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Stormwater Runoff from Elevated Highways: Prediction of COD from Field Measurements and TSS

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Stormwater Runoff from Elevated Highways:
Prediction of COD from Field Measurements and TSS

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

BMPs	Best Management Practices
BOD	Biochemical Oxygen Demand
C°	Degrees Celsius
Caltrans	California Department of Transportation
CDOT	Colorado Department of Transportation
CO_2	Carbon Dioxide
COD	Chemical Oxygen Demand
COV	Coefficient of Variation
CSOs	Combined Sewer Overflows
CWA	Clean Water Act
DO	Dissolved Oxygen
EPA	Environmental Protection Agency
H_2O	Water
HRM	Highway Runoff Manual
MS4s	Municipal Separate Storm Sewer Systems
NPDES	National Pollutant Discharge Elimination System
pH	Pondus Hydrogenii

R^2	Coefficient of Determination
S	Standard Deviation
SS	Suspended Solids
SSOs	Sanitary Sewer Overflows
SWMM	Storm Water Management Model
TDS	Total Dissolved Solids
TKN	Total Kjeldahl Nitrogen
TSS	Total Suspended Solids
UNO	University of New Orleans
U.S.	United States
VDS	Volatile Dissolved Solids
VSS	Volatile Suspended Solids

ABSTRACT

This proposed research focused on the prediction and identification of chemical oxygen demand (COD) concentrations in storm water runoff from elevated roadways, which transports a significant load of contaminants.

The objective of this research was to develop a mathematical model to relate COD concentration to different measurable parameters which are easily available and routinely measurable for elevated roadways.

The test site for this research was selected at the intersection of the Interstate-10 and Interstate-610, Orleans Parish, New Orleans, Louisiana. Subsequently a research test site was developed and highway storm water runoff was collected.

The developed model enables the user to predict COD concentrations within a prediction interval of 95 % confidence. The reliability of the model was verified by carrying out significant-difference tests for both sets of data, observed and predicted, for a 5% of significance level.

CHAPTER 1

INTRODUCTION

Storm water runoff from highways and other paved areas such as rooftops or parking lots has increased the risk of flooding and the mass loading of contaminants discharged to the receiving water systems such as lakes or rivers. The creation of the U.S. Environmental Protection Agency (EPA) and the passage of the Clean Water Act (CWA) in 1972 resulted in improved treatment of municipal and industrial wastewaters and an increased public awareness of water quality issues. However, regulatory efforts, aimed at contamination control, focused almost entirely on point sources during the first 18 years since the passage of the CWA. [1] During storm events, storm water over a wide spread area was addressed as a non point source and was therefore not affected by the regulations of the EPA. Thus, the EPA promulgated a program called the National Pollution Discharge Elimination System (NPDES). These regulations confirm storm water as a point source that must be regulated through discharge permits.

It is most important for the environment to prevent the receiving water systems from being severely contaminated. A major effort has been made to analyze the storm water runoff from elevated highways. Thus, for this thesis, a test site was built to collect the storm water runoff of an elevated highway. The test site was built in Orleans Parish.

The drainage pipe, where the samples were taken, collects the runoff of the three eastbound lanes of the highway intersection I-10 and I-610. There were two reasons for choosing an elevated highway. First, collecting samples from the drainage pipe of elevated roadways was easier than sampling on the grassy swales of a road shoulder. Second, the mass loading of contaminants could be addressed from a known, limited, and paved area.

Samples were collected during fourteen storm events in order to provide an extended dataset. Field measurements such as temperature, conductivity, pH-value, and redox potential and laboratory analyses such as chemical oxygen demand (COD) concentration, heavy metals analysis, and total suspended solids (TSS) were performed. Furthermore, the flow intensity for each sample was computed. Using a statistical approach on this dataset an equation to predict COD-concentration of storm water runoff was then developed.

COD of wastewaters or contaminated waters is a measure of the oxygen equivalent of the organic matter susceptible to oxidation by strong chemical oxidant. Thus, COD is used to define the strength of contaminated waters that are either not readily biodegradable or contain compounds that inhibit biological activity. [2] As shown in Chapter 4, COD values are more convenient to determine because of the limited reliability of the biochemical oxygen demand (BOD) test. This limited reliability implies that results of multiple analyses on an industrial wastewater sample or contaminated water sample often show considerable scatter. [2]

CHAPTER 2

SCOPE AND OBJECTIVES

This proposed research focused on storm water runoff from highways. These runoffs represent a considerable contaminant source for the surrounding receiving waters. Fourteen storm events were observed during this study and multiple storm water runoff samples were collected from each storm event and analyzed for many different parameters.

The fundamental goal of this research was to examine the storm water runoff quality characteristics from highways and further to determine COD concentrations and COD correlations associated with specific storm water runoff constituents from elevated roadways. In order to achieve the prescribed goal, the research was divided into three primary objectives:

Objective 1: The first objective of this research was to analyze samples collected from different storm events utilizing Standard Methods and to evaluate the data gathered in order to determine the most important variables affecting highway storm water runoff. [3]

Furthermore, the ranges of pollutant concentrations in storm water runoff were observed. This study focused especially on the range of COD concentrations and COD mass loadings, because of the importance of these two parameters. COD is an important parameter for determining the amount of organic pollution in water, and therefore the environmental impact of the polluted water. Furthermore, COD can be related empirically to BOD_5, and COD values are more convenient to determine because of the limited reliability of the BOD_5 test.

Objective 2: The second objective focused on calculating and evaluating scatter plots and statistical correlations between COD and several variables related to storm water runoff, such as TSS, hydrological variables and field measurements.

Objective 3: The third objective in this research was to construct a mathematical regression model to predict COD concentration in storm water runoff. The goal was to determine storm water parameters that are relatively easy and fast to analyze and show a strong correlation with COD concentration. The use of this mathematical model makes it possible to predict COD concentrations in the storm water runoff from roads and highways.

CHAPTER 3

LITERATURE REVIEW

3.1 Development of the NPDES Storm Water Program

The NPDES Storm Water Program has been established with the intention to regulate storm water runoff from point sources through permits. To accomplish these regulations a two phase program was induced. These two different phases will be discussed in the following.

3.1.1 Phase I NPDES Storm Water Program

In response to the 1987 Amendments to the CWA, the United States (U.S.) EPA developed Phase I of the NPDES Storm Water Program in 1990. The Phase I program addressed sources of storm water runoff that had the greatest potential to negatively impact water quality. Under Phase I, EPA required NPDES permit coverage for storm water discharges from:

- "Medium" and "large" municipal separate storm sewer systems (MS4s) located in incorporated places or counties with populations of 100,000 or more; and

- Eleven categories of industrial activity, one of which is construction activity that disturbs five or more acres of land.

Operators of the facilities, systems, and construction sites regulated under the Phase I NPDES Storm Water Program can obtain permit coverage under an individually tailored NPDES permit or a general NPDES permit. The first permit was developed for MS4 and some industrial facilities, whereas the second permit was used by most operators of industrial facilities and construction sites. [4,5]

3.1.2 Phase II NPDES Storm Water Program

The Phase II Final Rule was published in 1999. The purpose of the rule was to designate additional sources of storm water that need to be regulated to protect water quality. Two new classes of facilities were designated for automatic coverage on a nationwide basis: [6]

- Small municipal separate storm sewer systems (MS4s) located in urbanized areas (about 3500 municipalities); and
- Construction activity disturbing between 1 and 5 acres of land, such as small construction activities.

In addition to expanding the NPDES Storm Water Program, the Phase II Final Rule revises the "no exposure" exclusion and the temporary exemption for certain industrial facilities under Phase I of the NPDES Storm Water Program. [7]

3.1.3 Wet Weather Discharges

"Wet weather discharges" refers collectively to point source discharges that result from precipitation events, such as rainfall and snowmelt. Wet weather discharges include storm water runoff, combined sewer overflows (CSOs), and wet weather sanitary sewer overflows (SSOs). Storm water runoff accumulates contaminants such as oil and grease, chemicals, nutrients, metals, and bacteria as it travels across land. CSOs and wet weather SSOs contain a mixture of raw sewage, industrial wastewater and storm water, and have resulted in beach closings, shellfish bed closings, and aesthetic problems. Under the NPDES permit program, there are the following three program areas: Storm water runoff, CSOs and SSOs. Those address each of the wet weather discharges described above. EPA believes that wet weather discharges should be addressed in a coordinated and comprehensive fashion to reduce the threat to water quality, reduce redundant contamination control costs, and provide State and local governments with greater flexibility to solve wet weather discharge problems. To identify and address cross-cutting issues and promote coordination, EPA established the Urban Wet Weather Flows Federal Advisory Committee in 1995 (United States Environmental Protection Agency. [8]

3.2 Contaminant Sources and their Effects

In this section some background information on storm water runoff from highways will be discussed. Furthermore, definitions and explanations of the most

important aspects of the special topic of storm water runoff from elevated highways will be provided.

3.2.1 Distinction between Non-Point and Point Sources

Since there is often a misunderstanding in the meaning of non-point and point sources of pollution, a definition is given as the following.

3.2.1.1 Point Sources

Most people think of urban contamination as belching smokestacks, auto exhaust, and industrial waste – all of which originate from an identifiable source. This source can either be stationary such as industrial wastewaters or mobile such as auto exhaust gases. Technically, these contaminants are identified as coming from point sources, places that literally can be pointed out. [6]

3.2.1.2 Non-point sources

Storm water runoff collects contaminants from an undefined, mostly impervious area which enters the collection pipes without proper treatment. Though much less obvious than point sources, it can be equally as contaminated. Urbanization leads to an increase in impervious surfaces such as highways, parking lots, and rooftops. As storm water runoff flows over surfaces, it picks up and carries away contaminants that accumulate during dry periods, finally depositing them into lakes, rivers, wetlands, and groundwater. Runoff from highways and surrounding development may contain

contaminants such as oil, dirt, grease, and metals that can significantly impact the quality of receiving waters. [6]

Other impacts coming along with urbanization are the increasing amount of storm water runoff, contribution to stream bank erosion and possibility of downstream flooding. Impervious concrete and asphalt surfaces of new roadways prevent storm water from soaking into the ground, where it was once absorbed. This increases the total volume of storm water runoff. It also increases the value of the peak storm water discharge, and decreases the time it takes to reach this peak. Increased runoff volumes and peak discharge levels result in increased levels of flooding risk. [9]

Collecting runoff water from non-point sources, such as roadway shoulders, is difficult, thus in this research project, storm water runoff from an elevated highway has been analyzed. Samples were collected from the drainage pipe of this elevated highway, which collects water from a known impervious area. Consequently, calculating the volume of the storm water runoff and addressing the contaminant loading to this known area was possible.

3.2.2 Factors affecting runoff quality

Identifying the characteristics of the contaminants from elevated highways is an important aspect of this research effort.

3.2.2.1 Sources

One of the major contaminant sources of storm water runoff are vehicles. All means of transportation directly and indirectly contribute much to the contamination found in highway runoff. Vehicles are a source of metals, oil, grease, lead, asbestos, and rubber. Sometimes de-icing chemicals such as salts or other materials deposited on highways are also indirectly contributed to vehicles. Other major sources of contaminants in the runoff include dust that settles on the road and shoulders and dissolved constituents, such as acids and particulate matter from atmospheric fallout. Urban construction sites contribute sediment, plant debris, and asphalt. Storm water runoff also contains refuse such as street litter. A number of common highway maintenance practices, such as salting, also may adversely affect water quality. The nature of the materials, methods used, and the proximity of the maintenance activity to a body of water increase the likelihood of adverse effects. [9]

3.2.2.2 Highway Runoff Quality

Numerous factors may affect the quality of highway runoff including traffic volume, precipitation characteristics, roadway surface type, and the nature of the contaminants themselves. Research continues into the relationship between these factors and the concentration of contaminants in highway runoff because of the complexity and importance of this topic. The precipitation characteristics that may impact the water quality of highway runoff include the number of dry days preceding the event, the intensity of the actual and preceding storm event, and their durations. Intensity of the actual storm event has a significant impact because many of the contaminants are

associated with particulate matter, such as dust, which are more easily mobilized in high intensity storms. Constituents in storm water runoff showing a strong correlation with suspended solids include metals, organic compounds, total organic carbon, and biochemical oxygen demand. [6]

Higher concentrations of contaminants are often observed in the first runoff from a storm, a phenomenon referred to as first flush effect. This is especially true for dissolved components including nutrients, organic lead, and ionic constituents. [9] In general, concentrations of particle-associated contaminants show a more complex temporal variation related to rainfall intensity and the flushing of sediment through the drainage system.

The effect of highway paving material (asphalt versus concrete) on the quality of highway runoff appears to be minimal. Most studies have found that highway surface type was relatively unimportant compared to such factors as surrounding land use. [9] It has also been reported that the type of collection and conveyance system for highway runoff, such as storm sewer, grassy swale has a greater effect on runoff quality than pavement type. [9]

3.2.2.3 Effects of Highway Runoff

The type and size of the receiving body, the potential for dispersion, the size of the catchment's area, the relative amount of highway runoff, and the biological diversity of the receiving water ecosystem are just some of the factors that determine the extent and importance of highway runoff effects. Concentrations of contaminants in the water columns of receiving waters generally show small changes due to highway runoff. This

may be the result of dilution of the highway runoff by flow from the rest of the watershed. However, stream and lake sediments have been found to have high concentrations of heavy metals and are the primary source for the bioconcentration of metals in aquatic biota.

Bioassay tests of organisms from streams and lakes receiving highway runoff generally have not demonstrated acute toxicity, although very high traffic volumes or other site-specific conditions may produce a toxic response. Chronic toxicity resulting from bioaccumulation of contaminants in highway runoff has not been thoroughly investigated, although studies have documented higher concentrations of metals in fish and other aquatic biota living near highways. [9]

Highways can have an impact on groundwater, including changes in water quality in surface and shallow aquifers. Highway runoff that infiltrates into the ground may result in the contamination of groundwater with contaminants including metals, nitrogen, and organic compounds. The effects of highway runoff on groundwater are highly variable depending on depth to the water table, hydrological conditions, and soil characteristics. Soils can prevent or reduce the amount of some contaminants reaching groundwater through retention, modification, decomposition, or adsorption. Therefore, groundwater contamination is a particular concern where the aquifer is shallow (less than 4 feet). [9]

3.3 Definition of BOD, COD, and their Ratio

In the fields of effluent wastewater treatment and assessment of the impact of discharges on the aqueous environment, there are many terms employed that relate to the

oxygen demand and/or organic carbon content of the water. [10] Thus, the BOD, COD and the ratio of those two parameters will be defined in the next section of this thesis.

3.3.1 BOD

Biochemical Oxygen Demand (BOD) is a measurement of oxygen utilized during a specific incubation period, usually five days, for the biochemical degradation of organic material called carbonaceous demand and the oxygen used to oxidize inorganic material such as sulfides and ferrous iron. The BOD may also measure the oxygen used to oxidize reduced forms of nitrogen called nitrogenous demand unless their oxidation is prevented by an inhibitor. [11]

3.3.2 COD

The Chemical Oxygen Demand (COD) is used as a measure of the oxygen equivalent of the organic matter content of a sample that is susceptible to oxidation by a strong chemical oxidant. [11] The organic matter destroyed by a mixture of chromic and sulfuric acids is converted to carbon dioxide (CO_2) and water (H_2O). The standard test procedure is to add measured quantities of standard potassium dichromate, sulfuric acid reagent containing silver sulfate, and a measured volume of sample into a flask. [2] After thorough mixing, these flasks are attached to the reflux condenser and heat is applied. . A different procedure, where prepared vials from the HACH Company are used, was utilized for this research. This HACH-COD test will be described in Chapter 4.

3.3.3 Relationship between COD and BOD

As mentioned before, to measure oxygen demand, the BOD method relies on bacteria to oxidize readily available organic matter during a five day incubation period, referred to as BOD_5 test. In contrast, COD methods use strong chemicals to oxidize organic matter that are not readily biodegradable or non-biodegradable. Consequently, the COD test is not a direct substitute for the BOD_5 test. However, a ratio usually can be correlated between the two tests. This requires COD versus BOD testing over a specified period of time. Thus, for samples from a specific source, COD can be related empirically to BOD_5, organic carbon or organic matter. [11] If comparative data shows a direct correlation between COD and BOD_5 results, the regional USEPA office will usually allow COD testing for permit reporting purposes. COD values are often preferred to BOD_5 values in process control applications, because results are more reproducible and thus more reliable. Another advantage of COD testing is that the results are available in just a few hours compared to the five day incubation time of the BOD_5 test. [12]

3.4 Literature Research

The special topic of storm water runoff of an elevated highway required a literature research. Articles of current journals, newspapers and the Internet were collected. Then the findings were split into three groups, which define the next three Subchapters in this thesis. This division is a step-by-step procedure for solving the problem of contamination caused by storm water runoff. The first step is to conduct

runoff analyses for all kinds of parameters. After that models are developed which convert a physical problem into a mathematical equation. All kinds of statistic approaches are used to get results, such as regression equations or correlations. Finally, the last step is to apply the statistical derived equation to the most appropriate physical treatment system or process. In the literature this system development is called: Best Management Practices (BMPs).

3.4.1 Runoff Analyses

In a first article a four-year study of the quality of highway runoff had been conducted at the University of Texas in Austin. Storm water runoff from existing highways was characterized in this research. The collection of the samples was expedited using a unique rainfall simulator that was designed to operate over active highway traffic. Therefore, simulated and natural rainfall events could be analyzed. These data were used to formulate a regression model that explains the loading of TSS. They had built two sampling sites. One site was built in an urban area where the traffic was much lower than at the second site, which was located near the West 35th street overpass. The volume of runoff, intensity of rainfall, the duration of the antecedent dry period and the intensity of the proceeding storm runoff influenced the TSS load. Traffic, however, was not a significant variable in the model formulation. The overwhelming impact of dust fall, street maintenance activities, such as street sweeping, and other dry period conditions was mentioned as reason in the article. Efforts to reduce the load of TSS in highway storm water runoff should focus on the control of dirt and debris, which accumulate on the highway surface during the antecedent dry period. The model suggests that a

frequent street sweeping schedule will reduce expected TSS loads in highway runoff. [13]

Another study was conducted focusing on the correlations between heavy metals and suspended solids in highway runoff. Runoff data from eight highway sites in the United States and Europe were analyzed. Additionally, the data was used for testing the hypothesis that metal concentrations are significantly correlated to suspended solids in highway runoff. Thus, Sansalone, the author, analyzed storm water runoff from heavily traveled urban highways that can adversely affect the quality of the receiving waters. Non-point contaminants in highway runoff include heavy metals, suspended solids, micro-organics, oils and chlorides. These contaminants result from traffic activities, atmospheric deposition, engine exhaust, roadway degradation and highway maintenance. Results indicated a strong positive correlation between heavy metals and suspended solids for snow wash off events and a weaker positive correlation for rainfall events. [14]

The Colorado Department of Transportation (CDOT) conducted another study. Municipalities and transportation agencies have undertaken extensive storm water monitoring efforts. Findings and conclusions from these monitoring efforts, and comparisons between the different institutions are presented in this document. [15]

In another study storm water runoff was sampled from multiple storms at fourteen locations in Canada. Sites represented distinct types of land use: highway, commercial, residential. Additionally, the outflows of several types BMPs such as storm water treatment ponds, constructed wetlands and biofilters were also sampled. The greatest frequency and most severe toxicity were present in runoff from multilane divided highways. This toxicity was predominantly present in the winter months and may have

been due to contaminant accumulation in snow, high concentrations of road salts and mobilization of metals by chlorides. The toxicity was only present during the first 30 minutes of highway runoff. Thus, this indicated an evidence of a first flush effect. [16]

Another study was conducted by California Department of Transportation (Caltrans). In this research 72 station-storm events during the 1998-1999 and 1999-2000 wet seasons were collected and analyzed. As one of their results the authors present a correlation between TSS runoff concentrations and particulate runoff concentrations of some metals, such as copper, chromium and zinc, indicating that minimizing particulate matter may reduce total metals concentrations. [17]

In another article Pitt, the author, analyses storm water runoff from parking areas, streets, and vehicle service areas. In this study 87 storm water samples were analyzed for chemical constituents and toxicity using a special system called Microtox assay system. Organic contaminants were detected in 15-20% of the storm water samples, with the highest concentrations measured in samples from parking and vehicle service areas. Most of this organic contamination was associated with particulate matter. Metals were almost always detected in the samples and were associated with particulate matter, except for Zinc, which was mostly in the dissolved phase. Toxicity was detected in 41% of the samples, with again the highest percentage of toxic samples from parking lots. [18]

deHoop discusses in his paper that very little attention has been paid to the storm water runoff quality from log storage and handling facilities. In this project he determined the concentrations of the conventional parameters such as BOD_5, COD and TSS in over 100 storm water runoff samples. As results he presents that a portion of 1-13% of the COD value was biodegradable and the COD followed closely with TSS.

