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Quantitative Comparison and Modeling of Urban Storm Water Mass Loadings in the City of Lincoln, Nebraska

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QUANTITATIVE COMPARISON AND MODELING OF URBAN STORM WATER MASS LOADINGS IN THE CITY OF LINCOLN, NEBRASKA

by

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A THESIS

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QUANTITATIVE ANALYSIS AND MODELING OF URBAN STORM WATER MASS LOADINGS IN THE CITY OF LINCOLN, NEBRASKA

Patrick Ryan Hartman, M. S.

University of Nebraska, 2010

Advisors: Bruce I. Dvorak, David M Admiraal

The main goal of this study is to monitor, and then compare results related to the water quality and mass loadings of several constituents at two sites in Lincoln, NE. Differences in water quality were assessed using matched-pair t-tests. Mass loadings were examined using cumulative mass plots, and a predictive model for total suspended solids (TSS) was developed at both sites using real-time data obtained from a USGS data probe.

Statistical comparison tests were conducted on the collected water quality data to detect differences based on sample type (auto vs. grab) and sample location (Taylor Park vs. Colonial Hills) for both wet and dry weather events. Preliminary results indicate that there is statistically no difference between concentrations in the auto and grab samples at either site.

For flows during dry weather periods, the Nitrate, Phosphorous, and E. Coli concentrations at Taylor Park are higher than the concentrations at Colonial Hills with

95% confidence. The Turbidity and Chlorine levels at Colonial Hills are higher than the concentrations at Taylor Park with 90% confidence. These differences, particularly the higher concentrations at Taylor Park may be related to best management practices (BMPs) in the Colonial Hills watershed. The same match-pair analysis was conducted on data collected during wet weather flows to detect general differences in the water quality between the two sites. Conductivity concentrations were found to be statistically greater at the Colonial Hills site with 95% confidence.

The mass loadings of several contaminants were examined through the use of cumulative mass plots (CMP's). CMP's were developed for Turbidity, Dissolved Oxygen, and Conductivity for the 2009 sampling season. Results indicate that about 90% of the mass for Turbidity occurs at flow stages higher than the average annual flow. This suggests that the sampling focus in subsequent seasons should be placed on wet weather monitoring in order to accurately describe the mass loading relationship at the highest flows.

A statistical model was developed using log transformations to predict the TSS concentration as a function of the turbidity and flow rate. Preliminary results for the TSS models have an R^2 value of 0.711 at Taylor Park, and 0.906 at Colonial Hills. The average error generated using the models on a log/log scale are about 12% in both cases, and maximum errors were about 40% for both sites.

II. Acknowledgements

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Chapter 1. Introduction

1.1 Introduction and Background

Holmes Lake in southeastern Lincoln, NE was constructed by the U.S. Army Corps of Engineers in 1962. While the primary function of the lake is intended for flood control, secondary uses include recreational benefits, including public fishing. After years of upstream development with little contaminant control, the values for several variables (lake volume lost, in-lake visibility) were exceeding regulatory limits. In order to improve water quality in the lake, the City of Lincoln in partnership with several agencies began extensive lake restoration efforts which were completed in 2005. In addition to extensive mechanical efforts, several structural best management practices (BMP's), including 20 rain gardens were installed upstream of the lake (USEPA, 2008).

Because of these efforts the city of Lincoln has increasing need for timely and accurate estimation of contaminant mass loadings throughout the city. The City of Lincoln, the U.S. Geological Survey (USGS), and the Department of Civil Engineering at the University of Nebraska-Lincoln have been working together in this project to provide more accurate methods to quantify and predict the mass loadings at two sites in Lincoln, NE. Previous work done by Vegi (2008) at the University of Nebraska-Lincoln examined mass loadings throughout the city using Event Mean Concentrations (EMCs) which estimates mass loading by the generation of a mean constituent concentration which can be used in conjunction with flow data to estimate mass loadings. While EMCs are capable of yielding estimates of mass loading they require site-specific data for these estimates to be accurate. Furthermore since EMCs predict mass loading using a singular concentration assumed to be applicable to an entire storm, water quality variability, and seasonal effects are lost with this type of analysis.

1.2 Objectives

The main goal of this study is to monitor the water quality and mass loadings of several constituents at two sites in Lincoln, NE. Focus is placed on estimating mass loadings based on the real-time modeling of water quality parameters rather than the use of EMC values. Using preliminary real-time data, a multiple regression model for Total Suspended Solids was developed at each of the sites. Unlike with the application of EMC's, these models are capable of examining the water quality variation as well as seasonal effects. Significant emphasis was also placed on comparing the water quality between one site located within the Holmes Lake Watershed known to be influenced by structural and non-structural BMPs, to the water quality at a nearby site that has no formal BMP program. This comparison was conducted using matched-pair t- tests to identify differences in water quality during wet and dry weather flows for each site.

A secondary goal of this study is to develop mass loading models which can be used in real-time to predict a number of water quality parameters based on several other easy-to-measure surrogate parameters. Real time water quality data for Conducitivity, Turbidity, Dissolved Oxygen and Water Temperature was collected by the USGS at both sites throughout the course of this project. Discrete sample concentrations for several contaminants (including Nitrates, Phosphorous, and Suspended Sediments) were determined by the UNL Department of Civil Engineering for wet and dry weather events.

Continuous stage and flow meters were installed and maintained by the UNL Department of Civil Engineering.

The following report outlines the methodology used for this study, and provides the initial results for the quantitative comparison of water quality between sites. This report also outlines the development of a model for predicting the concentration of Total Suspended Solids. Specific emphasis is placed on methodological considerations to improve the data collection and analytical methods used in further work on this project.

Chapter 2. Literature Review

2.1 Introduction and Scope

The goal of this study is to model the water quality at two sites in Lincoln, NE. An additional goal of the study is to assess the use of instantaneous probe data in the development of predictive water quality models. The result of this analysis will be a set of models for hard-to-measure water quality contaminant concentrations based on a number of "surrogate" variables. This section identifies relevant material found in the technical literature that discusses: estimation methods, trends in contaminant transport, and modeling considerations.

2.2 Estimation of Mass Loading

Mass loading is defined as the total mass of contaminant passing a specified location during a specified time window. Several methods can be used to calculate mass loadings, the most common of which are the use of EMCs, and real-time monitoring.

A common method for predicting nutrient loading uses the concept of Event Mean Concentrations which can be used in conjunction with flow volume to estimate the mass loading for a rainfall event. The EMC method uses an average estimate of the water quality parameter to estimate the loading. This is generally completed using several discrete water quality samples from the same rainstorm event and a stream flow hydrograph. Mass loading for the entire storm is calculated by multiplying the concentrations obtained from the discrete samples with the flow rates obtained from the stream flow hydrograph. The EMC for a rainstorm event can be calculated using Equation 2.1 given below (USEPA, 1983):

$$EMC = \frac{\sum C_i V_i}{\sum V_i} = \frac{\text{Total Pollutant Mass}}{\text{Total Runoff Volume}} \qquad (2.1)$$

Where C, is the contaminant concentration of a discrete sample, and V is the corresponding volume of total flow that passed between the collection of the sample and the subsequent sample. The EMC of a rainfall event is defined as the mean contaminant concentration that when combined with the event hydrograph, produces a mass loading identical to the loading obtained if concentration variability was considered (USEPA, 1983). This concept is illustrated in Figure 2.1 below. Note that both of the concentration graphs given in Figure 2.1 produce the same estimate for total loading.

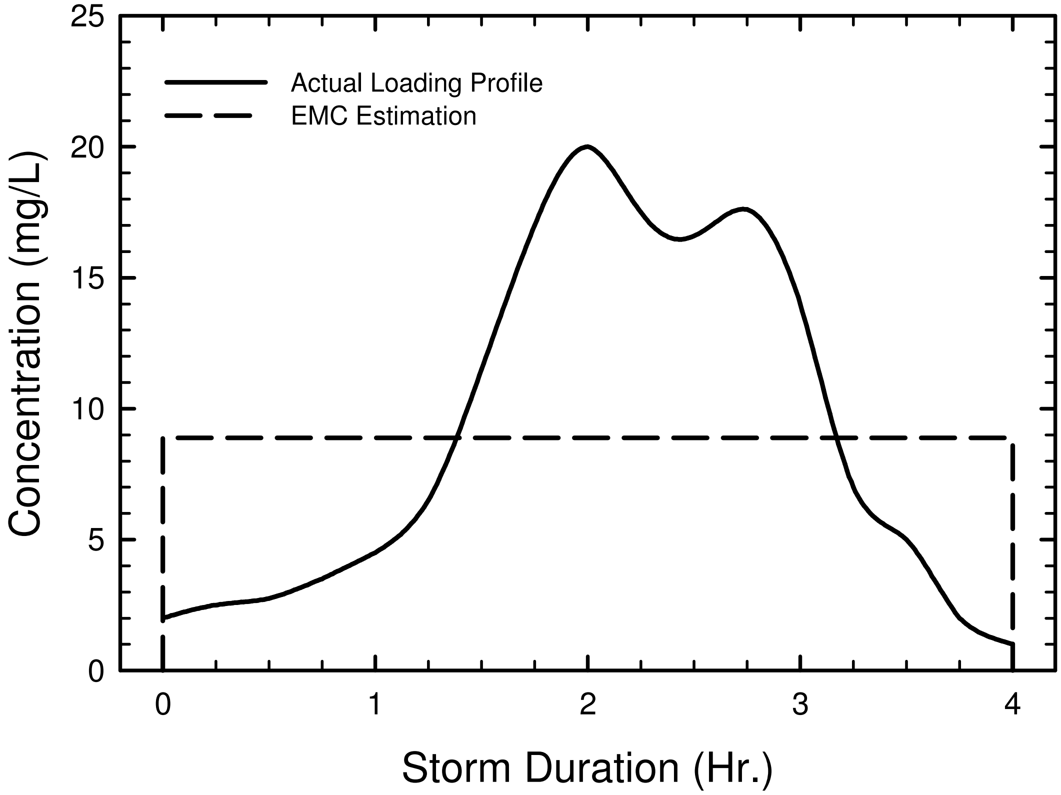

Figure 2.1: Illustration of EMC concept (After USEPA, 1983).

The major advantage of using EMC values is that no discrete water quality parameters are needed to predict the mass loading for a rainfall event. Due to the nature of EMC estimations, one major drawback to using this method is that the variability of water quality parameters during the storm is lost since the concentration for the rainstorm event is represented only as a mean value (Brezonik, 2002).

Another major type of loading estimation is real-time monitoring (Christensen et al, 2001). This type of estimation uses real-time water quality data coupled with flow estimations to produce mass loadings. The major advantage of this type of approach is that the loadings have the potential to be more accurate since concentration and flow rate data is generated frequently. The major disadvantage is that the maintenance cost for such analysis is generally much higher than for developing and using an EMC method. Additionally many water quality parameters, such as Total Suspended Solids require discrete samples to be taken in order to calculate concentrations, making real-time monitoring of these constituents impossible. In this project, real-time monitoring was done for Turbidity, Conductivity, and Dissolved Oxygen concentrations using USGS data probes installed at both sites.

2.3 Contaminant Loading Characteristics

Substantial work has been completed explaining the transport mechanics of water contaminants, particularly during rainfall events. This section of the report discusses the major trends in contaminant loading as seen in the literature.

Peters (2008) analyzed a substantial data set obtained from the USGS for urban stream water quality in Atlanta, GA. Results indicated that the concentrations of most major ions decrease with increasing stream flow, whereas suspended sediment related constituents such as Turbidity, E. Coli, and Total Phosphorous concentration increase with increasing stream flow. These results are consistent with findings by Bevan (1982) who also found that in-stream concentrations of chemical constituents generally decrease with increasing stream flow, except for Total Phosphorous which is associated with sediment transport and increase directly with stream flow. These results follow the expected behavior of water quality contaminants; as flow rate increases, velocity also increases resulting in greater turbulence within the flow, and therefore higher sediment transport potential. Since most rain water does not contain major ion contaminants, a reduction in the concentrations is expected during rainfall events.

Horowitz et al. (2008) examined mass loadings for most trace and major elements as well as suspended sediment-related constituents for a range of dry and wet-weather flow rates. Results indicated that >95% of suspended sediment related mass fluxes occurred in conjunction with storm-flow, suggesting extreme mobilization during storm flows. Evidence also suggested that the transport for most trace (Cu, Pb, Zn, Ni, Cr), and major elements (Fe, Mn, Al) occurred in association with the sediment related transport, and therefore >90% of the mass flux for trace and major elements occurred during storm-flows. Horowitz suggested that the dominance of storm-flow fluxes when compared to base-flow fluxes for total mass transport suggests that most of the contaminants measured were derived from non-point sources

2.4 Approaches for Modeling Mass Loading

Research aimed at developing models for predicting EMCs as a function of basin parameters (drainage area, slope, time of concentration), and storm-specific variables (depth of rainfall, intensity) has been completed.

May and Sivakumar (2009) compared the accuracy of various modeling types to predict contaminant concentrations at multiple sites across the nation using data collected as part of the Nationwide Urban Stormwater Program. Models predicting Event Mean Concentrations (EMC), Mean Metropolitan Area Concentrations (MMC), and Site Mean Concentrations (SMC) were developed and compared to multiple regression models that predict mass loadings. It was found that the SMC, and Multiple Regression approaches produced the most accurate results. The main drawback of using SMCs is that accurate results require site-specific data, but the models are incapable of explaining inter-storm concentration variability on-site since the contaminant concentration is assumed to be a constant.

Multiple regression models also require site-specific data and provide much of the same accuracy as SMC models but are also capable of detecting this inter-storm variability. Since multiple regression models generally consider a wide range of variables, they provide valuable insight into the most important processes influencing concentration in urban storm-water (May and Sivakumar, 2009).

2.5 Important Factors for Modeling Mass Loading

Brezonik and Stadelmann (2002) conducted a study which analyzed pollutant concentrations, using EMC's, in the Twin Cities Metropolitan Area. The study considered storm-specific characteristics (precipitation amount, storm duration, average storm intensity, and days since last event), and watershed-specific characteristics (drainage area, land use, and percent impervious area). The study considered the following water quality parameters: Total Suspended Solids (TSS), Volatile Suspended Solids (VSS), Total Phosphorous (TP), Dissolved Phosphorous (DP), Soluble Reactive Phosphorous (SRP), Chemical Oxygen Demand (COD), Total Kjeldahl Nitrogen (TKN), Total Nitrogen (TN), Nitrate plus Nitrite-Nitrogen (NN), and Lead (Pb).

Results from Brezonik and Stadelmann (2002) indicated that drainage area, total precipitation, and rainfall intensity were the most relevant variables for predicting contaminant loads. Precipitation estimates were interpolated using distance weighting from rainfall gauges stationed in, and around the Twin Cities Metropolitan area. Statistical correlations were determined between event loadings and watershed characteristics. Positive correlations (R values ranging from 0.28 for TSS, and 0.5 for NN) were witnessed for all loadings except Pb. As expected, these results indicated that mass loading generally increases as factors like drainage area, and percent impervious area also increase. Negative correlations to rainfall duration were seen with all water quality parameters except SRP and Pb, which suggests that longer storms generally produce more dilute runoff.

Concentrations for DP, COD, TKN, NN, and TN were all negatively correlated with precipitation amount which suggests that the contaminant concentrations in the watershed were supply-limited. These results are consistent with the results from May and Sivakumar (2009) which also found significant negative correlations between phosphorous and nitrate concentrations and rainfall depth.

2.6 Seasonal Effects on Contaminant Concentrations

Seasonal effects were considered in a study conducted by Brezonik and Stadelmann (2002), and were also considered in the study conducted by May and Sivakumar (2009). Results from Brezonik and Stadelmann (2002) indicated that significant seasonal differences (p values < 0.05) were detected for all the variables tested except for soluble reactive phosphorous (SRP). The highest yields for TSS, VSS, COD, and Pb concentrations occurred in the spring, and the yields for TN, TKN, and NN (Nitrate plus Nitrite-Nitrogen) were lowest in the fall months. These results were consistent with the findings from May and Sivakumar (2009), which indicated that the yields for most water quality parameters were greatest in the spring and summer months, and substantially lower in the fall and winter months.

Chloride concentrations are generally highest during the winter months due to the presence of roadway salts (Albert, 1964; Ziegler et. al, 1999). Mass loadings for chloride, however, are often highest during the spring and summer months due to the large stream flows common during those seasons. These results indicate that the seasonal variation in contaminant concentrations is not sufficient to explain the seasonal variability in mass loading. In fact, the seasonality in the frequency of runoff events may be more reflective of the trends seen in mass loading than any seasonal variation in contaminant concentration.

May and Sivakumar (2009) considered and modeled these seasonal changes using a seasonal coefficient defined as shown in equation (2.2):

$$C_s = \sin\left(2\pi \frac{j}{365}\right) \tag{2.2}$$

Where C_s is the seasonal coefficient used for modeling, and j is the Julian Day of the Year. If the average annual concentration, and the lower and upper ranges of concentrations witnessed during a sampling season are known for base flow levels, the annual variation in base flow contaminant concentrations can be described using equation 2.3.

$$C = C_A + \frac{V_A}{2}\sin\left(2\pi \frac{j}{365}\right) \tag{2.3}$$

Where C is the base flow contaminant concentration at time j, C_A is the Annual Average base flow concentration, and $V_A/2$ is the maximum deviation from the annual average base flow concentration.

2.7 Turbidity as a Surrogate for Other Parameters

Christensen et al. (2001) at the USGS water science center conducted a study predicting TSS concentrations as a function of turbidity, and E.Coli concentrations (in cfu/100ml) as a function of turbidity and the month of the year for two sites on the Little Arkansas River in Kansas. The study focused on comparing the mass loadings generated using the predictive model to loadings calculated using conventional means. Results indicated that the errors associated with the predictive models at each of the sites were large (83.7% and 242% for E. Coli, and 66.4 and 34.0% for TSS). The magnitude of these errors may be misleading since the in-stream nature of turbidity measurements could actually produce more accurate results than conventional means. The massive errors associated with the E.Coli estimates may have been related to the imprecision associated with E. Coli testing.

The results of sample size were discussed, and it was found that the magnitude of errors universally decreased as the sample size increased. Tables 2.1 and 2.2 below depict the changes in the standard error for the E. Coli and TSS loading predictions. From the tables it can be seen that the standard error (SSE) generally decreases as a function of sample size (Christensen et. al., 2001).

Table 2.1 – Standard Error of E.Coli Predictions (From Christensen et. al., 2001)

	Station 07143672				**Station 07144100**			
Calendar Year	**# of Samples**	**R2**	**SSE**	**Change in SSE (%)**	**# of Samples**	**R2**	**SSE**	**Change in SSE**
1995	20	-0.574	75.5	--	18	0.043	94.1	--
1996	42	0.578	30.1	-60.1	36	0.567	42.6	-54.7
1997	58	0.606	28.1	-6.64	50	0.593	40	-6.10
1998	75	0.620	27.1	-3.56	73	0.556	43.6	9.00

Table 2.2 – Standard Error of TSS Predictions (From Christensen et. al., 2001)

	Station 07143672				Station 07144100			
Calendar Year	**# of Samples**	**R2**	**SSE**	**Change in SSE (%)**	**# of Samples**	**R2**	**SSE**	**Change in SSE**
1995	19	0.907	2.79	--	19	0.881	3.24	--
1996	41	0.908	2.78	-0.36	35	0.879	3.28	1.23
1997	58	0.909	2.75	-1.08	51	0.885	3.12	-4.88
1998	74	0.911	2.69	-2.18	71	0.883	3.01	3.53

In a similar study completed by Christensen et al. (1999) concentrations for Alkalinity (ALK), Dissolved Solids (DS), Total Suspended Solids (TSS), Chloride (CL), SO_4, Atrazine, and E. Coli were estimated using multiple regression equations at several sites on the Little-Arkansas river in South-Central Kansas. These regressions relate the listed contaminant concentrations to Flow Rate (Q), Turbidity (Turb), Specific Conductance (SC), and season (month of year). The data were collected over 4 years using USGS data probes and standard flow rate measurements. Examples of regressions developed for one of the sites used in the study can be seen in Equations 2.4 – 2.10 below.

Atrazine:

$$\log_{10}(ALK) = 0.651\log_{10}(SC) - 0.101\log_{10}(Q) + 0.487 \quad (2.4)$$

Dissolved Solids:

$$DS = 0.545(SC) + 33.3 \quad (2.5)$$

Total Suspended Solids:

$$\log_{10}(TSS) = 0.920\log_{10}(Turb) + 0.243 \quad (2.6)$$

Chloride:

$$Cl = 0.255SC + 30.9\log_{10}(Q) - 140 \qquad (2.7)$$

Sulfate:

$$\log_{10}(SO_4) = 0.911\log_{10}(SC) - 1.12 \qquad (2.8)$$

Atrazine:

Atrazine concentrations were calculated by estimating the concentration of triazine. An empirical relation was develop that indicated the atrazine concentration is equal to the triazine concentration multiplied by 0.8.

$$\log_{10}(triazine) = 1.42e^{\frac{-(month-6.24)^2}{3.75}} - 0.0000288Q - 0.000581SC - 0.104 \qquad (2.9)$$

Fecal Coliform Bacteria:

$$\log_{10}(Bact) = (0.490)\cos\left(2\pi\frac{Month + 2.06}{8.76}\right) + 0.00106Turb - 0.417\log_{10}(Turb) + 1.65 \qquad (2.10)$$

In the regression equations given above it can be seen that the flow rate and the concentrations of specific conductance and turbidity concentrations play a major role in the regressions. The month of the year shows up in the regressions for atrazine, and fecal coliform bacteria.

These regression equations were used in conjunction with flow rate data to estimate mass-loadings at the various sites. These estimates were compared to loading estimates developed using instantaneous water quality measurements collected during 1999. Errors of less than 25% were seen between measured and estimated concentrations and loadings for Alkalinity, Dissolved Solids, Chloride, and Sulfate. Errors greater than 25% were seen for TSS, Atrazine, and Coliform Bacteria. Despite the large errors associated with some of the parameters, Christensen suggests that this type of analysis provides researchers with numerous advantages when compared to estimates generated through discrete manual sampling, the most valuable of which is the ability to detect water quality variability. This is particularly true for contaminants like TSS, and Coliform Bacteria which undergo extreme variance during rain-storm events.

2.8 Summary

This section of the report discussed relevant information found in the literature relating to this thesis. The general trends in constituent concentrations and loadings were discussed. The concentrations of most major ions generally decrease with increasing flow rate, whereas sediment related constituents (Turbidity, E. Coli, Total Phosphorous, TSS) increase with flow rate (Peters, 2009). Horowitz et al. (2008) determined that >95% of the loading suspended sediment related constituents, and >90% of loading for trace and major elements occur in conjunction with wet-weather flows. This suggests that wet-weather monitoring is extremely important when predicting mass loadings.

The most common methods for modeling mass loading were examined through the use of comparative analysis. It was found that multiple regression models generally offer more accurate results when compared to other types of modeling approaches, but require site-specific data to generate and therefore are more difficult to apply (May and Sivakumar, 2009). When modeling mass transport, watershed characteristics and rainfall characteristics should be considered. Drainage area, total precipitation, and rainfall intensity were the most useful variables in predicting contaminant EMCs (Brezonik and Stadelmann, 2002).

The USGS has been working with data collected using USGS data probes as a surrogate to model other contaminant concentrations (Christensen et. al, 1999, 2000). Models predicting TSS and E. Coli were developed for two sites in Kansas, and their accuracy was analyzed. Extremely large errors (83.7 and 242%) were associated with the E. Coli model, but these errors may be related to the imprecision in the E. Coli test. Errors for the predictive TSS model were lower (66.4% and 34.0%), but the magnitude of these errors could be misleading since the in-stream nature of probe data may actually produce more accurate results than conventional means.

The information contained in this literature review is critical for the understanding of the most important concepts that relate to the water-quality in urban storm water. The results of the study conducted by Christensen et al. at the USGS are particularly important because the methods and results from that study are similar to the intended results of project discussed in this thesis.

Chapter 3. Methods

3.1 Introduction

This section aims to describe the methods used for data collection in this project. This chapter is split into four sub-sections based on the primary methods required: Wet Weather Monitoring, Dry Weather Monitoring, Hydrology, and Biological and Chemical Analysis. This chapter also provides the rationale behind the site selection as well as site descriptions.

3.2 Site Selection

The aim of this study is to provide a comparison in water quality between a site targeted with structural and non-structural best management practices (BMPs) and a control site with no formal BMP program. Holmes Lake Reservoir in southeast Lincoln, NE underwent extensive water quality restoration efforts ending in 2005, and the City of Lincoln has implemented a number of BMPs in the contributing watersheds in hopes of improving the long term water quality. Because of these efforts the “targeted” site was chosen at a park on the southern end of the Colonial Hills housing development which is a sub-watershed of Holmes Lake. To determine if these BMPs have an impact on the water quality a control site where no BMPs are present is necessary. The following list of criteria was used when selecting a control site:

- Similarity of Drainage Area
- Similarity of Land Use
- Proximity to the Colonial Hills Site
- Flow Characteristics
- Accessibility and Safety
- Few or No upstream BMPs

With the above criteria in mind, the "Control" site was chosen at Taylor Park in Lincoln, NE. This site is located about 2.5 miles north of the Colonial Hills site and has similar flow characteristics, but has no formal BMP control upstream.

