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# WATER QUALITY MODELS FOR STORMWATER RUNOFF IN TWO LINCOLN, NEBRASKA URBAN WATERSHEDS

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# WATER QUALITY MODELS FOR STORMWATER RUNOFF IN TWO LINCOLN, NEBRASKA URBAN WATERSHEDS

by

**Jake Ross Fisher**

## A THESIS

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**Bruce I. Dvorak and David M. Admiraal**

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# WATER QUALITY MODELS FOR STORMWATER RUNOFF IN TWO LINCOLN, NEBRASKA URBAN WATERSHEDS

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University of Nebraska, 2011

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Water quality monitoring was conducted in two urban watersheds (Colonial Hills and Taylor Park) located in southeast Lincoln, NE over a three year period spanning from October 2008 through September 2011. In-line probes continuously measured for turbidity, conductivity, dissolved oxygen, and water temperature while other water quality constituents were analyzed for discrete water samples collected using grab and automatic sampling techniques. The water quality data was used to calculate event mean concentrations (EMCs) for sixteen storm events sampled over the duration of the project period. Three types of stormwater quality multiple linear regression models were developed for the estimation of the discretely measured parameters: (1) continuous concentration models using in-line probe and flow data along with climatic data as explanatory variables; (2) EMC models using only climatic data as explanatory variables; and (3) EMC models using in-line probe EMCs along with climatic data as explanatory variables.

Statistically significant multiple linear regression continuous and EMC models resulted for six water quality constituents (i.e., total suspended solids, soluble reactive phosphorus, total phosphorus, nitrate plus nitrite nitrogen, total kjeldahl nitrogen, and E.

coli). Generally, the addition of an in-line probe variable in the EMC models improved the model fit over climatic-only EMC models. The results suggested continuous models may be beneficial to urban watershed management through the recognition of important physical watershed characteristics. Because stormwater runoff concentrations change so rapidly in small urban watersheds, the continuous models provided an increased potential to recognize rapid, in-storm changes due to site-specific characteristics. Differences in 2010 mass loading trends for TSS between the two sites during large and small precipitation events suggested that different physical processes were at work (e.g., stream bank erosion may be an important contributing factor during large storm events within the Colonial Hills watershed).

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# Chapter 1

# Introduction

## 1.1 Background

Stormwater is a very complex medium through which many environmental contaminants are transported. The transport of pollutants is generally the highest when stormwater runoff washes off surrounding surfaces and carries nutrients, sediments, and other chemicals to a local stream. Runoff increases with the increase in impervious surface cover and, therefore, is of great concern in urban settings (US EPA 1983; Brezonik and Stadelmann 2002). The Nationwide Urban Runoff Program (NURP), implemented by the U.S. Environmental Protection Agency (EPA), confirmed that pollutant concentrations in urban stormwater runoff are highly variable within a storm event and differ by region (US EPA 1983). Also, it was noted that the concentrations were affected by rainfall characteristics.

The NURP selected the event mean concentration (EMC) as a method for storm characterization and for the calculation of pollutant loads (US EPA 1983). Through regression model development that related the EMC to climatic and land use datasets, EMCs could be estimated for any storm event. The EMC has remained the main tool for pollutant load estimation since.

In recent years, the U.S. Geological Survey (USGS) has used technological advancements to continuously monitor several water quality constituents through the installation of in-line probes; the probes have successfully provided continuous measurements for specific conductance, pH, water temperature, turbidity, and dissolved oxygen (e.g., Rasmussen et al. 2005). Continuous measurements of the previously mentioned constituents were combined with discrete water sample measurements to develop regression models. Utilizing regression models with a continuous dataset, it may become possible to develop a more accurate estimation of loads and yields for TMDL development, BMP monitoring, and understanding water quality trends in watersheds (Rasmussen et al. 2005).

## 1.2 Purpose for the Study

Holmes Lake, located in southeast Lincoln, NE, was listed as an impaired water body by the Nebraska Department of Environmental Quality (NDEQ) in 1998 for sedimentation, nutrients, dissolved oxygen, etc. under the governance of Section 303(d) of the Clean Water Act (1972) (NDEQ 2010; US EPA 2010). In order to improve the water quality in Holmes Lake, restoration efforts were made by the City of Lincoln (COL) in the form of structural and non-structural best management practices (BMPs). Water quality monitoring was conducted by the COL in collaboration with the University of Nebraska-Lincoln civil engineering department (UNL) and the U.S. Geological Survey Nebraska Water Science Center (USGS) on two, similar urban watersheds in southeast Lincoln, NE to evaluate the effectiveness of the BMPs and to better understand water quality trends (US Geological Survey 2010).

In 2008, the USGS installed in-line probes for the continuous measurement of water quality (i.e., turbidity, conductivity, dissolved oxygen, and water temperature). Following the installation of the in-line probes, UNL began to collect and analyze discrete water samples from the two streams during both wet and dry weather flows. Water quality monitoring of the two streams was conducted from the installation period in 2008 until the fall of 2011 during the warm sampling seasons (generally April through November).

## 1.3 Objectives

The goal of the project was for UNL researchers to use the three-year dataset from the water quality monitoring to better understand stormwater runoff in small urban watersheds. The objectives to be fulfilled were to:

1. Develop regression models using the continuous in-line probe data and easily obtained climatic data to estimate discretely monitored water quality parameters. The regression models were to be used to estimate seasonal mass loading trends for the two drainage basins.
2. Calculate EMCs and use them for the development of two types of EMC regression models: EMC models that are dependent upon climatic data only (e.g., rainfall characteristics and seasonal variables) and EMC models that are dependent on climatic variables along with in-line probe EMCs.
3. Use the regression models to estimate seasonal pollutant mass load trends for the two urban watersheds to determine if any of the models would be more applicable for urban watershed management.

## 1.4 Thesis Overview

This thesis is a product of research conducted by the UNL civil engineering department in collaboration with the City of Lincoln and USGS. The research project focuses on the study of stormwater quality in small urban watersheds. Altogether, the thesis consists of seven chapters and twenty appendices. Chapter 1 introduces the reader to the research. Chapter 2 is a review of literature pertaining to the research project. Chapter 3 describes the two urban watersheds being studied. An overview of the methods used for the research project is provided in Chapter 4. Chapter 5 presents the results from the water quality collection and statistical analysis of the data. Chapter 6 summarizes conclusions of the research project and offers recommendations of the future work that would supplement the presented results. Lastly, Chapter 7 provides the list of references cited throughout the thesis.

# Chapter 2

# Literature Review

## 2.1 Introduction

In recent decades, much work has been done to understand the effects of urbanization on receiving water bodies, and subsequently, the environment (US EPA 1983). Amendments to the Federal Water Pollution Control Act (Clean Water Act) in 1972 (P.L. 92-500) required the U.S. Environmental Protection Agency (US EPA) to examine the downstream water quality effect of urban storm runoff (US EPA 1983; McLeod et al. 2006). Each state, under the provision of Section 303(d) of the Clean Water Act (1972), was required to list all water bodies that did not meet water quality regulations and to develop a total maximum daily load (TMDL) for each parameter causing “impairment” to the water body (NDEQ 2010). Subsequent revisions to the Clean Water Act in 1977 (P.L. 95-217) led to the development of the Nationwide Urban Runoff Program (NURP). The purpose of NURP was to produce a guide for future water resources and environmental planning and policy (US EPA 1983; Driver and Tasker 1990).

With urbanization came an increase in impervious surface cover, leading to an increase in runoff (US EPA 1983; Brezonik and Stadelmann 2002). During dry periods, pollutants accumulate on the impervious surfaces causing them to wash off in high concentrations during storm events. Pollutants that could adversely affect water quality during storm flows are sediments, nutrients, bacteria, oxygen demanding substances, etc.

(Whipple et al. 1983; LeBoutillier et al. 2000). Nutrients, specifically nitrogen and phosphorus, are of main concern as these are known to lead to eutrophication in water bodies (US EPA 1983; Zhang et al. 2008; Casey and Klaine 2001; US EPA 2004). According to Whipple et al. (1983), sources of phosphorus and nitrogen include soil erosion, automobile exhaust, fossil fuels, lawn and garden chemicals, and animal waste (LeBoutillier et al. 2000).

## 2.2 Definition of Terms

To avoid ensuing confusion, several terms used in the remainder of the literature review and thesis are defined below. The terms described are non-structural BMPs, structural BMPs, event mean concentrations, constituent loads, and constituent yields.

### 2.2.1 Non-Structural BMPs

Non-structural BMPs are environmental and water resources management practices that use natural means to reduce or eliminate pollutant loads in stormwater (US EPA 2004). These practices require little to no construction. Examples of non-structural BMPs include: education, reducing and disconnecting impervious cover, decentralizing and distributing runoff, limiting pesticide use, limiting fertilizer use, etc. (US EPA 2004; StormwaterPA).

### 2.2.2 Structural BMPs

Structural BMPs are environmental and water resources management practices that involve the physical construction of devices and structures that reduce or eliminate pollutant loads in stormwater (US EPA 2004). Examples of structural BMPs include:

constructed wetlands, pervious pavement, rain gardens, detention ponds, etc. (StormwaterPA).

### 2.2.3 Event Mean Concentrations

One of the simplest procedures for estimating stormwater pollutant loads is the calculation of an event mean concentration (EMC) (US EPA 1983; Novotny 2003). The EMC is defined as "the total constituent mass discharge divided by the total runoff volume" (US EPA 1983), summarized by Equation 2.1 below:

$$\mathrm{EMC} = \frac{\mathrm{M}}{\mathrm{V}} = \frac{\int \mathrm{C(t)Q(t)dt}}{\int \mathrm{Q(t)dt}} \tag{2.1}$$

where, C(t) is the constituent concentration at time t and Q(t) is the stormwater discharge at time t (e.g., Charbeneau and Barrett 1998; Stenstrom and Kayhanian 2005). In other terms, the EMC is a flow weighted average concentration that is reported in the normal constituent units.

### 2.2.4 Constituent Loads

When both storm flow volume and a constituent concentration are known or have been estimated for the same time on a continuous basis, a constituent load for that constituent can be determined (US EPA 1983). The load is essentially the mass of pollutant transferred by the stream, generally expressed in kg. The constituent load is calculated by multiplying the estimated (or measured) concentrations by the corresponding stream discharge (Rasmussen et al. 2008). Equation 2.2 below is used to determine a pollutant load over a predefined time span.

$$\text{Load} = \int_0^t C(t)Q(t)dt \tag{2.2}$$

In Equation 2.2, C(t) represents the constituent concentration at time t; Q(t) is the stormwater discharge at time t; and dt is the time step between the concentration and flow measurements (US EPA 1983; Charbeneau and Barrett 1998).

### 2.2.5 Constituent Yields

A method for normalizing the constituent load would be to express it as a yield for an entire watershed or subwatershed. A constituent yield is calculated by dividing the constituent load by the contributing drainage area, expressed as a load per unit area (e.g., kg/ha) (Rasmussen et al. 2008). Yields use a normalized approach to provide a method for comparing load contributions between different watersheds (e.g., Rasmussen et al. 2008).

## 2.3 Best Management Practices

Best Management Practices (BMPs) have been the response to the deteriorating surface and ground water quality for the purpose of treating stormwater and protecting receiving water bodies (US EPA 2004). Both structural and non-structural BMPs are being implemented within urban watersheds for the protection and restoration of the following: urban streams, groundwater infiltration, riparian habitat, and biota (US EPA 2004). Storm runoff monitoring programs have provided much insight for stormwater quality control methods through pollutant type and load characterization and their effects on water bodies (US EPA 1983; Driver and Tasker 1990).

### 2.3.1 Low/No Phosphorus Fertilizers

One specific non-structural BMP that was implemented in the Holmes Lake watershed was a low/no phosphorus fertilizer incentive. Beginning in 2007, the COL provided a coupon for two bags of free no-phosphorus fertilizer attached to a survey sent out to the residents within the watershed. The coupon was an incentive for completing the survey to obtain a better understanding of lawn management practices upstream of Holmes Lake (City of Lincoln Watershed Management 2010). Similar BMPs have been studied in Minnesota and Michigan.

A study conducted by Barten et al. (2008) compared three sub-watersheds in Plymouth, Minnesota, where a city-initiated phosphorus lawn fertilizer restriction was placed into effect in 1999, to three sub-watersheds in Maple Grove, Minnesota, where a similar restriction was not effected until 2004. The six year project allowed for a comparison on three years of collected data to determine the differences in nutrient export between the two cities (Barten et al. 2008). After normalizing the phosphorus export to account for site differences, Barten et al. (2008) concluded the data “strongly suggested” a 12 to 15 percent reduction in phosphorus loading due to the phosphorus fertilizer ban. Interestingly, the reduction in phosphorus export seemed to be mainly attributed to the reduction shown in soluble reactive phosphorus (SRP). Also noteworthy, a reduction in phosphorus export at the Maple Grove sites was observed in the three years of data following the adoption of the statewide Minnesota Phosphorus Lawn Fertilizer Law in 2004 compared to the three years of data prior; however, the reduction was not significant ($p=0.172$) (Barten et al. 2008). The Minnesota Fertilizer Law was amended in

2004, making it the first statewide fertilizer ban for lawns and turf (Minnesota Department of Agriculture 2007).

Lehman et al. (2009) monitored the effects of a lawn ordinance at a city-wide level for Ann Arbor, MI. A monitoring station on the Huron River upstream of Ann Arbor acted as a control for three other stations, either within the city limits or downstream of the city. Phosphorus concentrations were compared by month between data collected in 2008 versus a historical dataset (2003 to 2005). Significant decreases in the total phosphorus concentration ($\alpha=0.10$) were noted in 10 out of 15 cases during the months of May through September; the average reduction in concentration was 28% for the 10 cases (Lehman et al. 2009). Somewhat contrary to the findings of Barten et al. (2008), a significant SRP reduction was only observed for one case. Overall, it is difficult to draw the conclusion that the reduction in total phosphorus was only due to the lawn ordinance because of the other BMPs that had been implemented as well as the confounding influence of phosphorus within sediment from erosion.

### 2.3.2 Rain Gardens

A rain garden (a.k.a. bioretention cell) is a structural BMP that can reduce pollutants and peak flow from stormwater runoff (Prince George's County 2007). Rain gardens are heavily vegetated, shallow depressions, strategically located in the path of urban stormwater runoff. Utilizing physical, biological, and chemical processes of permeable soils, microbes, and certain vegetation, pollutants can be captured and reduced through adsorption, infiltration, and filtration (Prince George's County 2007).

In several studies, rain gardens have greatly reduced solids and nutrient loads during urban stormwater runoff events (Prince George's County 2007; Davis et al. 2006). Davis et al. (2006) indicated a 70-85% removal of total phosphorus and a 55-65% reduction in TKN for rain gardens in College Park, MD that were 60 to 80 cm deep. The removal percentage was determined from samples collected from the percolating stormwater. A study conducted on two rain gardens in Haddam, CT showed significant retention rates for ammonia in the sampled infiltration water (Dietz and Clausen 2005). In another Maryland study, Li and Davis (2009) studied the water quality impact of two rain gardens; the cell located in College Park (CP) captured parking lot and local roadway runoff, and the cell in Silver Spring (SS) captured only parking lot runoff. For the CP rain garden, significant concentration reduction was exhibited for TSS (>90%), nitrite, and copper (Li and Davis 2009). The SS rain garden produced reduced concentrations for TSS (>90%), total nitrogen, nitrate, nitrite, total phosphorus, chloride, and E. coli (Li and Davis 2009).

Although rain gardens are known in many instances to reduce nutrients, there have been reports of an increase in effluent concentrations. Li and Davis (2009) reported that often several parameters indicated a concentration increase, including nitrogen species, total phosphorus, chloride, and E. coli. The increase in nutrient concentration could likely be attributed to vegetation and fauna in the top-soil and mulch (Li and Davis 2009). Dietz and Clausen (2005) also reported an export of total phosphorus from the system, which may have been attributed to a disturbance of the soil.

Besides improvements to water quality, rain gardens also tend to greatly reduce storm runoff quantities and increase lag times (Prince George's County 2007; Dietz and

Clausen 2005). Dietz and Clausen (2005), in a study of infiltration from roof runoff, reported that 98.8% of the runoff entering the rain garden exited through infiltration. In summary, the effectiveness of a rain garden to improve the effluent stormwater quality and quantity greatly hinges on the development of the vegetation, the properties of the subsurface media, and the size of the garden (Prince George's County 2007; Davis et al. 2006; Dietz and Clausen 2005).

## 2.4 Matched-Pair Tests for Statistical Difference Determination

When two groups of paired data are to be compared, three methods exist for testing the significance of difference between the datasets (Helsel and Hirsch 2002). The sign test and signed-rank test are both nonparametric tests for determining whether paired observations are significantly different. The paired t-test is a parametric equivalent. Paired tests require the computation of the difference ($D_i$) between the paired observations, $D_i = x_i - y_i$ where i = 1, 2, 3, etc. and x and y are from the same population (Helsel and Hirsch 2002). The three tests described in Chapter 6 of Helsel and Hirsch (2002) are summarized below.

1. The **sign test** determines whether the x population is generally larger, smaller, or different from the y population. The null ($H_0$) and alternative ($H_1$, $H_2$, $H_3$) hypotheses for this test are as follows:

$$\mathrm{H_0}: \mathrm{Prob}\ [\mathrm{x} > y] = 0.5$$
$$\mathrm{H_1}: \mathrm{Prob}\ [\mathrm{x} > y] \neq 0.5 \quad (2 - \text{tailed test for difference})$$
$$\mathrm{H_2}: \mathrm{Prob}\ [\mathrm{x} > y] > 0.5 \quad (1 - \textit{tailed test, is x greater than y?})$$
$$\mathrm{H_3}: \mathrm{Prob}\ [\mathrm{x} > y] < 0.5 \quad (1 - \textit{tailed test, is x smaller than y?})$$

The statistical software SAS generates an output for the sign test in the proc-univariate command. The sign test is considered to be more widely applicable than the other two tests.

2. The **Wilcoxon signed-rank test** is used to determine whether the median difference (D) of the magnitude between paired data populations is equal to zero. The signed-rank test is applicable because it does not operate under the assumption that the $D_i$'s are normally distributed; it does assume, however, that the $D_i$'s are symmetric. The hypotheses for the signed-rank test are:

   $H_0$: median[D] $= 0$
   $H_1$: median[D] $\neq 0$ (2 − tailed test for difference)
   $H_2$: median[D] $> 0$ (1 − tailed test, is x greater than y?)
   $H_3$: median[D] $< 0$ (1 − tailed test, is x smaller than y?)

   The statistical software SAS generates an output for the Wilcoxon signed-rank test in the proc-univariate command.

3. The **paired t-test** is the parametric test of the three. The paired t-test should only be used when the paired differences, $D_i$, follow a normal distribution. If this is true, the following hypotheses can be tested for:

   $H_0: \mu_x - \mu_y = 0$ (no difference exists between the means of x & $y$)
   $H_1: \mu_x - \mu_y \neq 0$ (2 − tailed t test for difference)
   $H_2: \mu_x - \mu_y > 0$ (1 − tailed t test, is x greater than y?)
   $H_3: \mu_x - \mu_y < 0$ (1 − tailed t test, is x smaller than y?)

   The statistical software SAS generates an output for the probability of a greater t (Pr > |t|). If the Pr > |t| falls below the α level, the null hypothesis ($H_0$) should be rejected. The t-test will generate misleading inferences if the $D_i$ is not normally distributed.

## 2.5 Regression Modeling

An equation or model that can be used to estimate the magnitude of a variable based on the values of a number of other variables is developed through a statistical process called multiple linear regression (MLR) (Helsel and Hirsch 2002). The purpose of MLR is to explain as much of the variance in the response (dependent- or y-) variable with significantly correlated explanatory (independent- or x-) variables as possible (Helsel and Hirsch 2002). Helsel and Hirsch (2002) provide a complete procedure for MLR model development in chapter 11.

Regression analysis of the standard pollutants defined by the US EPA (1983) has provided a better understanding of explanatory variables for water quality parameter estimation as well as a quick method for pollutant load estimation for TMDL development (Driver and Tasker 1990). Driver and Tasker (1990) compiled a database of storm monitoring results from 98 urban watersheds sampled by the USGS along with storm data from75 urban sampling stations monitored through the NURP. Regression models developed by the US EPA (1983), Driver and Tasker (1990), Brezonik and Stadelmann (2002), Maniquiz et al. (2010), and LeBoutillier et al. (2000) indicated that stormwater constituent loads and concentrations correlated significantly with certain land use characteristics, rainfall characteristics, and physical watershed characteristics.

### 2.5.1 Regression Statistics

In order to comprehend the characteristics and development of regression models, a basic statistics overview is presented. Helsel and Hirsch (2002) provide an excellent overview of the statistical analysis necessary for producing stormwater runoff models.

Chapter 1 of Helsel and Hirsch (2002) describes how to prepare the data to be modeled; also, questions of outliers and variable transformations are confronted. The procedure for MLR was presented in chapter 11. The general model (Equation 2.3) is given as:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_k x_k + \varepsilon \tag{2.3}$$

where y is the response variable, $\beta_0$ is the intercept, $\beta_1$ though $\beta_k$ are the slope coefficients for explanatory variables "1" through "k," and ε is the remaining unexplained noise or error in the data (Helsel and Hirsch 2002). The hypothesis for testing the significance of the overall model with the variables listed above would be:

$H_0: \beta_i = 0$ where i represents all explantory variables
$H_1: \beta_i \neq 0$ for at least one explantory variable

where $H_0$ is the null hypothesis (no linear correlation exists between the response and explanatory variables) and $H_1$ represents the alternative hypothesis (linear correlation exists for at least one variable pair) (Dowdy et al. 2004). The F statistic is utilized for the test of hypothesis for the MLR model as a whole. If the probability of a greater F value ($Pr > F$) is below the predetermined confidence level (α), then the null hypothesis is rejected and the alternative hypothesis is assumed to be true (Dowdy et al. 2004).

When testing for the statistical significance of individual explanatory variables in the model, the t statistic can be utilized. The hypothesis would be the same as above, but only this time the "i" represents only an individual variable; therefore, the test of statistical significance is conducted for each explanatory variable. Again, if the probability of a greater t value ($P > |t|$) is below the α level, the null hypothesis is rejected and one concludes the explanatory variable significantly accounts for some variance in the response variable (y) (Dowdy et al. 2004).

Chapter 1 of Helsel and Hirsch (2002) continues by providing guidelines for model building. The guidelines can be summarized by the following steps:

1. Consider transformation of the **response variable** by comparing the residual plots for the best transformed model with the same plots for the untransformed model. The logarithmic transformation has proven to be the best for stormwater constituents (e.g., Brezonik and Stadelmann 2002; Driver and Tasker 1990; Rasmussen et al. 2008; Rasmussen et al. 2009). The "best" transformation will produce residual plots indicating constant variance across the estimation of y, normality of residuals, and a linear pattern.
2. Consider transformation of the **explanatory variables** by checking for the same three patterns in the residual plots.
3. Perform regression diagnostics to reveal any deficiencies in the MLR model. The following should be considered:
    a. **Leverage and influence** statistics can indicate potential outliers in the dataset. The "outlier" should be carefully considered to determine if it is a real data point or erroneous. Helsel and Hirsch (2002) suggest that an "outlier" should not be removed based only on its unusualness. Even if no transformation achieves symmetry or normality in the residual, there must be strong evidence before an outlier is removed from the dataset.
    b. **Multi-collinearity** results when explanatory variables are strongly related to one another. Multi-collinearity amongst the variables can be tested for using the

variance inflation factor (VIF). When the VIF exceeds 10, a serious problem exists. One solution for multi-collinearity is to remove one of the worrisome variables through careful judgment.

4. The “best” **MLR model** should be selected. Several methods exist to help in the determination process; some methods include:
    a. **Automated selection methods** exist within statistical software packages to help the user determine the most significant models. Forward, backward, and stepwise selection procedures involve different processes for testing the significance of the explanatory variables and suggesting the overall “best” model. The forward selection method adds one explanatory variable at a time, beginning with the variable that accounts for the most variation, until a variable causes the model to be insignificant. Once a variable enters the model, it remains. The backward selection method starts with all the explanatory variables in the model, and then removes the variables one at a time accounting for the least variation, until the model becomes significant. Once a variable is removed, it will no re-enter the model. The stepwise selection method is a combination of the forward and backward methods. The method starts with the forward method, then checks if the previously entered variable should be deleted. In the stepwise method, it is possible for a variable to enter and leave the model several times until the most significant model is built (Parkhurst 2010).
    b. The **coefficient of determination ($R^2$)** measures the proportion of variability explained in the linear relationship between the response variable and the

explanatory variables (Driver and Tasker 1990; Dowdy et al. 2004). The larger the $R^2$ value, the more variability explained by the regression. Caution should be made when using the $R^2$ value for model justification (Parkhurst 2010). The $R^2$ value cannot decrease with added variables, and it does not consider the appropriateness of the model. Also, leverage and influence points can unrealistically increase the $R^2$ value (Parkhurst 2010).

c. **Mallow's Cp** statistic uses a criterion that seeks to explain as much variance in y as possible while minimizing the variance of the resulting residuals. The statistic estimates the standardized total mean square error (MSE) of the fitted values for each potential regression model (Parkhurst 2010). The lower the Cp value, the better the model. Helsel and Hirsch (2002) suggest using a statistic, like Cp, over automated selection methods so that the scientist can use judgment to select what variables would be best by running the proper regression diagnostics.

d. **Root-mean-squared error (RMSE)** is a measure of variance between the predicted values for y and the observed values (Rasmussen et al. 2009). The RMSE is approximately equal to one standard deviation (σ) and carries the same units as the response variable.

e. **Prediction error sum of squares (PRESS)** can easily be computed by summing the square of the residuals from a potential model. The PRESS statistic then acts as an evaluator between potential models for the same dependent variable. The model with the lowest PRESS value is considered the better fit. Although the criteria for model selection are different with the PRESS statistic than Mallow's Cp, the two generally agree on the "best" (Helsel and Hirsch 2002)(Helsel and Hirsch 2002)model fit (Helsel and Hirsch 2002).

f. The **Akaike Information Criterion (AIC)** quantifies the overall power of the model by weighing the precision of the fit against the number of parameters used (Parkhurst 2010). The lower the AIC, the better the model.

### 2.5.2 Bias Correction Factor

Any time the response variable is transformed and then needs to be retransformed, a bias is introduced. The bias is generated from retransformation of the regression estimates from log units back to units in a linear space. One way to account for the ensuing bias due to retransformation is to use a "smearing estimate" (Duan 1983). The equation developed by Duan (1983) was titled the bias correction factor (BCF) and modified by Rasmussen et al. (2009) to take the form of Equation 2.4 for the base-10 logarithmic transformation.

$$\mathrm{BCF} = \frac{\sum_{i=1}^{n} 10^{e_i}}{n} \tag{2.4}$$

where n is the number of samples and $e_i$ is the difference between the measured and estimated concentrations (residuals) in log units.

### 2.5.3 Continuous Water Quality Monitoring

In recent years, the U.S. Geological Survey (USGS) has used technological advancements to continuously monitor several water quality constituents, including: specific conductance, pH, water temperature, turbidity, and dissolved oxygen

(Rasmussen et al. 2005). Continuous measurements of the constituents were combined with discrete water sample measurements to develop MLR models (Rasmussen et al. 2005). Utilizing regression models with a continuous dataset, it became possible to develop a more accurate estimation of loads and yields for TMDL development and BMP monitoring (Rasmussen et al. 2005).

The USGS in Lawrence, Kansas has taken a lead role by establishing continuous water quality monitoring stations in several river basins in Northeast Kansas (Rasmussen et al. 2005; Rasmussen et al. 2008). Rasmussen et al. (2005) developed regression equations that correlated continuously measured data to discretely measured water sample data for very large (55,000 – 60,000 mi$^2$), mainly agricultural, watersheds. The results from the regression modeling were summarized in **Table 2.1** in **Section 2.5.7**. The regression equations were utilized with the continuous measurements to produce continuous datasets for the response variables. The continuous datasets were then combined with stream discharge measurements to calculate annual load estimates. A comparison of annual load estimates for the same parameter using different explanatory variables in the regression equations illustrated how drastically the results can vary based on which explanatory variables are included in the model (Rasmussen et al. 2005).

Rasmussen et al. (2008) performed a similar regression analysis on data collected from five streams in Johnson County, Kansas. The streams were medium-sized drainage basins (50 – 70 mi$^2$) of which three were mainly agricultural by land use (60-70%), one consisting of approximately half urban (49%) and one third agricultural (38%) land use, and one mainly urban (80%) watershed by land use. For a complete summary of the models produced and the corresponding watershed characteristics, refer to **Table 2.1** in

**Section 2.5.7**. The loads produced from the regression models indicated that the majority of mass transfer (>90%) occurred mainly during “large” storm runoff events, which was equivalent to less than two percent of the time (Rasmussen et al. 2008). A comparison of the models between the sites revealed more variability for models from more highly urbanized sites, likely attributed to the multiple contaminant sources and altered pathways (Rasmussen et al. 2008). Together, Rasmussen et al. (2005) and Rasmussen et al. (2008) concluded that continuous water quality monitoring has several advantages over traditional water quality studies, including the ability to identify land-use changes and the effects of BMPs through a more cost effective means.

### 2.5.4 In-Line Probe Measurements

For the scope of the research project, a surrogate was defined as a measurement that may be acting as a substituting variable for another parameter or physical/chemical process occurring in the watershed. The goal was to use MLR to determine which continuously measured constituents may be acting as a surrogate for the discretely measured parameters. If the correlation developed using the statistical software was not obvious, further explanation was needed to justify the inclusion of the variable in the regression equation, such as a potential surrogate for other physical/chemical processes. The four continuously measured parameters used for the project that were thought to be potential surrogates were: dissolved oxygen, specific conductance, turbidity, and water temperature.

Dissolved oxygen (DO) in surface water can be attributed to the water temperature, atmospheric pressure, ion concentrations, photosynthetic activity, and atmospheric aeration (Lewis 2006). Higher temperatures equate to lower oxygen solubility in water, which can be observed within a watershed (Rasmussen et al. 2008). The DO concentration is an excellent indicator of biological and biochemical reactions taking place in larger water bodies (Burden et al. 2002). Because of the direct dependency on sunlight and temperature, DO concentrations reflect a diurnal pattern (Burden et al. 2002; Jordan and Stamer 1995).

Specific conductance (conductivity) is the measure of the capacity of water to conduct an electrical current (Burden et al. 2002; Radtke et al. 2005). Conductivity concentrations have been found to be highly correlated to the dissolved ion concentrations in the water (Burden et al. 2002; Jordan and Stamer 1995; Radtke et al. 2005). However, the ability of water to conduct depends not only on the presence of ions, but also their total concentration, mobility, and valence. Conductivity is also correlated to temperature which influences the solubility of the ions in the water (APHA et al. 1998).

Turbidity is the measurement of the clarity of water (Burden et al. 2002). Turbidity is determined by measuring the degree to which suspended and colloidal matter in a water sample reflect light at a 90° angle to the entrance beam (Burden et al. 2002; APHA et al. 1998). The suspended and colloidal matter may include clay, silt, fine organic and inorganic matter, plankton, and other microorganisms (APHA et al. 1998; Malina 1996). Turbidity is dependent on total precipitation and runoff, rainfall intensity, storm duration, channel slope, channel geomorphics, water sources, and the time of travel from the source to the point of measurement (Rasmussen et al. 2008).

Water temperature impacts chemical and physical processes that can directly affect the quality of the surface water. Some important physical water properties related to temperature are density, specific weight, viscosity, surface tension, thermal capacity, enthalpy, vapor pressure, and specific conductance (Malina 1996). Increased chemical and biological reaction rates and activity are correlated with warmer temperatures (Rasmussen et al. 2008; Malina 1996).

### 2.5.5 Rainfall Characteristics

A project objective was to determine what significant correlation exists within EMC and load models for the response variable and rainfall characteristics. Four studies have considered rainfall characteristics as explanatory variables for EMC and load based models; the findings are summarized in the remainder of the section.

Maniquiz et al. (2010) developed MLR models using storm characteristics as explanatory variables for two small urban watersheds in Yongin City, Korea to predict constituent loads and EMCs. The four rainfall variables chosen for the analysis were: total rainfall, antecedent dry days (ADD), rainfall duration, and average rainfall intensity (Maniquiz et al. 2010). After constructing time series plots for the data, it was determined that no seasonal trends existed for the parameters under consideration (TSS, COD, total nitrogen, total phosphorus, etc.). Because ADD was weakly correlated to the pollutant loads and EMCs, it was removed from consideration for modeling purposes (Maniquiz et al. 2010). The modeling results along with watershed characteristics can be found in **Table 2.1** of **Section 2.5.7**.

Data from 68 watersheds in the Twin Cities Metropolitan Area, Minnesota were combined by Brezonik and Stadelmann (2002) and used to develop MLR models that predict EMCs and total loads for several water quality constituents. The storm characteristics considered for explanatory variables were: total rainfall, ADD (since total rainall > 2.5 mm), rainfall duration, and average rainfall intensity (Brezonik and Stadelmann 2002). The modeling statistics and corresponding explanatory variables were summarized in **Table 2.1** of **Section 2.5.7**. It was concluded that rainfall duration and ADD were the two most useful explanatory variables for the prediction runoff EMCs (Brezonik and Stadelmann 2002).

LeBoutillier et al. (2000) conducted a similar MLR analysis on data collected from a small urban watershed in Saskatoon, Canada to develop constituent load models. The precipitation characteristics that were considered for explanatory variables are: maximum 5-minute rainfall intensity, average 5-minute rainfall intensity, storm duration, rainfall depth, and antecedent dry period (LeBoutillier et al. 2000). The load models that were developed can be seen in **Table 2.1** of **Section 2.5.7**. The study took into consideration several antecedent conditions. The only load model that included antecedent dry days as an explanatory variable was dissolved phosphorus.

McLeod et al. (2006) also performed a regression analysis on urban runoff water quality pollutants in Saskatoon, Canada for the development of load models in small watersheds. The rainfall variables that were selected for the analysis were: total rainfall, average intensity, ADD, storm duration, maximum instantaneous intensity, and maximum 5 minute average intensity. The variable that was most frequently included in the models predicting pollutant loads (TSS, TKN, total phosphorus, COD, $Cl^-$) due to its significance was total rainfall (McLeod et al. 2006). ADD was not found to significantly account for variance in any of the models. For a complete summary of the models developed by McLeod et al. (2006), refer to **Table 2.1** in **Section 2.5.7**.

### 2.5.6 Seasonal Trends

In order to account for seasonality within a model, a variable must be defined that can take into consideration trends associated with the time of the year. A seasonal variable should be considered for stormwater runoff modeling because concentrations of many surface water parameters have exhibited seasonal patterns (Helsel and Hirsch 2002). For the scope of this project, many variables were considered for seasonality, including: water temperature, solar radiation, a periodic function, and growing degree days.

According to Helsel and Hirsch (2002), a common **sinusoidal periodic function** used to account for seasonal variability in the model regresses a sine and cosine variable. The form of the regression model including this function is shown in Equation 2.5 below:

$$Y = \beta_0 + \beta_1 \cdot \sin(2\pi T) + \beta_2 \cdot \cos(2\pi T) + \beta_3 \cdot T + \text{other terms} + \varepsilon \qquad (2.5)$$

where T is time expressed in years, months, or day of the year and “other terms” are the other explanatory variables being modeled (Helsel and Hirsch 2002). The significance of the function in the model is determined by conducting a trend test on the “T” slope coefficient ($\beta_3$) to see if it is significantly different than zero (Helsel and Hirsch 2002). Helsel and Hirsch (2002) recommend using the sine and cosine terms together rather than just the more significant of the two. Rasmussen et al. (2008) developed several models in which the periodic function significantly accounted for variation in the concentrations of the following parameters: orthophosphorus, ammonia nitrogen, total nitrogen, and total phosphorus.

Another variable that may be used for modeling in order to account for concentration variation due to seasonal changes was **growing degree days (GDD)**. GDD is a measurement of heat units and is often used in agricultural sciences with crop development (McMaster and Wilhelm 1997). GDD has been shown to greatly improve the description and prediction of seasonal variations in the climate. The calculation for GDD is simple, as given in Equation 2.6.

$$\mathrm{GDD} = \left[\frac{(\mathrm{T_{MAX}} + \mathrm{T_{MIN}})}{2}\right] - \mathrm{T_{BASE}} \tag{2.6}$$

where $T_{MAX}$ is the daily maximum air temperature, $T_{MIN}$ is the daily minimum air temperature, and $T_{BASE}$ is the lowest temperature at which the process of interest will take place (McMaster and Wilhelm 1997). If $[(T_{MAX} + T_{MIN})/2] < T_{BASE}$, then $[(T_{MAX} + T_{MIN})/2] = T_{BASE}$. According to McMaster and Wilhelm (1997), this is the most widespread GDD calculation method.

In the study performed by LeBoutillier et al. (2000) in Saskatoon, Canada, a "Julian date" variable was regressed to try and account for seasonality. The Julian date was defined as the elapsed days from the beginning of the year and hypothesized that it may allow for the identification of seasonal variations. The variable was found to be significantly correlated with the total phosphorus load, but in the end was not included in the model because it did not provide enough additional explanation (LeBoutillier et al. 2000).

### 2.5.7 Modeling Summary

Models developed by several researchers were presented in **Section 2.5**. Rasmussen et al. (2005) and Rasmussen et al. (2008) developed models based on different constituent concentrations measured from discrete samples collected throughout the duration of a storm hydrograph. Models for EMC prediction were constructed by Maniquiz et al. (2010), Brezonik and Stadelmann (2002), and Driver and Tasker (1990). Also, models used to estimate constituent loads from a given storm event developed by LeBoutillier et al. (2000) and McLeod et al. (2006) were presented. Constituent loads were calculated from discharge and pollutant concentration measurements collected throughout the duration of a storm (LeBoutillier et al. 2000). The models that were applicable to the COL project along with the corresponding explanatory variables and statistics were summarized in **Table 2.1**. Several other studies that were not mentioned in the previous sections were also referenced in the table. It should be noted that for the purpose of finding applicable literature to the COL project, models developed by researchers strictly for highway and parking lot runoff were not included. Although the models based on constituent concentrations were the most applicable to the project, EMC and load models were considered because they were developed for drainage areas much closer in size and land use percentages more similar to the two Lincoln, NE basins than the watersheds for the continuous concentration models.

The continuously measured variables, namely turbidity and conductivity, allowed the constituent concentration models to account for a much larger proportion of the model variation on average (higher $R^2$ value) than the EMC models. The EMC and load models used mainly rainfall and watershed characteristics for explanatory variables, while the concentration based models used only continuously measured water quality parameters (conductivity, dissolved oxygen, turbidity, and water temperature) and flow data as potential explanatory variables. A comparison of the average $R^2$ values for the three modeling categories (Conc., EMC, and load) in **Table 2.1** indicated that load models and continuously measured concentration models produced better data fits than did the EMC models.

**Table 2.1: Summary of modeling literature and study characteristics**

| Study - Location (St./Country) | Model Type | Explanatory Variables | DA Size ($mi^2$) | Urban Land Use (%) |
|---|---|---|---|---|
| Rasmussen et al. 2008 - KS | Conc. | Probes, Q | 65.7 | 23.0 |
| | | | 58.5 | 28.7 |
| | | | 63.1 | 82.0 |
| | | | 48.6 | 11.8 |
| | | | 58.8 | 49.3 |
| Rasmussen et al. 2005 - KS | Conc. | Probes, Q | 55,280 | 2.0 |
| | | | 56,720 | 2.0 |
| | | | 59,756 | 2.0 |
| Christensen et al. 2009 - AR/OK | Conc. | Probes, Q | 163 | 4.0 |
| | | | 59 | 4.0 |
| Miller et al. 2007 - MD | Conc. | Probes, Q | 73 | high |
| | | | 47 | high |
| Ryberg 2006 - ND | Conc. | Probes, Q | 6,800 | low |
| Christensen et al. 2003 - KS | Conc. | Probes, Q | 685 | - |
| | | | 1,165 | - |
| Maniquiz 2010* - Korea | EMC | Rainfall, Q | < 0.01 | 100 |
| Brezonik & Stadelmann 2002* - MN | EMC | Rainfall, WC | 0.02-0.83 | > 50 |
| Driver & Tasker 1990* - U.S. | EMC | Rainfall, WC, Q | 0.01-80.5 | 100 |
| | | | 0.02-40.4 | 100 |
| | | | 0.01-2.6 | 100 |
| Liu et al. 2011 - China | Load | Rainfall | 0.46 | 99 |
| McLeod 2006 - Canada | Load | Rainfall | 0.93 | 100 |
| | | | 2.4 | 100 |
| | | | 0.29 | 100 |
| LeBoutillier et al. 2000 - Canada | Load | Rainfall | 0.15 | 100 |

Note: * refers to data from multiple sites being used for modeling, Conc. = continuous constituent concentration, WC = Watershed Characteristics.

## Table 2.1 Continued

| Study | COD | | | $Cl^-$ | | | $NH_3$ | | | N+N | | | TKN | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Var | n | $R^2$ | Var | n | $R^2$ | Var | n | $R^2$ | Var | n | $R^2$ | Var | n | $R^2$ |
| Rasmussen et al. 2008 | | | | SC | 19 | 0.73 | TBY | 18 | 0.22 | | | | | | |
| | | | | SC | 22 | 0.92 | Y | 22 | 0.32 | | | | | | |
| | | | | SC | 27 | 0.94 | Y, Q | 25 | 0.54 | | | | | | |
| | | | | SC | 25 | 0.66 | TBY | 24 | 0.41 | | | | | | |
| | | | | SC | 23 | 0.92 | - | - | - | | | | | | |
| Rasmussen et al. 2005 | | | | SC | 19 | 0.97 | TBY, WT | 19 | 0.51 | Q, WT | 21 | 0.66 | TBY | 19 | 0.59 |
| | | | | SC | 22 | 0.97 | TBY, WT | 28 | 0.51 | Q, WT | 28 | 0.49 | TBY | 24 | 0.66 |
| | | | | SC | 27 | 0.95 | TBY, WT | 34 | 0.58 | Q, WT | 34 | 0.69 | TBY | 28 | 0.44 |
| Ryberg 2006 | | | | SC, Q | 13 | 0.95 | | | | Q, Y | 30 | 0.71 | | | |
| Christensen 2003 | | | | SC | 156 | 0.96 | | | | | | | | | |
| | | | | SC, Q | 131 | 0.94 | | | | | | | | | |
| Maniquiz 2010 | R, D, AI | 45 | 0.20 | | | | | | | | | | | | |
| Brezonik & Stadelmann 2002 | R, AI, CI | 116 | 0.41 | | | | | | | R, AI | 251 | 0.20 | R, AI | 201 | 0.24 |
| Driver & Tasker 1990 | R, DA, CI, NU, AR | 216 | 0.52 | | | | | | | | | | R, DA, CI, NU, MNL | 188 | 0.54 |
| | R, DA, CI, NU, AR | 792 | 0.20 | | | | | | | | | | R, DA, IA, MNL | 857 | 0.10 |
| | R, DA, CI, NU | 563 | 0.18 | | | | | | | | | | R, DA, NU, AR | 609 | 0.37 |
| Liu et al. 2011 | R, PI, AI, D | 15 | 0.89 | | | | | | | | | | | | |
| McLeod 2006 | R, PI | 15 | 0.82 | R, PI | 15 | 0.84 | | | | | | | R, PI | 15 | 0.79 |
| | R, PI | 26 | 0.75 | R, PI | 26 | 0.55 | | | | | | | R, D | 26 | 0.97 |
| | AI | 19 | 0.47 | AI, D | 19 | 0.94 | | | | | | | AI, D | 19 | 0.87 |
| LeBoutillier et al. 2000 | | | | | | | | | | PI, R | 27 | 0.63 | AI, R | 29 | 0.58 |

Note: Christensen et al. 2009 and Miller et al. 2007 did not produce any models for the above parameters. AI = average Intensity, ADD = antecedent dry days, AR = Mean annual rainfall, CI = commercial/industrial land use, D = duration, DA = drainage area, IA = impervious area, MNL = mean annual nitrogen load in precipitation, MJT = minimum January temperature, n = sample size, NU = nonurban land use, PD = population density, Q = flow rate, R = Total Rain, Res = residential land use, $R^2$ = coefficient of determination, SC = specific conductance, TBY = turbidity, Var = explanatory variables in the model, WT = water temperature, Y = seasonal function.

## Table 2.1 Continued

| Study | EC | | | SRP | | | TP | | | TSS | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Var | n | $R^2$ | Var | n | $R^2$ | Var | n | $R^2$ | Var | n | $R^2$ |
| Rasmussen et al. 2008 | TBY | 21 | 0.74 | Y, TBY | 19 | 0.68 | TBY | 19 | 0.88 | TBY | 18 | 0.96 |
| | TBY | 23 | 0.86 | Q | 21 | 0.57 | - | - | - | TBY | 21 | 0.96 |
| | TBY | 25 | 0.71 | SC | 25 | 0.77 | Q, TBY | 23 | 0.62 | TBY | 22 | 0.96 |
| | TBY | 27 | 0.79 | - | - | - | TBY | 24 | 0.81 | TBY | 24 | 0.93 |
| | TBY | 25 | 0.83 | SC, Y | 23 | 0.61 | TBY, Y | 22 | 0.70 | TBY | 22 | 0.95 |
| Rasmussen et al. 2005 | TBY | 52 | 0.54 | | | | TBY | 17 | 0.85 | TBY | 17 | 0.94 |
| | TBY | 59 | 0.56 | | | | TBY | 23 | 0.83 | TBY | 20 | 0.83 |
| | TBY | 50 | 0.71 | | | | TBY | 29 | 0.68 | TBY | 22 | 0.88 |
| Christensen et al. 2009 | | | | | | | TBY, Q | 43 | 0.96 | | | |
| | | | | | | | TBY, Q | 41 | 0.98 | | | |
| Miller et al. 2007 | | | | | | | TBY, Q | 62 | 0.88 | | | |
| | | | | | | | TBY, Q | 59 | 0.92 | | | |
| Ryberg 2006 | | | | | | | Q, TBY, Y | 30 | 0.77 | | | |
| Christensen 2003 | TBY | 23 | 0.63 | | | | TBY | 36 | 0.89 | TBY | 48 | 0.93 |
| | TBY | 28 | 0.73 | | | | TBY | 36 | 0.55 | TBY, SC | 54 | 0.91 |
| Maniquiz 2010 | | | | | | | ADD, R, D, AI | 45 | 0.32 | R, D, AI | 45 | 0.09 |
| Brezonik & Stadelmann 2002 | | | | AI, Res | 104 | 0.29 | R, AI, DA | 364 | 0.30 | R, D, AI, DA, ADD, Res | 319 | 0.24 |
| Driver & Tasker 1990 | | | | | | | R, DA, CI, NU, MAR | 186 | 0.51 | R, DA, D | 176 | 0.13 |
| | | | | | | | R, DA, IA, PI | 1090 | 0.15 | R, DA, IA, PD, MJT | 963 | 0.19 |
| | | | | | | | R, DA, CI, Res, NU, MJT | 635 | 0.29 | R, DA, CI, NU | 528 | 0.14 |
| Liu et al. 2011 | | | | | | | R, PI, AI, ADD | 15 | 0.88 | R, PI, AI, ADD, D | 15 | 0.85 |
| McLeod 2006 | | | | | | | R, PI | 15 | 0.82 | R | 15 | 0.89 |
| | | | | | | | R, D | 26 | 0.96 | R | 26 | 0.89 |
| | | | | | | | AI, D | 19 | 0.88 | AI, D, PI | 19 | 0.98 |
| LeBoutillier et al. 2000 | | | | | | | PI | 29 | 0.65 | AI, R | 29 | 0.80 |

Note: AI = average Intensity, ADD = antecedent dry days, AR = Mean annual rainfall, CI = commercial/industrial land use, D = duration, DA = drainage area, IA = impervious area, MNL = mean annual nitrogen load in precipitation, MJT = minimum January temperature, n = sample size, NU = nonurban land use, PD = population density, Q = flow rate, R = Total Rain, Res = residential land use, $R^2$ = coefficient of determination, SC = specific conductance, TBY = turbidity, Var = explanatory variables in the model, WT = water temperature, Y = seasonal function.

Analyzing the results for the continuously measured constituent concentrations (**Table 2.1**), turbidity was found to be the most important explanatory variable for the models. TSS produced very good models based solely on turbidity as an explanatory variable; only one TSS model included any variable other than turbidity. Total phosphorus, E. coli, TKN, and ammonia models included turbidity as a main variable. Water temperature showed up as a significant variable only in the ammonia and nitrate plus nitrate nitrogen models. Specific conductance was the main explanatory variable for chloride but also showed up in multiple SRP models. A sinusoidal seasonal variable, outlined in **Section 2.5.1**, significantly accounted for variation in the concentrations of ammonia, SRP, and total phosphorus. Stream discharge seemed to explain variance in several of the models, showing significance in some chloride, ammonia, nitrate plus nitrite nitrogen, SRP, and total phosphorus models. The stream discharge was not included in any TSS, E. coli, or TKN models.

## 2.6 Watershed Characteristics

The concentration and subsequent loading of pollutants in stormwater runoff can be attributed to several factors, such as: degree of urbanization, land use type, densities of automobile traffic and animal populations, and air pollution (Whipple et al. 1983). With the introduction of impervious surface land cover, urbanization will increase the volume of stormwater runoff and reduce the time of concentration; therefore, the peak of the unit hydrograph will be increased (Whipple et al. 1983; Novotny 2003). Imperviousness is the percentage of the entire watershed covered by roofs, driveways, parking lots, roads, and other impermeable surfaces (Novotny 2003). Increasing imperviousness leads to the alteration of natural drainage patterns, having negative implications on the stream ecosystem and the current human dependency (Novotny 2003; Poff et al. 1997).

### 2.6.1 Connected Drainage

Impervious areas directly connected to a stream or receiving water body through a pipe network or lined channels are defined as “effective impervious areas” or “connected drainage” (Hatt et al. 2004). Hatt et al. (2004) performed an investigative study on fifteen small subbasins in Melbourne, Australia to compare the modeling applicability of total impervious area and effective impervious area as an explanatory variable for watershed pollutant loads. The study demonstrated a statistically significant correlation between the connected drainage and electrical conductance, total phosphorus, and filterable reactive phosphorus concentrations. Because several parameters indicated a stronger correlation with drainage connection than total imperviousness, it was suggested that stream water quality deterioration may be attributed more to the manner through which an impervious area is connected to receiving waters than the presence of impervious cover alone (Hatt et al. 2004). Also, Hatt et al. (2004) suggested that a small amount of impervious cover may be capable of significant pollutant increases downstream if there is a connected path between the impervious area and the stream. These conclusions have several watershed management implications, namely, the hypothesis that a more effective water quality control can be achieved by minimizing drainage connection.

### 2.6.2 Land Use Modeling

In the study performed by McLeod et al. (2006), four small, urban catchments composed of storm sewer networks were modeled using only rainfall explanatory variables. The four catchments represented the following land uses: new residential area, old residential area, commercialized area, and industrial area. Based on the models that were developed amongst the catchments, McLeod et al. (2006) suggested that the differences in variables of significance may be attributed to differing land uses which may be significant for the prediction of event loads.

In the Brezonik and Stadelmann (2002) study, efforts were made to model loads, EMCs, and runoff volume based on physical and land-use characteristics of the small watersheds. The physical and land-use explanatory variables tested were: total drainage area, residential area, commercial and industrial (CI) land-use area, public and open area, and impervious area (Brezonik and Stadelmann 2002). Drainage area proved to be one of the most important variables for the prediction of runoff volume and storm loads, showing a strong positive correlation to most parameters. The positive correlation is a critical finding and suggests that a larger drainage area may result in more load and flow than a smaller drainage area. Impervious area was not significantly correlated to any EMCs or loads, but was included in two equations estimating storm runoff volume. Residential area and CI area were the only land-use variables that demonstrated any modeling significance. The median EMC value was lower for the larger drainage area for all six water quality constituents (TSS, VSS, total phosphorus, SRP, total nitrogen, and nitrate plus nitrite nitrogen) (Brezonik and Stadelmann 2002). This finding may be applicable to the COL project as the two drainage basins of the study were nearly 5 times different in magnitude of area.

### 2.6.3 Flashiness

The hydrologic term describing the rate of change of a storm hydrograph for a watershed is “flashiness.” The flashiness of a stream refers to how quickly the flow rate changes during a runoff event (Poff et al. 1997; Baker et al. 2004). A “flashy” stream is one with a rapid rate of change, and a “stable” stream has a slow rate of change. Baker et al. (2004) developed an equation to quantify the flashiness of a stream. The Richards-Baker (R-B) Flashiness Index is based on dividing a “pathlength” equal to changes in daily discharge volumes (or mean daily flows) by the sum of daily discharge volumes (or mean daily flows) over a given time period (Baker et al. 2004). The Index can be calculated using Equation 2.7 below:

$$\mathrm{R-B\ Index} = \frac{\sum_{i=1}^{n} |q_i - q_{i-1}|}{\sum_{i=1}^{n} q_i} \tag{2.7}$$

where, q is the daily discharge volume (or mean daily flow) (Baker et al. 2004). The R-B Index was computed for 515 Midwestern streams during the period of 1975 through 2001. The Index showed a positive correlation with increased frequency and magnitude of storm events, and a negative correlation with baseflow and watershed area (Baker et al. 2004).

### 2.6.4 Stream Bank Erosion

A recent USGS study on nutrient transport in the Missouri River basin unveiled some interesting findings for channel erosion as a noteworthy source of phosphorus stream load (Brown et al. 2011). Brown et al. (2011) utilized the USGS-developed SPARROW (SPAtially Referenced Regressions On Watershed attributes) model to produce nitrogen and phosphorus models based on data collected from 57 streams within the basin, having a wide range of sub-basin size (0.01 – 6,365 $km^2$). The total phosphorus model included stream channel as an explanatory variable, indicating that channel erosion and scouring may be significantly contributing to the total phosphorus load of the Missouri River due to previously deposited phosphorus sorbing to sediment and becoming re-suspended during high flows (Brown et al. 2011). The modeling concluded that sediment transported in medium and larger streams contributed approximately 23% of the overall phosphorus load of the river on average.

Laubel et al. (2003) investigated stream bank erosion processes and factors on 15 small (370 – 1520 ha) rural streams in Denmark over a two year period. The purpose of the research was to develop regression models that would explain the variation in stream bank erosion rates with factors, such as: bank angle, overhanging bank, total vegetation cover, and stream power. Bank erosion was found to be significantly larger for the lower bank section than the upper bank, suggesting that bank failure was less of a sediment contributor than fluvial erosion (Laubel et al. 2003). Another important outcome of the study was the ability to estimate total mass transport for TSS and phosphorus over the two year period; bank erosion accounted for 40-70% of the overall TSS load and 15-40% of the total phosphorus load in the 15 rural streams. This range for total phosphorus would cover the 23% approximation made by Brown et al. (2011).

## 2.7 Event Mean Concentration Comparison

In order to provide a means of justification for the EMCs calculated for the COL study, previous studies were consulted. An in-depth review of literature revealed several researchers who have reported EMCs based on their studies. The mean EMC values for several parameters measured in numerous studies conducted in residential-urban watersheds throughout the U.S. can be seen in **Table 2.2**. A Wetlands Regulatory Assistance Program report performed a review of EMC data observed throughout the United States and listed the mean and median EMC values for the measured parameters from several studies in summary tables (Lin 2004). Because there was difficulty in tracing back to the original sources, Lin (2004) was the reference used for the majority of the data in **Table 2.2** (Baldys et al. (1998), Guerard and Weiss (1995), Harper (1998), LACDPW (1999), and Line et al. (2002)).