Therefore he suggested that effective control of TSS would control the COD as well. [19]

The next study, which was performed by Lee and Bang, characterizes urban storm water runoff. The purposes of this study were to investigate the characteristics of contaminants overflow on storm events, relationships between pollutant load and runoff, and the first flush effect in urban areas. Therefore nine watersheds in the cities of Taejon and Chongju, Korea were selected for sampling. Runoff and quality parameters such as BOD_5, COD, suspended solids (SS), total kjeldahl nitrogen (TKN) and more were analyzed for the development of relationships between runoff and water quality. As results Lee and Bang presented that pollutant concentration peak occurred before the flow peak in smaller than 100 ha watersheds with an impervious area of more than 80%. [20]

3.4.2 Model Development

In his article Bujon present a model, called FLUPOL, which calculates the flow rates and discharges of suspended solids, BOD_5, COD, and total kjeldahl nitrogen downstream from an urban catchment area and its drainage system after a given rainfall. The simulated phenomena ranged from accumulation of contaminating matter on an urban surface during dry weather to transit of flow and contamination in the sewer, including possible deposition or resuspension processes. The FLUPOL Model was adjusted and subsequently validated using several series of measurements carried out in France. Additionally, the model has been used in several sewerage studies taking into account the polluting discharges during wet weather conditions. [21]

In the next document Irish, developed a regression model for predicting loads for a number of constituents commonly found in highway storm water runoff. Storm water data was collected from an expressway in the Austin, Texas area. Linear regression was found to be most appropriate for analyzing the data because of its ability to identify constituent specific causal variables. These variables can be measured during rainstorm event, antecedent dry period, and the previous rainstorm event. Loads of some constituents, such as TSS, were dependent on the characteristics of the current storm, antecedent dry period and the preceding storm indicating the importance of buildup and wash off processes. Other constituents, such as oil and grease, were dependent only on conditions during the current storm, such as runoff volume and number of vehicles during the event. [22]

Another model, called VISIOSED, was developed by Jilani and Wang to predict the total sediment yield from a watershed as a result of highway construction. Based upon Universal Soil Loss Equation and using the EPA Storm Water Management Model (SWMM) to calculate the total runoff from the site 10 rainfall events were selected for model simulations. [23]

3.4.3 Best Management Practices (BMPs)

In their paper Ana Estela Barbosa and Hvitved-Jacobsen Thorklid present that highway runoff disposal without concern for its specific characteristics may be associated with high material and environmental costs. An understanding of storm water management has enlightened the importance of the impacts that non-point contamination may cause to both surface waters and groundwater. Several systems for highway runoff

treatment exist, often based on detention and infiltration processes. In this paper infiltration ponds are said to be one of the BMPs for highway and storm water treatment and/or disposal. The infiltration ponds principle is based on capture and infiltration of the most polluted runoff. Seasonal variations in rainfall and evaporation were considered. Barbosa concludes that the method presented was based and applied to highway runoff but can be used for treatment of storm water runoff from other sources as well. [24]

In the next article Yu, Fitch and Earles mention that the wetland mitigation and storm water management provisions in the CWA significantly affect transportation agencies. The use of BMPs is required. Consequently, the Virginia Department of Transportation has constructed more than 200 wetlands and many storm water BMPs such as detention ponds. Furthermore, the authors state that a potentially cost-effective approach to satisfying wetland mitigation requirements and storm water regulations is to use mitigated wetlands as storm water BMPs. Thus, a multifunctional evaluation of two mitigated wetlands receiving highway runoff is presented to examine the feasibility of using mitigated wetlands as storm water BMPs. Influent and effluent water qualities were monitored at the sites during storm events. Three parameters, vegetation density, diversity, and wetland wildlife, were examined as functional indicators. As results the authors present removal rates for a system that combines a detention basin and a mitigated wetland in series. Removal rates were as high as 90% for TSS, 65% for COD and 50% for Zinc. As a final conclusion the authors state that both sites support apparently healthy and diverse vegetative communities and provide habitat for a variety of wildlife although the primary water source is highway runoff. [25]

The Washington State Department of Transportation developed a Storm Water Management Program to comply with state and federal laws. The program included an outfall inventory and retrofit program, a Highway Runoff Manual (HRM) and storm water research. Schaftlein, the author, states in this article that thirteen research projects had been funded to evaluate experimental BMPs, to determine BMP pollutant removal efficiencies, and to assess the costs and benefits of retrofitting outfalls. As a result Schaftlein mentions maintaining a computer database to facilitate storm water management activities. Additionally, a prioritization scheme was developed to identify priority sites for retrofit, based on the following factors: receiving water body, beneficial uses, pollution loading, present highway drainage, cost-pollution benefit, and values trade-off. [26]

In the next paper Taylor describes another comprehensive storm water management program conducted in California. This program was developed to meet the project, called Environmental Impact Report/Statement, mitigation measures. Furthermore, it included a new concept in water quality assessment termed evaluation monitoring by the program authors. A definition of storm water contamination as related to the California Porter-Cologne Act and the NPDES is also presented. As well, an analysis of the beneficial uses of the project receiving waters, potential aesthetic impact of structural BMPs and storm water quality are presented and discussed. [27]

The next paper, composed by Amick, analyses the storm water monitoring data, which was released by the EPA, to determine which contaminants are present in storm water runoff from transportation facilities. Several hundred facilities representing the railroad, highway, water, and air sector submitted their monitoring data. Each of these

sectors was discussed and appropriate BMPs were presented with the capability to reduce or eliminate the contaminants in storm water discharges. [28]

In the next article, Barrett states details about different types of storm water controls that are used to treat highway runoff. These controls were evaluated at the Center of Research in Water Resources at the University of Texas, in conjunction with the Texas Department of Transportation. A research program was investigating the contaminant removal efficiency and maintenance requirements of grassy swales, extended detention ponds, and sedimentation and/or filtration systems. As an outcome of this research the author reveals that grassy swales monitored during this study provided a surprisingly high level of treatment and had minimal maintenance requirements. Under optimum conditions the performance of grassy swales has rivaled that of sand filter systems. [29]

In the next article Pratt, the author, present the construction details of an experimental permeable pavement, comprising four separate sub-base conditions containing different stone and crushed rock. These sub-base drains had been monitored for discharge volume, flow rate and water quality parameters. Furthermore, preliminary results are presented indicating that useful volume and flow rate reductions may be obtained via permeable pavements. Additionally, the water quality may be enhanced by sedimentation and other treatment processes occurring within the pavement. Thus, the effluent quality may be improved as compared to discharges of usual impermeable highway surfaces in similar residential areas. [30]

CHAPTER 4

METHODOLOGY

In the following section the various methods used to complete this research effort will be explained. This included the development and identification of a test site as well as the collection and analyses of highway storm water runoff samples of fourteen different storm events.

4.1 Experimental Site Characteristics/Highway Runoff

In order to characterize the highway runoff water quality, a broad spectrum of storm events has been sampled at the experimental site. A maximum of fifteen fully labeled samples (date, sample number and time at which it was collected) have been collected for each storm, from the time of the start of observable rainfall. Samples were collected every 2 minutes until peak flow has been reached and then every 4 minutes thereafter. All the data recorded, measurements taken and samples collected have been logged on apposite data sheets alongside the time at which they have been taken.

The initial task of the research consisted of finding the right location for the experimental site. The site was located on the intersection of the I-10 and I-610

highways direction Baton Rouge beneath the eastbound lane of the I-610. This part of the highway was ideal for the research work because of the fast and easy access by car from the University-campus even during rush hours. This was from significant importance because samples had to be taken from the very first runoff flowing out of the pipe. Because weather forecast is not always reliable and rainfall not easy to predict the fast access of the test site by car was very important. Moreover part of the highway courses over a bridge where the drainage of the runoff can be determined easily. In this case it can be assumed that all storm water will run off each drainage-section of the bridge and can easily be collected. Therefore, it is easier to determine the area drained and the amount of storm-water runoff for each section. Last but not least, the site was located in a safe neighborhood, which made the work safe even during night hours. [31]

The sampling location was constructed beneath the Interstate-610 eastbound lane. (Figure 1). The I-610 elevated roadway has three eastbound lanes of Portland cement concrete. This highway carries an average daily traffic load of 40,000 vehicles per day. The mean annual precipitation at the experimental site is 62 in/yr (1572 mm/yr), with the highest monthly rainfalls, 6.2 in/month (156 mm/month), during the months of July and August. The specific drainage area of the elevated roadway section drains to two storm drains on the leading edge of the outside lane (Figure 2). This specific drainage area from which the storm water runoff had to be characterized is 6,288 ft^2 large (Figure 3).

The storm water runoff is discharged without treatment directly into the 17th Street Canal. This is representative of the heavily traveled elevated sections of major arterial highways that are typical of south Louisiana's elevated infrastructure. [31]

The area beneath the elevated highway was made ready for the establishment of the experimentation station. This involved the cleaning of a sufficient large area for the construction of the experiment station, installation of all necessary equipment for the performance of the measurements, lighting and finally making the facility secure by the installation of a fence off area. The process of site preparation also included the construction of a small concrete dam around the manhole where samples were collected from the two outflow pipes in order to prevent infiltration of surface runoff water from the surrounding environment to the runoff from the elevated highway section.

Figure 1: View of the experimental site and manhole

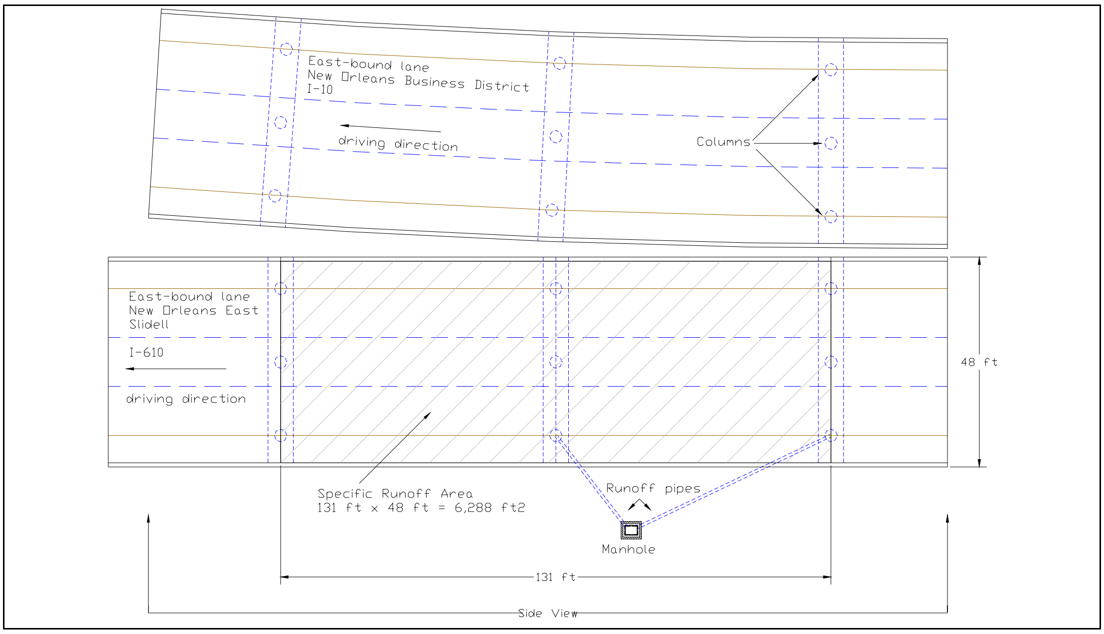

Figure 2: Plan view of the specific drainage area (6,288 ft^2) of the selected highway section of Interstate-610 in Orleans Parish, New Orleans, Louisiana.

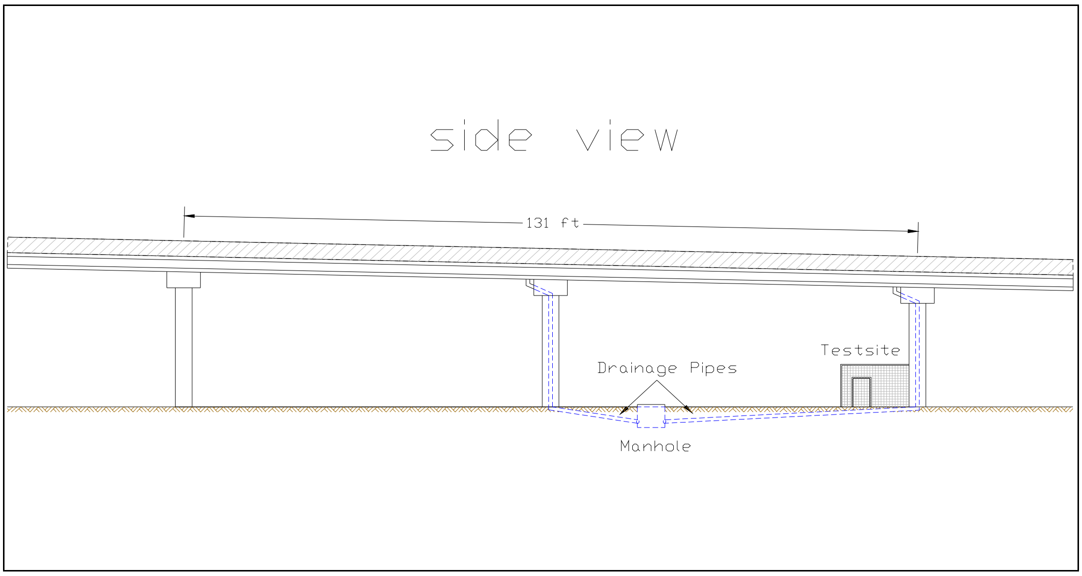

Figure 3: Side view of section through the selected I-610 highway section at the experimental site.

Figure 4: The experimental site beneath the east-bound lane of the Interstate-610.

Figure 5: Drainpipes in manhole from which the Highway runoff is collected.

4.2 Meteorological Information and Traffic Counts

Meteorological information was a crucial component in this study in order to facilitate the collection of highway storm water runoff samples at the very beginning of rainfall events. Vehicles potentially represent a major pollutant source in highway storm water runoff and for that reason traffic counts were performed.

4.2.1. Sources of Meteorological Information

The sources used to gather meteorological information were local weather forecasts for long-term predictions, the local DOPPLER radar and traffic cams along Interstate I-10 to track the location and progression of the storm events. The latter two were accessible online in the World Wide Web and could be used to track the storms at any desired time with good precision. [31]

The utilized links are shown below:

http://www.weather.com/weather/local/70122?whatprefs

http://nola.com/traffic/cams/

http://www.accuweather.com

Since the first flush of every storm event was very important for the research, this meteorological information was of fundamental significance. [31]

4.2.2. Traffic Counts

Traffic flow characteristics and hydrology are two of the principle variables that significantly affect pollutant loading. Consequently, vehicular counts were performed every 15 minutes, starting immediately upon arrival at the experimental site. The duration of each count was 2 to 4 minutes. In addition to these recordings, another traffic count was carried out, where counts where done hourly for 4 days (2 week days and 2 weekend days), in order to obtain a reasonable average value for the number of vehicles passing this specific highway section. [31]

4.3 Storm Water Runoff Sampling and Flow Measurements

Highway storm water runoff was collected in the storm sewer manhole displayed in Figure 5. Storm water runoff from the highway section was transported to the manhole through two drainage pipes. Flow intensity measurements and sampling collection was performed in the above mentioned manhole for both pipes. [31]

4.3.1. Flow Measurements

The collection of runoff samples was carried out using two 5-gallon-buckets; one for each drainpipe. Both buckets were marked with a liter scale in order to obtain the collection volume and were rinsed out with clean water before every collection. In addition, the collection time was recorded to be able to determine the runoff flow rate. Subsequently, the collected highway runoff from both drainpipes was mixed together for each sample and poured into clean polypropylene sample bottles. Fully labeled 1-liter

samples (date, sample number and time at which it was collected) were collected from the time of the first flow of storm water runoff coming out of the drainpipes at the manhole (defined as time 0) to the collection of 10 to 15 runoff samples, or the end of the particular storm event, which ever came first. Depending on the intensity of the storm and the associated runoff flow, samples were collected every two to four minutes. In event periods of very low runoff flows, the collection intervals were increased to obtain sufficient quantities of storm water runoff to perform all planned wet chemistry analyses.

Since flow measurements are essential to calculate mass loading contributions, recordings were carried out throughout the sampling duration of the storm, from the moment of first runoff flow generation (first runoff reaching the manhole through the drainpipes) until the completion of the particular rainfall runoff sample amount (usually between 10 – 15 samples). Volumetric flow rates were noted down with every collected sample by measuring the amount of collected water and the collection time. Storm water runoff from the elevated roadway section was sampled for fourteen storm events throughout the course of the study from which hydrologic and water quality data were collected. [31]

4.4 Storm Water Runoff Analyses

Prior to any analytical procedure the collected samples were fully mixed because of the high particulate loadings in almost all runoff samples. This was performed to ensure that measurements taken are representative for the parent samples and to ensure sample homogeneity.

Comprehensive documentation of the recognized Standard Methods, which are referenced as the analytical techniques for each analysis performed, is not restated in this thesis. The author has only listed any deviation from, or specific modifications to the recognized analytical procedures used. The reader is referred to the "APHA Standard Methods for the Examination of Water and Wastewater" if further detailed review of each of these procedures is necessary. [32]

4.4.1. Field Measurements

In addition to the collection of each storm water sample, field data analysis was performed immediately at the experimental site. After the storm water runoff collection, the samples were transported to the environmental engineering laboratory at the University of New Orleans for further analysis. The parameters measured at the test site are listed below:

- Temperature (^oC)
- pH (s.u.) (APHA Standard Method 4500-H+B)
- Redox potential (+mv) (APHA Standard Method 2580 B)
- Conductivity (μS/cm) (APHA Standard Method 2510)

All electronic devices were calibrated before and properly cleaned with distillation water after every storm event. A portable Orion 290-A+-meter with a silver/silver chloride (Ag/AgCl) combination electrode was used to measure oxidation/reduction potential, temperature and pH. This silver/silver chloride electrode was used instead of conventional potassium chloride probes because of the interference

of heavy metals on measuring Redox potential using conventional combination electrodes. [31]

An YSI Model 85 digital meter was used to measure conductivity and again to measure the temperature to make sure that the values of the two meters were equal in order to have an additional measurement device control.

4.4.2. Laboratory Procedures

This chapter focuses on the different analysis performed in the laboratory after collecting samples. First of all time sensitive analysis will be explained followed by the lab procedure sequence.

4.4.2.1. Time Sensitiveness and Analysis

After the cessation of the storm water runoff collection and the field analysis, the samples were transported to the environmental engineering laboratory at the University of New Orleans for further analysis. Time sensitive data analyses were performed immediately or at most within 12-hours of collection. If it was not possible to perform these analyses immediately, the samples were refrigerated at 5 °C and analysed within 12 hours of initial sample collection. All water quality parameters measured were documented in the laboratory notebook. All devices were calibrated prior to determine the samples.

Following analysis are time sensitive and were analysed as soon as possible:

- Chemical Oxygen Demand (total, particulate and dissolved) (mg/L) (APHA Standard Method 5220-D and Hach Method 8000 (1992))
- Acid preservation of 15-mL aliquot for heavy metal analysis

As soon as the time sensitive laboratory analyses were complete the non-time sensitive laboratory analyses proceeded. These analyses are specifically:

- Total Suspended Solids (mg/L) (APHA Standard Method 2540-D).
- Dissolved heavy metal analysis using an ICP-AES
- Suspended and Dissolved Solids (APHA Standard Methods 2540-D and 2540-E)

All data are logged in analysis specific laboratory notebooks, from which the data was than transferred to electronic files for interpretation. All analyses have been performed in triplicate for statistical verification. A blank and standard has been prepared for each batch of samples. The exact number of blanks will be approximately 5% of the number of samples run as recommended with QA/QC specifications of APHA Standard. Arithmetic means and standard deviations of the triplicates are calculated.

4.4.2.2. Suspended and Dissolved Solids

Storm water runoff samples were fractionated into total suspended solids (TSS), volatile suspended solids (VSS), total dissolved solids (TDS) and volatile dissolved solids (VDS). TSS and VSS were determined in accordance with APHA Standard Methods 2540-D and 2540-E, respectively. The methodology to determine VDS is not officially

documented in the APHA Standard Method Handbook with Method 2540 and was determined by igniting the residue from the TDS analysis in a similar fashion to the determination of VSS in Standard Method 2540-E.

4.4.2.3. Chemical Oxygen Demand (COD)

The chemical oxygen demand (COD) is used as a measure of the oxygen equivalent of the organic matter content of a sample that is susceptible to oxidation by a strong chemical oxidant. For samples from a specific source, COD can be related empirically to BOD, organic carbon, or organic matter. The Chemical Oxygen Demand (COD) test uses a strong chemical oxidant in an acid solution and heat to oxidize organic carbon to $C0_2$ and H_20. Oxygen demand is determined by measuring the amount of oxidant consumed. The measurement was performed on the HACH COD equipment in the environmental laboratory at the University of New Orleans in accordance with Standard Method 5220 (1992).

4.5 Statistical Data Analysis

The enormous amount of data collected from the analyzed storm water runoff events was transferred to an Excel spread sheet where it could be further examined. The database was comprised of 163 data samples. Mean values and total mass loadings were calculated from the obtained field and lab measurements. A list of the measured variables, their dimensional units and description is shown in Table 1. It is also very important to understand and observe the ranges of values for each of the parameters

collected and calculated. Table 2 lists the basic descriptive statistics for each of the parameters in the database, including mean, standard deviation, minimum and maximum values.

Analysis of the data was performed in order to identify the parameters which had the most influence on COD concentrations. This was done using scatter plots, basic statistical calculations and correlations.

	Definition	Unit
Dry_hours	Dry hours between rainfall	h
Raintime	Time until beginning of rainfall	min
Flow	Runoff flow from the elevated highway section	l/min
Runofftime	Runoff time starting at t=0 for the first observed pipe-outflow	min
Qt	Cumulative total runoff since first pipe-outflow	l/min
TSS	Total Suspended Solids	mg/l
COD	Chemical Oxygen Demand	mg/l
pH	pH	pH
Redox	Redox potential	+mv
Temp	Temperature	ºC
Cond	Conductivity	μS/cm
Flow mean	mean runoff flow	l/min
TSS mean	mean TSS concentration	mg/l
COD mean	mean COD concentration	mg/l
pH mean	mean pH value	pH
Redox mean	mean redox potential	+mv
Temp mean	mean temperature	ºC
Cond mean	mean conductivity	μS/cm
Qt tot	total runoff volume	l
TSS tot m.l.	total mass load TSS	mg
COD tot m.l.	total mass load COD	mg

Table 1: Descriptive Statistics: List of Variables and Units

	N	Minimum	Maximum	Mean	Std. Deviation
Dry hours	163	42	1032	273.64	274.18
Raintime	163	6	107	33.25	21.62
Flow	163	0.44	900	118.68	190.67
Runofftime	163	0	92	19.11	19.81
Qt	163	0	14240.21	1715.00	2788.64
TSS	163	4	1200	118.16	174.24
COD	163	30	1650	324.66	269.52
pH	150	0.74	8.3	7.62	0.68
Redox	148	-63	37.5	-44.09	16.72
Temp	163	11.1	30.2	19.12	5.05
Cond	161	34.2	2935	435.65	551.76

Table 2: Basic Descriptive Statistics of Database

Once a set of parameters were identified, a model or a series of models could be developed to describe COD concentrations in storm water runoff from elevated highways. The approach for the analysis of the data proceeded in four steps which are discussed in the following chapters.

4.5.1 Statistical Model Data Preparation

The first step consisted in developing correlation matrixes. This was done observing the original data first. The data set was then transformed. For the data set of this research the author applied a natural logarithmic transformation, a logarithmic transformation to the base 10, a square transformation, and a square root transformation. Moreover, for certain variables a constant was applied. This became necessary because some variables had negative or zero values. Such values were not able to be transformed without adding a constant.

A correlation matrix for each transformed data set was then developed. The values for the new correlation matrixes were then compared to the previously obtained values from the non transformed data. The following tables (Table 3-11) illustrate the calculations used to transform the raw data and the correlation matrix for the untransformed and transformed data sets.

