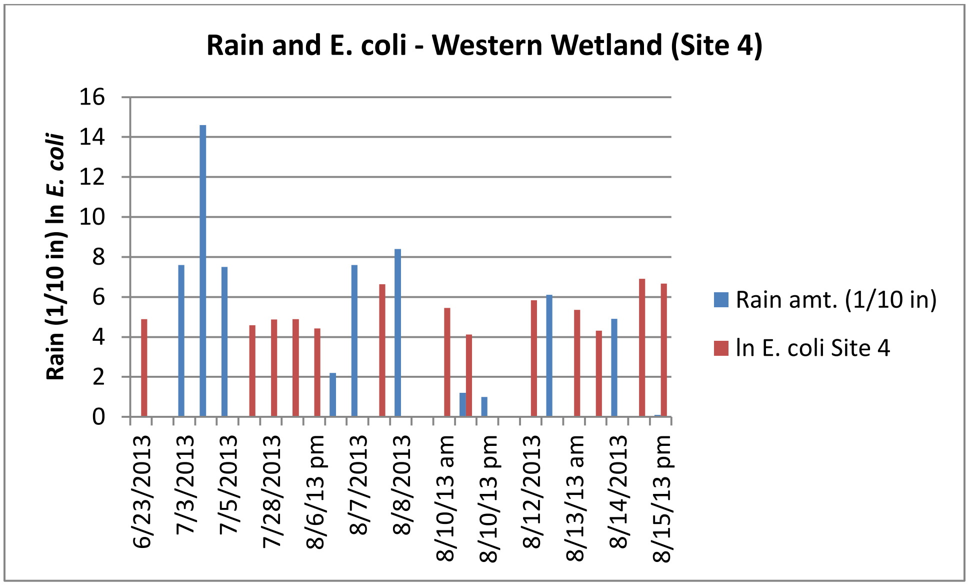


Figure 11. ***E. coli*** **(colonies/100 mL) / Rain (1/10 in.) Site 4**

(Rain data, USGS 2013).

There does not appear to be an association between rain and pH, DO_2, or conductivity (Tables1-8 in Appendix A). However, E. *coli*, total coliform, and turbidity measurements indicated an increase that may be associated with rain. Total coliform and *E. coli* experienced a general increase within 48 hours of rain except for a high total coliform on 8/6/13 at all sites (Figures 8-11). There was approximately 0.5 in rain 7/31/13 with no rain until 8/8/13. As stated earlier, GAEPD numerical limits for fecal coliform were used to designate high values of *E. coli*, while means were used for remaining parameters without numerical limits.

There were 6 *E. coli* samples over 500 colonies/mL at Site 1; of these, 5 samples occurred within 48 hours of rain (Figure 8), OR=19 (1.8, 201.7), RR =10 (1.3, 74.5), a broad range, yet significant . There were *2 E. coli* samples greater than 500 col/mL at Site 2 (Figure 9); both of which occurred within 48 hours of rain. The criteria used for *E. coli* at the lake (Site 3 – Figure 10) was 200 col/mL, per GAEPD fecal coliform water quality standards for recreational water. There was only one sample above this criteria and rain had occurred within 48 hours. Site 4 experienced 3 samples above 500 col/ml, all of which occurred within 48 hours of rain (Figure 11).

Total coliform does not appear to be as strongly associated with rain as *E coli.* There is no water quality standard for total coliform; therefore, the mean was used for comparison. Site 1 experienced 11 total coliform samples above the mean of 5895 col/100mL; 7 occurred within 48 hours of rain, OR=8.5 (1.5, 58.2) Mid-P Exact, RR=3.5(1.3, 9.2). However, a comparison limited to the summer months increases the mean to 12,388. There were 4 samples above the summer mean, 2 of which occurred within 48 hours of rain. Total coliform concentrations were much lower during the winter months with a mean of 929 col/100mL. There were 5 measurements above the winter mean and 2 occurred within 48 hours of rain. During the winter months, there were only 2 sample collection times that occurred within 48 hours of rain (Tables 1-2).

The effluent of the Eastern wetland, Site 2, experienced a total of 10 total coliform samples above the overall mean of 3822 col/100mL; 7 of these samples occurred within 48 hours of rain, OR 4.7 (0.297, 73.37). The summer mean increased to 8400 col/100mL with 8 total coliform samples exceeding the mean, 5 within 48 hours of rain, OR 1.1 (0.09, 12.52), RR=1.04 (0.43, 2.55). The winter mean decreased to 321 col/100 mL. There were 7 samples above the winter mean and none occurred within 48 hours of rain (Tables 3-4).

Site 3 (lake effluent) experienced 9 total coliform samples above its mean of 6106 col/100 mL, 7 of which occurred within 48 hours of rain. The mean total coliform for the effluent of the Western wetland, Site 4, was 8335 col/100mL and 7 samples were above the mean, 5 within 48 hours of rain (Tables 5-8).

There is no numerical limit for turbidity listed in GAEPD Water Quality Standards; therefore, the mean was used to designate high or low turbidity values. Site 1 experienced 10 turbidity values above the mean of 6.04 Nephelometric Turbidity Units (NTU) for the entire study, 7 of these occurred within 48 hours of rain. Considering only samples taken during the summer increases the mean turbidity to 7.29 NTU; 3 samples were above this mean and all occurred within 48 hours of rain. There were 5 samples that the exceeded the winter mean of 5.08 NTU. Both samples collected within 48 hours of rain during the winter were included in the 5 samples above the winter mean turbidity. Site 2 also experienced 10 samples in excess of its overall mean for turbidity, 7.47 NTU and 7 during a "wet" period. The summer mean increased to 10.1 NTU with 6 samples above the mean, 4 of these within 48 hours of rain. Both "wet" sample collections were included in the 10 samples that exceeded the winter mean of 5.45 NTU (Tables 1-4).

The lake, Site 3, had an overall turbidity mean of 4.31 NTU with 9 samples above the mean, 5 of these were within 48 hours of rain. The summer mean increased to 5.49 NTU while the winter mean decreased to 3.48 NTU. There were 6 samples above the summer mean, 5 were wet weather samples (Tables 3-4). None of the 5 samples above the winter mean were obtained during wet weather.

Site 4 experienced 12 samples above its overall turbidity mean of 6.68 NTU, 8 during wet weather. The summer mean increased to 9.45 NTU with 4 of the 5 samples above the mean obtained within 48 hours of rain. The winter mean decreased to 4.57 NTU; 8 samples were above the mean and 2 of these were wet samples (Tables 7-8). Again, there were only 2 sample collection times during the winter that occurred within 48 hours of rainfall.

DISCUSSION

Statistical analysis of total coliform results indicates Site 2, the effluent (downstream) of the Eastern wetland, had mean log difference of 0.7 when compared to Site 1, the influent (upstream) of the Eastern wetland (Figure 2). This difference indicates a significantly lower total coliform concentration assuming a normal distribution ($p<0.0001$; CI: 0.5, 0.9). Site 4, the Western wetland effluent had a statistically lower total coliform concentration than Site 1 with a mean log difference of 0.4, assuming a normal distribution Student's t-Test ($p= 0.0033$; CI: 0.2, 0.6), (Figure 3). All comparisons of total coliform had a Kolmogorov-Smirnov value >0.15, indicating a normal distribution..

Almost all samples obtained during the winter months were during periods of at least 48 hours of no rain. Total coliform concentrations at sample sites 1 and 2 were generally lower during the winter months, likely due to lower temperatures (Crump, 2005). Total coliform samples were not obtained at Sites 3 and 4 during the winter months. It is interesting to note that the log difference of total coliform concentration increased while the variability remained unchanged when compared to the overall data set. The mean log difference of total coliform concentration of Site 1 compared to Site 2 during the winter months was 1.0 ($p<0.0001$; CI: 0.8, 1.2), (Table 10). The hypothesis that constructed wetlands improve water quality by lowering the concentration of total coliform bacteria is supported by the data.