3.3 Site Descriptions

The two sites discussed in this study are both located in southeast Lincoln, NE. Figure 3.1 below depicts the site locations on a map of the City of Lincoln.

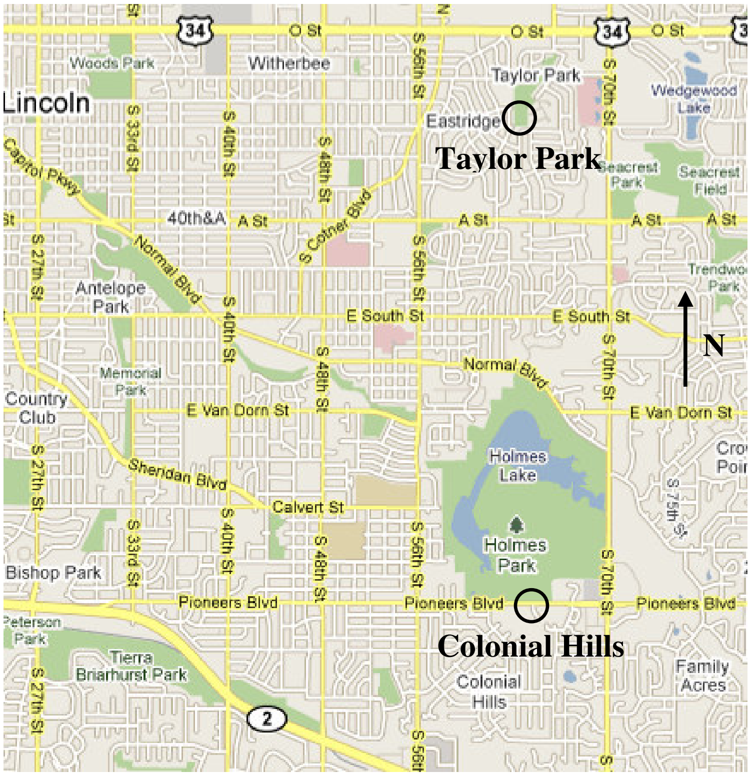

Figure 3.1: Site Locations

3.3.1 Colonial Hills

Colonial Hills is located at 63rd and Pioneers Blvd in Lincoln, NE. The watershed has an approximate drainage area of 0.96 square miles, and is part of the Holmes lake watershed. Because this watershed is directly upstream of Holmes lake reservoir, it was targeted for the installation of numerous BMP's and was used as the "target" site for this study. Figure 3.2 below shows the Colonial Hills site, and Figure 3.3 shows the location of the data probe installation.

Figure 3.2: Colonial Hills Site in Lincoln, NE, Facing Northwest

Figure 3.3: Probe Installation. The data probes are contained inside the white PVC pipe seen underneath the bridge here.

The flow meters and USGS data probe at the Colonial Hills site are installed in the stream underneath the bridge crossing as shown in Figure 3.3. The flow meters, auto samplers, and their batteries were kept in a green USGS gauging station on site, the inside of theses gauging stations can be seen in Figure 3.4 below.

Figure 3.4: USGS Gauging Station

The flow at the Colonial Hills Site is largely influenced by a downstream box culvert which acts as a weir, creating backwater in the upstream channel. The backwater from this weir can be seen as part of the upstream wetlands in Figure 3.5 below.

Figure 3.5: Wetlands upstream of the Colonial Hills sampling site.

During dry weather, the water level at the Colonial Hills site is relatively constant, the flow rate is very small, and the resulting stream flow velocities under these conditions are also very low. Because the flow meter used in this project is unable to accurately read very low velocities, the data logger flags the dry weather flow information as being in error. To circumvent this issue, the velocity and flow rate at the Colonial Hills site is assumed to be zero for dry weather events. While this assumption is not entirely accurate, the actual flow rates at Colonial Hills during dry weather flows are too small to measure directly so the assumption is reasonable.

3.3.2 Taylor Park

Taylor Park is located at 62nd and Mesaverde in Lincoln, NE and has an approximate drainage area of 0.14 square miles. The watershed is a tributary to Dead Mans Run, has no substantial BMPs installed, and is therefore used as a “control” watershed for this project. The flow at Taylor Park is predominately stormwater runoff, and site monitoring occurs directly downstream of a storm sewer outlet. Figure 3.6 below shows the Taylor Park site.

Figure 3.6: Taylor Park Monitoring Site, Facing South.

The USGS data probe and the ISCO stage monitor at the Taylor Park site are installed as shown in Figure 3.6 (connected to the white PVC pipe in the photo). Because the channel bottom is very narrow at this site, the flow meter could not be installed at the same location, and is installed in the upstream elliptical culvert instead. While this placement yields better flow estimation, any potential lag time between the two locations needs to be considered. This lag time is discussed subsequently in the Hydrology section.

Another concern at the Taylor Park site is overflow from the street. During very intense rainfall events the street directly upstream of the Taylor Park site often floods. In response, the City of Lincoln made a small overflow channel which can be seen in Figure 3.7 below.

Figure 3.7: Overflow Channel at the Taylor Park Site

Since the flow rates are determined in the culvert below this overflow channel, there was a concern about the possibility of underestimating the total flow rate because the overflow bypasses the flow meter. Preliminary estimates of the flow potential in the overflow channel were done using the rectangular weir equation, for multiple stages of flow in the overflow channel. Preliminary estimates of overflow rates for different depths are given in the results Section 4.5.1.

3.4 Dry Weather Monitoring

3.4.1 Definition

Dry weather monitoring refers to the collection of any samples not directly related to a rainfall event. Because this sampling is often done at base flow levels, the results of the dry weather monitoring give a general comparison of the water quality and contaminant mass loadings between the two sites under these conditions.

During sampling seasons, dry weather monitoring was performed bi-weekly. Bi-weekly monitoring provides a large enough data set so that meaningful comparisons could be made, and also allows for seasonal differences in water quality to be examined.

3.4.2 Sampling Preparation

To make sure that sampling was completed using the same methods for each sampling event, a standard operating procedure was followed on-site. For ease of sampling, a sampling kit was prepared in advance for each of the dry weather sampling events. Table 3.1 below outlines the sampling kit for dry weather monitoring.

Table 3.1: Dry Weather Monitoring Sampling Kit

Item Name	Quantity Needed	Purpose
Black Binder	1	Record Data, SOPs, Forms
Coolers	1 Green, 1 Red	Mobility
Cold packs	4	Sample cooling
Forms/Data Sheets	One for Each Site	Record Data and Maintain Organization
2L Bottles	4	CIVE water quality tests.
500 ml Bottles	4	Water Science Lab Tests
250 ml Glass Bottle	2	Water Science Lab Tests
100 ml E.Coli Bottles	4	State Lab Tests
DO Preservatives (Manganous, Alkali-Iodide-Acid, Conc. H_2SO_4)	3 Vials	Allow Ample Delivery Time
0.5M H_2SO_4	1 Vial	To Preserve Water Science Lab Samples
Thermometer	Electronic	-
Hach 2000 DR	1	Measure Chlorine Levels
Chlorine Test Vials	1 Set (have same #)	Run Field Chlorine Test
Chlorine Test Packets	2 Pillow Packets	Run Field Chlorine Test
Manhole Cover Remover	1	-
Telescopic Sampling Pole	1	Ease of Sample Collection
1 L Sample Collecting Beaker	1	-
Labeling Tape	1	Ensure Organization
Pen/Sharpie	1	-
Laptop Computer with Flowlink	1	Upload DW Data from ISCO 4100 Bubbler and ISCO 2150 Area-Velocity Meter
Automatic Pipette with Tips	1	Sample Preservation and Sample Testing
De-Ionized Water	1	Rinsing and Washing Bottles and Vials
Rubber Gloves	4+ Pairs	-
Kim Wipes	1 Box (4 is enough)	Wipe Finger Prints Off of Vials
Traffic Safety Vest	4+	-

To minimize potential confusion while sampling, all of the bottles used for dry weather monitoring were labeled in advance with the sample type, location, and the date when it was collected. For example, a dry weather auto sample (DW-A1) collected on May 7th, 2009 at the Taylor Park site would be labeled; DW-TP-A1-5/7/09.

3.4.3 Sample Collection

Two types of samples were collected during dry weather monitoring: Auto samples and Grab samples. Collecting the two types of samples simultaneously and testing the water quality parameters of each allows a comparison of the two collection methods. Since the concentrations of the water quality parameters should be the same in both samples, this comparison allows the detection of any bias in the data set that results from the sampling method.

Auto samples were collected using an ISCO 3700 series auto sampler (Teledyne Isco, 2005), which is shown in Figure 3.8 below. Auto samplers are useful for sampling if a large number of samples must be taken, or if the site is too dangerous or expensive to sample manually. Auto samplers are also extremely useful for sampling during rainfall events which cannot be controlled by the researcher.

Figure 3.8: Isco Auto Sampler

Grab samples were collected using telescopic sampling poles at approximately 6 inches below the water surface at both sites. To minimize potential error due to spatial concentration differences, these samples were collected as close to the auto sampler intake as possible.

3.4.4 On-Site Testing

During dry weather monitoring the water temperature and chlorine concentration were tested on-site. Temperature was measured using an electronic thermometer at about 6 inches below the water surface while the grab samples were collected. Because chlorine testing has a maximum holding time of three hours, the chlorine concentrations of the grab samples were also tested on site using Hach Method 8167.

Samples taken to the UNL water science lab to be tested for TKN, Ammonia, and Nitrate were preserved on-site using sulfuric acid (H_2SO_4), and delivered immediately. E. Coli samples were generated on-site using the collected auto and grab samples, and were delivered in sterile bottles to the State of Nebraska Public Health Laboratories immediately.

3.5 Wet Weather Monitoring

This section of the report discusses monitoring in conjunction with wet weather flows "wet-weather" is defined, and the major methods used for sample collection are given.

3.5.1 Definition

Contaminant concentrations during rainfall events are substantially higher than the concentrations under base flow conditions. Wet weather monitoring examines these concentrations by sampling during the rainfall event using a pre-determined sampling program.

An important concept of wet weather monitoring is the idea of "First Flush". The first flush of a rainstorm event occurs during the rising limb of the hydrograph, and usually contains the highest concentrations of contaminants. The higher concentrations in this stage of a rainfall event are related to the idea that the first water that contacts the surface will "wash off" the contaminants from the surface of the watershed. The first flush concept is particularly true in urban watersheds where much of the surface area is impervious.

In order for a rainfall event to be classified as a wet weather event, the precipitation depth must be at least 3/8 of an inch and provide a sufficient number of samples so that the entire hydrograph is represented in the data.

3.5.2 Weather Monitoring

Because weather forecasting is uncertain, weather monitoring was done frequently during sampling seasons using local weather forecasts. The graphical forecasts available at the National Weather Service's website (http://www.weather.gov) were used to predict expected precipitation depth for incoming storm events. Local precipitation chances as well as the local radar map were monitored using the Weather Channel's website (http://www.weather.com) multiple times a day during the sampling season.

3.5.3 Sampler Preparation and Control

Before each potential wet weather event the ISCO auto samplers were programmed to auto trigger based on a site specific sampling program. The two main components of the sampling program are the trigger condition, and sampler pacing, which control when the sampler begins sampling, and the frequency at which samples are collected, respectively.

In this project, a pre-determined trigger depth was used as the trigger condition. This trigger depth was determined using collected depth data for the summer of 2008. The trigger depths at both sites were set a couple of inches above the maximum base flow levels. Setting the trigger depth at these levels allows the sampler to ignore the diurnal variation in depth, allowing collection only during rainfall events.

Because erosion and deposition can have a substantial effect on the water levels in the channels, the depth data should be examined after most major storms to see if the stream bed elevation had changed. These stream bed elevation changes directly affect the trigger depth, and therefore the trigger depth is not constant for all wet weather events. The trigger depth used for every wet weather event, was recorded with the data to ensure no errors were made in the data analysis.

The ISCO auto samplers allow the user to define the sampler pacing either on time-based, or flow-based intervals. Time-based pacing collects samples at a pre determined temporal spacing, for example once the trigger depth had been reached a sample would be collected immediately and then every 15 minutes after. One major drawback to time-based sampling is that the times of sample collection can often “leap frog” the time of the peak flow, this is particularly true when the sampler pacing is large, and the runoff hydrograph is flashy.

Flow pacing collects samples based on the cumulative flow that has passed since the sampler was triggered. Flow pacing has one major advantage over time-based pacing in that the peaks are much less likely to be missed since sampling occurs more frequently as the flow increases. The major drawback to this method is that since the auto samplers are only capable of reading the flow depth, a good depth versus flow rating curve needs to be developed prior to using this method.

The wet weather events collected during this project were collected in the first year using a 15 minute time-based pacing while depth vs. flow data could be collected to generate sufficient rating curves. Wet weather events collected after the first year were conducted using flow-based pacing. The pacing to use was determined from actual storm data at each of the sites, and was done to provide a minimum of six samples at a 3/8” rainfall event. Additional information on sampler programming, and site specific detail can be seen in Appendix D.

3.5.4 Sample Collection and Delivery

After a wet weather event, the samples were removed from the auto samplers and transported back to the UNL civil engineering lab where they were labeled with the site, sample number and collection date. E. Coli samples were delivered to the Nebraska state labs within 24 hours of sample collection. Ammonia, TKN, and Nitrate samples were delivered to the UNL Water Sciences Lab within 24 hours of sample collection.

3.6 Hydrology

3.6.1 Flow Measurement

In order to calculate contaminant mass loadings flow information must be attained. In this project, flow measurements were recorded using an ISCO 2150 Area Velocity Flow Meter (Teledyne Isco, 2008), seen in Figure 3.9 below.

Figure 3.9: ISCO 2150 Area Velocity Meter

This device uses an acoustic signal to calculate the depth and velocity of flow at the sampling sites. Using this information flow rate was calculated using a depth to area relationship derived from cross-sectional surveys of the channel at both sites. The result is semi-continuous data for depth, velocity, and flow rate at the sampling sites.

During this project, flow data was collected at 15 minute intervals for both dry and wet weather monitoring. It is important to note that this device is capable of accurately measuring velocities above 0.3 ft/sec, and therefore the dry weather flow estimates at the Colonial Hills site are inaccurate since the stream at the Colonial Hills site has very low velocities during dry weather.

3.6.2 Stage Measurement

Flow stages were measured using ISCO bubbler flow meter (Teledyne Isco, 2008), seen in Figure 3.10 below. These monitors operate by creating bubbles at a constant rate to determine the water pressure at the probe.

Figure 3.10: ISCO Bubbler Flow Meter

Assuming a hydrostatic pressure distribution, the flow stage can be accurately determined using this pressure reading. Pressure readings were taken every minute and a depth reading was recorded at 15 minute intervals for both wet and dry weather monitoring.

3.6.3 Precipitation Measurement

Since wet weather events in this project were defined as any rainfall event greater than 3/8 of an inch, precipitation information for the sites is important. For the first year of the project this was done using data from a precipitation gauge at the Lincoln municipal airport (Data from this precipitation gauge can be seen at the website http://www.lincolnweather.org). The precipitation data for this website was used in conjunction with the flow data collected in the first year at 15 minute intervals to determine the trigger control and sampler pacing for the wet weather auto sampler programs for the 2009 sampling season.

In order to generate better site specific sampling programs, Onset RG3 Data Logging Rain Gauges, seen in Figure 3.11 below were installed at both sites at the start of the 2009 sampling season.

Figure 3.11: Onset Data Logging Rain Gauge

These data loggers provide precipitation depth as well as rainfall intensity as a function of time. This data allows the user a greater understanding of how hydraulic responses from the watershed change as a function of the rainfall intensity.

3.6.4 Rating Curves

As discussed previously, depth vs. flow rating curves at both of the sites were required in order to use a “Flow paced sampling” scheme during wet weather events. Because these rating curves were not available in the 2008 sampling season, “Time-paced sampling” was used instead. In order to develop these rating curves, the depth data collected using the ISCO bubbler flow meter, was plotted against the flow data collected using the ISCO 2150 Area Velocity meter for the entire 2008 sampling season. An example of one of these rating curves can be seen in Figure 3.12 below.

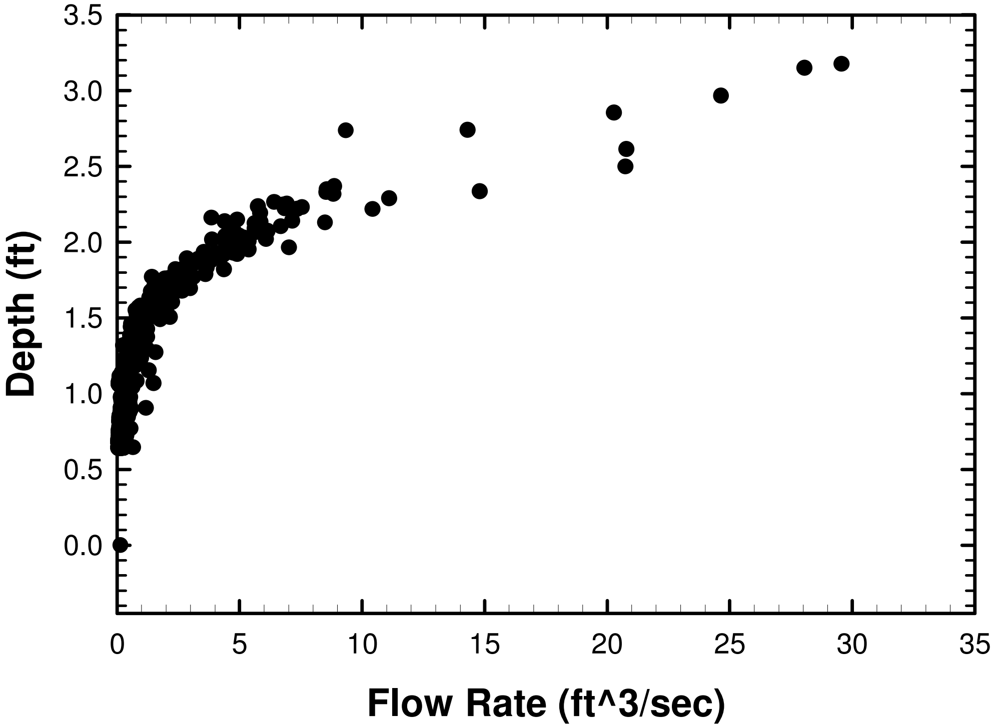

Figure 3.12: Example Rating Curve, Taylor Park 2008

It is important to note that since new depth and flow data are generated on a daily basis the rating curves for the sites should be regularly updated using the new data.

3.6.5 Lag Times

Due to site constraints, the 2150 Area Velocity meter at Taylor Park is roughly 200 feet upstream from the USGS station inside of an elliptical concrete culvert. While the data for flow and stage are taken simultaneously at the site, there is a time lag between the collected data. If the lag time between the 2150 area velocity meter and the ISCO bubbler is large enough, the resulting flow peak would appear shifted in time because the 2150 data is collected first. Figure 3.13 below illustrates an example of lag time at the site.

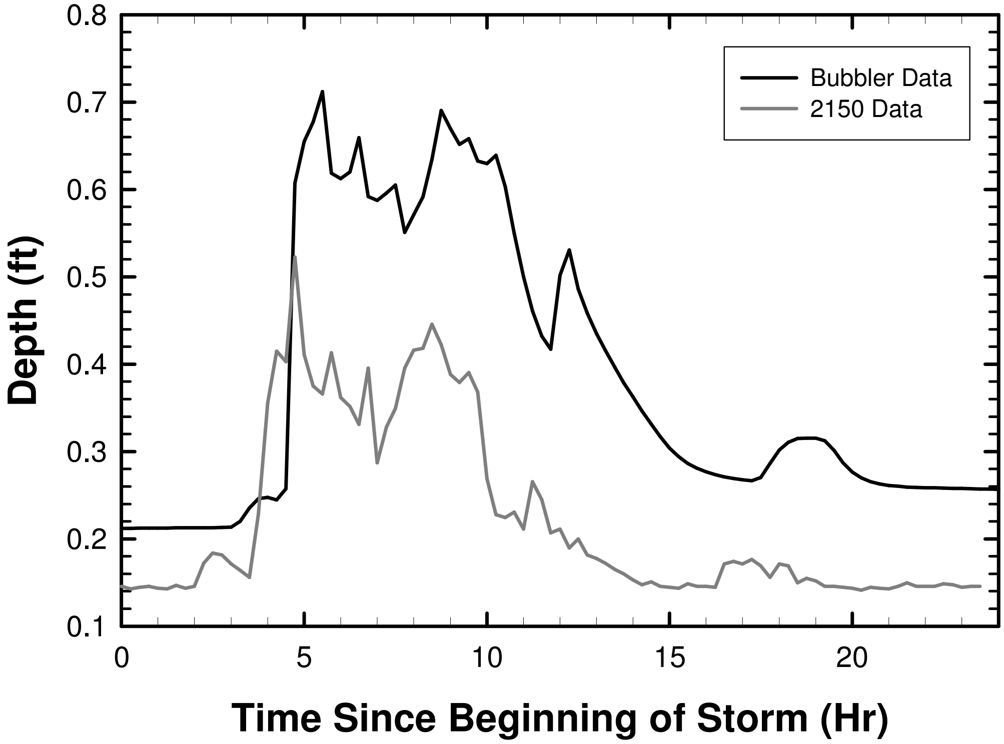

Figure 3.13: Lag in Instrument Reading Caused by Position Differences at Taylor Park

In the above figure it can be seen that both of the instruments are reading the exact same hydrograph, but the hydrograph recorded by the ISCO 2150 area velocity meter was recorded 30 minutes earlier than the hydrograph at the sampling site. This difference is caused by the lag between two instruments. In order to do accurate hydraulic comparisons and to create adequate rating curves, the lag in the data from the ISCO bubbler and the 2150 area velocity meter should be eliminated. The easiest way to eliminate this lag in the data is to come up with an estimation of the lag time between the two devices, and time shift the collected velocity data.

Lag estimation was done using floating tracers (e.g. breakfast cereal) during storm events several times during the course of the project. These tracers were released in the flow at the 2150 area velocity meter sensor, and the travel time to the ISCO bubbler was measured using a stopwatch. This method was repeated at different flow stages so that any changes in the lag time as a function of flow could be detected.

3.6.6 Data Collection and Validation

Hydraulic data were collected bi-weekly during dry weather monitoring and immediately following any rainfall events during the sampling season. Data collection was done using the Flowlink 4 software from Isco. At both sites the USGS installed a water quality sensor that provides real-time measurements of conductivity, dissolved oxygen, turbidity, and temperature. This data was used to validate the water quality concentrations during wet and dry weather monitoring. This real time data is available on the USGS website at http://ne.water.usgs.gov/projects/QWmonitoring.htm.

3.7 Chemical and Biological Analysis

3.7.1 Overview

The collected samples for wet and dry weather events were tested for a number of water quality parameters which will be discussed in further detail in the following sections. The concentrations of water quality parameters that the City of Lincoln had more interest in were determined more often for wet and dry weather events. Table 3.2 and 3.3 below show which samples were tested for each of the water quality parameters, where they were tested, and the maximum holding times for both dry and wet weather events.

Table 3.2: Water Quality Parameters Tested for Dry Weather Monitoring. X indicates the corresponding sample was tested for the applicable contaminant.

Water Quality Parameter	Sample Type		Lab	Maximum Hold Time
	Grab	Auto		
Nitrate	X	X	UNL Water Sciences	7 Days
Surfactants	X		UNL Civil Lab	24 Hours
Chlorine	X		UNL Civil Lab	3 Hours
Chloride	X		UNL Civil Lab	7 Days
Conductivity	X	X	UNL Civil Lab	24 Hours
Fluoride	X		UNL Civil Lab	7 Days
Soluble Reactive Phosphorous	X	X	UNL Civil Lab	24 Hours
Turbidity	X		UNL Civil Lab	24 Hours
COD	X	X	UNL Civil Lab	24 Hours
TSS	X	X	UNL Civil Lab	7 Days
pH	X	X	UNL Civil Lab	3 Hours
E. Coli	X	X	NE Public Health Lab	Deliver Immediately
DO	X		UNL Water Sciences	Deliver Immediately
Ammonia	X	X	UNL Water Sciences	Deliver Immediately
TKN	X	X	UNL Water Sciences	Deliver Immediately
Temperature	X		Field	--

Table 3.3: Water Quality Parameters Tested for Wet Weather Monitoring. X indicates the corresponding sample was tested for the applicable water quality parameter.

