Effects of biological activity and precipitation on stormwater retention basin water chemistry in Bryn Mawr, PA

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1. ABSTRACT

The Rhoads Pond waterway on Bryn Mawr College's campus is a small, but complex and dynamic system that accomplishes the job it was created to carry out. The scope of this study allowed for assertions to be made regarding the state of the waterway during the fall 2006 season as well as on a longer term time-scale. Data shows rain events dilute dissolved ion concentrations and cause electrical conductivity levels to drop. Two diurnal dissolved-oxygen studies as well as biweekly sampling put bounds on the date of autumnal cessation of biological uptake between the end of September and the second week of October. Comparison of all monitoring datasets since 2003 reveals chemical buildups in the retention basin. An assessment of water quality parameters reveals that the character of water leaving the retention basin and entering Mill Creek is less variable than the water entering the retention basin. Lastly, the derivation of an equation relating chloride concentrations and electrical conductivity can allow future estimations of chloride levels using only a handheld EC meter.

2. INTRODUCTION

In 2001, Bryn Mawr College built a retention basin to manage stormwater runoff from a small but heavily paved catchment in the town of Bryn Mawr, Pennsylvania. Water from the basin, which is referred to as Rhoads Pond, drains via Mill Creek to the Schuylkill River and eventually enters the Delaware River in Philadelphia. By design, Rhoads Pond serves both physical and chemical purposes: it attenuates peak runoff discharges, and it lowers the concentration of anthropogenic contaminants before they enter Mill Creek. Contaminant removal results from nutrient uptake by aquatic and wetland vegetation, algae and diatoms in the pond (Bryn Mawr College Facilities, 2006). In this study, water quality parameters were measured to examine the state of the water entering, passing through, leaving, and interacting with Rhoads Pond.

2-1. Study Site

Geologically, Bryn Mawr College is located in the Wissahickon Schist Formation (PA Geological Survey, 1981). The weather-resistant schist is responsible for the steeply incised stream valleys surrounding the college. Bryn Mawr, which means “great hill” in Welsh, is named after the steep, hilly physiography of the area. As can be seen in Figure 1, Taylor Hall occupies the crest of a large hill (Cooperman, 2004). Rhoads Pond is situated in a valley between the ridges of the town of Bryn Mawr and Bryn Mawr College.

Prior to Rhoads Pond’s creation in 2001, the parcel of land it now inhabits was repeatedly flooded during rain events. The flooding resulted in damp, mushy soil conditions downstream and around the site including athletic fields. The creation of the retention basin was aimed at not only controlling peak runoff to lessen damage caused by stormwater as it travels downstream on Mill Creek but also at managing amounts of heavy metals, sediment and nutrients being carried into Mill Creek, which had suffered from a drop in biological diversity (Bryn Mawr College Alumnae Newsletter, 2001). Stormwater quality and quantity are inextricably coupled and need to be controlled together (Pennsylvania, 2006).

State environmental agencies put forward two main options to hold stormwater in their Best Management Practices (BMP): a detention basin for temporarily storing an excess volume of stormwater runoff during a storm event or a retention basin for a more permanent impoundment of excess stormwater runoff with the added benefit of natural water contaminant treatment after the storm event. Rhoads Pond is a retention basin designed as two discrete water bodies to optimize contaminant and nutrient management. Water entering the pond through the inlet during normal precipitation conditions is deposited into the forebay (Figure 2). The forebay traps stormwater runoff sediment before the water passes into the main basin of the pond (Dauphin County, 2006). In the event of extremely high water levels, water being input into the pond system can bypass the forebay by way of a spillway. Emerson (2003) showed that the individual on-site attenuating effect of multiple retention or detention basins on peak stream flow is not additive and while the immediate downstream flow is affected, an individual basin's impact is lost further downstream if unaided by supplementary basins. Nonetheless, stormwater retention basins do effectively control stormwater at their specific sites.

High removal rates of suspended particles and soluble contaminants can be achieved in retention basins through gravitational settling, biological uptake and decomposition (Pennsylvania, 2006). Schueler et al. (1992, fide Virginia, 1999) showed sediment removal efficiencies to range from 50-90% and soluble nutrient removal efficiencies to range from 40-80%. Woodruff (2005) showed annual average removal efficiencies in excess of 50% removal.

Water passes from the forebay into the main basin of the pond through a gabion, a wire cage that contains coarse stones. Gabions are used to increase the resistance of stones to movement caused by flowing water. Once in the main basin, water is retained for some time. A drain at the bottom of the main basin (Figure 2) continually allows a small amount of water to leave the pond system.

Water draining from Rhoads Pond is piped underground to a culvert-fed tributary (see Figure 3 for a diagram of the entire waterway) that drains into Mill Creek near the bridge at the intersection of Old Gulph Road and North Roberts Road (Figure 4). Additional stormwater enters the tributary from storm drains along the course of the underground pipe.

In order to capture all aspects of the Rhoads Pond waterway it was necessary to monitor six locations (Figure 3): the pond inlet, the pond forebay, the pond main basin, the pond-fed tributary, upstream of the tributary/creek junction, and downstream of the tributary/creek junction. Water samples from the pond inlet represent the stormwater being input into the Rhoads Pond waterway system. Since the main basin of Rhoads Pond drains from the bottom, the water found in the culvert-fed tributary is analogous (in most ways; however, temperature for example changes as the water is piped underground to the tributary) during dry periods when the main basin is the tributary's sole source of input. The two creek locations are essential for recording any potential differential created by the Rhoads Pond water input.

2-2. Previous Research

The Rhoads Pond waterway has been previously studied by Geology classes (302, Low-Temperature Geochemistry) in 2003 and 2005, and by Kaitlin Friedman BMC'07 and Evan Pugh HC '07 during the summer of 2006. The data gathered at these various times by various groups is compiled online in the Bryn Mawr College Environmental

Database (Pugh et al., 2006). In a project separate from this thesis that was begun during the fall of 2006, water temperature, electrical conductivity, and rain sensors were installed on Rhoads Pond and a plan was laid out for the future installation of more sensors (Pugh, 2006). Bryn Mawr College Facilities (2006) mentioned an independent study done on the Pond to gauge its effectiveness in treating water chemistry.

3. METHODS

The general structure of fall 2006 data gathering for the water quality parameter study consisted of a total of eight biweekly field excursions between 9/14/06 and 11/2/06 to collect water samples and employ handheld probes. In this paper, *Fall* refers to the months of September – November. The six locations mentioned above were the sites for data collection for a survey of long term trends and shorter term storm event water chemistry fluctuations. Two 24-hour dissolved oxygen studies were performed at Rhoads Pond on 9/29/06 – 9/30/06 and 11/10/06 – 11/11/06. These data can be used to determine the role of pond functions as a source of CO_2 and evaluate the impact of algal activity using dissolved oxygen as a proxy for photosynthesis. A total of ten weekly samples were collected between 6/5/06 – 8/7/06 during the summer of 2006.

3-1. Field Sampling Procedure

At each study site, two water samples were gathered in 60mL Nalgene bottles. A Corning Checkmate II handheld electrical conductivity (EC) meter was used on location to record EC in μS/cm and water temperature in ºC. The probe was thoroughly rinsed in deionized water between measures. Dissolved oxygen levels were obtained using a

CHEMetrics photometer and O_2 vacuvials. A sample of water was collected in a CHEMetrics snap-off tube and an O_2 vacuvial was broken in the water and then inverted. After waiting thirty seconds, the vacuvial was loaded inside the photometer and results were recorded in ppm (CHEMetrics Dissolved, 2006). Only the first sampling day, 9/14/06, was actually during a rain event. Subsequent samplings either occurred on days when it did not rain or occurred before it rained on a particular day.

3-2. Ion Chromatograph

In the laboratory, samples were filtered through 0.2 μm Nalgene nylon filters and run through a Dionex ion chromatograph, using an eluent composition for anions of: 8.0 mM Na_2CO_3, 1.0 mM $NaHCO_3$ and for cations: 20.0 mM methanesulfonic acid (MSA) at a flow rate of 1 mL/min, with a 25 μL injection, and a temperature of 30°C. The ion chromatograph, in a comparison of ion species with a set of standards of a known composition, allowed for the measurement of the concentration of cations (Na^+, Mg^{2+}, K^+, Ca_2^+) and anions (NO_3^-, Cl^-, SO_4^{2-}) present in the water sample.

3-3. Lab Titrations and CHEMetrics Photometer

Bicarbonate concentrations were found using an alkalinity pool test kit for titration and then multiplying total alkalinity by molar ratios to convert to HCO_3^-. Silica concentrations were obtained using a CHEMetrics photometer and silica vacuvials (CHEMetrics Silica, 2006). The CHEMetrics photometer was also capable of detecting phosphate, but none was detected.

3-4. Rain Gauge

On 8/11/06, a tipping bucket-style HOBO Weather Station Rain Gauge Smart Sensor was calibrated and installed on the top of the inlet to Rhoads Pond and connected to a HOBO Micro Station Data Logger. The rain sensor records hourly rain totals. The data included in this study has been recorded through 12/11/06.

3-5. Diurnal Dissolved Oxygen Study

On 9/29/06-9/30/06 and 11/10/06-11/11/06 teams of researchers performed time-intensive 24-hour monitoring studies. These studies involved hourly dissolved oxygen, water temperature, and electrical conductivity measurements on both Rhoads Pond's main basin and forebay.

3-6. Quality Control

In instances where concentrations of all eight measured dissolved ions were available, charge balances were calculated (Appendix A). Ion balances with a percent error greater than 10% were reanalyzed until data confidence was established. Correlation significance in linear regressions was established using a table of correlation coefficients relative to degrees of freedom from Snedecor and Cochran (1967). *Sigma Plot 10.0* and *JMP IN 5.1* statistic packages were used to determine statistics.

4. RESULTS & DISCUSSION

Rhoads Pond water geochemistry exhibits signs of being driven by a few cycles with varying periodicity. Data from 2003 to 2006 reveals long term trends that indicate chemical buildup. Shorter scale cycles that develop from rain events show dilution of dissolved solids. At even short time-scales, biological cycles that take place within the bounds of a single day expose a respiratory rhythm.

Tables 1-A through 1-K give the mean, maximum, minimum, percent difference, and coefficient of variation of water quality data for summer and fall 2006. The results and discussion section will only refer to results of anions (NO_3^-, Cl^-, SO_4^{2-}, HCO_3^-), electrical conductivity, and dissolved oxygen and silica. Chloride ion is analyzed because it is a conservative tracer. Nitrate is analyzed because it is a biological tracer. Cations (Na^+, Mg^{2+}, K^+, Ca_2^+) undergo cation exchange and as a result are not as useful for analyzing temporal or spatial trends.

4-1. Long Term Temporal Trends

Figures 5 - 8 show time series for chloride, nitrate, electrical conductivity and bicarbonate for the recorded fall and summer seasons between 2003 and 2006. In all four graphed parameters, Mill Creek concentrations or levels stayed relatively constant (in most cases the slope was an order of magnitude smaller than the slopes for the pond locations). Chloride levels for the pond inlet, forebay, and main basin all significantly increase positively with time suggesting a buildup of the ion in water. An increased understanding of forebay/main basin retention times is necessary to ascertain if the external chloride source input is increasing with time or if chloride is simply not leaving the pond system. A buildup of chloride, seen most intensely in the inlet and forebay, makes intuitive sense because chloride ion is biologically inert and could only leave the pond system by physically flowing out of it through the drain box in the main basin.

Additionally, environments that undergo periods of atmospherically-induced wet and dry conditions are known to experience a progressive evaporative buildup of surface chloride concentrations (Bamforth 1993, fide Sagues, A. et al., 2001). Whether from an increase in source input, a gradual buildup, or both, chloride concentrations in the pond are on the rise.

The time series plot of nitrate in Figure 6 shows a similar phenomenon with progressively increasing concentrations. The pond inlet and pond forebay show positive significant correlations between time and nitrate concentrations. Mill Creek upstream and the pond main basin nitrate concentrations do not significantly vary with time. Nitrate encourages algal growth and concentrations reflect decaying organic matter as well as fertilizer input. As nitrate levels created by decomposition are roughly in equilibrium with nitrate uptake in photosynthesizing plants and algae, the ionic buildup is likely the result of increases in the frequency or size of external plugs of fertilizer in stormwater runoff.

Electrical conductivity levels also show an increase with time (Figure 7). The pond inlet shows a positive significant correlation between time and electrical conductivity. Mill Creek Upstream electrical conductivity levels have significant negative correlation with time. Both the pond forebay and pond main basin electrical conductivity levels do not vary significantly with time, but do show positive slopes. Figure 9 shows positive correlation between chloride ion and electrical conductivity at levels experienced in the retention basin during the fall season, resulting in the equation ($\alpha = 0.05$, $r^2 = 0.87$):

$$\textit{Chloride Concentration} = 0.284\ \textit{Electrical Conductivity} - 34.24$$

With such a correlation demonstrated in the waterway, the increase of electrical conductivity shown in the multi-year plot (Figure 7) could reflect the buildup of chloride ion previously discussed.

Lastly, the bicarbonate plot in Figure 8 shows much less drift and deviation. The pond main basin shows a significant weakly positive correlation between time and bicarbonate concentration. However, Mill Creek upstream, the pond inlet, and the pond forebay bicarbonate concentrations do not significantly vary with time. Bicarbonate concentrations reflect the dissolution of carbonate rocks (such as the dolomite found in the gabion) and the oxidation of organic carbon and photosynthesis. Perhaps the lack of an external source of bicarbonate allows the pond system to regulate itself to more stable levels over time.

4-2. Rain Events

The HOBO rain gauge stationed at the inlet to Rhoads Pond recorded various rain events during the fall of 2006. The largest of these rain events measured 85.62mm (≈ 3.4in.) as a daily total (Appendix B). There were seven distinct rain events from 9/14/06 – 11/2/06. Figure 10 is a graph of total daily rainfall (bars) versus date for Fall 2006 that shows the seven distinct rain events. For the purpose of this study, a rain event is described as being more than 10mm (≈ 0.4 inches) total daily rainfall. Compared to total monthly and seasonal rainfall since 2003 at the Philadelphia International Airport (Figure 11a & b), the fall of 2006 was much wetter than the past three fall seasons and the summer of 2006 was much wetter than the previous summer season but on par with the last three summer seasons in general (U.S. Climate, 2006).

Rain Event I (see figure 10) is the only rain event this study mapped with enough resolution to examine water quality trends for any meaningful data. Figure 12 shows electrical conductivity juxtaposed with total daily rainfall over the period of Rain Event I. As discussed in the previous section, Figure 9 shows the significant positive correlation between electrical conductivity and chloride ion. Electrical conductivity is not only a proxy for chloride ion, but for dissolved solids in general. The 9/14/06 sampling date took place during the rain event and EC levels reflect dilution of dissolved ions by rain water. As the week following the storm event progressed without more rain, the pond waterway was able to flush excess water downstream and out of the system. Within five days, EC levels had returned to their seasonal norm.

It is valuable to note in Figure 12 that even on the first sampling date that occurred during a rain event, EC levels in the tributary remained higher than those of the pond main basin. This is evidence for a major difference in concentration of dissolved solids between the surface and bottom of the main basin that even a plug of additional unprocessed stormwater to the tributary through non-pond storm drains could not mask.

4-3. Biological Cycles

Oxygen enters the water by absorption directly from the atmosphere or by aquatic plant and algal photosynthesis. Dissolved oxygen is removed from the water by respiration and decomposition of organic matter. Figure 13 A and B show the change in daily dissolved oxygen character on two sample dates 5 ½ weeks apart (Appendix C). During the September study oxygen levels rose and fell with the sun suggesting a direct relationship to photosynthesis. The nearly flat nature of graph B illustrates that by the time the November study occurred, algal activity had greatly slowed or even ceased. Calculated percent saturation levels (seen in graphs E and F) show that during periods of algal bloom, the forebay signal is dominated by decomposition and the main basin signal is dominated by photosynthesis. Once algal activity has slowed or stopped, both the forebay and main basin are dominated by decomposition. The two diurnal dissolved oxygen studies put bounds on the date of cessation of biological uptake between the end of September and beginning of November. Dissolved oxygen measurements from biweekly sampling (Appendix D) narrow the termination of biological activity to the first week of October.

To estimate seasonal biological activity, Figure 14 shows sulfate and nitrate concentrations versus chloride concentrations for all locations and also the main basin only. Since chloride is biologically inert, observed changes in nitrate and sulfate concentrations relative to chloride concentrations can be associated with biological activity. The biological involvement of nitrate has already been discussed. Sulfate is used by sulfate reducing bacteria during decomposition. The relationship between the sulfate and nitrate regression lines for the entire waterway when compared to those of the main basin by itself reveal which process, photosynthesis or decomposition, was being undergone in the main basin. In the case of sulfate, both the main basin line and the entire waterway line have nearly identical slopes, suggesting relative sulfate levels in the main basin do not vary from those in other parts of the waterway. However, for nitrate, the main basin line is more horizontal than the line for nitrate in the entire waterway. The differing nitrate slopes show that as chloride concentrations go up nitrate does not respond with the same intensity in the main basin, which is known to have photosynthesizing algal activity, as in the rest of the waterway.

Though not included in this study, the few summer pH studies conducted revealed that the main basin was basic. The high pH reflected the removal of CO_2 from the water by photosynthesizing algae.

4-4. Spatial Variation

Figures 15A-D show significant differences in the means of chloride, nitrate, dissolved oxygen, and silica concentrations between sampling sites during the summer and fall of 2006. Graph A illustrates the “downstream dilution” effect that is exactly what a retention basin is supposed to accomplish. Unprocessed stormwater is responsible for the pond inlet having the highest levels of chloride. The forebay has the next highest, followed by the pond-fed tributary. Levels of chloride in the retention basin-processed water leaving the pond system through the tributary were significantly lower than those entering through the inlet. Chloride in the pond system ranged from 58.8 mg/L to 225.4 mg/L, as opposed to Mill Creek which ranged from 38 mg/L to 118.5 mg/L.