Figure 5 illustrates that *E. coli* concentrations were also found to be significantly lower at Site 2 versus Site 1 with a mean log difference of 1.3 assuming a normal distribution (Kolmogorov-Smirnov >0.15), Student's T-Test with 95% confidence interval ($p<0.0001$; 1.0, 1.7). As with total coliform, Site 4 (Figure 6) also had a significantly lower *E. coli* concentration when compared to Site 1 with a mean log difference of 0.9, assuming a normal distribution Student's t-Test ($p= 0.0038$; 0.4, 1.5). As with total coliform, *E. coli* concentrations at sample sites 1 and 2 were generally lower during the winter months, again likely due to lower temperatures. *E. coli* samples were not obtained at Sites 3 and 4 during the winter. *E. coli* samples obtained during the winter months also indicated a greater mean log difference of 1.9 $p<0.0001$ (1.5, 2.2) when compared to the overall sampling period (Table 10). This analysis supports the hypothesis that constructed wetlands improve water quality by lowering the concentration of *E. coli* bacteria, even though wildlife such as ducks and turtles inhabit the wetlands.

Statistical analysis provided no evidence of significant difference in pH measurements of Site 1 compared to Site 2, mean difference of -0.0433 standard units (SU) assuming a normal distribution ($p=0.4487$). However, comparison of the other sample sites did result in a significant difference, as shown in Table 10. It is believed this difference in pH is due to additional sources of water other than the Eastern wetland, i.e. the spring feeding the lake and the intermittent stormwater flow in the culvert. There is a noticeable change in pH following a diurnal pattern on the days that were sampled twice, most likely due to photosynthesis and respiration of aquatic plants. As aquatic plants photosynthesize during the day, up taking carbon dioxide and thus, raising the pH of the water. The opposite occurs during nighttime respiration as plants release carbon dioxide into the water (Windell et al 1987).

The comparison of DO_2 of the Eastern wetland Site 1 and Site 2 (influent/effluent) yielded a mean difference of: 0.3193, which was not statistically significant significant, Kolmogorov-Smirnov value <0.15 indicates a non-normal distribution; Signed Rank $p=0.1531$ (Table 10). DO_2 is affected by flow rate or turbulence throughout the four sample sites. The water flow at Site 3 and Site 4 is turbulent with typically higher DO_2 measurements than Site 1 and Site 2. The influent and effluent flow rate of the Eastern wetland is at equilibrium with less turbulence. A distinct diurnal pattern was apparent during days that were sampled twice, morning and late afternoon. DO_2 measurements were higher later in the day. Given the temperature dependence of Henry's law constant, it would be expected that DO_2 would decrease later in the day as the water temperature increases throughout the day, causing more oxygen to volatilize from the water to the atmosphere (Spiro and Stigliani 1935).

Photosynthesis of aquatic plants is again the cause as oxygen is released into the water during the day and removed during nighttime respiration. However, there is a definite overall increase in DO_2 during the winter months, which demonstrates the inverse relation between DO_2 and water temperature dictated by the solubility of gas in water.

Statistical analysis of the difference in turbidity of the Eastern wetland effluent (Site 2) and influent (Site 1) resulted in mean difference of -1.4 NTU(-2.5, -0.4) Kolmogorov-Smirnov value <0.15, Signed-rank p-value of 0.005 indicating an actual increase in turbidity at the effluent, which was unexpected. This increase is likely due to the design of the effluent structure rather than the process of the wetland. The effluent channel is very shallow and draws water from the floor of the wetland causing slight turbulence and re-suspension of sediment. The influent sample point has a much greater depth and is an overflow design that allows settling of some solids. The mean difference in turbidity of Site 1 compared to Site 4 of -0.6437 NTU was not statistically significant, Signed Rank $p=0.2924$ (Table 10).

Conductivity is a general measure of stream water quality relating the water's ability to conduct an electrical current. It is affected by ions of inorganic dissolved solids, including but not limited to phosphate, iron, chloride, calcium, magnesium etc. Organic compounds like oil are not good conductors and do not generally affect conductivity of waters (EPA 2012). Snapfinger Creek is subject to typical urban runoff whose pollutants, such as phosphorus and metals, will likely effect conductivity measurements (Horner, et al, 2007). The conductivity of Site 1 was significantly higher, statistically, compared to Site 2, mean difference 3.3 (0.7, 6.0), Kolmogorov-Smirnov value <0.15, Signed Rank $p<0.0001$ (Table 10). However, the confidence interval is somewhat broad.

<u>Effect of rain on sample results</u>

The Atlanta region has relatively old sewer infrastructure that was placed in the low lying areas adjacent to streams. Thus, rainwater enters and eventually overwhelms the ability of the sewer's capacity and overflows into the creek ways. Similarly, older septic tanks can be overwhelmed and enter the environment. Some rain events do not overwhelm these systems, but some do. Discharge of cooking grease into sewers has been proven to stick and harden on the distribution system piped, decreasing pipe capacity and thus, increasing overflow of sewerage into the environment. This is the precise reason several municipalities, including City of Atlanta's Watershed Management, have established restaurant grease trap monitoring programs. However, these programs have no effect on individual household sources of grease. Fried foods are common in the southern states; unfortunately, many people dispose of cooking grease by pouring it down their kitchen sink.

Increases in *E. coli*, total coliform, and turbidity within 48 hours of rainfall were observed at all sampling sites (Tables 1-8 and Figures 8-11). The influent of the Eastern wetland, Site 1, experienced significant increases of *E. coli*, total coliform, and turbidity within 48 hours of rainfall. Site 1 was 10 times more likely to exceed the standard after a rain than before, with a CI of 1.3-75. The site was 3.5 times more likely to experience an elevation of total coliform, CI of 1.332, 9.194 and 4.7 times more likely to have increased turbidity, with a CI of 1.5, 14. The remaining sites experienced increases in *E. coli*, total coliform, and turbidity associated with rainfall; however, none of the increases were statistically significant.

LIMITATIONS

The relatively small sample number (n=30) was a notable limitation of the study, resulting in decreased power of the study design and increased confidence intervals. Bacteria samples in water often have a heterogeneous distribution (Edberg 1990). Perhaps samples taken in clusters would have reduced sample variation within a sample event – example 4 samples taken per site at the same time, using the geometric mean for a single data point for that sampling event. Statistical analysis could have then been performed with the geometric means as the source of data for comparison. Due to limited resources, this method would have greatly reduced the statistical power as well as the time span of the study.

While some samples were obtained within 48 hours of rain, it was done so out of necessity rather than planning. Sampling throughout the course of a rain event at specific intervals could determine a profile of the effect of rain on pollutant levels. The use of a rain gauge with data logger located within the study area would increase precision over USGS data of nearby sites. Including measurements of flow rates at each sample site may also provide further correlations between rain and pollutants.

This study did not analyze samples for metals or oil and grease due to budget constraints. Considering the commercial surroundings near the study site, road runoff is likely a large contributor to stormwater in the area. Runoff from heavily used roads may have elevated levels of metals from motor oil, brake dust, etc. A determination of the metals content and possible removal by the wetlands could be beneficial in determining future use of constructed wetlands in urban areas.

CONCLUSIONS

Constructed wetlands have an important role in "green" infrastructure (Wallace 2004). The intent of this study was to provide empirical evidence either supporting or not supporting that the wetlands constructed in the city of Pine Lake, Georgia do indeed improve water quality. Low sample numbers created less precision in the data – wide confidence intervals. However, statistical significance in small sample sizes is only evident in more extreme cases. Measurements of total coliform, *E. coli*, and conductivity were found to be significantly lower at the effluent of the Eastern wetland compared to the influent. Rainfall appeared to be associated with increases in total coliform, *E. coli*, and turbidity.

The data supports the hypothesis that a constructed wetland can improve water quality in an urban environment, perhaps most notably apparent in the decline of beach closures since completion. Further study is needed to determine if it is also useful for groundwater recharge**,** which is especially important in urban areas with excessive amounts of impervious surface such as in the metropolitan Atlanta area. This study supports green infrastructure as an effective solution for challenges of stormwater management in an urban setting.

