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First Flush Characterization of Storm Water Runoff

A Thesis

Submitted to the Graduate Faculty of the
University of New Orleans
in partial fulfillment of the
requirements for the degree of

Master of Science
in
The Department of Civil and Environmental Engineering

by

Simon Ringler

D.I. University of Innsbruck (A), 2005

May 2007

DEDICATION - WIDMUNG

(Mother Language: German)

Diese Arbeit widme ich meiner Familie **Ringler von Waidbruck** (Südtirol, Italien):

Mutter, **Plieger Johanna** – Ihre Hingabe zur Familie, harte Arbeit und unnachgiebiger Kampf gegen den Krebs gewährten mir kostbare Momente und Eindrücke.

Vater, **Gernot Hugo** – Seine selbstlose, harte Arbeit und Sein profundes Wissen ermöglichte mir einzig das Beste.

Großmutter, **Fiedler Josefine –** Ihre positive Lebenseinstellung ist mir ein gutes Vorbild.

Tante, **Ulrike Miccoli –** Ihr regelmäßiger Besuch und Part in der Familie ist sehr wichtig.

Geschwister, **Gudrun, Sigrid, Lorenz** und **Alexander** – Deren grenzenloser Zusammenhalt gemeinsam mit mir wohl einzigartig und die unverzichtbare Quelle unserer Familienstärke ist.

Nichte und Neffen, **Charly Anna, Jacob Alexander, Giuseppe Riccardo** und **Julian –** Deren kindliche Art und sorgenloses Lächeln ein wahrer Segen und große Freude für mich ist.

DEDICATION

(English)

This thesis is dedicated to my family **Ringler in Waidbruck** (South Tyrol, Italy):

Mother, **Plieger Johanna –** her dedication to her family, hard work and fierce fight against cancer has granted me with precious memories and inspiration.

Father, **Gernot Hugo –** his selfless hard work and profound knowledge has provided me with only the best.

Grandmother, **Fiedler Josefine –** her positive attitude set a good example for me.

Aunt, **Ulrike Miccoli –** her regular visits and her role in my family are very important.

Siblings, **Gudrun, Sigrid, Lorenz,** and **Alexander –** their along with mine unconditional support is probably unique and is the indispensable source of our family strength.

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LIST OF ABBREVIATIONS

ADT	Average Daily Traffic
APHA	American Public Health Association
APRA	Association of Professional Researchers for Advancement
BOD	Biochemical Oxygen Demand
BOD_5	Five Day Biochemical Oxygen Demand
BMPs	Best Management Practices
BPJ	Best Professional Judgment
COD	Chemical Oxygen Demand
CSOs	Combined Sewer Overflows
CWA	Clean Water Act
DEP	Department of Environmental Protection
DO	Dissolved Oxygen
ELGs	Effluent Limitations Guidelines
EMC	Event Mean Concentration
EPA	Environmental Protection Agency
gal	gallons
gpd	gallons per day
GS	Geological Survey
ICP-OES	Inductively Coupled Plasma-Optical Emission Spectrometer
LSU	Louisiana State University
mg/L	milligram per liters

MS4s	Municipal Separate Storm Sewer Systems
NPDES	National Pollutant Discharge Elimination System
PCC	Portland Cement Concrete
ppm	Parts per million
POTW	Publicly Owned Treatment Works
QA/QC	Quality Assurance/Quality Control
SSOs	Sanitary Sewer Overflows
TDS	Total Dissolved Solids
TMDLs	Total Maximum Daily Loads
TOC	Total Organic Carbon
TSS	Total Suspended Solids
UAs	Urban Areas
UNO	University of New Orleans
U.S.	United States
USA	United States Of America
USEPA	U.S. Environmental Protection Agency
UK	United Kingdom
UV	Ultra-violet
VSS	Volatile Suspended Solids
WWTP	Wastewater Treatment Plant

ABSTRACT

This proposed research focused on the characterization of first flush in storm water runoff from elevated roadways, to assist the establishment of a storm water program and to facilitate the selection of treatment technology. Storm water runoff from highways transports a significant load of contaminants, especially heavy metals and particulate matter, to receiving waters. Heavy metals, either in dissolved or particulate bound phases, are unique in the fact that unlike organic compounds, they are not degraded in the environment.

The objective was to develop a mass loading based diagram of the “first flush”. In order to achieve this goal, a general characterization of the most important variables affecting “first flush” from elevated highways was necessarily. Also point this study is the requirement of a “first flush” treatment associated with storm water runoff from elevated highways.

The test site was selected at the intersection of the Interstate-10 and Interstate-610, Orleans Parish, New Orleans, Louisiana.

1 INTRODUCTION

The enormous demands being placed on water supply and wastewater disposal facilities today have necessitated the development and implementation of far broader concepts in environmental engineering than those envisioned only a few years ago. The regulations and standards for water quality have significantly increased concurrently with a decrease in water quality. Evidence of water supply contamination by toxic and hazardous materials has become common and concern about broad water-related environmental issues has heightened. As populations throughout the world multiply at an alarming rate, environmental control and water management become increasingly urgent. [1]

During the past century, large areas were filled with urban construction to create business and residential centers and to enhance human life style. Infrastructures such as roadway pavements, parking lots, rooftops, sidewalks and driveways were built in order to improve people’s mobility and quality of life. These pavement surfaces are highly impervious in nature and were designed for a rapid and efficient transport of storm water flows. This higher hydraulic efficiency enhances the amount and the velocity of urban storm water runoff and consequently promotes the pollutant transport from infrastructures.

A consequence of the growing population densities in many areas of the world is the increasing traffic and the associated traffic-generated pollution. The increasing traffic causes a rise in the amount of contaminants accumulating on road surfaces, which results in higher concentrations of contaminants and contaminant loads transported off the impermeable infrastructures into receiving waters.

Storm water runoff from highways transports a significant load of contaminants, especially heavy metals and particulate matter, to receiving waters. Heavy metals, either in dissolved or particulate-bound phases, are unique in the fact that unlike organic compounds, they are not degraded in the environment. Because of their short- and long-term toxic effects, the maximum permissible concentrations of these heavy metals in drinking water as well as in municipal and industrial discharges are closely regulated through legislation [2].

Direct highway storm water runoff discharges from elevated structures to surface receiving water is of particular concern, given the challenging conditions prevalent in the coastal regions, where inter-urban transportation infrastructures are frequently elevated over ecologically sensitive and economically significant water bodies. The issues of storm water mitigation and treatment from highways is further complicated by logistical site constrains of elevated highway structures and in particular those located over water. The majority of conventional treatment alternatives, such as infiltration systems, wet detention systems or filter systems, typically applied to the treatment of urban storm water runoff, are precluded from their direct application to elevated structures because of the highly prohibitive spatial limitations. Elevated structures do not have hard shoulders or vegetative strips to the side, where contaminants can undergo physical, chemical, and biological transformations or where they could be taken up by plants or animals, or adsorbed on soil particles. Consequently, it is of particular importance to distinguish between storm water discharges from elevated roadways and runoff from highways situated over land.

Storm water runoff from elevated roadways is currently discharged directly and without treatment to the surrounding environment and represents a direct pathway of contaminants to estuaries, rivers or lakes. [3]

The U.S. Environmental Protection Agency (U.S. EPA) mandated amendments to the Clean Water Act (CWA) in 1987 [4, 5], addressing both point and non-point discharges. However, these amendments did not specifically address storm water runoff from highways, which were beyond the urban boundaries that delineated the regulatory requirement for treatment of storm water runoff. Phase II of the tiered National Pollution Discharge Elimination System (NPDES) strategy of the amendments to the CWA, promulgated in 1999, serves to specifically address the diffuse non-point source discharge of storm water runoff from federal highways not previously regulated in Phase I.[6]

The development of such a storm water program is associated with many issues and problems that have to be addressed. In order to limit the environmental impact of storm water runoff discharges, U.S. EPA will have to establish criteria or regulations considering either concentrations of particular pollutants for acute shock discharges or considering contaminant loadings for long-term chronic effects to the receiving waters. However, many investigations [3, 7] have shown the complexity of the behavior of storm water runoff because of the interaction of many uncontrollable factors that affect its quality and quantity. Of particular importance are the high temporal variability in actual occurrences of storm events and the very stochastic nature of the associated runoff.

Rainfall events exhibit a high degree of variability in the intensity of precipitation, the duration of these events and ultimately the duration, volume and composition of the runoff associated with them. Runoff volumes and flow rates can display differences in orders of magnitude between events and also within the same event. As a result, there are many questions that need to be addressed and many problems that are still not well understood, particularly at the “first flush” from storm water runoff.

"First flush" is the runoff that occurs at the beginning of a rainstorm. Generally thought to be more pronounced on impervious surfaces, the first flush carries with it concentrations of pollutants that have accumulated during the period of dry weather between storms, which could be one day or several months. Communities often struggle to adequately define first flush, such as what volume of rain it constitutes and whether or not it is affected by rainfall frequency or intensity, and to provide adequate treatment measures to counter it. First-flush concerns often figure prominently as smaller cities and counties work toward gaining compliance with Phase II of the NPDES, and with meeting EPA’s total maximum daily load (TMDL) requirements as specified by each state. Communities vary considerably in how they define first flush and how they treat it. [22]

In the past, investigations pointed out that the accumulation of contaminants on street surfaces results from two basic processes: deposition and removal. [8] The main portion of the deposition of contaminants on roadways occurs during dry periods, when pollutants are accumulated onto road surfaces. Some of these pollutants are organic substances leaked onto the pavement, such as oils, greases and gasoline from car and truck engines. Inorganic pollutants, such as heavy metals come from some "natural" sources such as minerals in rocks, vegetation, sand, and salt. However, in highway storm water runoff heavy metals mostly come from car and truck exhaust, worn tires and engine parts, brake linings, weathered paint, galvanized vehicle part, rust etc. [3]. Nevertheless, this deposition process is not infinite, but limited due to traffic, wind and other factors that prevent additional build up of pollutants on pavement surfaces. During rainfall the surface runoff washes the contaminants, accumulated on the catchment’s impervious surface, off the roadway and into grass swales, manholes or drainpipes. Through this removal process storm water runoff reaches the receiving waters without previous treatment. [9]

Highway runoff may have adverse effects if no measures are taken for the removal of excessive contaminants before the runoff reaches receiving waters. The presence of undesirable contaminants in surface or ground water may interfere with the vital functions of the organisms living in or from it. Our environment has its own assimilative capacity that, if not exceeded, can naturally assimilate and treat specific waste streams. However, heavy metals do not degrade in the environment and their occurrence in storm water runoff, along with the particulate loadings may result in a significant impairment of these receiving water bodies. As a consequence, natural bodies of water to which storm water runoff is discharging are increasingly failing to meet their utility levels for which they were originally designated.

2 OBJECTIVES

Storm water runoff from highways represents a considerable contaminant source for the surrounding receiving waters. During this study, multiple storm water runoff samples were analyzed for many different parameters, determining hydrological and qualitative results. [10]

The fundamental goal of this study was to characterize the “first flush” in storm water runoff from elevated roadways, to assist the establishment of a storm water program and to facilitate the selection of treatment technology. In order to achieve this prescribed goal, the research was divided into four objectives.

The first objective of this research effort was a general characterization of “first flush” of storm water runoff from roadways, which included the identification of contaminants and their sources, and the explanation of the pollutant accumulation process on road pavements. Information to accomplish this goal was gathered from a comprehensive literature review.

The second objective was the determination of the most important variables affecting “first flush” from elevated highways. This involved an evaluation of the data set, the determination of correlations between variables and the identification of significant patterns in the data set.

The third objective of this study was to identify the occurrence of a “first flush” response associated with storm water runoff from highways and to define this phenomenon as a variable dependent characteristic. In addition it was of importance to classify storm water runoff from roadways into a concentration based or a mass loading based environmental issue.

The fourth objective in this investigation was to construct a mass loading based diagram of the “first flush”. The use of this diagram would make it possible to predict how much volume of the discharged runoff occurs to treat a specific mass loading. The achievement of this objective may save considerable time and money for future rainfall runoff analyses and may consequently facilitate the selection of an adequate treatment technology.

3 THE REGULATORY FRAMEWORK OF STORMWATER RUNOFF

3.1 The Clean Water Act

In December 1970, as an outgrowth of the administration's environmental interests, a new independent body, the EPA, was created. This organization assumed the functions of several existing agencies relative to matters of environmental management. It brought together under one roof all of the pollution control programs related to water, air, solid wastes, pesticides, and radiation. The EPA was seen by the administration as the most effective way of recognizing that the environment must be looked on as a single, interrelated system. It is noteworthy, however, that the creation of the EPA made even more pronounced the separation of water quality programs from other water programs.

Even with the enactment of EPA, it was clear that a comprehensive response to water pollution issues was still lacking. It became evident during Congressional hearings in 1971 that, relative to the construction grants program, the program was under-funded. To rectify this situation, Congress passed the Water Pollution Control Act Amendments of 1972. Responding to public demand for cleaner water, the law ended two years of intense debate, negotiation, and compromise and resulted in the most assertive step taken in the history of national water pollution control activities, the Clean Water Act.

The act departed in several ways from previous water pollution control legislation. It expanded the federal role in water pollution control, increased the level of federal funding for construction of publicly owned treatment works, elevated planning to a new level of significance, opened new avenues for public participation, and created a regulatory mechanism requiring uniform technology-based effluent standards, together with a national permit system for all point-source dischargers as the means of enforcement. As pollution control measures for industrial process wastewater and municipal sewage were implemented and refined, it became increasingly evident that more diffuse sources of water pollution were also significant causes of water quality impairment. Specifically, storm water runoff draining from large surface areas, such as urban land, was found to be a major cause of water quality impairment, including the non-attainment of designated beneficial uses. [1]

3.2 NPDES Phase I Regulations

In response to the need for comprehensive NPDES requirements for discharges of storm water, congress amended the CWA in 1987 to require the EPA to establish phased NPDES regulations for storm water discharges. To implement these regulations, EPA published the initial permit application requirements for certain categories of storm water discharges associated with industrial activity and for discharges from municipal separate storm sewer systems (MS4s) located in municipalities with a population of 100,000 or more on November 16, 1990. Storm water discharge permits provided a mechanism for monitoring the discharge of pollutants from Phase I sources to waters of the United States and for establishing appropriate controls. [11]

The NPDES Phase I program was originally implemented to track point sources and require the Implementation of the controls necessary to minimize the discharge of pollutants. Initial efforts to improve water quality under the NPDES program primarily focused on reducing pollutants in industrial process wastewater and municipal sewage.

These discharge sources were easily identified as responsible for poor, often drastically degraded, water quality conditions. As pollution control measures for industrial process wastewater and municipal sewage were implemented and refined, it became increasingly evident that more diffuse sources of water pollution were also significant causes of water quality impairment. Specifically, storm water runoff draining to large surface areas, such as agricultural and urban land, was found to be a major cause of water quality impairment, including the non-attainment of designated beneficial uses. [6]

3.2.1 NPDES Phase I Coverage

NPDES Phase I sources included storm water discharges associated with industrial activities and storm water discharges from MS4s located in municipalities serving a population of 100,000 or more. The following describes, in more detail, the types of discharges covered by the Storm Water Phase I Program. [12]

3.1.1.1 Industrial Facilities Covered

EPA has defined the term “storm water discharge associated with industrial activity” in a comprehensive manner to address over 100,000 facilities. All storm water discharges associated with industrial activity that discharged through MS4s or that discharged directly to waters of the United States were required to obtain NPDES permit coverage, including those, which discharged through systems located in municipalities with a population of less than 100,000. Discharges of storm water to a sanitary sewer system or to a Publicly Owned Treatment Works (POTW) were excluded. Facilities with storm water discharges associated with industrial activity included: manufacturing facilities; construction operations disturbing five or more acres; hazardous waste treatment, storage, or disposal facilities; landfills; certain sewage treatment plants; recycling facilities; power plants; mining operations; some oil and gas operations; airports; and certain other transportation facilities. Operators of industrial facilities that were Federally, State or municipally owned or operated that met the description of the facilities listed in 40 CFR 122.26(b)(14)(I)-(xi) had also to submit applications. [12]

3.1.1.2 Municipal Applications

“Municipal separate storm sewer” was defined as any conveyance or system of conveyances that was owned or operated by a State or local government entity designed for collecting and conveying storm water, which was not part of a Publicly Owned Treatment Works. The application requirements did not apply to discharges from combined sewers (systems designed as both a sanitary sewer and a storm sewer), which did have NPDES obligation. MS4s that were addressed by the Phase I regulations included

- storm sewer systems located in an incorporated place with a population of 100,000 or more;
- located in 47 counties identified by EPA as having populations over 100,000 in unincorporated, urbanized areas;
- and systems that are designated by the Director based on consideration of the location of the discharge with respect to waters of the United States, the size of the discharge, the quantity and nature of the pollutants discharged to waters of

the United States, the interrelationship to other regulated storm sewer systems, and other factors.

Under the November 16, 1990, storm water rule those MS4s identified were required to submit a two-part application. The first part required information regarding existing programs and the means available to the major outfalls to detect illicit connections. Building on this information, the second part required a limited amount of representative quantitative data and a description of a proposed storm water management plan. [12]

3.3 NPDES Phase II Regulations

On August 7, 1995, EPA promulgated application regulations for Phase II of the NPDES Storm Water Program. The Phase II regulations established a sequential application process for all Phase II storm water discharges, which included all discharges, composed entirely of storm water, except those specifically classified as Phase I discharges. Such discharges included storm water from small municipal separate storm sewer systems, and commercial and institutional facilities. The application regulations included two tiers. The first tier was for Phase II dischargers, that the NPDES permitting authority determined were contributing to water quality impairment or were a significant contributor of pollutants to waters of the United States. Dischargers that have been designated by the permitting authority were required to obtain a permit and had to submit a permit application within 180 days of notification that an application was required. The second tier of the Phase II storm water application regulations required all remaining Phase II sources (i.e., all Phase II sources not designated by the permitting authority) to submit a permit application by August 7, 2001, but only if the Phase II regulatory Program in place at that time required permits. [11]

On January 9, 1998 (63 FR 1536), EPA proposed to expand the NPDES storm water program to include storm water discharges from MS4s and construction sites that were smaller than those previously included in the program. The proposal also addressed industrial sources that have “no exposure” of industrial activities and materials to storm water. [6]

3.3.1 NPDES Phase II Coverage

The second stage of the NPDES tiered strategy, the Storm Water Phase II Rule (promulgated in 1999) extended coverage of the NPDES storm water program to those not already regulated under Phase I and addresses (40 CFR § 122.26):

- Operators of small MS4s serving population centers (or equivalents) of at least 10,000 and satellite areas with a population density of 1,000 people per square mile.
- Land disturbing activity from 1 to 5 acres
- All highways and streets discharging to MS4s

Operators of designated MS4s had to develop comprehensive and fully site-specific storm water management programs. This mandate obligated operators of the MS4s to implement controls to reduce pollutant discharges to the maximum extent practicable, including best management practices, and other provisions as the Administrator or the States determined to be appropriate for the control of such pollutants.

Even though the NPDES Phase II ruling is designed to encompass the operators of those MS4s not covered under Phase I, the coverage was not without exception. Moreover, this applicability for coverage under the new ruling was bade on the size of the MS4, and its ability of the MS4s to have deleterious effects upon the receiving water body to which it discharges. [6]

3.3.2 Phase II Increased Coverage and Non-Point Source Discharges

The Phase II Final Rule included federal facilities not originally designated for regulation by Phase I, thereby including Federal MS4 operators in the Phase II legislation. As well as the specifically designated MS4 listed above, Phase II also addressed population equivalents, to include non-residential centers such as industrial parks, universities and federal and nonfederal highways discharging to MS4s. It is this inclusion of federal and nonfederal highways beyond the boundary of the defined urban areas (UAs) designated under Phase I that is of particular significance. Under Phase I provisions, storm water from urban areas, streets and paved surfaces within those boundaries were covered under the delineations of the defined medium and large MS4s. However, highways and paved surfaces beyond the boundaries of these urban areas or designated MS4s were not originally covered. It is the reduction in the threshold of applicable MS4 size (40 CFR § 122.26) that bring all highways discharging to an MS4, irrespective of size under the encompassing coverage of the NPDES Phase II ruling. [6]

3.3.3 NPDES Phase II Compliance Schedule

Specific compliance dates and exemption applications were set by each NPDES permitting authority:

- December 8, 1999: The final Phase II rule was published in the Federal Register, with Conditional “No Exposure Exclusion” option available 60 days later for facilities for which EPA is the permitting authority.
- October 2000 (1 year from the date of signature of the final rule): EPA was obligated to issue a menu of recommended BMPs for regulated small MS4s.
- October 2001 (1 year after the issuance of the menu of BMPs): EPA was obligated to issue guidance on the development of measurable goals for regulated small MS4s.
- December 8, 2002 (3 years from the date of publication of the final rule): The NPDES permitting authorities are required to issue general permits for Phase II regulated small MS4s and small (less than 5 acres) construction activity.
- March 10, 2003 (3 years and 90 days from the date of publication of the final rule, or by the time specified in the permit): Operators of Phase II regulated small MS4s and small construction activity are required to obtain permit coverage.

- By the end of their first permit terms (typically 5 years), operators of regulated small MS4s would have to fully implement their storm water management programs.

It is the immediacy of this schedule for compliance that is the fundamental driving force for highway storm water runoff management. [6]

3.4 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 [13].

3.5 Definition of Non-Point and Point Source Pollution

The following definition of non-point and point sources should prevent the misleading of these two terms.

3.5.1 Point Sources

The term point source is also defined very broadly in the Clean Water Act because it has been through 25 years of litigation. It means any discernible, confined and discrete conveyance, such as a pipe, ditch, channel, tunnel, conduit, discrete fissure, or container. It also includes vessels or other floating craft from which pollutants are or may be discharged. By law, the term "point source" also includes concentrated animal feeding operations, which are places where animals are confined and fed. By law, agricultural storm water discharges and return flows from irrigated agriculture are not "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. [15]

3.5.2 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 the runoff moves, it picks up and carries away natural and human-made pollutants that accumulate during dry periods, finally depositing them into lakes, rivers, wetlands, and even our underground sources of drinking water. Runoff from highways and surrounding development may contain contaminants such as oil, dirt, grease and heavy metals. States report that non-point source pollution is the leading remaining cause of water quality problems. The effects of non-point source pollutants on specific waters vary and may not always be fully assessed. However, we know that these pollutants have harmful effects on drinking water supplies, recreation, fisheries, and wildlife. [16]

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 [15].

3.6 NPDES Effluent Limits

When developing effluent limits for a NPDES permit, a permit writer must consider limits based on both the technology available to treat the pollutants (i.e., technology-based effluent limits), and limits that are protective of the water quality standards of the receiving water (i.e., water quality-based effluent limits). [17]

3.6.1 Quality-Based Effluent Limits

In response to recent questions regarding the type of water quality-based effluent limitations that are most appropriate for NPDES storm water permits, the EPA adopted an interim permitting approach for regulating wet weather storm water discharges. Due to the nature of storm water discharges, and the typical lack of information on which to base numeric water quality-based effluent limitations (expressed as concentration and mass), EPA uses an interim permitting approach for NPDES storm water permits.

The interim permitting approach uses best management practices (BMPs) in first-round storm water permits, and expanded or better-tailored BMPs in subsequent permits, where necessary, to provide for the attainment of water quality standards. In cases where adequate information exists to develop more specific conditions or limitations to meet water quality standards, these conditions or limitations are to be incorporated into storm water permits, as necessary and appropriate. This interim permitting approach is not intended to affect those storm water permits that already include appropriately derived numeric water quality-based effluent limitations. Since the interim permitting approach only addresses water quality-based effluent limitations, it also does not affect technology-based effluent limitations, such as those based on effluent limitations guidelines or developed using best professional judgment, that are incorporated into storm water permits.

Each storm water permit should include a coordinated and cost-effective monitoring program to gather necessary information to determine the extent to which the permit provides for attainment of applicable water quality standards and to determine the appropriate conditions or limitations for subsequent permits. Such a monitoring program may include ambient monitoring, receiving water assessment, discharge monitoring (as needed), or a combination of monitoring procedures designed to gather necessary information.

This interim permitting approach applies only to EPA; however, EPA also encourages authorized States and Tribes to adopt similar policies for storm water permits. This interim permitting approach provides time to more fully assess the range of issues and possible options for the control of storm water discharges for the protection of water quality. This interim permitting approach may be modified as a result of the ongoing Urban Wet Weather Flows Federal Advisory Committee policy dialogue on this subject. [18]

3.6.2 Technology-Based Effluent Limits

There are two general approaches for developing technology-based effluent limits for industrial facilities:

- using National Effluent Limitations Guidelines (ELGs) and
- using Best Professional Judgment (BPJ) on a case-by-case basis (in the absence of ELGs).

3.1.1.3 National Effluent Limitation Guideline (ELGs)

Technology-based effluent limits for Publicly Owned Treatment Works (POTWs) are derived from secondary treatment standards as shown in Table 1. The intent of a technology-based effluent limitation is to require a minimum level of treatment for industrial/municipal point sources based on currently available treatment technologies while allowing the discharger to use any available control technique to meet the limitations.

When developing technology-based effluent limitations for non-municipal dischargers, the permit writer must consider all applicable standards and requirements for all pollutants discharged.

Parameter	30-Day Average	7-Day Average
5-Day BOD	30mg/l	45mg/l
TSS	30mg/l	45mg/l
pH	6 – 9 s.u. (instantaneous)	---
Removal	85% BOD_5 and TSS	---

Table 1: Secondary Treatment Standards

EPA establishes effluent limitations guidelines and performance standards for different industrial categories since the best control technology for one industry is not necessarily the best for another. These guidelines are developed based on the degree of pollutant reduction attainable by an industrial category through the application of control technologies, irrespective of the facility location.

To date, EPA has established guidelines and standards for more than 50 different industrial categories (e.g., metal finishing facilities, steam electric power plants, iron and steel manufacturing facilities). These guidelines appear in 40 CFR Parts 405-499 [18].

3.1.1.4 Best Professional Judgment (BPJ) Limits

Best Professional Judgment limits (BPJ-based limits) are technology-based limits derived on a case-by-case basis for non-municipal (industrial) facilities. BPJ limits are established in cases where ELGs are not available for, or do not regulate, a particular pollutant of concern. BPJ is defined as the highest quality technical opinion developed by a permit writer after consideration of all reasonably available and pertinent data or information that forms the basis for the terms and conditions of a NPDES permit. The authority for BPJ is contained in Section 402(a)(1) of the CWA, which authorizes the EPA Administrator to issue a permit containing “such conditions as the Administrator determines are necessary to carry out the provisions of this Act”, prior to taking the necessary implementing actions, such as the establishment of ELGs. The NPDES regulations in 40 CFR §125.3 state that permits developed on a case-by-case basis under Section 402(a)(1) of the CWA must consider (1) the appropriate technology for the category class of point sources of which the applicant is a member, based on all available information, and (2) any unique factors relating to the applicant [17].

3.7 Total Maximum Daily Loads (TMDLs)

Over 40 % of United States waters still do not meet the water quality standards states, territories, and authorized tribes have set for them. This amounts to over 20,000 individual river segments, lakes, and estuaries. These impaired waters include approximately 300,000 miles of rivers and shorelines and approximately 5 million acres of lakes - polluted mostly by sediments, excess nutrients, and harmful microorganisms. An overwhelming majority of the population (218 million) lives within 10 miles of the impaired waters.

Under section 303(d) of the 1972 Clean Water Act, states, territories, and authorized tribes are required to develop lists of impaired waters. These impaired waters do not meet water quality standards that states, territories, and authorized tribes have set for them, even after point sources of pollution have installed the minimum required levels of pollution control technology. The law requires that these jurisdictions establish priority rankings for waters on the lists and develop TMDLs for these waters.

A TMDL specifies the maximum amount of a pollutant that a water body can receive and still meet water quality standards, and allocates pollutant loadings among point and non-point pollutant sources. By law, EPA must approve or disapprove lists and TMDLs established by states, territories, and authorized tribes. If a state, territory, or authorized tribe submission is inadequate, EPA must establish the list or the TMDL. EPA issued regulations in 1985 and 1992 that implement section 303(d) of the Clean Water Act - the TMDL provisions.

In an effort to speed the Nation's progress toward achieving water quality standards and improving the TMDL program, EPA began, in 1996, a comprehensive evaluation of EPA's and the states' implementation of their Clean Water Act section 303(d) responsibilities. EPA convened a committee under the Federal Advisory Committee Act, composed of 20 individuals with diverse backgrounds, including agriculture, forestry, environmental advocacy, industry, and state, local, and tribal governments. The committee issued its recommendations in 1998.

These recommendations were used to guide the development of proposed changes to the TMDL regulations, which EPA issued in draft in August 1999. After a long comment period, hundreds of meetings and conference calls, much debate, and the Agency's review and serious consideration of over 34,000 comments, the final rule was published on July 13, 2000. However, Congress added a "rider" to one of their appropriations bills that prohibits EPA from spending “FY2000” and “FY2001” money to implement this new rule.