The highest nitrate concentrations are found in the pond inlet, most likely because of fertilizer contaminants within incoming water (Figure 15B). The pond main basin had the lowest mean nitrate concentrations because the nitrate was being used by photosynthesizing algae. Nitrate in the pond system ranged from 1.3 mg/L to 20.9 mg/L, as opposed to Mill Creek which ranged from 4.7 mg/L to 10.3 mg/L.

The dissolved oxygen concentrations (Figure 15C) reflect dissolved O_2 production by photosynthesizing algae. The pond main basin had the greatest mean concentration. The pond forebay had a smaller concentration than the main basin, but a larger concentration than the other sites in the water way. Dissolved oxygen in the pond system ranged from 4.8 mg/L to 17.7 mg/L, as opposed to Mill Creek, which ranged from 5.6 mg/L to 8.8 mg/L.

Silica concentrations reflect diatom uptake and silicate weathering. Figure 15D shows that Mill Creek had significantly higher concentrations of silica. Perhaps the pond system had a greater number of diatoms than Mill Creek and was thus more of a dissolved silica sink. Alternatively, Mill Creek may be weathering the silica-rich Wissahickon schist bedrock. Additional biological and geological studies would need to be performed to ascertain which explanation is more realistic. Silica in the pond system ranged from 1.8 mg/L to 12.3 mg/L, as opposed to Mill Creek which ranged from 7.5 mg/L to 16.2 mg/L.

Percent difference of water quality parameters indicates the variability due to internal and external forcing. Figure 16 is a vertical point plot of parameter percent differences reported by location. Water temperature was not included in this plot because it varies based on volume. A one-way ANOVA with Tukey's HSD (Honestly Significantly Different) test reveals that the culvert-fed tributary has significantly less variability than the pond inlet, forebay and both Mill Creek sites. Lower variability suggests that the retention basin is successfully altering the water chemistry of the water fed through the system so that when it leaves the main basin through the drain box the composition is fairly consistent over the fall season.

Figure 17 is a Piper plot of average dissolved ion values from the fall of 2006 for each site along the waterway. Piper plots display constituent ions as percent composition of the water sample. The bottom right ternary diagram shows the decrease of chloride percent composition in samples as water flows downstream from the inlet. Rain water plots in the diamond labeled *Saline*. The large top diamond, useful in determining water type of a sample, is unhelpful in this instance for assigning a label to Rhoads Pond waterway samples. However, the top diamond does show chloride becoming less of a majority constituent and the water becoming in general less like stormwater (the model rain point) as water flows downstream through the waterway.

5. CONCLUSIONS

The Rhoads Pond waterway on Bryn Mawr College's campus is a complex, dynamic system that accomplishes the job it was created to carry out. The scope of this study allowed for assertions to be made regarding the state of the waterway during the fall 2006 season as well as on a longer time scale. Data showed rain events dilute dissolved ion concentrations and cause electrical conductivity levels to drop. Two diurnal dissolved-oxygen studies as well as biweekly sampling put bounds on the date of autumnal cessation of biological uptake between the end of September and the second week of October. Comparison of all monitoring datasets since 2003 revealed chemical buildups in the retention basin. An assessment of water quality parameters revealed that the quality of water leaving the retention basin and entering Mill Creek is more consistent than the water entering the retention basin. Lastly, the derivation of an equation relating chloride concentrations and electrical conductivity can allow in the future for the estimation of chloride levels using only a handheld EC meter, although this relationship needs to be investigated during winter road salting.

6. FUTURE WORK

The installation of the high resolution HOBO rain gauge on Rhoads Pond Inlet is a potential boon for studying storm event response in the waterways. Though pH monitoring was originally intended for this study, faulty equipment resulted in that parameter being excluded. A future study linking pH to rain events could address the acidity of Bryn Mawr area rain.

A small amount of work has been done to calculate accurate physical volumes and flow rates for Rhoads Pond and associated waterways, but more effort is needed. Meticulous sampling of depths in the forebay and main basin coupled with GPS location data could yield enough information for the creation of unique volume models. Installation of flow meters and a more thorough understanding of the volume of the corrugated pipes leading to the inlet and culvert-fed tributary could allow for the calculation of input and output discharge of the retention basin. As an auxiliary, with correct volume information a salt plug could be successfully modeled *and* then measured experimentally. A salt plug could also be used to determine the flow rates across the stone gabion separating the pond's forebay from the main basin.

A biological study of the pond system might aid interpretation of dissolved ion levels. Modeling nutrient uptake would allow for the prediction of total biomass growth. Measuring the spatial density and population of silica diatoms in the pond would help make sense of the silica relationship between the pond waterway and Mill Creek.

The GPS/GIS technology exists today to accurately map the extent of the Rhoads Pond waterway catchment. Perhaps with a handle on the percent of the catchment surface area that is impervious to water (paved ground, underground seals, or rooftops), one could determine if the artificial rerouting of stormwater through storm drains to Rhoads Pond is having a positive impact by decreasing runoff and is leading to an increase in water's ability make its way back down into aquifers. However, a serious potential side effect of the artificial redirection and retention of stormwater is an increase in the ability of contaminants to infiltrate soil and eventually reach groundwater and it must be investigated (Braga, 2004; Kwiatkowski, 2004).

Most importantly, the online database at the Bryn Mawr College Environmental Database (BMCED) has the potential to house an exhaustive and robust dataset. Currently BMCED only houses data from the fall/winter of 2003, fall of 2005, and summer/fall of 2006. The Bryn Mawr community could benefit from continued year-round monitoring of the pond and associated waterways. Data collected during the transition from winter to spring could provide important and interesting insight into the annual growth cycle of photosynthesizing algae and plants. Perhaps more significant, a fall/winter/spring study of electrical conductivity could trace road salt runoff contaminant levels.

This project has the potential to be a working prototype for other community water quality monitoring efforts. In the fall of 2006, the Haverford Township Citizens Ad Hoc Haverford State Advisory Board received a grant for the funding of watershed stewardship and education programs at the site of the former Haverford State Hospital (HSH) in Haverford Township. A section of Darby Creek flows through this 209-acre site on its way to the Delaware River. As a result of collaboration with Bryn Mawr

College faculty, the HSH project could benefit from Rhoads Pond waterway monitoring results and methods that are outlined in this thesis.

7. ACKNOWLEDGMENTS

I would like to thank Dr. Blythe Hoyle and Dr. Don Barber for their insightful advice and guidance during the development and implementation of this study. I would also like to thank Greg Nichols and Jim McGaffin of Facilities for being very accessible and helpful and Kaitlin Friedman BMC ’07 for her continued support of this project and aid in the field. Last but not least, thanks to Katina Krasnec, Frank Alvarez, Alexi Ernstoff, and Rob Korobkin for helping me pass the time during the 24-hour diurnal dissolved oxygen studies on the pond.

8. *REFERENCES*

Bamforth, P. B. (1993) Factors Influencing Chloride Ingress into Marine Structures *in* Concrete 2000, eds. R. K. Dhir, M. R. Jones, (London, UK : Chapman & Hall): p. 1105.

Braga, A. M. (2004) Chloride Concentration Evaluation: Villanova Porous Concrete Site. Master's thesis, Villanova University. <http://www3.villanova.edu/VUSP/to/Thesis/Braga-%20Chlorides.pdf>.

Bryn Mawr College Alumnae Newsletter. Summer 2001. <http://www.brynmawr.edu/alumnae/bulletin/newssu01.htm>.

Bryn Mawr College Environmental Database (BMCED). 2 September 2006. <http://geon.brynmawr.edu/bmced/>

Bryn Mawr College Facilities (2006) An Innovative and Collaborative Approach to Storm Water Management. <http://www.brynmawr.edu/facilities/documents/AnInnovativeandCollaborativeApproachtoStormWaterManagement.pdf>.

CHEMetrics. (2006) Methods: Dissolved Oxygen. <http://www.chemetrics.com/catalogpdfs/Oxygen,_Dissolved.pdf>.

------------- (2006) Methods: Silica. <http://www.chemetrics.com/catalogpdfs/Silica.pdf>.

Cooperman, E. (2004) Bryn Mawr College: Campus heritage preservation initiative. Andropogon Associates, LTD. <http://www.brynmawr.edu/facilities/documents/BrynMawr_report_final.pdf>.

Dauphin County Conservation District. 18 November 2006. Detention Basin fact sheet. <http://www.dauphincd.org/main/Detention%20Basin%20fact%20sheet.pdf>.

Emerson, C. H. (2003) Evaluation of the Additive Effects of Stormwater Detention Basins at the Watershed Scale. Master's thesis, Drexel University. <http://userpages.umbc.edu/~weltyc/Emerson_thesis.pdf>.

Hounslow, A. W. (1995) Water Quality Data Analysis and Interpretation: New York, Lewis Publishers.

Kwiatkowski, M. (2004) Water Quality Study of a Porous Concrete Infiltration Best Management Practice. Master's thesis, Villanova University. <http://www3.villanova.edu/VUSP/to/Thesis/Kwiat-Thesis.pdf>.

PA Geological Survey (1981) Norristown Quadrangle - Map 61 in Atlas of Preliminary Geologic Quadrangle Maps of Pennsylvania.

Pennsylvania Department of Environmental Protection. (2006) PA Stormwater Best Management Practices Manual. <http://www.dep.state.pa.us/dep/deputate/watermgt/wc/subjects/stormwatermanagement/BMP%20Manual/BMP%20Manual.htm>.

Pugh, E. (2006) Progress Report: Automated Water Quality Monitoring on Bryn Mawr College's Rhoads Pond Waterway. Unpublished manuscript.

Pugh, E. et al. (2006) Monitoring Suburban Water Quality: Using Technology and Field Activities To Teach Science and Stewardship In The Delaware River Watershed: Geological Society of America Abstracts with Programs, Vol. 38, No. 7, p. 230.

Sagues, A. et al. (2001) Corrosion Resistance and Surface Life of Drainage Culverts. Report to Florida Department of Transportation. University of South Florida. <www.dot.state.fl.us/research-center/Completed_Proj/Summary_SMO/FDOT_756_rpt.pdf>.

Schueler, T.R., P.A. Kumble, and M.A. Heraty (1992) A Current Assessment of Urban Best Management Practices. Washington, D.C.: Metropolitan Washington Council of Governments (MWCOG).

Smedecor, G.W. and Cochran, W.G. (1967). Statistical Methods. Iowa State University Press, Ames.

U.S. Climate At A Glance. (2006) National Climatic Data Center. <http://www.ncdc.noaa.gov/oa/climate/research/cag3/cag3.html>.

Virginia Department of Conservation and Recreation. (1999). Chapter 3: Minimum Standards in Virginia Stormwater Management Handbook. <http://www.state.va.us/dcr/sw/>.

Woodruff, G. L. (2005) Pollutant Removal Efficiency and Seasonal Variation of a Storm Water Wetland BMP. Master's thesis, Villanova University. <http://www3.villanova.edu/VUSP/to/Thesis/Woodruff-Thesis.pdf>.

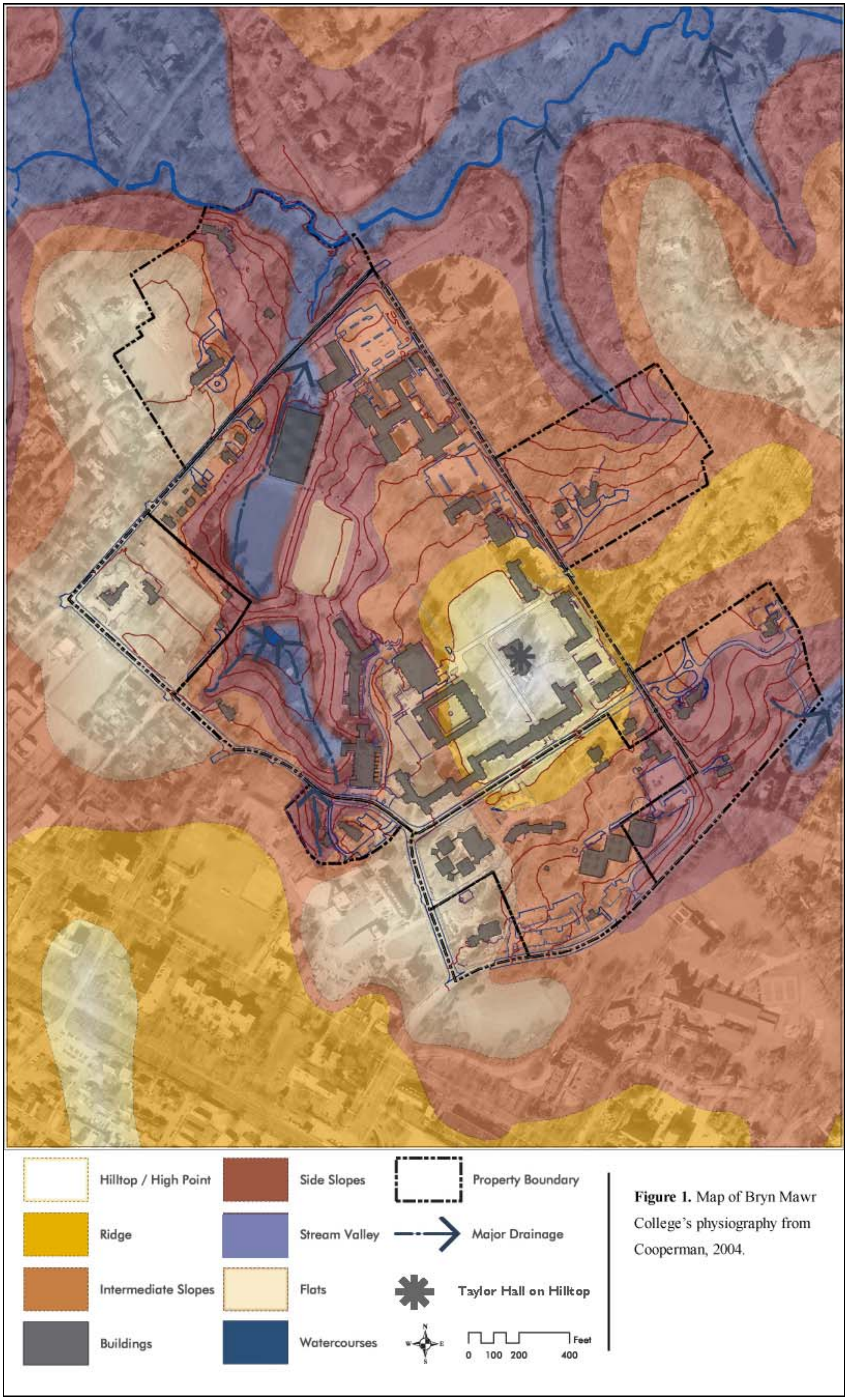

Figure 1. Map of Bryn Mawr College's physiography from Cooperman, 2004.

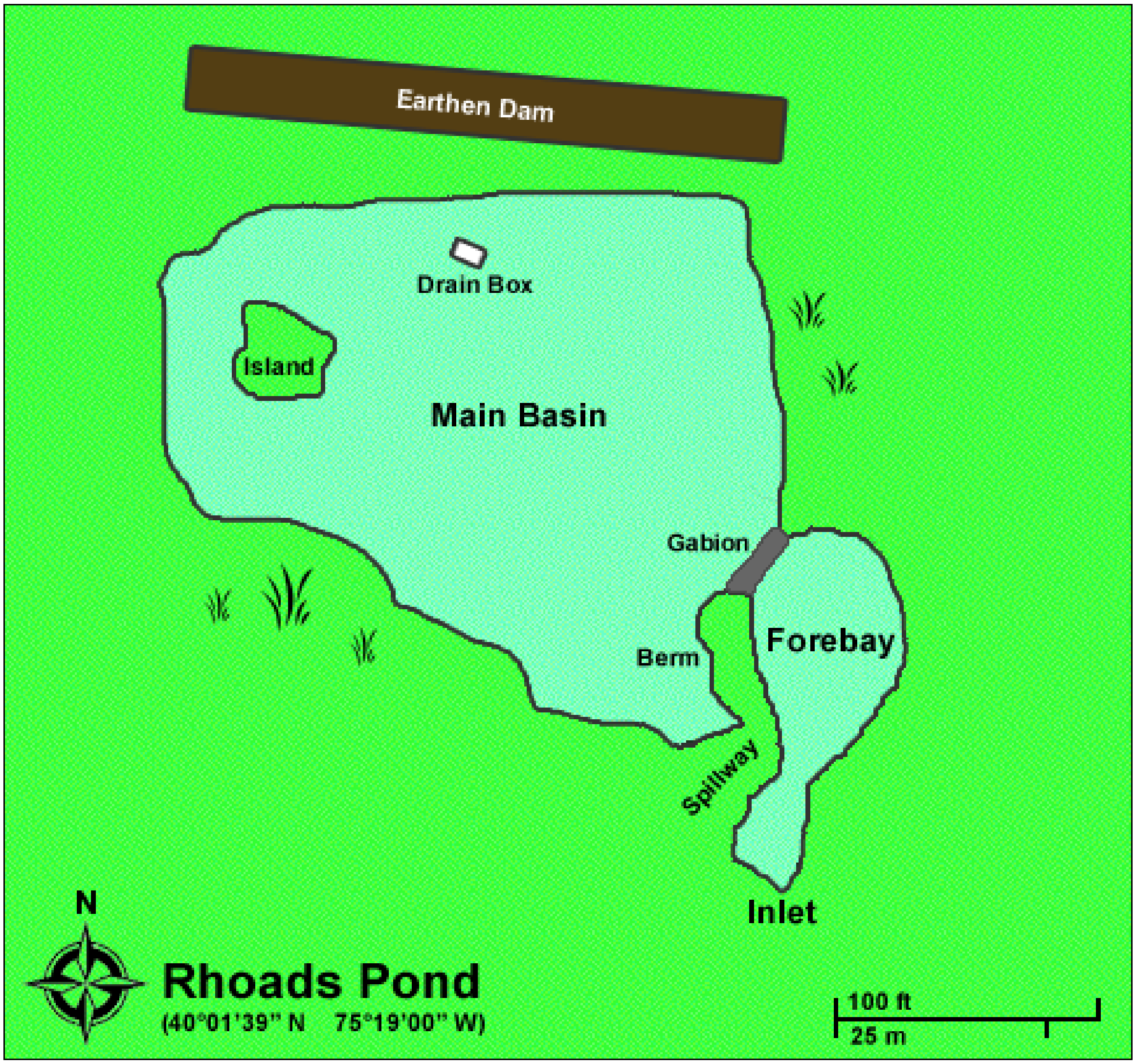

Figure 2. Map of Rhoads Pond derived from satellite images from Google Earth. Notable retention basin features are labeled. Map is taken from Bryn Mawr College Environmental Database (Pugh, 2006).

