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Shamim Altaf Noorani 4/15/2010

An Analysis of the Ecological Health of Urban Streams in Atlanta, Georgia

by

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Abstract

An Analysis of the Ecological Health of Urban Streams in Atlanta, Georgia

By Shamim Altaf Noorani

Atlanta, Georgia is one of the largest and fastest growing metropolitan cities in the United States and is a headquarters for business industry as well as air and water pollution. Urbanization has increased the impact of anthropogenic effects and this has adversely affected the physical, chemical, and biological properties of the streams and creeks that run through the city's landscape. This study conducted a water quality analysis to assess the ecological health of three creeks in the metropolitan Atlanta area: Tanyard Creek, Peavine Creek, and Stone Mountain Creek. Each creek was assessed for physical properties: water temperature, dissolved oxygen, and pH; chemical properties: ammonia, phosphate, nitrate, and copper; and biological analyses were conducted that surveyed the population and order richness of macroinvertebrates in the creeks. Frequency distributions and non-parametric tests were used to evaluate if there were statistically significant differences between the physical and chemical parameters of the creeks. Mean and median nitrate and phosphorus levels as well as the overall biological assessment score of the creeks were the main parameters that showed significant differences between creeks and were thus used to determine the ecological health ranking of the creeks. It was hypothesized that Stone Mountain Creek would have the best ecological health, followed by Peavine Creek with intermediate health, and then Tanyard Creek with the poorest health; however, results from this study suggested that Stone Mountain Creek had the best health, followed by Tanyard Creek with intermediate health, and Peavine Creek with the worst ecological health.

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Introduction

Urbanization can noticeably affect the stream's hydrology and geomorphology by impacting stream flow, turbulence, water velocity, stream width and depth, temperature, canopy cover, and substrate (Paul and Meyer, 2001). Urbanization can also affect molecular level characteristic of the water. Chemical properties that are altered by physical characteristics include dissolved oxygen levels and pH, as well as nutrient content. The biology of the stream is also altered by an increase in bacterial densities, a rise in pathogens in the water, antibiotic resistance in certain bacterial populations, and an alteration in the micro and macro-invertebrate populations that live in and around the stream's ecosystem (Paul and Meyer, 2001). The overarching impact of these parameters on the stream is an alteration in the ecological health of the stream's ecosystem.

This study analyzed the affects of urbanization on a stream by comparing two metropolitan Atlanta urban streams, Tanyard Creek and Peavine Creek, and then evaluating the overall health of the stream when compared to Stone Mountain Creek, a reference stream in a nearby forested area not affected by sewer overflows. The purpose of the study was to assess the creeks for select physical, chemical, and biological properties in reference to the United States Environmental Protection Agency and Georgia's Adopt-A-Stream guidelines, and then rank them in order of ecological health. It was hypothesized that Stone Mountain Creek would have the best ecological health rating followed by Peavine Creek, and then Tanyard Creek.

Background

Background on Creeks

In conjunction with the West Nile Virus Research Lab at Emory University, this study conducted water quality assessments at the same urban stream locations to add data to their ongoing study and to have additional field and lab support for this study. This study was conducted at three stream sites in the metropolitan Atlanta area: Tanyard Creek located in Fulton County, Peavine Creek located in DeKalb and Fulton Counties, and Stone Mountain Creek located in DeKalb County. At each stream, four locations (site A, site B, site C, and site D) were chosen in order to cover the length of the stream (Appendix A, Figure 1- Figure 3).

Tanyard Creek

Many urban areas use combined sewer systems that collect rainwater, domestic sewage, runoff, and industrial wastewater in a single pipe and then transport the water to a sewage treatment plant to be treated and discharged to a water body (Billah, 2009). However, when there is heavy rainfall the wastewater and untreated sewage can overwhelm the system and cause the untreated wastewater to overflow directly into nearby water bodies causing a combined sewer overflow (CSO) event to occur (Billah, 2009). CSO events add pathogens and pollutants to the water which degrade the ecological health of the water body and alter the properties of the water to make it unsafe for human consumption and harmful to the plant life, aquatic life, and surrounding ecosystem (Billah, 2009).

Tanyard Creek, located in northwest Atlanta in Fulton County, is one of the Atlanta's seven CSO facilities. Tanyard Creek is 3.4 km long and 10-15 meters wide; its headwaters originate at the CSO and the channel is paved with concrete for the first 1,043 meters of its flow. It then meanders through densely populated residential areas, public parks, and recreational facilities such as Bitsy Grant Tennis Center and Bobby Jones Golf Course, before it joins Peachtree Creek. The Tanyard Creek CSO facility is the smallest of the seven facilities in Atlanta, but it handles the largest volume of water. This is an unfortunate combination that leads to overflow with minimal precipitation (Mayor's Clean Water Advisory Panel, 2002). The sample sites at Tanyard Creek were TA which is nearest the concrete channel that connects the Tanyard CSO to the natural streambed, TB which is located in a residential area adjacent to Walthall Dr. NW and across from Tanyard Creek Park and Louise G. Park, TC which is within Tanyard Creek Park, and TD which is downstream from Bobby Jones Golf Course off of Overbrook Dr. NW (Appendix A, Figure 1).

Peavine Creek

Peavine Creek runs through DeKalb and Fulton counties before it joins the South Fork of Peachtree Creek. Peavine Creek is not located downstream of a CSO facility, but is a typical urban stream characterized by a high percentage of impervious surfaces in the watershed surrounding the creek and close proximity to county sewer lines. Peavine Creek is near the Emory University Campus and is approximately 436-1,257 meters downstream from the Druid Hills Golf Course. The sample sites at Peavine Creek were PA which is closest to an urban setting and upstream from the bridge at Oxford Road, PB which is directly downstream from the bridge, PC which is located in a residential area behind houses on Emory Road, and PD which is located past the neighborhood boundaries and closest to the divergence into another water body (Appendix A, Figure 2).

Stone Mountain Creek

Stone Mountain Creek runs through a privately managed state park located 16 miles east of downtown Atlanta. The creek is 65 meters long and is tucked away on one of the nature trails near the base of the granite mountain. Although the surrounding terrain is forested, the impervious granite does dramatically increase the stormwater flow that this stream receives during rain events. There are no adjacent sewer lines and there is no CSO facility that impacts this stream. Four sample sites, SA, SB, SC, and SD, were chosen as representative sites of the entire stream and included a pool, riffle, and run location. (Appendix A, Figure 3).

Background on Parameters

Physical Parameters

Water Temperature

Water temperature is an important factor that has direct effects on water chemistry and the health of aquatic organisms (Gordon et al., 2004). Water temperature influences the dissolved oxygen content of the water and it has a strong affect on the physiology of aquatic organisms. When the water temperature is too hot or too cold organisms become stressed and they lower their resistance to pollutants, diseases, and parasites. Water that is too cold may slow down metabolic processes in aquatic organisms and decrease the rate of plant photosynthesis which reduces productivity, as opposed to water that is too hot which holds less oxygen and increases the metabolic rate of aquatic organisms causing them to increase consumption of food in a shorter period of time (Ursinus.edu, 2009). Water temperature can be affected by natural influences such as sunlight, shade, air temperature, stream flow, turbidity, water depth, and daily and seasonal variation (Gordon et al., 2004). Human influences can also affect the temperature of stream water. Runoff from impervious surfaces such as parking lots can be heated during the summer months and when the runoff enters the stream it can change the water temperature. Removal of riparian vegetation decreases the amount of shade the water receives and can cause increased summer heating. Water temperature is a dependent variable, and therefore if water temperature is disturbed upstream then this will affect the water temperature downstream as well (Gordon et al., 2004).

pH

pH is a logarithmic scale measurement of how acidic or basic water is. Acidic solutions have an increased concentration of H^+ ions compared to OH^- ions, while the opposite holds true for basic solutions (Perlman, 2009). Ignoring acid as a pollutant, the average pH of rain is 5.6 (Watson, 1997). Typically pH values that are acidic and between 3.0-5.0 are not suitable for aquatic life and streams with a pH in this range show an absence of fish, frogs, and insects; pH values that are basic and between 8.2-11.5 affect the chemistry of the water and can lead to rapid death of salmonids and other species of fish (Ursinus.edu, 2009). A range of 6.5 to 8.2 is optimal for most aquatic organisms, but in the non-coastal areas of Georgia most healthy streams have a pH that ranges from 6.0 to 8.0. pH readings that fall outside of the range are considered problematic (Adopt-A-Stream, 2001).

Dissolved Oxygen

Dissolved Oxygen (DO) is vital to the existence of most aquatic organisms and is a measure of how much oxygen is dissolved in water. Oxygen gas is dissolved in water by diffusion between the atmosphere and water at its surface, aeration of water flows over rocks and other debris, and photosynthesis of aquatic plants (Gordon et al., 2004). Dissolved Oxygen is a property of water that is dependent on and affected by water temperature, water salinity, atmospheric pressure, altitude, and turbulence (Murphy, 2007). DO is one of the best indicators of the health of a water ecosystem because many aquatic organisms are very sensitive to changes in DO and oxygen is a key component in cellular respiration for both aquatic and terrestrial life (Gordon et al., 2004). The range of values for DO measurements is from 0-18 parts per million (ppm) or mg/L, but the typical natural water body requires 5-6 mg/L in order to support a diverse population; levels below 3 mg/L are considered stressful to most aquatic organisms and levels below 2 mg/L or 1 mg/L will not support fish. Low DO levels can be attributed to pollutants, decaying organic material, or the presence of sewage in the water (Adopt-A-Stream, 2001).

Chemical Parameters

Nutrients are naturally found in streams and in appropriate amounts they are essential for aquatic systems. However, urbanization and human activity has led to excessive amounts of nutrients in waters which results in harmful consequences, the worst of which is algae blooms which blocks sunlight and depletes oxygen as algae decompose (110th Congress, 2008). Other effects that can result include reduced habitat for fish, excess eutrophication, and hypoxia (110th Congress, 2008). Nutrients that are commonly measured to assess the health of streams are ammonia, phosphorus, and nitrate.

Ammonia

Ammonia is a common component in fertilizer, plastics, paper, and rubber (Fawell et al., 1996). It is used in the industrial setting as well as a coolant for melting and as cleansing agent for food additives (Fawell et al., 1996). Ammonia is found naturally in the groundwater at levels below 0.20 ppm. Higher concentrations up to 12 ppm may be caused by pollution, and levels that range from 0.53 ppm to 22.3 ppm NH_3 are acutely toxic to freshwater organisms (EPA Gold Book, 1986). Possible implications on freshwater organisms that are caused by high levels of ammonia include loss of equilibrium, hyperexcitability, increased breathing and oxygen uptake, and in extreme cases convulsions, coma, and death among fishes and other organisms; at lower concentrations fish experience developmental and morphological problems (EPA Gold Book, 1986). Factors that have been shown to influence ammonia toxicity include dissolved oxygen concentration, water temperature, pH levels, carbon dioxide concentration, salinity, and the presence of other toxicants (EPA Gold Book, 1986). The toxicity of Ammonia is inversely related to pH levels; as pH decreases the toxic effects of NH_3 on organisms increases (EPA Gold Book, 1986). Because ammonia is excreted by organisms it is found in abundance in water bodies and therefore strict regulations on optimal ammonia levels are not enforced. In accordance to this, ammonia levels in this study will not be a determining parameter in assessing the ecological health of the streams and data on ammonia levels are not reported.

Phosphorus

Phosphorus occurs naturally in water from organically bound phosphates from plant and animal matter, as well as from anthropogenic sources such as runoff from fertilizer, industrial soaps, sewage, and disturbed soil (Adopt-A-Stream, 2001). Phosphorous is a key element required by freshwater plants and it is generally present in the least amount relative to need in water bodies (EPA Gold Book, 1986). If the total phosphorus level is higher than 0.03 ppm P, then increased plant growth will occur which will lead to oxygen depletion. If the total phosphorus level is above 0.10 ppm P plant growth will be sufficiently stimulated to cause eutrophication (Adopt-A-Stream, 2001). Levels of phosphorus that exceed 0.10 ppm P indicate that the stream has been polluted by human sources and that the stream health is not suitable for the aquatic species (Adopt-A-Stream, 2001).

Nitrate

Nitrogen supports aquatic life and occurs naturally in water in the form of organically bound nitrogen, ammonia (NH_3), nitrite (NO_2), and nitrate (NO_3). In addition, nitrogen is used widely in the United States as a main component of fertilizer: 10,500,000 metric tons of nitrogen is applied to cropland pastures each year and 5,900.000 metric tons of nitrogen is used in animal manure (Hudak, 2000). Nitrogen's use in agriculture is a main reason why nitrogen infiltrates into groundwater and is also found in streams due to runoff. Unpolluted waters have a nitrate-nitrogen level below 1.00 ppm NO_3-N; levels above 1.00 ppm NO_3-N may indicate a sewage overflow (Adopt-A-Stream, 2001). Higher levels may indicate the presence of fertilizers and animal waste products in the waterbody. The United States drinking water standard, or maximum contaminant level of nitrate is 44.27 ppm NO_3-N, but it is recommended that infants do not drink water that has nitrate present in excess over 10.00 ppm NO_3-N because if high levels of nitrate are consumed by infants then this can cause infant methemoglobinemia or Blue Baby

Syndrome (Hudak, 2000). It has been reported that levels of nitrate or nitrogen at or below 5.00 ppm NO_3-N should be protective of most warm water fish (EPA Gold Book, 1986). Dangerous levels of nitrate that exceed 5 ppm NO_3-N are unlikely to occur in natural surface waters therefore restrictive criteria are not recommended by the EPA (EPA Gold Book, 1986). However, other agencies that are interested in water quality, such as Adopt-A Stream, have put forth regulation criteria for nitrate. Georgia's branch of Adopt-A-Stream indicates that levels of nitrate in surface water that are below 1.00 ppm NO_3-N indicate that the water is unpolluted, and levels above 10.00 ppm NO_3-N exceeds natural levels. For the purposes of this study, nitrate levels above 1.00 ppm NO_3-N will be considered unhealthy levels in streams based upon Adopt-A-Stream criteria that indicate pollution is present in water bodies.

Copper

Additional parameters that are useful to measure are the concentration of metals, such as copper. Copper is a mineral element found in the earth's crust and is used in many industrial settings such as mining and leather productions, as well as in automobiles and electric equipment (King, 2007).Copper can pollute streams by discharges from industrial plants and surface runoff that picks up copper from the brakes and tires of automobiles. Concentrations over .025 ppm Cu can be toxic to freshwater organisms such as fish but only concentrations over 1.00 ppm Cu are controlled. (EPA Gold Book, 1986). For the purposes of this study, concentrations of copper that are above 1.00 ppm Cu will be considered an unhealthy level for streams.

Biological Parameters

A biological assessment of macroinvertebrates was conducted to quickly assess the water quality of the stream. Macroinvertebrates are animals that have no backbone, are visible in the water without magnification, and are good indicators of stream quality because if they are present in the water then the physical, chemical, and biological conditions of the stream are healthy enough to support life (EPA Classification of Macroinvertebrates, 2010). An assessment of the biological community measures the abundance and order richness of macroinvertebrates. Different macroinvertebrates tolerate different levels of water quality criteria and can only exist in certain ranges. If there is a variety of macroinvertebrates present in the stream then the stream is healthy, if there is little variety with many or only a few types of macroinvertebrates then it is likely that the water is enriched with organic matter and is still healthy. If there is a variety of macroinvertebrates but only a few of each kind or no macroinvertebrates, even though the stream appears clean, then the stream has likely been affected by toxic pollutants. If there are few macroinvertebrates and the streambed is covered with sediment then the stream is a poor habitat (Adopt-A-Stream, 2001).

Methods

Study design

From November 4, 2009 to December 21, 2009 water sampling was conducted at Tanyard Creek, Peavine Creek, and Stone Mountain Creek with the objective of assessing the water quality and ecological health of each stream in reference to the EPA Gold Book standards and Georgia's Adopt-A-Stream criteria. Sampling at Tanyard and Peavine was done on a weekly basis, with Tanyard in the morning and Peavine in the afternoon. Sampling was done three times in total in the late afternoon at Stone Mountain Creek: once at the beginning of the study in week one, once in the middle during week three, and once at the end in week seven. During each field visit to each creek, twelve samples in total were collected: a pool sample, a riffle sample, and a run sample from four different sites along the length of the creek: site A being the furthest upstream to site D being the furthest downstream (Appendix A, Figure 1- Figure 3).

