CHARACTERIZING WATER QUALITY AND HYDROLOGY IN FLOW FROM OUTLETS

by

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ABSTRACT

PRANAY THERGAONKAR. Characterizing Water Quality and Hydrology in Flow from Outlets. (Under the direction of DR. NICOLE BARCLAY)

During a storm event, stormwater runoff is generated, and some discharge enters outlet pipes that lead to flow in outlet channels. With the increase in flow of discharge, the volume of stormwater entering the channel increases. These discharges from outlet pipes can result in erosive damage to the subsequent outlet channel and further downstream. Along with this, various pollutants wash into the channels and deteriorate the water quality entering the receiving waters and further damages the ecology.

This research was conducted to understand the water quality and hydrology characteristics of flow from outlet pipes along with highway sites. For this work, several water quality parameters were examined, and the hydrologic response was determined along three points of the monitored outlets and their respective channels. Water samples were collected after every eligible storm event and sent for laboratory analysis. The pollutant concentration results obtained from laboratory tests were further utilized in an excel-based load estimation tool known as a simple method. The tool was deployed for the estimation of pollutant loads generated by the watershed. The simple method utilizes various data sets related to the watershed, along with pollutant concentrations, to estimate pollutant loads that can be transmitted by the water channels.

The hydrological analysis was conducted to understand the relation of rainfall to change in the water-level. This analysis can help to understand the selected channels' response to water runoff caused by rainfall. The data used for this analysis were changes in the channels' water level on a 2-minute interval and water discharge from the channel.

The results from water quality, hydrological analysis, and pollutant load estimation can be used in future studies to mitigate pollutant loads in receiving waters. The results can also contribute to planning stormwater control measures and tools that analyze outlets and flow from it.

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LIST OF ABBREVIATIONS

Pb	Lead
Fe	Iron
Al	Aluminum
Cd	Cadmium
As	Arsenic
Ni	Nickel
Cr	Chromium
Cu	Copper
Zn	Zinc
VOCs	Volatile Organic Compound
PAH	Polycyclic Aromatic Hydrocarbons
MTBE	Methyl tert-butyl ether
ortho-P	Ortho Phosphate
TKN	Total Kjeldahl Nitrogen
TSS	Total Suspended Solids
TDS	Total Dissolved Solids
total P	Total Phosphorus
$NO_3 + NO_2$	Nitrate
NPS	Nonpoint Source Pollutant
EPA	Environment Protection Agency
SCM	Stormwater Control Measures
AADT	Annual average daily traffic
ADT	Antecedent dry period
US EPA	The United States Environmental Protection Agency
RCP	Reinforced concrete pipe
NO_3–Na	Sodium nitrate
NPDES	National Pollutant Discharge Elimination System
BMP	Best Management Practice

CHAPTER 1: INTRODUCTION

1.1 Problem Statement

During a storm event, runoff flows from highways carrying various kinds of contaminants. Some of this flow is directed off pavements via structural outlets and continue into outlet channels. The runoff amasses pollutants and impacts the quality of the water discharged into the channel (Khan et al., 2006). Throughout the globe, there has been a similarity in the contaminants found in highway runoff. As indicated in various research studies organic compounds, PAHs, herbicides and insecticides, multiple chemicals, petroleum product, metals, suspended solids, and sediment are found in highway runoff (Barrett et al., 1998; Lau et al., 2009; Lee et al., 2000; Wu et al., 1998). This polluted runoff flows through outlet channels, thereby affecting the stability of nearby surrounding biodiversity (EPA, 2017).

A storm's discharge enters the channel through outlets, and there are multiple cases of private property damage for the state of North Carolina because of runoff conveyed from highways through outlets. These damages include excessive amounts of stormwater discharge carried onto private property that result in land erosion. NCDOT is responsible for managing runoff discharges that flow into the channel, which is conveyed through outlets constructed on the highway's sides. The NCDOT has the Guidelines for Drainage Studies and Hydraulic Design manual, but it only provides general guidelines for evaluating the effects of discharges from storm drain system outlets (NCDOT, 2016). Due to the absence of specific guidelines, engineers' best professional judgment is required for the outlet analysis, which varies from location to location and is case dependent (NCDOT, 2017).

For achieving the aim to minimize soil erosion, NCDOT is governed by North Carolina Administrative code 15A NCAC 04B.0109 (NC Administrative Code). These codes enforce the NCDOT to carry outlet analysis for the proper discharge of the runoff. The appropriate discharge is when the runoff discharge conveyed through the outlet is having steady and uniform flow. These infer that runoff flowing is having equal flow velocity per unit area. This uniform flow means runoff flows are within controlled and permissible discharge velocity limit, as stated in the NCDOT's Guidelines for Drainage Studies and Hydraulic Design manual. Such uniform flow passes through a water channel without causing downstream erosion. The problem with the current outlet design is that it is not able to transfer the runoff from the highway in uniform flow and increases discharge velocity the increased velocity results in downstream erosion, channel souring, and deterioration of the channel section.

Additionally, NCDOT must apply the post-construction stormwater program (PCSP) for compliance with NPDES standards from a water quality perspective. The primary goal of the PCSP is to regulate the runoff from storms by using structural or non-structural measures to protect the water quality, stop water impairment, and reduce pollutant loading. For controlling the discharges, NCDOT also implements Best Management Practices (BMP) to curtail runoff velocity.

However, concerning structural outlets, the problem of downstream erosion and water quality impairments still exists. This is the reason there is a need to understand the characteristics of flow from outlets to appropriate measures for improving water quality and flow from outlets and prevent outlet channel deterioration. This will reduce drainage related Tort Claims and settlement costs, and demonstration of regulatory compliance.

1.2 Research Objectives

This research aims to monitor and analyze the hydrology and water quality of stormwater runoff, and estimate the pollutant loading in runoff that flows from two outlets along the US 601 highway in Cabarrus County in North Carolina. This monitoring is conducted to determine the effect of runoff conveyed by the channel's selected outlet. This work will help in determining the quality of storm runoff by estimating the pollutant loading in runoff using a load estimation model.

Runoff outlets are prefabricated reinforced concrete pipe structures constructed to transfer highway runoff to the water channel. The analysis of this outlet is done using just the broad guidance from Guidelines for Drainage Studies and Hydraulic Design standard. These design standards include the velocity of runoff as a parameter and are considered responsible for channel erosion and water impairment. However, these standards do not include water quality characteristics for designing or analyzing structural outlets. This research will address the gap by covering the analysis of water quality parameters for stormwater runoff conveyed by the outlets.

The North Carolina Department of Transportation (NCDOT) is bound to comply with the National Pollutant Discharge Elimination System (NPDES) standards to curb the pollutant below permissible contaminant standards. The values obtained after analyzing the water sample will be used to estimate pollutant loads in the channel. To estimate the total annual pollutant loading for both sediments and nutrients through the channel, a pollutant estimation tool has been implemented. The results obtained from the model will help to recommend the appropriate control measure to protect drainage infrastructure from further deterioration.

This study will quantify the water quality parameters and hydrological characteristics from six monitoring stations, situated along the existing channels for two highway outlets. For the estimation of pollutant concentration, hydrological, and water quality characteristics data will be used. After the sample collection and water quality analysis, the dataset will be formed, and the data analysis will help in understanding the trend of water quality parameters obtained from the highway runoff. The following objectives for this work include the following:

1. Calculate pollutant concentrations in the channels streaming from outlets for all the monitored storm events.
2. Determine the hydrology characteristics for both the channels on which monitoring is conducted.
3. Use the Simple Method to estimate pollutant loadings in runoff flowing from the selected outlets into the outlet channels.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This literature review is conducted to show the need for research on quantifying the impacts of highway runoff conveyed by structural outlets, and its effects on the associated outlet channels. In this literature review, various topics related to the research on monitoring and analyzing stormwater runoff from highways are covered. In this section, highway pollutants are characterized, and factors that cause such impurities are described.

Additionally, the factors affecting highway runoff are classified along with various contaminants that are found in water channels adjacent to highways are explained, highway stormwater outlet for removal of runoff from pavements, and downstream impacts of highway runoff to show the driving forces behind environmental protection from stormwater runoff. For better planning to determining the appropriate type of Stormwater Control Measure (SCM), various analysis methods are explained to estimate and predict the pollutant loading of outlet channels.

2.2 Characterization of Highway Stormwater Runoff

During a storm event, runoff flows from highways carrying various kinds of contaminants. Some of this flow is directed off pavements via structural outlets and continue into outlet channels. These pollutants are a mixture of contaminants from both the highway and land within the drainage area. As this runoff carries the contaminants and enters the outlet channel, it impacts the quality of water discharged in such channels (Khan et al., 2006). Pollutants generally found in highway runoff are organic compounds, PAHs, herbicides and insecticides, volatile organic compounds (VOCs), various chemicals, petroleum products, metals, and suspended solids (Barrett et al., 1998; Lau et al., 2009).

When this polluted runoff flows through outlets and subsequently to outlet channels, it affects the conditions of the channel, surrounding biodiversity, and can be dangerous to the ecoregion.

The pollutants that are generally observed in monitoring can be classified into three major categories: physical contaminants, chemical pollutants, and biological pollutants. The types of contaminants are classified in Table 1 and are defined below.

- Physical Pollutants: These are the pollutants that primarily affect the physical appearance of runoff. These pollutants can occur from the contaminants from the highway and through soil erosion and channel scouring.
- Chemical Pollutants: These are the pollutants that have a significant effect on the chemical characteristics of water. The generation of such contaminants is usually from agricultural activity or industrial activity.
- Biological Pollutants: These pollutants have primary effects on morphological characteristics of water. They are usually the organism or microbes which grow in water and affect the stability of the water channel and subsequent water bodies. An increase in biological contaminants can also be dangerous to aquatic life present and nearby surrounding land.

Table 1. Categories of Pollutants found in Highway Runoff (Han et al., 2006)

Physical Pollutants	Chemical Pollutants	Biological Pollutants
Heavy Metals (Pb, Fe, Al, Cd, As, Ni)	TSS	Organic compound
Solids	TKN	PAH
Oil and Grease	PO_4-P	Herbicides and insecticides
Rubbers	NO_3-N	Volatile organic compounds (VOCs)
Dust	Ortho-P	MTBE

The contaminants that are found in such stormwater runoff can be described by the formula of average mass load per unit of the land surface and can be explained with the event's mean concentration of pollutant discharges (Opher et al., 2010). Event Mean Concentration (EMC) is defined as a parameter that shows the average quantity of contaminants present in the runoff and can be formulated as a total load of pollutants from runoff divided by total runoff volume (Opher et al., 2010).

To understand the impact of pollutants on stormwater runoff, the EMC of pollutants should be determined, and the results can be used to find a control measure for reducing the concentration of pollutants. A comparative study of EMCs of runoff from different stormwater monitoring research is indicated in Table 2. The variability in the ranges of the different parameters can be observed because the monitoring studies were conducted in various environments, locations, and geographic terrains.

Table 2: Comparative analysis of stormwater parameters from highway runoff (Barrett et al., 1998; Driscoll et al., 1990; Kayhanian et al., 2007; Lee et al., 2000; Wu et al., 1998)

	TSS (mg/L)	TDS (mg/L)	TKN (mg/L)	Total-P (mg/L)	Ortho-P (mg/L)
Kayhanian 2003	148.1	184.1	2.0	0.3	0.1
Lee 2000	NA	NA	1.4-13.8	1.2-10.2	NA
Wu 1998	30-283	88-216	1-1.42	0.43-0.52	0.15-0.3
Barrett 1998	19-129	NA	NA	0.1-0.33	NA
Driscoll 1990	12-135	NA	0.34-2.19	NA	NA

2.3 Factors Affecting Highway Runoff

While multiple factors affect runoff quality, some of these factors have significantly more impact on the quality of water than the others. These factors are classified into two categories: controlled and non-controlled factors, as shown in Table 3. Controlled factors are that which can be supervised, measured, and checked to reduce their effect in polluting runoff from the highway. Non-controlled factors are those which occurs naturally and cannot be controlled.

Table 3: Factors Affecting Runoff

Controlled Factors	Non-Controlled Factors
Annual Average Daily Traffic (AADT): AADT is the average total number of vehicles on the road throughout the year per day. Research studies have found a relation between Total Suspended Solids and AADT (Wu et al., 1998).	Antecedent Dry Period: ADT is the time interval between two subsequent rainfall events (Trenouth, 2017). Several studies had found a linear correlation between ADP and pollutants built up along the highway (Hewitt et al., 1992; Kim et al., 2006).
Vehicular Traffic: This can be defined as an aggregation of different vehicles which are accessing the road.	Seasonal Effect: Changes in the climatic condition directly affect the hydrological cycle of the region and the increment in rainfall increases the pollutant concentration in the channel and affects stormwater system (Thakali et al., 2016)
Street Condition: Street condition is the quality of pavement on which traffic moves and the duration in which maintenance of pavement is performed.	Antecedent Precipitation: Antecedent Precipitation is a weighted summation of precipitation volume, which is applicable to measure the moisture in the soil (Trenouth, 2017).
Type of Pavement: Pavement type can be described as the type of road (rigid and flexible pavement). This is decided based on design consideration and owner specifications.	Average Rainfall Intensity (RFI): RFI is the measure of the water layer's total height from a rainfall event covering the road surface in a time interval. It is directly related to the concentration of contaminants washed into the outlet channel.