The current rule remains in effect until 30 days after Congress permits EPA to implement the new rule. TMDLs continue to be developed and completed under the current rule, as required by the 1972 law and many court orders. The regulations that currently apply are those that were issued in 1985 and amended in 1992 (40 CFR Part 130, section 130.7). These regulations mandate that states, territories, and authorized tribes list impaired and threatened waters and develop TMDLs. [19]

3.8 Best Management Practices (BMPs)

A storm water best management practice (BMP) is a technique, measure or structural control that is used for a given set of conditions to manage the quantity and improve the quality of storm water runoff in the most cost-effective manner. BMPs can be either engineered and constructed systems ("structural BMPs") that improve the quality and/or control the quantity of runoff such as detention ponds and constructed wetlands, or institutional, education or pollution prevention practices designed to limit the generation of storm water runoff or reduce the amounts of pollutants contained in the runoff ("non-structural BMPs"). No single BMP can address all storm water problems. Each type has certain limitations based on drainage area served, available land space, cost, pollutant removal efficiency, as well as a variety of site-specific factors such as soil types, slopes, depth of groundwater table, etc. Careful consideration of these factors is necessary in order to select the appropriate BMP or group of BMPs for a particular location. [20]

3.8.1 Goals of Storm Water BMPs

Storm water BMPs can be designed to meet a variety of goals, depending on the needs of the practitioner. In existing urbanized areas, BMPs can be implemented to address a range of water quantity and water quality considerations. For new urban development, BMPs should be designed and implemented so that the post-development peak discharge rate, volume and pollutant loadings to receiving waters are the same as pre-development values. In order to meet these goals, BMPs can be implemented to address three main factors: flow control, pollutant removal and pollutant source reductions. [20]

3.1.1.5 Flow Control

Flow control involves managing both the volume and intensity of storm water discharges to receiving waters. Urbanization significantly alters the hydrology of a watershed. Increasing development leads to higher amounts of impervious surfaces. As a result, the response of an urbanized watershed to precipitation is significantly different from the response of a natural watershed. The most common effects are reduced infiltration and decreased travel time, which significantly increase peak discharges and runoff volumes. Factors that influence the amount of runoff produced include precipitation depth, infiltrative capacity of soils, soil moisture, antecedent rainfall, cover type, the amount of impervious surfaces and surface retention. Travel time is determined primarily by slope, length of flow path, depth of flow and roughness of flow surfaces. Peak discharges are based on the relationship of these parameters, and on the total drainage area of the watershed, the time distribution of rainfall, and the effects of any natural or manmade storage (USDA/NRCS, 1986). [20]

3.1.1.6 Pollutant Removal

Urbanized areas export large quantities of pollutants during storm events. The high population of pollutant sources in urbanized areas contribute to large quantities of pollutants that accumulate on streets, rooftops and other surfaces. During rainfall or snowmelt, these pollutants are mobilized and transported from the streets and rooftops into the storm drain system, where they are conveyed and ultimately discharged to waterways. In order to reduce the impacts to receiving waters from the high concentrations of pollutants contained in the runoff, BMPs can be implemented to remove these pollutants. [20]

3.1.1.7 Pollutant Source Reduction

Source reduction is an effective non-structural way of controlling the amount of pollutants entering storm water runoff. A lot of different pollutants are washed off of impervious surfaces during runoff events. Removing these contaminants from the urban landscape prior to precipitation can effectively limit the amounts of pollutants contained in the storm water runoff. Source reduction can be accomplished by a number of different processes including: limiting applications of fertilizers, pesticides and herbicides; periodic street sweeping to remove trash, litter and particulates from streets; collection and disposal of lawn debris; periodic cleaning of catch basins; elimination of improper dumping of used oil, antifreeze, household cleaners, paint, etc., into storm drains; and identification and elimination of illicit cross-connections between sanitary sewers and storm sewers. [20]

3.8.2 Types of Storm Water BMPs

There is a variety of storm water BMPs available for managing urban runoff. Regardless of the type, storm water BMPs is most effective when implemented as part of a comprehensive storm water management program that includes proper selection, design, construction, inspection and maintenance. Storm water BMPs can be grouped into two broad categories: structural and non-structural. Structural BMPs are used to treat the storm water at either the point of generation or the point of discharge to either the storm sewer system or to receiving waters. Non-structural BMPs include a range of pollution prevention, education, institutional, management and development practices designed to limit the conversion of rainfall to runoff and to prevent pollutants from entering runoff at the source of runoff generation. [20]

3.8.3 BMP Selection

BMP selection is a complex process. There are a number of competing factors that need to be addressed when selecting the appropriate BMP or suite of BMPs for an area. It should be stressed that BMPs should be incorporated into a comprehensive storm water management program. Without proper BMP selection, design, construction and maintenance, BMPs will not be effective in managing urban runoff. BMP selection can be tailored to address the various sources of runoff produced from urbanized areas. For example, a particular suite of BMPs may be developed for use on construction sites and new land development, where opportunities exist for incorporating BMPs that are focused on runoff prevention, reducing impervious surfaces and maintaining natural drainage patterns. In established urban communities, a different suite of BMPs may be more appropriate due to space constraints. In these areas, BMPs may be selected to focus on pollution prevention practices along with retrofit of the established storm drain system with regional BMPs. Site suitability for selecting a particular BMP strategy is the key to successful performance. Most BMPs have limitations for their applicability, and therefore cannot be applied nationwide. [20]

3.8.4 Effectiveness of BMPs

The effectiveness of BMPs can be measured in various ways. Non-structural BMPs deal mainly with pollution prevention and limiting the amounts of pollutants that are carried away by runoff. Their effectiveness is best measured in terms of the degree of change in people's habits following implementation of the management program or by the degree of reduction of various pollutant sources. It is oftentimes very difficult to measure the success of non-structural BMPs in terms of pollution reduction and receiving stream improvements. Structural BMPs can be measured in terms in the reductions of pollutants discharged from the system and by the degree of attenuation of storm water flow rates and volumes discharged to the environment. Various physical, chemical and biological evaluation methods exist for determining the pollutant removal efficiency of structural BMPs. [20]

4 LITERATURE REVIEW

In this section some general information about “first flush” and storm water runoff from highways will be discussed.

4.1 Concept of the “First Flush”

The concept of the first flush was first advanced in the early 1970s. Runoff sampling methods of this era required the collection of multiple flow and water quality samples over the duration of a storm event. As researchers examined monitoring data during storms, they discovered that pollutant concentrations tended to be much higher at the beginning of a storm compared to the middle or the end of the event.

It was reasoned that the store of pollutants that had accumulated on paved surface in dry weather quickly washed off during the beginning of the storm. Although runoff rates were greater at the middle and tail end of a storm, the store of pollutants available for wash off was depleted, and consequently the concentration of pollutants declined.

Storm water managers quickly grasped the practical significance of the first flush phenomenon. If most of the urban pollutant load was transported in the beginning of a storm, then a much smaller volume of runoff storage would be needed to treat and remove urban pollutants. After further monitoring and modeling, the half inch rule was advanced. Essentially, the rule stated that 90% of the annual storm water pollutant load was transported in the first half inch of runoff.

Many communities adopted this simple standard as the basis for providing water quality control in developing areas: size your storm water practice to capture the first half inch of runoff, and you will treat 90% of the annual pollutant load. Other communities modified the treatment standard further, by requiring that storm water practices only capture the first half inch of runoff produced from impervious areas of the site.

With the advent of sophisticated automated sampling equipment to measure storm water runoff in the 1980s, entire storm events could be represented by a single composite sample-known as the event mean concentration (EMC). One consequence of this technological advance was that researchers were no longer analyzing multiple samples during storms, and therefore, could not examine the behavior of pollutant concentrations during individual storm events. Further research into the first flush waned, and the half-inch rule became somewhat an article of faith in the storm water community. [21]

4.2 Various Views of “First Flush”

"First flush" is the runoff that occurs at the beginning of a rainstorm. Generally thought to be more pronounced on impervious surfaces, the first flush carries with it concentrations of pollutants that have accumulated during the period of dry weather between storms, which could be one day or several months. Communities often struggle to adequately define first flush, such as what volume of rain it constitutes and whether or not it is affected by rainfall frequency or intensity, and to provide adequate treatment measures to counter it. First-flush concerns often figure prominently as smaller cities and counties work toward gaining compliance with Phase II of the NPDES, and with meeting EPA’s total maximum daily load (TMDL) requirements as specified by each state. Communities vary considerably in how they define first flush and how they treat it. [22]

Scott McClelland, a vice president of the international consulting, engineering, and construction firm Camp, Dresser & McKee, describes the phenomenon of first flush: "When things are dry, pollutants tend to store up on land, both pervious and impervious areas. Then when it rains even a little bit, pollutants are entrained and carried off the land, the majority in the first portion of the storm event." McClelland, who is based in Florida, works directly with cities, counties, and states on planning strategies to address their environmental issues. He specializes in storm water planning and management, including master plans and financial areas of storm water. In Florida, where it rains about 125 times each year, McClelland says it is important to consider those rainfall events "that occur 90% of the time (generally small, less than an inch)". To deal with storm water quality issues, McClelland stresses the importance of controlling the first half-inch or inch of rainfall, which occurs in the smaller storm events within the first half-hour. Components of first flush that are particularly easy to visualize are car and truck engine greases and oils that accumulate on roadways. These become major sources of storm water pollution if they are allowed to flush into surface waters. McClelland believes that for Florida, measuring first flush is no longer a critical issue because the benefits of controlling first flush for the frequent smaller storms the state receives, have already been convincingly documented. McClelland’s confidence stems partly from Florida’s extensive work in the areas of storm water treatment (it is one of only six or seven states with statewide storm water regulation) and in its pioneering efforts to define and treat first flush. "Controlling pollution is very important in the state of Florida," McClelland explains, "because it has an environment that is very sensitive to pollution it’s very easy to tip it over the edge." McClelland believes the focus on defining first flush is shifting to treating it: "I think we've gone beyond needing to know if first flush is an issue. We've come to a point where we need to know more about the effectiveness of the types of BMPs we use." [22]

McClelland's sentiments are echoed by a fellow Floridian, **Eric Livingston**, chief of the Florida Department of Environmental Protection (DEP) Bureau of Watershed Management. Involved since 1978 in the development, implementation, and evolution of Florida's non-point source and watershed management programs, essentially since their beginning, Livingston agrees that Florida has collected enough monitoring data to be confident of its storm water database. "We have enough data to feel very comfortable that we know what the pollutants are, what the loads are." But Livingston cautions that other states must collect their own data, because environmental considerations and pollutant loads vary considerably between locations: "You have to do your own data collection to come up with your own BMP design criteria that achieve a certain level of pollutant load reduction." Livingston recounts the history of the first-flush concept, citing its origins in Florida research that stemmed from the CWA (section 208) program, the first non-point source program, in the mid-1970s. Because there was very little knowledge about storm water at that time, Livingston explains, most of the early monitoring attempted to characterize different kinds of runoff from different land uses. "We conducted discrete monitoring over a hydrograph, a series of samples as the flow increased and decreased throughout the storm, so you could see what was happening with concentrations, and you could measure flow and take a look at total loads." One of the trends apparent in the data was the occurrence of the first flush, which was factored into designing BMP practices once storm water treatment became required in Florida as of

1979. With so many small storms occurring in Florida annually, most of them 1 in. or less rainfall, the apparent documentation of first flush led to the concept that "you really only need to capture that small amount of the first storms that come along." Livingston now says this was too simplistic a view, and even in the early days of monitoring, first flush did not hold for drainage basins larger than 100 ac. Livingston carries his doubts as far as to state, "I don't think you can talk about first flush as a general characteristic of storm water anymore." Many factors influence the occurrence and impact of a first-flush event. "First flush depends on a number of site characteristics: the time of concentration of the basin, the imperviousness of the basin, the kind of storm water routing in the basin and the pollutants of concern. Larger sites experience greater times of concentration (the time it takes for flow to get from one point in the drainage basin to another) and receive more sources coming in. In addition, larger, more complex sites might have natural mechanisms or depression storage areas, such as wetlands and flood plains that cut down on the runoff. In these cases, explains Livingston, "first flush just gets hidden by the myriad things going on." Very small sites with large impervious areas, such as office complexes on large parking lots, definitely exhibit a first flush, but otherwise, Livingston finds the trend to be very site-specific. In terms of monitoring, he supports the idea of characterizing a site through discrete sampling over a hydrograph, "to see if there are any discrete pollutants that pop in as the storm goes on," but he believes that storm water management needs to continue to focus on storm water loads, not concentrations, and TMDLs. Livingston explains that Florida's storm water program, similar to most in the United States, is "designed to get 80% average annual load reduction of total suspended solids." He says, "We've used the research we have - our information on loadings, rainfall, and rainfall distribution - to come up with design criteria for infiltration systems, wet detention systems, filter systems, various common kinds of BMPs. These presumptive design criteria are set forth in our rules, and they get periodically fine-tuned as we learn more about the treatment mechanisms of typical BMPs." [22]

Roger James is a California water resources management consultant with a long career in that field. He worked with the state's Regional Water Quality Control Board from 1960 to 1988, including a stint as executive officer, and as an operations and water-quality manager for the Santa Clara Valley Water District from 1988 to 1995. Now working primarily with municipalities, James also sounds a cautionary note when it comes to unqualified acceptance of the first-flush event: "I think anyone looking at pollutant loadings or trying to select and identify BMPs should not just blindly accept the first-flush theory. I think they need to know an awful lot more about their specific site and about the pollutants that they are dealing with." James finds that the belief of what constitutes the first flush varies considerably: "I think if you put 10 people in a room, you'd get 10 definitions of first flush." Of even greater concern to James is that first flush does not directly deal with pollutant loadings. "Now that we are into the TMDL program so much, I think if you only focus on first flush, you really haven't dealt with the real pollutant loading." [22]

James cites evaluations of the first-flush event in different parts of the country, which have produced highly variable findings. Groundbreaking work in Austin, TX, by **George Chang** and colleagues explored the assumption that the first half-inch of rainfall runoff washes off 90% of the pollutants. Investigators found instead that these pollutants make up only about 20% of the annual load and that much greater rainfall volumes -

maybe more than 1.25 inch - should be treated. Work by the City of Portland, OR, determined that first flush occurred with small and moderate storms for total pollutants, but only minimally for dissolved pollutants. Portland also found that treating first flush for its design storm of 0.83 in. would treat only about 20% of the pollutant load during major storm events. **Bob Pitt** at the University of Alabama has demonstrated that it takes containing more than an inch of rainfall in that area to trap most of the pollutant load, and **John Sansalone** of Louisiana State University has shown in his studies that most of the pollutants in the first flush are associated with large particles. These studies suggest that storm water treatment BMPs should be designed to capture or treat larger volumes of runoff to be effective in addressing pollutant loads and achieving compliance with TMDLs. [22]

Because of such a range of findings, James agrees with Eric Livingston’s assessment that first flush is very site-specific and is affected by many variables. "First flush could depend on many factors, including whether you have acid rain or not. It’s probably very dependent on the storm event itself. What is the intensity? If you get an inch of rain in an hour, versus the Pacific Northwest, where you get an inch over a day and a half, you see entirely different things. It could be the duration and intensity of the storm, or how many antecedent dry days since the last storm, and perhaps more important, the physical characteristics of the pollutants that are being addressed." [22]

Pollutant specificity has become a major concern of those evaluating the effectiveness of treating first flush. **Flint Holbrook** is an associate partner and project director for Woolpert LLP, which provides client services in engineering, architecture, design, and related services. Holbrook, who works in the Charlotte, NC, office, specializes in storm water work - NPDES compliance, municipal separate storm sewer system permitting, watershed master planning, erosion control activities, and so on - for state and local governments. Holbrook recounts the start of first-flush capture requirements in South Carolina in 1991, which specified the first half-inch of rainfall, a requirement generally interpreted as applying to impervious areas. Holbrook, who helped write the legislation, explains that the intent was always pollutant-specific: "Our focus was simply to capture particulate pollutants, pollutants attached to sediments, which is a post-construction condition. We never intended for it to capture dissolved pollutants. The sediments wash off the site, as do oils and greases, floatable material, and so forth." From the standpoint of capturing sediments, particulates, oil and greases, and floatable material, Holbrook believes that first-flush requirements are effective, but he cautions, "If you're trying to get dissolved pollutants, such as dissolved nitrogen and phosphorus in the water column, you're not going to have much success, particularly if you have a dry basin, and you should have a separation device to separate that first flush from the bypass flow." Holbrook says that some in the storm water field now believe that the dissolved pollutant concentrations in runoff continue to increase throughout a storm event. [22]

Gordon England, a project manager for Creech Engineers in Melbourne, FL, has accumulated many years of experience in dealing with storm water issues and currently works with clients in such areas of storm water management as NPDES permitting, TMDLs, and retrofitting for water-quality purposes and flood control. He believes that although a larger proportion of pollutants are found in the first flush, which he considers the first inch or so of rainfall, "you still see pollutants in rainfall runoff no matter what time in the storm event it is, whether first flush or last flush." England supports the idea of pollutant specificity: "You tend to see different pollutants at different times in the storm: greases and oils and sediments probably most at the first part of the storm - the first-flush effect - but the dissolved stuff, like fertilizer in yards, will continue to wash out of the yard throughout the storm. You probably don’t see too much of a first-flush effect with that type of pollutant." England believes that the first-flush effect is likely to be more pronounced in arid locations, where large concentrations of pollutants build up during the long periods between storms, than in places such as Florida, where storms are frequent but accumulation is small for most storms. He feels strongly that first flush must be considered for every storm, not just for those occurring at certain intervals. [22]

In many areas of the country, England acknowledges, the regulatory framework focuses on addressing suspended solids, making exclusive consideration of first flush somewhat more valid for determining treatment options. England and James both caution, however, that the US Geological Survey (USGS) recently published highly critical evaluations of the reliability of total suspended solid data, and they note that the USGS recommended that these data should not be used for design or performance evaluations of sediment-removal BMPs. [22]

In Florida, whose storm water program has evolved over the years, "We have learned that there’s a lot more to it than the first flush," says England, "and we ought to be looking at bigger storms and more complex criteria. It’s not simple. I wish it was." England explains that the focus in storm water treatment has shifted to picking BMPs "that will treat the whole storm." Much of Florida’s storm water activities are paid for through local user or utility fees that have been adopted by more than 100 local governments. "Everybody who contributes to the storm water burden pays a fee, relative to the amount they contribute," explains McClelland. "If you have controlled storm water on your site to the point that there’s no burden to the community, then you don’t pay a fee - that’s the concept at least. It’s a win-win situation." Other sources of funding for Florida’s storm water projects, which are often undertaken through funding partnerships, include taxes levied by regional water management districts, these districts’ own monies, and federal section 319 grant dollars administered through Florida’s DEP.

Although storm water managers might consider it far simpler to treat only first-flush runoff, some benefits of the "whole storm" approach might offset the effort involved. Gordon England describes an "ancillary benefit" of treating the whole storm that people often are not aware of: "When you put in the bigger ponds to treat more than the first flush, you’re storing more water in your system and releasing less to the downstream pipes, so you flood the downstream people less. So when you build the bigger ponds for more than the first flush, you’re helping with flood control throughout the rest of the community." [22]

4.3 Exceptions of “First Flush”

The existence of first flush should not be assumed in all cases. Intensive monitoring of storm water runoff from some (usually larger) catchments has failed to observe this phenomenon. Clearly the existence or non-existence of first flush is critical in the design of storm water pollution controls.

While the theory of first flush is straightforward, first flush may not be observed for one or more of the following reasons:

- The drainage characteristics of the catchments may prevent it. Particularly in large catchments, initial runoff from the most distant parts of the catchments may not reach the catchments outlet for some time after a storm starts. This time lag is rarely an issue for smaller, individual premises.
- The pollutants may not be very mobile. Rainfall does not remove some pollutants, like oils and greases, or soluble materials and fine dusts. Bare soils or vegetated surfaces are generally not 'cleansed' as easily or effectively as sealed surfaces. This is discussed further below.
- Pollutant sources that are effectively continuous may exist within the catchments. First flush is generally seen only where the supply of pollutants is limited. Sediment washing off from soil erosion, for example, will not give a first flush because the supply of soil particles is (for all practical purposes) unlimited. In cases like this, on-line, flow-through pollution controls will be needed.

Do not forget other pollution discharges that are not directly related to storm water runoff. For example, in urban catchments during large storms, continuous discharges from sewer overflows may mask any first flush associated with storm water runoff. [23]

4.4 Other Actual Programs

4.4.1 Litter Pollutograph and Loadograph

Abstract: Litter pollutographs and loadographs were prepared. The first flush phenomenon was evaluated and the impacts of various parameters such as rain intensity, drainage area, peak flow rate, and antecedent dry period on litter volume and loading rates were evaluated. Results obtained indicate that (i) first flush effect of gross pollutant concentrations was generally observed, (ii) the size of the drainage area did not increase the total litter mass loading, (iii) litter volume and loading rates appear to be directly related to storm intensity, (iv) weak or no correlation between litter volume and antecedent dry period was found, and (v) the ratio of biodegradable litter to non-biodegradable litter was roughly one to one across the entire event. However, a greater percentage of biodegradable litter was normally collected in the first flush. [24]

4.4.2 First Flush Phenomena for Highways: How it can be Meaningfully Defined

Abstract: A new terminology and definition is proposed to document mass first flushes of storm water pollutants. This newly defined terminology is applied to 52 storms over two wet seasons at nine highway sites. Most pollutants showed median mass first flushes where 30 percent of the mass is released in the first 20% of the runoff. Pollutants representing organic contaminants had the highest first flush ratios. [25]

4.4.3 First Flush Storm Water from Highway

Abstract: Storm water is now receiving attention from regulatory agencies and has become an important component in watershed planning. In many cases, pollutant mass emissions from storm water exceed those from wastewater treatment plants. Land use has been identified as an important parameter in predicting storm water quality. Land uses associated with vehicular activity, such as parking lots, are thought to be high contributors of storm water pollutants. Other factors, such as greater pollutant concentrations or mass emissions at the onset of rainfall, usually called a “first flush,” or higher emissions from the first storm of the season, usually called a “seasonal first flush,” have been identified. In order to determine the magnitude of the first flush from freeway runoff, three sites in the west Los Angeles area were sampled for 14 storms during the 1999-2000 rainy seasons. Samples were collected very early in the storm in order to compare water quality from the first runoff to water quality from the middle of the storm. A large range of water quality parameters and metals were analyzed. The data show large first flushes in concentration profiles and moderate first flushes in mass emission rates. [26]

5 METHODOLOGY

The purpose of this section is to explain the various methods used to complete this research effort. This included the development and identification of a test site, as well as the collection and analyses of highway storm water runoff samples.

5.1 Experimental Site Characteristics

The location of the experimental site used for this study was at the intersection of the Interstate-10 and Interstate-610, Orleans Parish, New Orleans, Louisiana. The sampling location was constructed beneath the Interstate-610 eastbound lane and is a designated NPDES Phase II region. The I-610 elevated roadway has three eastbound lanes of Portland Cement Concrete (PCC). This highway carries an average daily traffic load (ADT) of 40,000 vehicles per day. The mean annual precipitation at the experimental site is 1572 mm/yr, with the highest monthly rainfall in July and August, of 156 mm each month. The specific draining 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 (Figure 3). The area beneath the elevated highway has been made ready for the establishment of the experimentation station. This included the cleaning of sufficient area for the construction of the experiment station, installation of electrical cables, connection to a generator, lighting and finally making the facility secure by the installation of a fence off area (Figure 4). The process of the site preparation also required the construction of a small concrete dam to prevent surface runoff from the surrounding environment during collection (Figure 5).

The direct discharge of the storm water runoff into the 17th Street Canal is representative of the heavily traveled elevated sections of major arterial highways that are typical of south Louisiana's elevated infrastructure.

Figure 1: View of the Experimental Site and Manhole.

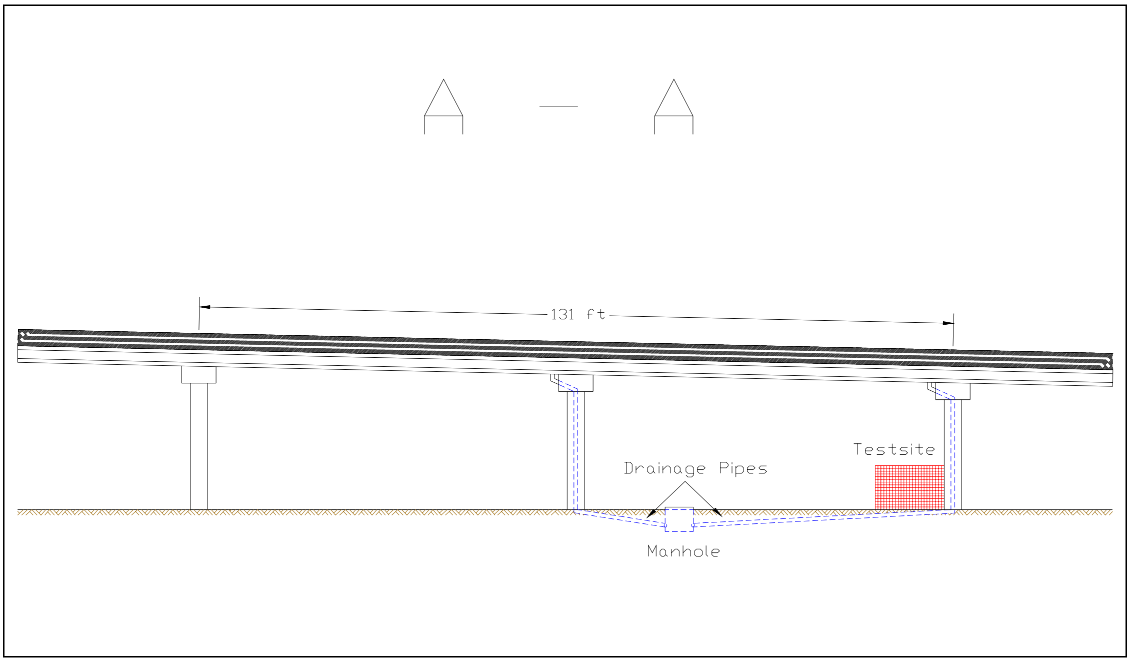

Figure 2: Section Through the Selected I-610 Highway Section at Experimental Site.

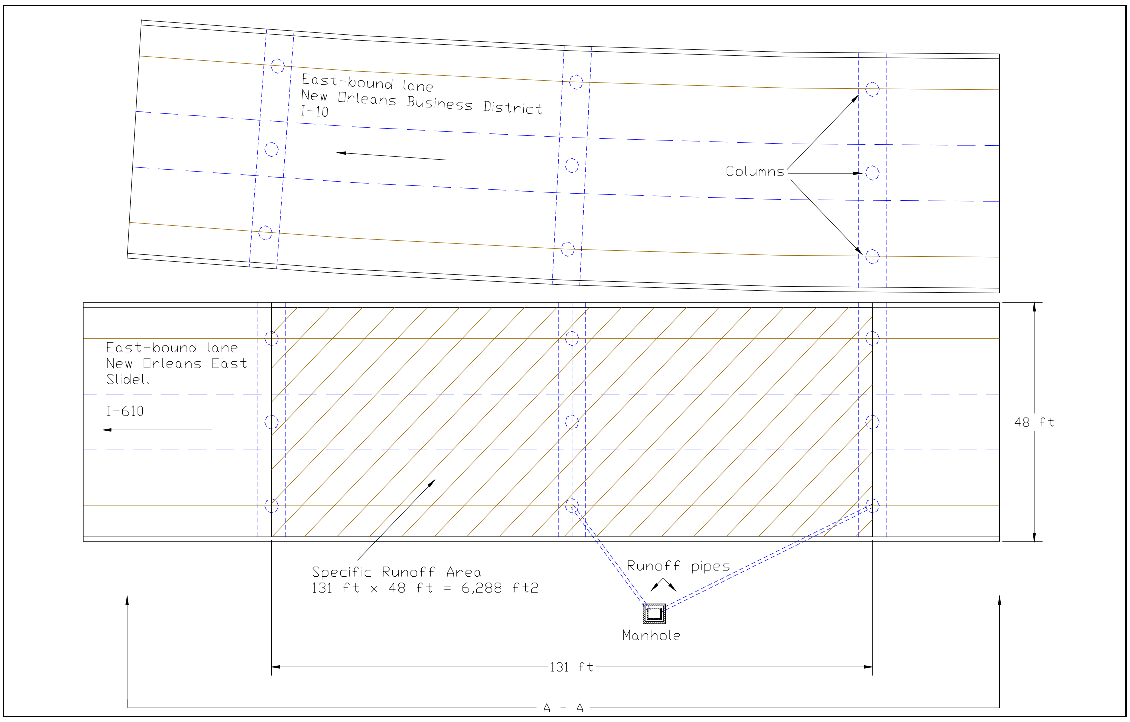

Figure 3: Plan View of the Specific Drainage Area (6,288 ft2) of the Selected Highway Section of Interstate-610 in Orleans Parish, New Orleans, Louisiana.

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.

5.2 Meteorological Information and Traffic Counts

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

5.2.1 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 the 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.

The used 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.

5.2.2 Traffic Count

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 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.

5.3 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 was transported to the manhole through 2 drainpipes, where the collection was carried out using two 5-gallon-buckets. These buckets were marked with a liter scale in order to obtain the collection volume and were rinsed out with clean water before any collection. In addition the collection time was recorded to be able to determine the runoff flow rate. Subsequently, the collected highway runoff was mixed together and filled into clean polypropylene sample bottles. Discrete fully labeled (date, sample number and time at which it was collected) 1-liter samples were collected from the time of the first flow of storm water runoff coming out of the drainpipes (defined as time 0) to the collection of 10 to 15 runoff samples, or the end of the particular storm event. Depending on the intensity of the storm and the associated runoff flow, samples were collected every 2 to 5 minutes. In event periods of 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 until the completion of the particular rainfall runoff sample amount. Volumetric flow rates were taken 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 eleven discrete events throughout the course of the study from which hydrologic and water quality data were collected. However, only samples from 10 runoff events were analyzed for dissolved heavy metals.

5.4 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 is performed to ensure that measurements or aliquots 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 re-stated in this section of this dissertation. The author has only listed any deviation from, or specific modifications to the recognized Standard Methods used. The reader is referred to the "APHA Standard Methods for the Examination of Water and Wastewater" [27] if further detailed review of each of these procedures is necessary.

5.4.1 Field Measurements

Upon the collection of any storm water sample, field data analysis was performed immediately at the experimental site. In sequence of the cessation of the storm water runoff collection, the samples were transported to the environmental engineering laboratory at the University of New Orleans for further analysis. The water quality parameters measured immediately at the test site were the following:

- Temperature (^{o}C)
- pH (s.u.) (APHA Standard Method 4500-H+B)
- Redox potential (+mv) (APHA Standard Method 2580 B)
- Conductivity (mS/cm) (APHA Standard Method 2510)

All devices were calibrated prior to every storm event.

Portable measuring equipment (Orion 290-A+) with a silver/silver chloride (Ag/AgCl) combination electrode was used to measure reduction/oxidation potential, temperature and pH. 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.

Furthermore, 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.

5.4.2 Laboratory Analyses

In sequence of 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. Laboratory procedures that were performed are:

- Acid preservation of 15-mL aliquot for heavy metal analysis
- Dissolved heavy metal analysis using an ICP-AES
- Suspended and Dissolved Solids (APHA Standard Methods 2540-D and 2540-E)
- Chemical Oxygen Demand (COD) (APHA Standard Method 5220 (1992)).

5.4.2.1 Dissolved Heavy Metal Analysis and Sample Preservation

All samples were collected and cooled immediately after collection and transported to the environmental laboratory at the University of New Orleans for analysis.