EMC values from NURP (US EPA 1983) were reported by Smullen et al. (1999) and can be found in the second row corresponding to the Smullen study of **Table 2.2**. EMC data gathered from the USGS, National Pollutant Discharge Elimination System (NPDES) stormwater permit, City of Austin, etc was added to the NURP database and reported in the first row corresponding to the Smullen study of **Table 2.2** (Smullen et al. 1999). Brezonik & Stadelmann (2002) reported the range of EMC values that were observed in their Minnesota study, not a mean value. A study performed in a 150 ha residential watershed in Calgary, Canada reported EMC values for ammonia, E. coli, and TSS which can be seen in **Table 2.2** (He et al. 2010)**.**

## Table 2.2: Summary of the average event mean concentrations (EMCs) from literature

| **Study - Location (St./Country)** | **Land Use Description** | **$NH_3$ (as N)** | **COD** | **EC** | **N+N (as N)** | **SRP (as P)** | **TKN (as N)** | **TP (as P)** | **TSS** |
|---|---|---|---|---|---|---|---|---|---|
| [1]Baldys et al. (1998)* - TX | Residential | | | | | | 1.5 | 0.38 | 127 |
| Brezonik & Stadelmann (2002)* - MN | Urban Res. > 40 ha | | | | 0.07-1.90 | 0.01-1.10 | 1.12-6.99 | 0.03-3.81 | 3-1570 |
| | Suburban Res. > 40 ha | | | | 0.05-2.10 | 0.02-0.18 | 0.42-18.5 | 0.08-3.40 | 6-2400 |
| [1]Guerard and Weiss (1995)* - CO | Residential | 0.49 | | | 0.59 | | 3.8 | 0.75 | 229 |
| [1]Harper (1998)* - FL | Low-Density Res. | | | | | | | 0.18 | 19.1 |
| | Single Family Res. | | | | | | | 0.3 | 27 |
| | Multi-family Res. | | | | | | | 0.49 | 71.7 |
| He et al. (2010) - Canada | Residential | 0.54 | | 1964 | | | | | 144 |
| [1]LACDPW (1999)* - CA | High-Density Res. | 0.29 | | | 0.38 | | 2.27 | 0.29 | 82 |
| | Multi-family Res. | 0.39 | | | 0.27 | | 1.5 | 0.13 | 31 |
| | Mixed Res. | 0.46 | | | 0.44 | | 2.23 | 0.25 | 65 |
| [1]Line et al. (2002) - NC | Residential | 0.79 | | | | | 5.92 | 0.59 | 73 |
| Smullen et al. (1999)* - U.S. | | | 52.8 | | 0.658 | 0.129 | 1.73 | 0.315 | 78.4 |
| | | | 66.1 | | 0.837 | 0.100 | 1.67 | 0.337 | 174 |
| Vegi (2008) - NE | Residential | | 38 | | | | 1.2 | 0.316 | 115 |
| **Average:** | | **0.49** | **52.3** | **1964** | **0.53** | **0.115** | **2.42** | **0.36** | **95** |

[1]Source data is Lin (2004)

* Data from multiple sites being used for modeling

## 2.8 First Flush

The first flush is the concept that pollutants exist in higher concentrations at the beginning of a storm runoff event than in the later parts of the storm (Stenstrom and Kayhanian 2005). Many researchers have noted that when a constituent concentration is plotted against the duration of a storm event (pollutograph), the pollutant concentration is highest at the beginning of the storm event followed by a gradual or rapid decrease toward the end of the event (Stenstrom and Kayhanian 2005). The importance of understanding the quantity of mass transport occurring during the first flush may prove valuable for BMP selection (Stenstrom and Kayhanian 2005). It also challenges the old system of reporting only an EMC which can overlook the high initial pollutant concentration. Using only the EMC for BMP selection can underestimate the BMP removal rates needed to provide improvements to effluent stormwater quality.

## 2.9 Summary

Many studies relating to the project conducted for the City of Lincoln were referenced and discussed throughout this chapter. The bulk of the chapter consisted of similar studies that developed regression models for water quality constituents analyzed in the COL project. After a thorough review of literature, it is believed that this thesis will provide new understanding for regression modeling in the Midwest and throughout the country. Many regression models have been developed using continuous water quality measurements (e.g., Rasmussen et al. 2005, Rasmussen et al. 2008, Christensen et al. 2009, etc.); however, little to none literature was found for models utilizing new sonde technology (i.e., continuous turbidity, conductivity, dissolved oxygen, and temperature measurements) within small, urban watersheds. For that reason, models developed using EMC and load values were consulted because the two provided relationships from small drainage basins comprised of mainly residential neighborhoods.

# Chapter 3

# Site Description

## 3.1 Site Selection

Holmes Lake Reservoir in southeast Lincoln, NE underwent extensive water quality restoration efforts ending in 2006 (City of Lincoln Watershed Management 2010). Following the lake restoration, the City of Lincoln implemented a number of BMPs (e.g., rain gardens, rain barrels, fertilizer education) in the contributing subwatersheds with the hope of maintaining good water quality. Because of the importance of Holmes Lake to the recreation of Lincoln residents, a site for water quality monitoring was established on a tributary to Antelope Creek in the Colonial Hills Park, just upstream of Holmes Lake. The location of the site is illustrated in **Figure 3.1**. The site location allowed for convenient sampling access in order to monitor the effectiveness of BMPs on the south tributary to Holmes Lake.

To investigate the relative impact on the water quality of the BMPs and the efficiency of the data collection methods, a second site outside the Holmes Lake watershed was studied. The following list of criteria was used when selecting the second monitoring site:

- Similar drainage area
- Similar land use
- Proximity to the Colonial Hills site

- Similar flow characteristics
- Accessibility and safety
- Few or no upstream BMPs

The location for the monitoring site was selected to be in Taylor Park on a tributary to Deadmans Run (see **Figure 3.1**). The site was located approximately 4.0 km (2.5 mi) north of the Colonial Hills site and had similar site characteristics without any widely installed upstream BMPs.

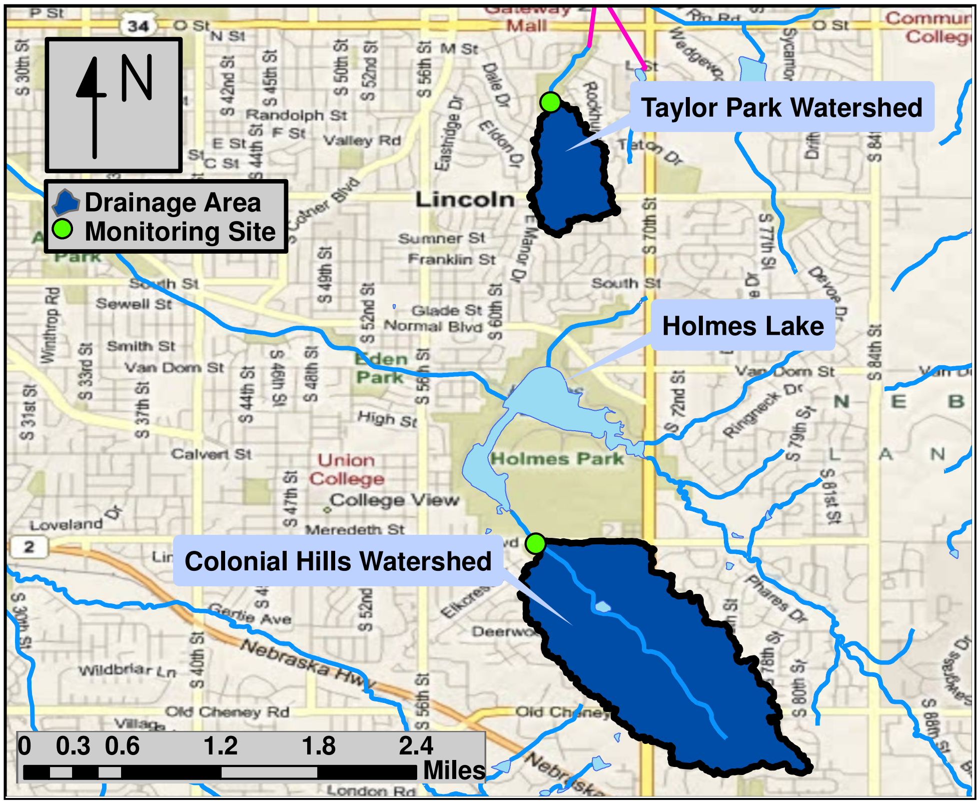

Figure 3.1: GIS map of the two monitored watersheds in southeast Lincoln, NE

The two neighboring watersheds were composed mainly of residential neighborhoods with similar land cover percentages (see **Table 3.1**). However, the sites had several differences. The drainage area for the Colonial Hills site (243 ha) was nearly five times the size of the Taylor Park site (49 ha), as delineated using ArcGIS 10. Because most of the drainage in the Taylor Park watershed traveled through concrete-lined channels (storm sewers), it had a much smaller normalized (by drainage area) erodible channel length. Even though the sites were in the same proximity, small differences in precipitation were recorded as well (see **Section 4.3.5**). A summary of the comparisons made between the two sites was shown in **Table 3.1**.

**Table 3.1: A comparison of site characteristics**

| Site Characteristics | Colonial Hills | Taylor Park |
|---|---|---|
| Drainage area | 243 ha | 49 ha |
| Land cover | | |
| Impervious | 40% | 37% |
| Parkland | 10% | 3% |
| Other (mainly lawns) | 50% | 60% |
| Normalized erodible channel length | 4.3 m/ha | 1.2 m/ha |
| BMPs | Yes | No |

The difference in "parkland" and "other (mainly residential lawns)" land cover percentages between the two sites may have been significant enough to cause dissimilarity in nutrient concentrations. This statement was made because a personal phone conversation with a regional manager in the City of Lincoln Parks Operations revealed a difference in fertilizer application between residential lawns and parkland. According to Dave Bomberger, the parks of Lincoln, NE have very rarely been fertilized in the past. There had been no regular fertilizer plan for the parkland, and the only justifiable reason for fertilizer application was the occasional thinning of the grass cover (Dave Bomberger, personal communication, Sept. 22, 2011). With the words of

Bomberger in mind, the 7% difference in parkland land use and 10% difference in "other" land use (**Table 3.1**) may result in higher stormwater runoff nutrient loadings in the Taylor Park watershed, where a higher percentage of the land cover was expected to be fertilized.

## 3.2 Monitoring Equipment

In 2008, the three collaborating agencies (USGS, UNL CIVE, and COL) established an enclosed monitoring station where stream gage, water sampling, and data transmitting equipment were concealed. A rain gage was installed at the site. Also, the USGS installed in-line probes for continuous water quality measurements. Photographs of the site layout at Colonial Hills and Taylor Park were provided in **Figure 3.2** and **Figure 3.3**, respectively.

At Colonial Hills, the monitoring equipment was located beneath a bridge (see **Figure 3.2**); the abutment provided a convenient installation foundation in a protected setting. The ISCO 2150 Area Velocity Flow Meter (AVFM) sensor was fastened to a concrete block and anchored into the channel bed directly below the bridge. The Taylor Park monitoring site was established approximately 60 meters (200 feet) downstream of a storm sewer outlet (**Figure 3.3**). At this point, the in-line probes and stream gage equipment were installed; however, the best location for the AVFM sensor was inside the upstream storm sewer. The storm sewer was selected because the consistent area of the sewer pipe simplified the discharge calculation through the use of a known depth to area relationship for an ellipse. Directly below a manhole, the location for the equipment also provided easy access for weekly maintenance routines.

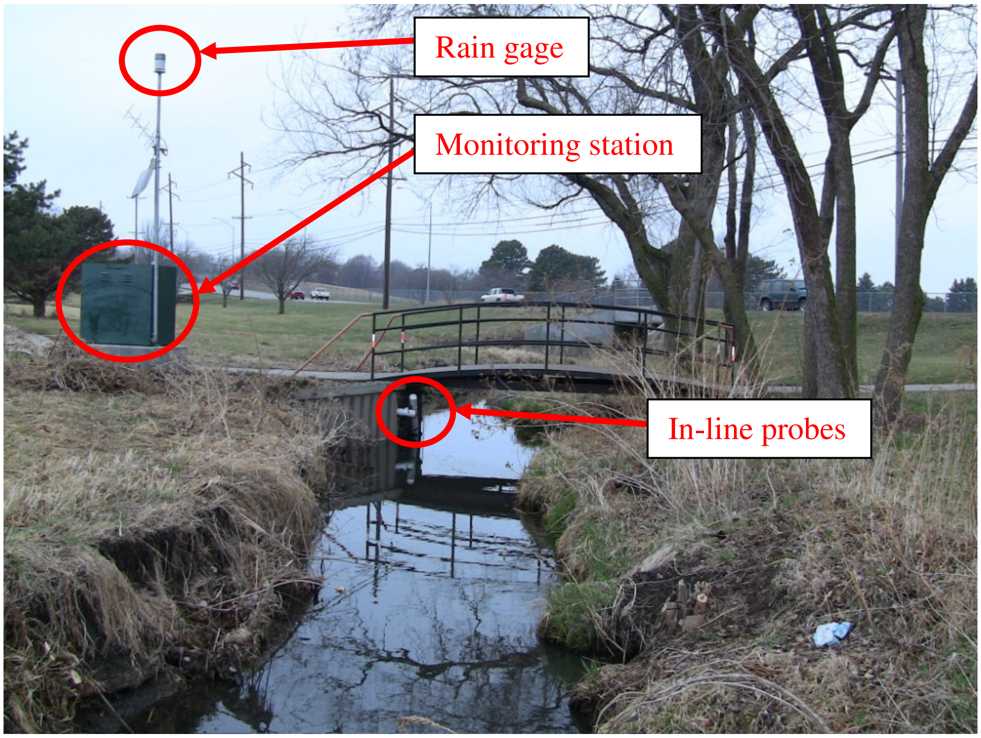

Figure 3.2: Looking downstream at the monitoring equipment at Colonial Hills

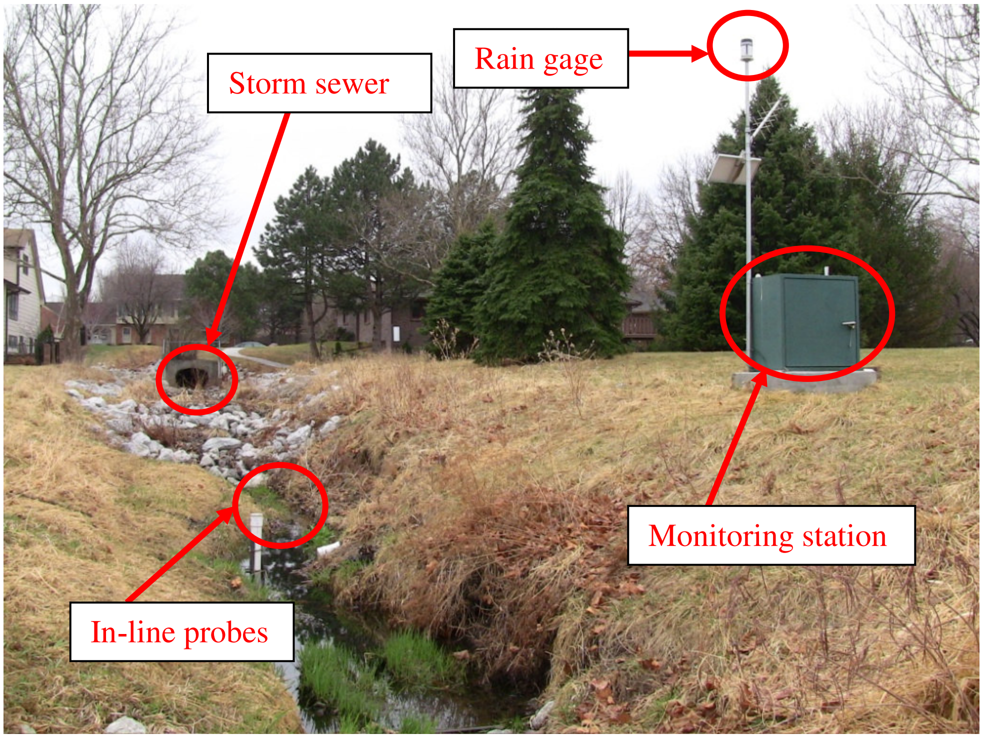

Figure 3.3: Looking upstream at the monitoring equipment at Taylor Park

## 3.3 Historical Climate Data

Lincoln, NE is located in the middle of the United States in a humid, continental climate. The average monthly minimum and maximum temperatures along with average total monthly precipitation values for the time period of June 1948 through December 2010 were obtained from the High Plains Regional Climate Center (HPRCC 2011); these averages were measured at the Lincoln, NE airport weather station and are presented in **Table 3.2**. Also provided in **Table 3.2** were average monthly temperatures and precipitation totals obtained from the Weather Underground database (Weather Underground 2011) for the Lincoln, NE airport weather station for the time period of the research project.

**Table 3.2: Average monthly temperatures and precipitation totals for Lincoln, NE**

| Month | June 1948 through Dec 2010[1] | | | Aug 2008 through Sept 2011[2] | | |
|---|---|---|---|---|---|---|
| | Average Max. Temp (°F) | Average Min. Temp (°F) | Average Total Precip (in.) | Average Max. Temp (°F) | Average Min. Temp (°F) | Average Total Precip (in.) |
| **Jan** | 33.7 | 12.2 | 0.71 | 30.0 | 10.0 | 0.80 |
| **Feb** | 39.7 | 17.6 | 0.84 | 37.7 | 16.0 | 0.81 |
| **Mar** | 50.8 | 27.5 | 2.01 | 51.7 | 28.3 | 0.87 |
| **Apr** | 63.8 | 38.9 | 2.89 | 65.3 | 39.3 | 2.43 |
| **May** | 73.9 | 50.2 | 4.21 | 74.0 | 50.3 | 3.62 |
| **Jun** | 84.5 | 60.8 | 3.94 | 84.0 | 62.3 | 6.51 |
| **Jul** | 89.2 | 66 | 3.36 | 87.7 | 66.7 | 3.07 |
| **Aug** | 86.8 | 63.7 | 3.38 | 87.3 | 63.5 | 3.67 |
| **Sep** | 78.6 | 53.1 | 2.96 | 77.3 | 52.0 | 3.03 |
| **Oct** | 66.3 | 40.4 | 2.01 | 65.0 | 39.3 | 3.05 |
| **Nov** | 50 | 27.5 | 1.47 | 53.3 | 28.7 | 1.08 |
| **Dec** | 37.1 | 16.1 | 0.87 | 33.3 | 12.0 | 1.15 |
| **Annual** | 62.9 | 39.5 | 28.65 | 62.2 | 39.0 | 30.09 |

[1] Data obtained from HPRCC (2011)

[2] Data obtained from Weather Underground, Inc. (2011)

The project period average precipitation totals indicated a slightly wetter than average climate in comparison to the 60 year period of record for Lincoln, NE. The majority of the difference came from a dryer than normal March and wetter than normal June, on average, as seen in **Table 3.2**. With a mean annual rainfall of 28.65 inches, Lincoln, NE falls into the Region II precipitation range (20 to 40 inches) defined by Driver and Tasker (1990) in a nationwide, urban stormwater runoff analysis.

## 3.4 Cross-Sectional Surveys

In the summer of 2010, a Sokkia total station was used to survey cross sections of the two monitored streams. The streams were surveyed in order to develop a stage to area relationship for each site so the volumetric flow rate could be calculated using the AVFM. The resulting cross sections were discussed in **Appendix B** for both Colonial Hills and Taylor Park. The figures in **Appendix B** provided only the cross sections that were surveyed at the location of the stream gages. Once the surveys were collected, HEC-RAS 4.1.0 was utilized to determine the cross sectional area for given stream depths. The stage to area relationships developed for the two sites based on the survey data are also provided in **Appendix B**.

At the Taylor Park monitoring site, the dimensions from the storm sewer pipe were easily determined. The pipe was elliptical in shape, having a width of 6.4 feet and a height of 4.1 feet. With this known channel size, the area was easily calculated for different stages using a known depth to area relationship. Therefore, the stream discharges could be calculated by multiplying the AVFM measured velocity by the cross-sectional area. Refer to **Appendix B** for a full description of the procedure used to develop the stage-discharge relationships for both monitoring sites.

## 3.5 Taylor Park Weir Installation

Due to the build-up and wash-off of debris on the riprap along with impeding channel vegetation at the Taylor Park site, very inconsistent baseflow gage height measurements were observed during the 2008 and 2009 sampling seasons. In order to produce a more consistent baseflow stream level, the collaborating agencies installed a sharp-crested weir downstream from the stream gage equipment on July 6, 2010. The result was a maintained baseflow stream level of 1.44' following this date. A photograph taken of the weir, looking upstream, is provided in **Figure 3.4**. Riprap was added downstream of the weir and along the banks to prevent any scour from occurring.

**Figure 3.4: Photograph of the weir at Taylor Park (looking upstream)**

# Chapter 4

# Materials and Methods

## 4.1 Introduction

This chapter describes the materials and methods used for data collection and data analysis throughout the duration of the project. The methods for the following aspects of the project are explained in detail: stage and flow monitoring, water quality monitoring, water quality analysis, EMC calculation, quality assurance/quality control, and statistical analysis.

## 4.2 Stage & Flow Monitoring

### 4.2.1 ISCO 4230 Bubbler Flow Meter

Flow stages were measured using an ISCO 4230 bubbler flow meter (bubbler). The bubbler operated by creating bubbles at a constant rate to determine the water pressure at the probe (Teledyne Isco 2005). Assuming a hydrostatic pressure distribution, the flow stage could accurately be determined using the pressure reading. Pressure readings were taken at a rapid pace and a stage reading was recorded at 15 minute intervals for the duration of the study. Because the bubbler was only capable of recording flow depth, a stage-discharge curve needed to be developed to convert the depth to volumetric flow. The stage-discharge curves were developed by correlating the stages measured with the ISCO 2150 area velocity meters and by considering calibration measurements recorded by the USGS; the curve development is discussed in greater detail in **Section 4.2.3** of this chapter.

### 4.2.2 ISCO 2150 Area Velocity Flow Meter

Stream stage and velocity measurements were recorded using an ISCO 2150 area velocity flow meter (AVFM). The device used a sensor installed in the stream bed to transmit acoustic pulses upstream (Teledyne Isco 2007). The waves were reflected back from particles within the stream and the average stream-wise velocity was calculated using the Doppler Effect. The sensor was equipped with a pressure transducer that calculated the hydrostatic pressure, knowingly equivalent to the level of the stream flow. Using this information, the flow rate was calculated using a depth to area relationship derived from cross-sectional surveys of the channel at Colonial Hills and a flow conversion equation for an elliptical channel at Taylor Park. A better description of the flow conversion process for each site was compiled in **Appendix B**. The AVFM measurements produced a “continuous” dataset for depth, velocity, and discharge for both sampling sites.

Throughout the project period, AVFM data was collected at a 15 minute interval for most dry and wet weather monitoring events. Toward the end of June 2010, a trigger depth was programmed to have the device record readings every 30 seconds when the stream flow reached a target stage. It should be noted that the device was incapable of accurately measuring velocities below 0.3 ft/sec, and therefore the dry weather flow estimates at the Colonial Hills site were considered inaccurate; the water velocity at

Colonial Hills was much slower than 0.3 ft/s during baseflow conditions (Teledyne Isco 2007).

### 4.2.3 Stage-Discharge Curve Development

Development of stage-discharge curves for both monitoring sites was a continual refining process. The bubbler produced measurements for gage height (stage), therefore a method for estimating the stream discharge based on that stage was needed. This was the main reason the AVFMs were installed on each site, to provide a continuous flow dataset that could be translated to the bubbler gage height measurements. Also, efforts were made by the USGS to develop and calibrate the stage-discharge curves by quantifying the stream flow using StreamPro ADCP and Flowtracker ADV measurement equipment. The methods used for the development of the final rating curve were different for Taylor Park and Colonial Hills and are summarized below.

#### Colonial Hills

At the Colonial Hills monitoring site, the USGS was able to record discharge measurements over a wide range of stream depths using StreamPro ADCP and Flowtracker ADV measurement equipment. These measurements were considered to be more accurate than the AVFM data because of the uncertainty in the low flow AVFM measurements; therefore, the stage-discharge curve was developed based on the USGS measurements. The corrected AVFM data were compared to the final curve to confirm the validity of the measurements. A complete summary of the USGS flow measurements and stage-discharge curve calibration was presented in **Appendix B**.

## Taylor Park

Unfortunately, there was no convenient way to calibrate flow measurements using the weir at the Taylor Park site; it acted only as a means for stream level stabilization. Instead, the USGS used a parshall flume to quantify the baseflow discharge following the installation of the weir. Because the AVFM was located upstream of the bubbler monitor, a method for translating the AVFM discharge measurements to the corresponding stage measurements recorded by the bubbler was needed. For that reason, the USGS obtained a YSI 6130 Rhodamine WT Sensor for the Taylor Park YSI sonde so that a dye tracer experiment could be conducted to determine the travel time between the two sets of equipment. The rhodamine experiment was performed during a storm runoff event in 2011. The determined relationship between the rhodamine travel times and the AVFM stage measurements was applied to match the AVFM discharge recordings to the downstream bubbler stage readings. This data translation then allowed for the development of the Taylor Park stage-discharge curve. **Appendix B** should be referenced for a detailed summary of the rhodamine experiment and eventual rating curve development.

In the end, two stage-discharge curves were developed for the Taylor Park site; one relationship for the bubbler measurements that were taken prior to the weir installation and a separate curve for the measurements recorded after July 6, 2011. It should be noted that the Manning’s equation was considered for discharge calculation at the Taylor Park site; but, because of the variation of the channel profile just downstream of the storm sewer, the Manning’s equation was not utilized. The relationship between the AVFM discharge and the bubbler stage measurements was combined with the baseflow recordings using the parshall flume to produce the two stage-discharge curves found in **Appendix B**.

## 4.3 Water Quality Monitoring

### 4.3.1 Continuous Water Quality Monitoring

The USGS installed a YSI 6600 water quality sonde in the stream at both sampling sites. The sonde was equipped with probes that had the capability of measuring conductivity (µS/cm), dissolved oxygen (mg/L), water temperature (˚C), and turbidity (FNU) (YSI Incorporated 2009). The sonde recorded measurements on a 15 minute interval during dry periods, but measurements were stored every 90 seconds during wet periods when the water level threshold was surpassed. This provided a near continuous water quality dataset which, for the purpose of the thesis, was regarded as "continuous." The continuous measurements provided a large dataset for the entire project period for these parameters with the hope that an estimation model could be developed in the future correlating these parameters with those tested during discrete sampling.

### 4.3.2 Discrete Sampling

A series of discrete water quality samples were collected from both sites during dry and wet weather periods. Discrete samples were comprised of "grab" and "auto" samples. Grab samples were those taken by hand from the stream using either a one liter beaker or a telescoping sampling pole. The samples were collected as close to the auto sampler intake as possible at approximately 6 inches below the water surface at both sites in order to minimize potential error. Reference **Figure 3.2** and **Figure 3.3** for the sample collection proximity within the two streams; the samples were collected near the “in-line probes” at both monitoring sites. Auto samples are those collected either manually or automatically using the ISCO 3700 full size portable sampler (autosampler) (Isco 1990). An autosample collected manually for regulatory purposes following a storm event was referred to as an “Auto Regulatory” (AReg) sample. In order to collect samples throughout the duration of a storm hydrograph, the autosampler was programmed to begin sampling when the ISCO bubbler met the trigger criteria for the level of the water surface.

Discrete samples were collected for two main reasons. First, the samples were tested for the same parameters as the USGS probes, providing a “calibration” dataset. Second, the samples were tested for numerous other water quality parameters in order to develop correlations to the USGS probe parameters. Discrete sampling can be divided into two categories: dry weather monitoring and wet weather monitoring. These are discussed in greater detail in the subsequent sections.

### 4.3.3 Dry Weather Monitoring

Dry weather monitoring referred to the collection of any samples not directly related to a rainfall event. These samples were collected bi-weekly throughout the sampling period on days at least 48 hours after a significant rainfall (greater than 0.2 inches). Because this sampling was often done at baseflow levels, the results of the dry weather monitoring provided a general comparison of the water quality and contaminant mass loadings between the two sites under these conditions.

Both auto samples and grab samples were collected during dry weather monitoring. The samples were collected at approximately the same time to allow for a comparison between the two methods for the resulting water quality concentrations. Since the concentrations of the water quality parameters should be the same in both samples, the comparison allowed for the detection of any bias in the data due to the sampling method.

### 4.3.4 Wet Weather Monitoring

Contaminant concentrations during rainfall events are substantially higher than those under base flow conditions (Rasmussen et al. 2008). Wet weather monitoring analyzes these concentrations by sampling during a rainfall event using a pre-determined sampling program. The funding provider defined the wet weather event as a storm with precipitation greater than 0.25” that provided a sufficient number of samples to represent the entire storm runoff hydrograph (6-7 samples) Also, the storms selected for sample collection were to be at least two weeks apart. Immediately following a storm event, precipitation websites were consulted to determine if a sufficient amount of rainfall had occurred (Weather Underground 2011; NE Department of Natural Resources 2011; NOAA 2011). Refer to **Appendix O** for the standard operating procedure for wet weather monitoring.

#### Trigger Depth

Before each potential wet weather event, the autosamplers were programmed to auto trigger based on a site specific sampling program. The timing for triggering the autosamplers was based on the forecasts from the Weather Channel (The Weather

Channel 2011) and the National Weather Service (NOAA 2011). The trigger depth was updated periodically throughout the duration of the project period depending on the base flow conditions for each site. The depths were set slightly above the maximum baseflow levels to ensure sample collection occurred only during rainfall events and to try and capture a sample from the initial flush.

## <u>Sampler Pacing</u>

The autosamplers allowed for a user-defined sample pacing on either time-based or flow-based intervals (Isco 1990). Time-based pacing collected samples at a pre-determined temporal spacing. For example, once the trigger depth was reached a sample was collected immediately and then every 15 minutes thereafter. One major drawback of time based sampling was that the times of sample collection often "leap frogged" the time of the peak flow; this was particularly true when the sample pacing was large and the runoff hydrograph was short. Flow pacing collected samples based on the estimated cumulative flow that had passed the site following the last sample (Isco 1990). Flow pacing had one major advantage over time based pacing in that the peaks were much less likely to be missed since sampling occurred more frequently as the flow increased. The major drawback to this method was because autosamplers were only capable of reading the flow depth, an accurate stage-discharge rating curve needed to be developed prior to relying on this method.

The wet weather events sampled during the project period were collected in the first year using a 15 minute time-based pacing while depth and flow data could be collected to generate sufficient rating curves. Wet weather monitoring was conducted after the first year using flow-based pacing. The pacing rate was determined from actual storm flow data at each of the sites based on an estimated six samples collected for a 3/8” rainfall event.

### Wet Weather Sampling Algorithm

After the samples had been collected, they were returned to the CIVE lab and a turbidity test was immediately conducted on all the auto samples to develop a “turbidity vs. time” hydrograph for each site. The *Wet Weather Sampling Algorithm* (shown in **Appendix C**) was then consulted to determine which samples would be selected for analysis. The project proposal allowed for 6-7 samples to be analyzed for each storm event per site, therefore the *Algorithm* was developed to provide a consistent sample selection process for all the storm events. The *Algorithm* was chosen to be based on the turbidity hydrograph throughout the duration of a storm event with an emphasis on sample collection from the peak concentration. This procedure was developed to provide a better characterization of the first flush of the storm, when pollutant concentrations have been cited to be the largest (Stenstrom and Kayhanian 2005), so that a more representative dataset might be developed for load estimation.

### 4.3.5 Precipitation Data

An Onset tipping bucket rain gage was installed on each site in order to provide on-site rainfall characteristics (Onset Computer Corporation 2001). However, due to ongoing clogging of the funnel, the recorded measurements were determined to be insufficient. Therefore, the High Plains Regional Climate Center (HPRCC) website was accessed to provide a continuous precipitation dataset (HPRCC 2011). The three climate observation stations in closest proximity to the monitoring sites were considered. The weather stations selected for the precipitation analysis were located near 50th and A St. (Lincoln 51E 13S), 84th and Van Dorn St. (Lincoln 82E 20S), and 27th and Old Cheney St. (Lincoln 27E 56S). The rain gage locations and relative distances to the center of the closest watersheds can be seen in **Figure 4.1**.

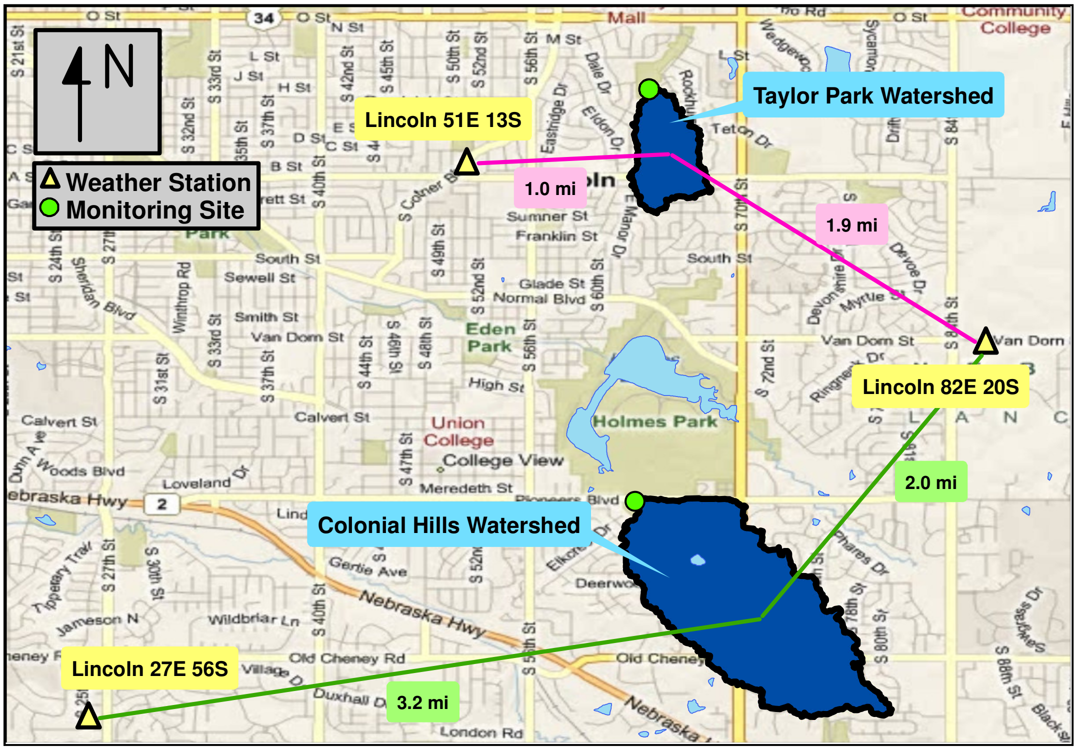

**Figure 4.1: HPRCC weather station locations relative to watersheds**

The Weather Underground website (Weather Underground 2011) indicated there was a weather station located in between the two watersheds near 59th and Franklin St; this station was also considered. An in-depth analysis was conducted to determine the most applicable rain gage observation sites for both drainage basins amongst the three HPRCC stations and the Weather Underground station. Total runoff volume in inches for individual storm events was plotted against storm specific rainfall recordings from the individual weather stations. The total runoff from the storm events was expected to be highly correlated to the storm precipitation. To produce higher correlations and in hope of a more accurate precipitation amount, weighted average precipitation values were also considered for the different combinations of the weather stations using the distances shown in **Figure 4.1** weighted with the Shepard's Method. The correlation between the precipitation values from the different combinations of stations and runoff values were compared using the $R^2$ value from the linear fit. During the process, the Weather Underground station was eliminated from consideration because it did not greatly improve the correlations and the data was unable to be retrieved on an hourly basis like the HPRCC data.

After consideration was given to a number of weather station combinations, a two-station weighted average for total storm precipitation was deemed the most trustworthy for both watersheds. This conclusion was affected by the previous knowledge of the UNL researchers that, in general, the spring and summer storms in Lincoln, NE move on a west to east track. Therefore, the precipitation values reported for the Taylor Park watershed were a weighted average of the Lincoln 51E 13S and the Lincoln 82E 20S stations; and for the Colonial Hills watershed, a combination of the Lincoln 82E 20S and Lincoln 27E 56S weather stations. For a detailed description of the weighted average equations and the weather station comparison, refer to **Appendix D**.

In order to determine the average and peak storm intensities, the same weighted average equation was used for the two sampling sites. However, instead of making a continual calculation as with the precipitation values, the overall peak and average intensity for a given storm event was first calculated with each weather station dataset; then the weighted average equations were applied using the overall storm average and peak intensities. During the modeling stage, the average and peak storm intensities were considered to be constant during the entire runoff event.

### 4.3.6 Rapid Sampling

During the spring of 2011, a rapid sampling procedure was implemented during a storm event (5/24/2011). The procedure called for a team of individuals to travel to the sites during a storm event prior to the first sign of runoff. During the entirety of the runoff event (2 hours), the team collected a grab sample and auto sample simultaneously on a three minute interval prior to and during the initial runoff period. The goal of the procedure was to better define site-specific physical and chemical processes along with the concentration flux that is known to occur during the “first flush” of a runoff event (Stenstrom and Kayhanian 2005). The sampling procedure was designed in such a way as to also provide a comparison between the auto samples and grab samples. The procedure that was used for the rapid sampling of a runoff event was documented in **Appendix E**.

## 4.4 Biological & Chemical Analysis

Immediately following the sample collection for both dry and wet weather monitoring, the samples were placed in coolers with ice and transported back to the civil engineering (CIVE) laboratory located in the Scott Engineering Center (SEC). Smaller aliquots taken from the sites and from the selected auto samples (determined by the *Algorithm*) were then transported to the Water Sciences Laboratory (WSL) on east campus to be tested for ammonia, nitrate plus nitrite nitrogen, TKN, and occasionally dissolved oxygen. Similarly, aliquots were occasionally transported to the State of Nebraska Health and Human Services (HHS) Laboratory to be tested for E. coli; the descriptions for dissolved oxygen and E. coli below explain why the testing was performed “occasionally.” Also, grab samples taken during wet weather events were submitted to the Theresa Street Waste Water Treatment Plant Laboratory to be analyzed for N-Hexane Extractable Material (oil & grease). Biological and chemical analyses were conducted on the parameters requested by the City of Lincoln following the methods determined by the project funder. **Table 4.1** lists the parameters tested for along with the corresponding abbreviations used periodically in the thesis; **Table 4.2** indicates dry and wet weather analyzed parameters and the methods used to conduct the testing.

**Table 4.1: Analyzed parameters and abbreviations**

| Water Quality Parameter | Abbreviation |
|---|---|
| Ammonia | $NH_3$ |
| Chemical Oxygen Demand | COD |
| Chloride | $Cl^-$ |
| Chlorine | $Cl_2$ |
| Conductivity | CDY |
| Dissolved Oxygen | DO |
| Escherichia coli | EC |
| Fluoride | $F^-$ |
| Nitrate plus Nitrite Nitrogen | N+N |
| Oil & Grease | OG |
| pH | pH |
| Soluble Reactive Phosphorus | SRP |
| Surfactants | SF |
| Suspended Sediment Concentration | SSC |
| Total Kjeldahl Nitrogen | TKN |
| Total Copper | Cu |
| Total Phosphorous | TP |
| Total Suspended Solids | TSS |
| Turbidity | TBY |
| Water Temperature | WT |

**Table 4.2: Water quality parameters and analytical methods**

| Test | Expressed as: | Standard Method[1] | Hach[2]/EPA[3] Method | Dry Weather | | Wet Weather | | |
|---|---|---|---|---|---|---|---|---|
| | | | | Grab | Auto | Auto | AReg | Grab |
| $NH_3$ | (mg $NH_3$-N)/L | 4500-$NH_3$ | EPA 350.1 | X | | X | | |
| COD | (mg COD)/L | 5220 | Hach 8000 | X | X | X | X | X |
| $Cl^-$ | (mg $Cl^-$)/L | 4500-$Cl^-$ | Hach 8113 | X | | X | | |
| $Cl_2$ | (mg $Cl_2$)/L | 4500-Cl | Hach 8167 | X | | | | X |
| CDY | µS/cm | 2510 | - | X | X | X | | |
| DO | (mg DO)/L | 4500-O | - | X | | | | X |
| EC | cfu/100 ml | 9223b | - | X | (X)* | X | (X)* | X |
| $F^-$ | (mg $F^-$)/L | 4500-$F^-$ | Hach 8029 | X | | | | |
| N+N | (mg $NO_3$+$NO_2$-N)/L | 4500-N | EPA 353.2 | X | | X | X | X |
| OG | (mg N-HEM)/L | - | EPA 1664A | | | | | X |
| pH | pH units | 4500-$H^+$ | - | X | X | | X | X |
| SRP | (mg $PO_4^{3-}$-P)/L | 4500-P | Hach 10209 | X | X | X | X | |
| SF | (mg LAS)/L | - | Hach 8028 | X | | | | |
| SSC | mg/L | - | - | | | | | X |
| WT | °C | 2550 | - | X | | X | X | X |
| TKN | (mg N)/L | 4500-$N_{org}$ | EPA 351.2 | X | | X | X | |
| Cu | (µg Cu)/L | 3030 | - | X | | X | | |
| TP | (mg $PO_4^{3-}$-P)/L | 4500-P | Hach 10210 | X | X | X | X | |
| TSS | mg/L | 2540D | - | X | X | X | X | X |
| TBY | NTU | 2130 | EPA 180.1 | X | | X | | X |

( )* = Parameters tested periodically for regulatory purposes
[1] From APHA (1998)
[2] From Hach (2007)
[3] From US EPA (2011)

It should be noted that during the 2010 project year the testing location for two of the water quality parameters changed. The Winkler Method procedure to test for dissolved oxygen was implemented in the CIVE lab after the procedure was determined to be accurately established by comparing several results with those produced by the WSL for the same samples. Following May 25, 2010, all the samples collected for dissolved oxygen were tested in the CIVE lab. Also, E. coli testing supplies were purchased from IDEXX and the Quanti-Tray/2000 procedure was implemented by CIVE lab technicians in a laboratory located in Chase Hall on east campus of UNL. After conducting a cost comparison, it was determined that the transition would provide a more cost efficient means for E. coli analysis. Again, samples were tested in both labs until the CIVE technicians could produce statistically comparable results. The new testing location was used as the only source of E. coli results beginning June 16, 2010. However, samples were periodically delivered to the HHS lab for E. coli QA/QC. The comparison of the results from the two labs can be seen in **Appendix F**.

It also should be noted that during the 2010 project year the testing procedure for soluble reactive phosphorus and total phosphorus changed. Prior to the 2010 sampling year, the two phosphorus parameters had been tested either in the CIVE lab following Hach Methods 8190 and 8048 or at the WSL. Beginning in 2010, the two parameters were tested solely in the CIVE lab following Hach Method 10209 for SRP and Hach Method 10210 for total phosphorus. The new Hach methods were determined to be in the best interest of the overall project accuracy for the results of the two parameters.

### 4.4.1 Ammonia

Ammonia ($NH_3$) was analyzed for both wet and dry weather samples by the UNL WSL and the results were reported to the CIVE Lab electronically. Samples were preserved upon collection with concentrated Sulfuric Acid ($H_2SO_4$) then filtered and frozen until testing could be conducted. The EPA Method 350.1 referencing Standard Methods 4500-$NH_3$ was followed using a Seal AQ2 Autoanalyzer (US EPA 2011). The results were reported in $NH_4$-N having a four year average reporting limit of 0.05 mg/L.

### 4.4.2 Chemical Oxygen Demand

Chemical oxygen demand (COD) was analyzed for both wet and dry weather samples in the CIVE Laboratory within the 7 day holding time. Hach Method 8000 referencing Standard Method 5220 was followed using the Hach DR/2400 Spectrophotometer (APHA et al. 1998; Hach 2007). The test had a four year average method detection limit of 3 mg/L.

### 4.4.3 Chloride

Chloride ($Cl^-$) was analyzed for both wet and dry weather samples in the CIVE Laboratory within the 7 day holding time. Hach Method 8113 was followed using the Hach DR/2800 Spectrophotometer (Hach 2007). The samples were filtered prior to the sample analysis. The test had a four year average method detection limit of 0.2 mg/L.

### 4.4.4 Chlorine

Chlorine ($Cl_2$) was analyzed for both wet and dry weather samples immediately following the collection on the testing site. Hach Method 8167 was followed using the portable Hach DR/2000 Spectrophotometer (Hach 2007). The test had a four year average method detection limit of 0.01mg/L.

### 4.4.5 Conductivity

Conductivity (CDY) was analyzed for both wet and dry weather samples in the CIVE Laboratory within the 24 hour holding time. Standard Methods 2510 was followed using the Hach HQ14d Conductivity Meter and Probe (APHA et al. 1998). The test had a four year average method detection limit of 1 μS/cm.

### 4.4.6 Copper, Total

Total copper (Cu) analysis was performed on both wet and dry weather samples in the CIVE Laboratory within the 3 month holding time. Standard Methods 3030 was followed using the flame Atomic Absorption Spectroscopy (AAS) method by filtering and then preserving the samples with 150 μL concentrated nitric acid ($HNO_3$) per liter of sample as required by Standard Methods 3010 (APHA et al. 1998). A Perkin Elmer 3100 AAS machine was used to conduct the testing. The test had a four year average method detection limit of 0.10 mg/L.

In order to determine the concentrations, a calibration curve was developed. Several standards were prepared with 1% $HNO_3$ (APHA et al. 1998). The standard concentrations (mg/L Cu) used were: blank (1% $HNO_3$), 0.05, 0.10, 0.50, 1.00, 2.50, and 5.00. The absorbance produced by the machine was plotted against the known concentration. The data set was fitted with a linear curve to provide an equation to determine the actual copper concentration. The calibration curve can be seen in **Appendix G**. Due to the continual resulting low concentrations at both test sites, the COL recommended it be necessary to only test one quarter of the wet weather samples collected. Therefore, beginning in 2011, only three samples were analyzed for each site during each wet weather event.

### 4.4.7 Dissolved Oxygen

Dissolved oxygen (DO) was analyzed for both wet and dry weather samples in the CIVE Laboratory within the 8 hour holding time. The Azide Modification from Standard Methods 4500-O (Winkler Titration Method) was followed for the testing (APHA et al.

1998). Prior to having the testing procedure well established in the CIVE Laboratory, the samples were analyzed with the same method at the UNL WSL. A statistical comparison was conducted between several results produced by the two labs and validated the results from the CIVE lab. Following May 25, 2010, the samples were analyzed mainly in the CIVE lab, utilizing the WSL for periodic QA/QC checks.

### 4.4.8 Escherichia coli

Escherichia coli (E. coli or EC) bacteria was analyzed for both wet and dry weather samples in a separate laboratory on the UNL east campus within the 30 hour holding time. The IDEXX Colilert and Quanti-Tray/2000 procedures were used to determine the most probable number (MPN) of coliform forming units (cfu) per 100 milliliters of sample (IDEXX 2011). In the beginning stages of the project, samples were delivered to the State of Nebraska Health and Human Services (HHS) Laboratory. However, it was determined that the same test procedure could feasibly be performed in the CIVE lab in a more cost effective way.

After comparing test results produced by the CIVE analysts and the HHS Laboratory from several different sampling events, it was determined that the CIVE analysts could produce accurate results. The new procedure was used as the only source of E. coli testing beginning June 16, 2010. Samples were periodically delivered to the HHS lab following this date to provide a QA/QC comparison. The statistical comparison compiled between the two labs can be seen in **Appendix F**.

### 4.4.9 Fluoride

Fluoride ($F^-$) was analyzed for the dry weather samples in the CIVE Laboratory within the 7 day holding time. Hach Method 8029 was followed referencing the Standard Methods 4500-$F^-$ using the Hach DR/2800 Spectrophotometer (APHA et al. 1998; Hach 2007). The test had a four year average method detection limit of 0.04 mg/L.

### 4.4.10 Nitrate plus Nitrite Nitrogen

Nitrate plus nitrite nitrogen ($NO_3$+$NO_2$-N or N+N) was analyzed for both wet and dry weather samples by the UNL WSL and the results were reported to the CIVE Lab electronically. Samples were preserved upon collection with concentrated $H_2SO_4$ then filtered and frozen until testing could be conducted. The EPA Method 353.2 referencing Standard Methods 4500-N for Cd-Reduction was followed for the analysis (APHA et al. 1998; US EPA 2011). According to Dr. Snow of the WSL, quality control checks performed using fortified matrix samples revealed that filtering prior to the analysis minimized any possible turbidity interferences. The results were reported as $NO_3$+$NO_2$-N having a four year average reporting limit of 0.05 mg/L.

### 4.4.11 Oil & Grease

Oil and grease (OG) was analyzed for wet weather samples by the Theresa Street Waste Water Treatment Plant Laboratory and the results were reported to the CIVE Lab electronically. The EPA Method 1664A was followed using the Horizon Spe-Dex® 4790 Automated Extraction System for analysis of N-Hexane Extractable Material (US EPA 2011). The results were reported as N-Hexane Extractable Material having a four year average reporting limit of 4.0 mg/L.

### 4.4.12 pH

The pH of both wet and dry weather samples was determined in the CIVE Laboratory within the 6 hour holding time. The pH was determined using a Thermo Scientific Orion 4-Star pH Meter. The instrument had a precision of 0.002 pH units (Thermo Fisher Scientific Inc. 2008).

### 4.4.13 Soluble Reactive Phosphorus

Soluble reactive phosphorus (SRP) was analyzed for both wet and dry weather samples in the CIVE Laboratory within the 24 hour holding time. Hach Method 10209 referencing Standard Methods 4500-P was followed using the Hach DR/2800 Spectrophotometer (APHA et al. 1998; Hach 2007). The samples were filtered prior to the sample analysis. The test had a four year average method detection limit of 0.008 mg/L as $PO_4^{3-}$-P.

### 4.4.14 Surfactants

Surfactants (SF) were analyzed for the dry weather samples in the CIVE Laboratory within the 24 hour holding time. Hach Method 8028 was followed using the Hach DR/2800 Spectrophotometer (Hach 2007). The test had a four year average method detection limit of 0.009 mg/L as LAS (linear alkylate sulfonate).

### 4.4.15 Suspended Sediment Concentration

Suspended sediment concentration (SSC) was analyzed for on grab samples taken from the stream following a wet weather event in the CIVE Laboratory within the 7 day holding time. A filtration procedure was used to determine the SSC concentration by following ASTM D3977-97, Method B (ASTM International 2011). The results were reported in mg/L and were used to check the TSS results.

### 4.4.16 Temperature

Temperature readings were recorded on the testing sites for both dry and wet weather monitoring. A VWR Traceable pocket-size thermometer was used to determine the temperature of the stream water. The thermometer had an accuracy of $\pm(1℃ \pm 0.75\%)$.

### 4.4.17 Total Kjeldahl Nitrogen

Total Kjeldahl Nitrogen (TKN) was analyzed for both wet and dry weather samples by the UNL WSL and the results were reported to the CIVE Lab electronically. Samples were preserved upon collection with concentrated $H_2SO_4$ then filtered and frozen until testing could be performed. The EPA 351.2 Method referencing Standard Methods 4500-$N_{org}$ (Semi-Micro-Kjeldahl Method) was followed for the sample analysis (APHA et al. 1998; US EPA 2011). The results were reported as mg N/L with a four year average reporting limit of 0.2 mg N/L.

### 4.4.18 Total Phosphorus

Total phosphorus (TP) was analyzed for both wet and dry weather samples in the CIVE Laboratory within the 24 hour holding time. Hach Method 10210 referencing Standard Methods 4500-P was followed using the Hach DR/2800 Spectrophotometer (APHA et al. 1998; Hach 2007). The sample vials were digested using a Hach Company COD reactor in order to convert all organic and inorganic forms of phosphorus to reactive orthophosphate. The test had a four year average method detection limit of 0.003 mg/L as $PO_4^{3-}$-P.

### 4.4.19 Total Suspended Solids

Total suspended solids (TSS) were analyzed for both wet and dry weather samples in the CIVE Laboratory within the 7 day holding time. Standard Method 2540D was followed for the TSS testing procedure using a vacuum filtration apparatus and a 105 °C drying oven (APHA et al. 1998).

### 4.4.20 Turbidity

Turbidity (TBY) was analyzed for both wet and dry weather samples in the CIVE Laboratory within the 8 hour holding time. Standard Method 2130 in accordance with EPA Method 180.1 was followed for the testing procedure using a Hach 2100N Turbidimeter (US EPA 2011). The results were recorded in Nephelometric Turbidity Units (NTU).

## 4.5 Event Mean Concentrations

Event mean concentrations (EMCs) were calculated for the sampled storms using the equation presented in **Section 2.7**. The trapezoidal method was used for the approximation of the integral. The corrected, continuous flow dataset was utilized along with the discrete sample concentrations for several constituents to calculate the EMC value. EMCs were calculated for the constituents measured on the discrete samples that provided a large enough dataset, which were: $NH_3$, COD, EC, N+N, SRP, TKN, TP, and

TSS. Also, an EMC value was determined for two of the continuously monitored water quality constituents – TBY and CDY.

The EMCs were calculated by matching the sample collection times with corresponding flow values at that time. When no near corresponding flow measurement time was available, a flow value was interpolated for the sample collection time. For some of the sampled runoff events, several hours had passed between the last collected auto sample and the collection of the grab sample. Because these concentrations may be significantly different in magnitude, it was thought that using the trapezoidal rule between these two concentrations may overestimate the EMC. Therefore, a procedure was developed in which the turbidity concentration was used as an indicator to determine when too large of a time gap existed between the collection times. If the percent difference between the turbidity concentrations was greater than 100%, the last auto sample concentration was duplicated for a set proportion of the turbidity concentration later in the hydrograph. This concentration was assumed to be constant over this time period, and the grab sample concentration was assumed to be constant over the remainder of the hydrograph. A more in-depth explanation of this procedure used for the EMC calculation can be found in **Appendix H**.

## 4.6 Quality Assurance/Quality Control

Quality assurance/quality control (QA/QC) is an important aspect of data collection in any study to ensure that the testing methods as well as the recorded data have the best quality possible. This section of the thesis outlines the determination of the method detection limit for the water quality parameters used in the study as well as discusses the use of standard solutions, duplicate samples, and travel blanks used to assure data quality. QA/QC was also performed on the recorded measurements from some of the monitoring equipment.

### 4.6.1 Auto Sampler Bias

Several autosampler experiments were conducted in the UNL hydraulics lab in the spring of 2010 prior to the sampling season. The experiments were performed to check for potential bias in the results for TSS. Fine clay was added to a known amount of distilled water in a bucket to make a known concentration of TSS. The sampling water was then mixed continuously using a drill and mixing paddle to ensure consistent solids concentration throughout the bucket. Several experiments were then conducted and produced the results that can be found in **Appendix I**.

The laboratory sampler intake line was arranged in a similar fashion to the on-site samplers, requiring the sample to be pumped over a two feet vertical length. The results indicated a possible bias in using the autosampler tubing over a long, uphill distance by an insufficient ability of the sampler to completely purge out the line of all solids from previous samples. A hypothesized solution to overcome the bias would be to discard the first sample taken during wet and dry weather monitoring to eliminate some of the residue from any previous samples taken. Therefore, the first autosample was disregarded beginning in 2010 as one can see in the *Algorithm* recommendation (**Appendix C**). However, because the first flush occurred so soon in the hydrograph at the Taylor Park watershed, the first sample was often analyzed in order to have at least one representative sample from the most concentrated runoff.

### 4.6.2 Gage Height QA/QC

The gage height data used for the calculation of the flow dataset underwent many electronic translations before it was output. The gage height was originally recorded by the bubbler, which had an expected measurement accuracy of ±0.010 ft for the observed gage height ranges (Teledyne Isco 2005). Because the bubbler only had the capability to store measurements as rapidly as 15 minutes, the USGS data logger was connected through the analog output so that gage height measurements could be recorded at a 90 second pace when the trigger depth was exceeded. The bubbler analog output board had an accuracy of ±0.5% of full-scale (Teledyne Isco 2005). Therefore, the final semi-continuous dataset was known to carry a certain degree of error. The USGS data logger recordings underwent USGS QA/QC protocol prior to being received by the civil engineering department.

A "tapedown" distance measurement from a reference point to the water surface was taken upon site visits at each monitoring location. The tapedown measurement was recorded on the Site Log Sheet (**Appendix J**) and subtracted from the total distance (reference point to the stream bed) to provide a check on the bubbler gage height recordings. Using these recordings, a method for correcting the gage height dataset was developed by USGS Hydrologist Dave Rus within Microsoft Excel. The procedure involved:

1. Correcting the 15 minute bubbler measurements with the closest temporal tapedown measurement using a time based algorithm;
2. Matching the corrected bubbler readings with the corresponding 90 second USGS data logger recordings;

3. Using an algorithm to interpolate the 90 second gage height values missing from the corrected bubbler dataset by using the USGS data logger measurements and the most near, previously corrected, bubbler gage height recording.

The final "corrected" gage height dataset was then plotted to verify the correction algorithms worked properly and no spikes were observed. The plots indicated the correction procedure was successful following the manual correction of a handful of spikes.

### 4.6.3 Stage-Discharge Curve QA/QC

Following the collection of water quality data, the discharge data calculated using the stage-discharge curves (stage-discharge curves discussed in **Section 4.2.3**) was utilized to determine the total stormwater runoff volume associated with each sampled storm event. During an analysis comparing the storm precipitation values to the runoff volume, a regression line was fit to the plot of total storm precipitation in inches vs. total unit-area storm runoff in inches (see **Section 4.3.5** and **Appendix D**). The regression equation produced for the two monitoring sites were compared. The comparison revealed very different and slightly unexpected infiltration rates (equation slope or unit runoff per unit rainfall) between the two sites. The runoff rate for the Colonial Hills site (0.50) was double that of the Taylor Park site (0.25). There does not seem to be any physical explanation for such a difference and has produced concern in the accuracy of the stage-discharge curves for the two monitoring sites. The unrealistic difference may be explained by a discharge overestimation for large storm events. Future calibration efforts should be made to determine more accurate stream discharge measurements.