Water Quality Parameter	Sample Type			Lab	Maximum Hold Time
	Auto	Auto Reg	Grab		
Nitrate	X			UNL Civil Lab	7 Days
Chlorine			X	UNL Civil Lab	3 Hours
Chloride	X			UNL Civil Lab	7 Days
Conductivity	X			UNL Civil Lab	24 Hours
Fluoride	X			UNL Civil Lab	7 Days
Soluble Reactive Phosphorus	X	X		UNL Civil Lab	24 hours
Turbidity	X		X	UNL Civil Lab	24 Hours
COD	X	X	X	UNL Civil Lab	24 Hours
TSS	X	X	X	UNL Civil Lab	7 Days
pH		X	X	UNL Civil Lab	3 Hours
E. Coli	X		X	State Lab	Deliver Immediately
DO			X	UNL Water Sciences	Deliver Immediately
Ammonia	X			UNL Water Sciences	Deliver Immediately
TKN	X	X		UNL Water Sciences	Deliver Immediately
Temperature			X	Field	--
Oil & Grease			X	City of Lincoln	Deliver Immediately

3.7.2 Nitrate

The major sources of nitrates in surface water are fertilizers and food processing. Understanding nitrate concentrations is important because nitrates play a vital role in plant growth, and therefore eutrophication processes. For this project, nitrates were tested at the UNL Water Sciences Lab using the Cd- Reduction Method (Standard Methods 4500-NO3). This test has a minimum detection limit of 0.02 mg/L, and a reporting limit of 0.05 mg/L.

3.7.3 Total Kjeldahl Nitrogen

Total Kjeldahl Nitrogen (TKN) is the sum of organic nitrogen, ammonia (NH_3), and ammonium (NH_4^+). TKN concentrations were tested at the UNL Water Science lab using the Semi-Micro Kjeldahl method (Standard Method 4500-Nitrogen Organic). The minimum detection limit for this test is 0.15 mg/L, and the reporting limit is 0.20 mg/L.

3.7.4 Ammonia

Ammonia (NH_3) is found in most fertilizers, and is often found in household cleaning chemicals. Aquatic life also contributes to ammonia concentrations in most surface water bodies. Ammonia is toxic in high concentrations, especially at low temperatures or in water with high pH.

Ammonia concentrations were determined at the UNL Water Sciences Lab using the alkaline phenate method on a Seal AQ2 Autoanalyzer following the EPA Standard

Method 350.1. Ammonia samples were delivered in clean bottles immediately following a wet or dry weather sampling event.

3.7.5 Anionic Surfactants

Anionic Surfactants are found in a range or detergents, and are often introduced into surface water through car washing, laundry, or illicit discharges. Surfactant concentrations were determined within 24 hours of collection in the UNL environmental engineering laboratory using Hach Method 8028 (Hach Company, 2002). This method is capable of detecting concentrations of 0.000 - 0.275 mg/L as Alkylate Sulfonate. The precision of these test is about ± 0.004 mg/L.

3.7.6 Chlorine

The main source of chlorine in surface water is through the disinfection of swimming pools and drinking water. Chlorine itself is toxic to aquatic organisms in high concentrations, and has the potential to react with organic substances to create carcinogenic compounds like trihalomethanes.

Because chlorine volatilizes in air its concentration must be tested within 3 hours using Hach Total Chlorine Powder Pillows and Hach Method 8167. This method is useful in detecting concentrations of 0.0 - 2.0 mg/L chlorine with a precision of ± 0.03 mg/L.

3.7.7 Chloride

Chlorides are found naturally in the environment in the form or salt, and are found in high concentrations in surface water near underlying salt water aquifers. Drinking water also generally has a chloride concentration of 10-20 mg/L. Chloride concentrations were determined using the Mecuric Thiocynate Method (Hach Method 8113) which is capable of detecting concentrations of 0-20 mg/L chloride with a precision of ± 0.5 mg/L. The maximum holding time for chloride samples is seven days.

3.7.8 Conductivity

Conductivity is a measure of a samples ability to hold electric current, and is generally used to determine mineralization, and suspended solids loading. Conductivity measured in a natural stream generally decreases as the flow increases as a result of a higher suspended solids concentration. Conductivity of the water samples was determined using a Hach HQ14d Conductivity meter. This meter has a minimum detection limit of 5mg/L, and is capable of measuring conductivity to the nearest 0.1 mg/L. The maximum holding time for conductivity samples is 24 hours.

3.7.9 Fluoride

Fluoride is found in regular tap water in concentrations of 1-1.2 mg/L and is introduced during drinking water treatment for dental health reasons. Fluoride does not volatilize in air and is toxic to humans and aquatic life in very high doses.

Fluoride concentrations were determined using Hach Fluoride Accu-Vac Ampuls, and Hach Method 8029, which is capable of detecting 0-2mg/L of fluoride with a precison of ± 0.03 mg/L. The maximum holding time for fluoride samples was 7 days.

3.7.10 Soluble Reactive Phosphorous

Phosphorous is an essential nutrient for plant development and is found in most lawn and plant fertilizers. Human and animal wastes also generally have relatively high concentrations of phosphorous. The eutrophication of water bodies, particularly lakes is often directly tied with phosphorous concentrations, and is therefore a very important water quality parameter. Soluble Reactive Phosporous concentrations were determined using Hach Method 8048, which is capable of detecting phosphorous concentrations of 0.02 – 2.5 mg/L. The maximum holding time for phosphorous samples is 24 hours.

3.7.11 Turbidity

Turbidity is a measure of the clarity, or cloudiness of a water sample, and is an optical measure of the samples ability to trasmit light. The turbidity of a water sample is directly related to the samples suspended sediment and colloidal concentrations in the sample. Turbidity was tested using method 2130 in the *Methods for Examination of Water and Wastewater,* 19th edition. A Hach 2100N Turbidmeter was used for testing and is capable of generating turbidity results of 0-4000 NTU (Nephelometric Turbidity Units). The holding time for turbidity samples was 24 hours.

3.7.12 Chemical Oxygen Demand

Chemical oxygen demand (COD) of surface water relates to the process by which organic compounds react with dissolved oxygen to form carbon dioxide, water, and ammonia. Chemical oxygen demand tests generally determine the amount of organic pollutants in the surface water sample. Chemical oxygen demand was determined using Hach Method 8000. This test measures the amount of organic compounds in water, and is able to detect concentration from 3-150 mg/L as COD. The maximum holding time for COD samples is seven days.

3.7.13 Total Suspended Solids

Total Suspended Solids, or TSS is a measure of the suspended matter in a water sample. Higher suspended sediment concentrations often indicate higher levels of bacteria and other pollutants. TSS was measured using Method 2540 D from *Standard Methods for Examination of Water and Wastewater,* 19th edition using standard filters and dried between 103 – 105°C. The maximum holding time for TSS samples is 24 hours.

3.7.14 pH

The pH of a sample is a measure of its acidity or alkalinity, and has very important effects on the samples biological and chemical processes of a water body. The toxic effects of many pollutants increase or decrease with pH; for example, low pH will increase the toxic effects of heavy metals in water samples. The pH of a sample was determined using a pH meter by Denver Instruments which is capable of reporting pH to the nearest 0.01 pH unit with a precision of 0.02 pH units.

3.7.15 E. Coli

E. Coli is a type of coliform bacteria which is used as an indicator of water quality. The presence of E. Coli in a water sample generally indicates recent fecal contamination. In surface water this is often a result of runoff containing animal feces. E. Coli concentrations were measured using the coli-lert-QT (quanti-tray method) by the State of Nebraska water sciences laboratory. Collection of E. Coli samples was done with special sterile bottles and were tested within 24 hours of collection.

3.7.16 Dissolved Oxygen

The dissolved oxygen concentration of a water sample indicates the amount of O_2 gas dissolved within the water. It is an important parameter for plant growth, as well as the health of aquatic life. Dissolved oxygen concentrations were determined by the UNL Water Sciences Laboratory using the Winkler Titration Method (Standard Method 4500-O). This method has minimum detection, and reporting limits of 0.1 mg/L. Maximum holding time for DO samples is 3 hours.

3.7.17 Temperature

The temperature of the water samples was tested in the field using an electronic thermometer, and was measured 6 inches below the water surface. The temperature of the bottled samples was also recorded to make sure the temperature measurement in the stream itself was valid.

3.8 Quality Assurance/Quality Control

Quality Assurance and Quality control of the data is important in any study to ensure that the testing methods as well as the recorded data have the best quality possible. This section of the report outlines the determination of the Minimum Detection Limits for the water quality parameters used in this study; as well as discusses the use of Standard Solutions, Duplicate Samples, and Travel Blanks used to assure data quality.

3.8.1 Minimum Detection Limits

Minimum detection limits (MDLs) were experimentally determined for the water quality parameters analyzed in the Civil Engineering laboratory. MDLs are defined by the Environmental Protection Agency (EPA) as the minimum concentration which can be determined with 99% confidence that the true concentration is greater than zero. The procedure follows the EPA's description outlined in 40 CFR 136 Appendix B.

Table 3.4 shows the calculated minimum detection limits for the analytical procedures used in 2009. These established MDLs were re-evaluated throughout the sampling process. When a concentration was found to be lower than the established MDL, the concentration was reported as "<MDL". Additional information regarding MDL's for this project and the data used to calculate them can be referenced in Mohlman et al. (2009).

Table 3.4: Minimum Detection Limits for Analytical Procedures

Analysis	Minimum Detection Limit	Laboratory Used
Chloride	0.30 (mg/L)	UNL Civil Engineering
Total Chlorine	0.017 (mg/L)	UNL Civil Engineering
Conductivity	1.63 (µs/L)	UNL Civil Engineering
COD	4.34 (mg/L)	UNL Civil Engineering
Copper	15 (µg/L)	UNL Civil Engineering
Fluoride	0.028 (mg/L)	UNL Civil Engineering
Nitrate	0.265 (mg/L)	UNL Civil Engineering
Soluble Reactive Phosphorous	0.025 (mg/L)	UNL Civil Engineering
Anionic Surfactants	0.005 (mg/L)	UNL Civil Engineering
Nitrates	0.02 mg/L	UNL Water Science Lab
Dissolved Oxygen	0.1 mg/L	UNL Water Science Lab
Total Kjeldahl Nitrogen (TKN)	0.20 mg/L	UNL Water Science Lab

3.8.2 Standards

The precision of each testing method was evaluated by testing known standards throughout the summer. Testing the standards ensured the tests were being performed correctly. All standards tested were found to be within an acceptable range of the known concentration. The standards were used to calculate the MDLs found in Table 3.4.

3.8.3 Duplicate Samples

Duplicate samples were taken for eight grab samples from the dry weather monitoring during the summer of 2009. These duplicates assisted in ensuring the consistency of sampling and testing methods. The “-“ in the table denotes that a test result lower than the minimum detection limit was observed, except for TSS. TSS was performed on samples with turbidity above 1.0 NTU.

Tables 3.5, and 3.6 show the relative percentage difference found between duplicate samples taken at each of the sites for dry weather monitoring and wet weather monitoring respectively. The percent difference is the absolute value of the difference between the two samples divided by the average of the two samples. The "-" used in the table denotes one or more of the duplicate samples had a result less than the minimum detection limit.

Good precision was seen for many parameters. Given that some of the concentrations were close to the MDL, reasonable precision was seen for the total chlorine, COD, total phosphorous, surfactants, turbidity, and conductivity results. A high relative percentage difference was seen for TSS due to the imprecision of the procedure at such low concentrations.

Table 3.5: Percent Difference Between Duplicate Dry Weather Samples

Sample ID	Chloride	Total Chlorine	COD	Fluoride	Nitrate
1	5%	14%	0%	1%	0%
2	5%	7%	-	3%	9%
3	16%	29%	7%	11%	0%
4	11%	15%	22%	2%	15%
5	5%	7%	24%	24%	0%
6	4%	6%	6%	9%	0%
7	0%	0%	19%	13%	-
8	5%	15%	8%	2%	-
Average	**6%**	**12%**	**12%**	**8%**	**4%**

Sample ID	Soluble Reactive Phosphorous	Surfactants	Turbidity	TSS	Conductivity
1	1%	11%	27%	29%	0%
2	1%	25%	85%	-	2%
3	6%	24%	30%	-	1%
4	0%	15%	1%	-	65%
5	76%	5%	12%	194%	-
6	8%	12%	14%	-	17%
7	0%	7%	17%	74%	-
8	7%	6%	3%	55%	-
Average	**12%**	**13%**	**24%**	**88%**	**17%**

Table 3.6: Percent Difference between Duplicated Wet Weather Samples

Sample ID	Conductivity	Chloride	Fluoride	Phosphorous	TSS	COD	Turbidity	pH
1	1%	6%	18%	7%	25%	20%	9%	0%
2	0%	7%	4%	9%	8%	10%	18%	0%
3	1%	3%	27%	13%	5%	10%	65%	0%
4	3%	6%	0%	8%	11%	6%	19%	1%
Average	1%	6%	12%	9%	12%	12%	28%	0%

3.8.4 Travel Blanks

Seven travel blanks were taken into the field. The travel blanks consisted of de-ionized water carried in clean, plastic bottles. Blanks were tested in the same manner as grab samples. The results from the travel blanks are listed in Table 3.7. The results indicate no significant source of contaminants from the sample bottles or travel conditions. A few samples had slightly elevated levels of phosphorous and surfactants. Both are found in soaps and are likely the effect of residues from washing.

Table 3.7: Travel Blank Results

Blank #	Date	Total Chlorine (mg.L)	Chloride (mg/L)	COD (mg/L)	Fluoride (mg/L)	Nitrate (mg/L)	Soluable Reactive Phosphorous (mg/L)	Surfactants (mg/L)
1	7/22	<MDL	<MDL	<MDL	<MDL	<MDL	**.03**	**.010**
2	7/22	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	**.007**
3	8/6	<MDL	<MDL	**6**	<MDL	**.3**	**.04**	<MDL
4	8/6	<MDL	<MDL	<MDL	**.03**	**.3**	**.07**	**.012**
5	8/6	<MDL	<MDL	<MDL	<MDL	<MDL	**.04**	<MDL
6	8/11	<MDL	<MDL	<MDL	**.03**	<MDL	<MDL	<MDL
7	8/11	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL

Chapter 4. Results

This section of the report outlines the data collected. Comparisons were conducted on water quality data to identify statistically significant differences, and those results are presented here. Mass loading models predicting the concentrations of TSS at both sites are also discussed.

4.1 Summary of Data Collected

4.1.1 Continuous Flow Measurement

ISCO bubble stage monitors maintained by the UNL Civil Engineering Department were used to continuously measure the stage at both sampling sites. Data were collected at 15 minute intervals, details can be seen in Table 4.1.

Table 4.1: Continuous Flow Measurement Sampling Dates

Year	Site	Begin Date	Ending Date
2008	Colonial Hills	8/12/2008	11/4/2008
	Taylor Park	8/6/2008	11/4/2008
2009	Colonial Hills	3/5/2009	9/23/2009
	Taylor Park	3/5/2009	9/23/2009

4.1.2 Discrete Flow Measurement

ISCO 2150 Area Velocity Loggers maintained by the UNL Civil Engineering Department were used to continuously measure the stage at both sampling sites. Data were collected at 15 minute intervals, details can be seen in Table 4.2

Table 4.2: Discrete Flow Measurement Sampling Dates

Year	Site	Begin Date	Ending Date
2008	Colonial Hills	8/12/2008	11/4/2008
	Taylor Park	8/6/2008	11/4/2008
2009	Colonial Hills	3/11/2009	9/23/2009
	Taylor Park	5/26/2009	9/23/2009

It is important to note that ISCO 2150 Area Velocity Meters are incapable of accurately measuring very low velocities. During dry weather monitoring it is common for the Colonial Hills site to have several feet of standing water with extremely low velocity. For this reason the collected flow rate data at the Colonial Hills site for low flows is suspect.

4.1.3 Pseudo-Continuous Water-Quality Sampling

The USGS has used a probe to gather temperature, turbidity, specific conductance and dissolved oxygen data. Data were collected at 15 minute intervals. Details can be seen in Table 4.3.

Table 4.3: Pseudo-Continuous Water-Quality Sampling Dates

Year	Site	Begin Date	Ending Date
2008	Colonial Hills	7/23/2008	11/11/2008
	Taylor Park	7/23/2008	11/11/2008
2009	Colonial Hills	3/5/2009	12/2/2009
	Taylor Park	3/6/2009	12/2/2009

4.1.4 Discrete Water-Quality Sampling

A series of water quality samples have been collected from both sites. These samples include:

<u>Dry Weather Samples (approximately every other week):</u>

15 events, 60 total samples. Details are provided in Table 4.4.

Table 4.4: Dry Weather Sampling Details

Year	Begin Date	Ending Date	Sampling Events	Number of Samples (Auto/Grab)
2008	8/13/2008	10/28/2008	5	10/10
2009	3/25/2009	11/7/2009	10	20/20

Wet Weather Samples (collected near the end of storm events for regulatory purposes):

6 events, 68 Auto Samples, 18 grab samples. Details are provided in Table 4.5 on the following page

Table 4.5: Wet Weather Sampling Details

Year	Event Date	Event Number	Samples at Taylor Park (Auto/Grab)	Samples at Colonial Hills (Auto/Grab)
2008	10/6/2008	1	6/1	6/1
2009	4/27/2009	2	5/1	1/1
2009	7/14/2009	3	8/1	4/1
2009	8/4/2009	4	6/1	7/1
2009	8/26/2009	5	6/1	1/1
2009	9/3/2009	6	6/1	6/1
2009	10/13/2009	--	3/3	3/3

4.2 Dry Weather Monitoring

Samples were collected at the sites during dry weather periods five times during the 2008 sampling season and 10 times during the 2009 sampling season for a total of 15 sampling events, and 60 total samples. This sampling was done at both sites, and at least one auto and one grab sample were collected during each sampling event. This section of the report discusses the water quality data collected during these sample events. In particular statistically significant differences between the water qualities of the samples and sampling methods are identified.

4.2.1 Auto Versus Grab Samples

The water quality of the Auto and Grab samples from collected during dry weather flows from both the 2008 and 2009 sampling seasons were compared to one another to identify any bias caused by sampling technique. This was done using a matched-pairs t test with both 90% and 95% confidence intervals (Dowdy et. al. 2003).

Table 4.6 shows the P-values associated with this statistical test. Very low P-values indicate significant differences, in this case a P-value less than 0.025 or 0.050 indicates significant statistical differences with 95% and 90% confidence respectively.

Table 4.6: P-Values for Auto and Grab Sample Comparison

Water Quality Parameter	P Values	
	Taylor Park	Colonial Hills
TKN	0.243	0.334
Nitrate	0.133	0.656
Conductivity	0.177	0.361
Soluble Reactive Phosphorous	0.157	0.433
pH	0.459	0.307
COD	0.560	0.354
TSS	0.826	0.270
E.Coli	0.301	0.237

As the above table indicates, there were no statistically significant differences detected between the two sampling types.

4.2.2 Taylor Park Versus Colonial Hills: Dry Weather

The concentrations from the dry weather monitoring samples for the Taylor Park and Colonial Hills samples were tested against one another to identify significant water quality differences between the two sites. This was done using a matched-pairs t test with both 90% and 95% confidence intervals. This comparison was made using the concentrations obtained using the arithmetic average of the concentrations detected in the auto and grab samples; in cases where no auto samples were collected this comparison was done using grab samples only. The samples collected at Taylor Park were paired with the samples collected at Colonial Hills and were paired based on the type of sample (Auto or Grab), and the date the samples were taken.

Table 4.7 shows the P-values associated with this statistical test. P-values less than 0.025 or 0.050 indicated statistically significant differences with 95% and 90% confidence levels, respectively.

As the table indicates, there are significant differences between the water quality concentrations at the two sites for some parameters. The Nitrate, Phosphorous, and E.Coli concentrations at Taylor Park are significantly higher than the concentrations at Colonial Hills with 95% confidence. These differences in concentrations may be related to the structural and educational BMPs used in the Colonial Hills watershed, but they may also be related to differences in other watershed characteristics.

Table 4.7: P-Values for Dry Weather comparison based on sampling site.
Bold – Different with 95% significance *Italic* – Different with 90% significance

Water Quality Parameter	P	Site With Greater Concentration	Average Difference
TKN	0.173	--	--
Nitrate	**0.023**	**Taylor Park**	**0.71 mg/L**
Surfactants	0.238	--	--
Chloride	0.150	--	--
Chlorine	*0.050*	*Colonial Hills*	*0.04 mg/L*
Fluoride	*0.028*	*Taylor Park*	*0.1 mg/L*
Conductivity	0.071	--	--
Soluble Reactive Phosphorous	**0.006**	**Taylor Park**	**0.31 mg/L**
pH	0.890	--	--
Turbidity	*0.033*	*Colonial Hills*	*1.38 NTU*
COD	0.400	--	--
TSS	0.290	--	--
E.Coli	**0.002**	**Taylor Park**	**1137 cfu/100ml**
Temperature	**0.025**	**Colonial Hills**	**2.4 °C**
Dissolved Oxygen	0.460	--	--

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The comparison of chlorine and fluoride concentrations at the sites indicates that the chlorine concentrations are higher at Colonial Hills, and the fluoride concentrations are higher at Taylor Park with 90% confidence. Both of these concentrations are generally directly related to the amount of drinking water present in the runoff, and therefore are expected to behave similarly. The fact that the fluoride and chlorine concentrations are not statistically higher at the same site may be attributed to differences in the groundwater contribution to flow at both sites.

Since the majority of the flow at Taylor Park is from a concrete storm sewer upstream of the sampling site, the contribution of groundwater to the flow is likely very minimal, but groundwater flow may have a much greater influence at Colonial Hills. It is important to note that these differences are only significant at the 90% confidence level, additional data is needed to detect differences at a higher significance level.

The water temperature at Colonial Hills is significantly different with 95% confidence. This difference is most likely related to the fact that the majority of the flow at the Colonial Hills site is above ground, whereas the majority of the upstream flow at the Taylor Park site occurs in a storm sewer. The flow at Colonial Hills is in direct sunlight for much of its flow path which results in a higher temperature. Additionally the flow at the Colonial Hills site moves slowly through ponds and wetlands which allows the water additional time to warm up.

4.3 Wet Weather Monitoring

4.3.1 Taylor Park versus Colonial Hills

Wet Weather samples were collected for one event in 2008, and five events in 2009. In order to compare the concentrations during wet weather events, t-tests were run on the data to detect any significant differences.

It is important to note that this t-test was conducted by comparing the concentrations detected in sequential auto samples. Therefore the first sample collected at Taylor Park was paired with the first sample collected at Colonial Hills, the second sample was paired with the second, and so on. Since the samples at both sites were not taken at identical times the differences between concentrations are generally large, the resulting variances for this comparison are large, and therefore these results are very general. The results from this analysis can be seen in Table 4.8.

Table 4.8: P-Values for Wet Weather Comparison between sites.
Bold – Different with 95% significance *Italic* – Different with 90% significance

Water Quality Parameter	P	Site With Higher Concentration	Average Concentration Taylor Park	Average Concentration Colonial Hills
Nitrate	0.946	**--**	0.67 mg/L	0.68 mg/L
Chloride	0.156	--	10.9 mg/L	15.4 mg/L
Conductivity	**0.021**	**Colonial Hills**	264 µs/cm	374 µs/cm
Soluble Reactive Phosphorous	0.873	**--**	0.72 mg/L	0.74 mg/L
Turbidity	*0.038*	*Colonial Hills*	72 NTU	172 NTU
COD	0.751	--	75.5 mg/L	78.6 mg/L
TSS	0.112	--	274 mg/L	524.8 mg/L
E.Coli	0.134	**--**	44000 cfu/100ml	16200 cfu/100ml

From the above table it can be seen that the conductivity at the Colonial Hills site is statistically greater than the concentration at Taylor Park with 95% confidence. The turbidity at Colonial Hills is higher with 90% confidence.

In addition to these statistically significant differences there were several notable differences within the wet weather data set. TSS concentrations at the Colonial Hills site were generally higher than the concentrations observed at Taylor Park. Additionally, E. Coli concentrations were higher at the Taylor Park site. While these differences were not significant statistically, they are worth noting and considering in further work on this project.

It is important to note, that wet weather samples were only tested using the soluble reactive phosphorous test; therefore, none of the sediment bound phosphorous is reflected in these numbers. Additional wet weather sampling should include the Total Phosphorous test to help quantify the phosphorous contained in the sediment at both sites.

4.3.2 UNL data versus USGS data

In an effort to verify the Turbidity and Conductivity concentrations for wet weather samples tested in the Civil Engineering Lab, a comparison between these discrete concentrations and interpolated values from the continuous USGS probe data set was conducted. The interpolation of the data supplied by the USGS data probe was done from 90 second resolution, and 15 minute resolution data. The results of the analysis can be reviewed in Table 4.9 below.

Table 4.9: P-Values for Comparison Between USGS and UNL Data: Wet Weather

	Taylor Park		Colonial Hills	
Parameter	**90 Second Data**	**15 Minute Data**	**90 Second Data**	**15 Minute data**
Turbidity	0.38	0.26	0.10	**0.005**
Conductivity	0.82	0.32	0.75	0.729

In Table 4.9 it can be seen that the turbidity concentrations interpolated from 15 minute data at Colonial Hills are statistically different with 95% confidence. This difference could be a result of a number of issues, the most likely of which is related to errors in the sample time estimations which directly affect the interpolation of the USGS data. To illustrate this concern the turbidity time series for the storm event at Colonial Hills on 8/4/2009, can be seen in Figure 4.1, below.