2.4 Sources of Highway Pollutants

Various sources can be identified when determining pollutants for monitoring and analyzing event mean concentration from the runoff generated from a storm event. Contaminants sources may include accidental spills (agricultural or chemical products) and traffic accidents (oil and gas spills) (Opher et al., 2010). Pollutant sources are represented in Figure 1.

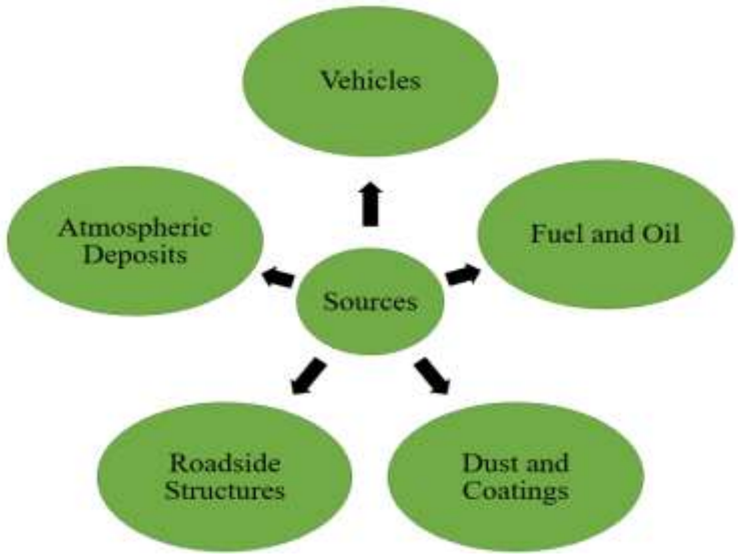


Figure 1: Sources of Highway Pollutants (Kayhanian et al., 2007; Lau et al., 2009)

2.5 Structural Outlets and Outlet Channels

Outlets are prefabricated pipe structures made of reinforced concrete that carry runoff from highways to downstream channels. The outlet's purpose is to control the velocity of storm runoff (USDA, 2010). The reason for controlling the velocity is that erosive velocity results in downstream erosion of the water channel. The downstream erosion and channel scoring cause damage to the water channel and impairment of water. This contaminated runoff water is carried from an outlet to a water channel.

In North Carolina, the NCDOT developed a Guidelines for Drainage Studies and Hydraulic Design document to follow the rules and regulations for maintaining the concentration of pollutants in runoff channels and water bodies (NCDOT, 2016). The problem with the provided guidelines is that it just indicates broad guidance about outlet erosion and does not deal with specific problems caused by the channel section's runoff outlet. Best professional judgment for evaluation of these outlets is done, which can result in the irregular assessment of outlet conditions.

The water channel is the section that carries storm runoff from the outlet to the outfall of the water creek and river basin. These channel sections are generally located adjacent to highways and directly connected with the drain networks (McCormick&Taylor, 2018). These channels are a crucial part of pavement design as it drains the pollutants from highways. The decreasing stability of the channel is due to storm runoff, which causes soil erosion, channel scouring, and water impairment.

A study done on developing an outfall crediting protocol describes the estimation of erosion from the outlet channel (McCormick&Taylor, 2018). The report analyzed the present situation of the channel by determining the dimensions (channel height, channel width, wetted width) of the channel. For estimating, the present erosion condition was compared with the possible future outcome, and the difference was considered as potential erodible pollutants.

The report recommended using control measures to reduce pollutants from entering the water channel and then determined the effect of these control measures on the channel (McCormick&Taylor, 2018). In an estimate, SCM efficiencies were calculated and found that with the 100% efficiency of SCM, a large amount of pollutants can be curtailed from entering channels.

2.6 Methods to Predict Pollutant Loads

Predictive analysis is crucial for determining and estimating pollutant loads draining into outlet channels and entering water bodies, in lieu of longitudinal monitoring studies. Several methods, techniques, and models can be utilized to analyze runoff samples and estimate the pollutant loading of runoff flowing into channels. These techniques are applied because pollutant loading is a better indicator of the total amount of soil loss due to erosion caused by runoff when compared with the pollutant concentration (EPA, 2013). These tools are utilized according to the requirement of research, availability of monitoring data, and needs of the project to which it is applied.

The EPA has categorized several pollutant load estimation and reduction models which can be used for predicting pollutant loads, ranging from simple to more complex models (EPA, 2018). These models require information such as the land type use of the monitored region, type of pollutant, type of monitoring event, and accuracy of the model in prediction of pollutant loading (EPA, 2018).

Some of the models like the NCANAT, Region 5, Simple Method, and STEPL models are described in further detail. These models are elaborated further as they closely comply with the objective of the research and type of input data in terms of pollutants, land type, and precipitation, collected during the field monitoring for this research. Besides that, these models are simple to use, are less data-intensive, and still uphold a certain level of accuracy in estimating pollutant loads.

2.6.1 NCANAT

North Carolina Agricultural Nutrient Assessment Tool is a pollutant load prediction model developed by North Carolina State University and North Carolina Department of

Agriculture & Consumer Services and the US Department of Agriculture (USDA). This tool was developed predominantly to predict the nutrient load, specifically nitrogen and phosphorus loads entering the water channel through the agricultural field (Deanna et al., 2014).

Predicting the nitrogen loading is required as the increase in nitrogen concentration can be a leading cause of water-quality impairment and degradation of water quality flowing in the water stream and channels (Deanna et al., 2001). For calculation of nitrogen loads, a tool known as Nitrogen Loss Estimation Worksheet (NLEW) is inducted into the model, which was planned to work for the field study. The worksheet's primary purpose is to estimate the nitrogen loading, which enters water channels through the agricultural field, and using the data determines the BMP for the reduction of nitrogen load (Deanna et al., 2001). This tool requires various agricultural data such as field size, soil type, fertilizer used, crop cover, realistic yield expectation (RYE), and taking this data and using the nitrogen balance equation, and the tool determines the nitrogen loads (EPA, 2018).

Similarly, another tool known as Phosphorus Loss Assessment Tool (PLAT) was introduced to estimate phosphorus loading and reduction. This tool categorized the different modes through which the Phosphorus enters the water channel. The modes of transportation from the agricultural field into the channel are through surface runoff, soil erosion, and subsurface drainages (Johnson et al., 2005). For the tool to function, it requires input data that consist of crop field information, nutrient application rate, soil data, drainage information, and hydrologic conditions (EPA, 2018). Taking the input data and the tool forms index values, these values are used to identify the phosphorus loss scenario along the region and estimates the amount of phosphorus exiting the agricultural field (Johnson et al., 2005).

2.6.2 Region 5

Region 5 is another Excel-based spreadsheet tool. It is named after Region 5 of EPA and is used to predict the pollutant loads of both sediments and nutrients which wash into the channel from agricultural fields and urban region. This spreadsheet determines the efficiency of both urban and agricultural BMPs applied to reduce pollutant loads across the regions (EPA, 2018).

The tool is used to determine the sediment load reduction and nutrient load reduction through Gully Erosion, Nutrient Reduction, and Bank Stabilization. The tool requires the following input data: Rainfall data, Type of Soil information, Soil Condition, Degree of Urbanization, Lateral Recession Rate (Soil) and type of BMP used for the reduction of loads for generating the results using the algorithms for BMP developed and created by EPA (EPA, 2018; ISDA, 2017).

For the efficient operation of this spreadsheet, few assumptions are considered. These assumptions are that the nutrients are not considered or included in load calculations, which are dissolved in runoff and flows through the water runoff. It is also assumed that stabilized condition is achieved after establishing BMPs and thus, additional loads generated after BMPs establishment are neglected and should not be considered in load calculation (ISDA, 2017).

2.6.3 Simple Method

The simple method is an Excel-based load prediction tool that uses empirical formulas embedded into the excel spreadsheet for estimating pollutant loading (Schueler, 1987). This estimation tool is usually used for both urban, semi-urban and developing areas (EPA, 2018). This tool compares two scenarios of pre-development and post-development and is relevant for the watershed, sub-watershed, forest, and urban region/area, which can have different land use (NHDES, 2008).

This tool is comparatively easy to use and needs moderate but pertinent data regarding land use. The tool requires data regarding the drainage area, concentration of pollutants, impervious cover data, precipitation date to be inserted into the input sheet (Beck, 2018). Taking the input data and using the formulas within the excel sheet the tool can estimate the pollutant loading of total suspended solids (TSS), total nitrates (TN), total phosphates (TP), biochemical oxygen demand (BOD) and other metals that might be present in runoff (EPA, 2018).

2.6.4 STEPL

Spreadsheet Tool for Estimating Pollutant Load (STEPL) is a pollutant load calculation tool developed under the guidance of the US EPA and is used to determine sediment loads and nutrient loads for various land types (TetraTech, 2018). It deploys various algorithms along with the spreadsheet for estimating the amount of pollutant load, which will be reduced or decreased after the execution of BMPs (EPA, 2018).

The tool can be used for both urban regions and rural regions and requires an adequate amount of information. For calculation of nutrient and sediment loads, the tool requires data regarding the amount of precipitation, type of irrigation, soil type, and used Universal Soil Loss Equation (USLE) for calculating the sediment loads caused due to gully erosion and stream erosion which washes into the water channel.

Taking the input data and using the formulas within the excel sheet, the tool can estimate the pollutant loading and find of estimation and calculation of watershed runoff, sediment loading, nutrient loading of both phosphorus and nitrogen (EPA, 2018). It can also compute the 5-day biological oxygen demand, along with different land types and land use. The load reduction, which results due to the implementation of BMPs, is calculated by taking the efficiency of the BMPs (TetraTech, 2018).

2.7 Conclusion

The water quality of runoff is deteriorating and the amount of pollutants entering the receiving waters is increasing. The factors that are primarily affecting the water quality are the sudden increment in peak velocity of runoff and the pollutants that wash-off from highways during rainfall events. Due to the absence of any controlling measure, there is no check on controlling the peak velocity of runoff. This runoff further deteriorates the condition on the discharge channel by entering the private properties and causing soil erosion on the surface and in the channel.

This research will contribute to addressing the gap by covering the analysis of water quality parameters for stormwater runoff conveyed by selected outlets and hydrological analysis of their outlet channels. Besides this the results obtained will also contribute to predicting the pollutant concentration of outlet channels and determine the pollutant loading generated during different storm events. Pollutant loads can have severe impacts on the biodiversity present inside the water and on nearby surrounding lands.

CHAPTER 3: METHODOLOGY

3.1 Introduction

The purpose of this research project is to assess water quality and hydrology parameters of highway stormwater runoff from two selected outlet monitoring sites to establish their baseline characteristics. Runoff quality and quantity are monitored at highway outlets and further downstream the outlet channels. The monitoring data obtained is analyzed to determine the pollutant concentrations of TSS, Ortho-P, and Nutrients in the water channel. Various criteria, including approachability, proximity, availability, and safety, discussed ahead, were used for finding ideal monitoring sites. For the scope of this work, there are two monitoring sites.

3.2 Selection of Monitoring Sites

Using historical data of highway outlets from NCDOT, a total of 19 sites were visited and observed in the Charlotte-Piedmont region located in Cabarrus County. Most of these sites were located along or in proximity to the US 601 highway. An observational study was done to identify the most optimum sites for equipment installation and monitoring of storm runoff from outlets. After the observation of all sites, the potentially workable sites were recorded for further decision for selection of monitoring sites. The two sites chosen for monitoring were in Cabarrus County, North Carolina, and shown in Figure 2. After observing sites, a well-scrutinized analysis of each site was done based on the following parameters:

- Outlet channel definition
- Length and depth of the outlet channel

- Condition of runoff outlet, and nearby surrounding area as it could create hindrance during sample collection.

Figure 2: Channel during the Fall season

3.3 Site Description

The two selected research sites for stormwater monitoring are located along the US 601 highway in Cabarrus County. The highway has an annual average daily traffic (AADT) of approximately 9,200 vehicles. The site names were designated as Site 591 and Site 573. Both sites varied in terms of location, channel size, and outlet pipe size. Site 591 is in a much more open space and has land cover ranges from the commercial areas to open developed lands, with the outlet monitoring station located with proximity to US 601 (Figure 3). Unlike this, Site 573 was situated in a wooded area with land cover includes mixed forest, deciduous forest, low development spaces.