While in the field, physical parameters of the water at each site and location were assessed including water temperature in degrees Celsius, pH, and dissolved oxygen in mg/L. The equipment used to measure pH was the combo pH and EC Waterproof Meter by HANNA, and the equipment used to measure dissolved oxygen and temperature levels was the YSI Model 55 Handheld Dissolved Oxygen and Temperature system. These physical parameters were measured directly from the stream water, while the chemical parameters were measured in the lab from the water samples collected. Water samples for chemical testing were collected on site and were then stored in Whirl-Pak bags and placed in the lab refrigerator at 2.78°C until they could be processed for nutrient and metal levels using the CHEMetrics Water Analysis Vacu-Vial test kits. Once during the sampling season area sampling of the creeks was conducted to evaluate the order richness of aquatic life that the stream could support. D-frame nets were used to sample for macroinvertebrate species as the 20 meter sample area in the stream was walked. The species that were captured were stored in 70-90% ethanol solution and brought back to the lab for identification.

Statistical analysis of the physical and chemical data was performed using Statistical Analysis Software, SAS. Relationships between the measured parameters in each creek were assessed using a non-parametric test: the Wilcoxon Rank Sum test (alternatively known as the Mann-Whitney U test), which generates a Chi-square p value to test for significance. Using the non-parametric test results relationships between the tested variables and the ecological health and ranking of the streams could then be assessed.

Water Collection Method

At each stream site (A, B, C, D) three samples were collected. The first sample was collected from a pool, the next from a riffle, and the final sample from a run. A pool is an easily identifiable feature of a stream because it is an area of deeper water with low velocity or still water (Spellman, 2009). A riffle is a shallow, coarser sediment section of a stream characterized by a "riffling" sound and usually well oxygenated water (Spellman, 2009). Unlike pools, riffles zones have above average velocity and the flow is shallower and more turbulent. A run is an area in the stream characterized by laminar flow (Spellman, 2009). These three types of water bodies within the stream were selected because they would provide a holistic assessment of the health of the stream.

Samples were collected in accordance with the Adopt-A-Stream protocol which required a glass sampling bottle. The bottle was dipped into the stream, one third of the stream's depth below the surface and filled with non-surface water in order to avoid trapping air bubbles or bubbling air into the sample which could add dissolved oxygen. The water was then swirled in the bottle and released downstream. This occurred two more times, and then the third sample was poured into the Whirl-Pak water bags for later analysis.

Physical Parameter Methods

Water temperature and dissolved oxygen measures were collected in the field by using the YSI Model 55 Handheld Dissolved Oxygen and Temperature system. The dual action probe was placed at each pool, riffle, and run location and recorded once stabilized. The temperature readings stabilized in about two minutes and were given in degrees Celsius, while the DO readings took between two minutes and fifteen minutes to stabilize and were given in mg/L. pH measures were collected in the filed by using the combo pH and EC Waterproof Meter by HANNA. Two pH meters were used during the duration of the study due to equipment malfunctions, but both pH meters were the same make and model. pH measures were taken by placing the device in the stream directly until the device stabilized, which took approximately two minutes. pH was recorded in the field for all Stone Mountain Creek visits, and for six out of eight Tanyard and Peavine creek visits. This was due to the pH meter breaking in the field during week six and not being replaced until week eight. Once the new pH meter was purchased it was calibrated and pH readings were recorded from the Whirl-Pak bags that were stored in the lab refrigerator at 2.78°C.

Chemical Parameter Methods

Nutrient and metal analysis of the each water sample was assessed in the lab using the CHEMetrics Water Analysis System which is approved by the United States Environmental Protection Agency. The CHEMetrics system includes CHEMetrics Vacu-Vial test kits and the CHEMetrics V-2000 multi-analyte photometer. Chemical test kits that were used included: Phosphate Vacu-vials kit (K-8513) range 0.10-2.64 ppm P, Nitrate Vacu-vials kit (K-6903) range 0.20-1.50 ppm NO_3-N, and Copper Vacu-Vials kit (K-3503) range 0.50-12.00 ppm Cu. All tests were run under a fume hood with proper safety regulations: goggles for eye protection and gloves to protect the skin. The Vacu-Vial test kit is a more precise and accurate method of assessing the nutrient and metal level in water as opposed to the LaMotte test kits which use the traditional Reagent Powder Pillow method which is recommended in the Adopt-A-Stream manual. The benefits of the CHEMetrics kit compared to the LaMotte test is an increase in safety for the operator because no chemicals are exposed, a decrease in operator error because there is no discrepancies in the reading, and a faster reaction time with less mixing and measuring (CHEMetrics, 2009).

Biological Parameter Methods

In this study biological monitoring was limited to only identifying and counting macroinvertebrates found in the streams. A biological assessment was conducted once at each site during the study period to assess the biological community of each stream. The methods used were in accordance with Georgia's Adopt-A-Stream volunteer monitoring program for biological assessment, which suggested area sampling of the creek using D-frame nets to capture macroinvertebrates. Twenty meter stretch areas that included pools, riffles, runs, stream banks, sediment beds, and vegetation overhangs were sampled for macroinvertebrates. The collected specimens from the nets were stored in 70-90% ethanol solution and brought back to the lab for identification.

Data Analysis Methods

Once all the samples were processed the data for the physical and chemical parameters were entered into a Microsoft Excel workbook. The data were organized in three ways: by stream (Tanyard, Peavine, Stone Mountain), by site (A, B, C, D) and by location (pool, riffle, run). The data were then imported into SAS and Univariate tests were performed which analyzed each stream individually for each parameter and generated basic statistical measures. The data from each stream were also plotted in a histogram to determine its distribution type: normal or non-normal distribution. The data for each parameter were not normally distributed so non-parametric measures were used to test for significance. The Wilcoxon Rank Sum test showed the independent relationship between each parameter among streams and generated a Kruskal-Wallis Test which produced the Chi-square p value to test whether there was a statistically significant difference between the streams in regards to specific parameters of interest.

Results

The experimental results for the physical, chemical, and biological parameters for each stream were tested independently against one another using statistical analysis software (SAS). These findings were then compared with the EPA Gold Book water quality criteria and Georgia's Adopt-A-Stream criteria to assess the ecological health of the stream.

Descriptive Statistics

The central objective of the study was to assess the ecological health of each stream and then rank the streams against one another comparing their health standards. In order to do this, the data were organized in three ways: by stream (Tanyard, Stone Mountain, Peavine), by site (A, B, C, D) and by location (pool, riffle, run) (Appendix A, Figure 8- Figure 13). The chemical parameters that were measured by the CHEMetrics Vacu-Vials test Kits: phosphate, nitrate, and copper, had minimum and maximum values indicating the range of the test measure. These values were (0.10-2.64 ppm P) for phosphate, (0.20-1.50 ppm NO_3-N) for nitrate, and (0.50-12.00 ppm Cu) for copper. All values that were under the minimum value measurable by the tests kits were adjusted to 0.05 ppm P for phosphate, 0.10 ppm NO_3-N for nitrate, and 0.25 ppm Cu for copper.
In total, of the 226 samples collected for all streams in the eight week sampling period 678 tests were run on the data. Of the 678 tests 431 of the results (63.56%) had to be adjusted because they were under the detectable range: 174 of the 226 phosphate tests (76.99%) had to be adjusted to 0.05 ppm P, 48 of the 226 nitrate tests (21.24%) had to be adjusted to 0.10 ppm NO_3-N, and 209 of the 226 copper tests (92.48%) had to be adjusted to 0.25 ppm Cu. Nutrient levels that are below the detection limit are commonly observed

and can either be discarded from the results or adjusted (Polteva et al., 2009). If the sample size is large then the sample can be discarded from the study or noted that the tests were under-range; however in this study the sample size was not large enough to discard the samples, therefore the samples were adjusted. Adjustments are necessary to provide the required compatibility of the data with respect to the volume of information on each pollutant (Nikanorov et al., 2005). It would not be accurate to only include the physical characteristics of the water and not the chemical parameters.

Tanyard Creek

Tanyard Creek was sampled once a week for eight weeks between the hours of 8AM and 12PM. During each field visit one sample was collected from a pool, a riffle, and a run (T1: pool, T2: riffle, and T3: run) from each of the four sites along the creek (TA, TB, TC, TD). In total 12 samples were collected a week; 96 samples were collected for the duration of the study. Of the 96 samples stored in the Whirl-Pak bags, two were inadequate for any of the chemical tests, and therefore the entire sample was voided from analysis. The remaining 94 water samples were assessed for their dissolved oxygen content, their pH level, and their chemical and nutrient content for phosphate, nitrate, and copper. The dissolved oxygen and pH data was not adjusted but 165 of the 282 (58.51%) CHEMetrics Vacu-Vials test results were below the detectable range of their respective tests and therefore had to be adjusted: 73 had to be adjusted to 0.05 ppm P for phosphate, 3 had to be adjusted to 0.10 ppm NO_3-N for nitrate, and 89 had to be adjusted to 0.25 ppm Cu for copper. All physical and chemical parameters were analyzed at a per site (A, B, C, D) basis and a per location basis (1, 2, 3) to assess the overall statistical standards of the creek (Appendix B, Table 1).

Peavine Creek

Peavine Creek was sampled once a week for eight weeks between the hours of 12PM and 4PM. During each field visit one sample was collected from a pool, a riffle, and a run (P1: pool, P2: riffle, and P3: run) from each of the four sites along the creek (PA, PB, PC, PD). In total 12 samples were collected a week; 96 samples were collected for the duration of the study. All 96 samples all were analyzed for their dissolved oxygen content, their pH level, and their chemical and nutrient content for phosphate, nitrate, and copper. The dissolved oxygen and pH data was not adjusted but 159 of the 288 (55.21%) CHEMetrics Vacu-Vials test results were below the confidence interval of their respective tests and therefore had to be adjusted: 66 had to be adjusted to 0.05 ppm P for phosphate, 9 had to be adjusted to 0.10 ppm NO_3-N for nitrate, and 84 had to be adjusted to 0.25 ppm Cu for copper. All physical and chemical parameters were analyzed at a per site (A, B, C, D) basis and a per location basis (1, 2, 3) to assess the overall statistical standards of the creek (Appendix B, Table 2).

Stone Mountain Creek

Stone Mountain Creek was sampled three times in the eight week study period between the hours of 2PM and 6PM. During each field visit one sample was collected from a pool, a riffle, and a run (S1: pool, S2: riffle, and S3: run) from each of the four sites along the 65 meter stretch of the creek (SA, SB, SC, SD). In total 12 samples were collected each visit; 36 samples were collected for the duration of the study. Of the 36 samples all were analyzed for their dissolved oxygen content, their pH level, and their chemical and nutrient content for phosphate, nitrate, and copper. The dissolved oxygen and pH data were not adjusted but 107 of the 108 (99.07%) CHEMetrics Vacu-Vials test results were below the confidence interval of their respective tests and therefore had to be adjusted: 35 had to be adjusted to 0.05 ppm P for phosphate, 36 had to be adjusted to 0.10 ppm NO_3-N for nitrate, and 36 had to be adjusted to 0.25 ppm Cu for copper. All physical and chemical parameters were analyzed at a per site (A, B, C, D) basis and a per location basis (1, 2, 3) to assess the overall statistical standards of the creek (Appendix B, Table 3).

Distribution

The adjusted data were plotted into a histogram to determine its distribution type. The histograms showed four different distribution types: skewed left when the frequency of values were predominantly smaller, skewed right when the values had an increased frequency of being larger, normal distribution when the values were evenly spread out over the sampling period, and no distribution when all of the values were the same.

For Tanyard Creek phosphate, and copper measurement frequencies showed a skewed left distribution while the measurement frequencies for dissolved oxygen, pH, and nitrate showed a normal distribution (Appendix A, Figure 9- Figure 13). For Peavine Creek phosphate and copper measurement frequencies showed a skewed left distribution, dissolved oxygen level frequency and nitrate concentration frequency showed a skewed right distribution, and pH showed a normal distribution of data (Appendix A, Figure 14- Figure 18). For Stone Mountain Creek phosphate measurement frequency showed a skewed left distribution and dissolved oxygen and pH levels showed a normal distribution (Appendix A, Figure 19- Figure 21). Nitrate and copper did not populate a histogram, because all 36 of the water samples had to be adjusted to 0.10 ppm NO_3-N and 0.25 ppm Cu to account for their under range reading.

The histograms showed different distribution types for different parameters which indicated that the data was sometimes normally distributed and sometimes not normally distributed. Non-parametric statistics can be used to analyze data that is normally or non-normally distributed (Cody, 2006).

Non-Parametric Test: Wilcoxon Rank Sum Test

The test for significance that was run on the data to compare the streams against one another for the six physical and chemical parameters was the Wilcoxon Rank Sum test. The test is used for normal or non-normally distributed data and does calculations based on the median value. This test is the best fit for the data because the median is a better indicator to gauge the actual measure of the parameter because it accounts for the adjusted data and the outliers that bias the mean value. The results of the Wilcoxon Rank Sum test generate a Kruskal-Wallis Test report which indicates if there is a statistically significant difference between the two independent variables. The Kruskal-Wallis Test generates two statistical values: the chi-squared test with the degrees of freedom and the probability test results which assess the significance of the chi squared test. If the probability of the p value is less than or equal to 0.05 then it is commonly interpreted as being statistically significant evidence to reject the null hypothesis that assumes that there is no difference between the two independent variables in regards to the parameter of interest.

The Kruskal-Wallis Test results from the Wilcoxon Rank Sum Test showed that there was a statistically significant difference between the 94 water samples collected from Tanyard Creek and the 36 water samples collected from Stone Mountain Creek in regards to pH ($p<0.0001$), nitrate ($p<0.0001$), and phosphate ($p< 0.0068$). It did not show a statistically significant difference in regards to dissolved oxygen ($p>0.1423$) or copper ($p>0.1599$) (Appendix B, Table 4).

The Kruskal-Wallis Test results from the Wilcoxon Rank Sum Test also showed that there was a statistically significant difference between the 96 water samples collected from Peavine Creek and the 36 water samples from Stone Mountain Creek in regards to dissolved oxygen concentration ($p<0.0003$), pH ($p<0.0001$), nitrate ($p<0.0001$), phosphate ($p<0.0003$), and copper ($p<0.0269$) (Appendix B, Table 5).

The Kruskal Wallis Test results from the Wilcoxon Rank Sum Test of the two urban creeks, Tanyard Creek and Peavine Creek, showed that there was a statistically significant difference between these two creeks only in regards to dissolved oxygen concentration ($p<0.0086$). It did not show a statistically significant difference in regards to pH ($p>0.7545$), nitrate ($p>0.4901$), phosphate ($p>0.0919$), or copper ($p>0.0958$) (Appendix B, Table 6).

<u>Biological Assessment</u>

On November 16, 2009 a biological assessment of Tanyard Creek and Peavine Creek was conducted, and on December 17, 2009 a biological assessment of Stone Mountain Creek was conducted to sample the creeks for macroinvertebrates. Macroinvertebrates are affected by the physical and chemical conditions of the stream rendering some macroinvertebrates to be more sensitive to pollutants than others, therefore the presence or absence of macroinvertebrates in a stream can be used as an indicator of water quality. All four sites, A, B, C, and D, were sampled for an average of twenty minutes to check for the abundance and order richness of macroinvertebrates in the area. Adopt-A-Stream's Biological and Chemical Stream Monitoring Manual reports index values for water quality based on the variety of organisms present in the creek. The index values are based on the sensitivity of the macroinvertebrates and the categories are broken up as follows: an index value greater than 22 is considered excellent water quality, an index value between 17 and 22 is considered good water quality, an index value between 11 and 16 is considered fair water quality, and an index value below 11 is considered poor water quality (Adopt-A-Stream, 2001).