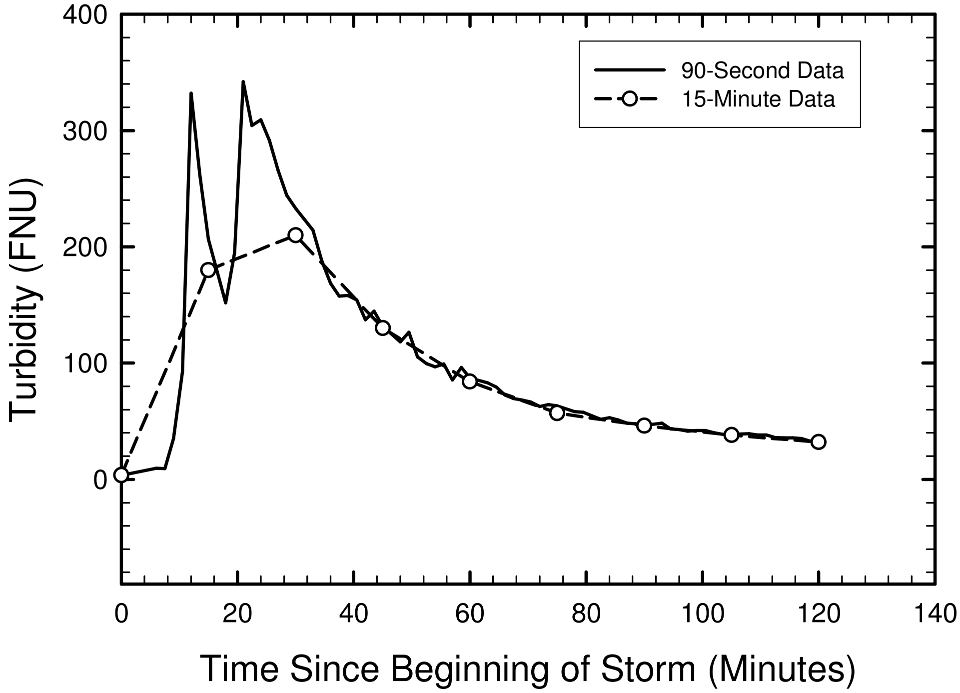

Figure 4.1: Comparison between 15 minute and 90 minute Data (8/4/2009 Event at Colonial Hills)

In Figure 4.1 it can be seen that the 15 minute data set is inadequate for accurately representing the turbidity when the concentrations change rapidly, which is common during storm events in small urban watersheds. Interpolation using the 15 minute data during this storm event would yield inappropriately low turbidities when compared to turbidities seen in the 90 second data. Therefore, whenever possible, interpolation from 90 second data should provide a more accurate estimation of the actual turbidity, than estimations derived from 15 minute data.

This difference could also be attributed to a problem with the sampling line at the Colonial Hills site. If the concentrations are very high at the site, which is true during wet-weather flows, the duration of the cleaning cycle may not be sufficient to “flush out” the line before subsequent samples are taken, resulting in inappropriately high concentrations. It is important to note that this concern is valid for all flows, but is more likey to occur during wet-weather flows when the concentrations are high.

Since turbidity is an optical parameter, differences in the methods used to obtain the concentrations should be considered. The UNL estimates for turbidity were recorded with the units of NTU, the USGS estimates were recorded with the units of FNU. While these units are theoretically equivalent, there is evidence which suggests that different methods used to obtain turbidity estimates often yield significantly different results even on the same sample (Ziegler, 2002). This consideration may explain why the P-values for Turbidity are lower for every comparison made with the USGS data sets.

It is important to note that the P-values associated with these comparisons are universally higher for the 90-second comparison. Since high P-values indicate that there are no significant differences between the data sets, this result suggests that concentrations interpolated using the 90 second data are more accurate than the 15 minute equivalent. Therefore 90 second data should be used whenever available.

4.4 Depth Time Series

Level and flow measurements were taken continuously during the 2009 sampling season between the months of May and October. Figures 4.2 and 4.3 show the depth vs. time series for Taylor Park and Colonial Hills between the months of May and September 2009, additional time series for depth can be found in Appendix A.

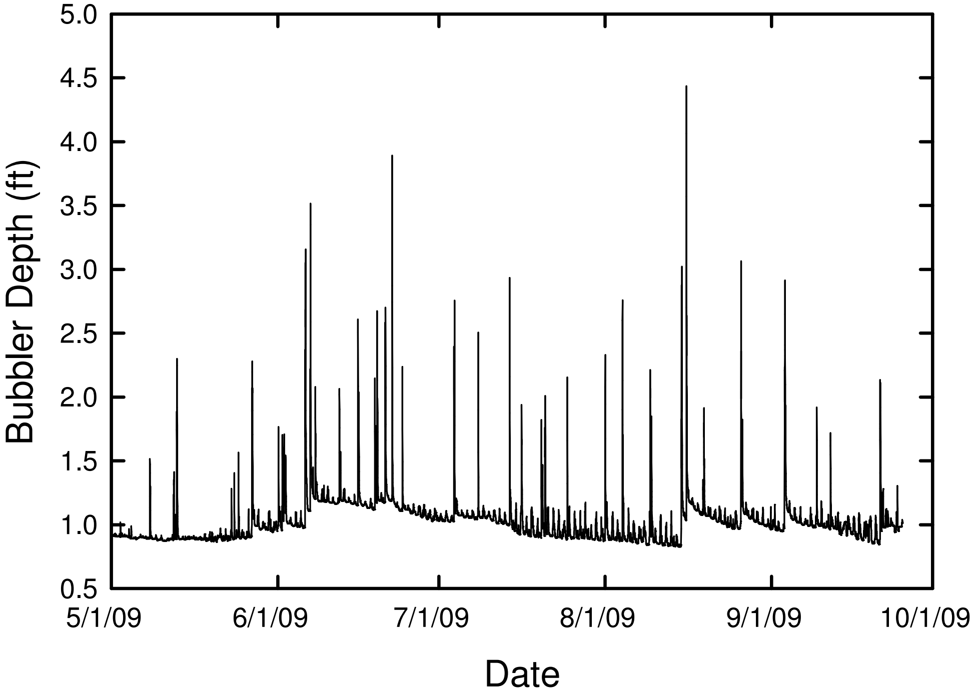

Figure 4.2: Taylor Park Depth Time Series

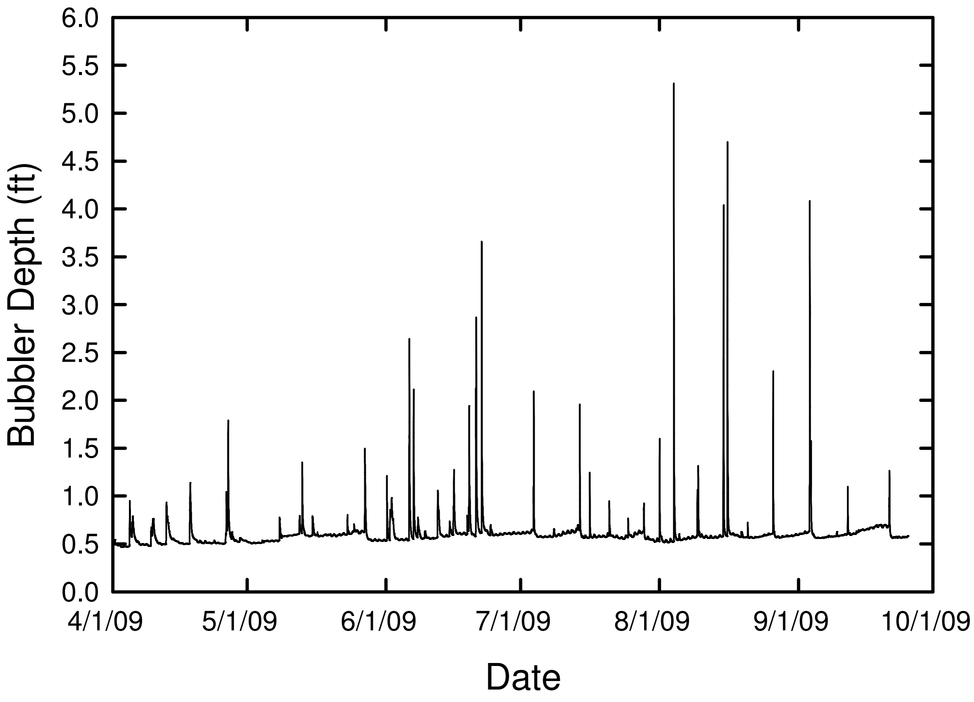

Figure 4.3: Colonial Hills Depth Time Series

4.5 Rating Curves

Rating curves have been developed at both sites to be used in the sampling program for wet weather monitoring. These rating curves relate the flow rate in the channel to depth of flow and will be used to determine the rate of sample collection during wet weather events in 2010.

4.5.1 Taylor Park Rating Curve

As mentioned above, the rating curve at Taylor Park was generated using the depth from the ISCO Bubbler meter, and the flow rate was measured using the 2150 area velocity meters.

Because the velocity meter is installed in the culvert upstream of the bubbler meter at the Taylor Park site, a lag time exists between the measurements. In order to generate an accurate rating curve this lag time needed to be removed. Estimates for this lag time were determined during a non sampled storm event on 6/15/2009 to be about 12 minutes during lower flows and between 7 to 9 minutes during higher flows. For simplicity, the flow data was shifted ahead in time by 15 minutes to account for this lag in the creation of the Taylor Park rating curve. Additional information about this lag time estimation can be seen in Appendix B.

Figure 4.4 shows the Taylor Park rating curve with this time correction

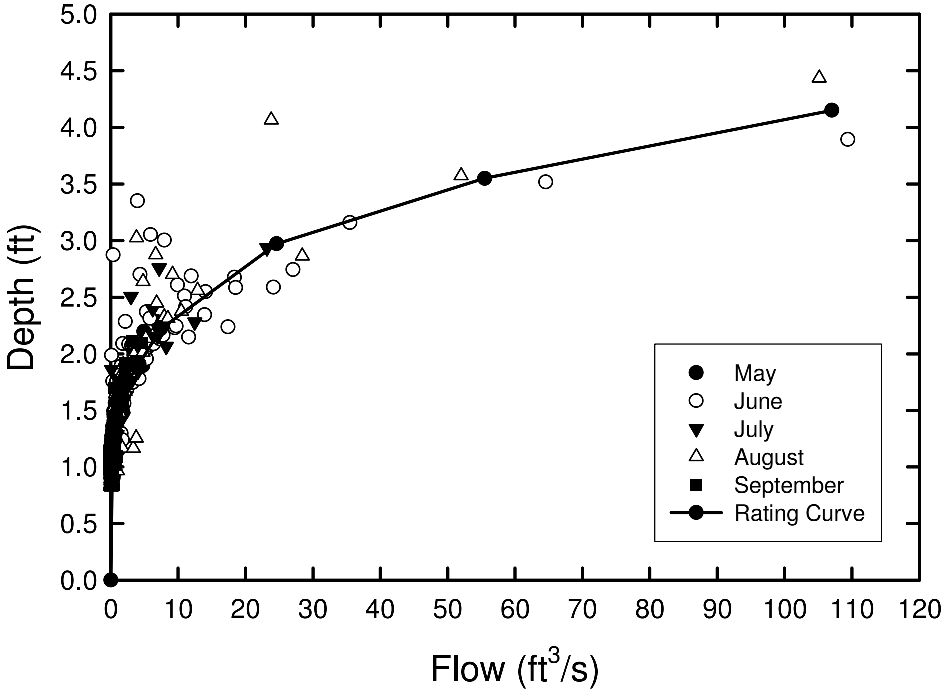

Figure 4.4: Taylor Park Rating Curve 2009, Time Adjusted

The rating curve used in the sampler program for 2009 is shown in Figure 4.4. Despite moderate scatter at the middle range of flows, the rating curve used in the second year of the study does a better job of predicting flow at low depths than the one used during the first year. Since higher magnitudes of flow were observed in the 2009 sampling season, a few additional points were added to the relationship. The new rating curve for Taylor Park is listed in Table 4.10.

Table 4.10: Taylor Park Rating Curve for 2010
(Italic Signifies Points added in 2009)

Depth	Flow
0.00	0.00
0.87	0.2
1.39	0.7
1.76	2.5
1.91	4.2
2.22	7.4
2.97	24.6
3.55	*55.5*
4.15	*107.0*

Since the flow and depth measurements at the Taylor Park site are not taken at the same location, the possibility of overland flow entering the stream between the two locations is a concern. The major contributor to this potential overland flow is from an overflow channel built to handle flows from the street during very severe rainfall events. In order to estimate this possible overflow, this channel was measured to be 8 ft wide and assumed to be rectangular. The flows were estimated for a range of depths using the broad-crested weir equation, flow rates for this type of weir are found using Equation 4.1:

$$Q = \frac{2}{3} C_d \sqrt{2g} D^{3/2} B \qquad (4.1)$$

Where C_d is the weir discharge coefficient, D is the depth, and B is the width of the channel. For this estimation the value for C_d was assumed to be a general value of 0.6. Table 4.11 below shows the results of the flow estimation for a range of depths.

Table 4.11: Overflow Estimation at Taylor Park

Depth (ft)	Flow (cfs)	% of Maximum Observed Flow in Main Channel
0.0	0.0	0.0
0.2	2.3	2.1
0.4	6.5	5.9
0.6	11.9	10.8
0.8	18.4	16.7
1.0	25.7	23.3

The "% of maximum flow" was based on the maximum flow rate of 110 cfs observed in the 2009 sampling season. In the above table it can be seen that ignoring the overflow if the depth in the channel is only 0.2 feet would result in 2.1% error in the flow rate estimation, but at a depth of 1.0 ft, the error would be 23.3%. This indicates that at very low overflow depths the error associated with omitting this overflow in the total flow rate causes errors which are well within the precision of the experiment, and therefore can be considered negligible.

It is important to note that these estimations use a discharge coefficient ($C_d = 0.6$) appropriate for flow rates in an engineered concrete channel. Actual flow rates on site would likely be less because the overflow channel is much rougher than concrete.

4.5.2 Colonial Hills Rating Curve

Because of the standing water present at the Colonial Hills site, the 2150 flow meter at the Colonial Hills site is unable to accurately measure the velocity in the channel. This inaccuracy results in a poor estimation of the flow rate during very low flows and infrequent measurements during storm events. In order to accurately describe the depth to flow relationship additional flow measurements were taken during non-sampled storm events on 8/26/2009, and 10/22/2009. The data collected during this sampling season is shown in Figure 4.5.

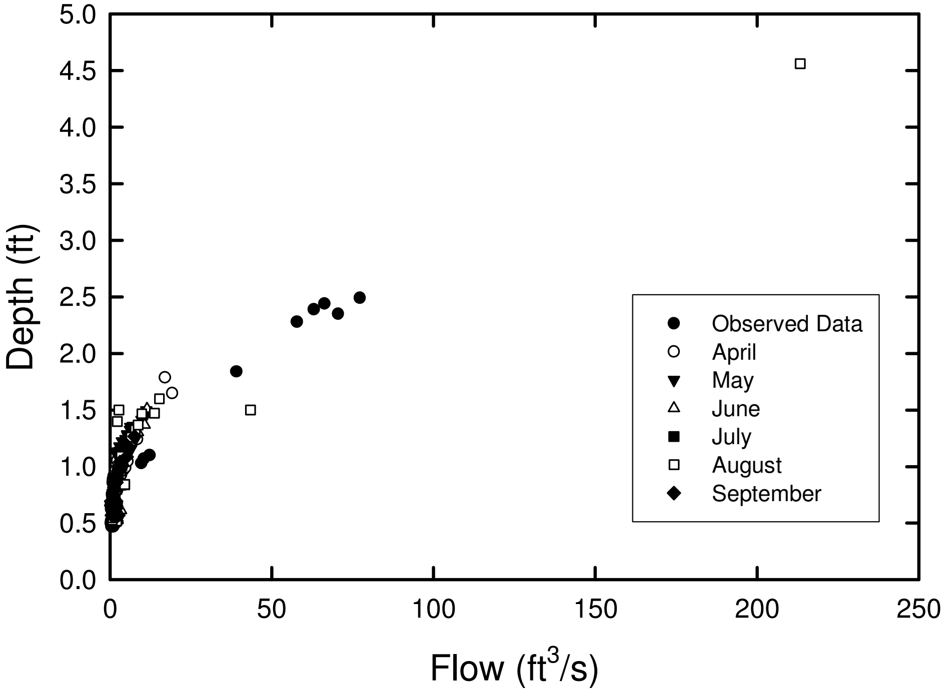

Figure 4.5: 2009 Colonial Hills Rating Curve

Since there is very limited data at high flows for this site, the rating curve for higher flows was generated using a depth to area relationship that was surveyed at the beginning of the study in 2008, and a depth to velocity relationship generated using the data from this year. Since flow can be calculated by multiplying velocity and area, this is a reasonable predictor for the flow rate where there is limited data. Figure 4.6 shows the depth to velocity relationship, and Table 4.12 shows the depth to area relationship.

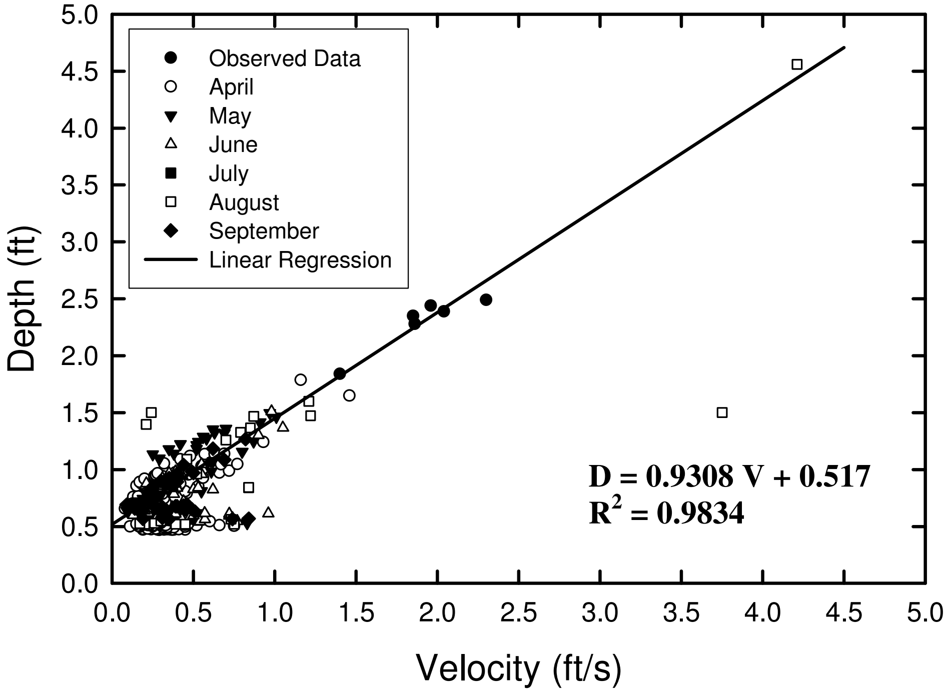

Figure 4.6: Depth vs. Velocity at Colonial Hills

Assuming that the depth to velocity relationship is linear, a standard linear regression was run on the data set observed during the 8/26/2009 and 10/22/2009 storm events. The regression has a good R^2 value, and it can be seen in Figure 4.6 that the majority of the data obtained at lower flows also follows this relationship.

Table 4.12: Depth to Area Relation at Colonial Hills

Depth (ft)	Area (ft^2)
0.000	0
0.500	2.56
1.000	6.68
1.500	11.59
2.000	16.95
3.000	28.36
3.500	36.52
3.860	42.89

Figure 4.7 shows the rating curve as predicted using the depth to velocity, and depth to area relationships. It can be seen that for the higher flows the estimation using this method is reasonable, but at lower levels this method overestimates the flow.

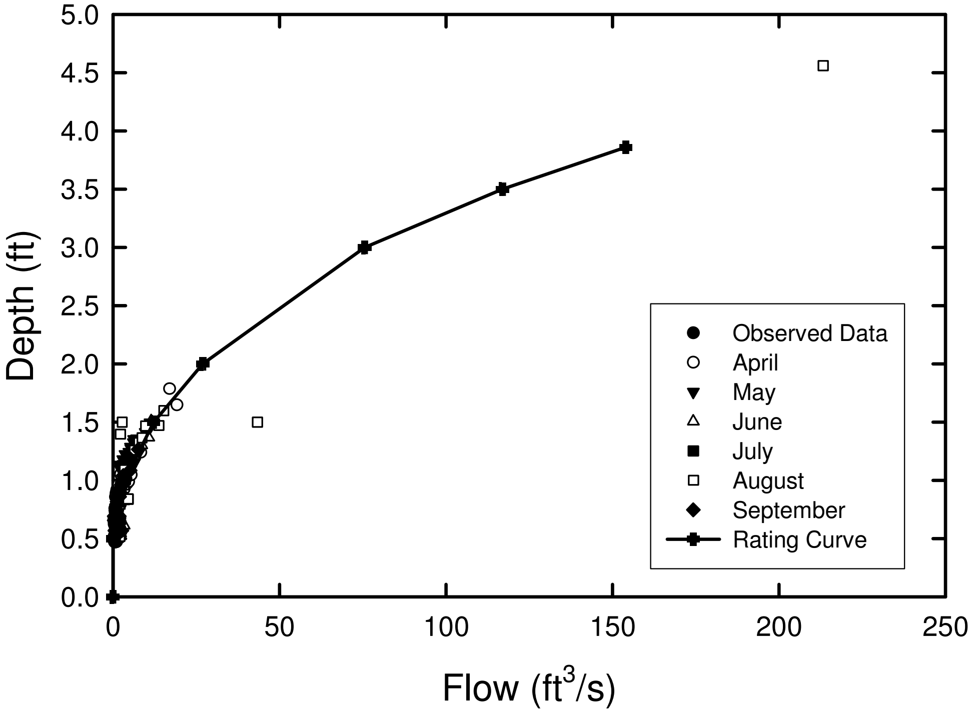

Figure 4.7: Estimated Rating Curve at Colonial Hills

The rating curve for 2010 for Colonial Hills is listed in Table 4.13

Table 4.13: Colonial Hills Rating Curve 2010

Depth (ft)	Flow (ft^3/s)
0.000	0.0
0.500	0.0
1.000	3.5
1.500	12.2
2.000	27.0
3.000	75.6
3.500	117.0
3.860	154.0

4.6 Mass Loadings

Mass loadings for this project were determined using a flow versus time data series as well as the collected water quality data. Since the water quality data collected via grab samples is sparse, the continuous USGS data probe concentrations were used in conjunction with flow rate data to calculate mass loadings for the 2009 sampling season. Since the USGS data probes are only capable of measuring conductivity, turbidity and dissolved oxygen the mass loading analysis has been completed for these constituents only.

Mass loadings were examined using a cumulative mass loading plot (CMP). This was done by multiplying the contaminant concentration by a normalized flow rate. In this case, the flow rate was normalized using the maximum flow during the sampling season at the site in question. The resulting incremental masses were then sorted in ascending order (based on flow rate), and the cumulative mass was determined. The resulting CMP explains the mass loading as a function of flow rate. The CMP for turbidity can be seen in Figure 4.8.

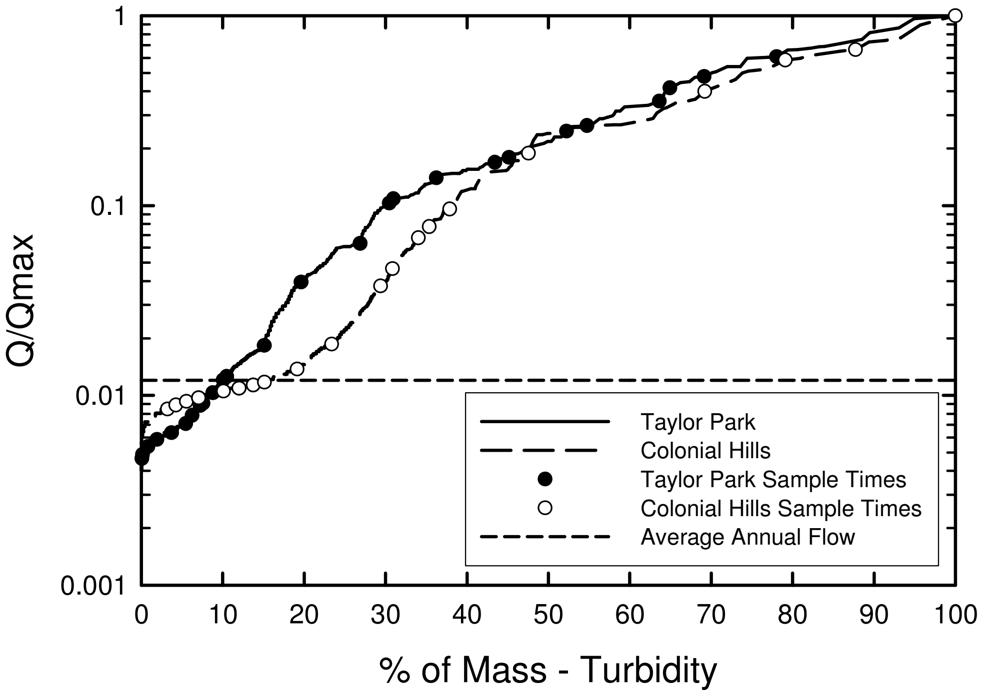

Figure 4.8: Cumulative Mass Plot for Turbidity (3/4/2009 to 9/3/2009)

The dashed line in the graph indicates the normalized average annual flow which was used as an arbitrary cutoff between dry weather and wet weather flows for the purpose of this project. For this case the normalized average annual flows for Taylor Park and Colonial Hills were both 0.012. Flow rates lower than this level signify dry weather flows, and flows higher than this level indicate high flow rates which can be associated with storm events. It is important to note that since the average annual flow averages base and storm flows, the actual cutoff between wet and dry weather flows would in reality be slightly lower than the cutoff used in this analysis. The points on the curves indicate that a grab sample was taken at that flow rate.