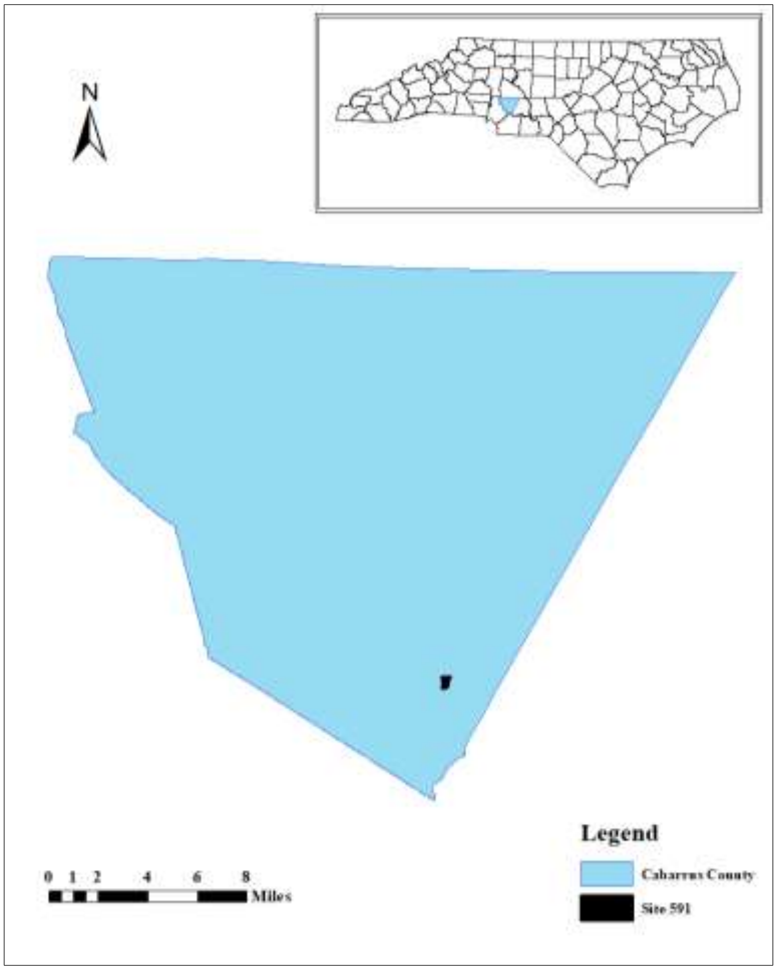


Figure 3: Site Location of Site 591

The sites' location in Cabarrus county have a typical rainfall season and receive rain all year round, with significant rainfall recorded from July to September as observed from historical data. The historical data obtained from 2011 to 2020 from USGS is shown in Table 4. The sites' location has an average annual rainfall of 12 inches more than the national average of 32.21 inches (NCE, 2017).

Table 4: Average Rainfall Data

Annual Rainfall Trend (2011-2020)		
Month	Rainfall (in)	Rainfall (mm)
January	3.07	77.98
February	2.79	70.87
March	3.21	81.53
April	3.64	92.46
May	3.75	95.25
June	4.11	104.39
July	3.31	84.07
August	4.28	108.71
September	4.00	101.60
October	3.70	93.98
November	3.50	88.90
December	4.17	105.92
Total Rainfall	43.53	1105.66

3.4 Site 591

Site 591 is identified by Pipe ID MP-013-00591 (35.25403, -80.50015) and is located near a Tractor Supply store in Cabarrus County at approximately about 19 miles from UNC Charlotte. The outlet channel is an open channel, stemming from a 48-inch diameter outlet pipe. For monitoring of runoff, three ISCO 6712 samplers were installed, as shown in Figure 5, with the first (Station 1) near the outlet, the second (Station 2) at an intermediate point of the channel, and the third (Station 3) at the outfall and represented in table 5. A 48-inch outlet pipe shown in Figure 4 shows that highway runoff is carried through a continuously eroding, unpaved channel section. The shape of the channel is in the form of a trapezoidal channel section with some change in the channel's dimensions at the different monitoring stations. At Station 1, the approximate size of the channel is 3.5 feet deep, 4.5 feet base width, and 15 feet top width. The channel dimension at Station 2 is approximately 2.5 feet in depth with the base width being 5 feet, and 8 feet top width. Station 3 has a depth of 2.5 feet, the base width of 4 feet, and a top width of 6 feet and indicated in Figures 6A and 6B.

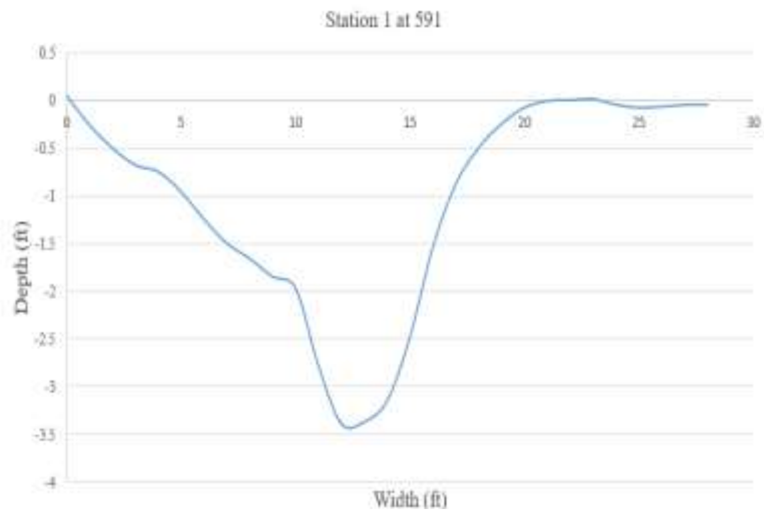
Due to easy approachability from Highway 601, the sampler can be an easy target for damage or theft. The sampler was placed in a sealed box for protection from tampering. Solar panels were used to provide the necessary power for the complete system to function.

Figure 4: The outlet for monitoring site 1(591)

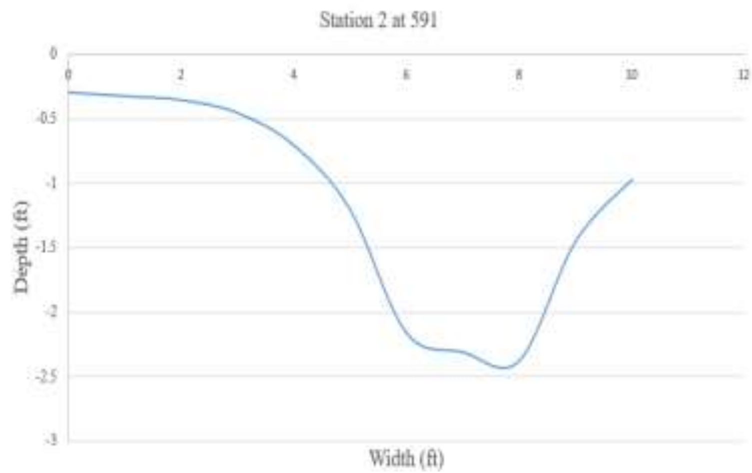
Table 5: Summary of Equipment Setup for Site 1 (Pipe ID 591)

Sampler No.	Station	Site Description	Sample Indicator	Power Source
Station 1 (Outlet)	Right next to the outlet pipe	The sampler is placed near the outlet of the channel for sample collection	Rain-Gauge	Solar panel and portable battery
Station 2 (Intermediate)	~300 feet from the outlet (Station 1)	The sampler is placed adjacent to the channel and requires portable batteries.	Level-enable	Portable batteries with systematic recharge
Station 3 (Outfall)	~700 feet from the outlet and ~400 feet from Station 2	The equipment is placed at the outfall	Level-enable	Portable batteries with systematic recharge

Figure 5: Equipment setup at Site 1(591)



6A



6B

Figure 6 (A and B): Cross Section of Channel for Site 1 (591)

3.5 Site 573

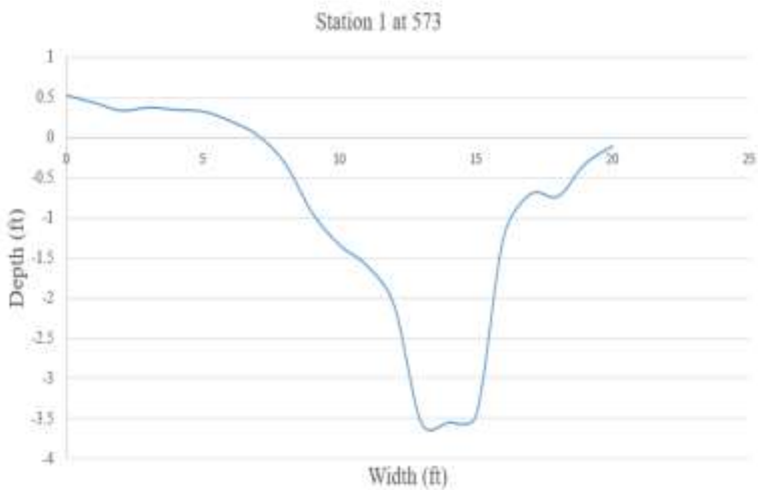
The 2nd site (Figure 7), identified from the Outlet Pipe ID MP-013-00573 (35.29624, -80.51313), is located around 15 miles from UNC Charlotte. For monitoring of runoff, three ISCO 6712 automated samplers were installed, at the beginning of the channel, at an intermediate point, and near the outfall. The site had a 42-inch outlet pipe showed in Figure 7, which carried the runoff from the highway, through an eroded, unpaved channel section.

The shape of the channel is in the form of a trapezoidal channel section with a change in the channel's dimension at different monitoring stations. At Station 1, the approximate size of the channel is 3.5 feet deep, 5 feet base width, and 13 feet top width. The channel dimensions at Station 2 are approximately 4 feet in depth, 5 feet base width, and 10 feet top width. Station 3 has a depth of 3 feet, a base width of 7 feet, and a top width of 10 feet. These are indicated in Figure 8A 8B and 8C.

Figure 7: Representing the channel and outlet for monitoring Site 2 (573)

Table 6: Summary of Equipment Setup for Site 2 (Pipe ID 573)

Sampler No.	Station	Site Description	Sample Indicator	Power Source
Station 1 (Outlet)	Right Next to the outlet pipe	The sampler is placed uphill over the channel for the collection	Rain-Gauge	Solar Panel and portable batteries
Station 2 (Intermediate)	550 feet from the outlet (Station 1)	The sampler is placed adjacent to the channel and requires portable batteries.	Level-enable	Portable batteries with systematic recharge
Station 3 (Outfall)	1500 feet from the outlet and 950 feet from Station 2	The equipment is placed at the outfall	Level-enable	Portable Batteries with systematic recharge



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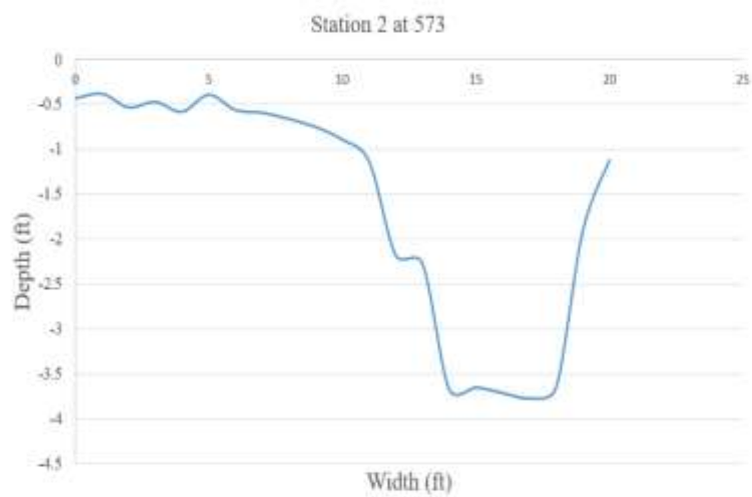

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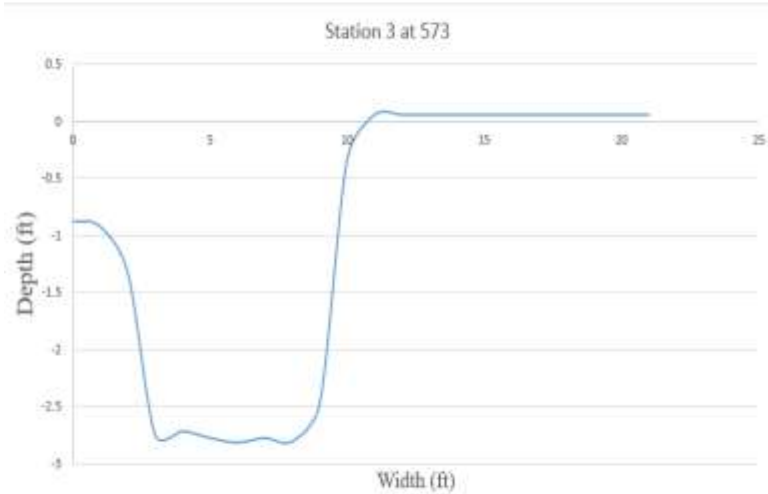


8C

Figure 8 (A, B, C): Cross Section for Channel for Site 2 (573)

3.6 Materials and Methods

3.6.1 Data Collection

Subsequent site visits provided detailed observations for the monitoring site and helped to developed site-specific equipment setup plans. For the research, an automatic sampler ISCO Teledyne (6712 Full-Size Portable Sampler) was set up at each monitoring station, and it is used for collecting water samples and hydrology data from the outlet channel. During the sampling for the different parameters (TSS, Ortho-P, and nutrients), they were collected in different sampling bottles and are submitted to the laboratory for determining and analyzing the pollutant concentration for parameters. Characterization of these parameters helped in deducing the pollutant loading and concentrations in the channels streaming from outlets for all the monitored storm events. This also determines the changes that may occur at outlet, intermediate, and outfalls in terms of water quality and hydrology, and helps establish the relationships between monitored pollutants, such as TSS, TN, and Ortho-P.

The equipment that is set up at the monitoring site for collecting the water samples from the channel includes ISCO 730 bubbler module, ISCO 6712 automated sampler, and a rain gauge. The rain gauges were connected to the sampler to measure the amount of precipitation from rainfall events, at both sites (Sites 591 and 573). Once the required precipitation level was achieved, the sampler was activated. Subsequent stations were fixed with level enabler for the collection of samples.