At Tanyard Creek 6 orders of 13 invertebrates were found. The crane fly larvae (Diptera Tipulidea) was the dominant order found in the riffle, leaf packed, woody debris, and sometimes silt, rocky, sandy, or gravel stream bed. Based on the Adopt-A-Stream biological assessment of water quality index Tanyard Creek scored a 9 which categorizes the creek as having poor water quality (Appendix B, Table 7).

At Peavine Creek 3 orders of 16 invertebrates were found. The caddis fly larvae (Trichoptera Hydroppsychidae) was the dominant order found in the riffle, leaf packed, woody debris, and rocky stream bed. Based on the Adopt-A-Stream biological assessment of water quality index Peavine Creek scored a 5 which categorizes the creek as having poor water quality (Appendix B, Table 8).

At Stone Mountain Creek 2 orders of 58 invertebrates were found along the 65 meter stretch of the creek. Isopods were the dominant species found in the leaf pack, woody debris vegetated bank, and granite bedrock streambed. Based on the Adopt-A-Stream biological assessment of water quality index Stone Mountain Creek scored 15 which categorizes the creek as having fair water quality (Appendix B, Table 9).

Ecological Health

Using the results generated by the non-parametric test and frequency tests a conclusion regarding the ecological health and ranking of the streams was assessed by comparing the different streams against one another.

According to the Wilcoxon Rank Sum Test results there is not a statistically significant difference in the median DO rank value between Stone Mountain Creek and Tanyard Creek ($p>0.1423$), but there is a statistically significant difference in DO levels between Stone Mountain Creek and Peavine Creek ($p<0.0003$) and Tanyard Creek and Peavine Creek ($p<0.0085$). The mean DO levels for all creeks, Tanyard (8.902 mg/L), Peavine (9.494 mg/L), and Stone Mountain (8.491 mg/L), are all above the 5-6 mg/L Adopt-A-Stream required levels for growth and activity, so are all at healthy levels. Different organisms thrive at different DO levels so the DO levels for all streams meet the Adopt-A-Stream health standard criteria and are equal in their ranking for this parameter.

The Wilcoxon Rank Sum Test results for pH indicate that a statistically significant difference between median rank value for pH exists between Tanyard Creek and Stone Mountain Creek ($p<0.0001$) and between Peavine Creek and Stone Mountain Creek ($p<0.0001$), but the median pH rank values between Tanyard Creek and Peavine Creek are not statistically significant from one another ($p>0.7545$). The mean pH for

Tanyard (6.990) and Peavine (6.983) Creeks is within the 6.5-8.2 range which is optimal for aquatic life; the mean pH for Stone Mountain Creek (5.361) is not within this range. Therefore, in regards to this parameter, Tanyard Creek and Peavine Creek meet the Adopt-A-Stream criteria for optimal pH levels, and Stone Mountain Creek does not.

The Wilcoxon Rank Sum Test for phosphate found a statistically significant difference between the median phosphate rank value in Tanyard Creek and Stone Mountain Creek ($p<0.0068$), and between Peavine Creek and Stone Mountain Creek ($p<0.0003$); however, a statistically significant difference did not exist between Tanyard Creek and Peavine Creek ($p>0.0919$). The two urban creeks, Tanyard and Peavine, have a greater concentration of phosphate than the urban forested stream, Stone Mountain Creek, as indicated by their mean phosphate levels. The mean phosphate level for Tanyard is 0.101 ppm P and mean phosphate level for Peavine is 0.111ppm P, whereas the mean phosphate for Stone Mountain is 0.051 ppm P. The regulation level for aquatic life is 0.100 ppm P which characterizes Tanyard Creek and Stone Peavine Creek as having unhealthy levels of phosphate.

The Wilcoxon Rank Sum test for nitrate found a statistically significant difference between median nitrate rank value in Stone Mountain Creek and Tanyard Creek ($p<0.0001$) and between Stone Mountain Creek and Peavine Creek ($p<0.0001$), but a statistically significant difference was not found between Tanyard Creek and Peavine Creek ($p>0.4917$). The mean nitrate levels for Tanyard, 0.994 ppm NO_3-N, and Peavine 0.912 ppm NO_3-N, are higher than Stone Mountain Creek's mean level, 0.100 ppm NO_3-N, but all values are within the 1.00 ppm NO_3-N regulation level for aquatic life.

The Wilcoxon Rank Sum test results for the copper found no statistical significance between the median copper rank value between Tanyard Creek and Peavine Creek ($p>0.0958$) or between Stone Mountain Creek and Tanyard Creek ($p>0.1599$), but did find a statistically significant difference between the median value of copper for Stone Mountain Creek and Peavine Creek ($p>0.0269$). The mean value of copper was 0.438 ppm Cu in Tanyard Creek, 0.376 ppm Cu in Peavine Creek, and 0.250 ppm Cu in Stone Mountain Creek, which are within the 1.00 ppm Cu regulation level for aquatic life.

When evaluating the combined health status of each Creek's physical, chemical, and biological parameters and taking into account the results of the Wilcoxon Rank Sum tests, EPA Gold Book regulations, and Adopt-A-Stream criteria and guidelines, it is seen that only two parameters, pH and phosphate levels, show a difference in values that are outside of the creek's optimal health range. pH is one of the most common water quality tests used but it is affected by several factors that are dependent on not only the chemical and nutrient aspects of the water but also on the physical characteristics of the area. pH is affected by the bedrock and soil composition through which the water moves and the amount of plant growth and organic material within the body of water (Perlman, 2009). Statistically significant differences in pH were present between Stone Mountain Creek and the urban streams, but this more acidic pH concentration can be due to organic acids from the decomposition of leaf litter or natural causes and should not be considered an unhealthy level when taking other factors into consideration (Gibbons, 1994). Phosphate and nitrate are much more accurate parameters to assess the stream's health by because phosphate and nitrate are one of the most important biogenic elements and the bioproductivity of water bodies appreciably depends on the quantity of phosphate and nitrogen compounds found in the water (Buck, 2000; Ryzhakov et al., 2010; Adopt-A-Stream, 2001). The mean nitrate levels in all creeks were all within healthy levels for aquatic life, but a statistically significant difference in nitrate levels existed between Stone Mountain Creek and Tanyard Creek ($p<0.0001$), and Stone Mountain Creek and Peavine Creek ($p<0.0001$). This is important to keep in mind when evaluating the stream's overall health. The other important parameter to take note of is the phosphate concentration. The mean phosphate level for Stone Mountain Creek was 0.051 ppm P, which is under the 0.100 ppm P cut off for health impairments to aquatic species. Mean phosphate levels for Tanyard Creek, 0.101 ppm P, and Peavine Creek, 0.111 ppm P, are just above the 0.100 ppm P cut off level and are therefore classified as an unhealthy nutrient standard for the creek. Furthermore, when taking into consideration the Adopt-A-Stream biological assessment score, Tanyard and Peavine both had a score of "poor" but Peavine's lower score of 5, compared with Tanyard's score of 9 and Stone Mountain's score of 15 makes it a worse habitat for aquatic species. When taking physical, chemical, and biological factors into account, it can be deduced that Stone Mountain Creek has the best ecological health assessment, followed by Tanyard, and then by Peavine.

Discussion

The study found that Stone Mountain Creek had the best ecological health rating based on all its chemical parameters falling within the range of healthy levels of streams and its biological assessment producing a score of 15 which classifies its water quality in the fair range. Stone Mountain Creek however, did have a below optimal pH level which is a key measure for aquatic life to thrive. The study also determined that Tanyard Creek has a lower ecological health rating than Stone Mountain Creek, but a higher ecological health rating than Peavine Creek. This was determined based on a 0.10 ppm lower difference in mean phosphate measurements and 4 unit measurement difference in biological assessment favoring Tanyard Creek over Peavine Creek for both chemical and biological health parameters.

Data Analysis- Statistical Tests

Statistical analysis of the data was run on SAS version 9.2 software. This software was selected because it is more tailored to natural sciences than SPSS which is more suitable for social sciences. In addition SAS is recommended to carry out the non-parametric test that this study used to analyze the data with because it executes exact permutation modeling (Bergmann et al., 2000).

The statistical test that was run on the data was a non-parametric test that calculated median values and assessed the creeks independently for each parameter and then compared parameters for one creek against one another. Non-parametric tests are the best choice for trend detection in water quality and are the recommended method to use for a first stage analysis (Berryman et al., 1988). The non-parametric test used in this study was the Wilcoxon Rank Sum test (equivalent to the Mann-Whitney U test), which is very popular in the applied sciences and is frequently used when the data are non-normally distributed (Cody, 2006; Rogozin et al., 2008). The Wilcoxon Rank Sum test is used when there are two independent variables that have measures for the same value (i.e. two creeks that have measures for the same parameter). The null hypothesis is that the median difference between the two independent variables is zero, and the alternative hypothesis is that the median difference between the two independent variables is not zero (Bergman et al., 2000). The test procedure requires that the two samples be tagged by their variable and then combined and ranked from smallest to largest. The samples are then separated and the ranks are totaled. The median values are now the W statistic and are compared against one another by the chi square p value; if the p value is less than 0.05 ($p < 0.05$) then there is a significant difference in the measured parameter (Corder and Dale, 2009). The Wilcoxon Rank Sum test is a basic analysis to assess significance between measures and to track trends but it does not take into account the multiple factors that impact streams. Multivariate analysis, Factor Analysis, and Principle Component Analysis are more thorough analyses used to assess water quality and have been used in several studies (Boyacioglu et al., 2006; Das et al., 2009; Kuppusamy et al., 2005; Papaioannou et al., 2009; Lambarakis et al., 2004; Parashar et al., 2008; Simenov et al., 2003; and Vega et al., 1998). However, these procedures were not conducted for this data because the sample size was small and severe adjustments had to be made to the data which compromised its power.

Physical Exposure Assessment

Water Temperature

Although water temperature is a key parameter to assess the physical health of streams, statistically significant tests for water temperature were not carried out for several reasons. First, because sampling was done at different times of the day for the creeks comparing water temperature levels against creeks would be confounded by the time of day the creek was sampled (Parashar et al., 2007). Second, water temperature varies depending on canopy cover, depth of the stream, and vegetation (Paul and Meyer, 2001). Third, according to Adopt-A-Stream significant levels for water temperature occur when the water temperature changes by more than 2°C in 24 hours, and since sampling at the same stream within a 24 hour period never occurred, it could not be determined if rapid temperature changes occurred. Finally, very little published data exits on temperature response of streams to urbanization (Paul and Meyer, 2001).

pH

pH values for all creeks were normally distributed for the eight week sampling season and statistically significant differences in pH were assessed by the Wilcoxon Rank Sum test (Appendix A: Figure 10, Figure 15, Figure 20). The Wilcoxon Rank Sum Test results for pH indicate that a statistically significant difference between median rank value for pH exists between Tanyard and Stone Mountain Creek ($p<0.0001$) and Peavine and Stone Mountain Creek ($p<0.0001$), but not between Tanyard Creek and Peavine Creek ($p>0.7545$). Also, when comparing the mean pH for Tanyard (6.990) and Peavine (6.983) to Stone Mountain (5.361) it is clear that there is a difference between the two urban streams and the protected stream.

Differences in pH between Stone Mountain Creek and the urban streams can possibly be attributed to the differences in physical properties that surround the creek. Stone Mountain Creek is shallower than the other creeks, has with fewer pools, has more riffles, has a greater concentration of rocks, and has an increase in vegetation on the banks due (Edullantes, 2001). Another factor that could attribute for the acidic pH reading could be the runoff from the granite bedrock of the mountain. Granite bedrock cannot effectively neutralize acid and therefore runoff from Stone Mountain that enters the creek is not readily absorbed in the soil and can cause a change in pH (Safe Drinking Water Foundation, 2007).

Another possible reasons for the difference in streams could be due to the change in equipment. During week six the pH meter broke in the field and was not replaced until late in week seven. Therefore week six and week seven water samples from Tanyard Creek and Peavine Creek were assessed in the lab which produced higher than average results for the water samples, while the pH meter was used in the field during week seven for Stone Mountain and measured lower than average results. Since Stone Mountain was only sampled three times during the study period 33.33% of data showed on average lower results and this could have driven down the mean and the median and account for the differences in pH between Stone Mountain and the other creeks.

Stone Mountain Creek is not within the 6.5-8.2 range which Adopt-A-Stream qualifies as optimal for aquatic life; however, although Stone Mountain's pH is on average 5.361 and more acidic it has the most aquatic life and most vegetation. In addition, this low pH level is close to the pH of rain, 5.6, and is not problematic (Watson, 1997). Stone Mountain's low pH level could also be caused by more organic acids from the decomposition of leaf litter or from other natural causes and therefore not have a negative effect on the health of the stream (Gibbons, 1994).

Dissolved Oxygen

Dissolved Oxygen values for Tanyard Creek and Stone Mountain Creek showed a normal distribution of DO while Peavine Creek showed a skewed right distribution of DO for the sampling season (Appendix A: Figure 9, Figure 14, Figure 19). The distribution of DO readings for Peavine indicates that more values were higher than lower and the higher values had a greater influence on the overall average. This difference in DO can be attributed to the physical habitat of the stream site sampled as well as the difference in volume and velocity of the water flowing in the water body.

The Wilcoxon Rank Sum Test results for DO indicate that a statistically significant difference between median rank value for DO existed between Peavine Creek and Stone Mountain Creek ($p<0.0003$) and between Tanyard Creek and Peavine Creek ($p<0.0086$), but not between Tanyard Creek and Stone Mountain Creek ($p>0.1423$). Taking into consideration that DO is dependent upon temperature (colder water can hold more oxygen than warmer water) and physical characteristics of the creek, this is a plausible observation because sampling was done at different times of the day for each creek and the adjacent land use of each creek differs from each other. Sampling at Tanyard Creek was done in the early morning between 8AM and 11AM, and the adjacent land use of the creek includes an increase in impervious surfaces near parks and residential areas and a golf course. Runoff from the impervious surfaces and from the golf course can cause an increase in chemical pollutants, and in addition Tanyard Creek is a CSO overflow facility which is victim to a decrease in nutrient content and an increase in salt and runoff into the water. Peavine Creek was sampled in the mid afternoon from 12PM to 2PM, and changes in the land use from site PA to site PD could be a possible cause for the fluctuations in DO throughout the stream. Stone Mountain Creek was sampled in the late afternoon between 3PM and 6PM and had the lowest average DO levels among the creeks: mean DO at Stone Mountain Creek was 8.491 mg/L, 8.902 mg/L at Tanyard Creek, and 9.494 mg/L at Peavine Creek. The lower average DO level at Stone Mountain is surprising because there is not runoff from impervious surfaces or from human interaction with the water. In addition because the creek is nestled away in the woods it is protected from the affects of development.

Dissolved Oxygen is an important indicator of how polluted the water is and how well the water can support aquatic plant and animal life. The DO results are not as hypothesized, because generally higher dissolved oxygen levels indicate better water quality; and in this study Peavine Creek had the highest DO level followed by Tanyard Creek, and then Stone Mountain Creek. However, all DO levels are in healthy ranges to support aquatic organisms and life. If dissolved oxygen levels were too low then organisms would not be able to survive. DO levels that are below 4 mg/L may cause some fish and macroinvertebrate populations to decline such as bass, trout, salmon, mayfly nyphs, and caddisfly larvae (Stevens Institute of Technology, 2009).

Chemical Exposure Assessment

<u>Phosphorus:</u>

Phosphate values for all creeks were skewed left in their distribution for the eight week sampling season, indicating that a greater proportion of phosphate readings were on the lower end of the spectrum and more specifically concentrated around the adjusted value of 0.05 ppm P (Appendix A: Figure 11, Figure 16 , Figure 21). This is expected given that 174 of the 226 tests were adjusted: 73 out of 94 samples were adjusted in Tanyard, 66 out of 96 had to be adjusted in Peavine, and 35 out of 36 had to be adjusted for Stone Mountain. Statistically significant differences in phosphate levels between creeks were assessed by the Wilcoxon Rank Sum test.