	Initial	Mathematical Calculation	Final	
Original untransformed variables	Dry_hours	LN (Dry_hours)	LN_Dry_hours	Obtained transformed variables
	Raintime	LN (Raintime)	LN_Raintime	
	Flow	LN (Flow)	LN_Flow	
	Runofftime	LN (Runofftime+1)	LN_Runofftime	
	Qt	LN (Qt+1)	LN_Qt	
	TSS	LN (TSS)	LN_TSS	
	COD	LN (COD)	LN_COD	
	pH	LN (pH)	LN_pH	
	Redox	LN (Redox+65)	LN_Redox	
	Temp	LN (Temp)	LN_Temp	
	Cond	LN (Cond)	LN_Cond	

Table 3: Mathematical Procedure for LN-Transformation of Variables

	Initial	Mathematical Calculation	Final	
Original untransformed variables	Dry_hours	LOG (Dry_hours)	LOG_Dry_hours	Obtained transformed variables
	Raintime	LOG (Raintime)	LOG_Raintime	
	Flow	LOG (Flow)	LOG_Flow	
	Runofftime	LOG (Runofftime+1)	LOG_Runofftime	
	Qt	LOG (Qt+1)	LOG_Qt	
	TSS	LOG (TSS)	LOG_TSS	
	COD	LOG (COD)	LOG_COD	
	pH	LOG (pH)	LOG_pH	
	Redox	LOG (Redox+65)	LOG_Redox	
	Temp	LOG (Temp)	LOG_Temp	
	Cond	LOG (Cond)	LOG_Cond	

Table 4: Mathematical Procedure for LOG-Transformation of Variables

	Initial	Mathematical Calculation	Final	
Original untransformed variables	Dry_hours	$(Dry\_hours)^2$	SQ_Dry_hours	Obtained transformed variables
	Raintime	$(Raintime)^2$	SQ_Raintime	
	Flow	$(Flow)^2$	SQ_Flow	
	Runofftime	$(Runofftime)^2$	SQ_Runofftime	
	Qt	$(Qt)^2$	SQ_Qt	
	TSS	$(TSS)^2$	SQ_TSS	
	COD	$(COD)^2$	SQ_COD	
	pH	$(pH)^2$	SQ_pH	
	Redox	$(Redox/ABS(Redox))*(Redox)^2$	SQ_Redox	
	Temp	$(Temp)^2$	SQ_Temp	
	Cond	$(Cond)^2$	SQ_Cond	

Table 5: Mathematical Procedure for Square-Transformation of Variables

	Initial	Mathematical Calculation	Final	
Original untransformed variables	Dry_hours	$(Dry\_hours)^{0.5}$	SQR_Dry_hours	Obtained transformed variables
	Raintime	$(Raintime)^{0.5}$	SQR_Raintime	
	Flow	$(Flow)^{0.5}$	SQR_Flow	
	Runofftime	$(Runofftime)^{0.5}$	SQR_Runofftime	
	Qt	$(Qt)^{0.5}$	SQR_Qt	
	TSS	$(TSS)^{0.5}$	SQR_TSS	
	COD	$(COD)^{0.5}$	SQR_COD	
	pH	$(pH)^{0.5}$	SQR_pH	
	Redox	$(Redox/ABS(Redox))*(ABS(Redox))^{0.5}$	SQR_Redox	
	Temp	$(Temp)^{0.5}$	SQR_Temp	
	Cond	$(Cond)^{0.5}$	SQR_Cond	

Table 6: Mathematical Procedure for Square-Root-Transformation of Variables

Cond	Temp	Redox	pH	COD	TSS	Qt	Runofftime	Flow	Raintime	Dry_hours	
0.64821	0.06197	0.30822	-0.03646	0.38385	0.15580	0.04186	0.12251	0.06545	0.27639	1.00000	Dry_hours
0.05225	-0.22266	-0.24499	0.29206	-0.16629	-0.25726	0.13910	0.96500	-0.12361	1.00000	0.27639	Raintime
-0.31292	0.11810	0.09707	-0.02297	-0.21709	-0.01558	0.57366	-0.06804	1.00000	-0.12361	0.06545	Flow
-0.11132	-0.24742	-0.30085	0.27322	-0.28051	-0.28458	0.24771	1.00000	-0.06804	0.96500	0.12251	Runofftime
-0.36773	0.06668	-0.15231	0.13789	-0.41396	-0.22576	1.00000	0.24771	0.57366	0.13910	0.04186	Qt
0.30007	0.09147	0.66994	-0.36187	0.55476	1.00000	-0.22576	-0.28458	-0.01558	-0.25726	0.15580	TSS
0.81284	0.03019	0.61120	-0.27489	1.00000	0.55476	-0.41396	-0.28051	-0.21709	-0.16629	0.38385	COD
-0.21450	0.11598	-0.42099	1.00000	-0.27489	-0.36187	0.13789	0.27322	-0.02297	0.29206	-0.03646	pH
0.44447	-0.08819	1.00000	-0.42099	0.61120	0.66994	-0.15231	-0.30085	0.09707	-0.24499	0.30822	Redox
0.05393	1.00000	-0.08819	0.11598	0.03019	0.09147	0.06668	-0.24742	0.11810	-0.22266	0.06197	Temp
1.00000	0.05393	0.44447	-0.21450	0.81284	0.30007	-0.36773	-0.11132	-0.31292	0.05225	0.64821	Cond

Table 7: Correlation Matrix for all Variables: Untransformed Raw Data Set

LN Cond	LN Temp	LN Redox	LN pH	LN COD	LN TSS	LN Qt	LN Runofftime	LN Flow	LN Raintime	LN Dry_hours	
0.47615	0.12431	0.49359	-0.02377	0.33473	0.21526	-0.09725	0.06570	-0.01426	0.16873	1.00000	LN_Dry_hours
-0.08413	-0.18052	-0.22373	0.27749	-0.22885	-0.46976	0.32948	0.88023	-0.20462	1.00000	0.16873	LN_Raintime
-0.57471	0.21404	0.02285	-0.07545	-0.31054	0.35977	0.55713	-0.00965	1.00000	-0.20462	-0.01426	LN_Flow
-0.31497	-0.13279	-0.29268	0.21008	-0.39563	-0.55843	0.64791	1.00000	-0.00965	0.88023	0.06570	LN_Runofftime
-0.71410	0.09099	-0.19379	0.05998	-0.63589	-0.32907	1.00000	0.64791	0.55713	0.32948	-0.09725	LN_Qt
0.25398	0.07268	0.40655	-0.23787	0.41843	1.00000	-0.32907	-0.55843	0.35977	-0.46976	0.21526	LN_TSS
0.80967	0.02715	0.55390	-0.15953	1.00000	0.41843	-0.63589	-0.39563	-0.31054	-0.22885	0.33473	LN_COD
-0.19153	0.05747	-0.20375	1.00000	-0.15953	-0.23787	0.05998	0.21008	-0.07545	0.27749	-0.02377	LN_pH
0.45856	-0.10506	1.00000	-0.20375	0.55390	0.40655	-0.19379	-0.29268	0.02285	-0.22373	0.49359	LN_Redox
0.10803	1.00000	-0.10506	0.05747	0.02715	0.07268	0.09099	-0.13279	0.21404	-0.18052	0.12431	LN_Temp
1.00000	0.10803	0.45856	-0.19153	0.80967	0.25398	-0.71410	-0.31497	-0.57471	-0.08413	0.47615	LN_Cond

Table 8: Correlation Matrix for all Variables: LN-Transformed Raw Data Set

LOG Cond	LOG Temp	LOG Redox	LOG pH	LOG COD	LOG TSS	LOG Qt	LOG Runofftime	LOG Flow	LOG Raintime	LOG Dry_hours	
0.47615	0.12431	0.43100	-0.02377	0.33473	0.21526	-0.09725	0.06570	-0.01426	0.16894	1.00000	LOG_Dry_hours
-0.08233	-0.18258	-0.26687	0.27350	-0.22712	-0.46585	0.32453	0.87929	-0.20454	1.00000	0.16894	LOG_Raintime
-0.57471	0.21404	-0.02835	-0.07545	-0.31054	0.35977	0.55713	-0.00965	1.00000	-0.20454	-0.01426	LOG_Flow
-0.31497	-0.13279	-0.30606	0.21008	-0.39563	-0.55843	0.64791	1.00000	-0.00965	0.87929	0.06570	LOG_Runofftime
-0.71410	0.09099	-0.21192	0.05998	-0.63589	-0.32907	1.00000	0.64791	0.55713	0.32453	-0.09725	LOG_Qt
0.25398	0.07268	0.39845	-0.23787	0.41843	1.00000	-0.32907	-0.55843	0.35977	-0.46585	0.21526	LOG_TSS
0.80967	0.02715	0.63088	-0.15953	1.00000	0.41843	-0.63589	-0.39563	-0.31054	-0.22712	0.33473	LOG_COD
-0.19153	0.05747	-0.20375	1.00000	-0.15953	-0.23787	0.05998	0.21008	-0.07545	0.27350	-0.02377	LOG_pH
0.53393	-0.00274	1.00000	-0.20375	0.63088	0.39845	-0.21192	-0.30606	-0.02835	-0.26687	0.43100	LOG_Redox
0.10803	1.00000	-0.00274	0.05747	0.02715	0.07268	0.09099	-0.13279	0.21404	-0.18258	0.12431	LOG_Temp
1.00000	0.10803	0.53393	-0.19153	0.80967	0.25398	-0.71410	-0.31497	-0.57471	-0.08233	0.47615	LOG_Cond

Table 9: Correlation Matrix for all Variables: LOG-Transformed Raw Data Set

SQ Cond	SQ Temp	SQ Redox	SQ pH	SQ COD	SQ TSS	SQ Qt	SQ Runofftime	SQ Flow	SQ Raintime	SQ Dry_hours	
0.68294	-0.03791	0.34327	-0.04891	0.38635	0.06300	0.03825	0.08708	0.00608	0.26734	1.00000	SQ_Dry_hours
0.03265	-0.23792	-0.24630	0.28291	-0.10129	-0.11817	0.05484	0.96678	-0.09415	1.00000	0.26734	SQ_Raintime
-0.12380	0.01879	0.15493	-0.02246	-0.12434	-0.05362	0.49868	-0.08005	1.00000	-0.09415	0.00608	SQ_Flow
-0.05968	-0.27125	-0.30828	0.26792	-0.14690	-0.10048	0.09072	1.00000	-0.08005	0.96678	0.08708	SQ_Runofftime
-0.14103	-0.01266	-0.12503	0.14080	-0.19822	-0.09518	1.00000	0.09072	0.49868	0.05484	0.03825	SQ_Qt
0.26819	0.05206	0.45005	-0.37259	0.63879	1.00000	-0.09518	-0.10048	-0.05362	-0.11817	0.06300	SQ_TSS
0.73276	0.00274	0.49796	-0.32317	1.00000	0.63879	-0.19822	-0.14690	-0.12434	-0.10129	0.38635	SQ_COD
-0.19772	0.16900	-0.57856	1.00000	-0.32317	-0.37259	0.14080	0.26792	-0.02246	0.28291	-0.04891	SQ_pH
0.36944	-0.23005	1.00000	-0.57856	0.49796	0.45005	-0.12503	-0.30828	0.15493	-0.24630	0.34327	SQ_Redox
-0.03168	1.00000	-0.23005	0.16900	0.00274	0.05206	-0.01266	-0.27125	0.01879	-0.23792	-0.03791	SQ_Temp
1.00000	-0.03168	0.36944	-0.19772	0.73276	0.26819	-0.14103	-0.05968	-0.12380	0.03265	0.68294	SQ_Cond

Table 10: Correlation Matrix for all Variables: Square-Transformed Raw Data Set

SQR Cond	SQR Temp	SQR Redox	SQR pH	SQR COD	SQR TSS	SQR Qt	SQR Runofftime	SQR Flow	SQR Raintime	SQR Dry_hours	
0.57849	0.10645	0.23277	-0.02995	0.35518	0.19804	-0.01269	0.10281	0.05794	0.23983	1.00000	SQR_Dry_hours
0.00431	-0.20376	-0.25841	0.28586	-0.20440	-0.37949	0.20014	0.93042	-0.15330	1.00000	0.23983	SQR_Raintime
-0.48902	0.18445	0.03692	-0.05076	-0.28495	0.12306	0.64959	-0.01776	1.00000	-0.15330	0.05794	SQR_Flow
-0.22297	-0.18906	-0.33148	0.25586	-0.37797	-0.49586	0.39915	1.00000	-0.01776	0.93042	0.10281	SQR_Runofftime
-0.60823	0.11282	-0.18874	0.11458	-0.57581	-0.32321	1.00000	0.39915	0.64959	0.20014	-0.01269	SQR_Qt
0.30240	0.09593	0.63930	-0.32163	0.50515	1.00000	-0.32321	-0.49586	0.12306	-0.37949	0.19804	SQR_TSS
0.83449	0.03611	0.50856	-0.21797	1.00000	0.50515	-0.57581	-0.37797	-0.28495	-0.20440	0.35518	SQR_COD
-0.20933	0.08536	-0.28110	1.00000	-0.21797	-0.32163	0.11458	0.25586	-0.05076	0.28586	-0.02995	SQR_pH
0.42108	0.01540	1.00000	-0.28110	0.50856	0.63930	-0.18874	-0.33148	0.03692	-0.25841	0.23277	SQR_Redox
0.09626	1.00000	0.01540	0.08536	0.03611	0.09593	0.11282	-0.18906	0.18445	-0.20376	0.10645	SQR_Temp
1.00000	0.09626	0.42108	-0.20933	0.83449	0.30240	-0.60823	-0.22297	-0.48902	0.00431	0.57849	SQR_Cond

Table 11: Correlation Matrix for all Variables: Square-Root-Transformed Raw Data Set

4.5.2 Independent Variables Selection

The second step corresponded to the selection of independent variables associated with the concentration of COD from the storm water runoffs. These independent variables were obtained on the basis of three different statistical methods, forward selection, backward elimination and stepwise procedure. The level of significance for the two-tailed test (α) was set at 0.05. A two-tailed test allowed the author to evaluate deviations from a statistical hypothesis in two directions. In other words, a value of the statistic that is sufficiently small or sufficiently large will lead to rejection of the hypothesis tested.

The forward procedure begins with no variables in the model. After each calculation step the software enters one variable. For each of the variables entered the forward procedure calculates the F-statistic which reflects the contribution of the test variable to the model. Variables are entered one by one into the model until none of the remaining variables produce a significant F-statistic. The limitation of this procedure is as follows: once a variable is entered into the model it will not be removed, even when it becomes insignificant in the presence of new variables entered into the model at a later time.

To overcome the limitation of the forward selection models were developed using the backward elimination procedure. This method is exactly the opposite of the forward selection procedure. This method begins by calculating F-statistics for each variable.
After that the variables are deleted from the model one by one, starting with the variable showing the least contribution. This procedure is repeated until all the variables remaining in the model produce F-statistics significant to five percent. The backward

elimination procedure has similar limitations as the forward selection procedure. Once the variable is excluded from the model it cannot be re-entered again even if it becomes significant after deleting other variables from the model. For this reason it is recommended to select the variables on basis of combination of different procedures.

The stepwise method was used as well to select the variables that significantly correlate to the concentration of COD. The stepwise procedure is a modification of the forward selection procedure. The difference is that the variables which are already included in a model do not necessarily remain in the model. After a variable is added the stepwise procedure examines all the variables already in the model and deletes these variables which are not significant at five percent due to adding the new variable. This means that a variable in a model can be significant at five percent for a certain combination of variables. After adding more and more variables, previous added and from the model excepted variables can become insignificant in combination with other variables. Therefore this procedure eliminates these variables. The stepwise procedure continues until none of the remaining variables outside the model are significant.

The following tables (Tables 12-16) show the significant variables for COD concentrations according to all three selection-procedures.

Varaible	
Dry_hours	
Raintime	
Flow	
Runofftime	
Qt	X
TSS	X
pH	
Redox	X
Temp	
Cond	X

Table 12: Selection of Variables Significantly Associated with COD

Varaible	
LN_Dry_hours	X
LN_Raintime	
LN_Flow	X
LN_Runofftime	X
LN_Qt	
LN_TSS	
LN_pH	
LN_Redox	X
LN_Temp	
LN_Cond	X

Table 13: Selection of Variables Significantly Associated with LN_COD

Varaible	
LOG_Dry_hours	X
LOG_Raintime	
LOG_Flow	X
LOG_Runofftime	X
LOG_Qt	X
LOG_TSS	
LOG_pH	
LOG_Redox	X
LOG_Temp	
LOG_Cond	X

Table 14: Selection of Variables Significantly Associated with LOG_COD

Varaible	
SQ_Dry_hours	
SQ_Raintime	
SQ_Flow	
SQ_Runofftime	
SQ_Qt	
SQ_TSS	X
SQ_pH	X
SQ_Redox	X
SQ_Temp	
SQ_Cond	X

Table 15: Selection of Variables Significantly Associated with SQ_COD

Varaible	
SQR_Dry_hours	X
SQR_Raintime	
SQR_Flow	X
SQR_Runofftime	
SQR_Qt	
SQR_TSS	X
SQR_pH	
SQR_Redox	
SQR_Temp	X
SQR_Cond	X

Table 16: Selection of Variables Significantly Associated with SQR_COD

4.5.3 Model Developing

The third step was to develop models for the concentration of COD. The information obtained from the first two steps was used to carry out these calculations. Models were developed using all data available and combining the information of the first two steps.

The coefficient of determination (R^2) was used for the selection of the appropriated model. The R^2 value can be interpreted as the proportion of the variance in Y attributable

to the variation in X. The R^2 value, also known as the Coefficient of Determination, is an indicator that ranges in value from 0 to 1. This coefficient reveals how closely the estimated values for the regression correspond to the actual data. A regression is most reliable when its R^2 value is at or near 1. Moreover, the Pearson Product Moment Correlation Coefficient R was calculated, a dimensionless index that ranges from -1.0 to 1.0 inclusive and reflects the extent of a linear relationship between two data sets where 0 represents no correlation and 1 represents an excellent correlation. A value of –1 shows a perfect reciprocal correlation. The value for R^2 was calculated using following formula:

$$R^2 = 1 - \frac{SSE}{SST}$$

where $SSE = \sum \left(Y_f - \hat{Y}_f\right)^2$

and $SST = \left(\sum Y_f^2\right) - \frac{\left(\sum Y_f\right)^2}{\eta}$

The Correlation Factor R for linear regression-functions can also be calculated directly using following formula: [33]

$$R = \frac{n\left(\sum XY\right) - \left(\sum X\right) * \left(\sum Y\right)}{\sqrt{\left[n\left(\sum X^2\right) - \left(\sum X\right)^2\right] * \left[n\left(\sum Y^2\right) - \left(\sum Y\right)^2\right]}}$$

For the statistical evaluation the software package “Statistical Package for the Social Sciences” (SPSS) was used.

A low absolute value of the correlation coefficient (R) can indicate a weak degree of linear correlation among the examined variables. On the other hand, a large R value does not necessarily guarantee that two variables are related. The value calculated for the correlation coefficient will tend to be inflated if there are only a few data pairs available.

Moreover, there could be a third variable causing the simultaneous change in the first two variables. The magnitude of the correlation coefficient is very sensitive to the presence of nonlinear trends which would cause the relationship to be underestimated or overestimated. Nonlinear trends and outliers can usually be detected in scatter-plots described above (section 4.5). Regardless of the magnitude of the correlation coefficient the value R may or may not be significant. Therefore, a significance test must be performed in order to determine if the observed correlation coefficient is significantly different from zero. If no correlation between two variables can be obtained, it is still possible that a high (positive or negative) sample correlation value may occur. For a true correlation of zero it can be shown that

$$t^* = R\frac{\sqrt{n-2}}{\sqrt{1-R^2}}$$

where R = correlation coefficient

n = number of samples

has a t-distribution with n-2 degrees of freedom and that both variables are normally distributed.

4.5.4 Model Verification

The fourth and last step consisted of verification of the model. Here a series of statistical analyses were conducted in order to determine the reliability and accuracy of the predicted values versus the observed values.

First the "Coefficient of Variation Test for Normality" (COV) was computed for the predicted and observed data. The COV was obtained by dividing the standard deviation (S) by the mean of the variable ($\bar{x}$). [34, 35]

$$COV = \frac{S}{\bar{x}}$$

A normal distributed data set is fundamental for any further statistical analysis. A COV-value less than one shows, that the data set is normal distributed while a COV value higher than one indicates that further analyses are required to identify whether the analyzed dataset is normally distributed or not. If the COV exceeds 1.0, there is strong evidence that the data is not normally distributed. [34, 35]

The Student's t-Test was used for comparing two samples for significance of difference. Previous to the use of the t-test it was, however, necessary to analyze both sets of data for significance difference between samples variances. This was done using the F-test. This test determines if two samples have a statistically different variance or not. This is important in order to see which t-test to use. The F-distribution is the sampling distribution of the ratio of two independent, unbiased estimates of the variance of a normal distribution. The variance ratio is defined as followed:

$$F = \frac{S_1^2}{S_2^2}$$

where, S1 is greater than S2 and represents the variance of both samples being compared. Should the F-ratio be lesser than the F-test, then there is not a statistically significant difference between the variances and the t-test for equal variances can be utilized. Otherwise the t-test for unequal variances has to be used.

Finally, the t-test was performed for comparing the set for significance of difference in the mean. If the predicted and the observed data set showed a statistically equal mean, the model was declared reliable on the 95% confidence interval which corresponds to the 5% significance level.

CHAPTER 5

DISCUSSION OF RESULTS

The fundamental goal of this study was to predict COD concentrations in storm water runoff from elevated roadways. In the following chapter the methods used to develop the prediction model will be explained. This includes the development and verification of the generated model as well as the comparison of the obtained results. For this research a total of fourteen different storm events was collected and analyzed as described in the Methodology.

The quality of highway storm water runoff is difficult to characterize, because it is affected by many factors, such as rainfall intensity, antecedent dry days, traffic conditions, climatic effects etc. For this study a total of 24 measured variables were used in order to characterize the factors affecting storm water runoff from elevated roadways. The high variations and fluctuations of these factors between rainfall events or during a single event made it difficult to find significant correlations. Figure 6 and Figure 7 show the variations in flow and accumulative flow of the fourteen observed storm events.