3.6.2 Sampler

The components of an ISCO 6712 Portable Sampler are shown in Figure 9 below. The sampler consists of a one 10-liter Nalgene bottle, which holds the samples of runoff. The sampler is powered using a 12 V deep cycle marine battery charged by a 20 W solar panel. These batteries power the sampler's pump to suck the water from the stream during the storm runoff using a pipe that is being placed in the channel section. The complete unit is placed in a closed enclosure to outlet, intermediate, and outfall station to protect from soil and animal movement, harsh weather, and theft.

Figure 9: ISCO 6712 Sampler with 730 Flow Bubbler Module

3.6.3 Laboratory Analysis

After the collection of water samples from the assigned stations, it was shipped to NCSU Center for Applied Aquatic Ecology (CAAE) Laboratory for analysis of water quality characteristics. The water parameters that are selected are Total Suspended Solids (TSS), Nutrients, and Ortho-P.

Table 7: Limit Standards for Parameters

Water	**Pollutant**	**Analytical Method**	**Reporting Limit**
Water	TKN	EPA Method 351.2	280 µg/L
Water	$NO_{2\text{-}3}$-N	Std. Method 4500 NO3 F EPA Method 353.2	5.6 µg/L
Water	TN	-	-
Water	O-PO_4^{3-}	Std. Method 4500 PF EPA Method 365.1	6 µg/L
Water	TP	Std. Method 4500 PF EPA Method 365.1	10 µg/L
Water	TSS	Std. Method 2540D	-

3.7 Sample Collection and Data Analysis Methods

During a storm event the sudden increment in water level flowing in the channel and peak velocity of runoff can result in downstream erosion of channel, scouring of the channel, and channel flow path, damaging the channel's stability. For further understanding, the effect of hydrological analysis and water quality monitoring was conducted.

Table 8: Sample Monitoring

Hydrology	• Data was collected using an ISCO 730 bubbler module. • Rainfall data was collected using a manual rain gauge and ISCO 674 tipping bucket rain gauge, which was installed at each outlet point with an area free of overhead obstructions. • All monitoring equipment recorded data on a two-minute interval. • The data was collected after each storm event (rainfall ≥ 0.10 in with minimum antecedent dry period (ADP) of 6 hours).

Water Quality	• Flow-proportional samples were collected using an ISCO 730 bubbler module, ISCO 6712 automated sampler, which were connected to rain gauge or level-enabled sampler.
	• The water sample handling requirements and analysis laboratories:
	  ○ Nutrient Samples: total Kjeldahl nitrogen (TKN), nitrate + nitrite nitrogen ($NO_{2\text{-}3}$-N), total nitrogen (TN), orthophosphate (O-PO_4^{3-}), total phosphorus (TP), total suspended solids (TSS)
	  ○ NCSU Center for Applied Aquatic Ecology (CAAE) Laboratory
	  ○ Container- TSS: 1 L Nalgene bottle; Nutrients: 125 mL pre-acidified (H_2SO_4) plastic bottle; O-PO_4^{3-}: 60 mL glass bottle (20 mL removed from TSS bottle and passed through a 0.45 µm filter)
	  ○ Preservation- Put on ice and chilled to ≤ 4°C
	  ○ Maximum holding time- O-PO_4^{3-}holding time is 48 hour, holding time for TSS is seven days, and 28 days for all other parameters (TP, TKN, $NO_{2\text{-}3}$-N, TN)
	  ○ TN was calculated using the respective TKN and $NO_{2\text{-}3}$-N samples.
	  ○ All data will be reported in µg/L.
	• Nutrient samples were stored in the corresponding bottles following procedures as provided by NCSU CAAE.

The hydrology analysis was conducted to determine the water discharge, which drains in the channel during the storm event in the form of runoff. To determine the discharge along the channel, changes in water level is measured for each site were calculated using data from the ISCO 730 bubbler module. Along with this, a laser level survey was conducted to determine the cross-section of the channel. After finding the dimension of the channel, the shape of the channel was determined. In this research, the shape of the channel was found to be generally trapezoidal. Taking the data from the laser-level survey and bubbler module, Manning's equation was used to find discharge from the water level.

1) Discharge (Q) = $\left(\frac{1}{n}\right) * A * R^{\frac{2}{3}} * \sqrt{S}$, where,

n = Manning's constant

A = Cross-sectional area of the channel,

H * (T + B)/2

H = Height of water level

T = Upper Base of Channel

B = Lower Base of Channel

R = Hydraulic Radius (A/P)

P = Wetted Perimeter, $(B + 2) * \sqrt{H^2 + (\frac{T-B}{2})^2}$

S = Slope of Channel

3.8 Pollutant Load Estimation

The Simple Method is a pollutant load estimation tool which is used to predict the pollutant loads generated by watersheds or developing areas (EPA, 2018). In terms of this study, the calculation of loading was important to understand the amount of soil erosion. The data obtained from the method is useful in determining the type of control measure required for the channel to mitigate the soil erosion and reduce the loading from entering receiving waters.

The tool of relevance to this research, the Simple Method, works even with the availability of limited data. Given the scenario of this research, only five storm events were recorded during the monitoring study. This tool is applicable to the watershed, sub-watershed, forest, and urban region/area, which can have different land use (NHDES, 2008). Another reason for the choice of this tool was the approach of the method to eliminate the bias which could occur due to the co-relation between the storm runoff and pollutant concentration. Such bias when occurring in the method could cause problems in estimating accurate pollutant loadings. This model helps to determine the load generated by any specific land type and allows the break-up the land use type in different categories including commercial, agriculture, roadways, residential (NYSSMDM, 2004). This land breakup helps to understand the loading generated and thus assist in the planning of any specific control measure. Besides that, this method was developed in such a manner that it can use any monitoring dataset for estimation of loads and can be easily modified according to changes in the condition of location or concentration of pollutants.

This model uses an empirical approach for calculating the pollutant loading from the storm runoff (EPA, 2018). For calculating the chemical constituents, the following equation was used.

$L = 0.226 \times R \times C \times A$

L = Annual loads (lb)

R = Annual runoff (inches)

C = Pollutant concentration (mg/l)

A = Area (acres)

0.226 = Unit conversion factor

For the calculation of chemical constituents, the values of pollutant concentration (C) was obtained from the dataset of monitored water quality samples. The area is the watershed area, which contributes to the pollutant loading in the channel. For the calculation of Annual Runoff (R), the following equation was used:

$R = P \times P_i \times R_v$

R= Annual runoff (inches)

P = Annual rainfall (inches)

P_i = Fraction of annual rainfall events that produce runoff

R_v = Runoff coefficient

Annual rainfall (P) data was obtained from the nearby USGS rain gauge station. Other than that value of the Fraction of annual rainfall events that produce runoff is a constant value with a numerical equal of 0.9. This value is constant for all the cases where the Simple Method is applied. The value of the runoff coefficient (R_v) was determined by using the following equation.

$R_v = 0.05 + 0.9I_a$

R_c = Runoff coefficient

I_a = Percent impervious area draining in stream

The value of I_a was found from the impervious land cover data of watershed. After using this data, the values obtained from equations will help in estimate loading for the site.

3.8.1 Estimation Procedure

For pollutant load estimation, the Simple Method was used. The following data was required for calculating the load: annual runoff, pollutant concentration, area, annual rainfall, runoff coefficient, and percentage of impervious area. The following stepwise procedure was used for obtaining, determining, and utilizing the required data.

1. First, the total rainfall from the storm-event and pollutant concentrations were determined through the field monitoring.

2. For finding the total area of the watershed, ArcGIS was used. The data used for determining the watershed was from United States Geological Survey (USGS's) Digital Elevation Model (DEM) for the state of North Carolina.

3. The DEM for the Cabarrus county was obtained by clipping the layer from the North Carolina's DEM data layer.

4. For watershed delineation, these steps were followed:

a) The flow direction tool was used to form a raster grid which contains the information of flow direction.

b) The sink tool was used to find all the sinks present in the DEM, and the fill tool was used to cover all the sinks.

c) The flow direction tool was used to provide the integer raster for the stream's direction of flow.

d) Then, the flow accumulation tool was used to tabulate the flow of the stream.

e) The source raster was then formed which was used for watershed delineation.

f) The conditioning tool was used to create the stream network which will be flowing in the watershed.

g) The network tool was used to create unique values for each stream in the network.

h) The watershed was then delineated using the watershed tool and using the flow direction data and stream link data.

i) The area of the watershed was calculated using the tool "calculate geometry" in the attribute table of the map.

5. After determining the watershed area, it was required to find the watershed's rainfall coefficient. As the formula indicates rainfall coefficient is dependent on the percentage of impervious area.

6. The land cover data layer was obtained from Multi-Resolution Land Characteristics Consortium (MRLC) for finding the percentage impervious cover.

7. The land cover layer was imposed over the watershed layer, and different land types were determined.

8. After determining the land cover, another layer of imaginary was utilized to determine the impervious land area and determine the percentage imperviousness.

9. All the obtained values are inserted in the excel-based Simple Method model, and the pollutant loading was calculated for the required pollutants.

The other value that was required for finding the total pollutant loading was pollutant concentration. For the finding pollutant concentration in the channel, the runoff samples were collected after a storm event (rainfall ≥ 0.10 inches) was observed. After the collection of these samples, chemical analysis was conducted on them. After chemical analysis, the value of pollutant concentration for each rainfall event was obtained. For this research, a total of five rainfall-events were sampled for three months.

The concentration values provided after the chemical analysis was used to insert into the spreadsheet of a simple method. The output obtained from the simple method was the total pollutant loading that would flow through the outlet channel.

CHAPTER 4: RESULTS AND DISCUSSION

This chapter includes results and analysis of the obtained monitoring data and pollutant load estimations. The hydrology section consists of determining the relationship between discharge, calculated from the changes in the water level of the channel, and rainfall occurrence. The results from this hydrological analysis can contribute to decision making for control measures required to curtail the peak velocity of water runoff which results in reducing downstream erosion. For further understanding of the effect of channel impairment, water quality was monitored. The concentration of different parameters (TSS, Ortho-P, and Nutrients) was compared for the two monitoring sites.

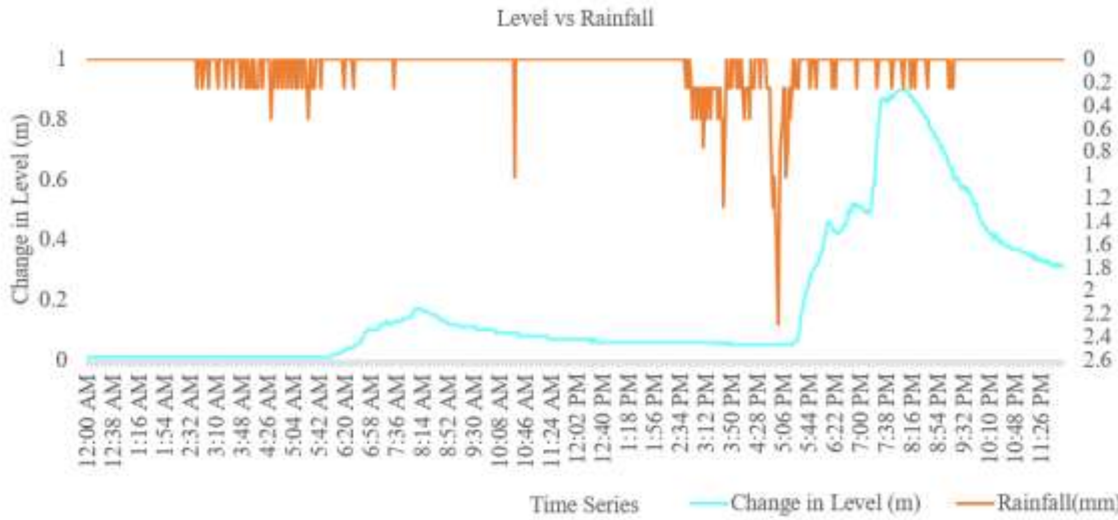
After the chemical analysis was conducted on pollutant samples collected during the monitoring, the values of pollutant concentrations of each storm event were obtained. The concentration value from the monitoring was used for finding the total pollutant loading for the channel. Results from water-quality will help in understanding the total pollutant entering the receiving waters. This loading will also be used to understand the amount of soil erosion occurring the channel and deteriorating the water quality characteristics.