References

Gosselink, J.,and Mitch, W. (1993). Wetlands. 2^{nd} ed. Van Nostrand Rheinhold, New York.

EPA, (1993). Subsurface flow constructed wetlands for wastewater treatment: A Technology assessment, US EPA Office of Water, EPA 832-R 93-008, Washington, DC.

Bekilou, M., Dermirer, N., and Korkuzsuz, E., (2005). Comparison of the treatment performances of blast furnace slag-based and grave-based vertical flow wetlands operated identically for domestic wastewater treatment in Turkey. *Ecological Engineering*, 24:187-200.

Barber, M., Hathorn, W., and Koob, T. (1999). Hydrologic design considerations of constructed wetlands for urban stormwater runoff. *Journal of American Water Resources Association*, 35(2), 323-331.

Fulcher, G. (1994). Urban stormwater quality from a residential catchment. *Science of the Total Environment*, Volumes 146-147, 535-542. http://dx.doi.org/10.1016/0048-9697(94)90279-8.

Bang, K., Lee, J. (2000). Characterization of Urban Stormwater Runoff. *Water Resources*. Vol. 34, No. 6, 1773-1780. PII: S0043-1354(99)00325-5.

Bang, K., Choe, L., Ketchumc, J. , Lee, J.. , Yu M. (2001). First flush analysis of urban storm runoff. *The Science of the Total Environment* 293, 163–175

Dwight, Ryan H.; Semenza, Jan C.; Baker, Dean B.; Olson, Betty H.(2002). Association of Urban Runoff with Coastal Water Quality in Orange County, California. *Water Environment Research*, Volume 74, Number 1, 82-90(9).

He, Q., Kong, L., Li, Q., Yin, C. (2007). First flush of storm runoff pollution from an urban catchment in China. *Journal of Environmental Sciences*, 19, Issue 3, 295-299. http://dx.doi.org/10.1016/S1001-0742(07)60048-5.

Boogaard, F., Langeveld, H., Liefting, H. (2012). Uncertainties of stormwater characteristics and removal rates of stormwater treatment facilities: Implications for stormwater handling. *Water Research,* 1 -1 3. http://dx.doi.org/10.1016/j.watres.2012.06.001

International Stormwater (2012): International Stormwater BMP database: Water Environment Research Foundation. Accessed September 10, 2013. http://bmpdatabase.org/BMPPerformance.htm

Zarus G. and Howland P; (2006), Enhancing Habitat while Treating Stormwater Runoff in a Small Urban Lake. North American Association of Lake Management. Annual Meeting. Macon, GA. January 2006. https://www.researchgate.net/publication/215624921_Enhancing_Habitat_while_Treating_Stormwater_Runoff_in_a_Small_Urban_Lake_Watershed?ev=prf_pub

Woolson, E, (2005). The price of a utility. *Stormwater* (editorial) Jul-Aug 2005. http://www.stormh2o.com/SW/Articles/The_Price_of_a_Utility_16683.aspx

Barker (2011). A History of Wastewater Irrigation in Melbourne, Australia *Journal of Water Sustainability*, Volume 1, Issue 2, September 2011, 31–50. © University of Technology Sydney & Xi'an University of Architecture and Technology.

Ledbetter, G (2012). Opposition to Chadron storm water project surfaces. *Chadron Record*. 12 April.

Brix H. (1994) Use of constructed wetlands in water pollution control: Historical development, present status, and future perspectives. *Water Science and Technology* 30(8), 209-223.

LIDC (2012). Rain garden design templates, Low impact development center, http://www.lowimpactdevelopment.org/raingarden_design/how2designraingarden.htm

Maryland Stormwater Design Manual Volumes I & II (2000). Section 2.7, BMP Group 3 (Infiltration), and BMP Group 4 (Filtration). Retrieved from http://www.mde.state.md.us/assets/document/sedimentstormwater/Introduction.pdf

Christianson, R., Barfield, B., Hayes, J., Gasem, K., and Brown, G. (2004) Modeling Effectiveness of Bioretention Cells for Control of Stormwater Quantity and Quality. Critical Transitions in Water and Environmental Resources Management: pp. 1-7. doi: 10.1061/40737(2004)37

Wong, T. and Breen, P. (2002). Recent advances in Australian practice on the use of constructed wetlands for stormwater treatment. *Strecker E.W. and Huber W.C. (eds.):Global solutions for urban drainage.*

Zarus G and Howland P (2012). Pine lake's wetland –a constructed urban system, the 2012 erosion and control exposition, DeKalb County Soil and Water Conservation District, Atlanta, GA. 31 May 2012. Available at: https://www.researchgate.net/publication/230691603_Pine_Lakes_Wetland_A_Constructed_Urban_System

Zarus G (2012) A new Pine Lake, DeKalb. We are DeKalb Magazine. https://www.researchgate.net/publication/216718362_A_New_Pine_Lake_(httpwww.wearedekalb.comflippingBookindex.html)?ev=prf_pub

Georgia EPD Integrated 305(b)/303(d) List, (2012). Rivers/Streams. A-223. Retrieved from http://www.gaepd.org/Documents/305b.html

Collier M., Foley K, Lennon M., and Scott M., (2013). EPA (Dublin). Delivering ecosystems services via spatial planning – reviewing the possibilities and implications of a green infrastructure approach. *Eco Plan – Delivering Green Infrastructure*.

Google Earth. Imagery Date 10/31/2012, 33^{o} 47'.27''N 84^{o} 12'22.38''W.

O'Dell, J. Method 180.1 Determination Of Turbidity By Nephelometry Environmental Monitoring Systems Laboratory, Office Of Research And Development, U.S. Environmental Protection Agency, Cincinnati, Ohio 45268. 1993.

NOAA, Jul-Dec 2013 National Climatic Data Center. Precipitation. (2013). Retrieved from https://www.ncdc.noaa.gov/sotc/service/national/Divisionalprank/201307-201312.gif

NOAA, July-December 2013 Regional Ranks. National Climatic Data Center. Precipitation. (2013). Retrieved from https://www.ncdc.noaa.gov/sotc/service/national/Regionalprank/201307-201312.gif

EPA 815-R-05-004 (January 2005). Criteria and Procedures Quality Assurance. Fifth Edition. *Manual for the Certification of Laboratories Analyzing Drinking Water* Retrieved from http://www.epa.gov/ogwdw/methods/pdfs/manual_labcertification.pdf

USGS Snapfinger Site Number "02203950 SNAPFINGER CREEK NEAR DECATUR,GA Dekalb County, Georgia; Hydrologic Unit Code 03070103; Latitude 33°45'48", Longitude 84°13'13" NAD27. Retrieved from http://waterdata.usgs.gov/nwis/uv?site_no=02203950

EPA. (2005). Standard Methods for the Examination of Water and Wastewater 21st Edition. #9223B Enzyme Substrate Coliform test, Colilert.

Dichter, G. (February 1990).Testing Waste Water for Fecal Coliforms and/or *E.coli* using Colilert® and Colilert®-18
& Quanti-Tray®. Retrieved from www.idexx.com/water

EPA (1989).Federal Register. National Primary Drinking Water Regulations: Analytical Techniques; Coliform Bacteria; Final Rule40 CFR 141 7-17-1989

Openepi - Dean AG, Sullivan KM, Soe MM. OpenEpi: Open Source Epidemiologic Statistics for Public Health, Version 2.3.1. www.OpenEpi.com, updated 2011/23/06, accessed 2014/04/13.

Georgia EPD (March 2012). 391-3-6-.03 Water Use Classifications and Water Quality Standards (6) Specific Criteria for Classified Water Usage. (i) Bacteria

Gaines, S. DeKalb County Board of Health Fecal Coliform Reports 2007-2013

Crump, B. Hobbie, J. (2005). Synchrony and seasonality in bacterioplankton communities of two temperate rivers *Limnol. Oceanogr.,* 50(6), 1718–1729 by the American Society of Limnology and Oceanography, Inc.