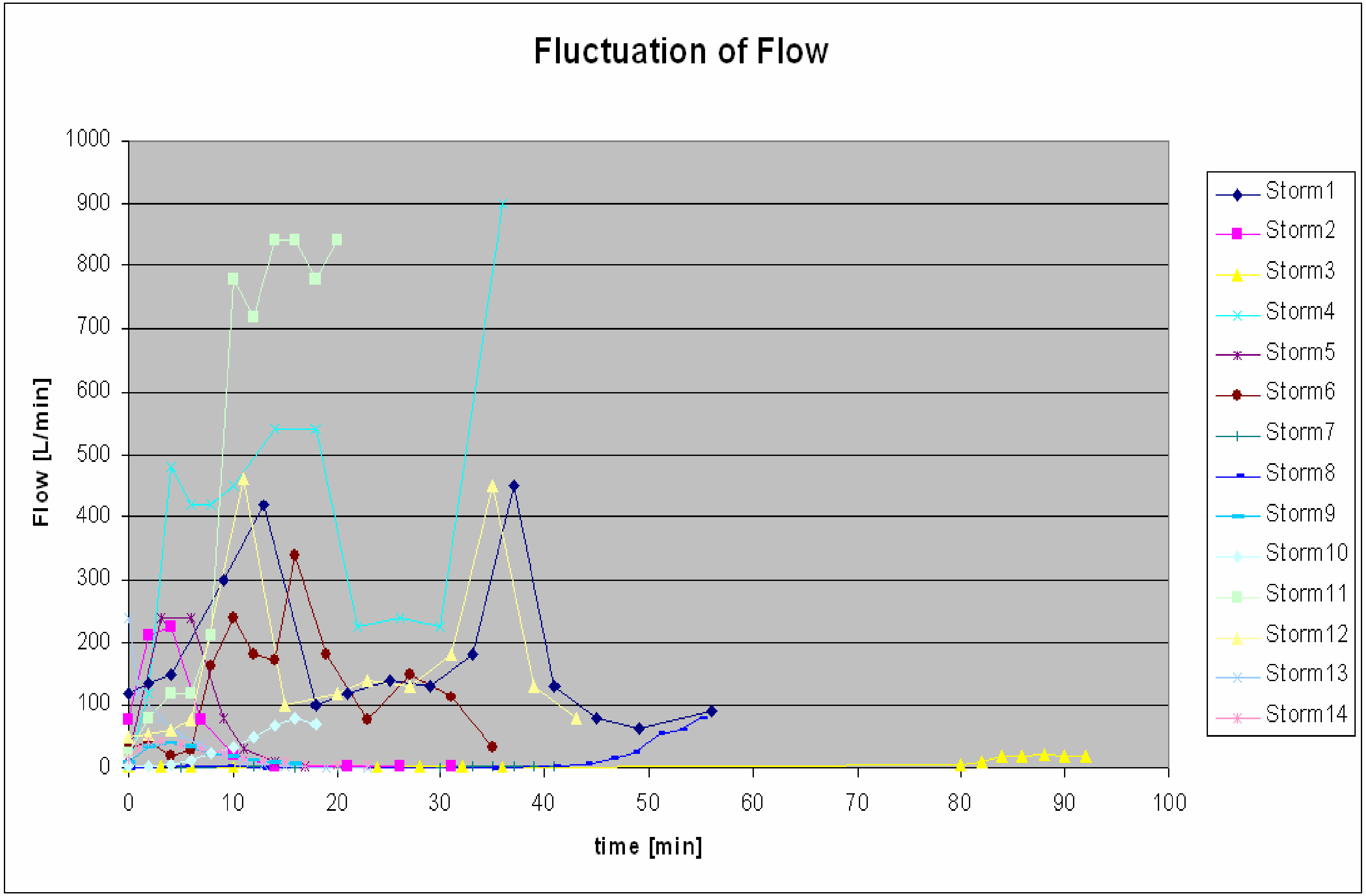

Figure 6: Fluctuation of Flow

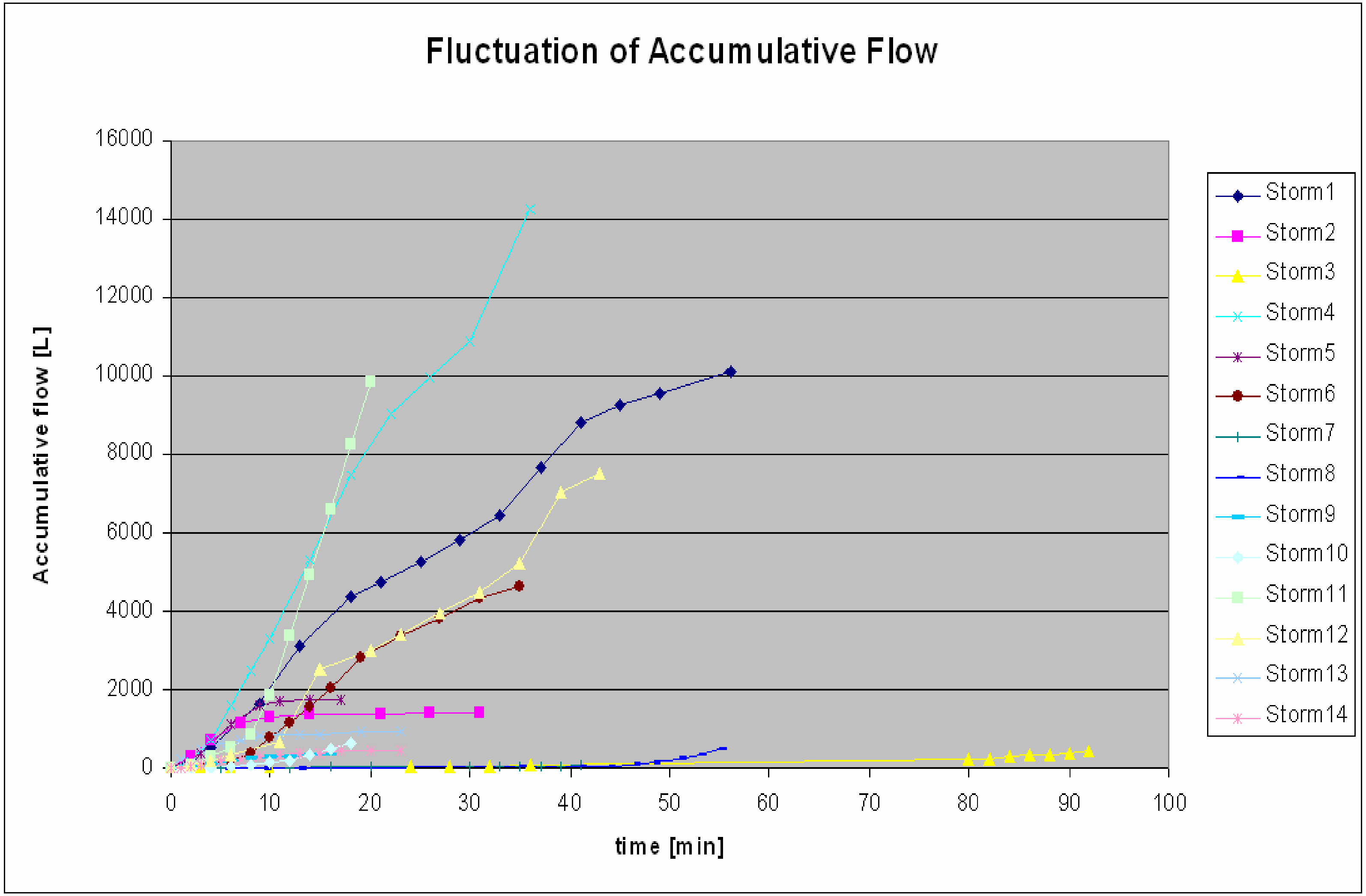

Figure 7: Fluctuation of Accumulative Flow

5.1. COD Range

Concentrations of COD for each sample of the fourteen observed storm events were measured using the HACH equipment as described in the Methodology. The minimum, maximum and average COD concentrations of he observed storm events are shown in Table 17 and in Figure 8.

Storm	COD Concentrations [mg/L]		
	Min	Mean	Max
1	91	239	614
2	53	190	1086
3	76	202	464
4	30	323	1650
5	96	161	317
6	51	165	354
7	326	359	392
8	434	737	960
9	372	394	481
10	380	395	403
11	308	409	879
12	46	112	464
13	74	126	395
14	660	715	1035
All storm events	30	325	1650

Table 17: COD Concentrations

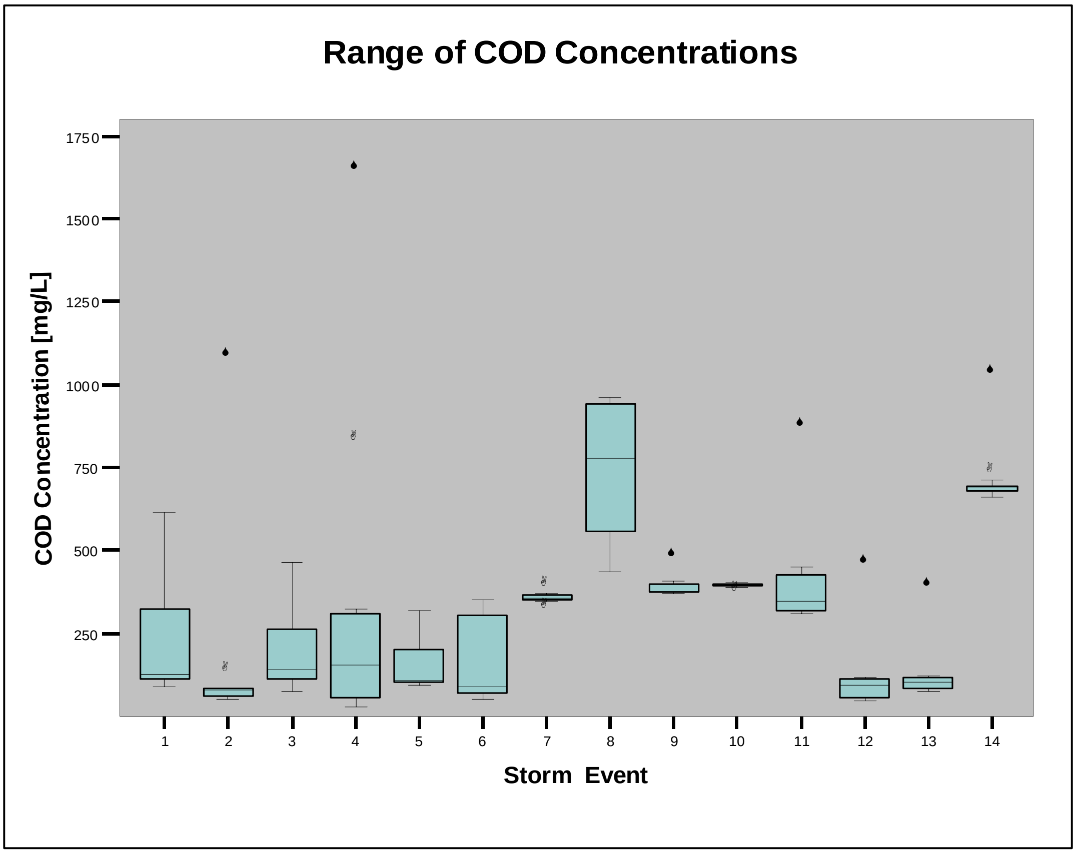

Figure 8: Range of COD Concentrations

It can be observed that the range of COD concentrations in collected samples during a certain storm event can vary greatly, either in a wide range (storm 8) or in a small range (storm 10). Figure 9 to Figure 22 show the COD concentrations and the COD mass loading of each storm event compared to the accumulative runoff volume.

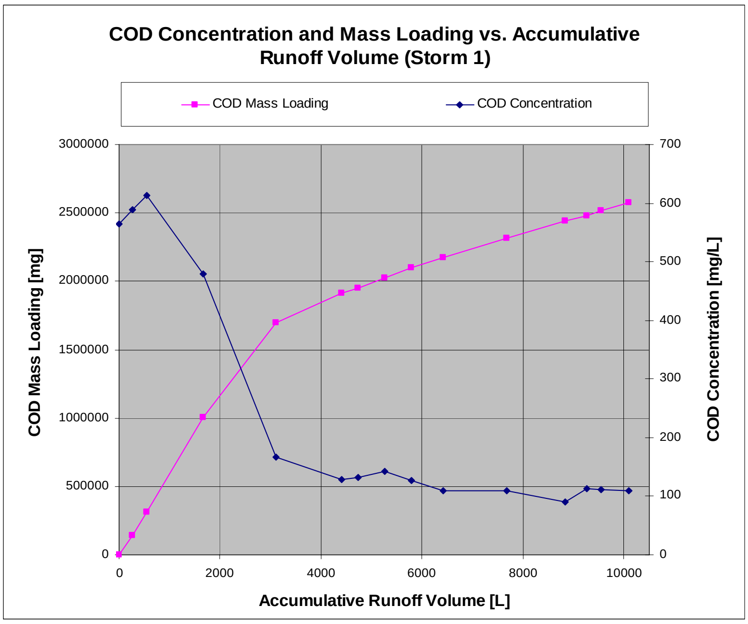

Figure 9: COD Concentration and Mass Loading vs. Accumulative Runoff Volume (Storm 1)

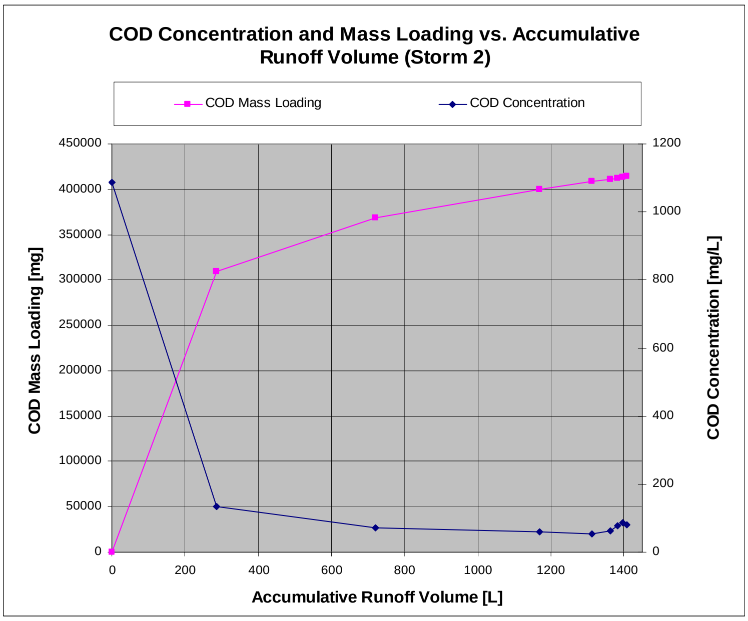

Figure 10: COD Concentration and Mass Loading vs. Accumulative Runoff Volume (Storm 2)

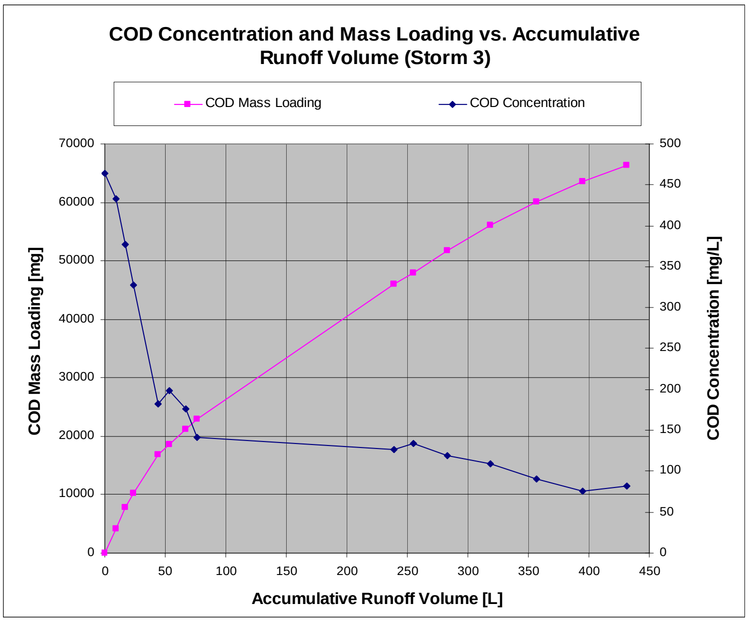

Figure 11: COD Concentration and Mass Loading vs. Accumulative Runoff Volume (Storm 3)

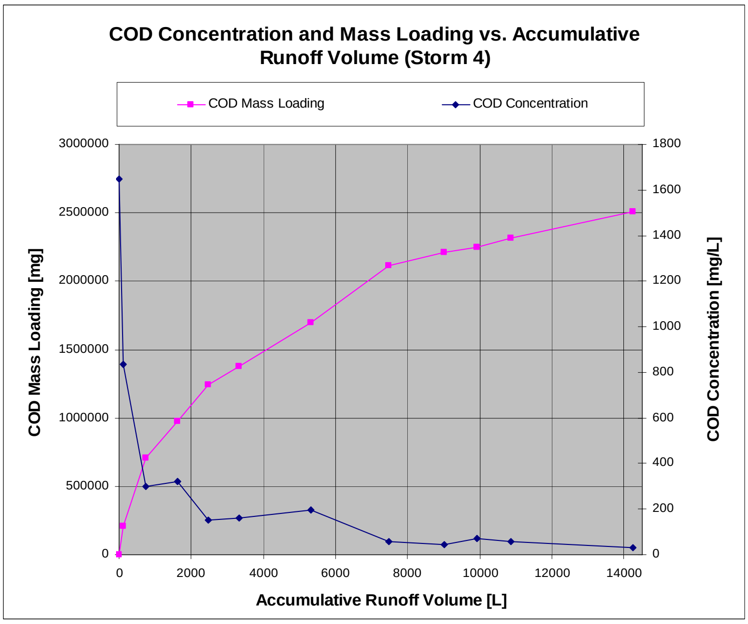

Figure 12: COD Concentration and Mass Loading vs. Accumulative Runoff Volume (Storm 4)

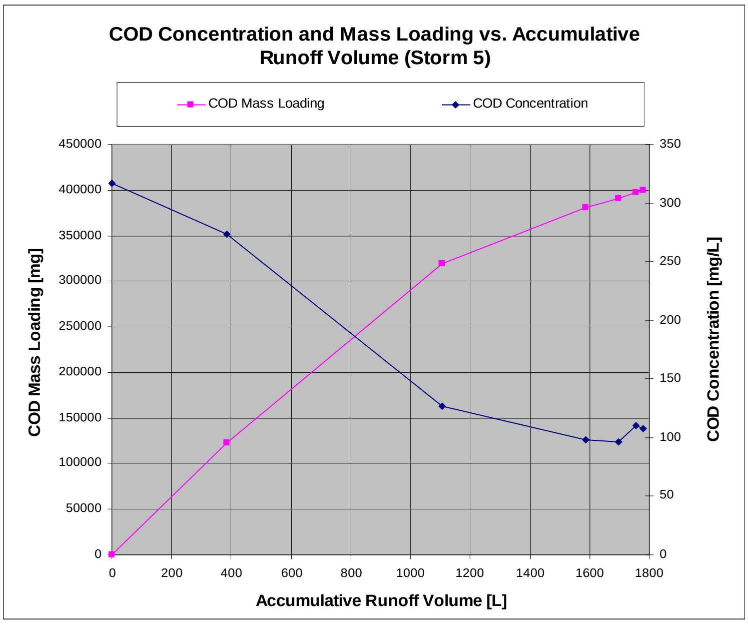

Figure 13: COD Concentration and Mass Loading vs. Accumulative Runoff Volume (Storm 5)

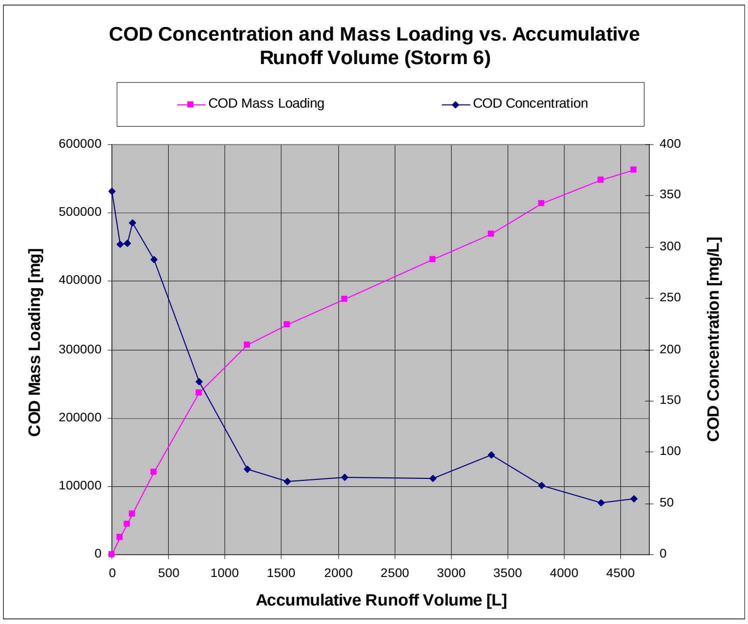

Figure 14: COD Concentration and Mass Loading vs. Accumulative Runoff Volume (Storm 6)

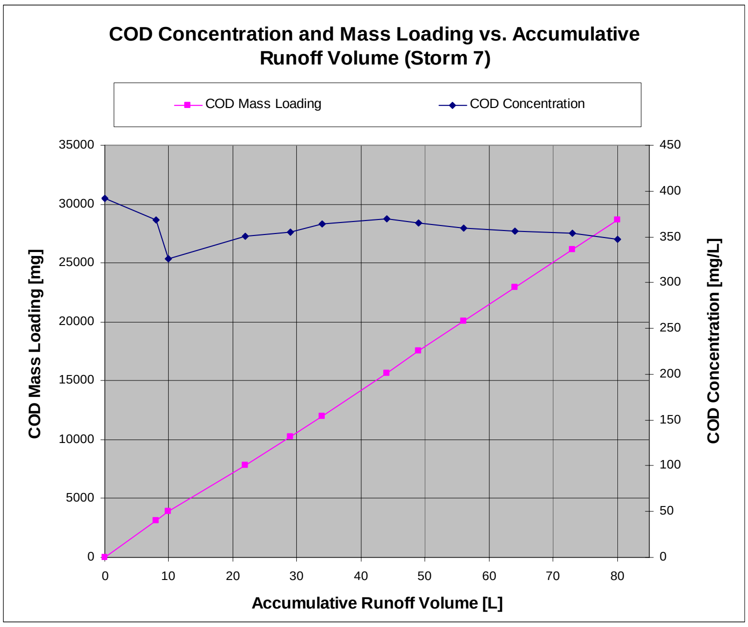

Figure 15: COD Concentration and Mass Loading vs. Accumulative Runoff Volume (Storm 7)