Metal element portioning between the dissolved and particulate-bonded phases in storm water runoff is a dynamic process. The dissolved phase is defined as metal elements that pass through a 0.45-mm cellulose acetate membrane filter. All filters were pre-washed to insure freedom from contamination. The filter device was pre-conditioned by rinsing it with de-ionized water. The dissolved phase filtrate was acid preserved in 15-ml polystyrene flasks to less then pH 2 with trace metal grade HNO_3 in accordance with APHA Standard Methods 3010-B. [27] For the first 4 rainfall runoff events, the preserved samples were sent to the environmental laboratory at Louisiana State University in Baton Rouge for dissolved heavy metal analyses. Dissolved heavy metal analyses for the remaining 7 events were performed in the chemistry department at the University of New Orleans, using an Inductively Coupled Plasma-Optical Emission

Spectrometer (ICP-OES) - Varian Vista MPX, in accordance with APHA Standard Method 3120-B. [27]

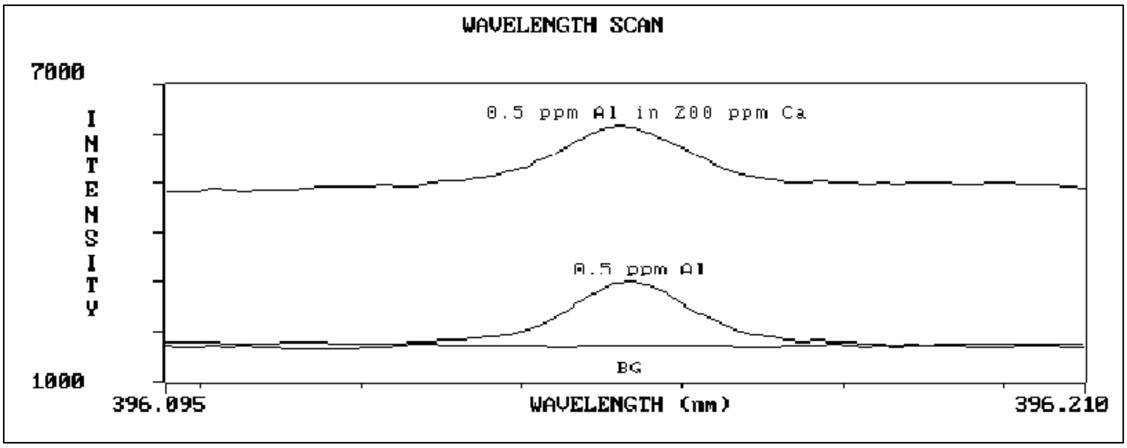

Figure 6: Example Diagram with Wavelength and Intensity of Al. [28]

Element	Wavelength [nm]	Instrument Detection Limit [mg/L]
Al	396.152	1
As	188.98	3
Cd	226.502	1
Cr	267.716	2
Cu	324.754	1
Fe	259.94	1
Mn	257.61	0.4
Ni	231.604	1
Pb	283.305	2
Zn	213.857	1

Table 2: Wavelengths Used for Each Element

Before starting heavy metal analysis it was necessary to prepare the computer program and to select the elements that had to be analyzed. The task here was to find a wavelength location, were elements had a high energy-intensity and possibly low interference with other elements. Every element was found at a certain wavelength and with certain intensity (Figure 6). Wavelengths for the analyzed heavy metals are shown in Table 2.

Subsequently the instrument had to be calibrated using multi-element standard solutions and a blank to give the device reference conditions. The blank and the standardized concentration were then used to generate a calibration line with energy intensity of the element as a function of its concentration.

After the ICP-OES was calibrated and the elements were selected the argon gas supply and the cooling system was activated. One hour later the test analysis was performed, analyzing samples with known concentrations to verify measuring precision. Furthermore, this test analysis was carried out after every 10 samples to guaranty accuracy of the analyses.

At that point, the instrument was ready for use and samples were analyzed for 10 different metal elements (Al, As, Cu, Cd, Cr, Fe, Mn, Ni, Pb, Zn). For the dissolved heavy metal analyses, three analyses were performed for every sample and the mean was used as sample concentration to minimize statistical errors. Furthermore, the sample supply tube was rinsed with distilled water after every analysis and a control sample with known concentration was analyzed after every 10 samples. All metal concentrations were automatically sent to the computer, were they were saved on the hard drive.

5.4.2.2 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. [27]

5.4.2.3 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 susceptible to oxidation by a strong chemical oxidant. For samples from a specific source, COD can be related empirically to Biochemical Oxygen Demand (BOD), organic carbon, or organic matter. The 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).

6 STORMWATER CHARACTERIZATION RESULTS AND DISCUSSION

In the following chapter all results of this research effort will be clearly documented and scientific important achievements will be stated.

6.1 General Characterization of "First Flush" of Roadways

The fundamental goal of this study was to characterize the "first flush" in storm water runoff from elevated roadways. In order to achieve this goal, it was necessary to get a clear understanding of the general behavior of storm water runoff.

6.1.1 Qualitative Characterization of "First Flush"

Direct highway storm water runoff discharges from elevated structures to surface receiving water are of particular concern, given the challenging conditions prevalent in the coastal regions, where inter-urban transportation infrastructures are frequently elevated over ecologically sensitive and economically significant water bodies. The issues of storm water mitigation and treatment from highways is further complicated by logistical site constrains of elevated highway structures and in particular those located over water. The majority of conventional treatment alternatives, such as infiltration systems, wet detention systems or filter systems, typically applied to the treatment of urban storm water runoff, are precluded from their direct application to elevated structures because of the highly prohibitive spatial limitations. Elevated structures do not have hard shoulders or vegetative strips to the side, where contaminants can undergo physical, chemical, and biological transformations or where they could be taken up by plants or animals, or adsorbed on clay particles. [3] Consequently, it is of particular importance to distinguish between storm water discharges from elevated roadways and runoff from highways situated over land. Storm water runoff from elevated roadways constitutes a direct pathway of contaminants to the surrounding receiving waters.

The quality of highway “first flush” storm water runoff is very difficult to characterize, because it is affected by so many uncontrollable factors, such as rainfall intensity, antecedent dry days, traffic, climatic effects, etc., which represent variables in this study. Especially the high variations and fluctuations of these factors between rainfall events or during one single event make it difficult to find significant correlations.

6.1.1.1 Contaminants Contained in Storm Water Runoff from Highways

Sediment is produced when soil particles are eroded from the land and transported to surface waters. The vegetation is removed and the soil is left exposed and will quickly be washed away in the next rain. Soil particles deposited on road surfaces are washed off and transported to receiving waters, where they settle out of the water or onto aquatic plants. This sediment prevents sunlight from reaching aquatic plants, clogs fish gills, chokes other organisms, and can smother fish spawning and nursery areas. Grass and shrub clippings and other organic wastes such as litter can also lead to unsightly and polluted waters. Organic substances such as oils and greases are leaked onto road surfaces from car and truck engines. Rain and snowmelt transport these pollutants directly to surface waters. [29]

Inorganic pollutants such as heavy metals adhere to sediment and are transported with it by wind and water. These pollutants degrade water quality and can harm aquatic life by interfering with photosynthesis, respiration, growth, and reproduction. Heavy metals come from some "natural" sources such as minerals in rocks, vegetation, sand, and salt. But they also come from car and truck exhaust, worn tires and engine parts, brake linings, weathered paint, and rust. Heavy metals are toxic to aquatic life and can potentially contaminate ground water. [38]

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. In addition, a number of common highway maintenance practices, such as salting, cleaning, painting, the use of fertilizers, pesticides and herbicides, 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. [39]

6.1.1.2 Effects of Highway Runoff

Some of the factors that determine the extent and importance of highway runoff effects are 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. 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, which are the primary source for the bioaccumulation 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 from highway runoff has not been thoroughly investigated, although studies have documented higher concentrations of metals in fish and other aquatic biota living near highways.

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. [15]

6.1.2 Quantitative Characteristics of Highway Runoff

Another very important aspect of this particular research is the quantitative identification of the contaminants associated with highway runoff.

6.1.2.1 Build-Up and Wash-Off of Pollutants on Urban Watersheds

In the past, many investigations have been performed to identify main controlling factors in regulating the load of heavy metals washed off from urban areas, such as elevated highways. 1972 Sartor and Boyd concluded that the quantity of materials existing on the urban street was dependent on the length of the time elapsed since the last rain. 1992 Jarvis suggested that the highway pollutant wash off was generally assumed to be a function of the amount of pollutant on the highway surface at the time on the storm and the rainfall intensity. 1975 Shaheen pointed out that the accumulation of contaminants on street surfaces results from two basic processes: deposition and removal. The removal of pollutants consists of two kinds of mechanisms: removal by wind or vehicles and removal by storm water. Therefore, the contaminant load on an urban catchments area could be determined using the balance of these processes. [25]

The buildup process usually occurs during non-rainfall periods. The buildup process requires that the contaminants deposited on the catchments surface be larger than the ones removed. The pollutant load is then accumulated with time in the area. The theory assumes that pollutant deposition occurs at a constant rate, and that pollutant removal is at a constant ratio of contaminants available in the area. Therefore, with increasing time, pollutant deposition and removal are equal, and the accumulation process stops. The pollutant load is said to have reached its maximum limit, or so called “loading capacity” of that catchments (Jarvis, 1992). [25]

The wash off process happens during rainfall, when the surface runoff carries the sediment accumulated on the catchment’s impervious surface to the storm sewer or manhole. During rainfall, pollutant removal is greater than pollutant accumulation in the catchments area, which means that contaminants are washed off the surface and discharged into receiving waters.

The cycling of pollutants in the urban catchments can then be expressed in terms of continuous buildup and wash off processes, i.e. the available contaminant load in the catchments after a long period of accumulation will be the initial condition of the wash off process (Figure 7). [25]

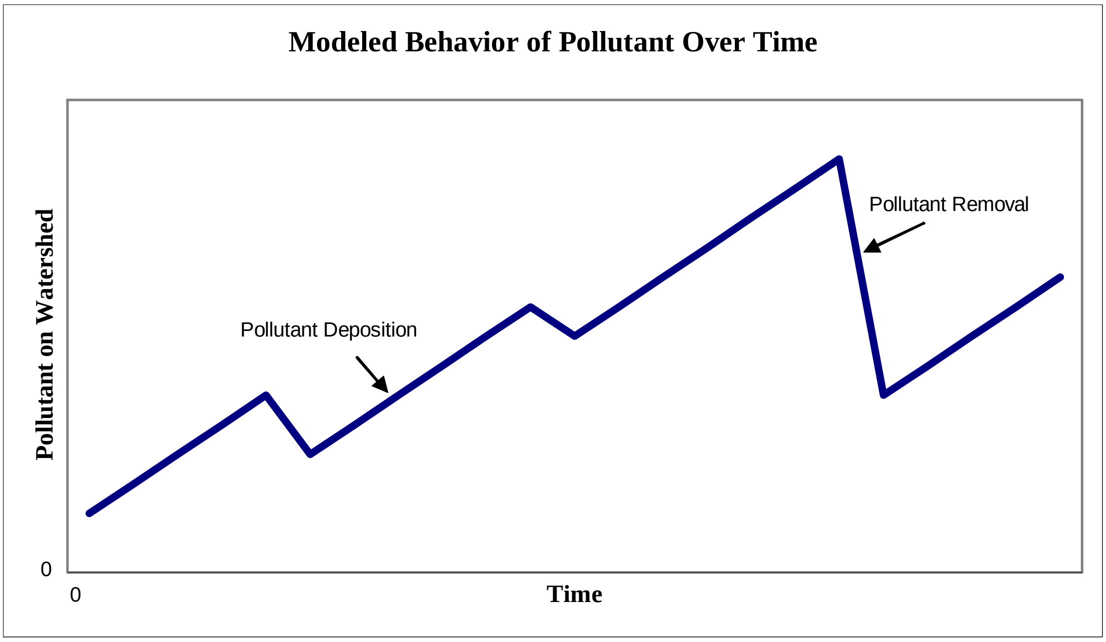

Figure 7: Modeled Behavior of Pollutant Over Time [32]

Climate is also a very important factor and should be taken into account. Very high intensity rainfalls allow for the possibility that, at times, the wash off capacity of a given storm may exceed the amount of pollutant that has accumulated on the surface. Thus, the process will be supply limited [25]. Further explanation about this specific topic is given in the following chapters.

6.1.2.2 High-Flow and Low-Flow Storm Events

During this research effort it became evident that the data from the analyzed storm events did not show uniform behavior or correlation. A total of fourteen storm events were analyzed. The type of rainfall event, however, depends on the actual season.

In general, in southeastern Louisiana there are two types of rainfall events. During the fall and winter rainfalls are generally strait form with low rainfall intensity and generally without thunderstorms but with a quite long duration.

During the spring- and summer months rainfall is usually convective which is a torrential rainfall accompanied by thunder, high rainfall intensities and short duration. Seven of the analyzed storms occurred within spring and summer months (between March 20 and September 23) and seven of them occurred during fall and winter months (between September 23 and March 20).

While evaluating the data of all storm events an important observation could be made, all analyzed storm events could mainly be divided into two major categories which than showed uniform behavior in the concentration of pollutants. One category of storm events included all events with high runoff flow intensity while the other category contained all events with low runoff flow intensity (Figure 8 - Figure 10). The high flow rainfalls were due to convective storm events while the low flow rain events were due to strait form storm events.

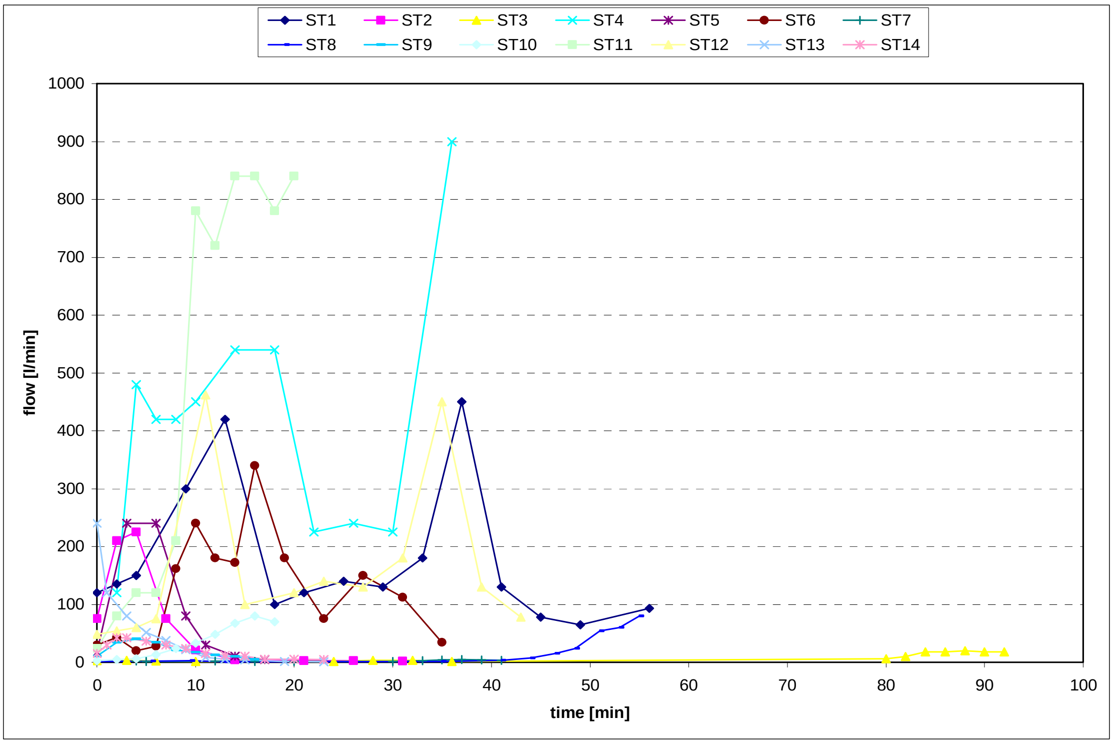

Figure 8: Flow-Intensity Diagram for All Storm Events

Figure 8 shows the difference in intensity between high flow data and low flow data. The huge difference in runoff intensity has an enormous impact on the rate at which contaminants are washed off the roadways. When dividing the data set into these two categories and evaluating the performed analysis, better correlation between the single storm events can be observed. Therefore all collected storm events were split into high flow data and low flow data and further examined. Figure 9 and Figure 10 illustrate the different categories.

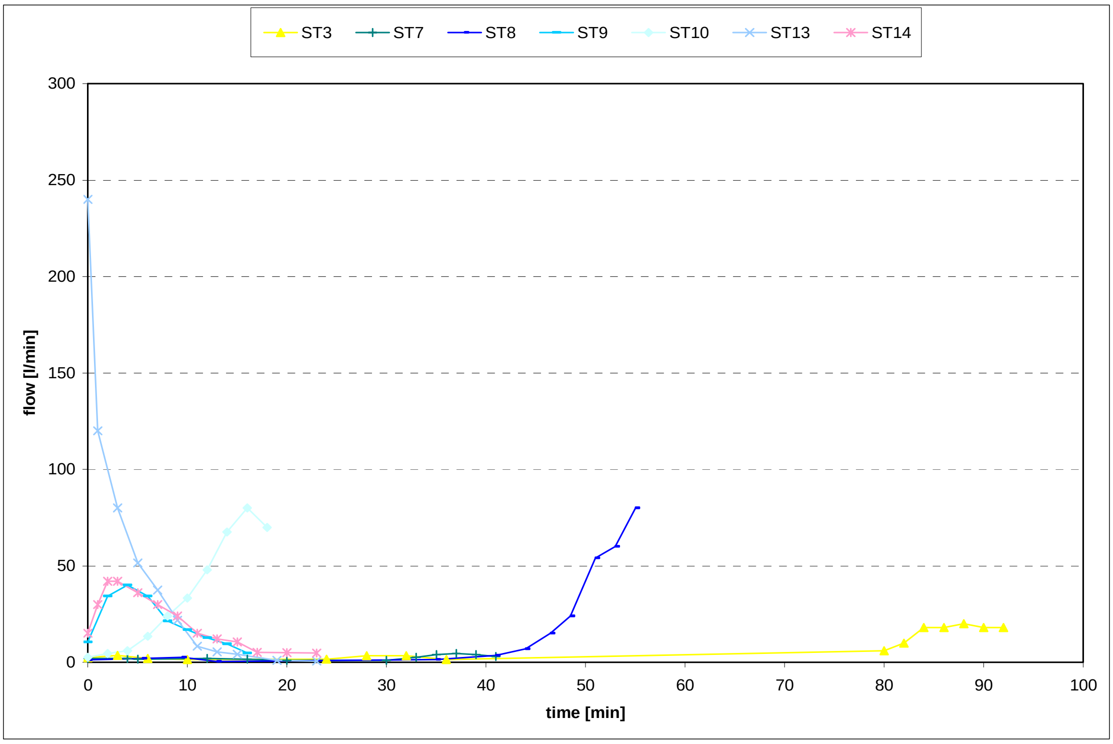

Figure 9: Low Flow Intensity Diagram

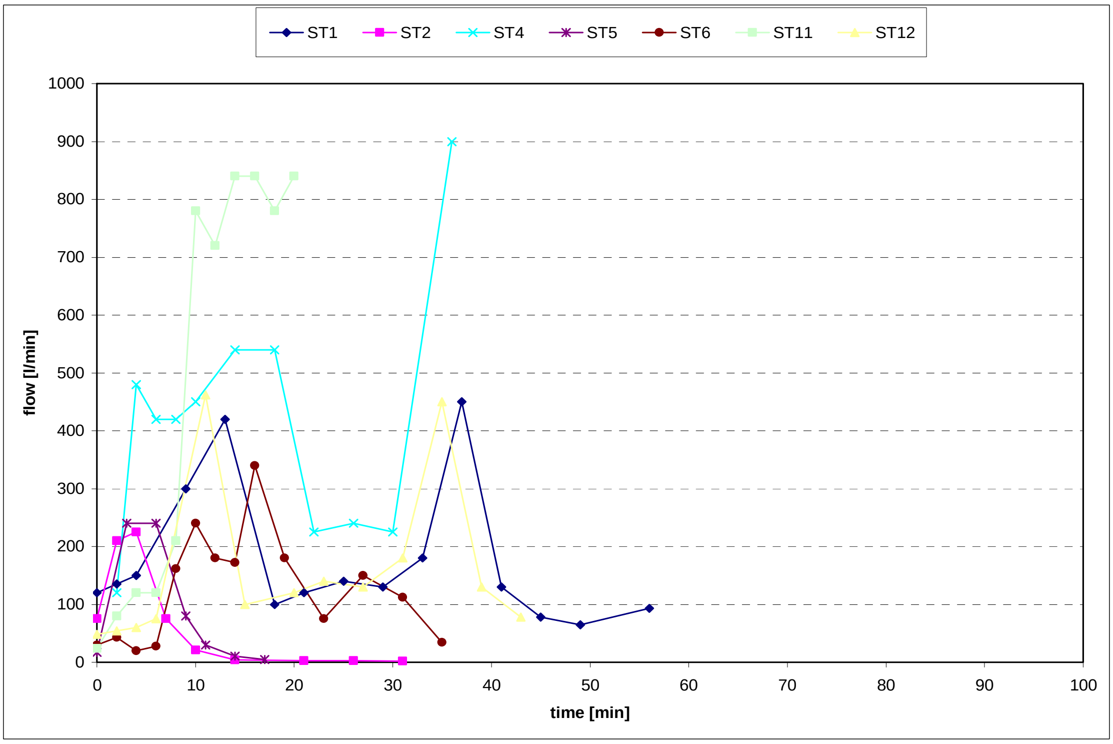

Figure 10: High Flow Intensity Diagram

The category for low flow intensity includes the storm events: ST3, ST7, ST8, ST9, ST10, ST13, ST14 while ST1, ST2, ST4, ST5, ST6, ST11, ST12 are considered as high flow intensity storm events. From Figure 9 and Figure 10 it can be observed that the low flow intensity storm events have maximal runoff intensities below 100 l/min (except at the beginning of ST13). The storm events included in the high flow category show a runoff intensity which is most of the time significantly above 100 l/min. In this research the threshold level between the two runoff intensity categories was set to 100 l/min.

Not only the flow intensity but also the accumulative runoff volume differs significantly between the two storm event categories as it can be observed in Figure 11 - Figure 13.

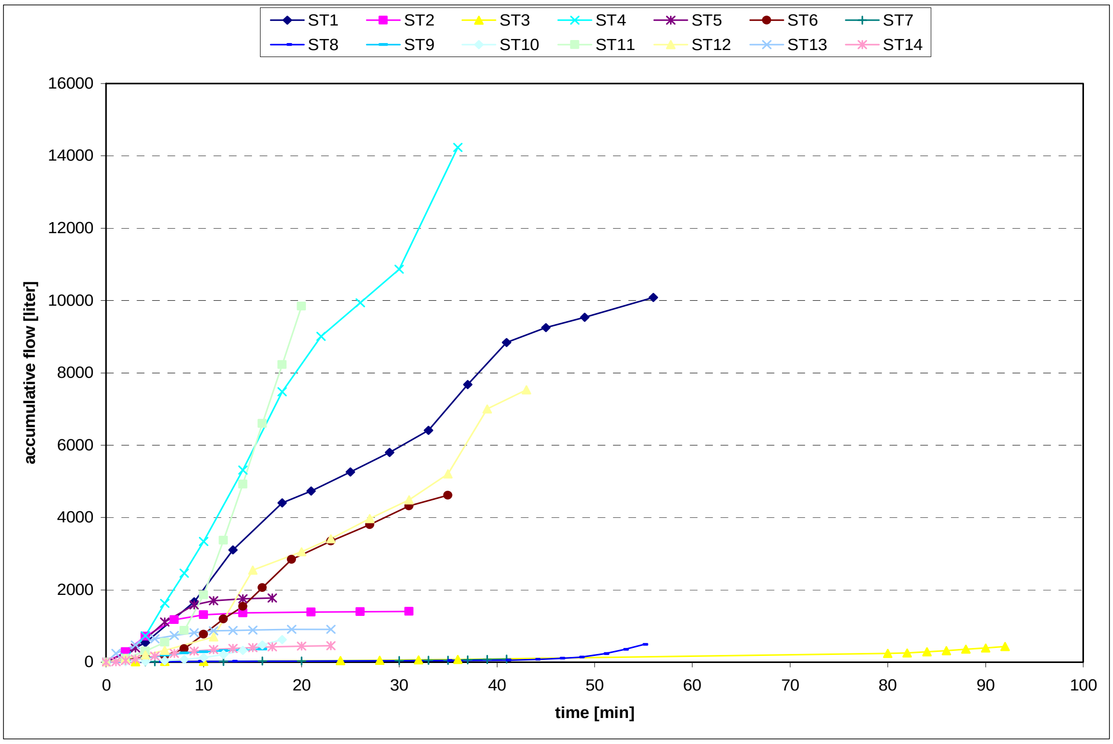

Figure 11: Accumulative Runoff Flow Diagram for All Storm Events

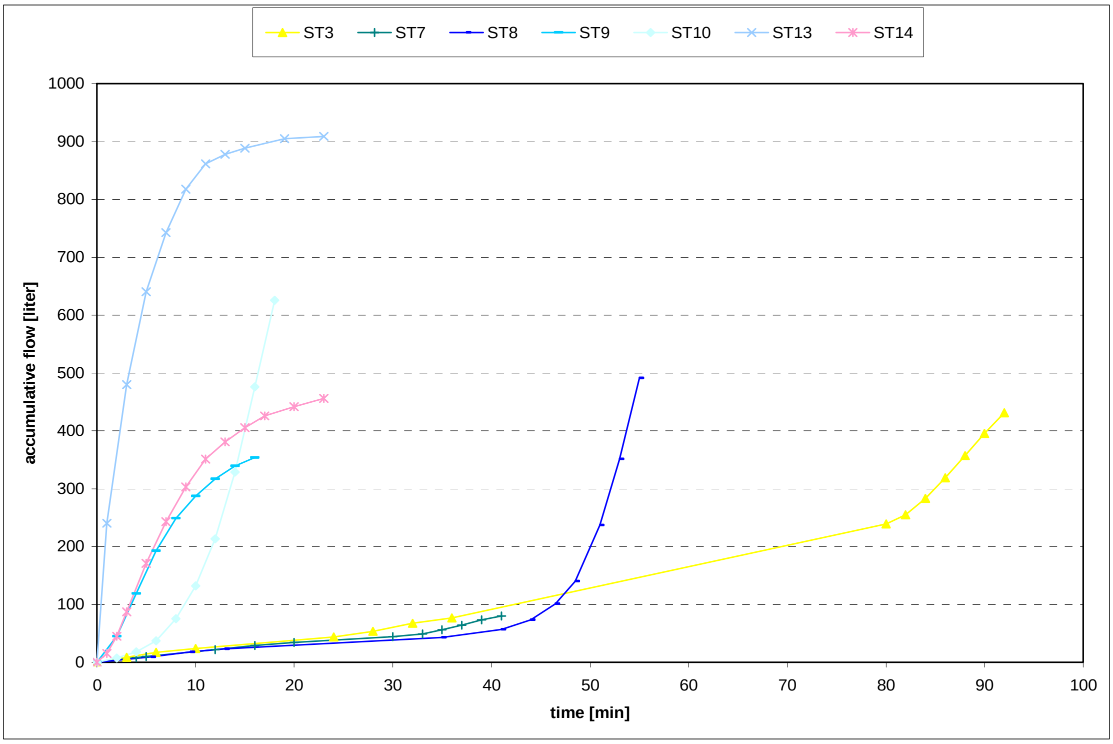

Figure 12: Accumulative Runoff Flow Diagram for Low Flow Storm Events

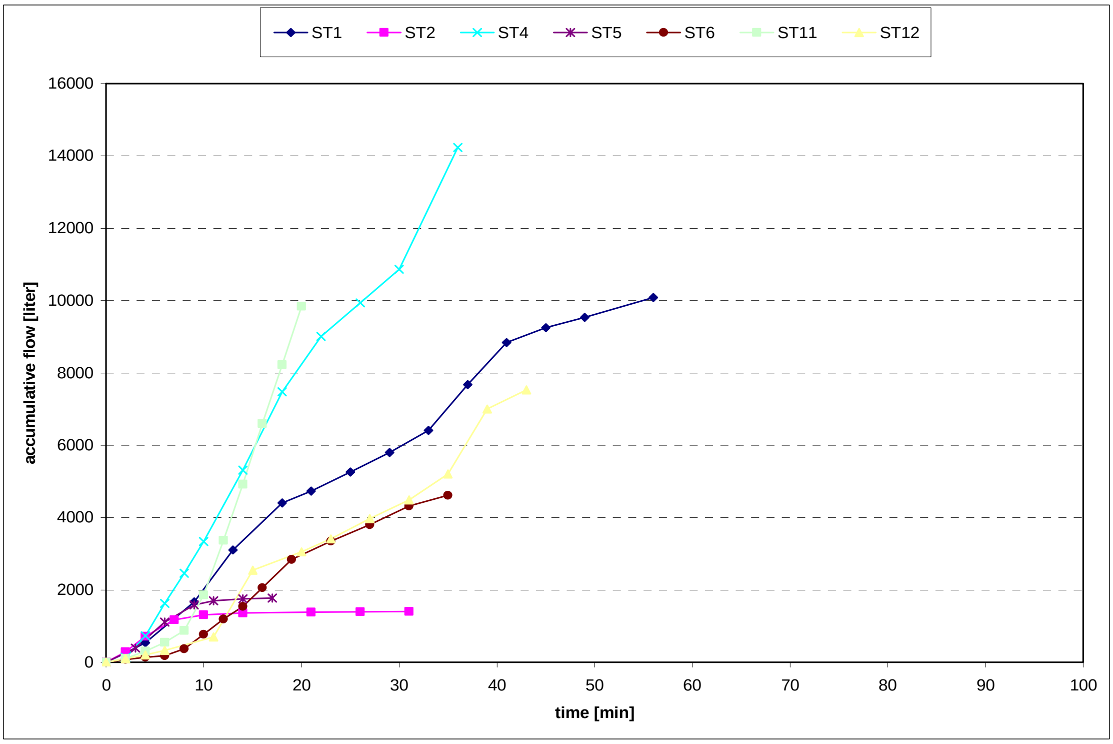

Figure 13: Accumulative Runoff Flow Diagram for High Flow Storm Events

The low flow storm events also have a low total runoff volume discharged from the highway at the end of the storm event. As it can be observed (Figure 11 - Figure 13), the total runoff volume is lower than 1,000 l for the entire storm event (inclusive of ST13). The total volume ranges from 350 to 910 l for this category. On the other hand the high flow data has a total runoff volume significantly higher than 1,000 l. The total runoff volume ranges from 1,400 to 14,200 l. Therefore, not only the runoff flow intensity but also the total runoff volume can be used to assign a single storm event to the two categories.

For this research the entire data set was observed for all storm events as well as for the two categories individually (high flow and low flow storm events).

6.1.3 Hydrological Characterization of "First Flush"

At the beginning of precipitation, and if precipitation remains light, little or no runoff is occurs. Heavy traffic on the roadway creates small airborne droplets that readily evaporate. As precipitation continues and becomes intense, water collects and runs off the highway lanes. The time from the start of observable rainfall at the site to the first generation of runoff at the point of collection for each event is referred as to initial pavement residence time. This time is a direct indication of the time required for the rainfall to wet the pavement surface and to fill any surface depression storage volume. The higher the intensity of the rainfall becomes, the higher the hydraulic wash-off force is going to be. The contaminant load transported off the roadway into swales, drainpipes, receiving waters, etc., depends on that hydraulic force together with other effects. Factors, such as slope and size of drainage area, as well as pavement surface properties represent “site-specific” characteristics and constitute an important disadvantage in constructing representative mathematical models for the prediction of contaminant loadings, applicable to different locations. 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. It has also been reported that the type of collection and conveyance system for highway runoff, such as storm sewer, grassy swale etc., has greater effect on runoff quality than pavement type [15].

6.2 Identification of Primary Variables Associated with Highway “First Flush” Storm Water Runoff

A very important step in this particular study was to identify variables that greatly affect quality and quantity of highway “first flush” storm water. During this research storm water runoff samples were analyzed for a variety of pollutant parameters. In this document only dissolved heavy metal-, TSS-, and COD- concentrations and hydrological variables were included and investigated. To understand the behavior of storm water runoff quality, it is of fundamental importance to know which factors show strong correlations between each other. Initially the raw data set contained 17 different variables, which are shown in Table 3.