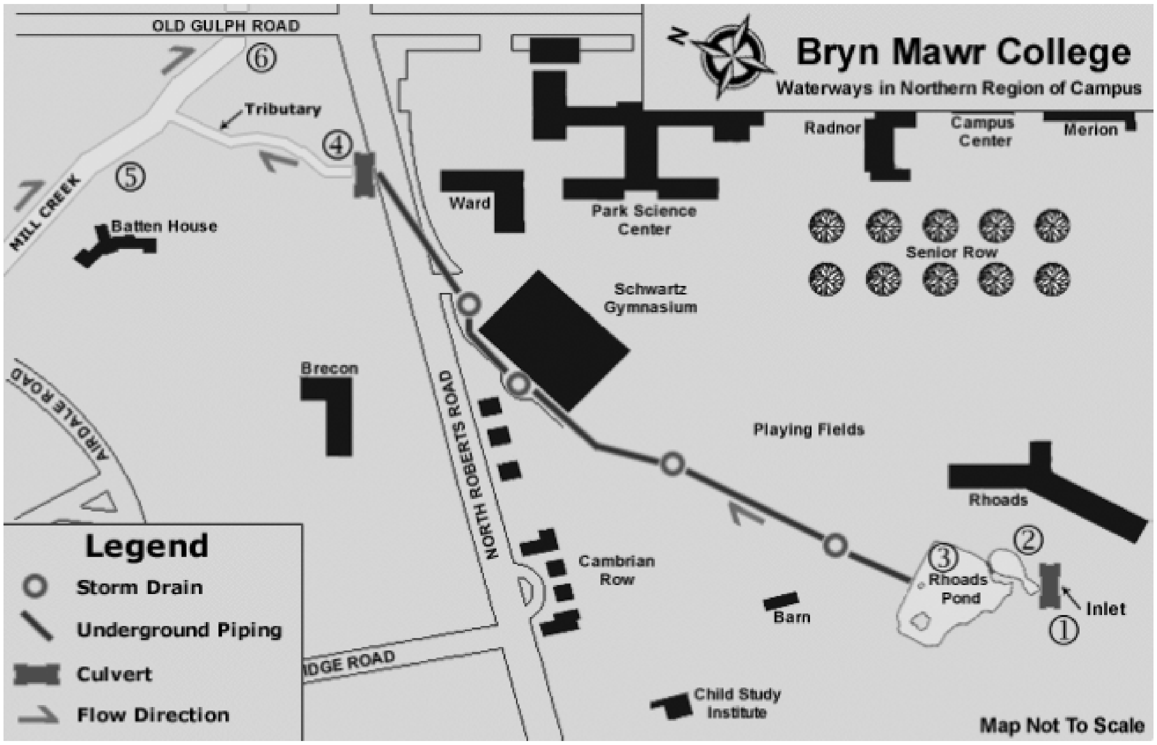

Figure 3. Schematic map of Rhoads Pond-related waterways on the northern part of Bryn Mawr College's campus. Map is taken from Bryn Mawr College Environmental Database (Pugh, 2006). Sites 1 through 6 are the pond inlet, pond forebay, pond main basin, pond-fed tributary, Mill Creek upstream, and Mill Creek downstream, respectively.

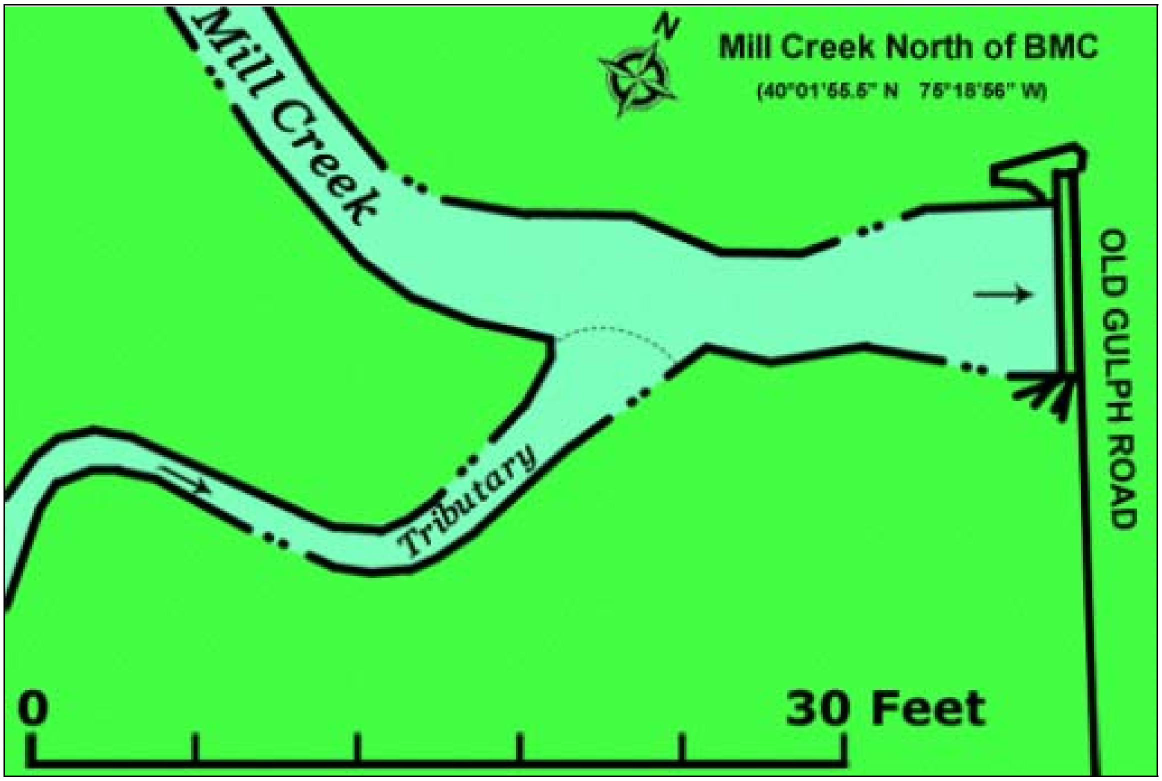

Figure 4. Map of the intersection of the culvert-fed tributary and Mill Creek. Map derived from USGS Topographical Quadrangle of Norristown, PA. Map is taken from Bryn Mawr College Environmental Database (Pugh, 2006).

Table 1-A: Rhoads Pond Inlet Data Statistics, Summer 2006.

Rhoads Pond Inlet Data Statistics, Summer 2006

Water Quality Parameter	Average	Maximum	Minimum	Percent Difference[5]	Coefficient of Variation[6]
Chloride[1]	199.8	225.4	168.9	28.7 %	8.5
Nitrate	17.2	18.6	14.4	25.6 %	7.2
Sulfate	41.3	43.8	37.7	15.0 %	4.7
Bicarbonate	122.3	201.3	92.0	74.5 %	36.7
Sodium	51.9	60.0	42.0	35.4 %	10.2
Potassium	6.1	6.6	5.1	25.8 %	7.6
Magnesium	32.1	36.2	26.4	31.3 %	9.5
Calcium	53.4	61.7	35.8	53.0 %	14.0
Electrical Conductivity[2]	760	840	682	20.8 %	6.8
Water Temperature[3]	18.0	18.7	17.4	7.2 %	2.7
Dissolved Oxygen[4]	8.1	11.5	6.4	57.0 %	29.1
Silica	10.5	12.3	8.4	37.7 %	18.5

1. Chloride, nitrate, sulfate, bicarbonate, sodium, potassium, magnesium, and calcium ion concentrations are given in mg/L.
2. Electrical conductivity is given in µS/cm.
3. Water temperature is given in °C.
4. Dissolved oxygen and silica concentrations are given in ppm.
5. Percent difference is calculated by taking the difference of the maximum and minimum values for each parameter and dividing by the average of the two.
6. Coefficient of variation is calculated by dividing the standard deviation by the mean and multiplying by 100%.

Table 1-B: Rhoads Pond Inlet Data Statistics, Fall 2006.

Rhoads Pond Inlet Data Statistics, Fall 2006

Water Quality Parameter	Average	Maximum	Minimum	Percent Difference[5]	Coefficient of Variation[6]
Chloride[1]	177.4	213.9	76.7	94.4 %	23.9
Nitrate	17.3	20.9	9.0	79.8 %	21.1
Sulfate	38.2	44.2	19.4	78.0 %	21.2
Bicarbonate	95.3	109.8	54.9	66.7 %	19.3
Sodium	50.3	58.5	24.6	81.5 %	21.2
Potassium	6.0	6.6	3.9	50.1 %	14.2
Magnesium	31.1	41.6	13.9	99.9 %	25.0
Calcium	44.9	56.5	27.4	69.2 %	19.0
Electrical Conductivity[2]	710	795	399	66.3 %	19.6
Water Temperature[3]	17.6	19.0	16.4	14.7 %	5.4
Dissolved Oxygen[4]	6.8	7.2	6.3	13.3 %	5.4
Silica	9.6	11.4	5.7	66.7 %	18.1

1. Chloride, nitrate, sulfate, bicarbonate, sodium, potassium, magnesium, and calcium ion concentrations are given in mg/L.
2. Electrical conductivity is given in μS/cm.
3. Water temperature is given in °C.
4. Dissolved oxygen and silica concentrations are given in ppm.
5. Percent difference is calculated by taking the difference of the maximum and minimum values for each parameter and dividing by the average of the two.
6. Coefficient of variation is calculated by dividing the standard deviation by the mean and multiplying by 100%.

Table 1-C: Rhoads Pond Forebay Data Statistics, Summer 2006.

Rhoads Pond Forebay Data Statistics, Summer 2006

Water Quality Parameter	Average	Maximum	Minimum	Percent Difference[5]	Coefficient of Variation[6]
Chloride[1]	167.1	210.9	65.6	105.1 %	25.7
Nitrate	12.3	17.0	5.6	100.9 %	25.8
Sulfate	35.5	43.0	17.2	85.7 %	22.1
Bicarbonate	96.7	110.0	67.0	48.6 %	19.5
Sodium	43.9	56.6	20.8	92.5 %	26.4
Potassium	5.4	6.3	3.5	58.2 %	18.8
Magnesium	27.1	34.3	11.5	99.7 %	28.2
Calcium	46.0	60.0	23.3	88.1 %	25.5
Electrical Conductivity[2]	625	822	230	112.5 %	31.3
Water Temperature[3]	22.5	28.5	19.5	37.5 %	13.4
Dissolved Oxygen[4]	11.6	16.7	9.4	55.9 %	29.9
Silica	8.8	11.7	7.2	47.6 %	22.9

1. Chloride, nitrate, sulfate, bicarbonate, sodium, potassium, magnesium, and calcium ion concentrations are given in mg/L.
2. Electrical conductivity is given in μS/cm.
3. Water temperature is given in °C.
4. Dissolved oxygen and silica concentrations are given in ppm.
5. Percent difference is calculated by taking the difference of the maximum and minimum values for each parameter and dividing by the average of the two.
6. Coefficient of variation is calculated by dividing the standard deviation by the mean and multiplying by 100%.

Table 1-D: Rhoads Pond Forebay Data Statistics, Fall 2006.

Rhoads Pond Forebay Data Statistics, Fall 2006

Water Quality Parameter	Average	Maximum	Minimum	Percent Difference[5]	Coefficient of Variation[6]
Chloride[1]	154.3	194.3	68.1	96.1 %	34.1
Nitrate	14.1	17.3	7.6	78.3 %	27.3
Sulfate	34.3	42.9	17.5	84.2 %	29.3
Bicarbonate	93.4	115.9	48.8	81.5 %	26.2
Sodium	44.8	54.8	18.6	98.7 %	34.1
Potassium	5.7	6.5	3.8	52.3 %	18.9
Magnesium	27.0	33.2	11.2	99.0 %	34.8
Calcium	43.2	57.0	20.5	94.3 %	32.1
Electrical Conductivity[2]	573	753	304	85.0 %	37.5
Water Temperature[3]	17.2	19.4	14.7	27.6 %	10.1
Dissolved Oxygen[4]	7.3	8.0	6.0	28.6 %	10.3
Silica	8.7	10.8	4.2	88.0 %	29.7

1. Chloride, nitrate, sulfate, bicarbonate, sodium, potassium, magnesium, and calcium ion concentrations are given in mg/L.
2. Electrical conductivity is given in µS/cm.
3. Water temperature is given in °C.
4. Dissolved oxygen and silica concentrations are given in ppm.
5. Percent difference is calculated by taking the difference of the maximum and minimum values for each parameter and dividing by the average of the two.
6. Coefficient of variation is calculated by dividing the standard deviation by the mean and multiplying by 100%.

Table 1-E: Rhoads Pond Main Basin Data Statistics, Summer 2006.

Rhoads Pond Main Basin Data Statistics, Summer 2006

Water Quality Parameter	Average	Maximum	Minimum	Percent Difference[5]	Coefficient of Variation[6]
Chloride[1]	93.7	142.3	60.3	81.0 %	31.1
Nitrate	2.2	3.1	1.3	82.9 %	32.3
Sulfate	19.5	28.8	13.4	72.9 %	25.3
Bicarbonate	72.0	85.0	55.0	42.9 %	15.3
Sodium	27.0	39.3	19.2	68.8 %	26.2
Potassium	3.8	5.8	1.1	138.8 %	43.4
Magnesium	16.2	25.1	11.4	75.3 %	27.7
Calcium	27.8	36.5	21.3	52.3 %	18.4
Electrical Conductivity[2]	364	493	247	66.5 %	23.4
Water Temperature[3]	28.3	33.9	25.6	27.9 %	10.0
Dissolved Oxygen[4]	11.4	17.7	5.9	100.0 %	44.2
Silica	3.7	6.3	1.8	111.1 %	53.1

1. Chloride, nitrate, sulfate, bicarbonate, sodium, potassium, magnesium, and calcium ion concentrations are given in mg/L.
2. Electrical conductivity is given in µS/cm.
3. Water temperature is given in °C.
4. Dissolved oxygen and silica concentrations are given in ppm.
5. Percent difference is calculated by taking the difference of the maximum and minimum values for each parameter and dividing by the average of the two.
6. Coefficient of variation is calculated by dividing the standard deviation by the mean and multiplying by 100%.

Table 1-F: Rhoads Pond Main Basin Data Statistics, Fall 2006.

Rhoads Pond Main Basin Data Statistics, Fall 2006

Water Quality Parameter	Average	Maximum	Minimum	Percent Difference[5]	Coefficient of Variation[6]
Chloride[1]	108.1	140.7	58.8	82.2 %	25.9
Nitrate	6.7	7.3	5.6	25.7 %	10.5
Sulfate	25.2	29.8	16.6	56.7 %	18.7
Bicarbonate	82.0	97.6	51.9	61.1 %	20.0
Sodium	31.9	41.5	17.5	81.5 %	24.1
Potassium	4.5	4.9	3.9	22.7 %	7.7
Magnesium	19.4	24.9	9.9	86.1 %	25.5
Calcium	28.5	32.9	20.2	47.6 %	15.5
Electrical Conductivity[2]	447	564	290	64.2 %	21.8
Water Temperature[3]	17.7	22.9	13.1	54.4 %	19.2
Dissolved Oxygen[4]	9.8	14.9	4.8	102.5 %	40.8
Silica	5.6	6.9	3.6	62.9 %	18.8

1. Chloride, nitrate, sulfate, bicarbonate, sodium, potassium, magnesium, and calcium ion concentrations are given in mg/L.
2. Electrical conductivity is given in µS/cm.
3. Water temperature is given in °C.
4. Dissolved oxygen and silica concentrations are given in ppm.
5. Percent difference is calculated by taking the difference of the maximum and minimum values for each parameter and dividing by the average of the two.
6. Coefficient of variation is calculated by dividing the standard deviation by the mean and multiplying by 100%.

Table 1-G: Pond-Fed Tributary Data Statistics, Summer 2006.