### 4.6.4 Method Detection Limits

Method Detection Limits (MDLs) were experimentally determined for the water quality constituents analyzed in the Civil Engineering laboratory. MDLs are defined by the Environmental Protection Agency (EPA) as *"the minimum concentration of a substance that can be measured and reported with 99% confidence that the analyte concentration is greater than zero and is determined from analysis of a sample in a given matrix containing the analyte."* (US Government Printing Office 2010). The definition and procedure follow the description outlined in 40 CFR 136 Appendix B.

The calculated MDLs from all four sampling seasons were provided in **Table 4.3**. Detection limits for the constituents analyzed in outside laboratories were reported as well. The MDL's were determined initially before any samples were collected in the spring and then re-evaluated throughout the project year in order to determine a more likely MDL at the end of the sampling season. When a measured concentration from a collected sample was found to be lower than the established MDL for the given year, the concentration was replaced with ½ the MDL concentration for the purpose of regression modeling, as suggested by Rasmussen et al. (2005) and Rasmussen et al. (2008).

**Table 4.3: Method detection limits for the lab tested constituents**

| Analysis | Procedure | 2008-2009 MDL | 2010 MDL | 2011 MDL | Four-year Average |
|---|---|---|---|---|---|
| $NH_3$ | EPA 350.1 | 0.05 | 0.05 | 0.05 | 0.05 |
| $Cl^-$ | Hach 8113 | 0.3 | 0.1 | 0.1 | 0.2 |
| $Cl_2$ | Hach 8167 | 0.02 | 0.01 | 0.01 | 0.01 |
| COD | Hach 8000 | 4 | 4 | 2 | 3 |
| CDY | SM 2510 | 2 | 1 | 1 | 1 |
| Cu | SM 3030 | 0.02 | 0.14 | 0.14 | 0.10 |
| $F^-$ | Hach 8029 | 0.03 | 0.07 | 0.03 | 0.04 |
| N+N | EPA 353.2 | 0.05 | 0.05 | 0.05 | 0.05 |
| OG | EPA 1664A | 5.0 | 5.0 | 2.0 | 4.0 |
| SRP | Hach 10209 | 0.008 | 0.008 | 0.006 | 0.008 |
| SF | Hach 8028 | 0.005 | 0.009 | 0.014 | 0.009 |
| TKN | EPA 351.2 | 0.2 | 0.2 | 0.1 | 0.2 |
| TP | Hach 10210 | - | 0.003 | 0.004 | 0.003 |

*Parameter abbreviations defined in **Table 4.1**

### 4.6.5 Standard Check

The precision of each testing method was evaluated by testing known standards throughout the sampling period. The testing of standards ensured the accuracy of analyses being performed and gave validity to the results determined. All standards tested were found to be within an acceptable range of the known concentration. The standard test results recorded throughout a given sampling season were used to calculate the final MDL values found in **Table 4.3**. Tables containing the results for the standard tests from 2011 for the determination of the MDL can be found in **Appendix K**.

### 4.6.6 Duplicate Samples

For quality assurance/quality control purposes, 20% of the samples were tested in duplicate over the duration of each sampling season. These duplicates assisted in ensuring the consistency of sampling and testing methods. **Table 4.4** and **Table 4.5** show the average “percent difference” found between duplicate samples taken at each of the sites in 2010 and 2011 for dry weather monitoring and wet weather monitoring, respectively. Unfortunately, no data could be found from the previous researcher for the 2008 through 2009 duplicate samples; for that reason, only the 2010 through 2011 duplicate data was used for the percent difference calculation. **Appendix L** should be consulted to see the errors calculated for each individual duplicate. The percent difference is the absolute value of the difference between the two samples divided by the average of the two samples, given by the following equation:

$$\text{Percent Difference} = \frac{|\text{Conc. 1-Conc. 2}|}{\left(\frac{\text{Conc. 1+Conc. 2}}{2}\right)} *100\% \qquad (4.1)$$

**Table 4.4: Percent difference for 2010-2011 dry weather duplicate samples**

| **Parameter** | **$Cl^-$** | **$Cl_2$** | **COD** | **CDY** | **DO** | **E. coli** | **Cu** |
|---|---|---|---|---|---|---|---|
| Average | 4.8% | 19.5% | 23.1% | 0.5% | 3.3% | 29.2% | - |
| # of Duplicates Used in Average | 8 | 4 | 13 | 14 | 9 | 9 | 0 |
| Total Duplicates | 8 | 4 | 15 | 14 | 10 | 9 | 4 |
| | | | | | | | |
| **Parameter** | **$F^-$** | **pH** | **TP** | **SRP** | **SF** | **TBY** | **TSS** |
| Average | 3.2% | 0.5% | 4.8% | 1.3% | 12.0% | 10.4% | 11.0% |
| # of Duplicates Used in Average | 9 | 16 | 13 | 12 | 8 | 8 | 6 |
| Total Duplicates | 9 | 16 | 13 | 12 | 8 | 8 | 12 |

*Refer to **Table 4.1** (page 60) for water quality abbreviation definitions

*Refer to **Table 4.2** (page 61) for measurement units and analytical methods

**Table 4.5: Percent difference for 2010-2011 wet weather duplicate samples**

| **Parameter** | **$Cl^-$** | **$Cl_2$** | **COD** | **CDY** | **DO** | **E. coli** | **Cu** |
|---|---|---|---|---|---|---|---|
| Average | 12.9% | 27.3% | 13.3% | 7.1% | 1.1% | 34.9% | 0.0% |
| # of Duplicates Used in Average | 26 | 6 | 35 | 28 | 2 | 30 | 1 |
| Total Duplicates | 26 | 6 | 35 | 28 | 2 | 30 | 15 |
| | | | | | | | |
| **Parameter** | **$F^-$** | **pH** | **TP** | **SRP** | **SF** | **TBY** | **TSS** |
| Average | - | 0.4% | 3.7% | 4.1% | - | 11.7% | 11.2% |
| # of Duplicates Used in Average | - | 8 | 32 | 31 | - | 32 | 35 |
| Total Duplicates | - | 8 | 32 | 32 | - | 32 | 36 |

*Refer to **Table 4.1** (page 60) for water quality abbreviation definitions

*Refer to **Table 4.2** (page 61) for measurement units and analytical methods

For the calculations involving one or more concentrations falling below the MDL, the result was expressed as "<MDL" (as seen in **Appendix L**). It should be noted that this calculation gave very misleading values when one of the concentrations was "zero." Often times the percentage exceeded 100%. This seemed to be especially true for the TSS duplicate dry weather samples and total copper duplicate dry and wet weather samples, as several involved a very small concentration or one equal to "zero." Therefore, the percent differences calculated above 100% were also reported as "<MDL" due to the low concentrations involved. The results reported as "<MDL" were not included in the calculation of the average. The total number of samples included in the average calculation was represented in the above tables as "# of Duplicates Used in Average." Therefore, it was recommended that not too much value be placed on these percentages unless the corresponding concentrations were first considered as well as the number of samples included in the calculation of the average percentage.

It should be noted that several of the concentrations involved in the percent difference calculations for the dry weather duplicates were close to the MDL, likely resulting in measurements with less precision as compared to the wet weather results with higher concentrations. The percent differences were believed to be acceptable for all the analyses for wet weather and dry weather sample collection. The precision was the least for the E. coli procedure, but this was expected due to the extremely imprecise ability to quantify bacteria. The average percent difference for COD during dry weather events was quite high; this likely was attributed to measurements very close to the MDL. Chlorine percent differences were less than ideal, indicating much uncertainty with the procedure conducted at the sampling sites.

### 4.6.7 Travel Blanks

Over the duration of each sampling season, three travel blanks were taken into the field as requested by the funding provider. Again, only results from 2010 and 2011 travel blanks were considered due to missing data prior to this time period. 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 were provided in **Table 4.6**. For several readings, the Hach spectrophotometer produced the error “Under Measurement Range” reading; these results were recorded as “<MDL” as well.

**Table 4.6: Travel blank results for 2010 and 2011**

| Date | $Cl^-$ (mg/L) | $Cl_2$ (mg/L) | COD (mg/L) | CDY (µS/cm) | E. coli (cfu/100mL) | Cu (mg/L) |
|---|---|---|---|---|---|---|
| 6/16/2010 | <MDL | - | 5 | 4.62 | <1.0 | <MDL |
| 8/16/2010 | <MDL | 0.03 | <MDL | 5.92 | <1.0 | <MDL |
| 11/8/2010 | <MDL | <MDL | 4 | <MDL | <1.0 | <MDL |
| 6/23/2011 | <MDL | 0.01 | 6 | 3.44 | >2419.6 | <MDL |
| 7/18/2011 | 1.3 | 0.07 | 9 | 1.45 | <1.0 | <MDL |
| 8/18/2011 | <MDL | <MDL | 8 | 2.57 | <1.0 | <MDL |

| Date | $F^-$ (mg/L) | SRP (mg/L) | TP (mg/L) | SF (mg/L) | TBY (NTU) |
|---|---|---|---|---|---|
| 6/16/2010 | <MDL | <MDL | <MDL | <MDL | 0.16 |
| 8/16/2010 | 0.11 | <MDL | <MDL | <MDL | 0.253 |
| 11/8/2010 | <MDL | <MDL | <MDL | 0.014 | 0.04 |
| 6/23/2011 | 0.21 | <MDL | <MDL | 0.015 | 0.316 |
| 7/18/2011 | 0.03 | <MDL | <MDL | <MDL | 0.404 |
| 8/18/2011 | <MDL | <MDL | <MDL | 0.030 | 0.697 |

*Highlighted cells are of most concern

The results indicated some potential instances of contamination due to the sample bottles, travel conditions, or other unknown source. The E. coli result from the June 23, 2011 travel blank was alarming and revealed some possible bacterial contamination in the bottle that day. The high E. coli result does not seem to be due to the de-ionized water as no other alarming measurement was recorded using the same source water. The fluoride result for the same sample was also an unexpected recording. Therefore, the high E. coli and Fluoride values were likely attributed to the use of a poorly washed bottle or one which had not even been washed at all. There was one high surfactants value recorded, indicating potential issues with the rinsing of the bottle following the use of cleaning detergents. The high chlorine concentration observed in the July 18, 2011 travel blank was also concerning.

### 4.6.8 Laboratory Blanks

Over the duration of each sampling season, six laboratory blanks were tested in the CIVE lab for the parameters analyzed during wet weather and dry weather monitoring. The laboratory blanks consisted of de-ionized water transported in clean glassware to the lab testing station. Blanks were tested in the same manner as grab samples. The results from the laboratory blanks were presented in **Table 4.7** below.

**Table 4.7: Laboratory blank results for 2010 and 2011**

| Blank # | Date | $Cl^-$ (mg/L) | $Cl_2$ (mg/L) | COD (mg/L) | CDY (µS/cm) | E. coli (cfu/100mL) | Cu (mg/L) |
|---|---|---|---|---|---|---|---|
| 1 | 8/16/2010 | 0.2 | <MDL | <MDL | <MDL | <1.0 | <MDL |
| 2 | 8/16/2010 | 0.2 | <MDL | <MDL | <MDL | <1.0 | <MDL |
| 3 | 8/16/2010 | 0.3 | 0.02 | <MDL | <MDL | <1.0 | <MDL |
| 4 | 9/8/2010 | 0.2 | <MDL | <MDL | <MDL | <1.0 | <MDL |
| 5 | 9/8/2010 | 0.2 | <MDL | <MDL | <MDL | <1.0 | <MDL |
| 6 | 9/8/2010 | 0.2 | <MDL | 4 | <MDL | <1.0 | <MDL |
| 7 | 6/23/2011 | <MDL | <MDL | <MDL | 3.25 | <1.0 | <MDL |
| 8 | 6/25/2011 | <MDL | <MDL | <MDL | 0.24 | <1.0 | <MDL |
| 9 | 6/25/2011 | 0.3 | 0.01 | <MDL | 0.2 | <1.0 | <MDL |
| 10 | 7/18/2011 | <MDL | 0.02 | <MDL | 0.45 | <1.0 | <MDL |
| 11 | 8/18/2011 | <MDL | <MDL | <MDL | 0.32 | <1.0 | <MDL |
| 12 | 8/18/2011 | <MDL | <MDL | <MDL | 0.29 | <1.0 | <MDL |

| Blank # | Date | $F^-$ (mg/L) | pH | SRP (mg/L) | TP (mg/L) | SF (mg/L) | TBY (NTU) |
|---|---|---|---|---|---|---|---|
| 1 | 8/16/2010 | <MDL | 6.58 | <MDL | <MDL | <MDL | 0.444 |
| 2 | 8/16/2010 | <MDL | 6.71 | <MDL | <MDL | <MDL | 0.234 |
| 3 | 8/16/2010 | <MDL | 7.03 | <MDL | <MDL | <MDL | 0.118 |
| 4 | 9/8/2010 | <MDL | 8.20 | <MDL | <MDL | <MDL | 0.112 |
| 5 | 9/8/2010 | <MDL | 7.33 | <MDL | <MDL | <MDL | 0.140 |
| 6 | 9/8/2010 | <MDL | 7.21 | 0.160 | <MDL | <MDL | 0.151 |
| 7 | 6/23/2011 | 0.19 | 6.63 | <MDL | <MDL | <MDL | 0.197 |
| 8 | 6/25/2011 | <MDL | 6.72 | <MDL | <MDL | <MDL | 0.062 |
| 9 | 6/25/2011 | <MDL | 6.74 | <MDL | <MDL | <MDL | 0.064 |
| 10 | 7/18/2011 | <MDL | 7.38 | <MDL | <MDL | <MDL | 0.167 |
| 11 | 8/18/2011 | <MDL | 8.46 | <MDL | <MDL | <MDL | 0.061 |
| 12 | 8/18/2011 | <MDL | 7.87 | <MDL | <MDL | <MDL | 0.054 |

The results indicated no significant source of contamination from the sample bottles or transport conditions within the laboratory setting. Nearly all of the concentrations from the lab blanks presented in **Table 4.7** fell below the MDL. For several readings, the Hach spectrophotometer produced the error “Under Measurement Range” reading; these results were recorded as “<MDL” as well. Overall, the results were quite encouraging, indicating little to no error attributed to laboratory testing procedures.

## 4.7 Regression Statistics

Multiple regression models were developed using SAS® 9.2. The procedure for developing regression equations was outlined in **Section 2.5**. The general step by step procedure followed during the regression analysis is presented below:

1. SAS was used to generate potential model options; the potential explanatory variable combinations were then considered using *PROC REG* in SAS.
2. The “Residual vs. Predicted Value” plot was consulted to check the model assumption of constant variance; if the variance in the plot was not constant (patterns or a skew existed), a logarithmic transformation of the dependent variable was considered.
3. The “RStudent vs. Leverage” plot was consulted to check for potential outliers; based on the recommendation of Helsel and Hirsch (2002), there must be a justifiable reason for removing a potential outlier from the dataset. A justifiable cause for this study was the fact that at the beginning of most storms, the probe measurement correlating to the sample collection time was clearly not an exact

match, as seen through a comparison of the TSS concentration from the autosample with the probe-measured turbidity value.

4. The univariate procedure was utilized to check for normality in the residuals using the Shapiro-Wilk W statistic; the residuals were assumed to be normally distributed if $(Pr < W) > 0.05$.
5. Check for the significance of the multiple regression model; the model was assumed to be statistically significant if $(Pr > F) < 0.05$.
6. Check if each of the explanatory variables significantly accounted for variance in the dependent variable; the explanatory variable was assumed to be significant to the overall model if $(Pr > |t|) < 0.05$ for that given variable.
7. Check for multi-collinearity amongst the explanatory variables being considered in the model; multi-collinearity exsited if the variance inflation factor (VIF) was greater than ten (10).
8. The "best" fit linear model was selected by maximizing the coefficient of determination ($R^2$) while minimizing the prediction error sum of squares (PRESS) through careful consideration that there was a justifiable cause for the inclusion of each explanatory variable.

Prior to the multiple regression analysis, autocorrelation was considered but then determined illogical for the scope of this project. The discrete measurements from the stormwater samples acting as dependent variables were not continuous and were not collected at even intervals throughout the year. In order for the models to be continuous throughout the year, the discrete measurements would also need to be known at the 15 minute and 90 second clip so that autocorrelation would be applicable.

## 4.8 Seasonal Explanatory Variables

For the goal of explaining some of the variation in water quality concentrations, three explanatory variables were considered that may account for concentration variation due to seasonal changes. The variables considered were growing degree days, solar radiation, and a sinusoidal periodic function recommended by Helsel and Hirsch (2002). The methods used for attaining the seasonal variables are explained below.

### 4.8.1 Growing Degree Days

A variable that could easily be determined and used as a potential explanation for variation in water quality concentration throughout the sampling season was growing degree days (GDD). The background and calculation for GDD was provided in **Section 2.5.6**. For the calculation of GDD for this project, the maximum and minimum daily temperatures for Lincoln, NE were retrieved from the Weather Underground website (Weather Underground 2011). For their own calculation of GDD, Weather Underground, Inc. used a $T_{BASE}$ value of 50° F; therefore, this research project utilized the same base value. For the purpose of regression modeling, the prior twenty-one day average of GDD was calculated and used for the GDD explanatory variable.

### 4.8.2 Solar Radiation

Solar radiation (SR) was another variable used to potentially account for climatic seasonal trends in water quality concentrations. Along with precipitation measurements, solar radiation values were obtained from weather stations through the High Plains Regional Climate Center (HPRCC 2011). Solar radiation was measured in watts per square meter (W/m$^2$) with a consistently-calibrated pyranometer. For the purpose of regression modeling, the prior twenty-one day average of solar radiation was calculated and used for the SR explanatory variable.

### 4.8.3 Sinusoidal Periodic Function

The sinusoidal periodic function was used to account for seasonal trends in water quality concentrations due to the Lincoln, NE climate. The function was presented in **Section 2.5.6**. The calculation (Equation 2.5) was simply performed by first expressing the date in years (T in the equation). For example, the sampled storm event on 10/6/2008 expressed in years was 2008.85.

# Chapter 5

# Results and Discussion

## 5.1 Introduction

Water quality data and stream flow data were recorded at both the Colonial Hills and Taylor Park monitoring sites over approximately a three year span, ranging from July 2008 through October 2011. The data were obtained using the equipment and methods described in Chapter 4. The periods of operation for the installed site monitoring equipment are provided in **Table 5.1**. Throughout this time period, discrete water quality samples were also collected and analyzed for dry weather and wet weather flows.

**Table 5.1: Seasonal equipment operational periods for both monitoring sites**

| Year | Site | Bubbler | AVFM | USGS Probes |
|---|---|---|---|---|
| 2008 | CH | Aug 12 - Nov 4 | Aug 12 - Nov 4 | July 23 - Nov 12 |
| | TP | Aug 6 - Nov 4 | Aug 6 - Nov 4 | July 23 - Nov 12 |
| 2009 | CH | March 5 - Sept 23 | March 11 - Sept 23 | March 4 - Dec 1 |
| | TP | March 5 - Sept 23 | May 26 - Sept 23 | March 4 - Dec 1 |
| 2010 | CH | April 6 - Nov 19 | April 6 - Nov 19 | April 1 - Dec 3 |
| | TP | April 6 - Nov 19 | April 6 - Nov 19 | March 17 - Dec 31 |
| 2011 | CH | April 28 - Sept 30 | March 25 - Sept 30 | March 15 - Sept 30 |
| | TP | April 28 - Sept 30 | March 25 - Sept 30 | March 15 - Sept 30 |

*Note, for this table CH = Colonial Hills and TP = Taylor Park

## 5.2 Dry Weather Water Quality

Samples were collected at the sites during dry weather periods five times during the 2008 sampling season, ten times in 2009, eleven times in 2010, and six times in 2011, for a total of thirty-two (32) sampling events. The water quality results from dry weather sampling can be found in **Appendix S**. Although there was not as much variation in the concentrations during dry weather flows as observed during storm flows for most of the water quality parameters, there was still a considerable amount of variation recognized in the sample results over the project duration. A table summarizing the statistics for the 2008 through 2011 measured constituents is shown below (**Table 5.2**).

**Table 5.2: Summary statistics for 2008 through 2011 dry weather samples**

| **Colonial Hills** | **$NH_3$** | **COD** | **$Cl^-$** | **EC** | **N+N** | **SRP** | **TP** | **TKN** | **TSS** | **WT** |
|---|---|---|---|---|---|---|---|---|---|---|
| Minimum | 0.03 | 2 | 5 | 28 | 0.03 | 0.02 | 0.07 | 0.02 | 0 | 7 |
| Maximum | 2.31 | 39 | 125 | 2,000 | 1.56 | 0.38 | 0.35 | 11.01 | 20 | 32 |
| Mean[1] | 0.22 | 16 | **53** | 245[2] | 0.64 | 0.13 | 0.14 | 0.99 | 5 | 20 |
| Std Dev | 0.45 | 7 | 25 | 455 | 0.43 | 0.08 | 0.07 | 2.23 | 4 | 6 |
| **Taylor Park** | **$NH_3$** | **COD** | **$Cl^-$** | **EC** | **N+N** | **SRP** | **TP** | **TKN** | **TSS** | **WT** |
| Minimum | 0.03 | 2 | 6 | 32 | 0.03 | 0.07 | 0.08 | 0.06 | 0 | 11 |
| Maximum | 2.17 | 33 | 62 | 15,000 | 2.6 | 0.57 | 0.35 | 3.67 | 47 | 25 |
| Mean[1] | 0.35 | 15 | 40 | **888**[2] | **1.51** | **0.22** | **0.20** | 0.79 | 4 | 18 |
| Std Dev | 0.56 | 7 | 13 | 2,916 | 0.78 | 0.09 | 0.06 | 0.84 | 7 | 4 |

*Refer to **Table 4.1** (page 60) for water quality abbreviation definitions

*Refer to **Table 4.2** (page 61) for measurement units and analytical methods

*Bolded mean values indicate the site with the higher value that was statistically different at the 95% confidence level calculated with a two-tail t-test

[1] The arithmetic mean was used for all parameters besides E. coli

[2] The geometric mean was used for E. coli measurements only

A simple match-paired t-test (two-tail) was performed on the dry weather sampling results to determine if any statistically significant differences existed at a 95 percent confidence level. The results indicated significant differences existed for $Cl^-$, EC, N+N, SRP, and TP between the two monitoring sites. The mean values shown in **Table 5.2** suggest that the higher results for EC, N+N, SRP, and TP were consistently observed at the Taylor Park monitoring site, while $Cl^-$ was higher for the Colonial Hills site. The significant differences for several of the water quality parameters revealed that notable differences existed between the baseflow water qualities for the two sites.

## 5.3 Wet Weather Water Quality

The goal of wet weather monitoring was to collect stormwater runoff samples from four or more storm events throughout the duration of each sampling season, at least two weeks apart (see **Section 4.3.4** for further description). Water quality measurements were obtained for sixteen storms over the three year period falling into the seasonal range of April through November; the wet weather water quality results can be found in **Appendix T**. The stormwater quality results appeared to be extremely variable throughout the sampling seasons, with most parameters exhibiting a very large data range. The summary statistics for water quality constituents measured for wet weather samples are presented in **Table 5.3**. A graph illustrating the large variation in TSS and SRP concentrations measured over the study period can be found in **Figure 5.1**. The same variation in measured data for TSS and SRP also held true for the other water quality parameters at Colonial Hills, which remained the case for the Taylor Park monitoring site as well.

**Table 5.3: Concentration ranges for the 2008 through 2011 wet weather samples**

| Colonial Hills | $NH_3$ | COD | $Cl^-$ | EC | N+N | SRP | TP | TKN | TSS | WT |
|---|---|---|---|---|---|---|---|---|---|---|
| Min. | <MDL | 11 | <MDL | 50 | <MDL | 0.07 | 0.22 | 0.36 | 1 | 7 |
| Max. | 0.27 | 204 | 68 | 480,000 | 3.11 | 0.76 | 0.90 | 5.66 | 1,854 | 25 |
| **Taylor Park** | **$NH_3$** | **COD** | **$Cl^-$** | **EC** | **N+N** | **SRP** | **TP** | **TKN** | **TSS** | **WT** |
| Min. | <MDL | 10 | <MDL | 410 | <MDL | 0.05 | 0.12 | 0.498 | 2 | 10 |
| Max. | 2.02 | 1,274 | 57 | 2,076,250 | 2.5 | 1.76 | 5.22 | 14.3 | 4,023 | 23 |

*Refer to **Table 4.1** (page 60) for water quality abbreviation definitions

*Refer to **Table 4.2** (page 61) for measurement units and analytical methods

*MDLs based on 2008 through 2011 average found in **Table 4.3**

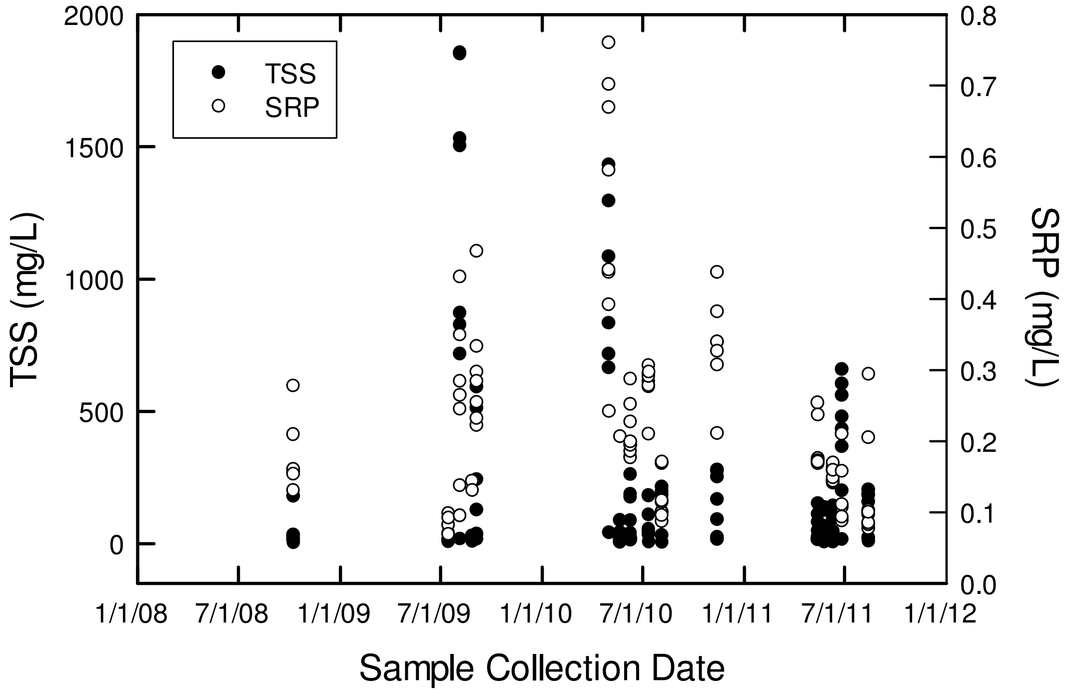

**Figure 5.1: Range of Colonial Hills TSS & SRP storm data from 2008 through 2011**

### 5.3.1 Precipitation Summary

The sampling dates along with the corresponding storm rainfall characteristics for the Colonial Hills and Taylor Park monitoring sites are provided in **Table 5.4** and **Table**

**5.5**, respectively. Also, a comparison between the total storm precipitations used for both sites represented in a bar graph can be found in **Figure 5.2**. A variety of precipitating storm events were sampled over the project period, ranging from the lowest of 0.26 inches to the highest of 1.93 inches (with a mean of 0.86 inches) amongst the two monitoring sites. However, **Figure 5.2** reveals that many more storms were sampled below the average than above the average storm precipitation. The majority of the "large" storms were well above the average, with a lack of precipitating storms near the average or slightly above the average 0.86 inches.

**Table 5.4: Rainfall characteristics summary for Colonial Hills**

| Date | Total Storm Rainfall (in) | Average Intensity (in/hr) | Peak Intensity (in/hr) | Auto Samples Tested |
|---|---|---|---|---|
| 10/6/2008 | 0.47 | 0.03 | 0.17 | 6 |
| 7/14/2009 | 0.40 | 0.16 | 0.31 | 4 |
| 8/4/2009 | 0.95 | 0.23 | 0.58 | 7 |
| 8/26/2009 | 0.87 | 0.15 | 0.63 | 1 |
| 9/3/2009 | 1.62 | 0.17 | 0.62 | 6 |
| 4/29/2010 | 1.38 | 0.22 | 0.77 | 7 |
| 5/20/2010 | 0.87 | 0.06 | 0.17 | 7 |
| 6/8/2010 | 0.66 | 0.26 | 0.38 | 7 |
| 7/11/2010 | 1.83 | 0.61 | 0.91 | 7 |
| 8/4/2010 | 0.78 | 0.09 | 0.46 | 6 |
| 11/12/2010 | 1.28 | 0.12 | 0.36 | 6 |
| 5/12/2011 | 0.26 | 0.05 | 0.17 | 6 |
| 5/24/2011 | 0.37 | 0.19 | 0.20 | 10 |
| 6/9/2011 | 0.66 | 0.57 | 0.64 | 7 |
| 6/25/2011 | 0.87 | 0.22 | 0.55 | 7 |
| 8/12/2011 | 1.58 | 0.13 | 0.49 | 6 |

**Table 5.5: Rainfall characteristics summary for Taylor Park**

| Date | Total Storm Rainfall (in) | Average Intensity (in/hr) | Peak Intensity (in/hr) | Auto Samples Tested |
|---|---|---|---|---|
| 10/6/2008 | 0.39 | 0.03 | 0.14 | 6 |
| 7/14/2009 | 0.29 | 0.12 | 0.26 | 8 |
| 8/4/2009 | 0.56 | 0.18 | 0.29 | 6 |
| 8/26/2009 | 0.82 | 0.11 | 0.60 | 6 |
| 9/3/2009 | 0.86 | 0.11 | 0.35 | 6 |
| 4/29/2010 | 1.14 | 0.19 | 0.61 | 7 |
| 5/20/2010 | 0.95 | 0.05 | 0.16 | 7 |
| 6/8/2010 | 0.65 | 0.14 | 0.40 | 7 |
| 7/11/2010 | 1.92 | 0.64 | 0.86 | 7 |
| 8/4/2010 | 0.70 | 0.14 | 0.42 | 6 |
| 11/12/2010 | 1.27 | 0.12 | 0.40 | 7 |
| 5/12/2011 | 0.33 | 0.06 | 0.18 | 7 |
| 5/24/2011 | 0.38 | 0.19 | 0.20 | 10 |
| 6/9/2011 | 0.46 | 0.46 | 0.46 | 7 |
| 6/25/2011 | 0.71 | 0.18 | 0.44 | 6 |
| 8/12/2011 | 1.35 | 0.12 | 0.61 | 6 |

Although the monitoring sites were only two and a half miles apart, the comparisons made in **Figure 5.2** indicated a slight difference in the precipitations determined for the two sites. The figure suggested there was a consistent high bias for the total precipitation used for the Colonial Hills site. There did not seem to be any obvious reason for the difference; the difference may have been real, though, and attributable to the observed storm patterns in Lincoln, NE favoring the southern region of the city throughout the project period. Despite the apparent bias, the data were not significantly different at the 95% confidence level using a match-paired t-test (p = 0.07).

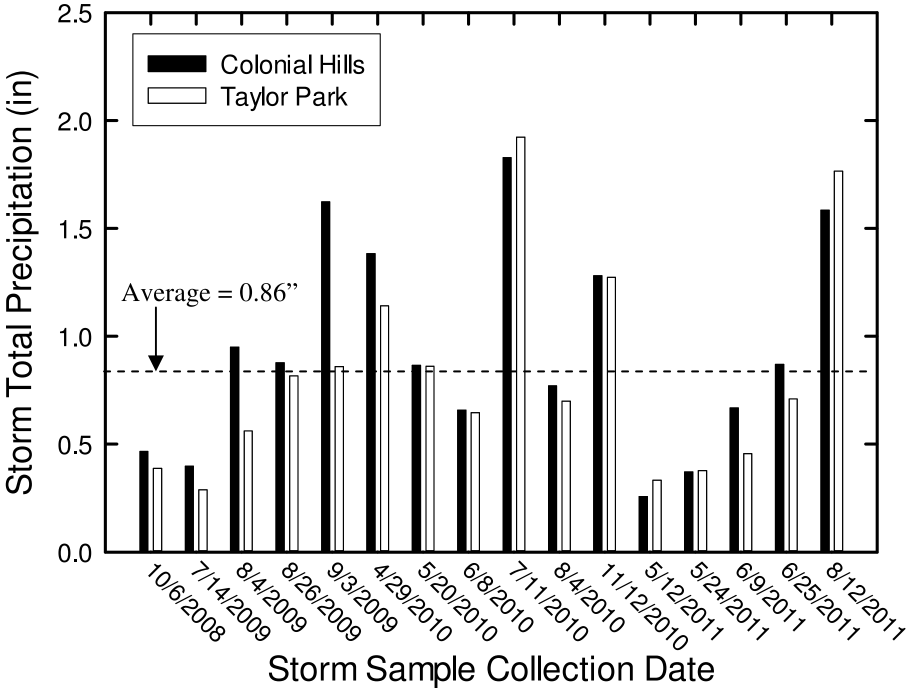

**Figure 5.2: Total precipitation comparison between the monitoring sites**

### 5.3.2 Event Mean Concentrations

Event mean concentrations (EMCs), as defined in **Section 2.2.3**, were calculated for several of the water quality constituents from each sampled storm event at the Colonial Hills and Taylor Park monitoring sites. EMC values for a given storm event at both the Colonial Hills and Taylor Park sites are presented in **Table 5.6** and **Table 5.7**, respectively. Measurements from the discrete samples were utilized to calculate all of the EMCs except conductivity and turbidity, which used the continuous measurements from the in-line probes. An EMC was calculated only if there were at least five measurements recorded during a given storm event. When less than five measurements were observed or when the parameter was not tested for that given storm event, the EMC was listed as "N/A" (not available). The N/As existed for total phosphorus (TP) prior to mid-2010 because the procedure had not been established in the laboratory yet. The other N/As were due to issues with sample analysis or samples that were collected past the hold time.

**Table 5.6: EMCs for the Colonial Hills monitoring site**

| **Date** | **$NH_3$** | **COD** | **CDY** | **EC** | **N+N** | **SRP** | **TP** | **TSS** | **TKN** | **TBY** |
|---|---|---|---|---|---|---|---|---|---|---|
| 10/6/2008 | 0.02 | 31 | 254 | 11,349 | 0.3 | 0.2 | N/A | 59 | N/A | 21 |
| 8/4/2009 | N/A | 115 | 102 | 17,711 | 0.4 | 0.2 | N/A | 762 | 2.2 | 120 |
| 9/3/2009 | N/A | 51 | 109 | 54,779 | 0.5 | 0.4 | N/A | 183 | 1.7 | 64 |
| 4/29/2010 | 0.16 | 91 | 125 | N/A | 0.5 | 0.4 | N/A | 583 | 0.7 | 191 |
| 5/20/2010 | 0.01 | 47 | 181 | 29,406 | 0.4 | N/A | N/A | 43 | 1.3 | 27 |
| 6/8/2010 | 0.07 | 47 | 127 | 60,989 | 0.4 | 0.2 | 0.3 | 70 | 1.3 | 37 |
| 7/11/2010 | 0.05 | 38 | 103 | 59,308 | 0.7 | 0.3 | 0.4 | 52 | 1.3 | 59 |
| 8/4/2010 | 0.07 | 82 | 101 | 25,755 | 0.6 | 0.1 | 0.5 | 156 | 1.8 | 27 |
| 11/12/2010 | 0.01 | 51 | 177 | 10,379 | 0.3 | 0.3 | 0.4 | 87 | 1.3 | 34 |
| 5/12/2011 | 0.16 | 90 | 381 | 13,005 | 0.4 | 0.2 | 0.5 | 86 | 2.4 | 54 |
| 5/24/2011 | N/A | N/A | 260 | 76,431 | N/A | N/A | 0.4 | 65 | N/A | 39 |
| 6/9/2011 | 0.04 | 22 | 223 | 164,511 | 0.7 | 0.2 | 0.4 | 95 | 2.4 | 42 |
| 6/25/2011 | 0.02 | 60 | 116 | 48,997 | 0.3 | 0.2 | 0.5 | 233 | 2.1 | 58 |
| 8/12/2011 | N/A | 31 | 133 | 23,239 | 0.6 | 0.2 | 0.3 | 47 | N/A | 18 |
| **Mean** | 0.06 | 58 | 171 | 45,835 | 0.5 | 0.2 | 0.4 | 180 | 1.7 | 57 |
| **n** | 10 | 13 | 14 | 13 | 13 | 12 | 9 | 14 | 11 | 14 |

* 4/27/2009, 7/14/2009, 8/26/2009 omitted because no EMC values

* N/A = "not available"; n = sample size

*Refer to **Table 4.1** (page 60) for water quality abbreviation definitions

*Refer to **Table 4.2** (page 61) for measurement units and analytical methods

**Table 5.7: EMCs for the Taylor Park monitoring site**

| Date | $NH_3$ | COD | CDY | EC | N+N | SRP | TP | TSS | TKN | TBY |
|---|---|---|---|---|---|---|---|---|---|---|
| 10/6/2008 | 0.02 | 39 | 141 | 53,565 | 0.3 | 0.2 | N/A | 50 | N/A | 36 |
| 7/14/2009 | N/A | 38 | 157 | N/A | N/A | 0.2 | N/A | 139 | N/A | 22 |
| 8/4/2009 | N/A | 133 | 273 | 116,440 | 0.6 | 0.1 | N/A | 464 | N/A | 79 |
| 8/26/2009 | 0.28 | 53 | 100 | N/A | 0.1 | 0.3 | N/A | 138 | N/A | 33 |
| 9/3/2009 | N/A | 53 | 96 | N/A | 0.7 | 0.3 | N/A | 54 | 1.3 | 26 |
| 4/29/2010 | 0.10 | 64 | 135 | N/A | 0.6 | 0.3 | N/A | 168 | 1.2 | 65 |
| 5/20/2010 | 0.11 | 83 | 144 | 46,090 | 0.4 | N/A | N/A | 43 | 1.8 | 33 |
| 6/8/2010 | 0.12 | 39 | 158 | 80,299 | 0.7 | 0.3 | 0.4 | 87 | 1.8 | 50 |
| 7/11/2010 | 0.08 | 36 | 86 | 31,780 | 0.9 | 0.2 | 0.3 | 73 | 1.2 | 45 |
| 8/4/2010 | 0.02 | 114 | 215 | 66,401 | 0.9 | 0.1 | 0.5 | 181 | 1.1 | 30 |
| 11/12/2010 | 0.12 | 79 | 144 | 18,385 | 0.9 | 0.4 | 0.5 | 67 | 2.1 | 23 |
| 5/12/2011 | 0.12 | 204 | 162 | 61,429 | 0.4 | 0.1 | 0.7 | 385 | 3.2 | 121 |
| 5/24/2011 | N/A | N/A | 141 | 142,103 | N/A | N/A | 0.4 | 52 | N/A | 23 |
| 6/9/2011 | 0.19 | 22 | 186 | 73,996 | 1.0 | 0.2 | 1.7 | 1356 | 3.2 | 216 |
| 6/25/2011 | 0.02 | 47 | 131 | 99,238 | 0.4 | 0.2 | 0.3 | 59 | 1.1 | 22 |
| 8/12/2011 | N/A | 30 | 126 | 61,017 | 1.2 | 0.3 | 0.4 | 40 | N/A | 27 |
| **Mean** | 0.11 | 69 | 150 | 70,895 | 0.7 | 0.2 | 0.6 | 210 | 1.8 | 53 |
| **n** | 11 | 15 | 16 | 12 | 14 | 14 | 9 | 16 | 10 | 16 |

* 4/27/2009 omitted because no EMC values

* N/A = "not available"; n = sample size

*Refer to **Table 4.1** (page 60) for water quality abbreviation definitions

*Refer to **Table 4.2** (page 61) for measurement units and analytical methods

A review of event mean concentrations reported in the literature (**Section 2.7**) provided past results from different locations in the nation for several parameters to which the EMCs calculated for the Lincoln, NE drainage basins could be compared. **Table 5.8** includes the mean EMC values calculated for the two monitoring sites along with EMC values from several literature references (see **Table 2.2** for complete literature review). It appears the ammonia concentration in the COL watersheds was well below the referenced values. There was a lot of variability in the referenced EMC values for N+N, TP, and TKN; the Colonial Hills and Taylor Park EMC values fell near the middle of these large observed ranges. However, TSS EMC values reported for the two monitoring sites were toward the upper end of the widely varying referenced EMCs. The TSS EMCs were substantially larger than those calculated for a residential area in Lincoln, NE by Vegi (2008). Overall, the Colonial Hills and Taylor Park EMC values were in the typical range reported in the literature, although TSS and several nutrients were higher than many referenced studies.

**Table 5.8: Comparison of mean EMC values from monitoring sites with literature**

| **Mean EMC Value** | **$NH_3$** | **COD** | **CDY** | **EC** | **N+N** | **SRP** | **TP** | **TSS** | **TKN** | **TBY** |
|---|---|---|---|---|---|---|---|---|---|---|
| Colonial Hills | 0.06 | 58 | 171 | 33,150[2] | 0.5 | 0.2 | 0.4 | 180 | 1.7 | 57 |
| Taylor Park | 0.11 | 69 | 150 | 62,430[2] | 0.7 | 0.2 | 0.6 | 210 | 1.8 | 53 |
| **Reference Study** | **Literature Review EMC Values** | | | | | | | | | |
| [1]Guerard and Weiss (1995) | 0.49 | | | | 0.6 | | 0.8 | 229 | 3.8 | |
| [1]LACDPW (1999) | 0.39 | | | | 0.3 | | 0.1 | 31 | 1.5 | |
| Smullen et al. (1999) | | 53 | | | 0.7 | 0.1 | 0.3 | 78 | 1.7 | |
| Vegi (2008) | | 38 | | | | | 0.3 | 115 | 1.2 | |

*Refer to **Table 4.1** (page 60) for water quality abbreviation definitions

*Refer to **Table 4.2** (page 61) for measurement units and analytical methods

[1] Source data is Lin (2004)

[2] Geometric mean used for E. coli data only

Because the EMCs were flow-weighted average concentrations, they provided a “normalized” method for comparing the wet weather concentrations from the two monitoring locations. In order to provide for a side by side concentration comparison between the two monitoring sites, only storm events that produced sufficient collected to estimate an EMC was considered for the two sites; the sampled storm events ranged in precipitation and intensity. The mean EMC value and standard deviation of the EMCs were reported for the two monitoring sites in **Table 5.9** along with the number of storm events producing EMC values at the two sites for each parameter. A paired t-test was conducted on the observed EMC values to determine if any significant differences in concentrations existed between the two monitoring sites.

**Table 5.9: EMC statistics for side by side comparison between the two sites**

| **Monitoring Site** | **EMC Statistic** | **$NH_3$** | **COD** | **EC** | **N+N** | **SRP** | **TP** | **TSS** | **TKN** |
|---|---|---|---|---|---|---|---|---|---|
| Colonial Hills | Mean | 0.06 | 58 | 31,780[1] | 0.46 | 0.23 | 0.41 | 180 | 1.6 |
| | Std Dev | 0.05 | 27 | 41,767 | 0.15 | 0.09 | 0.06 | 211 | 0.5 |
| Taylor Park | Mean | 0.09 | **72** | 62,430[1] | **0.71** | 0.23 | **0.57** | **220** | **1.8** |
| | Std Dev | 0.05 | 50 | 33,487 | 0.27 | 0.08 | 0.42 | 340 | 0.8 |
| **Number of Events:** | | 10 | 13 | 12 | 13 | 12 | 9 | 14 | 10 |
| **t-test (Pr > t):** | | 0.24 | **<0.01** | 0.17 | **0.01** | 0.09 | **<0.01** | **<0.01** | **<0.01** |

*Refer to **Table 4.1** (page 60) for water quality abbreviation definitions
*Refer to **Table 4.2** (page 61) for measurement units and analytical methods
***Bolded** values refer to larger site value significantly different at the 95% confidence level
[1] Geometric mean used for E. coli data only

Statistically significant differences were reported in **Table 5.9** above; the site with the larger significantly different mean EMC value was bolded. The results indicated a significant difference in COD, N+N, TP, TSS, and TKN at the 95% confidence level, all of which were consistently larger at the Taylor Park monitoring site. Generally, the Taylor Park site observed higher solids and nutrient concentrations during stormwater runoff, which was partially in agreement with differences in the observed dry weather concentrations reported in **Table 5.2**.

## 5.4 Wet Weather Continuous Concentration Models

Multiple linear regression (MLR) models were developed for several water quality constituents for both monitoring sites using the entire 2008 through 2011 dataset.

Only the wet weather dataset was used for the model production, because very little variation in the concentrations for most of the dry weather water quality constituents was observed throughout the sampling years. The goal was to develop regression models for discretely measured water quality constituents using continuously measured and easily obtained datasets. The models, in turn, could be used to estimate continuous measurements for the discretely measured parameters. The stormwater constituents considered for the models are provided in **Table 5.10** along with their abbreviation. The continuously measured and easily obtained data consisted of volumetric flow measurements, continuous water quality in-line probe measurements, and climatic data. The potential explanatory variables are outlined in **Table 5.11**.

The climatic dataset consisted of variables characterizing the storm event (i.e., P, $I_A$, $I_P$, and ADD) as well as variables that may explain variation due to seasonal trends (i.e., GDD, sin/cos, and SR); these variables were easily obtained from local weather stations. The volumetric flow rate (Q) was used to calculate the cumulative volume over the duration of each modeled storm event. The cumulative volume was then normalized by the total runoff volume for each storm event to provide a dimensionless, interchangeable variable ($V_n$).

**Table 5.10: Abbreviations for dependent modeling variables**

| Dependent Variable | Abbreviation |
|---|---|
| Escherichia coli (cfu/100 ml) | EC |
| Nitrate plus Nitrite Nitrogen (mg $NO_3$+$NO_2$-N / L) | N+N |
| Soluble Reactive Phosphorus (mg $PO_4^{3}$-P / L) | SRP |
| Total Kjeldahl Nitrogen (mg N / L) | TKN |
| Total Phosphorous (mg $PO_4^{3-}$-P / L) | TP |
| Total Suspended Solids (mg/L) | TSS |

**Table 5.11: Abbreviations for explanatory modeling variables**

| Explanatory Variable | Abbreviation |
|---|---|
| Average Storm Intensity (in/hr) | $I_A$ |
| Antecedent Dry Days (days) | ADD |
| Conductivity (μS/cm) | CDY |
| Cumulative Storm Volume normalized by Total Storm Volume (dimensionless) | $V_n$ |
| Dissolved Oxygen (mg/L) | DO |
| Growing Degree Days, 21 Day Average (base 50)[1] | GDD |
| Peak Storm Intensity (in/hr) | $I_P$ |
| Periodic Seasonal Variable[1] | sin/cos |
| Precipitation, Total Storm (in) | P |
| Solar Radiation, 21 Day Average ($W/m^2$) [1] | SR |
| Turbidity (FNU) | TBY |
| Volumetric Flow Rate ($ft^3/s$) | Q |
| Water Temperature (°C) | WT |

[1] Refer to **Section 4.8** (page 83) for further description

The procedure used for model development was clearly outlined in **Section 4.7**. During the continuous model development stage, two different types of statistically significant models were sought; a model that was the best overall fit that included only justifiable explanatory variables, and a model that included similar variables for both monitoring sites. For some of the sites, only one model was reported; this was the case when the best overall model also was “significant” for the other monitoring site.

The best fit regression models using continuous in-line probe data and climatic data for the continuous estimation of water quality concentrations for both monitoring sites are presented in **Table 5.12** (see **Appendix P** for another look at the models). To determine the best fit model, several steps of regression diagnostics were used; two of those, the coefficient of determination ($R^2$) and prediction error sum of squares (PRESS) statistics, were reported. Also, the far right column was used to denote which model was chosen to be the best fit for a monitoring site with more than one reported model, and thus, eventually used for mass load estimation. Two specific criteria were used for the continuous model development: (**1**) as recommended by Rasmussen et al. (2008), only correlated explanatory variables which had a physical basis for being correlated to the dependent variable were considered for inclusion in the best fit continuous models; and (**2**) because the models were to provide "continuous" concentration estimations on a 15 minute and 90 second interval, every model was to include at least one in-line probe or flow explanatory variable. With the production of best fit models from each monitoring site, **Table 5.13** was developed to provide a better illustration of the variety of explanatory variables that were of significance in the different regression models.

## Table 5.12: Summary statistics for the continuous MLR models

| Parameter | Site | Empirical Equation | BCF | n | $R^2$ | PRESS | Best Model |
|---|---|---|---|---|---|---|---|
| **TSS** | Colonial Hills | $\log_{10}TSS = -0.1737 + 1.2943*\log_{10}TBY$ | 1.13 | 108 | 0.89 | 5.53 | |
| | | $\log_{10}TSS = -0.2921 + 1.2705*\log_{10}TBY - 0.1737*\log_{10}V_n$ | 1.09 | 97 | 0.92 | 3.77 | X |
| | Taylor Park | $\log_{10}TSS = 0.3067 + 1.0678*\log_{10}TBY$ | 1.34 | 114 | 0.79 | 12.69 | X |
| **SRP** | Colonial Hills | $\log_{10}SRP = -0.3961 - 0.0008*Q + 0.6027*\log_{10}P + 0.4101*\sin(2\pi*day/365) + 0.1081*\cos(2\pi*day/365)$ | 1.07 | 83 | 0.58 | 2.37 | X |
| | Taylor Park | $\log_{10}SRP = -0.9472 + 0.3027*\log_{10}CDY + 0.371*\log_{10}I_P + 0.1801*\sin(2\pi*day/365) + 0.2127*\cos(2\pi*day/365)$ | 1.08 | 89 | 0.46 | 3.15 | X |
| **TP** | Colonial Hills | $\log_{10}TP = -0.2793 + 0.0032*TBY - 0.0006*SR$ | 1.02 | 68 | 0.74 | 0.45 | |
| | | $\log_{10}TP = -0.2015 + 0.0027*TBY - 0.0007*SR - 0.067*V_n$ | 1.01 | 61 | 0.77 | 0.36 | X |
| | Taylor Park | $\log_{10}TP = -0.1024 + 0.0023*TBY - 0.0009*SR$ | 1.08 | 60 | 0.72 | 1.73 | X |
| **N+N** | Colonial Hills | $\log_{10}N{+}N = -1.2203 + 0.2843*\log_{10}CDY + 0.0177*ADD - 0.1483*\sin(2\pi*day/365) - 0.1735*\cos(2\pi*day/365)$ | 1.05 | 92 | 0.40 | 2.00 | X |
| | | $\log_{10}N{+}N = -1.1114 + 0.2762*\log_{10}CDY + 0.0086*GDD$ | 1.06 | 92 | 0.31 | 2.17 | |
| | Taylor Park | $\log_{10}N{+}N = -1.245 + 0.3751*\log_{10}CDY + 0.0122*GDD$ | 1.14 | 94 | 0.32 | 5.21 | X |
| **TKN** | Colonial Hills | $\log_{10}TKN = -0.3403 + 0.1864*\log_{10}TBY - 0.6747*\log_{10}P + 0.0183*ADD - 0.1744*\sin(2\pi*day/365) - 0.0662*\cos(2\pi*day/365)$ | 1.09 | 79 | 0.42 | 3.10 | |
| | | $\log_{10}TKN = -0.7084 + 0.224*\log_{10}TBY - 0.8841*\log_{10}P - 0.1102*\log V_n + 0.04*ADD - 0.2429*\sin(2\pi*day/365) - 0.1825*\cos(2\pi*day/365)$ | 1.06 | 70 | 0.60 | 1.97 | X |
| | Taylor Park | $\log_{10}TKN = 3.1842 + 0.2316*\log_{10}TBY - 0.5376*\log_{10}P - 1.2818*\log_{10}SR$ | 1.12 | 75 | 0.52 | 3.34 | |
| | | $\log_{10}TKN = -0.0034 + 0.1268*\log_{10}TBY - 0.7331*\log_{10}P - 0.1877*\log V_n + 0.0188*ADD - 0.0153*GDD$ | 1.08 | 68 | 0.66 | 2.39 | X |
| **EC** | Colonial Hills | $\log_{10}EC = 3.5336 + 0.5533*\log_{10}TBY$ | 1.71 | 86 | 0.22 | 20.09 | |
| | | $\log_{10}EC = 2.5253 + 0.0685*\log_{10}TBY + 1.3067*I_A + 1.791*\log_{10}DO + 0.108*\sin(2\pi*day/365) - 0.3031*\cos(2\pi*day/365)$ | 1.26 | 77 | 0.64 | 8.58 | X |
| | Taylor Park | $\log_{10}EC = 3.7935 + 0.4417*\log_{10}TBY$ | 1.48 | 85 | 0.27 | 15.74 | X |

*Note: **all equations are unit-specific**; refer to **Table 5.10** (page 96) and **Table 5.11** (page 97) for the variable definitions and specific units

*n = sample size; BCF = Bias Correction Factor (see **Equation 2.4** from **Section 2.5**); $R^2$ and PRESS are defined in **Section 2.5.1** (page 14)

*"X" in the Best Model column refers to the best fit model for that site which was used for mass load estimation

**Table 5.13: Summary of included explanatory variables for the best fit continuous regression models selected for each site**

| **Explanatory Variable** | **Continuous Models (C = Colonial Hills; T = Taylor Park)** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **TSS** | | **SRP** | | **TP** | | **N+N** | | **TKN** | | **EC** | |
| | **C** | **T** | **C** | **T** | **C** | **T** | **C** | **T** | **C** | **T** | **C** | **T** |
| CDY | | | | ▨ | | | ▨ | ▨ | | | | |
| DO | | | | | | | | | | | ▨ | |
| TBY | ▨ | ▨ | | | ▨ | ▨ | | | ▨ | ▨ | ▨ | ▨ |
| WT | | | | | | | | | | | | |
| Q | | | ▨ | | | | | | | | | |
| $V_n$ | ▨ | | | | ▨ | | | | ▨ | ▨ | | |
| $I_A$ | | | | | | | | | | | ▨ | |
| $I_P$ | | | | ▨ | | | | | | | | |
| P | | | ▨ | | | | | | ▨ | ▨ | | |
| ADD | | | | | | | ▨ | | ▨ | | | |
| GDD | | | | | | | | ▨ | | | | |
| sin/cos | | | ▨ | ▨ | | | ▨ | | ▨ | | ▨ | |
| SR | | | | | | ▨ | | | | | | |

*Note: refer to **Table 5.10** (page 96) and **Table 5.11** (page 97) for the variable definitions and specific units

During the continuous modeling process, model quality control was performed to provide the most valid result. One method used for model QA/QC was to check how the range of estimated concentrations using the models compared to the observed range of concentrations used for the model development. For the purpose of mass load estimations, the models were not limited to only the range of observed data; however, the maximum limit for estimated concentration was set to be twice the concentration observed over the course of the project period. For example, the total phosphorus model at Colonial Hills produced estimated concentrations greater than twice the maximum observed TP concentration (0.90 mg/L from **Table 5.3**); therefore, when the estimated concentration was greater than 1.8 mg/L, the concentration was assumed to be 1.8 mg/L.

The models that that were adjusted using this method were: TP and TKN for Colonial Hills; and TP for Taylor Park.

After an analysis of the continuous models presented in **Table 5.12**, several conclusions could be made. The discussion of the analysis is provided in the list below.

- Among the selected models for each site, denoted by an "X" in the Best Model column, only the TKN models did not result in a higher $R^2$ value for the larger Colonial Hills watershed; all of the Colonial Hills models resulted in a lower PRESS value. These results were consistent with the findings of Phillips et al. (1999), which reported in a study on two rivers of different basin size that more accurate load estimations were consistently obtained from the larger drainage basin (Phillips et al. 1999).
- A comparison made between the models among the two sites that included similar explanatory variables revealed that neither site consistently produced better $R^2$ values for the models. The different coefficients of the explanatory variables for the same models across the two sites suggested that the continuous models might be explaining some physical differences between the two watersheds occurring within a storm event and throughout the season. An example would be the TSS models, in which the regression coefficients were somewhat different for the turbidity explanatory variable. Another example would be the slight differences in regression coefficients recorded for the TKN explanatory variables amongst the two sites.
- Every continuous model included a continuously measured in-line probe explanatory variable except SRP at Colonial Hills, which was related to the continuously measured volumetric flow rate instead.