The Wilcoxon Rank Sum test for phosphate shows a statistically significant difference in phosphate levels between Stone Mountain Creek and Tanyard Creek ($p<0.0068$) and Stone Mountain Creek and Peavine Creek ($p<0.0003$), but not between Tanyard Creek and Peavine Creek ($p>0.0919$). The differences between Tanyard Creek and Stone Mountain Creek, and Peavine Creek and Stone Mountain Creek can be attributed to all the phosphate values in Stone Mountain needing to be adjusted where as the range in values in the other creeks drove the median value to not be close to 0.05 ppm P like the range in Stone Mountain Creek. The increase level of phosphorus in Tanyard Creek is expected due to the fertilizer runoff from the Bobby Jones Golf Course, the residential garden and street runoff, and because Tanyard Creek is a CSO overflow facility releases increase phosphorus levels caused by sewage and waste. Phosphates can enter waterways from human body excretion and there is evidence that this increase in phosphorus is detrimental to the stream because it increases eutrophication rates (EPA Gold Book, 1986). Phosphorus levels also increase after overflow events, and due to the large amount of rain received during the fall and winter of 2009, over flow events occurred twice during the study period (Banner et al., 2009). Peavine Creek is naturally urban and urbanization and anthropogenic effects have three times the natural mobilization rate for phosphorus, and in addition phosphorus is associated with sediment as it is washed into streams (Banner et al., 2009). It is expected that the two urban creeks would have a higher level of phosphorus than Stone Mountain because they are more impacted by anthropogenic effects and human activities have intensified the release of phosphorus into the environment (Smil, 2000). Because Stone Mountain Creek is not vulnerable to overflow events, fertilizer runoff, or intense human influence it is protected from increased phosphorus levels.

Nitrate

Nitrate values for Tanyard Creek showed a normal distribution of data, Peavine Creek showed a skewed right distribution of data, and Stone Mountain did not show a distribution in data because all 36 points were adjusted to 0.1 ppm NO_3-N (Appendix A: Figure 12 and Figure 17). For Tanyard Creek a normal distribution of data indicated that nitrate levels were approximately evenly distributed throughout the sites and that the majority of the nitrate levels fall within one standard deviation of the mean. For Peavine Creek the skewed left distribution of the data indicates that a greater portion of the samples had higher nitrate concentrations than lower nitrate concentrations. This observation is surprising because the mean value for nitrate at Peavine creek, 0.912 ppm NO_3-N, is lower than the mean value for nitrate at Tanyard Creek, 0.994 ppm NO_3-N, and both creeks do not show any large outliers that would cause an increase of the average values.

The Wilcoxon Rank Sum test for nitrate shows a statistically significant difference in nitrate levels between Stone Mountain Creek and Tanyard Creek ($p< 0.0001$) and Stone Mountain Creek and Peavine Creek ($p<0.0001$), but not between

Tanyard Creek and Peavine Creek ($p>0.4901$). The differences between Tanyard Creek and Stone Mountain Creek, and Peavine Creek and Stone Mountain Creek can be attributed to the adjustment of all nitrate values in Stone Mountain causing there to be no range in distribution, where as a range in values exists in the other creeks which drove the median value to not be close to 0.10 ppm NO_3-N. The increase level of nitrate in Tanyard Creek and Peavine Creek is expected due to the runoff from the nearby urban centers that constitute a majority of the land use (Hudak, 2000).

Copper

Copper values for Tanyard Creek and Peavine Creek plotted a skewed left distribution in their histograms, indicating that values were more concentrated on the lower end of the spectrum, while Stone Mountain Creek did not show a distribution due to all 36 points being adjusted to 0.25 ppm Cu (Appendix A: Figure 13 and Figure 18). This is expected given that 209 of the 226 tests were adjusted: 89 out of 94 samples were adjusted in Tanyard, 84 out of 96 had to be adjusted in Peavine, and 36 out of 36 had to be adjusted for Stone Mountain. Statistically significant differences in copper levels were assessed by the Wilcoxon Rank Sum test.

The Wilcoxon Rank Sum test for copper does not show a statistically significant difference in copper levels between Tanyard Creek and Peavine Creek ($p > 0.0958$) or between Stone Mountain Creek and Tanyard Creek ($P > 0.1599$), but does show a statistically significant difference in copper levels between Stone Mountain Creek and Peavine Creek ($p > 0.0003$). Possible explanations for the difference between the streams could be explained by copper being in greater abundance in Peavine Creek, especially at site PA, due to the urban runoff of copper released from the wearing of brake pads in automobiles (King, 2007).

Biological Exposure Assessment

Species at Tanyard Creek included five crane fly larvae, a leech, snails, crayfish, worms, and a damsel fly larvae (Appendix B, Table 7). These species are all tolerant to pollution, but species at Tanyard are limited by the hydrology and geomorphology of the stream, the nutrient composition of the stream, and the availability of food in the stream. The stream bed is composed of coarse gravel, the stream flow is variable, and there are few true riffle areas for pollution intolerant, high oxygen species to thrive. Chemically, nitrate levels are high which could be a possible limitation of certain species and there is not an abundance of leaf litter for the organisms to thrive on.

Species at Peavine Creek include caddis fly larvae, damsel fly larvae, and crane fly larvae (Appendix B, Table 8). These species are tolerant to pollution but are limited by physical restrictions of the stream such as the hydrology, geomorphology, and the lack of available food for the macroinvertebrates to feed on. In addition, few riffle areas exists for oxygen mixing and the gravel size is too large for organisms to take advantage of. Species at Stone Mountain Creek include isopods and crayfish (Appendix B, Table 9). These species were found in large numbers and are tolerant to pollution but at a more sensitive level. A possible reason why there is an increase in macroinvertebrates at Stone Mountain Creek could be to the high concentration of leaf litter and accessible vegetation that the organisms could take advantage of and feed on.

Ecological Health Assessment

The ecological health assessment that took into consideration the physical, chemical, and biological parameters ranked Stone Mountain Creek as the healthiest, followed by Tanyard Creek, and then Peavine Creek. This finding is different from what was hypothesized: Stone Mountain healthiest, Peavine intermediate, and Tanyard poor health.

The driving factor that allowed ranking to occur was the concentration of nitrogen and phosphorus compounds in the aquatic environmental. Phosphorus and nitrogen are the most important biogenic elements and they can cause excessive algal growth which stresses the stream and may also cause taste and odor problems in the water supply (Ryzhakov et al., 2010; Christensen et al., 2008). There was a statistically significant difference between Tanyard Creek and Stone Mountain in regards to phosphate ($p<0.0068$) and nitrate ($p<0.0001$), and there was also a statistically significant difference between Peavine Creek and Stone Mountain Creek in regards to phosphate ($p<0.0003$) and nitrate ($p<0.0001$); however there was not a statistically significant difference between Tanyard Creek and Peavine Creek in regards to phosphate ($p>0.0919$) or nitrate ($p>.4901$). From these tests it is evident that Stone Mountain has the lowest levels of these compounds and has the best nutrient composition when compared against the urban creeks. The biological analysis adds a determining layer of analysis that provides strong evidence to make a determination of ecological health ranking.

According to the Adopt-A-Stream biological assessment protocol Stone Mountain Creek had the best biological assessment score, 15, categorizing it as having fair water quality. Stone Mountain only had two orders of macroinvertebrates, Isopoda and

Decapoda, found in the creek but in large numbers totaling 58 macroinvertebrates for the shortest stream length. Although there is little variety of macroinvertebrates found in the creek, Stone Mountain Creek can support a higher number of more sensitive species than the urban creeks because it is enriched with organic matter and has available food for the organisms to feed on. Tanyard Creek's biological assessment was intermediate among the three creeks with a score of 9, categorizing it as having poor water quality. Tanyard Creek had six orders of macroinvertebrates: Diptera, Hirundinea, Gastropoda, Decapoda, Megadrill and Microdrill, and Odonata and Zygoptera, but a low quantity of these tolerant species was found in the creek totaling up to only 13 macroinvertebrates. Peavine Creek had the lowest biological assessment score, 5, which categorizes the creek as having the poorest water quality of the three creeks, but equal in descriptive ranking to Tanyard Creek. However, what differentiates Tanyard from Peavine is the order richness of macroinvertebrates that were found in Tanyard; only 3 orders of macroinvertebrates were found in Peavine Creek: Trichoptera, Odonata and Zygoptera, and Diptera, totaling up to 16 macroinvertebrate species in total, as opposed to Tanyard Creek which has six orders and 13 macroinvertebrates.

The physical, chemical, and biological assessments can validate that Stone Mountain Creek has a better overall ecological health assessment when compared to Tanyard Creek and Peavine Creek, but differentiating ecological health between Tanyard Creek and Peavine Creek is not as easily distinguished. Assessing the streams based upon their individual and independent variables provides a great pilot study and trend analysis, but because the sample size was too small to discard the under range data, the data had to be adjusted, and this compromised the power of the study. Adjusting the data was necessary but complicated deriving ranking of the ecological health of the streams. Strategies that could have been utilized to mitigate these limitations and obstacles could have been to assess the stream for additional parameters including turbidity, hardness, and sedimentation, or completely following the Adopt-A-Stream protocol which suggested using the LaMotte test kits which use the traditional Reagent Powder Pillow method for chemical analysis instead of the CHEMetrics Vacu-Vial test Kits. The LaMotte test would have assessed the data while in the field instead of transporting the samples back to the lab for analysis which caused a change in temperature in the water for half of the parameters measured.

The statistical analyses run on the data was for trend analysis and is a primary analysis of the data. It is appropriate for a pilot study but does not take into account the multivariate complexity of the stream and does not analyze multiple parameters at the same time. More sophisticated analysis would have been factor analysis or PCA analysis, which was done by other studies including Boyacioglu et al., 2006; Kuppusamy et al.2006; Papaioannou et al., 2009; Lambarakis et al., 2004, and Parashar et al., 2007. However, our method of analysis of histograms, frequency calculations, and non-parametric measures is recommended by EPA and was used in several studies including Rogozin et al., 2008; Resende et al., 2009; Keithan et al., 1988; and Hudak, 2000.

Limitations

<u>Design</u>

The study was conducted in conjunction with the West Nile Virus Research Lab at Emory University and the sampling season was restricted to the winter months of

November and December of 2009. Sampling was done once a week at the urban impacted streams and sampling at the reference stream was done once at the beginnings of the study, once in the middle, and once at the end of the study period. The parameters measured had to benefit both projects so were restricted to include water temperature, DO, pH, phosphate, and nitrate; copper was added to the chemical parameters because metals are often enter streams through runoff and it would be interesting to see if there was a significant difference in the concentration of metals between a CSO impacted stream, an urban stream, and a protected stream (King, 2007). The equipment used to measure water temperature, DO, pH, and assess the chemical parameters was the current equipment used by the lab. Calibration problems were encountered with the pH meter during the sampling season leading to the device being replaced, however; stabilization times varied and when the pH meter was used in the field it gave low readings and when used in the lab it gave high readings for the same sample.

Methods

Physical parameters measured included water temperature, pH, and DO. Additional parameters that would have been beneficial to measure include conductivity, turbidity, fecal coliform levels, and alkalinity.

Chemical parameters were not measured in the field and were analyzed in the lab using CHEMetrics Water Analysis Systems. Although CHEMetrics is approved by the EPA, it did not accurately measure our parameters of interest due to the lowest detectable level measure not being within the acceptable range of the test kit.

The biological methods that were conducted during the study were in accordance with Georgia's Adopt-A-Stream volunteer monitoring program, but were limited to macroinvertebrate analysis. The advantage of this assessment is that it provides a straight forward assessment of the creek's health status and pollution level, but a disadvantage is that it does not tell us why certain types of macroinvertebrates are present or absent. Additional biological methods would have been beneficial in order to more accurately address the habitat of the creek.

Data

A major obstacle in the analysis was determining what to do with the data that produced under-range scores. Because our sample size was small, the data could not be discarded because this would have weakened the ability to see if there is an association between the exposure and outcome and the power of the study would have been compromised by not including the trace detected and below range detectable levels of the chemical tests. Therefore, the data was adjusted for and then included in the analysis. Of the 678 tests that were run on the 226 water samples, 431 of the 678 test results (63.56%) had to be adjusted because they were under the detectable range of the tests. All below detection values were increased for each measurable parameter to the mid value between 0.00 ppm and the lowest detection level; this raised the statistical measures of the data to show a more robust association. The association is more robust because each measure is greater than zero. However, adjusting the data also made assessing a difference in the chemical concentration between creeks much harder and the evidence to justify the difference much weaker because the new measured values were more similar in their ranges and medians than they would have been if they were not adjusted.

Conclusion

It was hypothesized that Stone Mountain Creek would have the best ecological health, followed by Peavine Creek with intermediate health, and then Tanyard Creek with the poorest health; however, results from this study suggested that Stone Mountain Creek has the best health, followed by Tanyard Creek with intermediate health, and Peavine Creek with the worst ecological health. A possible explanation of why Tanyard Creek has a better ecological health rating than Peavine Creek could be due to the continuous monitoring of the creek by the city of Atlanta. Tanyard Creek has to be closely monitored by city officials because overflow events have the potential to be disastrous and therefore precautions need to be taken to prevent overflow events and to quickly clean them up when they occur. On the other hand, Peavine Creek is an average urban stream that is located near commercial and residential property and is not as rigorously monitored by city officials. However, the validity of the findings is questionable due to the time specific water samples collected from sites and locations that were intended to represent the entire stream and a weak sample power due to 63.56% of the chemical test results having to be adjusted. In addition, pseudo replication was done as a sampling method which does not provide a strong sample size for the data, and multivariate tests were not run to assess the mutually dependent characteristics of the water.