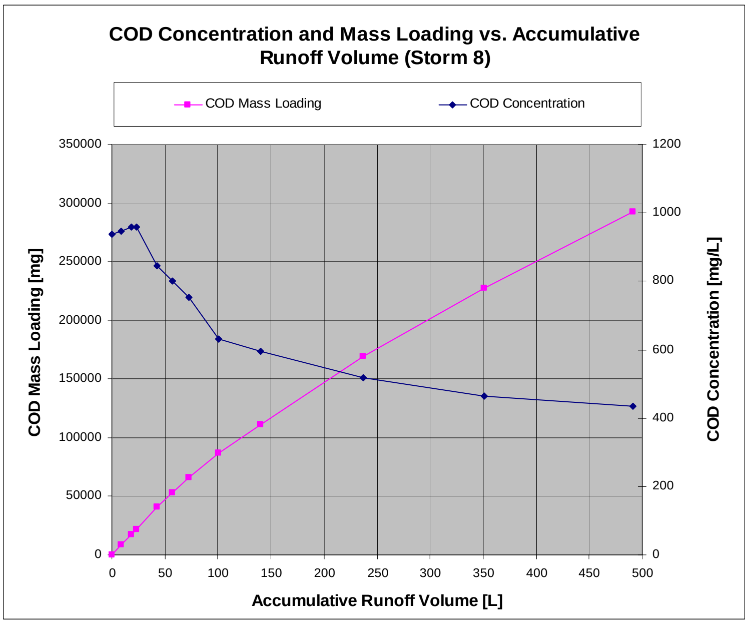

Figure 16: COD Concentration and Mass Loading vs. Accumulative Runoff Volume (Storm 8)

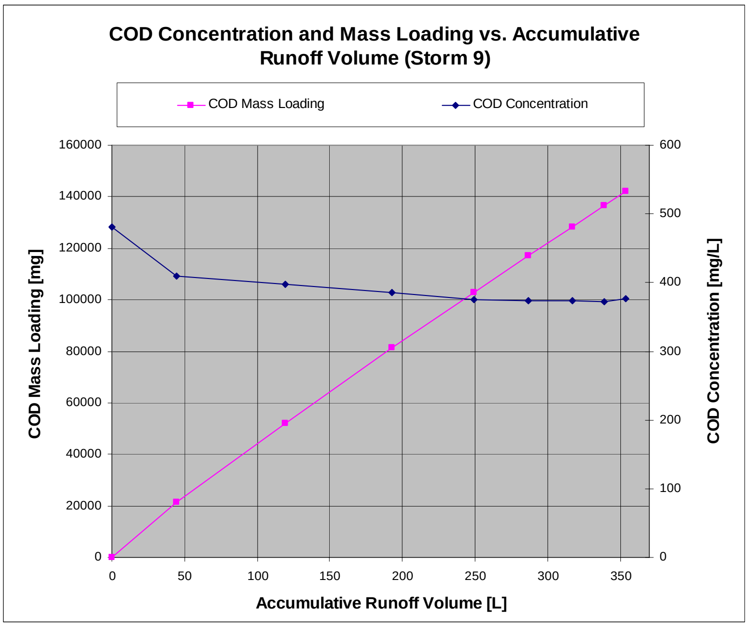

Figure 17: COD Concentration and Mass Loading vs. Accumulative Runoff Volume (Storm 9)

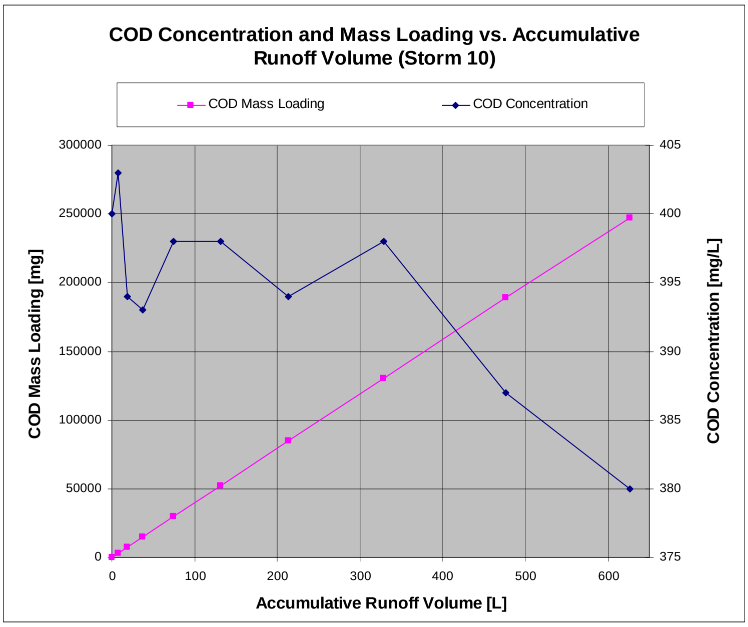

Figure 18: COD Concentration and Mass Loading vs. Accumulative Runoff Volume (Storm 10)

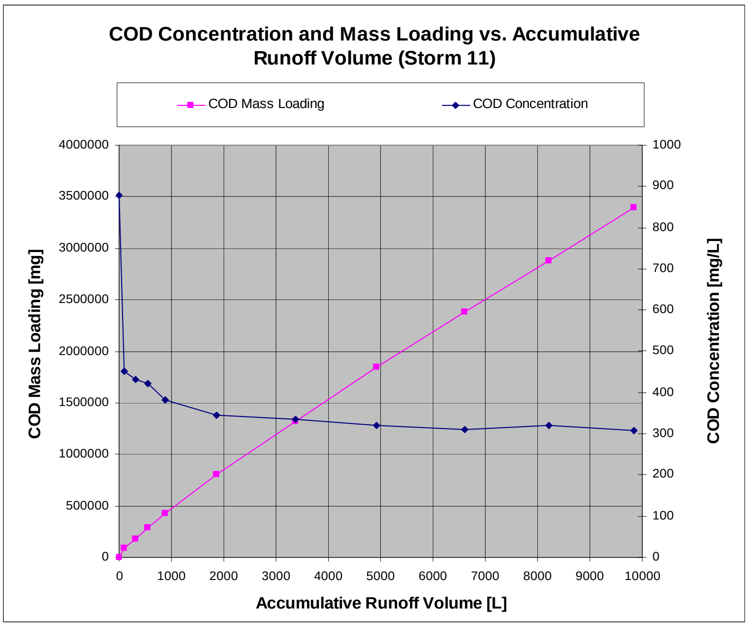

Figure 19: COD Concentration and Mass Loading vs. Accumulative Runoff Volume (Storm 11)

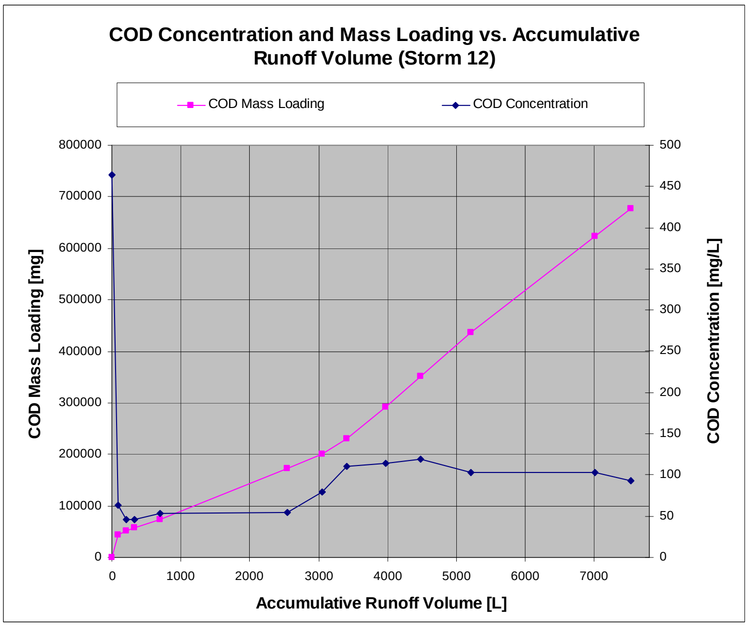

Figure 20: COD Concentration and Mass Loading vs. Accumulative Runoff Volume (Storm 12)

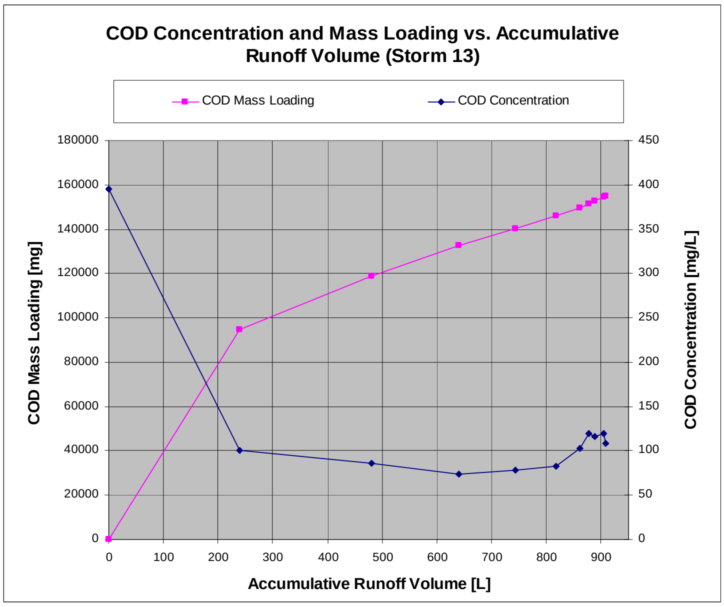

Figure 21: COD Concentration and Mass Loading vs. Accumulative Runoff Volume (Storm 13)

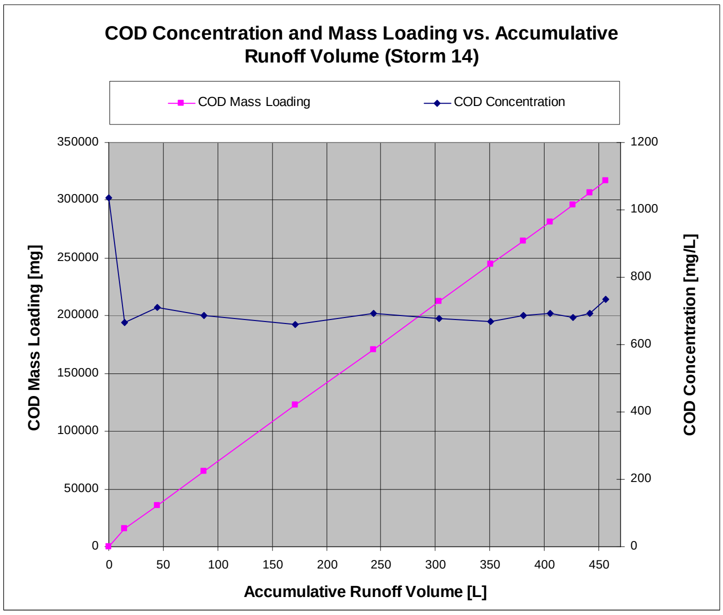

Figure 22: COD Concentration and Mass Loading vs. Accumulative Runoff Volume (Storm 14)

It is important to include the runoff volume together with the COD concentrations in order to adjust each single analyzed sample concentration to the impact to the environment. A large runoff volume in a certain amount of time with a certain COD concentration has a larger impact to the environment than a small runoff volume in the same amount of time with the same concentration, which is shown in Figure 9 to Figure 22. Therefore high runoff storm events have a significant higher impact on the environment.

5.2. Percentile Mass Loading of COD

Initially for this research the cumulative percentage of COD mass was plotted versus the cumulative percentage of discharged runoff volume for each storm event. As it can be observed from Figure 23, the cumulative percentage of COD mass load fluctuates significantly over the cumulative percentage of discharged runoff volume.

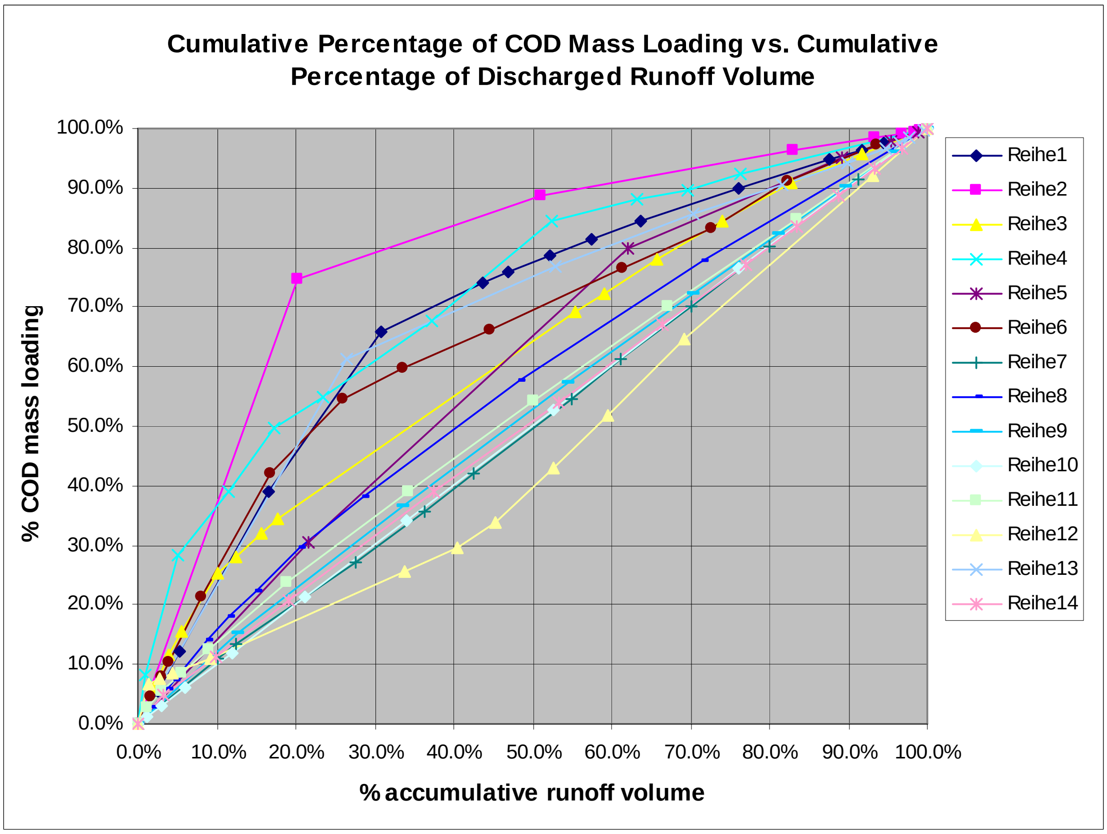

Figure 23: Cumulative Percentage of COD Mass Loading vs. Percentage of Discharged Runoff Volume

Figure 24 shows the mean cumulative percentage of COD mass loadings versus the cumulative percentage of discharged runoff volume. Also the minimal and maximal percentages measured for all storm events are illustrated.

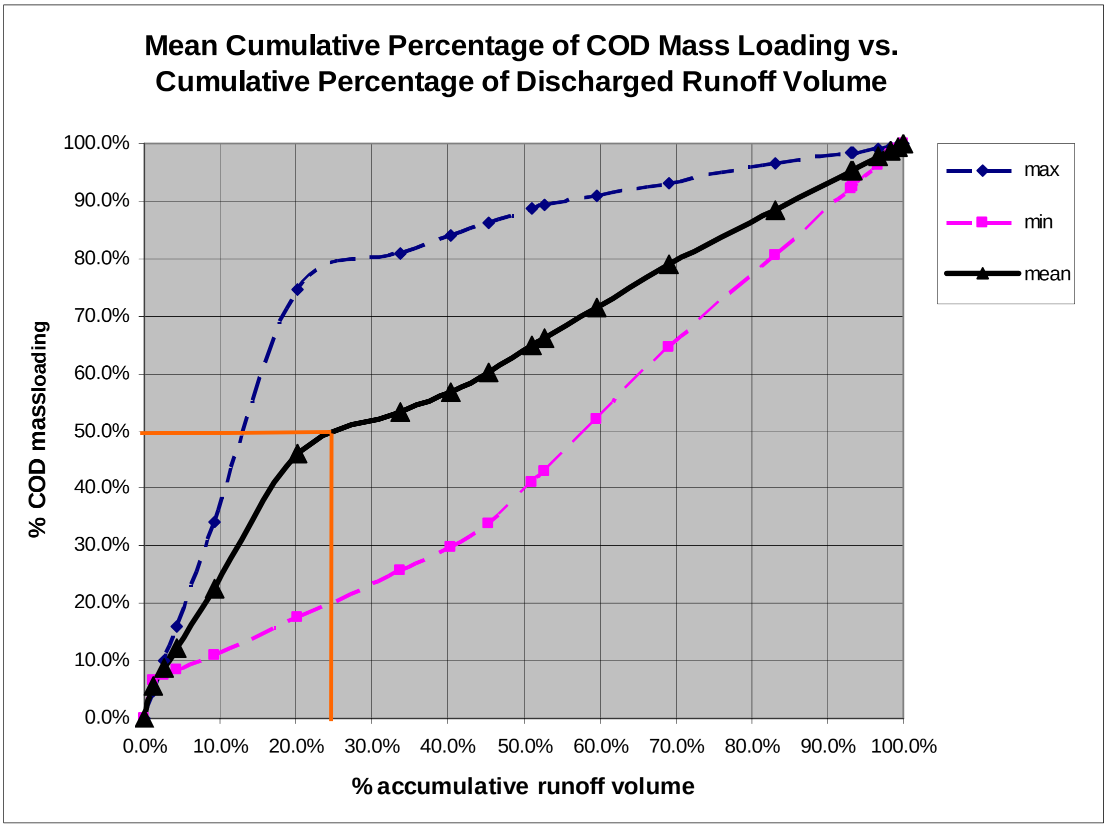

Figure 24: Mean Cumulative Percentage of COD Mass Loading vs. Percentage of Discharged Runoff Volume

The curve in Figure 24 shows a steep slope during the first fraction of the curve followed by a slighter flattening. The distribution of this curve illustrates the high wash-off of pollutants during the first part of the storm event. The first portion of storm water runoff discharged from highways had the highest mass loadings followed by a clear decline with increasing discharge of storm water runoff.

Examining Figure 24 it becomes evident that 50 percent of the COD total mass loading washed off the roadway during a storm event are contained, on average, in the first 25 percent of the discharged runoff volume.

5.3. Regression Model for COD

The development of the model was performed according to the procedures and explanations in the Methodology. All model equations were developed following statistical analyses which minimize the sampling error and the bias introduced into the model by some of the variables selection methods used (forward, backward and stepwise).

Using the software package SPSS the best possible statistical model for the prediction of COD was derived. The collected data was transformed using LN, LOG10, square, and square root transformation. Models were then developed using this data. The results of this statistical effort are illustrated in Table 18.

Type of Data Transformation	R	R Square	Adjusted R Square
none	**0.925**	**0.856**	**0.852**
LN	0.843	0.711	0.700
LOG10	0.879	0.773	0.764
Square	0.924	0.854	0.850
Square Root	0.913	0.834	0.828

Table 18: R and R^2 values for the Model Development for COD

The goal of this research effort was to obtain a prediction model for COD concentrations which is easy to use. Therefore the main objective was to exclude as many variables as possible while still obtaining high reliable prediction models.

The best regression model was obtained using the untransformed dataset. The selected variables were:

- Cumulative total runoff
- TSS
- Redox potential
- Conductivity

The obtained result was as follows:

$$COD = 241.055 - 0.006*Qt + 0.282*TSS + 2.349*Redox + 0.306*Cond$$

This equation, with an R^2 value of 0.856, was then examined. Before this model can be applied it is important to understand the significance of all included parameters and their logical effect on the concentration of COD in the runoff.

In the equation above the cumulative total runoff is correlated negatively to the concentration of COD. This is plausible, because with a progressing storm the accumulated total runoff volume is increasing and the concentration of COD is decreasing. The largest amount of pollutants and the highest concentration of contaminants are normally observed in the first part of the storm event. The majority of pollutants on the surface are washed off within a short time period at the beginning of the storm. This phenomenon is called the first flush effect. According to this at the beginning of the storm event, when the cumulative total runoff volume starts from zero,

COD-concentrations are high and decrease with the increase in the total runoff volume. Therefore, the negative correlation between these two parameters is plausible.

The TSS concentration is correlated positively to COD. Untreated wastewater is generally rich in organic matter. This organic matter feeds the bacteria and algae normally present in healthy water sources. The presence of excessive amounts of nutrients discharged as a result of untreated wastewater will cause an increase in concentration of both bacteria and algae within the surface water. Beside organic matter, wastewater also contains both organic and oxidizable inorganic compounds. These organic and inorganic compounds directly and indirectly consume the available oxygen present in the ecosystem. This process is called eutrification and will eventually kill off other living organisms (plants, animals, & insects) in the aquatic system. The suspended matter measured with the TSS concentration in the highway runoff may be either organic or inorganic matter or a combination of both, which increases the ammount of oxygen used in biological and non-biological oxidation of materials in water. Therefore the positive correlation with COD is plausible.

The redox potential is correlated positively to the concentration of COD in the runoff. The redox potential is a measure (in volts) of the affinity of a substance for electrons, its electronegativity, compared with hydrogen (which is set at 0). Substances more strongly electronegative than hydrogen (i.e., capable of oxidizing) have positive redox potentials. Redox is eminently important as an indicator not only of a system's capacity for cycling waste, but indeed of chemically supporting fish, plant, and invertebrate life. There are both oxidation and reduction that must occur readily in a truly closed system to support (macro-) life. Organisms respond to redox potentials in terms of

activity and survival indicating that the rate of degradation of organic matter is influenced by the redox potential. Therefore, redox potential measurement is a legitimate way to further characterize sediments, waters, and soils, despite the fact that no specific conclusions can be drawn with respect to which redox couples contribute to the measured redox potential.

The conductivity is correlated with a positive sign to the concentration of COD in the runoff. Conductivity is a measure of water's ability to conduct electrical current in water and is affected by the presence of organic and inorganic dissolved solids. Conductivity is expressed in units of microSiemens (uS) and is the reciprocal of electrical resistance (ohms). Measurements of conductivity provide a general indication of water quality. The geology of a lake's watershed establishes the normal ranges for conductivity in a lake. Some pollution discharges and polluted runoff into receiving lakes can cause changes in conductivity especially if the pollutants include inorganic dissolved solids such as ions: bicarbonate, sulfate, chloride, calcium, magnesium, sodium, potassium, and phosphate. The positive correlation of conductivity to the COD concentration, which can be observed in our case, is reasonable.

As explained above and discussed in detail all used variables are reasonable linked to the concentration of COD in the storm water runoff. The obtained coefficient of determination was high enough and the obtained prediction model was reasonable. Figure 25 was developed to show the relationship of COD concentration as predicted by the model to the observed values.