Other factors, such as yearly traffic flow, pavement type, drain pipe material, size of drainage area, slope of drainage area, etc., were not taken into consideration because the data were collected at one specific site and thus constant for all events.

	Variables	Units
1	Antecedent Dry Hours	[hours]
2	Observed Rainfall Duration	[minutes]
3	Observed Runoff Duration	[minutes]
4	Runoff Flow Rate	[liters/minute]
5	Runoff Volume	[liters]
6	Al	[microgram/liter]
7	Cr	[microgram/liter]
8	Mn	[microgram/liter]
9	Fe	[microgram/liter]
10	Ni	[microgram/liter]
11	Cu	[microgram/liter]
12	Zn	[microgram/liter]
13	As	[microgram/liter]
14	Cd	[microgram/liter]
15	Pb	[microgram/liter]
16	TSS	[microgram/liter]
17	COD	[microgram/liter]

Table 3: Initial Variables

The analysis of dissolved heavy metals using an ICP-AES, showed detection limit problems with the elements arsenic (detection limit: 3 microgram per liter), cadmium (detection limit: 1 microgram per liter) and lead (detection limit: 2 microgram per liter). Since more than 70 % of all analyzed samples showed As, Cd and Pb concentrations lower than the detection limits, these three parameters could not be used for further analysis in this study.

The essential goal in identifying a general pattern of diverse rainfall runoff data is to find similar distributions of dissolved heavy metal-, TSS-, and COD-concentrations for all events versus different variables. To show the basic behavior of highway “first flush” storm water quality, it was necessary to construct diagrams including the concentrations of the dissolved heavy metal elements, the runoff flow intensity and the elapsed runoff time. Originally, a 3-dimensional scatter-plot was constructed to graphically investigate these graphs about significant patterns. However, because of the high variability of runoff intensity and the high fluctuations in dissolved heavy metal-, TSS-, and COD-concentrations during the observed runoff period, it was almost impossible to observe correlations between the three variables. Consequently, in order to get a clear picture of the interaction of these three variables and to reduce the diagram from a 3-dimenstional problem to a 2-dimensional graph, the runoff flow rate and the runoff time were combined to the discharged runoff volume. Following diagrams (Figure 14 - Figure 31) show the behavior of dissolved heavy metal-, TSS-, and COD-concentrations in storm water runoff from highways as a function of discharged runoff volume.