Appendix A: Figures

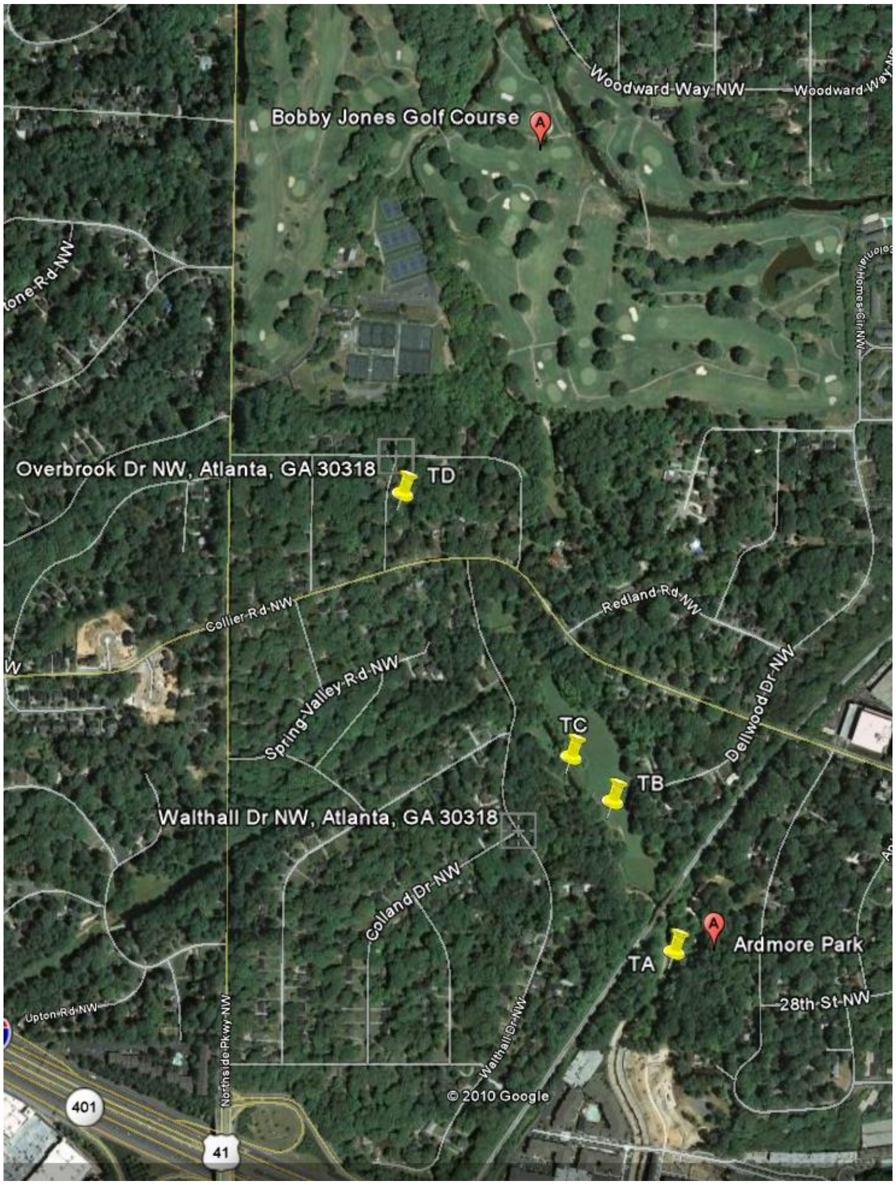

Figure 1: Google Earth Image of Tanyard Creek

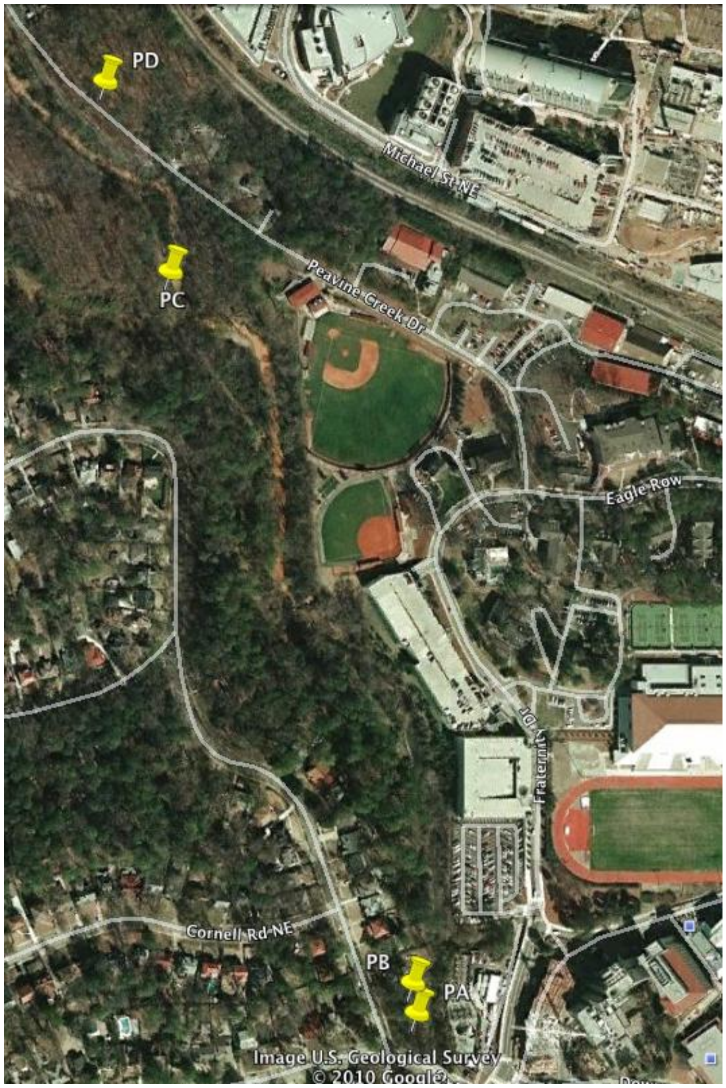

Figure 2: Google Earth Image of Peavine Creek

Figure 3: Google Earth Image of Stone Mountain Creek

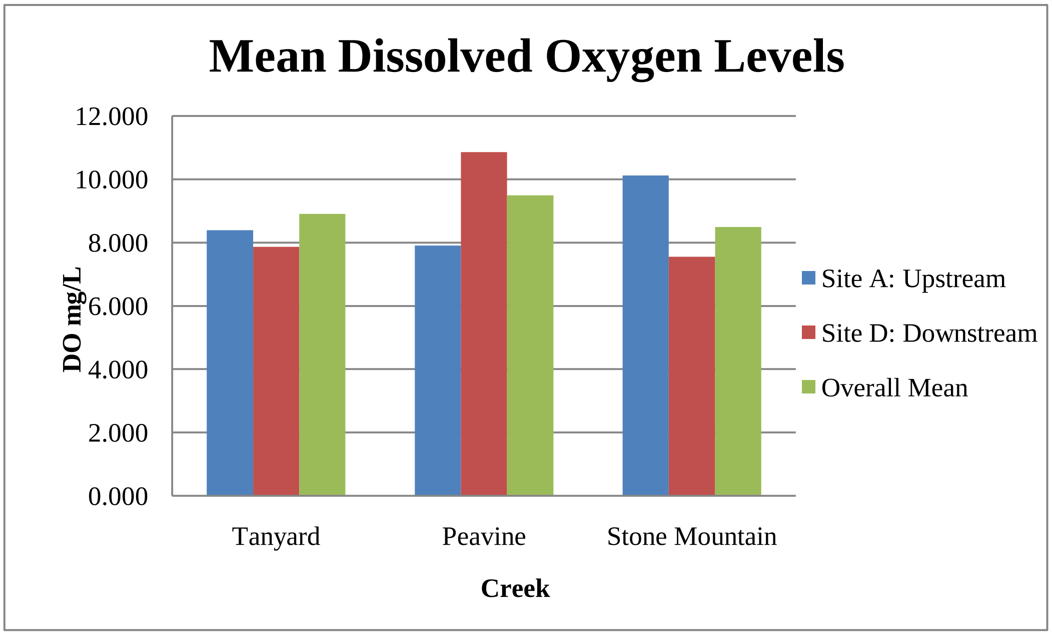

Figure 4: Frequency Graph comparing mean dissolved oxygen levels.
Comparison of dissolved oxygen concentration (mg/L) between creeks.

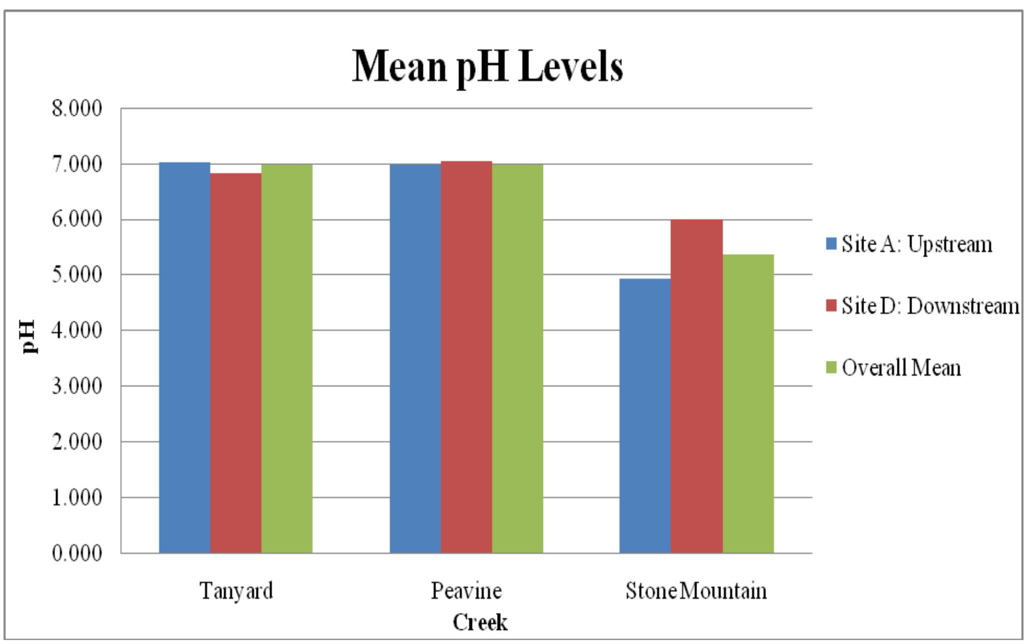

Figure 5: Frequency Graph comparing mean pH levels.
Comparison of pH levels within each creek and between creeks.

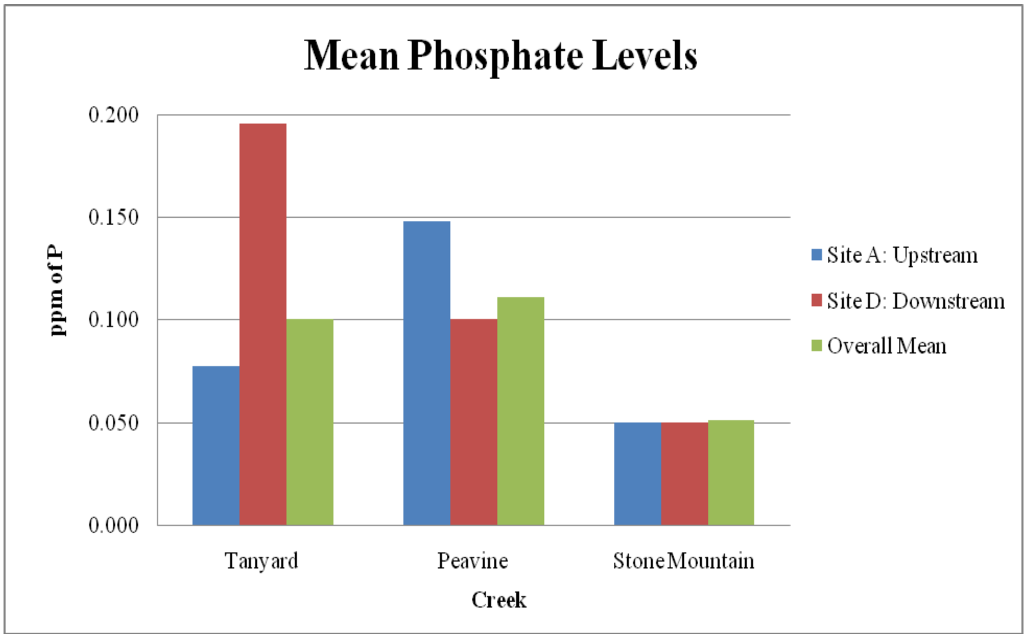

Figure 6: Frequency Graph comparing mean phosphate levels.
Comparison of phosphate concentration (ppm P) between creeks.

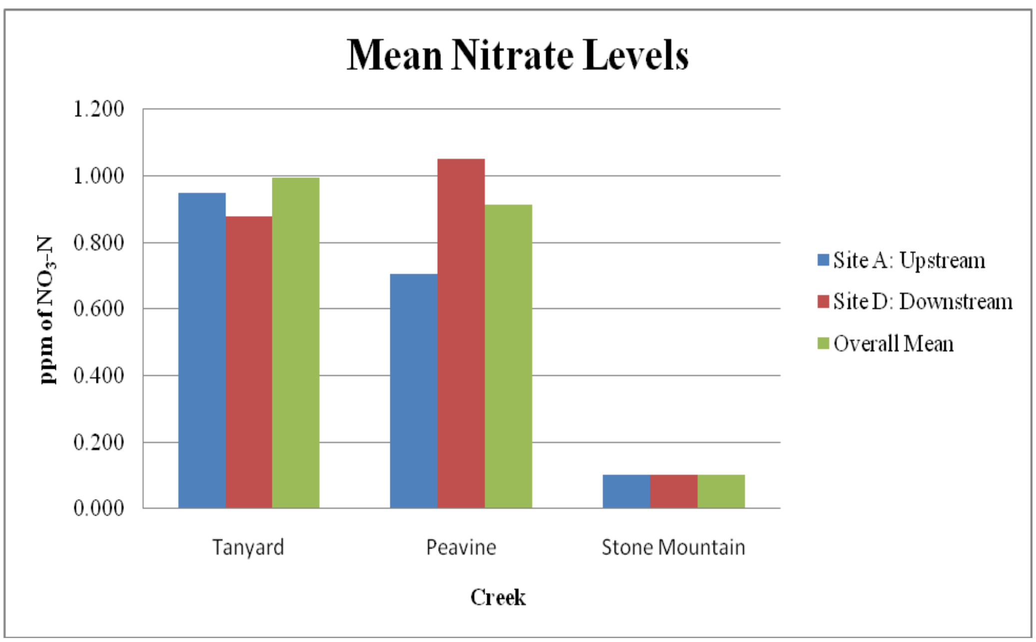

Figure 7: Frequency Graph comparing mean nitrate levels.
Comparison of nitrate concentration (ppm NO_3-N) between creeks.

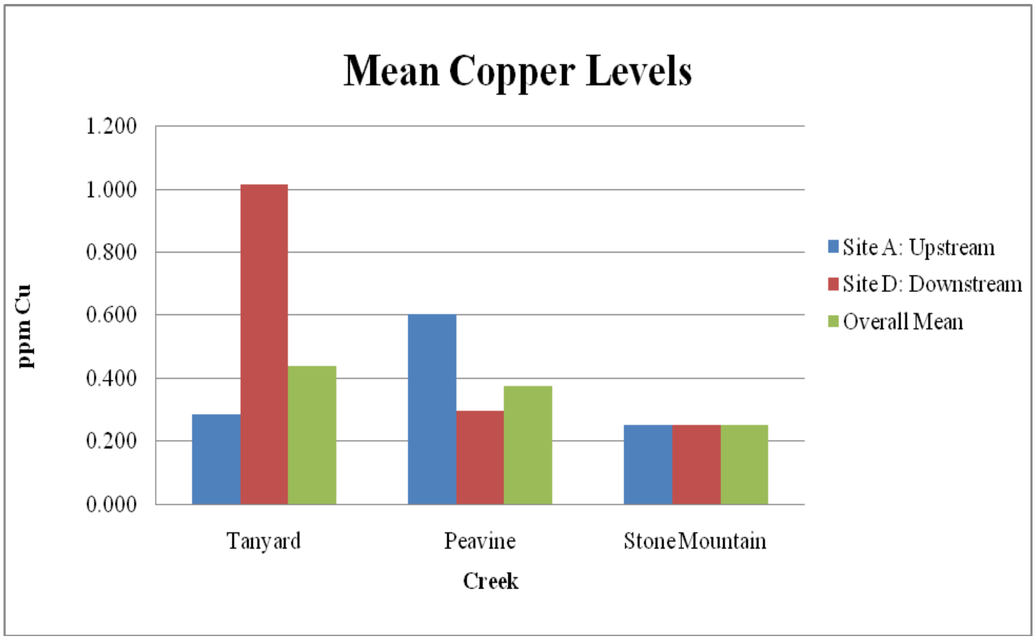

Figure 8: Frequency Graph comparing mean copper levels.
Comparison of copper concentration (ppm Cu) between creeks.

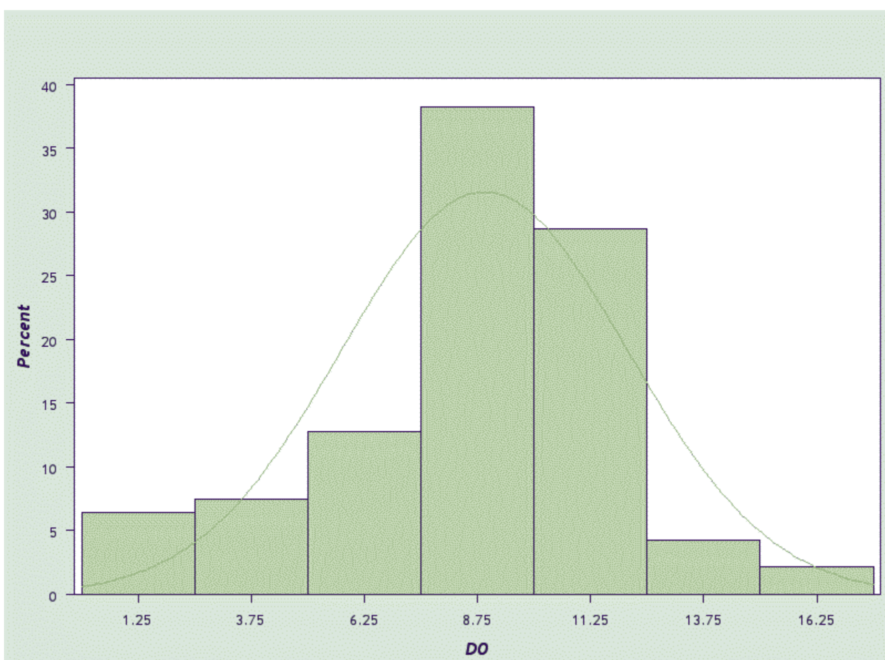

Figure 9: Histogram of Dissolved Oxygen level at Tanyard Creek
The histogram of DO levels (mg/L) at Tanyard Creek shows a normal distribution of measured values.