4.1 Precipitation and Flow

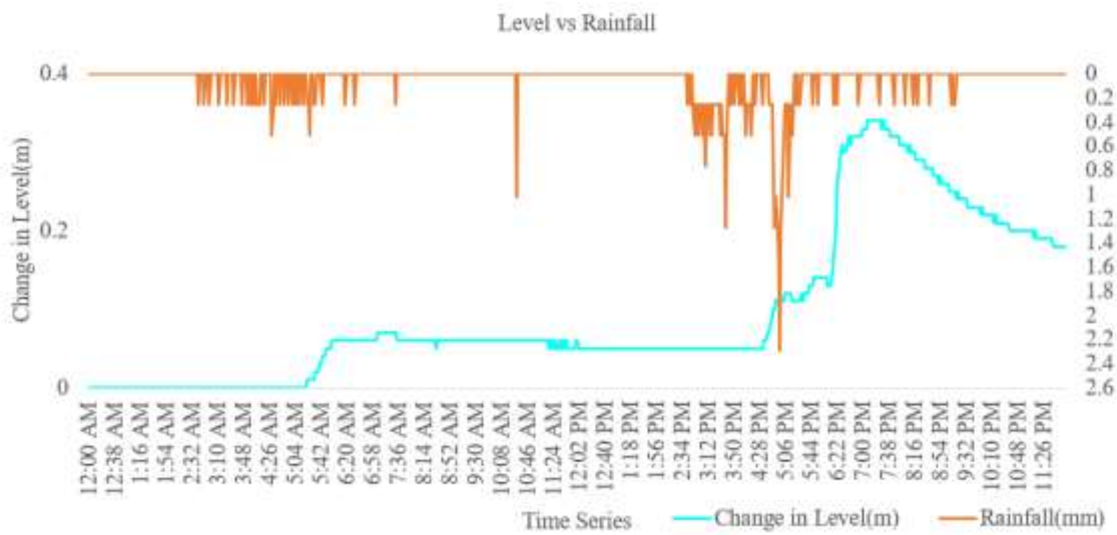
The monitoring was rain-dependent, and the samples were collected only after a significant rainfall event (for this study, rainfall ≥ 0.10 inches with the minimum antecedent dry period of 48 hours). Table 9 indicates the set of rainfall data observed during the collection of runoff samples. The rainfall data were cross-verified from precipitation data of closest United States Geological Survey (USGS) rain-gauge, situated at Rocky River Wastewater Treatment Plant, Concord, NC, with a proximity of 7 miles from the sites.

Besides the rainfall data, flow discharge data, as shown in Table 9 was calculated for the outlet channels using water level data recorded by the ISCO 730 bubbler flow module. This data is used for determining the correlation between rainfall and change in the water-level. The autosampler collects the data from the bubbler flow module to determine the changes in channel water levels for 2-minute increments and rain-gauge for finding the rainfall amount during the storm. Using the data from the storm event of January 24, 2020, a time series plot was graphed in Figure 10 A to show an example of the change in water level in the outlet channel over the course of the rainfall event. The reason for choosing the rainfall event of January 24, 2020, was due to the higher rainfall intensity when compared to other rainfall events observed during the monitoring period, duration of the total rainfall event, and the antecedent dry period. From Figure 10, it can be easily observed that the water level in the channel increases with an increase in rainfall intensity. From Manning's equation, it can be inferred that an increase in water level directly results in an increase of runoff discharge in the channel.

These increments in discharge are causes due to an increase in peak velocity of runoff during the storm-event. This sudden increment in peak velocity in the channel disturbs the surface of channel and channel bank and results in downstream erosion in the channel, damaging the shape and quality of water flowing through this channel. Along with that, the relation between the change in water-level and rainfall will additionally help in analyzing the channel's response to water runoff caused by rainfall. This type of analysis is useful in understanding the effect on channels caused by rainfall and determining the preventive/control action such as the implementation of stormwater control measures or along the water channel or at suitable points in the watershed for reducing downstream erosion and scouring in the channel.



Site 591 (A)



Site 573 (B)

Figure 10 (A & B): Time series plot for storm-event for Site 591 & 573

Twelve storm-events were observed for Site 591 to find the relationship between the change in water-level and rainfall events. The monitoring period was conducted from December 2019 until March 2020 and the values of these samples are indicated in Table 9.

The table consists of rainfall data, a change in water level, the dry period between two rainfall events, and water discharge during the rainfall event.

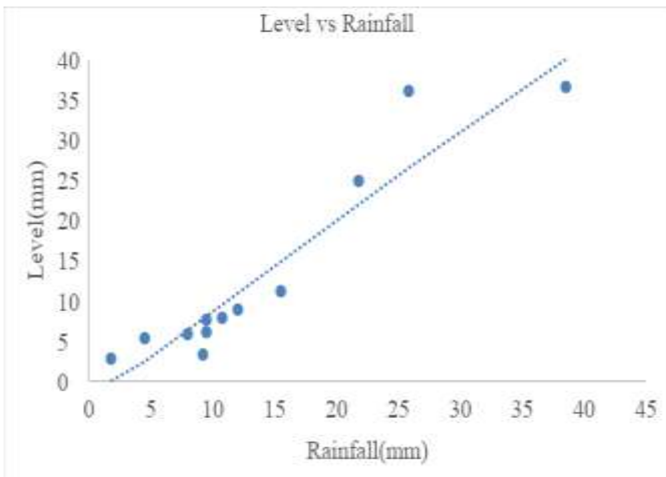
Table 9: Water level data for different storm-events

Rainfall Date	Rainfall(mm)	Average level (mm)	Dry Period (Days)	Discharge (cm^3/s)
12-13-19	36.07	25.82	2	1.15
12-17-19	8.89	12.02	4	0.32
12-22-19	7.87	10.75	9	0.26
01-02-20	7.62	9.48	6	0.21
01-11-20	5.84	7.96	1	0.16
1-13-20	24.89	21.78	7	0.87
1-24-20	36.58	38.52	6	2.20
1-31-20	11.18	15.49	4	0.49
05-02-20	2.79	1.77	4	0.02
11-02-20	5.33	4.50	1	0.07
2-13-20	6.10	9.48	4	0.23
2-18-20	3.30	9.20	4	0.02
Mean	13.04	13.90	4.36	0.50
St. Deviation	12.29	10.26	2.5	0.64

Observing Table 9, a general trend is predicted for the relation between rainfall and change in water-level during the rainfall event for the channel of Site 591, and a similar relationship is observed for the channel of Site 573. Subsequently, a similar trend can be observed for the rainfall and runoff discharge. Figures 11A and 11B show a scatter plot distribution along with the changes in water-level vs. rainfall, and it is observed that with an increase in rainfall, the water level in the channel also increases. The R^2 value of 0.89 and this indicates a high positive linear association between rainfall and change in the water-level of the channel.

From Table 9, it can be observed that with changes in rainfall, there will be changes in the runoff level flowing in the channel during the storm event. This relationship of rainfall and changes in water level represented in Figure 11 shows the extent to which the rainfall is directly related to the amount of runoff that has been discharged in the channel. Using manning's equation and the relations of rainfall vs. changes in water level shows that the rainfall is directly related to the amount of runoff discharged into the channel.

The value of the runoff coefficient can be determined using data of rainfall and change in the water-level as it relates to discharge. The coefficient values will be one of the critical factors determining the type of stormwater control measure that will be required to mitigate erosion in the channel.



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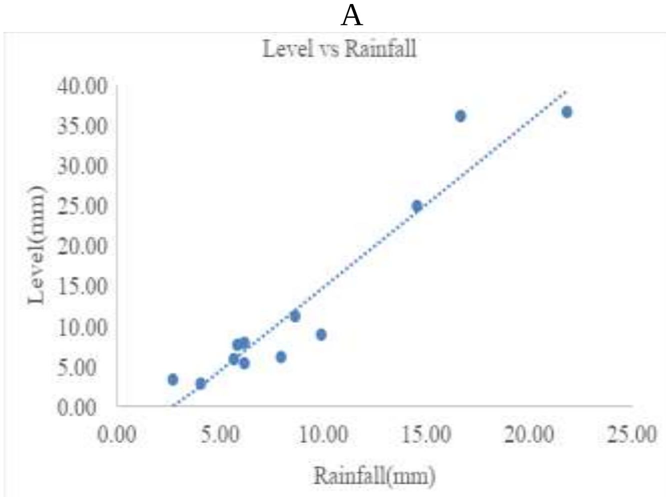

B

Figure 11: Level vs Rainfall for Site 591& Site 573

4.2 Channel Pollutant Concentration

The main research objective is to determine and quantify the water quality parameters of storm runoff from the monitoring channel Site 591 and Site 573. NCSU Center for Applied Aquatic Ecology (CAAE) Laboratory conducted the laboratory analysis on the samples, and the results of different parameters are indicated from Tables 10 to 12.

The water quality data in Tables 10, 11, and 12 are segregated according to the sample collection technique used during sample collection. For data analysis, Excel was used. The resulting graphs were plotted between the period of rainfall and the concentration of water parameters from both outlet channels at Sites 591 and 573 situated at Cabarrus County, NC.

The pollutant concentration for all parameters across the channel was determined and then categorized into three significant parameters, which are TSS, Ortho-P, and nutrients (TKN, TP, NO_3-NO_2, NH_3-N) that needs to be analyzed for determining the changes that may occur at the outlet, intermediate, and outfall. The obtained values are compared with the EMC estimates of the average EPA, NPDES, and NURP (Smullen et al., 1999). These values are pooled averages of national databases that have collected the pollutant concentration data for more than 20 years. This database enhances the accuracy of previously obtained databases and provides better mean concentration. Using these values to compare with the current results help to understand the condition and response of the channel to the storm runoff.

Table 10 indicates the concentrations of TSS that were collected from runoff for the different storm events. The data of all the stations are collected and converted into a graphical representation, as indicated in Figure 12, to show TSS's trend.

Table 10: Concentration of Total Suspended Solids (TSS)

TSS (mg/L)						
Date	591-1	591-2	591-3	573-1	573-2	573-3
12-11-19	15.66	9.84	16.41	29.52	18.67	9.38
2-3-20	21.89	12.77	21.97	22.17	-	23.80
2-11-20	25.57	55.18	-	44.76	-	121.00
2-14-20	73.20	36.01	52.67	-	-	-
2-26-20	10.97	23.83	91	-	-	-

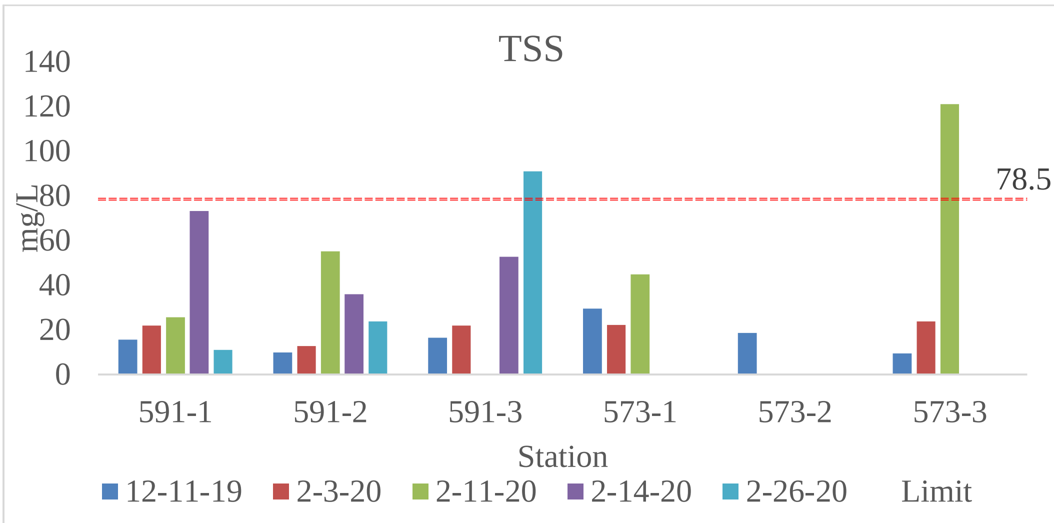

Figure 12: Trend of Total Suspended Solids (TSS) for Site 591 and Site 573.

The graph and Table 10 indicated the TSS concentration for both Site 591 and Site 573. The red line represents EMC of TSS found by pooled average of NURP, NPDES and EPA data. The peak value of concentration for Site 591 was 73.2 mg/L, and the sample was collected from station one on February 14, 2020. The least concentration for the site was 9.48 mg/L, and the sample collected was from station two on December 11, 2020. The average concentration of TSS for Site 591 is 34.71 mg/L.

The peak value of concentration for Site 573 is 121mg/L was achieved at station 3 for the storm event of February 11, 2020. The least concentration was collected from station 3 for the storm event of December 11, 2019, with a value of 9.34 mg/L, and the average concentration of TSS for Site 573 is 38.52 mg/L.

The values of TSS concentration obtained are represented in Figure 12. From the results, it is observed that most values of concentration obtained during different storm events were lower than the observed EMC limit of 51 mg/L for rural highways indicated in the NHDES load estimation manual. Although the overall concentration of TSS for both the sites is low, few events observed from station 3 of both sites crossed the average value of EMC.

A constant trend can be observed that station 3 of Site 591 generally had a higher pollutant concentration when compared with station 2 of Site 591. This shows that while coming downstream the storm's runoff is carrying more pollutants than upstream which indicates the channels' response towards the flow of runoff and an indicator that channel is not able to mitigate the damages caused due to the flows. The result of these runoff flows is soil erosion in the channel, causing distortion in the channel's stability. One of the reasons for such increment is the slope of the channel. During the laser-level surveying, the channel slope was determined by finding the levels at two different points of the station and divided them by the distance between those points. It was found that station 2 had a slope of 0.052 ft/ft which was almost double than slopes of station 1 (0.024 ft/ft) and station 3 (0.027 ft/ft), hence the velocity of runoff increases from station 2 to station 3. It was also observed that the channel is located near the open lands with no barrier to curtail the flow of runoff. Thus, it indicates that differences in concentration for stations are also due to difference in the land use type around the stations.