- The continuous models for TSS and TP included the same water quality parameters between the two sites, except for the inclusion of $V_n$ at Colonial Hills for the two constituents. The TKN models included very similar explanatory variables for both sites. The E. coli models both included the in-line turbidity measurement as an explanatory variable; however, the Colonial Hills model included three other explanatory variables to produce a much better $R^2$ value. SRP and N+N models were less similar between the two sites, but the models also produced lower $R^2$ values. Overall, the TSS, TP, and TKN models produced the highest $R^2$ values; all of these models happened to include the in-line turbidity measurement as an explanatory variable.
- The only potential explanatory variable that was not included in at least one model was the in-line probe water temperature measurement. The most consistently used explanatory variable was the in-line probe turbidity measurement, which was included in eight of the models
- Seasonal variables (i.e., GDD, sinusoidal periodic function, SR) were significant in several of the continuous models. For the Colonial Hills models, the sinusoidal function significantly accounted for variation in four of the models (i.e., SRP, N+N, TKN, and EC). The seasonal trends were captured at Taylor Park with the periodic inclusion of solar radiation and growing degree days as explanatory variables.
- The models that were produced were quite consistent with the literature cited in **Table 2.1** for continuous water quality monitoring. The inclusion of in-line probe TBY as a significant explanatory variable in the TSS, TP, TKN, and EC models was consistent with what had been reported by multiple references. Also, Rasmussen et al.

(2008) had previously reported the inclusion of CDY as a significant explanatory variable for SRP. The significance of the sinusoidal periodic function and GDD in the N+N models for Colonial Hills and Taylor Park, respectively, was consistent with the finding by Ryberg (2006) that N+N was seasonally varying.

- In general, the continuous models for the two monitored watersheds produced smaller $R^2$ values than the corresponding continuous models cited from literature in **Table 2.1**. This finding was not all that surprising given the fact that most of the watersheds modeled in the literature were many magnitudes larger in scale than the two small Lincoln, NE urban watersheds. It was expected that smaller, flashier urban watersheds would produce worse model fits due to increased sources and pathways, as suggested by Rasmussen et al. (2008).

## 5.5 EMC Mass Load Estimation Models

Multiple linear regression models were also developed using the EMC dataset presented for both monitoring sites in **Section 5.3.2**. Two different modeling approaches were used for the EMC data; to develop EMC MLR models similar to those found in literature using only climatic data for explanatory variables and EMC MLR models using the climatic datasets along with EMCs calculated for the in-line probe datasets as explanatory variables. The two different modeling approaches would provide two EMC estimates for each storm event which could be used to estimate the seasonal mass loads and trends. The stormwater constituents considered for the models were provided in **Table 5.10** along with their abbreviation. The potential explanatory variables were outlined in **Table 5.11** with the exception of in-line probe measurements for DO and WT.

It should be noted, though, that the explanatory variables for turbidity and conductivity no longer were continuous measurements in time; however, those continuous measurements were used to calculate an EMC value for the two in-line probe variables for each sampled storm event. These variables will now be referenced as $TBY_{EMC}$ and $CDY_{EMC}$.

The best fit, statistically significant MLR models using the two different modeling approaches for the estimation of EMCs are presented in **Table 5.14** (see **Appendix P** for another look at the models). In the third column of **Table 5.14**, the "Climatic" method refers to the EMC models developed using only climatic explanatory variables; the "Probe" method refers to EMC models developed using both in-line probe and climatic explanatory variables. This meant that the EMC-Probe model was required to have an in-line probe explanatory variable (i.e., turbidity or conductivity); if no in-line probe variable significantly accounted for variation in the EMC value, no model was reported. The EMC-Climatic models were not permitted to have any explanatory variables other than climatic variables. Unlike the continuous models, physical justification for the inclusion of an explanatory variable was not as strictly enforced for the EMC models in order to produce at least some models of significance due to the small sample size. To determine the best fit model, several steps of regression diagnostics were used; two of those, the coefficient of determination ($R^2$) and prediction error sum of squares (PRESS) statistics, were reported. The sample size (n) was different for the two monitoring sites because of a malfunction of the automated sampling equipment.

**Table 5.14: EMC model results using two different MLR modeling approaches**

| Parameter | Site | Method | Empirical Equation | BCF | n | $R^2$ | PRESS |
|---|---|---|---|---|---|---|---|
| **TSS** | Colonial Hills | Probe | $\log_{10}TSS_{EMC} = 1.6632 + 0.0069*TBY_{EMC}$ | 1.14 | 14 | 0.67 | 1.40 |
| | | Climatic | $\log_{10}TSS_{EMC} = 1.7976 - 0.7508*P + 3.2652*I_P - 2.4825*I_A$ | 1.11 | 14 | 0.75 | 0.93 |
| | Taylor Park | Probe | $\log_{10}TSS_{EMC} = 1.6704 + 0.0073*TBY_{EMC}$ | 1.14 | 16 | 0.73 | 1.06 |
| | | Climatic | $\log_{10}TSS_{EMC} = 3.2248 - 0.5976*P + 0.7935*\log_{10}I_A$ | 1.27 | 16 | 0.44 | 2.45 |
| **SRP** | Colonial Hills | Probe | $SRP_{EMC} = 0.0933 + 0.0008*TBY_{EMC} + 0.0977*P$ | NT | 12 | 0.59 | 0.06 |
| | | Climatic | $SRP_{EMC} = 0.2145 + 0.1384*P - 0.0063*GDD$ | NT | 12 | 0.75 | 0.05 |
| | Taylor Park | Probe | $SRP_{EMC} = 1.4943 - 0.0009*CDY_{EMC} - 0.4314*\log_{10}SR$ | NT | 14 | 0.61 | 0.07 |
| | | Climatic | $SRP_{EMC} = 0.6342 - 0.0008*SR + 0.2119*\log_{10}I_P$ | NT | 14 | 0.61 | 0.06 |
| **TP** | Colonial Hills | Probe | No Significant Model | - | - | - | - |
| | | Climatic | No Significant Model | - | - | - | - |
| | Taylor Park | Probe | $\log_{10}TP_{EMC} = -0.5329 + 0.0036*TBY_{EMC} + 0.431*I_A + 0.1704*\log_{10}ADD$ | 1.01 | 9 | 0.99 | 0.08 |
| | | Climatic | No Significant Model | - | - | - | - |

*Note: **all equations are unit-specific**; refer to **Table 5.10** and **Table 5.11** for the variable definitions and specific units

*n = sample size; BCF = Bias Correction Factor (see **Equation 2.4** from **Section 2.5**); NT = "no transformation"

*Probe Method: regression models based on probe & climatic data; Climatic Method: regression models based on climatic data only

**Table 5.14 Continued**

| Parameter | Site | Method | Empirical Equation | BCF | n | $R^2$ | PRESS |
|---|---|---|---|---|---|---|---|
| N+N | Colonial Hills | Probe | No Significant Model | - | - | - | - |
| | | Climatic | $\log_{10}N{+}N_{EMC} = -0.6511 + 0.2779*\log_{10}ADD - 0.0757*\sin(2\pi*day/365) - 0.224*\cos(2\pi*day/365)$ | 1.01 | 13 | 0.75 | 0.10 |
| | Taylor Park | Probe | $\log_{10}N{+}N_{EMC} = -3.6318 + 1.3773*\log_{10}CDY_{EMC} + 0.4752*\log_{10}P$ | 1.11 | 14 | 0.41 | 1.05 |
| | | Climatic | $N{+}N_{EMC} = 1.0693 + 0.4791*\log_{10}I_A$ | NT | 14 | 0.29 | 1.05 |
| TKN | Colonial Hills | Probe | $\log_{10}TKN_{EMC} = -1.5284 + 0.6877*\log_{10}CDY_{EMC} + 0.0149*GDD$ | 1.03 | 11 | 0.55 | 0.19 |
| | | Climatic | No Significant Model | - | - | - | - |
| | Taylor Park | Probe | $TKN_{EMC} = 6.6846 + 1.6354*\log_{10}TBY_{EMC} - 3.4492*I_P + 2.432*I_A - 2.5586*\log_{10}SR$ | NT | 10 | 0.95 | 4.32 |
| | | Climatic | $TKN_{EMC} = 2.7635 - 3.8713*\log_{10}P - 1.7768*\log_{10}GDD + 2.9973*I_A$ | NT | 10 | 0.87 | 1.56 |
| EC | Colonial Hills | Probe | $\log_{10}EC_{EMC} = 5.3993 - 0.0042*TBY_{EMC} + 0.8284*\log_{10}I_A$ | 1.10 | 13 | 0.66 | 0.93 |
| | | Climatic | $\log_{10}EC_{EMC} = 5.1103 + 0.7147*\log_{10}I_A$ | 1.13 | 13 | 0.58 | 0.89 |
| | Taylor Park | Probe | $EC_{EMC} = 22{,}9076 - 342.18*TBY_{EMC} - 7{,}4296*P - 2394.3*ADD + 7{,}4345*\log_{10}I_A$ | NT | 12 | 0.89 | $4*10^9$ |
| | | Climatic | $\log_{10}EC_{EMC} = 4.8385 - 0.3462*P - 0.2747*\sin(2\pi*day/365) - 0.2471*\cos(2\pi*day/365)$ | 1.02 | 12 | 0.84 | 0.21 |

*Note: **all equations are unit-specific**; refer to **Table 5.10** and **Table 5.11** for the variable definitions and specific units

*n = sample size; BCF = Bias Correction Factor (see **Equation 2.4** from **Section 2.5**); NT = “no transformation”

*Probe Method: regression models based on probe & climatic data; Climatic Method: regression models based on climatic data only

During the EMC modeling process, model quality control was performed to provide the most valid result. On rare occasions, it was noticed that several models produced negative EMC values. The reason for this may be due to models that were developed using a very small sample size which was not very representative for the entire year of 2010. Another reason could be due to the inclusion of variables that have low physical meaning for the model correlation, which could in turn produce a very unstable model. Whatever the case may be, the models were still utilized but the estimated EMC values were prevented from falling below zero through an algorithm developed in Excel. If the estimated EMC value was below zero, the 2010 average EMC value (see **Table 5.16**) was used instead for the calculation of the mass load estimate.

After an analysis of the EMC MLR models presented in **Table 5.14**, several conclusions could be made. The discussion of the analysis is provided in the list below.

- Only one significant model was produced for TP, likely due to the small sample size. The sample size for TP (9) was smaller than the other parameters because the parameter was not analyzed before the start of the 2010 sampling season. Therefore, the sampled storm events for 2008 and 2009 did not produce an EMC for TP.
- The models for the same parameters often included quite different explanatory variables between the two sites. This was much different from the continuous models which often included similar explanatory variables. The difference in included variables between the two sites may be due to the small sample size. It also could be attributed to the averaging that occurs in the calculation of an EMC which may eliminate any strong arguments that could be made for the physical meaning and implications of an included variable.

- The EMC-Probe models for TSS had very similar regression coefficients for TBY and the intercept. Although several differences are known to exist between the site characteristics of the two monitoring sites, the calculation performed for the EMCs seemed to have averaged out any differences. This finding was different from the continuous models for TSS where the coefficients were found to be slightly different between the two sites. The differences between the two model types suggest that a benefit to continuous modeling may be the ability to point out physical differences that may be occurring within a storm hydrograph; this would be consistent with a statement made by Stenstrom and Kayhanian (2005) that an EMC value can overlook high initial pollutant concentrations due to a first flush phenomenon, which can significantly contribute to overall mass loads. The different coefficients produced by the continuous models agree with the likelihood of different TBY to TSS ratio rates of change throughout a storm event between the two sites.
- Generally, the use of continuous in-line turbidity and conductivity measurements improved the data fit of EMC-Probe models compared to the EMC-Climatic models
- The Taylor Park EMC-Probe models generally produced higher $R^2$ values than those for Colonial Hills. This was different than the trend that was noticed for the continuous models, which consistently produced higher $R^2$ values for the Colonial Hills site. It is uncertain what may be causing the difference in trends. The small sample size and poor representation of storm characteristics throughout the sample season may be the cause for difference, though.
- In general, the EMC models developed for the two small Lincoln, NE urban watersheds produced models with much better $R^2$ values than those reported in

literature for the same parameters (see **Table 2.2**). This finding may be misleading, however, because all the models developed in the literature combined data from two or more urban watersheds; one could expect this to have a negative impact on the model fits as water quality has been reported to have high variance between watersheds due to physical site characteristics and climatic differences.

## 5.6 Mass Load Estimation (2010)

The models that were developed using the three different multiple linear regression approaches were in turn used to estimate storm mass loads for several water quality constituents during the 2010 monitoring season. Also, an additional estimate of annual storm mass load was made using the average EMC value for the entire sampling season. The 2010 monitoring season ranged from April 15 through November 1; this is a smaller range than that presented in **Table 5.1** because it was limited by the valid range of weather station data.

When the base-10 logarithmic transformation was used for the modeled variable, a retransformation of the dataset needed to be taken to achieve the proper, workable units. The retransformation of the data introduces bias due to the crossover of units from logarithmic to linear space (Rasmussen et al. 2009). The correction of the introduced retransformation bias would be the application of a bias correction factor (BCF), developed by Duan (1983). For further explanation of the BCF, see **Section 2.5.2**. An example for the retransformation of the Colonial Hills TSS regression model is provided in Equation 5.1.

$$\mathrm{TSS[mg/L]} = 10^{\left(-0.2921 + 1.2705 * \log_{10}\mathrm{TBY[FNU]} - 0.1737 * \log_{10}\mathrm{V_n}\right)} * 1.09 \qquad (5.1)$$

The BCF, represented by "1.09" in Equation 5.1, is applied by multiplying it by ten raised to the power of the regression equation.

Because the MLR models were developed using only storm runoff data, the models were applied only to periods of **storm flow** for the 2010 monitoring season. The estimation of mass load using the MLR models would then be equivalent to the total mass load of the stream for storm events during the 2010 sampling season. To estimate the entire mass load for April 15 through November 1, the dry weather concentrations had to be taken into consideration as well. Because of a lack of correlation and variation in the dry weather concentrations during the study period, no regression models were developed for the dry weather dataset. Therefore, the average dry weather concentration for 2010 was used for the estimation of the dry weather mass load for each water quality constituent by multiplying the average concentration by the total dry weather flow volume for a given time period. Equation 5.2 represents the calculation used for the estimation of dry weather mass loads.

$$\text{Dry Weather Mass Load} = C_{2010\ \text{avg}} * \int_0^t Q(t)_{\text{dry flows}}\,dt \tag{5.2}$$

In Equation 5.2, $C_{2010\ \text{avg}}$ is the average measured dry weather concentration for the 2010 sampling season; Q(t) is the measured flow rate at a given point in time, t; and dt is the time step between flow measurements. The 2010 dry weather average concentrations used for the mass load estimates are provided in **Table 5.15**. The dry weather flow volume was calculated by first calculating the entire sampling season flow volume and storm runoff volume. The dry weather flow volume was assumed to be the difference between the two. The mass load calculation used for the different estimation methods is provided in the following pages.

**Table 5.15: Average 2010 dry weather concentrations**

| Collection Site | Modeled Parameter | | | | | |
|---|---|---|---|---|---|---|
| | TSS (mg/L) | SRP (mg/L) | TP (mg/L) | N+N (mg/L) | TKN (mg/L) | EC (cfu/100ml) |
| Colonial Hills | 2.5 | 0.112 | 0.128 | 0.822 | 0.470 | 500 |
| Taylor Park | 1.5 | 0.189 | 0.207 | 1.767 | 0.564 | 2,687 |

### 5.6.1 Continuous Models

The regression models based on continuous in-line probe measurements and easily obtained climatic data from local weather stations (presented in **Table 5.12**) were used to estimate concentrations for measured water quality parameters (i.e., TSS, SRP, TP, N+N, TKN, E. coli). An estimate of the concentration on a near continuous basis was made using a variation of Equation 5.1. The storm mass load was calculated by summing the product of the average concentration estimate and the average runoff volume over a given time interval, shown by Equation 5.3. The trapezoidal method was used for integral estimation.

$$\text{Storm Mass Load} = \int_0^t C(t)_{\text{modeled}} * Q(t)\, dt \tag{5.3}$$

where $C(t)_{\text{modeled}}$ is the estimated concentration at a point in time, t, using the continuous MLR model; Q(t) is the measured flow rate at a given point in time, t; and dt is the time step between flow measurements (generally 90 seconds, but sometimes 15 minutes prior to the stream level surpassing the trigger threshold). For the estimation of the total mass load of a water quality constituent for the 2010 monitoring season, the sum of the mass load calculated for all of the storm events with Equation 5.3 was added to the dry weather mass load estimate obtained with Equation 5.2.

### 5.6.2 EMC Models

The EMC regression models based on climatic data only ("EMC-Climatic") and the EMC models regressed with in-line probe and climatic data ("EMC-Probe") were both used to estimate average storm concentrations for the discretely measured water quality parameters (i.e., TSS, SRP, TP, N+N, TKN, E. coli). An estimate of the EMC for every storm event was made using the model equations provided in **Table 5.14**. The storm mass load was calculated by summing the product of the EMC and the total event runoff volume, shown by Equation 5.4. The trapezoidal method was used for integral estimation.

$$\text{Storm Mass Load} = \text{EMC}_{\text{modeled}} * \int_0^t Q(t)\,dt \tag{5.4}$$

where $\text{EMC}_{\text{modeled}}$ is the estimated EMC for the given storm using the EMC MLR model; Q(t) is the measured flow rate at a given point in time, t, during the storm; and dt is the time step between flow measurements (generally 90 seconds, but sometimes 15 minutes prior to the stream level surpassing the trigger threshold). For the estimation of the total mass load of a water quality constituent for the 2010 monitoring season, the sum of the mass load calculated for all of the storm events with Equation 5.4 was added to the dry weather mass load estimate obtained with Equation 5.2.

### 5.6.3 EMC Average Estimate

Another approach to estimating the 2010 storm mass load would be to simply calculate the average measured EMC for the 2010 sampling season and multiply it by the total storm runoff volume for the monitoring period. The calculation is given in Equation 5.5 below.

$$\text{2010 Storm Mass Load} = \text{EMC}_{\text{2010 Ave}} * \int_0^t \text{Q(t)}_{\text{storm flow}}\,\text{dt} \tag{5.5}$$

where $\text{EMC}_{\text{2010 Avg}}$ is the average measured 2010 EMC provided in **Table 5.16**; Q(t) is the measured flow rate at a given point in time, t, during the storm; and dt is the time step between flow measurements (generally 90 seconds, but sometimes 15 minutes prior to the stream level surpassing the trigger threshold). Once again, the total mass load estimate of a water quality constituent for the 2010 monitoring season would equate to the estimated storm mass load calculated with Equation 5.5 added to the dry weather mass load estimate obtained with Equation 5.2.

**Table 5.16: Average 2010 EMC values used for mass load estimation**

| 2010 Mean EMC Value | EC (cfu/100ml) | N+N (mg/L) | SRP (mg/L) | TP (mg/L) | TSS (mg/L) | TKN (mg/L) |
|---|---|---|---|---|---|---|
| **Colonial Hills** | 37,167 | 0.5 | 0.3 | 0.4 | 165 | 1.3 |
| **Taylor Park** | 48,591 | 0.8 | 0.3 | 0.4 | 103 | 1.5 |

### 5.6.4 Mass Load Estimation Comparison: 2010 Yields

Using the methods and equations outlined in the previous three sections, mass load estimates for the 2010 monitoring season (April 15 through November 1) were attained. In order to view the two watersheds on a relative basis, the mass load values were normalized by each drainage area (drainage areas from **Table 3.1**); the results were mass load yields for the two basins in units of kilograms of contaminant mass per hectares of drainage area (kg/ha). The resulting mass load yields using the following four estimation techniques were reported in **Table 5.17**: MLR models based on continuous datasets (Continuous), climatic dependent only EMC MLR models (EMC-Climatic), in-line probe and climatic dependent MLR models (EMC-Probe), and EMC average method (EMC-Avg).

**Table 5.17: Comparison of 2010 mass load yields using different estimation methods**

| Monitoring Site | Estimation Method | TSS (kg/ha) | SRP (kg/ha) | TP (kg/ha) | N+N (kg/ha) | TKN (kg/ha) | EC (cfu*$10^9$)/ha |
|---|---|---|---|---|---|---|---|
| **Colonial Hills** | Continuous[1] | 410 | 0.7 | 1.2 | 1.6 | 3.9 | 1,370 |
| | EMC-Probe[2] | 510 | 0.9 | # | # | 5.5 | 1,080 |
| | EMC-Climatic[2] | 650 | 0.9 | # | 1.7 | # | 1,240 |
| | EMC-Avg | 430 | 0.7 | 1.1 | 1.6 | 3.7 | 970 |
| **Taylor Park** | Continuous[1] | 350 | 0.6 | 1.0 | 2.6 | 2.7 | 910 |
| | EMC-Probe[2] | 280 | 0.5 | 1.5 | 1.9 | 2.6 | 950 |
| | EMC-Climatic[2] | 160 | 0.5 | # | 2.6 | 3.3 | 790 |
| | EMC-Avg | 190 | 0.6 | 0.9 | 2.7 | 3.1 | 880 |

# = no significant model

[1] Values obtained using models found in **Table 5.12**

[2] Values obtained using models found in **Table 5.14**

The three estimation models along with the EMC average method produced comparable, but not identical, 2010 mass load yield estimates for the different water quality constituents at each of the two monitoring sites, as seen in **Table 5.17**. For each site, the percent differences amongst the mass load yield estimates were in the range of 5-50% for all the water quality constituents besides TSS at Taylor Park. The maximum percent difference amongst the different TSS yield estimates at Taylor Park was 75%, the only difference greater than fifty percent. The normalized estimated mass loads provided a comparative glance between the pollutant transfers in the two watersheds. The Colonial Hills site recorded higher mass load yields than Taylor Park in 2010 for TSS, SRP, TKN, and EC. On the other hand, Taylor Park experienced higher N+N mass load yields based on the 2010 estimates. Total phosphorus was the only water quality constituent that was not consistently greater amongst the estimation methods for one of the two monitoring sites.

It was a bit surprising that the N+N yields were higher at Taylor Park while the TKN yields were higher at Colonial Hills; however, based on the definition for TKN, the TKN parameter does not factor in nitrate or nitrite nitrogen but is composed of ammonia and organic forms of nitrogen (TKN = organic-N + $NH_3$-N) (Hach Company 2011). It is possible that the different TKN and N+N trends between the two sites are an indication of different chemical and physical processes affecting the nitrogen cycle in the two drainage basins. Nitrogen assimilation occurs when inorganic-N ($NH_4^+$, $NO_3^-$, and $NO_2^-$) is transformed into microbial or plant biomass and temporarily stored as organic-N. Organic-N can undergo ammonification resulting in $NH_4^+$, then nitrification to $NO_2^-$ and further to $NO_3^-$ (Collins et al. 2010). Different physical processes within the two urban watersheds are likely contributing to the different N+N and TKN mass load yield trends.

## 5.7 Model Comparison (2010 Data)

Statistically significant multiple linear regression models were developed for several water quality parameters using three different approaches. The modeling approaches (Continuous, EMC-Probe, EMC-Climatic) were described in **Section 5.6** and were used to estimate 2010 seasonal mass loads. The continuous method produced significant models for six water quality parameters, while EMC models failed to produce significance for some of the same parameters. The purpose for developing models of different type was to determine what benefit continuous water quality monitoring using in-line probes might provide to future small, urban watershed management and development. The models were already shown to produce similar, but not identical, mass load yield estimates in **Table 5.17**. Therefore, this section seeks to find any differences amongst estimated seasonal trends for the different models as well as deficiencies associated with any of the modeling methods.

### 5.7.1 Cumulative Mass Plots

One technique used to compare seasonal mass loading trends was the development of normalized cumulative mass plots (CMPs). In order to develop a CMP, the model estimates needed to be available throughout the sampling season. For the continuous models, this meant an instantaneous mass load estimate (kg) was needed. An example of the time series instantaneous mass load plot for TSS at the Colonial Hills monitoring site can be found in **Figure 5.3**.

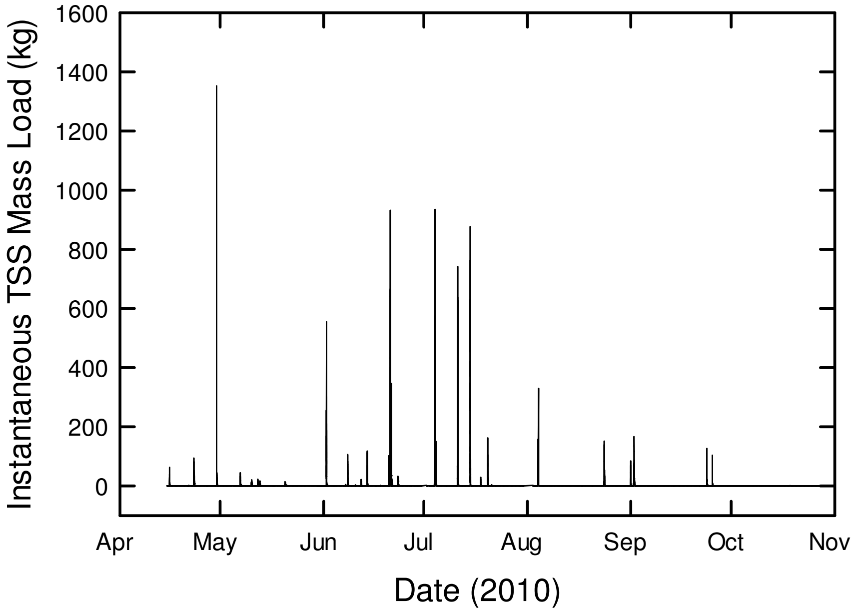

**Figure 5.3: Instantaneous TSS time series mass loading for Colonial Hills 2010**

Using the instantaneous mass load, a cumulative mass load could be calculated throughout the sampling season. The cumulative mass load estimated with each modeling approach was then normalized by the seasonal total mass load estimated with that same model approach, providing a way to compare the three models. Normalized CMPs were developed using the three modeling approaches for each of the six modeled water quality constituents; the CMPs can be found in **Figure 5.4**, **Figure 5.5**, and **Figure 5.6** for the two monitoring sites (Colonial Hills on the left and Taylor Park on the right). A jump in the data line corresponds to a time of significant mass contribution to the overall seasonal load; these jumps correlated to the dates of storm events.

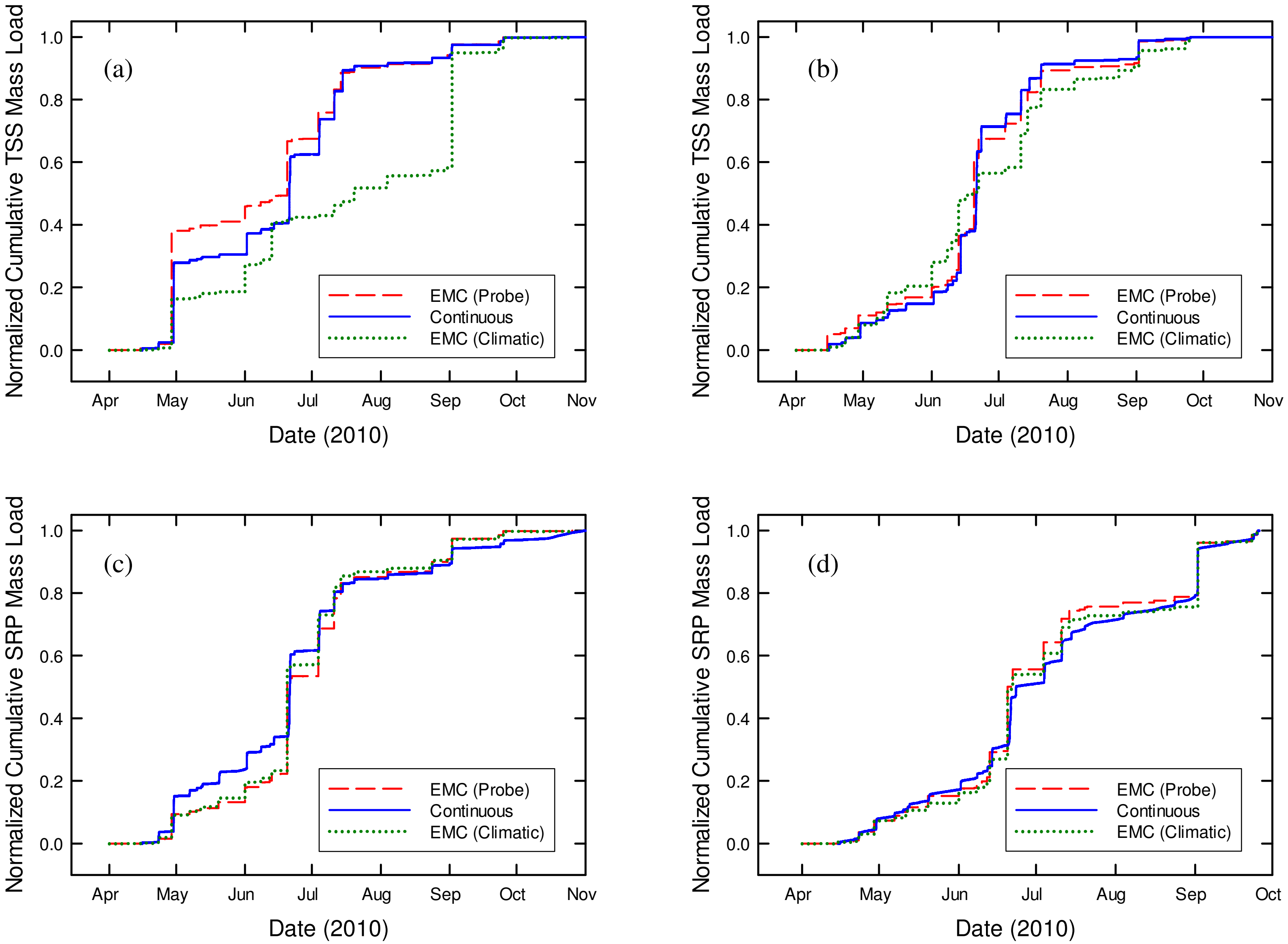

**Figure 5.4: 2010 cumulative mass load plots – normalized estimated mass loads by the total 2010 estimated mass load from three different model types for (a) Colonial Hills TSS; (b) Taylor Park TSS; (c) Colonial Hills SRP; (d) Taylor Park SRP**

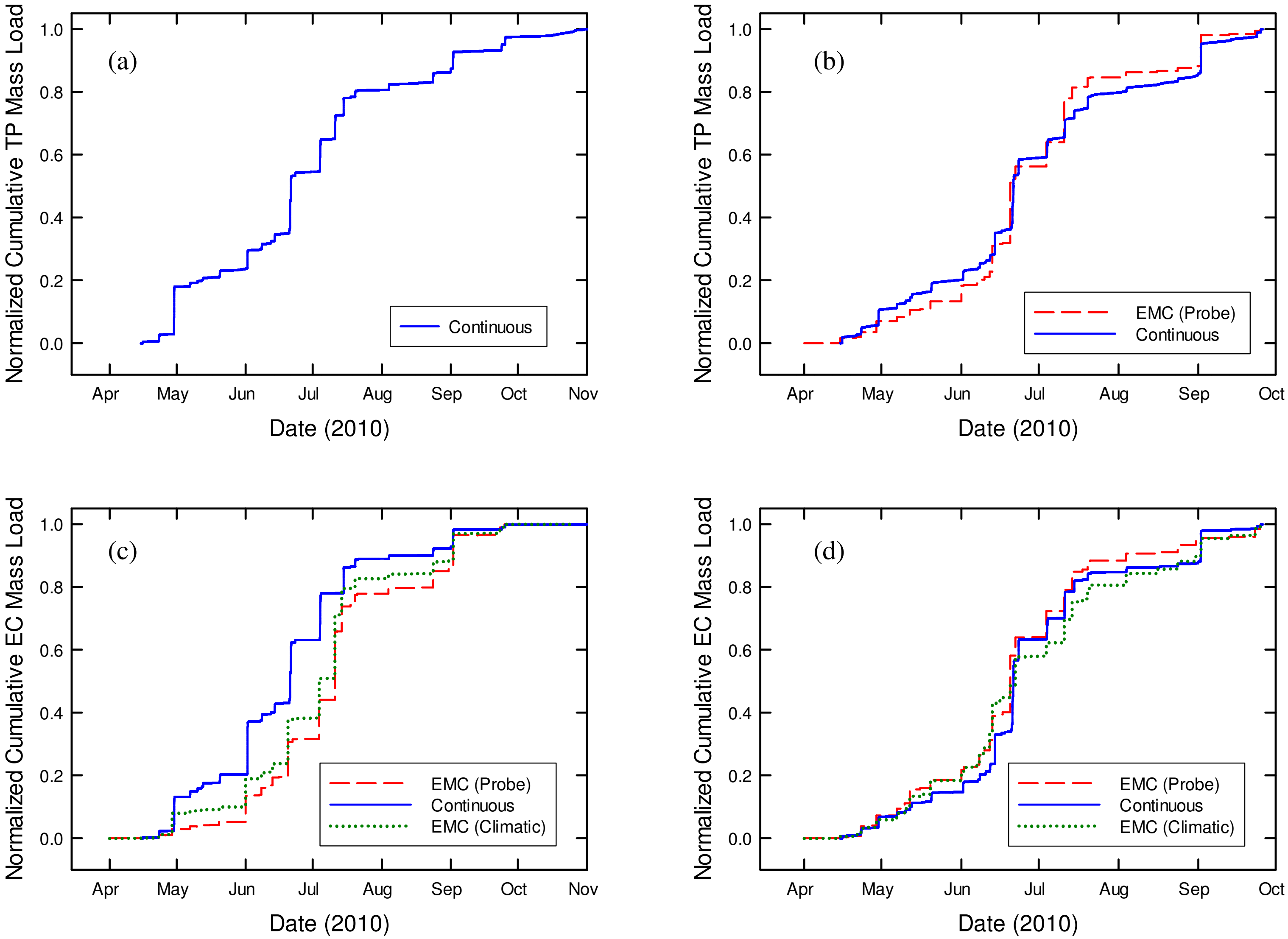

**Figure 5.5: 2010 cumulative mass load plots – normalized estimated mass loads by the total 2010 estimated mass load from three different model types for (a) Colonial Hills TP; (b) Taylor Park TP; (c) Colonial Hills EC; (d) Taylor Park EC**

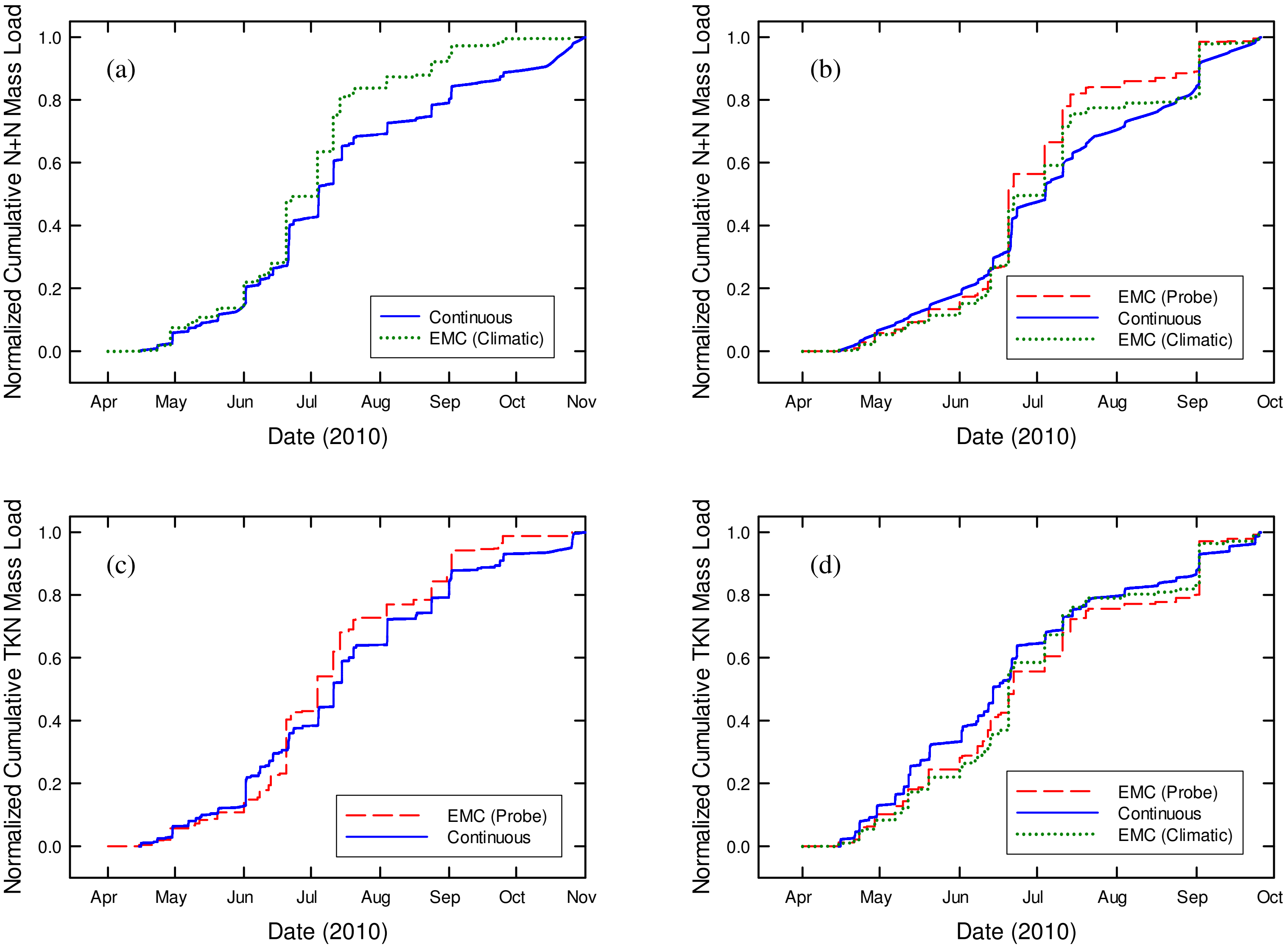

**Figure 5.6: 2010 cumulative mass load plots – normalized estimated mass loads by the total 2010 estimated mass load from three different model types for (a) Colonial Hills N+N; (b) Taylor Park N+N; (c) Colonial Hills TKN; (d) Taylor Park TKN**

Following an analysis of the cumulative mass plots using the three different MLR modeling approaches presented above, several conclusions could be made for the 2010 seasonal mass loading trends. The discussion of the analysis is provided below.

Generally, the two EMC models were in better agreement with each other than with the Continuous model. The main exception to this statement would be the TSS CMPs. For the Colonial Hills and Taylor Park TSS CMPs, the EMC-Climatic model produced different mass loading trends than the two models based on in-line probe measurements. This finding was not surprising, however, as turbidity and TSS are known to be highly correlated, as indicated in previous models developed by Rasmussen et al (2005), Rasmussen et al. (2008), and Christensen (2003). The Colonial Hills TSS CMPs clearly showed the benefit to using the turbidity in-line probe measurements as an explanatory variable. The large estimation of TSS mass load for the September 2nd storm event using the EMC-Climatic model seemed to be very unrealistic after analyzing the continuous in-line turbidity measurements for the event. The overestimation was due to instability in a climatic data only model, which included peak intensity and average intensity as explanatory variables. The 9/2/2010 storm event was a long lasting event which produced a very high peak intensity value and an alternatively low average intensity. As a result, the EMC-Climatic TSS model for Colonial Hills did a very poor job handling this storm event.

Very similar mass loading trends were produced amongst the three modeling approaches, with the exception of the Colonial Hills TSS models, Taylor Park TSS models, and Colonial Hills EC models. The CMPs indicate that the majority of the mass load is transported in several significant storm events throughout the season for some parameters (e.g., TSS and SRP) while other parameters increase more gradually (e.g., N+N and TKN).

### 5.7.2 Model Estimates vs. Measured Data (2010)

For a further comparison of the 2010 mass load estimates using the three different MLR models, a check to the actual measured data was performed. During the 2010 sampling season, water quality samples were collected from five storm events within the estimation range of the models (April 15 through November 1): 4/29/2010, 5/20/2010, 6/8/2010, 7/11/2010, and 8/4/2010. The measurements from the five storm events were used to calculate “actual EMCs.” The actual EMCs were then used to estimate the mass load for the corresponding storm events, referred to as the “actual mass load.” The actual mass load for the five events was then compared to the mass load estimates for those same events using the three regression models with a percent difference calculation.

The graphical results for the percent difference between the actual mass load and EMC-Probe mass load, EMC-Climatic mass load, and Continuous mass load for the six water quality parameters by storm event can be found in **Figure 5.7**, **Figure 5.8**, and **Figure 5.9** below. The EMCs and load estimates used for the development of these tables can be found in **Appendix Q**. It should be noted that the “actual EMCs” did not provide a “true” mass load estimate but the best guess that could be made with the data provided. The data used to calculate the actual EMCs was used for the development of the EMC models, so it cannot be used for model validation; it does, however, point out any errors in the developed models that may exist through comparison.

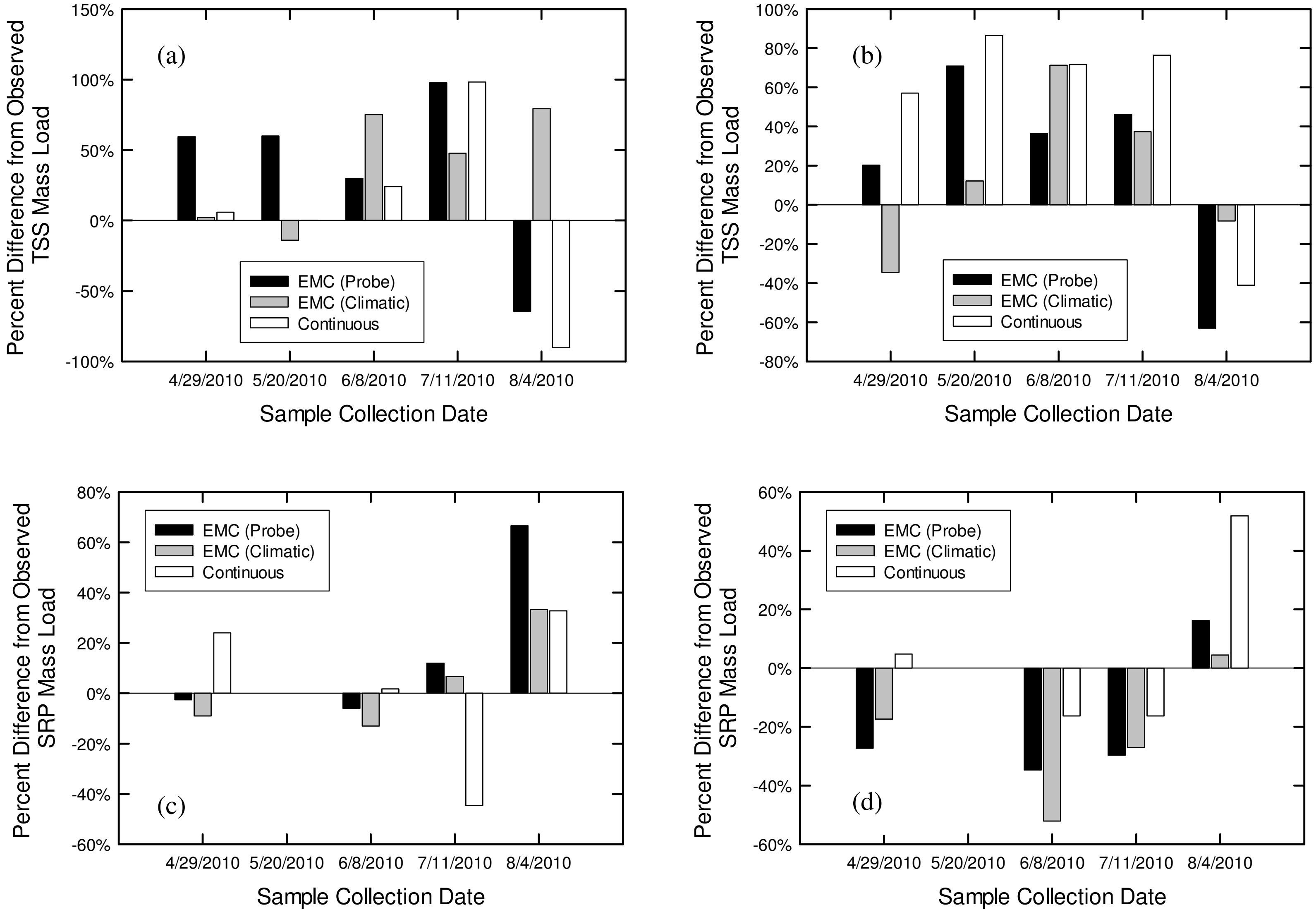

**Figure 5.7: Percent difference between mass loads calculated using measured data and mass loads estimated from the models for (a) Colonial Hills TSS; (b) Taylor Park TSS; (c) Colonial Hills SRP; (d) Taylor Park SRP**

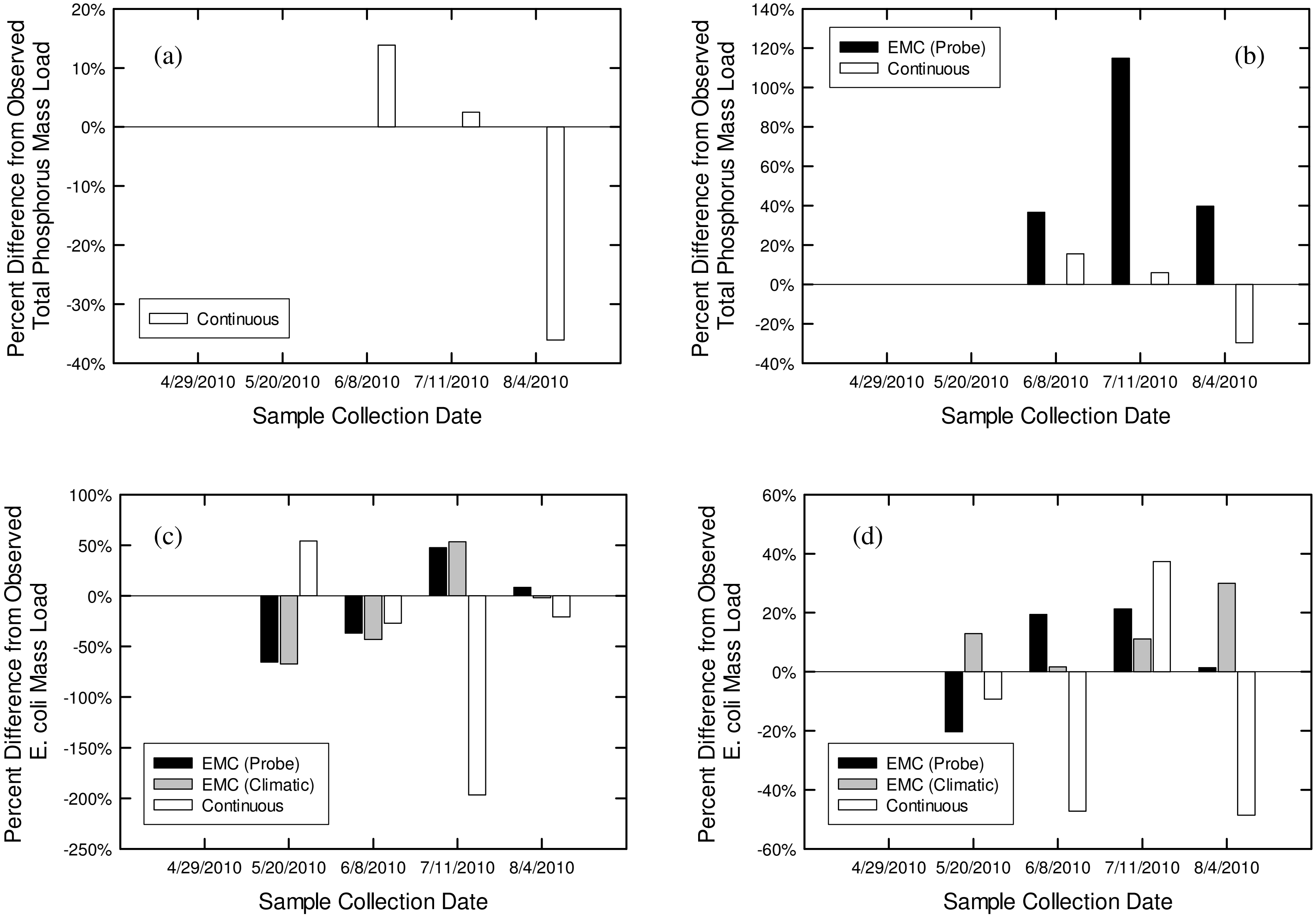

**Figure 5.8: Percent difference between mass loads calculated using measured data and mass loads estimated from the models for (a) Colonial Hills TP; (b) Taylor Park TP; (c) Colonial Hills EC; (d) Taylor Park EC**

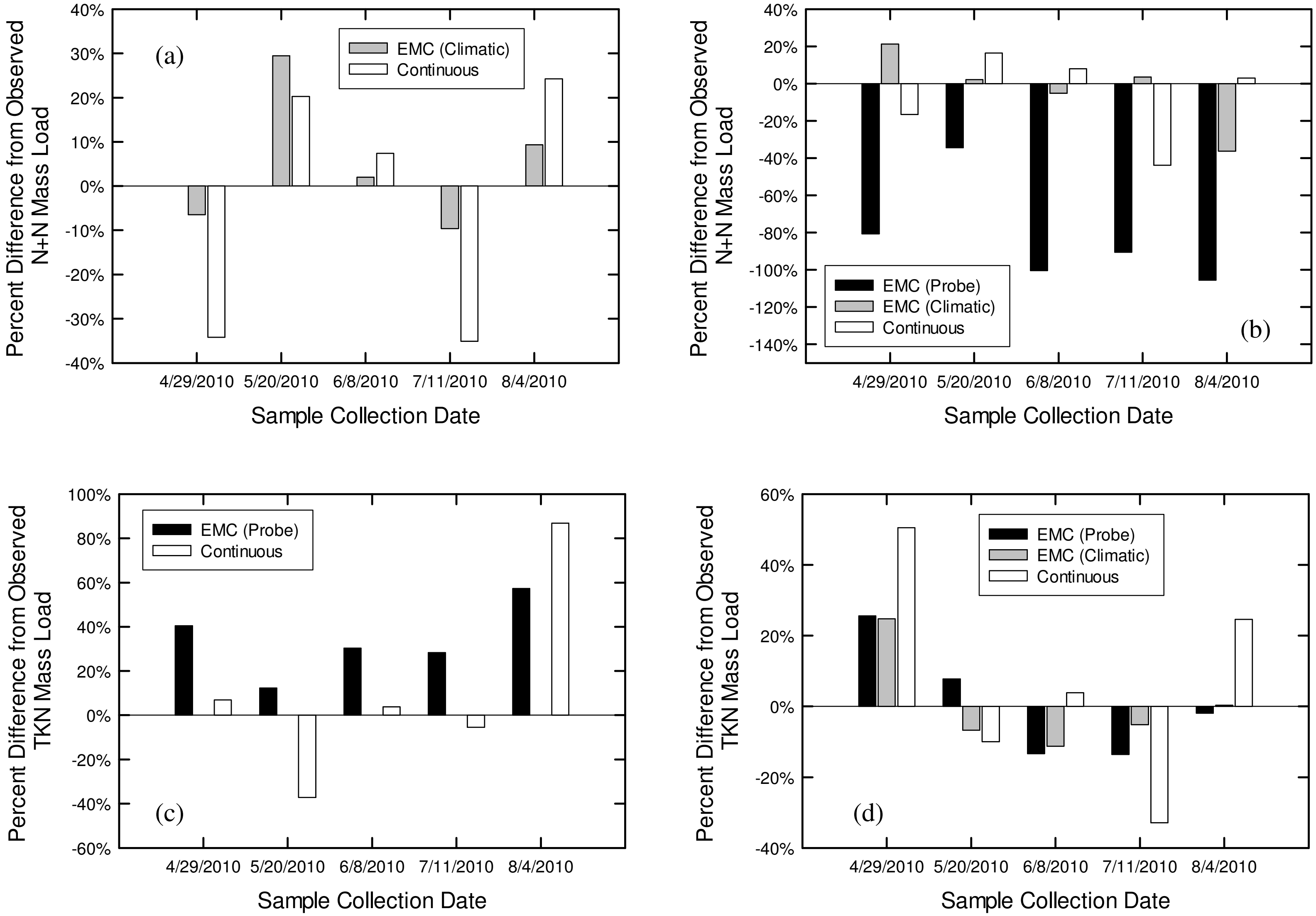

**Figure 5.9: Percent difference between mass loads calculated using measured data and mass loads estimated from the models for (a) Colonial Hills N+N; (b) Taylor Park N+N; (c) Colonial Hills TKN; (d) Taylor Park TKN**

Overall, the percent difference from the measured data, presented in the figures on the previous pages, did not reveal any important findings for the discredit of any of the models. There were no consistent trends recognized. The percent difference figures agreed with the conclusion drawn from the CMPs: generally, the EMC models are in closer agreement than with the continuous model. Again, the exception to this statement would be the TSS models, where the continuous and EMC probe models are in closer agreement. None of the models consistently "outperformed" the others; and in the same way, none of the models were consistently the highest percent difference from the measured data.

## 5.8 Storm Size Comparisons

Based on evidence from the CMPs that a majority of the 2010 seasonal pollutant mass was being produced by a few significant events during the 2010 sampling season, further investigation was needed to verify this. The mass load estimates produced by the EMC-Probe models (and EMC-Climatic models when an EMC-Probe model did not exist) were sorted to determine the top five mass loading events in 2010 for each water quality constituent for the two monitoring sites. The percentage of the total 2010 mass load contributed from the top five mass loading storms from 2010 are reported in **Table 5.18**. The purpose for this calculation was to verify that the seasonal total mass loads for some of the parameters were clearly driven by several large transporting events throughout the year.

**Table 5.18: Percent of 2010 load from top 5 mass loading storms**

| Site | TSS | SRP | TP | N+N | TKN | EC | Q |
|---|---|---|---|---|---|---|---|
| Colonial Hills | 74% | 65% | - | 45% | 47% | 64% | 44% |
| Taylor Park | 53% | 44% | 52% | 16% | 36% | 46% | 41% |

*Refer to **Table 4.1** (page 60) for water quality abbreviation definitions
*Refer to **Table 4.2** (page 61) for measurement units and analytical methods

Based on the estimates shown in **Table 5.18**, more of the mass load from all of the constituents can be attributed to the top five loading events at Colonial Hills than Taylor Park. The only parameter that was not driven by the large mass transporting events was N+N at Taylor Park. The five largest mass transporting events correlated to eight different storm events for each site, which are shown in **Table 5.19**. The largest loading events were not in agreement for each water quality parameter – that is why more than five storm dates are reported. The storm events that were only significant at one site were bolded in the table.

**Table 5.19: Dates that produced the top 5 mass loading events for the 5 water quality parameters**

| Colonial Hills | Taylor Park |
|---|---|
| 6/20/2010 | 6/20/2010 |
| 7/4/2010 | 7/4/2010 |
| 7/11/2010 | 7/11/2010 |
| 7/14/2010 | 7/14/2010 |
| 9/2/2010 | 9/2/2010 |
| **4/29/2010** | **5/20/2010** |
| **6/1/2010** | **6/13/2010** |
| **8/24/2010** | **6/22/2010** |

In order to better understand the mass load contribution of dry weather flows, **Table 5.20** was developed to indicate the percent of 2010 seasonal mass load for each modeled parameter that can be attributed to dry weather flows. Based on the estimates provided in **Table 5.20**, dry weather flows had a very minimal contribution on the overall mass loads for the majority of the water quality parameters. Two exceptions were N+N and SRP for Taylor Park. The cumulative runoff volume (Q) was included as well to determine what percentage of the total 2010 storm runoff was due to the top five runoff storm events at each site.

**Table 5.20: Percent of 2010 mass load from dry weather flows**

| Site | TSS | SRP | TP | N+N | TKN | EC | Q |
|---|---|---|---|---|---|---|---|
| Colonial Hills | 0.2% | 6% | 9% | 23% | 4% | 0.2% | 16% |
| Taylor Park | 0.4% | 28% | 11% | 73% | 17% | 3% | 30% |

*Refer to **Table 4.1** (page 60) for water quality abbreviation definitions
*Refer to **Table 4.2** (page 61) for measurement units and analytical methods

The CMP for TSS at Colonial Hills in **Figure 5.4** illustrated a very large mass load contribution due to the storm event on 4/29/2010; however, the Taylor Park TSS CMP did not indicate the same trend. In order to confirm that this difference was real, a comparison was performed between the estimated mass loads by the EMC models and the “actual mass loads.” The TSS mass loads were then normalized by the corresponding drainage area to produce the mass load yields shown in **Table 5.21**.