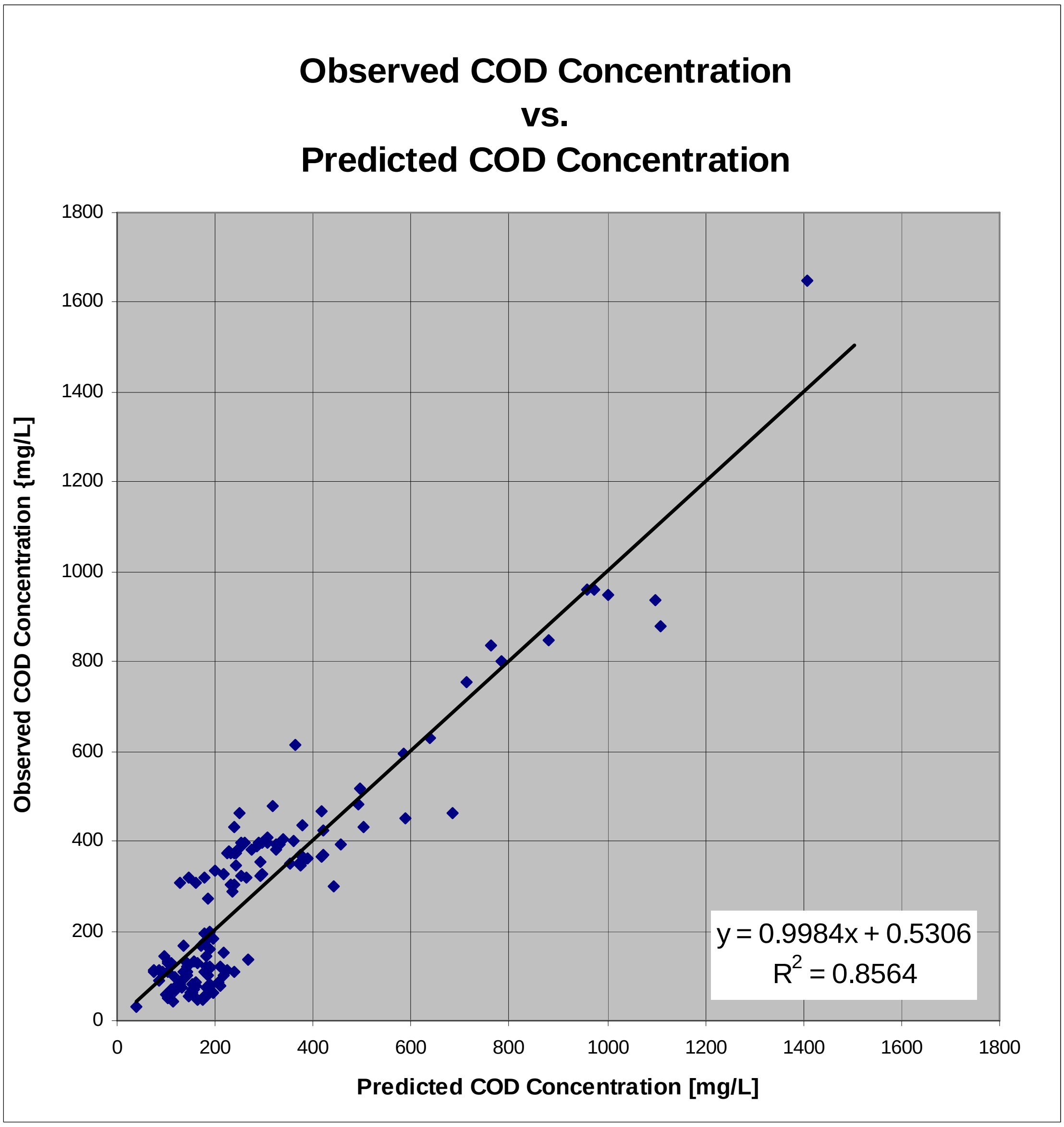

Figure 25: Observed COD Concentration vs. Predicted COD Concentration

The obtained regression line is illustrated in Figure 25. Although the R^2 value is high, the obtained correlation between observed and predicted data has to be further examined. It is necessary to understand the effects and significance of such a correlation

plot. The equation of the regression line is y=0.9984*x+0.5306. In this equation 0.9984 represents the slope of the correlation while 0.5306 is the y-segment where the regression line intersects the y-axis. Under ideal conditions the slope is 1.00 and the regression line would intersect the y-axis at 0 so that the y-segment would be 0.00. If the slope is less than 1.00 the predicted values are underestimated. On the other hand, if the slope of a multiple regression line is higher than 1.00 the model is overestimating the values. The y-segment, where the regression line is intersecting the y-axis, has an influence on the application of such a model. A y-segment value above 0.00 indicates that the model is not ideal. For an observed value of 0.00 the regression model would give a predicted value above 0.00. This would decrease the reliability of the model drastically. A y-segment value below 0.00 could be lead back to certain detection limits.

In our case both, the value of the slope and the value of the y-segment are very close to the ideal values. Therefore the model is reliable and applicable also from this point of view.

5.4. Model Verification

The developed model was verified for their reliability by carrying out a significant-difference test on the predicted and observed data set. For this purpose a Student’s t-Test was used to compare whether both sets of data have significance of difference. In order to validate the accuracy of the t-test a normal distributed data set has to be available. Therefore the predicted and observed values were tested for normal distribution and equal variances. This was done using the F-test. This test determines if

two samples have a statistically different variance or not. This is important in order to see which t-test to use. The F-distribution is the sampling distribution of the ratio of two independent, unbiased estimates of the variance of a normal distribution. Should the F-ratio be lesser than the F-test, then there is not a statistically significant difference between the variances, and the t-test for equal variances can be utilized. Otherwise the t-test for unequal variances has to be used.

Finally, the t-test was performed for comparing the set for significance of difference in the mean. If the predicted and the observed data set showed a statistically equal mean, the model was declared reliable on the 95% confidence interval which corresponds to the 5% significance level.

Table 19 illustrates the summary of the verification results obtained by comparing observed and predicted values for all developed models.

Parameter	Observed	Predicted
Mean	325	302
Standard Deviation	243.484	225.681
COV	0.86050	0.79780
Variance	59693.1	51283.0
F-ratio	1.31534	
F-test	1.16399	
t*	0.00280	
tc	1.96824	

Table 19: Summary of Model Verification Results

In Table 19 the COV values of the two data sets values are less than 1.0. This means that the data set is normally distributed. The F-ratio is higher than the F-test. Therefore the t-test for unequal variances had to be used.

The two values t* and tc can now be compared. If the t* is less than tc, the test indicates an insufficient evidence for a statistically significant difference between the means of both sets of the analyzed data. By inspecting the above illustrated tables, it is also possible to observe, that the model passed the F-test with a 95% confidence limit. This means that there is no statistical evidence of difference among the variances estimated and those observed in the raw data.

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

The fundamental goal of this study was to characterize and predict COD concentrations in storm water runoff from elevated roadways. The quality of highway storm water runoff is difficult to characterize, because it is affected by many factors, such as rainfall intensity, antecedent dry days, traffic conditions, climatic effects etc. The high variations and fluctuations between rainfall events or during each single event made it difficult to find significant correlations.

It became evident that 50 percent of the COD total mass loadings, washed off the roadway during a storm event, are contained as an average value in the first 25 percent of the discharged runoff volume (Figure 26).

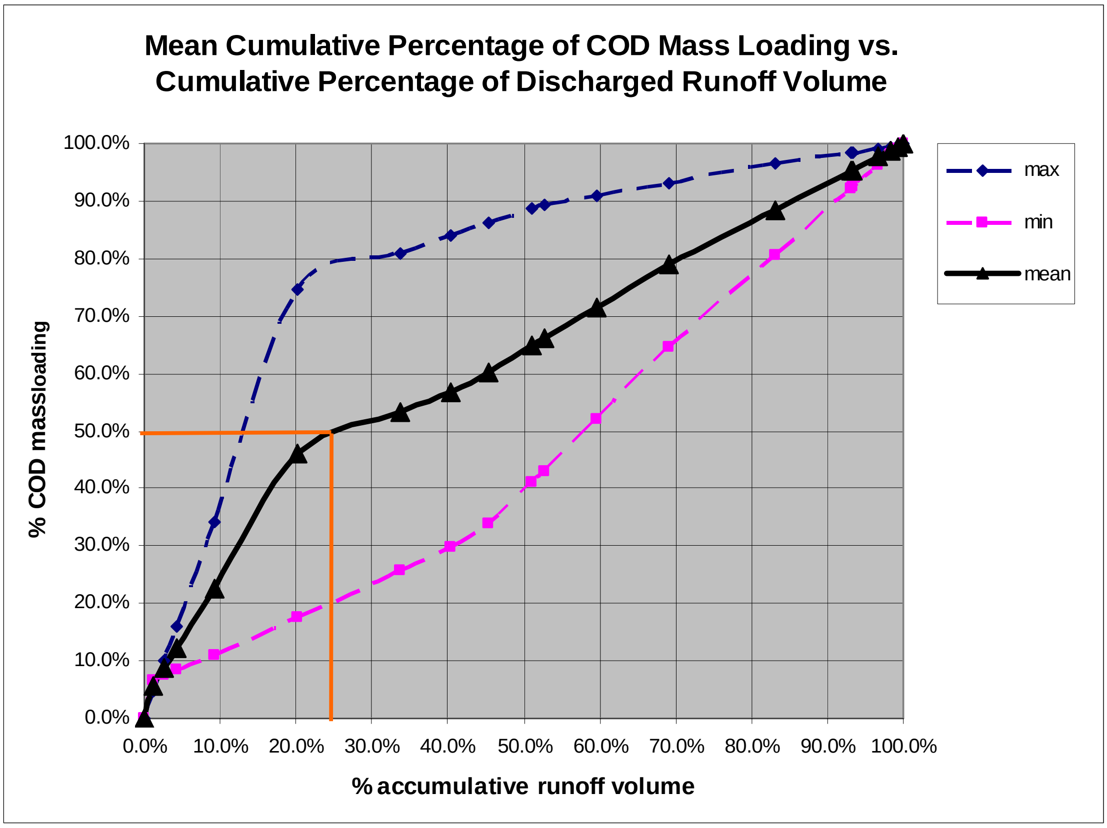

Figure 26: Mean Cumulative Percentage of COD Mass Loading vs. Percentage of Discharged Runoff Volume

The development of a regression model was performed for all the data sets, transformed and untransformed, and after evaluating the results a linear regression model was chosen. The developed model was as followed:

COD = 241.055 - 0.006*Qt + 0.282*TSS + 2.349*Redox + 0.306*Cond

This equation with an R^2 value of 0.856 was then verified and examined. The results are shown in Figure 27.

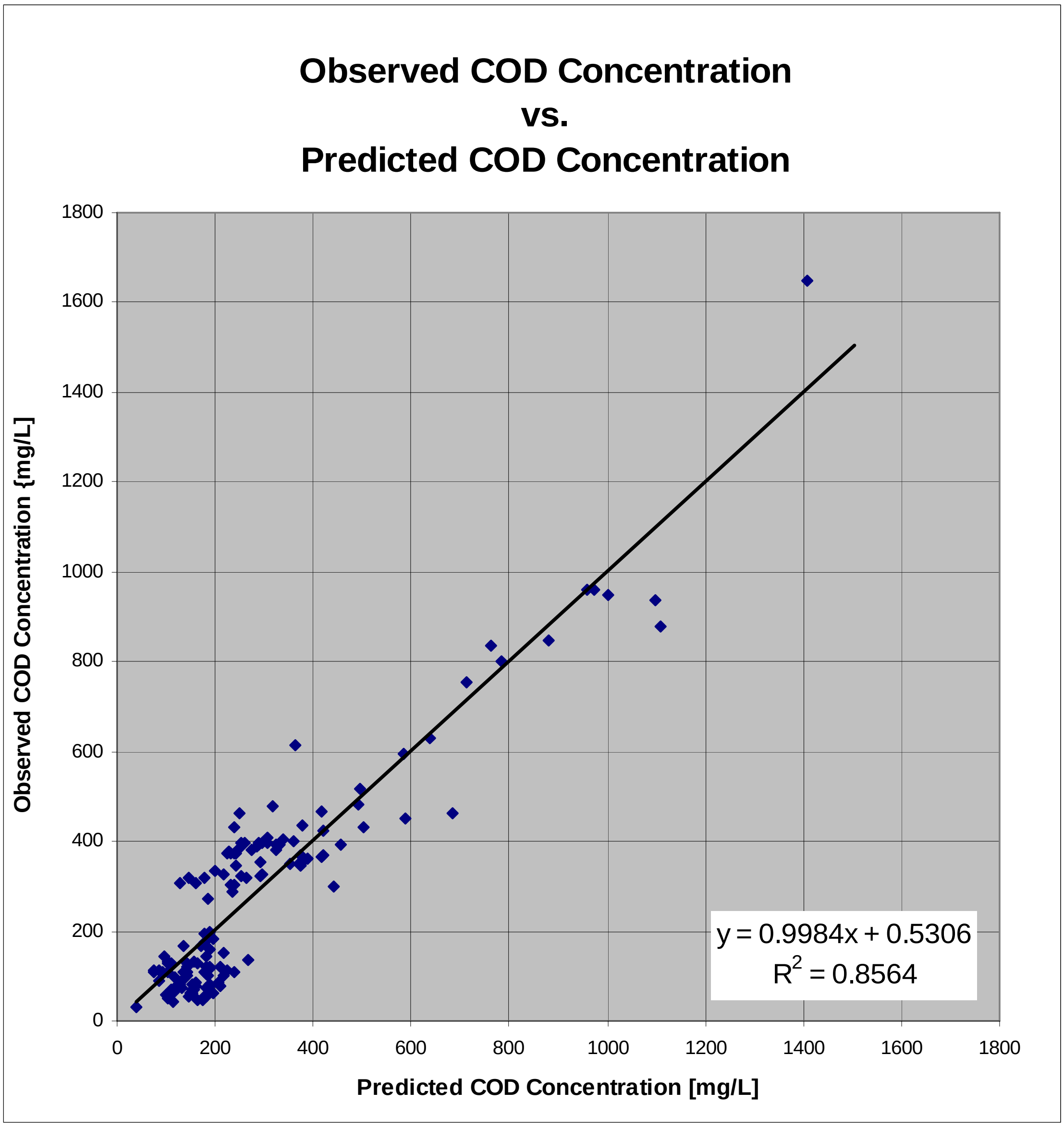

Table 27: Observed COD Concentration vs. Predicted COD Concentration

The model was then verified and passed the F-test with a 95% confidence limit. This means, that there is no statistical evidence of difference among the estimated variance and the one observed in the raw data.

The model was developed using a limited amount of data measured from fourteen storm events. The boundary conditions of this model are the investigation of only one storm water runoff site, which is located in Orleans Parish, New Orleans and the limited amount of collected rainfall events. Accordingly, the results, presented in Chapter 5, are only applicable for this specific test site. The obtained regression models can be used to roughly predict the COD concentration in storm water runoff from roadways during high flow storm events. Additional research would be needed to acquire supplementary data points from this test site as well as from other locations. Then a multi-parameter regression model could be developed to generalize those equations.

The developed equations can be useful for the treatment of storm water runoff. Expensive treatment technologies can be better brought into action in order to obtain optimal results. Also the advantage to obtain estimative results can reduce time and money and increase flexibility and efficiency of treatment technologies.

Almost all treatment plants are required to measure BOD or COD as a measure of the pollution value in the water. BOD is an empirical test that determines the relative oxygen requirements of wastewater, effluent and polluted waters. BOD tests measure the molecular oxygen utilized during a specified incubation duration for the biochemical degradation of organic material (carbonaceous demand) and the oxygen used to oxidize inorganic material such as ferrous iron and sulfides. The most common BOD test consists of a 5 day period in which a sample is placed in an airtight bottle under controlled conditions temperature (20ºC ± 1ºC), keeping any light from penetrating the sample to prevent photosynthesis. The Dissolved Oxygen (DO) in the sample is measured before and after the 5 day incubation period, and BOD is then calculated as the

difference between initial and final DO measurements. BOD can be considered a more "natural" test in determining the oxygen required to oxidize organic matter, however it does not account for rapid changes in conditions. COD is often preferred for daily analysis since it is inherently more reproducible, accounts for changing conditions and takes a short time to complete.

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APPENDIX A

Correlations: Untransformed Dataset

		Dry hours	Raintime	FLOW	Runofftime	Qt	TSS	COD	PH	Redox	Temp	Cond I
Dry hours	Pearson Correlation	1	.240**	.058	.103	-.013	.198*	.355**	-.030	.233**	.106	.578**
	Sig. (2-tailed)	.	.002	.463	.192	.872	.011	.000	.716	.004	.176	.000
	N	163	163	163	163	163	163	163	150	148	163	161
Raintime	Pearson Correlation	.240**	1	-.153	.930**	.200*	-.379**	-.204**	.286**	-.258**	-.204**	.004
	Sig. (2-tailed)	.002	.	.051	.000	.010	.000	.009	.000	.002	.009	.957
	N	163	163	163	163	163	163	163	150	148	163	161
FLOW	Pearson Correlation	.058	-.153	1	-.018	.650**	.123	-.285**	-.051	.037	.184*	-.489**
	Sig. (2-tailed)	.463	.051	.	.822	.000	.118	.000	.537	.656	.018	.000
	N	163	163	163	163	163	163	163	150	148	163	161
Runofftime	Pearson Correlation	.103	.930**	-.018	1	.399**	-.496**	-.378**	.256**	-.331**	-.189*	-.223**
	Sig. (2-tailed)	.192	.000	.822	.	.000	.000	.000	.002	.000	.016	.004
	N	163	163	163	163	163	163	163	150	148	163	161
Qt	Pearson Correlation	-.013	.200*	.650**	.399**	1	-.323**	-.576**	.115	-.189*	.113	-.608**
	Sig. (2-tailed)	.872	.010	.000	.000	.	.000	.000	.163	.022	.152	.000
	N	163	163	163	163	163	163	163	150	148	163	161
TSS	Pearson Correlation	.198*	-.379**	.123	-.496**	-.323**	1	.505**	-.322**	.639**	.096	.302**
	Sig. (2-tailed)	.011	.000	.118	.000	.000	.	.000	.000	.000	.223	.000
	N	163	163	163	163	163	163	163	150	148	163	161
COD	Pearson Correlation	.355**	-.204**	-.285**	-.378**	-.576**	.505**	1	-.218**	.509**	.036	.834**
	Sig. (2-tailed)	.000	.009	.000	.000	.000	.000	.	.007	.000	.647	.000
	N	163	163	163	163	163	163	163	150	148	163	161
PH	Pearson Correlation	-.030	.286**	-.051	.256**	.115	-.322**	-.218**	1	-.281**	.085	-.209*
	Sig. (2-tailed)	.716	.000	.537	.002	.163	.000	.007	.	.001	.299	.011
	N	150	150	150	150	150	150	150	150	148	150	148
Redox	Pearson Correlation	.233**	-.258**	.037	-.331**	-.189*	.639**	.509**	-.281**	1	.015	.421**
	Sig. (2-tailed)	.004	.002	.656	.000	.022	.000	.000	.001	.	.853	.000
	N	148	148	148	148	148	148	148	148	148	148	146
Temp	Pearson Correlation	.106	-.204**	.184*	-.189*	.113	.096	.036	.085	.015	1	.096
	Sig. (2-tailed)	.176	.009	.018	.016	.152	.223	.647	.299	.853	.	.224
	N	163	163	163	163	163	163	163	150	148	163	161
Cond I	Pearson Correlation	.578**	.004	-.489**	-.223**	-.608**	.302**	.834**	-.209*	.421**	.096	1
	Sig. (2-tailed)	.000	.957	.000	.004	.000	.000	.000	.011	.000	.224	.
	N	161	161	161	161	161	161	161	148	146	161	161

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Correlations: LN-transformed Dataset

		LN Dry hours	LN Raintime	LN FLOW	LN_ Runofftime	LN Qt	LN TSS	LN COD	LN PH	LN Redox	LN Temp	LN Cond I
LN Dry hours	Pearson Correlation	1	.169*	-.014	.066	-.097	.215**	.335**	-.024	.494**	.124	.476**
	Sig. (2-tailed)	.	.031	.857	.405	.217	.006	.000	.773	.000	.114	.000
	N	163	163	163	163	163	163	163	150	148	163	161
LN Raintime	Pearson Correlation	.169*	1	-.205**	.880**	.329**	-.470**	-.229**	.277**	-.224**	-.181*	-.084
	Sig. (2-tailed)	.031	.	.009	.000	.000	.000	.003	.001	.006	.021	.289
	N	163	163	163	163	163	163	163	150	148	163	161
LN FLOW	Pearson Correlation	-.014	-.205**	1	-.010	.557**	.360**	-.311**	-.075	.023	.214**	-.575**
	Sig. (2-tailed)	.857	.009	.	.903	.000	.000	.000	.359	.783	.006	.000
	N	163	163	163	163	163	163	163	150	148	163	161
LN_Runofftime	Pearson Correlation	.066	.880**	-.010	1	.648**	-.558**	-.396**	.210**	-.293**	-.133	-.315**
	Sig. (2-tailed)	.405	.000	.903	.	.000	.000	.000	.010	.000	.091	.000
	N	163	163	163	163	163	163	163	150	148	163	161
LN Qt	Pearson Correlation	-.097	.329**	.557**	.648**	1	-.329**	-.636**	.060	-.194*	.091	-.714**
	Sig. (2-tailed)	.217	.000	.000	.000	.	.000	.000	.466	.018	.248	.000
	N	163	163	163	163	163	163	163	150	148	163	161
LN TSS	Pearson Correlation	.215**	-.470**	.360**	-.558**	-.329**	1	.418**	-.238**	.407**	.073	.254**
	Sig. (2-tailed)	.006	.000	.000	.000	.000	.	.000	.003	.000	.357	.001
	N	163	163	163	163	163	163	163	150	148	163	161
LN COD	Pearson Correlation	.335**	-.229**	-.311**	-.396**	-.636**	.418**	1	-.160	.554**	.027	.810**
	Sig. (2-tailed)	.000	.003	.000	.000	.000	.000	.	.051	.000	.731	.000
	N	163	163	163	163	163	163	163	150	148	163	161
LN PH	Pearson Correlation	-.024	.277**	-.075	.210**	.060	-.238**	-.160	1	-.204*	.057	-.192*
	Sig. (2-tailed)	.773	.001	.359	.010	.466	.003	.051	.	.013	.485	.020
	N	150	150	150	150	150	150	150	150	148	150	148
LN Redox	Pearson Correlation	.494**	-.224**	.023	-.293**	-.194*	.407**	.554**	-.204*	1	-.105	.459**
	Sig. (2-tailed)	.000	.006	.783	.000	.018	.000	.000	.013	.	.204	.000
	N	148	148	148	148	148	148	148	148	148	148	146
LN Temp	Pearson Correlation	.124	-.181*	.214**	-.133	.091	.073	.027	.057	-.105	1	.108
	Sig. (2-tailed)	.114	.021	.006	.091	.248	.357	.731	.485	.204	.	.173
	N	163	163	163	163	163	163	163	150	148	163	161
LN Cond I	Pearson Correlation	.476**	-.084	-.575**	-.315**	-.714**	.254**	.810**	-.192*	.459**	.108	1
	Sig. (2-tailed)	.000	.289	.000	.000	.000	.001	.000	.020	.000	.173	.
	N	161	161	161	161	161	161	161	148	146	161	161