Pond-Fed Tributary Data Statistics, Summer 2006

Water Quality Parameter	Average	Maximum	Minimum	Percent Difference[5]	Coefficient of Variation[6]
Chloride[1]	139.1	163.0	107.2	41.3 %	12.5
Nitrate	8.2	9.0	6.4	33.8 %	8.7
Sulfate	29.6	33.5	23.0	37.2 %	10.1
Bicarbonate	103.8	116.0	73.0	45.5 %	15.9
Sodium	40.4	50.9	30.5	50.1 %	14.2
Potassium	5.1	6.6	3.7	57.2 %	16.6
Magnesium	25.5	35.0	19.2	58.4 %	17.5
Calcium	44.3	53.2	34.6	42.2 %	13.4
Electrical Conductivity[2]	561	677	353	62.9 %	16.8
Water Temperature[3]	20.1	20.7	19.2	7.5 %	2.7
Dissolved Oxygen[4]	6.1	6.8	5.1	28.6 %	14.4
Silica	9.0	9.6	8.7	9.8 %	4.7

1. Chloride, nitrate, sulfate, bicarbonate, sodium, potassium, magnesium, and calcium ion concentrations are given in mg/L.
2. Electrical conductivity is given in μS/cm.
3. Water temperature is given in °C.
4. Dissolved oxygen and silica concentrations are given in ppm.
5. Percent difference is calculated by taking the difference of the maximum and minimum values for each parameter and dividing by the average of the two.
6. Coefficient of variation is calculated by dividing the standard deviation by the mean and multiplying by 100%.

Table 1-H: Pond-Fed Tributary Data Statistics, Fall 2006.

Pond-Fed Tributary Data Statistics, Fall 2006

Water Quality Parameter	Average	Maximum	Minimum	Percent Difference[5]	Coefficient of Variation[6]
Chloride[1]	125.3	147.1	100.2	37.9 %	16.7
Nitrate	8.8	9.5	7.6	22.4 %	8.0
Sulfate	29.8	34.1	24.2	34.1 %	13.7
Bicarbonate	107.1	122.0	85.4	35.3 %	13.2
Sodium	40.0	47.5	32.1	38.7 %	15.3
Potassium	4.9	5.3	4.6	14.2 %	4.8
Magnesium	25.1	34.2	19.5	54.6 %	20.3
Calcium	35.9	49.4	30.7	46.8 %	16.5
Electrical Conductivity[2]	561	653	471	32.4 %	14.1
Water Temperature[3]	16.9	19.2	14.1	30.6 %	12.3
Dissolved Oxygen[4]	6.5	7.5	5.4	32.6 %	11.6
Silica	8.7	9.9	6.0	49.1 %	16.5

1. Chloride, nitrate, sulfate, bicarbonate, sodium, potassium, magnesium, and calcium ion concentrations are given in mg/L.
2. Electrical conductivity is given in μS/cm.
3. Water temperature is given in °C.
4. Dissolved oxygen and silica concentrations are given in ppm.
5. Percent difference is calculated by taking the difference of the maximum and minimum values for each parameter and dividing by the average of the two.
6. Coefficient of variation is calculated by dividing the standard deviation by the mean and multiplying by 100%.

Table 1-I: Mill Creek Upstream Data Statistics, Summer 2006.

Mill Creek Upstream Data Statistics, Summer 2006

Water Quality Parameter	Average	Maximum	Minimum	Percent Difference[5]	Coefficient of Variation[6]
Chloride[1]	88.1	107.5	45.7	80.7 %	23.1
Nitrate	8.2	9.5	4.8	65.7 %	18.9
Sulfate	27.3	32.2	16.6	64.0 %	18.7
Bicarbonate	102.0	110.0	92.0	17.8 %	6.1
Sodium	30.2	50.1	16.9	99.1 %	33.0
Potassium	4.1	6.2	3.6	52.9 %	22.8
Magnesium	18.5	33.8	9.7	111.0 %	40.1
Calcium	36.9	44.8	24.4	58.9 %	18.3
Electrical Conductivity[2]	394	468	261	56.8 %	23.2
Water Temperature[3]	20.8	23.2	19.2	18.9 %	7.2
Dissolved Oxygen[4]	6.0	6.7	5.6	17.9 %	10.1
Silica	14.4	15.0	13.8	8.3 %	3.4

1. Chloride, nitrate, sulfate, bicarbonate, sodium, potassium, magnesium, and calcium ion concentrations are given in mg/L.
2. Electrical conductivity is given in µS/cm.
3. Water temperature is given in °C.
4. Dissolved oxygen and silica concentrations are given in ppm.
5. Percent difference is calculated by taking the difference of the maximum and minimum values for each parameter and dividing by the average of the two.
6. Coefficient of variation is calculated by dividing the standard deviation by the mean and multiplying by 100%.

Table 1-J: Mill Creek Upstream Data Statistics, Fall 2006.

Mill Creek Upstream Data Statistics, Fall 2006

Water Quality Parameter	Average	Maximum	Minimum	Percent Difference[5]	Coefficient of Variation[6]
Chloride[1]	86.0	102.7	42.9	82.2 %	25.5
Nitrate	8.7	10.3	5.5	61.5 %	22.0
Sulfate	27.2	32.3	14.1	78.4 %	23.8
Bicarbonate	94.6	109.8	61.0	57.1 %	17.2
Sodium	27.2	32.3	13.9	79.8 %	24.7
Potassium	3.8	4.5	3.5	24.4 %	8.2
Magnesium	16.1	20.5	7.5	92.9 %	26.1
Calcium	29.4	34.5	20.8	49.3 %	13.6
Electrical Conductivity[2]	426	492	219	76.8 %	24.6
Water Temperature[3]	15.0	18.8	11.8	45.8 %	17.7
Dissolved Oxygen[4]	6.8	8.8	5.6	44.4 %	18.3
Silica	13.2	16.2	7.8	70.0 %	21.7

1. Chloride, nitrate, sulfate, bicarbonate, sodium, potassium, magnesium, and calcium ion concentrations are given in mg/L.
2. Electrical conductivity is given in μS/cm.
3. Water temperature is given in °C.
4. Dissolved oxygen and silica concentrations are given in ppm.
5. Percent difference is calculated by taking the difference of the maximum and minimum values for each parameter and dividing by the average of the two.
6. Coefficient of variation is calculated by dividing the standard deviation by the mean and multiplying by 100%.

Table 1-K: Mill Creek Downstream Data Statistics, Summer 2006.

Mill Creek Downstream Data Statistics, Summer 2006

Water Quality Parameter	Average	Maximum	Minimum	Percent Difference[5]	Coefficient of Variation[6]
Chloride[1]	96.1	118.5	43.1	93.3 %	22.3
Nitrate	8.5	9.3	4.7	65.7 %	16.0
Sulfate	28.5	32.2	16.4	65.0 %	16.1
Bicarbonate	101.0	104.0	92.0	12.2 %	5.0
Sodium	29.3	33.9	16.4	69.4 %	17.9
Potassium	3.9	4.9	3.6	31.5 %	10.4
Magnesium	17.8	21.1	9.2	78.4 %	20.4
Calcium	37.6	46.7	23.9	64.5 %	20.4
Electrical Conductivity[2]	432	523	260	67.2 %	22.0
Water Temperature[3]	20.7	23.4	18.9	21.3 %	7.8
Dissolved Oxygen[4]	6.4	6.7	6.1	9.4 %	4.8
Silica	13.8	14.7	12.6	15.4 %	6.9

1. Chloride, nitrate, sulfate, bicarbonate, sodium, potassium, magnesium, and calcium ion concentrations are given in mg/L.
2. Electrical conductivity is given in μS/cm.
3. Water temperature is given in °C.
4. Dissolved oxygen and silica concentrations are given in ppm.
5. Percent difference is calculated by taking the difference of the maximum and minimum values for each parameter and dividing by the average of the two.
6. Coefficient of variation is calculated by dividing the standard deviation by the mean and multiplying by 100%.

Table 1-L: Mill Creek Downstream Data Statistics, Fall 2006.

Mill Creek Downstream Data Statistics, Fall 2006

Water Quality Parameter	Average	Maximum	Minimum	Percent Difference[5]	Coefficient of Variation[6]
Chloride[1]	83.9	103.7	38.0	92.7 %	28.3
Nitrate	8.6	9.9	5.5	57.4 %	22.3
Sulfate	26.4	30.1	13.6	75.7 %	24.1
Bicarbonate	99.1	112.9	61.0	59.7 %	18.3
Sodium	28.1	33.5	14.1	81.5 %	25.7
Potassium	3.9	4.4	3.6	19.2 %	6.2
Magnesium	16.7	21.3	7.6	95.2 %	27.5
Calcium	28.5	33.4	21.0	45.7 %	12.7
Electrical Conductivity[2]	418	488	217	76.9 %	25.2
Water Temperature[3]	15.3	18.7	12.0	43.6 %	17.0
Dissolved Oxygen[4]	7.2	8.4	6.2	30.1 %	10.6
Silica	13.1	15.9	7.5	71.8 %	21.2

1. Chloride, nitrate, sulfate, bicarbonate, sodium, potassium, magnesium, and calcium ion concentrations are given in mg/L.
2. Electrical conductivity is given in μS/cm.
3. Water temperature is given in °C.
4. Dissolved oxygen and silica concentrations are given in ppm.
5. Percent difference is calculated by taking the difference of the maximum and minimum values for each parameter and dividing by the average of the two.
6. Coefficient of variation is calculated by dividing the standard deviation by the mean and multiplying by 100%.

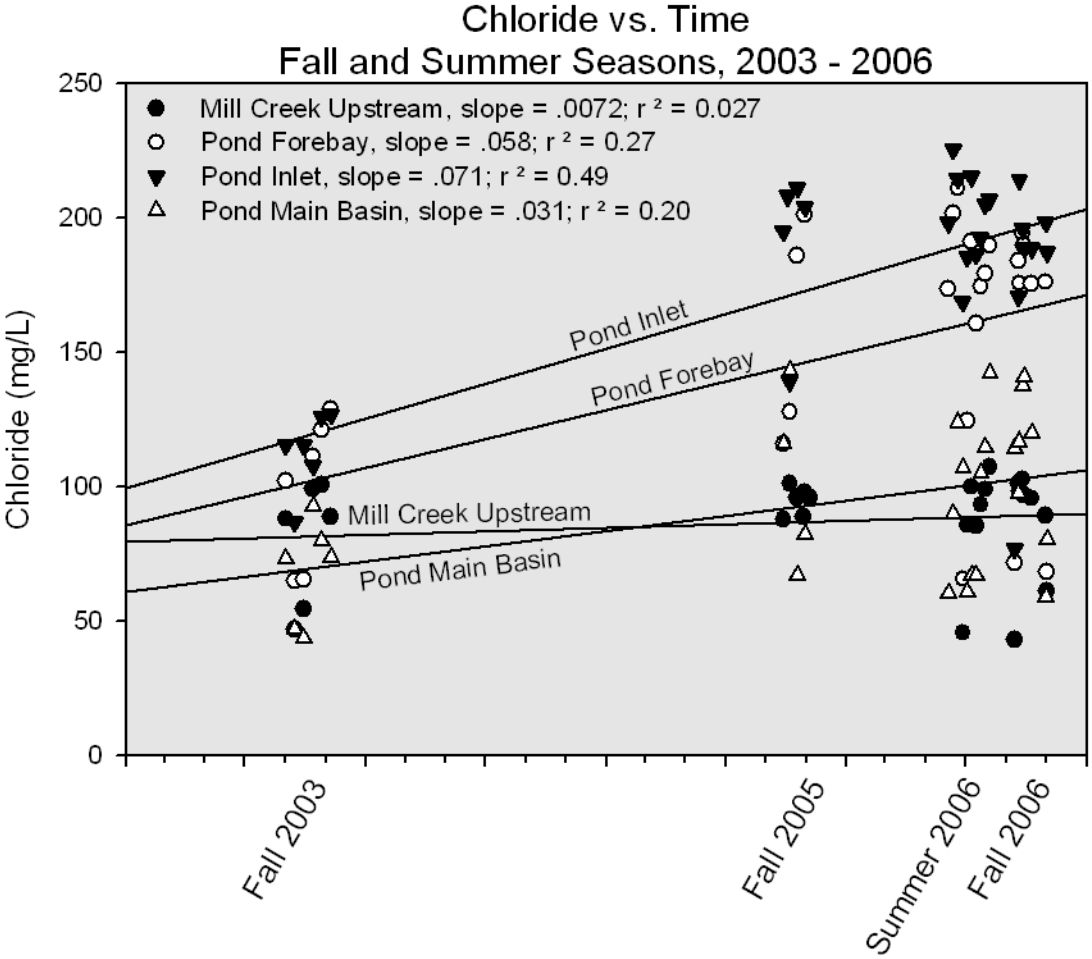

Figure 5. Graph of chloride concentrations gathered during the recorded fall and summer seasons between 2003 and 2006 plotted over time with regression lines. The points are sorted by location to include: Mill Creek, Rhoads Pond Forebay, Rhoads Pond Main Basin, and Rhoads Pond Inlet. Slopes are (mg/L)/day. At $\alpha = 0.05$, Pond Inlet, Pond Forebay, and Pond Main Basin show positive significant correlations between time and chloride concentration. Mill Creek Upstream chloride concentration does not significantly vary with time.

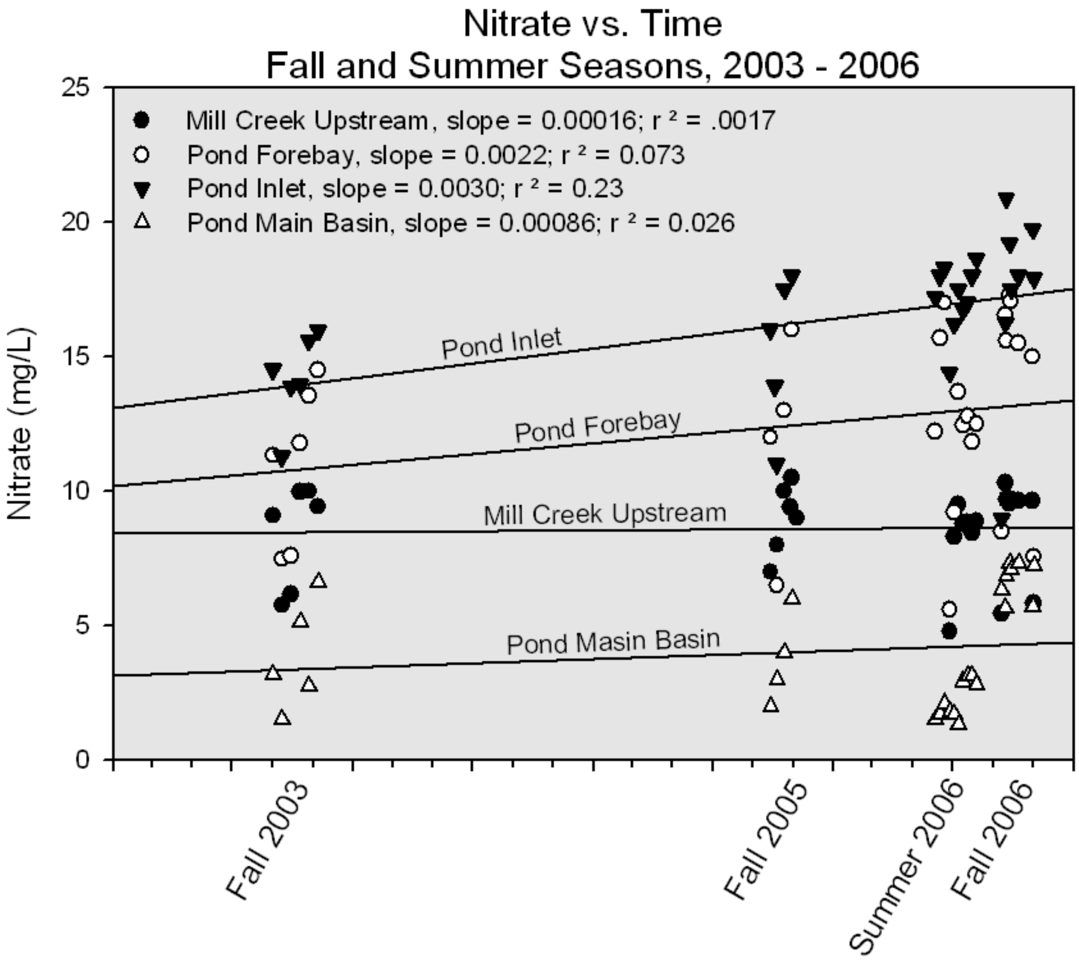

Figure 6. Graph of nitrate concentrations gathered during the recorded fall and summer seasons between 2003 and 2006 plotted over time with regression lines. The points are sorted by location to include: Mill Creek, Rhoads Pond Forebay, Rhoads Pond Main Basin, and Rhoads Pond Inlet. Slopes are (mg/L)/day. At α = 0.05, Pond Inlet and Pond Forebay show positive significant correlations between time and nitrate concentrations. Mill Creek Upstream and Pond Main Basin nitrate concentrations do not significantly vary with time.