In the case of turbidity, it can be seen in Figure 4.8 that 90% of the mass of turbidity occurs above the average annual flow or during storm event flows. Since turbidity increases dramatically with flow rate, this result is not unexpected. What this suggests is that in order to get an accurate determination of mass loading, emphasis should be placed on obtaining a good record of turbidity and other water quality parameter measurements at the highest flow rates. These results are consistent with the findings of Horowitz et. al. (2008) which suggested that >95% of loading for sediment related constituents like Turbidity and TSS occur in conjunction with storm-flows. In Figure 4.8 it can be seen that the sampling times for the 2009 season spanned the entire range of flow rates, but a much larger number of samples were taken around or below the average annual flow line (during dry weather monitoring).

The cumulative mass plots for conductivity and dissolved oxygen (DO) are provided in Figures 4.9 and 4.10. It is important to note that conductivity has an inverse relationship to flow rate; therefore, the concentration is higher during low flows. This relationship can be seen in the CMP for conductivity. About 25% of the total mass for the season occurred at flow rates higher than the average annual flow which suggests that the greatest contribution to conductivity mass loading is during low flows where the concentrations are high. The CMP for dissolved oxygen can be seen in Figure 4.10. The figure indicates that between 50% and 60% of the dissolved oxygen mass loading occurs at flow rates higher than the average annual flow. While theoretically the mass loadings for Conductivity and D.O. have little physical meaning, they have been included in this thesis as a point of comparison with the Turbidity CMP.

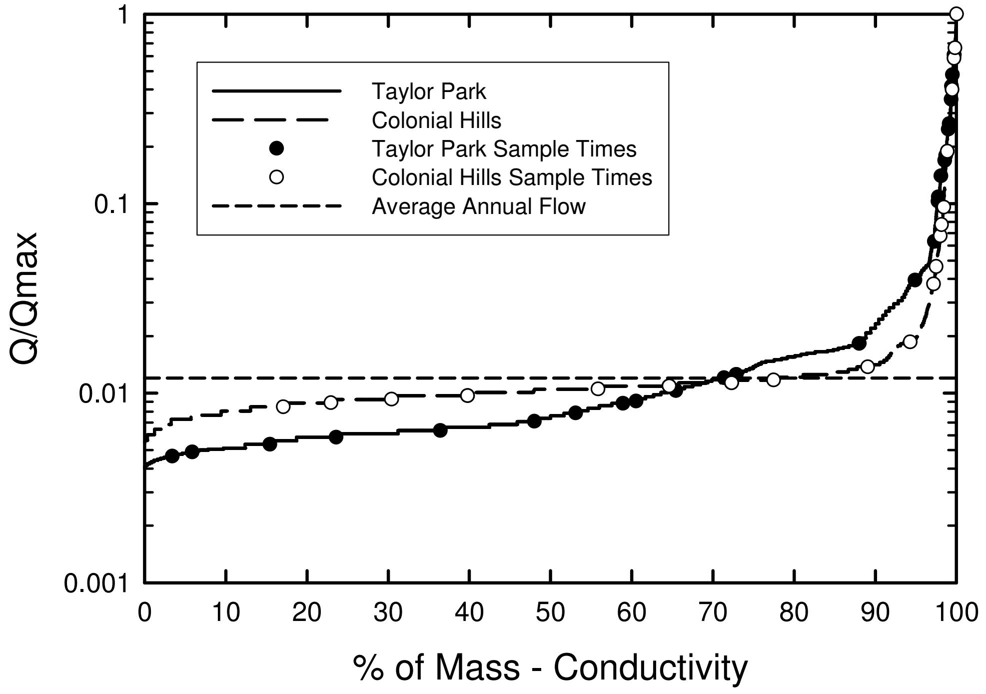

Figure 4.9: Cumulative Mass Loading Plot for Conductivity (3/4/2009 to 9/3/2009)

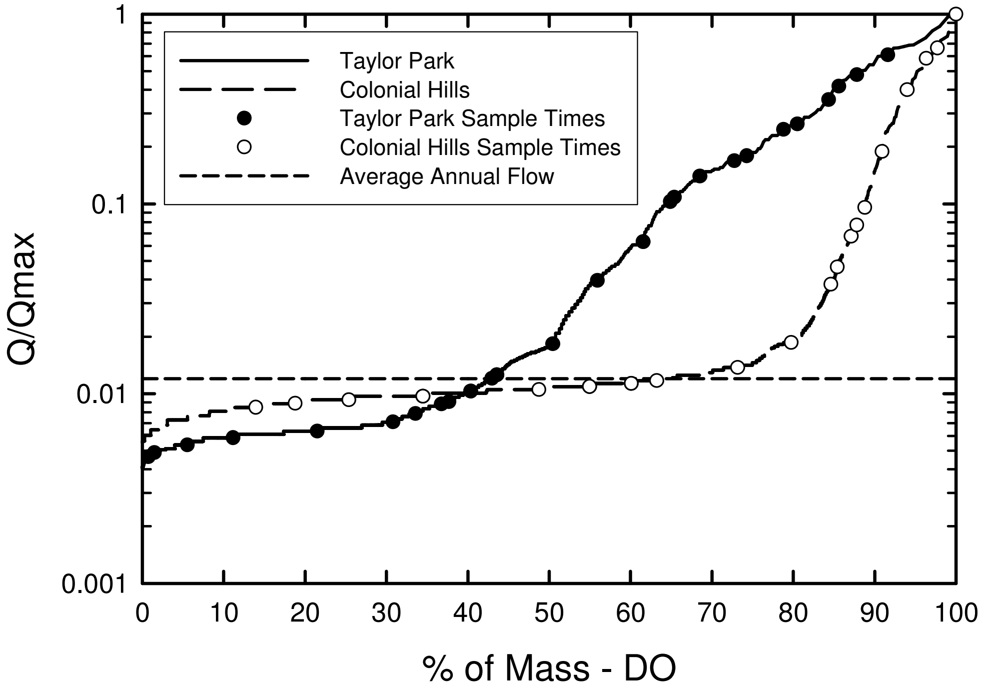

Figure 4.10: Cumulative Mass Loading Plot for DO (3/4/2009 to 9/3/2009)

4.7 TSS Mass Loading Model

One of the goals of this study was to develop accurate empirical models to predict water quality concentrations for hard-to-measure parameters, using the continuous USGS data set for Turbidity, Conductivity, Flow Rate, and Storm-Specific Rainfall Parameters (Intensity, Duration, Depth) as predictive variables.

To test the concept, simple empirical models predicting total suspended solids (TSS) based on other measurable contaminant concentrations and flow rate were developed. The TSS concentrations collected during wet weather monitoring, and the turbidity/stage data obtained from the USGS data probe were the main data sources used in the development of these models. Flow rates were calculated using the rating curves and the USGS stage data. For this model, several variables were examined to see if they could be used as predictors for the TSS concentration. It was found that the best predictors for TSS concentration were flow rate, turbidity, and in some cases average rainfall intensity.

The following sections outline the development of these TSS mass loading models, and discuss the quality of the results.

4.7.1 Taylor Park Model

Figures 4.11 and 4.12 show the relationship between TSS vs. Turbidity, and TSS vs. Flow Rate, respectively. The different symbols on the graph indicate different wet weather events. It is important to note that the TSS concentrations seen in these graphs were determined as part of the UNL data set during wet weather flows, the Turbidity concentrations were interpolated from the 90 second USGS data set, and flow rates were interpolated from the continuous data set.

From the figures, it can be seen that despite substantial scatter, there is a relationship between TSS, Flow Rate, and Turbidity. It is also clear that the relationship between the variables changes for each storm; therefore, a variable dependent on characteristics of each storm (Rainfall Intensity, Duration, Depth) should be used to improve regression models. For our models, average rainfall intensity was used as a storm specific factor.

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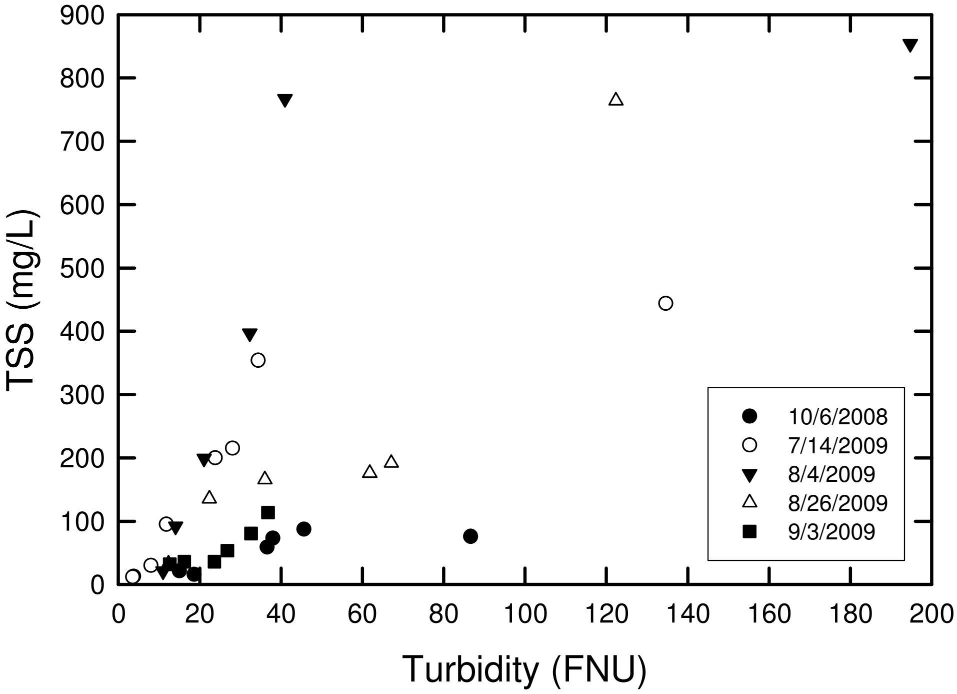

Figure 4.11: TSS vs. Turbidity (Taylor Park)

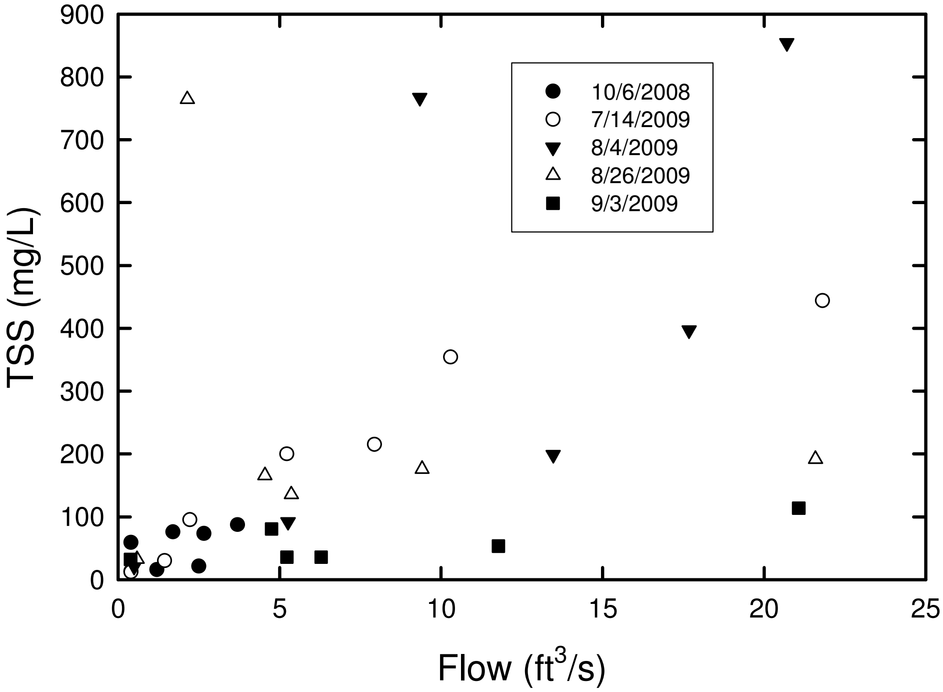

Figure 4.12: TSS vs. Flow Rate (Taylor Park)

Rainfall intensity for the events was calculated using precipitation data collected at the sampling sites. Average intensity was calculated using the total amount of rainfall during the storm event divided by the total duration, and converting the intensity to units of in/hr. Peak intensity was determined using the maximum rainfall in a 5 minute interval. Table 4.14 shows these calculated intensities for each storm. Note that no intensity data for the 10/6/2008 storm is available, because precipitation measurement began in the 2009 sampling season

Table 4.14: Average and Peak Intensities

Date of Event	Precipitation (in)	Duration (hr)	Avg Intensity (in/hr)	Peak Intensity (in/hr)
7/14/2009	0.28	1.21	0.23	0.60
8/4/2009	1.56	0.67	2.33	6.48
8/26/2009	0.37	1.62	0.23	0.84
9/3/2009	1.46	3.58	0.41	3.72

In Figures 4.11 and 4.12 it can be seen that the relationships between TSS vs. Turbidity and TSS vs. flow rate are non-linear. In order to develop a linear multi variable model the data should be transformed into linear form. In this case, log transformations were done on all of the variables. The transformed data can be seen in Figures 4.13 and 4.14.

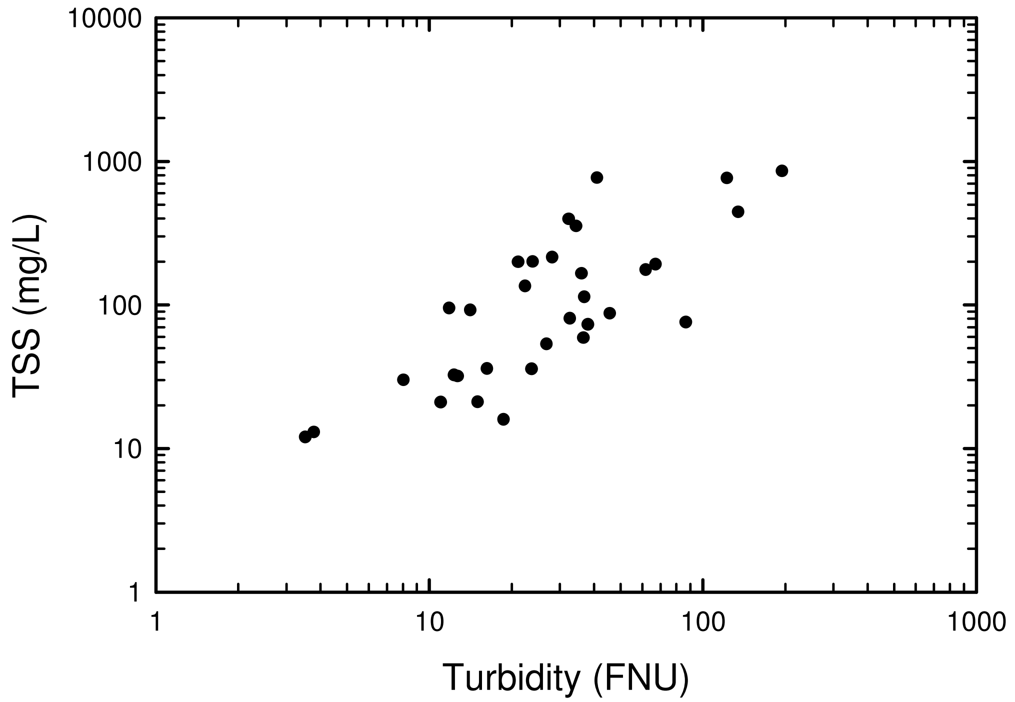

Figure 4.13: Log Transformation for TSS vs. Turbidity, Taylor Park

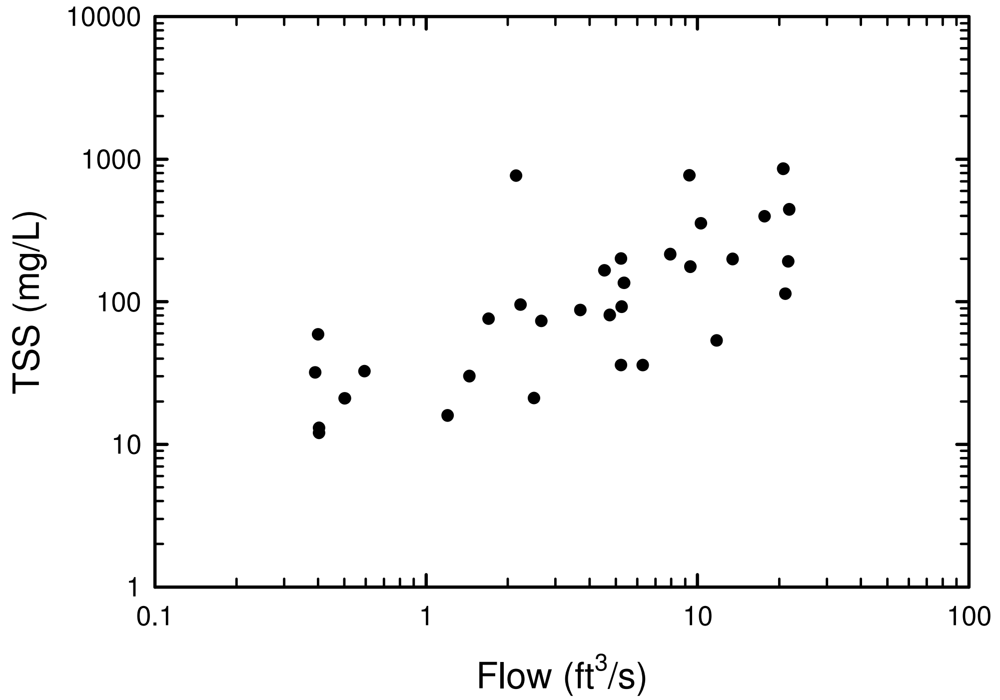

Figure 4.14: Log Transformation for TSS vs. Flow, Taylor Park

From the above figures it can be seen that both of the relationships have substantial scatter in the data set, but the trend is generally linear using a Log/Log transformation.

Three of the data points from the Taylor Park data set were removed because they were considered to be outliers, these points were the first samples collected during the 8/4/2009, 8/6/2009, and 9/3/2009 storm events. The reason these points are outliers is related to the inaccuracy of the sample time estimates. The turbidity and flow rate data were interpolated using the estimated sample times and the USGS data set. In most situations, inaccuracies due to the uncertainty of sample time do not cause major errors in this interpolation scheme because the turbidity concentrations and flow rate do not change rapidly. This is not true during the “first flush” of a rainfall event where flow rate and turbidity concentrations are known to change very rapidly. In this case, very slight errors in the time estimate can generate extremely high errors in the interpolated data. All of the data points that were removed had very large errors associated with them during this “first flush” time period, and therefore were considered outliers.

The statistical modeling of the data was completed using a statistical software package known as SigmaStat©. Two models were developed for Taylor Park. The first model uses the turbidity concentrations and the flow rate to predict the TSS, the second model uses average (rainfall) intensity as well. The results of the models are provided below, and are plotted in Figure 4.15. In the following models, TSS has units of mg/L, Turbidity is in formazin nephelometric units (FNU), and flow rate is in cfs (ft^3/second). Note that in the tests for variable significance, P values of less than 0.05 indicate a statistically significant relationship.

Taylor Park Model 1:

Log(Tss) = 0.984 + (0.478 * Log(Turb)) + (0.475 * Log (Flow))
Number of Observations = 29
Rsqr = 0.667
Standard Error of Estimate = 0.288
Test for Variable Significance (against the Null Hypothesis that the coefficients are zero):
Log(Turb): P = 0.023
Log(Flow): P = 0.001

Taylor Park Model 2:

Log(Tss) = 0.736 + (0.727 * Log(Turb)) + (0.281 * Log (Flow)) + (0.118 * Avg. I)
Number of Observations = 23
R^2 = 0.737
Standard Error of Estimate = 0.250
Test for Variable Significance (against the Null Hypothesis that the coefficients are zero):
Log(Turb): P = 0.033
Log(Flow): *P = 0.202*
Average Intensity: *P = 0.105*

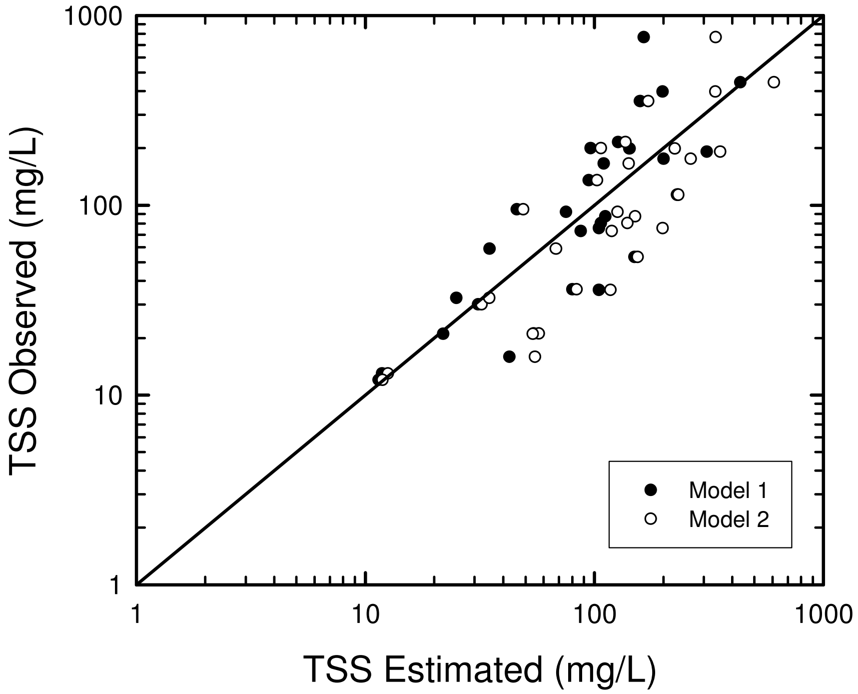

Figure 4.15: Taylor Park; Comparison of Model to Observed Results

Figure 4.15 shows a parity plot of the estimated TSS against the observed data, if the model were perfect, all of the data points on this graph would fall on the black line. It can be seen that there is some error associated with both of the models, but the overall fit of the model is decent. The average error of estimation for Log (TSS) is about 11.7% for Model 1 and 13.6% for Model 2. The maximum error associated with these models was 35.6% and 44.9%, respectively.

It is important to note that in Model 2 the test for variable significance for Log(Flow) and Average Intensity both fail with a 95% significance, while all of the variables in Model 1 seem to be significant. What this suggests is that the addition of average intensity to the model does not significantly improve the model results with the current data set. This can also be seen by the fact that the standard error for Model 2 is larger than the standard error for Model 1. Because of these differences, Model 1 will be used to predict the TSS concentrations at Taylor Park for the remainder of this report.

4.7.2 Colonial Hills Model

TSS modeling at Colonial Hills was completed using the same methods outlined during the discussion on the model at Taylor Park. Log/Log transformations were used to linearize the data. Figures 4.16 and 4.17 show the TSS vs. Turbidity and TSS vs. Flow relationships at Colonial Hills. The log transformations on the Colonial Hills data can be seen in Figures 4.18 and 4.19. Again, the relationships on the Log/Log transformation are generally linear, and therefore can be used in a multiple regression model.