**Table 5.21: TSS mass load yield comparison for 4/29/2010 storm event**

| Site | "Actual" EMC Yield (kg/ha) | EMC-Probe Yield (kg/ha) | EMC-Climatic Yield (kg/ha) |
|---|---|---|---|
| Colonial Hills | 99 | 182 | 101 |
| Taylor Park | 9 | 11 | 6 |

The mass load yield comparison for TSS between the actual EMC calculated with measured data and the estimated EMCs from the two different models confirmed the differences between the two sites recognized in the CMPs. Based on the TSS mass load estimates, the Colonial Hills site produced a much higher amount of TSS mass in this early spring storm than Taylor Park per unit-area (over ten times as much). The results are suggestive that much different pollutant sources exist between the two sites. This finding provoked the need to understand if similar trends existed for smaller precipitating storm events and how storm precipitation affected pollutant concentrations in stormwater runoff in the two watersheds.

Four "large" and four "small" sampled storm events were selected for the comparison of measured water quality data. A two-fold comparison was performed with the collected stormwater data between the two monitoring sites: (1) a comparison between calculated EMCs for large and small precipitating storm events and (2) a comparison between the measured peak concentration for large and small precipitating storm events. The EMC values for the four selected large and small precipitating storm events are shown in **Table 5.22** and **Table 5.23**, respectively. **Table 5.24** and **Table 5.25** report the measured peak concentrations for the same large and small precipitating storm events. In the four tables, a comparison was made between the two monitoring sites; the site with the larger value has been highlighted for the benefit of the reader. Also, a t-test was performed at the 90% confidence level between the sites; any probabilities that indicated a significant difference, (Pr > t) < 0.10, were bolded.

**Table 5.22: Comparison between measured EMC values for 4 “large” precipitating storm events captured during the project period**

| **Colonial Hills measured EMCs** | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Date** | **P (in)** | **EC (cfu/100 ml)** | **N+N (mg/L)** | **SRP (mg/L)** | **TP (mg/L)** | **TSS (mg/L)** | **TKN (mg/L)** |
| 4/29/2010 | 1.38 | NA | 0.47 | 0.39 | NA | 583 | 0.7 |
| 7/11/2010 | 1.83 | 59,308 | 0.70 | 0.29 | 0.37 | 52 | 1.3 |
| 11/12/2010 | 1.28 | 10,379 | 0.25 | 0.30 | 0.45 | 87 | 1.3 |
| 8/12/2011 | 1.58 | 23,239 | 0.65 | 0.20 | 0.35 | 47 | NA |
| **Taylor Park measured EMCs** | | | | | | | |
| **Date** | **P (in)** | **EC (cfu/100 ml)** | **N+N (mg/L)** | **SRP (mg/L)** | **TP (mg/L)** | **TSS (mg/L)** | **TKN (mg/L)** |
| 4/29/2010 | 1.14 | NA | 0.58 | 0.33 | NA | 168 | 1.2 |
| 7/11/2010 | 1.92 | 31,780 | 0.94 | 0.24 | 0.31 | 73 | 1.2 |
| 11/12/2010 | 1.27 | 18,385 | 0.93 | 0.40 | 0.51 | 67 | 2.1 |
| 8/12/2011 | 1.35 | 61,017 | 1.22 | 0.27 | 0.41 | 40 | NA |
| **t-test (Pr > t)** | 0.16 | 0.39 | **0.03** | 0.38 | 0.32 | 0.19 | 0.15 |

*NA = value not available; P = total storm precipitation
*Refer to **Table 5.10** for water quality abbreviations and units
*Highlighted cells indicate the larger value between the two sites
*t-test: significant differences between the two sites at the 90% confidence level are bolded

## Table 5.23: Comparison between measured EMC values for 4 "small" precipitating storm events captured during the project period

| Colonial Hills measured EMCs | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Date** | **P (in)** | **EC (cfu/100 ml)** | **N+N (mg/L)** | **SRP (mg/L)** | **TP (mg/L)** | **TSS (mg/L)** | **TKN (mg/L)** |
| 10/6/2008 | 0.47 | 11,349 | 0.28 | 0.17 | NA | 59 | NA |
| 6/8/2010 | 0.66 | 60,989 | 0.38 | 0.20 | 0.30 | 70 | 1.3 |
| 5/12/2011 | 0.26 | 13,005 | 0.40 | 0.19 | 0.48 | 86 | 2.4 |
| 6/9/2011 | 0.66 | 164,511 | 0.70 | 0.16 | 0.44 | 95 | 2.4 |
| **Taylor Park measured EMCs** | | | | | | | |
| **Date** | **P (in)** | **EC (cfu/100 ml)** | **N+N (mg/L)** | **SRP (mg/L)** | **TP (mg/L)** | **TSS (mg/L)** | **TKN (mg/L)** |
| 10/6/2008 | 0.39 | 53,565 | 0.31 | 0.25 | NA | 50 | NA |
| 6/8/2010 | 0.65 | 80,299 | 0.70 | 0.27 | 0.36 | 87 | 1.8 |
| 5/12/2011 | 0.33 | 61,429 | 0.40 | 0.14 | 0.67 | 385 | 3.2 |
| 6/9/2011 | 0.46 | 73,996 | 0.98 | 0.22 | 1.73 | 1356 | 3.2 |
| **t-test (Pr > t)** | 0.20 | 0.45 | **0.07** | 0.16 | 0.16 | 0.14 | **0.01** |

*NA = value not available; P = total storm precipitation
*Refer to **Table 5.10** for water quality abbreviations and units
*Highlighted cells indicate the larger value between the two sites
*t-test: significant differences between the two sites at the 90% confidence level are bolded

## Table 5.24: Comparison between measured peak storm concentrations for 4 "large" precipitating storm events captured during the project period

| Colonial Hills measured peak storm concentration | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Date** | **P (in)** | **EC (cfu/100 ml)** | **N+N (mg/L)** | **SRP (mg/L)** | **TP (mg/L)** | **TSS (mg/L)** | **TKN (mg/L)** |
| 4/29/2010 | 1.38 | NA | 0.97 | 0.76 | NA | 1430 | 2.3 |
| 7/11/2010 | 1.83 | 78,600 | 1.22 | 0.31 | 0.47 | 181 | 2.6 |
| 11/12/2010 | 1.28 | 46,110 | 1.06 | 0.44 | 0.90 | 278 | 3.2 |
| 8/12/2011 | 1.58 | 36,000 | 0.77 | 0.29 | 0.41 | 203 | 1.0 |
| **Taylor Park measured peak storm concentration** | | | | | | | |
| **Date** | **P (in)** | **EC (cfu/100 ml)** | **N+N (mg/L)** | **SRP (mg/L)** | **TP (mg/L)** | **TSS (mg/L)** | **TKN (mg/L)** |
| 4/29/2010 | 1.14 | NA | 0.89 | 0.45 | NA | 1422 | 3.0 |
| 7/11/2010 | 1.92 | 349,050 | 1.84 | 0.59 | 0.90 | 476 | 3.3 |
| 11/12/2010 | 1.27 | 92,080 | 2.50 | 1.12 | 1.47 | 392 | 8.9 |
| 8/12/2011 | 1.35 | 188,000 | 2.15 | 0.33 | 1.01 | 1320 | 3.6 |
| **t-test (Pr > t)** | 0.16 | **0.07** | **0.05** | 0.24 | **<0.01** | 0.12 | **0.07** |

*NA = value not available; P = total storm precipitation
*Refer to **Table 5.10** for water quality abbreviations and units
*Highlighted cells indicate the larger value between the two sites
*t-test: significant differences between the two sites at the 90% confidence level are bolded

**Table 5.25: Comparison between measured peak storm concentrations for 4 “small” precipitating storm events captured during the project period**

| Colonial Hills measured peak storm concentration | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Date** | **P (in)** | **EC (cfu/100 ml)** | **N+N (mg/L)** | **SRP (mg/L)** | **TP (mg/L)** | **TSS (mg/L)** | **TKN (mg/L)** |
| 10/6/2008 | 0.47 | 48,900 | 0.67 | 0.28 | NA | 178 | NA |
| 6/8/2010 | 0.66 | 98,100 | 0.46 | 0.29 | 0.55 | 327 | 2.3 |
| 5/12/2011 | 0.26 | 25,900 | 0.55 | 0.25 | 0.62 | 151 | 2.8 |
| 6/9/2011 | 0.66 | 480,000 | 0.89 | 0.17 | 0.66 | 236 | 5.7 |

| Taylor Park measured peak storm concentration | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Date** | **P (in)** | **EC (cfu/100 ml)** | **N+N (mg/L)** | **SRP (mg/L)** | **TP (mg/L)** | **TSS (mg/L)** | **TKN (mg/L)** |
| 10/6/2008 | 0.39 | 141,400 | 0.47 | 0.38 | NA | 87 | NA |
| 6/8/2010 | 0.65 | 141,400 | 1.72 | 0.38 | 0.63 | 429 | 3.4 |
| 5/12/2011 | 0.33 | 410,600 | 1.09 | 0.24 | 1.21 | 3904 | 3.9 |
| 6/9/2011 | 0.46 | 471,000 | 1.70 | 0.35 | 5.22 | 4023 | 6.8 |
| **t-test (Pr > t)** | 0.20 | 0.12 | **0.07** | **0.05** | 0.17 | **0.09** | **<0.01** |

*NA = value not available; P = total storm precipitation
*Refer to **Table 5.10** for water quality abbreviations and units
*Highlighted cells indicate the larger value between the two sites
*t-test: significant differences between the two sites at the 90% confidence level are bolded

Comparisons were made between measured EMC values for four large and four small storms in **Table 5.22** and **Table 5.23**, respectively. The results show only one statistically significant difference existed between the two sites for the large storms (i.e., N+N) and two for the small storms (i.e., N+N and TKN). In support of the claim for TSS differences made following **Table 5.21**, larger TSS EMC values were recorded at the Colonial Hills site for three out of four of the large storm events. However, the Taylor Park site was larger in TSS EMC values for three out of four of the small precipitating storm events. N+N was consistently larger at the Taylor Park site for both small and large storm events. Different trends were noticed between the two sites for which seemed to produce larger concentrations; TSS would be an example of inconsistent trends. The different trends suggest different processes may be occurring during stormwater runoff in the two urban watersheds. No statistically significant differences existed for the total storm precipitation values between the two sites.

**Table 5.24** and **Table 5.25** provide a comparison between the measured peak concentrations for the same four large and small precipitating storm events. The trends for the peak measured concentrations were not consistent with the EMC values calculated from measured data. The peak concentration comparison for the large and small storm events indicated consistently higher values recorded at the Taylor Park site, especially for the large storms, even though the EMC values do not indicate this. This finding would be supportive of the hypothesis that the Taylor Park site produces much flashier stormwater runoff because of the concrete-lined storm sewer. Several more statistically significant differences existed, all of which suggested Taylor Park to be higher in concentration.

In order to check if there was any significance to the TSS EMC trend based on storm size, **Figure 5.10** was developed. The difference between the TSS EMCs for Colonial Hills and Taylor Park from the sampled storm events was calculated and plotted against the average total storm precipitation between the two sites. The figure below shows a slight positive trend, indicating a higher EMC value for Colonial Hills during large precipitating storm events and a lower value than Taylor Park during smaller sampled events. The regression line was statistically significant at the 95 percent confidence level (P=0.20), but produced a poor data fit ($R^2 = 0.12$). It should be noted that the 6/9/2011 storm event produced an unusually high EMC value at Taylor Park; this value was considered an outlier and was not used for this analysis. Certainly storm intensity and seasonal factors had an impact, but there is clearly a difference in EMC values based on the size of the storm.

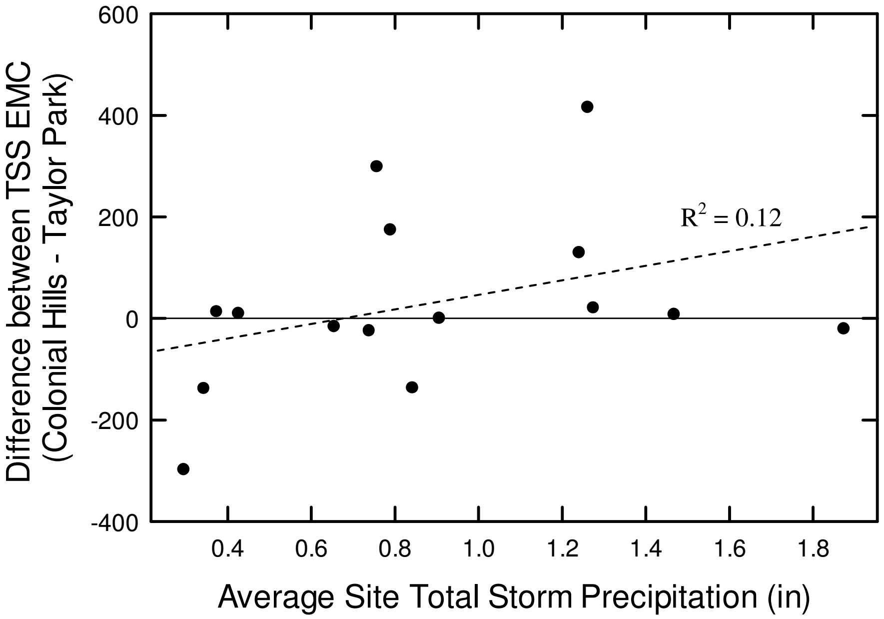

**Figure 5.10: TSS EMC site comparison by total storm precipitation**

The findings from the large vs. small storm comparison using measured EMC values and peak concentrations have suggested several claims. Different physical and chemical processes may be occurring during stormwater transport for the two urban watersheds. A potential process leading to the indicated nutrient and sediment differences may be stream bank erosion along the Colonial Hills channel and a natural attenuation occurring in small depressions within the larger Colonial Hills watershed. The stream bank erosion claim would be supported by larger TSS EMC values during more significant runoff events as shown in **Figure 5.10**. Stream bank erosion is expected to have a greater impact during large storm events, which would be more likely to occur at Colonial Hills where there is less protected stream bank. After a site inspection made by the UNL research team, several small depressions exist upstream of the Colonial Hills monitoring site; during small storm events, these may capture some overland runoff and increase the potential for infiltration and other attenuation processes to occur. These two hypothetical sources were supported by the different trends recognized in the TSS EMCs during the large and small storm events.

A rough calculation made to determine the difference in estimated TSS mass between the two sites during the 2010 sampling season was provided in **Appendix R**. The calculation indicated a difference of approximately 1.2 dump truck loads of soil (12 $m^3$) between the two sites, with Colonial Hills experiencing the higher solids mass load. It is not unreasonable to suspect that the 12 $m^3$ of soil volume difference could be solely attributed to the occurrence of stream bank erosion in the Colonial Hills watershed. This finding, if true, would be consistent with the results of Laubel et al. (2003) who found that stream bank erosion produced a very large portion of the overall seasonal TSS mass load. Further analysis should be performed on the 2009 and 2011 datasets to confirm the need for stream bank stabilization.

# Chapter 6

# Conclusions

## 6.1 Thesis Summary

Water quality monitoring using continuous in-line probe measurements and discrete water sample collection during dry weather and wet weather flows was performed for two urban watersheds in Lincoln, NE over a three year span (October 2008 through September 2011). The water quality results obtained from the storm data collection were combined with easily obtained climatic data for the development of stormwater quality estimation models. Three types of MLR estimation models were developed: (1) continuous models using continuous (mainly 90 second) in-line probe and flow data along with climatic data as explanatory variables; (2) EMC models using only climatic data as explanatory variables; and (3) EMC models using in-line probe EMCs for turbidity or conductivity along with climatic data as explanatory variables.

The stormwater models were used to estimate the seasonal mass loads for several water quality constituents during the 2010 sampling season (i.e., TSS, SRP, TP, N+N, TKN, and EC). Comparisons of the water quality models and resulting mass loading trends were made to determine if a certain modeling approach proved to be more beneficial in any way. The two watersheds that were studied were similar but not identical; thus, using the same monitoring and modeling approaches for both basins, one could identify important insights into water quality in small urban watersheds through similarities and differences. The conclusions based on the developed models and subsequent mass loadings are presented below.

### 6.1.1 Regression Model Results

1. Statistically significant continuous models were developed for six water quality constituents (i.e., TSS, SRP, TP, N+N, TKN, and EC). Every continuous model included a continuously measured in-line probe explanatory variable besides SRP at Colonial Hills, which was related to the continuous volumetric flow rate instead.
2. The continuous models developed for the larger Colonial Hills monitoring site performed better (higher $R^2$ value, lower PRESS value) than the corresponding water quality models for the smaller Taylor Park drainage basin for all but one parameter (TKN). A similar finding was reported by Phillips et al. (1999).
3. Statistically significant EMC models were developed for several water quality constituents using the two EMC MLR modeling approaches. Statistically significant regression models were unable to be obtained using both approaches for all six water quality constituents that produced continuous models (i.e., TSS, SRP, TP, N+N, TKN, and EC). The modeling discrepancy may have been due to the small sample size, which was in the range of nine to fourteen EMC values for the project period.
4. Seasonal variables, such as growing degree days (GDD), solar radiation (SR), and a sinusoidal periodic function (sin/cos), were found to significantly account for climatic dependence in several continuous and EMC water quality models. For all the water quality parameters, except TSS, at least one of the sites included a seasonal variable in the continuous models. The sinusoidal function was the most consistent seasonal explanatory variable, showing significance in five continuous models and two EMC

models. Both of the sites included a seasonal variable for their SRP and N+N model. Both the GDD and SR explanatory variables were significant in three EMC models.

5. Generally, the use of continuous in-line turbidity and conductivity measurements improved the data fit of EMC-Probe models compared to the EMC-Climatic models.
6. The model results suggest that continuous models may provide a benefit over EMC models in that important physical characteristics of a watershed have the potential to be recognized. Because stormwater runoff water quality concentrations change so rapidly in small urban watersheds, continuous models provide an increased potential to recognize rapid, in-storm changes due to site-specific characteristics. EMCs seem to average out any probable site characteristic differences and could potentially overlook large mass load contributions associated with the first flush, as suggested by Stenstrom and Kayhanian (2005).

### 6.1.2 Mass Load Yield Results

1. Based on the overall estimation of 2010 seasonal mass loading yields, it is unclear which modeling method provides the best estimate; no consistent trends were recognized. The models produced comparable, but not identical yield estimates.
2. Because several large mass loading events were shown to produce a significant amount of the total seasonal mass load (especially at Colonial Hills), much emphasis should be placed on sample collection from large runoff events in future stormwater quality experimental designs. These findings were in agreement with Rasmussen et al. (2008), who indicated that the majority of mass transfer (>90%) occurred mainly during “large” storm runoff events, which was equivalent to less than two percent of the time.

### 6.1.3 Storm Size Influences

A comparison was made between large and small precipitating storm events using measured data for the two sites. The conclusions made are listed below.

1. Differences in trends for TSS between the two sites during large and small events suggest the occurrence of different physical processes. This suggests the significant impact that stream bank erosion may be having during large storm events within the Colonial Hills watershed. A quick calculation, shown in **Appendix R**, indicated a difference of approximately 1.2 dump truck loads of soil (12 $m^3$) between the two sites, with Colonial Hills experiencing the higher solids mass load. It is possible that the 12 $m^3$ of soil volume difference could be solely attributed to the occurrence of stream bank erosion in the Colonial Hills watershed, which would be consistent with the results of Laubel et al. (2003) who found that stream bank erosion contributed to a large percentage of the overall seasonal TSS mass load.
2. Differences in trends for other water quality parameters between the two sites may suggest the occurrence of increased infiltration and natural attenuation during small storm events in the Colonial Hills drainage basin. Small storage depressions exist upstream of the monitoring site and may be capturing a portion of the runoff during small precipitating events for the improvement of the overall stormwater quality.
3. The research suggests the importance of small urban watershed management. There is a need for stream bank stabilization and larger capacity storage basins along stream channels to protect downstream water bodies and aquatic habitat from pollutant transport during large runoff events. These two management practices may improve the overall water quality in the Colonial Hills watershed.

## 6.2 Future Work

Due to a lack of time between the last storm sample collection and the deadline for thesis submittal, only a limited amount of data analysis could be performed using the entire dataset. Therefore, the majority of the analysis and conclusions were based on the 2010 monitoring season only. The dataset has the potential for important findings dealing with pollutant transport in urban stormwater runoff. With this in mind, the following recommendations are made for further study of the two urban watersheds.

1. A similar mass loading analysis should be performed for the 2009 and 2011 sampling seasons. Additional data analysis may support or discredit any conclusions made using the 2010 dataset.
2. Add the water quality measurements from the last storm collected in 2011 (October 10) to the dataset for analysis.
3. Further investigate the effect of small storage basins and stream bank erosion along the Colonial Hills stream using the collected data.
4. Compile the results for isotope analyses performed on water quality samples for nitrate and phosphate isotopes in 2010 and 2011. Use the data to potentially explain the different sources contributing to the pollutant concentrations, especially nutrients, in the two urban watersheds. The data may be used to identify physical and chemical differences in runoff transport between the two watersheds and between small and large storm events, especially those affecting the nitrogen cycle.
5. Determine the influence of connected impervious cover on the stormwater quality within the two watersheds using GIS software, as suggested by Hatt et al. (2004).

Also, further physical site characteristics may be identified by using the software to explain the results of the water quality models.

6. Because all the collected data was utilized for the model development, additional water quality data should be collected in 2012 and used to check the performance of the models.
7. If water quality monitoring continues in 2012, extensive calibration of the stream discharge should be performed for the entire range of observed stream stages.
8. Calculate the Flashiness Index for the same storm events between the two sites during the initial runoff period based on a certain percentage of the site time of concentration.
9. Determine confidence intervals for the multiple linear regression models so that uncertainty associated with each estimate could be reported. The uncertainties could then be applied to the mass load yield estimates to determine if they all fall within the confidence range.
10. Consider the sediment delivery ratio and particle size distribution for the potential identification of TSS sources.
11. Consider further implications of the rapid sampling event collected on May 24, 2011. Determine if there is a noteworthy bias due to water sampling methods.

# Chapter 7

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# Appendices

## Appendix A Glossary of Abbreviations

- AAS: Atomic Absorption Spectroscopy
- AIC: Akaike Information Criterion
- AReg: “Auto Regulatory” (an auto sample collected manually during a wet weather event for regulatory purposes)
- Autosampler: ISCO 3700 full size portable sampler
- AVFM: Area Velocity Flow Meter
- BCF: Bias Correction Factor, see Duan (1983)
- BMPs: Best Management Practices
- Bubbler: ISCO 4230 bubbler flow meter
- CDY: Conductivity
- CH: Colonial Hills
- CMP: Cumulative Mass Plot
- COD: Chemical Oxygen Demand
- COL: City of Lincoln
- CIVE: Civil Engineering (Laboratory)
- DO: Dissolved Oxygen
- EMC: Event Mean Concentration
- EMC-Climatic: EMC estimation models using only climatic explanatory variables
- EMC-Probe: EMC estimation models which used in-line probe and climatic data as explanatory variables
- EPA: Environmental Protection Agency
- E. coli: Escherichia coli
- EC: Escherichia coli
- FNU: Formazin Nephelometric Unit
- GDD: Growing Degree Days
- ha: Hectare
- HHS: Health and Human Services (State of Nebraska Laboratory)
- HPRCC: High Plains Regional Climate Center – Lincoln, NE
- kg: kilogram
- L: Liter
- LAS: Linear Alkylate Sulfonate
- MDL: Method Detection Limit
- mg: Milligram
- MLR: Multiple Linear Regression
- n: sample size
- N+N: nitrate plus nitrite nitrogen

- NDEQ: Nebraska Department of Environmental Quality
- N-HEM: Normal-Hexane Extractable Material
- $NH_3$: Ammonia
- $NO_2$: Nitrite
- $NO_3$: Nitrate
- NTU: Nephelometric Turbidity Units
- NURP: Nationwide Urban Runoff Program
- P: Total Storm Precipitation
- PRESS: Prediction Error Sum of Squares
- Q: Volumetric Flow Rate
- QA/QC: Quality Assurance/Quality Control
- RMSE: Root-Mean-Squared Error
- $R^2$: Coefficient of Determination
- SR: Solar Radiation
- SRP: Soluble Reactive Phosphorus
- SSC: Suspended Sediment Concentration
- TBY: Turbidity
- TKN: Total Kjeldahl Nitrogen
- TMDL: Total Maximum Daily Load
- TP: Taylor Phosphorus
- TSS: Total Suspended Solids
- UNL: University of Nebraska – Lincoln
- USGS: United States Geological Survey
- WSL: Water Sciences Laboratory, located on east campus of UNL
- WT: Water Temperature

# Appendix B Stream Discharge Determination

Different procedures were used for the ultimate determination of the stream discharge for both monitoring sites. This appendix describes the methods that were used to develop a relationship between the ISCO Bubbler stream gage height (GH) measurements and the stream discharge (Q).

## B.1 Colonial Hills

The Colonial Hills monitoring site was surveyed in the summer of 2010 to develop more accurate cross section profiles of the stream. The surveyed data for the cross section at the bridge was used to develop a new level to area relationship for the site. The surveyed bridge cross section can be seen in **Figure B.1**. Based on the surveyed cross section, a stream stage-area relationship was established and can be found in **Table B.1**. The stage-area relationship (provided in **Table B.1**) was programmed into the AVFM to calculate the discharge using the measured stream level and velocity.

The datum used for the AVFM was not the same as that of the Bubbler. Consulting the recorded measurements for the date and time (6/29/2010 11:45 am) the survey was conducted corresponded to a Bubbler and AVFM gage height reading of 0.68 ft and 0.54 ft, respectively. Based on the surveyed elevations, the base depth for that day was 994.56’ – 992.86’ = **1.70 ft.** The AVFM datum was calculated by adding the measured offset distance from the bed to the sensor of 0.45’ to the bed elevation (992.86’ + 0.45’ = **993.31’**).

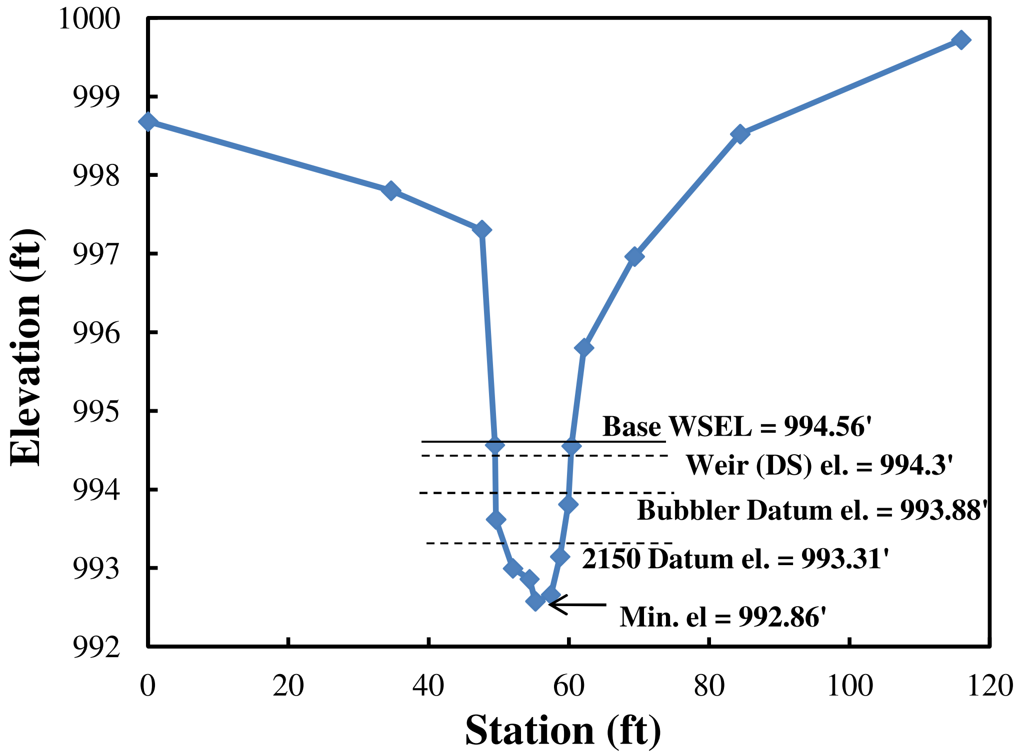


**Figure B.1: Colonial Hills surveyed cross section with important elevations**

**Table B.1: Stage-area relationship for the Colonial Hills channel**

| Stream Level (ft) | Discharge Area ($ft^2$) |
|---|---|
| 0 | 0 |
| 0.3 | 0.75 |
| 0.5 | 1.92 |
| 1.0 | 6.06 |
| 1.5 | 11.2 |
| 2.0 | 16.7 |
| 2.5 | 22.3 |
| 3.0 | 28.65 |
| 3.5 | 35.7 |
| 4.0 | 44.1 |
| 4.5 | 54.2 |
| 5.0 | 68.7 |
| 5.5 | 90.6 |

Over the span of three years (2008-2010), the USGS took flow measurements during different discharge stages in effort to calibrate the stage-discharge relationship for the Colonial Hills monitoring site. The results comparing the calibrated measurements with the 2010 (April – September) AVFM measurements can be found in **Figure B.2**. In order to perform the comparison, the gage heights for the USGS measurement points needed to be adjusted to the same datum as the AVFM. Because the gage heights were recorded by the Bubbler, they were corrected by **0.57 ft** based on the difference between the Bubbler and AVFM datums from **Figure B.1** (993.88' – 993.31' = **0.57'**).

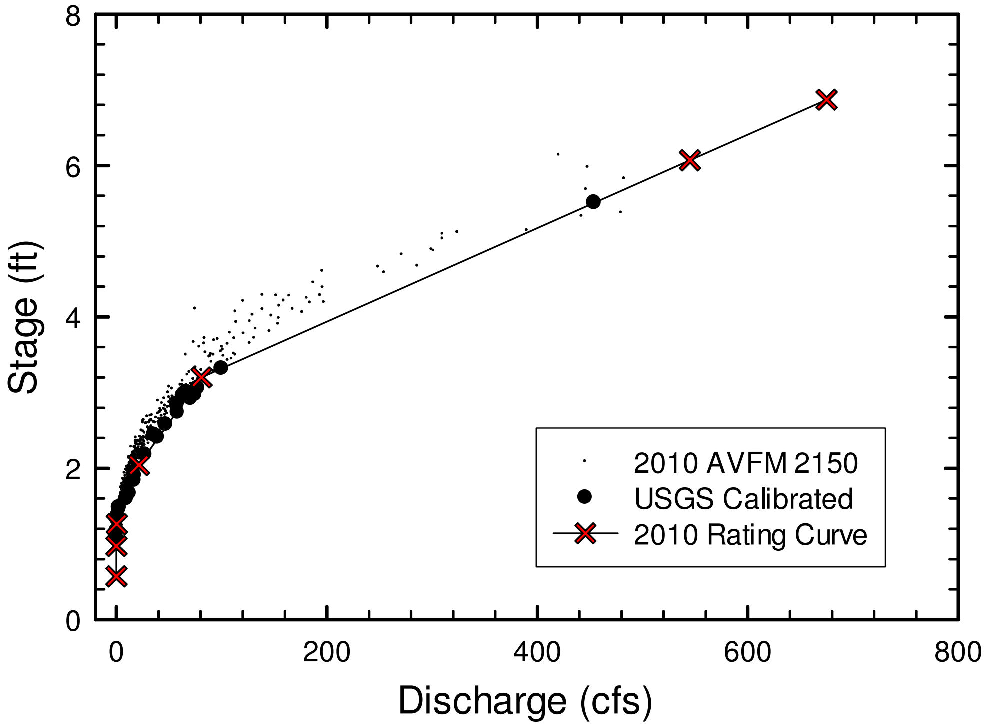


**Figure B.2: Colonial Hills flow calibration comparison**

The comparison made in **Figure B.2** was enough evidence to justify the use of the calibration points as the source data for the development of a stage-discharge rating curve for the Colonial Hills site. The data points used to produce the "2010 Rating Curve" illustrated in **Figure B.2** are provided in **Table B.2** and were utilized for the stream discharge estimation for the entire thesis. Because of the known elevation of the downstream weir at Colonial Hills park (from **Figure B.1**), the discharge was assumed to be zero below this stage (0.4’).

**Table B.2: Colonial Hills stage-discharge relationship**

| Stage (ft) | Discharge (cfs) |
|---|---|
| 0 | 0 |
| 0.4 | 0 |
| 0.69 | 0.26 |
| 1.47 | 21.29 |
| 2.63 | 80.75 |
| 5.5 | 545 |
| 6.3 | 675 |

## B.2 Taylor Park

The Taylor Park monitoring site had a much different discharge estimation approach. Because the AVFM was installed in the storm sewer upstream of the gage station, a pre-defined flow conversion for an elliptical channel was able to be utilized. The dimensions used for the channel conversion were a height of 4.1’ and a width of 6.4’. Using this conversion, the channel discharge could be calculated by the AVFM using the measured stream level and velocity.

In order to develop a stage-discharge relationship for the Taylor Park site using the AVFM discharge measurements, a time lag had to be determined for the travel between the AVFM equipment in the storm sewer to the downstream Bubbler equipment. This was accomplished through a series of time travel tests using rhodamine WT tracer dye with a USGS-owned rhodamine in-line probe. During a storm event on May 20, 2011, UNL and the USGS determined the time lag between the two equipment sets for different AVFM stages. The results of the experiment were used to produce regression line found in **Figure B.3**. The time lag regression line was used for the adjustment of all the AVFM discharge measurements prior to the weir installation in 2010 and all of those following the weir installation.

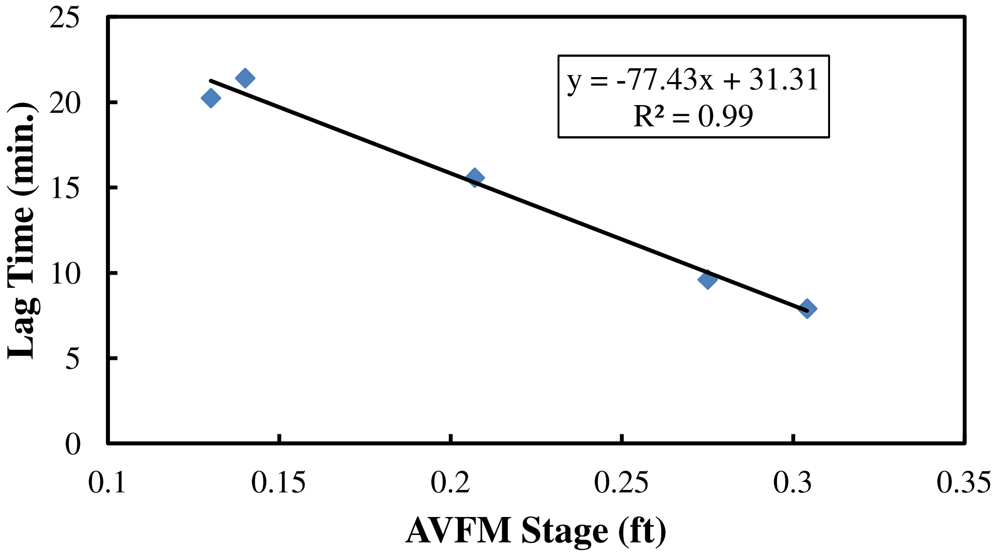


**Figure B.3: Time lag based on rhodamine tracer dye experiment**

The time-adjusted discharge was then matched to the nearest time recorded gage height for the Bubbler; the matched gage height and discharge values were then used for the development of the Taylor Park stage-discharge rating curve, shown in **Figure B.4**. Because the installation of the weir introduced a completely new baseflow level, separate rating curves needed to be developed. The stage-discharge relationships for Taylor Park prior to and after the weir installation on July 6, 2010 can be found in **Table B.3**. Discharge was assumed to be zero below the new baseflow elevation determined by the weir.

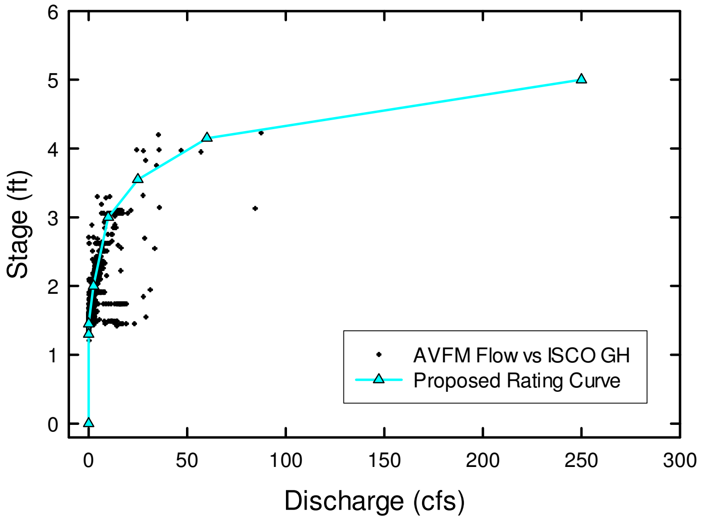


**Figure B.4: Stage-discharge curve development for Taylor Park**

**Table B.3: Taylor Park stage-discharge relationship prior to (left) and after (right) the weir installation on July 6, 2010**

| Prior to 7/6/2010 | | After 7/6/2010 | |
|---|---|---|---|
| **Stage (ft)** | **Discharge (cfs)** | **Stage (ft)** | **Discharge (cfs)** |
| 0 | 0 | 0 | 0 |
| 0.55 | 0 | 1.3 | 0 |
| 1.45 | 0.1 | 1.45 | 0.08 |
| 2 | 2.5 | 2 | 2.5 |
| 3 | 10 | 3 | 10 |
| 3.55 | 25 | 3.55 | 25 |
| 4.15 | 60 | 4.15 | 60 |
| 5 | 250 | 5 | 250 |

# Appendix C Wet Weather Sampling Algorithm

1. **If Bottles Sampled** $< 5$:

   ⇒ Throw away samples, and sample a different storm event

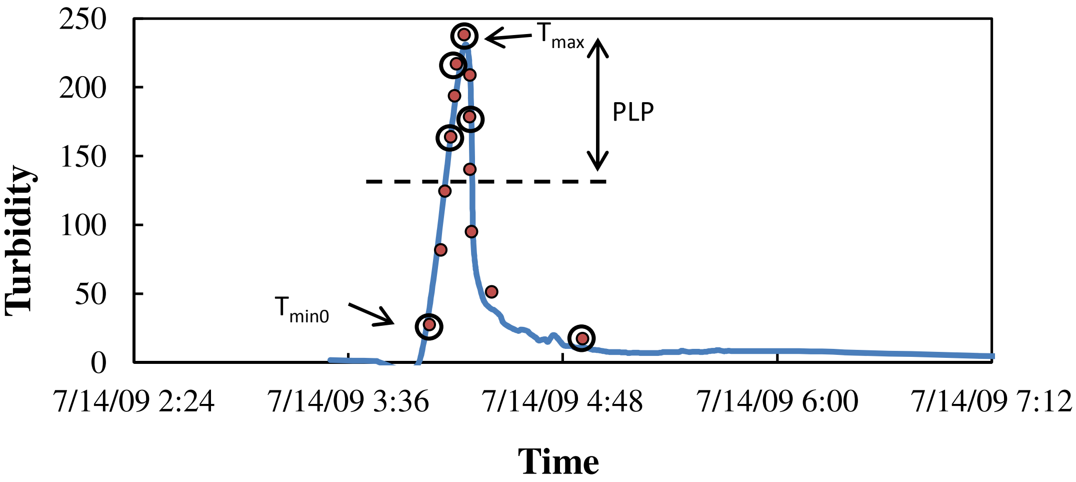
2. **5** $\leq$ **Bottles Sampled** $\leq$ **7**

   ⇒ Have all the bottles tested

3. **8** $\leq$ **Bottles Sampled** $\leq$ **24**

   ⇒ Return to the Civil Engineering labs immediately and perform a turbidity test on all the samples collected and develop a turbidity storm hydrograph

   a) If the turbidity storm hydrograph has **one** peak:



**This graph is an example of a one-peak hydrograph. The circled samples indicate those that should be kept to have analysis performed on them*

1) Determine $T_{max}$ & $T_{min0}$
2) Determine the Peak Loading Period (PLP)

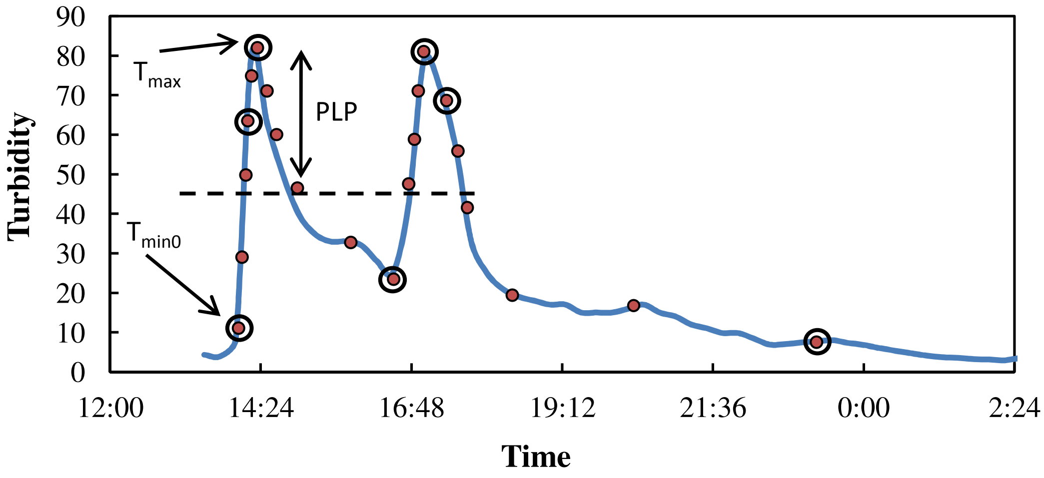
$$\text{PLP} = \frac{T_{max} - T_{min0}}{2}$$

3) Collect **4 samples** from the PLP, 1 of which is the peak
4) Collect **1 sample** from a time previous to the PLP, near the beginning of the storm (typically the 2nd autosample collected)

5) Collect **1 sample** from a time following the PLP, on the decline of the hydrograph (typically the last autosample collected)

6) A **total of 6 samples** will be analyzed for a storm similar to this

b) If the turbidity storm hydrograph has two peaks:



**This graph is an example of a two-peak hydrograph. The circled samples indicate those that should be kept to have analysis performed on them*

1) Determine $T_{max}$ & $T_{min0}$

2) Determine Peak Loading Period (PLP)

$$\mathrm{PLP} = \frac{\mathrm{T_{max}} - \mathrm{T_{min0}}}{2}$$

3) Collect **4 samples** from the PLP:
    1. -1 from each peak
    2. -1 on the incline of the first peak
    3. -1 on the decline of the second peak

4) Collect the sample **(1)** from the minimum Turbidity between the 2 peaks

5) Collect **1 sample** from a time previous to the PLP, near the beginning of the storm (typically the 2nd autosample collected)

6) Collect **1 sample** from a time following the PLP, on the decline of the hydrograph (typically the last autosample collected)

7) A **total of 7 samples** will be analyzed for a storm similar to this

# Appendix D Weather Station Selection

The High Plains Regional Climate Center (HPRCC) database was accessed for continuous climatic data. Three weather stations were found within close proximity of the monitoring sites, as shown in **Figure D.1.** To determine the best assumed rainfall characteristics for the two monitoring sites, a regression of the unit runoff (inches) recorded for each sampled storm event and the total storm precipitation (inches) for the corresponding storm events was performed. It was assumed that the data should theoretically produce a perfect linear relationship ($R^2 = 1$). When it was determined that precipitation data from only a single weather station was not a powerful enough fit to the data using the $R^2$ value, an averaging of two or more of the weather station datasets was considered.

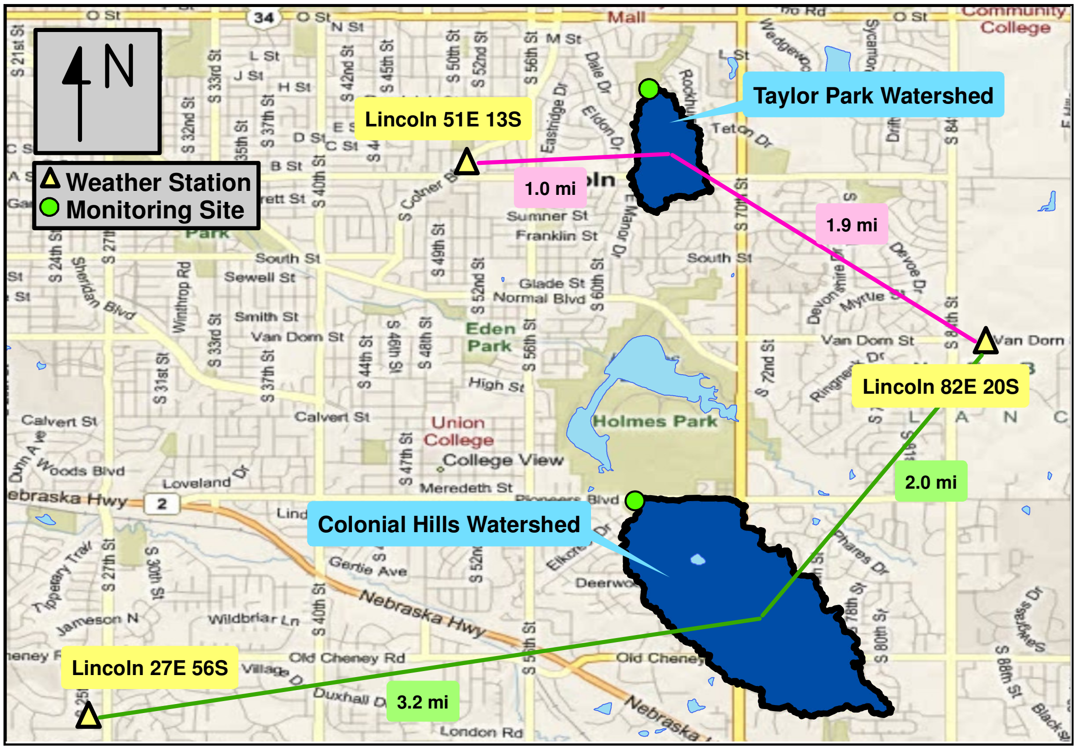


**Figure D.1: Weather station relative locations to the monitoring sites**

Precipitation values were averaged using the Shepard's Method; this was a weighted average of the weather station precipitation values based on the distance from the monitoring site. The best regression fit for the Colonial Hills unit area storm runoff was produced  from a weighted average of the precipitation values from weather stations Lincoln 51E 13S and Lincoln 82E 20S, while Taylor Park involved Lincoln 82E 20S along with Lincoln 27E 56S. The weighted average equation for the Colonial Hills site is

$$P_{CH} = \frac{2.6 * P_{82} + 1.625 * P_{27}}{4.225}$$

where $P_{CH}$ is the weighted average precipitation value used for the Colonial Hills climatic dataset; $P_{82}$ is the precipitation recording from the Lincoln 82E 20S weather station; and $P_{27}$ is the precipitation recording from the Lincoln 27E 56S weather station. The regression between the weighted average total precipitation value for all the sampled storm events and the corresponding unit area runoff can be found in **Figure D.2**. The weighted average equation for the Taylor Park site is

$$P_{TP} = \frac{2.9 * P_{51} + 1.526 * P_{82}}{4.426}$$

where $P_{TP}$ is the weighted average precipitation value used for the Taylor Park climatic dataset; $P_{82}$ is the precipitation recording from the Lincoln 82E 20S weather station; and $P_{51}$ is the precipitation recording from the Lincoln 51E 13S weather station. The regression between the Taylor Park weighted average total precipitation value for all the sampled storm events and the corresponding unit area runoff can be found in **Figure D.3**.

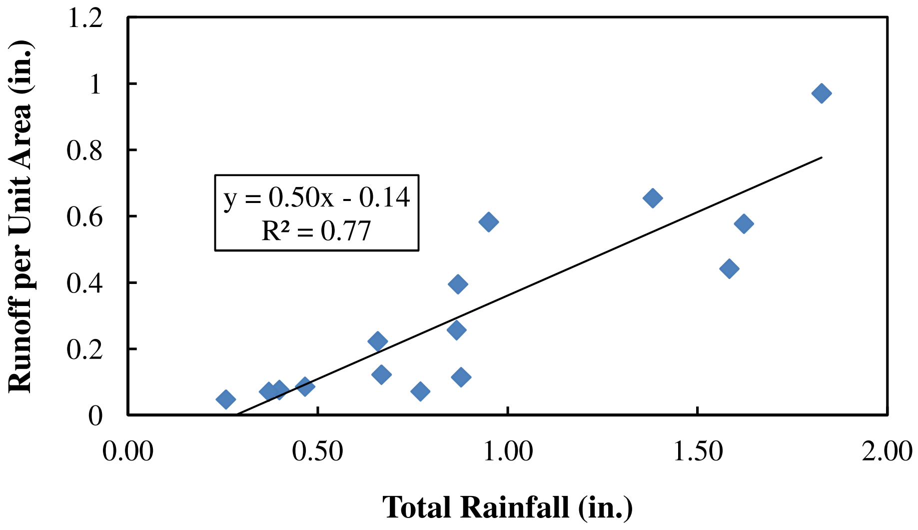


**Figure D.2: Regression of unit runoff per weighted-average storm precipitation at Colonial Hills**

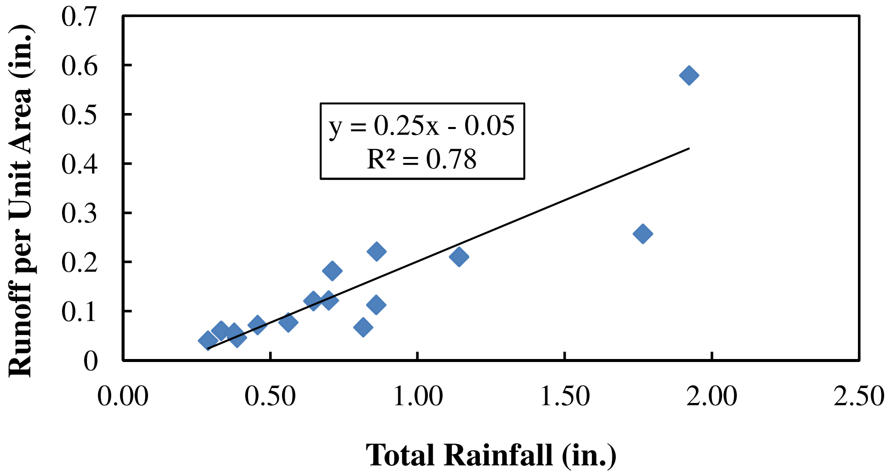


**Figure D.3: Regression of unit runoff per averaged storm precipitation at Taylor weighted-average Park**

# Appendix E Rapid Sampling Standard Operating Procedure

The purpose of this sampling is to gather data to better characterize the first flush of a storm which will allow for more precise correlations to be developed between the semi-continuous probe and flow data and the discretely measured water quality parameters. To achieve this, both auto and grab samples will simultaneously be collected at frequent intervals for two hours throughout the duration of a storm event. The large number of samples will provide not only strong statistical power but will also provide insight into the first flush of a storm event.

## Preview

### *24 Hours Prior to Storm Event*

1) Reserve 2 cars (1 for each sampling team) from UNL Transportation Services.

### *Prior to Storm Event*

2) Check the auto sampler to make sure it is full of empty bottles.

3) Program the auto sampler to collect samples every 3 minutes.
    a. Turn on the autosampler
    b. Press the “Enter/Program” button on bottom right
    c. Select “Time Paced Sampling”
    d. Sample every: 3 minutes
    e. Multiplex Samples? – No
    f. Sample Volumes of: 975 mL
    g. Enter Start Time? – No
    h. Select “Enter” and the program should now be on standby

4) Connect the laptop to the ISCO Bubbler
    a. Synchronize the Bubbler clock to the laptop time
    b. Under the *Sampler Control* tab, change *Sampler enable* to “Always”

5) Connect the laptop to the ISCO AVF meter
    a. Synchronize the Flow Meter clock to the laptop time
    b. Under the *Data Storage* tab, highlight *Level* and select “Set Up Data Storage”
    c. Primary Rate = 5 minutes, Secondary Rate = 30 seconds, check level every 15 seconds. Trigger depths = **0.2 ft** at TP & **1.5 ft** @ at CH
    d. Repeat these data storage changes for *Velocity* & *Flow Rate*

*Day of Storm*

6) Before going to the sites, check each sampling kit to make sure everything needed is packed and ready to go. For a rapid sampling event, **Table E.1** on the following page provides the required items. Steps 7-8 provide additional instruction on sample kit preparation.

**Table E.1. Required items for a Rapid Sampling Event**

| Item Name | Quantity Needed | Purpose | Location |
|---|---|---|---|
| Site Keys | 1 per Site | Access to gage station | Jake’s office |
| Black Binder | 1 per Site | Record Data, SOP's, Forms | Lab Counter |
| Coolers | 2 per Site | Mobility | Lab |
| Cold packs | Several per Cooler | Maintain Cool Temperatures for Sample Transport | Freezer in Oven Room |
| Gray Box Clipboard | 1 Per Site | Maintain Organization / Keep Forms Dry | Lab |
| 1 L Bottles (Grab) | 20 per Site | Run Lab Tests (Conductivity, Total Phosphorus, Turbidity, TSS, E. Coli) | Lab |
| 1 L Auto Sample Bottles | 41 per Site | Collect Auto Samples | Lab/Field |
| 250mL Bottles (SSC) | 10 per Site | SSC Testing | Lab |
| Auto Sampler Tray | 1 per Site | Hold Auto Sampler Bottles | Lab |
| Trash bags | 2 per site | To cover sampler bottles | Lab |
| 2 L Bottles | Varies – check with Jesse | Isotope Testing | Below sink in lab |
| Telescopic Sampling Pole | 2 per Site | Ease of Sample Collection | Lab |
| Labeling Tape | 1 per Site | Ensure Organization | Lab Counter |
| Pen/Sharpie | 1 per Site | Recording/Labeling | Lab Counter |
| RAIN COATS!<br>(or swimsuit) | Enough for Everyone | Stay dry! | Lab |
| Letter from City of Lincoln | 1 per Site | Authority | Black Binder |

7) Each team will need to pack a sampling kit. For safety, it is necessary that there be at least two people in each team (3 people per site is preferred).
    a) Label all bottles before going in the field using the labeling tape. Samples should be labeled according to the sampling site and how they were collected (auto or grab).
    (Ex: TP-G5. Be sure to note the date of sampling on the data collection sheet.)

    b) Have extra autosampler trays covered with a trash bag or other material to prevent rain water from filling the empty bottles and biasing the results.

8) Before visiting the site make sure you have your student ID, cell phone, City of Lincoln Letter, and **site keys** with you.

## On-Site Procedure

### *Collection of Samples*

9) The two teams will need to coordinate when to begin sampling. It is desired that both teams begin sampling at the same time so comparisons can be made between the two sites.

10) When the time for sampling comes, press "Start Sampling" on the auto sampler to begin collection. The first auto sample collected will be discarded so a grab sample will not be necessary. Grab samples will begin at minute 3 and SSC samples at minute 3. The Sampling Plan attached provides a general guideline for the sampling schedule. The gray boxes indicate that a sample is not required. **However, the sampling pacing is being left up to the discretion of the sampling team.** It is preferred that samples are collected every **6 minutes prior to the first flush**. At the sign of increasing water level (**greater than 1.5' at TP and 0.75' at CH**) corresponding to the first flush, grab samples will be collected **every 3 minutes**. As a general guideline, **10 samples** should be collected 3 minutes apart. After the 10, 3 minute samples have been collected, grab samples should now be taken at 9 minute intervals until all the bottles are used.

11) Using the sampling pole, collect a sample and **pour it directly** into the previously labeled 1 L grab sample bottle (e.g., TP-G1). Prior to the next sample, perform a quick rinse of the sampling bottle using the stream water.

    When an SSC sample is required, use the sampling pole with the 250 ml bottle attachment. The sample should be capped immediately and transferred to the cooler. A new 250 ml bottle should be attached in preparation for the next sample.

12) Prior to and during the first flush, grab samples will be collected every 3 minutes and SSC samples every 6 minutes beginning at minute 3. After the storm flow

has subsided, even though the auto sampler will continue collecting every 3 minutes, only collect a grab sample every 9 minutes and SSC samples every 18. Continue this process until all grab bottles are filled or until the stream level returns to normal depth (approx. **0.65' at CH** and **1.46' at TP**). In the end (if all bottles are filled) you will have 10 SSC samples, 20 grab samples, and 41 auto samples. The Sampling Plan table at the end of this document provides the anticipated sample frequency throughout the two hour event.

13) Be sure to keep track of how many auto samples the auto sampler has taken to ensure that empty bottles are available for samples. **Once 24 samples have been collected (after 69 minutes) the auto sampler tray will be full and will need to be replaced with a new tray of empty bottles.** At this point, the sampler program will halt; therefore, it is necessary to **record the sampler time of the 24th sample** so the next sample can be collected 3 minutes later. Replace the full tray with the empty tray, reprogram the sampler, and then begin sampling when 3 minutes has passed since the previous sample. Next, use the breaks to cap off the full bottles being sure the tray is covered while the samples are uncapped.