Looking at Table 10, it can be observed that a few data points are missing from the table. There are several factors were responsible for the lapse of such data-points:

- Equipment Malfunction: In a few cases, the sampler was unable to collect the samples due to false alarm of error in the device due to which the sampler stopped sampling of runoff from the channel.
- Error in the calibration of equipment: In the case of the intermediate monitoring site for Site 573, the level enabler technique failed to work for the collection of some samples. Even with few adjustments with the flow volume indicator of equipment, it never showed positive results in the collection of samples, thus the data was missing.

The concentration of Ortho-P is indicated in Table 11 and graphically represented in Figure 13. The graphs show the trend that has been followed by different stations of both channels for different storm events.

Table 11: Concentration of Orthophosphate (Ortho-P)

Ortho-P (mg/L)						
Date	591-1	591-2	591-3	573-1	573-2	573-3
12-11-19	0.03	0.011	0.015	0.033	0.027	0.01
02-03-20	0.019	0.017	0.041	0.017	-	0.024
02-11-20	0.018	0.016	-	0.083	-	-
2-14-20	-	-	-	-	-	-
2-26-20	0.019	0.014	0.03	-	-	-

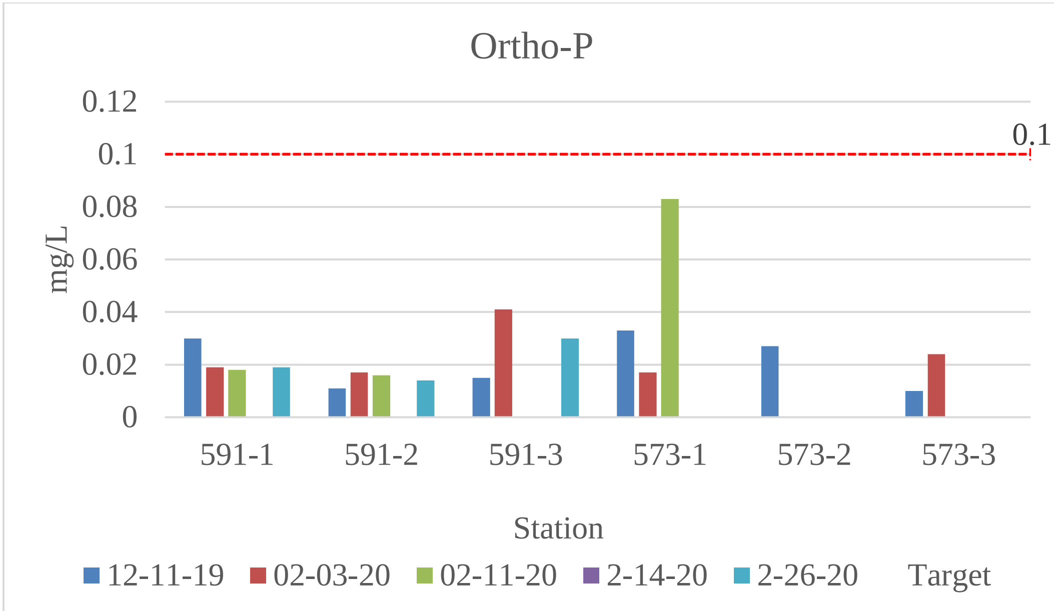

Figure 13: Trend of Orthophosphate (Ortho-P) for Site 591 and Site 573.

The red line represents EMC of Ortho-P found by pooled average of NURP, NPDES and EPA data. From the graph, the peak value of concentration for Site 591 was 0.041 mg/L obtained from station 3 for February 03, 2020 storm event, and the least concentration collected was 0.011 mg/L for storm event of February 11, 2020. The average concentration of ortho-P for Site 591 is 0.22 mg/L. The same was repeated for Site 573 with the peak value of concentration for Site 573 was collected on station 1 with a concentration value of 0.083 mg/L, and that was achieved at station 573-1 for the storm event of February 11, 2020. The least concentration was collected from station 3 for the storm event of December 12, 2019, with a value of 0.01 mg/L, and the average concentration of ortho-P for Site 573 is 0.032 mg/L.

The values of concentration obtained from both the channels are lower than the average EMC of 0.1 mg/L for highways (Smullen et al., 1999). An initial trend can be observed with an increased concentration of Ortho-P along with the downstream. For Site 591, a significant increase in pollutant concentration at station 3 can be observed when compared with concentrations of station 2. The reason for that is the slope of station 2 and the land type from station 2 to station 3. It indicates that the channel is not able to mitigate the concentration of pollutants along downstream. If this trend of increment of pollutants continues it can start the process of eutrophication in water. This process of eutrophication absorbs the present dissolved oxygen from the water due to the growth of algae over the water body and hinders the sunlight from entering the water body. Such a situation can be dangerous to aquatic life present in the water body.

The samples of nutrients (TKN, NO_3+NO_2, NH_3-N, TP) were collected along with TSS and Ortho-P. After the samples were collected, they were sent for lab analyzes, and the result of concentration are indicated from Table 12 to table 15. The trend of pollutants for the different station can be observed from figure 14 till figuring 17

Table 12: Concentration of Total Kjeldahl Nitrogen (TKN)

TKN	591-1	591-2	591-3	573-1	573-2	573-3
12-11-19	0.601	0.664	0.847	0.935	0.876	0.633
02-03-20	0.671	0.6	0.658	0.712	-	0.79
02-11-20	0.846	0.907	-	0.761	-	0.761
02-14-20	0.713	0.513	0.681	-	-	-
2-26-20	0.563	0.614	1.078	-	-	-

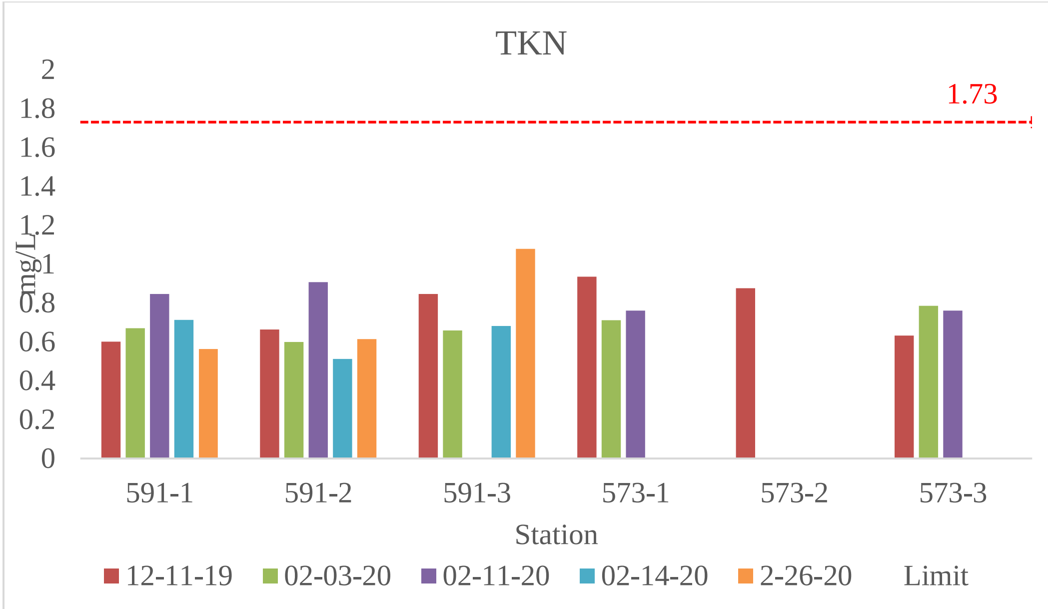

Figure 14: Trend of Total Kjeldahl Nitrogen (TKN) for Site 591 and Site 573.

The concentration of total kjeldahl nitrogen (TKN) present in stormwater is shown in Table 12 and represented in Figure 14. The red line in Figure 14 represents EMC of TKN found by pooled average of NURP, NPDES and EPA data. The peak value of the concentration of TKN for Site 591 was 1.1 mg/L collected from Site 591-3 on February 26, 2020. The least concentration of 0.52 mg/L was collected from station 591-2 for the storm event of February 14, 2020. The Site 573 had the highest concentration of 0.88 mg/L recorded from station 1 and the least concentration of .633 mg/L. All the observed values of TKN are lower than the average EMC values of 1.73 mg/L observed from the pooled estimated data of EPA, NPDES, and NURP (Smullen et al., 1999).

The concentration values for total phosphorus (TP) are indicated in table 13 and the trend for the concentration is shown in Figure 15. A similar trend of TSS and ortho-P was observed in the graph.

Table 13: Concentration of Total Phosphorus

TP	591-1	591-2	591-3	573-1	573-2	573-3
12-11-19	0.111	0.085	0.101	0.159	0.127	0.072
02-03-20	0.119	0.102	0.142	0.094	-	0.141
02-11-20	0.152	0.156	-	0.169	-	-
02-14-20	0.213	0.135	0.189	-	-	-
2-26-20	0.076	0.095	0.175	-	-	-

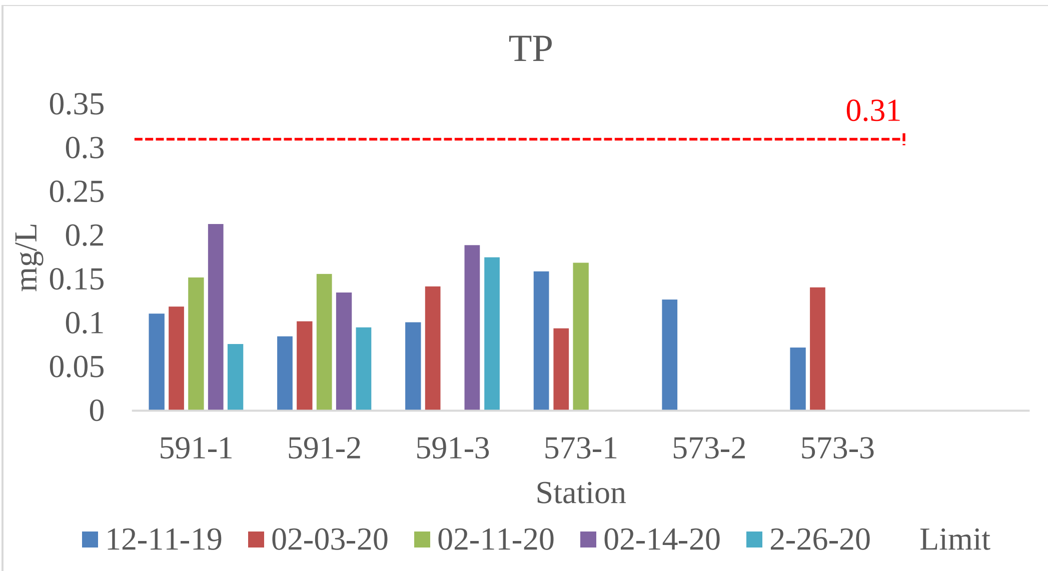

Figure 15: Trend of Total Phosphorus (TP) for Site 591 and Site 573.

The concentration of TP present in stormwater is shown in Table 13 and represented in Figure 15. The red line represents EMC of TP found by pooled average of NURP, NPDES and EPA data. The peak value of the concentration of Site 591 for TP was 0.213 mg/L collected from station 1 on the storm event of February 14, 2020. The least concentration of 0.076 mg/L was collected from station 1 for the storm event of February 26, 2020. The Site 573 had the highest concentration of 0.169 mg/L recorded from station 1 and the least concentration of 0.072 mg/L. All the observed values for TP are lower than the average EMC values of 0.31 mg/L observed from the pooled estimated data of EPA, NPDES, and NURP data. But the trend of increment is pollutant concentration is observed when the runoff flows downstream from station 2 to station 3.

The concentration values for Nitrates ($NO_3 + NO_2$) are indicated in table 14 and the trend for the concentration is shown in Figure 16.