Knud-Hansen, C.; Rink, L.; and Windell, J. (Aquatic Wetland Consultants, Inc.) 1987. A One Year, Biweekly, 24-Hour Sampling Study of Boulder Creek and Coal Creek Water Quality.

Spiro, T. Stigliani, W 1935, Chemistry of the Environment, 3rd Edition, Mill Valley, Calif.: University Science Books 2012.

Horner, R..; May, C.; Ridley, G.; Skupien, J.; Shaver, E.(2007).Fundamentals of Urban Runoff Management. Technical and Institutional Issues, 2nd Edition 50-62.

Edberg, Allen, Smith & Kriz. (1990). Enumeration of Total Coliforms and *Escherichia coli* from Source Water by the Defined Substrate Technology. *Applied and environmental Microbiology,* February 56(2): 366–369. PMCID: PMC183346

Wallace (2004). Engineered Wetlands Lead the Way. *Land and Water*, September/October 2004 pages 13-16.

EPA (2012). Water: Monitoring & Assessment, Water, Our Waters, Rivers & Streams, Monitoring & Assessment,5.9 Conductivity, *What is conductivity and why is it important?* Retrieved from http://water.epa.gov/type/rsl/monitoring/vms59.cfm.

APPENDIX A. Sampling Results

Table 1: Site 1 - Eastern Wetland Influent Summer Data

SITE 1 – Summer Sampling Data										
Date	Time	48 hr. rain amt. (in)	Air Temp C	Water Temp C	pH	DO$_2$ mg/L	Conductivity uS/cm	Turbidity NTU	Total Coliform col/100 mL	E. coli Site col/100 mL
6/23/2013	14:10	0	25.6	22.9	6.24	9.43	80.5	5.43	>2419.6	378.4
7/6/2013	14:38	2.21	26.1	27.3	6.92	8.54	57.3	16.4	4160	107
7/28/2013	15:47	0	28.3	25.2	6.86	9.53	76.1	5.99	595.5	192
8/6/13 am	9:00	0	25.0	23.0	6.61	6.51	78.8	5.23	17329	605
8/6/13 pm	14:40	0	30.0	24.2	6.78	10.71	74.0	4.99	24196	487
8/8/2013	9:00	0.98	23.3	23.7	6.60	6.49	50.1	12.0	>12098	2305.5
8/10/13 am	9:03	0.82	25.0	23.6	6.77	5.96	66.3	6.85	24196	583
8/10/13 pm	14:44	0.9	28.3	25.2	6.91	8.82	67.1	5.22	24196	1043
8/12/2013	9:02	0.22	25.0	23.6	6.74	5.97	68.7	6.52	10462	991
8/13/13 am	9:04	0.6	22.8	22.9	6.64	6.20	111.5	6.26	11199	350
8/13/13 pm	14:35	0	29.4	24.3	6.86	9.57	77.0	5.63	8164	359
8/15/13 am	9:16	0.03 8-13	19.4	22.6	6.96	6.35	70.7	7.48	>12098	832
8/15/13 pm	14:30	0.03 8-13	20.0	22.2	6.58	8.41	64.6	6.83	9931.5	385.5

Table 2: Site 1 - Eastern Wetland Influent Winter Data

SITE 1 – Winter Sampling Data										
Date	Time	48 hr. rain amt. (in)	Air Temp C	Water Temp C	pH	DO$_2$ mg/L	Conductivity uS/cm	Turbidity NTU	Total Coliform col/100 mL	E. coli Site col/100 mL
12/20/13 am	9:50	0	7.2	7.5	6.74	9.47	84	6.62	798	63
12/20/13 pm	15:00	0	13.3	8.87	6.77	8.04	86	4.25	1100	119
12/26/13 am	10:00	0	4.4	7.2	6.71	10.88	82.2	6.01	738	108
12/26/13 pm	15:12	0	12.2	7.8	7.03	10.51	80.5	5.69	712	85
12/27/13 am	10:26	0	5.0	6.78	6.92	9.16	83	6.23	705	199
12/27/13 pm	15:15	0	8.9	8.01	7.26	8.59	74	6.21	738	288
12/31/13 am	10:05	0.4	3.9	8.77	6.8	10.03	83.5	5.98	2142	379
12/31/13 pm	15:03	0.4	8.9	9.08	7.18	10.17	83.8	5.82	1624	311
1/19/14 am	10:05	0	1.7	5.28	6.78	9.09	80.5	5.88	816	211
1/19/14 pm	15:02	0	11.7	5.59	7.33	11.04	79.4	5.21	867	243
1/20/14 am	10:30	0	8.3	6.21	7.29	8.36	76	5.44	631	132
1/20/14 pm	15:05	0	19.4	8.53	7.34	9.87	77	5.26	288	52
1/24/14 am	10:29	0	0.0	2.00	7.65	9.65	78.2	4.02	910	226
1/24/14 pm	14:57	0	4.4	2.6	7.93	9.97	78.5	3.65	865	256
1/25/14 am	10:32	0	2.8	3.02	7.68	9.47	80.7	3.61	984	211
1/26/14 am	10:24	0	3.3	3.71	7.72	8.72	78.5	3.4	985	223
1/26/14 pm	15:22	0	12.8	5.42	7.81	11.06	79.2	3.02	889	144

Table 3: Site 2 - Eastern Wetland Effluent Summer Data

SITE 2 – Summer Sampling Data										
Date	Time	48 hr. rain amt. (in)	Air Temp C	Water Temp C	pH	DO_2 mg/L	Conductivity uS/cm	Turbidity NTU	Total Coliform col/100 mL	E. coli Site col/100 mL
6/23/2013	14:23	0	26.1	24.3	6.19	13.79	79.3	10.2	>2419.6	250.0
7/6/2013	15:15	2.21	30.0	27.7	7.02	8.43	49.2	15.4	1287	30
7/28/2013	16:00	0	28.9	25.8	6.92	7.91	77.8	12.3	1611.5	331.5
8/6/13 am	9:15	0	25.0	23.1	6.98	5.84	78.8	7.25	12997	327
8/6/13 pm	14:52	0	35.0	27.7	7.34	10.85	77.9	7.24	14136	322
8/8/2013	9:15	0.98	23.9	23.9	6.81	5.19	46.0	11.5	>12098	556
8/10/13 am	9:15	0.82	25.6	23.9	6.86	4.02	60.6	7.88	9208	256
8/10/13 pm	15:04	0.9	28.3	27.5	7.11	9.05	62.7	17.1	12997	359
8/12/2013	9:18	0.22	26.7	24.3	6.85	4.15	65.1	8.21	4884	110
8/13/13 am	9:18	0.6	24.4	23.3	6.78	4.53	73.9	6.79	6867	132
8/13/13 pm	14:48	0	31.7	27.3	7.29	9.94	73.0	9.08	8664	373
8/15/13 am	9:31	0.03 8-13	19.4	22.4	7.11	4.72	65.2	11.2	9931.5	1007.5
8/15/13 pm	14:46	0.03 8-13	22.2	23.1	7.26	8.66	64.9	7.28	>12098	383.5