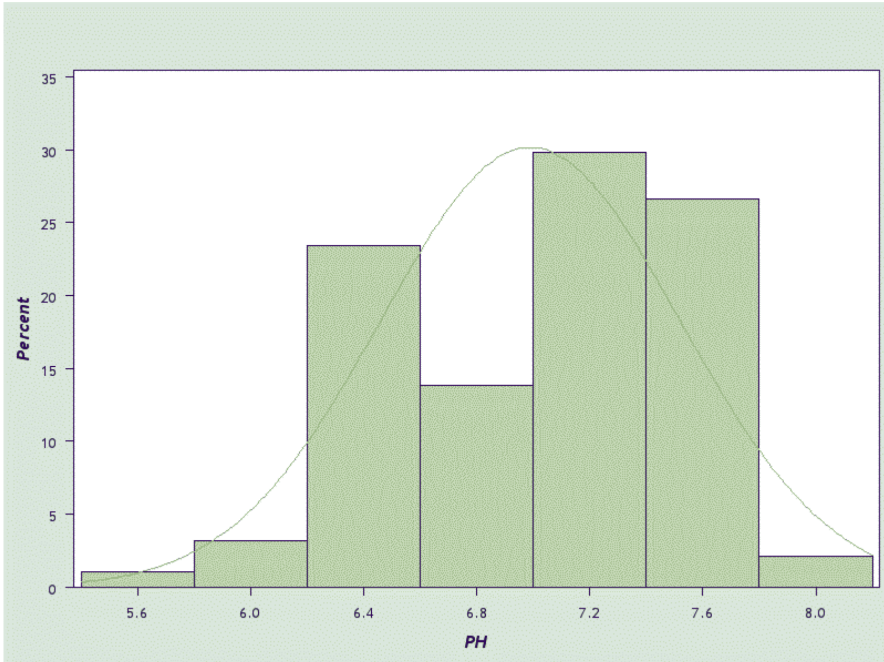

Figure 10: Histogram of pH level at Tanyard Creek
The histogram of pH levels at Tanyard Creek shows a normal distribution of measured values.

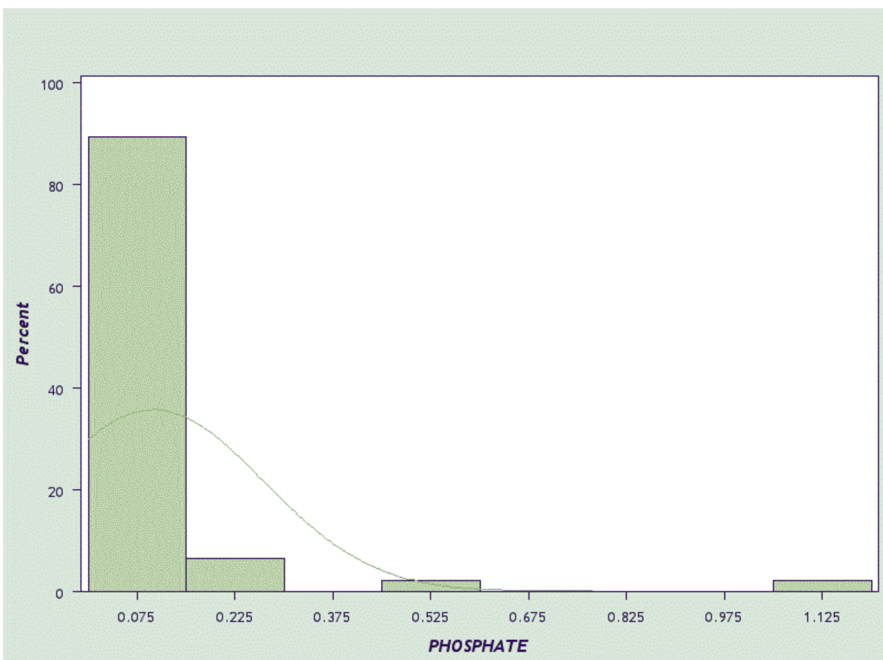

Figure 11: Histogram of phosphate level at Tanyard Creek
The histogram of phosphate concentration levels (ppm P) at Tanyard Creek shows a left distribution of measured values indicating that more recorded values were closer to zero.

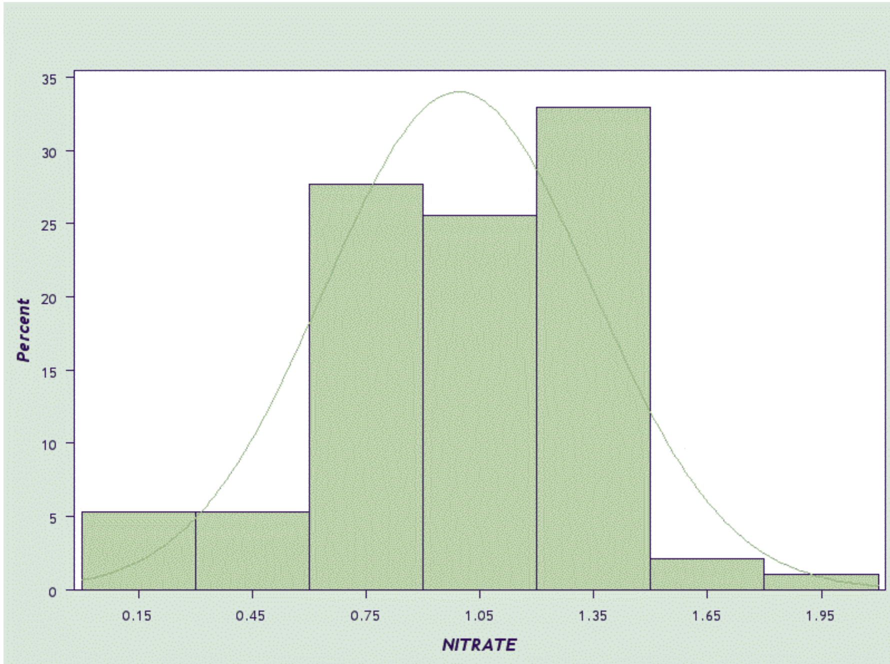

Figure 12: Histogram of nitrate level at Tanyard Creek
The histogram of nitrate levels (ppm NO_3-N) at Tanyard Creek shows a normal distribution of measured values.

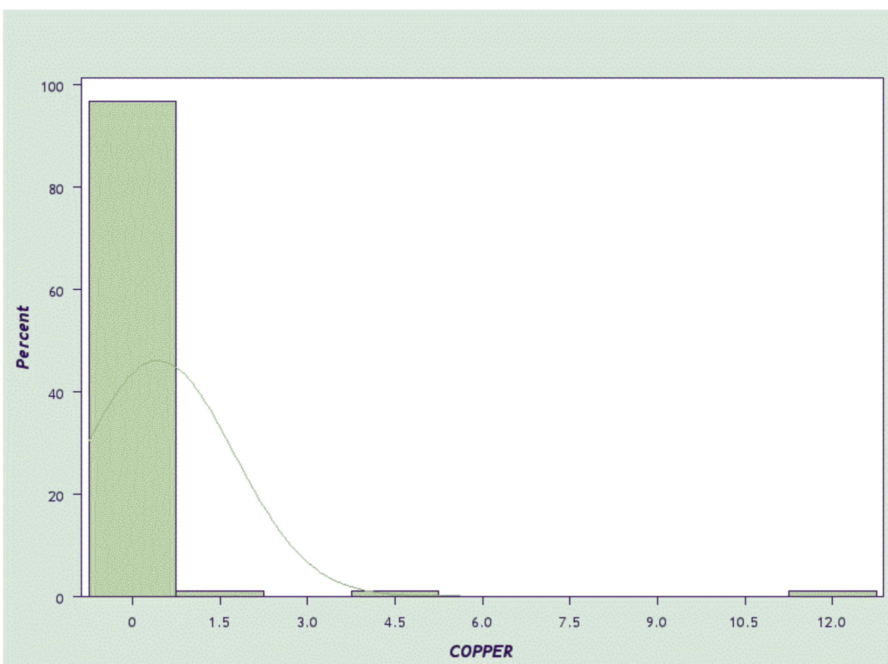

Figure 13: Histogram of copper level at Tanyard Creek
The histogram of copper concentration levels (ppm Cu) at Tanyard Creek shows a left distribution of measured values indicating that more recorded values were closer to zero.

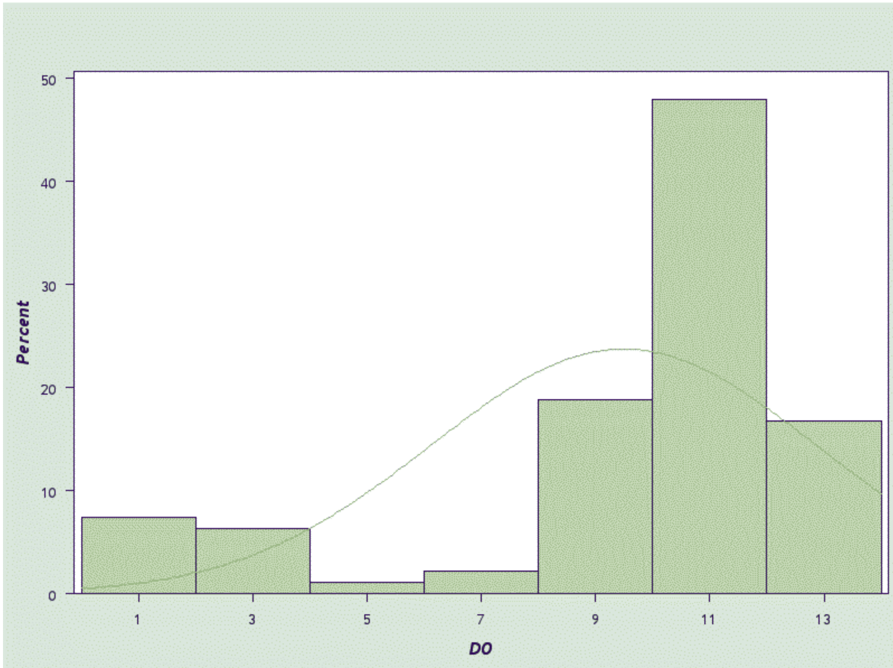

Figure 14: Histogram of Dissolved Oxygen level at Peavine Creek
The histogram of DO levels (mg/L) at Peavine Creek shows a right distribution of measured values indicating that more recorded values had a higher measured value of DO than a lower measured value.

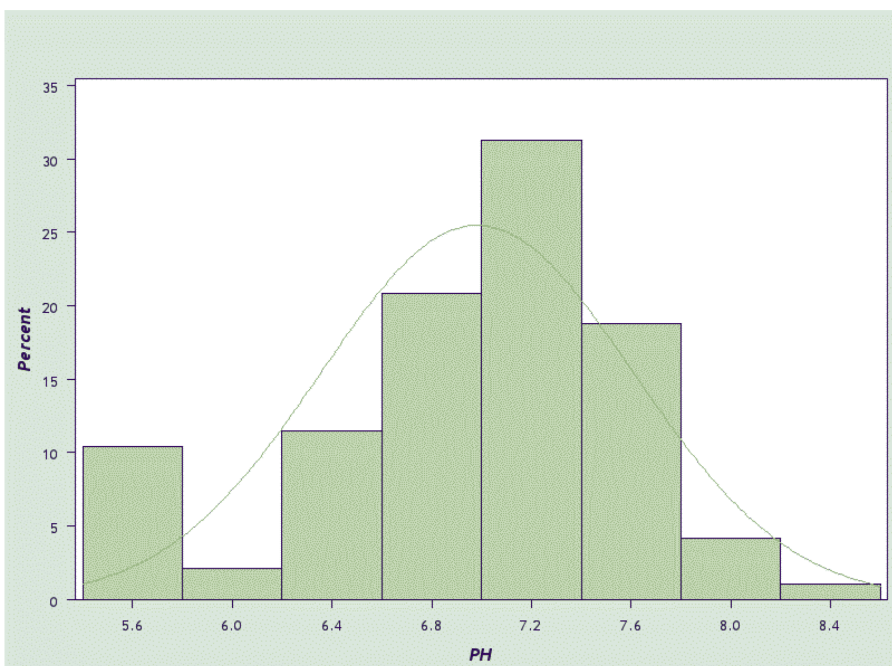

Figure 15: Histogram of pH level at Peavine Creek
The histogram of pH levels at Peavine Creek shows a normal distribution of measured values.

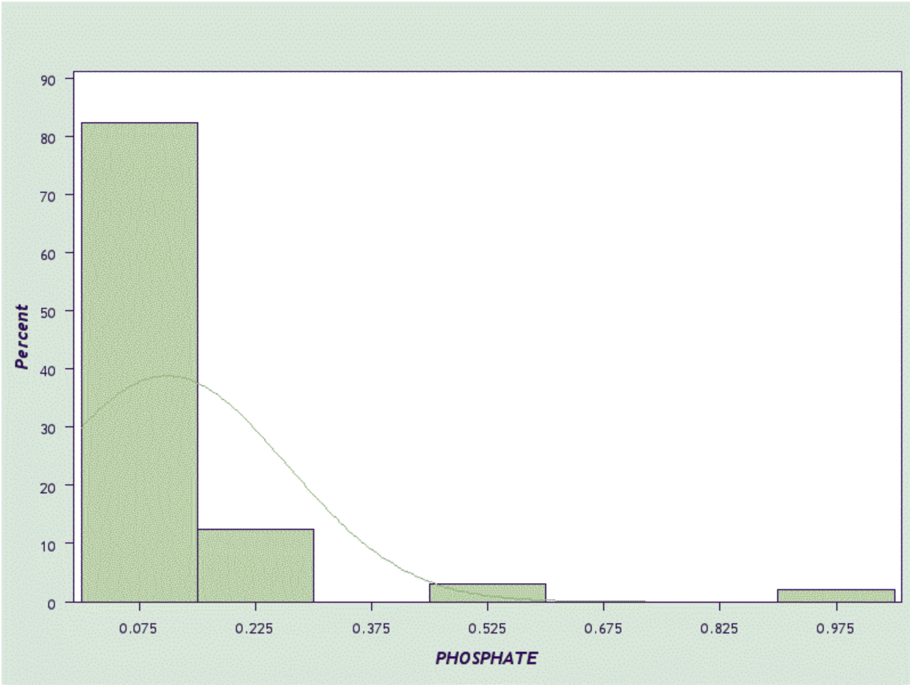

Figure 16: Histogram of phosphate level at Peavine Creek
The histogram of phosphate concentration levels (ppm P) at Peavine Creek shows a left distribution of measured values indicating that more recorded values were closer to zero.