Table 14: Concentration of Nitrates and Nitrites

$NO_3 + NO_2$	591-1	591-2	591-3	573-1	573-2	573-3
12-11-19	0.339	0.262	0.33	0.19	0.127	0.128
02-03-20	0.275	0.214	0.31	0.091	-	0.235
02-11-20	0.374	0.353	-	0.114	-	
02-14-20	0.174	0.168	0.197	0.175	-	-
2-26-20	0.192	0.2	0.317	-	-	-

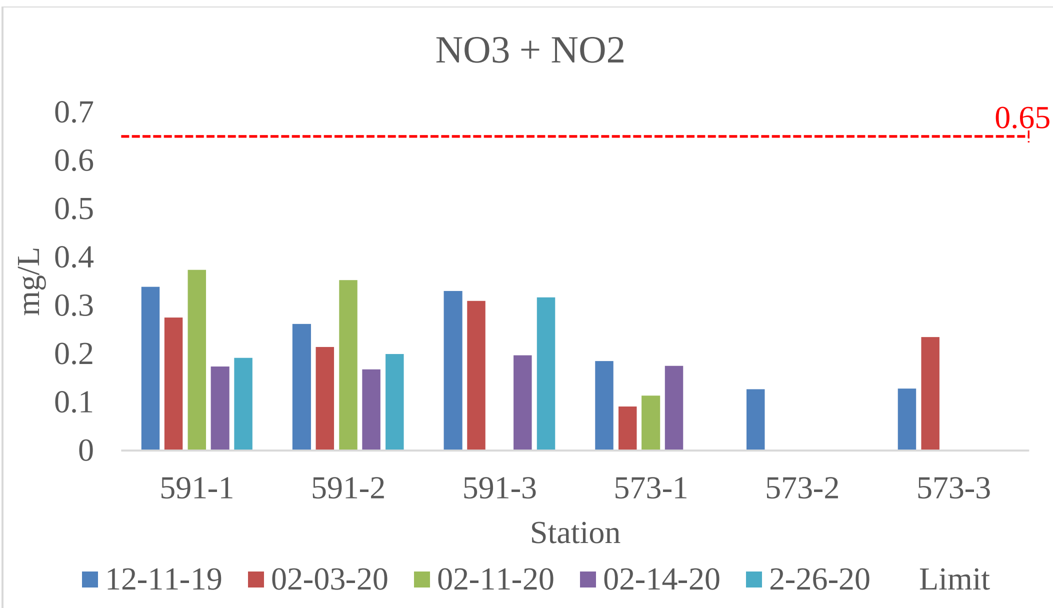

Figure 16: Trend of Nitrates and Nitrites for Site 591 and Site 573

The concentration of $NO_3 + NO_2$ present in the runoff is shown in Table 14 and represented in Figure 16. The red line represents EMC of Nitrate found by pooled average of NURP, NPDES and EPA data. The peak value of the concentration of Site 591 for $NO_3 + NO_2$ was 0.374 mg/L collected from station 1 for the storm event of February 26, 2020. The Site 573 had the highest concentration of 0.235 mg/L recorded from station 1 and the least concentration of 0.091 mg/L. All the observed values for NO_3 + NO_2 are lower than the average EMC values of 0.65 mg/L observed from the pooled estimated data of EPA, NPDES, and NURP data. But the trend of increment is pollutant concentration is observed when the runoff flows downstream from station 2 to station 3.

The concentration values for nitrates are indicated in Table 15 and the trend for the concentration is shown in figure 17.

Table 15: Concentration of total ammoniacal nitrogen (NH_3-N)

NH_3-N	591-1	591-2	591-3	573-1	573-2	573-3
12-11-19	0.15	0.095	0.134	0.041	0.036	0.021
02-03-20	0.141	0.115	0.146	0.05	-	0.134
02-11-20	0.177	0.184	-	0.071	-	0.065
02-14-20	0.063	0.032	0.058	-	-	-
02-26-20	0.104	0.1	0.273	-	-	-

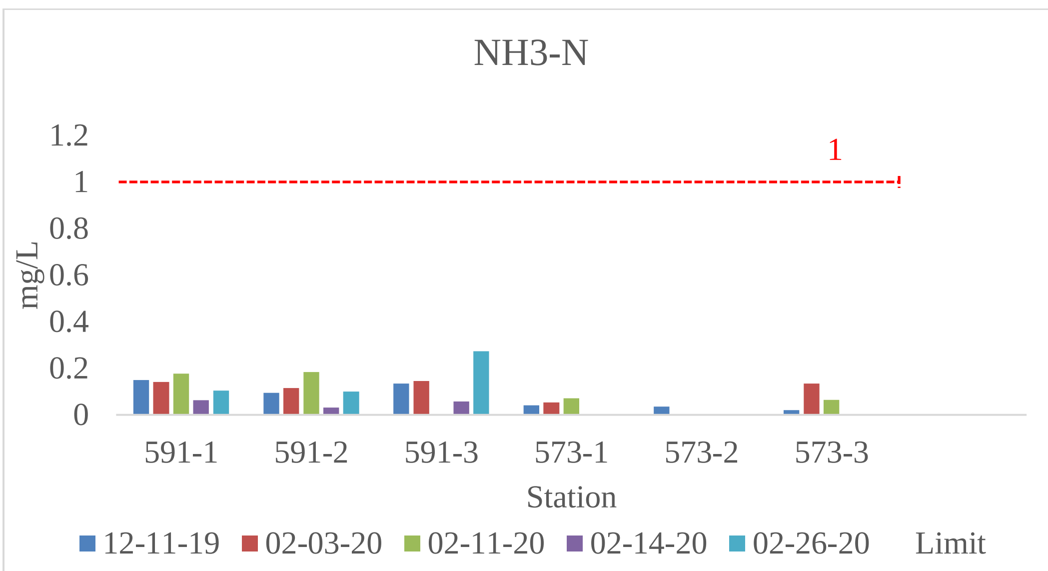

Figure 17: Trend of total ammoniacal nitrogen (NH_3-N) for Site 591 and Site 573

The concentration of NH_3-N present in stormwater is shown in Table 15 and represented in Figure 17. The red line represents EMC of Ammonia found by pooled average of NURP, NPDES and EPA data. The peak value of the concentration of Site 591 for NH_3-N was 0.374 mg/L collected from station 3 on the storm event of February 26, 2020. The least concentration of 0.032 mg/L was collected from station 2 for the storm event of February 26, 2020. The Site 573 had the highest concentration of 0.135 mg/L recorded from station 1 and the least concentration of 0.025 mg/L. All the observed values for NH_3-N are lower than the average EMC values of 1 mg/L observed from the pooled estimated data of EPA, NPDES, and NURP data. But the trend of increment is pollutant concentration is observed when the runoff flows downstream from station 2 to station 3.

All the values of concentration obtained from the channels show that the channel is not able to reduce the velocity of runoff flowing during the storm event. This result in an increased concentration of a pollutant at the outfall station leads to degrade the water quality even further. A need for a control measure is required for the remedial solution. The values of loading will be determined using the concentration values obtained during the monitoring.

4.3 Event Mean Concentration

The Event Mean Concentration (EMC) is the average of contaminants present in water runoff during a storm event. For this research, the samples were collected from December 2019 to February 2020, and 5 storm-events were sampled. The values of EMC for Site 591 are indicated in Table 16 and can be observed that the EMC value of TSS is 33.356 ± 25.202 mg/L. The peak value of concentration for Site 591 was 91 mg/L and collected on February 26, 2020, and the least concentration for the site was 9.48 mg/L collected on December 11, 2019. The values obtained from monitoring are lower than the EMC values of 51 mg/L obtained from pooled data of EPA and NPDES. As indicated in the water-quality analysis the concentration of TSS is increasing from station 2 to station

3 which is an indicator that the channel is having soil erosion distorting the channel's stability and deterioration of the water quality of receiving waters. A need for pollutant attenuation is required for reducing the concentration in the water flowing in the channel. For that purpose, there is a need to apply a control measure. The EMC value of Ortho-P is 0.02 ±0.01mg/L. The peak value of concentration for Site 591 was 0.04 mg /L and collected on February 26, 2020, and the least concentration for the site was 0.01 mg/L collected on December 11, 2019. The values obtained from are lower than 0.1 mg/L as obtained from the polled data.

During the sampling, the sample of nutrients was collected, and during analysis, it was segregated into four parameters (TKN, TP, NO3+NO2, NH3-N). The EMC value of TKN is 0.71 ± 0.16 mg/L. The peak value of concentration for Site 591 was 1.08 mg /L and collected on February 26, 2020, and the least concentration for the site was 0.51 mg/L collected on February 14, 2020. The values obtained from field monitoring was lower than the pooled average. But after water-quality analysis, it was observed that pollutant concentration of station 3 is a significantly higher concentration than station 2 of Site 591 this increase in the concentration can lead to the growth of aquatic algae and using the dissolved oxygen from water bodies. The EMC value of TP is lower than the pooled average EMC of value obtained as high as 0.14 ± 0.04 mg/L for the PQL of 0.01 mg/L. The highest concentration was obtained for the February 14, 2020 rainfall event with a concentration of 0.21 mg/L. With an increase in TP concentration above the permissible limit can be potentially harmful to the aquatic life as it reduces the amount of dissolved oxygen present in water.

From the obtained values of concentration and EMC calculation, it becomes clear that the channel is not producing more pollutant concentrations than the permissible limit of NPDES but the further reduction in pollutants will help in safeguard the water quality and biodiversity present in the water.

For the further reduction of these pollutants and enhancing the hydrology of the channel, some control measures can be applied as a preventive measure. Based on the application of both water quality and hydrology improvement, a Regenerative Stormwater Conveyance System (RSC) can be a possible fit for the channel. This storm-control measure can accommodate infiltration, treatment, and conveyance of stormwater treatment in a single system. It uses several shallow aquatic pools, vegetation, weir grade control, sand, and woodchip beds, which reduces the peak velocity of runoff during a storm event. This SCM will stop excessive stormwater from entering the properties and curtail the amount of erosion both land and downstream.

Table 16: EMCs for measured parameters

EMC-591	TKN	NO3+NO2	NH3-N	TP	Ortho-P	TSS
12-11-19	0.6	0.34	0.15	0.11	0.03	15.66
12-11-19	0.66	0.26	0.1	0.084	0.01	9.84
12-11-19	0.85	0.33	0.13	0.10	0.02	16.41
02-03-20	0.67	0.28	0.14	0.12	0.02	21.89
02-03-20	0.6	0.21	0.12	0.1	0.02	12.77
02-03-20	0.66	0.31	0.15	0.14	0.04	21.97
02-11-20	0.85	0.37	0.18	0.15	0.02	25.57
02-11-20	0.91	0.35	0.18	0.16	0.02	55.18
02-14-20	0.71	0.17	0.06	0.21	-	73.20
02-14-20	0.51	0.17	0.03	0.14	-	36.01
02-14-20	0.68	0.2	0.06	0.20	-	52.67
02-26-20	0.56	0.2	0.1	0.08	0.02	10.97
02-26-20	0.61	0.2	0.1	0.1	0.01	23.85
02-26-20	1.08	0.32	0.28	0.2	0.03	91
Mean	0.71	0.27	0.13	0.14	0.02	33.36
Std. Deviation	0.16	0.07	0.06	0.04	0.01	25.2

For further understanding of the EMCs results obtained from the monitoring study, the results are compared with EMCs obtained for the different monitoring studies conducted across the country. The data obtained are from studies conducted in different locations, geographic terrains, and time-periods. This comparative analysis is indicated in Table 17 and provides a comprehensive result. When the EMC results obtained from monitoring are compared with the EMCs of other monitoring studies, a similarity in the results can be observed with the results, as they fall within the ranges of other studies. But the concentrations found were on the lower end of these ranges of other studies. These results can be used to reduce the impact of pollutants on water-quality and find different remedial solution/control measures for reducing the concentration of pollutants along with the drainage infrastructure.

Table 17: Comparative analysis of EMC

	TSS (mg/L)	TDS (mg/L)	TKN (mg/L)	Total-P (mg/L)	Ortho-P (mg/L)
Kayhanian 2003	148.1	184.1	2.0	0.3	0.1
Lee 2000	NA	NA	(1.4-13.8)	(1.2-10.2)	NA
Wu 1998	(30-283)	(88-216)	(1-1.42)	(0.43-0.52)	(.15-.3)
Barrett 1998	(19-129)	NA	NA	(0.1-0.33)	NA
Driscoll 1990	(12-135)	NA	(.34-2.19)	NA	NA
Site 591	36.36	NA	0.711	0.135	0.02

For estimating the total pollutant discharge in the receiving water pollutant estimation tool known as the Simple Method is used. The simple method uses several parameters for the estimation of the pollutants present in the stormwater. These parameters include the rainfall amount for the storm-event, watershed area of the channel, land type of the watershed, and the impervious cover of land. For determining these parameters, the watershed area was first delineated using ArcGIS, and subsequently, other parameters were found using the data from the watershed area. The watershed area is shown in Figure 18.

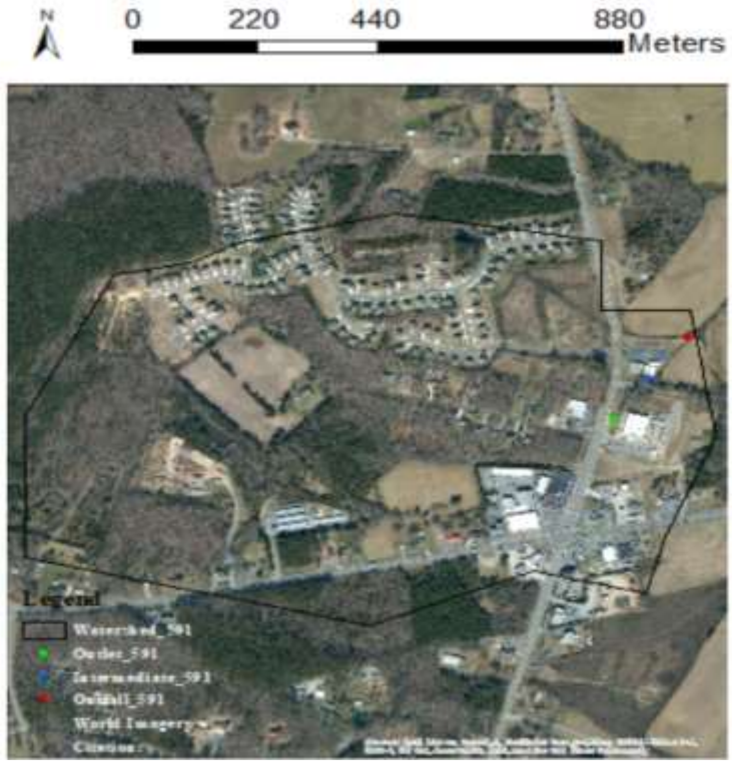

Figure 18: Watershed Area of Site 591

From the analysis, the total area of the watershed that channel 591 is in was estimated at 220.81 acres and indicated in Table 18. This area covers a variety of land types such as Commercial land, Forest, Agricultural, Residential, and waterbody. The total land breakup of the watershed is indicated in Table 18.