Table 4: Site 2 - Eastern Wetland Effluent Winter Data

SITE 2 – Winter Sampling Data										
Date	Time	48 hr. rain amt. (in)	Air Temp C	Water Temp C	pH	DO_2 mg/L	Conductivity uS/cm	Turbidity NTU	Total Coliform col/100 mL	E. coli Site col/100 mL
12/20/13 am	10:15	0	7.8	6.34	6.52	9.64	81	6.21	272	30
12/20/13 pm	15:18	0	13.9	9.56	7.17	11.9	81	10.2	541	41
12/26/13 am	10:17	0	5.0	6.7	6.85	10.9	80	6.11	305	20
12/26/13 pm	15:31	0	13.3	7.9	7.33	10.75	78	5.67	364	30
12/27/13 am	10:43	0	7.2	6.00	6.8	10.78	78	6.69	295	20
12/27/13 pm	15:32	0	9.4	8.72	7.34	10.21	71	6.27	345	31
12/31/13 am	10:20	0.4	3.9	8.48	6.82	10.44	81	6.01	272	10
12/31/13 pm	15:18	0.4	8.9	9.23	7.21	10.88	83	5.83	256	20
1/19/14 am	10:19	0	2.8	5.16	6.98	9.12	79	5.78	355	30
1/19/14 pm	15:18	0	12.2	5.72	7.18	11.33	77	5.6	327	30
1/20/14 am	10:46	0	10.0	4.67	7.06	8.89	77	5.42	448	41
1/20/14 pm	15:20	0	20.0	9.58	7.44	11.34	75	5.15	189	20
1/24/14 am	10:50	0	0.0	1.7	7.12	9.77	81	3.76	309	30
1/24/14 pm	15:12	0	5.0	2.8	7.41	10.2	78	3.47	269	31
1/25/14 am	10:48	0	3.3	2.7	7.2	9.72	80.1	3.58	228	20
1/26/14 am	10:38	0	4.4	3.01	7.23	9.24	76.5	3.52	373	30
1/26/14 pm	15:37	0	12.8	5.66	7.53	13.96	76.3	3.3	305	31

Table 5: Site 3 – Lake Effluent Summer Data

SITE 3 – Summer Sampling Data										
Date	Time	48 hr. rain amt. (in)	Air Temp C	Water Temp C	pH	DO_2 mg/L	Conductivity uS/cm	Turbidity NTU	Total Coliform col/100 mL	E. coli Site col/100 mL
6/23/2013	14:45	0	26.1	29.4	6.41	7.97	61.8	3.43	1011.2	42.8
7/6/2013	15:35	2.21	28.9	23.4	7.04	6.82	103.2	3.36	6015	333
7/28/2013	16:16	0	29.4	29.5	8.2	8.92	55.8	5.04	1384.5	20.5
8/6/13 am	9:31	0	26.1	27.3	7.55	7.59	59.3	5.10	10462	41
8/6/13 pm	15:07	0	32.2	30.5	8.00	7.96	67.4	6.19	>2419.6	31
8/8/2013	9:35	0.98	23.9	27.2	7.35	7.37	54.6	5.70	3065.5	129.5
8/10/13 am	9:33	0.82	25.6	27.7	7.51	7.91	54.1	7.17	>24196	41
8/10/13 pm	15:15	0.9	28.3	30.5	7.77	8.26	52.5	3.79	5172	63
8/12/2013	9:36	0.22	26.1	28.2	7.46	8.04	52.9	7.27	2851	933
8/13/13 am	9:35	0.6	25.0	27.9	7.55	7.86	53.1	7.94	8664	10
8/13/13 pm	15:04	0	31.1	30.9	8.16	8.69	53.1	4.16	5172	52
8/15/13 am	9:47	0.03 8-13	20.0	25.6	7.57	7.49	53.8	3.89	4542	42.5
8/15/13 pm	14:57	0.03 8-13	22.8	26.7	7.73	8.30	52.8	6.18	4332	37

Table 6: Site 3 – Lake Effluent Winter Data

SITE 3 – Winter Sampling Data										
Date	Time	48 hr. rain amt. (in)	Air Temp C	Water Temp C	pH	DO$_2$ mg/L	Conductivity uS/cm	Turbidity NTU	Total Coliform col/100 mL	E. coli Site col/100 mL
12/20/13 am	10:35	0	8.3	7.81	7.23	10.93	59.6	2.96	n/a	n/a
12/20/13 pm	15:33	0	13.9	9.77	7.33	12.06	58.1	5.43	n/a	n/a
12/26/13 am	10:30	0	5.6	7.62	7.37	11.44	57.2	3.78	n/a	n/a
12/26/13 pm	15:46	0	13.3	8.34	7.69	11.29	57	3.36	n/a	n/a
12/27/13 am	10:59	0	7.8	6.33	7.44	11.23	56.2	3.76	n/a	n/a
12/27/13 pm	15:44	0	10.6	8.98	7.89	11.01	55.3	3.98	n/a	n/a
12/31/13 am	10:37	0.4	4.4	9.04	7.22	11.18	58.3	3.21	n/a	n/a
12/31/13 pm	15:32	0.4	9.4	9.53	7.81	11.41	59.3	3.11	n/a	n/a
1/19/14 am	10:35	0	3.9	5.57	7.01	10.78	55.2	3.78	n/a	n/a
1/19/14 pm	15:32	0	12.2	5.89	7.43	11.89	54.1	3.44	n/a	n/a
1/20/14 am	10:59	0	10.0	6.25	7.22	9.73	54.5	3.28	n/a	n/a
1/20/14 pm	15:31	0	20.0	8.61	7.78	11.96	55.8	3.11	n/a	n/a
1/24/14 am	10:46	0	0.6	2.1	7.53	10.55	56.7	3.03	n/a	n/a
1/24/14 pm	15:27	0	5.6	3.26	7.89	10.99	57.4	2.98	n/a	n/a
1/25/14 am	10:43	0	3.9	3.23	7.7	10.56	58.9	3.31	n/a	n/a
1/26/14 am	10:55	0	6.7	4.04	8.16	12.62	58.5	3.32	n/a	n/a
1/26/14 pm	15:50	0	13.9	5.74	8.24	11.33	57.4	3.25	n/a	n/a

Table 7: Site 4 - Western Wetland Influent Summer Data

SITE 4 – Summer Sampling Data										
Date	Time	48 hr. rain amt. (in)	Air Temp C	Water Temp C	pH	DO$_2$ mg/L	Conductivity uS/cm	Turbidity NTU	Total Coliform col/100 mL	E. coli Site col/100 mL
6/23/2013	15:00	0	26.7	28.0	6.12	8.06	59.6	5.13	>2419.6	133.4
7/6/2013	16:01	2.21	28.3	29.3	7.33	8.50	41.3	17.3	1968	98
7/28/2013	16:38	0	31.1	30.2	7.70	8.57	51.0	8.97	368.5	131
8/6/13 am	9:56	0	27.8	26.4	7.26	6.10	55.6	10.4	15531	133
8/6/13 pm	15:22	0	32.2	30.6	7.68	8.13	52.1	8.67	15531	84
8/8/2013	9:51	0.98	25.6	25.8	7.11	5.61	53.0	11.7	12098	757.5
8/10/13 am	9:48	0.82	26.7	26.9	7.16	5.86	55.4	7.75	9208	231
8/10/13 pm	15:26	0.9	28.3	31.0	7.64	8.23	52.2	7.35	9208	62
8/12/2013	9:51	0.22	25.6	26.9	7.19	5.84	54.9	9.17	5794	341
8/13/13 am	9:53	0.6	26.1	26.3	7.19	5.78	55.4	7.7	8164	213
8/13/13 pm	15:19	0	31.7	30.2	7.80	8.60	52.6	8.18	3873	75
8/15/13 am	10:01	0.03 8-13	20.6	24.5	7.31	5.57	50.1	10.9	>12098	994.5
8/15/13 pm	15:14	0.03 8-13	22.8	25.3	7.40	7.87	49.3	9.60	>12098	788