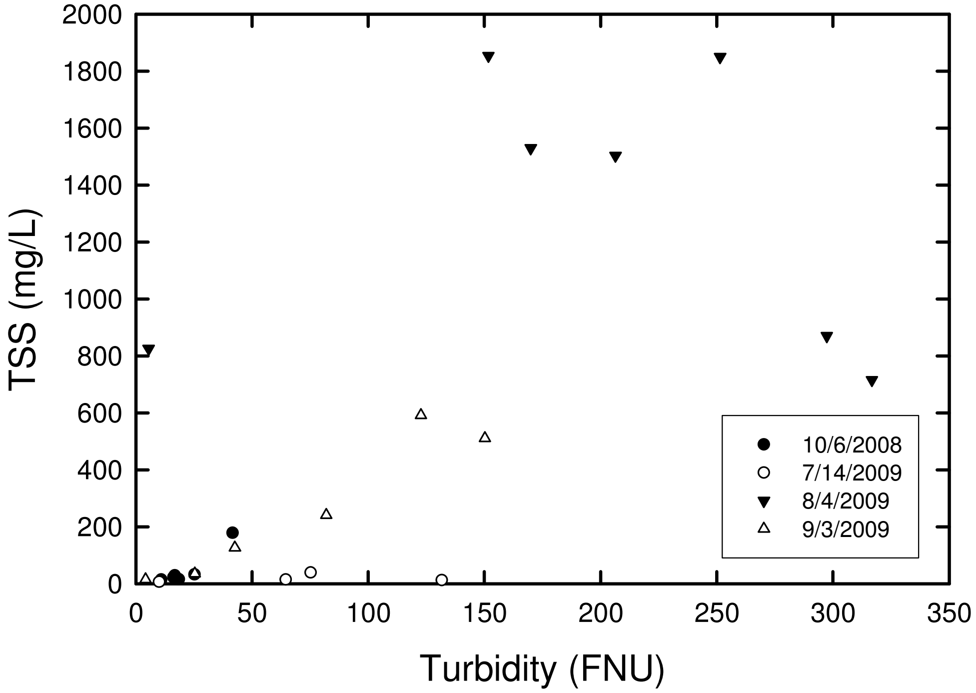

Figure 4.16: TSS vs. Turbidity (Colonial Hills)

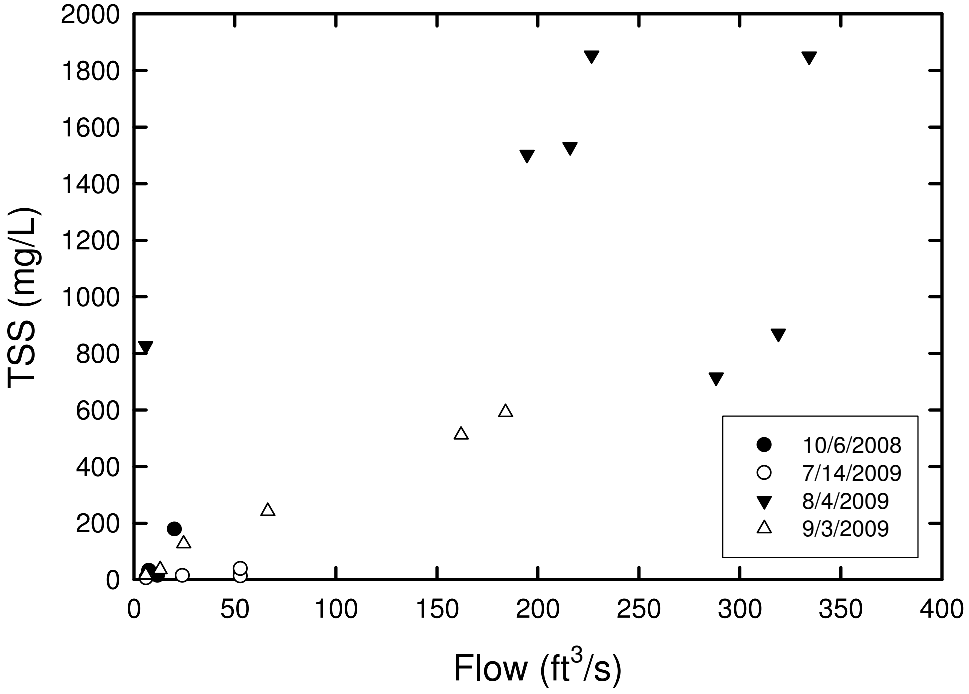

Figure 4.17: TSS vs. Flow Rate (Colonial Hills)

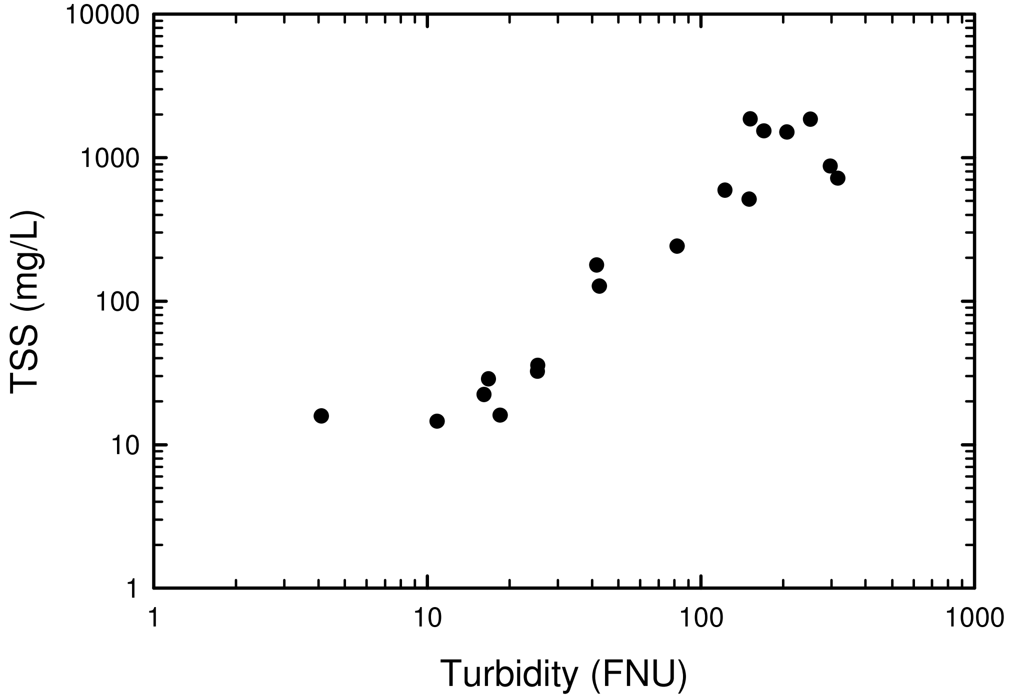

Figure 4.18: TSS vs. Turbidity; Log Transformation

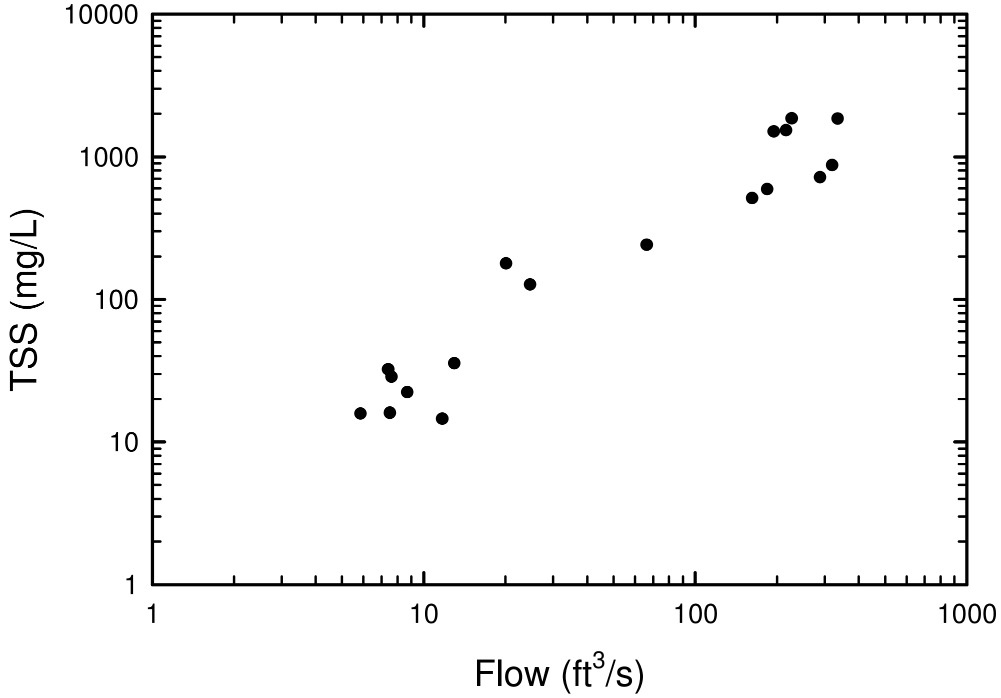

Figure 4.19: TSS vs. Flow Rate; Log Transformation

Two models were generated using SigmaStat, one with average intensity included and one with only turbidity and flow. The results from these models are listed below.

Colonial Hills Model 1:
Log(Tss) = 0.446 - (0.580 * Log(Turb)) + (1.616 * Log(Flow))
Number of Observations = 22
$R^2 = 0.813$
Standard Error of Estimate = 0.385
Test for Variable Significance (against the Null Hypothesis that the coefficients are zero):
Log(Turb): *P = 0.252*
Log(Flow): P = <0.001

Colonial Hills Model 2:
Log(Tss) = 0.626 - (0.415 * Log(Turb)) + (1.219 * Log(Flow)) + (0.221 * Avg. I)
Number of Observations = 18
$R^2 = 0.835$
Standard Error of Estimate = 0.373
Test for Variable Significance (against the Null Hypothesis that the coefficients are zero):
Log(Turb): *P = 0.405*
Log(Flow): P = 0.019
Average Intensity: P = 0.144

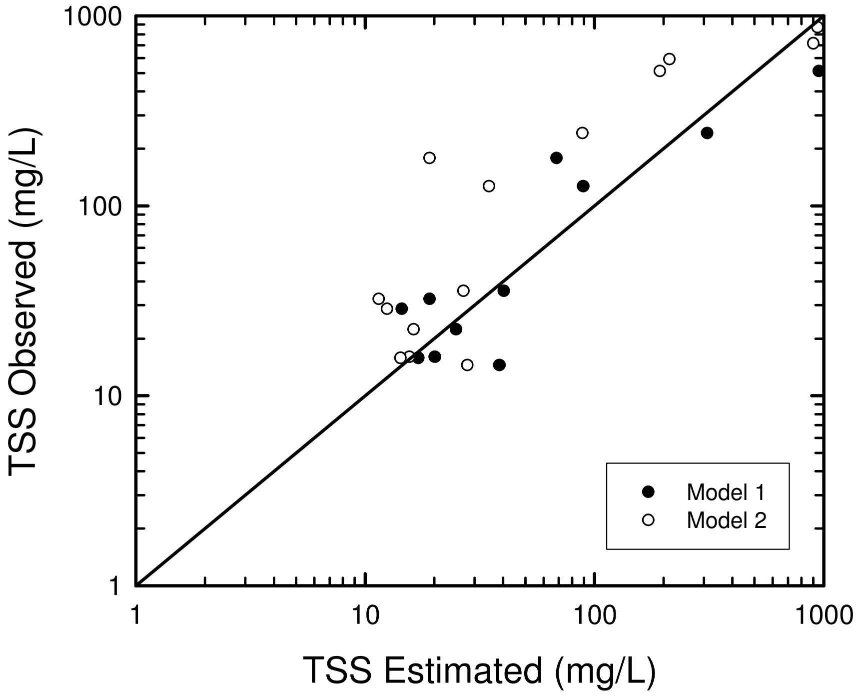

Figure 4.20: Colonial Hills Model Results

The average error for Log(TSS) is 10.01% and 16.19%, and the maximum error is 36.50% and 43.12% for Model 1 and Model 2, respectively. From the results, it can be seen that at the Colonial Hills site, the addition of average intensity improves the model's R^2 value as well as improves the standard error of the two models. From the results of the variable significance tests, it can be seen that statistically the turbidity concentrations do not seem to significantly contribute to the results of either model for this site. The relationship between TSS and Turbidity is clearly defined in the graph of TSS vs. Turbidity and so Turbidity was kept in both models despite its statistically insignificant contribution since its addition improved model results.

It is important to note that Model 1 is based on 22 observations, while Model 2 is based on 18 observations. The difference in the standard error as well as the R^2 values of the models may be an artifact of the increased sample size, rather than an actual difference in model quality. For this reason and because of the lack of intensity data for 2009, Model 1 will be used to estimate the TSS concentrations at Colonial Hills for the rest of this report. The results from Model 2 should not be disregarded, as they indicate a probable relationship between the TSS concentrations at Colonial Hills and the average rainfall intensity which should be considered in further work on this model.

4.7.3 TSS Results and Mass Loadings

Using the models described above (Model 1 in both cases), the TSS concentrations for the entire year were estimated at both sites. Figures 4.21 and 4.22 show the estimated TSS concentration time series for both Taylor Park and Colonial Hills, respectively.

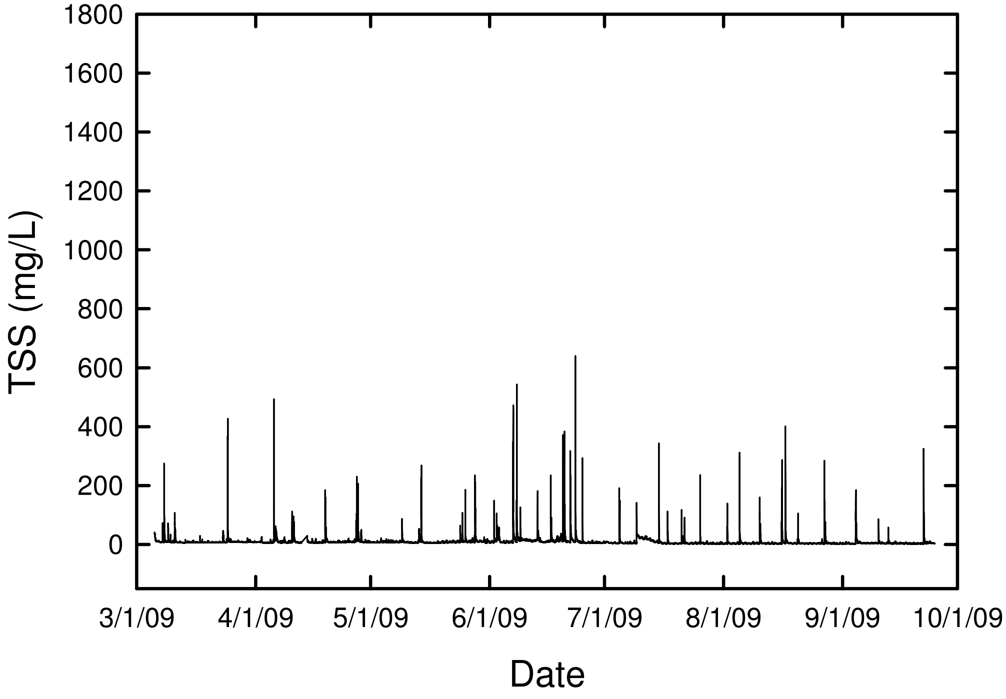

Figure 4.21: Prediction of TSS based on Flow and Turbidity; Taylor Park

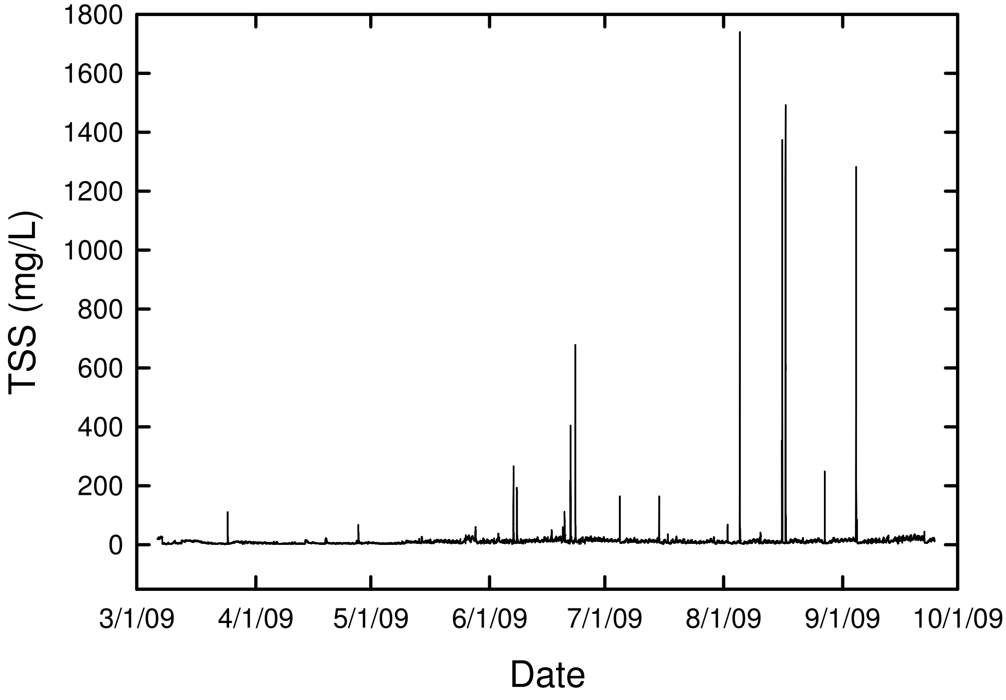

Figure 4.22: Prediction of TSS based on Flow and Turbidity; Colonial Hills

From Figures 4.21, and 4.22 it can be seen that the peak concentrations predicted using the model are much higher at Colonial Hills than they are at Taylor Park. Furthermore it can be seen that the models show a greater number of TSS spikes at the Taylor Park site. This difference may be related to the different land uses between the watersheds. The Taylor Park watershed has more impervious area which results in flashier storms or faster changes in contaminant concentrations. As discussed previously, any errors in the sample time estimates may cause substantial errors when interpolating the USGS data, particularly for flashy storms. These errors may account for some the scatter seen in the Taylor Park data set which has reduced the accuracy of the predictive model for that site.

In contrast, because the Colonial Hills site has a larger drainage area with substantially more overland flow, the changes in contaminant concentrations at this site are generally more gradual; causing the data set for this site to have less scatter, directly resulting in a better fit model

The maximum TSS concentrations observed during wet weather monitoring were 854 mg/L, and 1854 mg/L for Taylor Park and Colonial Hills, respectively. The maximum predicted concentrations for the two sites were 640 mg/L, and 1740 mg/L, respectively. Therefore it can be seen that the magnitude of the maximum concentrations obtained using the model generally agree with the magnitude of the measurements taken from wet weather monitoring.

Mass loading is defined as the amount of contaminant passing a given location in a specified amount of time. TSS mass loadings were calculated by multiplying the modeled TSS concentrations with flow rate, and flow duration. Since flow rates were recorded at 15 minute intervals, flow duration steps of 15 minutes were used in calculating the mass loadings.

TSS mass loading rates in kg/hr can be seen in Figures 4.23 and 4.24. Again, the instantaneous mass loadings for the Colonial Hills site are higher than the instantaneous loadings seen at the Taylor Park site.

The mass loading for TSS for the two sites was also examined using a cumulative mass plot like those discussed previously in this chapter. The cumulative mass plot for TSS is shown in Figure 4.25.

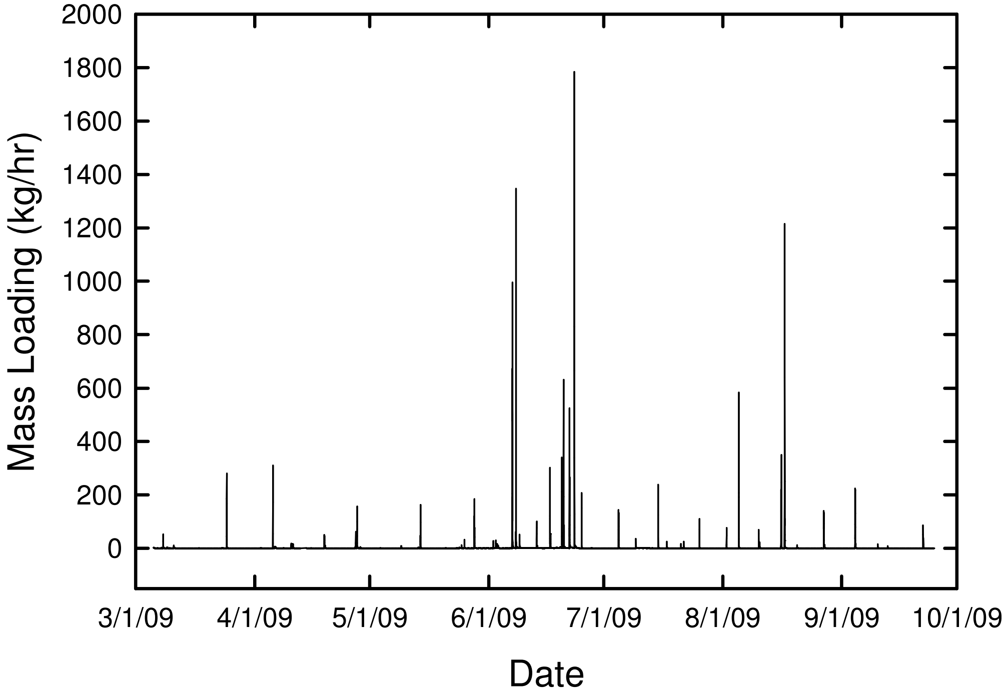

Figure 4.23: Modeled Instantaneous Mass Loadings, Taylor Park

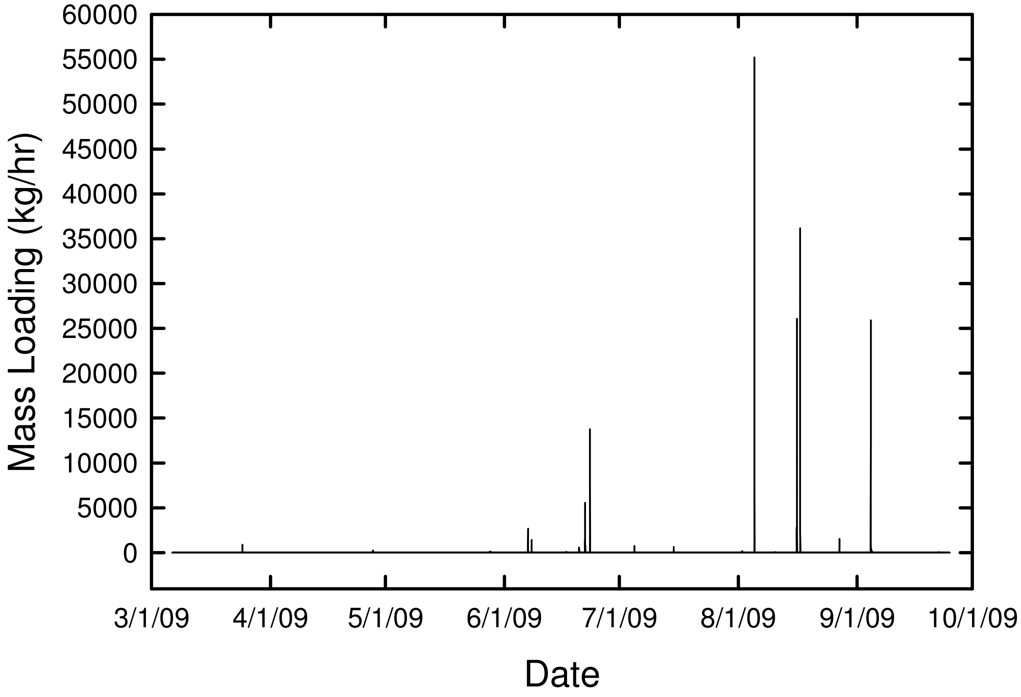

Figure 4.24: Modeled Instantaneous Mass Loadings, Colonial Hills

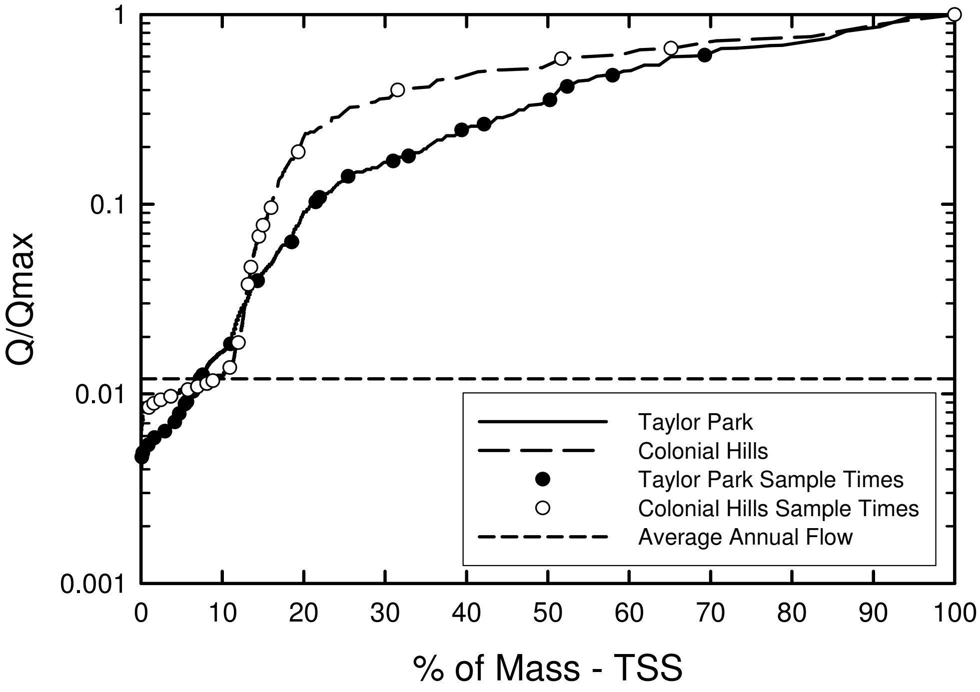

Figure 4.25: Cumulative Mass Plot, Modeled TSS (3/4/2009 to 9/3/2009)

Note that the dashed line on the graph indicates the normalized average annual flow (used as an arbitrary cutoff between dry and wet weather flows), and the points in the graph indicate places where samples were taken. For both sites, it can be seen that about 90% of the total mass occurs at flows higher than the average annual flow. What this indicates is that the majority of suspended solid mass loading is occurring at the higher flow rates, or during rainfall events. Again, these results are consistent with findings by Horowitz et. al. (2008) which determined that >95% of suspended sediment loading occurred in conjunction with storm flows.