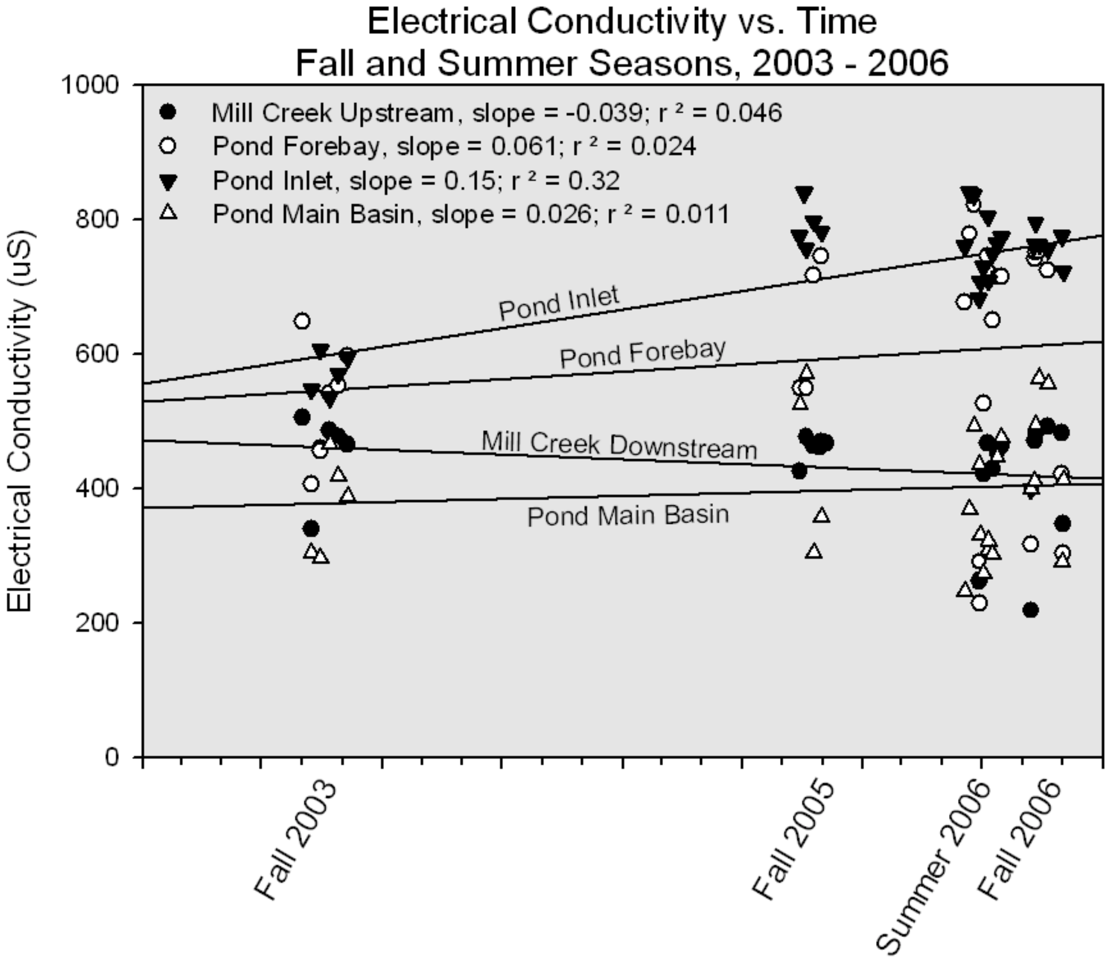

Figure 7. Graph of electrical conductivity levels gathered during the recorded fall and summer seasons between 2003 and 2006 plotted over time with regression lines. The points are sorted by location to include: Mill Creek, Rhoads Pond Forebay, Rhoads Pond Main Basin, and Rhoads Pond Inlet. Slopes are (mg/L)/day. At $\alpha = 0.05$, Pond Inlet shows a positive significant correlation between time and electrical conductivity. Mill Creek Upstream electrical conductivity levels significantly negatively correlate with time. Pond Forebay and Pond Main Basin electrical conductivity levels do not significantly vary with time.

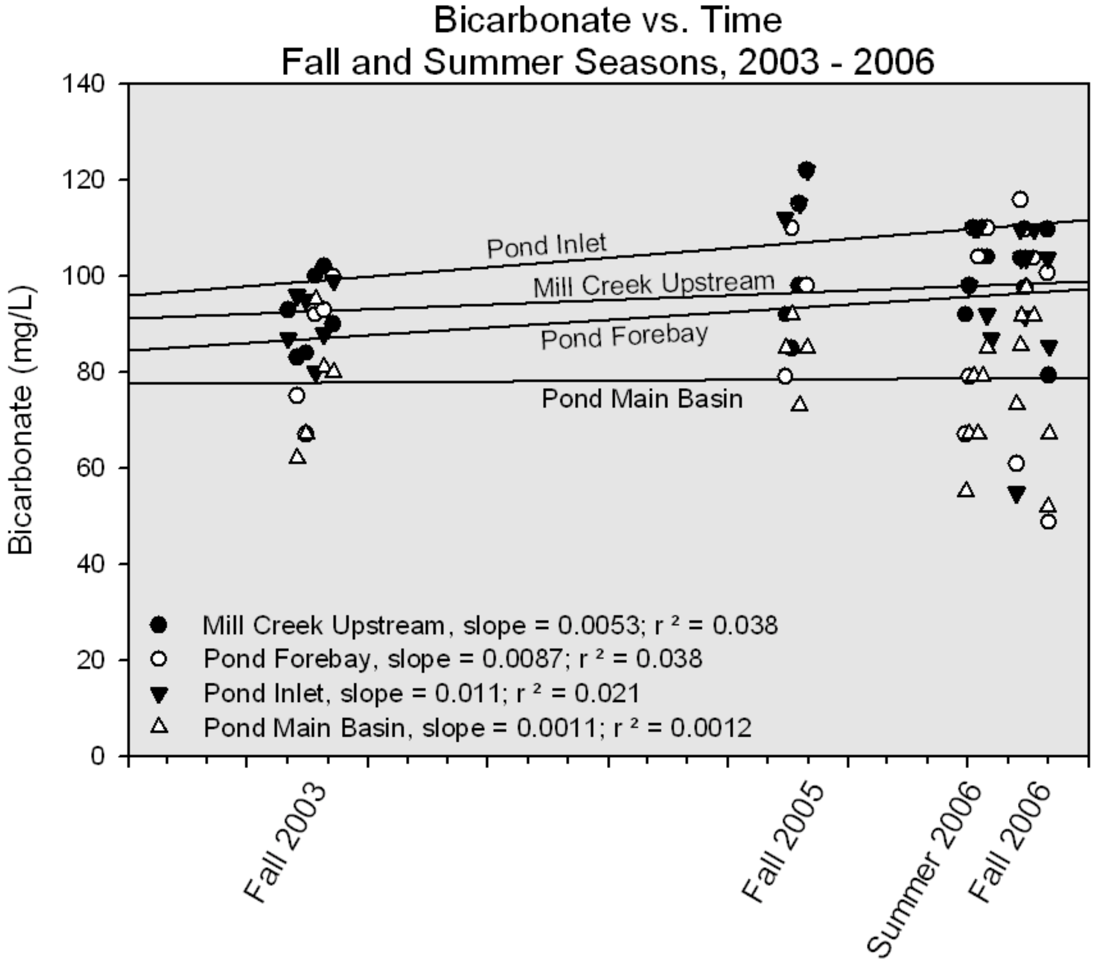

Figure 8. Graph of bicarbonate concentrations during the recorded fall and summer seasons between 2003 and 2006 plotted over time with regression lines. The points are sorted by location to include: Mill Creek, Rhoads Pond Forebay, Rhoads Pond Main Basin, and Rhoads Pond Inlet. Slopes are (mg/L)/day. At $\alpha = 0.05$, Pond Main Basin shows a weakly positive significant correlation between time and bicarbonate concentration. Mill Creek Upstream, Pond Inlet, and Pond Forebay bicarbonate concentrations do not significantly vary with time.

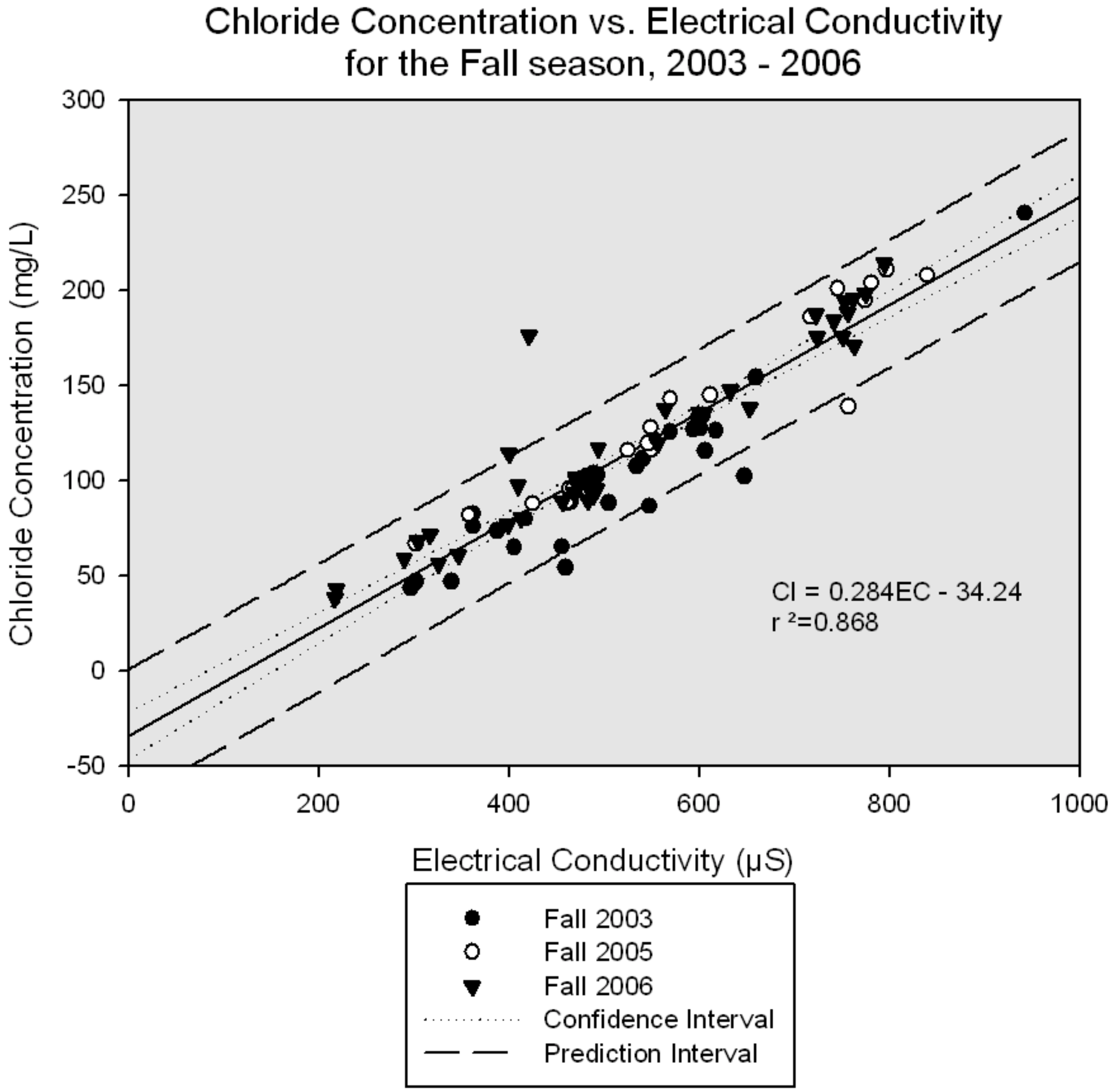

Figure 9. Graph of all available chloride concentrations below 250mg/L versus all available electrical conductivity values below 1000µS. The regression line shows a strongly positive significant correlation at α = 0.05 and r^2 = 0.868. Dotted lines represent confidence intervals and dashed lines represent prediction intervals. Confidence intervals illustrate the range where the regression line values will fall 95% percentage of the time for repeated measurements. Prediction intervals illustrate the range where the data values will fall 95% percentage of the time for repeated measurements. Data comes from all six locations over all three years of monitoring. One December data point, reflecting road salt runoff, exceeded the 1000µS upper bound and was omitted.

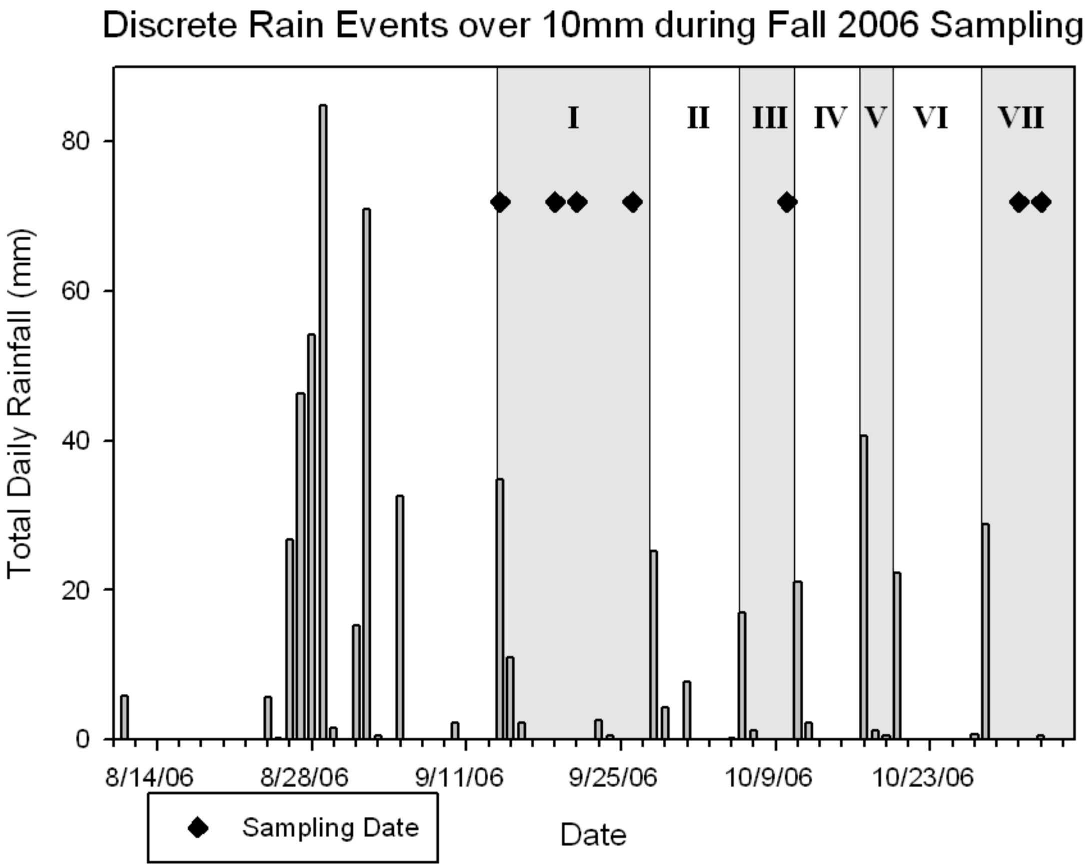

Figure 10. Graph of total daily rainfall (bars) versus date for the sampling period of Fall 2006. Diamonds represent dates on which sampling occurred. Discrete rain events are shown by different shaded backgrounds. For the purposes of this study, a rain event is described as being more than 10mm total daily rainfall.

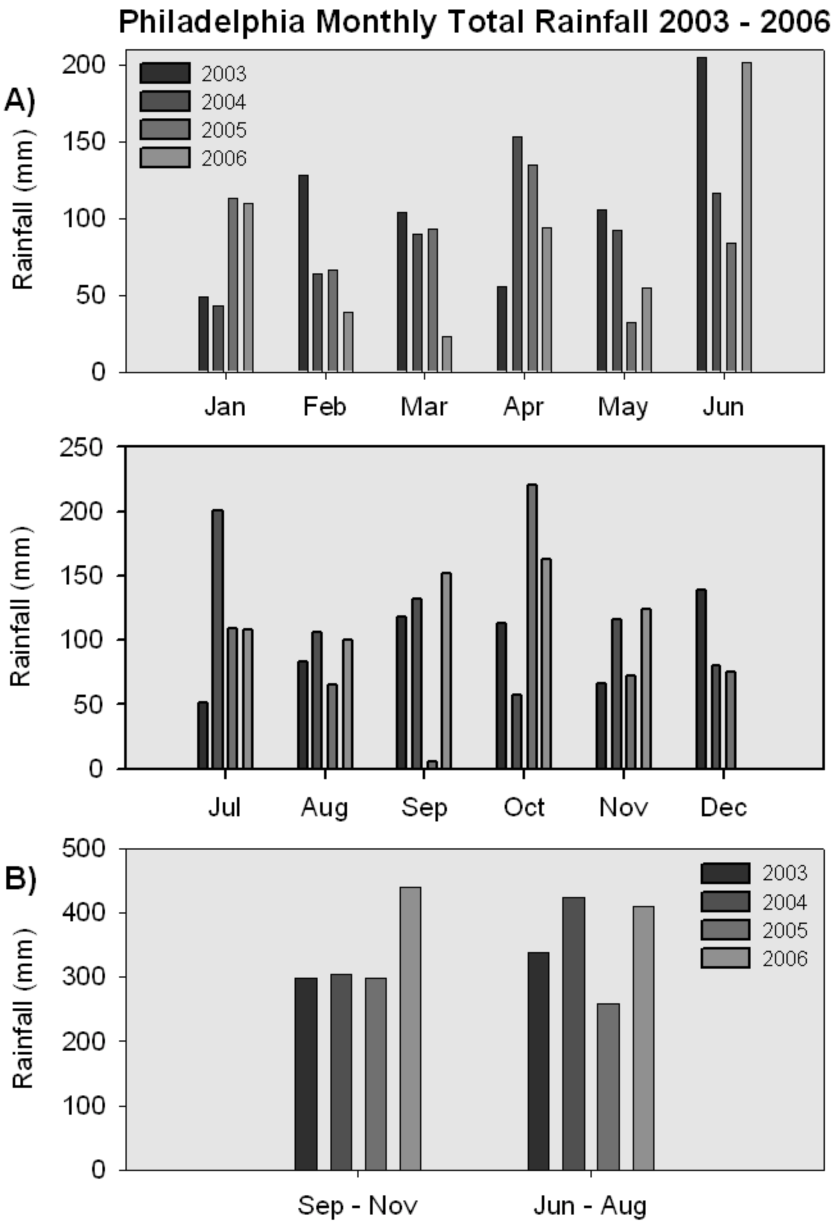

Figure 11. A) Monthly total rainfall at the Philadelphia International Airport, 2003 through 2006. B) Fall (Sep – Nov) and summer (Jun – Aug) seasonal rain totals at the Philadelphia International Airport, 2003 through 2006. Monthly totals are from U.S. Climate, 2006.