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Correlations: LOG-transformed Dataset

		LOG Dry hours	LOG_ Raintime	LOG FLOW	LOG_ Runofftime	LOG Qt	LOG TSS	LOG COD	LOG PH	LOG Redox	LOG Temp	LOG Cond I
LOG Dry hours	Pearson Correlation	1	.169*	-.014	.066	-.097	.215**	.335**	-.024	.431**	.124	.476**
	Sig. (2-tailed)	.	.031	.857	.405	.217	.006	.000	.773	.000	.114	.000
	N	163	163	163	163	163	163	163	150	161	163	161
LOG_Raintime	Pearson Correlation	.169*	1	-.205**	.879**	.325**	-.466**	-.227**	.274**	-.267**	-.183*	-.082
	Sig. (2-tailed)	.031	.	.009	.000	.000	.000	.004	.001	.001	.020	.299
	N	163	163	163	163	163	163	163	150	161	163	161
LOG FLOW	Pearson Correlation	-.014	-.205**	1	-.010	.557**	.360**	-.311**	-.075	-.028	.214**	-.575**
	Sig. (2-tailed)	.857	.009	.	.903	.000	.000	.000	.359	.721	.006	.000
	N	163	163	163	163	163	163	163	150	161	163	161
LOG_Runofftime	Pearson Correlation	.066	.879**	-.010	1	.648**	-.558**	-.396**	.210**	-.306**	-.133	-.315**
	Sig. (2-tailed)	.405	.000	.903	.	.000	.000	.000	.010	.000	.091	.000
	N	163	163	163	163	163	163	163	150	161	163	161
LOG Qt	Pearson Correlation	-.097	.325**	.557**	.648**	1	-.329**	-.636**	.060	-.212**	.091	-.714**
	Sig. (2-tailed)	.217	.000	.000	.000	.	.000	.000	.466	.007	.248	.000
	N	163	163	163	163	163	163	163	150	161	163	161
LOG TSS	Pearson Correlation	.215**	-.466**	.360**	-.558**	-.329**	1	.418**	-.238**	.398**	.073	.254**
	Sig. (2-tailed)	.006	.000	.000	.000	.000	.	.000	.003	.000	.357	.001
	N	163	163	163	163	163	163	163	150	161	163	161
LOG COD	Pearson Correlation	.335**	-.227**	-.311**	-.396**	-.636**	.418**	1	-.160	.631**	.027	.810**
	Sig. (2-tailed)	.000	.004	.000	.000	.000	.000	.	.051	.000	.731	.000
	N	163	163	163	163	163	163	163	150	161	163	161
LOG PH	Pearson Correlation	-.024	.274**	-.075	.210**	.060	-.238**	-.160	1	-.204*	.057	-.192*
	Sig. (2-tailed)	.773	.001	.359	.010	.466	.003	.051	.	.013	.485	.020
	N	150	150	150	150	150	150	150	150	148	150	148
LOG Redox	Pearson Correlation	.431**	-.267**	-.028	-.306**	-.212**	.398**	.631**	-.204*	1	-.003	.534**
	Sig. (2-tailed)	.000	.001	.721	.000	.007	.000	.000	.013	.	.973	.000
	N	161	161	161	161	161	161	161	148	161	161	159
LOG Temp	Pearson Correlation	.124	-.183*	.214**	-.133	.091	.073	.027	.057	-.003	1	.108
	Sig. (2-tailed)	.114	.020	.006	.091	.248	.357	.731	.485	.973	.	.173
	N	163	163	163	163	163	163	163	150	161	163	161
LOG Cond I	Pearson Correlation	.476**	-.082	-.575**	-.315**	-.714**	.254**	.810**	-.192*	.534**	.108	1
	Sig. (2-tailed)	.000	.299	.000	.000	.000	.001	.000	.020	.000	.173	.
	N	161	161	161	161	161	161	161	148	159	161	161

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Correlations: SQ-transformed Dataset

		SQ Dry hours	SQ Raintime	SQ FLOW	SQ Runofftime	SQ Qt	SQ TSS	SQ COD	SQ PH	SQ Redox	SQ Temp	SQ Cond I
SQ Dry hours	Pearson Correlation	1	.267**	.006	.087	.038	.063	.386**	-.049	.343**	-.038	.683**
	Sig. (2-tailed)	.	.001	.939	.269	.628	.424	.000	.552	.000	.631	.000
	N	163	163	163	163	163	163	163	150	148	163	161
SQ Raintime	Pearson Correlation	.267**	1	-.094	.967**	.055	-.118	-.101	.283**	-.246**	-.238**	.033
	Sig. (2-tailed)	.001	.	.232	.000	.487	.133	.198	.000	.003	.002	.681
	N	163	163	163	163	163	163	163	150	148	163	161
SQ FLOW	Pearson Correlation	.006	-.094	1	-.080	.499**	-.054	-.124	-.022	.155	.019	-.124
	Sig. (2-tailed)	.939	.232	.	.310	.000	.497	.114	.785	.060	.812	.118
	N	163	163	163	163	163	163	163	150	148	163	161
SQ Runofftime	Pearson Correlation	.087	.967**	-.080	1	.091	-.100	-.147	.268**	-.308**	-.271**	-.060
	Sig. (2-tailed)	.269	.000	.310	.	.249	.202	.061	.001	.000	.000	.452
	N	163	163	163	163	163	163	163	150	148	163	161
SQ Qt	Pearson Correlation	.038	.055	.499**	.091	1	-.095	-.198*	.141	-.125	-.013	-.141
	Sig. (2-tailed)	.628	.487	.000	.249	.	.227	.011	.086	.130	.873	.074
	N	163	163	163	163	163	163	163	150	148	163	161
SQ TSS	Pearson Correlation	.063	-.118	-.054	-.100	-.095	1	.639**	-.373**	.450**	.052	.268**
	Sig. (2-tailed)	.424	.133	.497	.202	.227	.	.000	.000	.000	.509	.001
	N	163	163	163	163	163	163	163	150	148	163	161
SQ COD	Pearson Correlation	.386**	-.101	-.124	-.147	-.198*	.639**	1	-.323**	.498**	.003	.733**
	Sig. (2-tailed)	.000	.198	.114	.061	.011	.000	.	.000	.000	.972	.000
	N	163	163	163	163	163	163	163	150	148	163	161
SQ PH	Pearson Correlation	-.049	.283**	-.022	.268**	.141	-.373**	-.323**	1	-.579**	.169*	-.198*
	Sig. (2-tailed)	.552	.000	.785	.001	.086	.000	.000	.	.000	.039	.016
	N	150	150	150	150	150	150	150	150	148	150	148
SQ Redox	Pearson Correlation	.343**	-.246**	.155	-.308**	-.125	.450**	.498**	-.579**	1	-.230**	.369**
	Sig. (2-tailed)	.000	.003	.060	.000	.130	.000	.000	.000	.	.005	.000
	N	148	148	148	148	148	148	148	148	148	148	146
SQ Temp	Pearson Correlation	-.038	-.238**	.019	-.271**	-.013	.052	.003	.169*	-.230**	1	-.032
	Sig. (2-tailed)	.631	.002	.812	.000	.873	.509	.972	.039	.005	.	.690
	N	163	163	163	163	163	163	163	150	148	163	161
SQ Cond I	Pearson Correlation	.683**	.033	-.124	-.060	-.141	.268**	.733**	-.198*	.369**	-.032	1
	Sig. (2-tailed)	.000	.681	.118	.452	.074	.001	.000	.016	.000	.690	.
	N	161	161	161	161	161	161	161	148	146	161	161

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Correlations: SQR-transformed Dataset

		SQR_Dry_ hours	SQR_ Raintime	SQR_Flow	SQR_ Runofftime	SQR_Qt	SQR_TSS	SQR_COD	SQR_pH	SQR_Redox	SQR_Temp	SQR_Cond
SQR_Dry_hours	Pearson Correlation	1	.240	.058	.103	-.013	.198	.355	-.030	.233	.106	.578
	Sig. (2-tailed)	.	.002	.463	.192	.872	.011	.000	.716	.004	.176	.000
	N	163	163	163	163	163	163	163	150	148	163	161
SQR_Raintime	Pearson Correlation	.240	1	-.153	.930	.200	-.379	-.204	.286	-.258	-.204	.004
	Sig. (2-tailed)	.002	.	.051	.000	.010	.000	.009	.000	.002	.009	.957
	N	163	163	163	163	163	163	163	150	148	163	161
SQR_Flow	Pearson Correlation	.058	-.153	1	-.018	.650	.123	-.285	-.051	.037	.184	-.489
	Sig. (2-tailed)	.463	.051	.	.822	.000	.118	.000	.537	.656	.018	.000
	N	163	163	163	163	163	163	163	150	148	163	161
SQR_Runofftime	Pearson Correlation	.103	.930	-.018	1	.399	-.496	-.378	.256	-.331	-.189	-.223
	Sig. (2-tailed)	.192	.000	.822	.	.000	.000	.000	.002	.000	.016	.004
	N	163	163	163	163	163	163	163	150	148	163	161
SQR_Qt	Pearson Correlation	-.013	.200	.650	.399	1	-.323	-.576	.115	-.189	.113	-.608
	Sig. (2-tailed)	.872	.010	.000	.000	.	.000	.000	.163	.022	.152	.000
	N	163	163	163	163	163	163	163	150	148	163	161
SQR_TSS	Pearson Correlation	.198	-.379	.123	-.496	-.323	1	.505	-.322	.639	.096	.302
	Sig. (2-tailed)	.011	.000	.118	.000	.000	.	.000	.000	.000	.223	.000
	N	163	163	163	163	163	163	163	150	148	163	161
SQR_COD	Pearson Correlation	.355	-.204	-.285	-.378	-.576	.505	1	-.218	.509	.036	.834
	Sig. (2-tailed)	.000	.009	.000	.000	.000	.000	.	.007	.000	.647	.000
	N	163	163	163	163	163	163	163	150	148	163	161
SQR_pH	Pearson Correlation	-.030	.286	-.051	.256	.115	-.322	-.218	1	-.281	.085	-.209
	Sig. (2-tailed)	.716	.000	.537	.002	.163	.000	.007	.	.001	.299	.011
	N	150	150	150	150	150	150	150	150	148	150	148
SQR_Redox	Pearson Correlation	.233	-.258	.037	-.331	-.189	.639	.509	-.281	1	.015	.421
	Sig. (2-tailed)	.004	.002	.656	.000	.022	.000	.000	.001	.	.853	.000
	N	148	148	148	148	148	148	148	148	148	148	146
SQR_Temp	Pearson Correlation	.106	-.204	.184	-.189	.113	.096	.036	.085	.015	1	.096
	Sig. (2-tailed)	.176	.009	.018	.016	.152	.223	.647	.299	.853	.	.224
	N	163	163	163	163	163	163	163	150	148	163	161
SQR_Cond	Pearson Correlation	.578	.004	-.489	-.223	-.608	.302	.834	-.209	.421	.096	1
	Sig. (2-tailed)	.000	.957	.000	.004	.000	.000	.000	.011	.000	.224	.
	N	161	161	161	161	161	161	161	148	146	161	161

APPENDIX B

Linear Regression

Descriptive Statistics

	Mean	Std. Deviation	N
COD	282.96	244.322	146
TSS	110.80136986301370	167.693300500029700	146
Qt	1880.53	2900.239	146
Redox	-44.054	16.8271	146
Cond I	409.62	569.069	146

Correlations

		COD	TSS	Qt	Redox	Cond I
Pearson Correlation	COD	1.000	.556	-.388	.620	.873
	TSS	.556	1.000	-.219	.675	.334
	Qt	-.388	-.219	1.000	-.154	-.353
	Redox	.620	.675	-.154	1.000	.444
	Cond I	.873	.334	-.353	.444	1.000
Sig. (1-tailed)	COD	.	.000	.000	.000	.000
	TSS	.000	.	.004	.000	.000
	Qt	.000	.004	.	.032	.000
	Redox	.000	.000	.032	.	.000
	Cond I	.000	.000	.000	.000	.
N	COD	146	146	146	146	146
	TSS	146	146	146	146	146
	Qt	146	146	146	146	146
	Redox	146	146	146	146	146
	Cond I	146	146	146	146	146

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
1	.925[a]	.856	.852	93.901	.856	210.158	4	141	.000	.720

a. Predictors: (Constant), Cond I, TSS, Qt, Redox

b. Dependent Variable: COD

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	7412237	4	1853059.159	210.158	.000[a]
	Residual	1243259	141	8817.443		
	Total	8655496	145			

a. Predictors: (Constant), Cond I, TSS, Qt, Redox

b. Dependent Variable: COD

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Interval for B		Correlations			Collinearity Statistics	
		B	Std. Error	Beta			Lower Bound	Upper Bound	Zero-order	Partial	Part	Tolerance	VIF
1	(Constant)	241.055	38.672		6.233	.000	164.602	317.508					
	TSS	.282	.064	.194	4.423	.000	.156	.409	.556	.349	.141	.530	1.885
	Qt	-.006	.003	-.070	-2.020	.045	-.012	.000	-.388	-.168	-.064	.856	1.168
	Redox	2.349	.665	.162	3.532	.001	1.035	3.664	.620	.285	.113	.486	2.060
	Cond I	.306	.016	.712	18.913	.000	.274	.337	.873	.847	.604	.720	1.390

a. Dependent Variable: COD

Coefficient Correlations(a)

Model			Cond I	TSS	Qt	Redox
1	Correlations	Cond I	1.000	-.001	.318	-.328
		TSS	-.001	1.000	.149	-.628
		Qt	.318	.149	1.000	-.097
		Redox	-.328	-.628	-.097	1.000
	Covariances	Cond I	.000	.000	.000	-.004
		TSS	.000	.004	.000	-.027
		Qt	.000	.000	.000	.000
		Redox	-.004	-.027	.000	.442

a Dependent Variable: COD

Residuals Statistics(a)

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	42.53	1408.30	282.96	226.095	146
Std. Predicted Value	-1.063	4.977	.000	1.000	146
Standard Error of Predicted Value	7.986	51.933	15.567	7.748	146
Adjusted Predicted Value	44.86	1312.16	283.28	227.018	146
Residual	-228.684	249.416	.000	92.597	146
Std. Residual	-2.435	2.656	.000	.986	146
Stud. Residual	-2.923	3.043	-.002	1.018	146
Deleted Residual	-329.454	337.836	-.328	99.342	146
Stud. Deleted Residual	-3.005	3.137	.000	1.027	146
Mahal. Distance	.056	43.358	3.973	6.415	146
Cook's Distance	.000	.753	.016	.088	146
Centered Leverage Value	.000	.299	.027	.044	146

a Dependent Variable: COD

APPENDIX C

Storm	Samplenr	Al	Cr	Mn	Fe	Ni	Cu	Zn	As	Cd	Pb	Dry hours	Raintime	FLOW	Runofftime	Qt	TSS	VDS	TDS	VSS	COD	PH	Redox	Temp	Cond l
1	1												6	120	0	0	229	240	720	94	565	7.78	-48.1	17	
1	2												8	135	2	255	286	210	560	144	588	0.74	-45.1	16.6	
1	3												10	150	4	540	143	460	620	73	614	7.74	-44.8	16.6	627
1	4												15	300	9	1665	111	180	520	58	480	7.75	-44.6	16.6	520
1	5												19	420	13	3105	60	30	20	28	167	7.99	-59.5	16.2	120
1	6												24	100	18	4405	30	610	40	21	128	7.99	-58.3	16.2	82.4
1	7												27	120	21	4735	38	10	50	20	132	8.03	-60.7	16.2	78.2
1	8												31	140	25	5255	12	200	30	9	142	8	-59.3	16.3	73.9
1	9												35	130	29	5795	33	117	90	11	127	7.95	-56.7	16.2	65.6
1	10												39	180	33	6415	30	290	20	16	110	7.86	-53	16.2	50.8
1	11												43	450	37	7675	21	90	10	12	110	7.85	-50.7	16	34.2
1	12												47	130	41	8835	25	260	0	3	91	7.88	-52	16.1	39.8
1	13												51	78	45	9251	16	220	50	10	113	7.9	-51.8	16.2	52.9
1	14												55	65	49	9537	30	120	40	19	111	7.99	-57.8	16.2	60.8
1	15												62	93	56	10090	21	250	80	10	110	7.95	-55.5	16	59.8
2	1											42	15	75	0	0	801	580	750	357	1086	6.92		16.4	144.5
2	2	16.2	3.42	27	254	4.96	14.4	164	0.429	0.436	0.528	42	17	210	2	285	294	170	410	211	135	8.05	-42.3	16.2	149
2	3	10.4	2.61	19.9	158	3.09	5.36	42.5	0.0998	0.164	0.106	42	19	225	4	720	52	360	390	29	70	7.93	-51.1	16.2	86.4
2	4	18.7	3.01	12.6	164	3.23	6.93	18.5	0.284	0.107	0.496	42	22	75	7	1170	32	180	380	13	61	7.85	-51.4	16.1	89.4
2	5	8.64	3.1	14.5	170	3.02	7.47	21.6	0.399	0.0661	0.0691	42	25	20.8	10	1314	20	240	270	19	53	7.9	-52.4	16.2	102.3
2	6	5.31	3.36	15.1	187	3.72	9.06	27.6	0.659	0.107	0.179	42	29	3.7	14	1363	7	170	370	6	62	7.88	-51.1	16.1	123.3
2	7	3.36	3.67	15.4	198	4.12	10.5	70.9	0.818	0.125	0.397	42	36	2.4	21	1384	8	80	350	7	78	7.89	-51.7	16.1	157.2
2	8	4.08	3.63	13.4	176	3.97	9.76	72.4	0.48	0.123	0.145	42	41	2.75	26	1397	9	260	370	7	86	7.92	-53.5	16.2	163.1
2	9	3.21	3.26	10.6	192	4.28	10.3	79.7	0.742	0.14	0.112	42	46	1.8	31	1408	8	50	350	6	80	7.93		16	157.1
3	1	17.5	7.94	4.24	513	15.4	30.3	19.5	1.14	0.488	0.366	72	15	2.3333	0	0	49	360	470	34	464	8.04	-60.6	13.5	447.5
3	2	10.1	8.36	70.4	512	16.9	31.4	423	1.22	0.45	0.218	72	18	3.6	3	8.9	47	310	390	42	433	7.97	-56	13	382.2
3	3	20.1	7.44	53	485	14.8	27.1	19.8	1.42	0.483	0.242	72	21	2	6	17.3	30	220	250	25	377	7.96	-55.2	12.9	351.4
3	4	26.5	7.7	30.9	492	12.5	24.7	558	1.2	0.453	0.244	72	25	1.3333	10	23.97	19	200	290	18	327	7.98	-56	12.9	339.6
3	5	5.67	5.14	18.8	374	8.9	18.1	145	1.13	0.231	0.156	72	39	1.5	24	43.8	18	120	150	16	182	8	-57.7	12.6	285.8
3	6	14.1	5.88	10.2	363	9.05	17.5	427	1.08	0.353	0.125	72	43	3.45	28	53.7	16	70	100	11	198	8.2	-57.3	12.7	258.4
3	7	13	7.11	11	332	8.58	17.1	16.7	3.31	0.335	0.0876	72	47	3.3333	32	67.27	15	150	180	14	176	8.3	-58.2	12.6	232
3	8	16.3	6.48	3.17	345	7.86	16.2	423	2.28	0.326	0.134	72	51	1.38	36	76.69	6	70	120	4	142	7.97	-55.7	12.5	226.3
3	9	18.2	6.3	7.79	245	5.58	12	267	2.07	0.219	0.206	72	95	6	80	239.1	72	20	30	55	127	8.07	-60.7	12.2	148.6
3	10	36.6	5.08	37.6	226	4.36	9.84	217	2.02	0.623	0.547	72	97	10	82	255.1	65	20	30	44	134	8.06	-60	12	130.5
3	11	23.8	4.91	7.09	189	4.11	9.25	145	1.21	0.189	0.213	72	99	18	84	283.1	51	20	20	19	119	8.07	-60.5	11.7	105.6
3	12	21.1	5.42	6.59	329	4.16	8.11	123	1.43	0.17	0.198	72	101	18	86	319.1	40	30	40	28	109	8.07	-60.7	11.6	95.4
3	13	19.3	4.82	4.23	167	3.35	6.7	110	1.26	0.596	0.229	72	103	20	88	357.1	28	20	40	23	90	8.07	-61	11.6	89.1
3	14	16.1	4.53	3.64	169	2.91	6.29	90.3	1.03	0.197	0.43	72	105	18	90	395.1	23	30	40	22	76	8.06	-60.5	11.6	84.4
3	15	19.5	4.08	4.07	168	2.98	6	80.2	1	0.128	0.198	72	107	18	92	431.1	23	10	10	14	82	8.06	-60.3	11.6	81.4
4	1											648	15	5.2083	0	0	1096				1650	6.44	28.4	22.1	2589
4	2	155	11.3	424	1210	48.7	83.1	869	2.32	2.06	1.04	648	17	120	2	125.2	837	180	880	397	834	7.07	-7.1	21.9	992
4	3	53	5.34	102	449	17.3	28.6	197	0.639	0.596	0.679	648	19	480	4	725.2	510	130	380	311	298	7.36	-23.3	21.5	382.7
4	4	47.3	4.76	65.1	317	10.8	19.8	136	0.448	0.335	1.17	648	21	420	6	1625	235	30	60	70	323	7.47	-30.6	21.5	214.5
4	5	71.5	3.75	35.7	234	7.44	12.8	65.3	0.25	0.218	1.11	648	23	420	8	2465	151	30	50	69	151	7.64	-38.7	21.4	129.6
4	6	97.7	3.8	24.7	221	6.43	10.8	43.8	0.219	0.188	1.55	648	25	450	10	3335	138	-40	20	36	160	7.74	-44.2	21.3	107.3
4	7	68.4	4.28	21.3	126	3.36	6.69	23.1	0.0658	0.073	0.866	648	29	540	14	5315	243	10	10	152	195	7.89	-51.4	21.2	67.8
4	8	87.2	5.05	14.4	142	2.96	6.44	29.6	0	0.101	0.538	648	33	540	18	7475	57	10	30	23	60	7.92	-54.2	21.1	59.8
4	9	89.5	2.4	12.6	141	3.69	6.63	24.5	0	0.128	0.93	648	37	225	22	9005	40	30	40	17	44.5	7.75	-44.6	21.2	67.3
4	10	131	3.02	14.5	182	3.76	7.72	27.5	0.0593	0.114	0.961	648	41	240	26	9935	51	10	40	23	70.5	7.78	-45.3	21.2	70.8
4	11	109	3.15	13.2	175	4.54	7.01	46.8	0.0926	0.241	1.4	648	45	225	30	10865	40	0	20	18	56.5	7.76	-45.6	21.2	68.1
4	12	192	4.43	15.6	255	3.48	11.9	115	0.0952	0.576	4.64	648	51	900	36	14240	67	30	20	25	30	8.01	-63	20.9	46.4