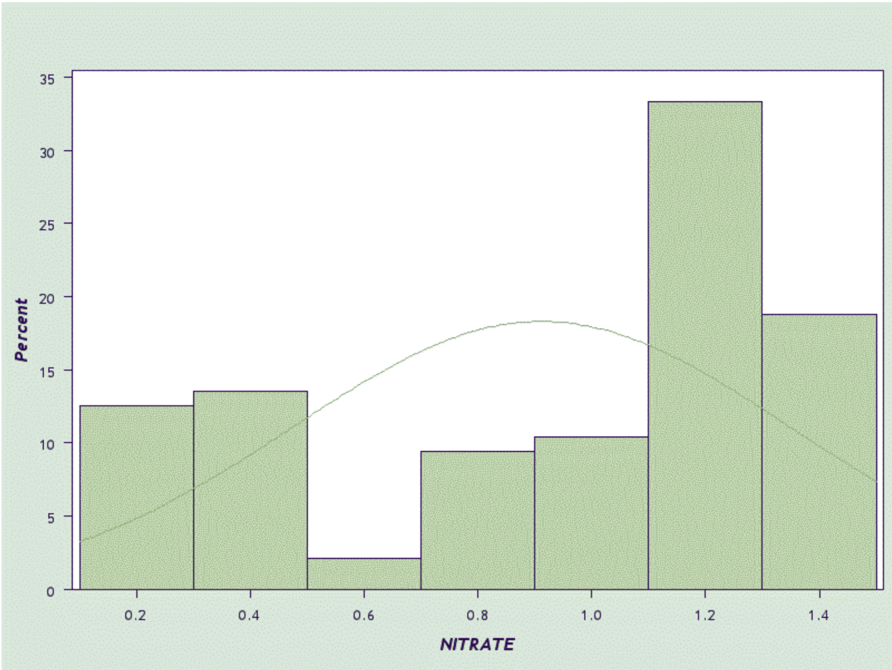

Figure 17: Histogram of nitrate level at Peavine Creek
The histogram of nitrate (NO_3-N) at Peavine Creek shows a right distribution of measured values indicating that more recorded values had a higher measured value of nitrate than a lower measured value.

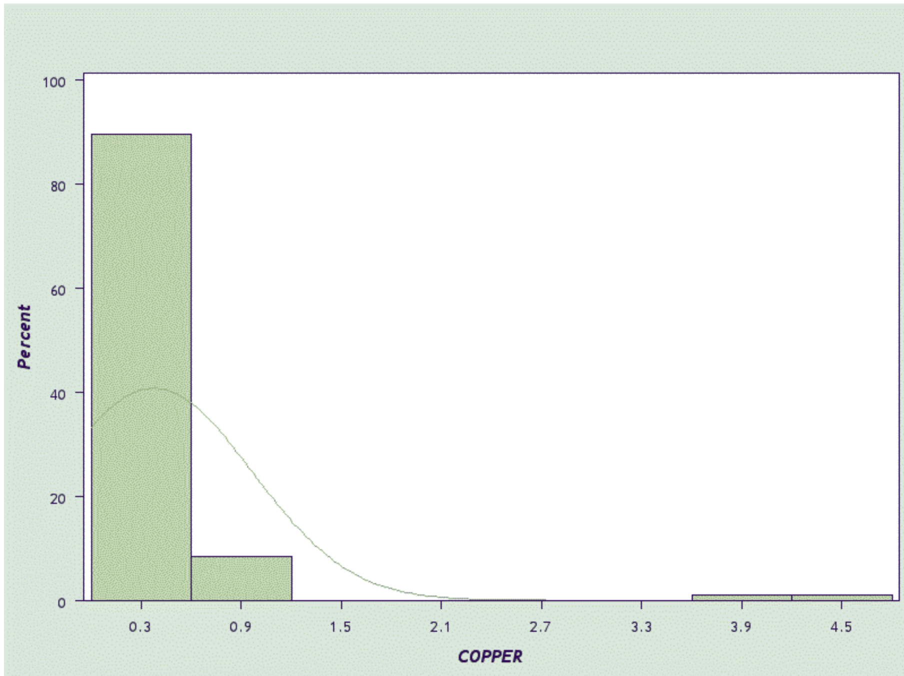

Figure 18: Histogram of copper level at Peavine Creek
The histogram of copper concentration levels (ppm Cu) at Peavine Creek shows a left distribution of measured values indicating that more recorded values were closer to zero.

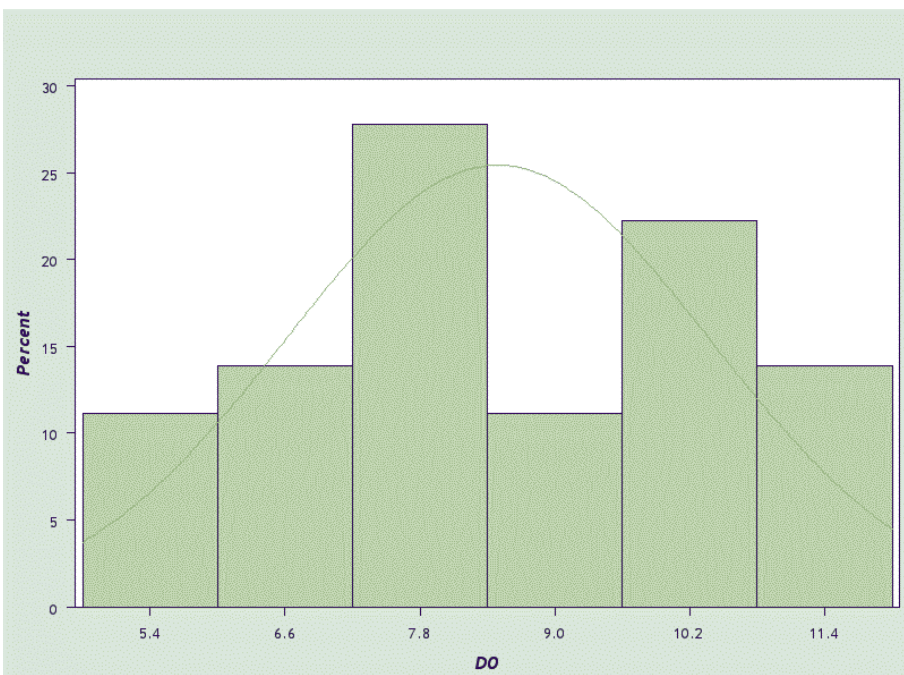

Figure 19: Histogram of Dissolved Oxygen level at Stone Mountain Creek
The histogram of DO levels (mg/L) at Stone Mountain Creek shows a normal distribution of measured values.

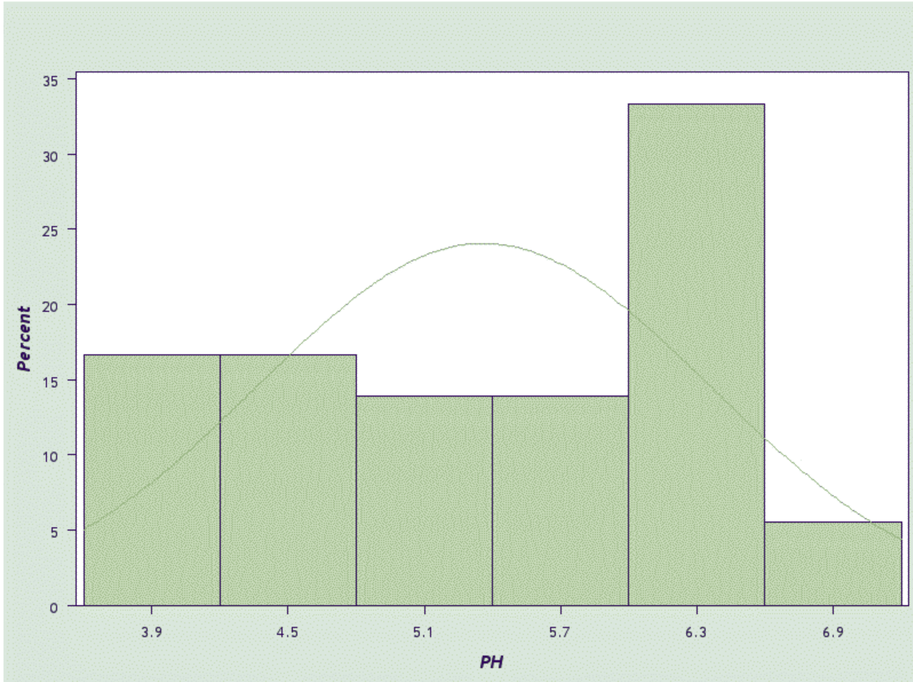

Figure 20: Histogram of pH level at Stone Mountain Creek
The histogram of pH levels at Stone Mountain Creek shows a normal distribution of measured values.

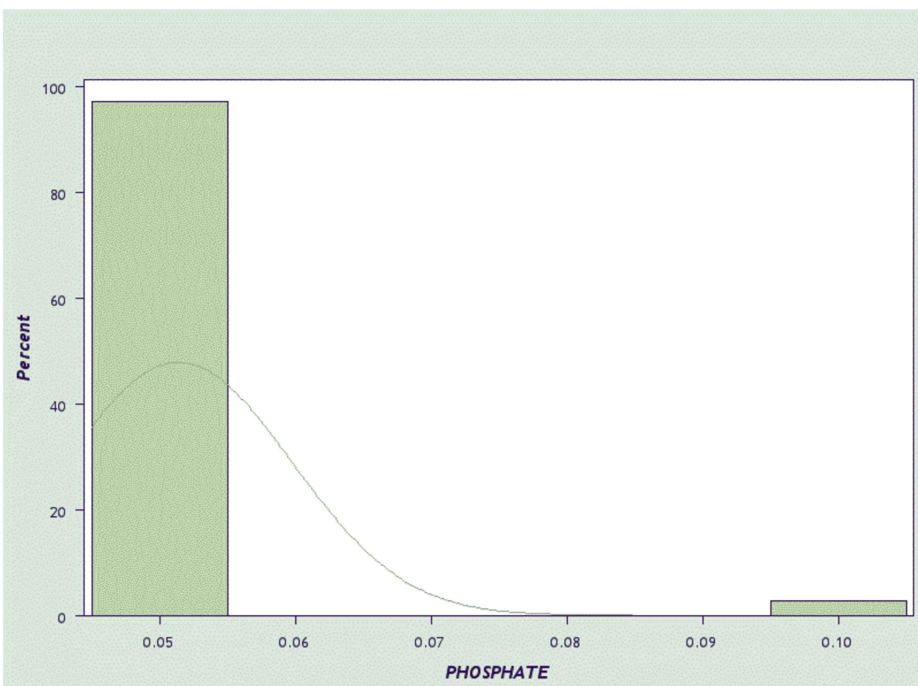

Figure 21: Histogram of phosphate level at Stone Mountain Creek
The histogram of phosphate concentration levels (ppm P) at Stone Mountain Creek shows a left distribution of measured values indicating that more recorded values were closer to zero.

Appendix B: Tables

Site and Location	DO (mg/L)	PH	Phosphate (ppm P)	Nitrate (ppm NO_3-N)	Copper (ppm Cu)
TA Mean	8.392	7.027	0.078	0.948	0.284
TB Mean	8.596	7.013	0.076	1.065	0.250
TC Mean	10.672	7.072	0.060	1.073	0.250
TD Mean	7.862	6.834	0.196	0.879	1.016
T1:Pools Mean	6.016	6.976	0.154	0.784	0.803
T2: Riffles Mean	10.587	6.962	0.066	1.090	0.250
T3:Runs Mean	10.197	7.031	0.079	1.114	0.250
Overall Mean	8.902	6.990	0.101	0.994	0.438
Median	9.450	7.030	0.050	1.020	0.250
Mode	3.280	6.270	0.050	0.800	0.250
Standard Deviation	3.156	0.529	0.168	0.352	1.299
Variance	9.960	0.280	0.028	0.124	1.688
Range	15.760	2.500	1.050	1.880	11.750

Table 1: Standard Statistical Measures for Tanyard Creek
Assessment of the 94 complete water samples that were collected and processed during the eight week sampling period from November 4, 2009 to December 21, 2009. Data are stratified by sampling site (A, B, C, D) and by location (1, 2, and 3). The overall mean, median, mode, standard deviation, variance, and range, was calculated using the original raw data before stratification. Statistics were produced using SAS Univariate Analysis.

Site and Location	DO (mg/L)	PH	Phosphate (ppm P)	Nitrate (ppm NO_3-N)	Copper (ppm Cu)
PA Mean	7.903	6.970	0.148	0.706	0.605
PB Mean	10.812	6.973	0.111	1.047	0.340
PC Mean	8.407	6.953	0.086	0.845	0.263
PD Mean	10.855	7.035	0.100	1.051	0.295
P1:Pools Mean	6.351	6.944	0.154	0.667	0.555
P2: Riffles Mean	11.323	7.008	0.084	1.047	0.284
P3:Runs Mean	10.808	6.996	0.096	1.023	0.288
Overall Mean	9.494	6.983	0.111	0.912	0.376
Median	10.600	7.055	0.050	1.105	0.250
Mode	9.500	6.880	0.050	0.100	0.250
Standard Deviation	3.366	0.626	0.154	0.436	0.588
Variance	11.331	0.392	0.024	0.191	0.346
Range	13.074	2.740	0.960	1.390	4.450

Table 2: Standard Statistical Measures for Peavine Creek
Assessment of the 96 complete water samples that were collected and processed during the eight week sampling period from November 4, 2009 to December 21, 2009. Data are stratified by sampling site (A, B, C, D) and by location (1, 2, and 3). The overall mean, median, mode, standard deviation, variance, and range, was calculated using the original raw data before stratification. Statistics were produced using SAS Univariate Analysis.

Site and Location	DO (mg/L)	PH	Phosphate (ppm P)	Nitrate (ppm NO_3-N)	Copper (ppm Cu)
SA Mean	10.119	4.941	0.050	0.100	0.250
SB Mean	9.913	5.020	0.056	0.100	0.250
SC Mean	6.376	5.493	0.050	0.100	0.250
SD Mean	7.558	5.991	0.050	0.100	0.250
S1:Pools Mean	7.707	5.393	0.050	0.100	0.250
S2: Riffles Mean	8.930	5.379	0.050	0.100	0.250
SA3:Runs Mean	8.838	5.312	0.054	0.100	0.250
Overall Mean	8.491	5.361	0.051	0.100	0.250
Median	8.195	5.425	0.050	0.100	0.250
Mode	7.700	6.280	0.050	0.100	0.250
Standard Deviation	1.883	0.995	0.008	0.000	0.000
Variance	3.544	0.990	0.000	0.000	0.000
Range	6.470	3.210	0.050	0.000	0.000

Table 3: Standard Statistical Measures for Stone Mountain Creek
Assessment of the 36 complete water samples that were collected and processed during the eight week sampling period from November 4, 2009 to December 21, 2009. Sampling at Stone Mountain only occurred three times during the study period, 12 samples collected each time (a pool, a riffle, and a run, from sites A, B, C, and D). Data are stratified by sampling site (A, B, C, D) and by location (1, 2, and 3). The overall mean, median, mode, standard deviation, variance, and range, was calculated using the original raw data before stratification. Statistics were produced using SAS Univariate Analysis.

Parameter	Chi-Square	DF	Pr> Chi-Square
DO	2.153	1	0.1423
pH	56.847	1	<0.0001*
Phosphate	7.335	1.000	0.0068*
Nitrate	74.657	1.000	<0.0001*
Copper	1.975	1.000	0.1599

Table 4: Kruskal-Wallis Test Results from the Wilcoxon Rank Sum Test comparing Tanyard Creek and Stone Mountain Creek
Chi-Square- Assesses the distribution of a sample for significant testing
DF-Degrees of Freedom
Pr>Chi-Square- Probability measure that assess the significance of the chi-square test: if the probability value (p value) is less than 0.05 then it is commonly interpreted as being statistically significant evidence to reject the null hypothesis that assumes that there is no difference between the two variables in regards to the parameter of interest.
An * is used to indicate significance.

Parameter	Chi-Square	DF	Pr> Chi-Square
DO	12.976	1	0.0003*
pH	58.209	1	<0.0001*
Phosphate	13.368	1.000	0.0003*
Nitrate	66.678	1.000	<0.0001*
Copper	4.898	1.000	0.0269*

Table 5: Kruskal-Wallis Test Results from the Wilcoxon Rank Sum Test comparing Peavine Creek and Stone Mountain Creek
Chi-Square- Assesses the distribution of a sample for significant testing
DF-Degrees of Freedom
Pr>Chi-Square- Probability measure that assess the significance of the chi-square test: if the probability value (p value) is less than 0.05 then it is commonly interpreted as being statistically significant evidence to reject the null hypothesis that assumes that there is no difference between the two variables in regards to the parameter of interest.
An * is used to indicate significance.