**Note:** Be sure to record when (ISCO Bubbler time) the first sample is taken. Also, since all the bottles are labeled in the lab, be sure to fill the correct bottle at the appropriate time.

**Note:** Although it is recommended that a two hour storm event be sampled it is acceptable to sample a storm of shorter duration. If the storm does not last the full two hours, check to make sure that there is at least 0.20" of precipitation, and continue to sample until the stream is flowing at its normal depth (approx. **0.65' at CH** and **1.46' at TP**).

14) Once sampling is complete, turn off the auto sampler, close and lock the gauging station, and return to the lab. Make sure that all the grab samples are in the coolers on ice and that all items taken to the test sites are returned to the lab.

## Testing and Sample Storage

15) Upon returning to the lab **Table E.2** should be followed as a guide for the order of importance of lab test to be performed.

    a. If there are 4 technicians it is recommended that 2 technicians immediately begin working on turbidity while the other 2 technicians perform the dilutions for the E. coli tests (1/10,000 dilution likely).
    b. Samples prepared for turbidity can then be used for conductivity analysis.
    c. When turbidity and conductivity tests are complete, technicians should focus on the total phosphorus test. Be sure to consider diluting the samples prior to analysis, especially the Taylor Park samples.

16) Only the autosamples that have a corresponding grab sample collected at the same time will be analyzed. The rest can be overlooked for the purpose of testing.

17) Turbidity, conductivity, and TSS tests will be run on all the grab samples (20 per site) and corresponding autosamples (20 per site).

18) For total phosphorus and E. coli analysis, Dr. Dvorak and Jake should be consulted as to which ones will be selected for testing.

**Table E.2.** Rapid Sampling Lab Testing Order of Importance

| **Level of Importance** | **Water Quality Parameter** | **Hold Time** | **# of Samples Tested** | **Approx. Time to Perform** |
|---|---|---|---|---|
| 1 | Turbidity | 8 hrs | 80 | 3 hrs |
| 2 | Total Phosphorus | 24 hrs | 40 | 3 hrs |
| 3 | Conductivity | 24 hrs | 80 | 3 hrs |
| 4 | E. Coli | 30 hrs | 40 | 7 hrs |
| 5 | TSS | 7 days | 80 | 5.5 hrs |
| 6 | SSC | 7 days | 20 | 1.5 |

19) For TSS testing, it is recommended that multiple filtering stations be set up to speed up the process, based on the number of lab technicians available.

20) While in the lab the auto and grab samples should be kept in the refrigerator at all times unless they are in use.

21) Once all tests have been performed the bottles should be thoroughly washed for future use.

| | **Time (min)** | **Autosampler** | **Grab (1 L)** | **SSC (250 ml)** | |
|---|---|---|---|---|---|
| **Beginning of Rainfall →** | **0** | 1 | | | **Start Time:** |
| | **3** | 2 | 1 | 1 | |
| | **6** | 3 | | | |
| | **9** | 4 | 2 | 2 | |
| | **12** | 5 | | | **Sampling Location:** |
| | **15** | 6 | 3 | 3 | |
| **First Flush begins →** | **18** | 7 | 4 | | |
| | **21** | 8 | 5 | 4 | |
| | **24** | 9 | 6 | | **Sampling Crew:** |
| | **27** | 10 | 7 | 5 | |
| | **30** | 11 | 8 | | |
| | **33** | 12 | 9 | | |
| **Grab samples:** | **36** | 13 | 10 | | **SSC samples:** |
| Every 6 minutes | **39** | 14 | 11 | | Every 6 minutes |
| initially; | **42** | 15 | 12 | 6 | for first 5 samples; |
| Every 3 minutes | **45** | 16 | | | then every 18 min. |
| during first flush - | **48** | 17 | | | starting with last |
| collect 10 samples; | **51** | 18 | 13 | | of the 10 grab |
| after the 10 samples | **54** | 19 | | | samples during |
| collect at every 9 min. | **57** | 20 | | | first flush |
| | **60** | 21 | 14 | 7 | |
| | **63** | 22 | | | |
| | **66** | 23 | | | |
| **Change out bottles →** | **69** | 24 | 15 | | |
| | **72** | 25 | | | |
| | **75** | 26 | | | |
| | **78** | 27 | 16 | 8 | |
| | **81** | 28 | | | |
| | **84** | 29 | | | |
| | **87** | 30 | 17 | | |
| | **90** | 31 | | | |
| | **93** | 32 | | | |
| | **96** | 33 | 18 | 9 | |
| | **99** | 34 | | | |
| | **102** | 35 | | | |
| | **105** | 36 | 19 | | |
| | **108** | 37 | | | |

* Gray boxes indicate times at which no sample is collected

# Appendix F E. coli Laboratory Comparison

The results from the two different laboratories, found in **Table F.1** and **Table F.2**, were compared using a matched pair t-test. The t-test indicated there was a statistical difference ($p < 0.01$) between the two labs at the 95% confidence level, indicating a slightly low bias toward the CIVE laboratory results. Although the two result datasets differed statistically, the UNL team determined the results produced by the CIVE technicians to be very comparable, taking the known difficulty for achieving reproducible bacteria counts into consideration. A strong argument was made by noticing that the results from the two labs very rarely differed in magnitude.

**Table F.1: E. coli 2010 results comparison between CIVE and HHS labs**

| Sample Event | Site | Date | Sample Type | E. Coli CIVE LAB (cfu/100 ml) | E. Coli HHS LAB (cfu/100 ml) |
|---|---|---|---|---|---|
| DW | Taylor Park | 5/25/2010 | Grab | 1.12E+03 | 1.45E+03 |
| DW | Colonial Hills | 5/25/2010 | Grab | 4.88E+02 | 4.70E+02 |
| WW | Taylor Park | 6/8/2010 | A1 | 7.50E+02 | 2.10E+03 |
| WW | Taylor Park | 6/8/2010 | A2 | 9.70E+03 | 2.91E+04 |
| WW | Taylor Park | 6/8/2010 | A3 | 1.69E+04 | 4.89E+04 |
| WW | Taylor Park | 6/8/2010 | A4 | 2.95E+04 | 4.36E+04 |
| WW | Taylor Park | 6/8/2010 | A5 | 2.85E+04 | 9.81E+04 |
| WW | Taylor Park | 6/8/2010 | A6 | 4.52E+04 | 1.41E+05 |
| WW | Taylor Park | 6/8/2010 | A7 | 2.72E+04 | 6.49E+04 |
| WW | Taylor Park | 6/8/2010 | Grab | 1.05E+04 | 2.42E+04 |
| WW | Colonial Hills | 6/8/2010 | A1 | 2.49E+04 | 4.36E+04 |
| WW | Colonial Hills | 6/8/2010 | A2 | 3.41E+04 | 5.18E+04 |
| WW | Colonial Hills | 6/8/2010 | A3 | 3.41E+04 | 8.67E+04 |
| WW | Colonial Hills | 6/8/2010 | A4 | 4.55E+04 | 4.11E+04 |
| WW | Colonial Hills | 6/8/2010 | A5 | 4.10E+04 | 3.88E+04 |
| WW | Colonial Hills | 6/8/2010 | A6 | 4.57E+04 | 4.62E+04 |
| WW | Colonial Hills | 6/8/2010 | A7 | 5.12E+04 | 9.81E+04 |
| WW | Colonial Hills | 6/8/2010 | Grab | 2.49E+04 | 4.89E+04 |
| WW | Taylor Park | 6/2/2010 | Grab | 6.49E+04 | 6.14E+04 |
| WW | Colonial Hills | 6/2/2010 | Grab | 1.20E+06 | 1.99E+06 |
| WW | Taylor Park | 11/11/2010 | A2 | 4.54E+04 | 3.45E+04 |
| WW | Taylor Park | 11/12/2010 | A3 | 1.25E+04 | 2.15E+04 |
| WW | Taylor Park | 11/12/2010 | A4 | 9.21E+04 | 6.87E+04 |
| WW | Taylor Park | 11/12/2010 | A5 | 1.53E+04 | 9.10E+03 |
| WW | Taylor Park | 11/12/2010 | A6 | 1.50E+04 | 1.02E+04 |
| WW | Colonial Hills | 11/12/2010 | A2 | 4.61E+04 | 3.26E+04 |
| WW | Colonial Hills | 11/12/2010 | A3 | 2.49E+04 | 3.45E+04 |
| WW | Colonial Hills | 11/12/2010 | A4 | 2.72E+04 | 2.29E+04 |
| WW | Colonial Hills | 11/12/2010 | A5 | 9.87E+03 | 9.10E+03 |

*DW = dry weather; WW = wet weather

Table F.2: E. coli 2011 results comparison between CIVE and HHS labs

| Sample Event | Site | Date | Sample Type | E. Coli CIVE LAB (cfu/100 ml) | E. Coli HHS LAB (cfu/100 ml) |
|---|---|---|---|---|---|
| WW | Taylor Park | 5/12/2011 | A1 | 4.11E+05 | 4.39E+05 |
| WW | Taylor Park | 5/12/2011 | A2 | 1.39E+04 | 1.30E+05 |
| WW | Taylor Park | 5/12/2011 | A3 | 6.57E+04 | 7.71E+04 |
| WW | Taylor Park | 5/12/2011 | A4 | 7.38E+04 | 1.30E+04 |
| WW | Taylor Park | 5/12/2011 | A5 | 7.94E+04 | 7.20E+04 |
| WW | Colonial Hills | 5/12/2011 | A2 | 8.50E+03 | 8.00E+03 |
| WW | Colonial Hills | 5/12/2011 | A3 | 2.59E+04 | 1.85E+04 |
| WW | Colonial Hills | 5/12/2011 | A4 | 1.38E+04 | 2.36E+04 |
| WW | Colonial Hills | 5/12/2011 | A5 | 1.20E+04 | 2.30E+04 |
| WW | Taylor Park | 6/9/2011 | A1 | 4.50E+05 | 1.08E+06 |
| WW | Taylor Park | 6/9/2011 | A2 | 7.40E+04 | 8.60E+05 |
| WW | Taylor Park | 6/9/2011 | A3 | 5.35E+04 | 1.10E+05 |
| WW | Taylor Park | 6/9/2011 | A7 | 1.51E+05 | 3.80E+05 |
| WW | Colonial Hills | 6/9/2011 | A1 | 3.51E+05 | 5.80E+05 |
| WW | Colonial Hills | 6/9/2011 | A2 | 4.80E+05 | 6.20E+05 |
| WW | Colonial Hills | 6/9/2011 | A3 | 2.36E+05 | 4.10E+05 |
| WW | Colonial Hills | 6/9/2011 | A5 | 2.22E+05 | 4.00E+05 |
| WW | Colonial Hills | 6/9/2011 | A7 | 1.15E+05 | 1.10E+05 |
| WW | Taylor Park | 8/12/2011 | A1 | 4.10E+04 | 1.90E+04 |
| WW | Taylor Park | 8/12/2011 | A2 | 1.88E+05 | 2.29E+05 |
| WW | Taylor Park | 8/12/2011 | A3 | 9.75E+04 | 1.85E+05 |
| WW | Taylor Park | 8/12/2011 | A4 | 8.00E+04 | 1.05E+05 |
| WW | Taylor Park | 8/12/2011 | A5 | 4.10E+04 | 4.70E+04 |
| WW | Taylor Park | 8/12/2011 | A6 | 9.80E+04 | 4.00E+04 |
| WW | Taylor Park | 8/12/2011 | Grab | 1.21E+04 | 9.00E+03 |
| WW | Colonial Hills | 8/12/2011 | A1 | 2.55E+04 | 2.50E+04 |
| WW | Colonial Hills | 8/12/2011 | A2 | 1.50E+04 | 3.70E+04 |
| WW | Colonial Hills | 8/12/2011 | A3 | 3.60E+04 | 4.10E+04 |
| WW | Colonial Hills | 8/12/2011 | A4 | 2.55E+04 | 4.60E+04 |
| WW | Colonial Hills | 8/12/2011 | A5 | 2.00E+04 | 2.70E+04 |
| WW | Colonial Hills | 8/12/2011 | A6 | 3.10E+04 | 3.00E+04 |
| WW | Colonial Hills | 8/12/2011 | Grab | 1.45E+04 | 2.60E+04 |
| DW | Taylor Park | 8/18/2011 | Grab | 7.50E+03 | 1.00E+04 |
| DW | Colonial Hills | 8/18/2011 | Grab | 6.30E+02 | 8.00E+02 |

*DW = dry weather; WW = wet weather

# Appendix G Total Copper Calibration Curve

**Table G.1: AAS readings for total copper standard concentrations**

| Testing Order | Standard Concentration (mg/L) | Absorbance | Std. Dev. |
|---|---|---|---|
| 0 | 0.00 | 0.000 | 0.0001 |
| 4 | 0.05 | 0.002 | 0.0001 |
| 1 | 0.10 | 0.003 | 0.0001 |
| 2 | 0.50 | 0.016 | 0.0001 |
| 5 | 1.00 | 0.028 | 0.0002 |
| 3 | 2.50 | 0.070 | 0.0004 |
| 6 | 5.00 | 0.139 | 0.0006 |

*Notes: Standards prepared with 3% HNO3

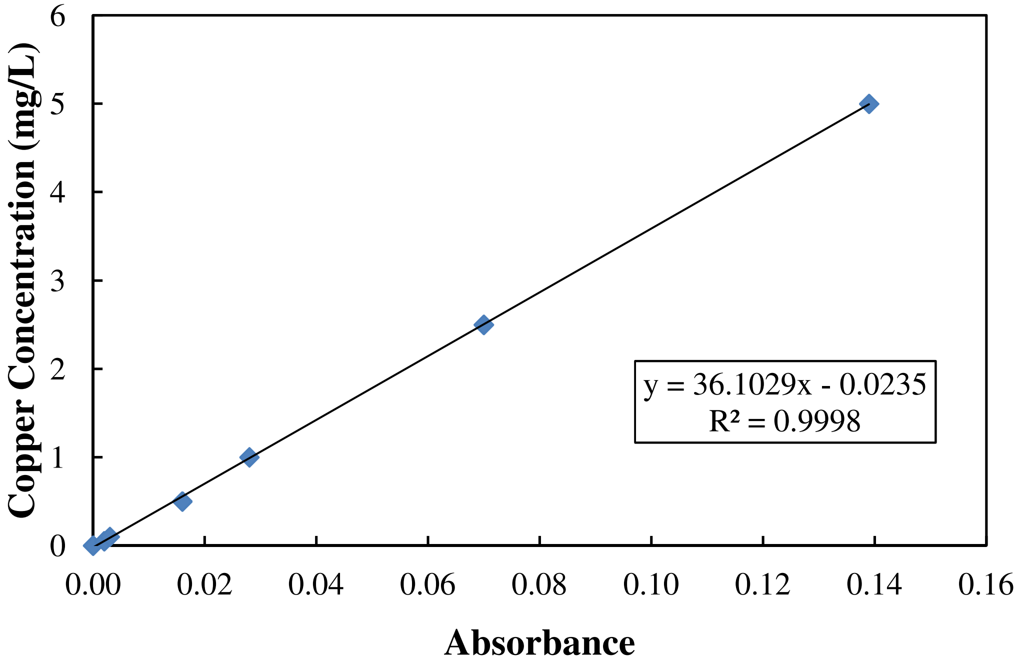


**Figure G.1: Calibration curve for AAS total copper measurements**

# Appendix H Event Mean Concentration Determination

Event mean concentrations (EMCs) were calculated for the 2008 through 2011 sampled storm events. The EMC value was determined using the equation provided in **Section 2.2.3** of **Chapter 2** (page 7). During most sampled events, autosamples were collected during the initial runoff period and a grab sample was collected following the return to baseflow conditions. **Figure H.1** illustrates the stream discharge hydrograph for the 4/30/2010 storm event at Colonial Hills along with the TSS pollutograph (change in constituent concentration during a storm runoff event) based on the measurements from the discrete samples. As shown in the figure, the grab sample was a great while after the last collected autosample; over eight hours had elapsed between the collection of the two discrete samples.

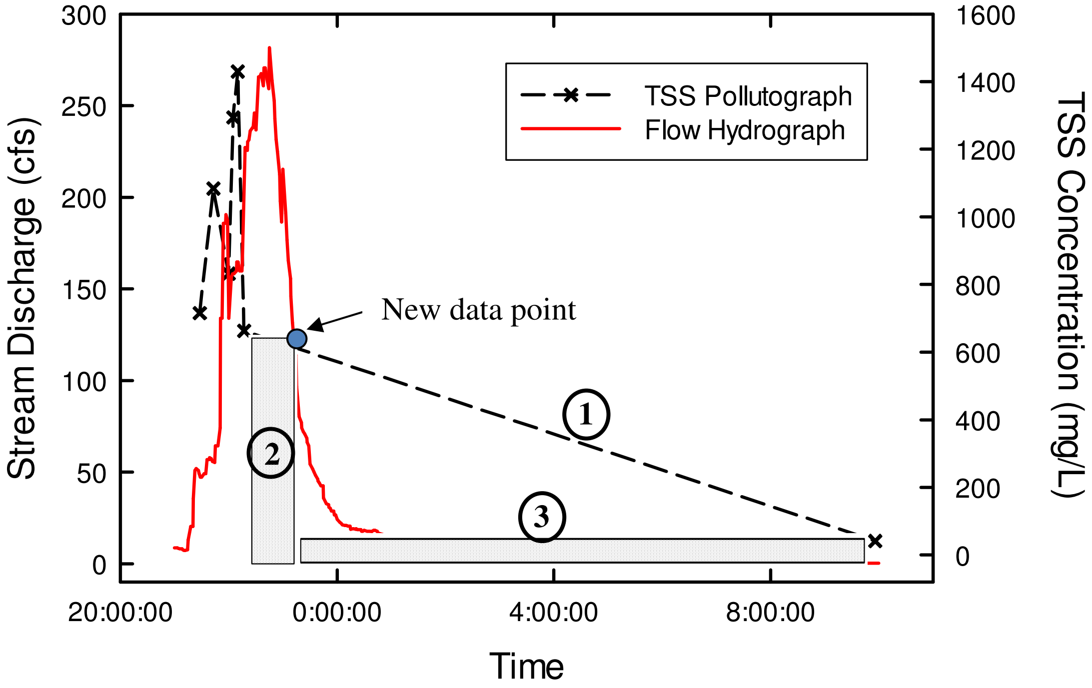


**Figure H.1: Example of the 4/30/2010 sampled storm event at Colonial Hills**

The concern was that for most water quality constituents, the return to baseflow conditions would mean a return to baseflow concentration. Therefore, the generic estimation for the average constituent concentration between the last two data points, illustrated in **Figure H.1** by the circled number 3, would most likely overestimate the EMC value for the storm by the assumption that the concentration changes linearly over the large time gap. To prevent an overestimation for the EMC value when similar cases arose at the two monitoring sites, a standard algorithm was developed. The turbidity concentration was used as the consistent reference indicator. When the percent difference in turbidity concentration between the last collected autosample and the grab sample exceeded 100%, an adjustment was made to the EMC calculation procedure. A new estimation for the last time step assumed a constant concentration based on the results of the last autosample until a determined percent difference in the turbidity concentration had resulted. This was illustrated in **Figure H.1** by the "New data point," which provided a new estimate for the last time interval by adding area "2" and area "3" beneath the pollutograph curve. For the Colonial Hills site, the new data point was added for the time when the turbidity concentration was 50% less that of the last autosample measurement. For the Taylor Park site, the new data point was added for the time when the turbidity concentration was 30% less that of the last autosample measurement. The discrepancy in reference percent differences between the two monitoring sites was due to the more rapid hydrograph and pollutograph changes recorded at the Taylor Park site due to the flashier nature of the watershed.

## Appendix I Autosampler Laboratory Experiments

Several auto sampler experiments were conducted in the UNL hydraulics lab in the spring of 2010 prior to any sampling. The experiments were performed to check for bias in the results for total suspended solids (TSS) between sampling methods. Fine clay was added to a known amount of water in a bucket to produce a theoretical concentration for TSS. The sampling water was then mixed continuously using a drill and mixing paddle to ensure consistent solids concentration throughout the bucket.

An experiment was performed on March 2, 2010 to check the accuracy of the auto sampler samples. Clay was used to mix a theoretical TSS concentration of 500 mg/L. A grab sample was taken in between each auto sampler sample near the same location as the autosampler intake line. The samples were then tested in the CIVE lab for TSS, which produced the results shown in **Table I.1**.

**Table I.1: Results from the 3/2/2010 lab experiment**

| Sample Type | Pan # | Initial Mass, M1 (g) | Volume, V (mL) | Final Mass, M2 (g) | TSS (mg/L) |
|---|---|---|---|---|---|
| A | 1 | 0.1249 | 100 | 0.1724 | 475 |
| G | 2 | 0.1245 | 100 | 0.1552 | 307 |
| A | 3 | 0.1251 | 100 | 0.1626 | 375 |
| G | 4 | 0.1165 | 100 | 0.1522 | 357 |
| A | 5 | 0.1245 | 100 | 0.1559 | 314 |
| G | 6 | 0.1160 | 100 | 0.1518 | 358 |
| A | 7 | 0.1252 | 100 | 0.1625 | 373 |
| G | 8 | 0.1188 | 100 | 0.1528 | 340 |
| A | 9 | 0.1160 | 100 | 0.1542 | 382 |
| G | 10 | 0.1247 | 100 | 0.1579 | 332 |

*A = autosample; G = grab sample

The results were very scattered. One important observation was the average concentration was considerably higher for the autosamples (380 mg/L) than for the grab samples (340 mg/L). The difference was thought to be due to solids that had remained in the sampler line since it had been noticed that the sampler pump did not have enough power to completely purge the tubing.

Another experiment was conducted on March 9, 2010. It was hypothesized that because the sampler did not totally purge the intake line before and after the sample collection, that some solids may remain in the line, increasing the TSS concentration of the ensuing sample. Therefore, two different water sources were used to test this hypothesis. Again, a bucket with a theoretical TSS concentration of 500 mg/L was used, but a bucket filled with high purity (distilled) water was also used. The auto sampler was used to alternate samples between the two buckets. The results from the experiment are provided in **Table I.2**.

**Table I.2: Results from the 3/9/2010 lab experiment**

| Sample Type | Pan # | Initial Mass, M1 (g) | Volume, V (mL) | Final Mass, M2 (g) | TSS (mg/L) | Turbidity (NTU) |
|---|---|---|---|---|---|---|
| TM | 1 | 0.1198 | 100 | 0.1524 | 326 | 87.8 |
| HP | 2 | 0.1174 | 100 | 0.1180 | 6 | 1.92 |
| TM | 3 | 0.1195 | 100 | 0.1576 | 381 | 84 |
| HP | 4 | 0.1193 | 100 | 0.1203 | 10 | 3.39 |
| TM | 5 | 0.1185 | 100 | 0.1548 | 363 | 82.9 |
| HP | 6 | 0.1184 | 100 | 0.1194 | 10 | 4.45 |
| TM | 7 | 0.1112 | 100 | 0.1499 | 387 | 78.8 |
| HP | 8 | 0.1134 | 100 | 0.1153 | 19 | 4.08 |
| TM | 9 | 0.1181 | 100 | 0.1554 | 373 | 71 |
| HP | 10 | 0.1181 | 100 | 0.1197 | 16 | 8.2 |
| TM | 11 | 0.1191 | 100 | 0.1555 | 364 | 76.3 |
| HP | 12 | 0.1163 | 100 | 0.1179 | 16 | 3.92 |

*TM = turbid mixture (500 mg/L); HP = high purity water

It was observed that the TSS concentration in the HP solution increased throughout the experiment, producing possible evidence that some remaining solids in the line had been added to the HP solution when the samples were collected.

A final experiment was conducted on April 1, 2010. For this experiment, the hypothesis remained the same as for the 3/9/2010 experiment. Again, a bucket with a theoretical TSS concentration of 500 mg/L was used, along with a bucket filled with high purity (distilled) water. This time, the autosampler was used to alternate three (3) samples between the two buckets. A grab sample was taken from the bucket after the three samples were collected. For example, the three concentrated samples were taken from the turbid mixture using the autosampler and then the grab sample was collected. The procedure was repeated then for the high purity bucket with a theoretical concentration of 0 mg/L. The results were provided in **Table I.3** along with summary statistics in **Table I.4** and **Table I.5**.

The results are very similar to what was hypothesized. Looking at the average TSS concentrations in **Table I.5**, it is noticed that the first sample taken from the HP bucket collects some solids retained in the line from the previous 3 concentrated samples. The 2 ensuing samples then considerably decrease in concentration from the first main flushing of the line by the HP water sample. Also, the 3 sequential concentrated samples (except for the first set, which may be due to not flushing the line with HP water prior to testing) generally increase in concentration. The first sample generally was lower than the ensuing two samples.

**Table I.3: Results from the 4/1/2010 lab experiment**

| Sample Type | Pan # | Initial Mass, M1 (g) | Volume, V (mL) | Final Mass, M2 (g) | TSS (mg/L) |
|---|---|---|---|---|---|
| A-TM | 1 | 0.1187 | 100 | 0.1548 | 361 |
| A-TM | 2 | 0.1174 | 100 | 0.1551 | 377 |
| A-TM | 3 | 0.1193 | 100 | 0.1530 | 337 |
| A-HP | 4 | 0.119 | 100 | 0.1200 | 10 |
| A-HP | 5 | 0.1207 | 100 | 0.1210 | 3 |
| A-HP | 6 | 0.1191 | 100 | 0.1191 | 0 |
| A-TM | 7 | 0.1179 | 100 | 0.1476 | 297 |
| A-TM | 8 | 0.1185 | 100 | 0.1554 | 369 |
| A-TM | 9 | 0.1195 | 100 | 0.1552 | 357 |
| A-HP | 10 | 0.1196 | 100 | 0.1210 | 14 |
| A-HP | 11 | 0.1176 | 100 | 0.1177 | 1 |
| A-HP | 12 | 0.1185 | 100 | 0.1187 | 2 |
| A-TM | 13 | 0.1173 | 100 | 0.1480 | 307 |
| A-TM | 14 | 0.1168 | 100 | 0.1498 | 330 |
| A-TM | 15 | 0.1188 | 100 | 0.1548 | 360 |
| A-HP | 16 | 0.1163 | 100 | 0.1175 | 12 |
| A-HP | 17 | 0.1159 | 100 | 0.1160 | 1 |
| A-HP | 18 | 0.1178 | 100 | 0.1179 | 1 |
| G-TM | 19 | 0.1155 | 100 | 0.1414 | 259 |
| G-TM | 20 | 0.1189 | 100 | 0.1488 | 299 |
| G-TM | 21 | 0.1196 | 100 | 0.1520 | 324 |
| G-HP | 22 | 0.1174 | 100 | 0.1174 | 0 |
| G-HP | 23 | 0.1181 | 100 | 0.1182 | 1 |
| G-HP | 24 | 0.1178 | 100 | 0.1178 | 0 |

***Notes:** TM = turbid mixture of 500 mg/L TSS
HP = high purity water
G = grab sample; A = autosample

**Table I.4: Comparison of average TSS concentrations for the experiments**

| | A-TM | G-TM | A-HP | G-HP |
|---|---|---|---|---|
| **Average TSS (mg/L)** | 343.9 | 294.0 | 4.9 | 0.3 |
| **Standard Deviation** | 35.7 | 32.8 | 5.5 | 0.6 |

**Table I.5: Progression of average TSS concentration in autosamples**

| | A-HP (1) | A-HP (2) | A-HP (3) |
|---|---|---|---|
| **Average TSS (mg/L)** | 12.0 | 1.7 | 1.0 |
| **Standard Deviation** | 2.0 | 1.2 | 1.0 |

Therefore, the hypothesis of there being a bias due to solids remaining in the line is proved to be correct. However, this amount of solids retained is small and can be assumed to be insignificant for the duration of the sampling period. These experiments were conducted for a worse-case scenario as the line was designed to have a loop in it where water could collect and be unable to be completely purged back into the bucket. The intake line design would be expected to have produced an even greater bias due to solids residual. The intake line design for the two monitoring sites is much different; the sites have been designed so that the line continually drops from the autosampler down to the sampled stream.

**Experiment conclusions:**

1. During dry weather monitoring, flush the intake line by collecting an autosample that is not intended to be used. Discard the first autosample taken and use any samples collected after that.
2. Avoid using the first autosample taken during a wet weather event so the line can be flushed by the first collection; the following samples will be used for the sample analysis.

# Appendix J Site Visit Logs

## J.1 Colonial Hills

Phone #'s: Dave Rus, USGS: 328-4127 or 416-5857(cel); Matt Moser, USGS: 402-429-1672 (cel); Bruce Dvorak, UNL: 472-3431, 326-8391(cel); Dave Admiraal, UNL: 472-8568; Jake Fisher, UNL: 469-5592(cel); Rock Krzycki, City of Lincoln, 441-4959

In case of observed spills, contact the First Response Hotline at 441-8200

To get USGS datalogger time and level, toggle through screens using the button on the right side of the logger

Tapedown point is a chiseled arrow on the upstream side of the walkway bridge deck. **TD elev = 4.716 feet**

| Date/ Time | Party | Reason for Visit | Stream Disturbed (Y/N) | ISCO Time | USGS datalogger Time | Tapedown distance- TD (ft) | Tapedown level (4.716 - TD dist) | ISCO 4230 level (ft) | USGS datalogger level (ft) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | |
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| | | | | | | | | | |

## J.2 Taylor Park

Phone #'s: Dave Rus, USGS: 328-4127 or 416-5857(cel); Matt Moser, USGS: 402-429-1672 (cel); Bruce Dvorak, UNL: 472-3431, 326-8391(cel); Dave Admiraal, UNL: 472-8568; Jake Fisher, UNL: 469-5592(cel); Rock Krzycki, City of Lincoln, 441-4959

In case of observed spills, contact the First Response Hotline at 441-8200

To get USGS datalogger time and level, toggle through screens using the button on the right side of the logger

Tapedown point is the top of the channel iron holding the PVC in the channel. **TD elev = 2.654 feet**

| Date/ Time | Party | Reason for Visit | Stream Disturbed (Y/N) | ISCO Time | USGS datalogger Time | Tapedown distance- TD (ft) | Tapedown level (2.654 - TD dist) | ISCO 4230 level (ft) | USGS datalogger level (ft) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | |
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# Appendix K 2011 Standard Checks for MDL Calculation

## Chlorine

| Number | Date | Known 0.05 (mg/L) | Deviation (mg/L) |
|---|---|---|---|
| **1** | 9-Aug | 0.06 | 0.01 |
| **2** | 9-Aug | 0.06 | 0.01 |
| **3** | 9-Aug | 0.06 | 0.01 |
| **4** | 9-Aug | 0.05 | 0.00 |
| **5** | 9-Aug | 0.06 | 0.01 |
| **6** | 9-Aug | 0.06 | 0.01 |
| **7** | 9-Aug | 0.05 | 0.00 |
| **8** | 9-Aug | 0.06 | 0.01 |
| **9** | 9-Aug | 0.06 | 0.01 |
| **10** | 9-Aug | 0.06 | 0.01 |
| **Average** | **0.058** | | |
| **Std. Dev.** | **0.0042** | | |
| **MDL** | **0.012** | | |

## Fluoride

| Number | Date | Known 0.15 (mg/L) | Deviation (mg/L) |
|---|---|---|---|
| **1** | 9-Aug | 0.10 | 0.05 |
| **2** | 9-Aug | 0.10 | 0.05 |
| **3** | 9-Aug | 0.12 | 0.03 |
| **4** | 9-Aug | 0.12 | 0.03 |
| **5** | 9-Aug | 0.10 | 0.05 |
| **6** | 9-Aug | 0.10 | 0.05 |
| **7** | 9-Aug | 0.10 | 0.05 |
| **8** | 9-Aug | 0.12 | 0.03 |
| **9** | 9-Aug | 0.10 | 0.05 |
| **10** | 9-Aug | 0.10 | 0.05 |
| **Average** | **0.106** | | |
| **Std. Dev.** | **0.0097** | | |
| **MDL** | **0.027** | | |

## Chloride

| Number | Date | Known 0.3 (mg/L) | Deviation (mg/L) |
|---|---|---|---|
| **1** | 9-Aug | 0.2 | 0.1 |
| **2** | 9-Aug | 0.2 | 0.1 |
| **3** | 9-Aug | 0.2 | 0.1 |
| **4** | 9-Aug | 0.2 | 0.1 |
| **5** | 9-Aug | 0.2 | 0.1 |
| **6** | 9-Aug | 0.2 | 0.1 |
| **7** | 9-Aug | 0.3 | 0.0 |
| **8** | 9-Aug | 0.2 | 0.1 |
| **9** | 9-Aug | 0.1 | 0.2 |
| **10** | 9-Aug | 0.2 | 0.1 |
| **Average** | **0.200** | | |
| **Std. Dev.** | **0.0471** | | |
| **MDL** | **0.133** | | |

## Surfactants

| Number | Date | Known 0.02 (mg/L) | Deviation (mg/L) |
|---|---|---|---|
| **1** | 10-Aug | 0.024 | 0.004 |
| **2** | 10-Aug | 0.021 | 0.001 |
| **3** | 10-Aug | 0.026 | 0.006 |
| **4** | 10-Aug | 0.033 | 0.013 |
| **5** | 10-Aug | 0.034 | 0.014 |
| **6** | 10-Aug | 0.026 | 0.006 |
| **7** | 10-Aug | 0.021 | 0.001 |
| **8** | 10-Aug | 0.024 | 0.004 |
| **9** | 10-Aug | 0.021 | 0.001 |
| **10** | 10-Aug | 0.020 | 0.000 |
| **Average** | **0.025** | | |
| **Std. Dev.** | **0.0050** | | |
| **MDL** | **0.014** | | |

### Total Copper

| Number | Date | Known 0.3 (mg/L) | Deviation (mg/L) |
|---|---|---|---|
| **1** | 17-Aug | 0.338 | 0.04 |
| **2** | 17-Aug | 0.338 | 0.04 |
| **3** | 17-Aug | 0.338 | 0.04 |
| **4** | 17-Aug | 0.338 | 0.04 |
| **5** | 17-Aug | 0.338 | 0.04 |
| **6** | 17-Aug | 0.338 | 0.04 |
| **7** | 17-Aug | 0.338 | 0.04 |
| **8** | 17-Aug | 0.338 | 0.04 |
| **9** | 17-Aug | 0.338 | 0.04 |
| **10** | 17-Aug | 0.338 | 0.04 |
| **Average** | **0.338** | | |
| **Std. Dev.** | **0.0000** | | |
| **MDL** | **0.000** | → abs. = 0.004 | |

### Conductivity

| Number | Date | Known 5. (µS/cm) | Deviation (µS/cm) |
|---|---|---|---|
| **1** | 9-Aug | 5.50 | 0.50 |
| **2** | 9-Aug | 5.67 | 0.67 |
| **3** | 9-Aug | 5.69 | 0.69 |
| **4** | 9-Aug | 5.75 | 0.75 |
| **5** | 9-Aug | 5.66 | 0.66 |
| **6** | 9-Aug | 5.68 | 0.68 |
| **7** | 9-Aug | 5.69 | 0.69 |
| **8** | 9-Aug | 5.65 | 0.65 |
| **9** | 9-Aug | 5.71 | 0.71 |
| **10** | 9-Aug | 5.70 | 0.70 |
| **Average** | **5.67** | | |
| **Std. Dev.** | **0.0660** | | |
| **MDL** | **0.186** | | |

### Total Phosphorous (Digested)

| Number | Date | Known 0.5 (mg/L) | Deviation (mg/L) |
|---|---|---|---|
| **1** | 9-Aug | 0.524 | 0.024 |
| **2** | 9-Aug | 0.517 | 0.017 |
| **3** | 9-Aug | 0.528 | 0.028 |
| **4** | 9-Aug | 0.524 | 0.024 |
| **5** | 9-Aug | 0.522 | 0.022 |
| **6** | 9-Aug | 0.529 | 0.029 |
| **7** | 9-Aug | 0.529 | 0.029 |
| **8** | 9-Aug | 0.521 | 0.021 |
| **9** | 9-Aug | 0.52 | 0.020 |
| **10** | 9-Aug | 0.526 | 0.026 |
| **Average** | **0.524** | | |
| **Std. Dev.** | **0.0041** | | |
| **MDL** | **0.011** | | |

### Soluble Reactive Phosphorous

| Number | Date | Known 0.5 (mg/L) | Deviation (mg/L) |
|---|---|---|---|
| **1** | 9-Aug | 0.522 | 0.022 |
| **2** | 9-Aug | 0.519 | 0.019 |
| **3** | 9-Aug | 0.523 | 0.023 |
| **4** | 9-Aug | 0.531 | 0.031 |
| **5** | 9-Aug | 0.528 | 0.028 |
| **6** | 9-Aug | 0.539 | 0.039 |
| **7** | 9-Aug | 0.529 | 0.029 |
| **8** | 9-Aug | 0.532 | 0.032 |
| **9** | 9-Aug | 0.528 | 0.028 |
| **10** | 9-Aug | 0.516 | 0.016 |
| **Average** | **0.53** | | |
| **Std. Dev.** | **0.0068** | | |
| **MDL** | **0.019** | | |

## COD (DR 2400)

| Number | Date | Known 10. (mg/L) | Deviation (mg/L) |
|---|---|---|---|
| **1** | 9-Aug | 11 | 1 |
| **2** | 9-Aug | 10 | 0 |
| **3** | 9-Aug | 12 | 2 |
| **4** | 9-Aug | 12 | 2 |
| **5** | 9-Aug | 12 | 2 |
| **6** | 9-Aug | 12 | 2 |
| **7** | 9-Aug | 12 | 2 |
| **8** | 9-Aug | 12 | 2 |
| **9** | 9-Aug | 11 | 1 |
| **10** | 9-Aug | 10 | 0 |
| **Average** | **11.400** | | |
| **Std. Dev.** | **0.8433** | | |
| **MDL** | **2.379** | | |

# Appendix L QA/QC: Duplicate Results (2010-2011)

**Table L.1: Duplicate Results for dry weather samples collected 2010-2011**

| Site | Date | Sample Type | COD | $Cl^-$ | $Cl_2$ | CDY | Cu | DO | EC | $F^-$ | pH | SRP | TP | SF | TSS | TBY |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TP | 6/16/2010 | G | 60.0% | 3.8% | | 0.2% | <MDL | 1.7% | 10.9% | 1.8% | 0.4% | 0.7% | 1.3% | 8.0% | | 34.3% |
| TP | 6/16/2010 | A | 34.5% | | | 0.5% | | | | | 0.2% | 1.6% | 0.0% | | 0.0% | |
| CH | 6/16/2010 | G | 0.0% | 1.8% | | 0.1% | <MDL | 1.4% | 43.0% | 3.8% | 0.1% | 0.7% | 0.8% | 17.1% | <MDL | 10.4% |
| CH | 6/16/2010 | A | 27.0% | | | 0.6% | | | | | 0.1% | 0.0% | 0.0% | | <MDL | |
| TP | 7/28/2010 | G | <MDL | 9.1% | | 0.2% | <MDL | 8.4% | 23.6% | 0.0% | 0.4% | 0.0% | 1.9% | 13.3% | | 0.3% |
| TP | 7/28/2010 | A | <MDL | | | 0.4% | | | | | 0.7% | 0.7% | 22.9% | | <MDL | |
| CH | 7/28/2010 | G | 28.6% | 5.8% | | 0.4% | <MDL | 0.0% | 66.7% | 1.9% | 0.6% | 1.2% | 0.4% | 27.0% | 0.0% | 0.7% |
| CH | 7/28/2010 | A | 11.8% | | | 0.2% | | | | | 0.5% | 2.4% | 4.5% | | <MDL | |
| TP | 11/8/2010 | G | 0.0% | 8.2% | 15.4% | | | | | | | | | | | 8.9% |
| TP | 11/8/2010 | A | 66.7% | | | 1.2% | | | | | 0.4% | | 0.5% | | <MDL | |
| CH | 11/8/2010 | G | 28.6% | 1.5% | 16.7% | | | | | 1.5% | | | | | | 1.0% |
| CH | 11/8/2010 | A | | | | 1.9% | | | | | 0.1% | | | | 46.2% | |
| CH | 4/29/2011 | G | | | | | | 1.6% | | | | | | | | |
| TP | 6/23/2011 | G | 5.4% | 4.3% | | 0.0% | | 3.2% | 6.2% | 9.2% | 0.9% | 1.5% | 6.5% | 2.1% | 0.0% | 6.3% |
| TP | 6/23/2011 | A | 16.2% | | | 0.3% | | | 4.4% | | 0.2% | 0.4% | 6.4% | | 0.0% | |
| CH | 6/23/2011 | G | 10.0% | 4.0% | | 0.2% | | 0.0% | 33.1% | 3.9% | 0.4% | 1.2% | 16.4% | 2.2% | <MDL | 21.1% |
| CH | 6/23/2011 | A | 11.8% | | | 0.8% | | | 1.7% | | 0.7% | 5.5% | 0.3% | | 20.0% | |
| TP | 7/18/2011 | G | | | 12.5% | | | 13.5% | | | | | | | | |
| CH | 7/18/2011 | G | | | 33.3% | | | 0.0% | | | | | | | | |
| TP | 8/18/2011 | G | | | | | | | | 4.4% | 1.5% | | | 15.4% | | |
| CH | 8/18/2011 | G | | | | | | | 73.0% | 1.7% | 0.5% | | | 10.8% | | |
| **Average Percent Difference** | | | 23.1% | 4.8% | 19.5% | 0.5% | - | 3.3% | 29.2% | 3.2% | 0.5% | 1.3% | 4.8% | 12.0% | 11.0% | 10.4% |
| **Number of Duplicates** | | | 13 | 8 | 4 | 14 | 0 | 9 | 9 | 9 | 16 | 12 | 13 | 8 | 6 | 8 |

*Refer to **Table 4.1** (page 60) for water quality abbreviation definitions & **Table 4.2** (page 61) for measurement units and analytical methods

*CH = Colonial Hills; TP = Taylor Park; A = autosample; G = grab sample

## Table L.2: Duplicate Results for wet weather samples collected 2010-2011

| Site | Date | Sample Type | COD | Cl- | Cl2 | CDY | Cu | DO | EC | pH | SRP | TP | TSS | TBY |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TP | 8/4/2010 | A1 | 20.2% | 15.1% |  | 0.4% | 0.0% |  | 52.5% |  | 0.8% | 6.8% | 10.0% | 12.0% |
| TP | 8/4/2010 | A2 | 11.7% | 7.4% |  | 0.0% |  |  | 29.7% |  | 4.0% | 0.5% | 13.3% | 3.4% |
| TP | 8/4/2010 | A3 | 8.2% | 10.0% |  | 0.0% | <MDL |  | 21.7% |  | U.R. | 2.2% | 6.5% | 32.6% |
| TP | 8/4/2010 | A4 | 3.2% | 2.4% |  | 0.2% |  |  | 27.5% |  | 3.0% | 0.9% | 2.4% | 5.3% |
| TP | 8/4/2010 | A5 |  | 2.7% |  | 0.5% |  |  | 22.7% |  | 27.4% | 4.3% | 3.9% | 14.1% |
| TP | 8/4/2010 | A6 | 36.4% | 0.0% |  | 0.7% |  |  | 10.4% |  | 0.8% | 0.9% | 2.7% | 12.5% |
| TP | 8/4/2010 | AR | 6.6% |  |  |  |  |  |  | 0.0% | 2.4% | 1.0% | 28.6% |  |
| TP | 8/4/2010 | G | 9.3% |  | 28.6% |  |  | 0.0% | 11.0% | 0.3% |  |  | 40.0% | 3.0% |
| CH | 8/4/2010 | A1 | 6.1% | 1.2% |  | 0.8% |  |  | 7.8% |  | 1.0% | 9.2% | 0.5% | 12.6% |
| CH | 8/4/2010 | A2 | 7.9% | 9.1% |  | 0.7% | <MDL |  | 30.2% |  | 2.2% | 1.6% | 1.1% | 13.2% |
| CH | 8/4/2010 | A3 | 6.2% | 5.1% |  | 0.9% |  |  | 23.7% |  | 3.3% | 6.4% | 5.1% | 16.0% |
| CH | 8/4/2010 | A4 | 3.5% | 6.8% |  | 0.1% |  |  | 41.0% |  | 1.7% | 9.2% | 2.0% | 10.6% |
| CH | 8/4/2010 | A5 | 6.1% | 9.6% |  | 0.1% | <MDL |  | 60.8% |  | 5.3% | 0.0% | 10.2% | 8.3% |
| CH | 8/4/2010 | A6 | 1.6% | 3.8% |  | 1.1% |  |  | 22.1% |  | 4.9% | 1.2% | 6.5% | 16.5% |
| CH | 8/4/2010 | AR | 6.6% |  |  |  |  |  |  | 0.3% | 1.7% | 0.3% | 22.2% |  |
| CH | 8/4/2010 | G | 7.1% |  | 0.0% |  |  | 2.1% | 39.4% | 0.4% |  |  | <MDL | 24.5% |
| TP | 6/9/2011 | A1 | 0.0% | 95.4% |  | 1.0% | <MDL |  | 9.6% |  | 5.2% | 6.0% | 24.9% | 3.1% |
| TP | 6/9/2011 | A3 | 47.9% | 16.9% |  | 7.6% |  |  | 162.6% |  | 3.1% | 17.2% | 24.5% | 17.5% |
| TP | 6/9/2011 | A5 | 81.5% | 5.4% |  | 8.9% |  |  |  |  | 2.0% | 2.8% | 21.0% | 6.5% |
| TP | 6/9/2011 | A7 | 0.0% | 21.2% |  | 0.8% |  |  | 40.5% |  | 3.1% | 7.9% | 16.2% | 3.1% |
| CH | 6/9/2011 | A1 | 17.5% | 42.8% |  | 0.6% |  |  | 21.4% |  | 6.2% | 0.7% | 7.3% | 12.9% |
| CH | 6/9/2011 | A3 | 34.9% | 11.5% |  | 2.1% |  |  | 33.1% |  | 1.2% | 3.9% | 5.9% | 6.3% |
| CH | 6/9/2011 | A5 | 14.8% | 12.7% |  | 0.0% |  |  | 5.4% |  | 1.8% | 1.9% | 3.2% | 13.9% |
| CH | 6/9/2011 | A7 | 37.0% | 6.5% |  | 0.6% |  |  | 8.7% |  | 3.7% | 0.0% | 5.7% | 8.0% |
| TP | 6/25/2011 | G |  |  | 40.0% |  |  |  | 6.9% |  |  |  |  |  |
| CH | 6/25/2011 | G |  |  | 0.0% |  |  |  | 82.0% |  |  |  |  |  |

## Table L.2 Continued

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TP | 8/12/2011 | A1 | 1.5% | 7.4% | | 1.1% | <MDL | | | | 0.3% | 1.4% | 13.4% | 17.9% |
| TP | 8/12/2011 | A2 | 9.7% | 0.0% | | 0.5% | | | 29.8% | | 4.2% | 0.1% | 5.8% | 6.4% |
| TP | 8/12/2011 | A3 | 30.4% | 0.0% | | 163.4% | <MDL | | 23.6% | | 0.0% | 0.0% | 13.9% | |
| TP | 8/12/2011 | A4 | 0.0% | | | 1.2% | | | 42.5% | | 8.1% | 2.9% | 26.6% | |
| TP | 8/12/2011 | A5 | 2.4% | | | | <MDL | | | | 10.8% | 0.1% | | 1.0% |
| TP | 8/12/2011 | A6 | 7.1% | | | | | | | | | | 3.6% | |
| TP | 8/12/2011 | AR | | | | | | | | 0.5% | | | 40.0% | 3.8% |
| TP | 8/12/2011 | G | | | 66.7% | | | | | 0.8% | | | | 21.3% |
| CH | 8/12/2011 | A1 | 0.0% | 11.8% | | 0.6% | <MDL | | 43.1% | | 5.2% | 4.3% | 0.9% | 2.7% |
| CH | 8/12/2011 | A2 | 11.4% | 18.2% | | 0.7% | | | 66.7% | | 1.6% | 12.9% | 14.3% | 34.4% |
| CH | 8/12/2011 | A3 | 4.3% | 13.3% | | 3.1% | <MDL | | 27.8% | | 9.4% | 0.9% | 7.6% | |
| CH | 8/12/2011 | A4 | 13.3% | | | 0.0% | | | 43.1% | | 0.0% | 2.4% | 2.7% | |
| CH | 8/12/2011 | A5 | 3.2% | | | | <MDL | | | | 1.3% | 8.4% | | 4.7% |
| CH | 8/12/2011 | A6 | 8.0% | | | | | | | | | | 0.0% | |
| CH | 8/12/2011 | AR | | | | | | | | 0.4% | | | 0.0% | 11.4% |
| CH | 8/12/2011 | G | | | 28.6% | | | | | 0.3% | | | | 13.3% |
| **Average Percent Error** | | | 13.3% | 12.9% | 27.3% | 7.1% | 0.0% | 1.1% | 34.9% | 0.4% | 4.1% | 3.7% | 11.2% | 11.6% |
| **Number of Duplicates** | | | 35 | 26 | 6 | 28 | 1 | 2 | 30 | 8 | 31 | 32 | 35 | 32 |

*Refer to **Table 4.1** (page 60) for water quality abbreviation definitions & **Table 4.2** (page 61) for measurement units and analytical methods

*CH = Colonial Hills; TP = Taylor Park; A# = autosample; AR = auto regulatory sample; G = grab sample

# Appendix M QA/QC: Travel Blank Results (2010-2011)

**Table M.1: Travel blank results for 2010 through 2011**

| Date | $Cl^-$ (mg/L) | $Cl_2$ (mg/L) | COD (mg/L) | CDY (µS/cm) | E. coli (cfu/100mL) | Cu (mg/L) |
|---|---|---|---|---|---|---|
| 6/16/2010 | <MDL | - | 5 | 4.62 | <1.0 | <MDL |
| 8/16/2010 | <MDL | 0.03 | <MDL | 5.92 | <1.0 | <MDL |
| 11/8/2010 | <MDL | <MDL | 4 | <MDL | <1.0 | <MDL |
| 6/23/2011 | <MDL | 0.01 | 6 | 3.44 | >2419.6 | <MDL |
| 7/18/2011 | 1.3 | 0.07 | 9 | 1.45 | <1.0 | <MDL |
| 8/18/2011 | <MDL | <MDL | 8 | 2.57 | <1.0 | <MDL |
| | | | | | | |
| **Date** | **$F^-$ (mg/L)** | **pH** | **SRP (mg/L)** | **TP (mg/L)** | **SF (mg/L)** | **TBY (NTU)** |
| 6/16/2010 | <MDL | 6.82 | <MDL | <MDL | <MDL | 0.16 |
| 8/16/2010 | 0.11 | 7.94 | <MDL | <MDL | <MDL | 0.253 |
| 11/8/2010 | <MDL | 7.34 | <MDL | <MDL | 0.014 | 0.04 |
| 6/23/2011 | 0.21 | 6.67 | <MDL | <MDL | 0.015 | 0.316 |
| 7/18/2011 | 0.03 | 7.68 | <MDL | <MDL | <MDL | 0.404 |
| 8/18/2011 | <MDL | 7.04 | <MDL | <MDL | 0.030 | 0.697 |

# Appendix N QA/QC: Laboratory Blank Results (2010-2011)

**Table N.1: Laboratory blank results for 2010 through 2011**

| Blank # | Date | $Cl^-$ (mg/L) | $Cl_2$ (mg/L) | COD (mg/L) | CDY (µS/cm) | E. coli (cfu/100mL) | Cu (mg/L) |
|---|---|---|---|---|---|---|---|
| 1 | 8/16/2010 | 0.2 | <MDL | <MDL | <MDL | <1.0 | <MDL |
| 2 | 8/16/2010 | 0.2 | <MDL | <MDL | <MDL | <1.0 | <MDL |
| 3 | 8/16/2010 | 0.3 | 0.02 | <MDL | <MDL | <1.0 | <MDL |
| 4 | 9/8/2010 | 0.2 | <MDL | <MDL | <MDL | <1.0 | <MDL |
| 5 | 9/8/2010 | 0.2 | <MDL | <MDL | <MDL | <1.0 | <MDL |
| 6 | 9/8/2010 | 0.2 | <MDL | 4 | <MDL | <1.0 | <MDL |
| 7 | 6/23/2011 | <MDL | <MDL | <MDL | 3.25 | <1.0 | <MDL |
| 8 | 6/25/2011 | <MDL | <MDL | <MDL | 0.24 | <1.0 | <MDL |
| 9 | 6/25/2011 | 0.3 | 0.01 | <MDL | 0.2 | <1.0 | <MDL |
| 10 | 7/18/2011 | <MDL | 0.02 | <MDL | 0.45 | <1.0 | <MDL |
| 11 | 8/18/2011 | <MDL | <MDL | <MDL | 0.32 | <1.0 | <MDL |
| 12 | 8/18/2011 | <MDL | <MDL | <MDL | 0.29 | <1.0 | <MDL |
| | | | | | | | |
| **Blank #** | **Date** | **$F^-$ (mg/L)** | **pH** | **SRP (mg/L)** | **TP (mg/L)** | **SF (mg/L)** | **TBY (NTU)** |
| 1 | 8/16/2010 | <MDL | 6.58 | <MDL | <MDL | <MDL | 0.444 |
| 2 | 8/16/2010 | <MDL | 6.71 | <MDL | <MDL | <MDL | 0.234 |
| 3 | 8/16/2010 | <MDL | 7.03 | <MDL | <MDL | <MDL | 0.118 |
| 4 | 9/8/2010 | <MDL | 8.20 | <MDL | <MDL | <MDL | 0.112 |
| 5 | 9/8/2010 | <MDL | 7.33 | <MDL | <MDL | <MDL | 0.140 |
| 6 | 9/8/2010 | <MDL | 7.21 | 0.160 | <MDL | <MDL | 0.151 |
| 7 | 6/23/2011 | 0.19 | 6.63 | <MDL | <MDL | <MDL | 0.197 |
| 8 | 6/25/2011 | <MDL | 6.72 | <MDL | <MDL | <MDL | 0.062 |
| 9 | 6/25/2011 | <MDL | 6.74 | <MDL | <MDL | <MDL | 0.064 |
| 10 | 7/18/2011 | <MDL | 7.38 | <MDL | <MDL | <MDL | 0.167 |
| 11 | 8/18/2011 | <MDL | 8.46 | <MDL | <MDL | <MDL | 0.061 |
| 12 | 8/18/2011 | <MDL | 7.87 | <MDL | <MDL | <MDL | 0.054 |

# Appendix O Wet Weather Standard Operating Procedure

## Preparation

1.) Before going to the sites, check your sampling kit to make sure you have everything you need. For dry weather monitoring you will need the following items in the sampling kit.

| **Item Name** | **Quantity Needed** | **Purpose** | **Location** |
|---|---|---|---|
| Black Binder | 1 | Record Data, SOP's, Forms | Lab Counter |
| Coolers | 1 Green, 1 Red | Mobility | Lab |
| Cold packs | 4 | Maintain Cool Temperatures for Sample Transport | Freezer in Oven Room |
| Forms/Data Sheets | One for Each Site | Record Data and Maintain Organization | Black Binder |
| 1L Bottles (TP-G1, CH-G1) | 2 | Run CIVE Lab Tests | Box under the sink |
| 250 ml Bottles (TP-G1, CH-G1) | 2 | SSC Test to be done at the CIVE lab | East cabinet |
| 250 ml Nitrate Bottle | 2 | Water Science Lab Tests (TP-G1, CH-G1) | East cabinet |
| 250 ml Glass Bottle with Stopper for Dissolved Oxygen (DO) | 2 | Water Science Lab Tests (TP-G1, CH-G1) | |
| HHS 100 ml E. coli Bottles | 2 | State Lab (TP-G1, TP-A1, CH-G1, CH-A1) | HHS box |
| Blue Cap Teflon Coated Jars | 2 | Theresa Street Waste Water Treatment Plant (Oil & Grease) | East cabinet |
| Auto sampler bottle tray with clean bottles | 2 | To replace the bottles filled from the storm | Lab |
| Extra Auto sampler bottles | 4 | In the case all the bottles were used during the storm | Lab |
| DO Preservatives (Manganous, Alkali-Iodide-Acid, Conc. $H_2SO_4$) | 3 Vials | Allow Ample Delivery Time | Refrigerator in Oven Room |
| 0.5M $H_2SO_4$ | 1 Vial | To Preserve 500 mL Water Science Lab Samples | Refrigerator in Oven Room |
| Thermometer | Electronic | - | Cooler |

| Item Name | Quantity Needed | Purpose | Location |
|---|---|---|---|
| Hach 2000 DR | 1 | Measure Chlorine Levels | Cooler |
| Manhole Cover Remover & Cone | 1 | - | Lab |
| Chlorine Test Vials | 1 Set (have same #) | Run Field Chlorine Test | Drying Rack |
| Chlorine Test Packets | 2 Pillow Packets | Run Field Chlorine Test | Cooler |
| Telescopic Sampling Pole | 1 | Ease of Sample Collection | Lab |
| 1 L Sample Collecting Beaker (Plastic) | 1 | - | Lab |
| Labeling Tape | 1 | Ensure Organization | Lab Counter |
| Pen/Sharpie | 1 | - | Lab Counter |
| Laptop Computer with Flowlink | 1 | Upload DW Data from ISCO 4100 Bubbler and ISCO 2150 Area-Velocity Meter | Lab |
| Automatic Pipette with Tips | 1 | Sample Preservation and Sample Testing | Lab |
| De-Ionized Water | 1 | Rinsing and Washing Bottles and Vials | Lab |
| Rubber Gloves | 4+ Pairs | - | Lab |
| Kim Wipes | 1 Box (4 is enough) | Wipe Finger Prints Off of Vials | Lab |
| Letter from City of Lincoln | 1 | Authority | Black Binder |
| Traffic Safety Vest | Enough for Everyone | - | Lab |

2.) Before the storm, **make sure that the auto samplers are setup to run by enabling the sampler** and that the battery levels are sufficient. Also ensure that the auto sampler is completely full of clean bottles and that there are enough caps on-site to close them all.