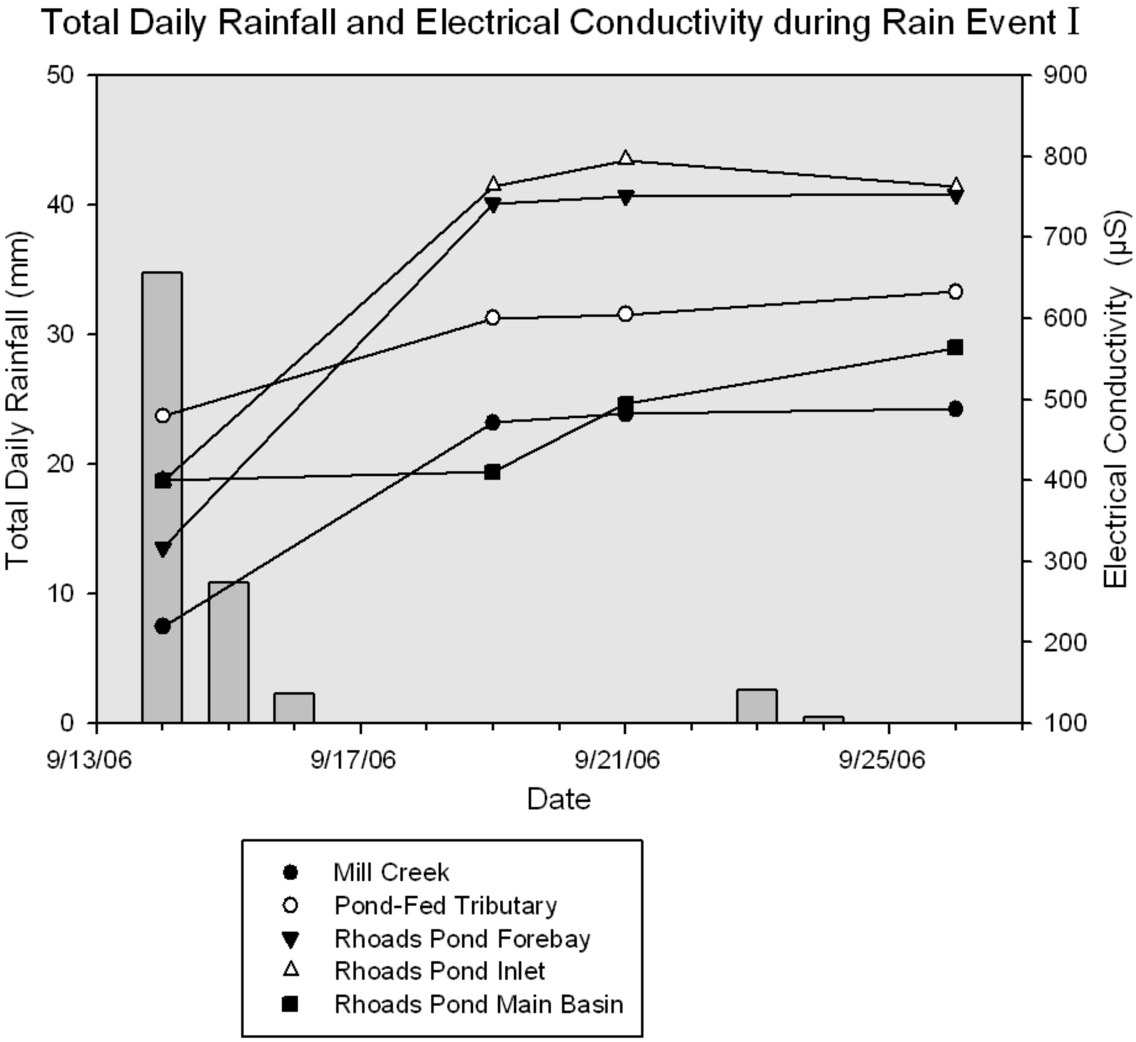

Figure 12. Graph of total daily rainfall (bars) and electrical conductivity (points) during Rain Event I.

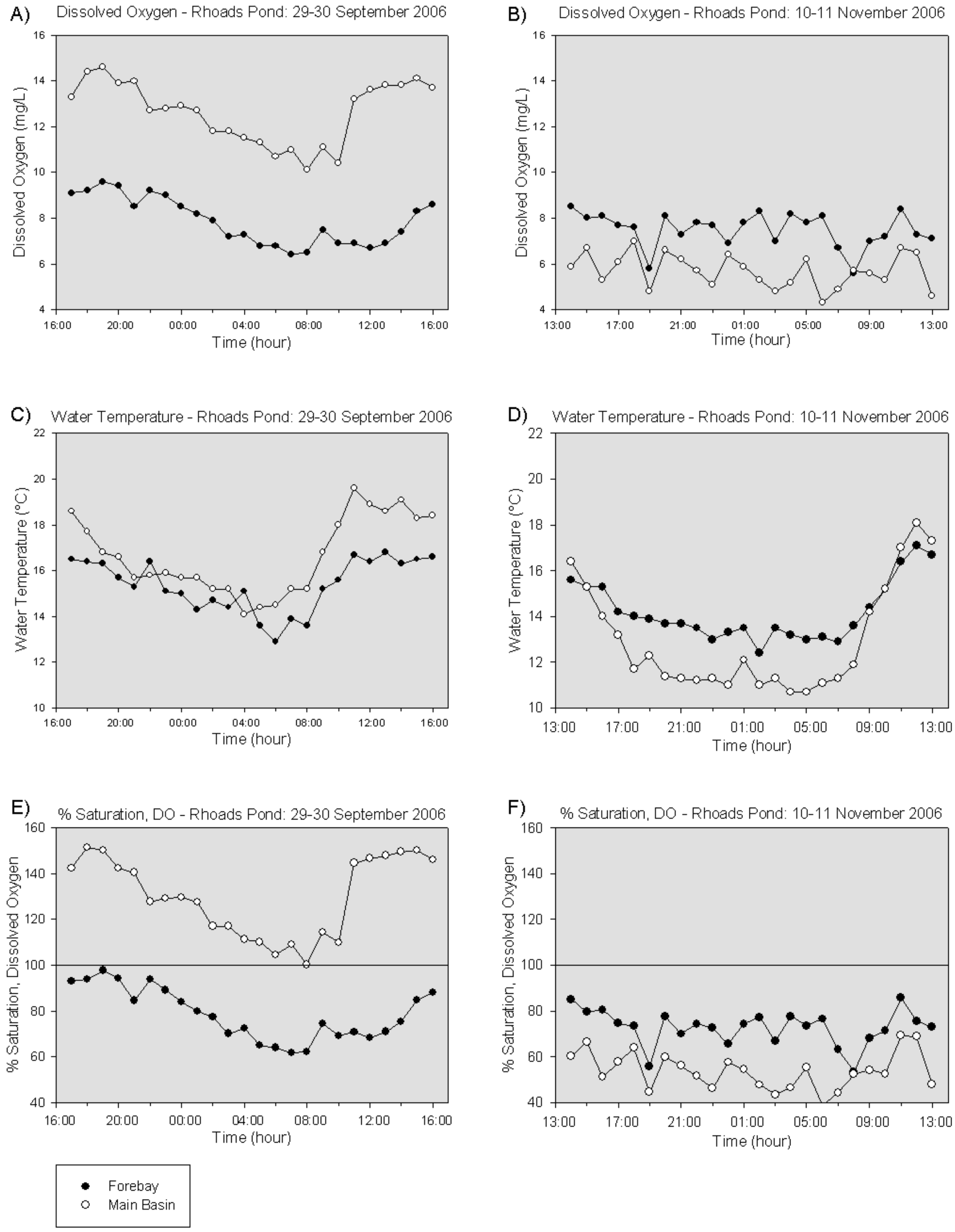

Figure 13. Suite of graphs of data gathered during two 24-hour diurnal studies. Graphs A and B are dissolved oxygen measurements in Rhoads Pond over 24-hour periods. Graphs C and D are water temperature measurements in Rhoads Pond over 24-hour periods. Graphs E and F are percent saturation of dissolved oxygen in Rhoads Pond over 24-hour periods. Percents were calculated using theoretical dissolved oxygen data found with the equation: *DO = 0.0035T2 - 0.3373T + 14.395*

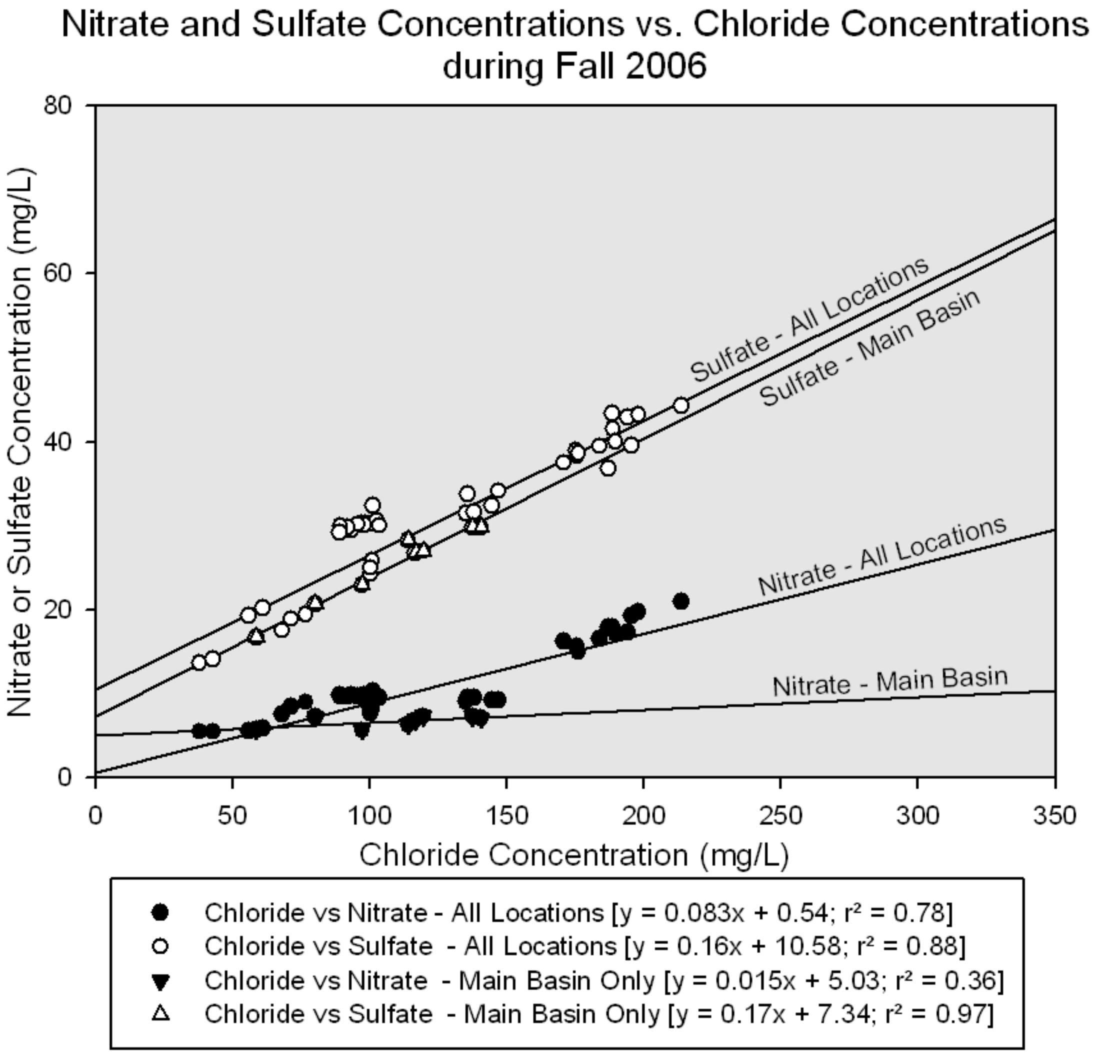

Figure 14. Graph of nitrate and sulfate concentrations versus chloride concentrations during the fall of 2006. Two sets of plots appear: all 6 study locations and the pond main basin only. All lines show significant positive correlations with chloride concentrations.

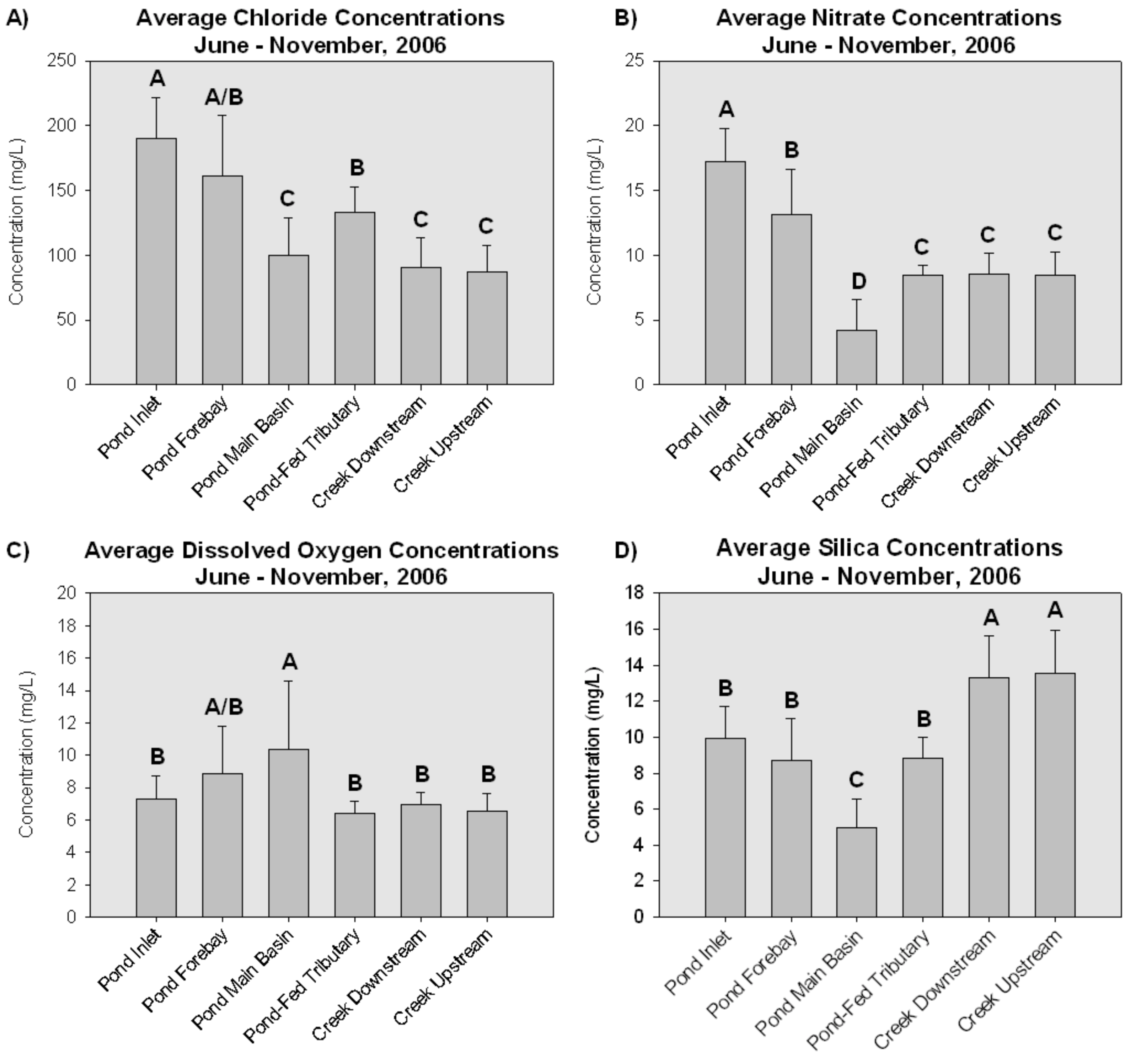

Figure 15. Set of bar graphs showing average chloride, nitrate, dissolved oxygen, and silca concentrations from June to November, 2006 by location along the Rhoads Pond waterway. Error bars show one standard deviation. For each graph, different letters above bars indicate significant differences between means at $\alpha = .05$ using Tukey HSD. Graph A is a bar graph of average chloride concentrations from June to November, 2006 by location along the Rhoads Pond waterway. Graph B is a bar graph of average nitrate concentrations from June to November, 2006 by location along the Rhoads Pond waterway. Graph C is a bar graph of average dissolved oxygen concentrations from June to November, 2006 by location along the Rhoads Pond waterway. Graph D is a bar graph of average silica concentrations from June to November, 2006 by location along the Rhoads Pond waterway.