Table 8: Site 4 - Western Wetland Effluent Winter Data

SITE 4 – Winter Sampling Data										
Date	Time	48 hr. rain amt.	Air Temp C	Water Temp C	pH	DO$_2$	Conductivity	Turbidity	Total Coliform	E. coli Site
12/20/13 am	10:55	0	7.8	6.86	7.13	9.88	57.1	4.53	n/a	n/a
12/20/13 pm	15:49	0	13.9	7.52	7.19	11.42	57.3	6.33	n/a	n/a
12/26/13 am	10:47	0	5.6	6.81	7.21	10.78	56.7	5.78	n/a	n/a
12/26/13 pm	15:59	0	12.8	6.97	7.57	10.92	56.4	5.54	n/a	n/a
12/27/13 am	11:15	0	8.3	4.13	7.61	10.41	48	4.25	n/a	n/a
12/27/13 pm	15:57	0	11.1	5.81	7.88	14.04	53	5.35	n/a	n/a
12/31/13 am	10:51	0.4	5.0	8.31	7.34	10.28	56.6	5.23	n/a	n/a
12/31/13 pm	15:48	0.4	9.4	7.94	7.78	10.59	56.9	5.11	n/a	n/a
1/19/14 am	10:52	0	3.3	3.76	7.05	9.31	54.2	5.13	n/a	n/a
1/19/14 pm	15:47	0	12.2	4.09	7.51	11.12	53.3	5.01	n/a	n/a
1/20/14 am	11:16	0	9.4	5.66	7.34	8.93	54.1	4.54	n/a	n/a
1/20/14 pm	15:52	0	19.4	4.9	8.19	12.56	56	4.33	n/a	n/a
1/24/14 am	11:02	0	0.6	1.7	7.51	9.88	56.1	3.67	n/a	n/a
1/24/14 pm	15:41	0	5.0	2.95	7.79	10.02	56.6	3.44	n/a	n/a
1/25/14 am	10:58	0	3.9	2.98	7.89	9.91	58.2	3.36	n/a	n/a
1/26/14 am	11:09	0	7.8	2.13	8.22	12.38	58.1	3.21	n/a	n/a
1/26/14 pm	16:01	0	13.3	3.86	8.49	12.91	54.7	2.81	n/a	n/a

Appendix B Statistical Analysis

Table 10. Statistical Analysis

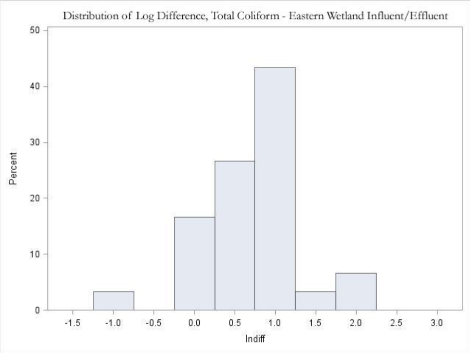
Parameter	Comparison Sites	Mean Difference	Confidence Interval	Kolmogorov-Smirnov Distribution	Student's t-Test or Wilcoxon Signed Rank p-Value
Total Coliform col/100 mL	1 vs 2	natural log 0.700	(0.471, 0.928)	>0.15 = Normal	t-Test $p<0.0001$
	1 vs 4	natural log 0.398	(0.160, 0.635)	>0.15 = Normal	t-Test $p=0.0033$
E. coli col/100 mL	1 vs 2	natural log 1.336	(0.980, 1.691)	>0.15 = Normal	t-Test $p<0.0001$
	1 vs 4	natural log 0.914	(0.357, 1.471)	>0.15 = Normal	t-Test $p=0.0038$
pH S.U.	1 vs 2	-0.0433	(-0.159, 0.072)	>0.15 = Normal	t-Test $p=0.4487$
	1 vs 4	-0.473	(-0.584,-0.362)	>0.15 = Normal	t-Test $p<0.0001$
	1 vs 3	-0.561	(-0.711, -0.411)	>0.15 = Normal	t-Test $p<0.0001$
	3 vs 4	0.0883	(0.004, 0.173)	>0.15 = Normal	t-Test $p=0.0416$
	2 vs 3	-0.5177	(-0.618, (-0.417)	>0.15 = Normal	t-Test $p<0.0001$
	2 vs 4	-0.4293	(-0.527, -0.332)	<0.05 = Non-Normal Dist	Signed-Rank $p<0.0001$

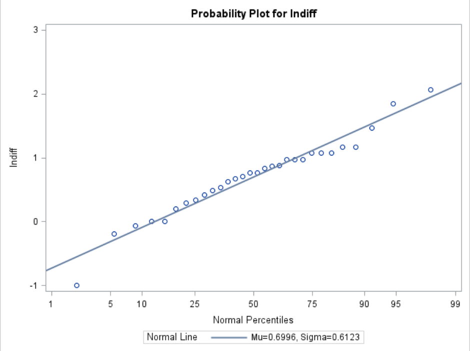
Table 10. Statistical Analysis, continued

Parameter	Comparison Sites	Mean Difference	Confidence Interval	Kolmogorov-Smirnov Distribution	Student's t-Test or Wilcoxon Signed Rank p-Value
DO_2 mg/L	1 vs 2	-0.3193	(-0.882, 0.243)	<0.05 = Non-Normal Dist	Signed-Rank p=0.1531
	1 vs 4	-0.383	(-0.989, 0.223)	<0.05 = Non-Normal Dist	Signed-Rank p=0.6013
	1 vs 3	-0.919	(-1.470, -0.368)	<0.05 = Non-Normal Dist	Signed-Rank p=0.0.0014
	2 vs 3	-0.5997	(-1.367, 0.168)	<0.05 = Non-Normal Dist	Signed-Rank p=0.1210
	2 vs 4	-0.0637	(-0.685, 0.558)	<0.05 = Non-Normal Dist	Signed-Rank p=0.6225
	3 vs 4	0.536	(0.106, 0.966)	<0.05 = Non-Normal Dist	Signed-Rank p=0.0024
Conductivity uS/cm	1 vs 2	3.347	(0.427, 5.951)	<0.05 = Non-Normal Dist	Signed-Rank p<0.0.001
	1 vs 4	22.730	(19.293, 26.167)	<0.05 = Non-Normal Dist	Signed-Rank p<0.0001
Turbidity NTU	1 vs 2	-1.429	(-2.455, -0.403)	<0.05 = Non-Normal Dist	Signed-Rank p=0.0051
	1 vs 4	-0.6437	(-1.320, 0.033)	<0.05 = Non-Normal Dist	Signed-Rank p=0.2924
	1 vs 3	1.7607	(0.747, 2.775)	<0.05 = Non-Normal Dist	Signed-Rank p=0.0051
	2 vs 3	3.1897	(1.934, 4.445)	<0.05 = Non-Normal Dist	Signed-Rank p<0.0001
	2 vs 4	0.7853	(-0.107, 1.677)	<0.05 = Non-Normal Dist	Signed-Rank p=0.0822
	3 vs 4	-2.4043	(-3.464, -1.345)	<0.05 = Non-Normal Dist	Signed-Rank p<0.0001

APPENDIX C. SAS 9.3 Output

The MEANS Procedure – Site 1 vs Site Total Coliform





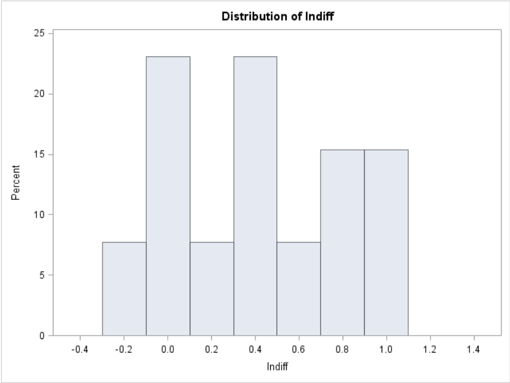
Analysis Variable : lndiff

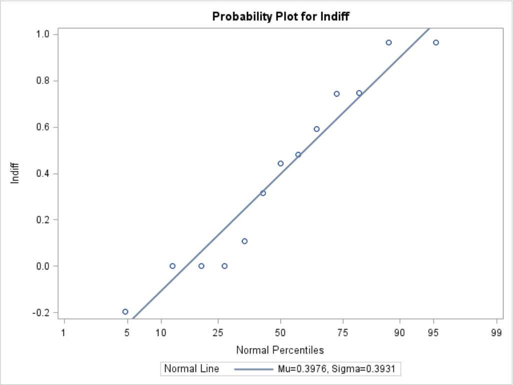
Mean	Lower 95% CL for Mean	Upper 95% CL for Mean
0.7	0.5	0.9