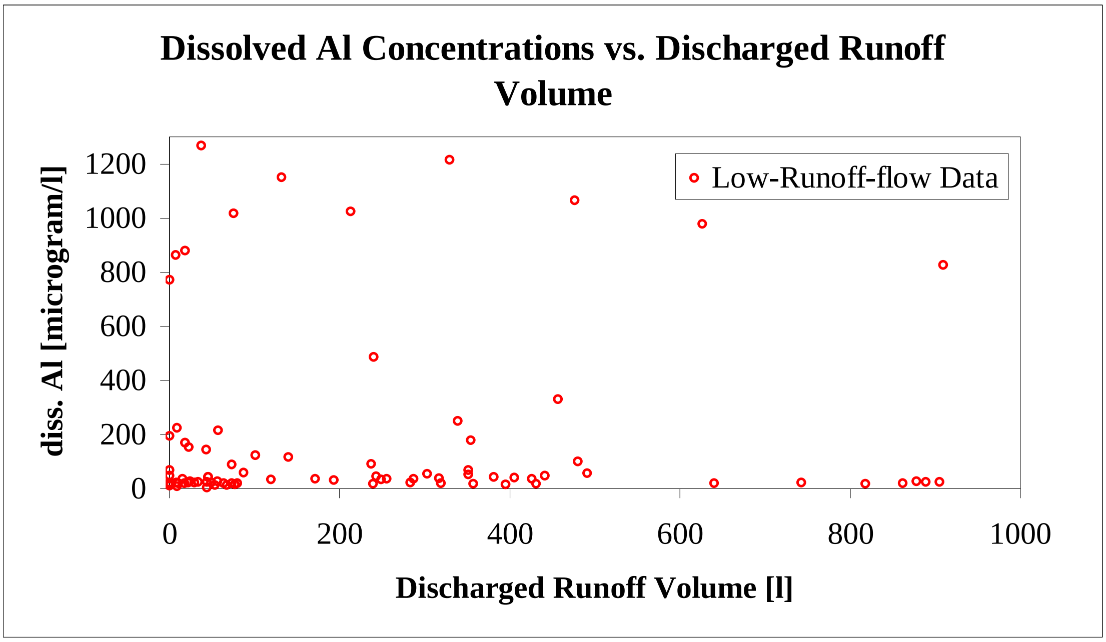

Figure 14: Low Runoff: Dissolved Al Concentrations vs. Discharged Runoff Volume

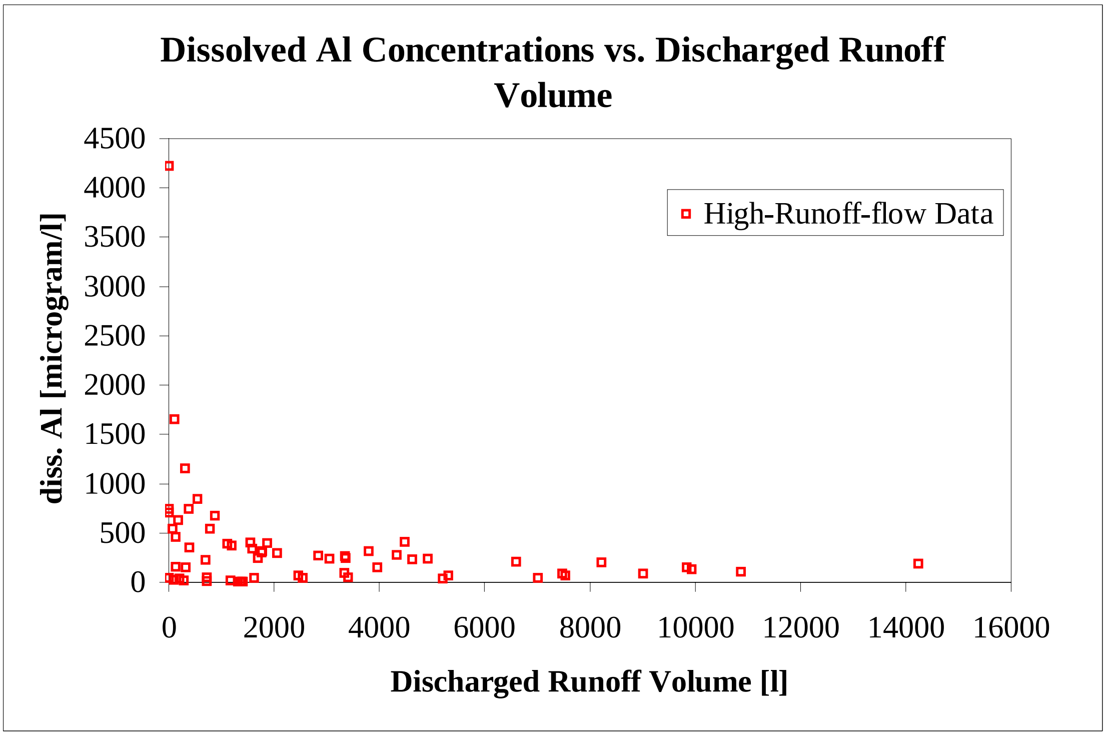

Figure 15: High Runoff: Dissolved Al Concentrations vs. Discharged Runoff Volume

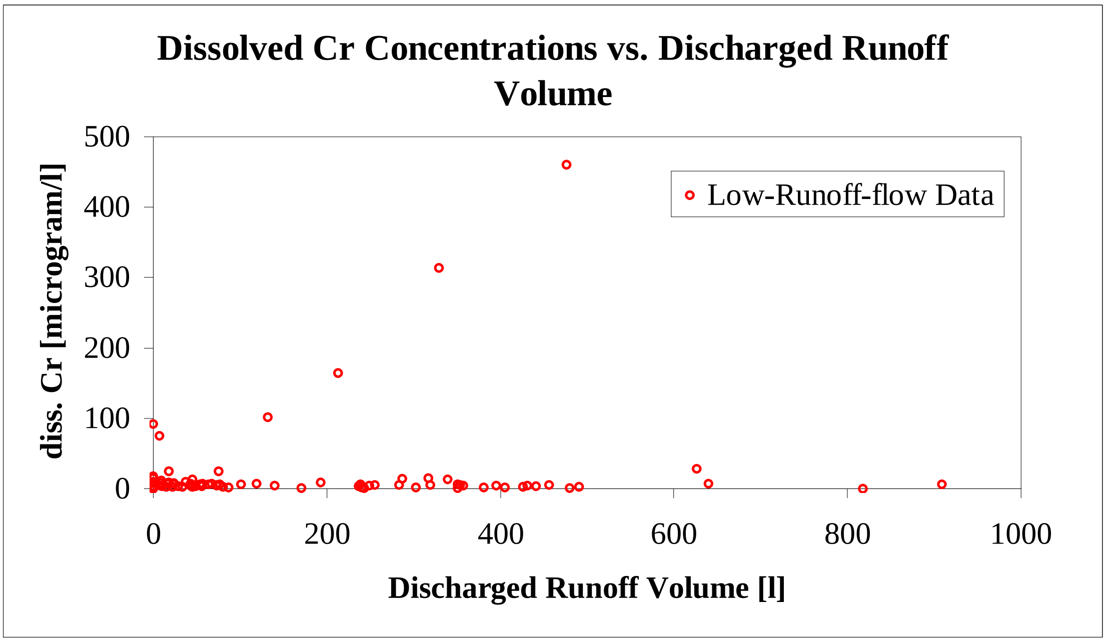

Figure 16: Low Runoff: Dissolved Cr Concentrations vs. Discharged Runoff Volume

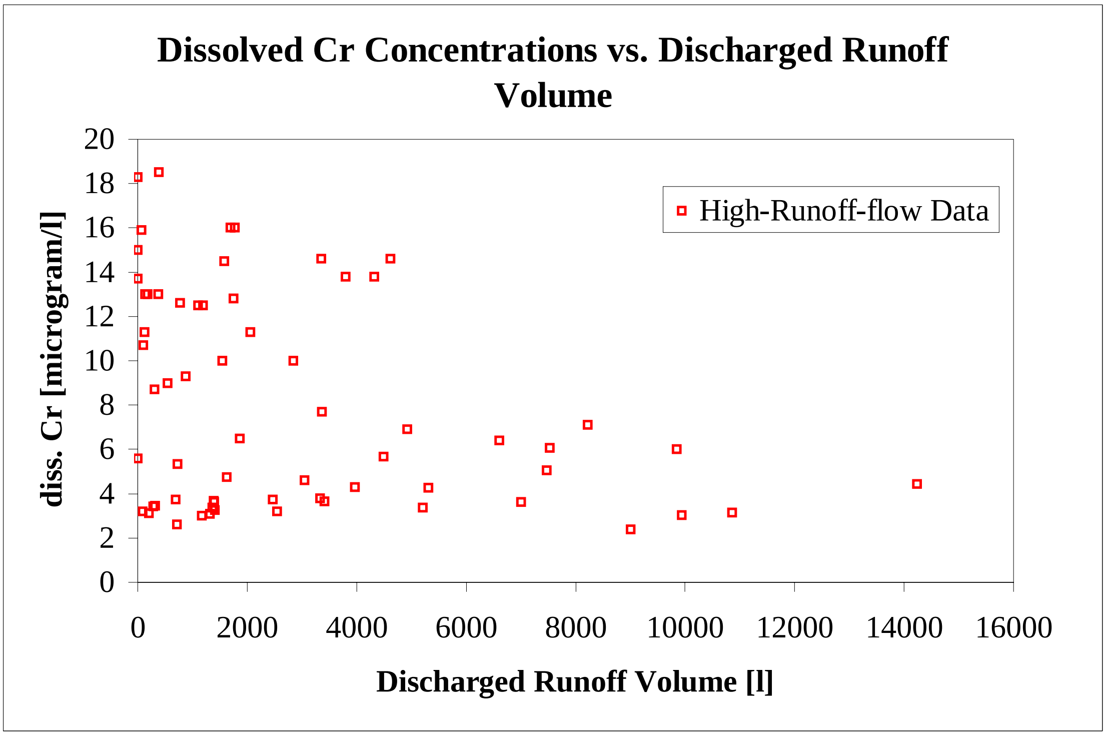

Figure 17: High Runoff: Dissolved Cr Concentrations vs. Discharged Runoff Volume

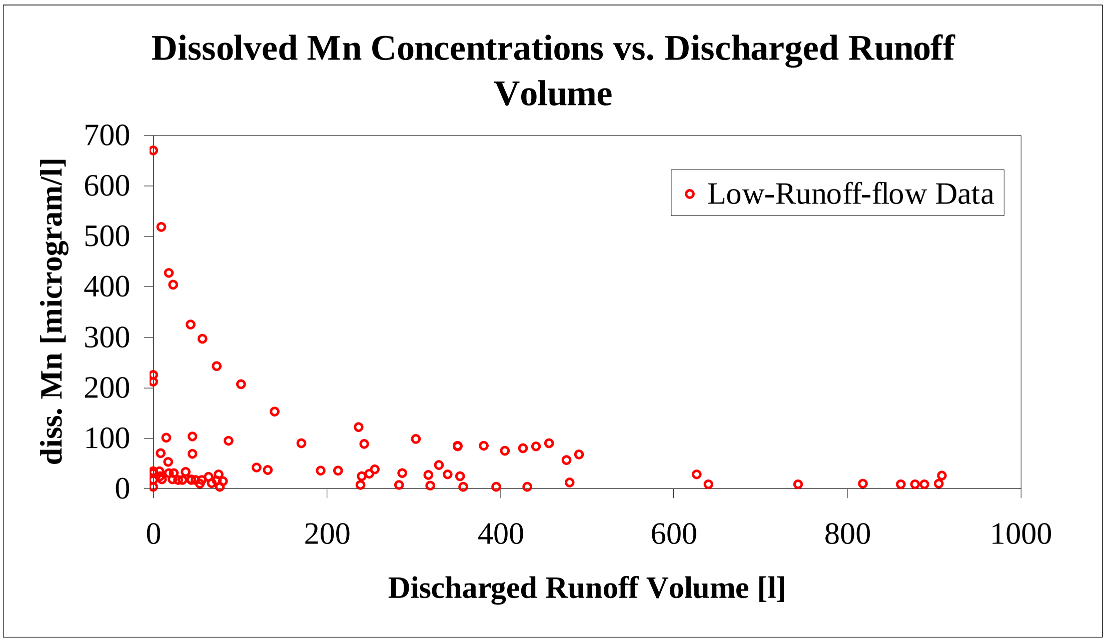

Figure 18: Low Runoff: Dissolved Mn Concentrations vs. Discharged Runoff Volume

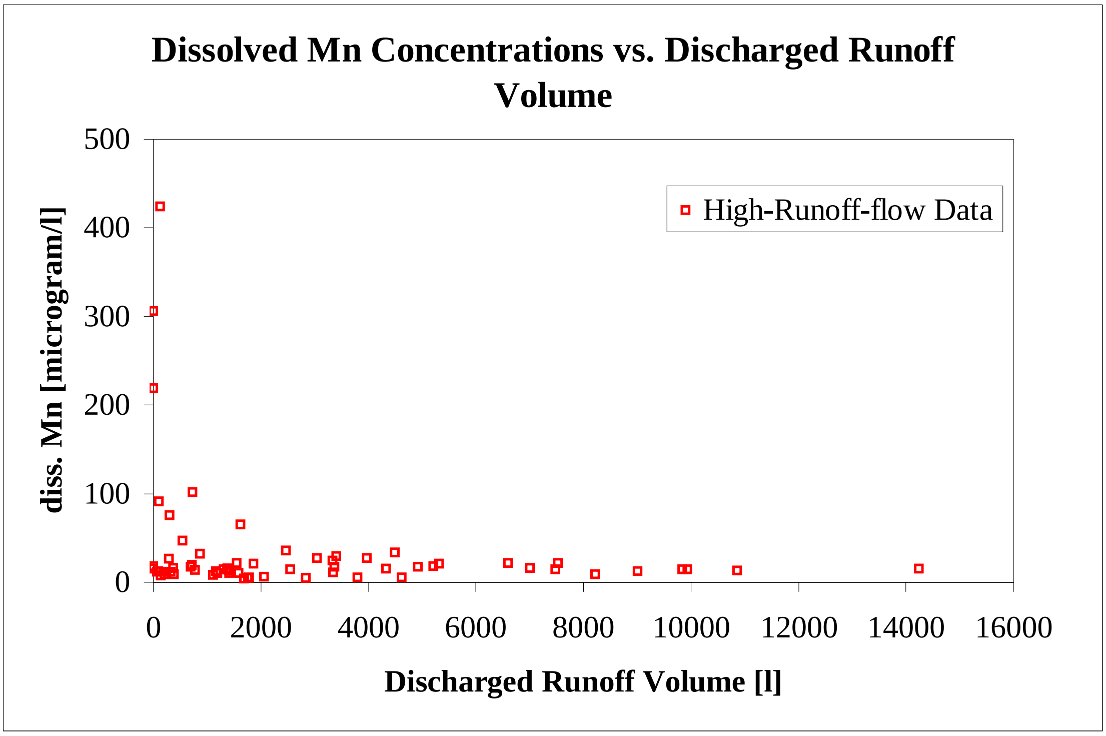

Figure 19: High Runoff: Dissolved Mn Concentrations vs. Discharged Runoff Volume

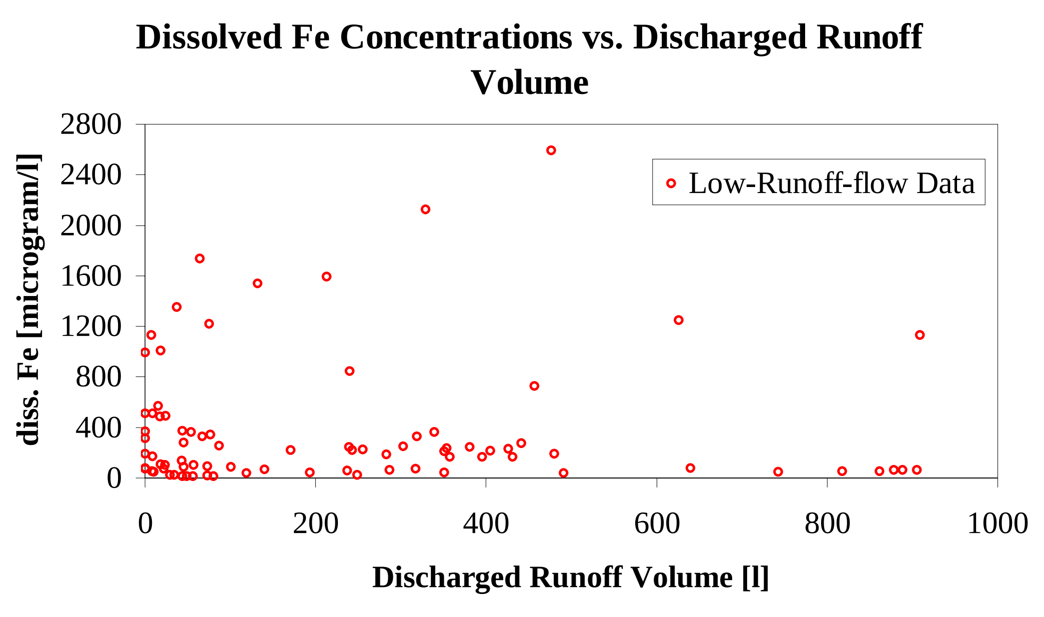

Figure 20: Low Runoff: Dissolved Fe Concentrations vs. Discharged Runoff Volume

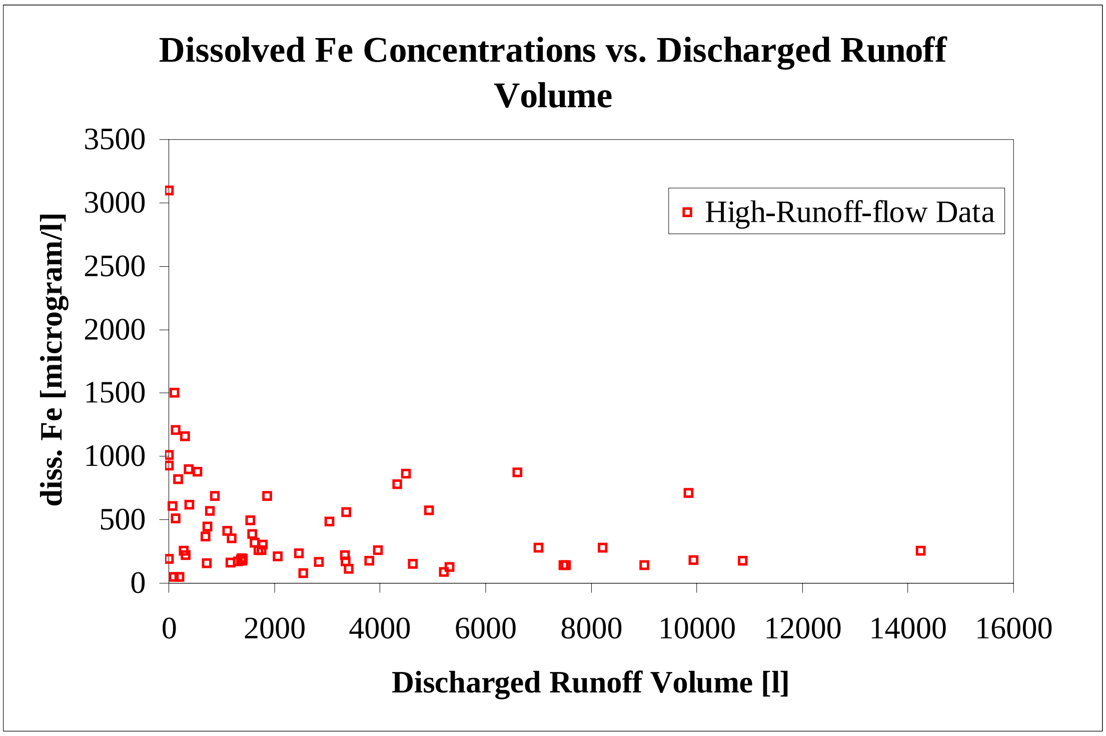

Figure 21: High Runoff: Dissolved Fe Concentrations vs. Discharged Runoff Volume

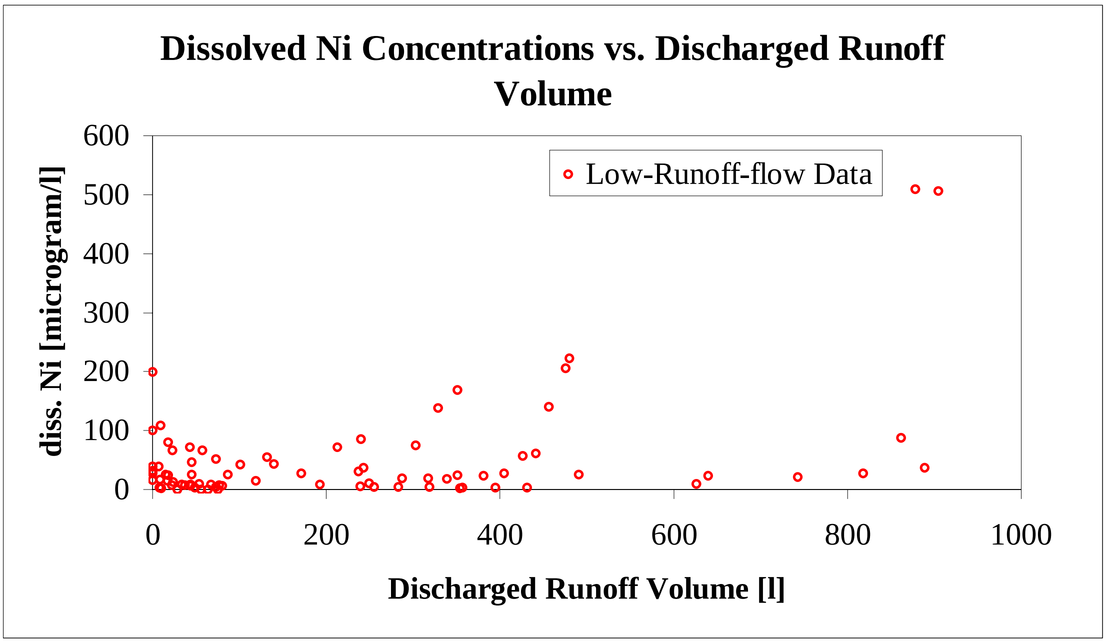

Figure 22: Low Runoff: Dissolved Ni Concentrations vs. Discharged Runoff Volume

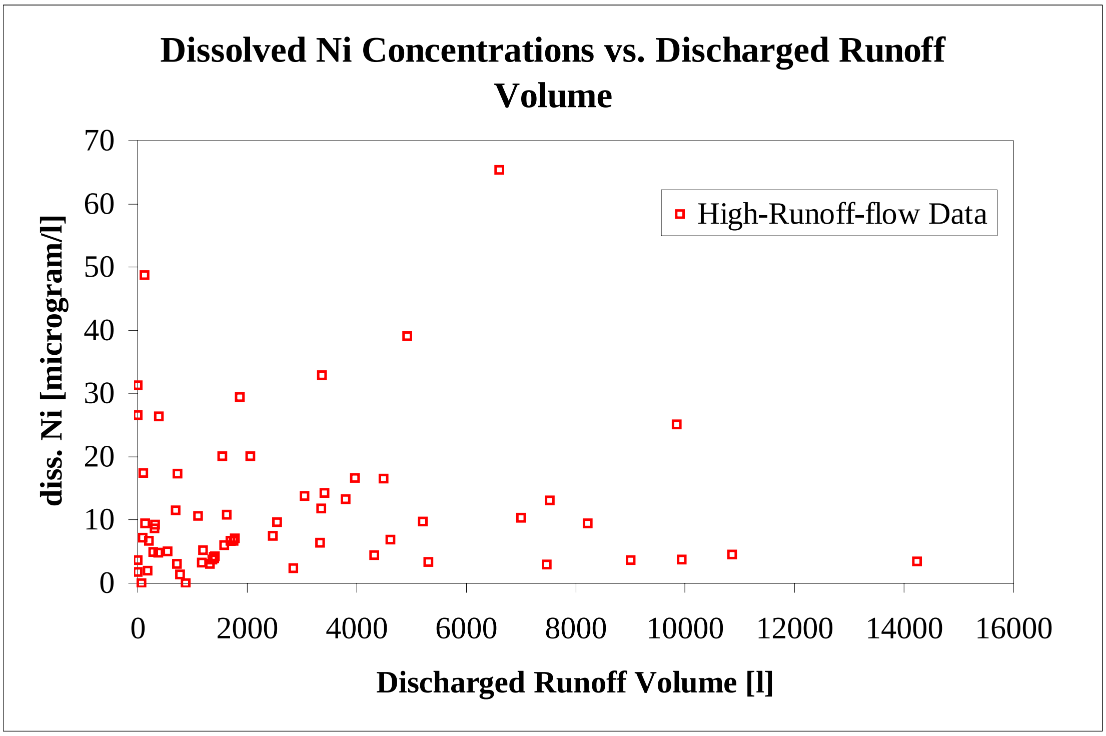

Figure 23: High Runoff: Dissolved Ni Concentrations vs. Discharged Runoff Volume

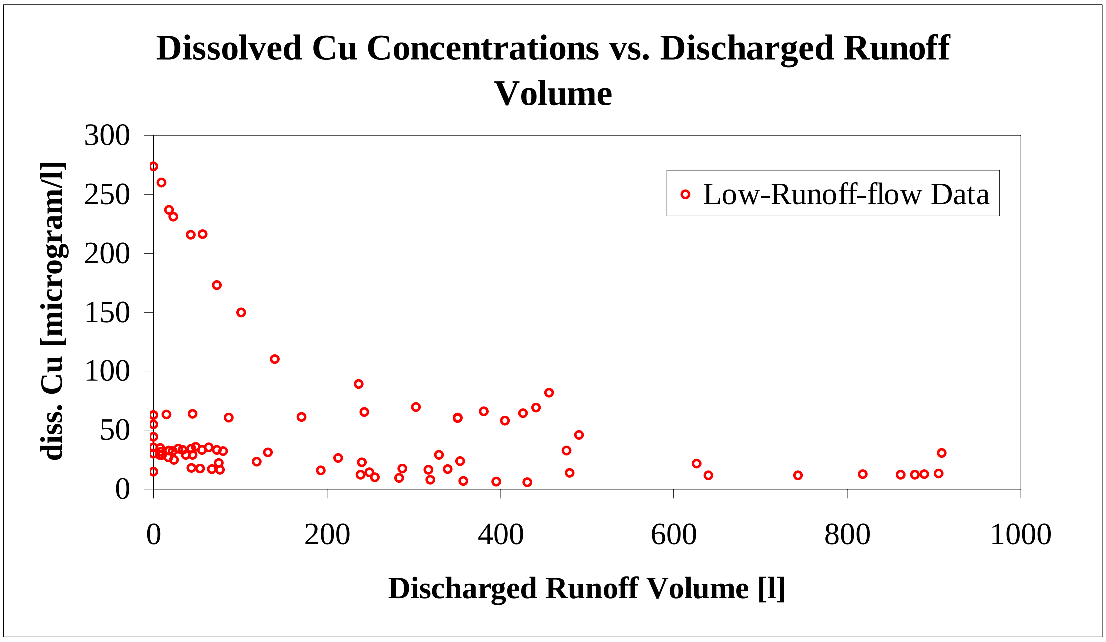

Figure 24: Low Runoff: Dissolved Cu Concentrations vs. Discharged Runoff Volume

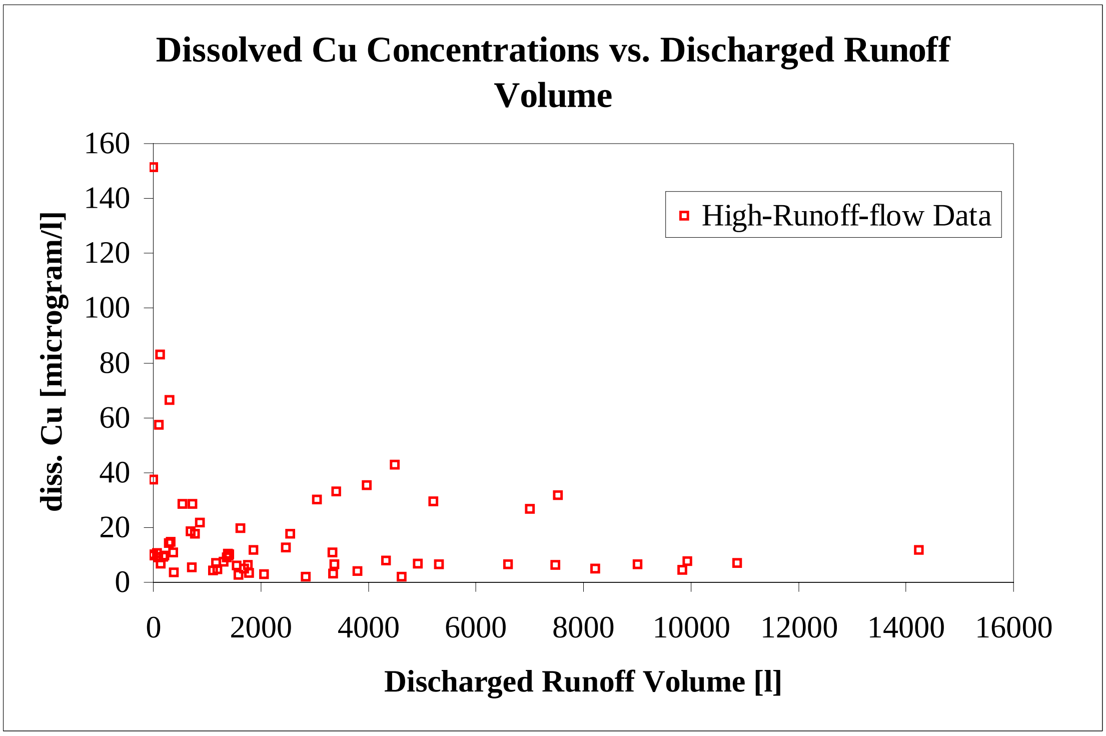

Figure 25: High Runoff: Dissolved Cu Concentrations vs. Discharged Runoff Volume

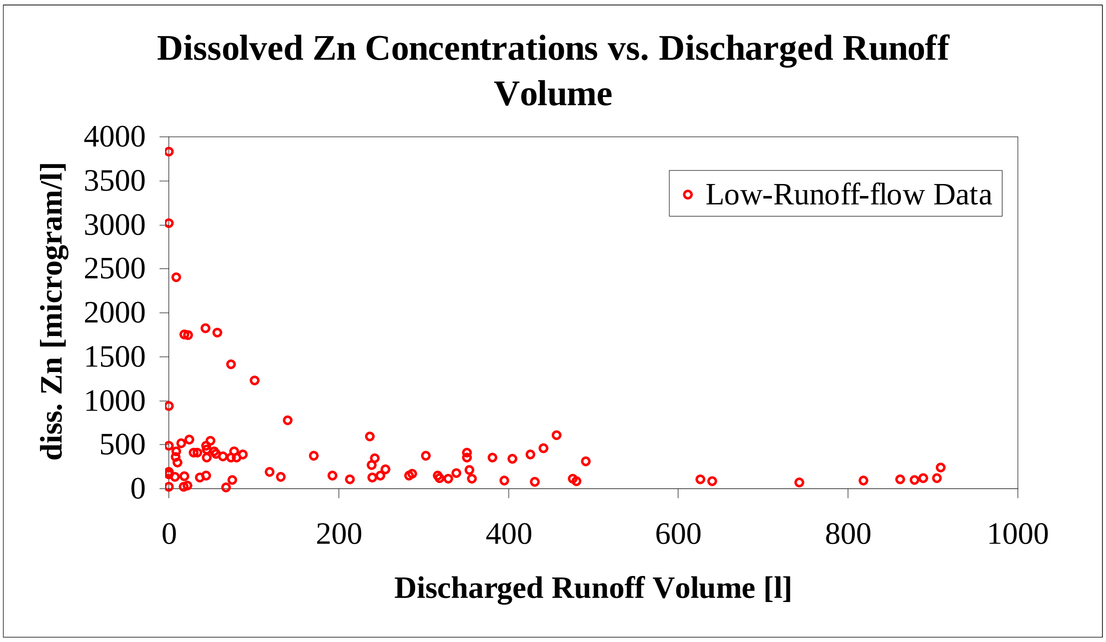

Figure 26: Low Runoff: Dissolved Zn Concentrations vs. Discharged Runoff Volume

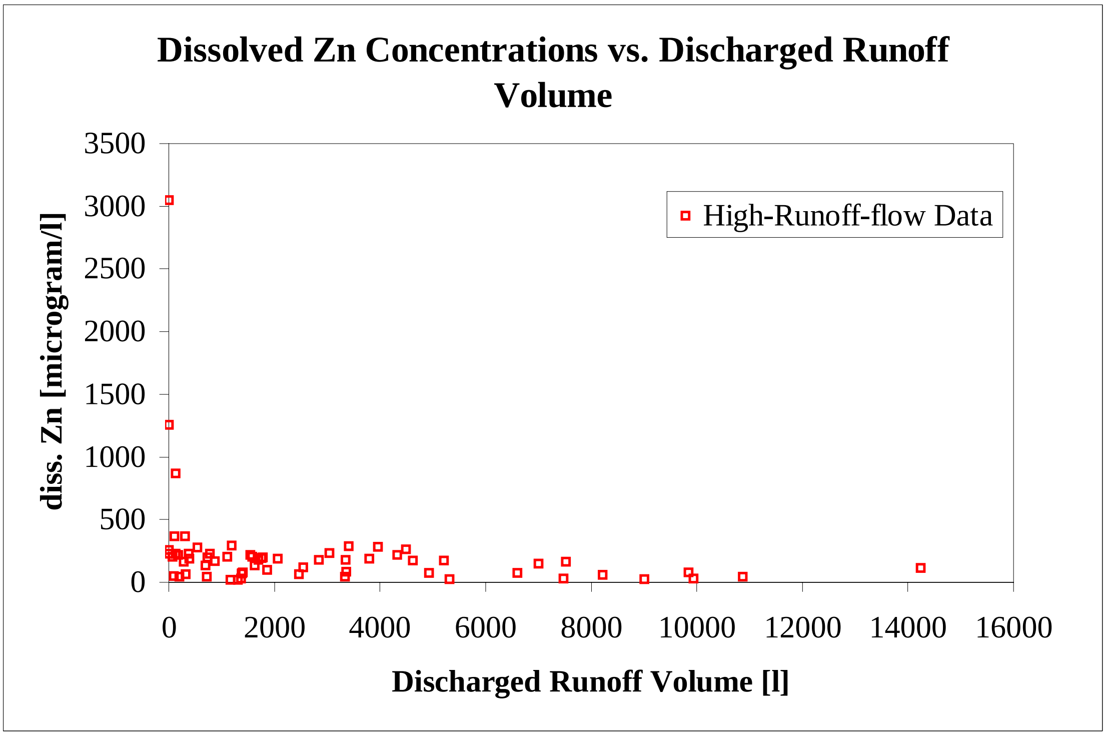

Figure 27: High Runoff: Dissolved Zn Concentrations vs. Discharged Runoff Volume

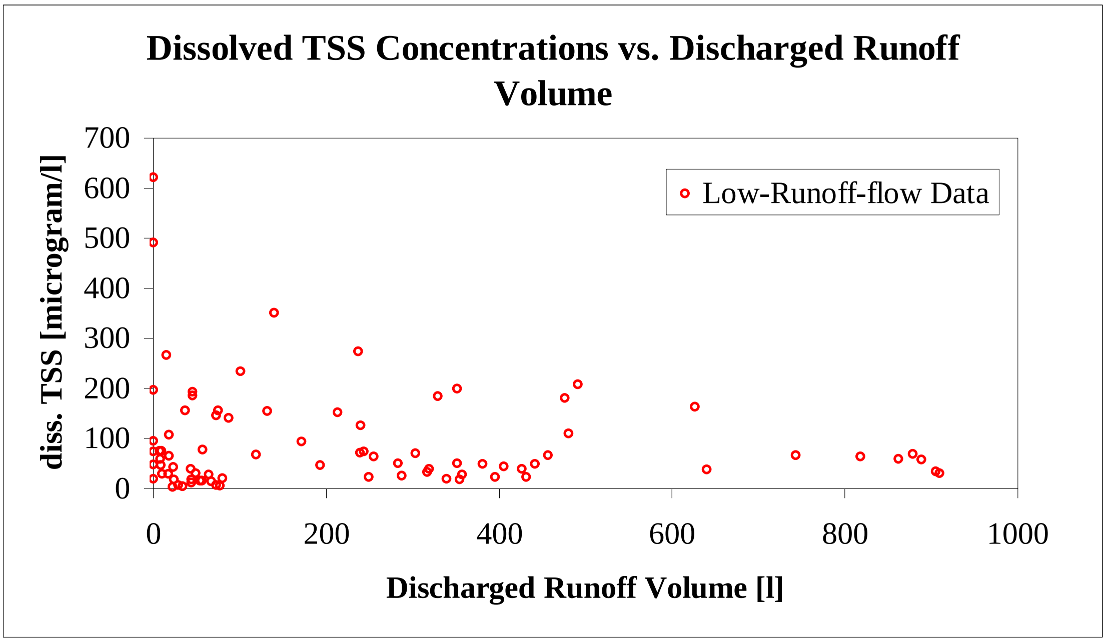

Figure 28: Low Runoff: Dissolved TSS Concentrations vs. Discharged Runoff Volume

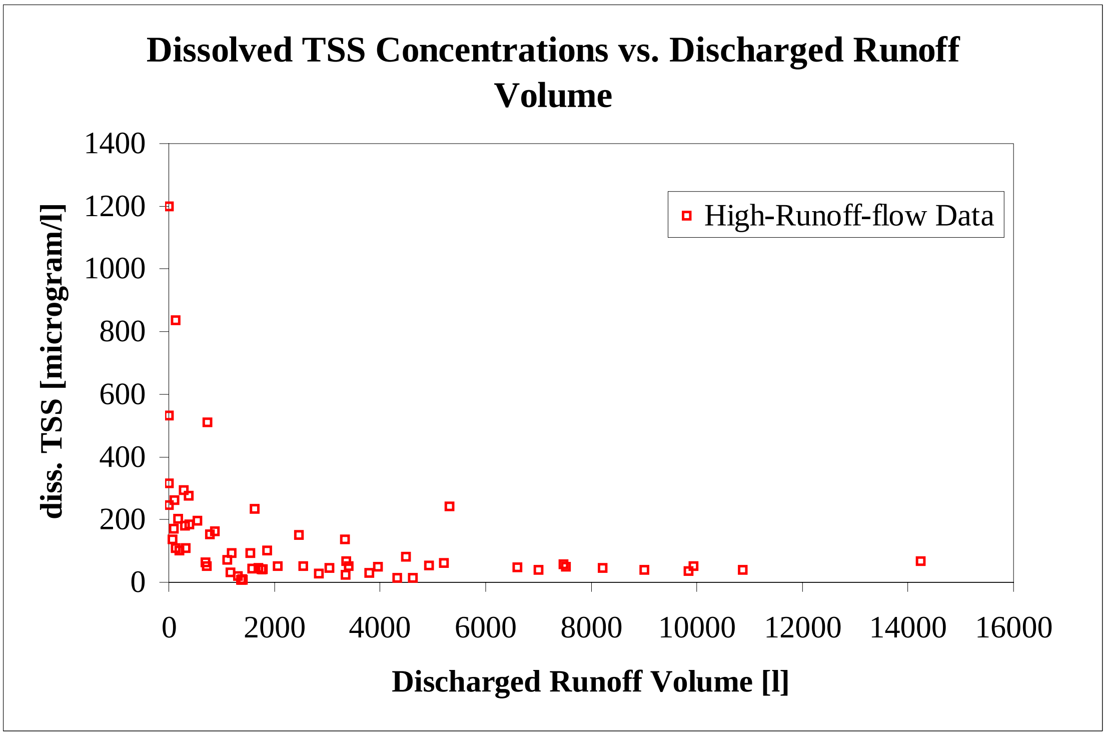

Figure 29: High Runoff: Dissolved TSS Concentrations vs. Discharged Runoff Volume

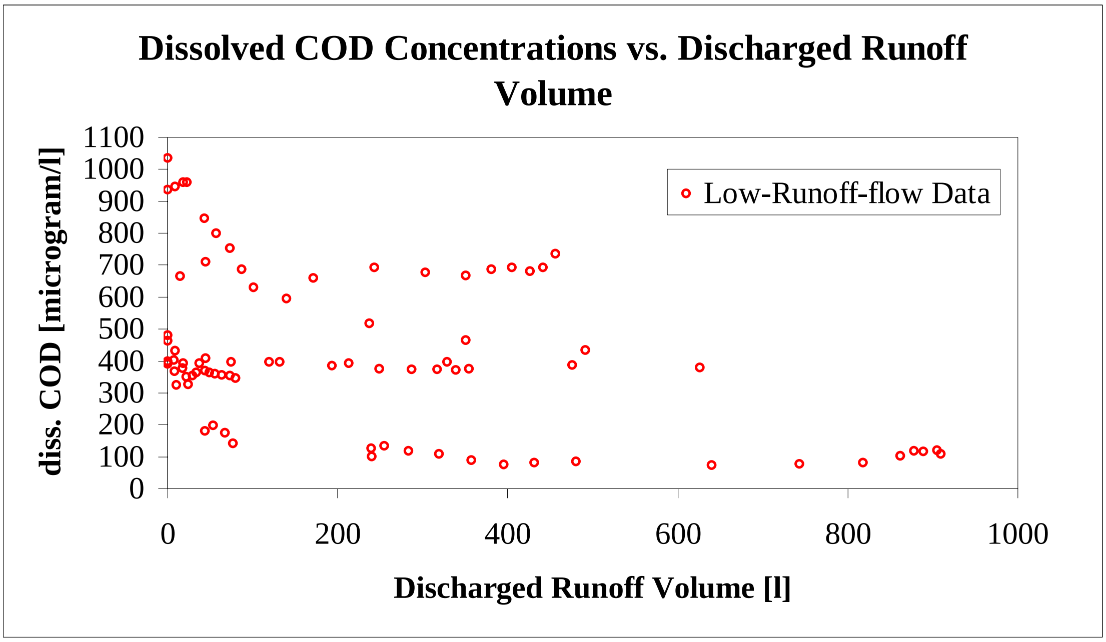

Figure 30: Low Runoff: Dissolved COD Concentrations vs. Discharged Runoff Volume

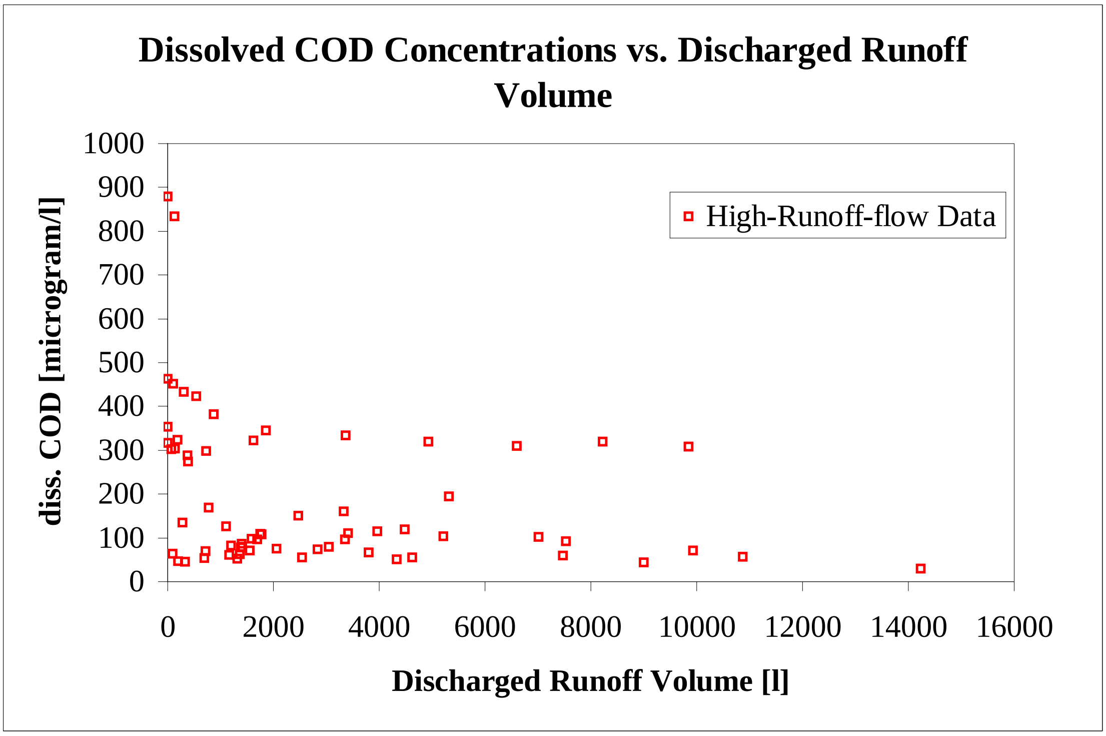

Figure 31: High Runoff: Dissolved COD Concentrations vs. Discharged Runoff Volume

The difference between high-runoff-flow data and low-runoff-flow data is evident after examining all diagrams.

High-runoff-flow data in most cases show a very fast decline in concentrations with elapsing discharge of runoff volume, which is due to the high hydraulic wash-off force and the high runoff flow rate; except Ni and a low decline in concentration of Cr. It is observable that the first fraction of the runoff volume contains most contaminants, whereas the latter part of the observed runoff duration shows much reduced dissolved concentrations.

The low-runoff-flow data points are all within the first fraction of the storm, because of the low storm water runoff volume discharged, and show almost the same distribution as the first part of high-runoff-flow data. This behavior is apparent looking at all dissolved heavy metal distributions except Al, Fe, and TSS, where the low-runoff-flow concentrations are significantly lower.

6.3 Occurrence of a "First Flush" Response Associated with Storm Water Runoff from Highways

The "first flush" effect" in storm water runoff discharged from elevated highways is a very complex phenomenon, which has been investigated by many researchers in the past and has been defined differently multiple times. In general, the "first flush" effect was defined as the first fraction of a storm water runoff event, during which the major portion of the contaminants are washed off the road surfaces. However, the issue in defining the "first flush" phenomenon is its identification as a specific and variable dependent characteristic. Furthermore, it is important to distinguish between concentration-based and mass-loading-based classifications of the “first flush” occurrence.

At the beginning of this particular investigation it was essential to analyze the constructed data set to find significant statistical patterns in order to be able to classify highway storm water runoff into a general characteristic behavior, which was performed in subchapter 6.2. That subchapter included the characterization of “first flush” in highway storm water and the determination of variables that primarily affect its quality. Because of the high fluctuations of dissolved heavy metal, TSS, and COD concentrations with increasing observed runoff time or runoff flow rate, the combination of volumetric flow rate and observed runoff time to one variable, the discharged runoff volume, was a very important step to facilitate the identification of the “first flush” phenomenon. The identification of storm water runoff as a volumetric characteristic was one of the fundamental findings in this study.

The principal factors in the treatment of contaminated water in general are the quantity and the qualitative characteristics of the water that has to be treated. Knowledge of these to factors is inevitable in order to be able to optimize treatment efficiencies and to minimize economic effects. In addition, spatial limitations for many applications, especially for elevated highway structures, require the determination of the amount of storm water runoff that is of environmental concern to possibly reduce the total treatment volume. Consequently, it is of fundamental importance to investigate and evaluate the gathered data with the goal to determine a potential portion of storm water runoff of each event that represents the runoff portion that has to be addressed in terms of water treatment.

All constructed scatter plots (Figure 14 - Figure 31) in the previous subchapter, where dissolved heavy metal-, TSS-, and COD-concentrations were plotted versus discharged runoff volume, exhibited approximately the same distribution, which was an essential discovery in this research. The general pattern of high dissolved heavy metal, TSS, and COD concentrations appearing within the first fraction of the runoff volume discharged followed by a strong decrease of these concentrations was the evidence of a concentration-based "first flush". Following histograms (Figure 32 - Figure 40) demonstrate the concentration-based "first flush" effect using 1000-liter-average-concentrations for each dissolved heavy metal element, TSS, and COD to reduce their high fluctuations.