Table 18: Land Type Use

Land Type	Area (Acres)	Area Percentage
Commercial	19.87	16%
Water	0.22	0%
Forest	75.44	34%
Agriculture	32.93	15%
Residential	92.63	35%
Total Area	220.81	100%

From Table 18, it can be observed that almost 70% of land use in watershed consists of Forest and Low developed (Residential) area type. This land breakup shows that the site is in a semi-urban region. For such a region, the simple method can be a good fit for estimating the pollutant loads. It was previously used in studies conducted on Gregg lake in New Hampshire, which also shares a similar land-use area as the watershed for the Site 591. For obtaining the pollutant estimates, the imperviousness of the land use was required. The data was calculated using the layers of Land Use and Parcel data in the GIS for the watershed. The data obtained for the impervious cover is shown in Table 19.

Table 19: Impervious Area of Watershed

Land Type	Land Area (Acre)	Impervious Area (Acre)	Percentage Impervious
High Developed	12.205	10.595	87%
Medium Developed	23.310	9.521	41%
Low Developed/Open Developed	76.868	12.093	16%

From Table 19 of the impervious area, it can be observed that the watershed has around 32 acres of impervious land, and this land imperviousness indicates the value of the runoff coefficient for this area. For this project, the pollutants like TSS, Nutrients (TKN, TP, NO_3-NO_2, NH_3-N) and Ortho-P were sampled and monitored. The Simple Method was utilized for estimating the pollutant loading of the watershed for these pollutants. For this estimation, the data of pollutant concentration is taken from the runoff samples collected during monitoring and other required data is obtained through the GIS analysis of watershed. The runoff coefficients per the land use category were determined and shown in Table 20.

Table 20: Runoff Coefficients for areas of different land use

Land Use	Impervious %	Runoff Co-efficient
Commercial	64%	0.626
Water	0%	0.05
Forest	0%	0.05
Agriculture	0%	0.05
Residential	19%	0.221

After finding and inputting all required values in the Simple Method formula sheet, the pollutant loads were calculated and shown in Table 21.

Table 21: Estimated Pollutant Load Values

Pollutant	Pollutant Load (Kg/ha)
TSS	25.32
Ortho-P	0.01
TKN	0.11
TP	0.03
NO3 + NO2	0.04
NH3-N	0.02

For this study, the estimation of pollutant loading is critical to understanding the response of the channel to soil erosion. The pollutant loading provides a better idea of the amount of pollutant generated through the channel. The data determined through this estimation tool will be helpful in deciding the control measure that can be used to reduce the load generated and control the peak velocity of runoff. This will help to mitigate the problem of soil erosion causing in the channel. The results from load estimation will provide the data to help determine the most suitable SCMs for reducing the pollutant loads from the channel and improving the related biodiversity.

Table 22: Total Pollutant Loading for the year (Horner, 1994)

Pollutant	Pollutant Load (Kg/ha)	Pollutant Load (Kg/ha) (EPA)
TSS	25.32	112.1
Ortho-P	0.01	N/A
TKN	0.11	1.41
TP	0.03	0.30
NO3 + NO2	0.04	0.84
NH3-N	0.02	0.29

When compared the obtained loading data with the EPA's result of pollutant load export rate (Horner, 1994), a similarity in proportion and consistency in the data can be observed. Most of the estimated results of loading are proportional to the pollutant concentration obtained. As the concentration obtained was on the lower end of the EMCs range similarly, results obtained for the loading were low when compared with EPA's results. The proportionality in concentration to pollutant loading can be observed for dataset of simple method and pooled average of EPA, and NURP. This indicates that the simple method provides similar kind of results.

From Table 22, it was observed that the runoff collected a large concentration of insoluble particles from the watershed area and washed into the water channel. Looking at the region, this is a developing region and a large portion of land covers the open developed, residential, and commercial land types. Due to such land types, there is presence of a certain portion of the impervious surface, that leads to increment of rainfall-runoff ratio. This imperviousness causes an increase in peak velocity entering the channel. This increment in peak velocity causes the runoff to enter the surrounding land and to cause soil erosion. TSS loading found around 25.32 kg/ha shows the amount of soil that is getting washed off.

Similarly, the pollutant loading for Ortho-P was found around 0.01 kg/ha. Ortho-P is responsible for possible eutrophication in the channel. Eutrophication can be considered as an indicator of the poor water quality present in the water body. This process of eutrophication can be harmful to other aquatic life present in the water body as it creates a layer of algae over the surface of the water and stops sunlight from entering the water surface. It also consumes the dissolved oxygen present inside water required for the existence of biodiversity in the water.

The pollutant loading of nutrients was also estimated. The total loading for TKN was estimated at 0.11 kg/ha, along with this pollutant loading of TP was estimated at 0.03 kg/ha. Other pollutants estimated were nitrates and total ammoniacal nitrogen. The values for loading were found to 0.04 kg/ha and 0.02 kg/ha.

The results also convey that runoff is carrying pollutants from the land surface and washing into the receiving waters and contaminating the water quality.

4.4 Recommendation for Stormwater Control Measure

The inability of a channel to control the peak flow from stormwater runoff contributes to the so-called “Urban Stream Syndrome” (Wheeler et al., 2005). The pollutant washes in the runoff flow and results in affecting the water quality and surface of channel and channel banks. Control measures are necessary for reducing the deteriorating effects of runoff, which can lead to hydrologic changes in the channel. Stormwater control measures (SCMs) are used across the globe to reduce the concentration of pollutants from runoff and improve water quality entering the outlet channel. They are the steps of measures deployed along with drainage infrastructure to reduce the pollutant concentration of runoff, which will drain into receiving waters (EPA, 2017).

Structural control measures are permanently physical built structures that are constructed and operated by using engineering knowledge. To detain runoff and provide treatment for the removal of pollutants from the storm runoff. Structural control measures that are generally used at highway sites are based on the availability of land, land used, and efficiencies in reducing pollutants and water quality obtained before applying SCM. The SCMs which are preferred for highway sites include Regenerative Stormwater Conveyance systems (RSC), Vegetated Swales, and Retention basin (Greensboro-nc.gov, 2009) and represented in Table 23.

Table 23: Stormwater Control Measures

SCM	Regenerative Stormwater Conveyance System (RSC)	Retention Basin	Vegetated Swale
Details	Accommodate infiltration, treatment, and conveyance of stormwater treatment in a single system. It uses several shallow pools, vegetation, sand, and woodchip beds.	Improve the treatment ability of watersheds. There is a process of sedimentation to remove biochemical particles and organisms.	It is used to remove the impurities by reducing the flow velocity.
Advantage	Reduce the pollutant concentration to meet the permissible limits. Restore the developed channels that are eroded and have degraded runoff outfall.	Enhances the ability to clean the stormwater by retaining and recharging groundwater. Also enhances aesthetics.	This system can be standalone or used with other SCM's to reduce the pollutants
Disadvantage	It needs a large impervious area. It does not provide a stable conveyance for channel runoff.	Cannot be used in all regions. The upfront cost is high. Requires regular maintenance.	Not useful in flat gradient and sloppy gradient.
Efficiency	RSC is effective in the reduction of pollutant loads for any watershed. It can reduce from a range of (17- 35) % of TSS from discharge but the efficiency can increase with improvement in design.		

CHAPTER 5: CONCLUSION

Runoff carries contaminants from highways that impact the quality of water discharged into downstream channels (Khan et al., 2006). These contaminants then flow into the channel, affecting the nearby biodiversity stability and cause impairment of water (EPA, 2017). The other problem is the outlets are not able to mitigate the sudden increment in the peak velocity of runoff, and thus the velocity of runoff increases more than the expected velocity. Due to the excessive amount of stormwater discharge conveyed onto private property, there is land erosion downstream erosion of the water channel and scouring of the channel.

This monitoring study contributes to the understanding of baseline characteristics of water quality and hydrology of two outlet channels to inform planning and design for future mitigation strategies. During the monitoring, a related dataset of rainfall received, channel discharge, and pollutant concentration observed was created, which covered the 2019-2020 winter season's rainfall events. The dataset created will contribute to NCDOT's database on the outlet's characteristics for water quality and hydrology. Using monitoring data, the water quality analysis was conducted, and pollutant loads were estimated. The estimated values can be used for mitigating the situation to reduce peak runoff velocity and control the erosion of land and channels.

The research can conclude that the channel is carrying lower pollutant concentrations than permissible limits for the season of data collection and analysis covered in this research. The EMCs obtained for the pollutants were within the ranges of other similar research studies however they were comparatively on the lower end of these ranges. This indicates that the channel can control the pollutant concentration and the values obtained are not concerning when compared with EMC's of similar type studies. But it was also observed that the pollutant concentration for Site 591 increases when the runoff flows from station 2 to station 3. The slope of the channel is one the reason for increment in runoff velocity and the land type from station 2 to station 3 which provides no barrier to reduce the flow of runoff, due to which the velocity of runoff is not checked and thus causing soil erosion in the channel and increasing the width of the channel.

The channel is not able to attenuate the peak velocity of runoff because the estimation of pollutant loading was almost similar to other studies (Horner, 1994). The attenuation of peak velocity is required to stop runoff water from entering private lands and causing erosion. For improvement on this condition of channel, some control measures are required to be applied before the flow enters the channel. For further enhancement of water quality, reduction of pollutant loading, and curtailing peak velocity of runoff, some of the recommended SCM can be considered for use.

5.1 Future Works

This research and the obtained data can be a contribution to determining the remedial control measure for attenuation of peak velocity. The results of pollutant concentration from different stations along the channel will help in identifying the location in the channel which are not able to withstand the velocity of runoff and causing the soil erosion and channel deterioration.

Yearlong extensive monitoring and collection of samples for all the seasons including fall, winter, spring, summer is needed. These results will help to understand the channel's response throughout the year and help to compare the response for different seasons. Along with that, after gathering further results from the monitoring, the dataset for both concentration and loading can use appropriate statistical methods to determine the current conditions of channels and have a better analysis of water-quality and hydrology of channel.

5.2 Limitations

There were several limitations to the research conducted. Time was a significant limitation for monitoring as the period for monitoring was confined to the winter months from December 2019 until February 2020 and covered just five qualifying storm events; thus, it did not cover year-round seasonal data, which limited the analysis of results.

There were some limitations within the load estimation tool "simple method" that was used to estimate the pollutant loading including the following:

- This tool estimates pollutant loading possibility nearest to the actual value for watershed or sub-watershed area, but it is also important to understand that the result obtained will not be exact (Schueler, 1987).
- The tool sometimes overestimates the pollutant loading, although the additional loading predicted can be used as a factor of safety when planning for control measures (NYSSMDM, 2004).
- The tool provides tentative load estimates for the area it is deployed but requires more sophisticated estimation tools for the highly complex watershed.

Another factor affecting the monitoring was a malfunctioning of the ISCO equipment, which resulted in not collecting samples. The absence of complete sample sets for each storm event at each site created deficiencies in the dataset.

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APPENDIX

Appendix: Rejected sites (NC DOT Intern's field notes, 2019)

Pipe ID	Route Name	Latitude	Longitude	Net Assessment Value (NAV)
MP-013-00608	NC-24	35.24935	-80.5381	no channel
MP-013-00607	NC-24	35.2497	-80.52049	no channel
MP-013-00606	NC-24	35.24977	-80.51512	no channel
MP-013-00605	NC-24	35.24976	-80.51448	no channel
MP-013-00587	US-601	35.26231	-80.50158	too many trees
MP-013-00582	US-601	35.27438	-80.49998	no channel
MP-013-00576	US-601	35.28976	-80.51108	no channel
MP-013-00569	US-601	35.30444	-80.51404	no channel
MP-013-00555	US-601	35.33984	-80.52095	no channel
MP-013-00549	US-601	35.35595	-80.5366	no channel

Sites of Monitoring (NC DOT Intern's field notes, 2019)

Pipe ID	Route Name	Latitude	Longitude	Pipe Type	Pipe Size	NAV
MP-013-00591	US-601	35.25403	-80.50015	RCP	48	can assess, maybe monitor, need AVM
MP-013-00581	US-601	35.27646	-80.50061	RCP	24	maybe on both, need AVM
MP-013-00580	US-601	35.28063	-80.50321	RCP	18	Can monitor right at pipe but no channel
MP-013-00574	US-601	35.29524	-80.51285	RCP	48	maybe on both, need AVM
MP-013-00573	US-601	35.29624	-80.51313	RCP	42	yes, to both, can use a weir
MP-013-00564	US-601	35.31339	-80.51527	RCP	18x36	maybe, can put a weir on it
MP-013-00563	US-601	35.31414	-80.51548	RCP	18x36	potential site for monitoring stops in 1st 100 ft
MP-013-00561	US-601	35.32048	-80.51563	RCP	18x36	can assess, maybe monitor, need AVM
MP-013-00562	US-601	35.31936	-80.5157	RCP	18x36	can put a weir and monitor