It can be seen that the range of flows the samples were taken from span the entire flow regime, but are heavily centered at lower flows. In order to generate a better TSS model, more samples need to be taken at higher flows to accurately represent where the majority of the mass is being generated.

Tabular data on TSS mass loading for the 2009 sampling season (March 4 through September 23, 2009) can be seen in Tables 4.15 and 4.16. Mass loadings are in Mg (Megagrams), and Total Flow is in acre-ft. Watershed yields were calculated by dividing the total mass loading by the drainage area of the watershed. The drainage areas at the Taylor Park and Colonial Hills Sites are 0.14 mi^2 and 0.96 mi^2 respectively.

From Tables 4.15 and 4.16, it can be seen that the mass loading, and watershed yields at Colonial Hills are higher than at Taylor Park. These differences could be attributed to differences in water quality at the sites, but mass loadings are also heavily influenced by differences in watershed characteristics as outlined by Brezonik and Stadelmann (2002). Watersheds with higher drainage area tend to produce greater mass loading and watershed yields. Since the drainage area at Colonial Hills is nearly ten times larger than the Taylor Park site, it reasons that the mass loadings and watershed yields at Colonial Hills would be larger.

Table 4.15: Taylor Park Mass Loadings 2009

Time Period	Cumulative Rainfall: (in)	Total Flow: (acre-ft)	Estimated TSS Loading: (Mg)	Watershed Yield: (Mg/mi^2)	Number of Discrete Samples Collected: Total (dry)
March 4-31	0.46	14.41	0.40	2.85	2 (2)
April 1-30	1.59	17.43	0.66	4.74	5 (0)
May 1-31	1.43	20.74	0.65	4.67	2 (2)
June 1-30	4.95	53.72	5.28	37.70	6 (6)
July 1-31	1.73	17.64	0.49	3.53	12 (4)
August 1-31	3.77	24.61	1.89	13.48	14 (2)
September 1-23	1.69	13.39	0.40	2.86	8 (2)
Total	15.62	161.94	9.78	69.83	

Table 4.16: Colonial Hills Mass Loadings 2009

Time Period	Cumulative Rainfall: (in)	Total Flow: (acre-ft)	Estimated TSS Loading: (Mg)	Watershed Yield: (Mg/mi^2)	Number of Discrete Samples Collected: Total (dry)
March 4-31	0.46	194.00	2.63	2.74	2 (2)
April 1-30	1.59	198.26	1.84	1.92	1 (0)
May 1-31	1.43	228.95	3.31	3.45	2 (2)
June 1-30	4.95	304.02	22.24	23.17	6 (6)
July 1-31	1.73	231.24	3.96	4.12	8 (4)
August 1-31	3.77	293.75	83.03	86.49	10 (2)
September 1-23	1.69	212.58	30.28	31.54	8 (2)
Total	15.62	1662.80	147.30	153.44	

It is important to note that the flow rates used for this model were generated using the USGS level data and the rating curves discussed earlier in this chapter.

Chapter 5. Conclusions and Recommendations

5.1 General Discussion

This thesis discussed the methods of data collection, and a preliminary statistical comparison of water quality between the two sites. A preliminary model to predict TSS based on the turbidity and flow rate was also developed. Statistical comparison tests were conducted on the collected water quality data to detect differences based on collection method (Auto vs. Grab), and sample location. This was done using a matched pairs t-test with 90% and 95% confidence. Preliminary results indicate that there is statistically no difference between concentrations in the Auto and Grab samples. This suggests that errors associated with the sample type are not a major concern for this project.

Preliminary results from the statistical comparison of the Colonial Hills to the Taylor Park data indicate that some water quality parameters have higher concentrations at one of the sites. The Nitrate, Phosphorous, and E. Coli concentrations at Taylor Park are higher than the concentrations at Colonial Hills with 95% confidence for dry weather flows. The Turbidity and Chlorine levels at Colonial Hills are higher than the concentrations at Taylor Park with 90% confidence for dry weather flows.

Statistical comparisons were also performed on wet weather concentrations in an attempt to identify general trends in the wet weather data. It was found that the Conductivity concentrations were higher at the Colonial Hills site with 95% confidence, and the Turbidity concentrations were also higher at this site with 90% confidence. In addition to these statistically significant differences, it was noted that the TSS concentrations at the Colonial Hills site appeared to be higher than the concentrations observed at Taylor Park. Conversely, the E. Coli concentrations appear to be higher at the Taylor Park site. While these trends are not statistically significant due to the high variation in concentrations during wet weather flows, the trends are worth noting and should be considered in further work on this project.

The mass loadings of several contaminants were examined through the use of a cumulative mass plot (CMP). CMP's were developed for Turbidity, Dissolved Oxygen, and Conductivity for the 2009 sampling season. Results indicate that about 60% of the mass for Dissolved Oxygen, and 90% of the mass for Turbidity occur at flow stages higher than the average annual flow. This suggests that the sampling focus in subsequent seasons should be placed on wet weather monitoring in order to accurately describe the mass transfer relationship at the higher flows. These results are consistent with similar work done by Horowitz et. al. (2008) who examined contaminant loadings in Atlanta, GA and found that >95% of mass loading for suspended sediment related constituents (TSS, Turbidity), and >90% of the loading for trace and major elements occurred in conjunction with storm-flows.

A statistical model was developed using log transformations to predict the TSS concentration as a function of the turbidity and flow rate. Preliminary results for the TSS models have an R^2 value of 0.711 at Taylor Park, and 0.906 at Colonial Hills. The average error generated using the models on a log/log scale are about 12% in both cases, maximum errors were about 40% for both sites. These results are consistent with work done by Christensen et. al (1999-2000) which examined the possibility of using continuous turbidity measurements as a means to predict concentrations of TSS. Errors in their models ranged from between 34% and 66%, depending on the site.

The TSS model was used to generate a TSS concentration time series for the 2009 sampling season, and mass loading was examined. It was found that 90% of the mass loading for TSS occurs during storm-flows; therefore, sampling done in the following seasons should focus on these flow conditions in order to improve the model. Again, these results are consistent with the study conducted by Horowitz et. al. (2008).

5.2 Suggestions for Future Sampling

This report has focused on giving some preliminary results from the data collected in the 2008 and 2009 sampling seasons. In order to improve the project in future years, some consideration should be given to the following suggestions:

- **Sample More Frequently at the Higher Flow Rates:** Since the majority of mass loading is occurring during wet weather, emphasis should be placed on obtaining a robust data set during the higher flow rates.

- **Sample Less Frequently During Dry Weather Flows:** While dry weather concentrations are important from day-to-day water quality perspective, their contribution to overall mass loading for most constituents is generally small.

- **Collect "Rapid Sampling" Events:** Rapid sampling will allow the researcher to very accurately describe how the contaminant concentrations are changing within a single storm hydrograph. It also ensures that many samples, rather than a single one are taken during the peak flows where the majority of the mass loading is occurring.

- **Record Sample Times:** The ISCO bubbler meter is capable of recording the time the auto sampler creates a sample, make sure there is a data partition in the sampler program to record these times. Knowing the exact sample time increases the accuracy of any interpolation necessary on the data, it also allows for easy comparisons between concentrations detected on the USGS data probe and concentrations measured with the sampler.

- **Emphasize Site Maintenance and Data Recovery:** Level and Flow Data should be collected and downloaded on a weekly basis. While at the site be sure to check battery levels, record all the instrument times and the USGS tape down level.

- **Obtain Wet Weather Duplicate Samples:** Duplicate samples should be collected during the highest flows for wet weather events. Since the contaminant concentrations change rapidly at very high flow rates, this will allow for a better estimate of the concentrations during these flows.

- **Verify that the ISCO Samplers are "Cleaning the Lines":** Confirm that the ISCO sampler removes all of the water from the tubing between sample collections. Failure to thoroughly purge the lines allows sediment to settle inside the collection line resulting in inappropriately high concentrations.

- **Consider Seasonal Differences:** Evidence in the literature suggests that seasonality plays an important role in the concentrations of virtually all water quality parameters, particularly at base flow levels. Seasonal differences should be considered in further work on these models.

- **Consider Storm Specific Factors:** Evidence in this report suggests that the addition of average intensity as a storm specific factor increases the accuracy of the predictive model at the Colonial Hills site. Storm specific factors such as intensity, total precipitation, and antecedent moisture conditions should be considered in further work on this project.

- **Verify Units of Measurement:** Make sure you record units when testing wet and dry weather samples. A few of the instruments in the civil engineering lab (Turbidmeter, Conductivity Meter) will adjust the unit output based on the concentrations observed. Keep this in mind when recording the data.

- **Consider Differences Between Soluble and Total Phosphorous:** Work completed by Tim Adams in December 2008 suggested that there was statistically no difference between the concentrations of Total Phosphorous and Soluble Phosphorous when TSS concentrations are low (i.e. dry-weather monitoring). This should be verified for wet-weather events. If the concentrations between the Total and Soluble Phosphorous vary significantly, it suggests that sediment-bound phosphorous plays an important role in the mass loading; therefore, Total Phosphorous should replace the Soluble Phosphorous test for wet-weather monitoring.

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Appendix A: Flow Rate and Stage Plots

Additional flow rate and stage plots for the 2008 and 2009 sampling seasons.

2008 Data:

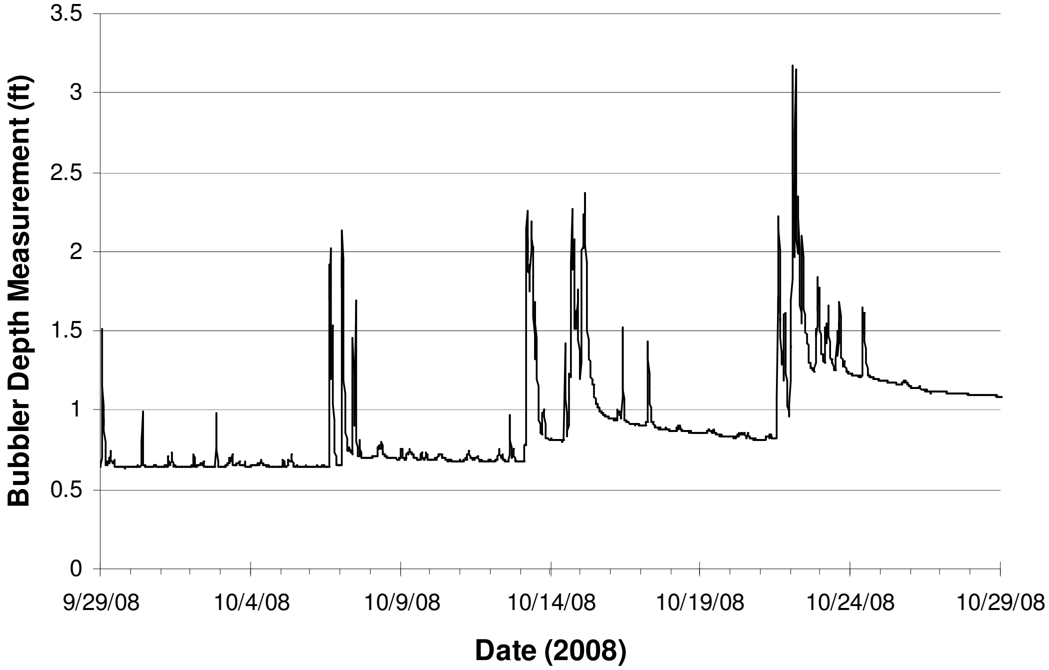

Figure A.1: Depth vs. Time – Taylor Park 2008

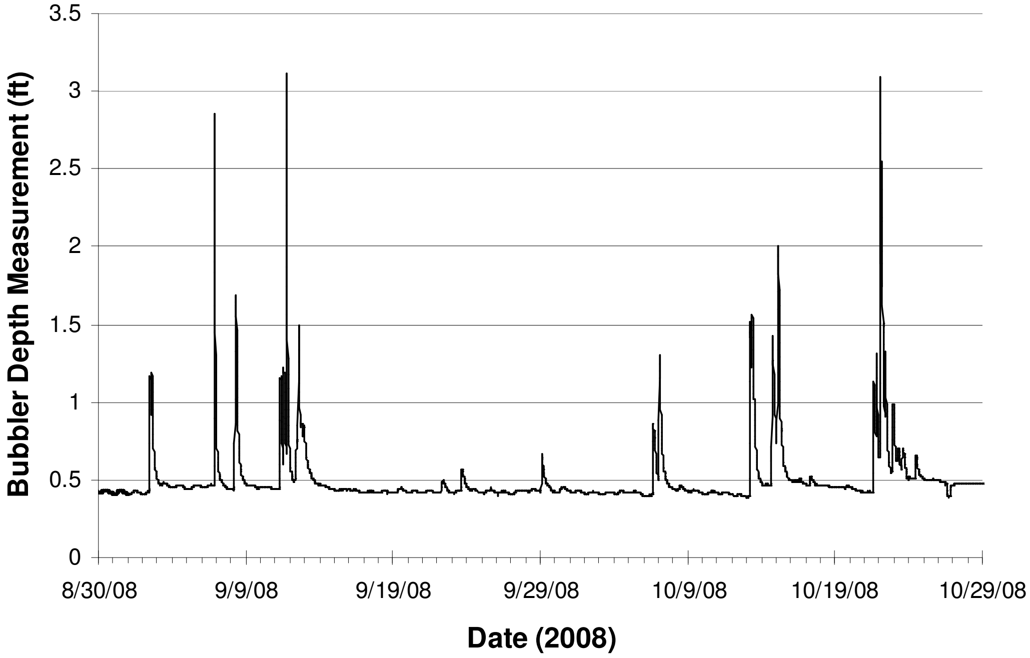

Figure A.2: Depth vs. Time – Colonial Hills 2009

2009 Data:

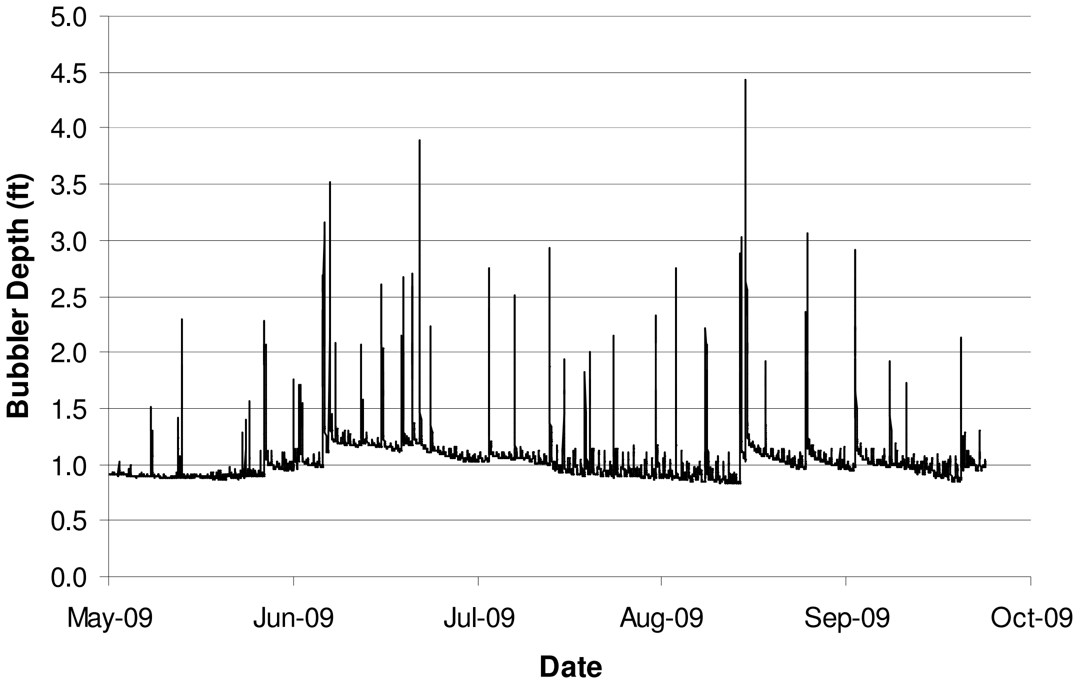

Figure A.3: Stage vs. Time – Taylor Park 2009

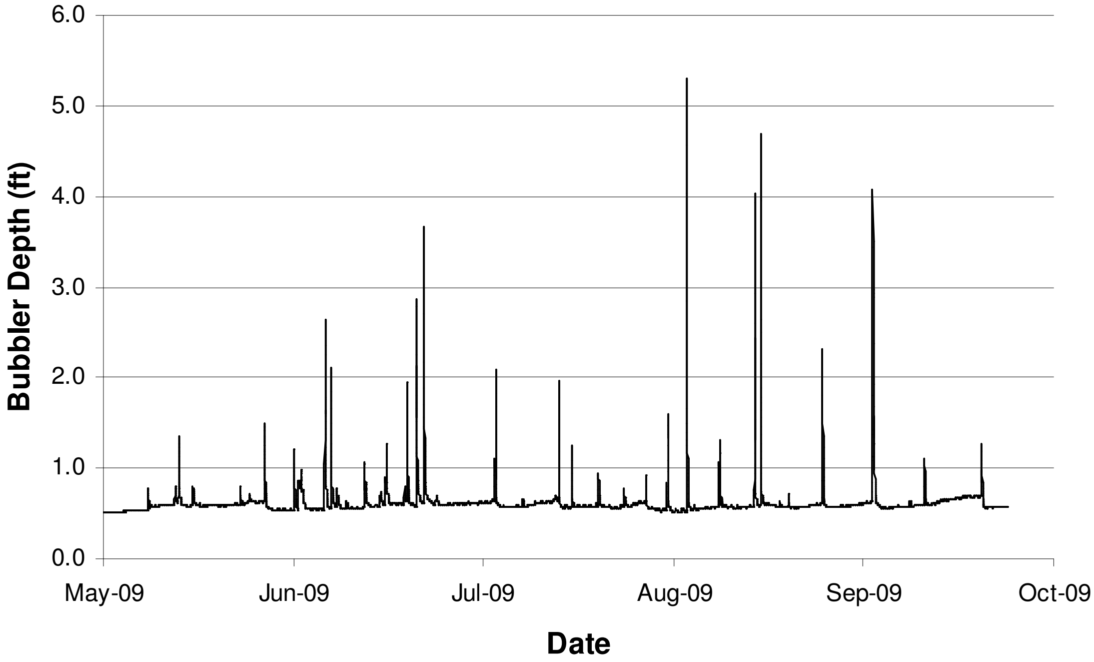

Figure A.4: Stage vs. Time – Colonial Hills 2009

Appendix B: Lag Time Estimates

As discussed previously, the ISCO bubbler which measures stage, and the 2150 area velocity meter which measures flow are not at the same location at they Taylor Park sites. In order to generate accurate rating curves an estimate of the lag time, or the duration of flow between the two locations needed to be determined. This was completed using floatables for a storm event on 6/12/2009. The lag times from this analysis can be seen in Table B-1 below.

Table B.1: Lag Time Estimates

Drop #	Floatable type	Time of Estimate	Travel Time (minutes)
1	Cheerios	11:26:20 AM	12.27
2	Fruit Loops	11:33:50 AM	9.84
3	Cinnamon Toast Crunch	11:41:07 AM	7.45
4	Honey Comb	11:47:57 AM	7.36

In order to relate these travel times to the stream flow hydrograph, the time of the estimate was plotted in excel with the flow data obtained from the 2150 area velocity meter. This plot can be seen in Figure B-1 below:

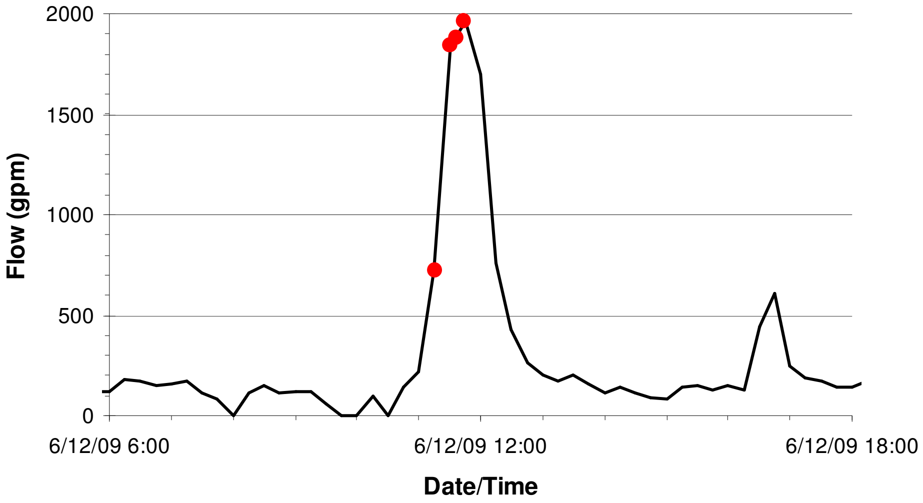

Figure B.1: Location of Lag Estimations

From Figure B-1, and Table B-1 it can be seen that the travel time between the 2150 Flow Meter, and the ISCO Bubbler decreases as the flow rate increases. This result is expected since the velocity of the flow also generally increases with flow rate. The largest travel time observed was 12.27 minutes, at a flow rate of about 600gpm. Since most of the data is dry weather data, it was assumed that a 15 minute shift would be adequate to correct for this time difference in the majority of the data. While this 15 minute estimation is not exact, implementation was simple since flow measurements were recorded at 15 minute intervals.

Appendix C: Water Quality Data: Wet Weather

The following tables contain all of the Wet Weather water quality data collected in 2008 and 2009. Data is organized into tables by storm event. Abbreviations, parameters, and units can be seen in the table C.1 below.