Storm	Samplenr	Al	Cr	Mn	Fe	Ni	Cu	Zn	As	Cd	Pb	Dry hours	Raintime	FLOW	Runofftime	Qt	TSS	VDS	TDS	VSS	COD	PH	Redox	Temp	Cond I
5	1	707.6	13.7	18.2	1011.4	1.8	9.7	260.1	0	0	0	120	8	17.15	0	0	315	120	160	102	317	7.8	-60.8	27	253.3
5	2	354.2	18.5	9	620.5	26.4	3.6	186.2	0	0	4.9	120	11	240	3	385.7	185	110	140	55	274	8.02	-60.6	27	122.5
5	3	392.1	12.5	8.2	410.7	10.6	4.4	205.7	0	0	0	120	14	240	6	1106	72	90	120	21	127	7.97	-58.2	26.9	83.5
5	4	342.9	14.5	10.6	390.2	6	2.8	202.9	0	0	0	120	17	80	9	1586	43	60	80	20	98	7.93	-56	27.1	87.5
5	5	248.2	16	4.4	259.4	6.7	5	178.8	0	0	0	120	19	30	11	1696	46	40	60	14	96	7.96	-57.8	27.2	100.8
5	6	305.1	12.8	4.9	262.4	6.7	6.4	191.9	0	0	0	120	22	10.5	14	1756	42	40	70	14	110	7.93	-57.2	27.2	115.2
5	7	315.6	16	5.8	302.8	7.1	3.5	196.4	0	0	0	120	25	4.3	17	1779	42	40	60	27	108	7.97	-58.4	27.2	127.3
6	1	746.1	15	15.2	929.8	3.6	10.3	229.9	0	0	0	48	16	30	0	0	246	110	250	84	354	7.8	-51.9	28.8	333.9
6	2	539.9	15.9	11.9	608.2	0	10.6	205.6	0	0	0.4	48	18	42.9	2	72.9	137	320	300	69	303	7.9	-54.2	30.2	281.1
6	3	461.6	13	7.9	510.9	9.5	6.8	229	0	0	21.9	48	20	19.5	4	135.3	109	240	240	51	304	7.9	-54.1	30.2	291.7
6	4	634.1	13	12.2	818.3	2	9.3	220.9	0	0	1	48	22	27.9	6	182.7	203	150	190	61	324	7.9	-55.5	29.7	280.9
6	5	744.5	13	16.3	898.4	4.8	10.9	230.5	0	0	0	48	24	162	8	372.6	277	70	70	83	288	8	-57.4	28.9	175.5
6	6	544.7	12.6	13.8	568.7	1.4	17.8	226.3	0	0	0	48	26	240	10	774.6	152	800	260	50	169	8	-60.3	28.9	112.5
6	7	372.1	12.5	10.6	352.8	5.2	4.8	291.6	0	0	0	48	28	180	12	1195	93	130	80	38	83	7.9	-60	28.9	109
6	8	401.7	10	21.9	494.2	20.1	6.1	218.5	0	0	0	48	30	172.5	14	1547	94	110	240	33	71	7.9	-57.8	28.8	96.2
6	9	298.3	11.3	6	210	20.1	2.9	189.3	0	0	0	48	32	340	16	2060	51	100	180	23	75	7.9	-57.4	28.8	79.2
6	10	268.7	10	4.9	165.6	2.4	2.1	178.4	0	0	0	48	35	180	19	2840	27	50	200	16	74	7.9	-58.3	28.7	79.2
6	11	262.7	14.6	10.9	174	11.8	3.2	176.5	0	0	0	48	39	75	23	3350	24	0	190	16	97	7.9	-58.2	28.6	90.6
6	12	317.7	13.8	5.6	177.6	13.3	4	187	0	0	0	48	43	150	27	3800	29	160	250	20	67	7.9	-58	28.8	84.1
6	13	280	13.8	15.6	782.6	4.4	8	218.3	0	0	2.9	48	47	112.5	31	4325	13	50	160	13	51	7.9	-59.7	28.8	84.1
6	14	231.4	14.6	5.4	152.1	6.9	2	172.3	0	0	0	48	51	34.3	35	4618	14	110	200	13	55	8	-60.3	28.8	94.6
7	1	22.5	17.4	31.2	77.3	31.6	44.4	490.5	17.7	6.1	0	432	23	2	0	0	20	380	1130	16	392	7.9	-49.6	24.1	1065
7	2	22.9	4.3	24.7	55.4	3.5	34.7	357.6	4.4	10.9	0	432	27	2	4	8	59	290	770	44	368	7.9	-50.9	23.5	777
7	3	21.1	3.6	18	49.1	1.6	29.1	297	4	5.2	20.1	432	26	1.5	5	10	30	130	400	30	326	7.8	-46.1	22.8	504
7	4	22.4	2.9	18.6	75.8	7.4	32.3	37.3	9.6	0.5	23.1	432	35	2	12	22	4	190	670	2	351	7.7	-43.6	23.1	698
7	5	23.4	3.2	17.8	25.8	0	34.3	409.3	6	1.6	60.6	432	39	1.5	16	29	7	70	680	4	355	7.8	-46	23.3	795
7	6	24.2	2.4	17	22.9	8.7	33.3	407	10.4	0	6.8	432	43	1	20	34	5	130	710	2	364	7.8	-47.8	23.2	807
7	7	24.6	3.8	17.3	13.2	6.2	34.3	485	6.4	0	23.1	432	53	1	30	44	13	30	940	9	370	7.9	-51.6	23.4	968
7	8	24	3.3	17.6	12.9	3.6	35.7	546.6	13.7	0.6	46.4	432	56	2.5	33	49	31	170	900	29	365	7.9	-51.2	23.5	941
7	9	27.7	3.2	17.4	13.7	0	33	397.4	3.4	0	33.4	432	58	4	35	56	16	250	810	9	360	7.9	-50	23.6	857
7	10	20.1	6	23.9	1735.4	0.2	35.3	367	7	0	21.7	432	60	4.5	37	64	28	350	980	23	356	7.8	-48.3	23.5	803
7	11	21.2	4.7	16.3	18	3.8	33.2	353	2.7	0	0	432	62	4	39	73	8	120	730	5	354	7.8	-47.3	23.5	788
7	12	20.8	2.6	14.9	13.8	5.8	32.2	352.3	9.1	0	13	432	64	3	41	80	21	140	740	16	347	7.9	-46.6	23.5	775
8	1	195	9.7	670.8	192.4	99.9	273.7	3831.9	15.9	3.2	100.1	1032	27	1.14	0	0	96	150	486	53	937	7.53	-29.6	17.3	2935
8	2	226	11.8	518.3	172.1	108.8	259.9	2400.4	10.6	2.8	108.1	1032	32.5	2	5.5	9	76	93	430	47	947	7.52	-29.7	17.4	2645
8	3	170.4	8.4	427.3	108.8	79.8	236.6	1752.9	6.7	2.1	58.7	1032	36.5	2.67	9.5	18	66	134	407	43	960	7.54	-31	17.5	2574
8	4	154.8	7.1	404	102.7	66.3	230.9	1744	18.3	1.1	47.3	1032	40	0.44	13	23	44	109	386	33	960	7.54	-31.4	17.6	2542
8	5	143.6	7.5	324.8	136.3	71.5	215.6	1824.9	15.1	1.3	67.1	1032	62	1.33	35	43	40	111	353	25	846	7.64	-36.8	17.5	2337
8	6	216.2	6.9	297.2	105.6	66.1	216	1772.2	0	1.4	28.6	1032	68	3.5	41	57	78	57	290	47	801	7.65	-37.8	17.6	1998
8	7	90	5.1	242.7	93	51.2	172.9	1415.7	3.5	0.8	71.1	1032	71	7	44	73	147	55	229	73	753	7.62	-35.7	17.8	1683
8	8	123.8	6	206.7	91	41.8	149.9	1233.2	0	0.6	24.6	1032	73.5	15	46.5	101	235	56	175	101	631	7.62	-35.3	17.9	1353
8	9	116.6	4.6	152.8	71.3	42.9	110.2	780	6.1	0.4	12.8	1032	75.5	24	48.5	140	351	28	130	147	595	7.63	-36.1	17.9	1078
8	10	91.2	3.1	122.3	58.6	31.1	89.3	596.6	0	0.4	5.2	1032	78	54	51	237	274	14	85	102	517	7.63	-36.5	18	862
8	11	68.2	5.9	84.5	46.4	24.5	60.8	409.8	0.2	0.4	0	1032	80	60	53	351	200	14	70	83	465	7.62	-35.6	18	673
8	12	57.6	2.7	68	39.8	25.5	46.1	311.8	0	0	9.2	1032	82	80	55	491	209	4	56	76	434	7.66	-38.2	18	554
9	1	48.6	14.6	212.2	314.3	199.3	62.9	3019.9	5.5	1.3	30.4	168	9	10.5	0	0	491	720	730	170	481	7.7	-41.1	18.6	683
9	2	43.2	13.5	68.9	87.8	46.5	28.8	354	0	0	0	168	11	34.3	2	45	193	390	410	91	409	7.7	-49.7	18.6	413
9	3	33.5	7.5	41.9	40.6	14.9	23	192.1	1.2	0	5.3	168	13	40	4	119	68	120	360	25	397	7.8	-47.8	18.4	367
9	4	32.2	9	36.3	45.8	8.7	15.9	145.6	7.3	0	24.9	168	15	34.3	6	193	47	120	400	20	386	7.8	-47.2	18.5	350
9	5	33.4	4.6	30	26.9	10.1	14.2	151.6	2.1	0	20.9	168	17	21.4	8	249	24	280	350	10	375	7.8	-45.5	18.4	338
9	6	37.2	13.9	30.9	66.4	18.7	17.4	171.3	0	0	0	168	19	16.9	10	287	26	250	330	11	373	7.8	-45.7	18.4	325
9	7	38.3	14.8	26.9	72.6	19.2	16.2	150.6	0	0	11.2	168	21	12.6	12	317	33	110	410	15	374	7.8	-46.8	18.2	302
9	8	250.5	12.9	27.8	364	18.2	16.8	176.5	0	0	4.1	168	23	9.6	14	339	20	70	270	11	372	7.8	-46.3	18.4	294
9	9	178.2	5.2	24.2	235.5	1.7	23.7	214.8	3.6	0	3.6	168	25	4.8	16	354	18	30	310	13	376	7.8	-46.8	18.6	313

Storm	Samplenr	Al	Cr	Mn	Fe	Ni	Cu	Zn	As	Cd	Pb	Dry hours	Raintime	FLOW	Runofftime	Qt	TSS	VDS	TDS	VSS	COD	PH	Redox	Temp	Cond l
10	1	770.9	91.7	34.4	992.6	39.2	35.2	163	0	0	0	192	20	2.5	0	0	75	200	510	33	400	7.7	-37.9	11.6	608
10	2	864.4	75.1	34.3	1129.6	39.2	28.8	131.9	13.3	0	0	192	22	4.5	2	7	76	230	390	36	403	7.7	-37	11.2	530
10	3	879.6	24.5	31.3	1009.6	24.7	32.9	139.8	8	0	0	192	24	6	4	18	108	230	380	38	394	7.7	-36.7	11.1	474
10	4	1267.6	9.8	33.5	1352.3	7.3	28.8	130.1	5.1	0	0	192	26	13.5	6	37	157	220	370	62	393	7.6	-35.9	11.2	401
10	5	1017.7	25	28.9	1218.5	0	22.2	101.5	9.8	0	0	192	28	24	8	75	157	180	280	72	398	7.6	-33.8	11.3	329
10	6	1150.5	102	37.3	1538	55	31.3	132.4	6.1	0	5.3	192	30	33.3	10	132	155	150	250	57	398	7.6	-32.5	11.4	289
10	7	1023.6	164.4	36.3	1593.2	71.9	26.4	107.6	0	0	13.4	192	32	48	12	213	153	150	200	60	394	7.6	-31.9	11.4	259
10	8	1216.1	313.2	46.7	2127.3	138	29.2	114.9	0	0	28.7	192	34	67.5	14	329	185	110	170	82	398	7.5	-30.7	11.4	222
10	9	1065.3	460.2	57	2592.1	205.3	32.5	114.3	0	0	0	192	36	80	16	476	181	140	230	72	387	7.5	-26.4	11.4	184
10	10	978.5	28.4	27.9	1251	10	21.5	104.7	0	0	0	192	38	70	18	626	164	50	80	69	380	7.5	-25.6	11.4	165
11	1	4223.9	18.3	219.3	3097.3	26.6	151.4	1255.6	14.6	9.5	56.2	195	11	24	0	0	1200	580	1350	350	879	6.3	37.5	20.9	1439
11	2	1653.3	10.7	91.2	1502.4	17.4	57.5	369.5	5.8	4	0	195	13	80	2	104	263	260	690	115	451	6.7	16.5	21.2	766
11	3	1156.3	8.7	75.9	1156.3	8.7	66.5	365.9	0	0.2	0	195	15	120	4	304	181	190	610	68	433	6.8	9	20.9	619
11	4	847.1	9	47.2	877.3	5	28.7	279.1	0	1.6	0	195	17	120	6	544	196	190	370	98	423	7	-0.9	20.7	427
11	5	674.7	9.3	32.1	685.9	0	21.8	166.6	0	0.7	0	195	19	210	8	874	163	120	230	47	382	7.2	-10.1	20	212
11	6	400.3	6.5	21.1	686.8	29.4	11.7	97.5	0	0	0	195	21	780	10	1864	101	60	130	31	345	7.3	-19.4	19.4	99.7
11	7	244.7	7.7	17.6	561.5	32.9	6.6	83.3	0	0	0	195	23	720	12	3364	67	30	70	23	334	7.4	-25.9	19	63.6
11	8	237.1	6.9	17.5	573.5	39.1	6.9	72	0	0	0	195	25	840	14	4924	53	40	50	19	320	7.5	-27.5	18.9	50.8
11	9	206.6	6.4	22.1	873.4	65.4	6.5	73.4	0	0	0	195	27	840	16	6604	48	90	150	19	309	7.5	-29.7	18.9	50.1
11	10	201	7.1	8.8	282.2	9.5	5	61.2	0	0	0	195	29	780	18	8224	45	50	80	22	319	7.5	-31.2	18.7	49.7
11	11	153	6	14.5	709.5	25.1	4.5	79.7	0	0	0	195	31	840	20	9844	35	50	60	11	308	7.5	-33.1	18.6	45.1
12	1	45	5.59	306	192	31.3	37.5	3050	4.44	3.62	1.31	423	10	48	0	0	532	72	119	155	463.7	6.7	2.4	21.2	936
12	2	25.3	3.21	12.5	48.9	7.19	9.08	49.1	0.346	0.629	0.216	423	12	54	2	96	171	126	15	54	63.33	7.35	-62	19.9	167.5
12	3	38.3	3.12	9.1	50.5	6.65	9.67	43.7	0.392	0.545	0.314	423	14	60	4	204	101	15	17	37	46.33	7.43	-59	19.9	113.7
12	4	149	3.46	11.9	220	9.23	14.7	66.5	0.549	0.529	2.46	423	16	75	6	324	110	19	13	39	46	7.51	-54.7	20	103
12	5	228	3.74	17.4	369	11.5	18.5	134	0.775	0.775	4.3	423	21	462	11	699	63	16	14	27	53.67	7.57	-48.5	20.1	124.4
12	6	41.3	3.19	14.7	76.9	9.69	17.7	118	0.806	1.27	0.498	423	25	100	15	2547	51	20	19	29	55	7.51	-44.8	20.1	153.1
12	7	237	4.62	27.1	485	13.8	30.1	232	1.49	1.54	5.22	423	30	120	20	3047	45	26	25	29	79.33	7.55	-40.7	20.3	227
12	8	48	3.66	29.5	113	14.3	33.1	287	1.45	2.38	0.835	423	33	140	23	3407	52	27	31	37	110.7	7.58	-34.8	20.4	277.8
12	9	152	4.3	27.4	258	16.6	35.3	284	1.62	2.67	2.44	423	37	130	27	3967	49	32	29	33	114.7	7.56	-37.5	20.6	270.5
12	10	408	5.67	33.4	863	16.5	43	263	1.61	1.89	10.1	423	41	180	31	4487	81	24	28	49	119.3	7.62	-41.1	20.4	223
12	11	37.5	3.38	18.5	90.8	9.73	29.5	173	1.15	1.98	0.753	423	45	450	35	5207	61	27	31	36	103.3	7.68	-42.1	20.2	177
12	12	46.9	3.61	16.4	281	10.3	26.8	149	1.11	2.08	0.805	423	49	130	39	7007	39	27	30	30	102.7	7.7	-42.7	19.9	103.3
12	13	68.4	6.06	21.8	141	13.1	31.7	165	1.42	5.65	1.6	423	53	78	43	7527	50	29	22	34	93	7.76	-45.5	19.9	102
13	1	10.8	0.099	17.5	73.5	27	15	192	0.746	0.667	0.51	102	10	240	0	0	197	0	13	87	395	6.6	-41.8	13.8	183.3
13	2	486	2.14	25.2	847	85.3	22.9	129	0.654	0.571	8.02	102	11	120	1	240	127	5	20	60	100.3	6.7	-39.5	13.9	118
13	3	100	0.494	12.7	194	222	13.8	87.6	0.622	0.601	1.96	102	13	80	3	480	111	2	17	55	85.67	6.9	-41.8	13.7	117.4
13	4	19.8	6.93	8.95	79.5	22.8	11.5	83.4	0.365	0.404	0.28	102	15	51.429	5	640	38	0	7	26	74	6.9	-41.8	13.6	104
13	5	23.7	-1.09	8.45	48.9	21.2	11.7	69	0.393	0.435	0.296	102	17	37.5	7	742.9	67	0	10	35	78	6.9	-41.8	13.6	105.7
13	6	18.5	-0.387	9.29	55.4	27.8	12.5	95.3	0.605	0.551	0.435	102	19	21.818	9	817.9	65	6	12	36	82.33	6.9	-41.8	13.5	106.3
13	7	21.7	-0.966	8.63	54.5	87.7	12	105	0.537	0.584	0.769	102	21	8.2759	11	861.5	60	0	11	33	103	6.9	-41.8	13.5	103.3
13	8	26.9	-0.833	8.75	61.6	509	12.3	99.5	0.863	0.599	1.29	102	23	5.2941	13	878	69	1	13	31	119.3	6.9	-41.9	13.5	106.7
13	9	24.4	-1.09	9.18	65.4	37.4	12.8	122	0.47	0.633	0.504	102	25	4.0909	15	888.6	58	0	11	27	116	6.9	-41.9	13.5	111.4
13	10	25.3	-0.807	9.4	65.1	506	13.2	121	1.3	0.9	0.654	102	29	1.0169	19	905	35	2	12	21	120	6.9	-41.9	13.4	108.2
13	11	828	6.33	26.4	1130	3990	30.6	237	3.39	1.53	11.8	102	33	0.5	23	909.1	31	2	15	20	108.3	6.9	-41.8	13.3	109.5
14	1	69.5	3.63	226	367	29.5	54.8	941	2.77	1.86	2.14	174	12	15	0	0	622	63	109	397	1035			22	901
14	2	36.6	2.9	101	572	25.6	63.3	514	1.19	1.23	2.29	174	13	30	1	15	267	40	84	174	666			22.1	764
14	3	44	2.7	104	280	25.6	64	444	1.52	1.36	1.17	174	14	42	2	45	186	52	91	102	711			21.8	770
14	4	60.4	1.94	94.8	258	24.8	60.4	390	1.41	1.18	1.25	174	15	42	3	87	142	44	79	70	687.7			21.9	745
14	5	36.2	0.992	89.9	220	27.4	61.4	375	1.34	1.87	0.766	174	17	36	5	171	94	42	88	59	660			21.9	722
14	6	46.6	1.28	89.2	222	37.1	65.6	349	1.36	1.12	0.957	174	19	30	7	243	74	44	71	59	692.3			22	740
14	7	54.2	1.97	98.6	249	75.3	69.5	378	1.63	1.34	1.05	174	21	24	9	303	71	45	78	55	677.7			22	749
14	8	52	0.915	83.6	213	169	60	350	1.5	1.23	0.972	174	23	15	11	351	51	52	86	46	668.7			22	767
14	9	43.4	1.5	84.6	246	23.6	66.1	355	1.54	1.1	1.11	174	25	12	13	381	50	55	91	50	686.7			22.1	756
14	10	41.7	1.82	74.7	215	27.4	58.2	338	1.6	0.999	1.36	174	27	10.5	15	405	45	47	90	40	693.3			22	755
14	11	37.2	2.34	80.2	229	57.1	64.1	391	1.73	1.41	0.982	174	29	5.1429	17	426	40	46	96	40	682			22.1	790
14	12	47.2	3.83	83.8	274	61.6	69.3	462	1.99	1.93	1.45	174	32	5	20	441.4	50	57	97	48	693.3			22	792
14	13	331	5.17	89.9	728	140	81.6	606	2.52	2.24	9.47	174	35	4.8	23	456.4	67	48	82	51	735			22	782

VITA

The author Claudio L'Altrella was born in Sterzing, (Southtirol, Italy) to Silvio L'Altrella and Monika Zihl on April 26, 1979. He graduated from "Realgymnasium Sterzing" High School of Sterzing in 1998.

The author began his studies in the field of Civil and Environmental Engineering at the "Leopold Franzens University" of Innsbruck in Austria where he achieved his "Vordiplom" in 2001. He even participated at courses for "Engineering Mechanics" at the Technical University of Vienna, Austria, which where offered in English. His studies until this point were equivalent to the Bachelor Degree in Engineering.

He entered the Graduate Program at University of New Orleans in august, 2003, and conducted research on storm water runoff characteristics. On July 31, 2004, he finished his class work for the degree in Master of Science in Engineering at the Department of Civil and Environmental Engineering at the University of New Orleans.

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