3.) Label all bottles before going in the field using the labeling tape. Samples should be labeled according to the sampling site, sampling type, how they were collected (auto, auto-reg, or grab), and the date they were collected. Ex: For Wet Weather Monitoring at Taylor Park, a grab sample collected on June 5th, 2008 would be labeled TP-WW-G1-06052008.

4.) Make sure that you have sample submittal forms for the State Labs, and the Water Science Labs. Also be sure you have enough wet-weather water quality sheets to do the analysis.

5.) Before visiting the site make sure you have your student ID, cell phone, City of Lincoln Letter, and site keys with you. The letter can be found in the black binder.

## On-Site Procedure

### *Visual Inspection and Data Collection*

1.) When arriving on-site, perform a visual inspection of the probes, the white tubes in the stream, to make sure there is no debris collected on it (**do not remove the debris now but wait until all the sampling has been finished**). Also, make sure the gauging station, or the green, metal box, does not have any holes in it. Record the precipitation amount in the plastic rain gauge located on the side of the gauging station.

2.) Check to make sure there are a sufficient number of samples to test a wet weather event. Follow the *sampling plan algorithm* provided. If you are unsure, contact your advisor via cell phone and discuss it with him. Faculty phone numbers can be found in the Contacts section of this manual. If there are a sufficient number of samples, remove the sample bottle tray from the gauging, which you will bring back to the civil engineering lab. Labeling is easily done back in the lab since all the bottles on the tray are in order. If the bottles are not to be used, empty them and replace them with clean bottles.

### *Collection of Grab Samples*

3.) Using the telescopic sampling pole, collect water and use it to fill the 1 L grab sample bottle for the appropriate site. The location of this collection should be as close to the USGS data probe as possible, and at about 1 foot below the water surface. Place this sample in the cooler and note the time that the sample was taken.

4.) Measure the temperature of the water in the stream using the electronic thermometer. This should be done as close to the USGS data probe as possible, and about 6 inches below the water surface. Record this temperature on the appropriate wet-weather monitoring sheet found in the black binder. Indicate that the temperature was taken inside the stream.

5.) Using the sampling pole, collect 2 L more of grab sample and determine its temperature again using the electronic thermometer. Let the temperature stabilize for about 2 minutes, then record the temperature on the appropriate wet-weather monitoring sheet. Indicate that the temperature was taken outside of the stream.

6.) Use the 2 L grab sample to fill the blue cap Teflon coated jar (500 ml), and be sure the jar is labeled correctly.

7.) Use the 2 L grab sample to fill the 250 mL SSC bottle for the appropriate site. This bottle will be used for the SSC test so be sure to fill it exactly to the 250 mL mark. Place this sample in the cooler and note the time that the sample was taken.

8.) Fill one 100 ml E.Coli sample bottle with the grab sample water. Then, fill out the form given with the bottle, and place it in the cooler. Do this for all of the grab samples taken. These samples are to be delivered to the Nebraska HHS Public Health lab.

9.) Fill a 250 ml grab sample bottle for the appropriate site. Preserve this sample by using the automatic pipette to add 1 ml of concentrated $H_2SO_4$ and place it in the cooler. This sample is to be delivered to Tong at the UNL Water Science lab to be tested for **Nitrate only**.

10.) Use the remaining grab sample water to run an on-site chlorine test. Refer to the on-site chlorine SOP if you are unfamiliar with the test.

11.) Dump out the excess water into the stream.

12.) Fill the 250 ml Glass Bottle by hand directly from the stream as close to the probe as possible. Be sure to cap the bottle immediately after pulling it from the stream. Refer to the SOP for on-site creation of a DO sample if you are not familiar with making one. Transport this sample using the cup holders in the car so that the water seal does not break. This sample is also delivered to the UNL Water Science lab to be tested for DO. Note: DO preservation requires 2 ml each of Manganese, Alkali-Iodide-Acid, and Conc. $H_2SO_4$ per sample.

### *Collection of Auto Samples*

13.) Make sure there are bottles (1 L) in the auto sampler, and that the auto sampler is on by opening the top lid of the auto sampler.

14.) Press [Manual Sample] to collect 1000 ml of water. Record the time. Collect one more sample by pressing [Next Bottle] to move to the next bottle. Remove the sampler lid; **discard the first sample taken as this may have some bias from previous sampling** and place a cap on the second full bottle. Immediately label the sample you collected manually as Auto-Reg and place it in the cooler to be returned.

15.) Replace any of the auto sampler bottles that need to be replaced. Close the sampler lid and be sure to disable the sampler.

### *Data Collection and Site Cleanup*

16.) Use the lap-top computer (password = W348NH) to download the data from the ISCO 3700 bubbler, ISCO 2150 Area-Velocity Meter, and the Onset Rain Gauge. Be sure to check the uploaded data to make sure that the programs and sampler are running correctly. At Taylor Park the 2150 meter is inside of the manhole. You will need to use the manhole cover remover and have your sampling partner wear the orange traffic vest and re-direct traffic while you collect the data.

17.) Close and Lock the USGS gauging station and be sure that you have left no trash lying around the station. **Be sure to now remove any debris that may be caught around the probe before leaving the site! This can be done using a stick or another object.**

### *Sample Delivery and Storage*

18.) Return to the Civil Engineering lab and immediately test each AutoSampler sample for turbidity to determine the storm hydrograph. Use Microsoft Excel on the laptop to quickly generate the graph and be sure to save it as that day's date (Hydrograph-MM-DD-YY). Follow the *sampling plan algorithm* provided to determine which bottles should be tested at the Water Science Lab and the Nebraska State Laboratories.

19.) Once the samples have been selected, a 250 ml bottles for each sample and label the bottles accordingly. Preserve each sample by using the automatic pipette to add 1 ml of concentrated $H_2SO_4$ and place it in the cooler. These samples are to be delivered to Tong at the UNL Water Science lab to be tested for **TKN, Ammonia, and Nitrate**.

20.) Fill a 100 ml E. coli sample for each of the auto samples selected. Fill out the supplied forms as you do this so the samples do not get mixed up. Be sure to correctly label the bottles for which auto sample is being tested.

21.) Now a 250 ml bottles for each **Auto-Reg sample** and label the bottles accordingly. Preserve each sample by using the automatic pipette to add 1 ml of concentrated $H_2SO_4$ and place it in the cooler. These samples are to be delivered to Tong at the UNL Water Science lab to be tested for **TKN and Nitrate.**

22.) The samples that will be tested in the CIVE lab should be stored in the refrigerator in the Civil Engineering labs until testing can be completed with them.

23.) After bottling has been completed, immediately deliver the E. coli samples to the Nebraska State Laboratories. The State Laboratories are located at S. 13th and Stockwell in Lincoln.

24.) Deliver all of the preserved 250 ml samples to Tong at the Water Science Lab on east campus. Make sure you have the sample submittal form completed when you submit your samples to him.

25.) Deliver the blue capped Teflon jars to the laboratory at the Theresa Street Waste Water treatment plant just west of 27th and Theresa Street.

26.) Upon returning to the lab, make sure all necessary items and paperwork are ready and available for the next sampling trip.

# Appendix P Regression Equations

## P.1 Continuous Models

### TSS Estimation Model

**Colonial Hills**

1: $\log_{10}TSS = -0.1737 + 1.2943*\log_{10}TBY$

2: $\log_{10}TSS = -0.2921 + 1.2705*\log_{10}TBY - 0.1737*\log_{10}V_n$ (BEST)

**Taylor Park**

$\log_{10}TSS = 0.3067 + 1.0678*\log_{10}TBY$

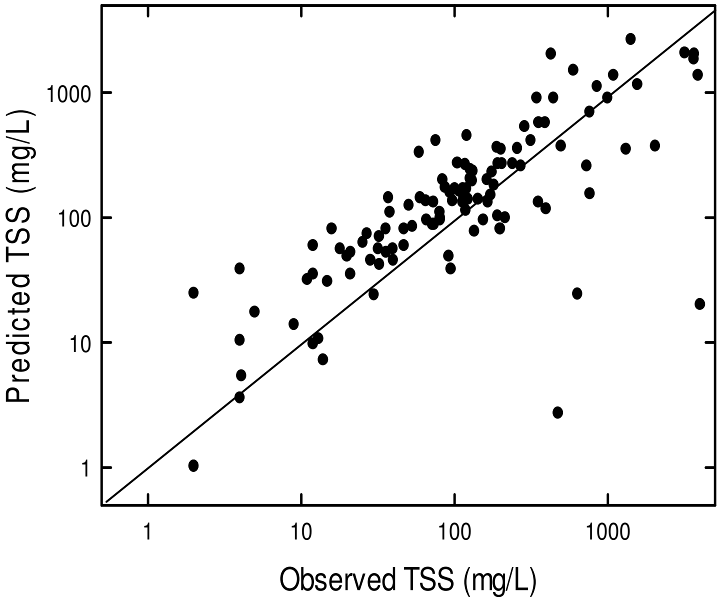

**Figure P.1: Example of regression results for Taylor Park TSS**

### SRP Estimation Model

**Colonial Hills**

$\log_{10}SRP = -0.3961 - 0.0008*Q + 0.6027*\log_{10}P + 0.4101*\sin(2\pi*day/365) + 0.1081*\cos(2\pi*day/365)$

**Taylor Park**

$\log_{10}SRP = -0.9472 + 0.3027*\log_{10}CDY + 0.371*\log_{10}I_P + 0.1801*\sin(2\pi*day/365) + 0.2127*\cos(2\pi*day/365)$

>>The intercept is not significant at the 5% level

## Total Phosphorus Estimation Model

**Colonial Hills**

1: $\log_{10}TP = -0.2793 + 0.0032*TBY – 0.0006*SR$

>>Similar to the Taylor Park model

2: $\log_{10}TP = -0.2015 + 0.0027*TBY – 0.0007*SR – 0.067*V_n$ (BEST)

3: $\log_{10}TP = -0.3666 + 0.0031*TBY – 0.0004*SR + 0.0057*ADD$

**Taylor Park**

$\log_{10}TP = -0.1024 + 0.0023*TBY - 0.0009*SR$ (BEST)

## NO3+NO2-N Estimation Model

**Colonial Hills**

1: $\log_{10}N+N = -1.2203 + 0.2843*\log_{10}CDY + 0.0177*ADD – 0.1483*\sin(2\pi*day/365) – 0.1735*\cos(2\pi*day/365)$ (BEST)

>>Residuals are not normally distributed

2: $\log_{10}N+N = -1.1114 + 0.2762*\log_{10}CDY + 0.0086*GDD$

>>Similar to the Taylor Park equation; residuals are not normally distributed

**Taylor Park**

$\log_{10}N+N = -1.245 + 0.3751*\log_{10}CDY + 0.0122*GDD$

## TKN Estimation Model

### Colonial Hills

1: $\log_{10}\mathrm{TKN} = -0.3403 + 0.1864*\log_{10}\mathrm{TBY} - 0.6747*\log_{10}\mathrm{P} + 0.0183*\mathrm{ADD} - 0.1744*\sin(2\pi*\mathrm{day}/365) - 0.0662*\cos(2\pi*\mathrm{day}/365)$

>>The cosine function is not significant at the 5% level; all variables are significant and produced the proper sign (according to Pearson r correlation)

2: $\log_{10}\mathrm{TKN} = -0.7084 + 0.224*\log_{10}\mathrm{TBY} - 0.8841*\log_{10}\mathrm{P} - 0.1102*\log \mathrm{V}_n + 0.04*\mathrm{ADD} - 0.2429*\sin(2\pi*\mathrm{day}/365) - 0.1825*\cos(2\pi*\mathrm{day}/365)$ (BEST)

>>GDD is correlated to the sine/cosine functions making it similar to the 2nd Taylor Park equation; the intercept is not significant at the 5% level; all variables are significant and produced the proper sign (according to Pearson r correlation)

### Taylor Park

$\log_{10}\mathrm{TKN} = 3.1842 + 0.2316*\log_{10}\mathrm{TBY} - 0.5376*\log_{10}\mathrm{P} - 1.2818*\log_{10}\mathrm{SR}$

$\log_{10}\mathrm{TKN} = -0.0034 + 0.1268*\log_{10}\mathrm{TBY} - 0.7331*\log_{10}\mathrm{P} - 0.1877*\log \mathrm{V}_n + 0.0188*\mathrm{ADD} - 0.0153*\mathrm{GDD}$ (BEST)

>>GDD is correlated to the sine/cosine functions making it similar to the 2nd Colonial Hills equation; the intercept is not significant at the 5% level

## Ammonia Estimation Model

### Colonial Hills

>>What to do about the "< MDL" values which were reported as ½ MDL value? I have tried with all of them and then removing every other. There are 17 total.

### Taylor Park

>>What to do about the "< MDL" values which were reported as ½ MDL value? I have tried with all of them and then removing every other. There are 17 total.

## E. coli Estimation Model

### Colonial Hills

1: $\log_{10}\mathrm{EC} = 3.5336 + 0.5533*\log_{10}\mathrm{TBY}$

2: $\log_{10}EC = 3.1288 + 1.8437*I_a + 0.1072*\log_{10}TBY + 0.9845*\log_{10}DO$

>>Turbidity is not significant at the 5% level (Pr>t = 0.30); residuals are not normally distributed

3: $\log_{10}EC = 2.5253 + 0.0685*\log_{10}TBY + 1.3067*I_A + 1.791*\log_{10}DO + 0.108*\sin(2\pi*day/365) - 0.3031*\cos(2\pi*day/365)$ (BEST)

>> Turbidity is not significant at the 5% level (Pr>t = 0.46); the sine function is not significant at the 10% level (Pr>t = 0.27)  residuals are not normally distributed

**Taylor Park**

$\log_{10}EC = 3.7935 + 0.4417*\log_{10}TBY$

## P.2 EMC Models

### Total Suspended Solids EMC Models

**Colonial Hills**

$\log_{10}TSS_{EMC} = 1.6632 + 0.0069*TBY_{EMC}$

$\log_{10}TSS_{EMC} = 1.7976 - 0.7508*P + 3.2652*I_p - 2.4825*I_a$

**Taylor Park**

$\log_{10}TSS_{EMC} = 1.6704 + 0.0073*TBY_{EMC}$

$\log_{10}TSS_{EMC} = 3.2248 - 0.5976*P + 0.7935*\log_{10}I_a$

### Soluble Reactive Phosphorus EMC Models

**Colonial Hills**

$SRP_{EMC} = 0.0933 + 0.0008*TBY_{EMC} + 0.0977*P$

$SRP_{EMC} = 0.2145 + 0.1384*P - 0.0063*GDD$

**Taylor Park**

$SRP_{EMC} = 1.4943 - 0.0009 * CDY_{EMC} - 0.4314 * \log_{10} SR$

$SRP_{EMC} = 0.6342 - 0.0008 * SR + 0.2119 * \log_{10} I_P$

## Total Phosphorus EMC Models

**Colonial Hills**

No significant models

**Taylor Park**

$\log_{10} TP_{EMC} = -0.5329 + 0.0036 * TBY_{EMC} + 0.431 * I_A + 0.1704 * \log_{10} ADD$

No significant hydrologic model

## NO3+NO2-N EMC Models

**Colonial Hills**

$\log_{10} N{+}N_{EMC} = -0.6511 + 0.2779 * \log_{10} ADD - 0.0757 * \sin(2\pi * day/365) - 0.224 * \cos(2\pi * day/365)$

No Significant Probe-only models

**Taylor Park**

$\log_{10} N{+}N_{EMC} = -3.6318 + 1.3773 * \log_{10} CDY_{EMC} + 0.4752 * \log_{10} P$

$N{+}N_{EMC} = 1.0693 + 0.4791 * \log_{10} I_A$

## TKN EMC Models

### Colonial Hills

$\log_{10}TKN_{EMC} = -1.5284 + 0.6877 * \log_{10}CDY_{EMC} + 0.0149 * GDD$

No significant hydrologic-only models

### Taylor Park

$TKN_{EMC} = 6.6846 + 1.6354 * \log_{10}TBY_{EMC} - 3.4492 * I_P + 2.432 * I_A - 2.5586 * \log_{10}SR$

$TKN_{EMC} = 2.7635 - 3.8713 * \log_{10}P - 1.7768 * \log_{10}GDD + 2.9973 * I_A$

## E. coli EMC Models

### Colonial Hills

$\log_{10}EC_{EMC} = 5.3993 - 0.0042 * TBY_{EMC} + 0.8284 * \log_{10}I_A$

$\log_{10}EC_{EMC} = 5.1103 + 0.7147 * \log_{10}I_A$

### Taylor Park

$EC_{EMC} = 22{,}9076 - 342.18 * TBY_{EMC} - 7{,}4296 * P - 2394.3 * ADD + 7{,}4345 * \log_{10}I_A$

$\log_{10}EC_{EMC} = 4.8385 - 0.3462 * P - 0.2747 * \sin(2\pi * day/365) - 0.2471 * \cos(2\pi * day/365)$

# Appendix Q Actual vs. Modeled Mass Load Comparison

For the tables below, refer to the table title to understand the data included. The results for Colonial Hills are on the left and Taylor Park on the right. The top row of tables is the calculated EMCs using the measured data from the storm events. The concentrations are milligrams per liter [mg/L] for all the water quality parameters except E. coli which is in [cfu/100 ml]. Subsequently, the mass load estimates are provided in kilograms [kg] for all the parameters except for E. coli, which is reported in [cfu*$10^9$].

**COLONIAL HILLS**

| Date | Measured EMCs | | | | | |
|---|---|---|---|---|---|---|
| | EC | N+N | SRP | TP | TSS | TKN |
| 4/29/2010 | NA | 0.5 | 0.4 | NA | 583 | 0.7 |
| 5/20/2010 | 29,406 | 0.4 | NA | NA | 43 | 1.3 |
| 6/8/2010 | 60,989 | 0.4 | 0.2 | 0.3 | 70 | 1.3 |
| 7/11/2010 | 59,308 | 0.7 | 0.3 | 0.4 | 52 | 1.3 |
| 8/4/2010 | 25,755 | 0.6 | 0.1 | 0.5 | 156 | 1.8 |

| Date | Measured EMC Loads | | | | | |
|---|---|---|---|---|---|---|
| | EC | N+N | SRP | TP | TSS | TKN |
| 4/29/2010 | NA | 19 | 16 | NA | 23,992 | 31 |
| 5/20/2010 | 5,305 | 7 | NA | NA | 772 | 24 |
| 6/8/2010 | 8,394 | 5 | 3 | 4 | 970 | 18 |
| 7/11/2010 | 35,097 | 41 | 17 | 22 | 3,065 | 76 |
| 8/4/2010 | 4,380 | 11 | 2 | 8 | 2,656 | 30 |

| Date | EMC-Probe Modeled Loads | | | | | |
|---|---|---|---|---|---|---|
| | EC | N+N | SRP | TP | TSS | TKN |
| 4/29/2010 | 5,150 | NA | 16 | NA | 44,225 | 46 |
| 5/20/2010 | 2,690 | NA | 4 | NA | 1,432 | 27 |
| 6/8/2010 | 5,789 | NA | 3 | NA | 1,311 | 24 |
| 7/11/2010 | 57,054 | NA | 19 | NA | 8,917 | 101 |
| 8/4/2010 | 4,762 | NA | 3 | NA | 1,363 | 54 |

**TAYLOR PARK**

| Date | Measured EMCs | | | | | |
|---|---|---|---|---|---|---|
| | EC | N+N | SRP | TP | TSS | TKN |
| 4/29/2010 | NA | 0.6 | 0.3 | NA | 168 | 1.2 |
| 5/20/2010 | 46,090 | 0.4 | NA | NA | 43 | 1.8 |
| 6/8/2010 | 80,299 | 0.7 | 0.3 | 0.4 | 87 | 1.8 |
| 7/11/2010 | 31,780 | 0.9 | 0.2 | 0.3 | 73 | 1.2 |
| 8/4/2010 | 66,401 | 0.9 | 0.1 | 0.5 | 181 | 1.1 |

| Date | Measured EMC Loads | | | | | |
|---|---|---|---|---|---|---|
| | EC | N+N | SRP | TP | TSS | TKN |
| 4/29/2010 | NA | 1.5 | 0.9 | NA | 444.0 | 3.1 |
| 5/20/2010 | 1439 | 1.3 | NA | NA | 135.5 | 5.6 |
| 6/8/2010 | 1206 | 1.0 | 0.4 | 0.5 | 131.1 | 2.6 |
| 7/11/2010 | 2503 | 7.4 | 1.9 | 2.4 | 575.2 | 9.1 |
| 8/4/2010 | 1013 | 1.4 | 0.2 | 0.7 | 276.5 | 1.7 |

| Date | EMC-Probe Modeled Loads | | | | | |
|---|---|---|---|---|---|---|
| | EC | N+N | SRP | TP | TSS | TKN |
| 4/29/2010 | 1,478 | 0.7 | 0.7 | 2.2 | 544 | 4 |
| 5/20/2010 | 1,173 | 0.9 | 0.6 | 1.6 | 285 | 6 |
| 6/8/2010 | 1,465 | 0.3 | 0.3 | 0.8 | 190 | 2 |
| 7/11/2010 | 3,099 | 2.8 | 1.4 | 9.0 | 920 | 8 |
| 8/4/2010 | 1,027 | 0.4 | 0.2 | 1.1 | 144 | 2 |

## COLONIAL HILLS

| Date | EMC-Climatic Modeled Loads | | | | | |
|---|---|---|---|---|---|---|
| | EC | N+N | SRP | TP | TSS | TKN |
| 4/29/2010 | 20,301 | 18 | 15 | NA | 24,490 | NA |
| 5/20/2010 | 2,633 | 9 | 6 | NA | 671 | NA |
| 6/8/2010 | 5,411 | 5 | 2 | NA | 2,137 | NA |
| 7/11/2010 | 60,550 | 38 | 18 | NA | 4,990 | NA |
| 8/4/2010 | 4,299 | 12 | 2 | NA | 6,143 | NA |

| Date | Continuous Model Loads | | | | | |
|---|---|---|---|---|---|---|
| | EC | N+N | SRP | TP | TSS | TKN |
| 4/29/2010 | 35,998 | 14 | 20 | 45 | 25,458 | 33 |
| 5/20/2010 | 9,236 | 8 | 7 | 6 | 770 | 16 |
| 6/8/2010 | 6,389 | 6 | 3 | 5 | 1,236 | 19 |
| 7/11/2010 | 296 | 29 | 11 | 22 | 8,993 | 72 |
| 8/4/2010 | 3,558 | 13 | 2 | 5 | 1,002 | 77 |

## TAYLOR PARK

| Date | EMC-Climatic Modeled Loads | | | | | |
|---|---|---|---|---|---|---|
| | EC | N+N | SRP | TP | TSS | TKN |
| 4/29/2010 | 900 | 1.9 | 0.7 | NA | 314 | 4 |
| 5/20/2010 | 1,637 | 1.3 | 0.4 | NA | 153 | 5 |
| 6/8/2010 | 1,226 | 1.0 | 0.2 | NA | 276 | 2 |
| 7/11/2010 | 2,796 | 7.7 | 1.4 | NA | 840 | 9 |
| 8/4/2010 | 1,370 | 1.0 | 0.2 | NA | 255 | 2 |

| Date | Continuous Model Loads | | | | | |
|---|---|---|---|---|---|---|
| | EC | N+N | SRP | TP | TSS | TKN |
| 4/29/2010 | 1,545 | 1.3 | 0.9 | 2.3 | 799 | 5 |
| 5/20/2010 | 1,311 | 1.5 | 0.6 | 1.3 | 342 | 5 |
| 6/8/2010 | 745 | 1.1 | 0.3 | 0.6 | 277 | 3 |
| 7/11/2010 | 3,653 | 4.8 | 1.6 | 2.6 | 1,286 | 7 |
| 8/4/2010 | 617 | 1.5 | 0.3 | 0.5 | 182 | 2 |

# Appendix R TSS Site Load Difference

**2010 TSS Seasonal Mass Load Estimates (from continuous models)**

Colonial Hills TSS mass load = 100,000 kg

Taylor Park TSS mass load = 17,150 kg

>>Assume a soil bulk density of 1.20 g/cm$^3$

**Convert solids mass to soil volume (1 cm$^3$ = 0.000001 m$^3$)**

**Drainage area factor between two watersheds (Colonial Hills = 243 ha; Taylor Park = 49 ha; CH/TP Factor = 243 ha/49 ha = 5.0)**

Colonial Hills TSS soil volume = 83.3 m$^3$

Taylor Park TSS soil volume = 14.3 m$^3$ * 5.0 (scale up) = 71.5 m$^3$

>>Assume a dump truck has a 10 m$^3$ soil capacity

**Difference = 83.3 – 71.5 = 11.8 m$^3$ = $\boxed{\textbf{1.2 dump truck loads}}$**

## Appendix S Dry Weather Water Quality Measurements

For the tables in this appendix, refer to **Table 4.1** (page 60) for water quality abbreviation definitions and **Table 4.2** (page 61) for measurement units and analytical methods. In the tables, “auto” refers to an autosample collected manually during the on-site monitoring and “grab” to the grab sample taken during dry weather monitoring.

**Table S.1: Colonial Hills Dry Weather Raw Data for 2008-2010 water quality monitoring**

| Date | Sample Type | $NH_4$ | COD | $Cl^-$ | $Cl_2$ | CDY | DO | EC | $F^-$ | N+N | pH | SRP | SF | WT | TKN | Cu | TP | TSS | TBY |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 8/13/2008 | Grab | < 0.05 | 19 | 59 | 0.28 | 958 | 5.3 | 630 | 0.68 | 0.56 | 8.26 | 0.50 | 0.026 | 24 | 0.30 | 0.056 |  | 16 | 2.47 |
| 8/13/2008 | Auto | < 0.05 | 21 |  |  | 920 |  | 450 |  | 0.76 | 8.18 | 0.46 |  |  | < 0.20 | 0.054 |  | 12 |  |
| 8/20/2008 | Grab | < 0.05 | 10 | 51 | 0.12 | 908 | 8.4 | 89 | 0.62 | < 0.05 | 8.26 | 0.17 | 0.018 | 25 | < 0.20 |  |  | 6 | 1.59 |
| 8/20/2008 | Auto | < 0.05 | 11 |  |  | 895 |  | 89 |  | < 0.05 | 8.21 | 0.17 |  |  | < 0.20 |  |  | 2 |  |
| 8/26/2008 | Grab | <0.05 | 12 | 54 | 0.23 | 897 | 11.4 | 42 | 0.65 | 0.91 | 8.32 | 0.10 | 0.019 | 23 | 0.28 |  |  | 4 | 1.40 |
| 8/26/2008 | Auto | <0.05 | 12 |  |  | 897 |  | 28 |  | 0.81 | 8.33 | 0.09 |  |  | 0.33 |  |  | 3 |  |
| 9/16/2008 | Grab | 0.28 | 12 | 66 | 0.13 | 1111 |  | 192 | 0.61 | 0.28 | 8.05 | 0.11 | 0.019 | 22 |  |  |  | 2 | 1.83 |
| 9/16/2008 | Auto | <0.05 | 13 |  |  | 1099 |  | 144 |  | 0.38 | 8.02 | 0.08 |  |  |  |  |  | 10 |  |
| 10/28/2008 | Grab | <0.05 | 5 | 63 | 0.15 | 1172 | 11.7 |  | 0.64 | 1.56 | 7.9 | 0.07 | 0.029 | 7 |  |  |  | 12.6 | 2.75 |
| 10/28/2008 | Auto | <0.05 | < MDL |  |  | 1177 |  |  |  | 1.48 | 7.9 | 0.52 |  |  |  |  |  | 3.7 |  |
| 3/25/2009 | Grab | 0.05 | 39 |  | 0.19 | 1123 | 11.00 | 134 |  |  | 8.12 | 0.71 |  | 10 | 0.27 |  |  | 3 | 7.41 |
| 3/25/2009 | Auto | 2.31 | 18 |  |  | 1135 |  |  |  |  | 7.89 | 0.61 |  |  | 0.41 |  |  |  |  |
| 5/20/2009 | Grab | <0.05 | 18 | 24.2 | < MDL | 992 | 9.3 | 250 | 0.63 |  | 8.03 | 0.72 | 0.55 | 23 | < 0.20 |  |  | 12 | 6.82 |
| 5/20/2009 | Auto | <0.05 | 14 |  |  | 984 |  | 326 |  |  | 8.12 | 0.66 |  |  | < 0.20 |  |  | 14 |  |
| 6/3/2009 | Grab | <0.05 | 22 | O.R. | 0.27 | 752 | 7.5 | 98 | 0.3 |  | 7.8 | 0.78 | 0.052 | 23 | 0.6 |  |  | 2.1 | 7.52 |
| 6/3/2009 | Auto | 0.05 | 24 |  |  | 735 |  | 130 |  |  | 7.81 | 1.17 |  |  | <0.20 |  |  | 12.0 |  |

## Table S.1 Continued

| Date | Sample Type | $NH_4$ | COD | $Cl^-$ | $Cl_2$ | CDY | DO | EC | $F^-$ | N+N | pH | SRP | SF | WT | TKN | Cu | TP | TSS | TBY |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 6/17/2009 | Grab | <0.05 | 28 | 68.3 | 0.18 | 757 | 4.4 | 472 | 0.49 |  | 7.78 | 0.79 | 0.027 | 24 | 0.38 |  |  | 7.3 | 1.67 |
| 6/17/2009 | Auto | <0.05 | 12 |  |  | 799 |  | 1164 |  |  | 7.98 | 0.73 |  |  | 0.38 |  |  | 11.6 |  |
| 6/30/2009 | Grab | <0.05 | 13 | 63.2 | 0.22 | 864 | 4.6 | 134 | 0.51 |  | 7.87 | 0.47 | 0.069 | 26 | < 0.20 |  |  | 2.4 | 0.983 |
| 6/30/2009 | Auto | 0.05 | < MDL |  |  | 865 |  | 156 |  |  | 8.04 |  |  |  | < 0.20 |  |  | 1.8 |  |
| 7/15/2009 | Grab | 0.22 | 23 | 34.8 | 0.14 | 753 | 4 | 978 | 0.61 |  | 7.9 | 0.39 | 0.063 | 23 |  |  |  | 6.6 | 2.78 |
| 7/15/2009 | Auto | 0.19 | 31 |  |  | 719 |  | 1036 |  |  | 7.91 | 0.35 |  |  |  |  |  | 7.5 |  |
| 7/29/2009 | Grab |  | 9 | 19.2 | 0.33 | 537 |  | 240 | 0.42 |  | 7.99 | 0.34 | 0.08 | 19 | 0.77 |  |  | 2.3 | 2.57 |
| 7/29/2009 | Auto |  | < MDL |  |  | 522 |  | 268 |  |  | 7.90 | 0.28 |  |  | 1.1 |  |  | 2.5 |  |
| 8/12/2009 | Grab | <0.05 | 17 | 25.4 | 0.16 | 832 |  | 364 | 0.91 | <0.05 | 7.94 | 0.31 | 0.12 | 24 |  |  |  | 2 | 2.9 |
| 8/12/2009 | Auto | 0.14 | 29 |  |  | 890 |  | 552 |  | <0.05 | 8.22 | 0.25 |  |  |  |  |  |  |  |
| 9/25/2009 | Grab | <0.05 | 12 | 19.4 | 0.08 | 979 |  |  | 0.71 |  | 1.56 | 0.58 |  |  | 0.6 |  |  | 1.5 | 1.56 |
| 9/25/2009 | Auto | <0.05 | 19 |  |  | 954 |  |  |  |  | 7.88 | 0.28 |  |  | 0.6 |  |  | 6 |  |
| 11/7/2009 | Grab | <0.05 |  | 26 | 0.09 | 1142 |  | 60 | 0.57 |  | 7.95 | 0.74 |  |  | 0.47 |  |  | 4.4 | 1.81 |
| 11/7/2009 | Auto | <0.05 |  |  |  | 1123 |  | 48 |  |  | 8.03 | 0.56 |  |  | 0.33 |  |  | 2.9 |  |
| 4/9/2010 | Grab | 0.792 | 11 | 125.4 | 0.10 | 1274 | -- | 119 | 0.69 | 0.792 | 7.95 | 0.35 | 0.020 | 16 | 10.06 | < MDL | -- | 5 | 5.92 |
| 4/9/2010 | Auto | 0.918 | 13 | 97.8 |  | 1303 |  | 100 | 0.68 | 0.918 | 8.00 | 0.33 | 0.015 |  | 11.01 |  | -- | 5 | 5.54 |
| 4/27/2010 | Grab | 1.505 | 12 | 32.5 | 0.20 | 702 | 7.9 | 215 | 0.31 | 0.795 | 7.73 | 0.55 | 0.048 | 18 | 0.55 | < MDL | 0.61 | 3 | 4.07 |
| 4/27/2010 | Auto | 0.819 | 8 |  |  | 703 |  | 261 |  | 0.819 | 7.85 | 0.54 |  |  | 2.22 |  | 0.63 | 4 |  |
| 5/25/2010 | Grab | <0.05 | 9 | 92 | 0.12 | 1081 | 2.8 | 470 | 0.67 | 0.317 | 8.01 | 0.451 | 0.024 | 20 | 0.62 | < MDL | 0.526 | 0 | 2.14 |
| 5/25/2010 | Auto |  | 14 |  |  | 1068 |  |  |  |  | 7.94 | 0.436 |  |  |  |  | 0.526 | 0 |  |
| 6/16/2010 | Grab | <0.050 | 17 | 66.4 | -- | 1037 | 7.1 | 805 | 0.53 | 0.799 | 8.20 | 0.432 | 0.016 | 23 | 0.47 | < MDL | 0.478 | 3 | 1.09 |
| 6/16/2010 | Auto |  | 16 |  |  | 1046 |  |  |  |  | 8.10 | 0.445 |  |  |  |  | 0.485 | 0 |  |
| 7/8/2010 | Grab | <0.050 | 16 | 52.8 | 0.20 | 967 | 6.9 | 1,610 | 0.57 | 1.420 | 7.97 | 0.506 | 0.039 | 21 | 0.96 | < MDL | 0.557 | 0 | 1.15 |
| 7/8/2010 | Auto |  | 19 |  |  | 948 |  |  |  |  | 7.94 | 0.493 |  |  |  |  | 0.539 | 2 |  |
| 7/28/2010 | Grab | <0.050 | 11 | 62.2 | 0.12 | 1044 | 9.2 | 150 | 0.53 | 0.608 | 8.28 | 0.168 | 0.019 | 27 | 0.395 | < MDL | 0.246 | 2 | 1.46 |
| 7/28/2010 | Auto |  | 9 |  |  | 1031 |  |  |  |  | 8.28 | 0.166 |  |  |  |  | 0.218 | 2 |  |
| 8/16/2010 | Grab | <0.050 | 14 | 58.8 | 0.08 | 993 | 5.0 | <100 | 0.70 | 0.532 | 7.98 | 0.263 | 0.013 | 22 | 0.46 | < MDL | 0.315 | 7 | 1.73 |
| 8/16/2010 | Auto |  | 21 |  |  | 1001 |  | 200 |  |  | 7.96 | 0.272 |  |  |  |  | 0.359 | 5 |  |

## Table S.1 Continued

| Date | Sample Type | NH$_4$ | COD | Cl$^-$ | Cl$_2$ | CDY | DO | EC | F$^-$ | N+N | pH | SRP | SF | WT | TKN | Cu | TP | TSS | TBY |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 9/8/2010 | Grab | <0.050 | 19 | 52.8 | 0.15 | 971 | 9.1 | 1,100 | 0.75 | 0.710 | 8.02 | 0.229 | 0.019 | 18 | 0.24 | < MDL | 0.284 | 2 | 0.936 |
| 9/8/2010 | Auto |  | 15 |  |  | 978 |  | 1,220 |  |  | 8.02 | 0.227 |  |  |  |  | 0.266 | 2 |  |
| 9/29/2010 | Grab | <0.050 | 9 | 51.6 | 0.07 | 1062 | 5.3 | 410 | 0.57 | 1.220 | 7.97 | 0.373 | 0.013 | 16 | 0.35 | < MDL | 0.413 | 1 | 1.16 |
| 9/29/2010 | Auto |  | 11 |  |  | 1038 |  | <100 |  |  | 8.03 | 0.366 |  |  |  |  | 0.396 | 1 |  |
| 10/20/2010 | Grab | 0.437 | 14 | 58 | 0.09 | 994 | 7.0 | 63 | 0.57 | 1.040 | 7.98 | 0.219 | 0.015 | 11 | 0.78 | < MDL | 0.222 | 0 | 2.97 |
| 10/20/2010 | Auto |  | 15 |  |  | 1000 |  | 84 |  |  | 7.95 | 0.210 |  |  |  |  | 0.241 | 2 |  |
| 11/8/2010 | Grab | 0.380 | 16 | 54.8 | 0.11 | 1086 | 7.8 | 37.9 | 0.66 | 0.713 | 7.97 | 0.261 | 0.049 | 9 | 0.30 | < MDL | 0.271 | 5 | 3.88 |
| 11/8/2010 | Auto |  | 13 |  |  | 1079 |  | 35.5 |  |  | 7.94 | 0.247 |  |  |  |  | 0.269 | 5 |  |
| 4/29/2011 | Grab | <0.050 | 14 | 59.2 | 0.17 | 1150 | 6.4 | 51.2 | 0.59 | 0.257 | 7.84 | 0.125 | 0.02 | 14 | 0.99 | < MDL | 0.135 | 0 | 3.96 |
| 4/29/2011 | Auto |  | 11 |  |  | 1026 |  |  |  |  | 7.9 | 0.124 |  |  |  |  | 0.135 | 0 |  |
| 5/23/2011 | Grab | <0.050 | 18 | 5.2 | 0.07 | 1082 | 2.9 | 520 | 0.27 | 0.49 | 7.96 | 0.317 | 0.024 | 20 | 0.78 | < MDL | 0.336 | 2 | 3.45 |
| 5/23/2011 | Auto |  | 18 |  |  | 1083 |  | 200 |  |  | 7.85 | 0.321 |  |  |  |  | 0.346 | 20 |  |
| 6/23/2011 | Grab | <0.050 | 19 | 69.2 | 0.16 | 994 | 3.9 |  | 0.78 | 0.749 | 8.09 | 0.185 | 0.09 |  | 0.586 | < MDL | 0.235 | 0 | 2.41 |
| 6/23/2011 | Auto |  | 27 |  |  | 987 |  | 1,200 |  |  | 8.05 | 0.174 |  |  |  |  | 0.196 | 9 |  |
| 7/18/2011 | Grab | 0.694 | 32 | 22.4 | 0.2 | 938 | 6.4 | 1,000 | 0.57 | 0.068 | 8.00 | 0.064 | 0.045 | 32 | < 0.20 | 0.059 | 0.114 | 5 | 5.39 |
| 7/18/2011 | Auto |  | 31 |  |  | 943 |  | 2,000 |  |  | 8.18 | 0.057 |  |  |  |  | 0.094 | 5 |  |
| 8/18/2011 | Grab | 0.066 | 21 | 62.8 | 0.12 | 939 | 4.5 | 630 | 0.6 | 0.077 | 8.26 | 0.064 | 0.044 | 22 | 1.010 |  | 0.074 | 0.6 | 1.2 |
| 8/18/2011 | Auto |  | 23 |  |  | 950 |  |  |  |  | 7.95 | 0.062 |  |  |  |  | 0.072 | 1.8 |  |
| 9/27/2011 | Grab |  | 15 | 52 | 0.09 | 997 | 10.4 | 100 | 0.63 | 0.377 | 8.00 | 0.059 | - | 20 | 0.367 |  | 0.073 | 2 | 1.57 |
| 9/27/2011 | Auto |  | 19 |  |  | 1003 |  |  |  |  | 7.98 | 0.049 |  |  |  |  | 0.067 | 5 |  |

## Table S.2: Taylor Park Dry Weather Raw Data for 2008-2010 water quality monitoring

| Date | Sample Type | NH$_4$ | COD | Cl$^-$ | Cl$_2$ | CDY | DO | EC | F$^-$ | N+N | pH | SRP | SF | WT | TKN | Cu | TP | TSS | TBY |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 8/13/2008 | Grab | 0.07 | 18 | 41 | 0.05 | 809 | 9.9 | 2250 | 0.84 | 0.97 | 8.03 | 0.78 | 0.014 | 24 | < 0.20 | 0.023 |  | 1 | 2.44 |
| 8/13/2008 | Auto | 0.07 | 13 |  |  | 817 |  | 2360 |  | 1.74 | 7.87 | 0.89 |  |  | 0.44 | 0.028 |  | 2 |  |
| 8/20/2008 | Grab | 0.08 | 14 | 55 | 0.14 | 876 | 5.7 | 1987 | 0.85 | 2.32 | 7.96 | 1.07 | 0.030 | 23 | 2.74 |  |  | 7 | 2.47 |
| 8/20/2008 | Auto | 0.11 | 14 |  |  | 882 |  |  |  | 2.28 | 8.02 | 0.99 |  |  | 2.61 |  |  | 6 |  |
| 8/26/2008 | Grab | < 0.05 | 11 | 32 | 0.1 | 906 | 8.6 | 173 | 0.84 | <0.05 | 8.15 | 0.60 | 0.020 | 23 | < 0.20 |  |  | 2 | 1.51 |
| 8/26/2008 | Auto | < 0.05 | 11 |  |  | 902 |  | 131 |  | <0.05 | 8.43 | 0.59 |  |  | 0.39 |  |  | 3 |  |
| 9/16/2008 | Grab | 0.23 | 14 | 62 | 0.09 | 1260 | - | 732 | 0.83 | 0.87 | 7.79 | 0.42 | 0.024 | 21 |  |  |  | 1 | 1.21 |
| 9/16/2008 | Auto | 0.08 | 25 |  |  | 1229 |  | 822 |  | 0.62 | 7.75 | 0.41 |  |  |  |  |  | 5 |  |
| 10/28/2008 | Grab | 0.13 | - | 41 | 0.14 | 1486 | 5.3 |  | 0.66 | 1.85 | 6.2 | 0.37 | 0.019 | 11 |  |  |  | 4.8 | 1.28 |
| 10/28/2008 | Auto | 0.16 | 5 |  |  | 1309 |  |  |  | 1.95 | 6.9 | 0.46 |  |  |  |  |  | 6 |  |
| 3/25/2009 | Grab | < 0.05 | 15 |  | 0.19 | 1099 | 7.2 | 53 |  |  | 7.89 | 0.59 |  | 11 | < 0.20 |  |  | 3 | 1.77 |
| 3/25/2009 | Auto | < 0.05 | 10 |  |  | 1135 |  |  |  |  | 7.77 | 0.51 |  |  | < 0.20 |  |  | 2 |  |
| 5/20/2009 | Grab | 0.09 | 12 | 24.5 | 0.02 | 1005 | 5.3 | 1454 | 0.68 |  | 7.91 | 0.99 | 0.031 | 16 | 0.22 |  |  | 5 | 1.67 |
| 5/20/2009 | Auto | < 0.05 | 14 |  |  | 1039 |  | 924 |  |  | 7.87 | 0.95 |  |  | 0.20 |  |  | 7 |  |
| 6/3/2009 | Grab | 0.37 | 15 | 18.3 | 0.22 | 1089 | 8.7 | 478 | 0.54 |  | 7.89 | 1.66 | 0.035 | 17 | 0.82 |  |  | 9.7 | 1.81 |
| 6/3/2009 | Auto | 0.21 | 18 |  |  | 1112 |  | 4480 |  |  | 7.84 | 1.02 |  |  | 0.74 |  |  | 17.7 |  |
| 6/17/2009 | Grab | 0.08 | 5 | 49 | 0.21 | 1193 | 4.3 | 1298 | 0.55 |  | 7.96 | 0.7 | 0.023 | 18 | 1.45 |  |  | 11.9 | 1.69 |
| 6/17/2009 | Auto | 0.12 | 5 |  |  | 1185 |  | 1734 |  |  | 7.97 | 0.76 |  |  | 1.43 |  |  | 7.1 |  |
| 6/30/2009 | Grab | < 0.05 | 21 | 35.5 | 0.11 | 948 | 9.5 | 1734 | 0.77 |  | 8.21 | 0.78 | 0.04 | 20 | < 0.20 |  |  | 1.6 | 0.555 |
| 6/30/2009 | Auto | < 0.05 | 13 |  |  | 967 |  | 1454 |  |  | 8.07 | 0.78 |  |  | 0.21 |  |  | 1.0 |  |
| 7/15/2009 | Grab | 0.20 | 16 | 30.1 | 0.16 | 987 | 4 | 3974 | 0.73 |  | 7.8 | 0.85 | 0.042 | 19 |  |  |  | 2.7 | 1.27 |
| 7/15/2009 | Auto | 0.19 | 23 |  |  | 915 |  | 4840 |  |  | 8.02 | 0.74 |  |  |  |  |  | 1.8 |  |
| 7/29/2009 | Grab |  | 5 | 33.4 | 0.21 | 1474 |  | 582 | 0.66 |  | 7.85 | 0.79 | 0.04 | 18 | 0.74 |  |  | 0.7 | 0.658 |
| 7/29/2009 | Auto |  | 5 |  |  | 925 |  | 314 |  |  | 8.08 | 0.72 |  |  | 0.88 |  |  | 0.6 |  |

## Table S.2 Continued

| Date | Sample Type | $NH_4$ | COD | $Cl^-$ | $Cl_2$ | CDY | DO | EC | $F^-$ | N+N | pH | SRP | SF | WT | TKN | Cu | TP | TSS | TBY |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 8/12/2009 | Grab | 0.15 | 30 | 34.4 | 0.13 | 921 | | 1956 | 0.77 | 0.1 | 8.17 | 0.22 | 0.05 | 20 | | | | | 3.25 |
| 8/12/2009 | Auto | 0.16 | 33 | | | 852 | | 1644 | | 0.08 | 7.78 | 0.42 | | | | | | 5 | |
| 9/25/2009 | Grab | 2.17 | 14 | 34.4 | 0.08 | 987 | | | 0.48 | | 7.54 | 1.75 | | | 3.12 | | | 3.6 | 1.84 |
| 9/25/2009 | Auto | 1.73 | 13 | | | 977 | | | | | 7.7 | 1.34 | | | 3.67 | | | 9.4 | |
| 11/7/2009 | Grab | < 0.05 | | 26.6 | 0.11 | 1199 | | 40 | 0.55 | | 7.84 | 1.07 | | | 0.33 | | | 5.9 | 1.87 |
| 11/7/2009 | Auto | < 0.05 | | | | 1182 | | 32 | | | 7.86 | 0.83 | | | 0.33 | | | 9.8 | |
| 4/9/2010 | Grab | 1.712 | 5 | 57 | 0.28 | 1176 | - | | 0.60 | 1.712 | 7.90 | 0.53 | 0.016 | 17 | 0.41 | < MDL | - | 1 | 1.73 |
| 4/9/2010 | Auto | 1.656 | 4 | 53 | | 1195 | | | 0.67 | 1.656 | 7.95 | 0.48 | 0.011 | | 0.25 | | - | 1 | 1.80 |
| 4/27/2010 | Grab | 1.507 | < MDL | 48.5 | 0.17 | 1164 | 3.6 | | 0.52 | 1.507 | 7.83 | 0.58 | 0.039 | 15 | 0.77 | < MDL | 0.75 | 0 | 1.17 |
| 4/27/2010 | Auto | 0.795 | < MDL | | | 1157 | | | | 1.505 | 7.87 | 0.58 | | | 0.38 | | 0.67 | 1 | |
| 5/25/2010 | Grab | 0.069 | 11 | 53.2 | 0.10 | 1143 | 2.6 | 1,120 | 0.64 | 1.443 | 7.88 | 0.811 | 0.024 | 17 | 0.96 | < MDL | 0.947 | | 6.71 |
| 5/25/2010 | Auto | | 11 | | | 1151 | | | | | 7.81 | 0.712 | | | | | 0.791 | 1 | |
| 6/16/2010 | Grab | 0.097 | 13 | 51.6 | 0.23 | 1135 | 6.0 | 3,680 | 0.56 | 2.021 | 8.26 | 0.580 | 0.013 | 18 | 0.42 | < MDL | 0.608 | 0 | 2.29 |
| 6/16/2010 | Auto | | 17 | | | 1147 | | | | | 8.08 | 0.572 | | | | | 0.593 | 1 | |
| 7/8/2010 | Grab | < 0.05 | 9 | 45.2 | 0.16 | 1080 | 7.1 | 1,350 | 0.62 | 2.219 | 8.13 | 0.486 | 0.018 | 19 | 0.29 | < MDL | 0.508 | 2 | 1.03 |
| 7/8/2010 | Auto | | 13 | | | 1096 | | | | | 8.18 | 0.471 | | | | | 0.514 | 1 | |
| 7/28/2010 | Grab | < 0.05 | < MDL | 39.4 | 0.23 | 1046 | 11.9 | 975 | 0.57 | 2.365 | 8.32 | 0.457 | 0.015 | 22 | 0.261 | < MDL | 0.483 | 0 | 0.899 |
| 7/28/2010 | Auto | | 4 | | | 1064 | | | | | 8.35 | 0.435 | | | | | 0.464 | 1 | |
| 8/16/2010 | Grab | < 0.05 | 17 | 36.4 | 0.12 | 928 | 4.9 | 1,320 | 0.88 | 2.187 | 7.99 | 0.629 | 0.015 | 19 | 0.55 | < MDL | 0.656 | 2 | 1.39 |
| 8/16/2010 | Auto | | 20 | | | 923 | | 1,850 | | | 8.08 | 0.609 | | | | | 0.665 | 4 | |
| 9/8/2010 | Grab | < 0.05 | 15 | 31.6 | 0.27 | 931 | 7.2 | 3,180 | 0.88 | 1.929 | 8.08 | 0.684 | 0.014 | 19 | 0.48 | < MDL | 0.722 | 0 | 1.47 |
| 9/8/2010 | Auto | | 18 | | | 931 | | 1,690 | | | 8.06 | 0.710 | | | | | 0.730 | 6 | |
| 9/29/2010 | Grab | < 0.05 | 17 | 30 | 0.06 | 962 | 4.3 | 15,000 | 0.71 | 1.930 | 7.89 | 0.712 | 0.013 | 17 | 1.27 | < MDL | 0.763 | 4 | 2.73 |
| 9/29/2010 | Auto | | 18 | | | 941 | | 12,230 | | | 7.90 | 0.706 | | | | | 0.756 | 2 | |
| 10/20/2010 | Grab | 0.653 | 20 | 44.4 | 0.04 | 1026 | 4.7 | 200 | 0.69 | 1.980 | 7.82 | 0.618 | 0.016 | 13 | 0.98 | < MDL | 0.634 | 1 | 0.966 |
| 10/20/2010 | Auto | | 23 | | | 1029 | | 310 | | | 7.93 | 0.599 | | | | | 0.633 | 1 | |

## Table S.2 Continued

| Date | Sample Type | $NH_4$ | COD | $Cl^-$ | $Cl_2$ | CDY | DO | EC | $F^-$ | N+N | pH | SRP | SF | WT | TKN | Cu | TP | TSS | TBY |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 11/8/2010 | Grab | 0.925 | 15 | 42 | 0.07 | 1077 | 4.4 | 41.4 | 0.67 | 0.148 | 7.99 | 0.391 | 0.073 | 11 | 0.37 | < MDL | 0.419 | 2 | 0.823 |
| 11/8/2010 | Auto |  | 14 |  |  | 1083 |  | 39.7 |  |  | 7.93 | 0.375 |  |  |  |  | 0.415 | 0 |  |
| 4/29/2011 | Grab | < 0.05 | 7 | 40.8 | 0.18 | 1121 | 7.8 | 1553.1 | 0.63 | 1.87 | 8.01 | 0.084 | 0.015 | 15 | 1.23 | 0 | 0.084 | 24 | 0.83 |
| 4/29/2011 | Auto |  | 2 |  |  | 1138 |  |  |  |  | 7.97 | 0.089 |  |  |  |  | 0.093 | 0 |  |
| 5/23/2011 | Grab | < 0.05 | 18 | 5.9 | 0.22 | 1116 |  | 520 | 0.32 | 2.31 | 8 | 0.121 | 0.018 | 16 | 0.917 | 0 | 0.133 | 47 | 7.96 |
| 5/23/2011 | Auto |  | 19 |  |  | 1094 |  | 850 |  |  | 7.9 | 0.124 |  |  |  |  | 0.129 | 12 |  |
| 6/23/2011 | Grab | < 0.05 | 19 | 57.2 | 0.11 | 1060 | 6.4 | 2,030 | 0.62 | 2.60 | 8.23 | 0.149 | 0.048 |  | 0.666 | 0 | 0.176 | 3 | 2 |
| 6/23/2011 | Auto |  | 20 |  |  | 1061 |  | 2,920 |  |  | 8.11 | 0..454 |  |  |  |  | 0.163 | 6 |  |
| 7/18/2011 | Grab | 0.074 | 25 | 10.4 | 0.15 | 1005 | 15.9 | < 1,000 | 0.73 | 1.98 | 7.93 | 0.212 | 0.014 | 25 | < 0.20 | 0.059 | 0.236 | 3 | 0.936 |
| 7/18/2011 | Auto |  | 33 |  |  | 1005 |  | 1,000 |  |  | 8.00 | 0.224 |  |  |  |  | 0.246 | 2 |  |
| 8/18/2011 | Grab | 0.617 | 21 | 44.8 | 0.1 | 1030 | 6.4 | 7,500 | 0.69 | 1.23 | 8.33 | 0.158 | 0.03 | 21 | 0.593 | - | 0.171 | 1.4 | 1.05 |
| 8/18/2011 | Auto |  | 22 |  |  | 1065 |  |  |  |  | 7.98 | 0.157 |  |  |  |  | 0.172 | 0.4 |  |
| 9/27/2011 | Grab |  | 20 | 59.2 | 0.07 | 1074 | 5.3 | 100 | 0.76 | 2.47 | 7.81 | 0.293 | - | 20 | 4.2 | - | 0.296 | 2 | 1.34 |
| 9/27/2011 | Auto |  | 22 |  |  | 1084 |  |  |  |  | 7.76 | 0.342 |  |  |  |  | 0.349 | 3 |  |

# Appendix T Wet Weather Water Quality Measurements

For the tables in this appendix, refer to **Table 4.1** (page 60) for water quality abbreviation definitions and **Table 4.2** (page 61) for measurement units and analytical methods. In the tables, “A#” refers to the autosample number collected automatically during the storm event, “AReg” refers to an auto-regulatory sample collected manually during the on-site monitoring visit, and “grab” refers to the grab sample taken during dry weather monitoring.