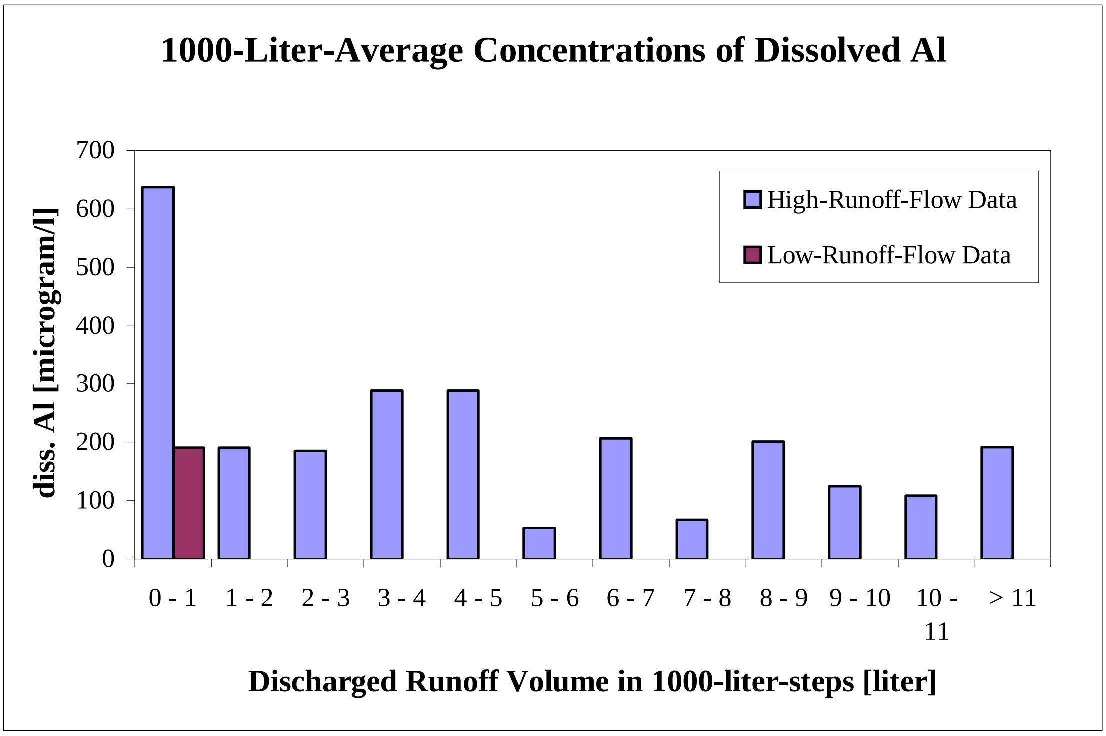

Figure 32: Concentration-Based “First Flush” for Dissolved Aluminum

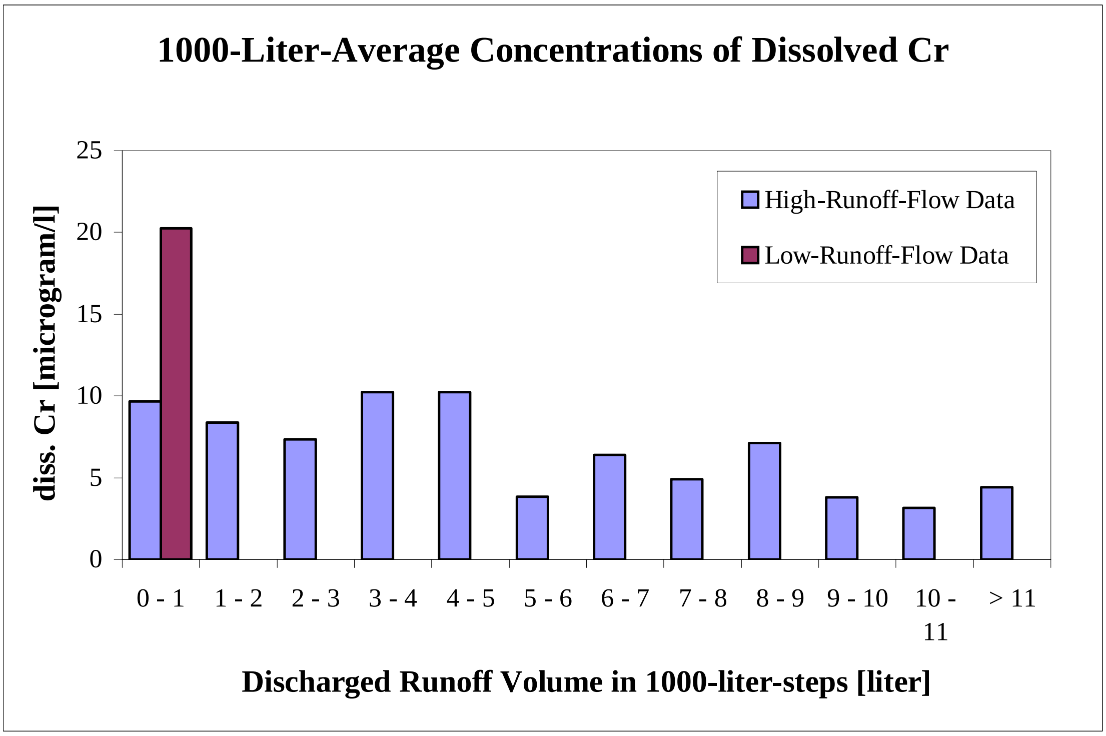

Figure 33: Concentration-Based “First Flush” for Dissolved Chromium

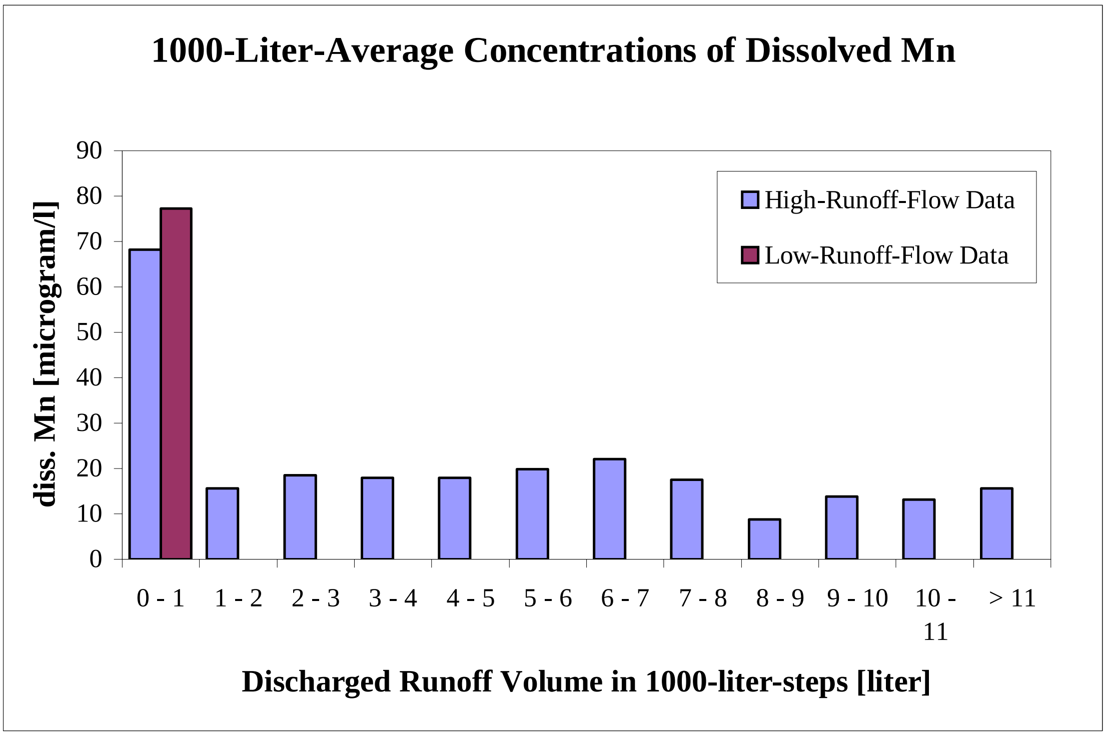

Figure 34: Concentration-Based “First Flush” for Dissolved Manganese

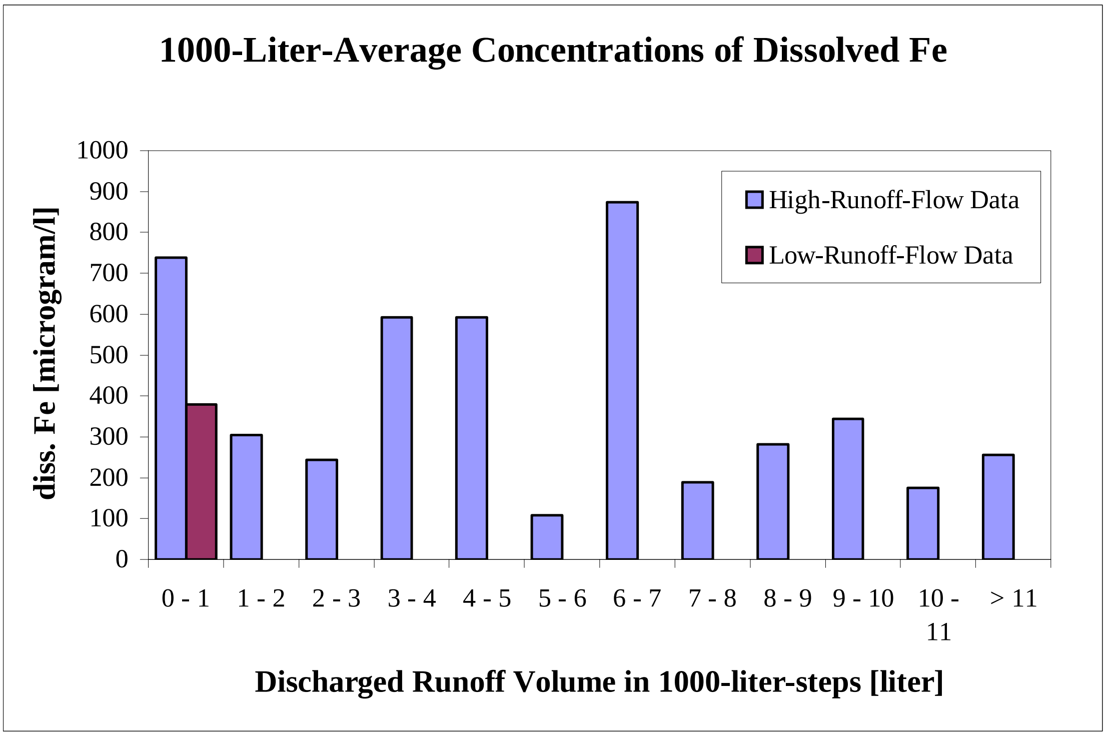

Figure 35: Concentration-Based “First Flush” for Dissolved Iron

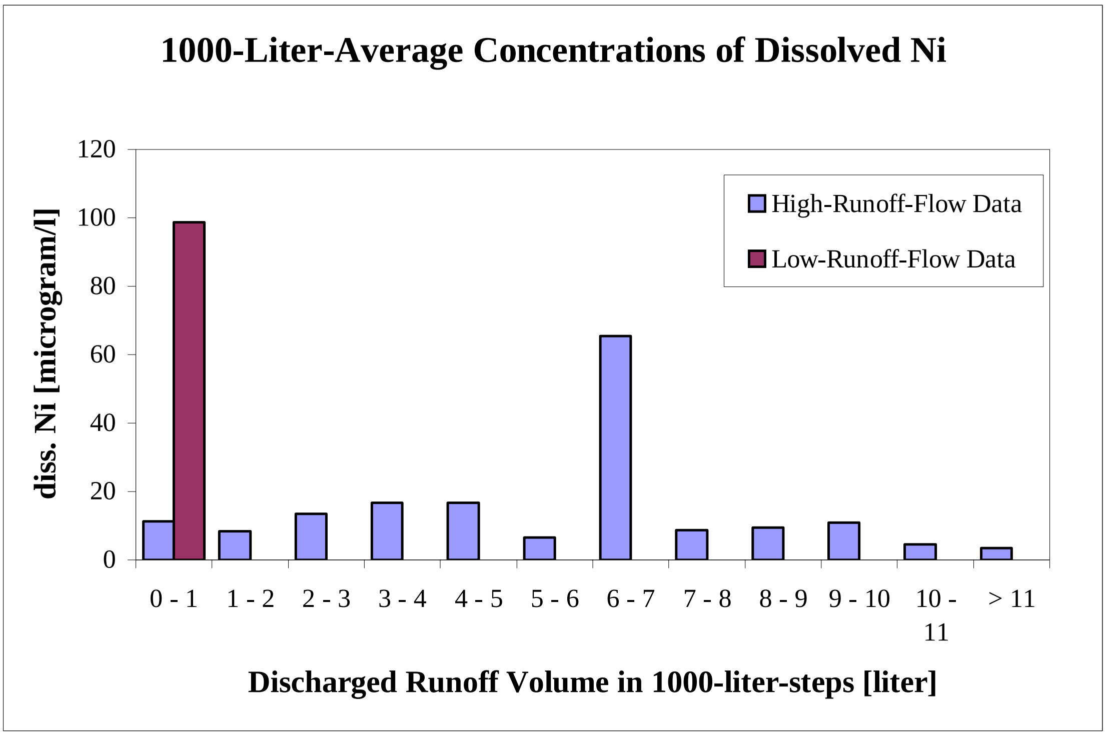

Figure 36: Concentration-Based “First Flush” for Dissolved Nickel

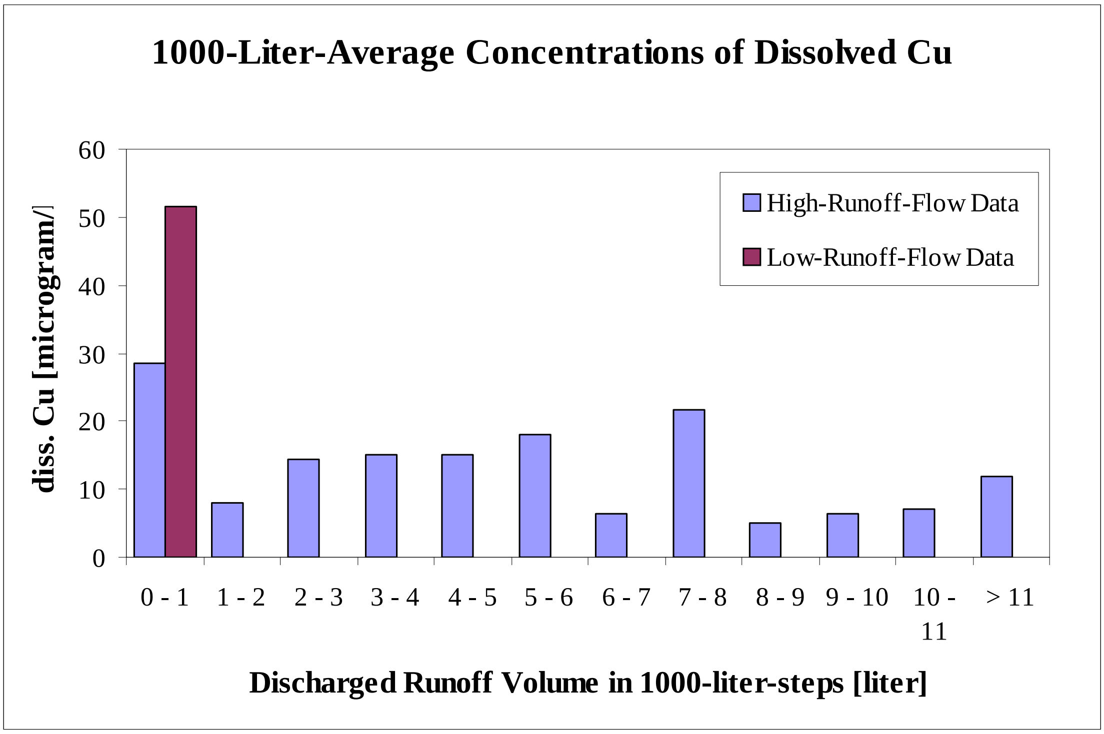

Figure 37: Concentration-Based “First Flush” for Dissolved Copper

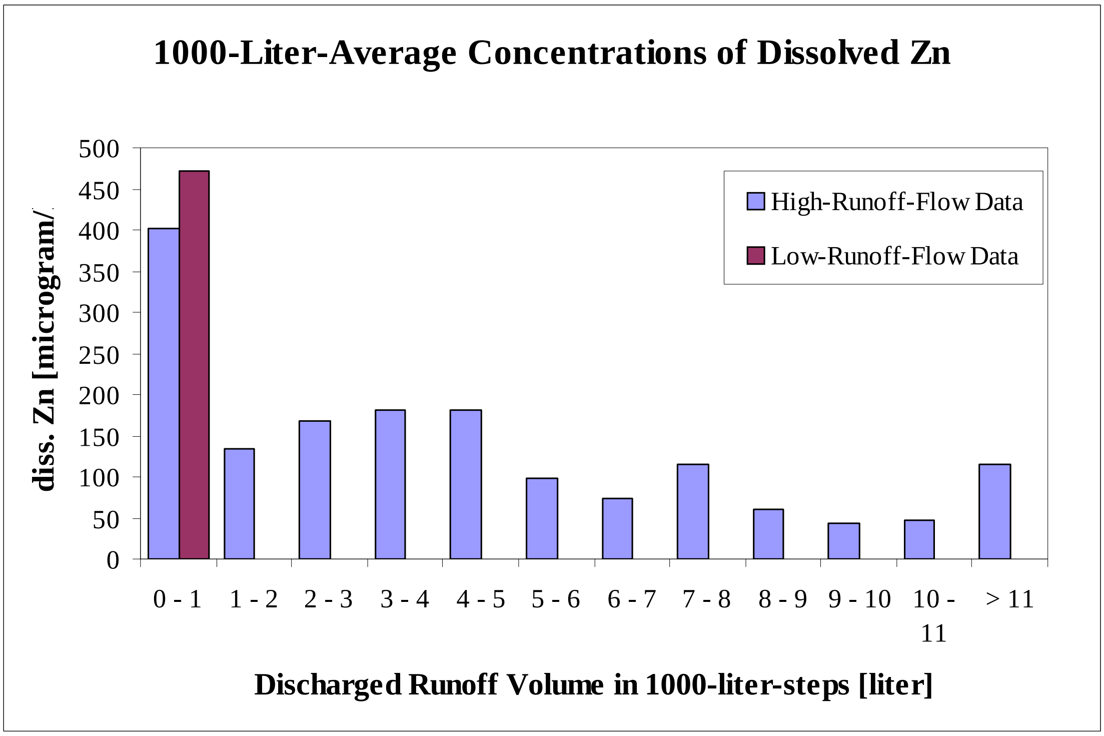

Figure 38: Concentration-Based “First Flush” for Dissolved Zinc

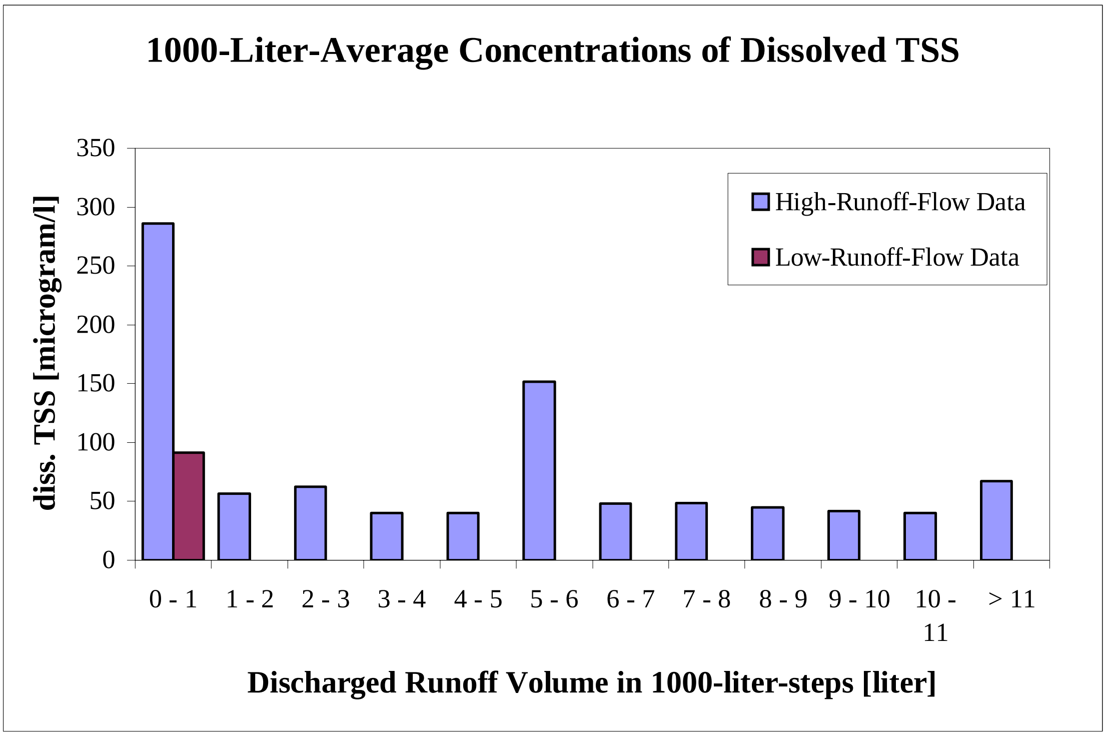

Figure 39: Concentration-Based “First Flush” for Total Suspended Solids

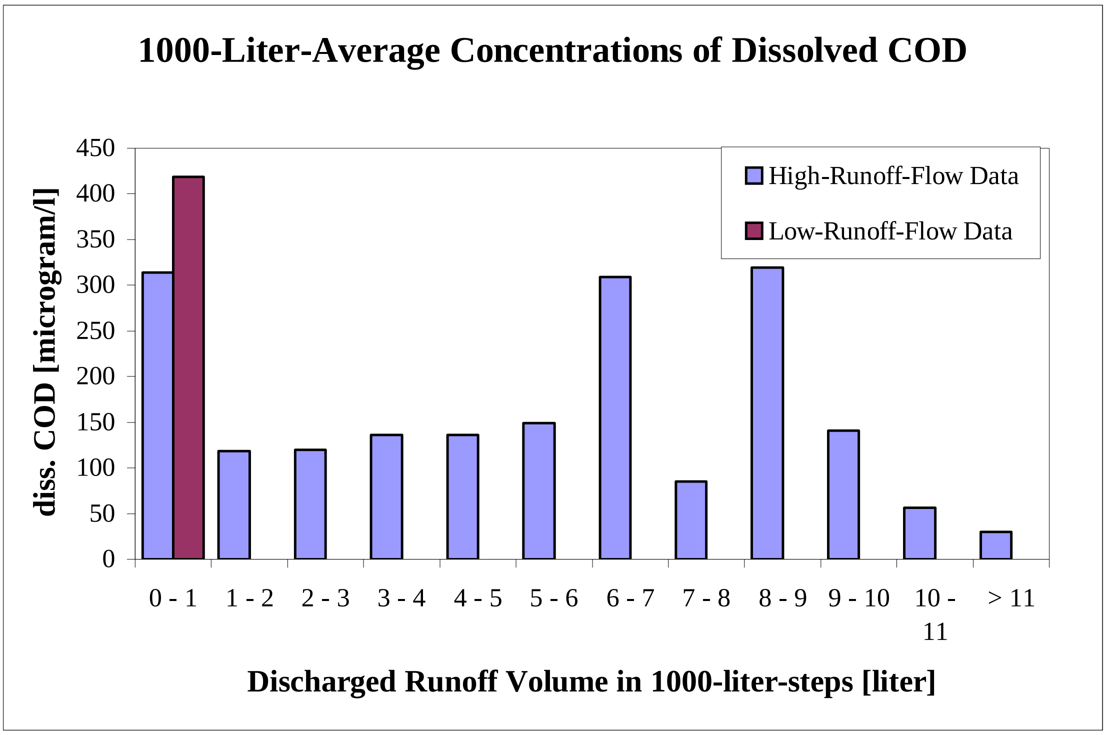

Figure 40: Concentration-Based “First Flush” for Chemical Oxygen Demand

Almost all histograms show the highest 1000-liter-average concentration of each dissolved heavy metal element within the first fraction of the highway runoff volume discharged (except Fe, and Ni). The differences in high-runoff-flow concentrations between the first 1000-liter-average-concentation and the latter are remarkably high. The maximum observed runoff volume in low-runoff-flow events was 910 liters and could not be compared with data after 1000 liters of discharge. However, given that high-runoff-flow data were exclusively higher compared to low-runoff-flow data, it was justifiable to use them to demonstrate the exhibition of the concentration-based “first flush”, which is a fundamental characteristic of storm water runoff from roadways.

6.4 Mass-Loading-Based Effect of “First Flush”

The next important step was to examine highway storm water runoff for dissolved mass loadings. The task was to determine, whether storm water runoff discharged from roadways shows not only the evidence of concentration-based, but also a mass-loading-based “first flush”. The motive of this task is again the potential reduction of the amount of highway storm water of concern and to understand the relationship between mass loading and discharged runoff volume. To achieve the prescribed goal, it was necessary to fit a mathematical function to every single distribution.

The two mathematical functions that represented the general pattern of the distributions in the best way were the exponential function and power law function:

Exponential Function:

$$y = ce^{bx}$$

c, b = constants
e = base of the natural logarithm

Power Law Function:

$$y = cx^{b}$$

c, b = constants

Following diagram shows an exponential fit in Figure 41 and power law fit in Figure 42 to the collected high-flow-data for dissolved aluminum.

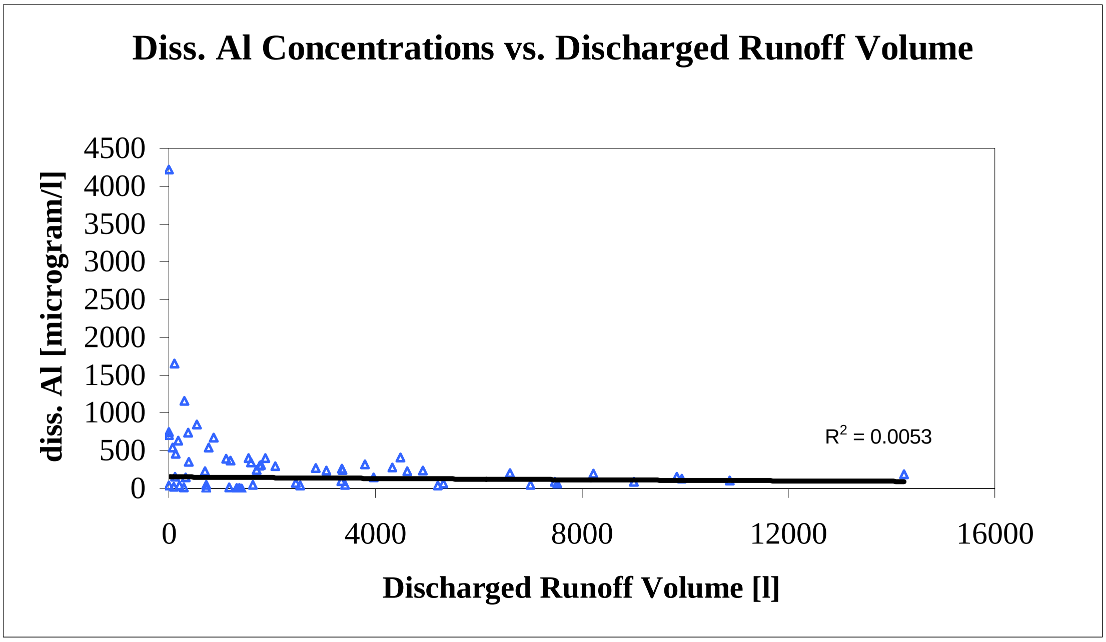

Figure 41: Exponential Fit to High-Runoff-Flow Data for Dissolved Aluminum

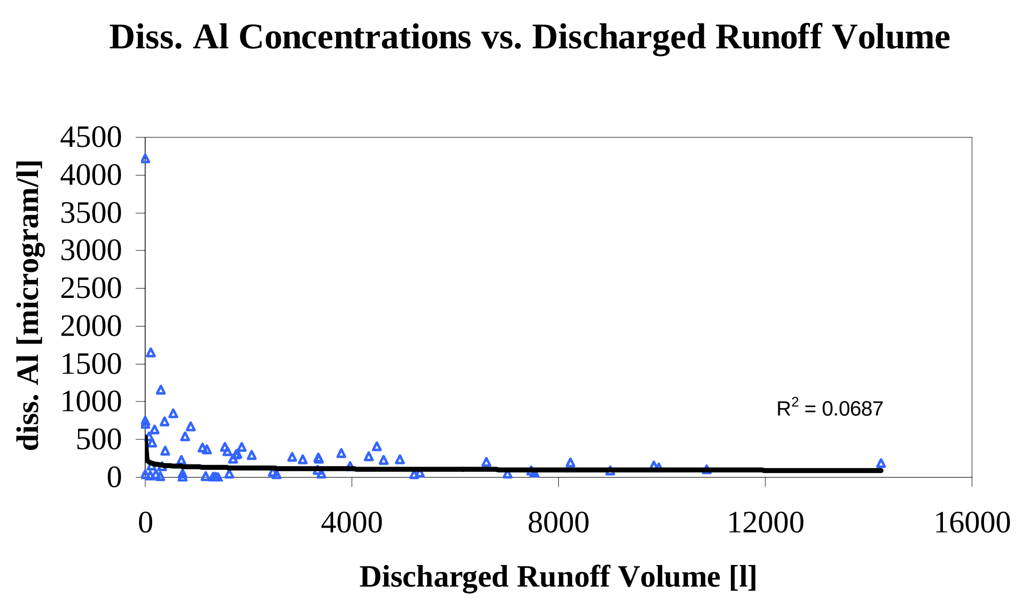

Figure 42: Power Law Fit to High-Runoff-Flow Data for Dissolved Aluminum

The power law was a better fit compared to the exponential function, but the two diagrams made clear that both line fits did not optimally represent the data points. The reason for this is the high variability of the concentrations at a specific discharged runoff volume in different storm water runoff events. In order to decrease the variability of these data and consequently, to get an understanding of the underlying trend, the original “raw” data were transformed to “moving average” data. A “moving average” is a form of average, which has been adjusted to allow for seasonal or cyclical components of a time series. “Moving average smoothing” is a technique to make the long-term trends of a time series clearer. Since dissolved heavy metal, TSS, and COD were graphed against discharged runoff volume (runoff flow integrated over runoff time) and showed very high variations, it made it difficult to see underlying trends. These variations were eliminated or decreased by using a suitable “moving average”, which resulted in better conditions for fitting an appropriate function to these new data points. The number of new data points in the “moving average trend-lines” equals the total number of points in the original data series less the number of data that were specified for the “moving average period”. This resulted in a reduction of data points from 64 to 54, because each moving average was calculated from 10 original data. After plotting the moving average series for all dissolved heavy metal elements, TSS, and COD versus discharged runoff volume, a power law function seemed appropriate to fit a new trend-line. Figure 43 to Figure 51 display moving averages and power law functions fits for all different elements.

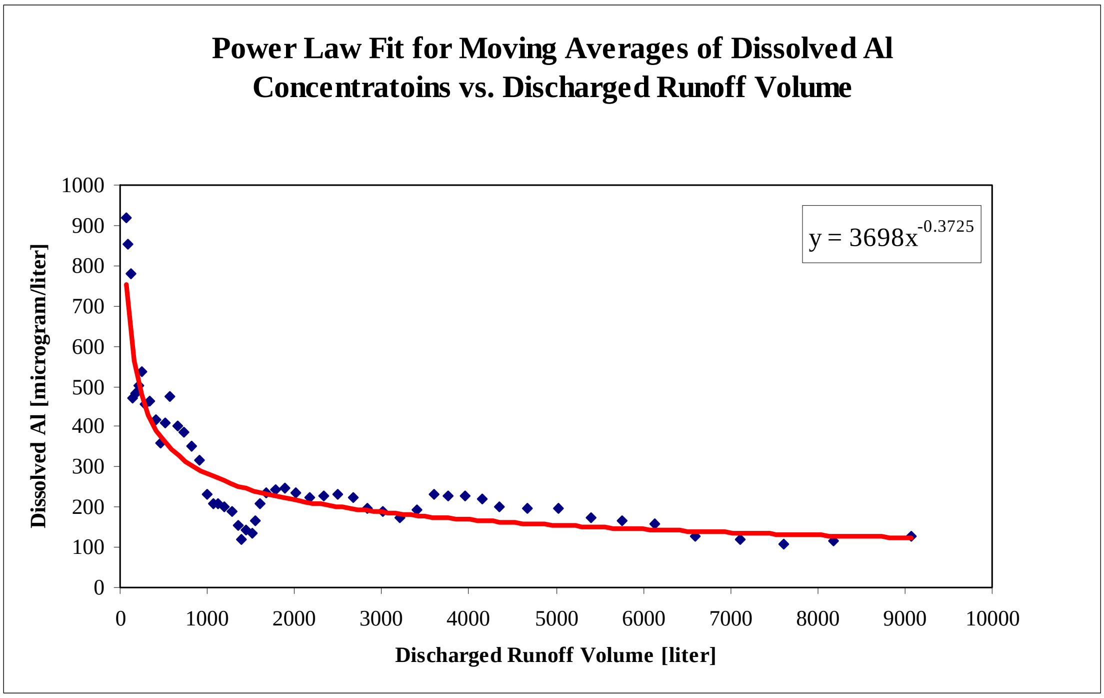

Figure 43: Power Law Fit to Moving Averages of Dissolved Al vs. Discharged Runoff Volume

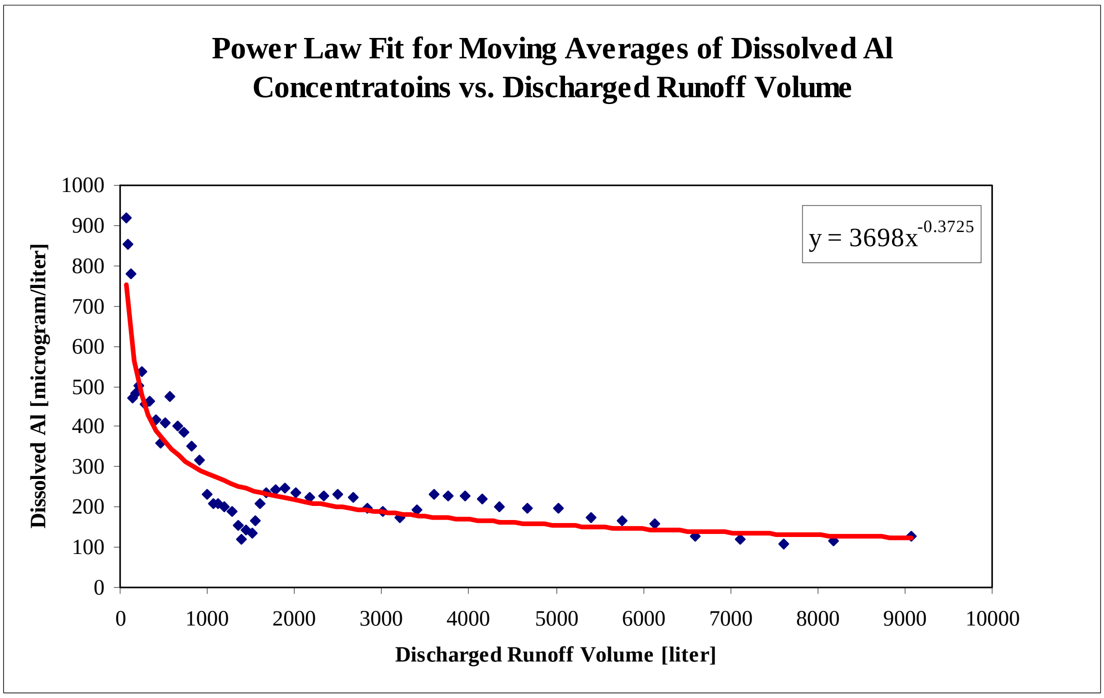

Figure 44: Power Law Fit to Moving Averages of Dissolved Cr vs. Discharged Runoff Volume

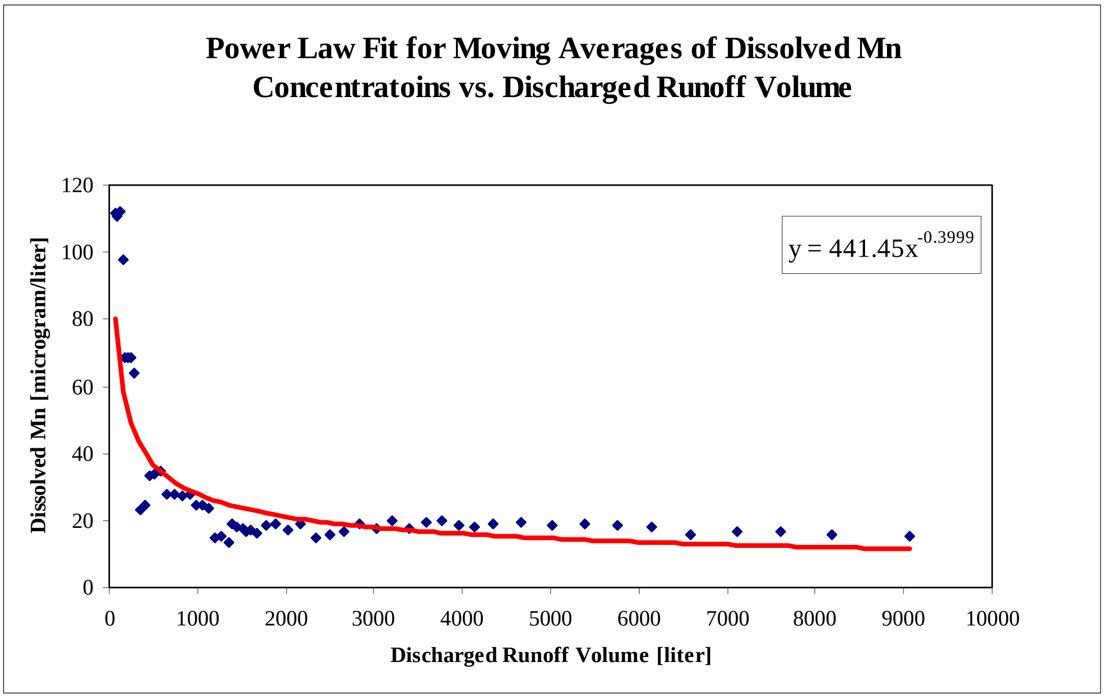

Figure 45: Power Law Fit to Moving Averages of Dissolved Mn vs. Discharged Runoff Volume

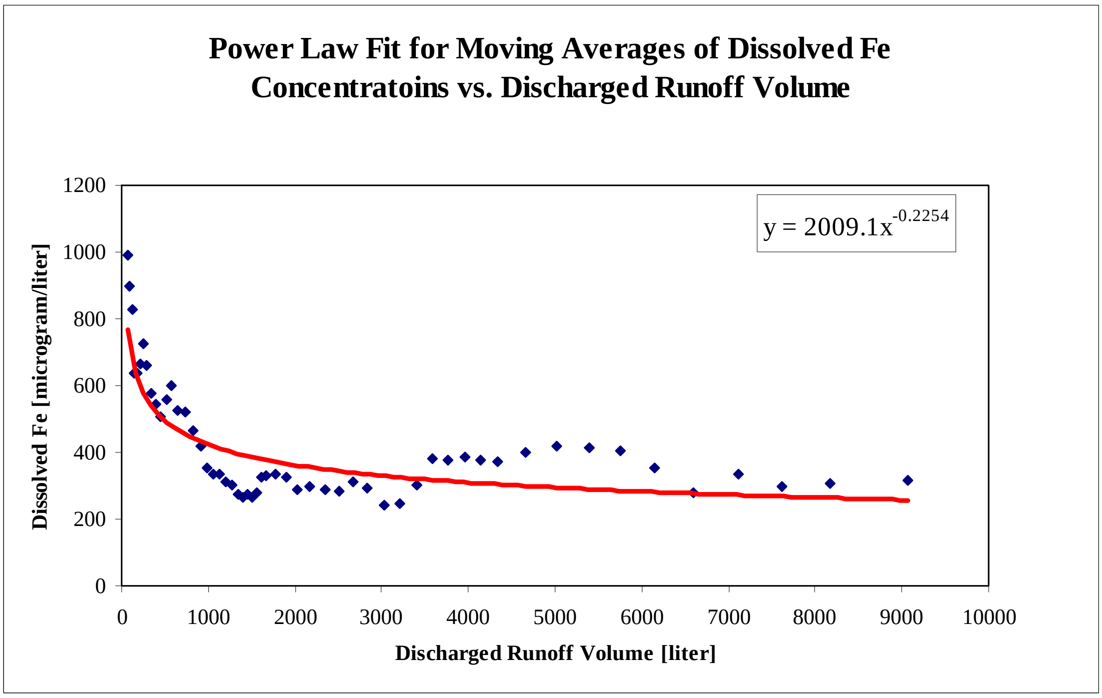

Figure 46: Power Law Fit to Moving Averages of Dissolved Fe vs. Discharged Runoff Volume