Moments			
N	30	**Sum Weights**	30
Mean	0.69958255	**Sum Observations**	20.9874765
Std Deviation	0.61234784	**Variance**	0.37496987
Skewness	-0.3306969	**Kurtosis**	1.35282404
Uncorrected SS	25.5565986	**Corrected SS**	10.8741263
Coeff Variation	87.5304619	**Std Error Mean**	0.11179891

Basic Statistical Measures			
Location		**Variability**	
Mean	0.699583	**Std Deviation**	0.61235
Median	0.761092	**Variance**	0.37497
Mode	0.000000	**Range**	3.05921
		Interquartile Range	0.72727

The MEANS Procedure - Site 1 v Site 4 Total Coliform





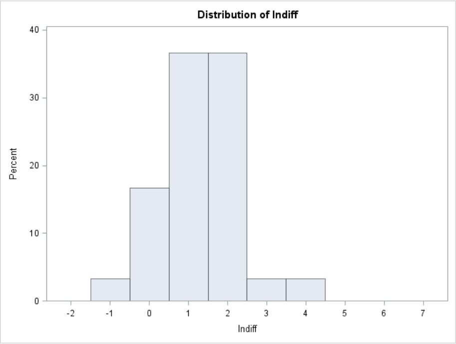
Analysis Variable : lndiff

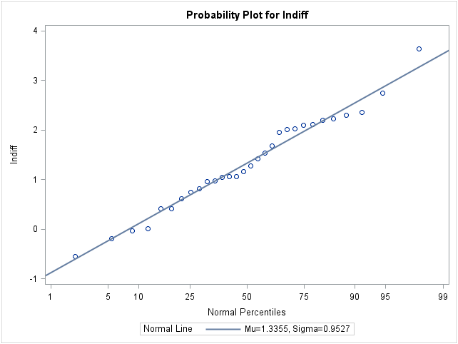
Mean	Lower 95% CL for Mean	Upper 95% CL for Mean
0.4	0.2	0.6

Moments			
N	13	**Sum Weights**	13
Mean	0.39761332	**Sum Observations**	5.16897315
Std Deviation	0.39314894	**Variance**	0.15456609
Skewness	0.06015096	**Kurtosis**	-1.3452547
Uncorrected SS	3.91004561	**Corrected SS**	1.85479303
Coeff Variation	98.8772048	**Std Error Mean**	0.1090399

Basic Statistical Measures			
Location		**Variability**	
Mean	0.397613	**Std Deviation**	0.39315
Median	0.443349	**Variance**	0.15457
Mode	0.000000	**Range**	1.16344
		Interquartile Range	0.74570

The MEANS Procedure – Site 1 vs Site 2 *E. coil*





Analysis Variable : lndiff

Mean	Lower 95% CL for Mean	Upper 95% CL for Mean
1.3	1.0	1.7

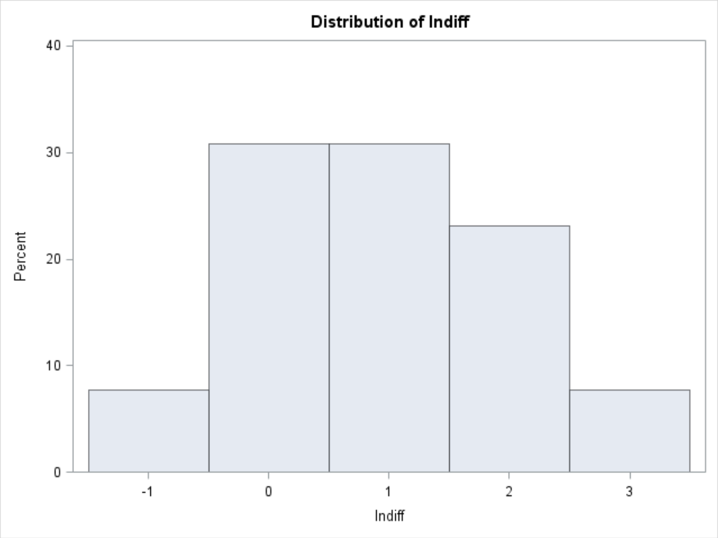
Moments

N	30	**Sum Weights**	30
Mean	1.33554449	**Sum Observations**	40.0663347
Std Deviation	0.95266785	**Variance**	0.90757603
Skewness	0.10436058	**Kurtosis**	-0.0969428
Uncorrected SS	79.8300776	**Corrected SS**	26.319705
Coeff Variation	71.3317944	**Std Error Mean**	0.17393256

Basic Statistical Measures

Location		Variability	
Mean	1.335544	**Std Deviation**	0.95267
Median	1.220431	**Variance**	0.90758
Mode	.	**Range**	4.18108
		Interquartile Range	1.34993

The MEANS Procedure – Site 1 vs Site 4 *E. coli*



Analysis Variable : lndiff

Mean	Lower 95% CL for Mean	Upper 95% CL for Mean
0.9	0.4	1.5

Moments

N	13	**Sum Weights**	13
Mean	0.91404226	**Sum Observations**	11.8825494
Std Deviation	0.92224678	**Variance**	0.85053913
Skewness	0.20681069	**Kurtosis**	0.48180805
Uncorrected SS	21.0676218	**Corrected SS**	10.2064695
Coeff Variation	100.897609	**Std Error Mean**	0.25578524

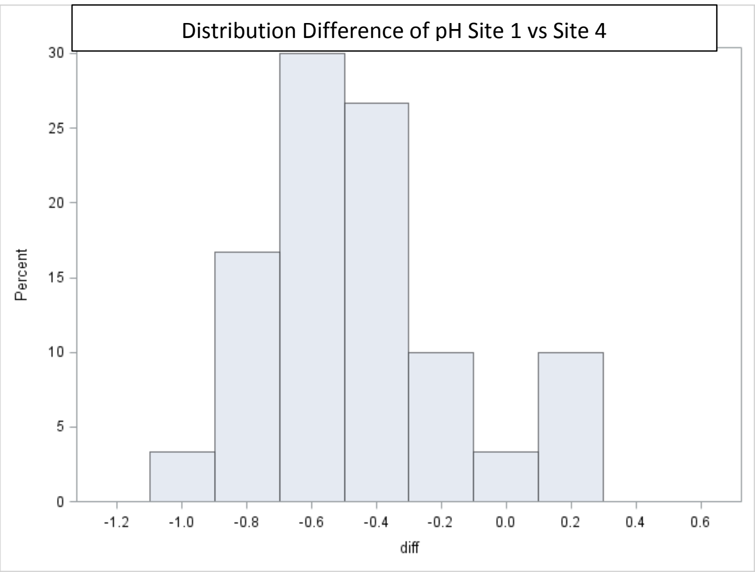
Basic Statistical Measures

Location		Variability	
Mean	0.914042	**Std Deviation**	0.92225
Median	1.042600	**Variance**	0.85054
Mode	.	**Range**	3.53768
		Interquartile Range	1.13258

The MEANS Procedure – Site 1 vs Site 2 pH

Analysis Variable : diff

Mean	Lower 95% CL for Mean	Upper 95% CL for Mean
-0.5	-0.6	-0.4


Distribution Difference of pH Site 1 vs Site 4

Moments

N	30	**Sum Weights**	30
Mean	-0.4726667	**Sum Observations**	-14.18
Std Deviation	0.29682148	**Variance**	0.08810299
Skewness	0.60043869	**Kurtosis**	-0.0826344
Uncorrected SS	9.2574	**Corrected SS**	2.55498667
Coeff Variation	-62.797209	**Std Error Mean**	0.05419194