**Table T.1: Colonial Hills Wet Weather Raw Data for 2008-2010 water quality monitoring**

| Date | Time | Sample Type | $NH_4$ | COD | $Cl^-$ | $Cl_2$ | CDY | DO | EC | N+N | OG | pH | SRP | SSC | WT | TKN | Cu | TP | TSS | TBY |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10/6/2008 | 16:22 | A1 | <0.05 | 62 | 33.0 |  | 827 |  | -- | 0.32 |  |  | 0.4 |  |  |  |  |  | 28.6 | 6.4 |
| 10/6/2008 | 16:47 | A2 | <0.05 | 30 | 24.0 |  | 607 |  | 11,200 | 0.49 |  |  | 0.64 |  |  |  |  |  | 22.3 | 13.1 |
| 10/6/2008 | 17:37 | A4 | <0.05 | 41 | 18.8 |  | 480 |  | 48,900 | 0.67 |  |  | 0.85 |  |  |  |  |  | 16.0 | 13.0 |
| 10/7/2008 | 1:17 | A1 | <0.05 | 28 | 10.1 |  | 293 |  | 3,260 | 0.22 |  |  | 0.48 |  |  |  |  |  | 32.3 | 21.4 |
| 10/7/2008 | 2:07 | A2 | <0.05 | 45 | 9.2 |  | 229 |  | 9,810 | 0.22 |  |  | 0.49 |  |  |  |  |  | 178.3 | 86.4 |
| 10/7/2008 | 3:47 | A4 | <0.05 | 23 | 7.6 |  | 173 |  | 9,810 | 0.20 |  |  | 0.47 |  |  |  |  |  | 14.5 | 12.7 |
| 10/7/2008 | 9:45 | Grab |  | 20 |  |  |  | 4.0 | 4,890 |  | <5.0 | 7.55 |  |  |  |  |  |  | 3.5 |  |
| 10/7/2008 | 9:50 | AReg |  | 23 |  |  |  |  |  |  |  | 7.51 |  |  |  |  |  |  | 8.2 |  |
| 4/27/2009 | 14:30 | A1 | 1.17 | 14 | 24.3 |  | 290 |  | 7,950 | 0.48 |  |  |  |  |  | 0.47 |  |  | 66.2 | 32.8 |
| 4/27/2009 | 16:30 | Grab | 0.08 | 25 |  | 0.13 |  |  | 1,550 | 0.8 | <5.0 | 7.6 |  |  |  | 0.96 |  |  | 2.9 | 15.1 |
| 4/27/2009 | 16:35 | AReg |  | 32 |  |  |  |  |  |  |  | 7.63 |  |  |  |  |  |  | 53.9 |  |
| 7/14/2009 | 4:19 | A1 |  | 31 | 61.0 |  | 852 |  | 50 |  |  |  | 0.3 |  |  |  |  |  | 6.5 |  |
| 7/14/2009 | 4:33 | A2 |  | 24 | 57.3 |  | 856 |  | 88 |  |  |  | 0.25 |  |  |  |  |  | 14.7 |  |
| 7/14/2009 | 4:38 | A3 |  | 24 | 36.3 |  | 848 |  | 74 |  |  |  | 0.25 |  |  |  |  |  | 12.8 |  |
| 7/14/2009 | 4:51 | A4 |  | 36 | 19.9 |  | 294 |  | 4,188 |  |  |  | 0.21 |  |  |  |  |  | 39.0 |  |
| 7/14/2009 | 11:45 | Grab |  | 36 |  | 0.11 | 287 |  | -- |  | <5.0 | 7.71 |  |  |  |  |  |  | 13.0 |  |
| 7/14/2009 | 11:50 | AReg |  | 37 |  |  | 279 |  |  |  |  | 8.07 | 0.28 |  |  |  |  |  | 16.0 |  |

## Table T.1 Continued

| Date | Time | Sample Type | $NH_4$ | COD | $Cl^-$ | $Cl_2$ | CDY | DO | EC | N+N | OG | pH | SRP | SSC | WT | TKN | Cu | TP | TSS | TBY |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 8/4/2009 | 4:47 | A1 |  | 116 | 7.6 |  | 73.1 |  | -- | 0.35 |  |  | 0.29 |  |  | 3.23 |  |  | 826 | 298 |
| 8/4/2009 | 5:00 | A2 |  | 144 | 6.2 |  | 78.5 |  | 38,800 | 0.4 |  |  | 0.87 |  |  | 2.38 |  |  | 1503 | 360 |
| 8/4/2009 | 5:02 | A3 |  | 171 | 6.8 |  | 90.1 |  | 29,900 | 0.38 |  |  | 1.07 |  |  | 2.77 |  |  | 1530 | 349 |
| 8/4/2009 | 5:03 | A4 |  | 182 | 1.9 |  | 97.1 |  | 34,500 | 0.39 |  |  | 1.32 |  |  | 2.27 |  |  | 1854 | 350 |
| 8/4/2009 | 5:07 | A6 |  | 102 | 3 |  | 74.2 |  | -- | 0.38 |  |  | 0.75 |  |  | 1.86 |  |  | 716 | 171 |
| 8/4/2009 | 5:10 | A8 |  | 120 | 5.6 |  | 85.4 |  | 21,900 | 0.33 |  |  | 0.42 |  |  | 1.56 |  |  | 870 | 209 |
| 8/4/2009 | 5:13 | A10 |  | 198 | 9.8 |  | 162.7 |  | 19,870 | 0.36 |  |  | 0.29 |  |  | 2.11 |  |  | 1850 | 371 |
| 8/4/2009 | 12:00 | Grab |  | 60 |  | 0.06 |  |  | -- |  | <5.0 | 7.87 |  |  |  |  |  |  | 17 | 7.12 |
| 8/4/2009 | 12:05 | AReg |  | 74 |  |  |  |  |  | 1.14 |  | 7.67 | 0.81 |  |  | 1.29 |  |  | 171 |  |
| 8/26/2009 | 8:00 | A1 | 0.27 | 17 | 5.1 |  | 873 |  | -- | 0.37 |  |  | 0.44 |  |  |  |  |  | 28.2 | 7.43 |
| 8/26/2009 | 11:30 | Grab | 0.13 | 37 |  | 0.04 |  |  | -- | <0.05 | <5.0 | 7.71 |  |  |  |  |  |  | 7.8 | 16.8 |
| 8/26/2009 | 11:35 | AReg | 0.14 | 34 |  |  |  |  |  | <0.05 |  | 7.80 | 0.4 |  |  |  |  |  | 15.3 |  |
| 9/3/2009 | 10:50 | A1 |  | 46 | 39.8 |  | 883 |  | 598 | 0.09 |  |  | 0.68 |  |  | 0.6 |  |  | 15.8 | 7.63 |
| 9/3/2009 | 11:29 | A3 |  | 48 | 1.8 |  | 642 |  | 20,500 | -- |  |  | 1.02 |  |  | 1.81 |  |  | 35.6 | 27.1 |
| 9/3/2009 | 11:57 | A5 |  | 66 | 1.4 |  | 275 |  | 15,540 | 0.88 |  |  | 0.91 |  |  | 1.81 |  |  | 126.8 | 58.9 |
| 9/3/2009 | 12:12 | A7 |  | 58 | 1.4 |  | 135 |  | 9,680 | 0.86 |  |  | 0.87 |  |  | 1.73 |  |  | 241.4 | 83.3 |
| 9/3/2009 | 12:18 | A9 |  | 80 | 0.0 |  | 106 |  | 15,540 | 0.88 |  |  | 0.71 |  |  | 2.08 |  |  | 511.4 | 156 |
| 9/3/2009 | 12:21 | A11 |  | 72 | 1.4 |  | 88.9 |  | 19,870 | 0.44 |  |  | 0.78 |  |  | 1.7 |  |  | 591.2 | 162 |
| 9/3/2009 | 14:30 | Grab |  | 43 |  | <MDL |  |  | 72,700 | 0.37 | <5.0 | 7.75 |  |  |  | 1.67 |  |  | 33.1 | 26.3 |
| 9/3/2009 | 14:35 | AReg |  | 49 |  |  |  |  |  | 0.34 |  | 7.65 | 1.43 |  |  | 1.59 |  |  | 45.6 |  |
| 4/29/2010 | 21:28 | A1 | 0.164 | 144 | 19.8 |  | 207 |  | -- | 0.430 |  |  | 1.34 |  |  | 0.99 | <MDL | -- | 715 | 225.0 |
| 4/29/2010 | 21:43 | A2 | 0.228 | 196 | 22.2 |  | 158 |  | -- | 0.390 |  |  | 2.33 |  |  | 1.26 | <MDL | -- | 1084 | 363.0 |
| 4/29/2010 | 21:53 | A3 | 0.189 | 184 | 15.4 |  | 106 |  | -- | 0.286 |  |  | 1.78 |  |  | 2.27 | <MDL | -- | -- | 410.0 |
| 4/29/2010 | 22:00 | A4 | 0.083 | 134 | 12.8 |  | 98.1 |  | -- | 0.319 |  |  | 1.35 |  |  | 0.52 | <MDL | -- | 832 | 257.0 |
| 4/29/2010 | 22:05 | A5 | 0.215 | 204 | 18.6 |  | 113 |  | -- | 0.274 |  |  | 2.15 |  |  | 0.85 | <MDL | -- | 1294 | 386.0 |
| 4/29/2010 | 22:10 | A6 | 0.218 | 176 | 19.6 |  | 117 |  | -- | 0.253 |  |  | 2.05 |  |  | 0.36 | 0.153 | -- | 1430 | 350.0 |
| 4/29/2010 | 22:17 | A7 | 0.100 | 88 | 16.8 |  | 110 |  | -- | 0.313 |  |  | 1.20 |  |  | 0.63 | <MDL | -- | 663 | 225.0 |
| 4/30/2010 | 9:56 | AReg |  | 36 |  |  |  |  | -- | 0.972 |  | 7.92 | 0.74 |  |  | 0.82 |  | -- | 41 |  |
| 4/30/2010 | 9:50 | Grab |  | 27 |  | 0.06 |  | 6.8 | -- | 1.107 | <5.0 | 7.83 |  | -- | 14 |  |  | -- | 3 | 14.6 |

## Table T.1 Continued

| Date | Time | Sample Type | $NH_4$ | COD | $Cl^-$ | $Cl_2$ | CDY | DO | EC | N+N | OG | pH | SRP | SSC | WT | TKN | Cu | TP | TSS | TBY |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5/20/2010 | 5:38 | A1 | 0.096 | 40 | 67.6 |  | 871 |  | 8,670 | 0.691 |  |  | -- |  |  | 0.91 |  | -- | 4 | 5.2 |
| 5/20/2010 | 6:27 | A2 | <0.05 | 44 | 21.9 |  | 311 |  | 15,540 | 0.541 |  |  | -- |  |  | 1.21 | <MDL | -- | 42 | 18.9 |
| 5/20/2010 | 6:42 | A3 | <0.05 | 38 | 19.7 |  | 320 |  | 29,100 | 0.602 |  |  | -- |  |  | 0.85 | <MDL | -- | 35 | 18.8 |
| 5/20/2010 | 7:56 | A4 | <0.05 | 24 | 5.7 |  | 139.4 |  | 48,900 | 0.311 |  |  | -- |  |  | 0.92 |  | -- | 16 | 13.6 |
| 5/20/2010 | 8:55 | A5 | <0.05 | 48 | 8.1 |  | 147.2 |  | 19,870 | 0.334 |  |  | -- |  |  | 1.05 |  | -- | 25 | 20.2 |
| 5/20/2010 | 9:30 | A6 | <0.05 | 20 | 8.9 |  | 147.1 |  | 22,500 | 0.267 |  |  | -- |  |  | 1.30 |  | -- | 39 | 27.5 |
| 5/20/2010 | 9:56 | A7 | 0.051 | 56 | 8.8 |  | 131.5 |  | 26,200 | 0.232 |  |  | -- |  |  | 1.41 | <MDL | -- | 87 | 38.2 |
| 5/20/2010 | 17:05 | AReg |  | 56 |  |  |  |  |  | 0.495 |  | 7.88 | 0.632 |  |  | 1.56 |  | 0.796 | 13 |  |
| 5/20/2010 | 17:00 | Grab |  | 72 |  | 0.03 |  | 7.2 | -- | 0.470 | 7.0 | 7.82 | 0.629 | -- | 15 |  |  | 0.781 | 7 | 23.4 |
| 6/8/2010 | 4:07 | A1 | 0.100 | 40 | 17.2 |  | 154.6 |  | 43,600 | 0.375 |  |  | 0.540 |  |  | 1.27 |  | 1.060 | 174 | 64.2 |
| 6/8/2010 | 4:12 | A2 | 0.071 | 28 | 15.3 |  | 137.2 |  | 51,800 | 0.375 |  |  | 0.771 |  |  | 1.54 | <MDL | 1.370 | 260 | 88.0 |
| 6/8/2010 | 4:15 | A3 | 0.112 | 72 | 12.0 |  | 172.6 |  | 86,700 | 0.416 |  |  | 0.879 |  |  | 2.30 |  | 1.700 | 327 | 101.0 |
| 6/8/2010 | 4:22 | A4 | 0.063 | 50 | 12.0 |  | 122.0 |  | 41,100 | 0.380 |  |  | 0.695 |  |  | 1.72 |  | 1.150 | 186 | 70.2 |
| 6/8/2010 | 4:34 | A5 | 0.106 | 32 | 8.9 |  | 89.4 |  | 38,800 | 0.338 |  |  | 0.568 |  |  | 1.28 | <MDL | 0.854 | 86 | 38.0 |
| 6/8/2010 | 4:51 | A6 | 0.073 | 20 | 8.1 |  | 98.3 |  | 46,200 | 0.350 |  |  | 0.596 |  |  | 0.92 |  | 0.812 | 38 | 25.3 |
| 6/8/2010 | 5:56 | A7 | 0.053 | 72 | 9.9 |  | 130.9 |  | 98,100 | 0.405 |  |  | 0.594 |  |  | 1.33 |  | 0.852 | 19 | 18.8 |
| 6/8/2010 | 9:50 | AReg |  | 60 |  |  |  |  |  | 0.460 |  | 7.74 | 0.609 |  |  | 1.45 |  | 0.889 | 12 |  |
| 6/8/2010 | 9:45 | Grab |  | 52 |  | 0.07 |  | 5.8 | 48,900 | 0.527 | <5.0 | 7.71 |  | 12.7 | 20 |  |  |  | 6 | 14.5 |
| 7/11/2010 | 2:03 | A1 | <0.05 | 54 | 22.1 |  | 314.0 |  | 78,600 | 0.629 |  |  | 0.642 |  |  | 2.03 | <MDL | 1.130 | 181 | 71.1 |
| 7/11/2010 | 2:16 | A2 | <0.05 | 49 | 10.1 |  | 152.8 |  | 56,100 | 0.536 |  |  | 0.869 |  |  | 2.59 |  | 1.330 | 181 | 68.0 |
| 7/11/2010 | 2:27 | A3 | <0.05 | 41 | 5.6 |  | 95.6 |  | 76,300 | 0.454 |  |  | 0.901 |  |  | 1.87 |  | 1.440 | 179 | 46.0 |
| 7/11/2010 | 2:37 | A4 | <0.05 | 31 | 5.6 |  | 85.1 |  | 37,400 | 0.429 |  |  | 0.846 |  |  | 1.68 |  | 1.140 | 108 | 44.7 |
| 7/11/2010 | 2:50 | A5 | 0.058 | 35 | 5.5 |  | 93.3 |  | 42,500 | 0.470 |  |  | 0.852 |  |  | 1.12 | <MDL | 1.070 | 53 | 31.2 |
| 7/11/2010 | 3:14 | A6 | <0.05 | 37 | 6.5 |  | 114.6 |  | 66,900 | 0.677 |  |  | 0.938 |  |  | 1.27 |  | 1.170 | 34 | 33.6 |
| 7/11/2010 | 3:25 | A7 | 0.061 | 38 | 5.7 |  | 110.6 |  | 69,200 | 0.688 |  |  | 0.891 |  |  | 1.23 |  | 1.120 | 43 | 24.2 |
| 7/11/2010 | 10:30 | AReg |  | 38 |  |  |  |  |  | 1.218 |  | 7.85 | 0.910 |  |  | 1.05 |  | 1.050 | 6 |  |
| 7/11/2010 | 10:25 | Grab |  | 37 |  | 0.23 |  | 6.3 | 13,550 | 1.245 | <5.0 | 7.79 |  | 5.7 | 22 |  |  |  | 4 | 15.0 |

## Table T.1 Continued

| Date | Time | Sample Type | NH$_4$ | COD | Cl$^-$ | Cl$_2$ | CDY | DO | EC | N+N | OG | pH | SRP | SSC | WT | TKN | Cu | TP | TSS | TBY |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 8/4/2010 | 3:37 | A1 | 0.061 | 95 | 16.0 | | 261.0 | | 37,350 | 0.692 | | | 0.307 | | | 1.57 | | 1.370 | 195 | 58.1 |
| 8/4/2010 | 3:43 | A2 | 0.064 | 92 | 9.2 | | 150.5 | | 32,400 | 0.592 | | | 0.266 | | | 1.73 | <MDL | 1.260 | 182 | 49.0 |
| 8/4/2010 | 3:47 | A3 | 0.058 | 117 | 14.2 | | 226.0 | | 36,650 | 0.803 | | | 0.304 | | | 2.99 | | 2.270 | 306 | 84.3 |
| 8/4/2010 | 3:51 | A4 | 0.069 | 117 | 9.9 | | 206.5 | | 34,600 | 0.798 | | | 0.349 | | | 2.53 | | 2.170 | 302 | 95.3 |
| 8/4/2010 | 3:55 | A5 | 0.094 | 96 | 8.7 | | 160.8 | | 28,600 | 0.708 | | | 0.291 | | | 2.41 | <MDL | 1.850 | 213 | 76.4 |
| 8/4/2010 | 4:21 | A6 | 0.070 | 63 | 8.0 | | 121.8 | | 20,800 | 0.571 | | | 0.356 | | | 0.98 | | 0.751 | 30 | 17.8 |
| 8/4/2010 | 10:05 | AReg | | 78 | | | | | | 1.005 | | 7.89 | 0.522 | | | 1.11 | | 0.762 | 4 | |
| 8/4/2010 | 10:00 | Grab | | 73 | | 0.07 | | 4.7 | 13,850 | 0.207 | <5.0 | 7.92 | | 4.7 | 25 | | | | 1 | 10.3 |
| 11/12/2010 | 0:16 | A1 | <0.05 | 56 | 44.4 | | 862.0 | | 46,110 | 1.060 | | | 1.34 | | | 1.91 | | 1.51 | 23 | 14.9 |
| 11/12/2010 | 1:12 | A2 | 0.092 | 90 | 20.2 | | 320.0 | | 46,110 | 0.524 | | | 1.17 | | | 2.65 | | 2.46 | 273 | 89.3 |
| 11/12/2010 | 1:21 | A3 | 0.103 | 96 | 13.3 | | 234.0 | | 24,890 | 0.536 | | | 1.04 | | | 3.24 | <MDL | 2.77 | 278 | 109.0 |
| 11/12/2010 | 1:29 | A4 | 0.107 | 94 | 8.5 | | 167.0 | | 27,230 | 0.435 | | | 1.04 | | | 1.74 | | 2.74 | 251 | 95.4 |
| 11/12/2010 | 1:50 | A5 | 0.053 | 62 | 4.0 | | 83.1 | | 9,870 | 0.223 | | | 0.645 | | | 1.49 | <MDL | 1.81 | 166 | 61.4 |
| 11/12/2010 | 2:28 | A6 | <0.05 | 52 | 4.1 | | 85.1 | | 4,730 | 0.330 | | | 0.941 | | | 0.99 | | 1.20 | 90 | 34.1 |
| 11/12/2010 | 9:50 | AReg | | 38 | | | | | 8,800 | 0.090 | | 7.76 | 1.00 | | | 1.20 | | 1.10 | 15 | 10.1 |
| 11/12/2010 | 9:45 | Grab | | 37 | | 0.02 | | 9.0 | 5,560 | 0.940 | <5.0 | 7.70 | | 7.1 | 7 | | | | 16 | 10.1 |
| 5/12/2011 | 19:18 | A1 | 0.158 | 77 | 30.4 | | 667.0 | | <1000 | 0.110 | | | 0.777 | | | 1.63 | <MDL | 1.160 | 14 | 31.5 |
| 5/12/2011 | 21:18 | A2 | 0.143 | 98 | 32.8 | | 524.0 | | 8,500 | 0.279 | | | 0.725 | | | 2.68 | | 1.540 | 80 | 51.2 |
| 5/12/2011 | 21:40 | A3 | 0.236 | 105 | 17.5 | | 312.0 | | 25,900 | 0.547 | | | 0.537 | | | 2.68 | | 1.900 | 151 | 95.0 |
| 5/12/2011 | 22:02 | A4 | 0.209 | 97 | 18.8 | | 304.0 | | 13,800 | 0.541 | | | 0.528 | | | 2.82 | <MDL | 1.700 | 110 | 93.0 |
| 5/12/2011 | 23:01 | A5 | 0.062 | 78 | 13.9 | | 250.0 | | 12,000 | 0.355 | | | 0.515 | | | 2.24 | | 1.170 | 47 | 53.2 |
| 5/13/2011 | 0:06 | A6 | 0.113 | 70 | 10.3 | | 225.0 | | 14,600 | 0.466 | | | 0.526 | | | 2.14 | <MDL | 0.954 | 25 | 38.4 |
| 5/13/2011 | 0:08 | AReg | | 72 | | | | | 8,600 | 0.491 | | 7.53 | 0.522 | | | 1.44 | | 0.958 | 22 | |
| 5/13/2011 | 0:00 | Grab | | 65 | | 0.00 | | 3.3 | 8,600 | 0.476 | <5.0 | 7.58 | | 67.0 | 18 | | | | 20 | 36.1 |

## Table T.1 Continued

| Date | Time | Sample Type | $NH_4$ | COD | $Cl^-$ | $Cl_2$ | CDY | DO | EC | N+N | OG | pH | SRP | SSC | WT | TKN | Cu | TP | TSS | TBY |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 6/9/2011 | 1:29 | A1 | 0.151 | 26 | 36.6 | | 526.0 | | 313,000 | 0.896 | | | 0.439 | | | 5.66 | <MDL | 1.500 | 124 | 46.3 |
| 6/9/2011 | 1:40 | A2 | 0.086 | 40 | 12.0 | | 239.0 | | 480,000 | 0.597 | | | 0.486 | | | 4.11 | | 2.030 | 236 | 80.0 |
| 6/9/2011 | 1:46 | A3 | 0.088 | 37 | 9.8 | | 236.0 | | 197,000 | 0.659 | | | 0.485 | | | 2.66 | <MDL | 1.780 | 228 | 80.9 |
| 6/9/2011 | 1:52 | A4 | <0.05 | 32 | 12.2 | | 247.0 | | 161,000 | 0.799 | | | 0.440 | | | 3.50 | | 1.560 | 141 | 60.7 |
| 6/9/2011 | 2:06 | A5 | 0.053 | 25 | 9.6 | | 200.2 | | 216,000 | 0.888 | | | 0.454 | | | 3.23 | <MDL | 1.580 | 125 | 54.3 |
| 6/9/2011 | 2:15 | A6 | <0.05 | 20 | 7.9 | | 159.6 | | 158,000 | 0.713 | | | 0.498 | | | 2.72 | | 1.600 | 94 | 57.6 |
| 6/9/2011 | 2:47 | A7 | <0.05 | 16 | 7.9 | | 139.6 | | 120,000 | 0.673 | | | 0.518 | | | 1.39 | <MDL | 1.030 | 45 | 26.4 |
| 6/9/2011 | 11:31 | AReg | | 11 | | | | | 24,100 | 0.499 | | -- | 0.487 | | | 1.12 | | 0.684 | 6 | |
| 6/9/2011 | 11:25 | Grab | | 12 | | 0.14 | | 5.2 | 21,600 | 0.446 | 2.3 | -- | | 3.5 | 18 | | | | 4 | 5.4 |
| 6/25/2011 | 5:06 | A1 | <0.05 | 70 | 4.0 | | 90.2 | | 86,000 | 0.261 | | | 0.330 | | | 1.84 | <MDL | 1.080 | 366 | 83.1 |
| 6/25/2011 | 5:11 | A2 | <0.05 | 90 | 5.7 | | 132.9 | | 86,000 | 0.373 | | | 0.326 | | | 3.42 | | 2.230 | 559 | 175.0 |
| 6/25/2011 | 5:12 | A3 | <0.05 | 87 | 5.7 | | 130.0 | | 30,000 | 0.448 | | | 0.274 | | | 3.81 | <MDL | 2.480 | 603 | 165.0 |
| 6/25/2011 | 5:15 | A4 | <0.05 | 89 | 4.5 | | 108.2 | | 75,000 | 0.429 | | | 0.268 | | | 3.50 | | 2.680 | 657 | 172.0 |
| 6/25/2011 | 5:18 | A5 | <0.05 | 75 | 3.9 | | 90.5 | | 75,000 | 0.336 | | | 0.285 | | | 3.54 | <MDL | 2.650 | 432 | 167.8 |
| 6/25/2011 | 5:21 | A6 | <0.05 | 102 | 3.5 | | 81.3 | | 63,000 | 0.346 | | | 0.339 | | | 2.49 | | 2.160 | 478 | 150.0 |
| 6/25/2011 | 5:33 | A7 | <0.05 | 49 | 3.5 | | 75.4 | | 41,000 | 0.243 | | | 0.482 | | | 2.05 | | 1.380 | 199 | 73.2 |
| 6/25/2011 | 8:30 | AReg | | 56 | | | | | 50,200 | 0.577 | | 7.69 | 0.642 | | | 1.46 | | 0.956 | 15 | |
| 6/25/2011 | 8:25 | Grab | | 55 | | 0.04 | | 6.5 | 29,500 | 0.511 | 2.2 | 7.64 | | 4.9 | 18 | | | | 11 | -- |
| 8/12/2011 | 1:10 | A1 | 0.210 | 33 | 8.0 | | 197.5 | | 25,500 | 0.532 | | | 0.235 | | | 0.671 | <MDL | 0.823 | 109 | 40.9 |
| 8/12/2011 | 1:18 | A2 | 0.167 | 37 | 6.0 | | 169.0 | | 15,000 | 0.239 | | | 0.252 | | | 0.886 | | 1.240 | 182 | 46.0 |
| 8/12/2011 | 1:21 | A3 | 0.174 | 46 | 8.0 | | 193.9 | | 36,000 | 0.507 | | | 0.313 | | | 1.02 | <MDL | 1.160 | 203 | 56.1 |
| 8/12/2011 | 1:23 | A4 | 0.164 | 40 | 5.0 | | 163.4 | | 25,500 | 0.577 | | | 0.260 | | | 1.03 | | 1.250 | 185 | 58.7 |
| 8/12/2011 | 1:28 | A5 | 0.243 | 32 | 3.0 | | 109.9 | | 20,000 | -- | | | 0.306 | | | 0.599 | <MDL | 1.120 | 157 | 51.8 |
| 8/12/2011 | 2:27 | A6 | 0.139 | 26 | 3.0 | | 120.0 | | 31,000 | 0.642 | | | 0.627 | | | 0.471 | | 0.977 | 21 | 13.3 |
| 8/12/2011 | 10:05 | AReg | | 39 | | | | | | 0.767 | | 7.79 | 0.900 | | | 0.686 | | 1.250 | 8 | 15.8 |
| 8/12/2011 | 9:55 | Grab | | 33 | | 0.08 | | 6.7 | 14,500 | 0.774 | <2.0 | 7.60 | | 10.1 | 20 | | | | 8 | 15.2 |

## Table T.2: Taylor Park Wet Weather Raw Data for 2008-2010 water quality monitoring

| Date | Time | Sample Type | $NH_4$ | COD | $Cl^-$ | $Cl_2$ | CDY | DO | EC | N+N | OG | pH | SRP | SSC | WT | TKN | Cu | TP | TSS | TBY |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10/6/2008 | 15:10 | A1 | <0.05 | 89 | 20.0 | | 193.2 | | -- | <0.05 | | | 1.15 | | | | | | 59.0 | 24.1 |
| 10/6/2008 | 15:35 | A2 | <0.05 | 57 | 10.0 | | 115.8 | | 141,400 | 0.13 | | | 0.87 | | | | | | 87.3 | 35.4 |
| 10/6/2008 | 17:40 | A7 | <0.05 | 44 | 2.9 | | 208.4 | | 19,870 | 0.23 | | | 1.04 | | | | | | 15.9 | 17.2 |
| 10/7/2008 | 1:05 | A1 | <0.05 | 38 | 5.0 | | 155.2 | | 43,600 | 0.39 | | | 0.76 | | | | | | 75.8 | 20.5 |
| 10/7/2008 | 1:30 | A2 | <0.05 | 37 | 6.0 | | 185.2 | | 68,700 | 0.45 | | | 0.47 | | | | | | 73.1 | 26.8 |
| 10/7/2008 | 2:20 | A4 | <0.05 | 22 | 3.5 | | 122.1 | | 23,600 | 0.47 | | | 0.66 | | | | | | 21.1 | 16.4 |
| 10/7/2008 | 9:15 | Grab | | 11 | | | | 7.0 | 3,260 | | <5.0 | 7.27 | | | | | | | 4.1 | |
| 10/7/2008 | 9:20 | AReg | | 14 | | | | | | | | 7.57 | | | | | | | 7.9 | |
| 4/27/2009 | 11:30 | A1 | 0.2 | 22 | 24.5 | | 355 | | 9,680 | 0.83 | | | | | | 0.66 | | | 16.3 | 15.4 |
| 4/27/2009 | 12:00 | A2 | 0.17 | 26 | 18.5 | | 291 | | -- | 0.8 | | | | | | 0.6 | | | 30.4 | 12.5 |
| 4/27/2009 | 12:30 | A3 | 0.26 | 11 | 7.5 | | 140 | | 13,000 | 0.5 | | | | | | 0.36 | | | 165.8 | 54.1 |
| 4/27/2009 | 12:45 | A5 | 0.24 | 11 | 4.5 | | 95.1 | | 12,000 | 0.31 | | | | | | 0.55 | | | 149.5 | 48.8 |
| 4/27/2009 | 13:30 | A7 | 0.28 | 22 | 14.7 | | 273 | | 6,930 | 1.07 | | | | | | 1.37 | | | 16.0 | 13.2 |
| 4/27/2009 | 16:00 | Grab | 0.25 | 18 | | 0.07 | | | 2,190 | 1.1 | <5.0 | 7.51 | | | | 1.48 | | | 31.5 | 12.5 |
| 4/27/2009 | 16:05 | AReg | 1.58 | 17 | | | | | | 0.78 | | 7.53 | | | | 1.81 | | | 46.5 | |
| 7/14/2009 | 4:17 | A1 | | 28 | 34.8 | | 607 | | -- | | | | 1.12 | | | | | | 444.0 | 23.9 |
| 7/14/2009 | 4:27 | A2 | | 31 | 32.2 | | 562 | | 6,932 | | | | 0.85 | | | | | | 354.0 | 23.3 |
| 7/14/2009 | 4:29 | A3 | | 28 | 22.1 | | 550 | | 7,948 | | | | 0.51 | | | | | | 215.0 | 20.2 |
| 7/14/2009 | 4:35 | A4 | | 31 | 0.7 | | 83.5 | | 3,974 | | | | 0.5 | | | | | | 200.0 | 6.33 |
| 7/14/2009 | 4:51 | A5 | | 43 | 3.0 | | 128.7 | | -- | | | | 0.63 | | | | | | 95.0 | 6.42 |
| 7/14/2009 | 5:32 | A6 | | 46 | 12.0 | | 183.1 | | -- | | | | 0.64 | | | | | | 30.0 | 10 |
| 7/14/2009 | 7:46 | A7 | | 45 | 25.2 | | 555 | | -- | | | | 0.95 | | | | | | 13.0 | |
| 7/14/2009 | 7:59 | A8 | | 44 | 30.7 | | 590 | | -- | | | | 1.06 | | | | | | 12.0 | |
| 7/14/2009 | 12:00 | Grab | | 35 | | 0.05 | 746 | | -- | | <5.0 | 7.91 | | | | | | | 4.0 | |
| 7/14/2009 | 12:05 | AReg | | 31 | | | 723 | | | | | 7.82 | 0.9 | | | | | | 21.0 | |

## Table T.2 Continued

| Date | Time | Sample Type | $NH_4$ | COD | $Cl^-$ | $Cl_2$ | CDY | DO | EC | N+N | OG | pH | SRP | SSC | WT | TKN | Cu | TP | TSS | TBY |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 8/4/2009 | 4:50 | A1 |  | 205 | <MDL |  | 132.3 |  | 308,000 | 0.61 |  |  | 0.34 |  |  | 1.65 |  |  | 854 | 196.0 |
| 8/4/2009 | 5:07 | A2 |  | 161 | 0.5 |  | 77.2 |  | -- | 0.49 |  |  | 0.43 |  |  | 1.78 |  |  | 767 | 169.0 |
| 8/4/2009 | 5:16 | A3 |  | 140 | 1.4 |  | 56.5 |  | 86,700 | 0.47 |  |  | 0.57 |  |  | 1.46 |  |  | 397 | 50.3 |
| 8/4/2009 | 5:25 | A4 |  | 131 | 2 |  | 62.8 |  | 64,900 | 0.57 |  |  | 0.3 |  |  | 1.26 |  |  | 199 | 37.1 |
| 8/4/2009 | 5:36 | A6 |  | 59 | 2.1 |  | 69.5 |  | 14,100 | 0.55 |  |  | 0.48 |  |  | 1.01 |  |  | 92 | 17.0 |
| 8/4/2009 | 7:39 | A8 |  | 54 | 3.6 |  | 233 |  | 29,100 | 1.26 |  |  | 0.19 |  |  | 1.45 |  |  | 21 | 5.4 |
| 8/4/2009 | 11:30 | Grab |  | 58 |  | 0.04 |  |  | 6,490 |  | <5.0 | 7.86 |  |  |  |  |  |  | 14 | 2.91 |
| 8/4/2009 | 11:35 | AReg |  | 53 |  |  |  |  |  | 0.91 |  | 7.58 | 0.9 |  |  | 1.26 |  |  | 7 |  |
| 8/26/2009 | 7:25 | A1 | 0.66 | 92 | <MDL |  | 638 |  | 198,700 | 0.84 |  |  | 1.49 |  |  |  |  |  | 764.1 | 291 |
| 8/26/2009 | 7:36 | A2 | 0.58 | 80 | 0.7 |  | 165 |  | -- | 0.08 |  |  | 0.74 |  |  |  |  |  | 175.7 | 67.2 |
| 8/26/2009 | 7:45 | A3 | 0.36 | 75 | 1.6 |  | 128 |  | -- | <0.05 |  |  | 0.72 |  |  |  |  |  | 165.7 | 55.4 |
| 8/26/2009 | 8:03 | A4 | 0.28 | 68 | 2 |  | 107 |  | -- | <0.05 |  |  | 0.75 |  |  |  |  |  | 191.6 | 67.3 |
| 8/26/2009 | 8:26 | A6 | 0.22 | 42 | 2.2 |  | 105 |  | 30,800 | <0.05 |  |  | 0.77 |  |  |  |  |  | 135.3 | 25.7 |
| 8/26/2009 | 9:41 | A8 | 0.38 | 40 | 3.6 |  | 217 |  | 20,200 | 0.33 |  |  | 0.85 |  |  |  |  |  | 32.5 | 17.2 |
| 8/26/2009 | 11:15 | Grab | 0.59 | 40 |  | 0.06 |  |  | -- | 0.22 | <5.0 | 7.31 |  |  |  |  |  |  | 14.9 | 14.4 |
| 8/26/2009 | 11:20 | AReg | 0.45 | 42 |  |  |  |  |  | <0.05 |  | 7.75 | 0.8 |  |  |  |  |  | 59.9 |  |
| 9/3/2009 | 10:11 | A1 |  | 39 | 44.6 |  | 998 |  | 794 | 0.11 |  |  | 1.23 |  |  | 1.04 |  |  | 31.9 | 11.7 |
| 9/3/2009 | 10:59 | A3 |  | 78 | 24.5 |  | 103 |  | 58,000 | 1.02 |  |  | 0.98 |  |  | 1.89 |  |  | 80.5 | 32.2 |
| 9/3/2009 | 11:43 | A5 |  | 64 | 11.3 |  | 88.2 |  | -- | 0.61 |  |  | 0.82 |  |  | 1.01 |  |  | 36 | 37.2 |
| 9/3/2009 | 12:08 | A7 |  | 52 | 4.3 |  | 79.3 |  | 15,540 | 0.95 |  |  | 0.77 |  |  | 1.37 |  |  | 53.4 | 37.5 |
| 9/3/2009 | 12:22 | A9 |  | 50 | 3.9 |  | 59.6 |  | -- | 0.3 |  |  | 0.68 |  |  | 0.9 |  |  | 113.5 | 22.3 |
| 9/3/2009 | 12:40 | A11 |  | 40 | 4.2 |  | 88.2 |  | 27,300 | 0.9 |  |  | 0.92 |  |  | 1.34 |  |  | 35.8 | 28.9 |
| 9/3/2009 | 14:45 | Grab |  | 50 |  | 0.04 |  |  | 17,330 | 0.71 | <5.0 | 7.56 |  |  |  | 1.56 |  |  | 32.4 | 22 |
| 9/3/2009 | 14:50 | AReg |  | 44 |  |  |  |  |  | 0.57 |  | 7.26 | 0.58 |  |  | 1.42 |  |  | 40.2 |  |

## Table T.2 Continued

| Date | Time | Sample Type | NH$_4$ | COD | Cl$^-$ | Cl$_2$ | CDY | DO | EC | N+N | OG | pH | SRP | SSC | WT | TKN | Cu | TP | TSS | TBY |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4/29/2010 | 20:24 | A1 | <0.05 | 180 | 31.5 | | 319 | | -- | 0.886 | | | 1.23 | | | 2.58 | <MDL | -- | 346 | 152.0 |
| 4/29/2010 | 20:49 | A2 | <0.05 | 112 | 28.5 | | 313 | | -- | 0.590 | | | 0.52 | | | 2.58 | <MDL | -- | 105 | 58.9 |
| 4/29/2010 | 21:12 | A3 | 0.084 | 592 | 16.0 | | 174 | | -- | 0.361 | | | 5.40 | | | 2.58 | <MDL | -- | 1422 | 367.0 |
| 4/29/2010 | 21:18 | A4 | 0.156 | 244 | 3.0 | | 85.6 | | -- | 0.258 | | | 1.38 | | | 1.26 | <MDL | -- | 600 | 164.0 |
| 4/29/2010 | 21:36 | A5 | <0.05 | 55 | 4.0 | | 94.1 | | -- | 0.486 | | | 0.94 | | | 3.04 | <MDL | -- | 121 | 46.7 |
| 4/29/2010 | 21:47 | A6 | 0.127 | 130 | 3.0 | | 72.1 | | -- | 0.233 | | | 1.05 | | | 1.29 | <MDL | -- | 638 | 120.0 |
| 4/29/2010 | 22:10 | A7 | 0.161 | 42 | 4.5 | | 97.3 | | -- | 0.845 | | | 1.14 | | | 1.04 | <MDL | -- | 84 | 41.5 |
| 4/30/2010 | 8:49 | AReg | | 18 | | | | | -- | 0.303 | | 7.99 | 0.53 | | | 0.76 | | -- | 9 | |
| 4/30/2010 | 8:50 | Grab | | 16 | | 0.05 | | 6.3 | -- | 1.978 | <5.0 | 7.83 | | 9.9 | 13 | | | -- | 3 | 5.3 |
| 5/20/2010 | 5:22 | A1 | 0.089 | 92 | 25.6 | | 435 | | 51,800 | 1.002 | | | -- | | | 2.64 | <MDL | -- | 126.7 | 54.9 |
| 5/20/2010 | 5:44 | A2 | 0.07 | 88 | 10.5 | | 151.1 | | 17,330 | 0.548 | | | -- | | | 2.91 | <MDL | -- | 97.3 | 45.1 |
| 5/20/2010 | 7:41 | A3 | 0.056 | 116 | 6.9 | | 130.7 | | 48,900 | 0.328 | | | -- | | | 1.49 | | -- | 25.3 | 17.4 |
| 5/20/2010 | 8:37 | A4 | 0.050 | 184 | 6.5 | | 102.2 | | 51,800 | 0.285 | | | -- | | | 1.59 | | -- | 50.7 | 31.6 |
| 5/20/2010 | 9:35 | A5 | <0.05 | 80 | 6.2 | | 92.8 | | 30,800 | 0.216 | | | -- | | | 1.77 | <MDL | -- | 65.3 | 36.9 |
| 5/20/2010 | 10:03 | A6 | 0.068 | 58 | 6.7 | | 90.2 | | 32,600 | 0.187 | | | -- | | | 1.96 | | -- | 60.0 | 51.5 |
| 5/20/2010 | 10:12 | A7 | 2.023 | 48 | 7.5 | | 95.5 | | 54,800 | <0.050 | | | -- | | | 1.32 | | -- | 37.3 | 37.7 |
| 5/20/2010 | 15:50 | AReg | | 48 | | | | | | 1.096 | | 7.88 | 0.632 | | | 2.11 | | 0.879 | 12 | |
| 5/20/2010 | 15:45 | Grab | | 76 | | 0.02 | | 5.6 | 58,000 | 1.067 | 7.0 | 7.65 | 0.629 | 8.52 | 14 | | | 0.879 | 8 | 19.6 |
| 6/8/2010 | 3:17 | A1 | 0.097 | 12 | 56.8 | | 1034.0 | | 2,100 | 1.718 | | | 0.975 | | | 0.75 | | 1.030 | 2 | 1.8 |
| 6/8/2010 | 3:48 | A2 | 0.122 | 164 | 13.3 | | 123.2 | | 29,100 | 0.454 | | | 1.150 | | | 2.40 | <MDL | 1.940 | 429 | 139.0 |
| 6/8/2010 | 3:51 | A3 | 0.138 | 120 | 11.4 | | 84.3 | | 48,900 | 0.391 | | | 0.963 | | | 3.35 | | 1.510 | 355 | 126.0 |
| 6/8/2010 | 3:55 | A4 | 0.137 | 88 | 12.5 | | 79.3 | | 43,600 | 0.393 | | | 0.907 | | | 1.55 | | 1.340 | 288 | 120.0 |
| 6/8/2010 | 4:03 | A5 | 0.128 | 62 | 12.8 | | 83.8 | | 98,100 | 0.385 | | | 0.847 | | | 1.49 | <MDL | 1.180 | 190 | 86.6 |
| 6/8/2010 | 4:15 | A6 | 0.142 | 60 | 15.8 | | 108.8 | | 141,400 | 0.576 | | | 0.918 | | | 2.04 | | 1.250 | 118 | 72.6 |
| 6/8/2010 | 5:11 | A7 | 0.084 | 10 | 15.6 | | 159.2 | | 64,900 | 0.594 | | | 0.727 | | | 1.77 | | 0.998 | 38 | 30.2 |
| 6/8/2010 | 9:05 | AReg | | 30 | | | | | | 1.345 | | 7.95 | 0.789 | | | 1.51 | | 0.951 | 2 | |
| 6/8/2010 | 9:00 | Grab | | 46 | | 0.07 | | 4.4 | 24,200 | 1.294 | <5.0 | 7.82 | | 36.3 | 20 | | | | 5 | 9.7 |

## Table T.2 Continued

| Date | Time | Sample Type | $NH_4$ | COD | $Cl^-$ | $Cl_2$ | CDY | DO | EC | N+N | OG | pH | SRP | SSC | WT | TKN | Cu | TP | TSS | TBY |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 7/11/2010 | 1:49 | A1 | <0.05 | 141 | 16.8 |  | 201.2 |  | 349,050 | 0.861 |  |  | 1.810 |  |  | 3.25 | <MDL | 2.760 | 476 | 141.0 |
| 7/11/2010 | 1:57 | A2 | 0.097 | 48 | 2.8 |  | 43.2 |  | 25,500 | 0.394 |  |  | 0.751 |  |  | 1.57 |  | 0.965 | 182 | 48.8 |
| 7/11/2010 | 2:02 | A3 | 0.070 | 38 | 2.8 |  | 43.8 |  | 17,500 | 0.401 |  |  | 0.652 |  |  | 1.40 |  | 0.874 | 94 | 30.4 |
| 7/11/2010 | 2:09 | A4 | 0.057 | 14 | 3.2 |  | 46.9 |  | 40,500 | 0.425 |  |  | 0.817 |  |  | 1.28 |  | 1.050 | 114 | 41.9 |
| 7/11/2010 | 2:13 | A5 | 0.098 | 36 | 3.8 |  | 49.8 |  | 36,750 | 0.477 |  |  | 0.894 |  |  | 1.16 | <MDL | 1.210 | 108 | 29.3 |
| 7/11/2010 | 2:20 | A6 | 0.116 | 38 | 3.6 |  | 58.9 |  | 39,500 | 0.583 |  |  | 1.050 |  |  | 1.50 |  | 1.320 | 120 | 43.3 |
| 7/11/2010 | 3:23 | A7 | <0.05 | 40 | 2.8 |  | 69.5 |  | 28,700 | 0.434 |  |  | 0.653 |  |  | 1.37 |  | 0.934 | 81 | 24.5 |
| 7/11/2010 | 9:35 | AReg |  | 23 |  |  |  |  |  | 1.835 |  | 8.05 | 0.646 |  |  | 0.588 |  | 0.722 | 5 |  |
| 7/11/2010 | 9:30 | Grab |  | 29 |  | 0.11 |  | 7.1 | 13,150 | 1.985 | <5.0 | 7.90 |  | 2.6 | 20 |  |  |  | 2 | 6.6 |
| 8/4/2010 | 3:13 | A1 | 0.104 | 480 | 33.0 |  | 731.0 |  | 145,900 | 1.846 |  |  | 0.616 |  |  | 4.49 | 0.272 | 10.700 | 2052 | 408.0 |
| 8/4/2010 | 3:16 | A2 | 0.050 | 129 | 2.8 |  | 81.4 |  | 19,850 | 0.567 |  |  | 0.306 |  |  | 1.90 |  | 2.150 | 498 | 115.0 |
| 8/4/2010 | 3:18 | A3 | <0.05 | 105 | 1.9 |  | 63.8 |  | 36,800 | 0.448 |  |  | U.R. |  |  | 1.20 | <MDL | 1.330 | 240 | 56.3 |
| 8/4/2010 | 3:20 | A4 | <0.05 | 92 | 4.2 |  | 57.3 |  | 25,050 | 0.480 |  |  | 0.163 |  |  | 0.99 |  | 1.150 | 205 | 49.2 |
| 8/4/2010 | 3:22 | A5 | <0.05 | 90 | 3.7 |  | 56.3 |  | 71,950 | 0.548 |  |  | 0.428 |  |  | 1.21 |  | 1.180 | 131 | 30.4 |
| 8/4/2010 | 3:28 | A6 | <0.05 | 117 | 4.4 |  | 66.8 |  | 109,600 | 0.755 |  |  | 0.389 |  |  | 0.88 |  | 1.080 | 74 | 24.8 |
| 8/4/2010 | 9:30 | AReg |  | 73 |  |  |  |  |  | 1.931 |  | 8.01 | 0.610 |  |  | 0.93 |  | 0.880 | 4 |  |
| 8/4/2010 | 9:20 | Grab |  | 79 |  | 0.03 |  | 4.0 | 7,925 | 0.351 | <5.0 | 7.91 |  | 3.6 | 23 |  |  |  | 3 | 6.1 |
| 11/11/2010 | 22:26 | A1 | <0.05 | 116 | 49.2 |  | 1061.0 |  | 410 | 2.500 |  |  | 0.523 |  |  | 5.11 | <MDL | 2.81 | 392 | 106.0 |
| 11/11/2010 | 23:06 | A2 | 0.333 | 214 | 17.0 |  | 250.0 |  | 45,410 | 0.854 |  |  | 3.44 |  |  | 8.84 |  | 3.81 | 66 | 23.4 |
| 11/12/2010 | 0:28 | A3 | 0.311 | - | 24.2 |  | 362.0 |  | 12,540 | 0.887 |  |  | 2.73 |  |  | 8.89 | <MDL | 4.50 | 316 | 99.4 |
| 11/12/2010 | 0:39 | A4 | 0.152 | 212 | 6.2 |  | 125.8 |  | 92,080 | 0.418 |  |  | 1.53 |  |  | 4.60 |  | 3.33 | 258 | 77.5 |
| 11/12/2010 | 1:09 | A5 | 0.091 | 76 | 3.0 |  | 72.2 |  | 15,290 | 0.228 |  |  | 1.15 |  |  | 2.58 |  | 1.51 | 72 | 25.0 |
| 11/12/2010 | 1:43 | A6 | 0.103 | 68 | 3.7 |  | 92.3 |  | 15,000 | 0.480 |  |  | 1.18 |  |  | 2.02 |  | 1.41 | 40 | 13.7 |
| 11/12/2010 | 2:10 | A7 | 0.069 | 76 | 2.7 |  | 71.9 |  | 13,910 | 0.316 |  |  | 0.984 |  |  | 2.17 |  | 1.28 | 81 | 27.2 |
| 11/12/2010 | 9:15 | AReg |  | 55 |  |  |  |  | 13,910 | 2.080 |  | 7.78 | 1.35 |  |  | 0.87 |  | 1.43 | 11 | 14.4 |
| 11/12/2010 | 9:10 | Grab |  | 52 |  | 0.00 |  | 6.7 | 15,970 | 1.560 | <5.0 | 7.53 |  | 9.4 | 10 |  |  |  | 10 | 8.0 |

## Table T.2 Continued

| Date | Time | Sample Type | $NH_4$ | COD | $Cl^-$ | $Cl_2$ | CDY | DO | EC | N+N | OG | pH | SRP | SSC | WT | TKN | Cu | TP | TSS | TBY |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5/12/2011 | 20:57 | A1 | 0.133 | 1,274 | 12.3 |  | 264.0 |  | 410,600 | 0.222 |  |  | 0.350 |  |  | 14.30 | 0.16 | -- | 3904 | 1386.0 |
| 5/12/2011 | 20:59 | A2 | 0.266 | 492 | 3.3 |  | 94.9 |  | 13,900 | 0.398 |  |  | 0.308 |  |  | 9.39 |  | -- | 1094 | 393.0 |
| 5/12/2011 | 21:05 | A3 | 0.206 | 272 | 2.8 |  | 82.1 |  | 65,700 | 0.323 |  |  | 0.260 |  |  | 3.88 |  | 3.720 | 484 | 204.0 |
| 5/12/2011 | 21:24 | A4 | 0.119 | 133 | 3.0 |  | 111.3 |  | 73,800 | 0.511 |  |  | 0.502 |  |  | 2.44 | <MDL | 1.870 | 131 | 92.2 |
| 5/12/2011 | 21:59 | A5 | 0.065 | 87 | 5.6 |  | 161.0 |  | 79,400 | 0.348 |  |  | 0.667 |  |  | 1.78 |  | 1.530 | 43 | 30.4 |
| 5/12/2011 | 22:45 | A6 | 0.082 | 90 | 9.4 |  | 311.0 |  | 9,500 | 0.681 |  |  | 0.746 |  |  | 1.53 | <MDL | 1.330 | 20 | 25.0 |
| 5/12/2011 | 23:30 | A7 | 0.182 | 84 | 6.8 |  | 238.0 |  | 7,300 | 1.090 |  |  | 0.717 |  |  | 1.90 |  | 1.230 | 18 | 25.0 |
| 5/12/2011 | 23:45 | AReg |  | 82 |  |  |  |  | 10,900 | 0.402 |  | 7.46 | 0.736 |  |  | 1.49 |  | 1.210 | 13 |  |
| 5/12/2011 | 23:30 | Grab |  | 84 |  | 0.00 |  | 5.2 | 15,600 | 0.586 | <5.0 | 7.50 |  | 36.0 | 15 |  |  |  | 10 | 19.1 |
| 6/9/2011 | 1:19 | A1 | 0.114 | 26 | 35.6 |  | 1027.0 |  | 471,000 | 0.994 |  |  | 0.750 |  |  | 6.38 | <MDL | 12.050 | 4023 | 1143.0 |
| 6/9/2011 | 1:31 | A2 | 0.215 | 11 | 8.4 |  | 182.3 |  | 74,000 | 1.320 |  |  | 0.642 |  |  | 6.83 |  | 6.080 | 1569 | 418.0 |
| 6/9/2011 | 1:46 | A3 | 0.168 | 44 | 3.2 |  | 101.4 |  | 10,000 | 0.790 |  |  | 0.588 |  |  | 4.95 | <MDL | 8.080 | 3193 | 677.0 |
| 6/9/2011 | 1:52 | A4 | 0.219 | 26 | 2.0 |  | 87.8 |  | 75,000 | 0.567 |  |  | 0.418 |  |  | 3.35 |  | 16.000 | 3679 | 860.0 |
| 6/9/2011 | 1:55 | A5 | 0.245 | 76 | 1.8 |  | 80.2 |  | <10,000 | 0.616 |  |  | 0.402 |  |  | 3.69 | <MDL | 14.300 | 3662 | 597.0 |
| 6/9/2011 | 1:57 | A6 | 0.231 | 21 | 1.6 |  | 72.2 |  | 10,000 | 0.661 |  |  | 0.374 |  |  | 2.18 |  | 3.800 | 1001 | 239.0 |
| 6/9/2011 | 2:48 | A7 | 0.156 | 11 | 8.0 |  | 240.0 |  | 120,000 | 1.270 |  |  | 1.084 |  |  | 2.46 | <MDL | 1.848 | 155 | 46.9 |
| 6/9/2011 | 10:54 | AReg |  | 19 |  |  |  |  | 5,200 | 1.700 |  | -- | 0.606 |  |  | 2.75 |  | 1.038 | 40 |  |
| 6/9/2011 | 10:50 | Grab |  | 18 |  | 0.24 |  | 5 | 14,500 | 1.720 | 2.8 | -- |  | 75.2 | 19 |  |  |  | 20 | 22.9 |
| 6/25/2011 | 4:40 | A1 | <0.05 | 157 | 23.6 |  | 745.0 |  | 63,000 | 1.800 |  |  | 0.315 |  |  | 3.06 | <MDL | 2.520 | 732 | 147.0 |
| 6/25/2011 | 4:44 | A2 | 0.065 | 93 | 3.4 |  | 92.9 |  | 41,000 | 0.682 |  |  | 0.306 |  |  | 2.16 |  | 1.240 | 272 | 85.3 |
| 6/25/2011 | 4:49 | A3 | 0.069 | 67 | 2.1 |  | 59.4 |  | 10,000 | 0.304 |  |  | 0.311 |  |  | 2.21 | <MDL | 0.952 | 173 | 44.4 |
| 6/25/2011 | 4:55 | A4 | 0.061 | 62 | 1.7 |  | 46.0 |  | 74,000 | 0.412 |  |  | 0.275 |  |  | 1.87 |  | 1.070 | 123 | 48.2 |
| 6/25/2011 | 5:01 | A5 | <0.05 | 43 | 1.8 |  | 47.5 |  | 52,000 | 0.342 |  |  | 0.351 |  |  | 1.23 | <MDL | 1.040 | 119 | 40.5 |
| 6/25/2011 | 5:26 | A6 | <0.05 | 50 | 3.9 |  | 84.4 |  | 181,000 | 0.433 |  |  | 0.765 |  |  | 1.44 |  | 1.280 | 47 | 30.1 |
| 6/25/2011 | 7:54 | AReg |  | 51 |  |  |  |  | 30,100 | 0.549 |  | 7.66 | 0.667 |  |  | 0.63 |  | 0.941 | 12 |  |
| 6/25/2011 | 7:45 | Grab |  | 39 |  | 0.02 |  | 7.3 | 28,100 | 0.406 | 2.8 | 7.63 |  | 15.9 | 19 |  |  |  | 12 | -- |

## Table T.2 Continued

| Date | Time | Sample Type | $NH_4$ | COD | $Cl^-$ | $Cl_2$ | CDY | DO | EC | N+N | OG | pH | SRP | SSC | WT | TKN | Cu | TP | TSS | TBY |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 8/12/2011 | 0:28 | A1 | 0.162 | 131 | 26.0 |  | 865.0 |  | 41,000 | 2.150 |  |  | 0.375 |  |  | 3.59 | <MDL | 3.088 | 1320 | 265.0 |
| 8/12/2011 | 0:31 | A2 | 0.517 | 76 | 2.0 |  | 109.1 |  | 188,000 | 0.843 |  |  | 0.437 |  |  | 1.84 |  | 0.821 | 202 | 48.5 |
| 8/12/2011 | 0:34 | A3 | 0.567 | 72 | 1.0 |  | 70.3 |  | 97,500 | 0.763 |  |  | 0.246 |  |  | 0.981 | <MDL | 0.848 | 127 | 35.8 |
| 8/12/2011 | 0:38 | A4 | 0.491 | 46 | 1.0 |  | 59.4 |  | 80,000 | 0.668 |  |  | 0.273 |  |  | 0.800 |  | 0.887 | 115 | 27.5 |
| 8/12/2011 | 0:48 | A5 | 0.455 | 42 | 1.2 |  | 54.5 |  | 41,000 | -- |  |  | 0.376 |  |  | 0.498 | <MDL | 0.983 | 101 | 29.9 |
| 8/12/2011 | 1:31 | A6 | 0.245 | 29 | 1.1 |  | 98.5 |  | 98,000 | 1.090 |  |  | 1.000 |  |  | 0.513 |  | 1.430 | 27 | 17.2 |
| 8/12/2011 | 9:39 | AReg |  | 19 |  |  |  |  |  | 1.890 |  | 7.88 | 0.902 |  |  | 0.585 |  | 1.170 | 4 | 18.8 |
| 8/12/2011 | 9:21 | Grab |  | 37 |  | 0.03 |  | 6.7 | 12,100 | 1.680 | 1.0 | 7.66 |  | 5.7 | 20 |  |  |  | 8 | 12.6 |