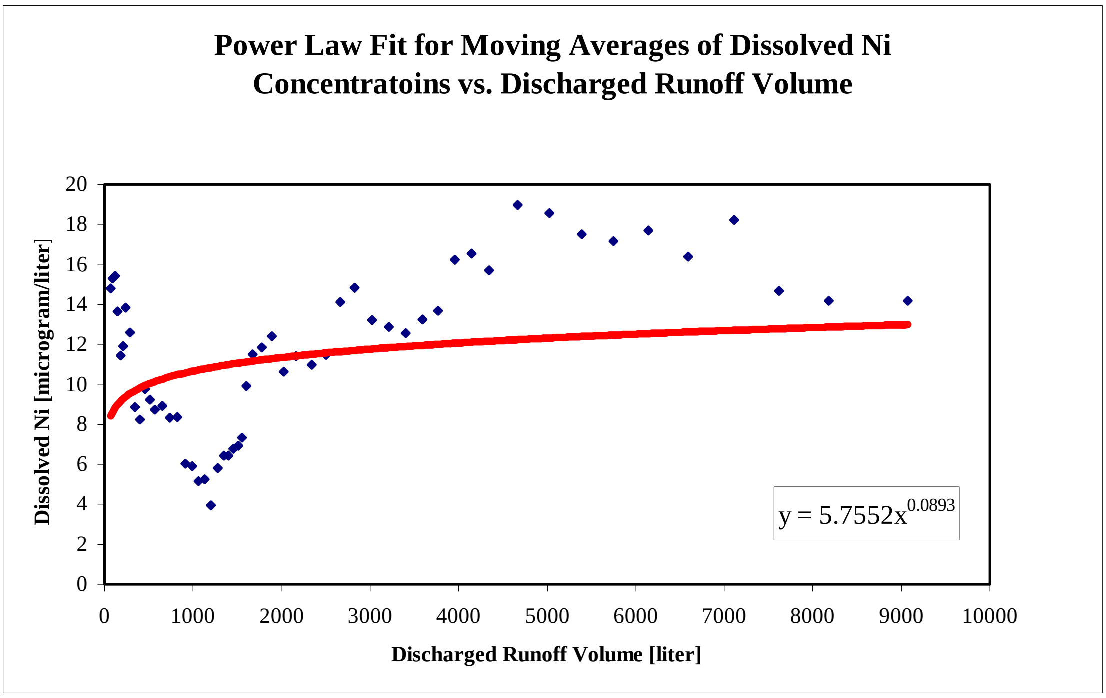

Figure 47: Power Law Fit to Moving Averages of Dissolved Ni vs. Discharged Runoff Volume

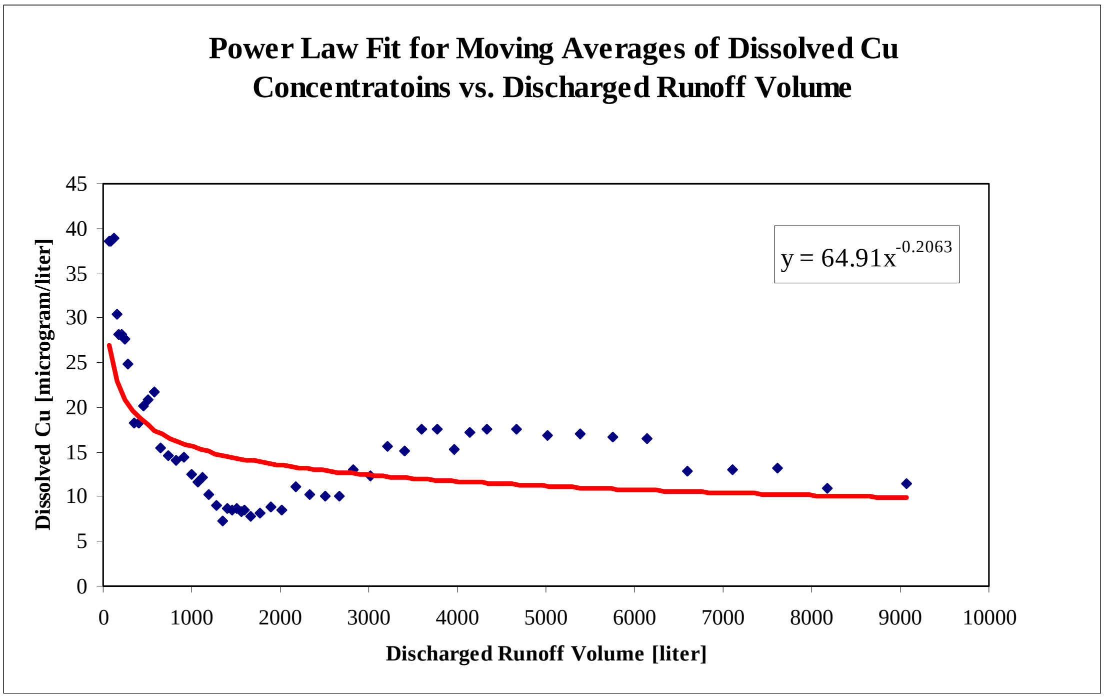

Figure 48: Power Law Fit to Moving Averages of Dissolved Cu vs. Discharged Runoff Volume

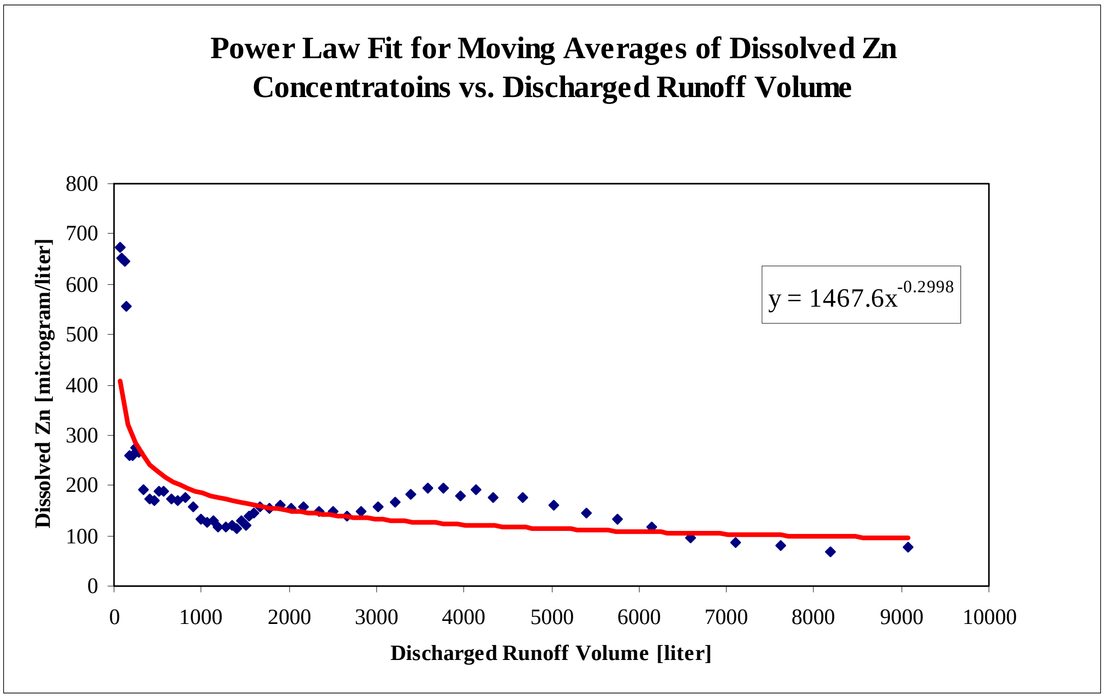

Figure 49: Power Law Fit to Moving Averages of Dissolved Zn vs. Discharged Runoff Volume

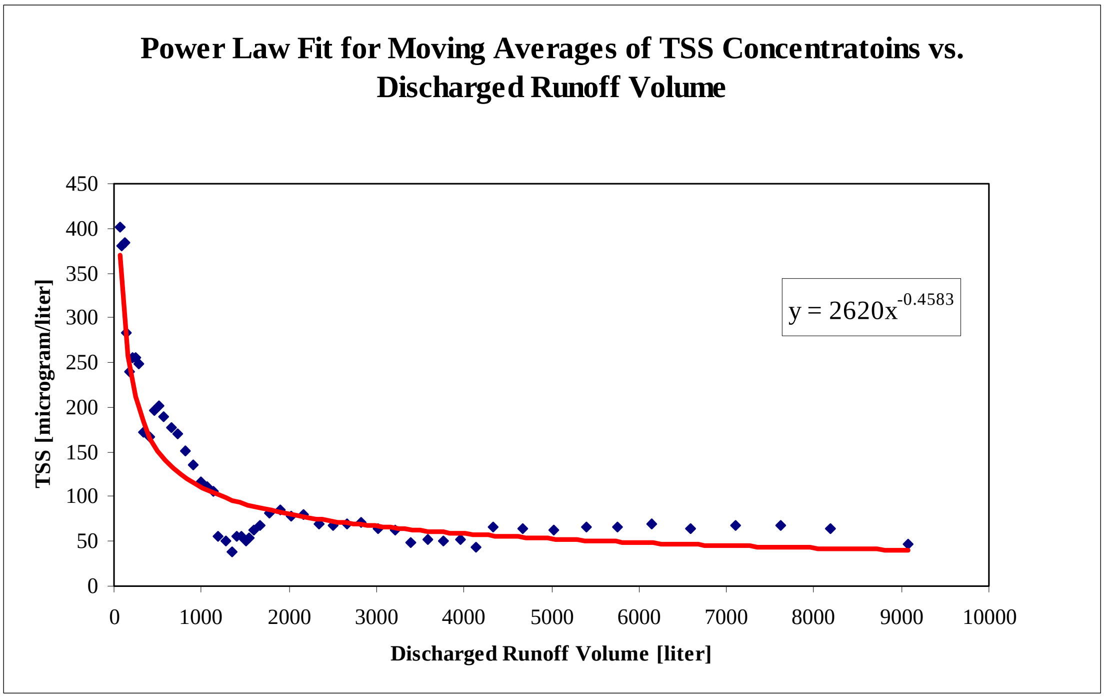

Figure 50: Power Law Fit to Moving Averages of TSS vs. Discharged Runoff Volume

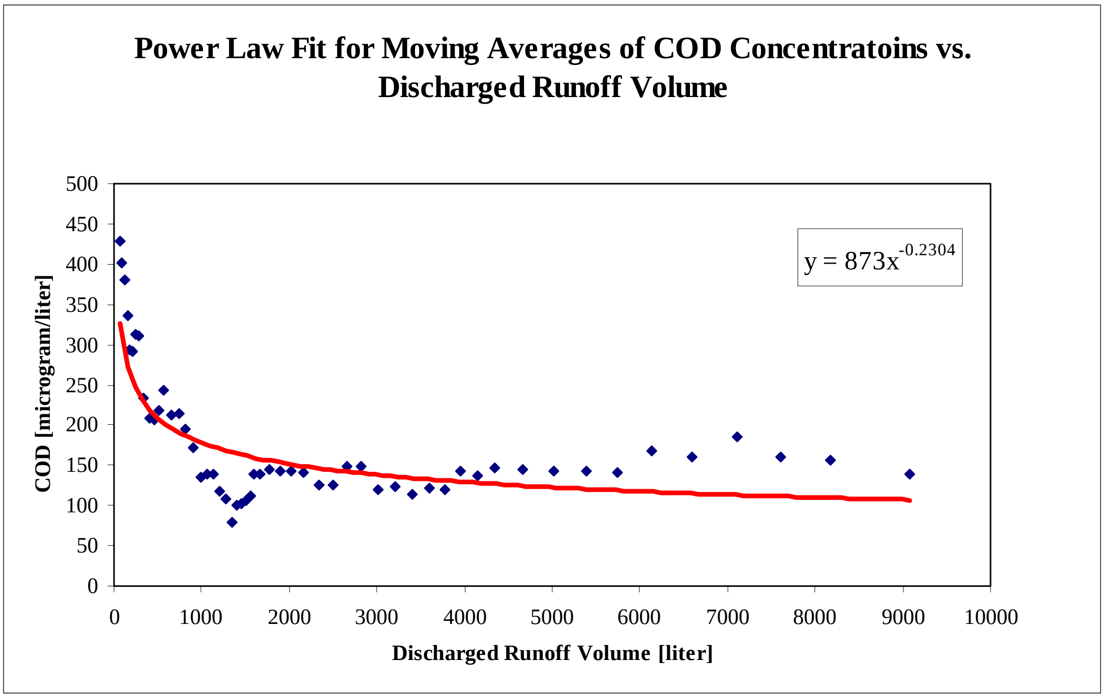

Figure 51: Power Law Fit to Moving Averages of COD vs. Discharged Runoff Volume

The accompanying power law functions displayed in every single graph were used for further calculations. R-squared values were not shown in the graphs because they did not represent the fit characteristics to the original data, but to the moving averages.

The mass loading of contaminated water is the total mass of a specific pollutant that is contained in the total volume of that water. In this study, mass loadings were determined by integrating the fitted power law functions. The upper limit for the integrals was determined by using the average rainfall duration calculated from hourly precipitation data measured at a weather station located at Lake Pontchartrain (Louisiana University Marine Consortium) [33], which was multiplied with the average rainfall runoff flow to establish the average total runoff volume discharged from the highway section.

In the calculation of the average rainfall duration, rainfall events were divided into spring/summer events and fall/winter events. The average rainfall duration, calculated from hourly precipitation data between January 1999 and May 2004, was determined to be 1.97 hours (118 minutes) for summer/spring events and 2.74 hours (164 minutes) for fall/winter rainfall events. The average runoff flow was calculated from the mean runoff flow values for each specific rainfall/runoff event. For spring/summer events the average runoff flow resulted to be 218 liters per minute, compared to the average runoff flow in fall/winter events of 22.8 liters per minute. The decision was made to use the average runoff flow for spring and summer to calculate the mass loadings because of the significantly higher generation of runoff volume and consequently higher mass loadings. The upper limit for all integrals was set to be 26,000 liters as an average value for the total rainfall runoff volume discharged from the highway section in a spring or summer storm event. Following equation shows the integral over a power law function, which was used to calculate mass loadings for each dissolved heavy metal element.

$$M = \int_{0}^{V_T} cV^b dV$$

M = mass loading [g]

c, b = constants

V = actual discharged runoff volume [liters]

V_T = upper limit (total runoff volume) [liter]

Runoff Volume		Dissolved Al		Dissolved Cr		Dissolved Mn		Dissolved Fe		Dissolved Ni	
Discharged Runoff Volume [liter]	Cumulative % of Runoff Volume [%]	Mass Loading [mg]	Cumulative % of Mass Loading [%]	Mass Loading [mg]	Cumulative % of Mass Loading [%]	Mass Loading [mg]	Cumulative % of Mass Loading [%]	Mass Loading [mg]	Cumulative % of Mass Loading [%]	Mass Loading [mg]	Cumulative % of Mass Loading [%]
0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
100	0.4%	86	2.5%	1.1	0.6%	9.2	2.8%	83	1.2%	0.8	0.2%
200	0.8%	143	4.2%	2.1	1.2%	15.2	4.7%	148	2.2%	1.7	0.5%
300	1.2%	191	5.5%	3.0	1.8%	20.0	6.2%	206	3.0%	2.7	0.8%
400	1.5%	232	6.7%	3.9	2.3%	24.3	7.5%	260	3.8%	3.6	1.1%
500	1.9%	270	7.8%	4.8	2.8%	28.1	8.7%	310	4.6%	4.6	1.4%
600	2.3%	306	8.9%	5.6	3.3%	31.7	9.7%	359	5.3%	5.6	1.7%
700	2.7%	339	9.8%	6.5	3.8%	35.0	10.8%	405	6.0%	6.7	2.0%
800	3.1%	370	10.7%	7.3	4.3%	38.1	11.7%	451	6.6%	7.7	2.3%
900	3.5%	400	11.6%	8.1	4.8%	41.1	12.6%	495	7.3%	8.8	2.6%
1000	3.8%	429	12.4%	8.9	5.3%	43.9	13.5%	537	7.9%	9.8	2.9%
2000	7.7%	671	19.5%	16.7	9.9%	67.6	20.8%	924	13.6%	20.9	6.1%
3000	11.5%	872	25.3%	24.1	14.3%	86.9	26.8%	1268	18.6%	32.4	9.5%
4000	15.4%	1049	30.4%	31.3	18.5%	103.8	32.0%	1588	23.3%	44.4	13.0%
5000	19.2%	1210	35.1%	38.2	22.6%	119.1	36.7%	1889	27.8%	56.6	16.6%
6000	23.1%	1360	39.5%	45.1	26.6%	133.2	41.0%	2178	32.0%	69.0	20.3%
8000	30.8%	1633	47.4%	58.4	34.5%	158.8	48.9%	2724	40.0%	94.4	27.7%
10000	38.5%	1882	54.6%	71.5	42.2%	182.0	56.0%	3240	47.6%	120.3	35.3%
15000	57.7%	2432	70.6%	103.0	60.9%	232.7	71.6%	4438	65.2%	187.1	54.9%
20000	76.9%	2918	84.7%	133.5	78.9%	277.1	85.3%	5549	81.6%	256.0	75.1%
25000	96.2%	3360	97.5%	163.2	96.5%	317.2	97.7%	6598	97.0%	326.4	95.8%
26000	100.0%	3445	100.0%	169.1	100.0%	324.8	100.0%	6802	100.0%	340.7	100.0%

Table 4: Contains Cumulative Percentage Mass loadings for Each Element and the Cumulative Percentage of Runoff Volume.

Runoff Volume		Dissolved Cu		Dissolved Zn		TSS		COD		Average	
Discharged Runoff Volume [liter]	Cumulative % of Runoff Volume [%]	Mass Loading [mg]	Cumulative % of Mass Loading [%]	Mass Loading [mg]	Cumulative % of Mass Loading [%]	Mass Loading [mg]	Cumulative % of Mass Loading [%]	Mass Loading [mg]	Cumulative % of Mass Loading [%]	Mass Loading [mg]	Cumulative % of Mass Loading [%]
0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
100	0.4%	2.9	1.1%	45	1.8%	44	3.7%	35	1.3%	34	1.7%
200	0.8%	5.2	2.0%	78	3.0%	70	6.0%	63	2.2%	59	2.9%
300	1.2%	7.3	2.8%	106	4.1%	91	7.7%	87	3.1%	79	3.9%
400	1.5%	9.2	3.5%	131	5.1%	109	9.3%	110	3.9%	98	4.8%
500	1.9%	11.1	4.2%	155	6.0%	125	10.6%	131	4.6%	116	5.6%
600	2.3%	12.8	4.9%	177	6.9%	139	11.9%	152	5.4%	132	6.4%
700	2.7%	14.5	5.6%	198	7.7%	153	13.0%	171	6.1%	148	7.2%
800	3.1%	16.2	6.2%	218	8.5%	165	14.1%	190	6.7%	163	7.9%
900	3.5%	17.8	6.8%	238	9.2%	177	15.1%	209	7.4%	177	8.6%
1000	3.8%	19.4	7.4%	257	10.0%	188	16.1%	227	8.0%	191	9.3%
2000	7.7%	33.7	12.9%	420	16.3%	280	23.9%	389	13.8%	314	15.2%
3000	11.5%	46.7	17.9%	561	21.8%	353	30.1%	533	18.8%	420	20.3%
4000	15.4%	58.7	22.5%	688	26.7%	415	35.4%	666	23.6%	516	25.1%
5000	19.2%	70.2	26.9%	806	31.3%	471	40.1%	792	28.0%	606	29.5%
6000	23.1%	81.1	31.1%	917	35.6%	521	44.4%	912	32.2%	691	33.6%
8000	30.8%	102.0	39.2%	1123	43.6%	612	52.2%	1139	40.3%	849	41.5%
10000	38.5%	121.9	46.8%	1315	51.1%	693	59.1%	1353	47.9%	998	49.0%
15000	57.7%	168.2	64.6%	1749	67.9%	866	73.9%	1850	65.4%	1336	66.1%
20000	76.9%	211.5	81.2%	2141	83.2%	1015	86.6%	2309	81.7%	1646	82.0%
25000	96.2%	252.5	96.9%	2505	97.3%	1148	97.9%	2743	97.0%	1935	97.1%
26000	100.0%	260.5	100.0%	2575	100.0%	1173	100.0%	2827	100.0%	1991	100.0%

Table 5: Contains Cumulative Percentage Mass loadings for Each Element and the Cumulative Percentage of Runoff Volume.

The cumulative percentage of mass loadings for every single dissolved heavy metal element, TSS, and COD was plotted versus the cumulative percentage of discharged runoff volume (Figure 52). The graph was examined for the potential occurrence of a mass-loading-based “first flush”. Despite the similar appearance of all curves, an average distribution was added to the chart, in order to be able to express the general mass loading behavior with one single curve.

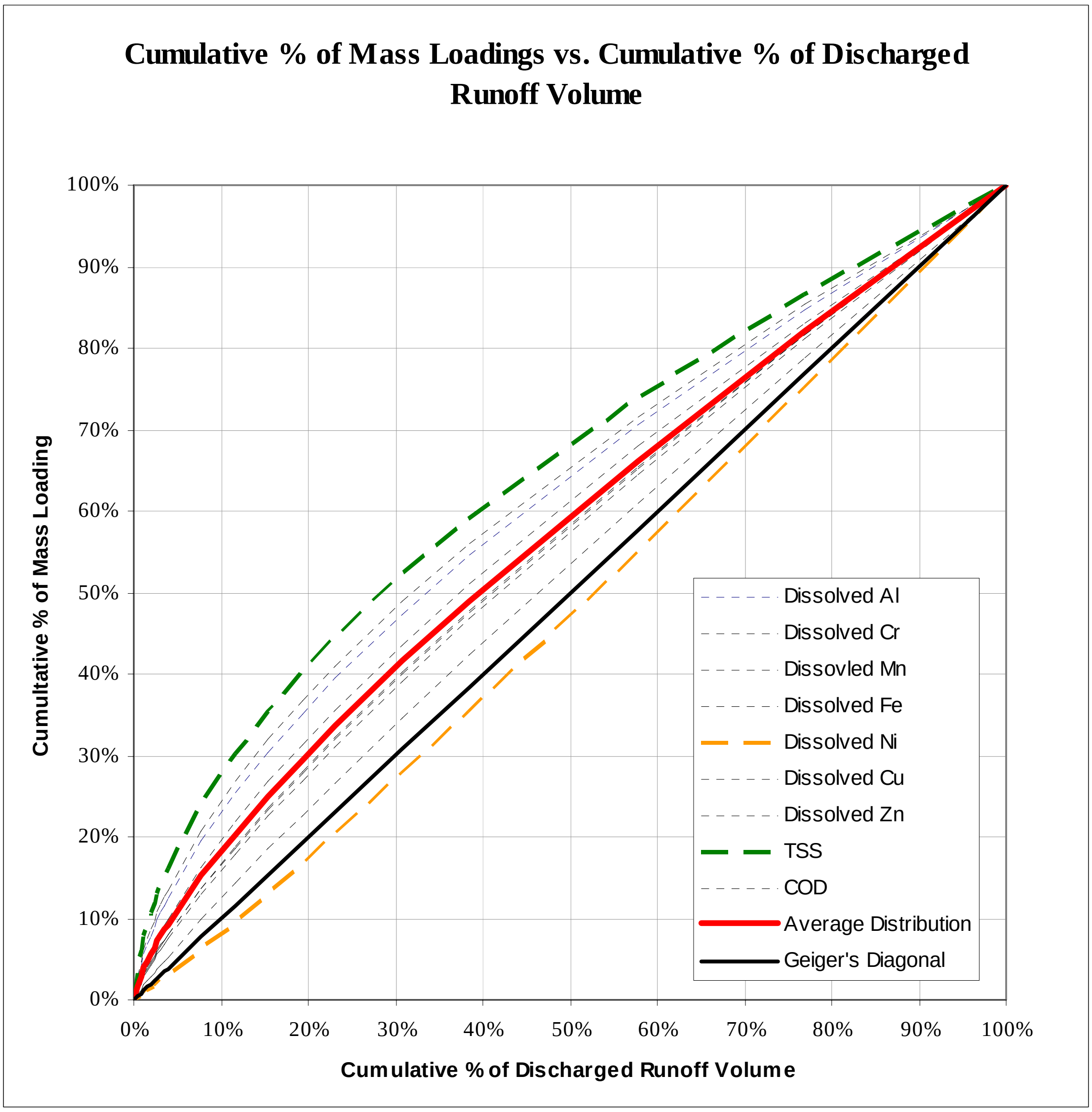

Figure 52: Cumulative % Mass Loadings vs. Cumulative % Discharged Runoff Volume

All curves (except Ni-curve) in Figure 52 show a steep slope during the first fraction of the curve followed by a slight flattening. Only Ni proceed below the Geiger's [34] diagonal definition of the mass emission line slop. The distributions of all these curves proved the occurrence of a mass-loading-based "first flush" effect, even though it was not as marked as the concentration-based. The first portion of storm water runoff discharged from highways showed the highest mass loadings followed by a clear decline with increasing discharge of storm water runoff. Examining the chart it became evident, that 50 percent of the total mass loadings, washed off the roadway during a storm event, are contained in the first 40 percent of the discharged runoff volume. Potentially, this particular curve makes it possible for a regulator to determine the volume of storm water runoff that has to be treated in order to address a certain percentage of dissolved heavy metal mass loading.

7 CONCLUSION AND SUMMARY

Highway runoff can have adverse effects if no measures are taken for the removal of excessive contaminants before the runoff reaches the receiving water. The most common contaminants in highway runoff are heavy metals, inorganic salts, aromatic hydrocarbons, and suspended solids that accumulate on the road surface as a result of regular highway operation and maintenance activities. The presence of undesirable contaminants in surface or ground water may interfere with the vital functions of the organisms living in or from it.

Toxicity of highway runoff depends largely on the physical and chemical form of the heavy metals, their availability to aquatic organisms, and the existing conditions of the receiving waters. Highway runoff contains higher concentrations of metals, particularly lead, zinc, iron, chromium, cadmium, nickel, manganese, arsenic, aluminum, and copper, which result from the ordinary wear of brakes, tires, and other vehicle parts. Although leaded gasoline was outlawed 25 years ago, lead is still being deposited on highway surfaces, (though in dramatically smaller quantities) through such sources as paints used on the right of ways and atmospheric deposition.

Heavy metals in highway runoff generally undergo physical, chemical, and biological transformations as they reach adjacent ecosystems. Sometimes, they are taken up by plants or animals, or adsorbed on clay particles. This conventional mitigation of highway storm water runoff is not suitable for elevated structures. More often than not, this prelusion is based on simple space availability. Elevated structures do not have hard shoulders or vegetative strips to the side, which could be utilized for the implement of reducing contaminants. Other times, they settle to bottom sediments, or re-dissolve into solution. Particulate fractions settling to the bottom surface of receiving waters may develop into sediments after several years of continuous deposition. These sediments may or may not leach metals depending on the condition and sensitivity of the receiving water. The form of a metal and its availability to organisms determine in great part the toxicity of water. Waters with high total metal concentrations, which are the sum of the concentrations in both dissolved and suspended fractions, may indeed be less toxic than one having lower concentrations but different forms of the same metal. Ionic copper, for instance, is more harmful to aquatic organisms than organically bound or elemental copper.

Of particular importance in the findings of this study is not only the high temporal variability in actual occurrence of storm events, but also the very stochastic nature of the associated runoff. The events characterized at the site have exhibited a high degree of variability in the amount of precipitation originally deposited, the duration of these events and ultimately the duration, volume and composition of the runoff events associated with them. Runoff volumes and flow rates have not only displayed orders of magnitude differences between events but also an order of magnitude fluctuation was frequently observed within the same event.

Nevertheless, one parameter common to all the events characterized is the strength of the waste stream and the orders of magnitude increase in priority pollutants, namely particulates and some dissolved heavy metals (aluminum, iron, and lead). Suspended solids (TSS and VSS), dissolved solids (TDS and VDS), alkalinity and chemical oxygen demand, exceeded the concentrations in equivalent waste stream flows for untreated domestic wastewater. Unregulated discharges of waste streams of comparable chemical composition strength would result in substantial regulatory violations and extended periods of non-attainment. Event Mean Concentrations of aluminum, manganese and iron exceeded the secondary drinking water regulations in more than one case. However, these regulations are non-enforceable guidelines, although EPA recommends these standards to water systems. The primary drinking water standards were exceeded by lead concentrations during the October 10 event. Concurrent with these violations and non-attainments would be regulatory constraints that control the diffuse and non-point discharges form locations that this site typifies, storm water runoff from highways, both elevated and otherwise, situated over land or over water, is being discharged directly and without treatment to the environment. As a result, storm water runoff from highways has to be treated.

Question concerning the treatment of highway storm water runoff that need to be addressed, are which amount of runoff should be treated. A majority of pollutant parameters show highest concentrations during the first flush and show lower concentrations after this initial runoff period. Examination of Figures 43 to 51 indicates that treatment systems should be designed to treat only an initial fraction of the storm water hydrograph while ignoring the latter portion of the storm. This method should improve the quality of the storm water runoff to an acceptable discharge concentration. Depending on the physical and economical treatment possibilities, this initial time period could be determined and the flow, which needs to be treated, could be calculated.

Finally it became evident, that 50 percent of the total mass loadings, washed off the roadway during a storm event, are contained in the first approximately 30 to 50 percent of the discharged runoff volume (Figure 52).