Parameter	Chi-Square	DF	Pr> Chi-Square
DO	6.914	1	0.0086*
pH	0.0978	1	0.7545
Phosphate	2.841	1.000	0.0919
Nitrate	0.476	1.000	0.4901
Copper	2.774	1.000	0.0958

Table 6: Kruskal-Wallis Test Results from the Wilcoxon Rank Sum Test comparing Tanyard Creek and Peavine Creek
Chi-Square- Assesses the distribution of a sample for significant testing
DF-Degrees of Freedom
Pr>Chi-Square- Probability measure that assess the significance of the chi-square test: if the probability value (p value) is less than 0.05 then it is commonly interpreted as being statistically significant evidence to reject the null hypothesis that assumes that there is no difference between the two variables in regards to the parameter of interest.
An * is used to indicate significance.

Macroinvertebrate	Order	Quantity
Crane fly larvae	Diptera	5
Leech	Hirundinea	1
Snail	Gastropoda	2
Crayfish	Decapoda	2
Worm	Megadrill and Microdrill	2
Damsel fly larvae	Odonata, Zygoptera	1
TOTAL:	*6*	*13*

Adopt-A-Stream Score: 9: poor Water Quality

Table 7: Biological Assessment of Tanyard Creek
The biological assessment of Tanyard Creek occurred on November 16, 2009 to assess the biological community of the waterbody. Methods used were in accordance with Georgia's Adopt-A-Stream biological assessment protocol. The ratings were determined based on the tolerance and quantity of macroinvertebrates found in the stream. A formula was used and water quality ratings were as follows: excellent: >22, good: 17-22, fair: 11-16, and poor: <11.

Macroinvertebrate	Order	Quantity
Caddis fly larvae	Trichoptera	13
Damsel fly larvae	Odonata, Zygoptera	2
Crane fly larvae	Diptera	1
TOTAL:	*3*	*16*

Adopt-A-Stream Score: 5: Poor Water Quality

Table 8: Biological Assessment of Peavine Creek
The biological assessment of Peavine Creek occurred on November 16, 2009 to assess the biological community of the waterbody. Methods used were in accordance with Georgia's Adopt-A-Stream biological assessment protocol. The ratings were determined based on the tolerance and quantity of macroinvertebrates found in the stream. A formula was used and water quality ratings were as follows: excellent: >22, good: 17-22, fair: 11-16, and poor: <11.

Macroinvertebrate	Order	Quantity
Isopods	Isopoda	30
Crayfish	Decapoda	28
TOTAL:	*2*	*58*

Adopt-A-Stream Score: 15: Fair Water Quality

Table 9: Biological Assessment of Stone Mountain Creek
The biological assessment of Stone Mountain Creek occurred on December 17, 2009 to assess the biological community of the waterbody. Methods used were in accordance with Georgia's Adopt-A-Stream biological assessment protocol. The ratings were determined based on the tolerance and quantity of macroinvertebrates found in the stream. A formula was used and water quality ratings were as follows: excellent: >22, good: 17-22, fair: 11-16, and poor: <11.

Literature Cited

"Acid Rain." *Safe Drinking Water Foundation*. Safewater.org, 2007. Web. 23 Mar. 2010. <http://www.safewater.org/PDFS/resourcesknowthefacts/Acid_Rain.pdf>.

Banner, Eric, Anthony J. Stahl, and Walter K. Dodds. "Stream Discharge and Riparian Land Use Influence In-Stream Concentrations and Loads of Phosphorus from Central Plains." *Environmental Management* 44.3 (2009): 552-65. *SpringerLink*. 14 July 2009. Web. 12 Mar. 2010. <http://www.springerlink.com/content/x82471nj65v21xwr/fulltext.pdf>.

Bergmann, Reinhard, John Ludbrook, and Will Spooren. "Different Outcomes of the Wilcoxon-Mann-Whitney Test from Different Statistics Packages." *The American Statistician* 54.1 (2000): 72-77. *Jstor*. American Statistical Association. Web. 11 Mar. 2010. <http://www.jstor.org/stable/2685616>.

Berryman, David, Bernard Bobee, Daniel Cluis, and John Haemmerli. "Nonparametric Tests for Trend Detection in Water Quality Time Series." *Journal of the American Water Resources Association* 3rd ser. 24 (1988): 545-56. Web. 10 Mar. 2010. <http://dx.doi.org/10.1111/j.1752-1688.1988.tb00904.x>.

Billah, Mohammad. "EPA Combined Sewer Overflows - Office of Wastewater Management." *U.S. EPA ColdFusion Server*. 30 Apr. 2009. Web. 15 Mar. 2010. <http://cfpub.epa.gov/npdes/home.cfm?program_id=5>.

Boyacioglu, Hulya, and Hayal Boyacioglu. "Surface Water Quality Assessment by Environmetric Methods." *Environmental Monitoring Assessment* 131 (2006): 371-76. Print.

Buck, Sharon. *Nutrient Criteria Technical Guidance Manual*. Tech. no. Epa-822-b-00-002. United States Environmental Protection Agency, July 2000. Web.

CHEMetrics. *Operator's Manual V-2000 Photometer*. Calverton: CHEMetrics, 2009. Print.

Christensen, V.G., P.P. Rasmussen, and A.C. Ziegler. "USGS - Real-Time Water-Quality Monitoring and Regression Analysis to Estimate Nutrient and Bacteria Concentrations in Kansas Streams." *USGS - Water Resources in Kansas*. United States Geological Survey, 17 Sept. 2008. Web. 16 Mar. 2010. <http://ks.water.usgs.gov/pubs/reports/vgc.0610.html>.

Cody, Ronald P., and Jeffrey K. Smith. *Applied Statistics and the SAS Programming Language*. 5th ed. Upper Saddle River, N.J.: Pearson Prentice Hall, 2006. Print.

Corder, Gregory W., and Dale I. Foreman. *Nonparametric Statistics for Non-statisticians: a Step-by-step Approach*. Hoboken, N.J.: Wiley, 2009. Print.

Das, Madhumita, A. Kumar, M. Mohapatra, and S.D. Muduli. "Evaluation of Drinking Quality of Groundwater through Multivariate Techniques in Urban Area." *Environmental Monitoring Assessment* 9 (2009): 991-99. Print.

Edullantes, Brisneve C. *Physicochemical Comparison between Upstream and Downstream and Biological Characterizations of Diningasan River, Camiguin*. Rep. 2001. Web. 11 Mar. 2010. <http://www.scribd.com/doc/19967008/Physicochemical-Comparison-between-Upstream-and-Downstream-and-Biological-Characterization-of-Diningasan-River-Camiguin>.

"EPA - Classifications of Macroinvertebrates." *U.S. Environmental Protection Agency*. Web. 14 Mar. 2010. <http://www.epa.gov/bioindicators/html/invertclass.html>.

EPA Gold Book: Quality Criteria for Water. 1986. *Environmental Protection Agency*. United States Environmental Protection Agency. Web. 7 Mar. 2010. <http://www.epa.gov/waterscience/criteria/library/goldbook.pdf>.

Fawell, J.K., U. Lund, B. Mintz, H. Galal-Gorchev, R. Helmer, X. Bonnefoy, O. Espinoza, and Marla Sheffer. *Ammonia in Drinking-water*. Tech. no. WHO/SDE/WSH/03.04/01. 2nd ed. Vol. 2. Geneva: World Health Organization, 1996. Print. Health Criteria and Other Supporting Information.

Frumkin, Howard, Lawrence D. Frank, and Richard Jackson. *Urban Sprawl and Public Health: Designing, Planning, and Building for Healthy Communities*. Washington, DC: Island, 2004. Print.

Georgia Adopt-A-Stream Staff. *Biological and Chemical Stream Monitoring*. Department of Natural Resources, 2001. Print.

Gibbons, Maribeth V. *A Citizen's Guide to Understanding and Monitoring Lakes and Streams: Chapter 3: Streams*. Rep. no. Ecology Publication 93-93. State of Washington: Department of Ecology, Jan. 1994. Web. 16 Mar. 2010. <http://www.ecy.wa.gov/programs/wq/plants/management/joysmanual/streamph.html>.

Gordon, Nancy D., Thomas A. McMahon, Brian L. Finlayson, Christopher J. Gippek, and Rory J. Nathan. *Stream Hydrology: An Introduction for Ecologists*. 2nd ed. Chichester, West Sussex, England: Wiley, 2004. Print.

Hudak, P.F. "Regional Trends in Nitrate Content of Texas Groundwater." *Journal of Hydrology* 228 (2000): 37-47. Print.

Keithan, Elaine D., Rex L. Lowe, and Hudson R. Deyoe. "Benthic Diatom Distibution in a Pennsylvania Stream: Role of PH and Nutrients." *Journal of Phycology* 24.4 (1988): 581-85. Dec. 1988. Web. 11 Mar. 2010.

<http://web.ebscohost.com/ehost/pdf?vid=4&hid=9&sid=5fd8881c-5578-425f-9024-612e6e0d2ed8%40sessionmgr14>.

King, Ephraim S. *Aquatic Life Ambient Freshwater Quality Criteria-Copper*. Publication no. 7440-50-8. United States Environmental Protection Agency: Office of Water, Office of Science and Technology, 2007. Web. 8 Mar. 2010. <http://www.epa.gov/waterscience/criteria/aqlife.html>.

Kuppusamy, M.R., and V.V. Giridhar. "Factor Analysis of Water Quality Characterisitics including Trace Metal Speciation in the Coastal Environment System of Chennai Ennore." *Environment International* 32 (2006): 174-79. Print.

Lambrakis, Nicolaos, Andreas Antonakos, and George Panagopoulos. "The Use of Multicomponent Statisticial Analysis in Hydrogeological Environmental Research." *Water Research* 38 (2004): 1862-872. Print.

Mayor's Clean Water Advisory Panel. *City of Atlanta CSO Remedial Measures Authorized Plan, Briefing*. Presentation. 2002. Print.

Murphy, Shelia. "BASIN: General Information on Dissolved Oxygen." *Boulder Community Network - Serving Boulder County since 1994*. USGS, 23 Apr. 2007. Web. 11 Mar. 2010. <http://bcn.boulder.co.us/basin/data/NEW/info/DO.html>.

Nikanorov, A.M., and V.P. Yemelyanova. "Comprehensive Evaluation of Continental Surface Water Quality." *Water Resources* 32.1 (2005): 56-64. *SpringerLink*. MAIK Nauka, 25 Feb. 2005. Web. 11 Mar. 2010. <http://www.springerlink.com/content/mk67274849212923/fulltext.pdf>.

Papaioannou, Agelos, Athina Mavridou, Christos Hadjichristoudoulou, Panagiotis Papastergiou, Olga Pappa, Eleni Dovriki, and Ioannis Rigas. "Application of Multivariate Statistical Methods for Groundwater Physiochemical and Biologial Quality Assessment in the Context of Public Health." *Environmental Monitoring Assessment* 9 (2009): 1217-X. Print.

Parashar, Charu, Neelam Verma, Savita Dixit, and Rajneesh Shrivastava. "Multivariate Analysis of Drinking Water Quality Parameters in Bhopal, India." *Environmental Monitoring Assessment* 140 (2008): 119-22. Print.

Paul, Michael J., and Judy L. Meyer. "Streams in the Urban Landscape." *Annual Reviews of Ecology and Systematics* 32 (2001): 333-65. Web. 1 Oct. 2009. <arjournals.annualreviews.org>.

Perlman, Howard. "Water Properties: PH, from USGS Water Science for Schools." *USGS Georgia Water Science Center*. U.S. Department of the Interior, 6 Oct. 2009. Web. 11 Mar. 2010. <http://ga.water.usgs.gov/edu/phdiagram.html>.

Pickett, S.T.A., M.L. Cadenasso, J.M. Grove, C.H. Nilon, R.V. Pouyat, W.C. Zipperer, and R. Costanza. "Urban Ecological System: Linking Terrestrial, Ecologinal, Physical, and Socieoeconomic Components of Metropolitan Areas." *Annual Reviews of Ecology and Systematics* 32 (2001): 127-57. Web. 12 Mar. 2010. <http://arjournals.annualreviews.org/doi/pdf/10.1146/annurev.ecolsys.32.081501.114012>.

Polteva, A. V., E. M. Latkovskaya, and A.V. Leonov. "Assessment of the Background Ecological State of Water in the Chayvo Bay, Northeastern Sakhalin." *Water Resources* 36.1 (2009): 86-98. *SpringerLink*. MAIK Nauka, 4 Feb. 2009. Web. 11 Mar. 2010. <http://www.springerlink.com/content/d400658k3x706120/?p=0e373da7cc6c452bb0efbbc91a952998&pi=0>.

Resende, Paula C., Paul Resende, Miguel Pardal, Salome Almedia, and Ulisses Azeiteiro. "Use of Biological Indicators to Assess Water Quality of the UI River (Portugal)." *Environmental Monitoring Assessment*. 29 Dec. 2009. Web. 8 Mar. 2010.

Rogozin, A.G., and S.V. Gavrikina. "Causes for High Concentration of Copper and Zinc in the Water of Some Lakes in the Southern Urals." *Water Resources* 35.6 (2008): 701-07. *SpringerLink*. MAIK Nauka, 09 Nov. 2008. Web. 11 Mar. 2010. <http://www.springerlink.com/content/d34278421221j7n8/?p=b57e08ef20824bb4be9507687bac8191&pi=32>.

Ryzhakov, A. V., N.A. Kukkonen, and P.A. Lozovik. "Determination of the Rate of Ammonification and Nitrification in Natural Water by Kinetic Method." *Water Resources* 37.1 (2010): 70-74. *SpringerLink*. MAIK Nauka, 2 Feb. 2010. Web. 11 Mar. 2010. <http://www.springerlink.com/content/7804756260678434/fulltext.pdf>.

Simeonov, V., J.A. Stratis, C. Samara, G. Zachariadis, D. Voutsa, A. Anthemidis, M. Sofoniou, and Th. Kouimtzis. "Assessment of the Surface Water Quality in Northern Greece." *Water Research* 37 (2003): 4119-124. Print.

Smil, Vaclav. "PHOSPHORUS IN THE ENVIRONMENT: Natural Flows and Human Interferences." *Annual Review of Energy and the Environment* 25 (2000): 35-88. Web. 12 Mar. 2010. <http://arjournals.annualreviews.org/doi/abs/10.1146/annurev.energy.25.1.53?prevSearch=urban%2Bstream%2Bnitrate%2Blevels&searchHistoryKey=>.

Spellman, Frank R. "Water Ecology." *Handbook of Water and Wastewater Treatment Plant Operations*. Boca Raton: CRC/Taylor & Francis, 2009. 487. Print.

Stevens Institute of Technology. "Dissolved Oxygen." *The Center for Innovation in Engineering and Science Education*. Stevens Institute of Technology, 2009. Web. 11 Mar. 2010. <http://www.ciese.org/curriculum/dipproj2/en/fieldbook/oxygen.shtml>.

United States. Cong. House. Committee on Transportation and Infrastructure. *Field Hearing on the Impacts of Nutrients on Water Quality in the Great Lakes*. 110th Cong., 2nd sess. H. Doc. Washington DC, 2008. Print.

Vega, Marisol, Rafael Pardo, Enrique Barrado, and Luis Deban. "Assssment of Seasonal and Polluting Effects on the Quality of River Water by Exploratory Data Analysis." *Water Resources* 32.12 (1998): 3581-592. Print.

"Vernier Qater Quality Labs: Stream Study." *Ursinus College Academic Web*. 2009. Web. 16 Mar. 2010. <http://academic.ursinus.edu>.

Vorsey, Jr., Louis De. "Maps in Colonial Promotion: James Edward Oglethorpe's Use of Maps in 'Selling' the Georgia Scheme." *Imago Mundi* 38 (1986): 35-45. Web. <http://www.jstor.org/stable/1150866>.

Watson, John. "What Is Acid Rain? [USGS]." *USGS Publications Warehouse*. 21 July 1997. Web. 03 Apr. 2010. <http://pubs.usgs.gov/gip/acidrain/2.html>.

Wilcoxon, Frank. "Individual Comparisons by Ranking Methods." *Biometrics Bulletin* 1.6 (1945): 80-83. *Jstor*. International Biometric Society. Web. 11 Mar. 2010. <http://www.jstor.org/stable/3001968>.