Table C.1: Definition of Contaminant Abbreviations and Units

Abbreviation	Contaminant	Units
CON	Conductivity	µs/cm
Cl	Chlorine	mg/L
Cl^-	Chloride	mg/L
F	Fluoride	mg/L
SRP	Soluable Reactive Phosphorous	mg/L
TSS	Total Suspended Solids	mg/L
COD	Chemical Oxygen Demand	mg/L
NIT	Nitrate with Nitrate Nitrogen	mg/L
AMM	Ammonia	mg/L
TKN	Total Kjeldhal Nitrogen	mg/L
TRB	Turbitity	NTU
pH	pH	--
SURF	Anionic Surfactants	mg/L
TEMP	Water Temperature	^oC

Table C.2: Wet Weather Data for Event on 10/6/2008

Date	Time	Location	Sample #	CON	Cl	Cl^-	F	SRP	TSS	COD	NIT	AMM	TKN	TRB	pH	Oil and Grease	E. Coli
10/6/2008	15:10	TP	1-1	193.2	20.0	0.39	1.15	59.0	89	<0.05	<0.05	24.1	--	--	--	--	>242000
10/6/2008	15:35	TP	1-2	115.8	10.0	0.27	0.87	87.3	57	0.13	<0.05	35.4	--	--	--	--	141400
10/6/2008	17:40	TP	1-7	208.4	2.9	0.33	1.04	15.9	44	0.23	<0.05	17.2	--	--	--	--	19870
10/7/2008	1:05	TP	2-1	155.2	5.0	0.26	0.76	75.8	38	0.39	<0.05	20.5	--	--	--	--	43600
10/7/2008	1:30	TP	2-2	185.2	6.0	0.27	0.47	73.1	37	0.45	<0.05	26.8	--	--	--	--	68700
10/7/2008	2:20	TP	2-4	122.1	3.5	0.24	0.66	21.1	22	0.47	<0.05	16.4	--	--	--	--	23600
10/6/2008	16:22	CH	1-1	827	33.0	0.62	0.4	28.6	62	0.32	<0.05	6.4	--	--	--	--	--
10/6/2008	16:47	CH	1-2	607	24.0	0.57	0.64	22.3	30	0.49	<0.05	13.1	--	--	--	--	11200
10/6/2008	17:37	CH	1-4	480	18.8	0.52	0.85	16.0	41	0.67	<0.05	13.0	--	--	--	--	48900
10/7/2008	1:17	CH	1-1	293	10.1	0.34	0.48	32.3	28	0.22	<0.05	21.4	--	--	--	--	3260
10/7/2008	2:07	CH	1-2	229	9.2	0.28	0.49	178.3	45	0.22	<0.05	86.4	--	--	--	--	9810
10/7/2008	3:47	CH	1-4	173	7.6	0.28	0.47	14.5	23	0.20	<0.05	12.7	--	--	--	--	9810
10/7/2008	9:15	TP	Grab Reg	--	--	--	--	4.1	11	--	--	--	7.27	<10	7.27	<10	3260
10/7/2008	9:15	TP	Auto Reg	--	--	--	--	7.9	14	--	--	--	7.57	--	7.57	--	--
10/7/2008	9:45	CH	Grab Reg	--	--	--	--	3.5	20	--	--	--	7.55	<10	7.55	<10	4890
10/7/2008	9:45	CH	Auto Reg	--	--	--	--	8.2	23	--	--	--	7.51	--	7.51	--	--

Table C.3: Wet Weather Data for Event on 4/27/2009

Date	Time	Location	Sample #	CON	Cl	Cl^-	F	SRP	TSS	COD	NIT	AMM	TKN	TRB	pH	Oil and Grease	E. Coli
4/27/2009		TP	1	355	--	24.5	0.26	--	16.3	22	0.83	0.2	0.66	15.4	--	--	9680
4/27/2009		TP	2	291	--	18.5	0.21	--	30.4	26	0.8	0.17	0.6	12.5	--	--	24200
4/27/2009		TP	3	140	--	7.5	0.18	--	165.8	11	0.5	0.26	0.36	54.1	--	--	13000
4/27/2009		TP	5	95.1	--	4.5	0.18	--	149.5	11	0.31	0.24	0.55	48.8	--	--	12000
4/27/2009		TP	7	273	--	14.7	0.32	--	16.0	22	1.07	0.28	1.37	13.2	--	--	6930
4/27/2009		CH	1	290	--	24.3	0.22	--	66.2	14	0.48	1.17	0.47	32.8	--	--	7950
4/27/2009		TP	Grab	--	0.07	--	--	--	31.5	18	1.1	0.25	1.48	12.5	7.51	0.05	2190
4/27/2009		TP	Auto Reg	--		--	--	--	46.5	17	0.78	1.58	1.81		7.53		
4/27/2009		CH	Grab	--	0.13	--	--	--	2.9	25	0.8	0.08	0.96	15.1	7.6	0.05	1550
4/27/2009		CH	Auto Reg	--		--	--	--	53.9	32					7.63		

Table C.4: Wet Weather Data for Event on 7/14/2009

Date	Time	Location	Sample #	CON	Cl	Cl^-	F	SRP	TSS	COD	NIT	AMM	TKN	TRB	pH	Oil and Grease	E. Coli
7/14/2009	4:17	TP	1	607	--	34.8	0.66	1.12	444.0	28	--	--	--	23.9	--	--	9680
7/14/2009	4:27	TP	2	562	--	32.2	0.61	0.85	354.0	31	--	--	--	23.3	--	--	6932
7/14/2009	4:29	TP	3	550	--	22.1	0.55	0.51	215.0	28	--	--	--	20.2	--	--	7948
7/14/2009	4:35	TP	4	83.5	--	0.7	0.18	0.5	200.0	31	--	--	--	6.33	--	--	3974
7/14/2009	4:51	TP	5	128.7	--	3.0	0.32	0.63	95.0	43	--	--	--	6.42	--	--	4840
7/14/2009	5:32	TP	6	183.1	--	12.0	0.39	0.64	30.0	46	--	--	--	10	--	--	9680
7/14/2009	7:46	TP	7	555	--	25.2	0.78	0.95	13.0	45	--	--	--	--	--	--	9680
7/14/2009	7:59	TP	8	590	--	30.7	0.83	1.06	12.0	44	--	--	--	--	--	--	9680
7/14/2009	4:19	CH	1	852	--	61.0	0.69	0.3	6.5	31	--	--	--	--	--	--	50
7/14/2009	4:33	CH	2	856	--	57.3	0.65	0.25	14.7	24	--	--	--	--	--	--	88
7/14/2009	4:38	CH	3	848	--	36.3	0.59	0.25	12.8	24	--	--	--	--	--	--	74
7/14/2009	4:51	CH	4	294		19.9	0.38	0.21	39.0	36	--	--	--	--	--	--	4188
7/14/2009		TP	Grab	746	0.05	-	-		4.0	35	--	--	--	--	7.91	0.05	4840
7/14/2009		TP	Auto Reg	723		-	-	0.9	21.0	31	--	--	--	--	7.82	--	--
7/14/2009		CH	Grab	287	0.11	-	-		13.0	36	--	--	--	--	7.71	0.05	4840
7/14/2009		CH	Auto Reg	279		-	-	0.28	16.0	37	--	--	--	--	8.07	--	--

Table C.5: Wet Weather Data for Event on 8/4/2009

Date	Time	Location	Sample #	CON	Cl	Cl^-	F	SRP	TSS	COD	NIT	AMM	TKN	TRB	pH	Oil and Grease	E. Coli
8/4/2009	4:50	TP	1	132.3	--	0.1	0.12	0.34	854	205	0.61	--	--	196.0	--	--	308000
8/4/2009	5:07	TP	2	77.2	--	0.5	0.18	0.43	767	161	0.49	--	--	169.0	--	--	24200
8/4/2009	5:16	TP	3	56.5	--	1.4	0.27	0.57	397	140	0.47	--	--	50.3	--	--	86700
8/4/2009	5:25	TP	4	62.8	--	2	0.36	0.3	199	131	0.57	--	--	37.1	--	--	64900
8/4/2009	5:36	TP	6	69.5	--	2.1	0.45	0.48	92	59	0.55	--	--	17.0	--	--	14100
8/4/2009	7:39	TP	8	233	--	3.6	0.71	0.19	21	54	1.26	--	--	5.4	--	--	29100
8/4/2009	4:47	CH	1	73.1	--	7.6	0	0.29	826	116	0.35	--	--	298	--	--	24200
8/4/2009	5:00	CH	2	78.5	--	6.2	0	0.87	1503	144	0.4	--	--	360	--	--	38800
8/4/2009	5:02	CH	3	90.1	--	6.8	0	1.07	1530	171	0.38	--	--	349	--	--	29900
8/4/2009	5:03	CH	4	97.1	--	1.9	0	1.32	1854	182	0.39	--	--	350	--	--	34500
8/4/2009	5:07	CH	6	74.2	--	3	0.21	0.75	716	102	0.38	--	--	171	--	--	24200
8/4/2009	5:10	CH	8	85.4	--	5.6	0.02	0.42	870	120	0.33	--	--	209	--	--	21900
8/4/2009	5:13	CH	10	162.7	--	9.8	0	0.29	1850	198	0.36	--	--	371	--	--	19870
8/4/2009		TP	Grab	--	0.04	--	--	--	14	58	--	--	--	2.91	7.86	0.05	6490
8/4/2009		TP	Auto Reg	--	--	--	--	0.9	7	53	0.91	--	--	--	7.58	--	--
8/4/2009		CH	Grab	--	0.06	--	--	--	17	60	--	--	--	7.12	7.87	0.05	24200
8/4/2009		CH	Auto Reg	--	--	--	--	0.81	171	74	1.14	--	--	--	7.67	--	--

Table C.6: Wet Weather Data for Event on 8/4/2009

Date	Time	Location	Sample #	CON	Cl	Cl^-	F	SRP	TSS	COD	NIT	AMM	TKN	TRB	pH	Oil and Grease	E. Coli
8/26/2009	7:25	TP	1	638	--	*0.2*	0.18	1.49	764.1	92	0.84	0.66	--	291	--	--	198700
8/26/2009	7:36	TP	2	165	--	*0.7*	0	0.74	175.7	80	0.08	0.58	--	67.2	--	--	242000
8/26/2009	7:45	TP	3	128	--	*1.6*	0	0.72	165.7	75	<0.05	0.36	--	55.4	--	--	24200
8/26/2009	8:03	TP	4	107	--	*2*	0	0.75	191.6	68	<0.05	0.28	--	67.3	--	--	20500
8/26/2009	8:26	TP	6	105	--	*2.2*	0	0.77	135.3	42	<0.05	0.22	--	25.7	--	--	30800
8/26/2009	9:41	TP	8	217	--	*3.6*	0.26	0.85	32.5	40	0.33	0.38	--	17.2	--	--	20200
8/26/2009		CH	1	873	--	*5.1*	0.43	0.44	28.2	17	0.37	0.27	--	7.43	--	--	0
8/26/2009	11:15	TP	Grab	--	0.06	--	--		14.9	40	0.22	0.59	--	14.4	7.31	0.05	34500
8/26/2009	11:15	TP	Auto Reg	--	--	--	--	0.8	59.9	42	<0.05	0.45	--	--	7.75	--	--
8/26/2009	11:30	CH	Grab	--	0.04	--	--		7.8	37	<0.05	0.13	--	16.8	7.71	0.05	24200
8/26/2009	11:30	CH	Auto Reg	--	--	--	--	0.4	15.3	34	<0.05	0.14	--	--	7.80	--	

Table C.7: Wet Weather Data for Event on 8/4/2009

Date	Time	Location	Sample #	CON	Cl	Cl^-	F	SRP	TSS	COD	NIT	AMM	TKN	TRB	pH	Oil and Grease	E. Coli
9/3/2009	10:11	TP	1	998	--	44.6	0.61	1.23	31.9	39	0.11	--	--	11.7	--	--	794
9/3/2009	10:59	TP	3	103	--	24.5	0.14	0.98	80.5	78	1.02	--	--	32.2	--	--	58000
9/3/2009	11:43	TP	5	88.2	--	11.3	0.16	0.82	36	64	0.61	--	--	37.2	--	--	24200
9/3/2009	12:08	TP	7	79.3	--	4.3	0.10	0.77	53.4	52	0.95	--	--	37.5	--	--	15540
9/3/2009	12:22	TP	9	59.6	--	3.9	0.05	0.68	113.5	50	0.3	--	--	22.3	--	--	24200
9/3/2009	12:40	TP	11	88.2	--	4.2	0.16	0.92	35.8	40	0.9	--	--	28.9	--	--	27300
9/3/2009	10:50	CH	1	883	--	39.8	0.55	0.68	15.8	46	0.09	--	--	7.63	--	--	598
9/3/2009	11:29	CH	3	642	--	1.8	0.45	1.02	35.6	48	3.11	--	--	27.1	--	--	20500
9/3/2009	11:57	CH	5	275	--	1.4	0.19	0.91	126.8	66	0.88	--	--	58.9	--	--	15540
9/3/2009	12:12	CH	7	135	--	1.4	0.03	0.87	241.4	58	0.86	--	--	83.3	--	--	9680
9/3/2009	12:18	CH	9	106	--	0.0	0.00	0.71	511.4	80	0.88	--	--	156	--	--	15540
9/3/2009	12:21	CH	11	88.9	--	1.4	0.00	0.78	591.2	72	0.44	--	--	162	--	--	19870
9/3/2009		TP	Grab	--	0.04	--	--	--	32.4	50	0.71	--	--	22	7.56	0.05	17330
9/3/2009		TP	Auto Reg	--	--	--	--	0.58	40.2	44	0.57	--	--	--	7.26	--	--
9/3/2009		CH	Grab	--	0.00	--	--	--	33.1	43	0.37	--	--	26.3	7.75	0.05	72700
9/3/2009		CH	Auto Reg					1.43	45.6	49	0.34				7.65		

Appendix D: Water Quality Data: Dry Weather

All abbreviations and units are consistent with the Wet Weather data.

Table D.1: Dry Weather Data for 2008

Site Name	Date	Time	Type	TKN	NIT	AMM	SURF	Cl	Cl$^-$	CON	F	SRP	TRB	COD	TSS	pH	E. Coli	Temp	DO
Taylor Park	8/13/2008	10:45	Grab	< 0.20	0.97	0.07	0.014	0.05	41	809	0.84	0.78	2.44	18	1	8.03	2250	26	9.9
Taylor Park	8/13/2008	10:45	Auto	0.44	1.74	0.07	--	--	--	817	--	0.89	--	13	2	7.87	2360	--	--
Colonial Hills	8/13/2008	12:45	Grab	0.30	0.56	< 0.05	0.026	0.28	59	958	0.68	0.50	2.47	19	16	8.26	630	26	5.3
Colonial Hills	8/13/2008	12:45	Auto	< 0.20	0.76	< 0.05	--	--	--	920	--	0.46	--	21	12	8.18	450	--	--
Taylor Park	8/20/2008	12:00	Grab	2.74	2.32	0.08	0.030	0.14	55	876	0.85	1.07	2.47	14	7	7.96	1987	25	5.7
Taylor Park	8/20/2008	12:00	Auto	2.61	2.28	0.11	--	--	--	882	--	0.99	--	14	6	8.02	--	--	--
Colonial Hills	8/20/2008	12:50	Grab	< 0.2	< 0.05	< 0.05	0.018	0.12	51	908	0.62	0.17	1.59	10	6	8.26	89	26	8.4
Colonial Hills	8/20/2008	12:50	Auto	< 0.2	< 0.05	< 0.05	--	--	--	895	--	0.17	--	11	2	8.21	89	--	--
Taylor Park	8/26/2008	3:00	Grab	< 0.20	<0.05	<0.05	0.020	0.1	32	906	0.84	0.60	1.51	11	2	8.15	173	25	8.6
Taylor Park	8/26/2008	3:00	Auto	0.39	<0.05	<0.05	--	--	--	902	--	0.59	--	11	3	8.43	131	--	--
Colonial Hills	8/26/2008	3:40	Grab	0.28	0.91	<0.05	0.019	0.23	54	897	0.65	0.10	1.40	12	4	8.32	42	25	11.4
Colonial Hills	8/26/2008	3:40	Auto	0.33	0.81	<0.05	--	--	--	897	--	0.09	--	12	3	8.33	28	--	--
Taylor Park	9/16/2008	2:45	Grab	--	0.87	0.23	0.024	0.09	62	1260	0.83	0.42	1.21	14	1	7.79	732	23	--
Taylor Park	9/16/2008	2:45	Auto	--	0.62	0.08	--	--	--	1229	--	0.41	--	25	5	7.75	822	--	--
Colonial Hills	9/16/2008	3:45	Grab	--	0.28	0.28	0.019	0.13	66	1111	0.61	0.11	1.83	12	2	8.05	192	24	--
Colonial Hills	9/16/2008	3:45	Auto	--	0.38	<0.05	--	--	--	1099	--	0.08	--	13	10	8.02	144	--	--
Taylor Park	10/28/2008	2:45	Grab	--	1.85	0.13	0.019	0.14	41	1486	0.66	0.37	1.28	--	4.8	6.2	--	13	5.3
Taylor Park	10/28/2008	2:45	Auto	--	1.95	0.16	--	--	--	1309	--	0.46	--	5	6	6.9	--	--	--
Colonial Hills	10/28/2008	3:45	Grab	--	1.56	<0.05	0.029	0.15	63	1172	0.64	0.07	2.75	5	12.6	7.9	--	9	11.7
Colonial Hills	10/28/2008	3:45	Auto	--	1.48	<0.05	--	--	--	1177	--	0.52	--	1	3.7	7.9	--	--	

Table D.2: Dry Weather Data for 2009

Site Name	Date	Time	Type	TKN	NIT	AMM	SURF	Cl	Cl^-	CON	F	SRP	TRB	COD	TSS	pH	E. Coli	Temp	DO
Taylor Park	3/25/2009	14:45	Grab	<0.2	--	<0.05	--	0.19	--	1099	--	0.59	1.77	15	3	7.89	53	11	7.2
Taylor Park	3/25/2009	14:45	Auto	<0.2	--	<0.05				1135		0.51		10	2	7.77			
Colonial Hills	3/25/2009	15:45	Grab	0.27	--	0.05	--	0.19	--	1123	--	0.71	7.41	39	3	8.12	134	10	11
Colonial Hills	3/25/2009	15:45	Auto	0.41	--	2.31				1135		0.61		18	158	7.89			
Taylor Park	5/20/2009	13:00	Grab	0.22	--	0.09	0.031	0.02	24.5	1005	0.68	0.99	1.67	12	5	7.91	1454	16	5.3
Taylor Park	5/20/2009	13:00	Auto	0.20	--	<0.05				1039		0.95		14	7	7.87	924		
Colonial Hills	5/20/2009	14:00	Grab	<0.20	--	<0.05	0.55	0.01	24.2	992	0.63	0.72	6.82	18	12	8.03	250	23	9.3
Colonial Hills	5/20/2009	14:00	Auto	<0.20	--	<0.05				984		0.66		14	14	8.12	326		
Taylor Park	6/3/2009	13:30	Grab	0.82	0.49	0.37	0.035	0.22	18.3	1089	0.54	1.66	1.81	15	9.7	7.89	478	17	8.7
Taylor Park	6/3/2009	13:30	Auto	0.74	0.52	0.21				1112		1.02		18	17.7	7.84	4480		
Colonial Hills	6/3/2009	15:15	Grab	0.6	0.22	<0.05	0.052	0.27	over	752	0.3	0.78	7.52	22	2.1	7.8	98	23	7.5
Colonial Hills	6/3/2009	15:15	Auto	<0.2	0.21	0.05				1735		1.17		24	12.0	7.81	130		
Taylor Park	6/17/2009	11:00	Grab	1.45	1.49	0.08	0.023	0.21	49	1193	0.55	0.7	1.69	5	11.9	7.96	1298	18	4.3
Taylor Park	6/17/2009	11:00	Auto	1.43	1.49	0.12				1185		0.76		5	7.1	7.97	1734		
Colonial Hills	6/17/2009	12:00	Grab	0.38	0.11	<0.05	0.027	0.18	68.3	757	0.49	0.79	1.67	28	7.3	7.78	472	24	4.4
Colonial Hills	6/17/2009	12:00	Auto	0.38	0.20	<0.05				799		0.73		12	11.6	7.98	1164		
Taylor Park	6/30/2009	13:00	Grab	<0.20	0.89	<0.05	0.04	0.11	35.5	948	0.77	0.78	0.555	21	1.6	8.21	1734	20	9.5
Taylor Park	6/30/2009	13:00	Auto	0.21	1.96	<0.05				967		0.78		13	1.0	8.07	1454		
Colonial Hills	6/30/2009	14:00	Grab	<0.20	0.08	<0.05	0.069	0.22	63.2	864	0.51	0.47	0.983	13	2.4	7.87	134	26	4.6
Colonial Hills	6/30/2009	14:00	Auto	<0.20	0.15	0.05				865		1.81		0	1.8	8.04	156		
Taylor Park	7/15/2009	10:30	Grab	--	1.78	0.20	0.042	0.16	30.1	987	0.73	0.85	1.27	16	2.7	7.8	3974	19	4.0
Taylor Park	7/15/2009	10:30	Auto	--	1.91	0.19				915		0.74		23	1.8	8.02	4840		
Colonial Hills	7/15/2009	11:30	Grab	--	0.27	0.22	0.063	0.14	34.8	753	0.61	0.39	2.78	23	6.6	7.9	978	23	4.0
Colonial Hills	7/15/2009	11:30	Auto	--	0.17	0.19				719		0.35		31	7.5	7.91	1036		
Taylor Park	7/29/2009	11:00	Grab	--	0.53	--	0.04	0.21	33.4	1474	0.66	0.79	0.658	5	0.7	7.85	582	18	--
Taylor Park	7/29/2009	11:00	Auto	--	0.54					925		0.72		5	0.6	8.08	314		
Colonial Hills	7/29/2009	11:45	Grab	--	0.25	--	0.08	0.33	19.2	537	0.42	0.34	2.57	9	2.3	7.99	240	19	--
Colonial Hills	7/29/2009	11:45	Auto	--	0.21					522		0.28		0	2.5	7.90	268		

Table D.2: Dry Weather Data for 2009 (cont.)

Site Name	Date	Time	Type	TKN	NIT	AMM	SURF	Cl	Cl$^-$	CON	F	SRP	TRB	COD	TSS	pH	E. Coli	Temp	DO
Taylor Park	8/12/2009	11:00	Grab	--	<0.05	0.15	0.05	0.13	34.4	921	0.77	0.22	3.25	30	30	8.17	1956	20	--
Taylor Park	8/12/2009	11:00	Auto	--	0.29	0.16	--	--	--	852	--	0.42	--	33	5	7.78	1644	--	
Colonial Hills	8/12/2009	11:45	Grab	--	0.35	<0.05	0.12	0.16	25.4	832	0.91	0.31	2.9	17	2	7.94	364	24	--
Colonial Hills	8/12/2009	11:45	Auto	--	<0.05	0.14	--	--	--	890	--	0.25	--	29	37	8.22	552	--	
Taylor Park	9/25/2009	11:00	Grab	--	--	2.17	--	0.08	34.4	987	0.48	1.75	1.84	14	3.6	7.54	--	19	--
Taylor Park	9/25/2009	11:00	Auto	--	--	1.73	--	--	--	977	--	1.34	--	13	9.4	7.7	--	--	
Colonial Hills	9/25/2009	11:45	Grab	--	--	<0.05	--	0.08	19.4	979	0.71	0.58	1.56	12	1.5	1.56	--	23	--
Colonial Hills	9/25/2009	11:45	Auto	--	--	<0.05		--	--	954	--	0.28	--	19	6	7.88	--	--	
Taylor Park	11/7/2009	11:00	Grab	--	--	<0.05	--	0.11	26.6	1199	0.55	1.07	1.87	--	5.9	7.84	40	16	--
Taylor Park	11/7/2009	11:00	Auto	--	--	<0.05	--	--	--	1182	--	0.83	--	--	9.8	7.86	32	--	
Colonial Hills	11/7/2009	11:45	Grab	--	--	<0.05	--	0.09	26	1142	0.57	0.74	1.81	--	4.4	7.95	60	22	--
Colonial Hills	11/7/2009	11:45	Auto	--	--	<0.05	--	--	--	1123	--	0.56	--	--	2.9	8.03	48	--	

Appendix E: Device Setup

Table E.1: Device Setup; 4230 Bubbler Flow Meter

Prog. #	Program Sequence	Colonial Hills Site	Taylor Park Site
1.0	Mode of Operation	Flow	Flow
1.1	Flow Conversion Type	Data	Data
1.2	Units of Level Measure	Feet	Feet
1.3	Flow Rate Units	cfs	cfs
1.4	Totalized Volume Units	acre-ft	acre-ft
1.25	Enter Data Point Set	See Rating Curves	See Rating Curves
1.26	Level Units for Data Entry	Feet	Feet
1.27	Flow Units for Data Entry	cfs	cfs
2.0	Sampler Flow Pacing	Flow Interval	Flow Interval
2.1	Sampler Intervale (Pulse)	0.35 acre-ft	0.2 acre-ft
2.2	Level to Enable	0.7 ft.	1.25 ft.
2.21	Level to Disable	--	--
2.22	Once Enabled Sampler Will	Stay Enabled	Stay Enabled
2.23	Set to Disabled State?	Yes	Yes
2.24	Plotter with Sampler?	No	No
3.0	Plot Mode of Operation	Off	Off
6.0	Time	Set Current	Set Current
7.0	Site ID Number	Colonial Hills	Taylor Park
8.0	Auto-Purge Frequency	--	--
9.0	Adjust Level (No Adj.)	Current Level	Current Level
10.0	Reset Flow Totalizer	No	No
12.0	Enable Program Lock	No	No

Table E.2: Device Setup; ISCO Auto Sampler

S.NO.	Program Sequence	Colonial Hills Site	Taylor Park Site
Sampler Program Mode			
1	Samples Every Pulse	1	1
2	Multiplex Samples (y/n)	yes	yes
3	Samples Per Bottle or Bottles per Sample?	Bottles per Sample	Bottles Per Sample
4	# of Bottles per Sample	1	1
5	Sample Volume	1000 ml	950 ml
6	Calibrate Sample Volume	no	no
7	Enter Start Time	no	no
Recommended Sampler Configuration Mode			
8	Set Clock	Set Current	Set Current
9	Bottles and Sizes	Portable	Portable
		24 bottles	24 bottles
		1000 ml	1000 ml
10	Suction Line	3/8" ID	3/8" ID
		polyprophene	polyprophene
11	Length of Tubing (ft.)	20-25 ft	25-30 ft
12	Liquid Detector	Enabled	Enabled
		0 Rinse Cycles	0 Rinse Cycles
		Do not Enter Head	Do not Enter Head
		Retry Sample Once	Retry Sample Once
13	Programming Mode	Basic	Basic
14	Calibrate Sampler	Enabled	Enabled
15	Sampling Stop/Resume	Default	Default
16	Start Time Delay	0 min.	0 min.
17	Enable Pin	Default	Default
18	Event Mark	Default	Default
19	Purge Counts	Default	Default
20	Tubing Life	Default	Default
21	Program Lock	Default	Default
22	Sampler ID	Colonial Hills	Taylor Park
23	Run Diagnostics	Default	Default