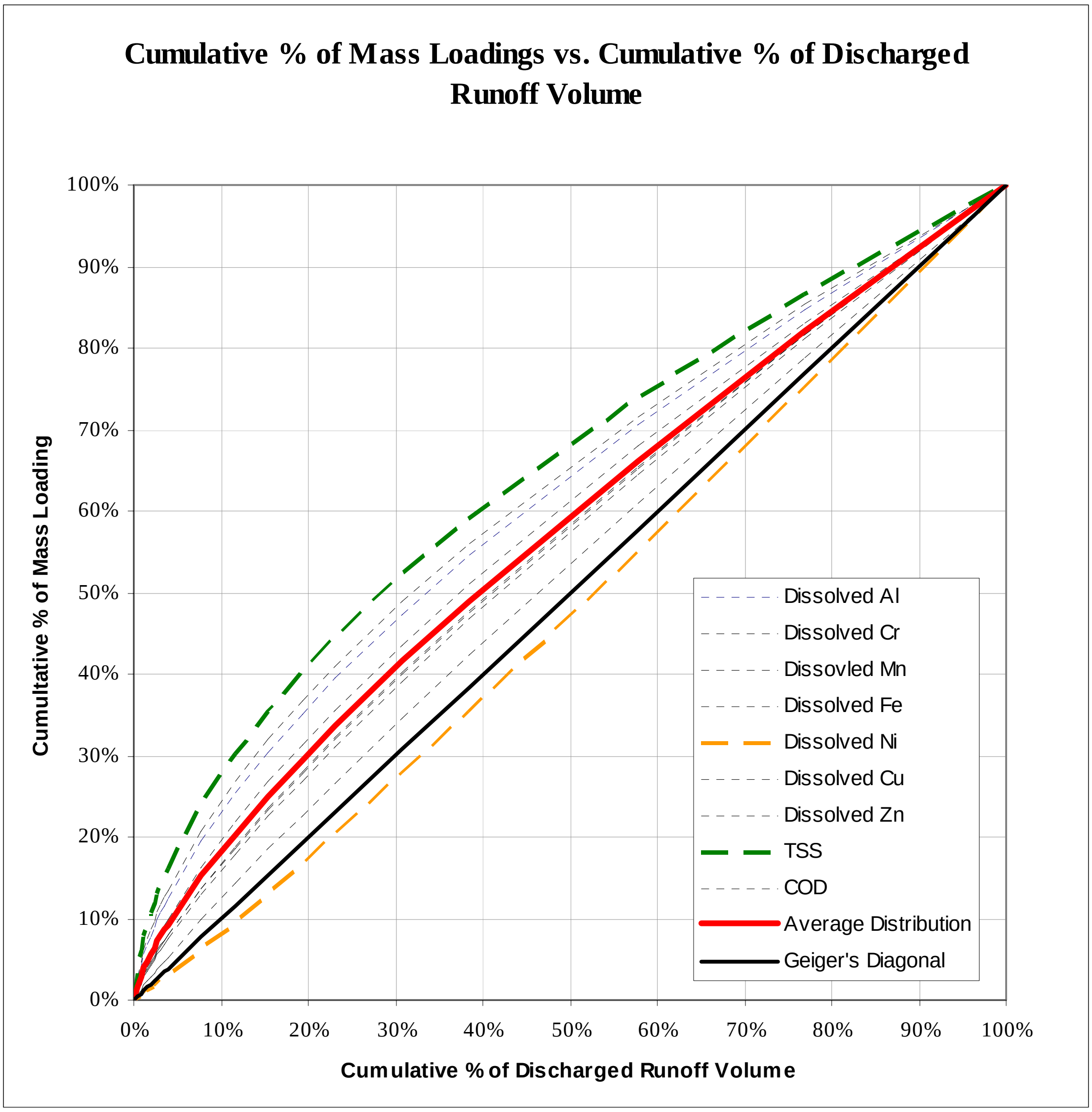

Figure 52: Cumulative % Mass Loadings vs. Cumulative % Discharged Runoff Volume

8 APPENDIX

Storm	Sample#	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
		[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[h]	[min]	[l/min]	[min]	liter	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[s.u.]	[+mv]	[°C]	[mS/cm]
1	1												6	120	0	0	229	240	720	94	565	7.78	-48.1	17.0	
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
1	7												27	120	21	4735	38	10	50	20	132	8.03	-60.7	16.2	78
1	8												31	140	25	5255	12	200	30	9	142	8.00	-59.3	16.3	74
1	9												35	130	29	5795	33	117	90	11	127	7.95	-56.7	16.2	66
1	10												39	180	33	6415	30	290	20	16	110	7.86	-53.0	16.2	51
1	11												43	450	37	7675	21	90	10	12	110	7.85	-50.7	16.0	34
1	12												47	130	41	8835	25	260	0	3	91	7.88	-52.0	16.1	40
1	13												51	78	45	9251	16	220	50	10	113	7.90	-51.8	16.2	53
1	14												55	65	49	9537	30	120	40	19	111	7.99	-57.8	16.2	61
1	15												62	93	56	10090	21	250	80	10	110	7.95	-55.5	16.0	60
2	1											42	15	75	0	0	801	580	750	357	1086	6.92		16.4	145
2	2	16.2	3.4	27.0	254.0	5.0	14.4	164.0	0.4	0.4	0.5	42	17	210	2	285	294	170	410	211	135	8.05	-42.3	16.2	149
2	3	10.4	2.6	19.9	158.0	3.1	5.4	42.5	0.1	0.2	0.1	42	19	225	4	720	52	360	390	29	70	7.93	-51.1	16.2	86
2	4	18.7	3.0	12.6	164.0	3.2	6.9	18.5	0.3	0.1	0.5	42	22	75	7	1170	32	180	380	13	61	7.85	-51.4	16.1	89
2	5	8.6	3.1	14.5	170.0	3.0	7.5	21.6	0.4	0.1	0.1	42	25	21	10	1314	20	240	270	19	53	7.90	-52.4	16.2	102
2	6	5.3	3.4	15.1	187.0	3.7	9.1	27.6	0.7	0.1	0.2	42	29	4	14	1363	7	170	370	6	62	7.88	-51.1	16.1	123
2	7	3.4	3.7	15.4	198.0	4.1	10.5	70.9	0.8	0.1	0.4	42	36	2	21	1384	8	80	350	7	78	7.89	-51.7	16.1	157
2	8	4.1	3.6	13.4	176.0	4.0	9.8	72.4	0.5	0.1	0.1	42	41	3	26	1397	9	260	370	7	86	7.92	-53.5	16.2	163
2	9	3.2	3.3	10.6	192.0	4.3	10.3	79.7	0.7	0.1	0.1	42	46	2	31	1408	8	50	350	6	80	7.93		16.0	157
3	1	17.5	7.9	4.2	513.0	15.4	30.3	19.5	1.1	0.5	0.4	72	15	2	0	0	49	360	470	34	464	8.04	-60.6	13.5	448
3	2	10.1	8.4	70.4	512.0	16.9	31.4	423.0	1.2	0.5	0.2	72	18	4	3	9	47	310	390	42	433	7.97	-56.0	13.0	382
3	3	20.1	7.4	53.0	485.0	14.8	27.1	19.8	1.4	0.5	0.2	72	21	2	6	17	30	220	250	25	377	7.96	-55.2	12.9	351
3	4	26.5	7.7	30.9	492.0	12.5	24.7	558.0	1.2	0.5	0.2	72	25	1	10	24	19	200	290	18	327	7.98	-56.0	12.9	340
3	5	5.7	5.1	18.8	374.0	8.9	18.1	145.0	1.1	0.2	0.2	72	39	2	24	44	18	120	150	16	182	8.00	-57.7	12.6	286
3	6	14.1	5.9	10.2	363.0	9.1	17.5	427.0	1.1	0.4	0.1	72	43	3	28	54	16	70	100	11	198	8.20	-57.3	12.7	258
3	7	13.0	7.1	11.0	332.0	8.6	17.1	16.7	3.3	0.3	0.1	72	47	3	32	67	15	150	180	14	176	8.30	-58.2	12.6	232
3	8	16.3	6.5	3.2	345.0	7.9	16.2	423.0	2.3	0.3	0.1	72	51	1	36	77	6	70	120	4	142	7.97	-55.7	12.5	226
3	9	18.2	6.3	7.8	245.0	5.6	12.0	267.0	2.1	0.2	0.2	72	95	6	80	239	72	20	30	55	127	8.07	-60.7	12.2	149
3	10	36.6	5.1	37.6	226.0	4.4	9.8	217.0	2.0	0.6	0.5	72	97	10	82	255	65	20	30	44	134	8.06	-60.0	12.0	131
3	11	23.8	4.9	7.1	189.0	4.1	9.3	145.0	1.2	0.2	0.2	72	99	18	84	283	51	20	20	19	119	8.07	-60.5	11.7	106
3	12	21.1	5.4	6.6	329.0	4.2	8.1	123.0	1.4	0.2	0.2	72	101	18	86	319	40	30	40	28	109	8.07	-60.7	11.6	95
3	13	19.3	4.8	4.2	167.0	3.4	6.7	110.0	1.3	0.6	0.2	72	103	20	88	357	28	20	40	23	90	8.07	-61.0	11.6	89
3	14	16.1	4.5	3.6	169.0	2.9	6.3	90.3	1.0	0.2	0.4	72	105	18	90	395	23	30	40	22	76	8.06	-60.5	11.6	84
3	15	19.5	4.1	4.1	168.0	3.0	6.0	80.2	1.0	0.1	0.2	72	107	18	92	431	23	10	10	14	82	8.06	-60.3	11.6	81
4	1											648	15	5	0	0	1096				1650	6.44	28.4	22.1	2589
4	2	155.0	11.3	424.0	1210.0	48.7	83.1	869.0	2.3	2.1	1.0	648	17	120	2	125	837	180	880	397	834	7.07	-7.1	21.9	992
4	3	53.0	5.3	102.0	449.0	17.3	28.6	197.0	0.6	0.6	0.7	648	19	480	4	725	510	130	380	311	298	7.36	-23.3	21.5	383
4	4	47.3	4.8	65.1	317.0	10.8	19.8	136.0	0.4	0.3	1.2	648	21	420	6	1625	235	30	60	70	323	7.47	-30.6	21.5	215
4	5	71.5	3.8	35.7	234.0	7.4	12.8	65.3	0.3	0.2	1.1	648	23	420	8	2465	151	30	50	69	151	7.64	-38.7	21.4	130
4	6	97.7	3.8	24.7	221.0	6.4	10.8	43.8	0.2	0.2	1.6	648	25	450	10	3335	138	-40	20	36	160	7.74	-44.2	21.3	107
4	7	68.4	4.3	21.3	126.0	3.4	6.7	23.1	0.1	0.1	0.9	648	29	540	14	5315	243	10	10	152	195	7.89	-51.4	21.2	68
4	8	87.2	5.1	14.4	142.0	3.0	6.4	29.6	0.0	0.1	0.5	648	33	540	18	7475	57	10	30	23	60	7.92	-54.2	21.1	60
4	9	89.5	2.4	12.6	141.0	3.7	6.6	24.5	0.0	0.1	0.9	648	37	225	22	9005	40	30	40	17	45	7.75	-44.6	21.2	67
4	10	131.0	3.0	14.5	182.0	3.8	7.7	27.5	0.1	0.1	1.0	648	41	240	26	9935	51	10	40	23	71	7.78	-45.3	21.2	71
4	11	109.0	3.2	13.2	175.0	4.5	7.0	46.8	0.1	0.2	1.4	648	45	225	30	10865	40	0	20	18	57	7.76	-45.6	21.2	68
4	12	192.0	4.4	15.6	255.0	3.5	11.9	115.0	0.1	0.6	4.6	648	51	900	36	14240	67	30	20	25	30	8.01	-63.0	20.9	46
5	1	707.6	13.7	18.2	1011.4	1.8	9.7	260.1	0.0	0.0	0.0	120	8	17	0	0	315	120	160	102	317	7.80	-60.8	27.0	253

Storm	Sample#	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
		[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[h]	[min]	[l/min]	[min]	liter	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[s.u.]	[+mv]	[°C]	[mS/cm]
5	2	354.2	18.5	9.0	620.5	26.4	3.6	186.2	0.0	0.0	4.9	120	11	240	3	386	185	110	140	55	274	8.02	-60.6	27.0	123
5	3	392.1	12.5	8.2	410.7	10.6	4.4	205.7	0.0	0.0	0.0	120	14	240	6	1106	72	90	120	21	127	7.97	-58.2	26.9	84
5	4	342.9	14.5	10.6	390.2	6.0	2.8	202.9	0.0	0.0	0.0	120	17	80	9	1586	43	60	80	20	98	7.93	-56.0	27.1	88
5	5	248.2	16.0	4.4	259.4	6.7	5.0	178.8	0.0	0.0	0.0	120	19	30	11	1696	46	40	60	14	96	7.96	-57.8	27.2	101
5	6	305.1	12.8	4.9	262.4	6.7	6.4	191.9	0.0	0.0	0.0	120	22	11	14	1756	42	40	70	14	110	7.93	-57.2	27.2	115
5	7	315.6	16.0	5.8	302.8	7.1	3.5	196.4	0.0	0.0	0.0	120	25	4	17	1779	42	40	60	27	108	7.97	-58.4	27.2	127
6	1	746.1	15.0	15.2	929.8	3.6	10.3	229.9	0.0	0.0	0.0	48	16	30	0	0	246	110	250	84	354	7.80	-51.9	28.8	334
6	2	539.9	15.9	11.9	608.2	0.0	10.6	205.6	0.0	0.0	0.4	48	18	43	2	73	137	320	300	69	303	7.90	-54.2	30.2	281
6	3	461.6	13.0	7.9	510.9	9.5	6.8	229.0	0.0	0.0	21.9	48	20	20	4	135	109	240	240	51	304	7.90	-54.1	30.2	292
6	4	634.1	13.0	12.2	818.3	2.0	9.3	220.9	0.0	0.0	1.0	48	22	28	6	183	203	150	190	61	324	7.90	-55.5	29.7	281
6	5	744.5	13.0	16.3	898.4	4.8	10.9	230.5	0.0	0.0	0.0	48	24	162	8	373	277	70	70	83	288	8.00	-57.4	28.9	176
6	6	544.7	12.6	13.8	568.7	1.4	17.8	226.3	0.0	0.0	0.0	48	26	240	10	775	152	800	260	50	169	8.00	-60.3	28.9	113
6	7	372.1	12.5	10.6	352.8	5.2	4.8	291.6	0.0	0.0	0.0	48	28	180	12	1195	93	130	80	38	83	7.90	-60.0	28.9	109
6	8	401.7	10.0	21.9	494.2	20.1	6.1	218.5	0.0	0.0	0.0	48	30	173	14	1547	94	110	240	33	71	7.90	-57.8	28.8	96
6	9	298.3	11.3	6.0	210.0	20.1	2.9	189.3	0.0	0.0	0.0	48	32	340	16	2060	51	100	180	23	75	7.90	-57.4	28.8	79
6	10	268.7	10.0	4.9	165.6	2.4	2.1	178.4	0.0	0.0	0.0	48	35	180	19	2840	27	50	200	16	74	7.90	-58.3	28.7	79
6	11	262.7	14.6	10.9	174.0	11.8	3.2	176.5	0.0	0.0	0.0	48	39	75	23	3350	24	0	190	16	97	7.90	-58.2	28.6	91
6	12	317.7	13.8	5.6	177.6	13.3	4.0	187.0	0.0	0.0	0.0	48	43	150	27	3800	29	160	250	20	67	7.90	-58.0	28.8	84
6	13	280.0	13.8	15.6	782.6	4.4	8.0	218.3	0.0	0.0	2.9	48	47	113	31	4325	13	50	160	13	51	7.90	-59.7	28.8	84
6	14	231.4	14.6	5.4	152.1	6.9	2.0	172.3	0.0	0.0	0.0	48	51	34	35	4618	14	110	200	13	55	8.00	-60.3	28.8	95
7	1	22.5	17.4	31.2	77.3	31.6	44.4	490.5	17.7	6.1	0.0	432	23	2	0	0	20	380	1130	16	392	7.90	-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	0.0	432	27	2	4	8	59	290	770	44	368	7.90	-50.9	23.5	777
7	3	21.1	3.6	18.0	49.1	1.6	29.1	297.0	4.0	5.2	20.1	432	26	2	5	10	30	130	400	30	326	7.80	-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	7.70	-43.6	23.1	698
7	5	23.4	3.2	17.8	25.8	0.0	34.3	409.3	6.0	1.6	60.6	432	39	2	16	29	7	70	680	4	355	7.80	-46.0	23.3	795
7	6	24.2	2.4	17.0	22.9	8.7	33.3	407.0	10.4	0.0	6.8	432	43	1	20	34	5	130	710	2	364	7.80	-47.8	23.2	807
7	7	24.6	3.8	17.3	13.2	6.2	34.3	485.0	6.4	0.0	23.1	432	53	1	30	44	13	30	940	9	370	7.90	-51.6	23.4	968
7	8	24.0	3.3	17.6	12.9	3.6	35.7	546.6	13.7	0.6	46.4	432	56	3	33	49	31	170	900	29	365	7.90	-51.2	23.5	941
7	9	27.7	3.2	17.4	13.7	0.0	33.0	397.4	3.4	0.0	33.4	432	58	4	35	56	16	250	810	9	360	7.90	-50.0	23.6	857
7	10	20.1	6.0	23.9	1735.4	0.2	35.3	367.0	7.0	0.0	21.7	432	60	5	37	64	28	350	980	23	356	7.80	-48.3	23.5	803
7	11	21.2	4.7	16.3	18.0	3.8	33.2	353.0	2.7	0.0	0.0	432	62	4	39	73	8	120	730	5	354	7.80	-47.3	23.5	788
7	12	20.8	2.6	14.9	13.8	5.8	32.2	352.3	9.1	0.0	13.0	432	64	3	41	80	21	140	740	16	347	7.90	-46.6	23.5	775
8	1	195.0	9.7	670.8	192.4	99.9	273.7	3831.9	15.9	3.2	100.1	1032	27	1	0	0	96	150	486	53	937	7.53	-29.6	17.3	2935
8	2	226.0	11.8	518.3	172.1	108.8	259.9	2400.4	10.6	2.8	108.1	1032	33	2	6	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	37	3	10	18	66	134	407	43	960	7.54	-31.0	17.5	2574
8	4	154.8	7.1	404.0	102.7	66.3	230.9	1744.0	18.3	1.1	47.3	1032	40	0	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	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	216.0	1772.2	0.0	1.4	28.6	1032	68	4	41	57	78	57	290	47	801	7.65	-37.8	17.6	1998
8	7	90.0	5.1	242.7	93.0	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	6.0	206.7	91.0	41.8	149.9	1233.2	0.0	0.6	24.6	1032	74	15	47	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	780.0	6.1	0.4	12.8	1032	76	24	49	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	0.4	5.2	1032	78	54	51	237	274	14	85	102	517	7.63	-36.5	18.0	862
8	11	68.2	5.9	84.5	46.4	24.5	60.8	409.8	0.2	0.4	0.0	1032	80	60	53	351	200	14	70	83	465	7.62	-35.6	18.0	673
8	12	57.6	2.7	68.0	39.8	25.5	46.1	311.8	0.0	0.0	9.2	1032	82	80	55	491	209	4	56	76	434	7.66	-38.2	18.0	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	11	0	0	491	720	730	170	481	7.70	-41.1	18.6	683
9	2	43.2	13.5	68.9	87.8	46.5	28.8	354.0	0.0	0.0	0.0	168	11	34	2	45	193	390	410	91	409	7.70	-49.7	18.6	413
9	3	33.5	7.5	41.9	40.6	14.9	23.0	192.1	1.2	0.0	5.3	168	13	40	4	119	68	120	360	25	397	7.80	-47.8	18.4	367
9	4	32.2	9.0	36.3	45.8	8.7	15.9	145.6	7.3	0.0	24.9	168	15	34	6	193	47	120	400	20	386	7.80	-47.2	18.5	350
9	5	33.4	4.6	30.0	26.9	10.1	14.2	151.6	2.1	0.0	20.9	168	17	21	8	249	24	280	350	10	375	7.80	-45.5	18.4	338
9	6	37.2	13.9	30.9	66.4	18.7	17.4	171.3	0.0	0.0	0.0	168	19	17	10	287	26	250	330	11	373	7.80	-45.7	18.4	325
9	7	38.3	14.8	26.9	72.6	19.2	16.2	150.6	0.0	0.0	11.2	168	21	13	12	317	33	110	410	15	374	7.80	-46.8	18.2	302
9	8	250.5	12.9	27.8	364.0	18.2	16.8	176.5	0.0	0.0	4.1	168	23	10	14	339	20	70	270	11	372	7.80	-46.3	18.4	294

Storm	Sample#	Al [mg/l]	Cr [mg/l]	Mn [mg/l]	Fe [mg/l]	Ni [mg/l]	Cu [mg/l]	Zn [mg/l]	As [mg/l]	Cd [mg/l]	Pb [mg/l]	Dry hours [h]	Raintime [min]	FLOW [l/min]	Runofftime [min]	Qt liter	TSS [mg/l]	VDS [mg/l]	TDS [mg/l]	VSS [mg/l]	COD [mg/l]	PH [s.u.]	Redox [+mv]	Temp [°C]	Cond [mS/cm]
9	9	178.2	5.2	24.2	235.5	1.7	23.7	214.8	3.6	0.0	3.6	168	25	5	16	354	18	30	310	13	376	7.80	-46.8	18.6	313
10	1	770.9	91.7	34.4	992.6	39.2	35.2	163.0	0.0	0.0	0.0	192	20	3	0	0	75	200	510	33	400	7.70	-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	0.0	192	22	5	2	7	76	230	390	36	403	7.70	-37.0	11.2	530
10	3	879.6	24.5	31.3	1009.6	24.7	32.9	139.8	8.0	0.0	0.0	192	24	6	4	18	108	230	380	38	394	7.70	-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	0.0	192	26	14	6	37	157	220	370	62	393	7.60	-35.9	11.2	401
10	5	1017.7	25.0	28.9	1218.5	0.0	22.2	101.5	9.8	0.0	0.0	192	28	24	8	75	157	180	280	72	398	7.60	-33.8	11.3	329
10	6	1150.5	102.0	37.3	1538.0	55.0	31.3	132.4	6.1	0.0	5.3	192	30	33	10	132	155	150	250	57	398	7.60	-32.5	11.4	289
10	7	1023.6	164.4	36.3	1593.2	71.9	26.4	107.6	0.0	0.0	13.4	192	32	48	12	213	153	150	200	60	394	7.60	-31.9	11.4	259
10	8	1216.1	313.2	46.7	2127.3	138.0	29.2	114.9	0.0	0.0	28.7	192	34	68	14	329	185	110	170	82	398	7.50	-30.7	11.4	222
10	9	1065.3	460.2	57.0	2592.1	205.3	32.5	114.3	0.0	0.0	0.0	192	36	80	16	476	181	140	230	72	387	7.50	-26.4	11.4	184
10	10	978.5	28.4	27.9	1251.0	10.0	21.5	104.7	0.0	0.0	0.0	192	38	70	18	626	164	50	80	69	380	7.50	-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	6.30	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	0.0	195	13	80	2	104	263	260	690	115	451	6.70	16.5	21.2	766
11	3	1156.3	8.7	75.9	1156.3	8.7	66.5	365.9	0.0	0.2	0.0	195	15	120	4	304	181	190	610	68	433	6.80	9.0	20.9	619
11	4	847.1	9.0	47.2	877.3	5.0	28.7	279.1	0.0	1.6	0.0	195	17	120	6	544	196	190	370	98	423	7.00	-0.9	20.7	427
11	5	674.7	9.3	32.1	685.9	0.0	21.8	166.6	0.0	0.7	0.0	195	19	210	8	874	163	120	230	47	382	7.20	-10.1	20.0	212
11	6	400.3	6.5	21.1	686.8	29.4	11.7	97.5	0.0	0.0	0.0	195	21	780	10	1864	101	60	130	31	345	7.30	-19.4	19.4	100
11	7	244.7	7.7	17.6	561.5	32.9	6.6	83.3	0.0	0.0	0.0	195	23	720	12	3364	67	30	70	23	334	7.40	-25.9	19.0	64
11	8	237.1	6.9	17.5	573.5	39.1	6.9	72.0	0.0	0.0	0.0	195	25	840	14	4924	53	40	50	19	320	7.50	-27.5	18.9	51
11	9	206.6	6.4	22.1	873.4	65.4	6.5	73.4	0.0	0.0	0.0	195	27	840	16	6604	48	90	150	19	309	7.50	-29.7	18.9	50
11	10	201.0	7.1	8.8	282.2	9.5	5.0	61.2	0.0	0.0	0.0	195	29	780	18	8224	45	50	80	22	319	7.50	-31.2	18.7	50
11	11	153.0	6.0	14.5	709.5	25.1	4.5	79.7	0.0	0.0	0.0	195	31	840	20	9844	35	50	60	11	308	7.50	-33.1	18.6	45
12	1	45.0	5.6	306.0	192.0	31.3	37.5	3050.0	4.4	3.6	1.3	423	10	48	0	0	532	72	119	155	464	6.70	2.4	21.2	936
12	2	25.3	3.2	12.5	48.9	7.2	9.1	49.1	0.3	0.6	0.2	423	12	54	2	96	171	126	15	54	63	7.35	-62.0	19.9	168
12	3	38.3	3.1	9.1	50.5	6.7	9.7	43.7	0.4	0.5	0.3	423	14	60	4	204	101	15	17	37	46	7.43	-59.0	19.9	114
12	4	149.0	3.5	11.9	220.0	9.2	14.7	66.5	0.5	0.5	2.5	423	16	75	6	324	110	19	13	39	46	7.51	-54.7	20.0	103
12	5	228.0	3.7	17.4	369.0	11.5	18.5	134.0	0.8	0.8	4.3	423	21	462	11	699	63	16	14	27	54	7.57	-48.5	20.1	124
12	6	41.3	3.2	14.7	76.9	9.7	17.7	118.0	0.8	1.3	0.5	423	25	100	15	2547	51	20	19	29	55	7.51	-44.8	20.1	153
12	7	237.0	4.6	27.1	485.0	13.8	30.1	232.0	1.5	1.5	5.2	423	30	120	20	3047	45	26	25	29	79	7.55	-40.7	20.3	227
12	8	48.0	3.7	29.5	113.0	14.3	33.1	287.0	1.5	2.4	0.8	423	33	140	23	3407	52	27	31	37	111	7.58	-34.8	20.4	278
12	9	152.0	4.3	27.4	258.0	16.6	35.3	284.0	1.6	2.7	2.4	423	37	130	27	3967	49	32	29	33	115	7.56	-37.5	20.6	271
12	10	408.0	5.7	33.4	863.0	16.5	43.0	263.0	1.6	1.9	10.1	423	41	180	31	4487	81	24	28	49	119	7.62	-41.1	20.4	223
12	11	37.5	3.4	18.5	90.8	9.7	29.5	173.0	1.2	2.0	0.8	423	45	450	35	5207	61	27	31	36	103	7.68	-42.1	20.2	177
12	12	46.9	3.6	16.4	281.0	10.3	26.8	149.0	1.1	2.1	0.8	423	49	130	39	7007	39	27	30	30	103	7.70	-42.7	19.9	103
12	13	68.4	6.1	21.8	141.0	13.1	31.7	165.0	1.4	5.7	1.6	423	53	78	43	7527	50	29	22	34	93	7.76	-45.5	19.9	102
13	1	10.8	0.1	17.5	73.5	27.0	15.0	192.0	0.7	0.7	0.5	102	10	240	0	0	197	0	13	87	395	6.60	-41.8	13.8	183
13	2	486.0	2.1	25.2	847.0	85.3	22.9	129.0	0.7	0.6	8.0	102	11	120	1	240	127	5	20	60	100	6.70	-39.5	13.9	118
13	3	100.0	0.5	12.7	194.0	222.0	13.8	87.6	0.6	0.6	2.0	102	13	80	3	480	111	2	17	55	86	6.90	-41.8	13.7	117
13	4	19.8	6.9	9.0	79.5	22.8	11.5	83.4	0.4	0.4	0.3	102	15	51	5	640	38	0	7	26	74	6.90	-41.8	13.6	104
13	5	23.7	-1.1	8.5	48.9	21.2	11.7	69.0	0.4	0.4	0.3	102	17	38	7	743	67	0	10	35	78	6.90	-41.8	13.6	106
13	6	18.5	-0.4	9.3	55.4	27.8	12.5	95.3	0.6	0.6	0.4	102	19	22	9	818	65	6	12	36	82	6.90	-41.8	13.5	106
13	7	21.7	-1.0	8.6	54.5	87.7	12.0	105.0	0.5	0.6	0.8	102	21	8	11	861	60	0	11	33	103	6.90	-41.8	13.5	103
13	8	26.9	-0.8	8.8	61.6	509.0	12.3	99.5	0.9	0.6	1.3	102	23	5	13	878	69	1	13	31	119	6.90	-41.9	13.5	107
13	9	24.4	-1.1	9.2	65.4	37.4	12.8	122.0	0.5	0.6	0.5	102	25	4	15	889	58	0	11	27	116	6.90	-41.9	13.5	111
13	10	25.3	-0.8	9.4	65.1	506.0	13.2	121.0	1.3	0.9	0.7	102	29	1	19	905	35	2	12	21	120	6.90	-41.9	13.4	108
13	11	828.0	6.3	26.4	1130.0	3990.0	30.6	237.0	3.4	1.5	11.8	102	33	1	23	909	31	2	15	20	108	6.90	-41.8	13.3	110
14	1	69.5	3.6	226.0	367.0	29.5	54.8	941.0	2.8	1.9	2.1	174	12	15	0	0	622	63	109	397	1035			22.0	901
14	2	36.6	2.9	101.0	572.0	25.6	63.3	514.0	1.2	1.2	2.3	174	13	30	1	15	267	40	84	174	666			22.1	764
14	3	44.0	2.7	104.0	280.0	25.6	64.0	444.0	1.5	1.4	1.2	174	14	42	2	45	186	52	91	102	711			21.8	770
14	4	60.4	1.9	94.8	258.0	24.8	60.4	390.0	1.4	1.2	1.3	174	15	42	3	87	142	44	79	70	688			21.9	745
14	5	36.2	1.0	89.9	220.0	27.4	61.4	375.0	1.3	1.9	0.8	174	17	36	5	171	94	42	88	59	660			21.9	722
14	6	46.6	1.3	89.2	222.0	37.1	65.6	349.0	1.4	1.1	1.0	174	19	30	7	243	74	44	71	59	692			22.0	740

Storm	Sample#	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
		[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[h]	[min]	[l/min]	[min]	liter	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[s.u.]	[+mv]	[°C]	[mS/cm]
14	7	54.2	2.0	98.6	249.0	75.3	69.5	378.0	1.6	1.3	1.1	174	21	24	9	303	71	45	78	55	678			22.0	749
14	8	52.0	0.9	83.6	213.0	169.0	60.0	350.0	1.5	1.2	1.0	174	23	15	11	351	51	52	86	46	669			22.0	767
14	9	43.4	1.5	84.6	246.0	23.6	66.1	355.0	1.5	1.1	1.1	174	25	12	13	381	50	55	91	50	687			22.1	756
14	10	41.7	1.8	74.7	215.0	27.4	58.2	338.0	1.6	1.0	1.4	174	27	11	15	405	45	47	90	40	693			22.0	755
14	11	37.2	2.3	80.2	229.0	57.1	64.1	391.0	1.7	1.4	1.0	174	29	5	17	426	40	46	96	40	682			22.1	790
14	12	47.2	3.8	83.8	274.0	61.6	69.3	462.0	2.0	1.9	1.5	174	32	5	20	441	50	57	97	48	693			22.0	792
14	13	331.0	5.2	89.9	728.0	140.0	81.6	606.0	2.5	2.2	9.5	174	35	5	23	456	67	48	82	51	735			22.0	782

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10 VITA

The author Simon Ringler was born in Bozen/Bolzano (Italy), to Johanna Juliane Plieger and Gernot Hugo Ringler on January 22, 1978. He graduated from “Mittelschule der Franziskaner” Middle School of Bozen/Bolzano (South Tyrol, Italy) in 1992, and from “Oberschule für Geometer, Peter Anich” technical High School of Bozen/Bolzano (South Tyrol, Italy) 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 intermediate exam (germen: “Vordiplom”) in 2001.

He also participated at courses for “Engineer of Economy in the field of Constructions” at the Technical University of Graz, Austria.

During the time studying at Universities, the author worked for technical and engineering offices as well as for construction-companies in order to obtain practical experience and knowledge in the engineering field.

He entered the Graduate Program at University of New Orleans in August, 2003 and conducted research on “Water and Wastewater Quality Monitoring Techniques” until May, 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 in the summer 2004.

On October 2004, he conducted research on “Compound-Analysis of Reinforced Concrete with Steel and Synthetic Fibers” (original germen title: “Untersuchung zum Faserverbund im Stahl- und Kunststofffaserverstärktem Beton”) in partial fulfillment of the requirements for the Master’s program in Civil Engineering, and received his academic degree of “Diplom-Ingenieur (D.I.)” at the Department of “Constructive Engineer” (germen: “Konstruktiver Ingenieur”) at the “Leopold-Franzens-University” of Innsbruck in April 2005.

In January 2006 he finished his last examination of the “Practical Engineering State Exam” in Italy, received his Engineering License, and became a member of the Italian Engineering Association.

His master thesis was honored and won the promoting price competition of the company "SCHRETTER & CIE" in January 2006 .