Basic Statistical Measures

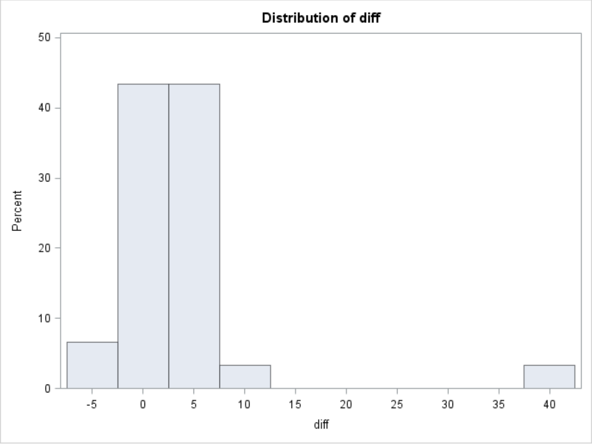
Location		**Variability**	
Mean	-0.47267	**Std Deviation**	0.29682
Median	-0.50500	**Variance**	0.08810
Mode	-0.54000	**Range**	1.08000
		Interquartile Range	0.33000

The MEANS Procedure – Site 1 vs Site 2 Turbidity

Analysis Variable : diff		
Mean	**Lower 95% CL for Mean**	**Upper 95% CL for Mean**
-1.4	-2.5	-0.4

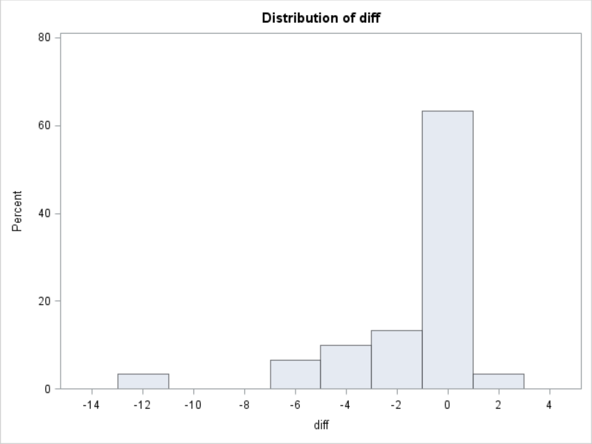
Moments			
N	30	**Sum Weights**	30
Mean	-1.429	**Sum Observations**	-42.87
Std Deviation	2.74893001	**Variance**	7.55661621
Skewness	-2.378652	**Kurtosis**	6.47347478
Uncorrected SS	280.4031	**Corrected SS**	219.14187

Basic Statistical Measures			
Location		**Variability**	
Mean	-1.42900	**Std Deviation**	2.74893
Median	-0.20000	**Variance**	7.55662
Mode	0.02000	**Range**	12.88000
		Interquartile Range	2.05000
Coeff Variation	-192.36739	**Std Error Mean**	0.50188366

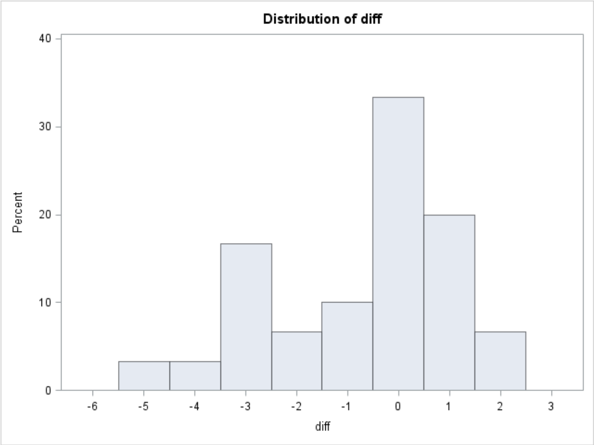


Conductivity 1 vs Site 2
Mean Difference= 3.3 (0.7, 6.0)
Kolmogorov-Smirnov <0.15
=Not Normal Distribution;
Signed Rank p=<.0001

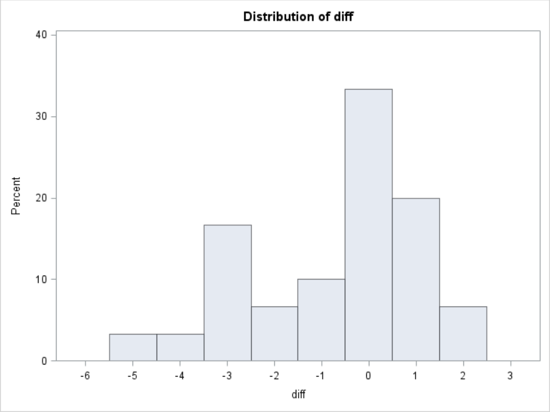
Turbidity (NTU)



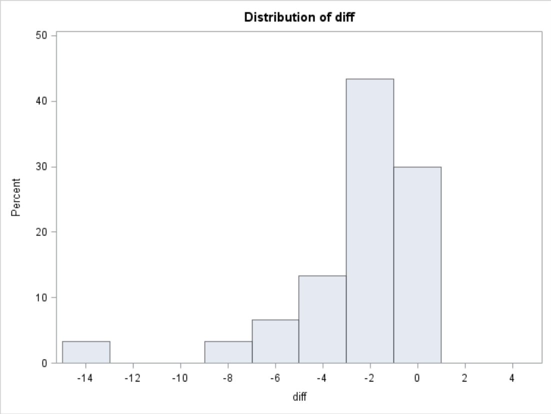
Site 1 vs Site 2 Mean Difference Turbidity = -1.4 NTU (-2.5, -0.4)
Kolmogorov-Smirnov <0.15 =Non Normal Distribution; **Signed Rank p=0.0051**



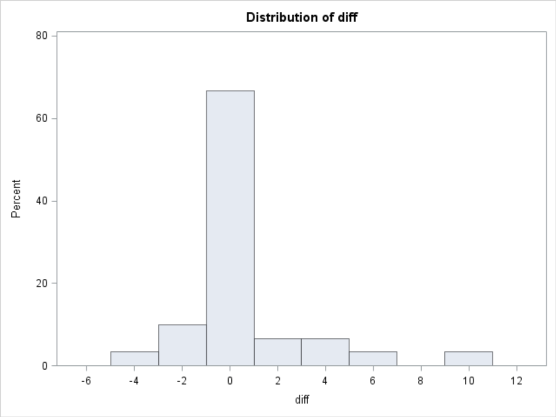
Site 1 vs 4 Mean Difference Turbidity = -0.6437 NTU
Kolmogorov-Smirnov <0.15 =Not Normal Distribution;
Signed Rank p=0.2924



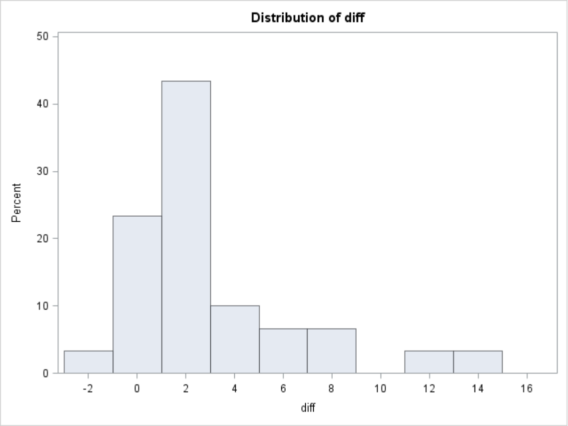
Site 1 vs Site 3 Mean Difference Turbidity = 1.7607 NTU
Kolmogorov-Smirnov <0.15 =Non Normal Distribution; **Signed Rank p=0.0051**



Site 3 v Site 4 Mean Difference Turbidity = -2.4043 NTU Kolmogorov-Smirnov <0.15 =Not Normal Distribution; **Signed Rank p<0.0001**



Site 2 v Site 4 Mean Difference Turbidity=0.7853 NTU
Kolmogorov-Smirnov <0.15 =Not Normal Distribution;
Signed Rank p=0.0476



Site 2 vs Site 3 Mean Difference Turbidity =3.1897 NTU
Kolmogorov-Smirnov <0.15 =Not Normal Distribution;
Signed Rank p<0.0001