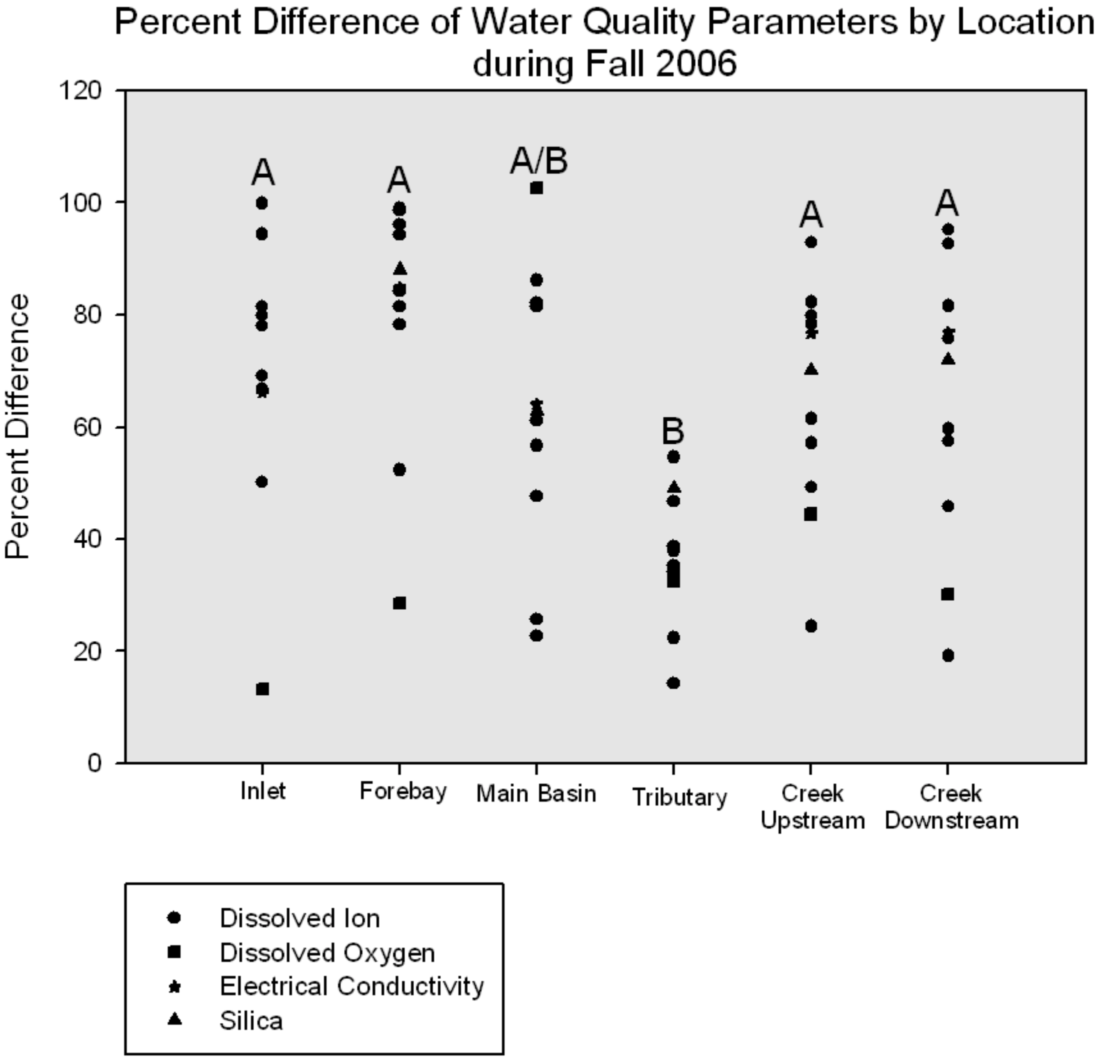

Figure 16. Percent difference of water quality parameters reported by location during the fall of 2006. The dissolved ion label includes chloride, nitrate, sulfate, bicarbonate, sodium, potassium, magnesium, and calcium. Percent difference was calculated by taking the difference of the maximum and minimum values for each parameter and dividing by the average of the two. Different letters above vertical point plots indicate significant differences between means at α = .05 using Tukey HSD.

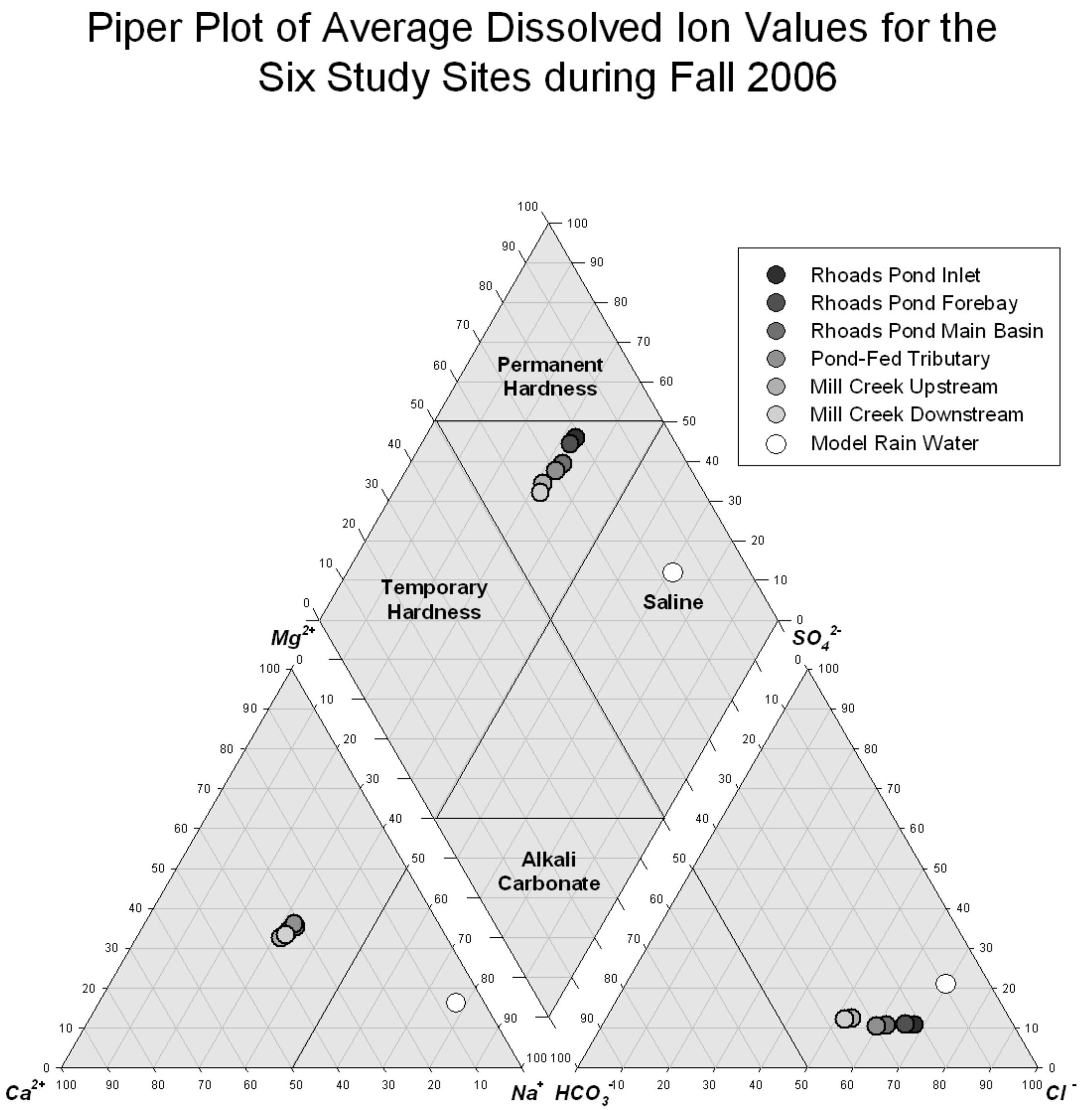

Figure 17. Piper plot of average dissolved ion values for the six Rhoads Pond waterway study sites during the fall of 2006. Piper plots present dissolved ions as percent composition of the water sample. Water types taken from Hounslow, 1995. The model rain water point is not a measured sample, but is included to demonstrate the relative spatial relationship between Rhoads Pond waterway samples and rain water.

Appendix A: Dissolved Ions

Date	Location	Chloride (mg/L)	Nitrate (mg/L)	Sulfate (mg/L)	Bicarbonate (mg/L)	Sodium (mg/L)	Potassium (mg/L)	Magnesium (mg/L)	Calcium (mg/L)	Charge Balance (meq/L)
6/5/06	Inlet	198	17.2	43.2	•	53.6	6.2	31.6	57.2	•
6/5/06	Forebay	173.6	12.2	36.8	•	48.7	6.0	29.0	53.2	•
6/5/06	Main Basin	60.3	1.5	13.4	•	19.3	2.0	11.4	21.3	•
6/5/06	Culvert	133.7	8.1	28.6	•	39.4	4.7	23.7	46.0	•
6/5/06	Creek Down[1]	110.6	8.7	29.5	•	33.6	4.4	20.5	44.1	•
6/12/06	Inlet	225.4	18	41.8	•	60.0	6.4	34.6	59.5	•
6/12/06	Forebay	201.6	15.7	41.4	•	52.3	6.0	33.8	57.7	•
6/12/06	Main Basin	89.7	1.7	17.5	•	26.3	1.1	14.7	28.1	•
6/12/06	Culvert	152.8	8.4	31.6	•	41.5	4.4	26.4	48.7	•
6/12/06	Creek Down	118.5	9.3	31.7	•	33.9	3.8	21.1	45.3	•
6/19/06	Inlet	214.4	18.3	43	•	52.7	6.4	36.2	61.7	•
6/19/06	Forebay	210.9	17	41.7	•	56.6	6.3	34.3	60.0	•
6/19/06	Main Basin	123.8	2.1	22.9	•	35.4	4.8	19.7	36.5	•
6/19/06	Culvert	163	9	33.5	•	45.4	4.9	29.1	53.2	•
6/19/06	Creek Down	114	9.2	31.9	•	33.4	3.8	20.6	46.7	•
6/27/06	Inlet	168.9	14.4	37.7	•	47.3	5.6	28.4	51.3	•
6/27/06	Forebay	65.6	5.6	17.2	•	20.8	3.5	11.5	23.3	•
6/27/06	Main Basin	107.1	1.8	19.3	•	29.8	1.9	18.8	29.0	•
6/27/06	Culvert	107.2	6.4	23	•	30.5	3.7	19.2	34.6	•
6/27/06	Creek Up[2]	45.7	4.8	16.6	•	16.9	3.9	9.7	24.4	•
6/27/06	Creek Down	43.1	4.7	16.4	•	16.4	3.8	9.2	23.9	•
7/3/06	Inlet	185.3	16.2	39.3	98	50.0	5.9	31.1	55.0	0.3
7/3/06	Forebay	124.6	9.2	27.1	79	35.9	5.2	22.2	40.0	0.0
7/3/06	Main Basin	60.9	1.7	13.8	67	19.2	4.0	11.7	21.6	0.2
7/3/06	Culvert	124.4	8.3	27.7	98	35.4	4.7	22.0	41.2	0.3
7/3/06	Creek Up	85.6	8.3	26	98	27.4	3.8	16.1	39.0	0.1
7/3/06	Creek Down	93.8	8.8	26.9	98	27.3	3.8	16.1	38.7	0.4
7/10/06	Inlet	215.2	17.5	39.5	110	58.8	6.4	32.3	58.2	0.7
7/10/06	Forebay	191.2	13.7	38.5	110	51.7	5.8	31.8	56.1	0.4

Appendix A: Dissolved Ions

Date	Location	Chloride (mg/L)	Nitrate (mg/L)	Sulfate (mg/L)	Bicarbonate (mg/L)	Sodium (mg/L)	Potassium (mg/L)	Magnesium (mg/L)	Calcium (mg/L)	Charge Balance (meq/L)
7/10/06	Main Basin	67	1.3	16.4	79	21.1	5.1	12.7	25.0	0.2
7/10/06	Culvert	136.3	7.9	29.9	116	39.5	5.4	24.5	46.3	0.3
7/10/06	Creek Up	100	9.5	29.7	110	30.5	3.6	17.5	42.4	0.4
7/10/06	Creek Down	99.2	9.3	29.7	104	30.3	3.6	17.4	42.3	0.3
7/17/06	Inlet	186.5	16.7	40.9	110	51.2	6.1	31.5	56.5	0.4
7/17/06	Forebay	160.8	12.4	34.7	104	44.6	5.6	26.6	48.9	0.5
7/17/06	Main Basin	66.9	2.9	16.5	67	20.2	4.6	12.0	23.4	0.2
7/17/06	Culvert	124.5	8.3	27.8	110	36.0	4.9	22.0	42.5	0.4
7/17/06	Creek Up	85.4	8.8	27.6	104	26.9	3.9	16.1	39.4	0.3
7/17/06	Creek Down	83.3	8.7	27.8	104	26.4	4.0	15.8	39.0	0.3
7/24/06	Inlet	192.4	17.0	41.5	•	54.0	6.4	33.6	49.5	•
7/24/06	Forebay	174.3	12.8	37.0	110	47.9	5.8	29.9	43.8	0.8
7/24/06	Main Basin	104.8	3.1	22.6	79	31.0	5.5	18.3	27.5	0.4
7/24/06	Culvert	140.8	8.1	29.9	116	40.8	6.1	25.0	38.6	0.7
7/24/06	Creek Up	93.2	8.8	29.1	104	28.7	3.6	16.7	33.2	0.7
7/24/06	Creek Down	94.4	8.9	29.7	104	29.0	3.6	16.9	32.9	0.7
7/31/06	Inlet	205.1	18.0	41.9	92	42.0	5.1	26.4	35.8	2.5
7/31/06	Forebay	179.1	11.8	37.5	110	29.0	3.7	18.0	32.3	3.4
7/31/06	Main Basin	114.7	3.1	23.9	85	28.7	3.7	17.9	32.7	0.7
7/31/06	Culvert	150.5	8.8	31.2	110	50.9	6.6	35.0	51.7	-1.0
7/31/06	Creek Up	99.1	8.4	29.8	104	50.1	6.2	33.8	44.8	-2.1
7/31/06	Creek Down	97.0	8.4	29.6	104	32.5	4.9	20.7	27.4	0.6
8/7/06	Inlet	206.5	18.6	43.8	•	49.6	6.6	35.4	49.3	•
8/7/06	Forebay	189.6	12.5	43.0	•	51.3	6.3	33.7	44.6	•
8/7/06	Main Basin	142.3	2.8	28.8	•	39.3	5.8	25.1	33.3	•
8/7/06	Culvert	157.8	8.6	32.2	•	44.3	5.5	28.4	40.0	•
8/7/06	Creek Up	107.5	8.9	32.2	•	30.9	3.6	19.4	35.4	•
8/7/06	Creek Down	107.0	8.8	32.2	•	30.5	3.6	19.3	35.2	•
9/14/06	Inlet	76.7	9.0	19.4	24.6	3.9	13.9	27.4	76.7	-0.1

Appendix A: Dissolved Ions

Date	Location	Chloride (mg/L)	Nitrate (mg/L)	Sulfate (mg/L)	Bicarbonate (mg/L)	Sodium (mg/L)	Potassium (mg/L)	Magnesium (mg/L)	Calcium (mg/L)	Charge Balance (meq/L)
9/14/06	Forebay	71.5	8.5	18.9	21.8	3.8	12.5	25.4	71.5	0.2
9/14/06	Main Basin	114.0	6.3	28.2	73.2	31.8	4.8	21.9	24.7	0.6
9/14/06	Culvert	100.4	7.6	24.2	32.7	4.8	19.5	36.8	100.4	0.0
9/14/06	Creek Up	42.9	5.5	14.1	13.9	3.5	7.5	20.8	42.9	0.2
9/14/06	Creek Down	38.0	5.5	13.6	14.1	3.6	7.6	21.0	38.0	0.1
9/19/06	Inlet	170.7	16.3	37.5	52.9	6.4	32.2	56.5	170.7	-0.3
9/19/06	Forebay	183.9	16.5	39.5	53.7	6.4	32.0	56.7	183.9	0.2
9/19/06	Main Basin	97.2	5.6	22.9	29.1	4.5	17.1	32.7	97.2	0.3
9/19/06	Culvert	135.6	9.5	33.7	115.9	47.5	5.3	34.2	37.0	-0.3
9/19/06	Creek Up	101.1	10.3	32.3	103.7	32.3	4.0	20.5	29.4	0.7
9/19/06	Creek Down	93.5	9.9	29.5	103.7	32.7	4.1	21.3	30.3	0.3
9/21/06	Inlet	213.9	20.9	44.2	103.7	58.5	6.4	32.9	43.1	1.4
9/21/06	Forebay	175.7	15.6	38.3	53.1	6.4	32.4	57.0	175.7	-0.3
9/21/06	Main Basin	116.7	6.8	26.7	91.5	34.0	4.4	20.1	26.6	0.9
9/21/06	Culvert	135.1	9.0	31.4	115.9	42.0	5.0	25.7	31.4	0.9
9/21/06	Creek Up	98.3	9.7	30.3	103.7	30.4	3.6	18.0	29.5	0.9
9/21/06	Creek Down	101.4	9.6	30.1	109.8	32.8	3.9	19.5	27.5	0.9
9/26/06	Inlet	195.6	19.2	39.5	91.5	51.1	6.6	34.4	46.1	0.6
9/26/06	Forebay	194.3	17.3	42.9	109.8	54.1	6.2	32.9	46.2	0.9
9/26/06	Main Basin	137.5	7.3	29.7	97.6	40.1	4.1	24.0	32.0	0.8
9/26/06	Culvert	147.1	9.2	34.1	115.9	44.3	4.8	27.2	34.6	0.9
9/26/06	Creek Up	102.7	9.5	30.6	97.6	31.7	3.7	18.0	31.5	0.8
9/26/06	Creek Down	103.7	9.5	30.0	103.7	33.5	3.9	19.5	29.0	0.8
9/28/06	Inlet	188.7	17.5	41.5	103.7	56.8	6.0	41.6	50.6	-0.4
9/28/06	Forebay	189.7	17.0	40.0	103.7	54.8	6.5	33.2	44.8	0.6
9/28/06	Main Basin	140.7	7.1	29.8	97.6	41.5	3.9	24.9	32.9	0.7
9/28/06	Culvert	144.6	9.2	32.4	122.0	44.7	4.8	27.5	34.8	0.8
9/28/06	Creek Up	96.9	9.7	30.2	97.6	30.3	3.6	17.8	30.7	0.7
9/28/06	Creek Down	97.9	9.8	30.0	112.9	31.8	3.7	18.7	29.9	0.9

Appendix A: Dissolved Ions

Date	Location	Chloride (mg/L)	Nitrate (mg/L)	Sulfate (mg/L)	Bicarbonate (mg/L)	Sodium (mg/L)	Potassium (mg/L)	Magnesium (mg/L)	Calcium (mg/L)	Charge Balance (meq/L)
10/10/06	Inlet	188.4	18.0	43.4	109.8	52.9	6.1	32.1	40.3	1.2
10/10/06	Forebay	175.3	15.5	39.0	103.7	50.5	6.0	31.6	40.7	0.7
10/10/06	Main Basin	119.6	7.3	27.0	91.5	34.6	4.8	21.7	28.9	0.7
10/10/06	Culvert	138.1	9.5	31.5	43.0	5.2	26.8	49.4	138.1	-0.1
10/10/06	Creek Up	95.6	9.6	30.1	103.7	29.9	3.7	17.7	31.4	0.8
10/10/06	Creek Down	92.0	9.6	29.8	109.8	30.0	3.7	17.8	30.1	0.8
10/31/06	Inlet	198.1	19.7	43.2	103.7	52.7	6.0	31.1	47.2	1.1
10/31/06	Forebay	176.1	15.0	38.6	51.9	6.3	30.3	54.5	176.1	0.0
10/31/06	Main Basin	58.8	5.7	16.6	17.5	4.3	9.9	20.2	58.8	0.2
10/31/06	Culvert	101.0	8.1	25.8	94.6	33.9	4.6	20.3	32.4	0.2
10/31/06	Creek Up	89.4	9.6	29.9	109.8	29.9	3.9	17.4	34.5	0.5
10/31/06	Creek Down	89.1	9.8	29.1	109.8	30.2	4.0	17.6	33.4	0.5
11/2/06	Inlet	187.1	17.9	36.8	85.4	53.2	6.3	30.3	48.1	0.4
11/2/06	Forebay	68.1	7.6	17.5	48.8	18.6	4.2	11.2	20.5	0.3
11/2/06	Main Basin	80.2	7.2	20.7	26.8	4.9	15.7	29.7	80.2	-0.2
11/2/06	Culvert	100.2	8.3	25.0	85.4	32.1	4.7	19.5	30.7	0.2
11/2/06	Creek Up	61.0	5.8	20.1	79.3	19.5	4.5	12.1	27.6	0.2
11/2/06	Creek Down	56.1	5.6	19.2	82.4	19.5	4.4	11.9	27.0	0.1

1. *Creek Down* refers to Mill Creek downstream of the Rhoads Pond-fed tributary.
2. *Creek Up* refers to Mill Creek upstream of the Rhoads Pond-fed tributary.

Appendix B: Rainfall

Date	Daily Total (mm)	Date	Daily Total (mm)	Date	Daily Total (mm)
8/11/06	5.84	9/24/06	0.51	11/7/06	2.03
8/12/06	0	9/25/06	0	11/8/06	85.62
8/13/06	0	9/26/06	0	11/9/06	0.5
8/14/06	0	9/27/06	0	11/10/06	0
8/15/06	0	9/28/06	25.16	11/11/06	0
8/16/06	0	9/29/06	4.3	11/12/06	13.2
8/17/06	0	9/30/06	0	11/13/06	23.12
8/18/06	0	10/1/06	7.62	11/14/06	0.25
8/19/06	0	10/2/06	0	11/15/06	0
8/20/06	0	10/3/06	0	11/16/06	37.09
8/21/06	0	10/4/06	0	11/17/06	0
8/22/06	0	10/5/06	0.25	11/18/06	0
8/23/06	0	10/6/06	17.02	11/19/06	0
8/24/06	5.59	10/7/06	1.27	11/20/06	0
8/25/06	0.25	10/8/06	0	11/21/06	0
8/26/06	26.67	10/9/06	0	11/22/06	7.87
8/27/06	46.23	10/10/06	0	11/23/06	24.64
8/28/06	54.1	10/11/06	21.07	11/24/06	0.25
8/29/06	84.85	10/12/06	2.28	11/25/06	0
8/30/06	1.5	10/13/06	0	11/26/06	0
8/31/06	0	10/14/06	0	11/27/06	0
9/1/06	15.24	10/15/06	0	11/28/06	0
9/2/06	70.87	10/16/06	0	11/29/06	0
9/3/06	0.5	10/17/06	40.64	11/30/06	0
9/4/06	0	10/18/06	1.25	12/1/06	11.93
9/5/06	32.52	10/19/06	0.51	12/2/06	0
9/6/06	0	10/20/06	22.34	12/3/06	0
9/7/06	0	10/21/06	0	12/4/06	0
9/8/06	0	10/22/06	0	12/5/06	0
9/9/06	0	10/23/06	0	12/6/06	0
9/10/06	2.29	10/24/06	0	12/7/06	0
9/11/06	0	10/25/06	0	12/8/06	0
9/12/06	0	10/26/06	0	12/9/06	0
9/13/06	0	10/27/06	0.76	12/10/06	0
9/14/06	34.78	10/28/06	28.71	12/11/06	0
9/15/06	10.89	10/29/06	0		
9/16/06	2.29	10/30/06	0		
9/17/06	0	10/31/06	0		
9/18/06	0	11/1/06	0		
9/19/06	0	11/2/06	0.51		
9/20/06	0	11/3/06	0		
9/21/06	0	11/4/06	0		
9/22/06	0	11/5/06	0		
9/23/06	2.54	11/6/06	0		

24-Hour Study: 9/29/06 – 9/30/06

Date	Time	Dissolved Oxygen		Electrical Conductivity		Water Temperature		Percent Saturation	
		Forebay	Main Basin	Forebay	Main Basin	Forebay	Main Basin	Forebay	Main Basin
9/29/06	17:00	9.1	13.3	565	442	16.5	18.6	93.0	142.5
9/29/06	18:00	9.2	14.4	509	459	16.4	17.7	93.8	151.2
9/29/06	19:00	9.6	14.6	510	428	16.3	16.8	97.7	150.3
9/29/06	20:00	9.4	13.9	522	428	15.7	16.6	94.4	142.4
9/29/06	21:00	8.5	14	579	425	15.3	15.7	84.5	140.5
9/29/06	22:00	9.2	12.7	556	423	16.4	15.8	93.8	127.8
9/29/06	23:00	9	12.8	340	428	15.1	15.9	89.1	129.1
9/30/06	24:00	8.5	12.9	597	429	15	15.7	84.0	129.5
9/30/06	1:00	8.2	12.7	604	420	14.3	15.7	79.7	127.5
9/30/06	2:00	7.9	11.8	601	423	14.7	15.2	77.5	117.1
9/30/06	3:00	7.2	11.8	615	431	14.4	15.2	70.2	117.1
9/30/06	4:00	7.3	11.5	633	446	15.1	14.1	72.3	111.3
9/30/06	5:00	6.8	11.3	613	468	13.6	14.4	65.0	110.1
9/30/06	6:00	6.8	10.7	620	449	12.9	14.5	64.0	104.5
9/30/06	7:00	6.4	11	661	488	13.9	15.2	61.6	109.2
9/30/06	8:00	6.5	10.1	636	461	13.6	15.2	62.2	100.2
9/30/06	9:00	7.5	11.1	687	458	15.2	16.8	74.4	114.2
9/30/06	10:00	6.9	10.4	726	502	15.6	18	69.1	110.0
9/30/06	11:00	6.9	13.2	683	475	16.7	19.6	70.9	144.6
9/30/06	12:00	6.7	13.6	701	451	16.4	18.9	68.3	146.7
9/30/06	13:00	6.9	13.8	689	460	16.8	18.6	71.0	147.9
9/30/06	14:00	7.4	13.8	712	453	16.3	19.1	75.3	149.5
9/30/06	15:00	8.3	14.1	652	468	16.5	18.3	84.8	150.1
9/30/06	16:00	8.6	13.7	618	452	16.6	18.4	88.1	146.2

Appendix C: Diurnal Dissolved Oxygen Study

24-Hour Study: 11/10/06 – 11/11/06

Date	Time	Dissolved Oxygen		Electrical Conductivity		Water Temperature		Percent Saturation	
		Forebay	Main Basin	Forebay	Main Basin	Forebay	Main Basin	Forebay	Main Basin
11/10/06	14:00	8.5	5.9	750	236	15.6	16.4	85.1	60.2
11/10/06	15:00	8	6.7	752	262	15.3	15.3	79.6	66.6
11/10/06	16:00	8.1	5.3	717	259	15.3	14	80.6	51.2
11/10/06	17:00	7.7	6.1	734	241	14.2	13.2	74.7	57.8
11/10/06	18:00	7.6	7	743	259	14	11.7	73.4	64.1
11/10/06	19:00	5.8	4.8	714	248	13.9	12.3	55.9	44.5
11/10/06	20:00	8.1	6.6	744	246	13.7	11.4	77.7	60.0
11/10/06	21:00	7.3	6.2	728	253	13.7	11.3	70.0	56.2
11/10/06	22:00	7.8	5.7	704	266	13.5	11.2	74.4	51.6
11/10/06	23:00	7.7	5.1	721	256	13	11.3	72.6	46.2
11/11/06	0:00	6.9	6.4	713	251	13.3	11	65.5	57.6
11/11/06	1:00	7.8	5.9	749	258	13.5	12.1	74.4	54.5
11/11/06	2:00	8.3	5.3	721	260	12.4	11	77.2	47.7
11/11/06	3:00	7	4.8	705	263	13.5	11.3	66.8	43.5
11/11/06	4:00	8.2	5.2	717	274	13.2	10.7	77.7	46.5
11/11/06	5:00	7.8	6.2	718	268	13	10.7	73.6	55.4
11/11/06	6:00	8.1	4.3	713	278	13.1	11.1	76.6	38.8
11/11/06	7:00	6.7	4.9	698	279	12.9	11.3	63.1	44.4
11/11/06	8:00	5.6	5.7	704	284	13.6	11.9	53.6	52.4
11/11/06	9:00	7	5.6	693	288	14.4	14.2	68.2	54.3
11/11/06	10:00	7.2	5.3	700	291	15.2	15.2	71.5	52.6
11/11/06	11:00	8.4	6.7	709	291	16.4	17	85.7	69.3
11/11/06	12:00	7.3	6.5	692	293	17.1	18.1	75.6	68.9
11/11/06	13:00	7.1	4.6	765	333	16.7	17.3	72.9	47.9

Appendix D: Electrical Conductivity, Water Temperature, Dissolved Oxygen, Silica, Wet/Dry Sample

Date	Location	Electrical Conductivity (µS/cm)	Water Temperature (°C)	DO (ppm)	Silica (ppm)	Wet/Dry Sample
6/5/06	Inlet	760	•	•	•	•
6/5/06	Forebay	677	•	•	•	•
6/5/06	Main Basin	247	•	•	•	•
6/5/06	Culvert	563	•	•	•	•
6/5/06	Creek Downstream	491	•	•	•	•
6/12/06	Inlet	840	•	•	•	•
6/12/06	Forebay	779	•	•	•	•
6/12/06	Main Basin	369	•	•	•	•
6/12/06	Culvert	631	•	•	•	•
6/12/06	Creek Downstream	523	•	•	•	•
6/19/06	Inlet	836	•	•	•	•
6/19/06	Forebay	822	•	•	•	•
6/19/06	Main Basin	493	•	•	•	•
6/19/06	Culvert	677	•	•	•	•
6/19/06	Creek Downstream	519	•	•	•	•
6/28/06	Inlet	708	18.5	11.5	•	•
6/28/06	Forebay	230	28.5	9.4	•	•
6/28/06	Main Basin	330	33.9	17.7	•	•
6/28/06	Culvert	353	20.7	6.3	•	•
6/28/06	Creek Upstream	264	23.2	6.7	•	•
6/28/06	Creek Downstream	262	23.4	6.1	•	•
7/3/06	Inlet	729	17.4	729	•	•
7/3/06	Forebay	527	23.1	527	•	•
7/3/06	Main Basin	274	27.3	274	•	•
7/3/06	Culvert	535	20.3	535	•	•
7/3/06	Creek Upstream	421	20.5	421	•	•
7/3/06	Creek Downstream	430	20.4	430	•	•
7/10/06	Inlet	805	17.6	6.7	8.4	•
7/10/06	Forebay	745	19.8	10.3	7.8	•
7/10/06	Main Basin	308	25.6	9.3	2.7	•
7/10/06	Culvert	591	19.2	5.1	8.7	•
7/10/06	Creek Upstream	468	19.2	5.7	13.8	•
7/10/06	Creek Downstream	470	19.2	6.3	14.7	•
7/17/06	Inlet	750	18.1	•	12.3	•
7/17/06	Forebay	650	21.9	•	11.7	•
7/17/06	Main Basin	302	28	•	6.3	•
7/17/06	Culvert	556	20.2	•	9	•
7/17/06	Creek Upstream	430	21.1	•	14.4	•
7/17/06	Creek Downstream	436	20.9	•	13.5	•
7/24/06	Inlet	765	17.7	6.4	9.3	•
7/24/06	Forebay	714	19.5	9.8	8.4	•
7/24/06	Main Basin	446	25.8	5.9	3.9	•
7/24/06	Culvert	604	19.8	6.8	9.6	•

Appendix D: Electrical Conductivity, Water Temperature, Dissolved Oxygen, Silica, Wet/Dry Sample

Date	Location	Electrical Conductivity (µS/cm)	Water Temperature (°C)	DO (ppm)	Silica (ppm)	Wet/Dry Sample
7/24/06	Creek Upstream	451	19.3	5.6	14.4	•
7/24/06	Creek Downstream	456	18.9	6.7	12.6	•
7/31/06	Inlet	773	18.7	•	12	•
7/31/06	Forebay	715	21.4	•	7.2	•
7/31/06	Main Basin	476	27.9	•	1.8	•
7/31/06	Culvert	635	20.5	•	8.7	•
7/31/06	Creek Upstream	464	21.6	•	15	•
7/31/06	Creek Downstream	475	21.2	•	14.4	•
9/14/06	Inlet	399	19	•	5.7	Wet
9/14/06	Forebay	317	18.9	•	5.1	Wet
9/14/06	Main Basin	400	19.5	•	5.1	Wet
9/14/06	Culvert	479	19.2	•	6.0	Wet
9/14/06	Creek Upstream	219	18	•	7.8	Wet
9/14/06	Creek Downstream	217	18.1	•	7.5	Wet
9/19/06	Inlet	763	18.6	6.6	10.8	Dry
9/19/06	Forebay	742	19.4	7.1	10.8	Dry
9/19/06	Main Basin	410	22.9	12.5	5.4	Dry
9/19/06	Culvert	600	19.2	5.4	9.6	Dry
9/19/06	Creek Upstream	471	18.8	6.2	14.7	Dry
9/19/06	Creek Downstream	469	18.7	6.5	15.0	Dry
9/21/06	Inlet	795	16.8	6.3	10.5	Dry
9/21/06	Forebay	751	17	7.7	9.9	Dry
9/21/06	Main Basin	494	18.9	10.1	5.7	Dry
9/21/06	Culvert	605	17.2	6.1	9.6	Dry
9/21/06	Creek Upstream	482	14.3	5.6	13.2	Dry
9/21/06	Creek Downstream	480	14.4	7.3	14.7	Dry
9/26/06	Inlet	762	17.8	7.1	11.4	Dry
9/26/06	Forebay	753	17.8	7.9	10.8	Dry
9/26/06	Main Basin	564	19.1	13.3	6.6	Dry
9/26/06	Culvert	633	17.5	6.3	9.9	Dry
9/26/06	Creek Upstream	488	14.7	6.1	15.0	Dry
9/26/06	Creek Downstream	487	14.9	6.9	13.5	Dry
9/28/06	Inlet	•	•	6.5	9.3	Dry
9/28/06	Forebay	•	•	6	10.2	Dry
9/28/06	Main Basin	•	•	14.9	6.9	Dry
9/28/06	Culvert	•	•	6.1	9.3	Dry
9/28/06	Creek Upstream	•	•	5.6	13.8	Dry
9/28/06	Creek Downstream	•	•	6.2	13.2	Dry
10/10/06	Inlet	756	17.3	7.2	9.9	Dry
10/10/06	Forebay	724	17.4	6.6	9.6	Dry
10/10/06	Main Basin	556	16.6	7	6.3	Dry
10/10/06	Culvert	653	17.1	7.2	9.9	Dry
10/10/06	Creek Upstream	492	15.3	8.8	16.2	Dry

Appendix D: Electrical Conductivity, Water Temperature, Dissolved Oxygen, Silica, Wet/Dry Sample

Date	Location	Electrical Conductivity (µS/cm)	Water Temperature (°C)	DO (ppm)	Silica (ppm)	Wet/Dry Sample
10/10/06	Creek Downstream	488	16.6	7.2	15.9	Dry
10/31/06	Inlet	775	16.4	7.2	9.3	Dry
10/31/06	Forebay	421	15.3	7.7	9.0	Dry
10/31/06	Main Basin	290	13.1	4.8	3.6	Dry
10/31/06	Culvert	487	14.2	7.5	7.8	Dry
10/31/06	Creek Upstream	483	11.8	8	14.7	Dry
10/31/06	Creek Downstream	456	12	8.4	14.4	Dry
11/2/06	Inlet	723	17.2	6.7	10.2	Dry
11/2/06	Forebay	304	14.7	8	4.2	Dry
11/2/06	Main Basin	413	14	5.7	5.1	Dry
11/2/06	Culvert	471	14.1	7.1	7.5	Dry
11/2/06	Creek Upstream	347	12.2	7	9.9	Dry
11/2/06	Creek Downstream	326	12.5	7.9	10.5	Dry